ラオス人民民主共和国
ラオス国持続可能な森林経営及びREDD+のための国家森林情報システム構築に係る能力向上プロジェクト
（第2年次）

業務完了報告書

添付資料８：リモートセンシング基礎理論講義資料

Theory of Remote Sensing

Technical Training
July 22st - August 1st, 2014

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

Mitsuru NASU, Ph.D.
Forest Remote Sensing

CONTENTS

References

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	
28 (Mon)	Image Interpretation Key 4	Lecture 4
29 (Tue)	Lecture 5	Image Interpretation Key 5
30 (Wed)	Lecture 6	Image Interpretation Key 6
31 (Thu)	Lecture 7	Image Interpretation Key 7
8/01 (Fri)	Report writing	

Introduction

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.

The Remote Sensing Process

Statement of The Problem → Data Collection → Data-to-Information Conversion → Information Presentation

Statement of The Problem
◇Formulate Purpose and Result
◇Select Appropriate Logic
-Inductive
-Deductive
-Technological
◇Select Appropriate Model
-Empirical
-Knowledge-based
-Process-based

Data Collection
✚*In Situ* Measurements
-Field (GPS, biomass, spectroradiometer)
-Laboratory
✚Collateral Data
-DEM
-Soil/Geology Map
-Climate
-etc.
✚Remote Sensing
-Passive
Camera,
Multispectral scanner
Hyperspectral sensor
-Active
Radar
Lidar

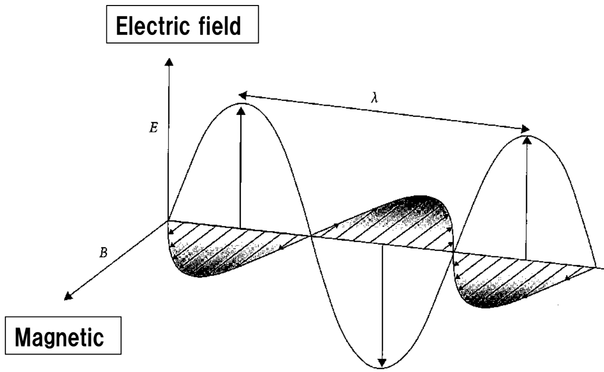
Data-to-Information Conversion
●Visual Image Processing
-Image interpretation
●Digital Image Processing
-Preprocessing
=Enhancement
-Photogrammetric Analysis
-Parametric, such as
-Maximum likelihood
-Nonparametric, such as
-Artificial neural networks
-Nonmetric, such as
-Expert system
-Decision-tree classification
-Change detection
-Modeling using GIS

Information Presentation
◎Accuracy Assessment
◎Analog and Digital Maps
- Paper maps
-GIS databases
-Simulation results
◎Statistics
◎Graphs

2.Radiation Physics

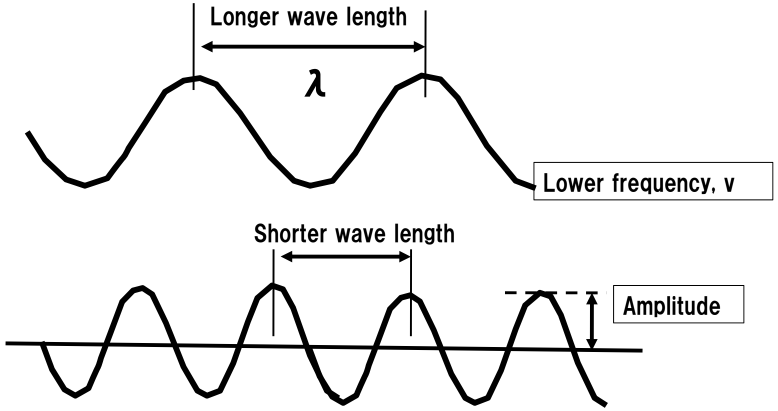
2. Basics of Radiation Physics for Forest Remote Sensing

Electromagnetic Radiation



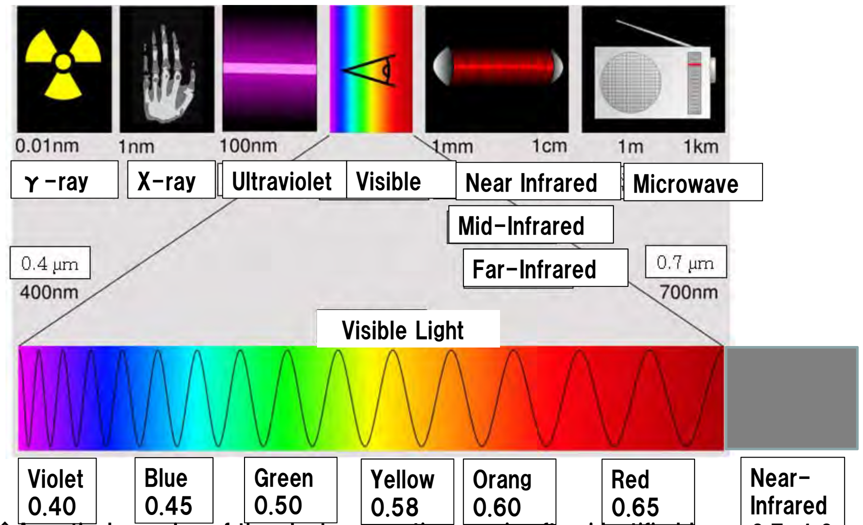
◇Electromagnetic radiation from the object is a key element of Remote Sensing.
◇Electromagnetic radiation consists of time-varying electric and magnetic fields that travel in the form of a wave at the speed of light c (3 x 10^8 ms^{-1}).
◇Once the wave has been formed, it will continue to travel directly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

Elecromagnetic Radiation



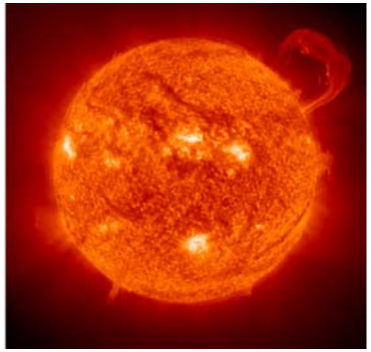
◇The longer the wave length, the lower the frequency
◇The amplitude of tan electromagnetic wave is the height of the wave
◇Frequency of an wave： measured in cycles per second or herz

Electromagnetic Spectrum



◇A particular region of the electromagnetic wave is often identified by a beginning and ending of the wavelength（the unit is in general micrometer）.

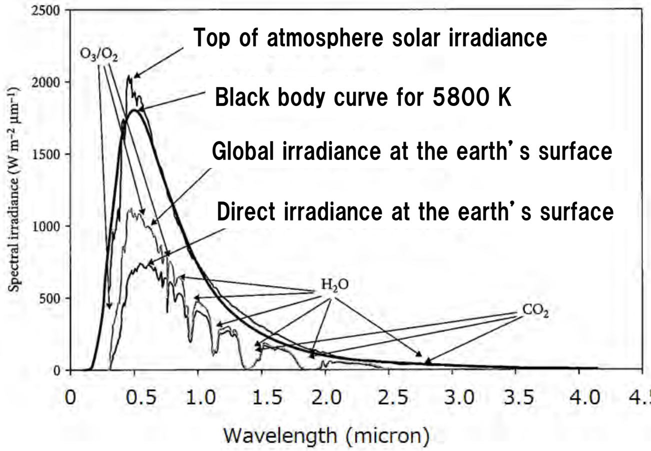
Sources of Electromagnetic Radiation



(Image: NASA)

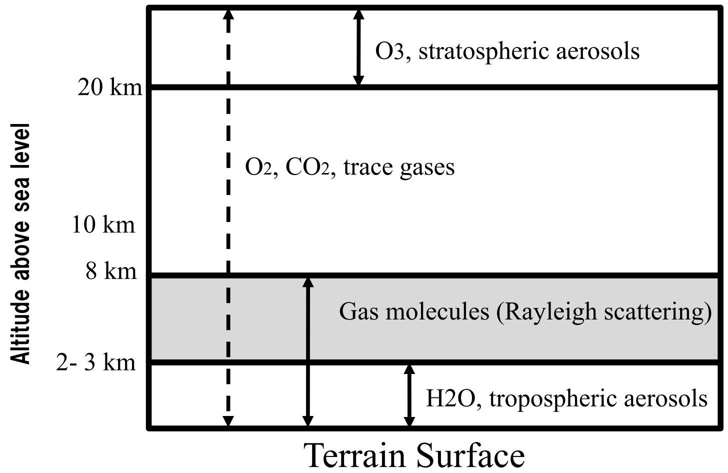
◇The Sun is a major source of electromagnetic radiation.
◇The Sun approximates a 6000 K blackbody with a dominant wavelength of about 0.48 μm (Green)
◇The Sun produces 41% of its energy in the visible region from 0.4 to 0,7 μm. The 59% is in other regions.

Solar Spectrum



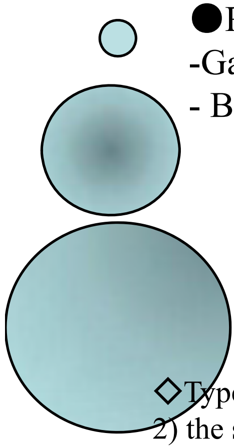
◇The Earth intercepts only a very small portion of the electromagnetic energy produced by the Sun.

Atmospheric Scattering



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

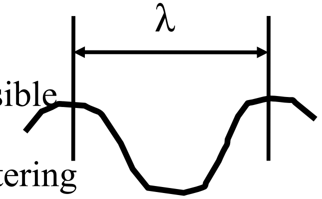
Atmospheric Scattering



●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)



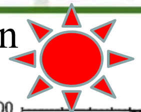
Photon of electromagnetic energy modeled as a wave

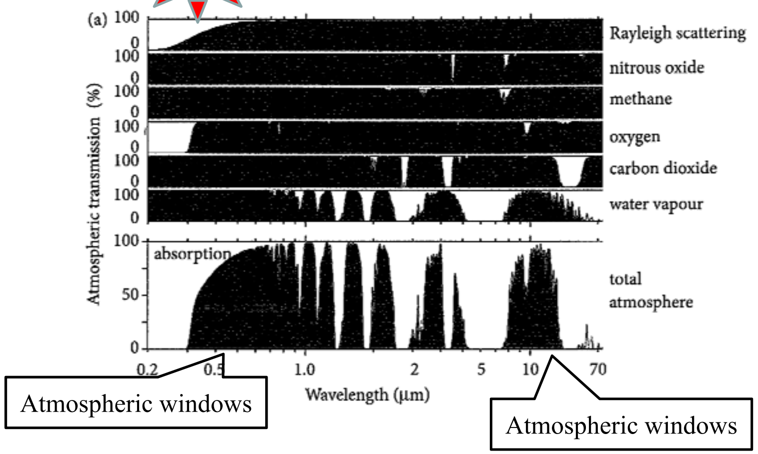
◇Type of scattering is a function of 1)the wavelength and 2) the size of the gas molecule, dust particle, and/or water vapor encountered.

◇The intensity of Rayleigh scattering varies inversely with the fourth power of the wavelength (λ^{-4})

Atmospheric Absorption

Sun



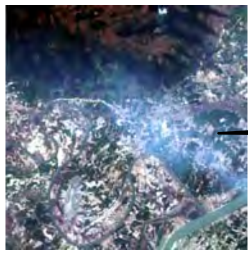


Atmospheric Transmission (H.G.Jones & A. Vaughan)

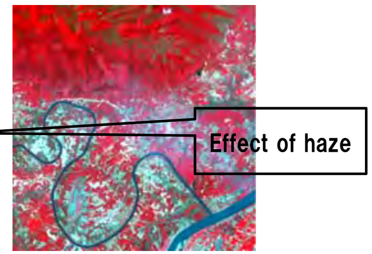
Atmospheric Scattering

Examples: LANDSAT 8_OLI

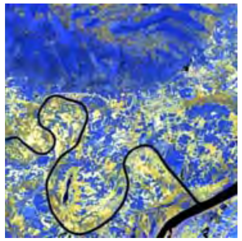
RGB=B3,2,1



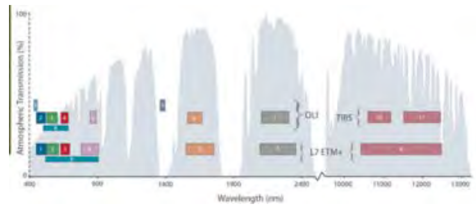
RGB=B4,3,2



RGB=B5,4,3

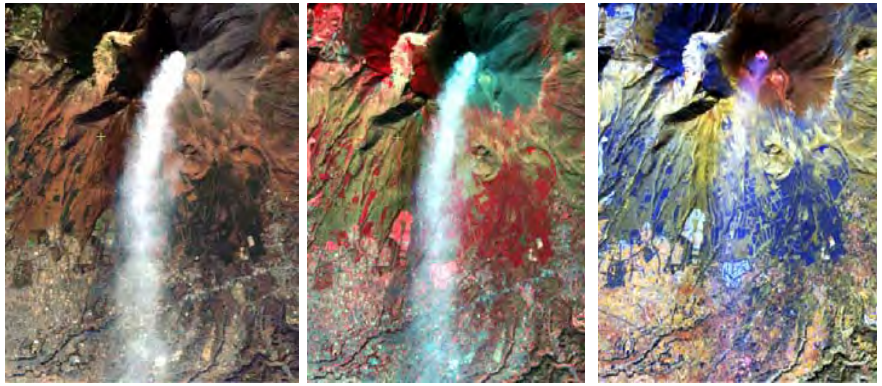


RGB=B7,6,5



●LANDSAT8 OLI Sensing bands

Atmospheric Scattering



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)

Correction of Atmospheric Effects

◇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)

Atmospheric Corrections

(1) Absolute atmospheric correction

- Model atmosphere
- Model atmosphere + in situ data

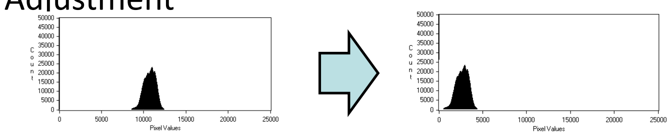
- Atmospheric correction based on Radiative Transfer Modeling (FLAASH(ENVI), ACORN(DLR), ASTERM, ATCOR(Leica), etc.)

◇Atmospheric properties are difficult to acquire !

Atmospheric Corrections

(2) Relative Atmospheric Correction

❶Single-image Normalization Using Histogram Adjustment



❷Multiple-date Image Normalization Using Regression
◇Select radiometric ground control points
◇Regression analysis
◇Apply radiometric correction by the regression model

Radiation Properties

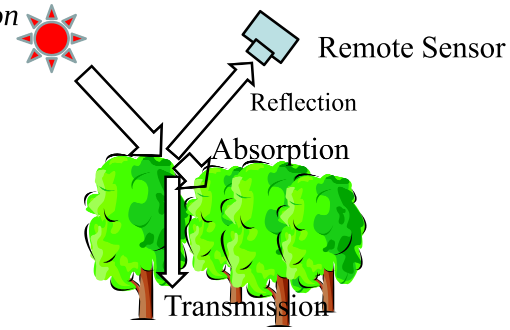
3. Radiation Properties of Vegetation, Soil, and Water

Interactions with Target Surfaces

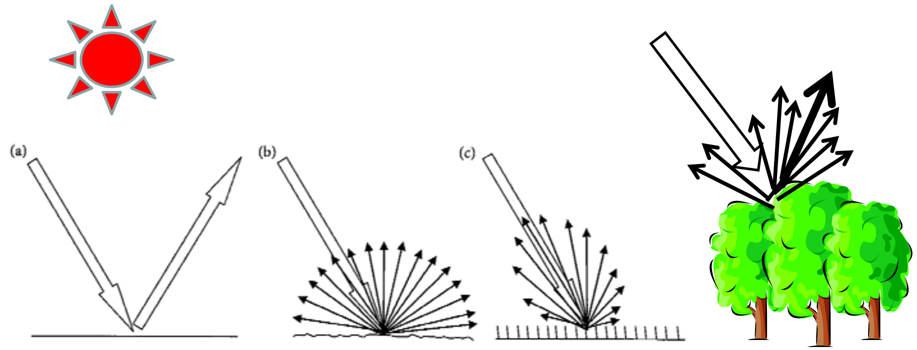
● *Reflection*: The solar radiation that is not absorbed by the target is reflected back to space. The spatial arrangement and density of leaves and branches in the canopy space leads to a strong dependence of reflection. High reflectance in the near infrared.

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

● *Transmission*



Interactions with Target Surfaces



(a) Perfect Specular reflector (b) Lambertian or perfect diffusion reflection (c) Typical asymmetric Scattering (d) Near perfect diffuse reflection

◇ There are various types of reflecting surfaces.

