



# Theory of Remote Sensing

## Part-2 (No.1)

Technical Training  
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Forest Remote Sensing



1. Introduction
2. Characteristics of the Light (Sun Light) for Forest Remote Sensing
3. Earth Observation Systems
4. Terrain and Landform Interpretation
5. Radiation Properties of Vegetation, Soil, and Water
6. Understanding Actual Spectral Characteristics of Land Use/Land Cover
7. Understanding Vegetation Indices of Forest and Various Land-Cover Features



### I . Review of Theory of RS - Part 1



#### 1. Introduction

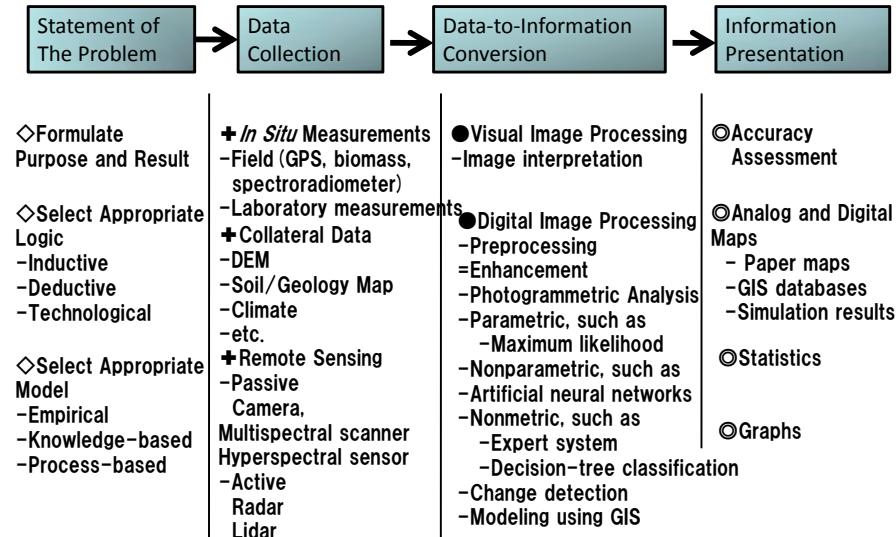
- ◊ Remote sensing uses sensors to measure the amount of electromagnetic radiation from an object from a distance.
- ◊ RS extracts valuable information from the data for forest monitoring and management.
- ◊ RS needs many fundamental knowledge of sciences and technologies.



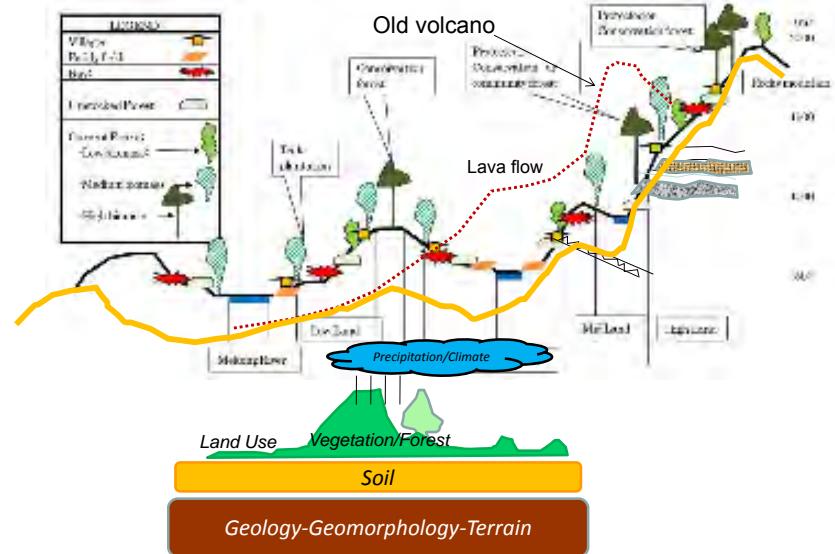
- ◊ "Theory of Remote Sensing" aims to contribute for improving fundamental knowledge of remote sensing practices in the field of Forestry.



