

Lao People's Democratic Republic

The Capacity Development Project for

Establishing National Forest Information System

for Sustainable Forest Management and REDD+

(Phase II)

Completion Report

Annex8 : Material for RS training



Theory of Remote Sensing

Technical Training
July 22st - August 1st, 2014

DOF/FIPP KOKUSAI KOGYO CO.,LTD. ASIA AIR SURVEY CO.,LTD.

Mitsuru NASU, Ph.D.
Forest Remote Sensing



1. Introduction
2. Basics of Radiation Physics for Forest Remote Sensing
3. Radiation Properties of Vegetation, Soil, and Water
4. Earth Observation Systems
5. Processing of Optical Remote Sensing Data
6. Use of Multi-Spectral Information for Sensing Vegetation Properties and for Image Classification
7. Sampling, Errors, and Accuracy Analysis
8. Summary



References

1. Jones, H.G., Vaughan, R. A.: *Remote Sensing of Vegetation, Principle, Techniques, and Applications*, Oxford.
2. Jensen, John R., *Introductory Digital Image Processing, A Remote Sensing Perspective*, Pearson Prentice Hall.

Time Schedule

	AM	PM
7/22 (Tue)	Arrangement of works	Lecture 1
23 (Wed)	Lecture 2	Image Interpretation Key 1
24 (Thu)	Lecture 3	Image Interpretation Key 2
25 (Fri)	Image Interpretation Key 3	Lecture 4
28 (Mon)	Image Interpretation Key 4	Image Interpretation Key 5
29 (Tue)	Lecture 5	Image Interpretation Key 6
30 (Wed)	Lecture 6	Image Interpretation Key 7
31 (Thu)	Lecture 7	
8/01 (Fri)	Report writing	

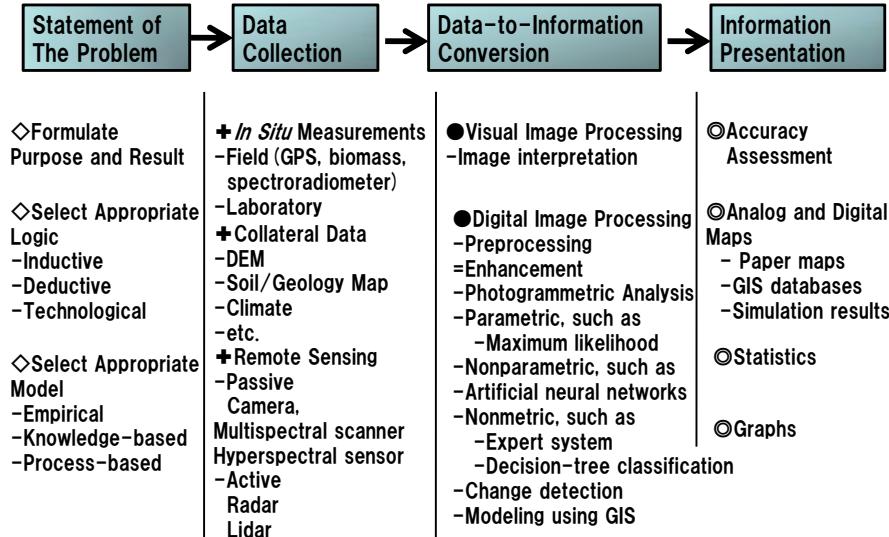


1. Introduction

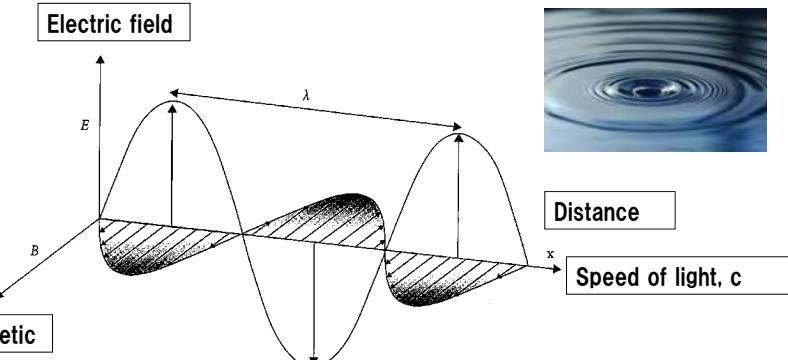
- ◊ Remote sensing uses sensors to measure the amount of electromagnetic radiation from an object from a distance.
- ◊ RS extracts valuable information from the data for forest monitoring and management .
- ◊ RS needs many fundamental knowledge of sciences and technologies.



- ◊ "Theory of Remote Sensing" aims to contribute for improving fundamental knowledge of remote sensing practices in the field of Forestry.

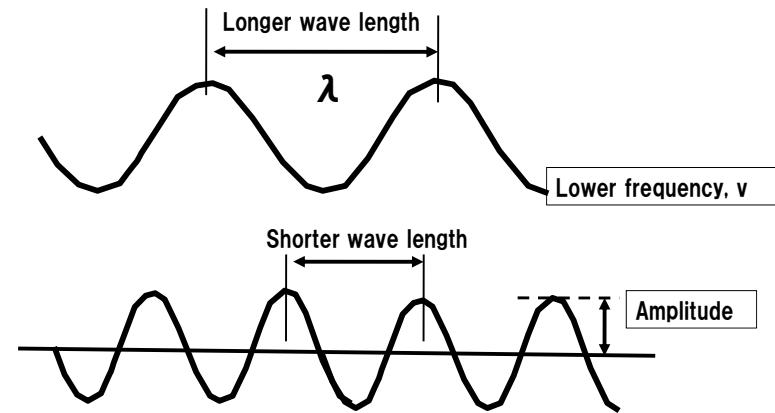


2. Basics of Radiation Physics for Forest Remote Sensing



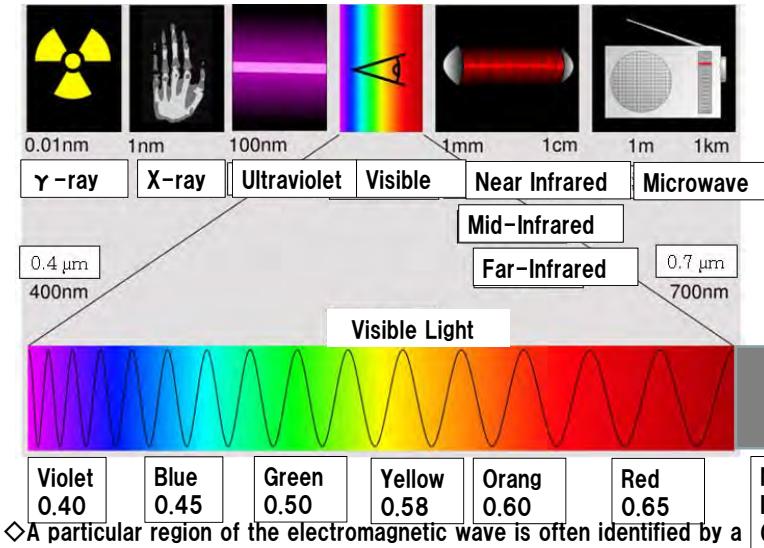
- ◊ Electromagnetic radiation from the object is a key element of Remote Sensing.
- ◊ Electromagnetic radiation consists of time-varying electric and magnetic fields that travel in the form of a wave at the speed of light c (3×10^8 ms $^{-1}$).
- ◊ Once the wave has been formed, it will continue to travel directly from the source, and does not require a medium in which to travel.

Electromagnetic Radiation

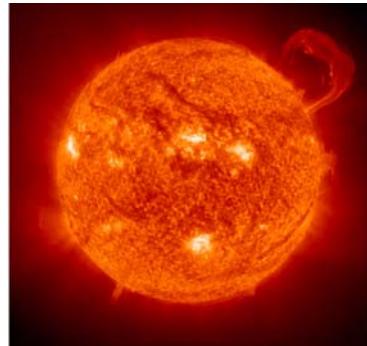


- ◇ The longer the wave length, the lower the frequency
- ◇ The amplitude of an electromagnetic wave is the height of the wave
- ◇ Frequency of a wave : measured in cycles per second or hertz

Electromagnetic Spectrum



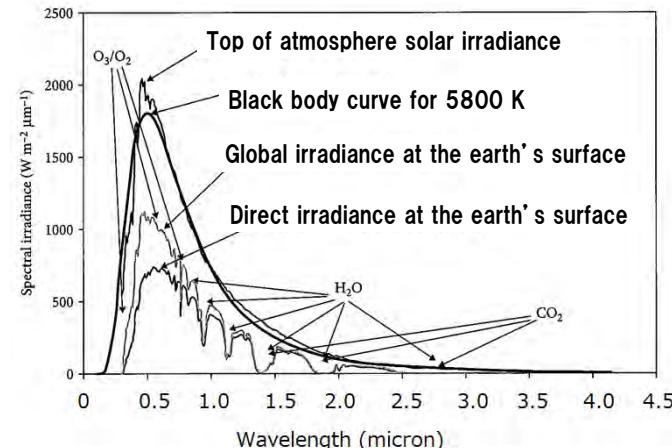
Sources of Electromagnetic Radiation



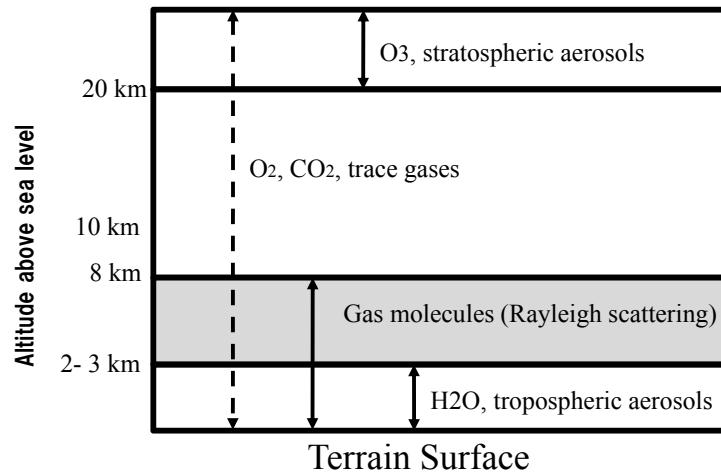
(Image: NASA)

- ◇ The Sun is a major source of electromagnetic radiation.
- ◇ The Sun approximates a 6000 K blackbody with a dominant wavelength of about 0.48 μm (Green)
- ◇ The Sun produces 41% of its energy in the visible region from 0.4 to 0.7 μm. The 59% is in other regions.

Solar Spectrum



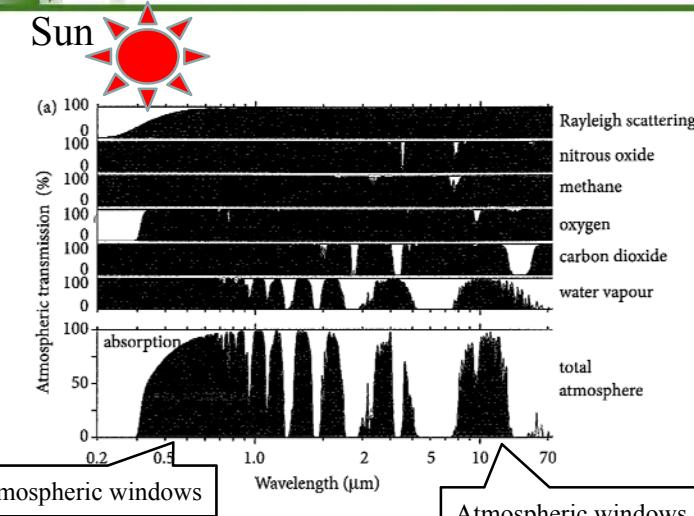
- ◇ The Earth intercepts only a very small portion of the electromagnetic energy produced by the Sun.



◇ Atmospheric layers and Types of molecules and aerosols in each layer (Miller and Vermote)



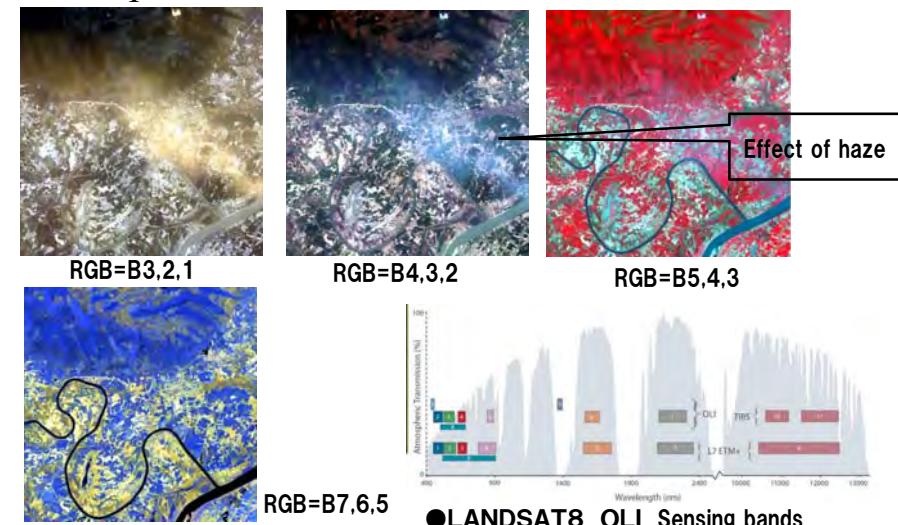
- Rayleigh Scattering
 - Gas molecule ($1/1000$ of λ of visible light)
 - Blue sky
 - Mie Scattering
 - Smoke, dust (λ of visible light)
 - Nonselective Scattering
 - Water vapor (fog)
- Photon of electromagnetic energy modeled as a wave
- ◇ Type of scattering is a function of 1) the wavelength and 2) the size of the gas molecule, dust particle, and/or water vapor encountered.
- ◇ The intensity of Rayleigh scattering varies inversely with the fourth power of the wavelength (λ^{-4})



Atmospheric Transmission (H.G.Jones & A. Vaughan)



Examples: LANDSAT 8_OLI





RGB=Band 3,B2,B1



RGB=B4,B3,B2



RGB=B7,B5,B4

**Atmospheric scattering caused by volcanic smoke
(Landsat TM image of Mt. Asama, Japan)**



◊ Sometimes it is possible to ignore atmospheric effects in RS data completely.

Ex. Single date RS data analysis using a maximum likelihood classification algorithm using the training data.

◊ It is usually necessary to apply atmospheric correction if biophysical parameters are going to be extracted from vegetation or water bodies.

Ex. Contributions from the atmosphere to NDVI are significant and can amount to 50% or more over thin or broken vegetation cover. (J.R.Jensen)



(1) Absolute atmospheric correction

- Model atmosphere
- Model atmosphere + in situ data

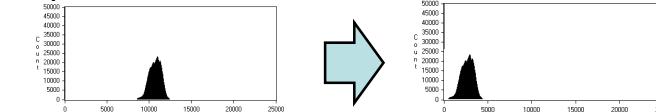
- Atmospheric correction based on Radiative Transfer Modeling (FLAASH(ENVI), ACORN(DLR), ASTERM, ATCOR(Leica), etc.)

◊ Atmospheric properties are difficult to acquire !



(2) Relative Atmospheric Correction

① Single-image Normalization Using Histogram Adjustment



② Multiple-date Image Normalization Using Regression

- ◊ Select radiometric ground control points
- ◊ Regression analysis
- ◊ Apply radiometric correction by the regression model



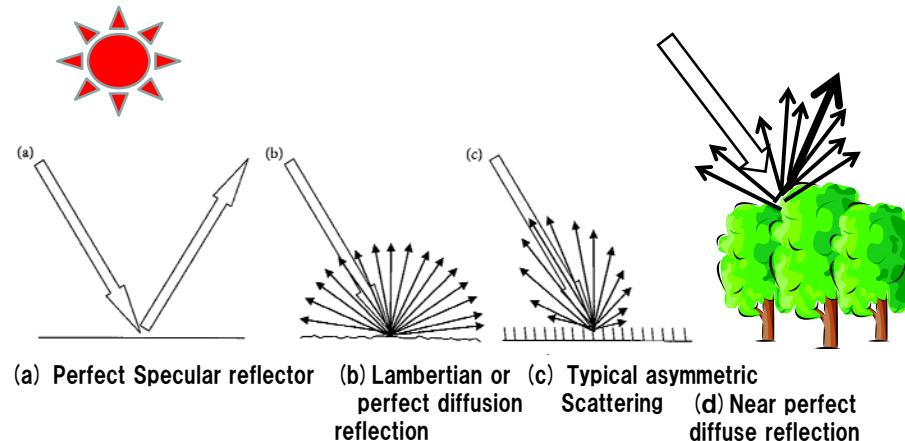
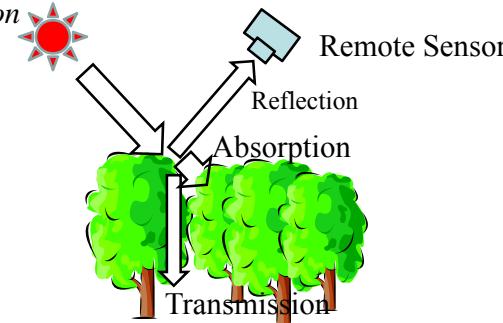
3. Radiation Properties of Vegetation, Soil, and Water



● **Reflection:** The solar radiation that is not absorbed by the target is reflected back to space. The spatial arrangement and density of leaves and branches in the canopy space leads to a strong dependence of reflection. High reflectance in the near infrared.

● **Absorption:** A large proportion of the sunlight is absorbed in the processes of photosynthesis, evapotranspiration, etc.

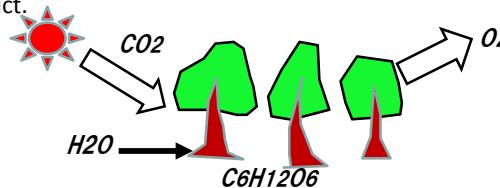
● **Transmission**



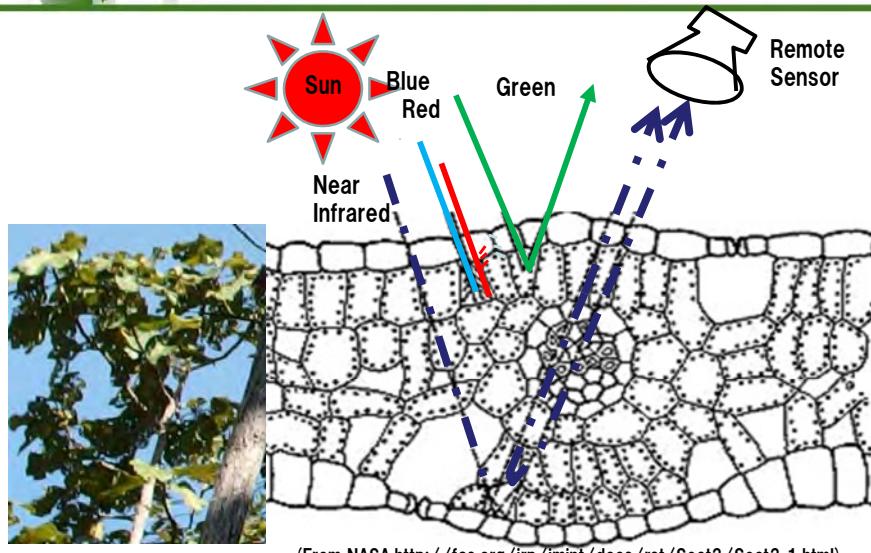
◊ There are various types of reflecting surfaces.