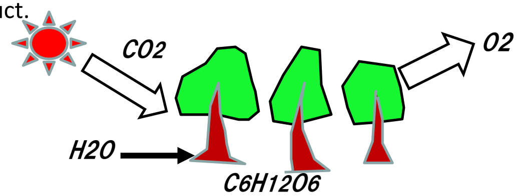
Photosynthesis by Plants

6CO2 + 6 H2O + Light Energy → *C6H12O6 + 6 O2*

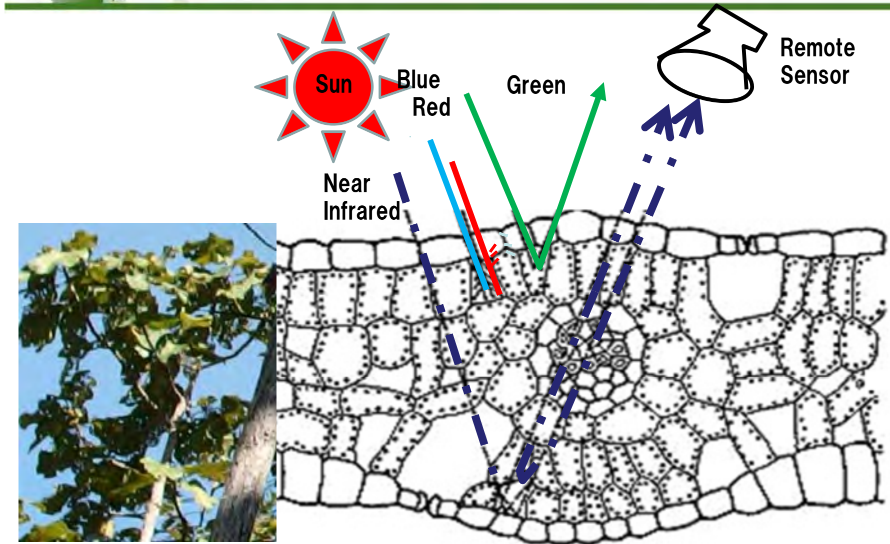
◇ Photosynthesis is an energy-storing process that takes place in leaves and other green parts of plants in the presence of light.

◇ The light energy is stored in a simple sugar molecule (glucose) that is produced from carbon dioxide (CO2) present in the air and water (H2O) absorbed by the plant primarily through the root system.

◇ When the carbon dioxide and water are combined and form a sugar molecule (*C6H12O6*) in a chloroplast, 0xygen gas (*O2*) is released as a by-product.

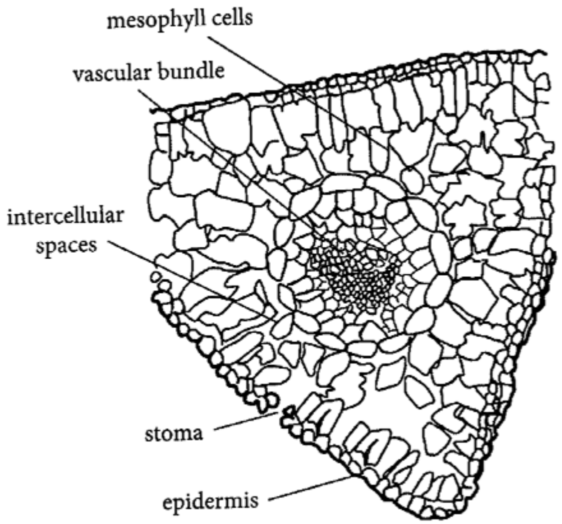


Reflection and Absorption(Broadleaf)



(From NASA,http://fas.org/irp/imint/docs/rst/Sect3/Sect3_1.html)

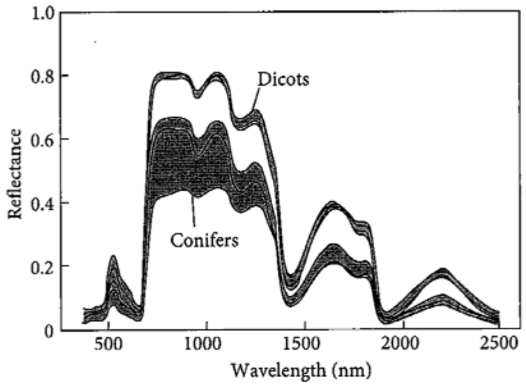
Plant Leaves (Pine needle)



H.G.Jones＆R.A.Vaughan）

General Characteristics

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



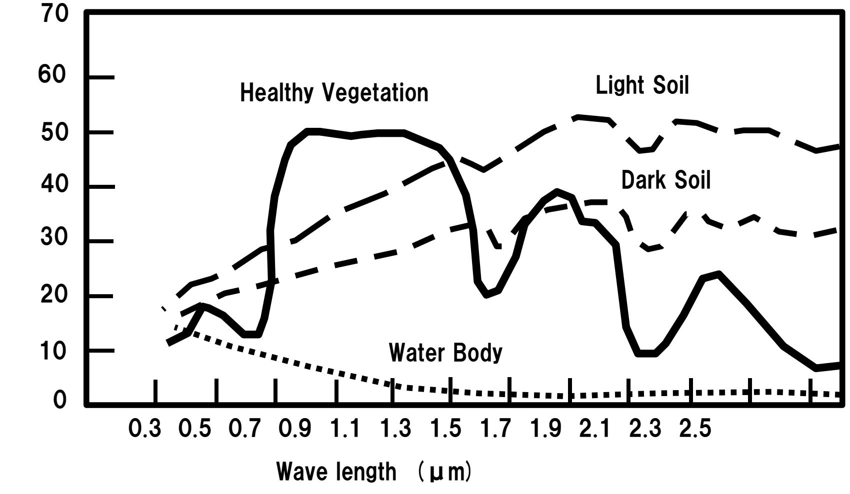
http://ies.jrc.ec.europa.eu/data-portals.html#dp28

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)

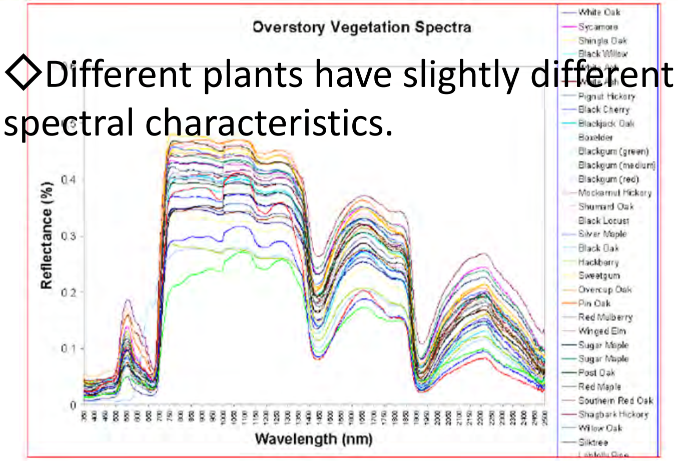
General Spectral Characteristics of Vegetation, Soils and Water



Vegetation has a very characteristic spectral signature.

Spectral Characteristics of Vegetation

◇Different plants have slightly different spectral characteristics.

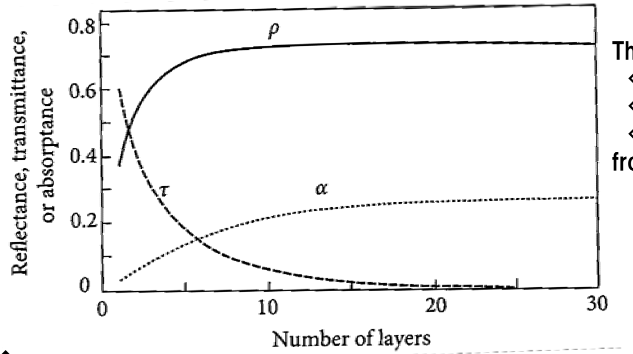


BGR ← Near IR →← Mid-Infrared → (USGS)

http://speclab.cr.usgs.gov/spectral.lib06/ds231/datatable.html

The Effect of Increasing Leaf Thickness

◇Effect if Increasing Leaf Thickness (Number of layers)

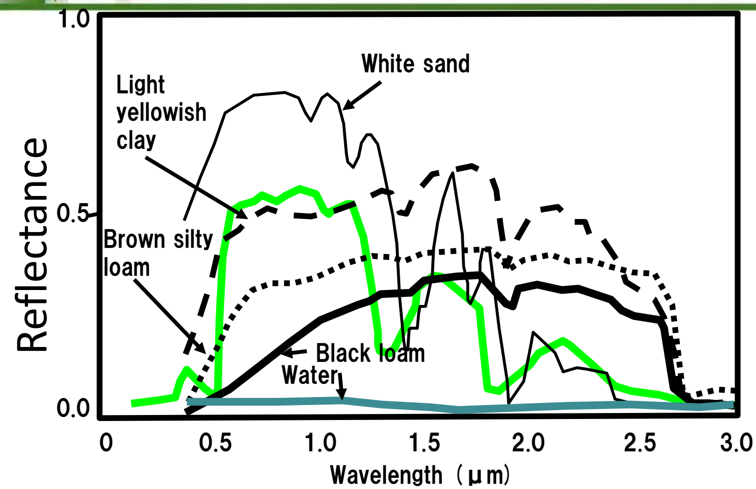


The effect of
◇Transmission: τ
◇Absorption : α
◇Reflection : ρ
from a leaf

◇Typical reflection coefficients for single leaves (Jones)

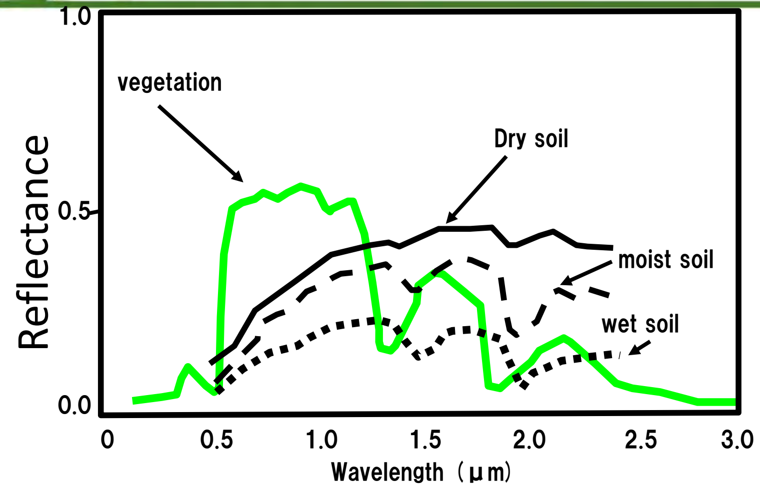
Conifer needles	12 %
Deciduous broad leaves	23 – 29 %
Young leaves	39 %

Spectral Reflectance Characteristics



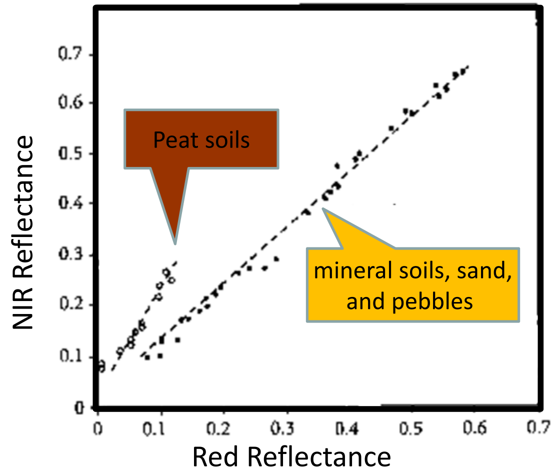
◇Spectral reflectance of different soils as compared with vegetation

Spectral Reflectance Characteristics



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

Spectral Characteristics of background



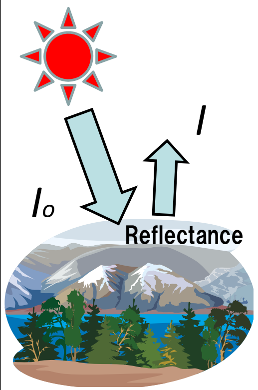
◇Relationships between Red and NIR reflectance for different soils as water content changes.

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

Total Reflectivity or Albedo

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

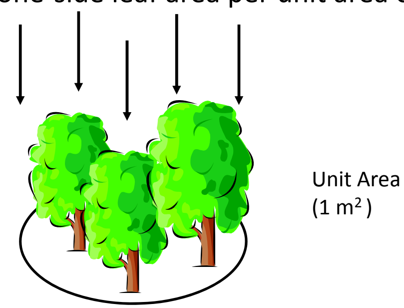


$P = I / I_o$

Leaf Area Index

[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.

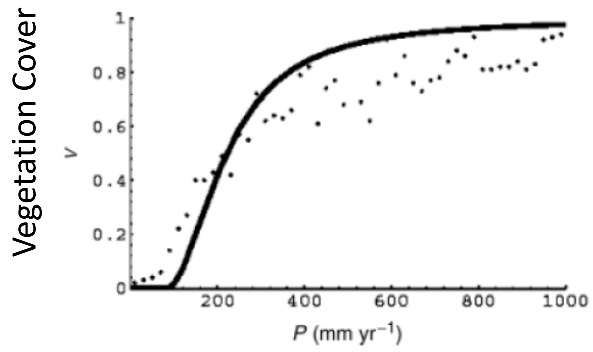
Global Survey of LAI of Landscape Classes

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	1.81	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)

Factors affecting LAI

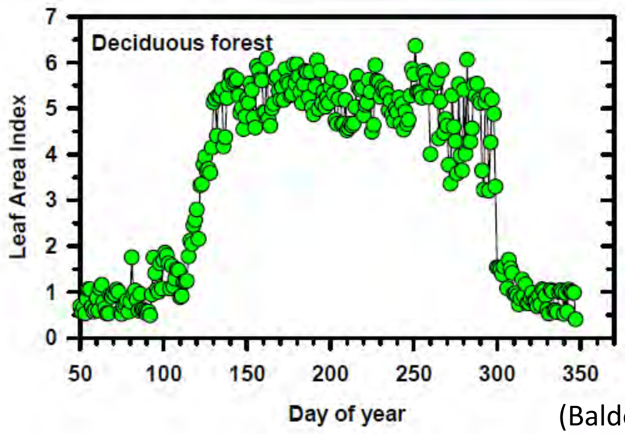
◇Correlative and biogeographical analyses suggests that leaf area index strongly tied to site water balance and nutrient status (Baldocchi)



Precipitation

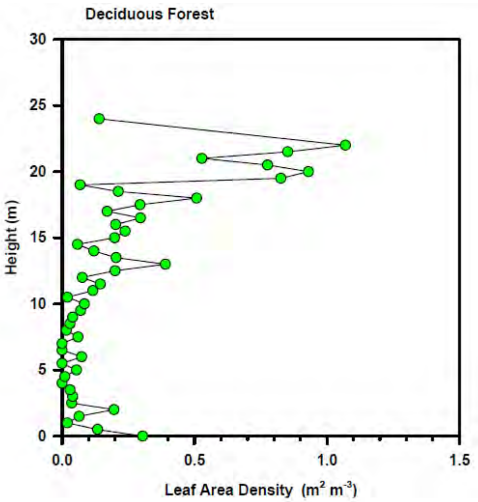
Mixed Deciduous Forest（Kamukheut District, Bol.）

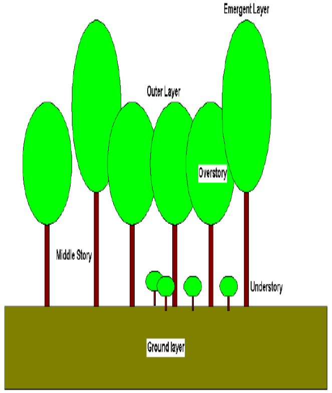
Seasonal Change in LAI



(Baldocchi)

Leaf Area Profile





(Baldocchi)

Radiative Properties

◇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.

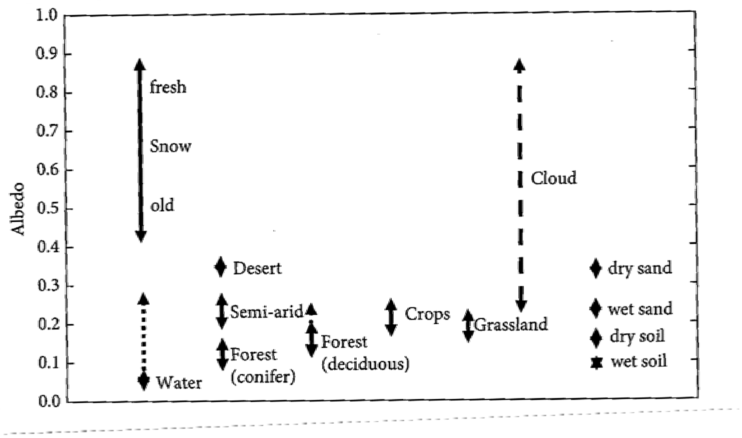
◇Because of differing reflectance of leaves in the visible and near infrared wavelengths, the relative attenuation in these wavebands will depend on the number of reflections at leaf surfaces.

◇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.

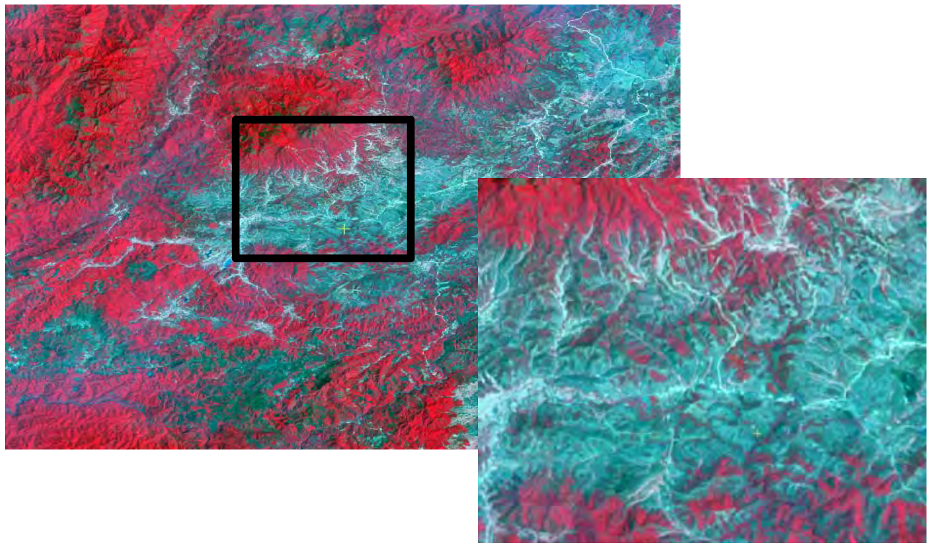
◇The strong decrease in soil reflectance as it get wet can have a substantial effect on overall canopy albedo for sparse canopies.