### The Remote Sensing Process



## Elements of Forest Remote Sensing Survey



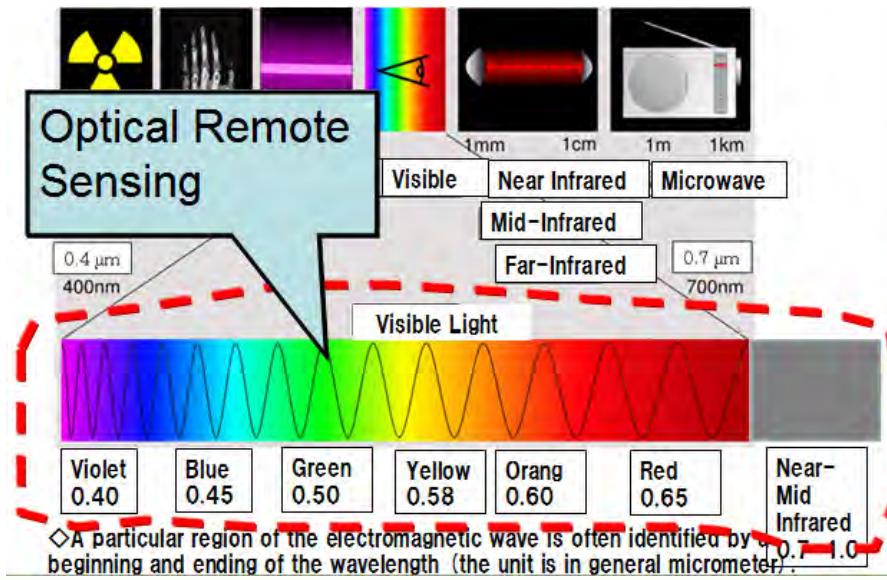
## 2.Radiation Physics

### 2. Characteristics of the Light (Sun Light) for Forest Remote Sensing

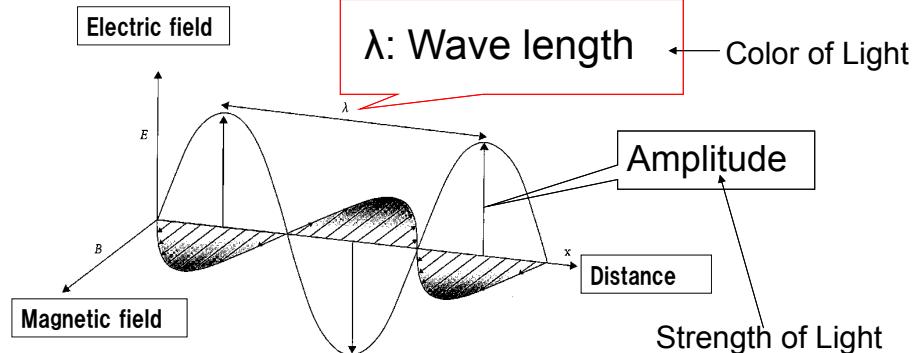


Namha National Protected Area, Oudom Xay

## Electromagnetic Spectrum

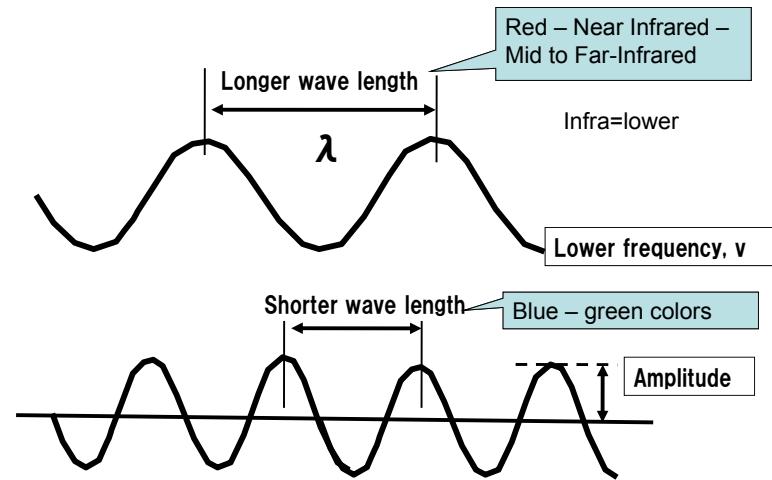


## Electromagnetic Radiation

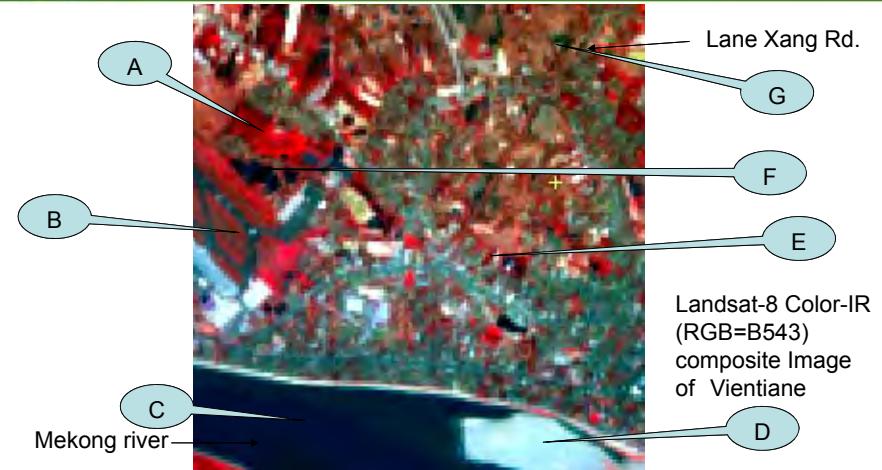


- ◊ Electromagnetic radiation from the object is a key element of Remote Sensing.
- ◊ Electromagnetic radiation consists of time-varying electric and magnetic fields that travel in the form of a wave at the speed of light  $c$  ( $3 \times 10^8 \text{ ms}^{-1}$ ).
- ◊ Once the wave has been formed, it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

## Electromagnetic Radiation



## Electromagnetic Radiation



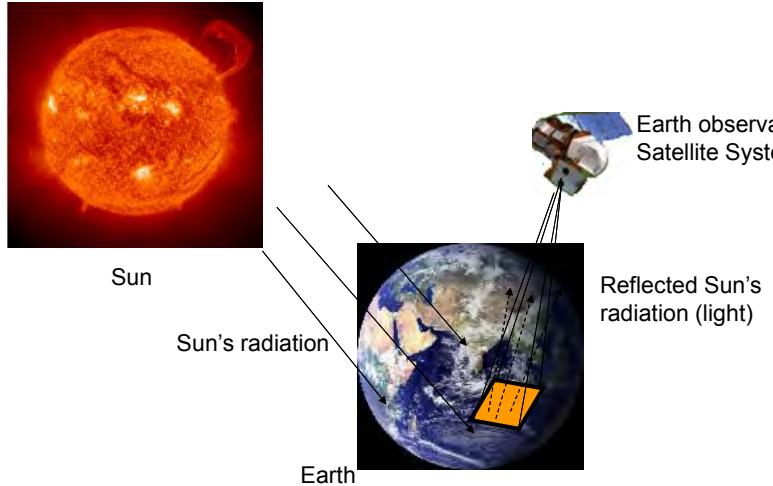
◊ Which features have longer wavelength electromagnetic radiation ?

( ) A ( ) B ( ) C ( ) D ( ) E ( ) F ( ) G

◊ Which features have higher amplitude electromagnetic radiation ?