- ◊ Photosynthesis is an energy-storing process that takes place in leaves and other green parts of plants in the presence of light.
- ◊ The light energy is stored in a simple sugar molecule (glucose) that is produced from carbon dioxide (CO_2) present in the air and water (H_2O) absorbed by the plant primarily through the root system.
- ◊ When the carbon dioxide and water are combined and form a sugar molecule ($C_6H_{12}O_6$) in a chloroplast, Oxygen gas (O_2) is released as a by-product.

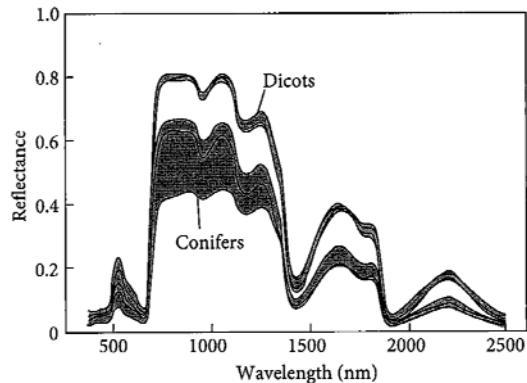


Reflection and Absorption(Broadleaf)

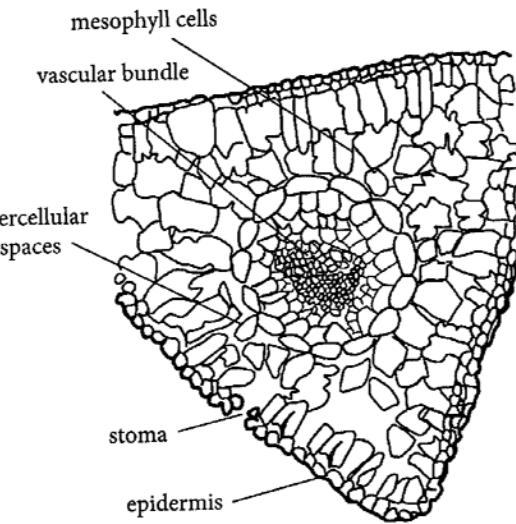


General Characteristics

◇ Typical patterns of radiation absorption, transmission, and reflection for plant leaves.



Plant Leaves (Pine needle)

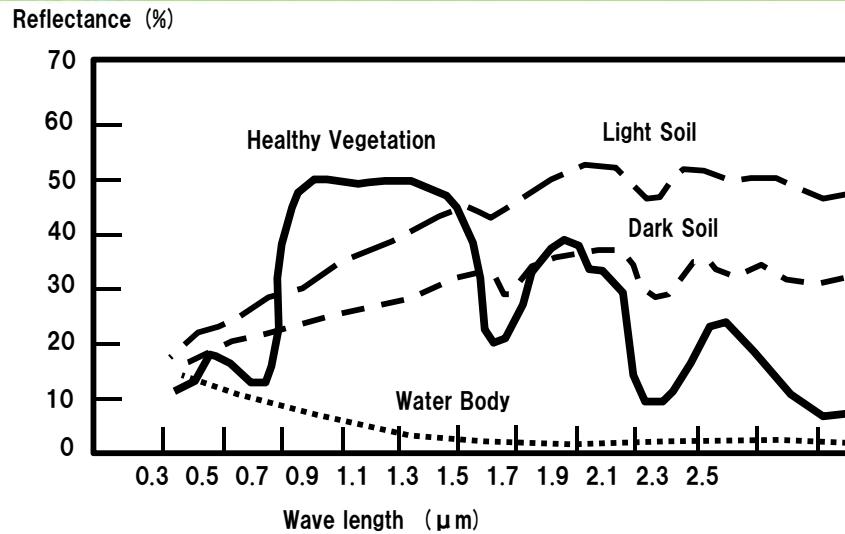


(H.G.Jones & R.A.Vaughan)

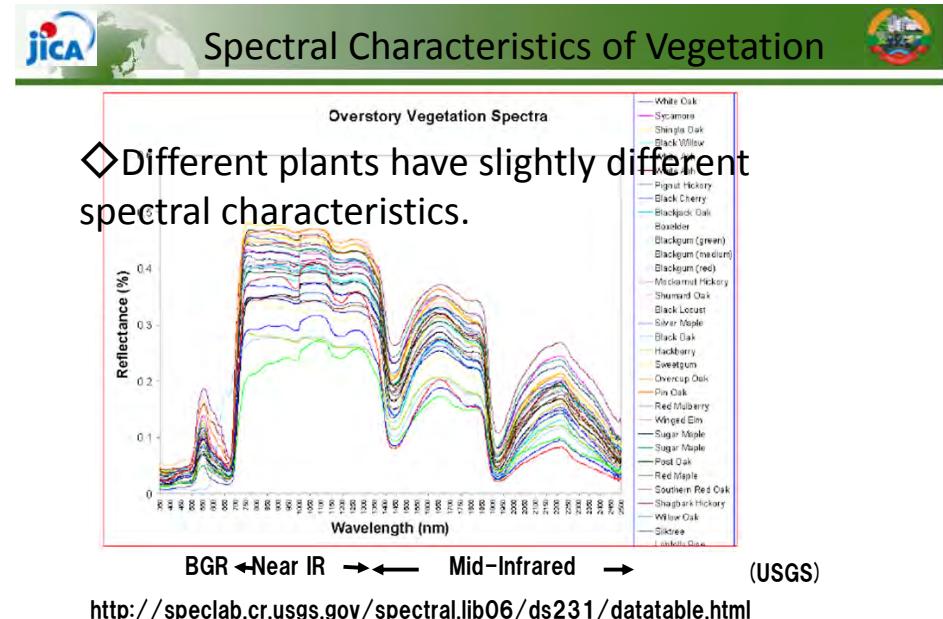
Absorption Features in Visible and NIR

Wavelength (microns)	Chemical
0.43, 0.46, 0.64, 0.66	Chlorophyll
0.97, 1.20, 1.40, 1.94	Water
1.51, 2.18	Protein, nitrogen
2.31	Oil
1.69	Lignin
1.78	Cellulose and sugar

Absorption features in visible and near IR related to leaf components.
Note that many of the absorption bands in the mid-infrared are subject to substantial atmospheric absorption and so have rather limited use for remote sensing, being of greater value in close-field situations.
(H.G.Jones & R.A.Vaughan)

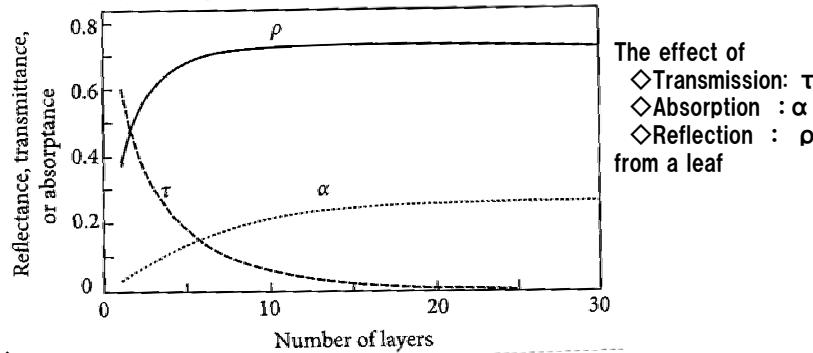


Vegetation has a very characteristic spectral signature.



jica The Effect of Increasing Leaf Thickness

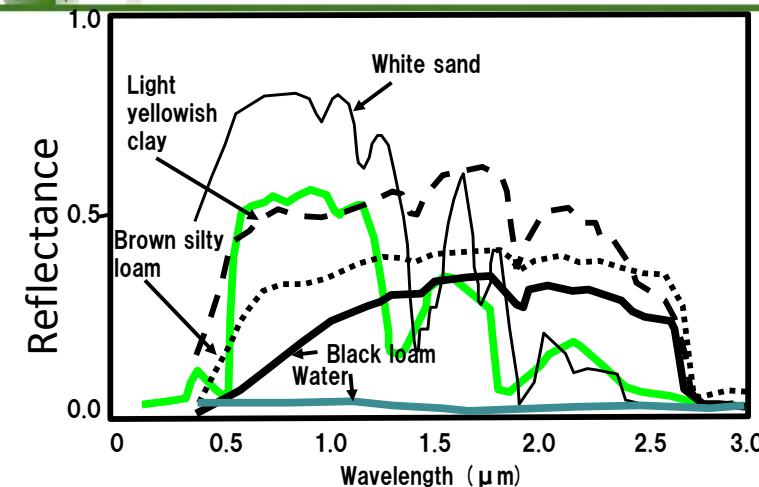
◇Effect if Increasing Leaf Thickness (Number of layers)



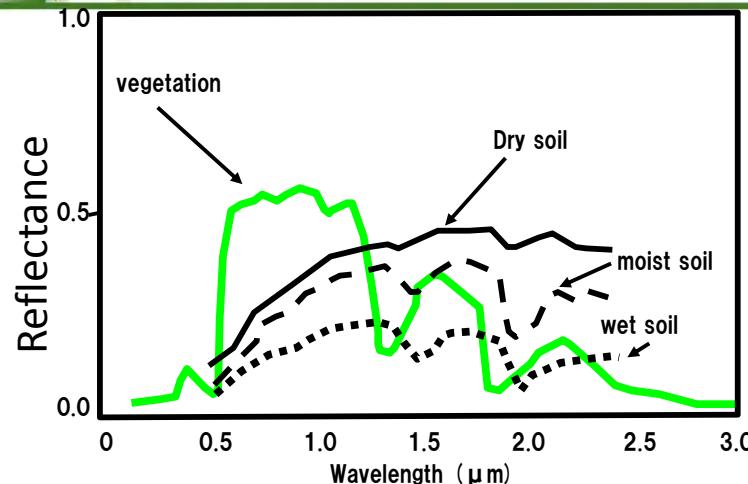
◇Typical reflection coefficients for single leaves (Jones)

Conifer needles	12 %
Deciduous broad leaves	23 – 29 %
Young leaves	39 %

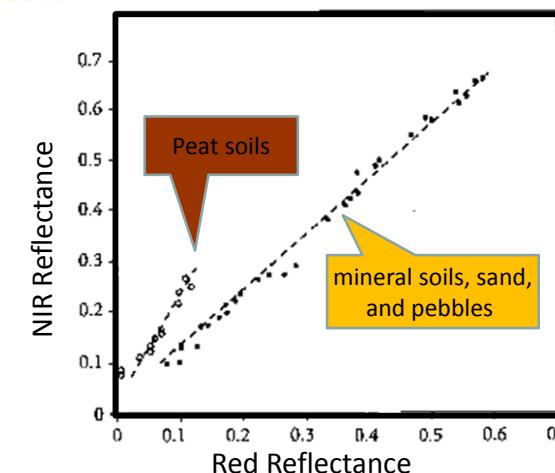
jica Spectral Reflectance Characteristics



◇Spectral reflectance of different soils as compared with vegetation



◇ Typical spectral reflectance of different soil moisture content as compared with vegetation (Jones)



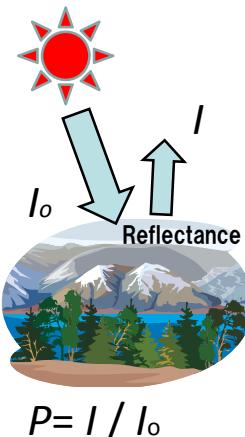
◇ Relationships between Red and NIR reflectance for different soils as water content changes.

◇ The slope of the line differs between organic (peaty) soils and mineral soils (Jones)



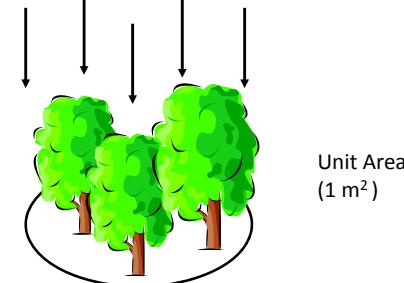
Total Reflectivity or Albedo

Deciduous forest	0.10 - 0.20
Coniferous forest	0.05 - 0.15
Grass	0.20
Rainforest	0.10 - 0.13
Water	0.02 - 0.05
Dry soil	0.13 - 0.18
Wet soil	0.08 - 0.10
Sand (dry, white)	0.35
Snow (fresh)	0.75 - 0.95
Wheat	0.20
Maiz	0.19



[Definition of Leaf Area Index]

◇ LAI : The amount of one-side leaf area per unit area of ground



◇ For conifers, that have cylindrical needles, one may consider the projected area of the needles or hemi-surface area of the needles.



Functional type	Mean LAI	Std Dev
Polar desert/alpine tundra	3.85	2.37
Moist tundra	.82	.47
Boreal forest woodland	3.11	2.28
Temperate savanna	1.37	.83
Temperate evergreen broadleaved forest	5.4	2.32
Temperate mixed forest	5.26	2.88
Temperate conifer forest	6.91	5.85
Temperate deciduous forest	5.3	1.96
Temperate wetland	6.66	2.41
Cropland Temperate	4.36	3.71
Plantation Temperate	9.19	4.51
Tall medium grassland	2.03	5.79
Short grassland	2.53	.32
Arid shrubland	1.88	.74
Mediterranean shrubland	1.71	.76
Tropical wetland	4.95	.28
Tropical savanna	5.81	1.81
Tropical evergreen rain forest	5.23	2.61
Tropical deciduous forest	4.67	3.08
Tropical pasture	2.85	2.62
Crop tropical	3.65	2.14
Plantation tropical	9.91	4.31

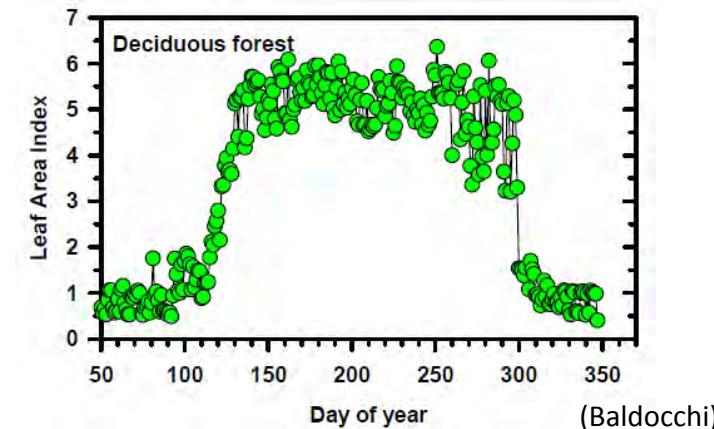
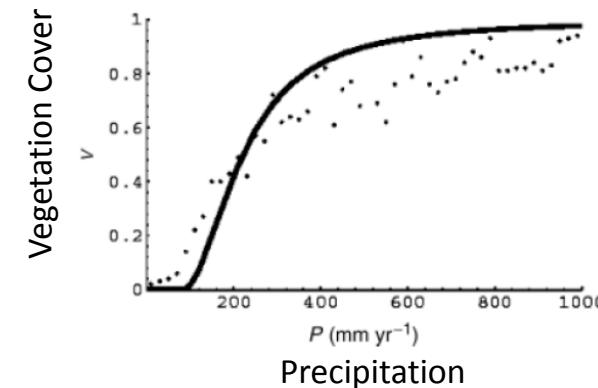
(Baldocchi)

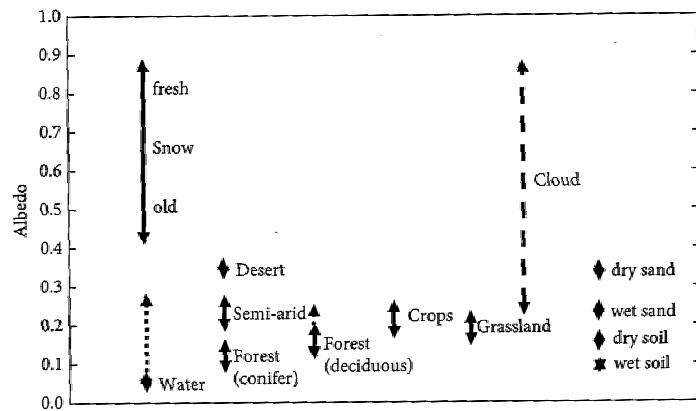
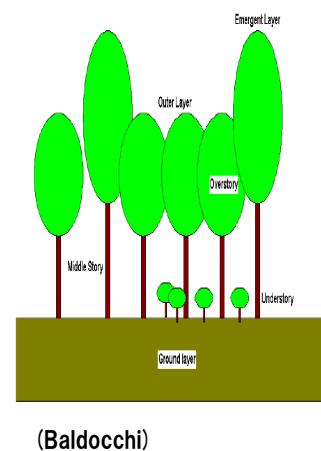
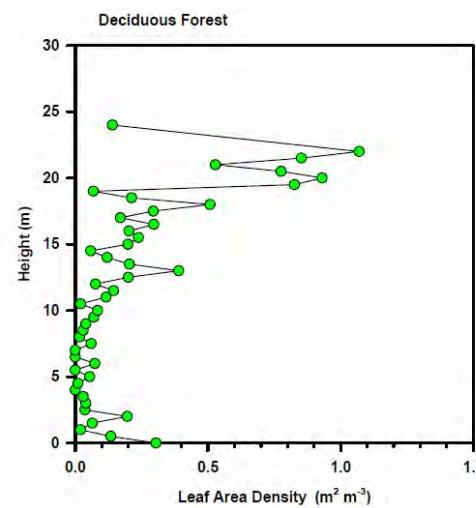


Mixed Deciduous Forest (Kamukheut District, Bol.)