Reflection from Natural Surfaces



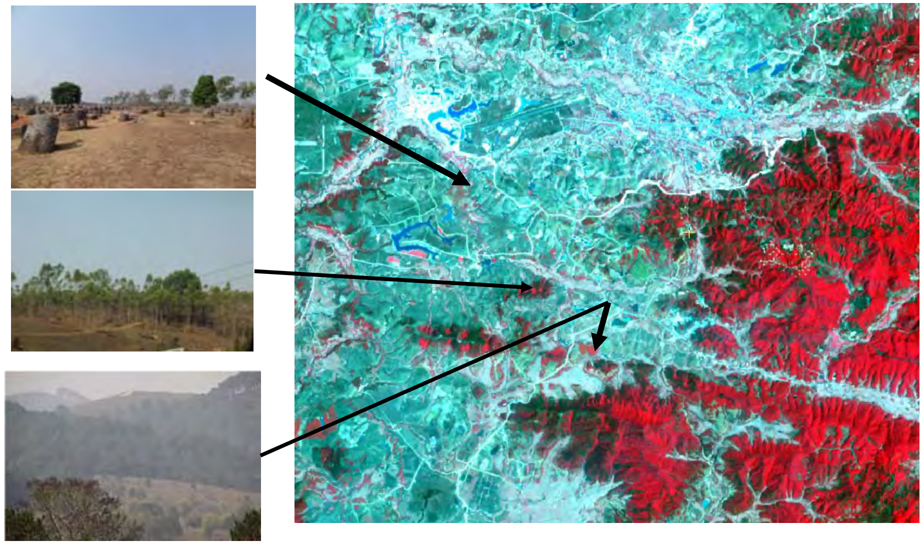
Typical ranges of albedo (total reflection) from natural surfaces (Jones)

Surface Reflection

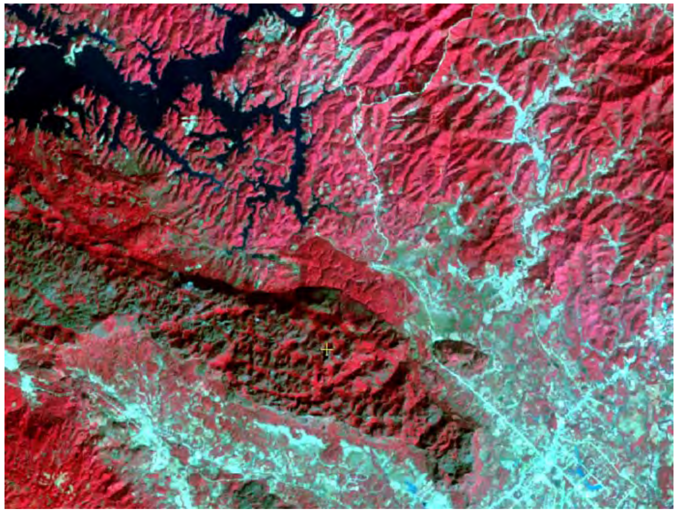


Solar Reflectances

(Pine)

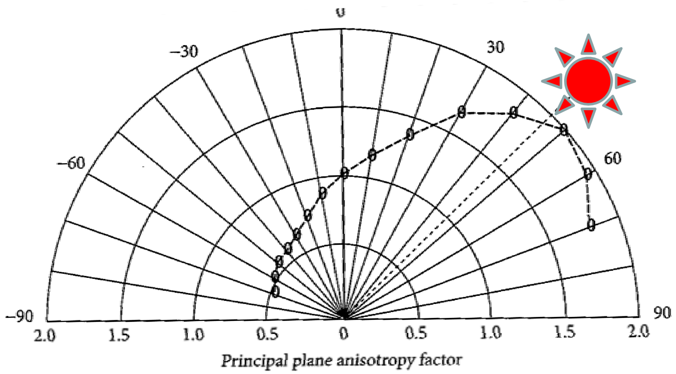


Reflectance of Various Features



(Landsat 8 LakSao)

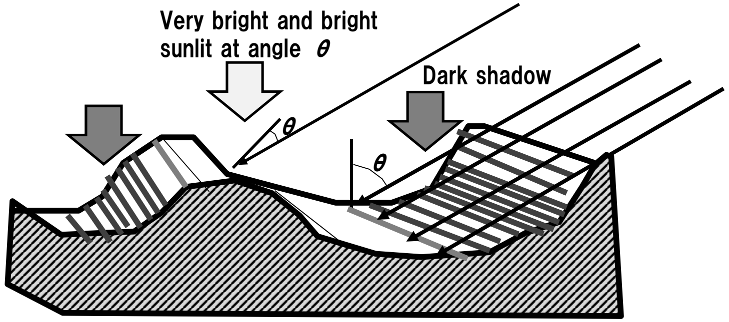
Directional Property of Radiation



◇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.

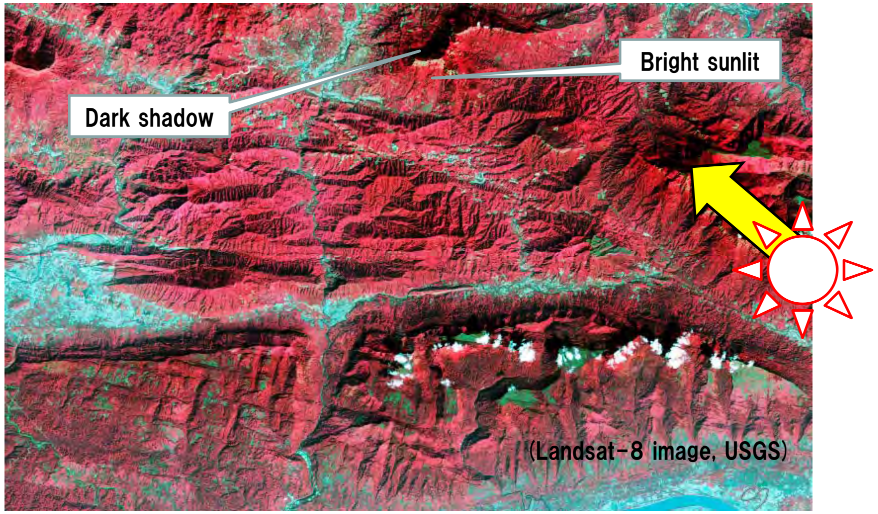
Sun Angle and Viewing Geometry



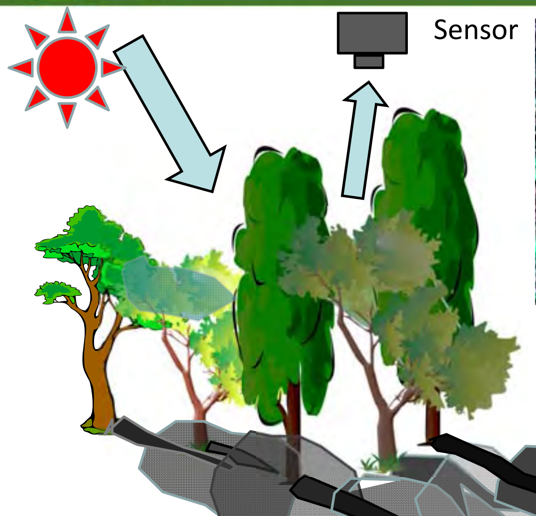
◇Surfaces in shadow appear less bright than surfaces in full sunlight.

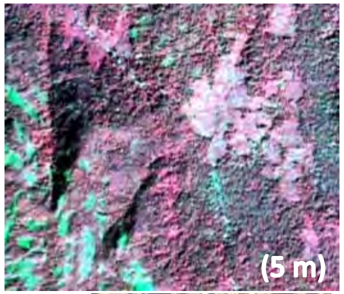
◇Irradiance on the slope facing the sun is higher than on the horizontal and the apparent reflectance is also greater.

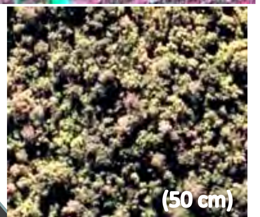
Topographic Shadow



Effect of Crown Shadows







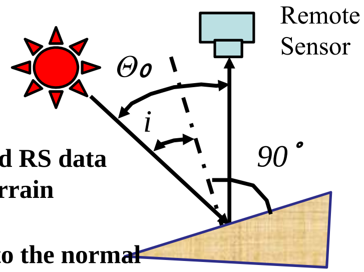
◇Crown shadows are sometimes very good keys for vegetation analyses.

Correction of Slope and Aspect Effects

Correction of Slope and Aspect Effects

❶Cosine Correction

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



L_H=radiance of slope-aspect corrected RS data

L_γ=radiance observed over sloped terrain

Θo=Sun's zenith angle

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

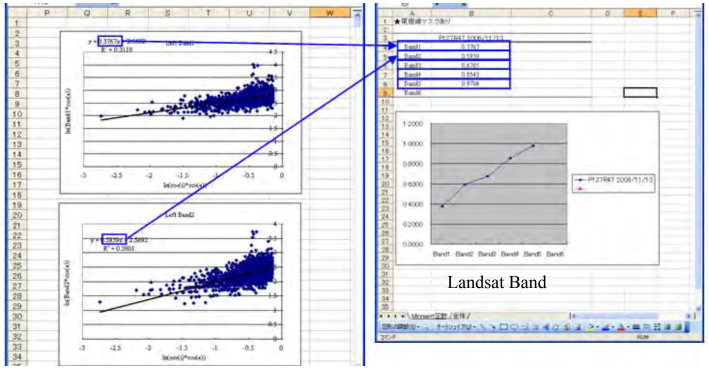
❷Minnaert Correction

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

where k = the Minnaert constant.

Correction of Slope and Aspect Effects

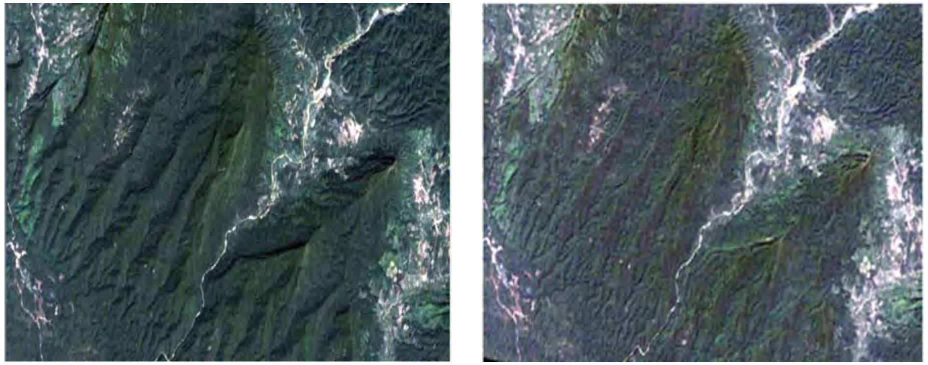
●Correction of "topographic effect" using DEM and the Minnaert method.



(Oono, 2010)

Slope-Aspect Correction

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

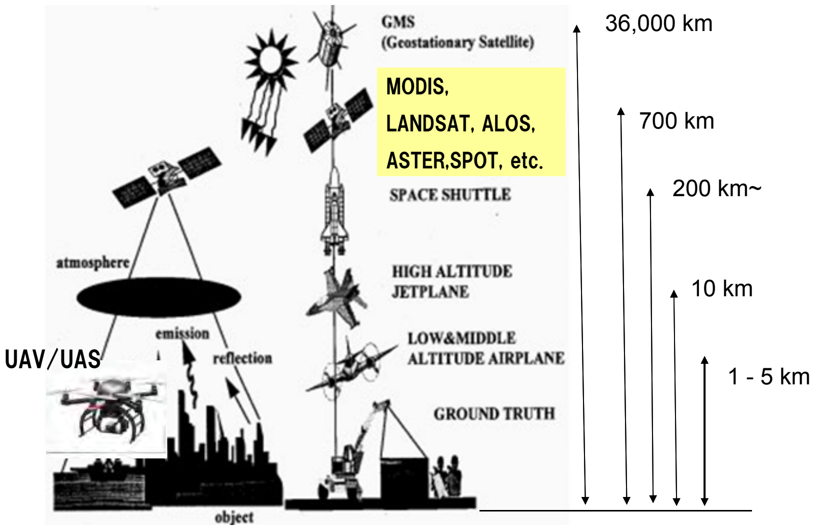


(Oono, 2010)

Earth Observation Systems

4. Earth Observation Systems

Remote Sensing Systems and Platforms



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

Remote Sensing Platforms

Classification of Small Satellites

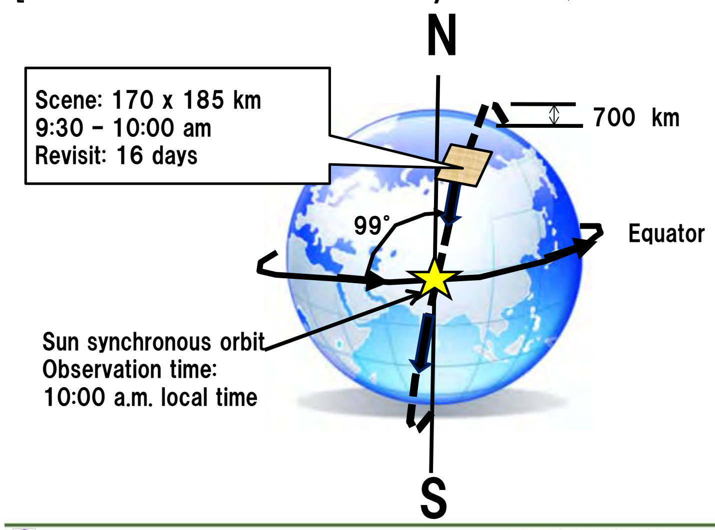
Satellite Class	Mass	Cost (US$)
Large satellite	> 1000 kg	> 20 million
Minisatellites	100 – 1000 kg	5- 20 million
Microsatellites	10 – 100 kg	2 – 5 million
Nanosatellites	1 – 10 kg	< 1 million
Picosatellites	0.1 – 1 kg	
Femtosatellites	1 – 100 g	Satellite-on-a-chip

(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.

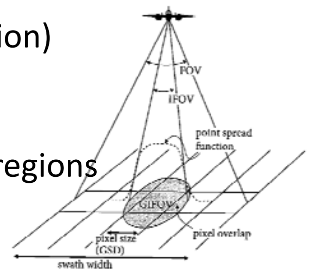
RS Observation System

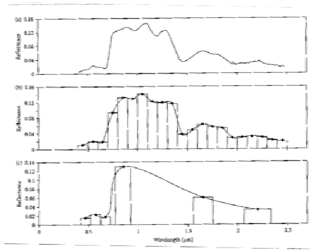
[Satellite Observation System （Ex. Landsat)]



Sensor Design

- ◇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



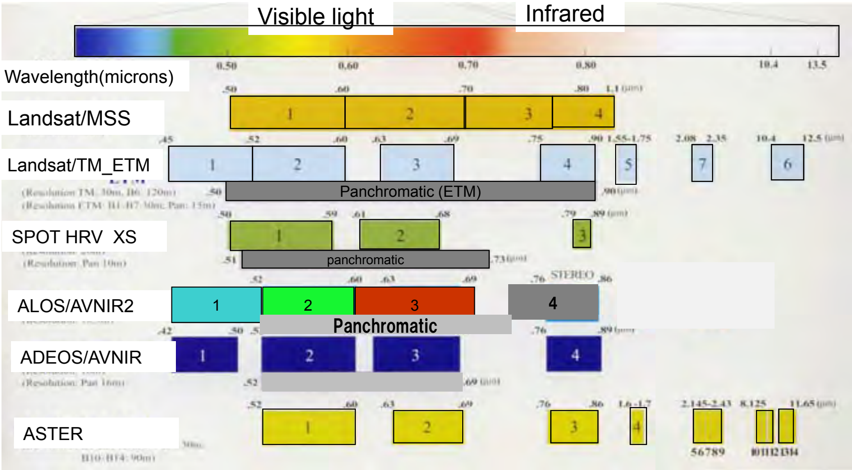


Satellite Data with Different Resolutions

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/km2 Recent Data $0.02 - $0.5/km2	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.