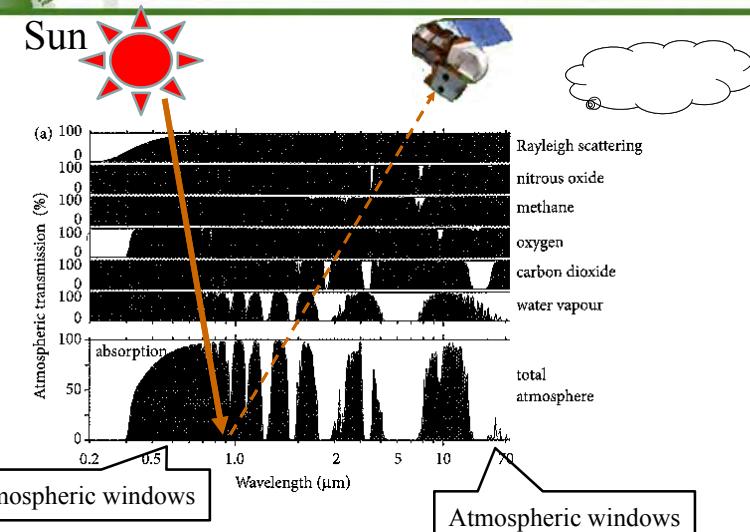
( ) A ( ) B ( ) C ( ) D ( ) E ( ) F ( ) G

## Electromagnetic Radiation



◊ The Sun's radiation is a primary source of Earth's radiation.

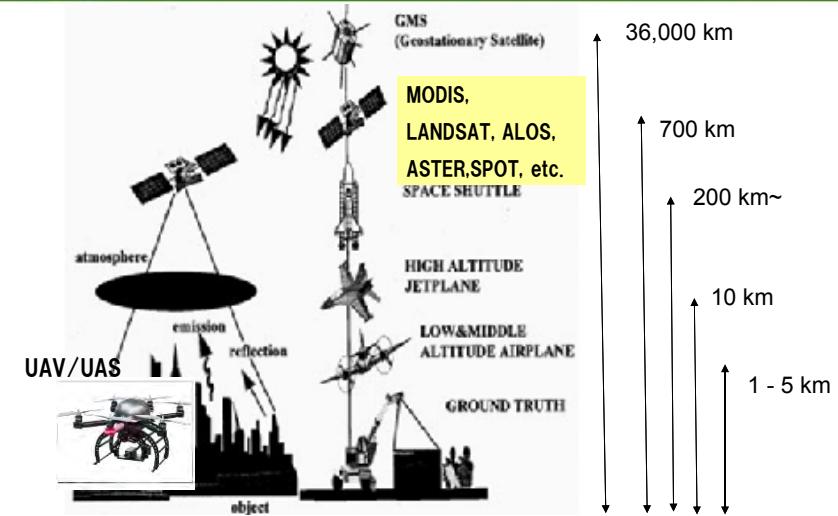
## Atmospheric Absorption and Transmission



Atmospheric Transmission



### 3. Earth Observation Systems



(NASA: [http://rst.gsfc.nasa.gov/Intro/Part2\\_1x.html](http://rst.gsfc.nasa.gov/Intro/Part2_1x.html))



<http://www.satimagingcorp.com/satellite-sensors/skysat-2/>

<http://www.firstimager.skybox.com/hd-video/2014/10/20/skysat-1-video-of-mount-ontake-on-october-16-2014>



<http://www.firstimager.skybox.com/hd-video/2014/10/20/skysat-1-video-of-mount-ontake-on-october-16-2014>



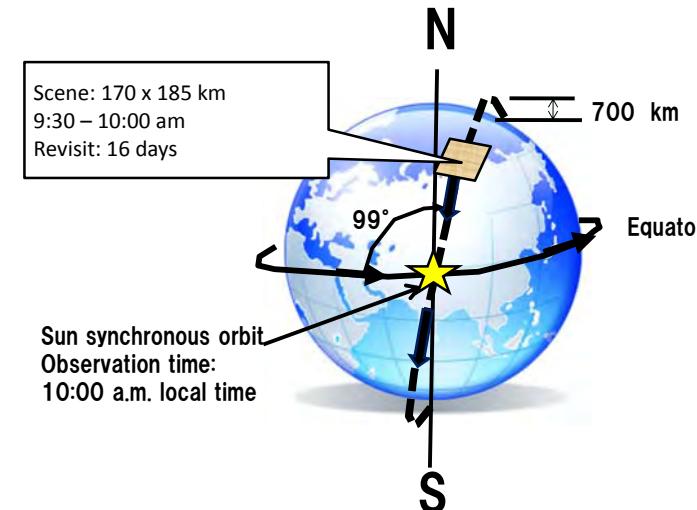
## Classification of Remote Sensing Satellites

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

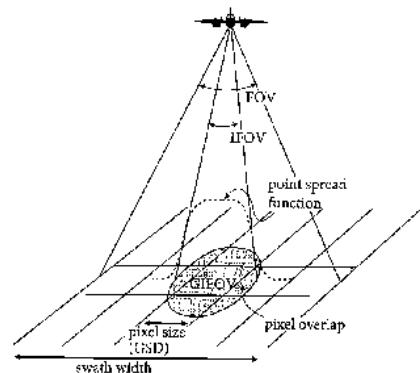


## [ Satellite Observation System (Ex. Landsat) ]



### ◇Ground resolution (Spatial resolution)-Pixel Size

- 0.5m – 1 km



FOV: Field of View  
IFOV: Instantaneous field of View  
GIFOV: Ground Instantaneous Field of View  
GSD: Ground Sampling Distance