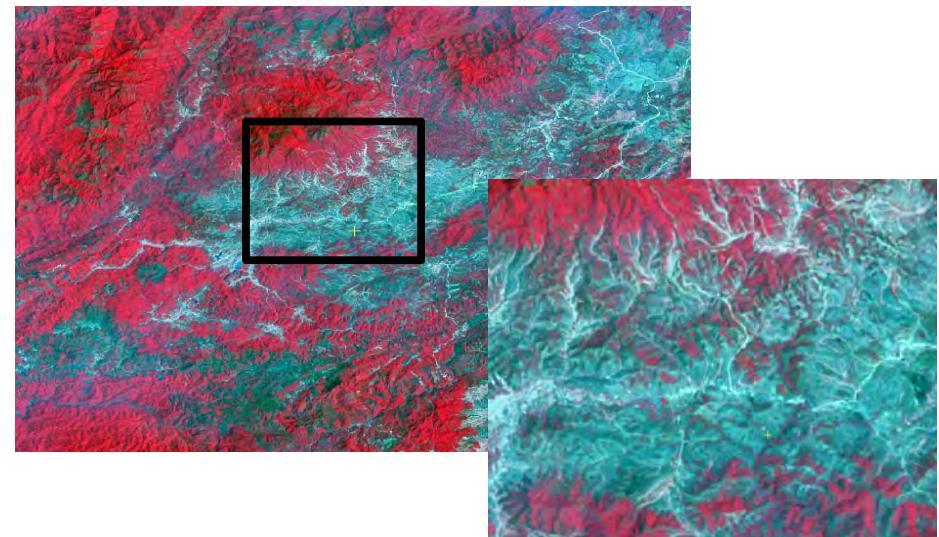
◊ Correlative and biogeographical analyses suggests that leaf area index strongly tied to site water balance and nutrient status (Baldocchi)





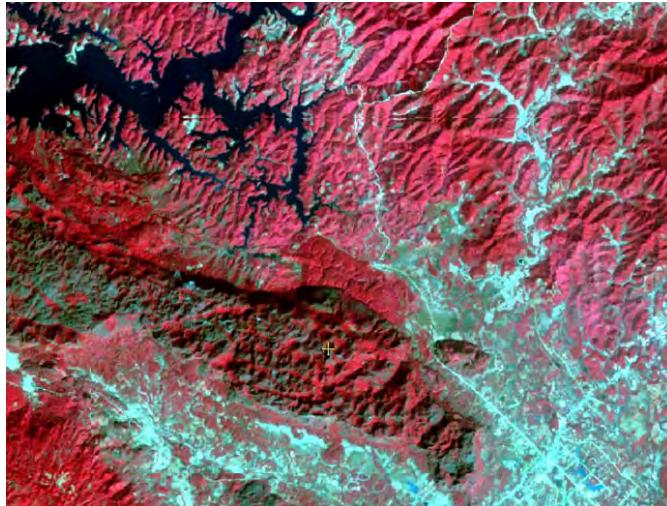
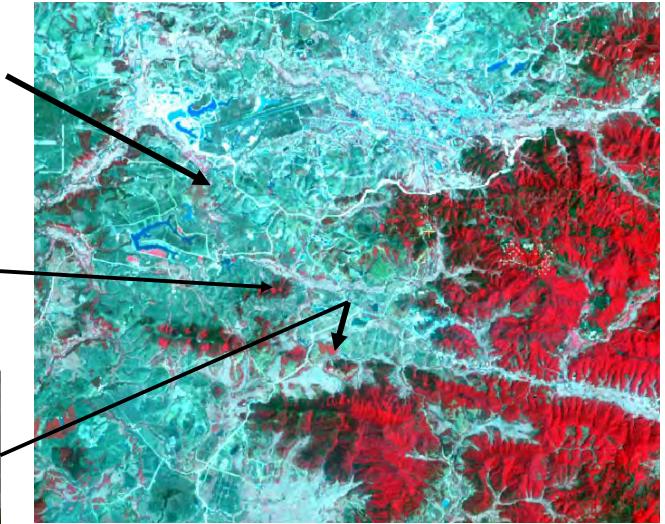
Typical ranges of albedo (total reflection) from natural surfaces (Jones)

- ◊ Much of the light reflected from a canopy has undergone more than one reflection. Thus, the overall reflectance of a dense canopy is usually substantially less than the reflectance measured for a single leaf.
- ◊ As leaf-area index decreases, the canopy reflectance tends to that of the underlying soil.
- ◊ Because of differing reflectance of leaves in the visible and near infrared wavelengths, the relative attenuation in these wavebands will depend on the number of reflections at leaf surfaces.
- ◊ Radiation becomes enriched in the infrared both as the number of reflections at leaf surfaces increases and with increasing depth in the canopy.
- ◊ Because the canopy albedo depends critically on canopy structure, albedo changes as a function of time of day as the solar angle changes.
- ◊ The strong decrease in soil reflectance as it gets wet can have a substantial effect on overall canopy albedo for sparse canopies.

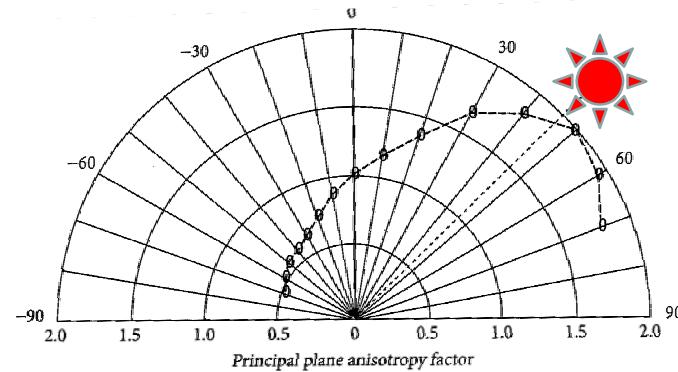




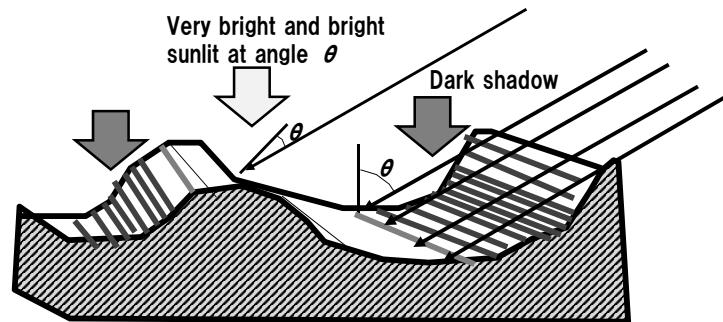
(Pine)



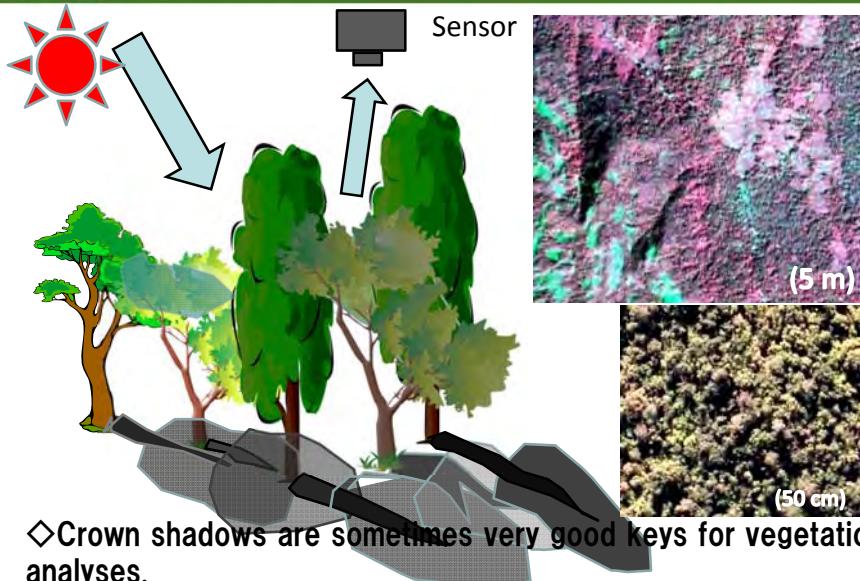
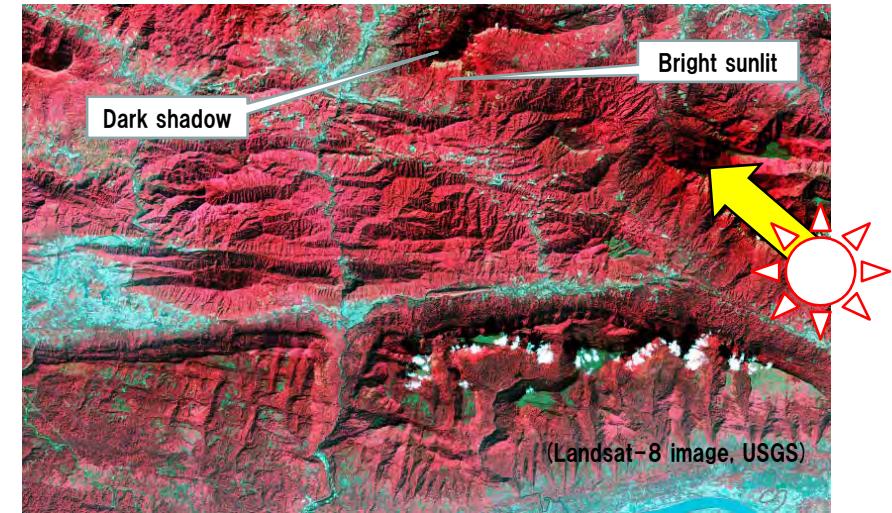
(Landsat 8 LakSao)



- ◊ Reflection of radiation from vegetation depends on the radiative properties of the individual components of vegetation (leaves, stems, soils, water, etc.).
- ◊ The angular distribution of the incident radiation and the orientation of the sensor.



- ◇ Surfaces in shadow appear less bright than surfaces in full sunlight.
- ◇ Irradiance on the slope facing the sun is higher than on the horizontal and the apparent reflectance is also greater.



Correction of Slope and Aspect Effects

① Cosine Correction

$$L_H = \frac{\cos \theta_o}{\cos i} L_T$$

L_H =radiance of slope-aspect corrected RS data

L_T =radiance observed over sloped terrain

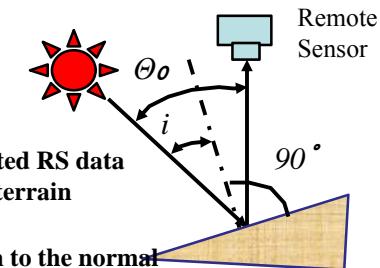
θ_o =Sun's zenith angle

i =Sun's incidence angle in relation to the normal on a pixel.

② Minnaert Correction

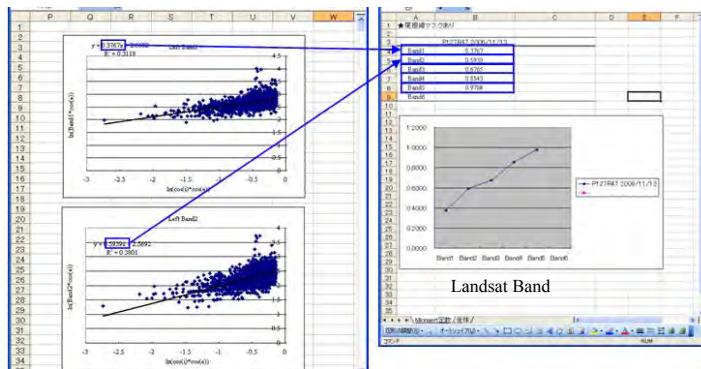
$$L_H = L_T \left(\frac{\cos \theta_o}{\cos i} \right)^k$$

where k = the Minnaert constant.





● Correction of "topographic effect" using DEM and the Minnaert method.



(Oono, 2010)



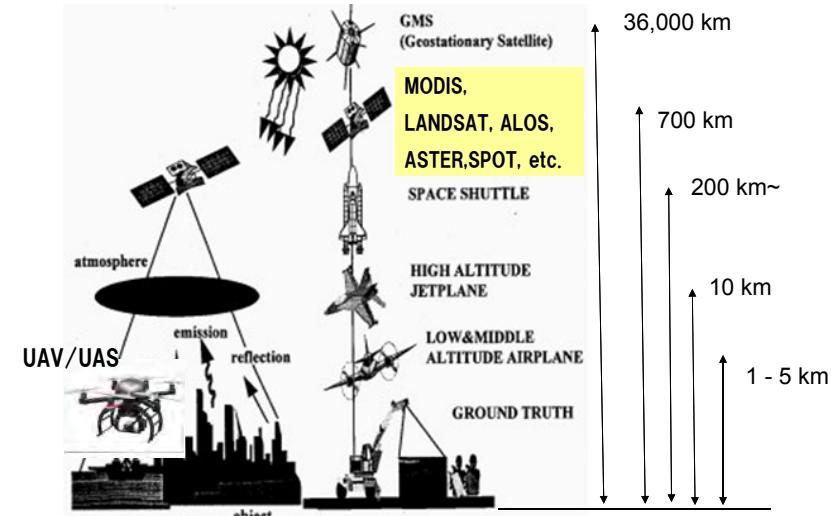
Example of Correction for Slope and Aspect Effects
(The Minnaert Correction)



(Oono, 2010)



4. Earth Observation Systems



(NASA: http://rst.gsfc.nasa.gov/Intro/Part2_1x.html)



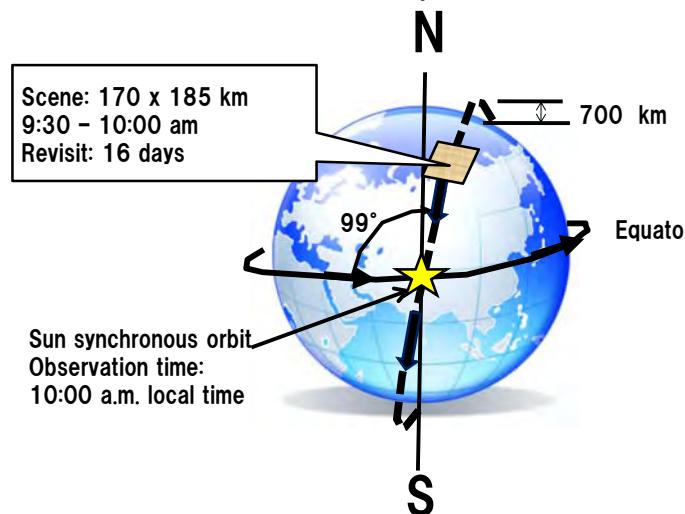
Classification of Small Satellites

Satellite Class	Mass	Cost (US\$)
Large satellite	> 1000 kg	> 20 million
Minisatellites	100 – 1000 kg	5- 20 million
Microsatellites	10 – 100 kg	2 – 5 million
Nanosatellites	1 – 10 kg	< 1 million
Picosatellites	0.1 – 1 kg	
Femtosatellites	1 – 100 g	Satellite-on-a-chip (H.G.Jones)

Small and many satellites may be useful for increasing temporal resolution of remote sensing and to improve chances to obtain cloud-free optical images.



[Satellite Observation System (Ex. Landsat)]



◇Ground resolution (Spatial resolution)

- 0.5 – 1 km

◇ Spectral resolution

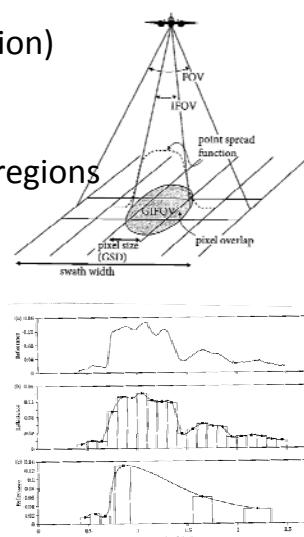
- Number of bands and spectral regions

◇ Radiometric resolution

- 8-bits or 16-bits

◇ Temporal resolution

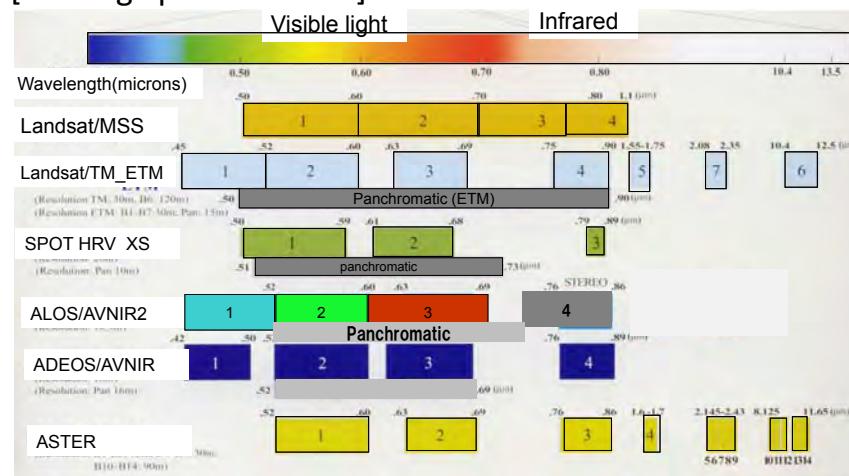
- 2 – 16 days



Sensor resolution	Examples of present sensors	Minimum mapping units	Cost	Utilization for Monitoring
Coarse (250-1000m)	SPOT-VGT(1998-) Terra-MODIS(2000-) Envisat-MERIS (2004-)	~ 100ha ~ 10-20ha	Low or free	Consistent pan-tropical annual monitoring to identify large clearings and locate "hotspots" for further analysis with mid Resolution
Medium (10-60m)	Landsat-TM or ETM+, Terra-ASTER IRS AWIFS or LISS III CBERS HRCCD DMC SPOT HRV	0.5 – 5 ha	Landsat and CBERS became free from 2009; Past data <\$0.001/km ² Recent Data \$0.02 - \$0.5/km ²	Primary tool to map deforestation and estimate area change.
Fine (<5m)	IKONOS Quick Bird Aerial Photos	< 0.1 ha	High or extremely high	Validation of results from analysis with coarser resolution and training of algorithm.



[Sensing Spectral Bands]



- Various spectral bands are designed in order to observe the spectral signatures (characteristics) of objects.



- 250 m ground resolution (Visible and NIR bands)
- Observation frequency: Twice/day
- Available two-week global mosaicked image

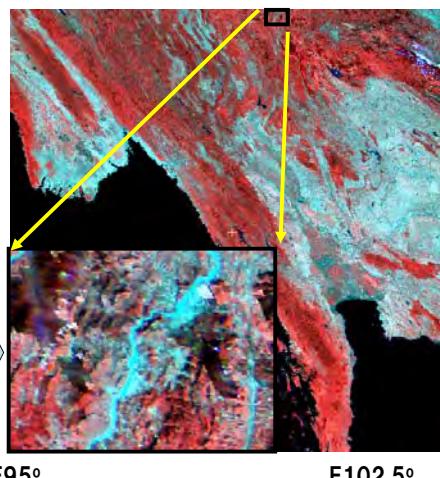


[16 days Mosaic Image]

N17.5°

Channels available:

- _16DAY_250m_500m_VI: 250m 16 days NDVI;
- _16DAY_250m_500m_VI: 250m 16 days EVI;
- _16DAY_250m_500m_VI: 250m 16 days VI Quality;
- _16DAY_250m_500m_VI: 250m 16 days red reflectance;
- _16DAY_250m_500m_VI: 250m 16 days NIR reflectance;
- _16DAY_250m_500m_VI: 250m 16 days blue reflectance;
- _16DAY_250m_500m_VI: 250m 16 days MIR reflectance;
- _16DAY_250m_500m_VI: 250m 16 days sun zenith angle;
- _16DAY_250m_500m_VI: 250m 16 days relative azimuth angle;
- _16DAY_250m_500m_VI: 250m 16 days composite day of the year



Color IR Composite Image
R = NIR (Near Infrared)
G = Red
B = Blue
(250 m ground resolution)

N10°

E102.5°



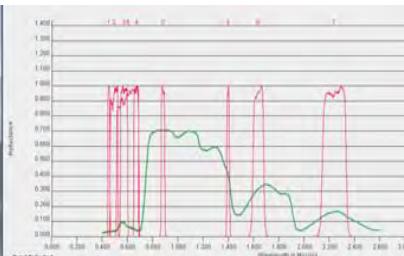
Landsat 8 Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS)
Launched February 11, 2013

Landsat 8 Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS)	Bands	Wavelength (micrometers)	Resolution (meters)
Band 1 - Coastal aerosol	0.43 - 0.45	30	
Band 2 - Blue	0.45 - 0.51	30	
Band 3 - Green	0.53 - 0.59	30	
Band 4 - Red	0.64 - 0.67	30	
Band 5 - Near Infrared (NIR)	0.85 - 0.88	30	
Band 6 - SWIR 1	1.57 - 1.65	30	
Band 7 - SWIR 2	2.11 - 2.29	30	
Band 8 - Panchromatic	0.50 - 0.68	15	
Band 9 - Cirrus	1.36 - 1.38	30	
Band 10 - Thermal Infrared (TIRS) 1	10.60 - 11.19	100 * (30)	
Band 11 - Thermal Infrared (TIRS) 2	11.50 - 12.51	100 * (30)	

* TIRS bands are acquired at 100 meter resolution, but are resampled to 30 meter resolution.