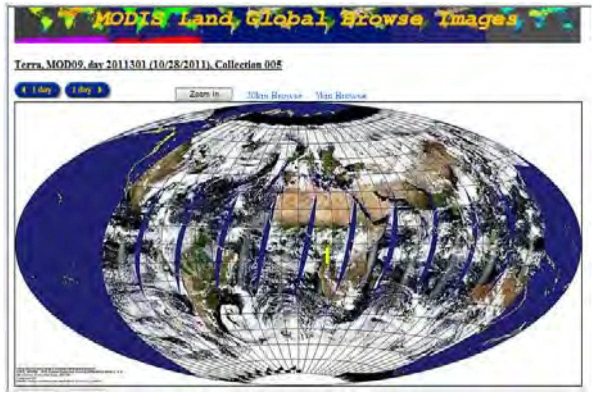
Various Optical Passive Remote Sensors

[Sensing Spectral Bands]



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

MODIS Images



-250 m ground resolution (Visible and NIR bands)

- Observation frequency: Twice/day

- Available two-week global mosaicked image

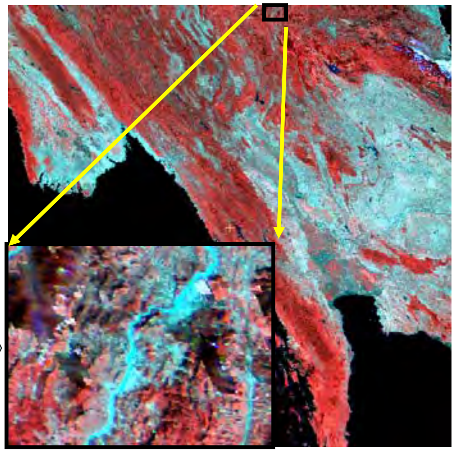
Example of MODIS LAND Products

[16 days Mosaic Image]

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

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

N17.5°



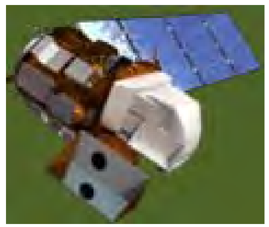
N10°

E95° E102.5°

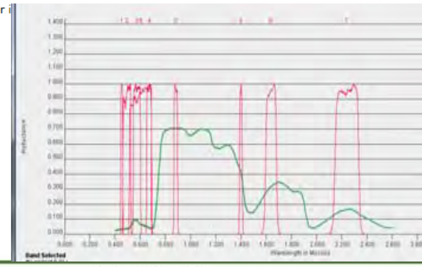
Landsat 8 OLI Sensor

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

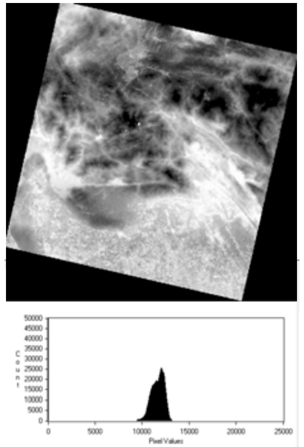


(USGS)



Example of RS Imagery

Band 1:

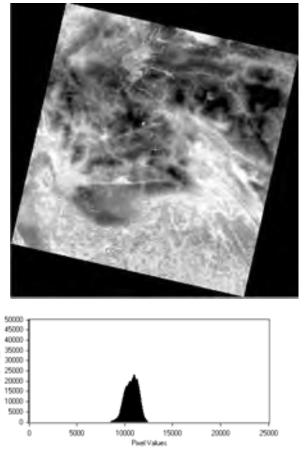


Ocean Blue 0.43-0.45 μm

Statistics

Number of pixels:	59916681	Median value:	11246
Mean value:	8084.18	Standard deviation:	5408.63
Minimum value:	0	Maximum value:	36484

Band 2:

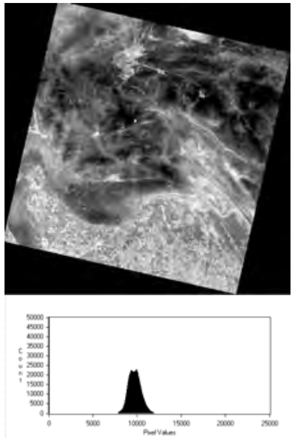


Blue o.45 - 0.51

Statistics

Number of pixels:	59916681	Median value:	10274
Mean value:	7422.08	Standard deviation:	4972.79
Minimum value:	0	Maximum value:	38450

Band 3:



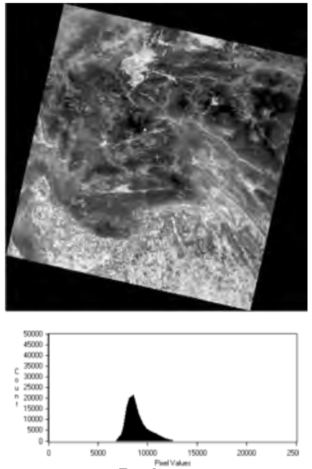
Green

Statistics

Number of pixels:	59916681	Median value:	9285
Mean value:	6751.74	Standard deviation:	4531.75
Minimum value:	0	Maximum value:	42183

Example of RS Imagery

Band 4:

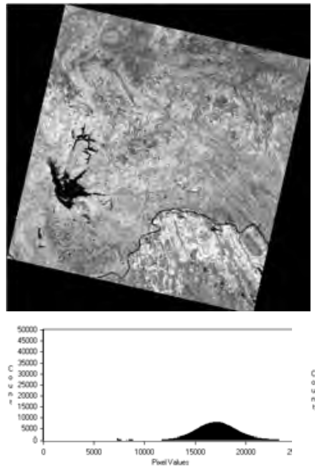


Red

Statistics

Number of pixels:	59916681	Median value:	8226
Mean value:	6188.04	Standard deviation:	4217.76
Minimum value:	0	Maximum value:	57235

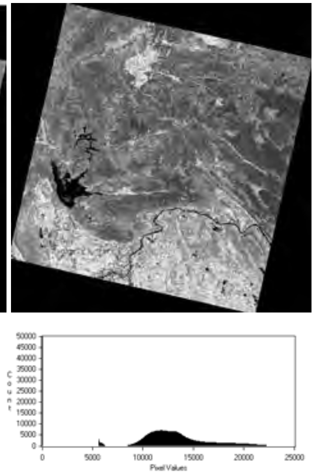
Band 5:



Statistics

Number of pixels:	59916681	Median value:	15816
Mean value:	11760.7	Standard deviation:	8105.87
Minimum value:	0	Maximum value:	51436

Band 6:

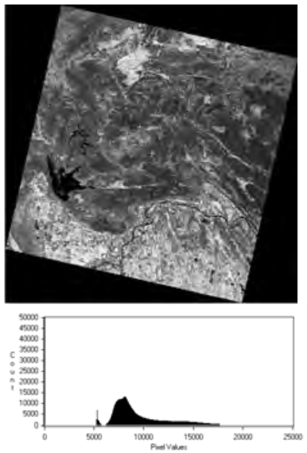


Statistics

Number of pixels:	59916681	Median value:	11434
Mean value:	9302.25	Standard deviation:	6763.13
Minimum value:	0	Maximum value:	65535

Example of RS Imagery

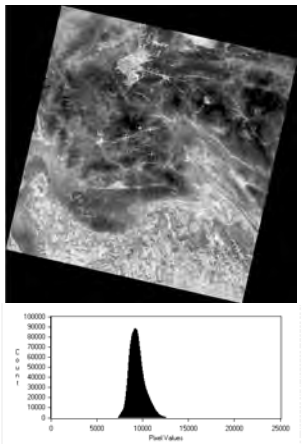
Band 7:



Statistics

Number of pixels:	59916681	Median value:	7770
Mean value:	6637.87	Standard deviation:	4993.22
Minimum value:	0	Maximum value:	64341

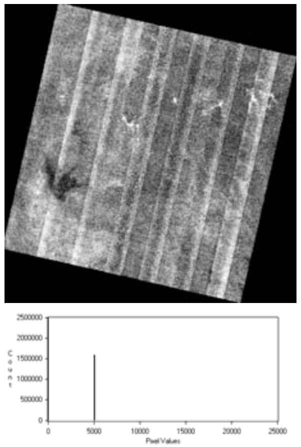
Band 8:



Statistics

Number of pixels:	239635761	Median value:	8874
Mean value:	6528.82	Standard deviation:	4393.51
Minimum value:	0	Maximum value:	62054

Band 9:

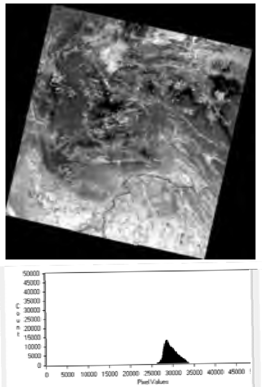


Statistics

Number of pixels:	59916681	Median value:	5052
Mean value:	3505.3	Standard deviation:	2333.2
Minimum value:	0	Maximum value:	11614

Example of RS Imagery

Band 10:

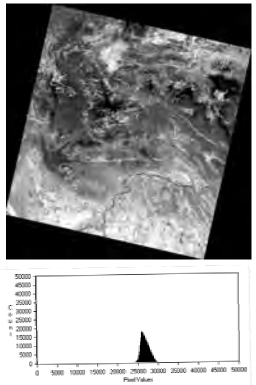


Thermal IR1

Statistics

Number of pixels:	59916681	Median value:	28430
Mean value:	19882.6	Standard deviation:	13876.2
Minimum value:	0	Maximum value:	65535

Band 11:

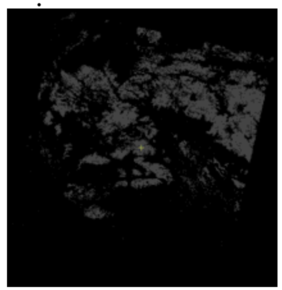


Thermal IR2

Statistics

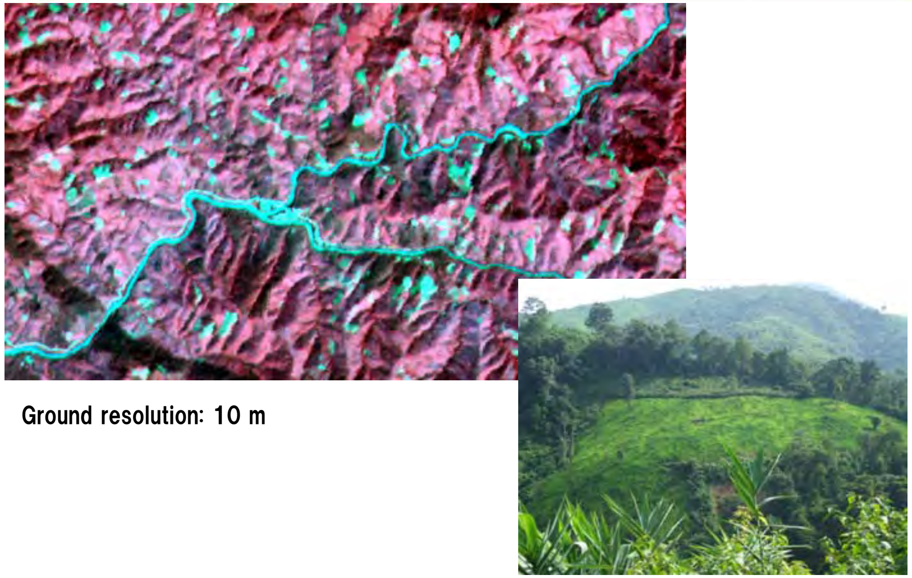
Number of pixels:	59916681	Median value:	26145
Mean value:	18224.1	Standard deviation:	12592.1
Minimum value:	0	Maximum value:	56941

Band BQA



Quality Analysis Data

SPOT 5 Image (Example)

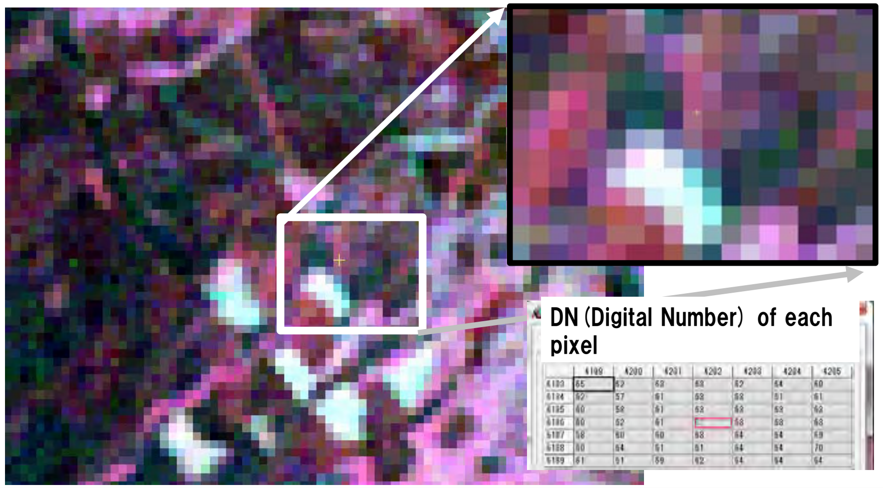


Ground resolution: 10 m

Pixel

[Picture and Pixels]

Pixel = Element of Image



Remote sensing System

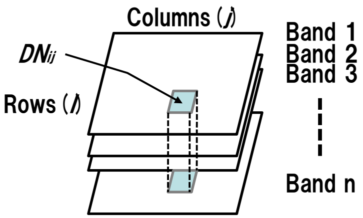
What is in a Pixel?

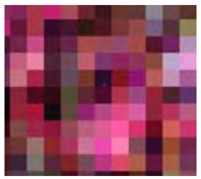
◇ Pixel: A two-dimensional picture element

◇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.



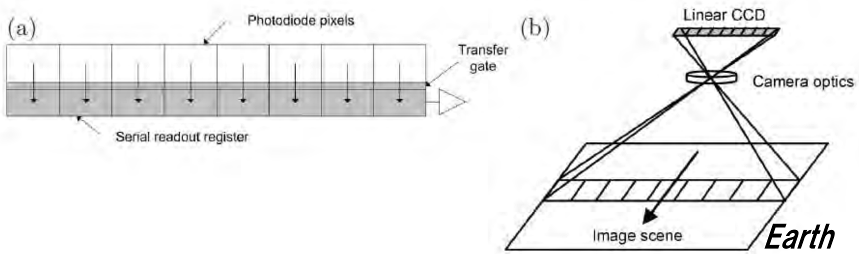


(5 m)

(0.5 m)

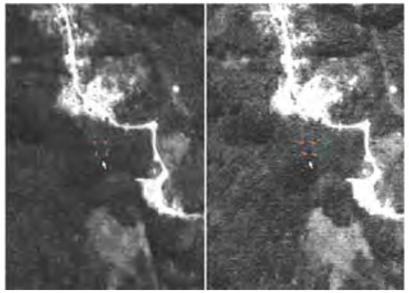
Optical Sensing System

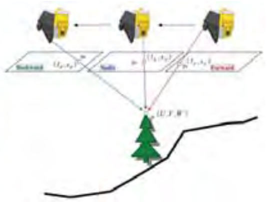
Linear Array “Pushbroom” Sensor (Example)



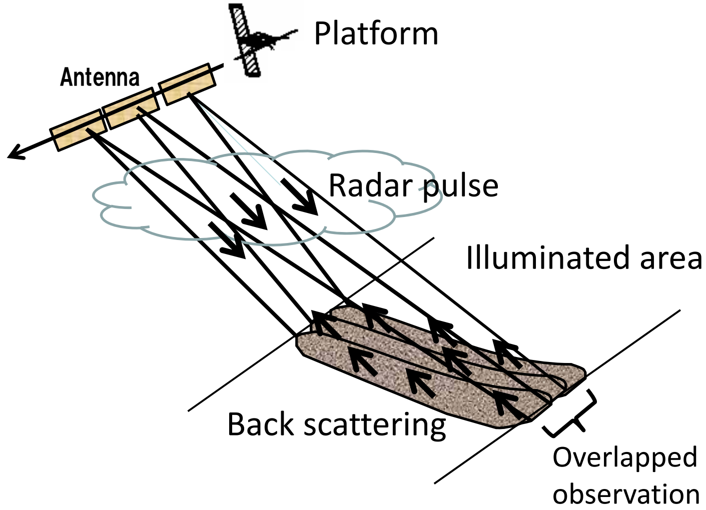
Optical sensors can provide

Three Dimensional Measurement using Optical Sensor Stereo Imagery

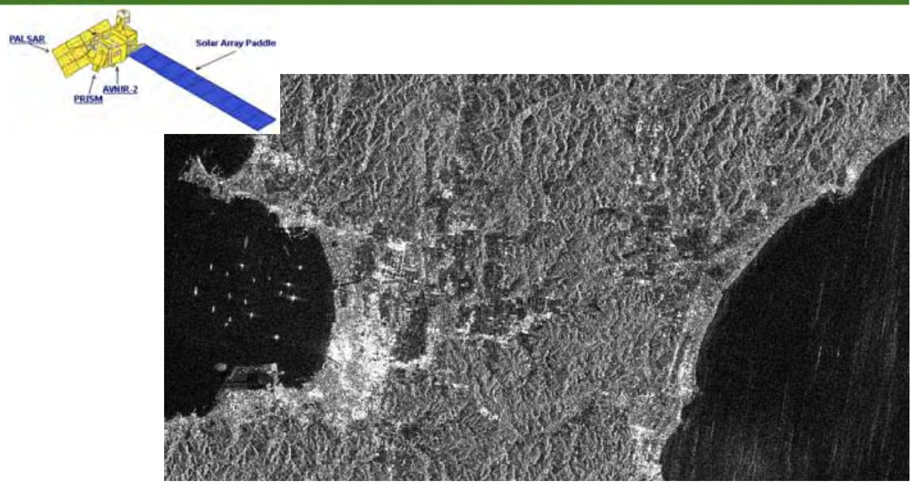




SAR Microwave Sensing System



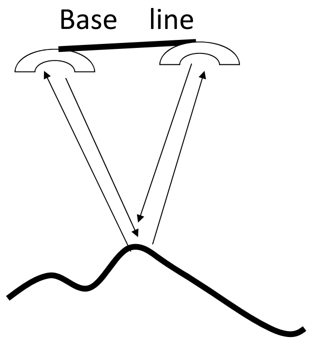
SAR (Microwave) Technology for Forest Monitoring

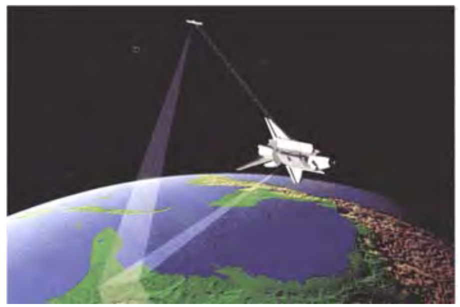


(JAXA)

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.