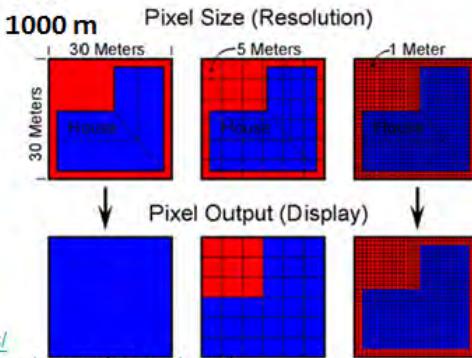


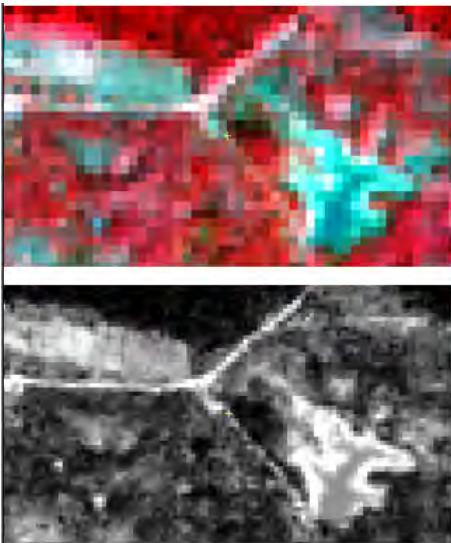
## Characterization of Satellite Remote Sensing Systems

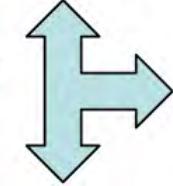
### Spatial Resolution

High spatial resolution: 0.41 - 4 m

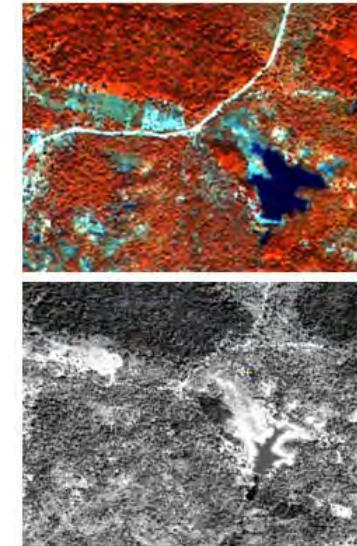
Low spatial resolution: 30 - > 1000 m





Multispectral Image  
Bandwidth: 0.1 micron  
  
 Pan-sharpen CIR Image  
 Panchromatic Image  
Bandwidth: 0.3 micron

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RapidEye

(6 m)

ALOS/PRISM-  
Panchromatic

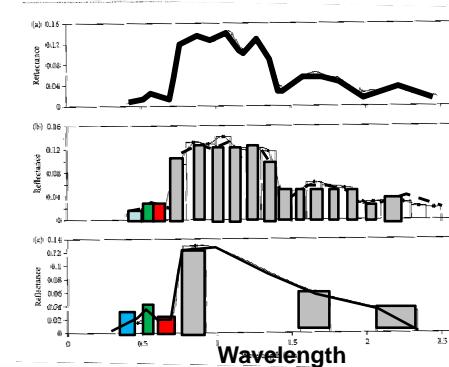
(2.5 m)



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 <sup>2</sup> Recent Data \$0.02 - \$0.5/km <sup>2</sup>	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.



- ◊ Spectral resolution
  - Number of bands and spectral regions



Spectral Characteristic of Vegetation (Example)

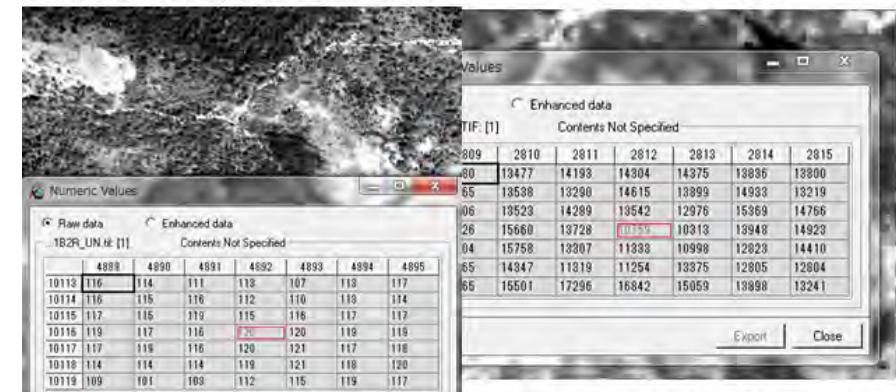
Hyperspectral Sensor

Typical Optical Sensor (Example)

## Spectral Resolution

- High spectral resolution: - 220 bands
- Medium spectral resolution: 3 - 15 bands
- Low spectral resolution: - 3 bands

◊ Radiometric resolution - 8-bits or 16-bits



What is advantage and disadvantage of 16 bits data over 8 bits data?

◊ Temporal resolution (Re-visited time)  
- 2 – 16 days

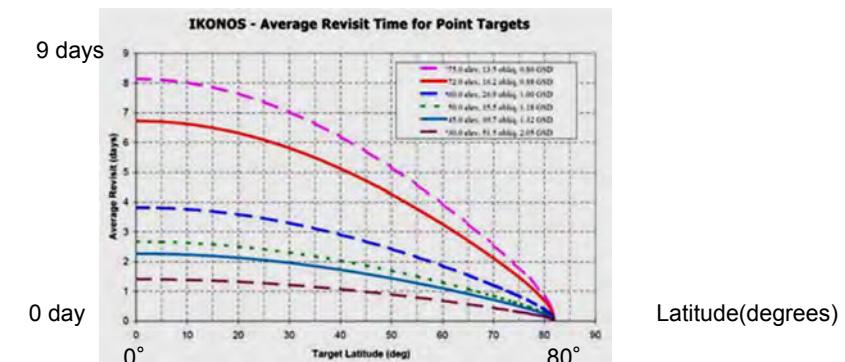
- Landsat 8: 16 days
- Rapid Eye: 6 satellites/
- Spot
- MODIS