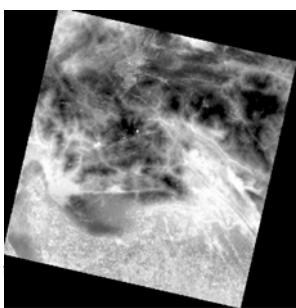


(USGS)

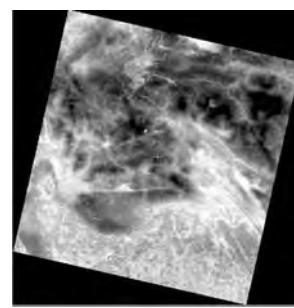


Example of RS Imagery

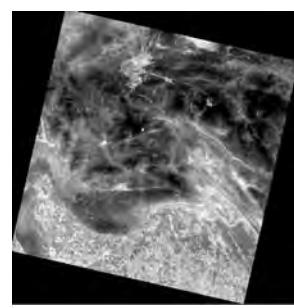
Band 1:



Band 2:



Band 3:



Ocean Blue 0.43–0.45 μm

Statistics	
Number of pixels:	59916801
Mean value:	8984.18
Minimum value:	0
Median value:	11246
Standard deviation:	5408.83
Maximum value:	36484

Blue 0.45 – 0.51

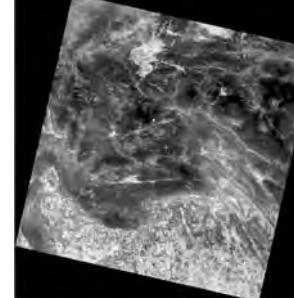
Statistics	
Number of pixels:	59916801
Mean value:	7422.08
Minimum value:	0
Median value:	10274
Standard deviation:	4972.79
Maximum value:	38450

Green

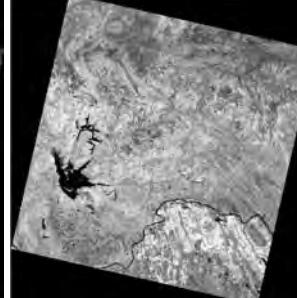
Statistics	
Number of pixels:	59916801
Mean value:	6751.74
Minimum value:	0
Median value:	9295
Standard deviation:	4817.75
Maximum value:	42163

Example of RS Imagery

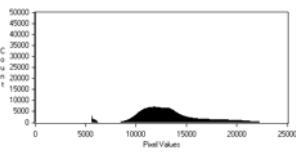
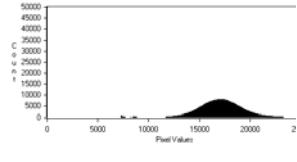
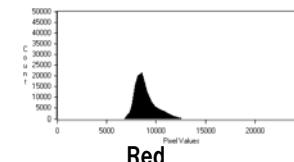
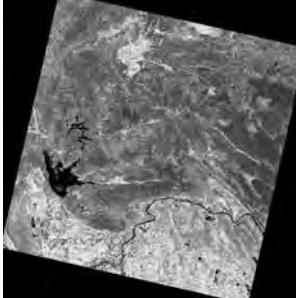
Band 4:



Band 5:



Band 6:



Red

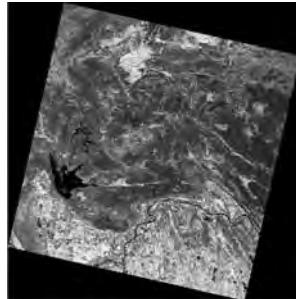
Statistics	
Number of pixels:	59916801
Mean value:	6198.04
Minimum value:	0
Median value:	8226
Standard deviation:	4217.76
Maximum value:	15816

Statistics	
Number of pixels:	59916801
Mean value:	11760.7
Minimum value:	0
Median value:	8105.87
Standard deviation:	51436
Maximum value:	3002.25

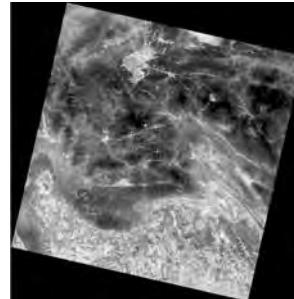
Statistics	
Number of pixels:	59916801
Mean value:	6763.13
Minimum value:	0
Median value:	11434
Standard deviation:	6763.13
Maximum value:	69535

Example of RS Imagery

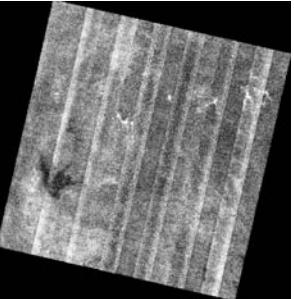
Band 7:



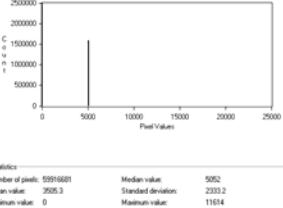
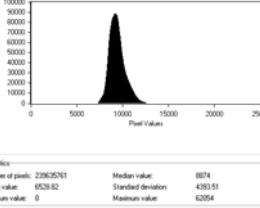
Band 8:



Band 9:



Statistics	
Number of pixels:	59916801
Mean value:	6637.07
Minimum value:	0
Median value:	7770
Standard deviation:	4993.22
Maximum value:	64041

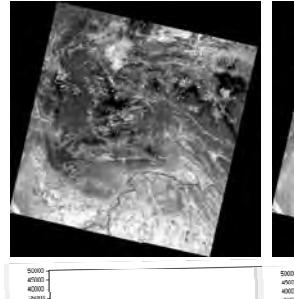


Statistics	
Number of pixels:	22916791
Mean value:	6526.82
Minimum value:	0
Median value:	8874
Standard deviation:	4933.51
Maximum value:	62054

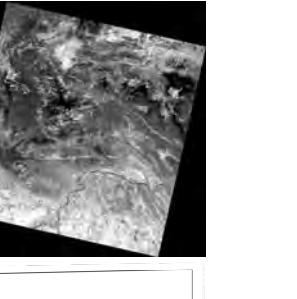
Statistics	
Number of pixels:	59916801
Mean value:	3505.3
Minimum value:	0
Median value:	5052
Standard deviation:	2393.2
Maximum value:	11614

Example of RS Imagery

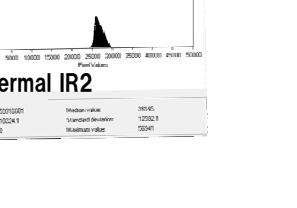
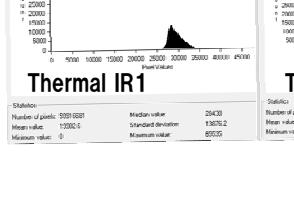
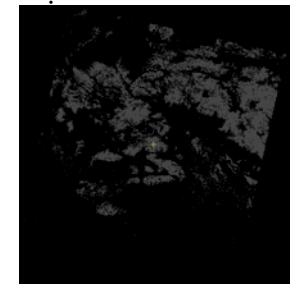
Band 10:



Band 11:



Band BQA



Statistics	
Number of pixels:	59916801
Mean value:	12930.5
Minimum value:	0
Median value:	29430
Standard deviation:	13870.2
Maximum value:	62055

Statistics	
Number of pixels:	59916801
Mean value:	10324.1
Minimum value:	0
Median value:	34515
Standard deviation:	12324.1
Maximum value:	55041

Statistics	
Number of pixels:	59916801
Mean value:	6763.13
Minimum value:	0
Median value:	12241
Standard deviation:	6763.13
Maximum value:	69535

Statistics	
Number of pixels:	59916801
Mean value:	11434
Minimum value:	0
Median value:	12241
Standard deviation:	6763.13
Maximum value:	69535

Statistics	
Number of pixels:	59916801
Mean value:	11434
Minimum value:	0
Median value:	12241
Standard deviation:	6763.13
Maximum value:	69535

Statistics	
Number of pixels:	59916801
Mean value:	11434
Minimum value:	0
Median value:	12241
Standard deviation:	6763.13
Maximum value:	69535

Statistics	
Number of pixels:	59916801
Mean value:	11434
Minimum value:	0
Median value:	12241
Standard deviation:	6763.13
Maximum value:	69535

Statistics	
Number of pixels:	59916801
Mean value:	11434
Minimum value:	0
Median value:	12241
Standard deviation:	6763.13
Maximum value:	69535

Statistics	
Number of pixels:	59916801
Mean value:	11434
Minimum value:	0
Median value:	12241
Standard deviation:	6763.13
Maximum value:	69535

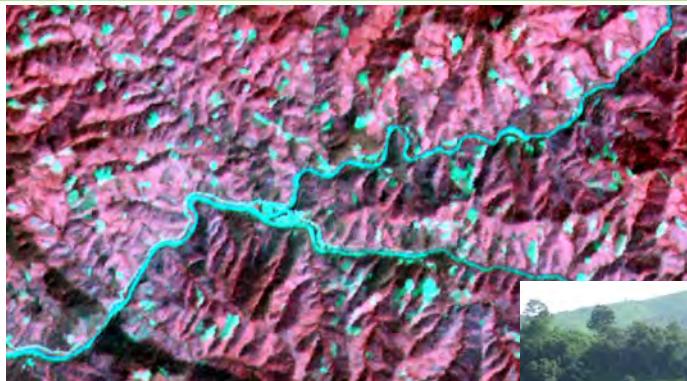
Statistics	
Number of pixels:	59916801
Mean value:	11434
Minimum value:	0
Median value:	12241
Standard deviation:	6763.13
Maximum value:	69535

Statistics	
Number of pixels:	59916801
Mean value:	11434
Minimum value:	0
Median value:	12241
Standard deviation:	6763.13
Maximum value:	69535

Statistics	
Number of pixels:	59916801
Mean value:	11434
Minimum value:	0
Median value:	12241
Standard deviation:	6763.13
Maximum value:	69535

Statistics	
Number of pixels:	59916801
Mean value:	11434
Minimum value:	0
Median value:	12241
Standard deviation:	6763.13
Maximum value:	69535

||
||
||

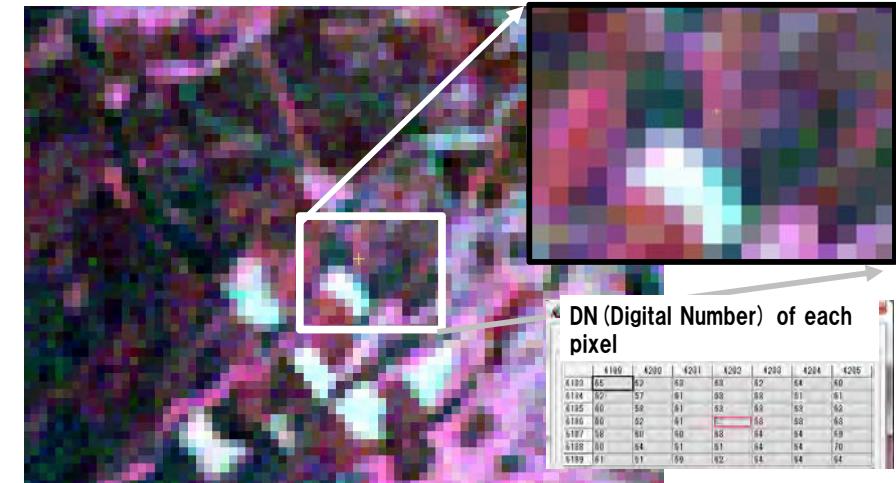


Ground resolution: 10 m



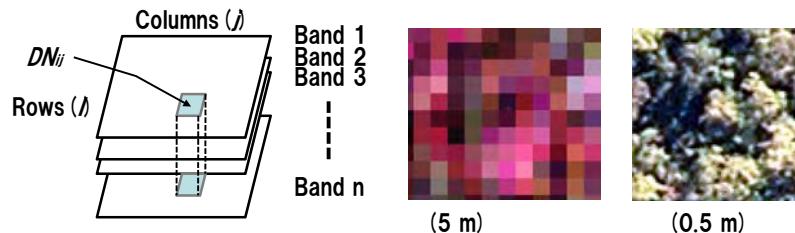
[Picture and Pixels]

Pixel = Element of Image

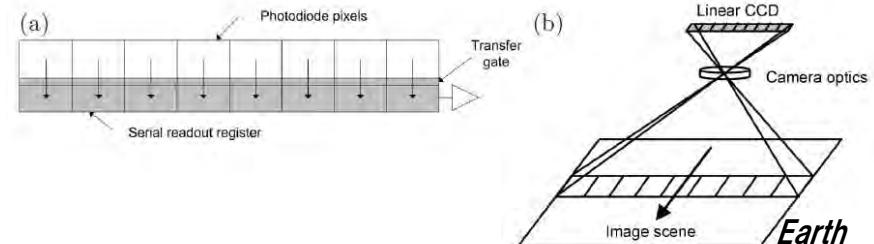


What is in a Pixel?

- ◊ Pixel: A two-dimensional picture element
- ◊ Each pixel at row (i) and column (j) in the image has an original brightness value associated with a digital number (DN) value.
- ◊ The data set may consist of n individual bands of multi-spectral imagery.
- ◊ The n band are all geometrically registered to one another.

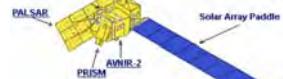
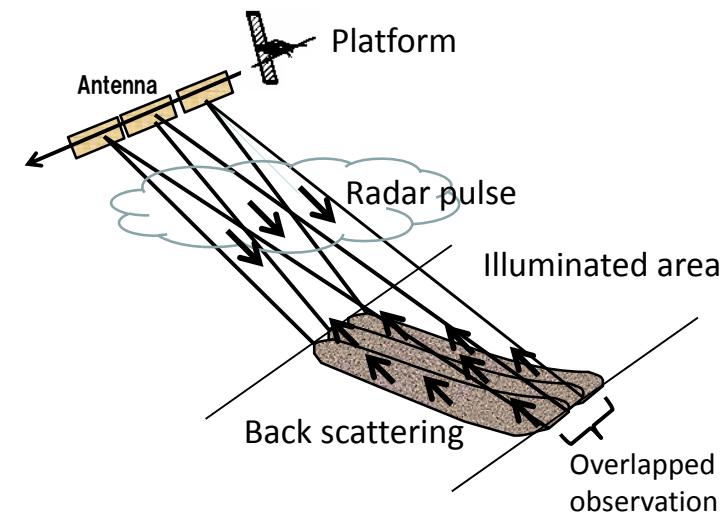
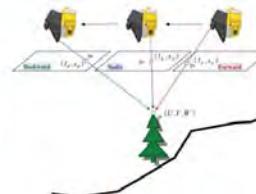
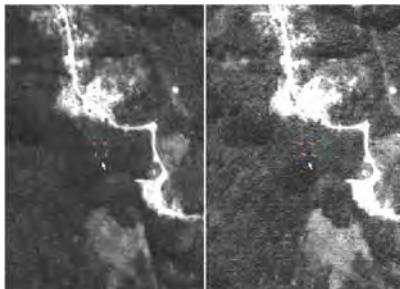


Linear Array “Pushbroom” Sensor (Example)



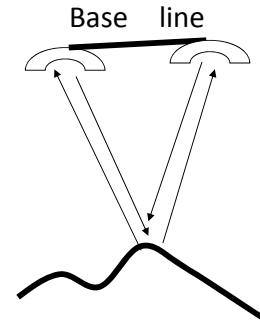
Optical sensors can provide

Three Dimensional Measurement using Optical Sensor Stereo Imagery



SAR acquires images in day-and-night, all weather conditions.
SAR sensors operate in the microwave region (3–70 cm).
Some microwaves penetrate into forest canopies.

(JAXA)

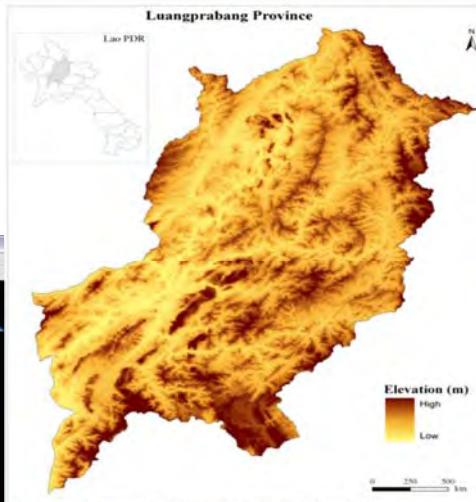


(SRTM Mission, NASA)

- ◊ IFSAR is a technique for using pairs of high resolution SAR images to generate high quality terrain elevation maps, called digital elevation maps (DEMs), using phase interferometry methods.
- ◊ The use of phase-based measurements at microwave frequencies attains height accuracies of 5 - 30 meters.



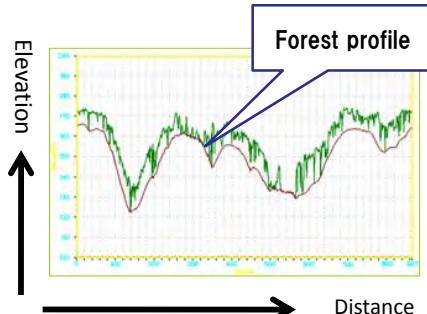
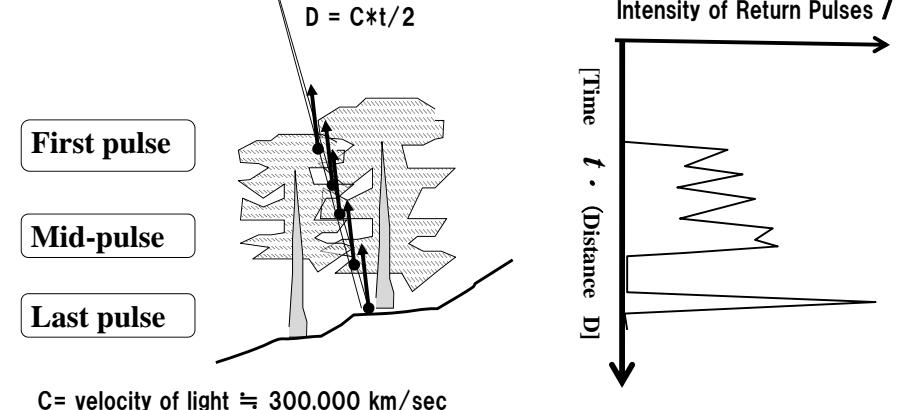
[SRTM Data]



Lidar Technology for Forest Measurement

Lidar Sensing System

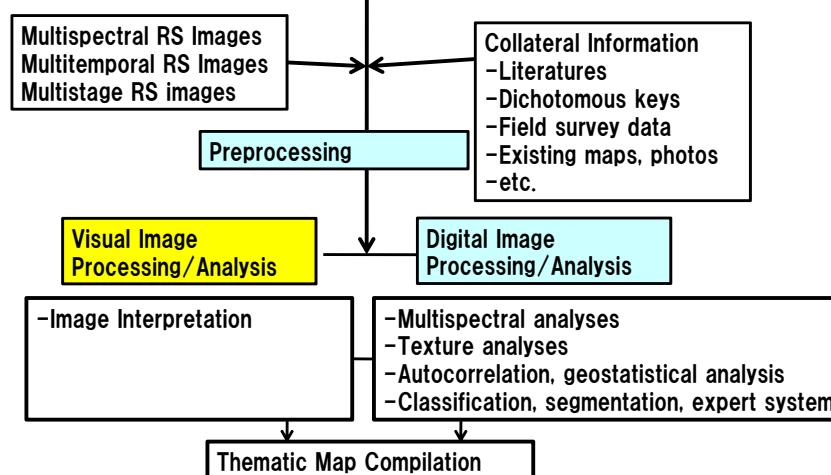
Emitted Lidar Pulse: 100,000-500,000/sec