Interferometric SAR





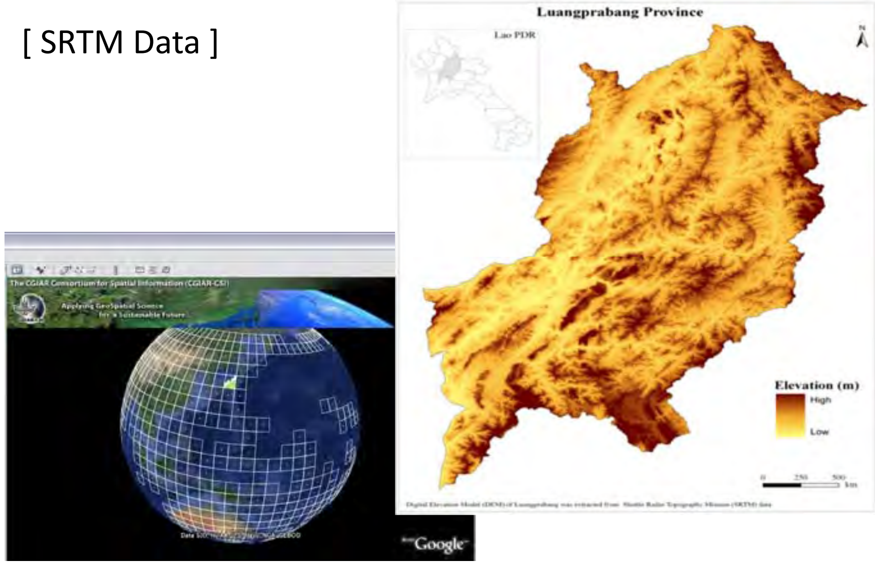
(SRTM Mission, NASA)

◇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.

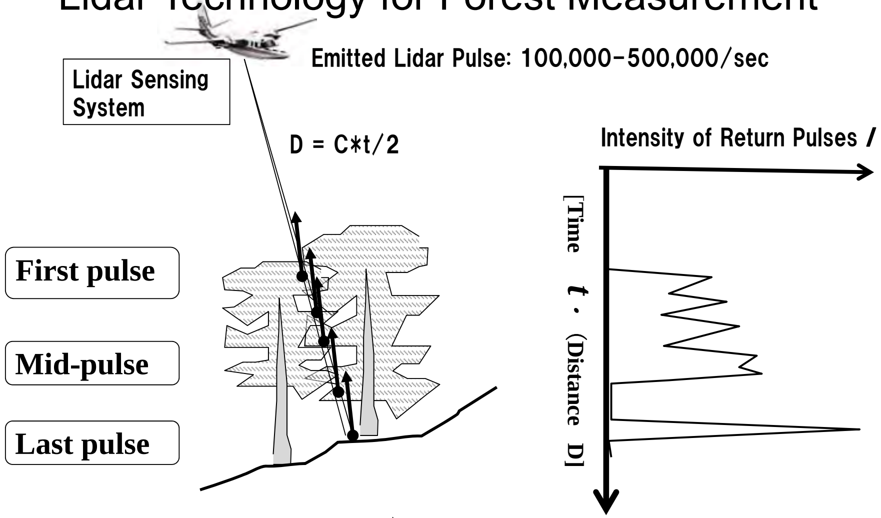
Microwave Remote Sensing

[SRTM Data]



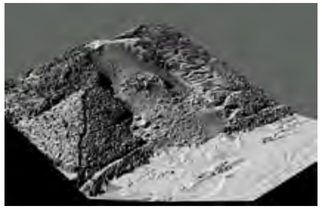
Lidar Mapping System

Lidar Technology for Forest Measurement



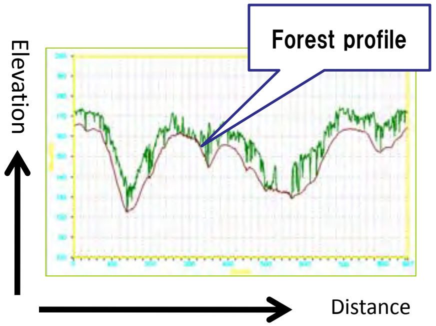
C= velocity of light ≒ 300,000 km/sec

Lidar Sensing System



First Pulse Data

Last Pulse Data



6. Image Processing

5. Processing of Optical Remote Sensing Data

Flow of Image Analyses

Basic Image Analysis Tasks

- Multispectral RS Images
- Multitemporal RS Images
- Multistage RS images

Collateral Information
- Literatures
- Dichotomous keys
- Field survey data
- Existing maps, photos
- etc.

→ Preprocessing

Visual Image Processing/Analysis
- Image Interpretation

Digital Image Processing/Analysis
- Multispectral analyses
- Texture analyses
- Autocorrelation, geostatistical analysis
- Classification, segmentation, expert system

→ Thematic Map Compilation

Geometric Correction

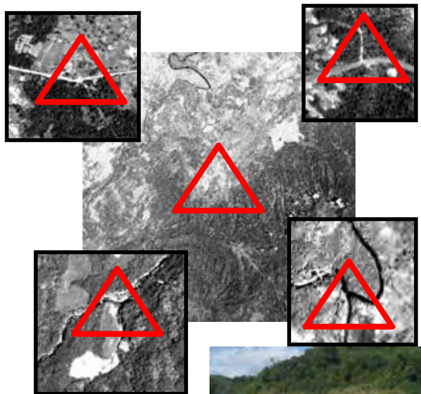
Geometric Correction of RS Imagery

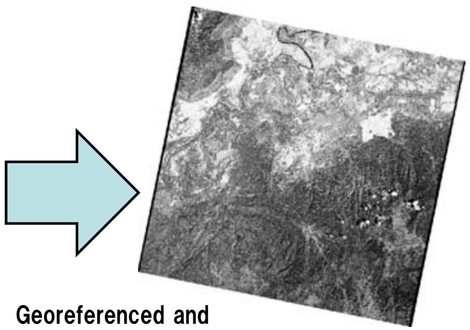
● Types of Geometric Correction
- Image-to-map (GCP) rectification
- Image-to-image registration

● Spatial Interpolation Using Coordinate Transformation
- Helmart Transformation: $X = a + bx + cy$, $Y = d - cx + by$
- Affine Transformation: $X = a' + b'x + c'y$, $Y = d' + ex + f'y$
- Higher-order polynomial Transformation:

$$X = a_0 + a_1 x + a_2 y + a_3 xy + a_4 x^2 + a_5 y^2$$
$$Y = b_0 + b_1 x + b_2 y + b_3 xy + b_4 x^2 + b_5 y^2$$

Image Processing of Remote Sensing Data





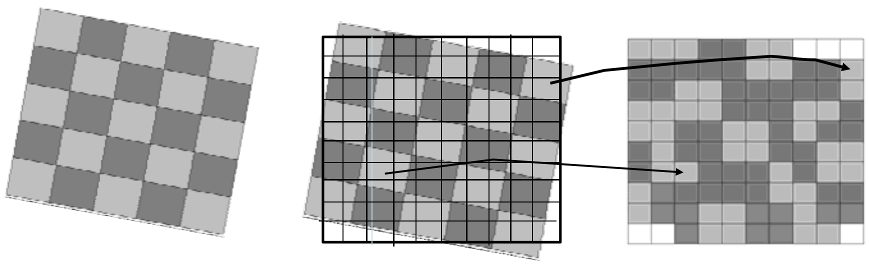
Georeferenced and rectified Image data

GPS Survey for GCPs collection

◇The least square method is applied to estimate the most probable values of unknown parameters.

Intensity Interpolation

[Intensity Interpolation in rectification process]



◇Nearest neighbor
◇bilinear interpolation
◇Cubic convolution

} Resampling

Basic Image Processing

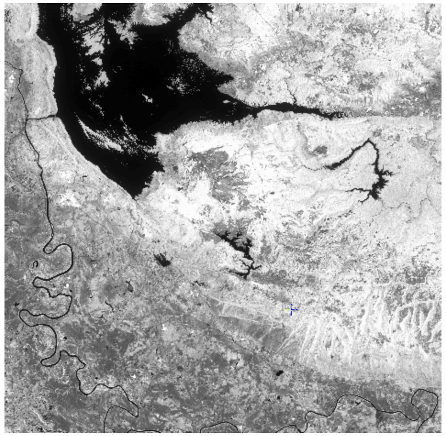
◇Density Slicing

- 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.

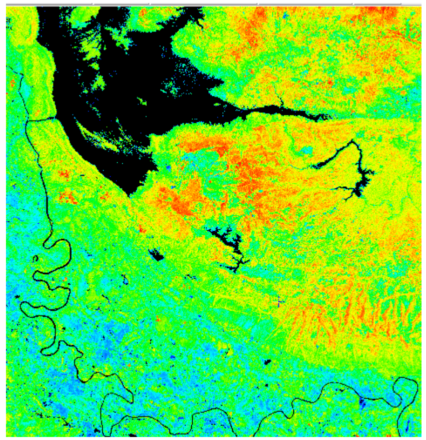
-Density slicing is a technique normally applied to a single-band grayscale values (0-255) for converting into a series of different colors.

Example of Density Slicing

[NDVI]



（Grey scale）



（Density slicing, Level slicing））

Color Composites

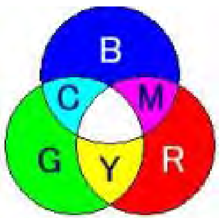
◇Multispectral images ➔ Color composites

◇Only feasible to view the information from three channels at once

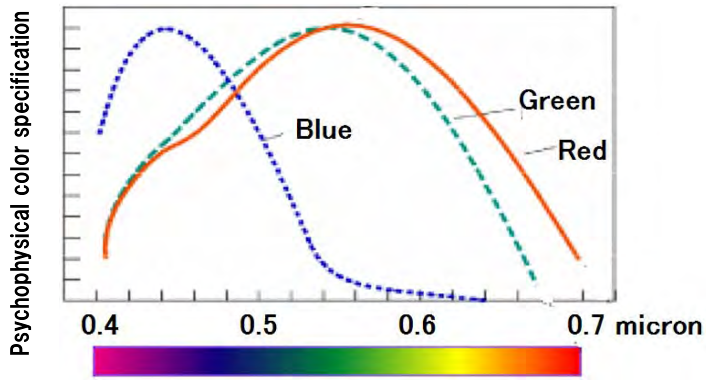
◇Natural color composite(R:r, G:g, B:b)

◇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.



Color Perception of Human Eye

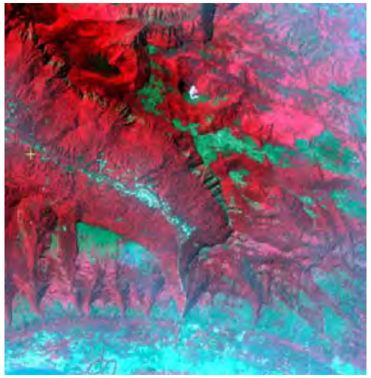


◇The highest sensitivity for green color

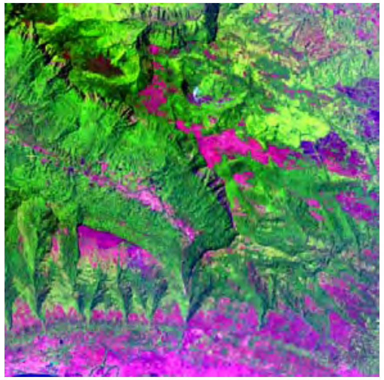
◇Wider sensitivity for red color

Color Composites

[Color Composites(LANDSAT8_OLI)]



(RGB=B5,4,3)



(RGB=B6,5,4)

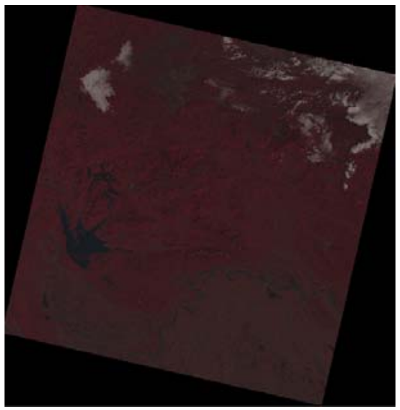
Image Enhancement

◇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.

Image Enhancement

◇ Contrast Stretching



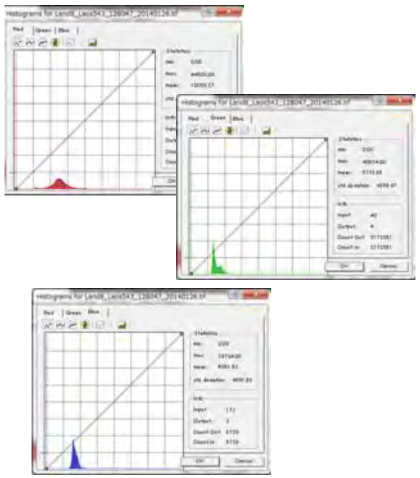
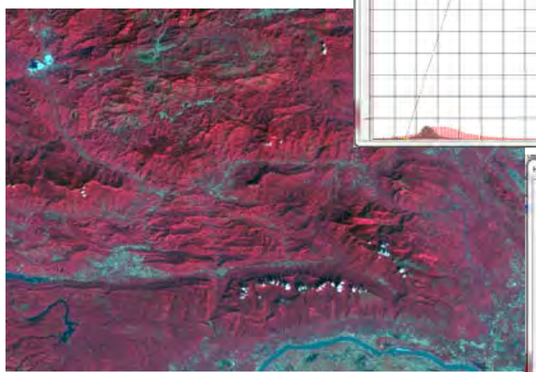


Image Enhancement

◇Custom (Custom Histogram Adjustment)



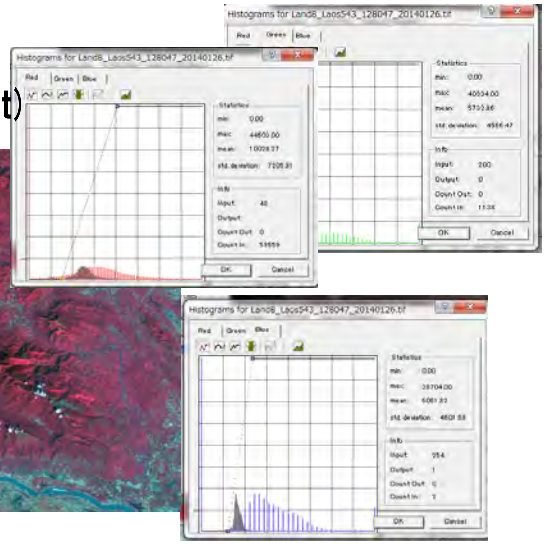
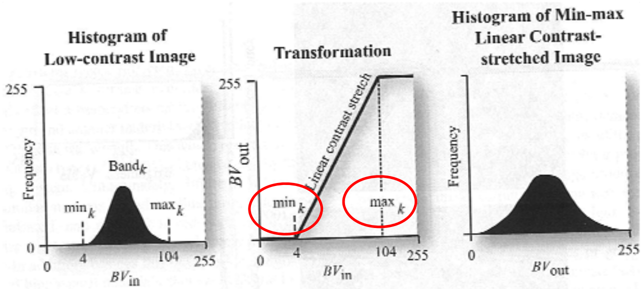
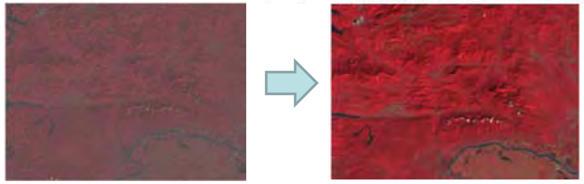


Image Enhancement

◇Maximum-Minimum Range Adjustment



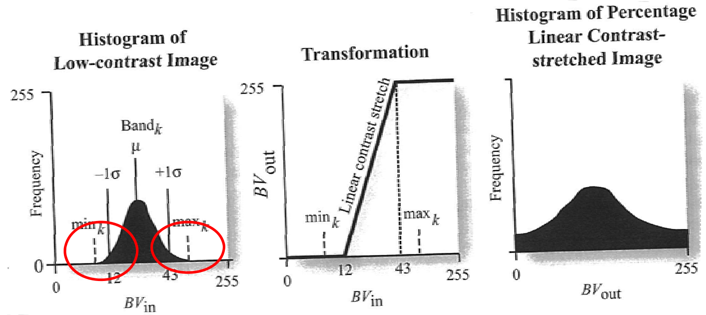


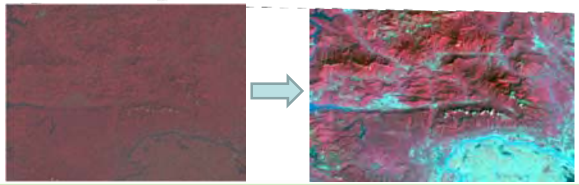
(Jensen)

Not quite good due to cloud coverage.