## Temporal Resolution

High temporal resolution: < 24 hours - 3 days

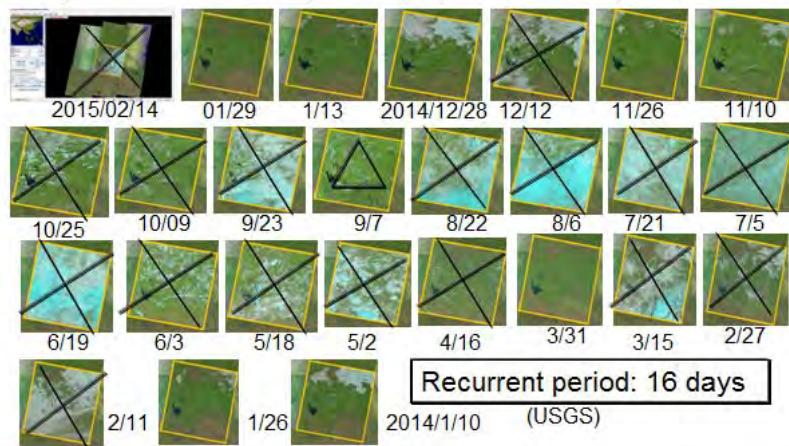
Medium temporal resolution: 4 - 16 days

Low temporal resolution: > 16 days

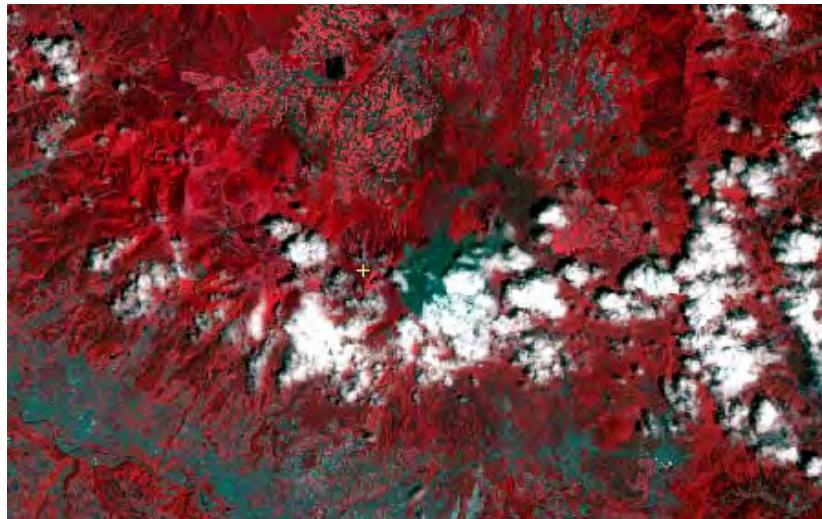




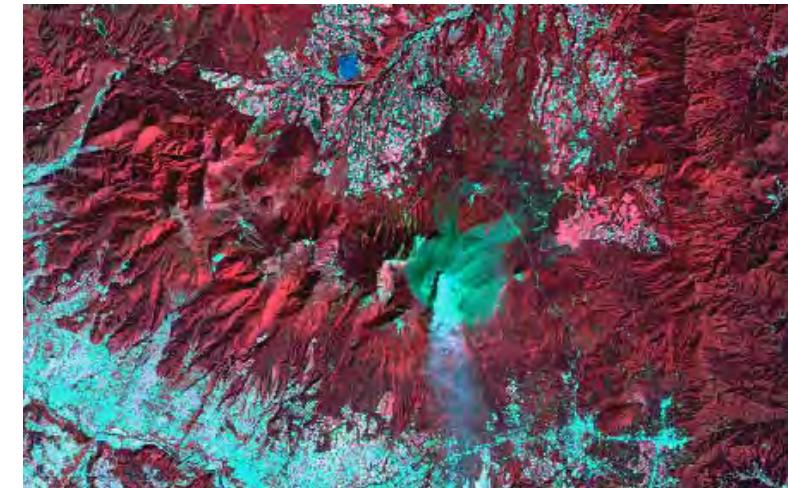
Landsat 8 Observation Data 2014-2015 (Difficulty to acquire cloud-free image using Optical Sensors)



25 May, 2014 Landsat 8 Image



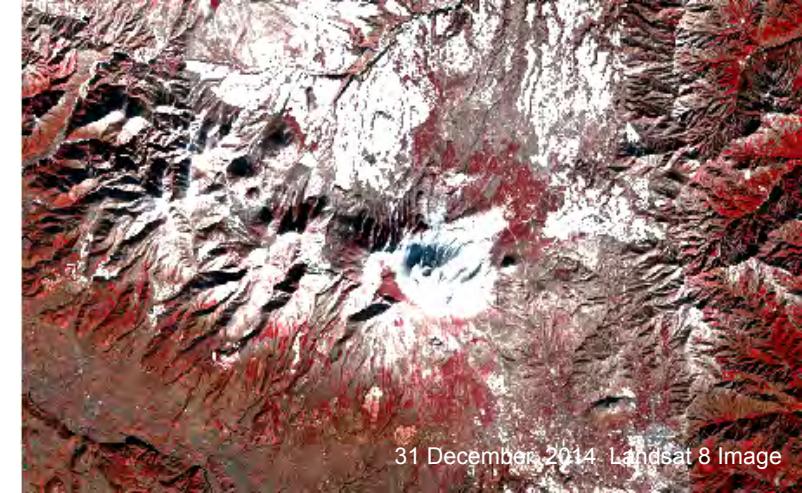
25 July, 2014 Landsat 8 Image



15 September, 2004 Landsat ETM+ Image



31 October, 2014 Landsat 8 Image



31 December, 2014 Landsat 8 Image

Multi-temporal images provide a lot of information on the ground features. However, it is not easy to acquire the good multi-temporal images in practice.



Japan Cedar





## Beech



DOF/FIPD

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## Pine trees



DOF/FIPD

KOKUSAI KOGYO CO.,LTD. ASIA AIR SURVEY CO.,LTD.