5. Processing of Optical Remote Sensing Data



Basic Image Analysis Tasks



Geometric Correction of RS Imagery

● Types of Geometric Correction

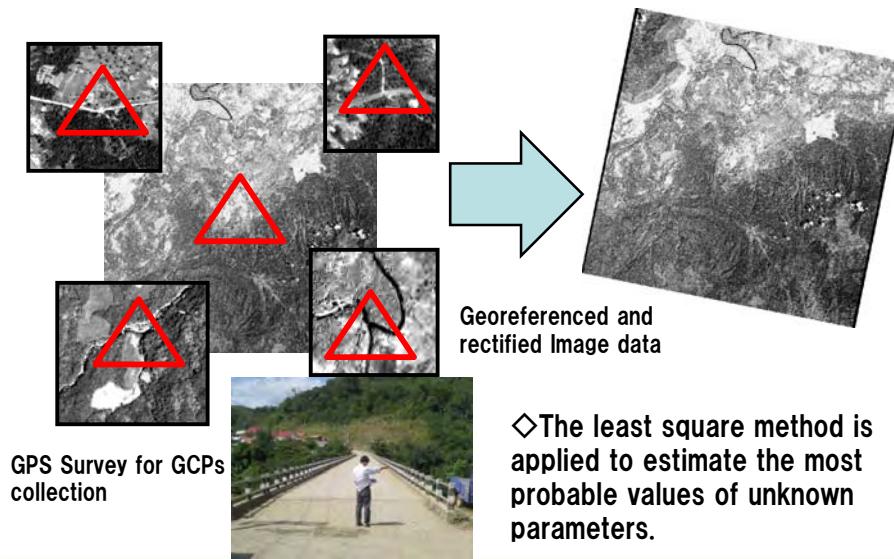
- Image-to-map (GCP) rectification
- Image-to-image registration

● Spatial Interpolation Using Coordinate Transformation

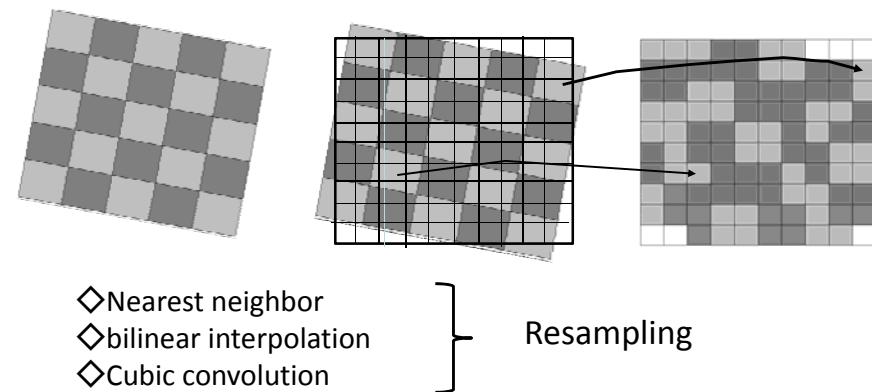
- Helmert Transformation: $X = a + b x + c y$
 $Y = d - c x + b y$
- Affine Transformation: $X = a' + b'x + c'y$
 $Y = d' + ex + f'y$
- Higher-order polynomial Transformation:

$$X = a_0 + a_1 x + a_2 y + a_3 xy + a_4 x^2 + a_5 y^2$$

$$Y = b_0 + b_1 x + b_2 y + b_3 xy + b_4 x^2 + b_5 y^2$$



[Intensity Interpolation in rectification process]



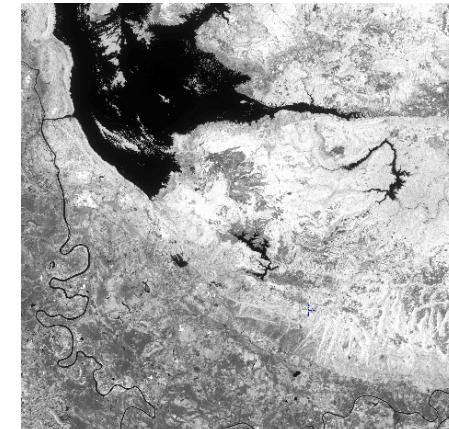


◇Density Slicing

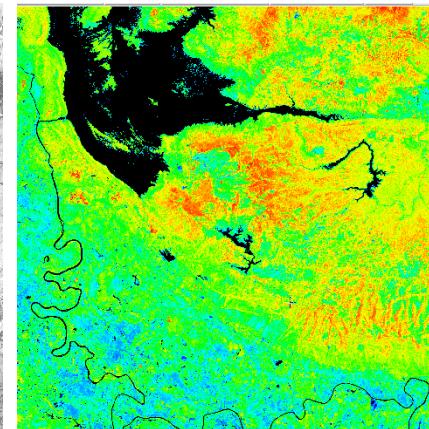
- The human eye/brain system is not very efficient when it comes to quantitative analysis. It is difficult to recognize a particular shade of grey or color if the surroundings changes.
- Density slicing is a technique normally applied to a single-band grayscale values (0-255) for converting into a series of different colors.



[NDVI]



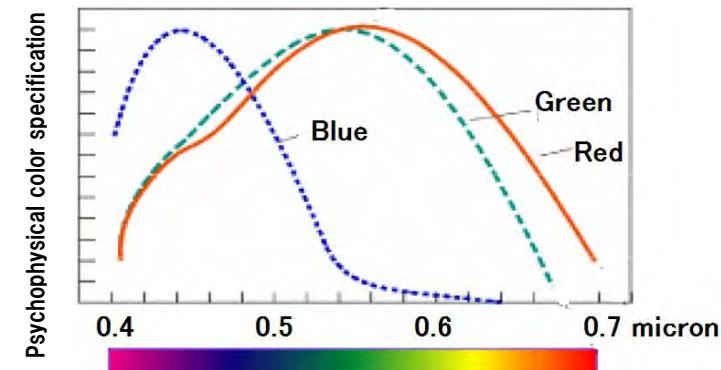
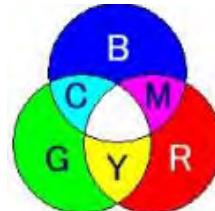
(Grey scale)



(Density slicing, Level slicing)



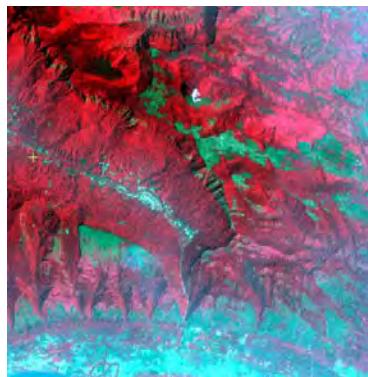
- ◇ Multispectral images → Color composites
 - ◇ Only feasible to view the information from three channels at once
 - ◇ Natural color composite(R:r, G:g, B:b)
 - ◇ Color Infrared composite, False color composite(R:nir, G:r, B:g) is useful for studying the type and condition of vegetation.
- The human eyes are capable of distinguishing small difference of reddish color.



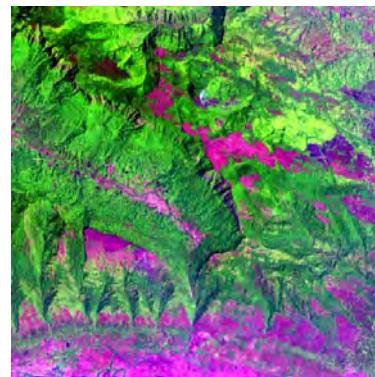
- ◇ The highest sensitivity for green color
- ◇ Wider sensitivity for red color



[Color Composites(LANDSAT8_OLI)]



(RGB=B5,4,3)



(RGB=B6,5,4)

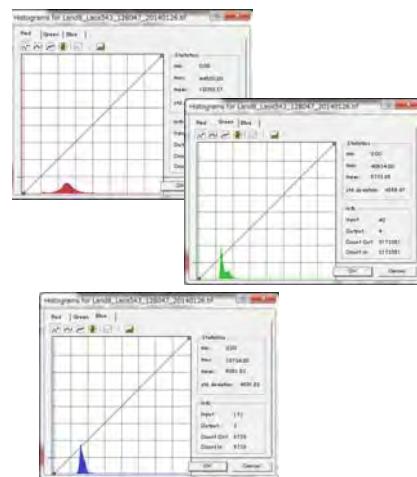
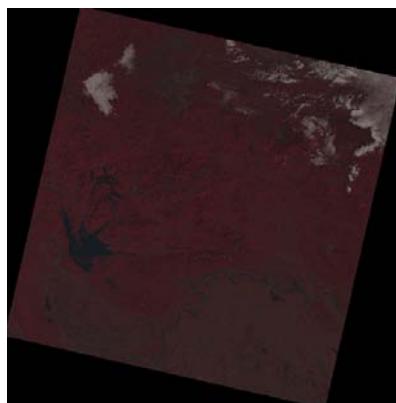


◊ The eye is not very acute at differentiating between small intensity or color variations, whereas a computer can easily distinguish between two adjacent digital numbers.

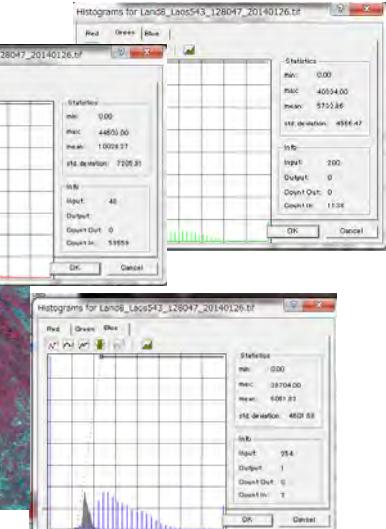
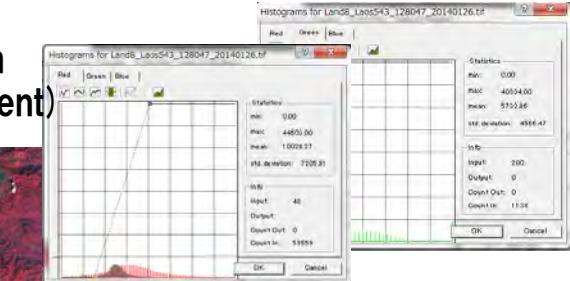
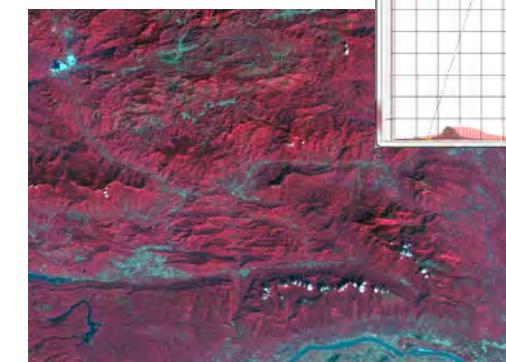
◊ A wide range of data transforms is available to enhance the appearance of images.



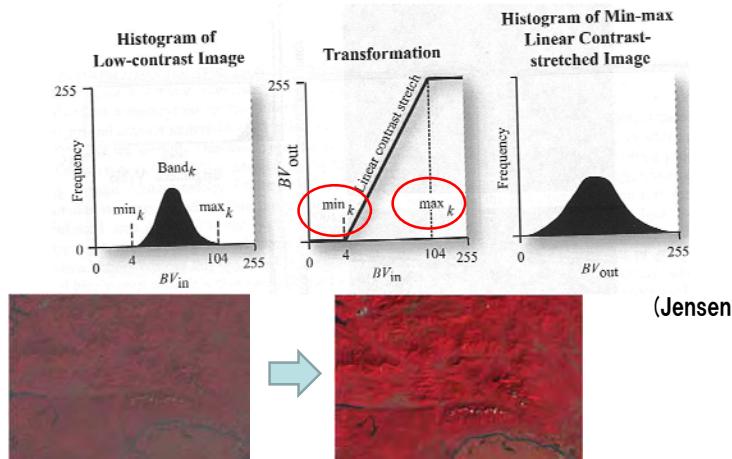
◊ Contrast Stretching



◊ Custom (Custom Histogram Adjustment)

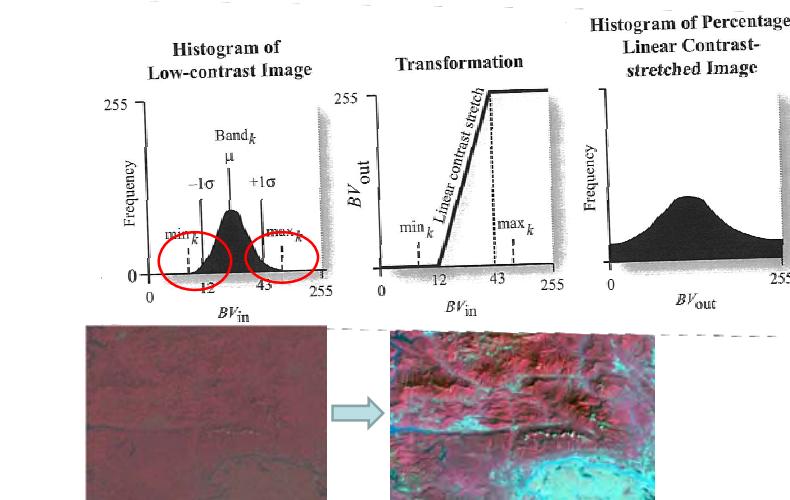


◆Maximum-Minimum Range Adjustment



Not quite good due to cloud coverage.

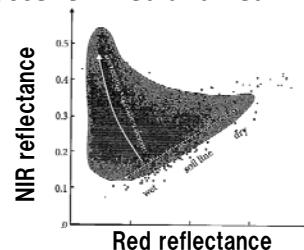
◆Standard Deviation



◆Scientists have known since the 1960s that a *direct* relationship exists between response in the near-infrared region and various biomass measurements.

◆It has also been shown that an *inverse* relationship between the response in the visible region, particularly red, and plant biomass.

◆The best way to show this is to plot all of the pixels in a typical remote sensing scene in red and near-infrared reflectance space.



Distribution of Pixels in Red and Near-infrared Spectral Space

Soil line

(Jensen)



● Simple Ratio: $SVI = \frac{\rho_{red}}{\rho_{nir}}$.

● Normalized Difference Vegetation Index

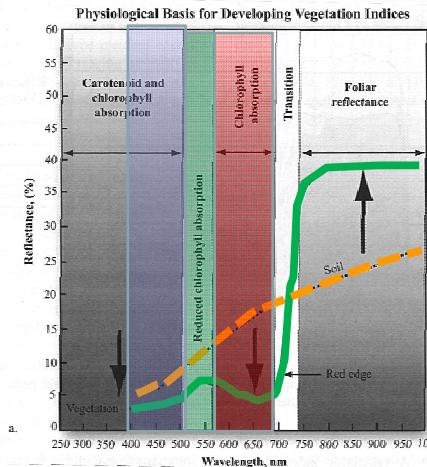
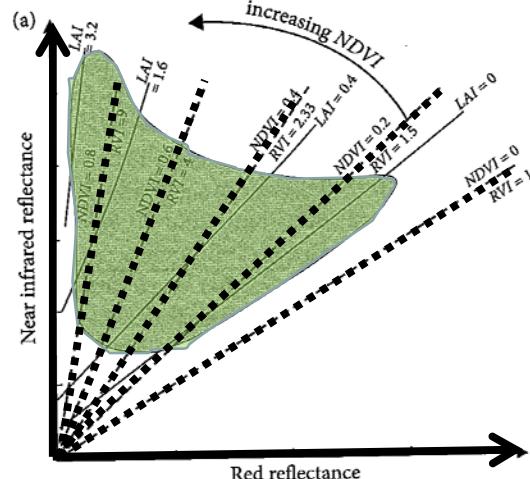
$$NDVI = \frac{\rho_{nir} - \rho_{red}}{\rho_{nir} + \rho_{red}}$$

● Enhanced vegetation Index:

$$EVI = G \frac{\rho^*_{nir} - \rho^*_{red}}{\rho^*_{nir} + C_1 \rho^*_{red} - C_2 \rho^*_{blue} + L} (1 + L)$$

Vegetation Indices

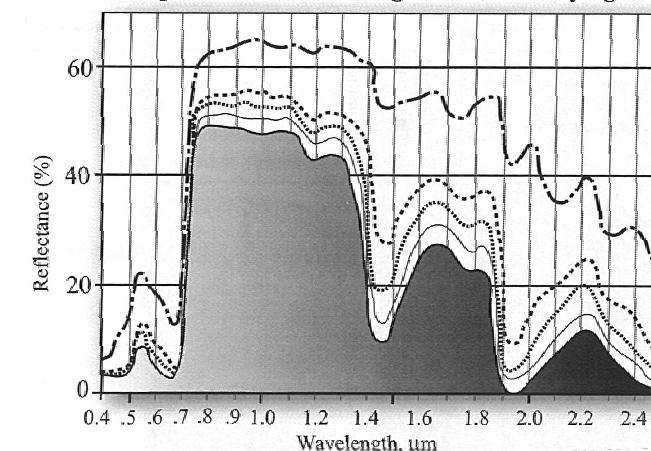
Equal NDVI, equal RVI(=SVI), and equal LAI(Leaf-Area Index) Lines



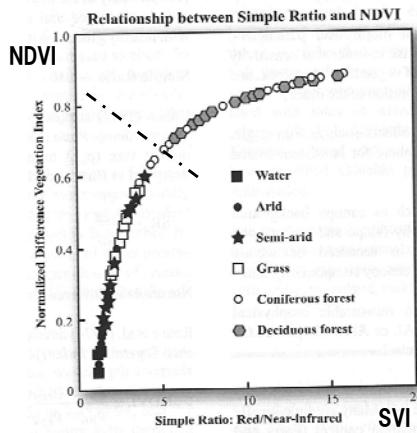
◇ Typical spectral reflectance characteristics for healthy green vegetation and bare dry soil for the wavelength from 0.25 to 1.0 μm .

◇ This is the physiological basis for developing vegetation indices.

Spectral Effects of Progressive Leaf Drying



◇ Reflection response of a single magnolia leaf to decreased relative water content. As moisture content decreased, reflectance increased throughout the 0.4 to 2.5 μm .



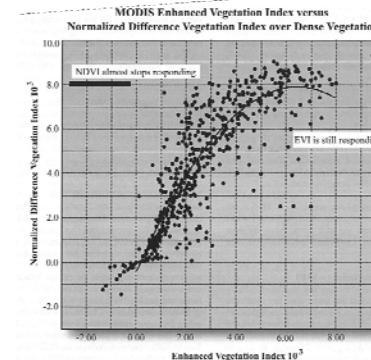
$$SVI = \frac{\rho_{red}}{\rho_{nir}}$$

$$NDVI = \frac{\rho_{nir} - \rho_{red}}{\rho_{nir} + \rho_{red}}$$

◇ The NDVI is a normalized ratio of the near-infrared and red bands, and functionally equivalent to and is a nonlinear transform of the simple ratio.



$$EVI = G \frac{\rho^*_{nir} - \rho^*_{red}}{\rho^*_{nir} + C_1 \rho^*_{red} - C_2 \rho^*_{blue} + L} (1 + L)$$



- ◇ A comparison of the sensitivity of the MODIS-derived NDVI values and MODIS EVI values for dense vegetation (Didan, 2002)
- ◇ Improved sensitivity to high-biomass regions.