Image Enhancement

◇**Standard Deviation**



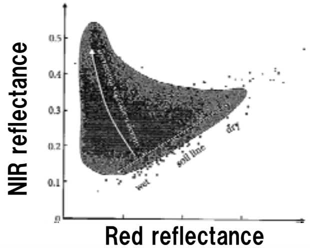


Vegetation Transformations (Indices)

◇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.



Vegetation Indices

Distribution of Pixels in Red and Near-infrared Spectral Space

(Jensen)

Various Vegetation Indices

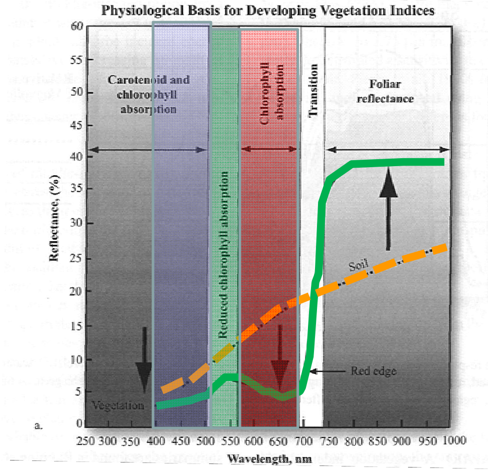
- Simple Ratio: $SVI = \frac{\rho_{red}}{\rho_{nir}}.$

- Normalized Difference Vegetation Index $NDVI = \frac{\rho_{nir} - \rho_{red}}{\rho_{nir} + \rho_{red}}$

- Enhanced vegetation Index:

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

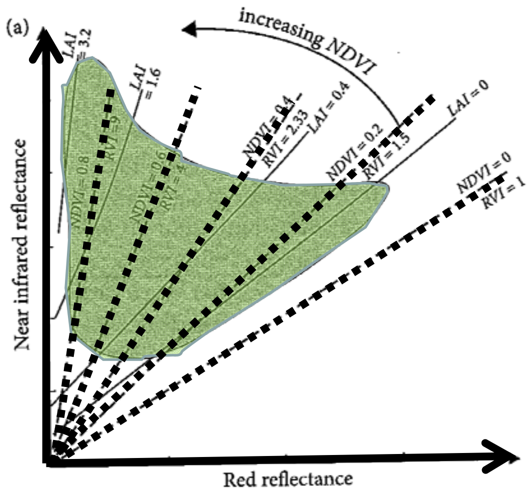
Basic



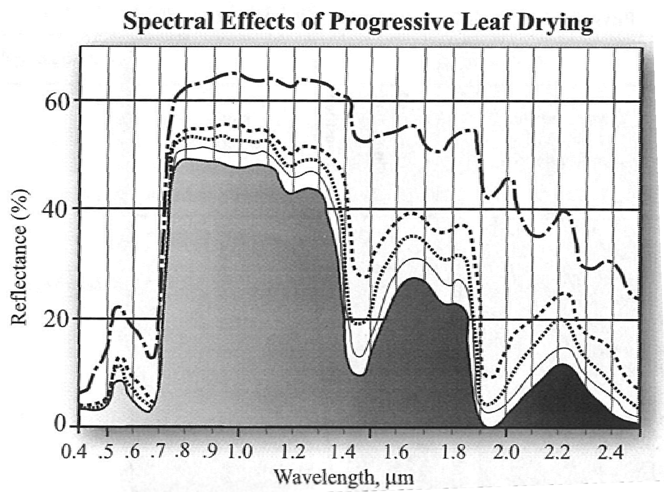
◇Typical spectral reflectance characteristics for healthy green vegetation and bare dry soil for the wavelength from 0.25 to 1.0 µm.
◇This is the physiological basis for developing vegetation indices.

Vegetation Indices

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

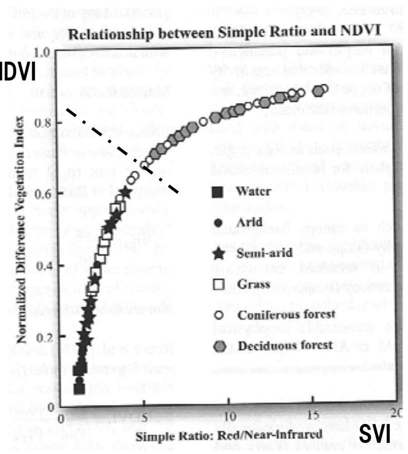


Vegetation Indices



◇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.

Relationship between SVI and NDVI



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

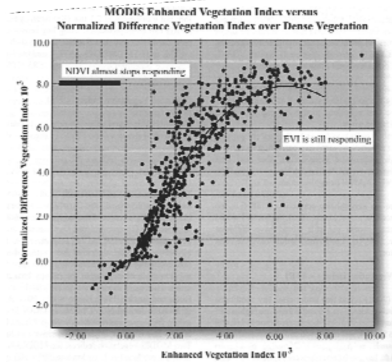
$$NDVI = \frac{\rho_{nir} - \rho_{red}}{\rho_{nir} + \rho_{red}}$$

(Jensen)

◇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.

NDVI vs. EVI

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



- L (Soil adjustment factor): 1.0
- C1 (red): 6.0, and C2 (blue): 7.5 for atmospheric aerosol scattering
- G (gain factor): 2.5 (empirically determined)

(Jensen)

◇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.

Classifications

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

Thematic Information Extraction

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

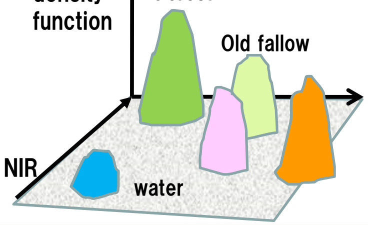
●Process RS data to extract thematic information
- Radiometric correction - Geometric correction
- Selection of the most appropriate bands
- Image classification - Extract thematic information

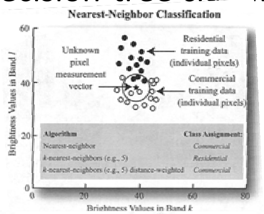
●Perform accuracy assessment ●Use the results

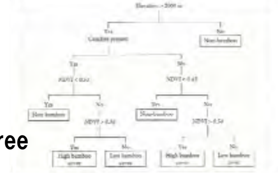
Image Classification Logics

● 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)





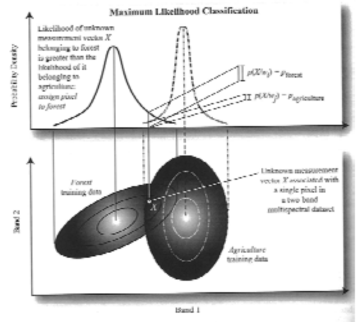


Decision tree classifier

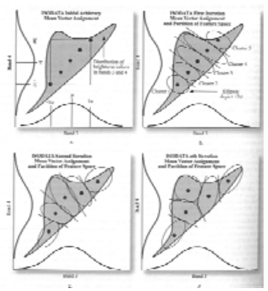
Image Classification Algorithm

● Image Classification Algorithm:

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

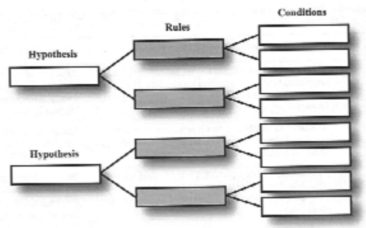


ISODATA



Classification Methods

● Expert System



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

Image Classification

● 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 homogenious.

Object-oriented Classification

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 $0 \leqq w_{color} \leqq 1$,

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

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

Theory of Image Interpretation

●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.

Image Interpretation

●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).

Image Interpretation

●Devising a Plan

◇ Once the problem is understood, a plan for its solution can be devised.
- Already identified objects ←→ Interpretation objects

◇ Method of search
- Smallest scale to larger scale search (to minimize bias)
- General to specific
- Segment the image into areas

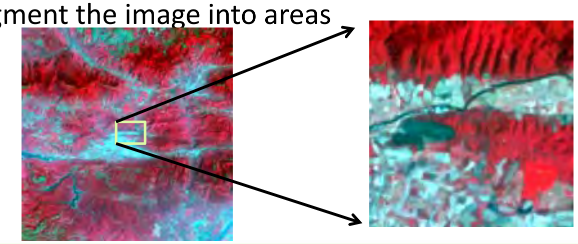


Image Interpretation

●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 answer is probably correct.

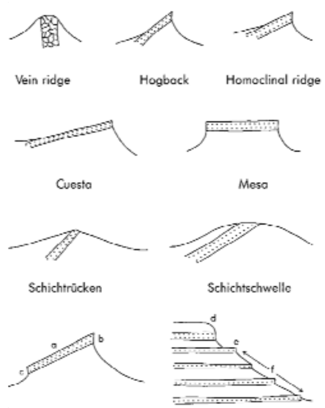


Image Interpretation

●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*.

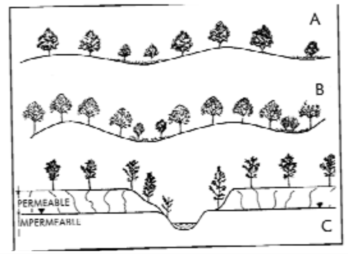


Image interpretation

●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

Image Interpretation

●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

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

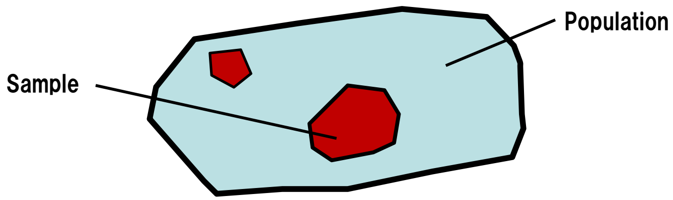
↓

Accuracy assessment report and judgement

Fundamental Aspects of Elementary Statistical Sampling Theory

◇***Population***: an infinite or finite set of elements
Satellite RS images= a finite population

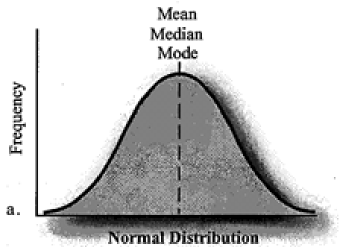
◇***Sample***: a subset of the elements taken from a population used to make inferences about certain characteristics of the population



◇***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)**

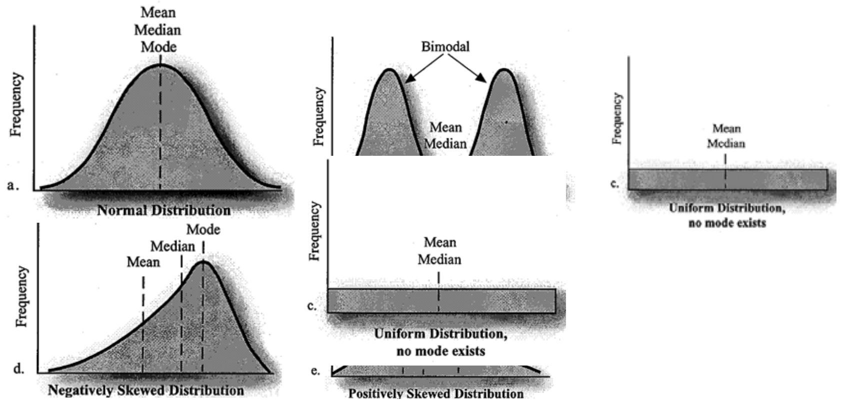
◇***Sampling error***: **the difference between the true value of a population characteristic and the value of the characteristic inferred from a sample.**

Sampling Theory



◇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?

Histogram



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

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.

Sampling Strategies

[Sampling Strategies]

(Jones)

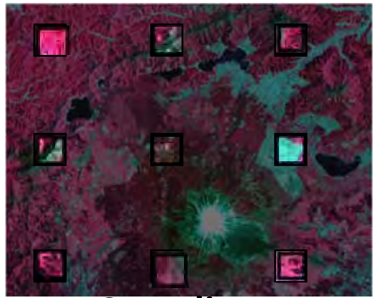
Sampling Strategies

[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 or Sampling



Wall-to-wall vs. Sampling

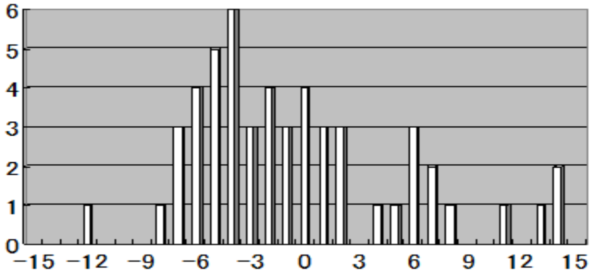
Wall-to-wall:

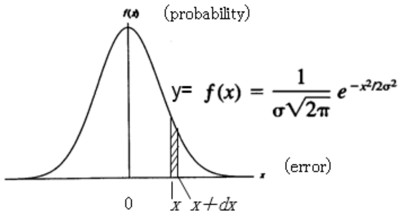
- No data omission in the project area
- Large effort and cost
- Difficult to obtain cloud free data
- Applicable to sub-national or project levels

Sampling:

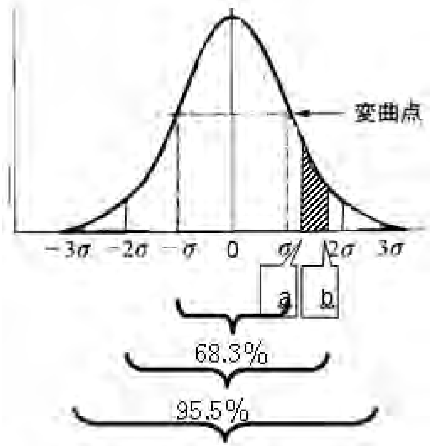
- Accuracy is varied by sampling rate (more than 20% is required for accurate estimation (Hirata, 2011))
- Enable to reduce effort and cost
- Easier to obtain cloud free data
- Difficult to apply sub-national or project levels

Normal Distribution





Characteristics of Normal Distribution



Chi Square Distribution

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:

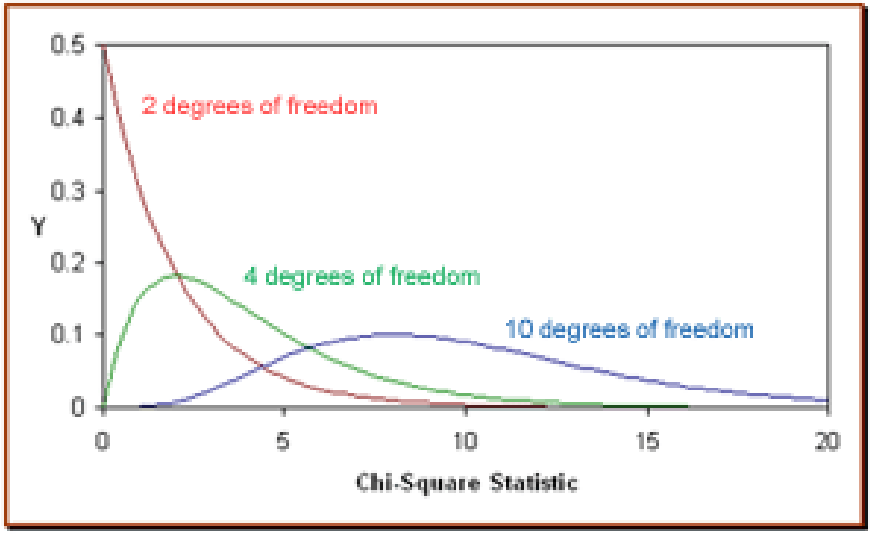
$$X^2 = [(n - 1) * s^2] / \sigma^2$$

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:

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

where Y_0 is a constant that depends on the number of degrees of freedom, X^2 is the chi-square statistic, $v = n - 1$ 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-

Chi Square Distribution



Chi Squre Test

Calculate Chi-square statistic

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

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

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

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

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: $N = 2^2 (85)(15)/ 5^2$ = a minimum of 203 points.

Sample Size

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

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%,
bi is the desired precision (e.g., 5%) for this class, B is the upper (α/k)x100th percentile of the chi square (χ^2) distribution with 1 degree of freedom, and *k* is the number of classes.

Symbols in Mathematics

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

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

Sample size $N = \frac{B\Pi_i(1-\Pi_i)}{b_i^2}$ Π_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 χ2 table with 1 degree of freedom and 1-α/*k* as $\chi^2_{(1,0.99375)}$ =7.568:

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

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

These 636 samples should be randomly selected to adequately fill the error matrix. About 80 samples per class are required)e.g., 8x80=640).

Sample Size

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 (o.05 ^{2})} = 757 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)

Sample Size

Confidence interval = 85 %

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

Precision = 5% Value for B = 5.695.

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

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.