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## White birch



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## Silver Fir



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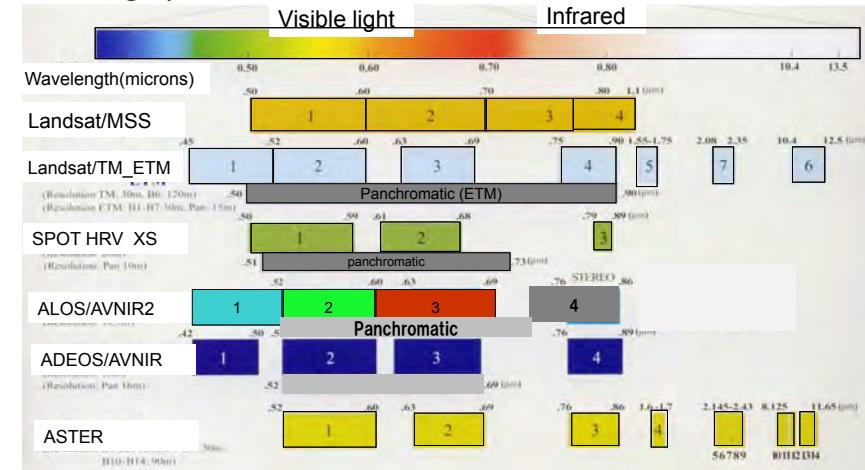


## Resolution Trade-Off

- The different spatial, temporal and spectral resolutions are the limiting factor for the utilization of the satellite image data for different applications.
- A high spatial resolution is associated with a low spectral resolution and vice versa.
- That means that a system with a high spectral resolution can only offer a medium or low spatial resolution.



### [Sensing Spectral Bands]



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

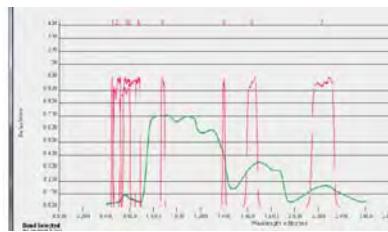


Landsat 8 Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS) Launched February 11, 2013	Bands	Wavelength (micrometers)	Resolution (meters)
	Band 1 - Coastal aerosol	0.43 - 0.45	30
	Band 2 - Blue	0.45 - 0.51	30
	Band 3 - Green	0.53 - 0.59	30
	Band 4 - Red	0.64 - 0.67	30
	Band 5 - Near Infrared (NIR)	0.65 - 0.00	30
	Band 6 - SWIR 1	1.57 - 1.05	30
	Band 7 - SWIR 2	2.11 - 2.29	30
	Band 8 - Panchromatic	0.50 - 0.00	15
	Band 9 - Cirrus	1.26 - 1.30	30
	Band 10 - Thermal Infrared (TIRS) 1	10.00 - 11.15	100 ± (30)
	Band 11 - Thermal Infrared (TIRS) 2	11.50 - 12.51	100 ± (30)

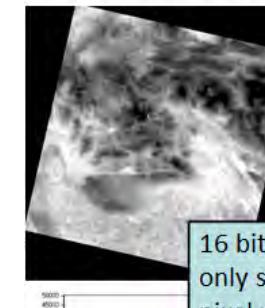
\* TIRS bands are acquired at 300 meter resolution, but are resampled to 30 meter in delivered data product.



(USGS)

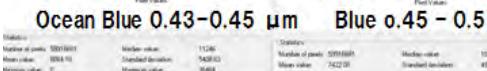


Band 1: Extreme Blue

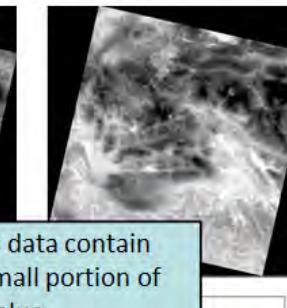


16 bits data contain only small portion of pixel value.

Ocean Blue 0.43-0.45 µm



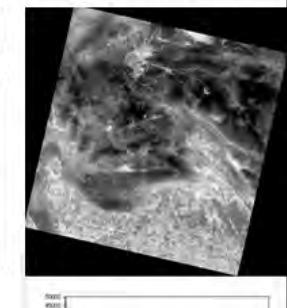
Band 2: Blue



Blue 0.45 - 0.51



Band 3: Green



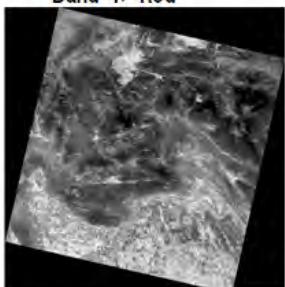
Green



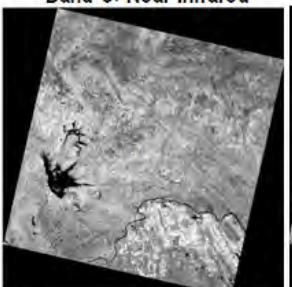
# Example of RS Imagery



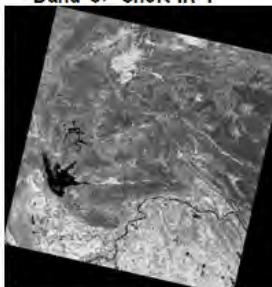
Band 4: Red



Band 5: Near Infrared



Band 6: Short IR 1



Red

Statistics  
Number of pixels: 3091621  
Mean value: 2785.54  
Minimum value: 0  
Median value: 4226  
Standard deviation: 627.76

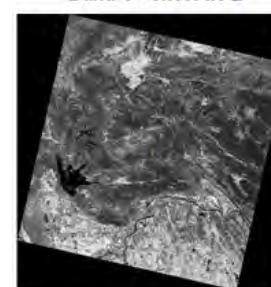
Statistics  
Number of pixels: 3091621  
Mean value: 17762.7  
Minimum value: 0  
Median value: 17762.7  
Standard deviation: 57436

Statistics  
Number of pixels: 3091621  
Mean value: 11424  
Minimum value: 0  
Median value: 11424  
Standard deviation: 6351.12  
Maximum value: 68625