6. Use of Multi-Spectral Information for Sensing Vegetation Properties and for Image Classification



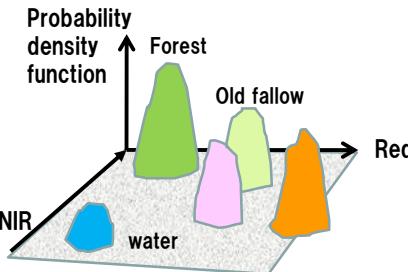
General Steps Used to Extract Thematic Land-Cover Information Using Digital Image Processing Method

- Define purpose and the nature of the land-cover classification problem
- Acquire appropriate RS and initial ground reference data
 - Spatial, spectral, temporal, and radiometric resolution
 - Environmental condition
 - Obtain initial ground reference data based on a priori knowledge of the study area
- Process RS data to extract thematic information
 - Radiometric correction - Geometric correction
 - Selection of the most appropriate bands
 - Image classification - Extract thematic information
- Perform accuracy assessment
- Use the results

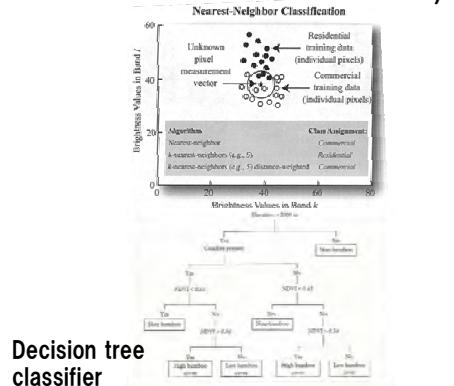


● Image Classification Logics:

- (1) Parametric (e.g., maximum likelihood, clustering)
- (2) Nonparametric (e.g., nearest-neighbor)
- (3) Nonmetric (e.g., rule-based decision-tree classifier)



DOF/FIPD

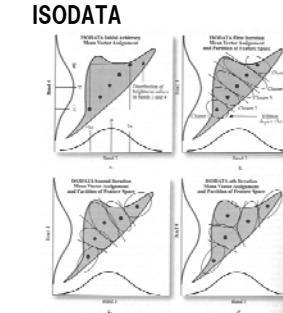
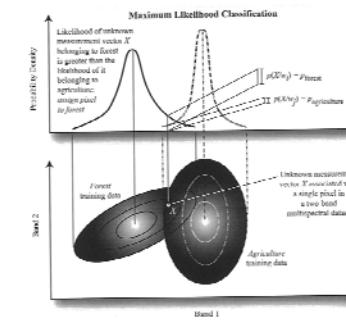


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● Image Classification Algorithm:

- (1) Supervised (maximum likelihood, etc)
- (2) Unsupervised (ISODATA, etc.)
- (3) Hybrid (Expert system, decision-tree, etc)

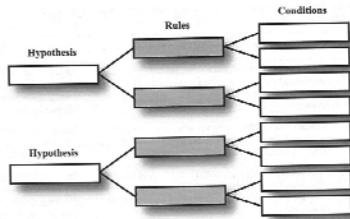


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● Expert System



Hypothesis	Variables	Conditions
White Fir	Aspect Elevation Slope Multispectral	Aspect= 300 to 45 degrees Elevation > 1200 m Slope = 25 to 50 degrees Reflectance Blue = 44 to 52 Green = 32 to 40 Red = 22 to 32 NIR = 30 to 86 NDVI = 0.2 to 0.6

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● Classification Based on Object-oriented Image Segmentation

- ◊ Classification algorithms based on single pixel analysis often are not capable of extracting information we desire from high-spatial-resolution remote sensor data.
- ◊ Improved algorithms are needed that take into account not only the spectral characteristics of a single pixel but those of the surrounding pixels.
- ◊ In addition, we need information about the spatial characteristics of the surrounding pixels so that we can identify areas (or segments) of pixels that are homogenous.

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General Segmentation Function S_f :

$$S_f = w_{color} * h_{color} + (1 - w_{color}) * h_{shape}$$

where the user defined weight for spectral color versus shape is $0 \leq w_{color} \leq 1$,

h_{color} = Spectral heterogeneity (Standard deviation of image data),

h_{shape} = Shape heterogeneity (compactness of shape, smoothness).

● Advantages of Visual Image Interpretation

- ◊ Less time required to create a usable product,
- ◊ Little expense incurred beyond the acquisition of the image,
- ◊ Image illumination "problems" (such as shadows and brightly illuminated surfaces) can be used as an interpretation aid,
- ◊ Minimal expertise required to interpret the image, and
- ◊ Uses the power of the brain.

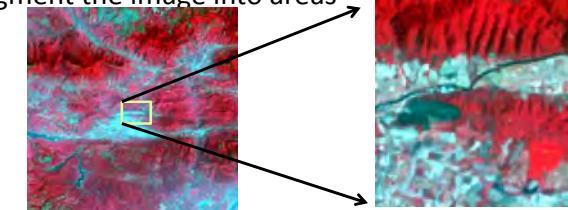


● Understanding the Problem

- ◊ The characteristics of the images (image scale, date and time of acquisition, general geographic coverage, and identified objects and phenomena,
- ◊ the nature of the objects to be interpreted ,
- ◊ the purpose of the interpretation, and
- ◊ any ancillary information about the geographical area (e.g. maps and reports).

● Devising a Plan

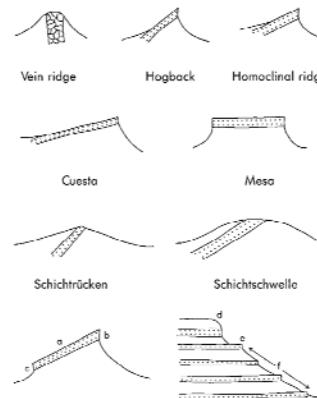
- ◊ Once the problem is understood, a plan for its solution can be devised.
 - Already identified objects \leftrightarrow Interpretation objects
- ◊ Method of search
 - Smallest scale to larger scale search (to minimize bias)
 - General to specific
 - Segment the image into areas





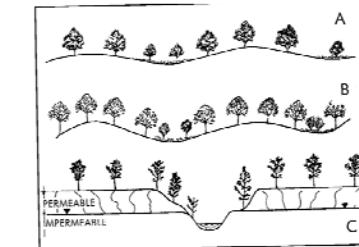
●Convergence of Evidence

- ◊ Very often, what is to be interpreted is not immediately obvious.
- ◊ Image interpreter needs to look at answers to related problems or to similar problems that are of slightly different form.
- ◊ If these known answers point to, or converge on, a single solution to the current problem, then that answer is probably correct.



●Formalization of Plan as Image Interpretation Keys

- ◊ the solution plan should be formalized as much as possible to improve its repeatability.
- ◊ *Image interpretation keys* helps to organize, preserve, and transfer expert knowledge.
- ◊ Image interpretation keys are generally organized by selection or elimination. A very efficient elimination algorithm is found in the *dichotomous key*.



●Carrying out the Plan (Image interpretation)

- ◊ The actual image interpretation should be straightforward.
- ◊ The image interpreter should take care to carry out fully each step of a plan and not jump to conclusion based on preliminary observations.

●Checking the Results

- ◊ The result of the image interpretation should be checked.
- ◊ Whenever possible, the outputs from the image interpretation should be checked in the field.
- ◊ Both final and intermediate outputs should be checked.
- ◊ Higher resolution images can serve as “field check” for lower resolution images.

●Importance of experience and knowledge base

●Basic Elements of Image interpretation

- ◊ Tone and color
- ◊ Geometry of objects
 - Size
 - Shape
 - height
 - Shadow
- ◊ Spatial arrangement of tonal boundaries
 - Texture
 - Pattern
- ◊ Context of objects and phenomena
 - Site
 - Association
 - Time

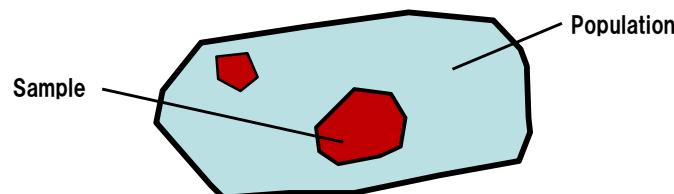


7. Sampling, Errors, and Accuracy Analysis



Fundamental Aspects of Elementary Statistical Sampling Theory

- ◊ **Population:** an infinite or finite set of elements
Satellite RS images= a finite population
- ◊ **Sample:** a subset of the elements taken from a population used to make inferences about certain characteristics of the population



General Steps to Assess the Accuracy of Thematic Information Derived from RS Data

State the nature of the thematic accuracy assessment problem

- discrete or continuous ?
- points or areal sampling units

Select method of thematic accuracy assessment

- Qualitative confidence-building assessment (check by experts)
- Statistical measurements

Select sampling design (scheme)

- Random
- Systematic
- Stratified random
- Stratified systematic unaligned sample
- Cluster sampling

Obtain ground reference data

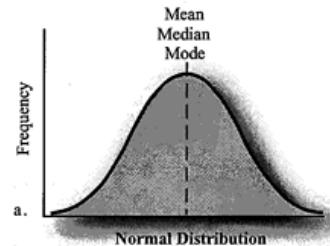
Error matrix creation and analysis

Accuracy assessment report and judgement



◊ **Biased sample:** Observation with certain characteristics which are systematically excluded from the sample deliberately or inadvertently (ex. By selecting image obtained only in the spring of the year)

◊ **Sampling error:** the difference between the true value of a population characteristic and the value of the characteristic inferred from a sample.



- ◊ Large samples drawn randomly from natural populations usually produces a systematical frequency distribution, and is called a normal distribution.
- ◊ Many statistical tests used in the analysis of remote sensing data assume the brightness values recorded in a scene are normally distributed.
- ◊ Unfortunately, remote sensing data may not be normally distributed?

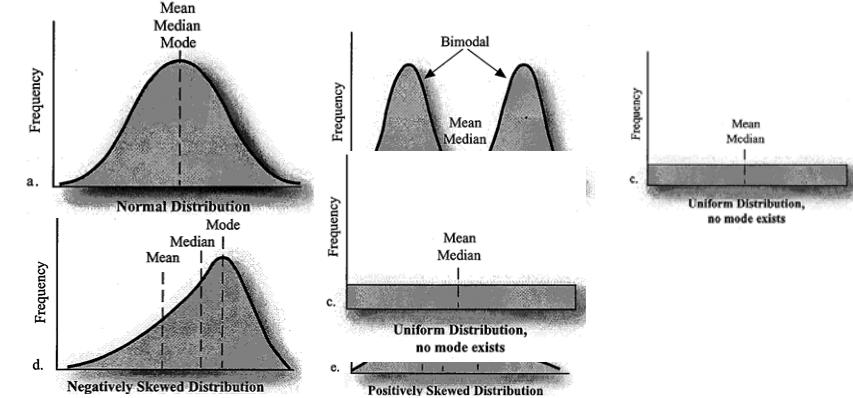
Sources of Error in Thematic Products



Sources of Errors

- ◊ Remote sensing data themselves
- ◊ Geometric error (incorrect geographic location)
- ◊ Radiometric errors (remaining atmospheric and topographic effect errors)
- ◊ Classification error (Image interpretation error, digital classification error)
- ◊ Errors of reference data (Ground Truth data).
Difference of time or date of RS and Ground Truth data.

(Jones)



- ◊ The histogram is a useful graphic representation of the information content of a data.



Sampling Strategies

[Sampling Strategies]





[Sampling Strategies]

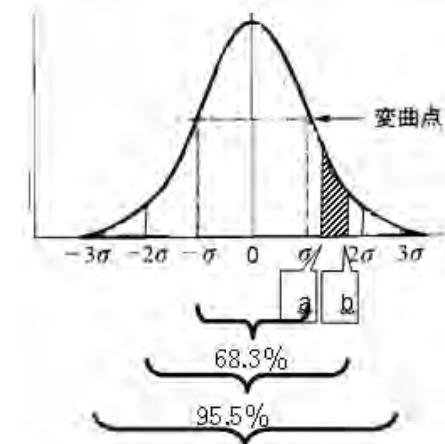
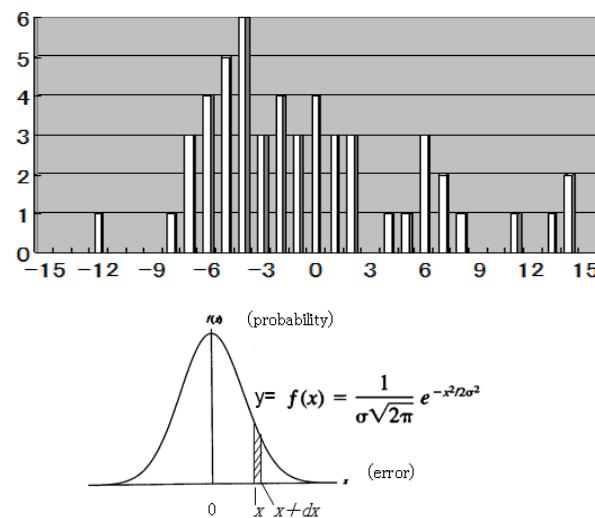
Name	Advantages	Disadvantages
Random	◊Statistically optimal ◊Avoid bias	◊Smaller categories may be undersampled or missed ◊Possible inaccessibility of points in difficult terrain
Stratified random	◊Reduces chance of undersampled categories ◊Largely avoids bias ◊Often the most efficient strategy	◊Possible inaccessibility of points
Regular	◊Ease of sampling	◊Lacks true statistical randomness ◊Possible bias for linear feature
Clustered	◊Reduce travel time in the field	◊Possibility of autocorrelation
Transect	◊Ease of access and sampling	◊Generally non random (Jones)



Wall-to-wall vs.

Sampling

- No data omission in the project area
- Large effort and cost
- Difficult to obtain cloud free data
- Applicable to sub-national or project levels
- Accuracy is varied by sampling rate (more than 20% is required for accurate estimation (Hirata, 2011))
- Enable to reduce effort and cost
- Easier to obtain cloud free data
- Difficult to apply sub-national or project levels





The Chi-Square Statistic

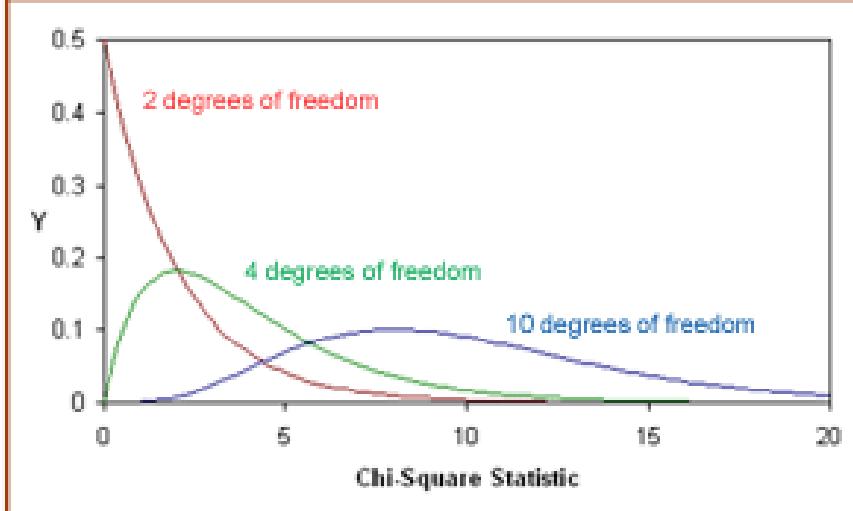
Suppose we conduct the following [statistical experiment](#). We select a random sample of size n from a normal population, having a standard deviation equal to σ . We find that the standard deviation in our sample is equal to s . Given these data, we can define a [statistic](#), called **chi-square**, using the following equation:

$$\chi^2 = [(n - 1) * s^2] / \sigma^2$$

If we repeated this experiment an infinite number of times, we could obtain a [sampling distribution](#) for the chi-square statistic. The **chi-square distribution** is defined by the following [probability density function](#):

$$Y = Y_0 * (X^2)^{(\nu/2 - 1)} * e^{-X^2/2}$$

where Y_0 is a constant that depends on the number of degrees of freedom, X^2 is the chi-square statistic, $\nu = n - 1$ is the number of [degrees of freedom](#), and e is a constant equal to the base of the natural logarithm system (approximately 2.71828). Y_0 is defined, so that the area under the chi-



Calculate Chi-square statistic

With these sets of figures, we calculate the chi-square statistic as follows:

$$\text{Chi - square} = \text{Sum of } \frac{(observed \times frequency - expected \times frequency)^2}{(expected \times frequency)}$$

In the example above, we get a chi-square statistic equal to:

$$\chi^2 = \frac{(46 - 40.97)^2}{40.97} + \frac{(37 - 42.03)^2}{42.03} + \frac{(71 - 76.03)^2}{76.03} + \frac{(83 - 77.97)^2}{77.97}$$

$$\chi^2 = 1.87$$

Assess significance level

Lastly, to determine the significance level we need to know the "degrees of freedom." In the case of the chi-square test of independence, the number of degrees of freedom is equal to the number of columns in the table minus one multiplied by the number of rows in the table minus one.

In this table, there were two rows and two columns. Therefore, the number of degrees of freedom is:

$$df = (2 - 1) \times (2 - 1) = 1$$

We then compare the value calculated in the formula above to a standard set of tables. The value returned from the table is $p < 20\%$. Thus, we cannot reject the null hypothesis and conclude that boys are not significantly more likely to get in trouble in school than girls.



Sample Size Based on Binomial Probability Theory (Fitzpatrick-Lins(1981))

$$\text{Sample size } N = \frac{Z^2(p)(q)}{E^2}$$

where P is the expected percent accuracy of the entire map, $q = 1 - p$, E = allowable error, $Z = 2$ from the standard normal deviate of 1.96 for the 95% two-side confidence level.

For a sample for which the expected accuracy is 85% at an allowable error of 5%, the number of points necessary for reliable results is: $N = 2^2 (85)(15) / 5^2 = \text{a minimum of 203 points.}$



Sample Size Based on Multinomial Distribution (Congalton and Green(1999))

$$\text{Sample size } N = \frac{B\Pi_i(1 - \Pi_i)}{b_i^2}$$

where Π_i = the proportion of a population in the i th class out of k classes that has the proportion closest to 50%, b_i is the desired precision (e.g., 5%) for this class, B is the upper $(\alpha/k) \times 100$ th percentile of the chi square (χ^2) distribution with 1 degree of freedom, and k is the number of classes.



In general, Greek letters are used for measures of the population (called "parameters") and Latin letters are used for measures of one or more samples (called "statistics"). The pronunciation and vernacular for each symbol is included as well.

Concept	Symbol	
	Population	Sample
Number of Observations (size)	N (big "en")	n (little "en")
Mean	μ ("mu")	\bar{x} ("x-bar")
Variance	σ^2 (lower case "sigma" squared)	s^2 ("ess-squared")
Standard Deviation	σ (lower case "sigma")	s ("ess")
Proportion	π (lower case "pi")	p (little "pea")
Correlation Coefficient	ρ (lower case "rho")	r (little "are")



Sample Size Based on Multinomial Distribution (Congalton and Green(1999))

$$\text{Sample size } N = \frac{B\Pi_i(1 - \Pi_i)}{b_i^2} \quad \Pi_i$$

For example, a land-cover map contains 8 classes ($k=8$) and we know that class Π_i occupies approximately 30% of the map area and that this proportion is closest to 50%. We desire a level of confidence of 95% and a precision (b_i) of 5%.

B is determined from the χ^2 table with 1 degree of freedom and $1 - \alpha/k$ as $\chi^2_{(1,0.99375)} = 7.568$:

$$1 - \frac{\alpha}{k} = 1 - \frac{0.05}{8} = 0.99375 \quad N = \frac{7.568(0.30)(1 - 0.30)}{0.05^2}$$

$$N = \frac{1.58928}{0.0025} = 636 \text{ samples}$$

These 636 samples should be randomly selected to adequately fill the error matrix.

About 80 samples per class are required (e.g., $8 \times 80 = 640$).