Error Matrix

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

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)

Accuracy Assessment

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

$\sum_{i=1}^{k}(x_{i+}\times x_{+i})$ = (88x73)+(58x60)+(99x103)+(41x50)+(121x121)=36,792

Thus, $\hat{K}$ = {407x(382) - 36792}/{407x407 - 36792=
= (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

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

Mitsuru NASU, Ph.D.
Forest Remote Sensing

Image Interpretation

●Understanding the Problems

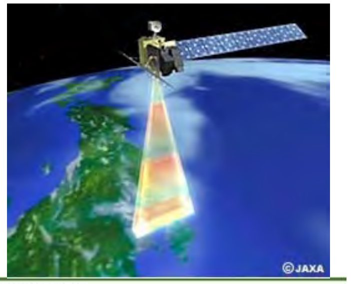
◇Correction of FIM utilizing RadidEye Images of 2010
◇Mapping Old Fallows2010 using ALOS/PALSAR Images
◇Mapping Decidus/Evergreen Forest Types using Spectral and Spatial Data
◇Mapping of Forest/Non-forest Maps (SPOT Images 2005 and the Corrected 2010 FIM)----4 km Grid Points
◇Mapping of Forest/Nonforest 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

Image Interpretation

●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)



GT Survey 2014

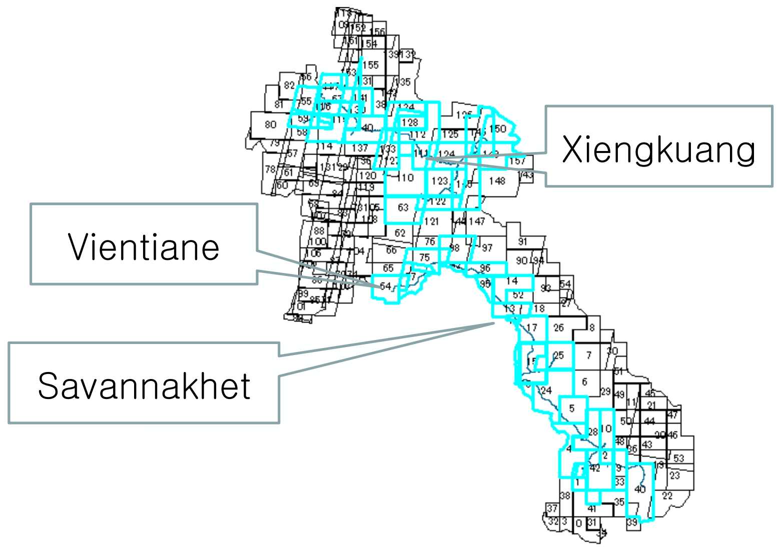
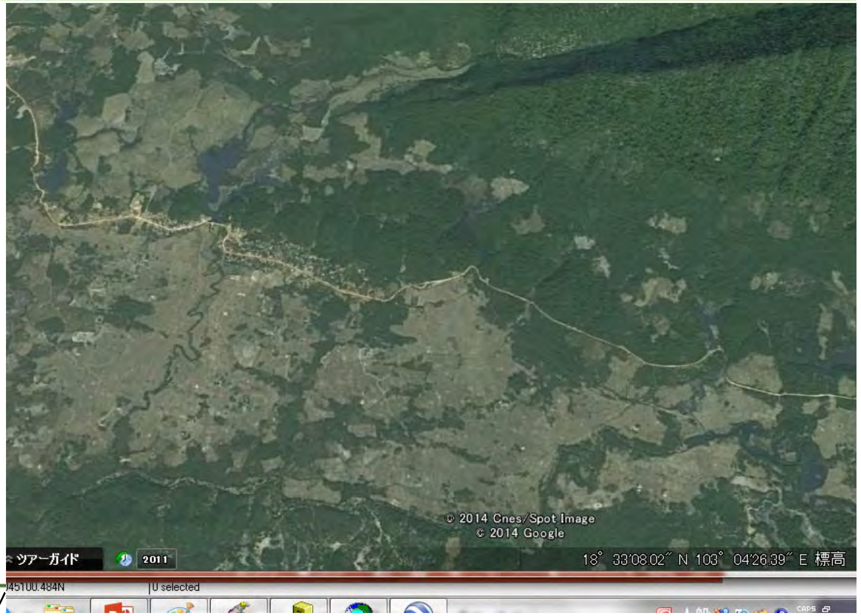


Image Interpretation

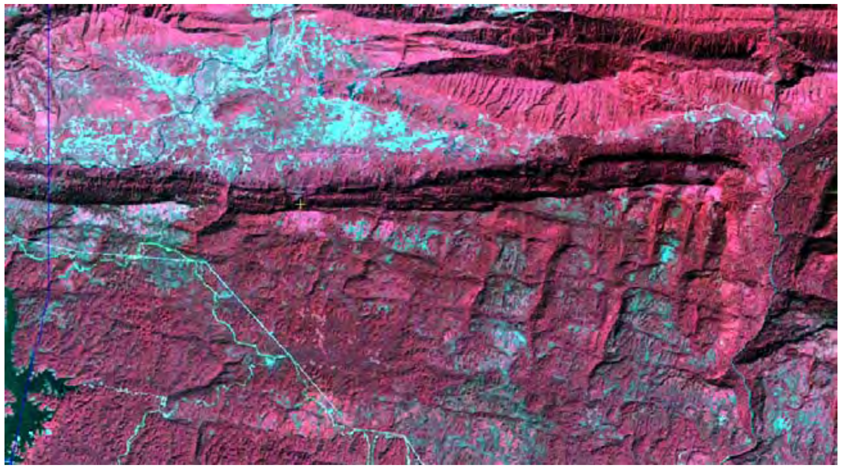
● Basic Elements of Image interpretation

◇ 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
-

GoogleEarth



Landsat 1999/12/27



SPOT 2005

- SPOT 33-0401 2005

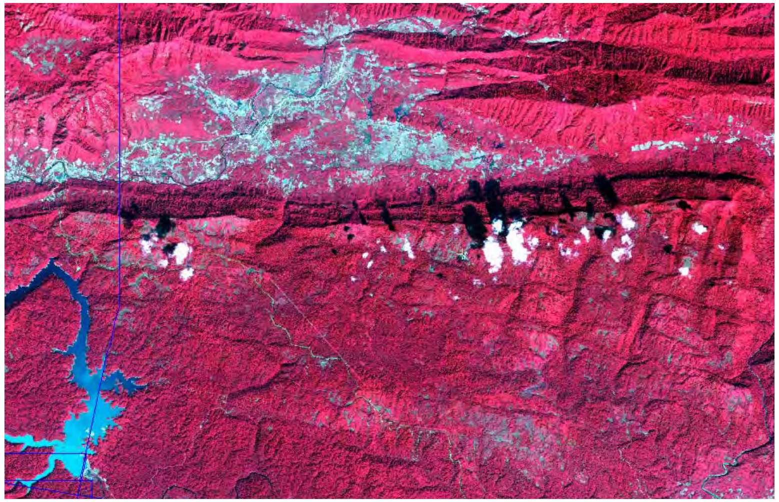


Image Interpretation

RapidEye 04391901

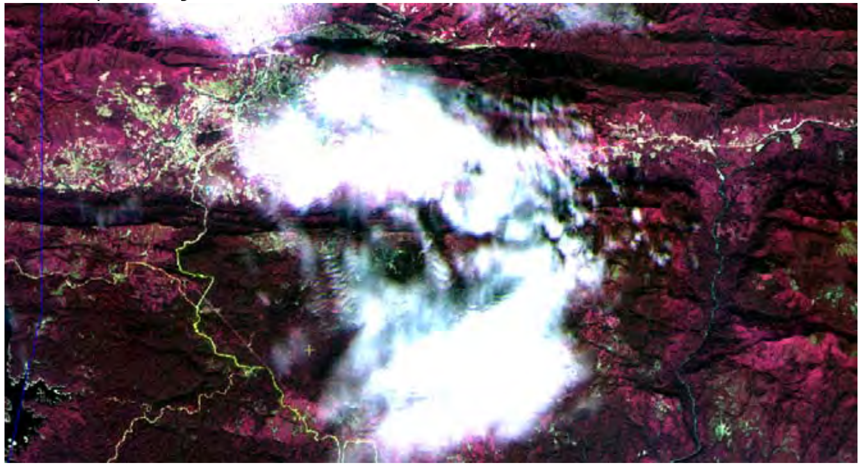
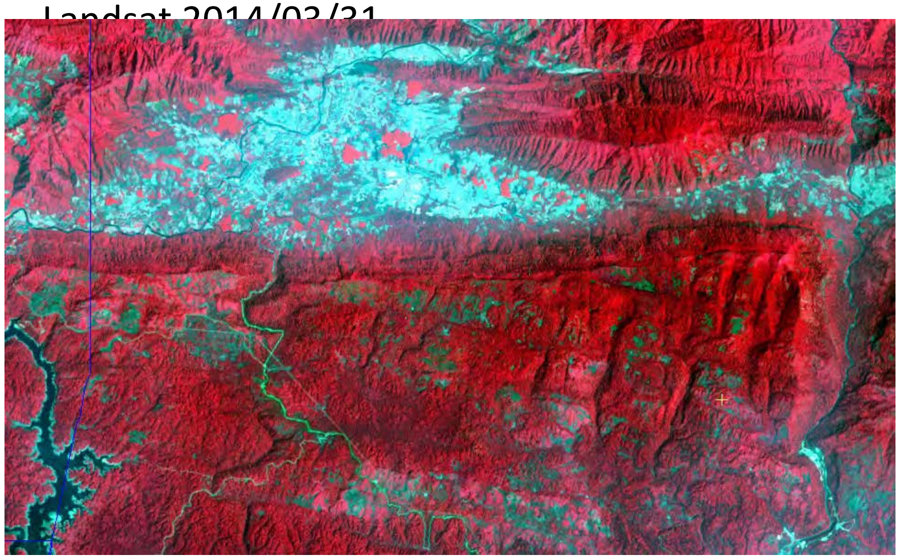
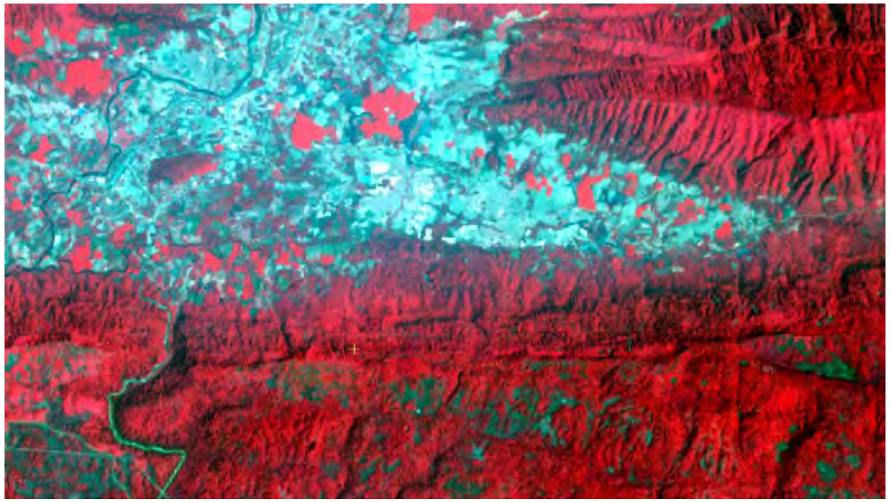


Image Interpretation

Landsat 2014/03/31



- 2014 Landsat8 Enlarged



Aerial Photos

Aerial Photos

Aerial Photo3

Enlarged Aerial

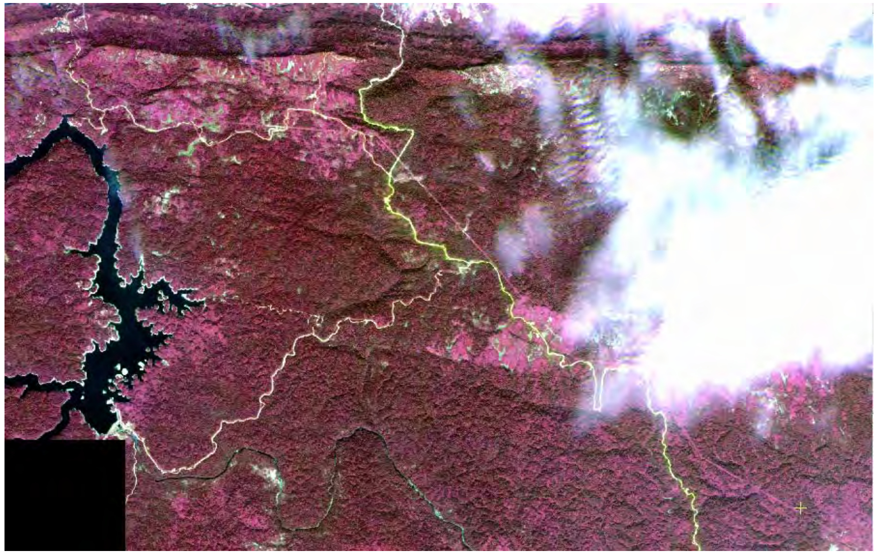
Enlarged

Rubber Plantation?

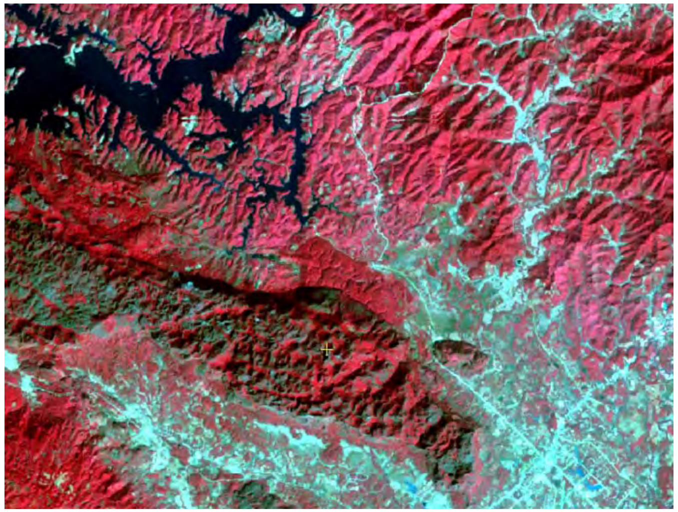
Enlarged

Enlarged Aerial Photo

RapidEye again

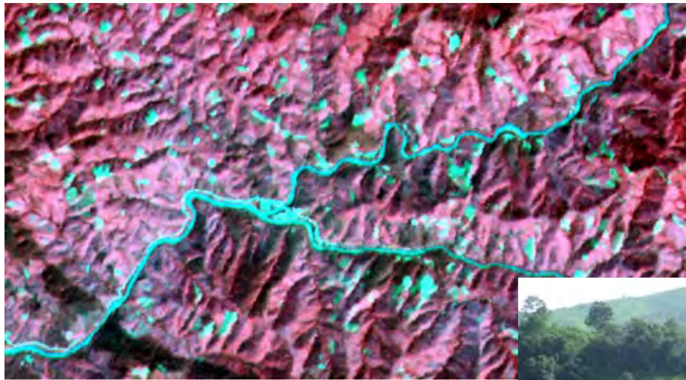


Reflectance of Various Features



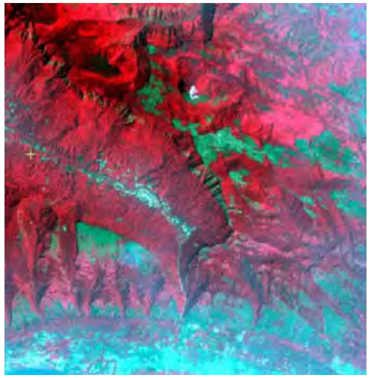
(Landsat 8 Lak Xao)

SPOT 5 Image (Example)

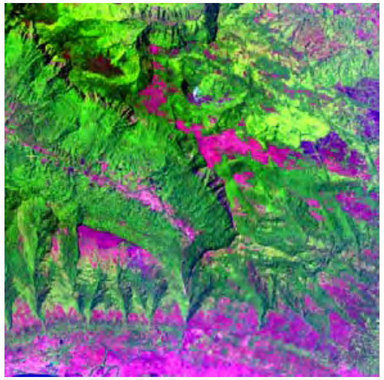


Ground resolution: 10 m

[Color Composites(LANDSAT8_OLI)]



(RGB=B5,4,3)



(RGB=B6,5,4)

●Basic Elements of Image interpretation

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

Theory of Remote Sensing
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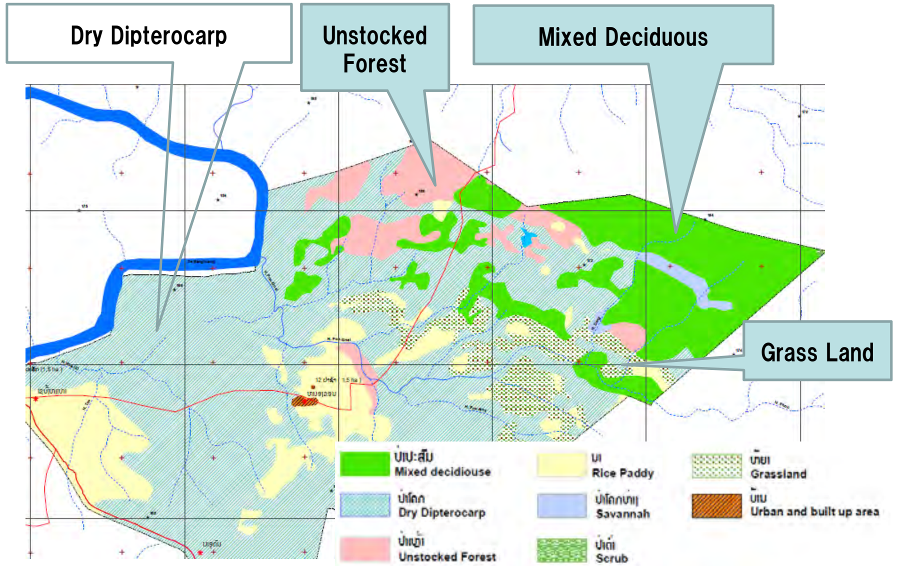
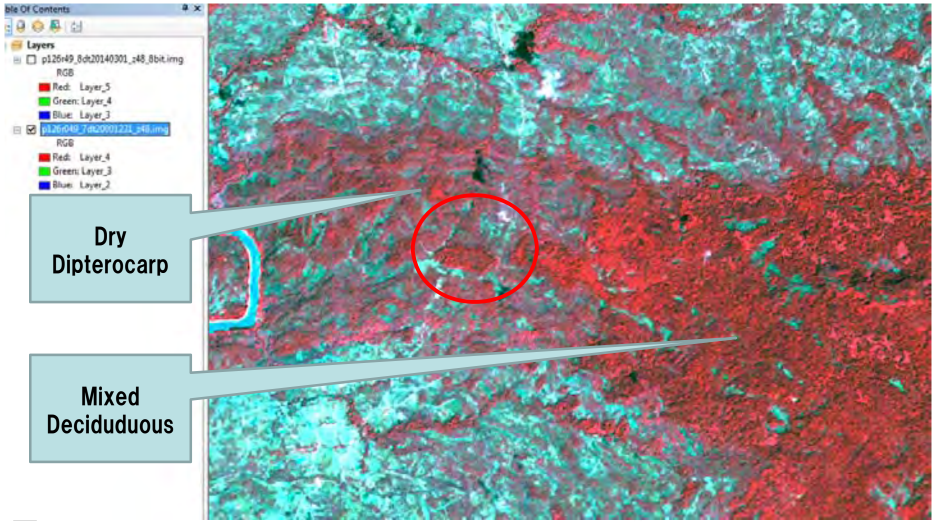
Existing Forest Map