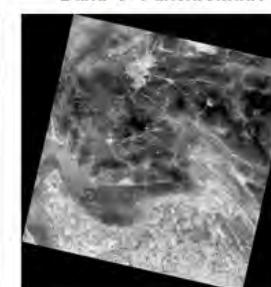
# Example of RS Imagery



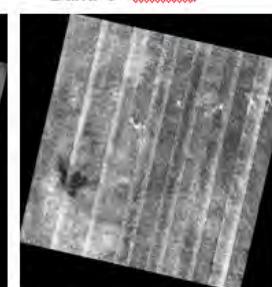
Band 7: Short IR 2



Band 8: Panchromatic



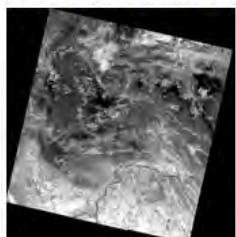
Band 9: Sceera



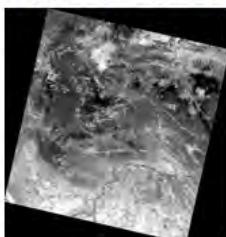
# Example of RS Imagery



Band 10: Thermal 1



Band 11: Thermal 2



Band BQA



Quality Analysis Data

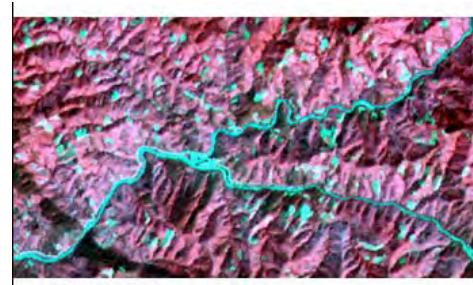
Thermal IR1

Statistics  
Number of pixels: 3091621  
Mean value: 3082.1  
Minimum value: 0  
Median value: 3082.1  
Standard deviation: 637.1

Thermal IR2

Statistics  
Number of pixels: 3091621  
Mean value: 10234.1  
Minimum value: 10234.1  
Median value: 10234.1  
Standard deviation: 6360.1

# SPOT 5 Image (Example)



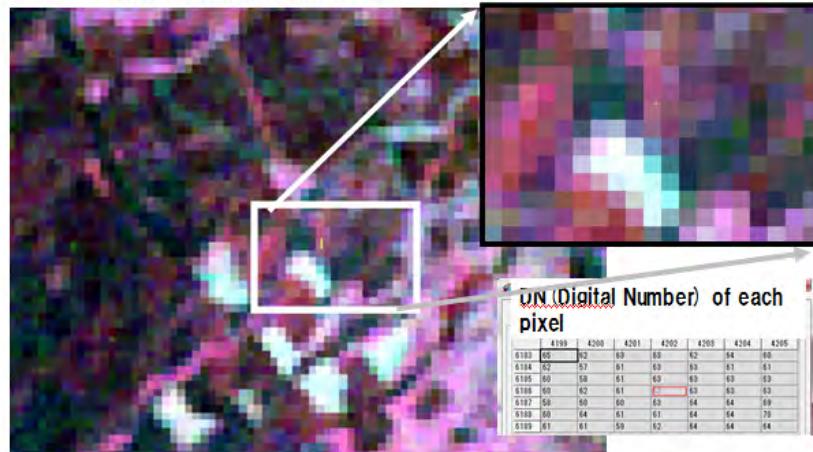
Ground resolution: 10 m





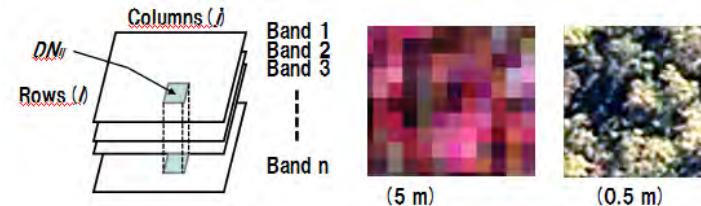
## [Picture and Pixels]

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.