If we have no idea about the proportion of any of the classes in the land-cover map, then we can use the worst-case multinomial distribution algorithm where we assume that one class occupies 50% of the study area:

$$N = B / 4 b^2$$

Holding the precision constant at 5% for all k classes yields:

$$N = 7.568 / \{4 (0.05^2)\} = 757 \text{ samples}$$

Thus, 757 random samples would have to be obtained because we did not have priori knowledge about the true proposition of any of the k classes in the worst-case scenario. (Jones)



Confidence interval = 85 %

$$\chi^2_{(1,0.98125)}$$

Precision = 5% Value for B = 5.695.

$$1 - \frac{\alpha}{k} = 1 - \frac{0.15}{8} = 0.98125 \quad N = \frac{5.695(0.30)(1 - 0.30)}{0.05^2}$$

Approximately 60 samples per class

- ◊ It is not always possible to obtain such large numbers of random samples. A balance between what is statistically sound and what is practicably attainable must be found.
- ◊ Collect a minimum of 50 samples for each class in the error matrix. 75 to 100 samples.
- ◊ The number of samples can also be adjusted based on the relative importance of the categories.
- ◊ Obtain an unbiased, representative sample.



Reference Data

Classification Data	Evergr.	Mixed Dec.	Dry Dip	Coni	Water	Row total	User's accuracy
Evergreen	70	5	0	13	0	88	=70/88=80% 20% com.error
Mixed Dec	3	55	0	0	0	58	=55/58=95% 5% com.error
Dry Dip	0	0	99	0	0	99	=99/99=100% 0% com.error
Coniferous	0	0	4	37	0	41	=37/41=90% 10% com.error
Water	0	0	0	0	121	121	121/121=100% 0% com.error
Col.total	73	60	103	50	121	407	Overall accuracy
Producer's Accuracy	=70/73 =96%	=55/60 =92%	=99/103 =96%	=37/50 =74%	=121/121 =100%		382/407 =94%
Omission error	4%	8%	4%	26%	0%		



Error Matrix (Classification accuracy assessment)

- ◊ *Overall accuracy*: The total of correctly classified samples (values in the major diagonal) divided by the total number of samples
- ◊ *Producer's accuracy*: The number of correct samples for a class
- Omission error : The number of known samples for that class that were not correctly identified
- ◊ *User accuracy*: One divides the number of correctly classified samples in a category by the total number of classified in that group (reliability of the classification, commission error)



Kappa Analysis

$$\hat{K} = \frac{N \sum_{i=1}^k x_{ii} - \sum_{i=1}^k (x_{i+} \times x_{+i})}{N^2 - \sum_{i=1}^k (x_{i+} \times x_{+i})}$$

k: Number of categories (classes) :

N: Number of Ground reference test samples=407

$$\sum_{i=1}^k x_{ii} = (70+55+99+37+121) = 382$$

$$\sum_{i=1}^k (x_{i+} \times x_{+i}) = (88 \times 73) + (58 \times 60) + (99 \times 103) + (41 \times 50) + (121 \times 121) = 36,792$$

$$\text{Thus, } \hat{K} = \frac{407 \times (382) - 36792}{407 \times 407 - 36792} = \frac{(155474 - 36792)}{(165649 - 36792)} = 118682/128857 = 0.92 = 92\%$$

$\hat{K} = 0$ =====> No agreement

$\hat{K} = 1$ =====> Perfect match between the classification output and the reference data



8. Summary

- ◊ RS practice needs many fundamental knowledge of sciences and technology.
- ◊ The lecture “theory of remote sensing” tried to cover very basic topics from radiation physics to accuracy analysis of final results.
- ◊ In addition to these basic knowledge, practical study of image interpretation combined with field works would be useful to improve skills for the remote sensing image analysis.

(Kopchai LaiLai)



Theory of Remote Sensing

Part 2

Photo Interpretation Practice

Technical Training
July 22st - August 1st, 2014

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Mitsuru NASU, Ph.D.
Forest Remote Sensing



● Understanding the Problems

- ◊ Correction of FIM utilizing RadidEye Images of 2010
- ◊ Mapping Old Fallows2010 using ALOS/PALSAR Images
- ◊ Mapping Decidus/Evergreen Forest Types using Spectral and Spatial Data
- ◊ Mapping of Forest/Non-forest Maps (SPOT Images 2005 and the Corrected 2010 FIM)----4 km Grid Points
- ◊ Mapping of Forest/Nonforest Maps (LANDSAT 2000 and the Corrected 2010 FIM)----4 km Grid Points
- ◊ Accuracy of Forest/Nonforest 80%, Forest Types 70%
Accuracy Assessment by ALOS/PRISM(2.5m)+AVNIR2 Pan-sharpen Images

DOF/FIPP

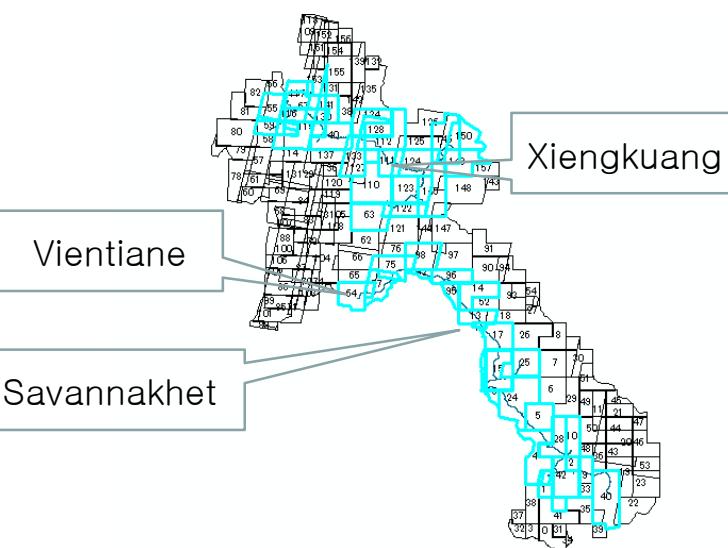
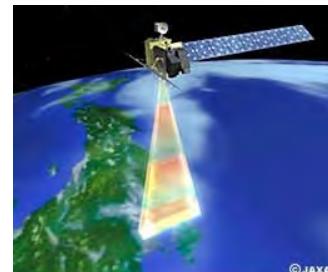
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2



■ ● The characteristics of the images

- ◊ RapidEye-2010 (5 m)
- ◊ SPOT5-2005 (5 m)
- ◊ LANDSAT-2000 & 2014 (15+30 m)
- ◊ ALOS/AVNIR2 (2.5 m +10 m)



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4



● Basic Elements of Image interpretation

◇ Tone and color

◇ Geometry of objects

- Size

- Shape

- height

- Shadow

◇ Spatial arrangement of tonal boundaries

- Texture

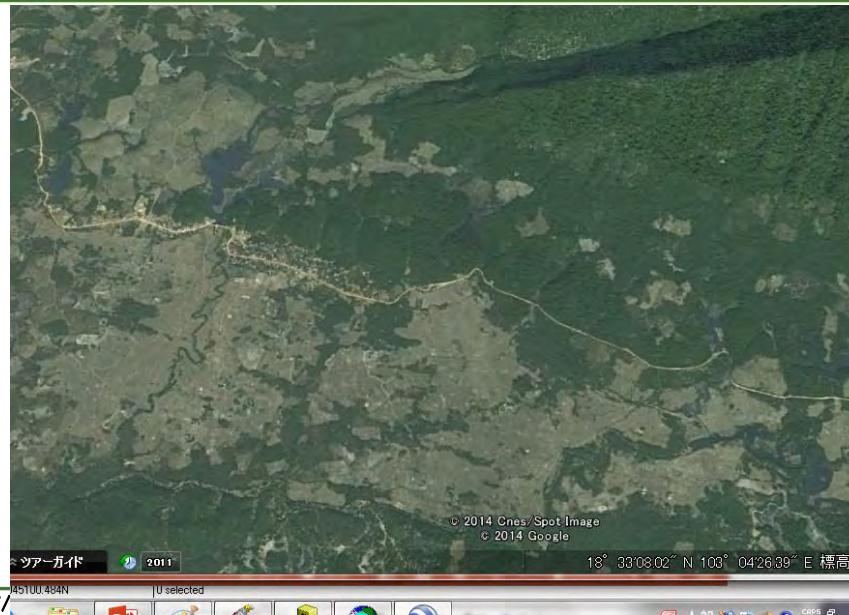
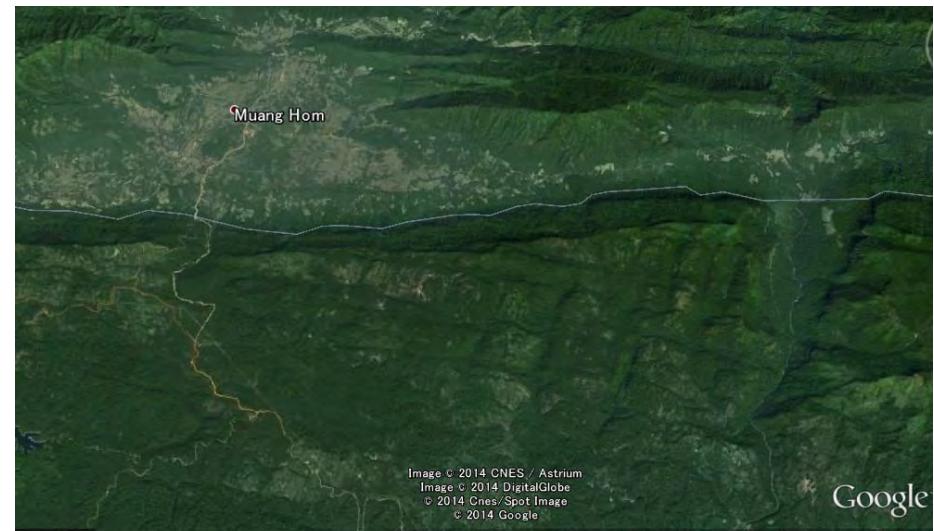
- Pattern

◇ Context of objects and phenomena

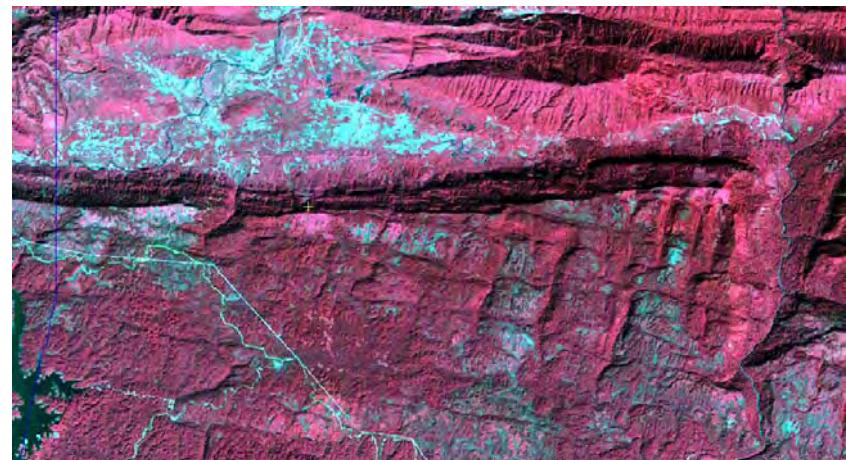
- Site

- Association

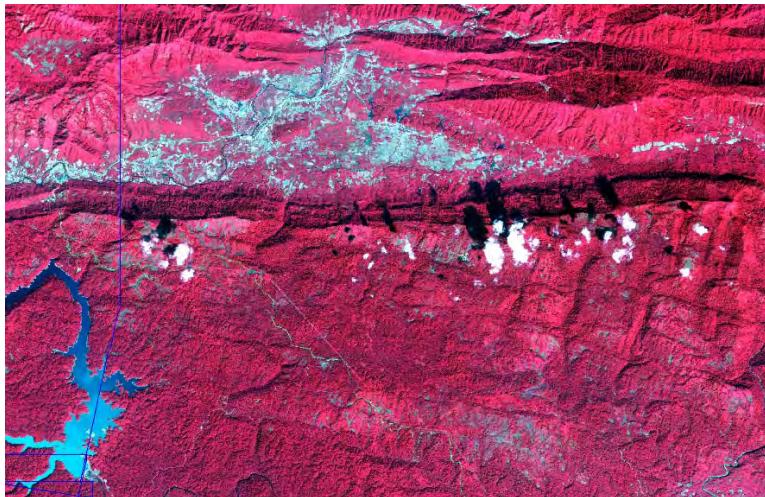
- Time



Landsat 1999/12/27



■ SPOT 33-0401 2005

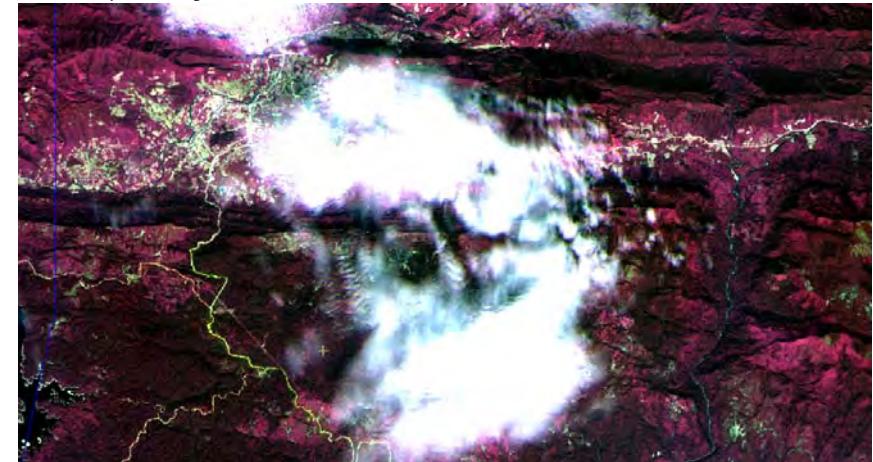


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RapidEye 04391901

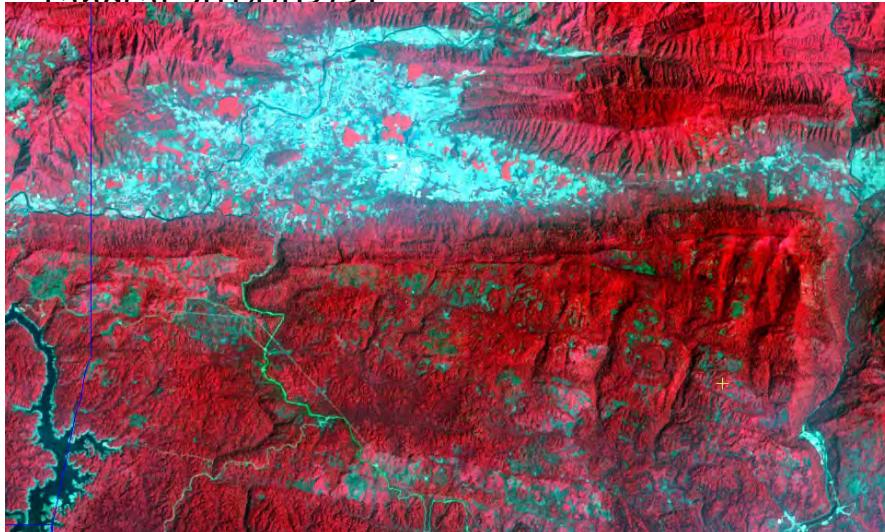


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Landsat 2014/02/21

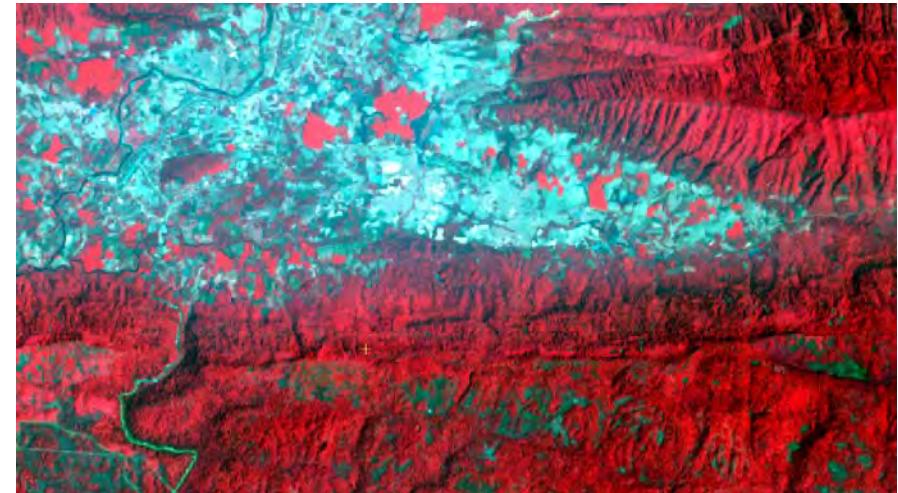


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11

■ 2014 Landsat8 Enlarged



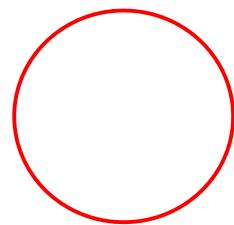
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12



Aerial Photos



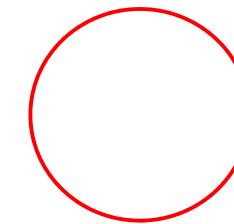
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13



Aerial Photos



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Aerial Photo3



Enlarged Aerial



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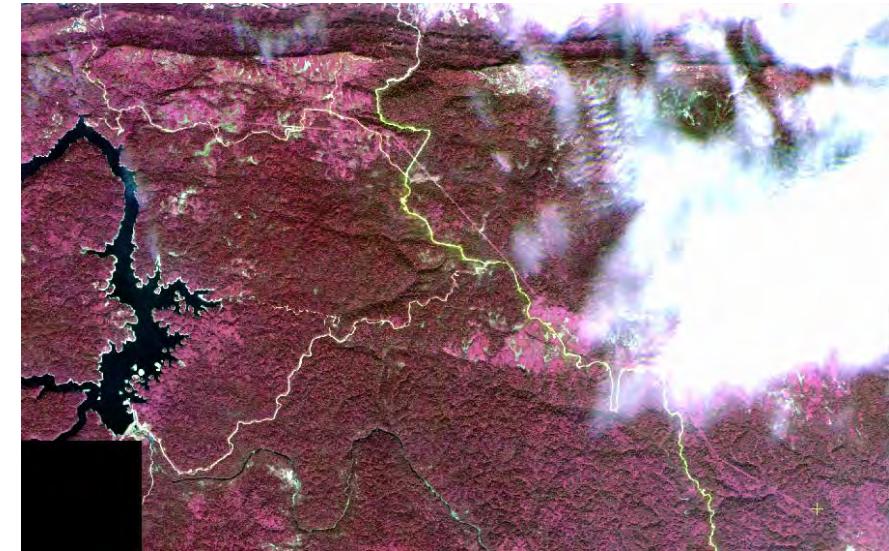
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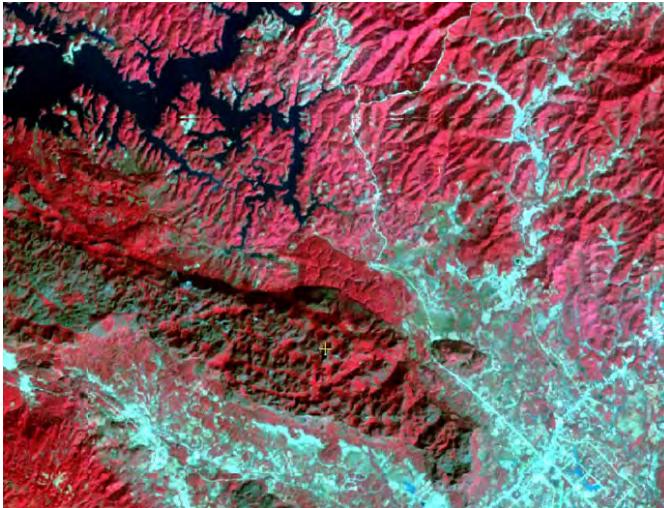
16

Rubber Plantation?