Landsat 2000

Savannakhet Landsat 2000
P126R49-20001231[standdev.display]



SPOT 2005

SPOT5 2005 – SK1004-56-0601

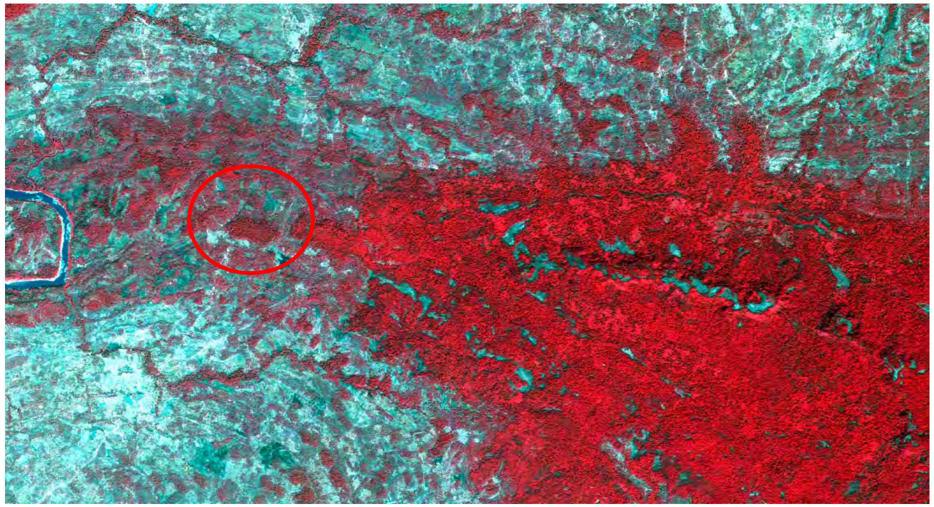


Image Interpretation

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

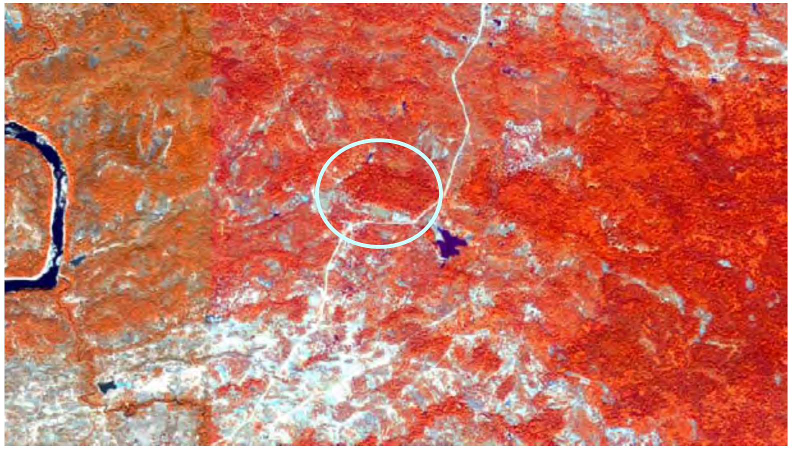
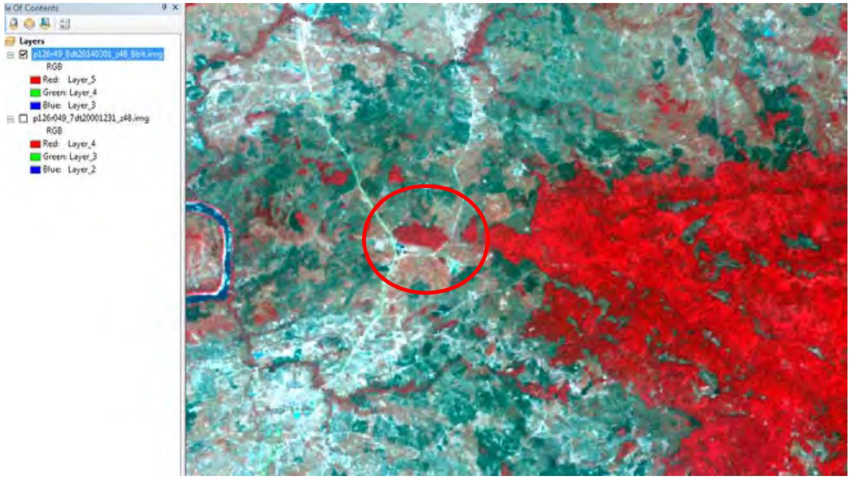
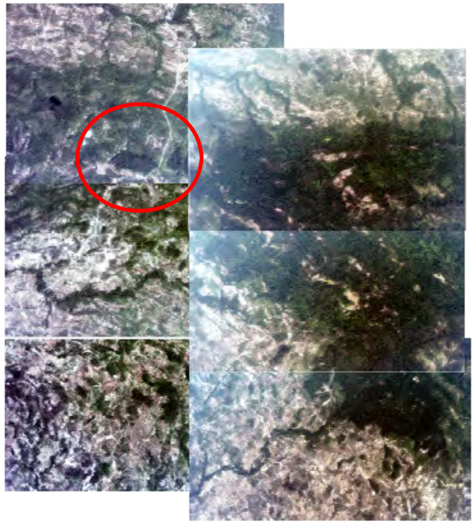


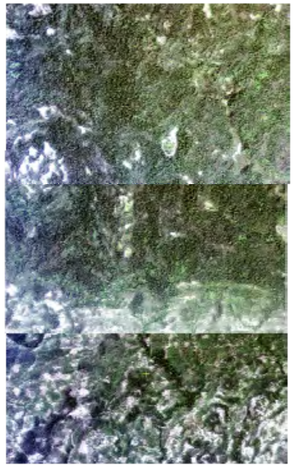
Image Interpretation

Landsat8 2014/03/1



Aerial Photos

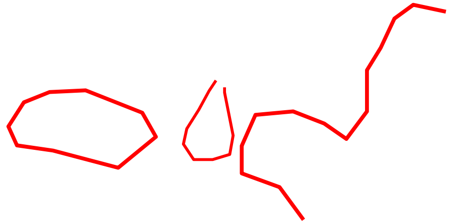




Aerial Photo3

Enlarged Aerial Photo

Enlarged

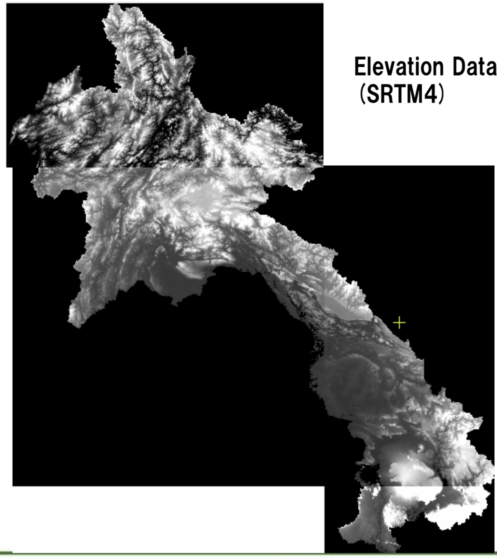


Various land-covers

Image Interpretation

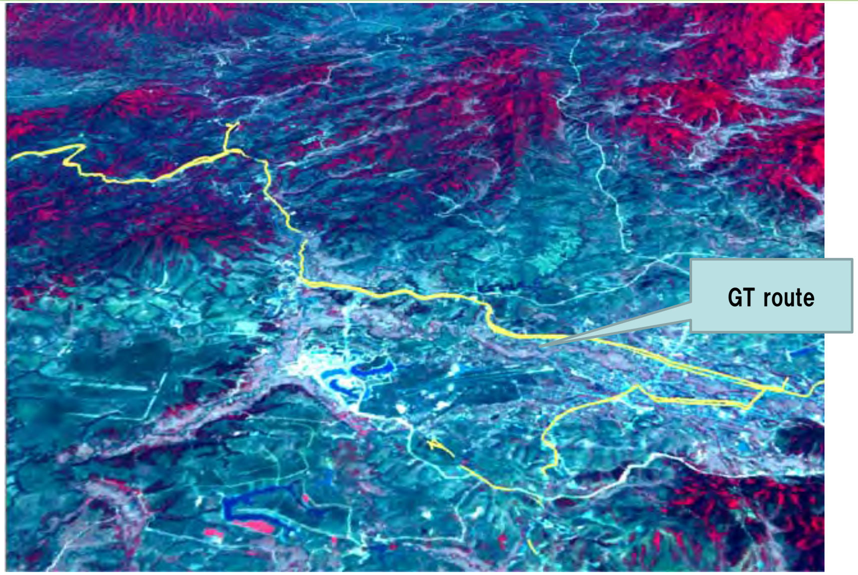
- Although colors and tone (darkness) are, in general, very important information on the forest and land covers, they may change depending on sensor sensitivity, sun's intensity and altitude, condition of the land cover (season, water condition, age, soil moisture, etc.), condition of the atmosphere,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

Use of SRTM

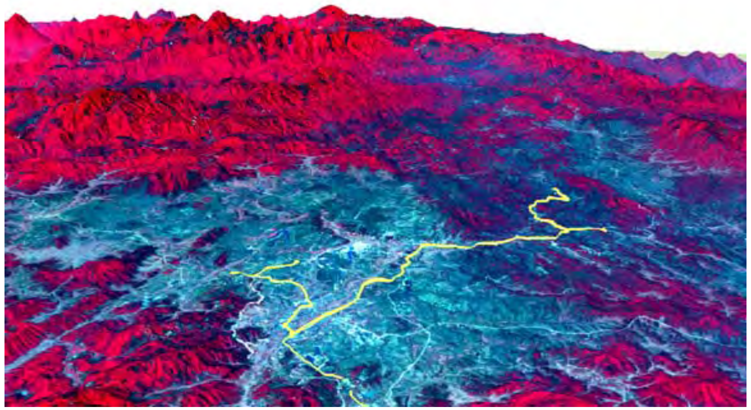


Elevation Data from NASA
(SRTM4)

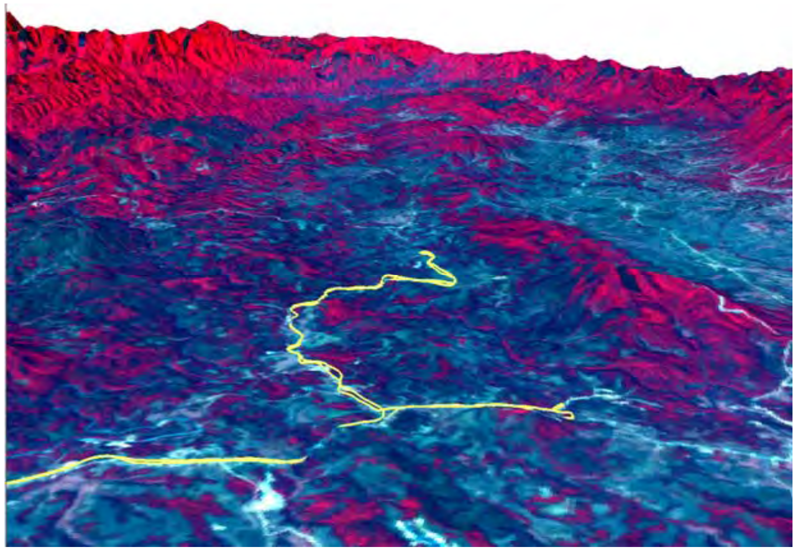
3D Presentation by Arc Scene



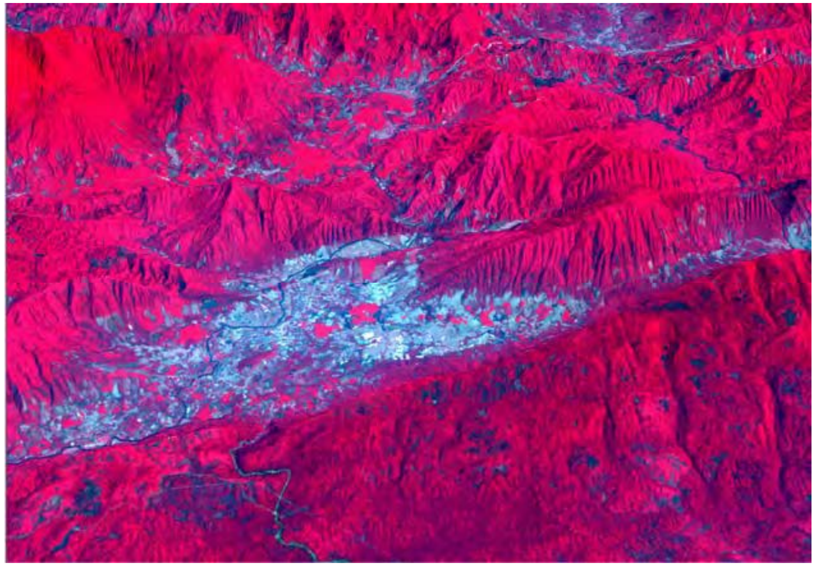
3D Presentation by Arc Scene



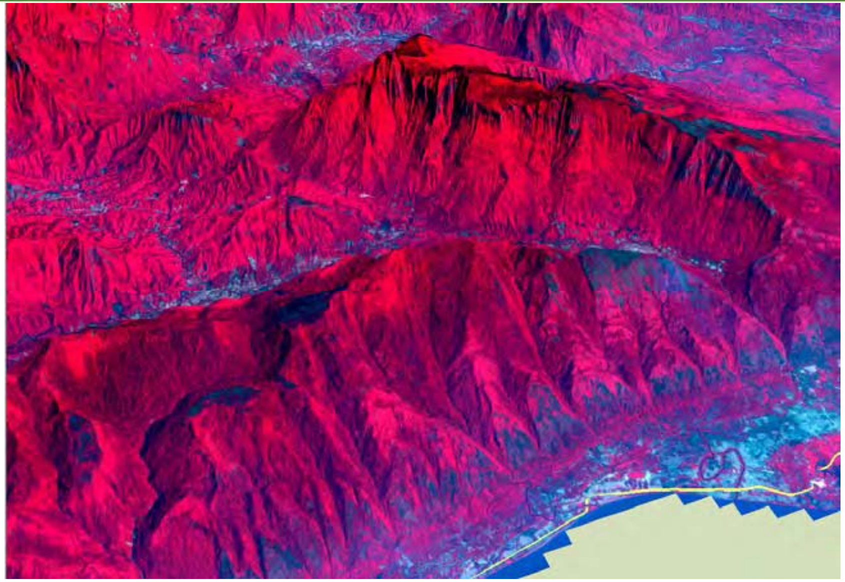
3D Presentation by Arc Scene



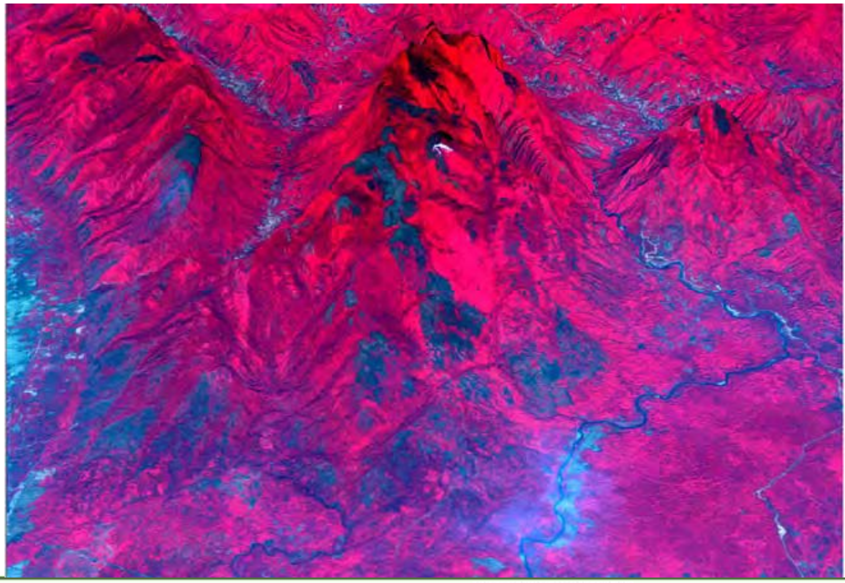
3D Presentation by Arc Scene



3D Presentation by Arc Scene



3D Presentation by Arc Scene



3D Presentation by Arc Scene

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