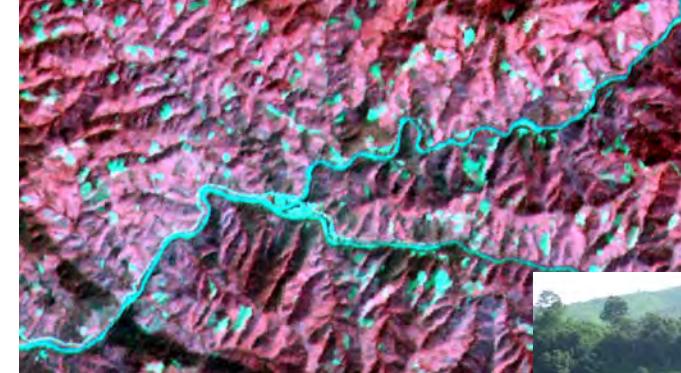


Reflectance of Various Features



(Landsat 8 Lak Xao)

SPOT 5 Image (Example)

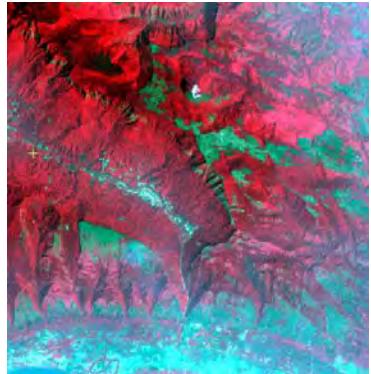


Ground resolution: 10 m

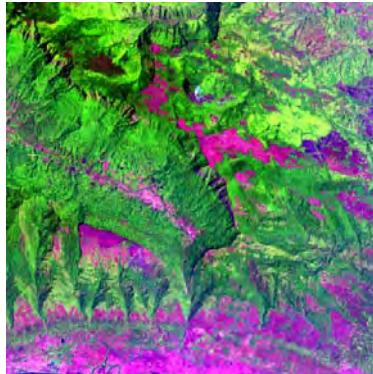




[Color Composites(LANDSAT8_OLI)]



(RGB=B5,4,3)



(RGB=B6,5,4)



● Basic Elements of Image interpretation

- ◊ Tone and color
- ◊ Geometry of objects
 - Size
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 - Pattern
- ◊ Context of objects and phenomena
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Theory of Remote Sensing

Part 3

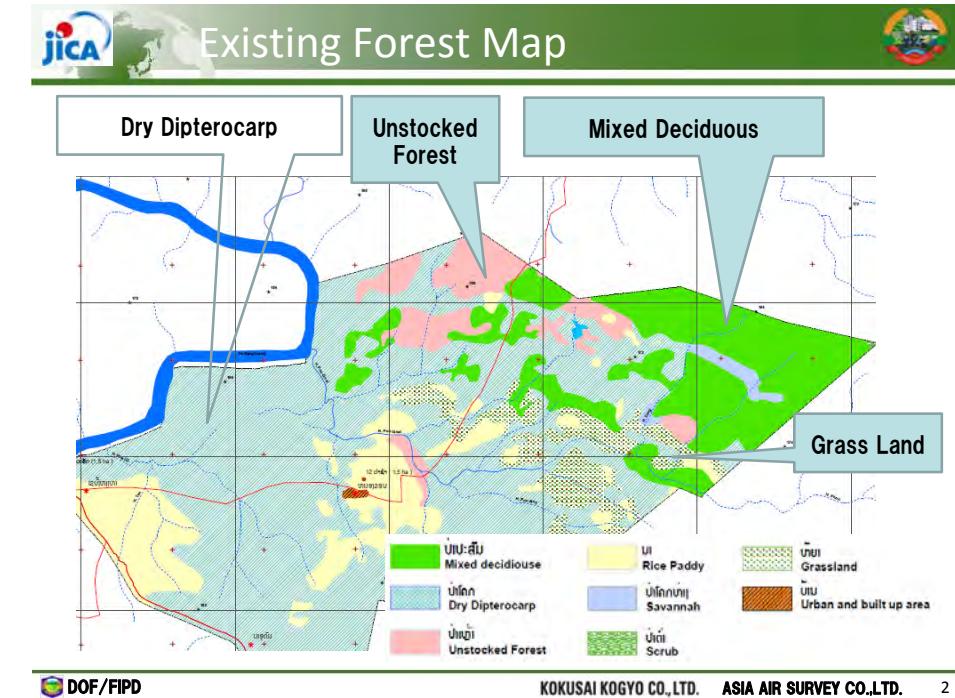
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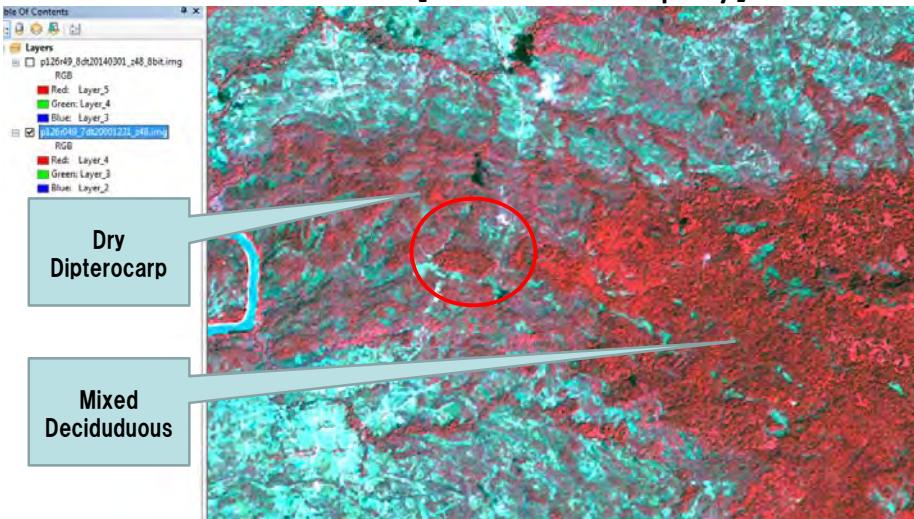


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Forest Remote Sensing



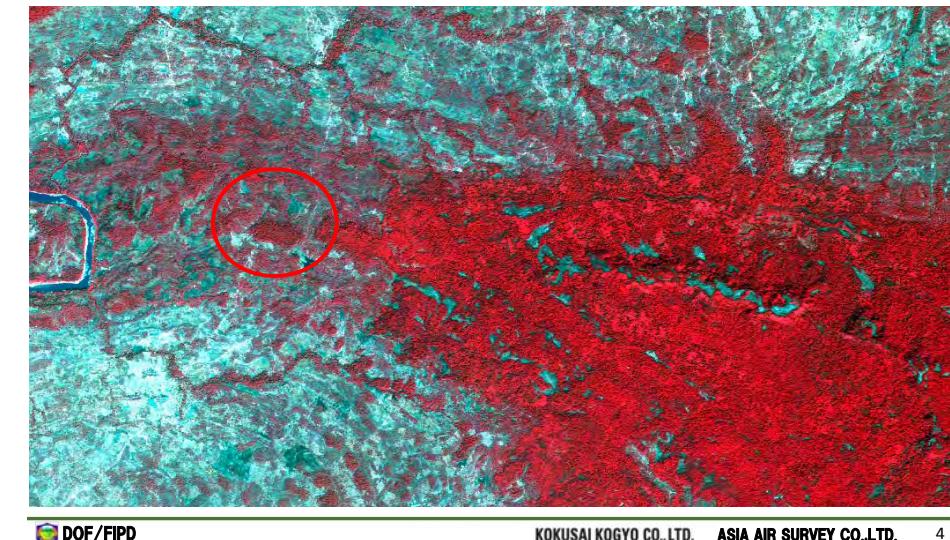
jica Landsat 2000

Savannakhet Landsat 2000
P126R49-20001231[standdev.display]

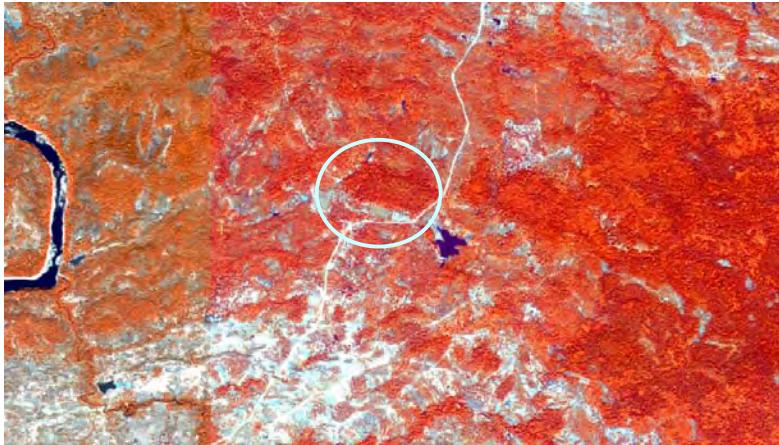


jica SPOT 2005

SPOT5 2005 - SK1004-56-0601



RapidEye 2010---20101227t-042418-01
20101121t-043029-02a



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Landsat8 2014/03/1

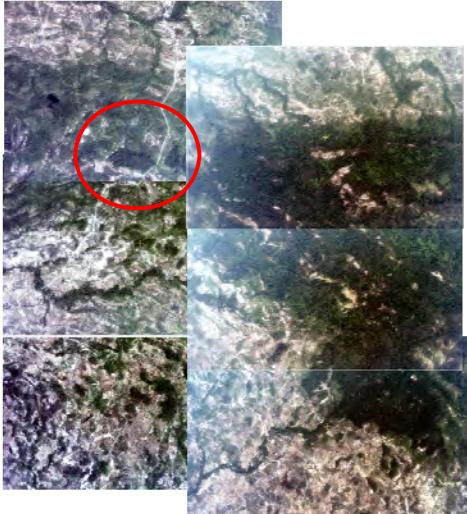
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Green: Layer_4	Green: Layer_3
Blue: Layer_3	Blue: Layer_2
p12049_7d20001231_u48.img	RGB
Red: Layer_4	Red: Layer_4
Green: Layer_3	Green: Layer_3
Blue: Layer_2	Blue: Layer_2



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6



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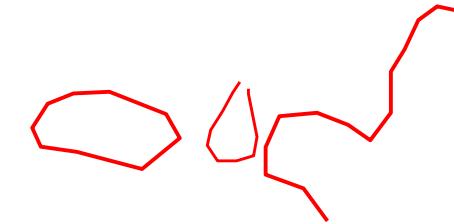
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7

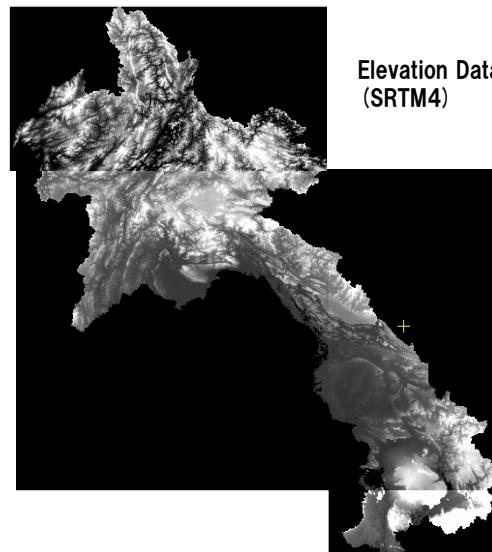
DOF/FIPD

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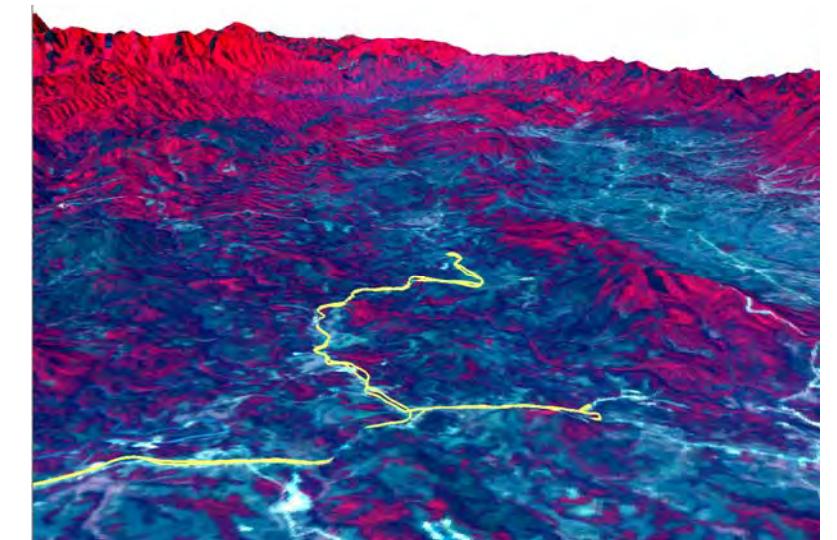
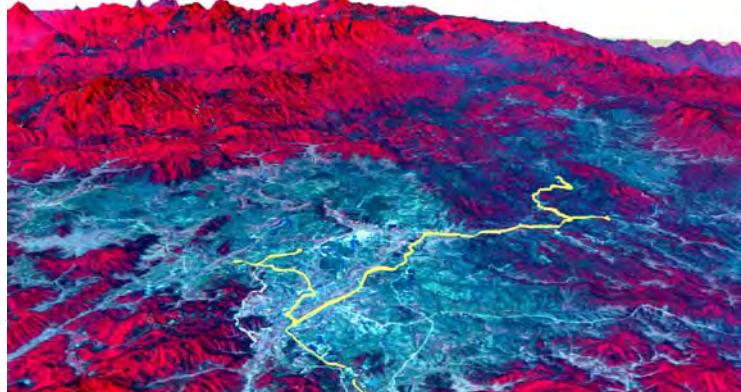
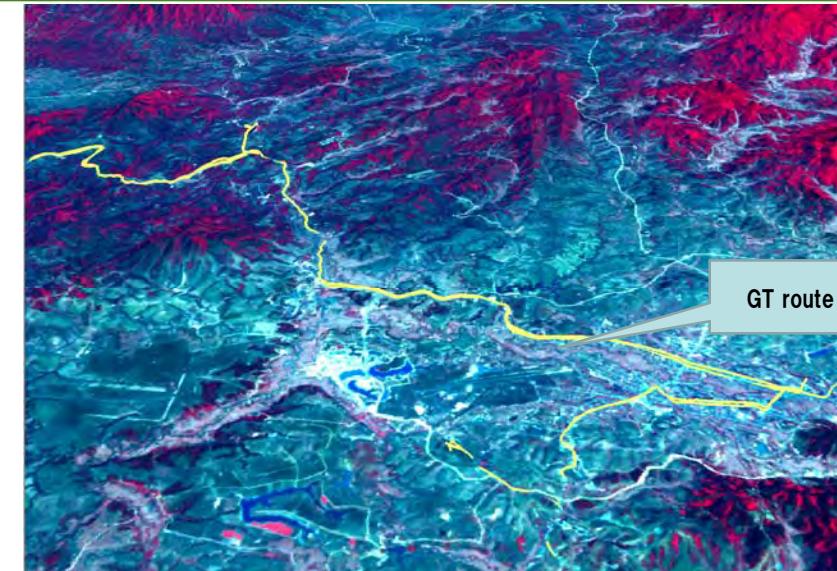
8



- Although colors and tone (darkness) are, in general, very important information on the forest and land covers, they may change depending on sensor sensitivity, sun's intensity and altitude, condition of the land cover (season, water condition, age, soil moisture, etc.), condition of the atmosphere, image enhancement method, etc.
- It is therefore important to consider various parameters when we make interpretation of remote sensing imagery.
-



Elevation Data from NASA
(SRTM4)

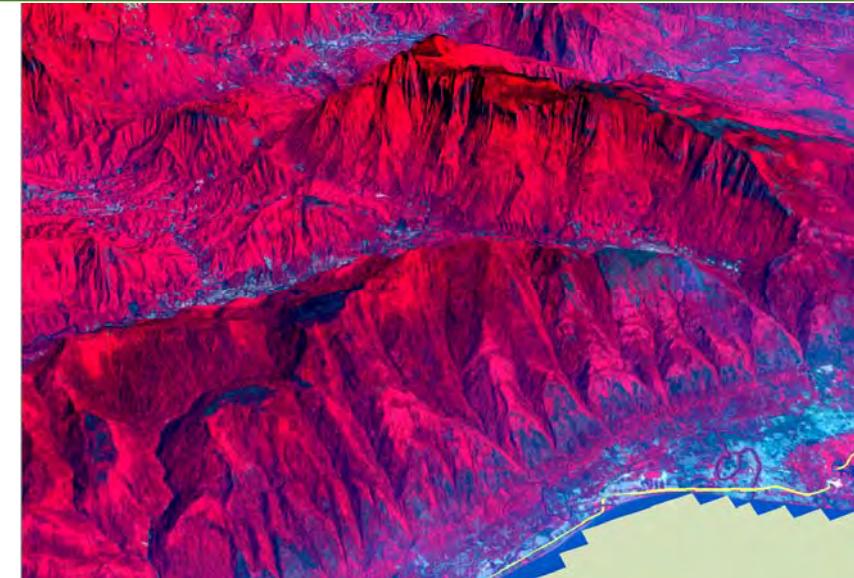




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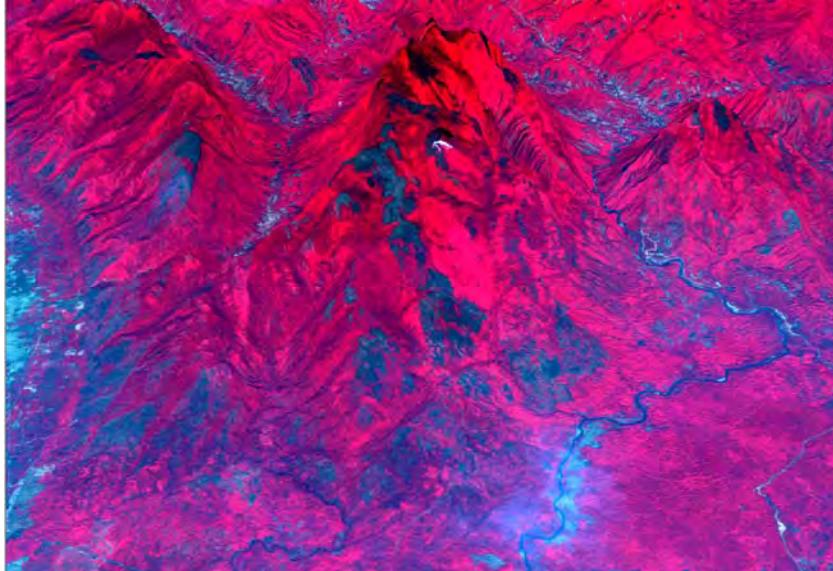
17



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18



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19



Table of Contents

- Scene layers
- GPSLogger_UTM8N
- Landsat8_20150221T171717.tif
Res 1: 0.033
Red Band_8
Green Band_2
Blue Band_3
- MTSAStudyArea05UTM8N.tif
- MTSAStudyArea05UTM8N.tif
Value
High: 200
Low: 139



- Composite Image of RGB=643 bands(Landsat8)
- Different image composite may sometimes be useful.

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20