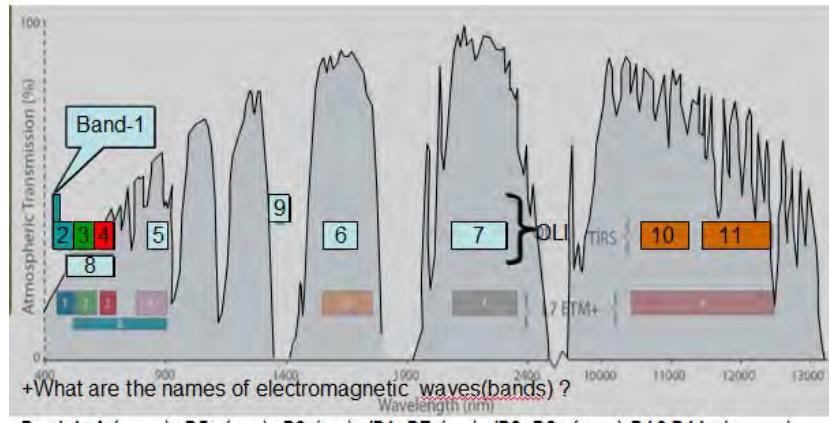


## Remote Sensor's Observation Bands



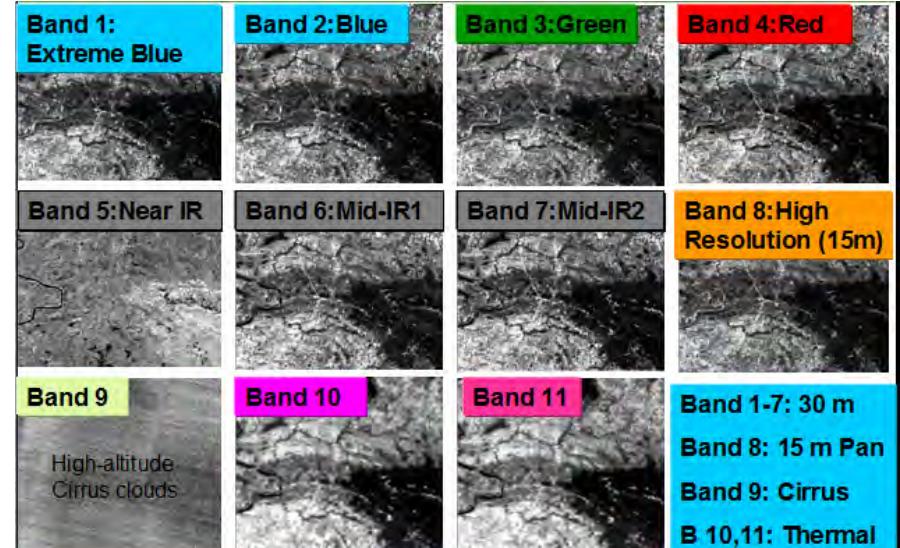
LANDSAT 8 Sensors: OLI: Optical Land Imaging

TIRS: Thermal Infrared Imaging Sensor



+ Ground resolution of Band5 is ( )m. How about Band8 ? ( )m. Why it is possible?

## LANDSAT 8 Sensors (Example)



## Landsat-8 OLI and TIRS Sensors

**Band\_1:** 0.433–0.453 $\mu\text{m}$ , Extreme Blue, Detection of Atmospheric Particles, Coastal Water Mapping

**B\_2:** 0.450–0.515 $\mu\text{m}$ , Blue, Coastal Water Mapping, Soil/Vegetation and Coniferous/Broad Leaf Discrimination

**B\_3:** 0.525–0.600 $\mu\text{m}$ , Green, Visible Greenlight, Measurement of Reflected Light from Healthy Vegetation

**B\_4:** 0.630–0.680 $\mu\text{m}$ , Red, Discrimination of Different Types of Vegetation based on Chlorophyll Absorption of Light

## Landsat-8 OLI and TIRS Sensors

**B\_5:** 0.845–0.885 $\mu\text{m}$ , Near-Infrared, Biomass Survey and Water Mapping

**B\_6:** 1.560–1.660 $\mu\text{m}$ , Shortwave Infrared\_1, Water Stress of Vegetation, Discrimination of Cloud and Snow

**B\_7:** 2.100–2.300 $\mu\text{m}$ , Shortwave Infrared\_2, Rock Type Classification

**B\_8:** 0.500–0.680 $\mu\text{m}$ , Panchromatic, Cultural Details and Topographic Mapping

## Landsat-8 OLI and TIRS Sensors

**B\_9:** 1.360–1.390 $\mu\text{m}$ , Cirrus Mapping for Evaluating Atmospheric Effect

**B\_10:** 10.300–11.300 $\mu\text{m}$ , Thermal Infrared\_1, Earth's Surface Temperature Mapping, Water Stress of Vegetation, Soil Moisture Mapping

**B\_11:** 11.500–12.500 $\mu\text{m}$ , Thermal Infrared\_2, Infrared\_1, Surface Temperature Mapping, Water Stress of Vegetation, Soil Moisture Mapping

\* Bands 2 – 8 can be used for Forest Mapping.

## 4. Terrain and Landform Interpretation

- A landform is defined as a certain arrangement and configuration of surficial materials to produce characteristic land features.

- Topography, tone, drainage pattern, gully erosion, vegetation or land use and boundary characteristics are the photo interpretation features used to interpret landforms.

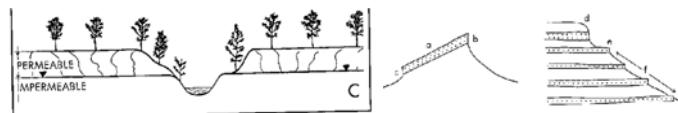


## ① Topography

Topography feature gives an indication of how the material got to its present location, and/or the resistance of the material to erosion:

- flat topography is usually formed by the deposition of materials in still water;
- hilly topography indicates bedrock control;

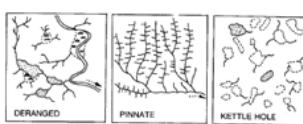
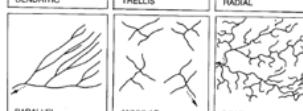
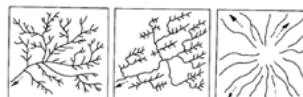
The first item to look at on RS image is the topography.



## ③ Drainage Patterns

Drainage patterns give an indication of parent material, and/or bedrock control.

- Dendritic** drainage patterns indicate fine textured parent material such as till and lacustrine silts or clay.
- Parallel** drainage patterns indicate gently sloping topography, usually because of bedrock control.



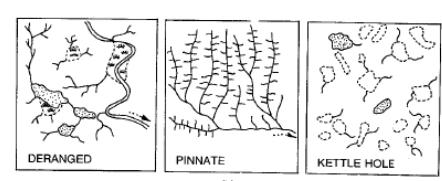
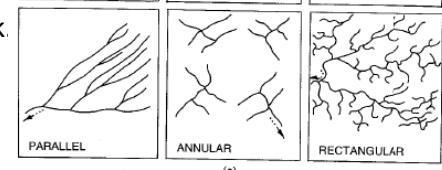
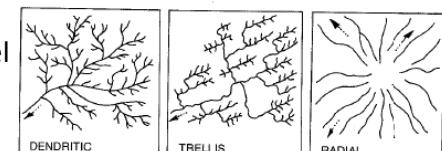
## ② Photo Tone of Landform

- This feature gives an impression of soil moisture:
- A light tone indicates dry soil which is usually coarse textured.
- A medium tone indicates a moist soil.
- A dull, monotonous tone indicates a wet soil which is usually fine textured. However, the hot dry weather can air-dry the silty and clay soils, thus making them highly reflective. Such air-dry soils can appear very light to whitish on RS image.
- A uniform tone indicates a uniform soil condition.
- A mottled tone (e.g. light and dark) indicates a variable soil condition.



## ③ Drainage Patterns (2)

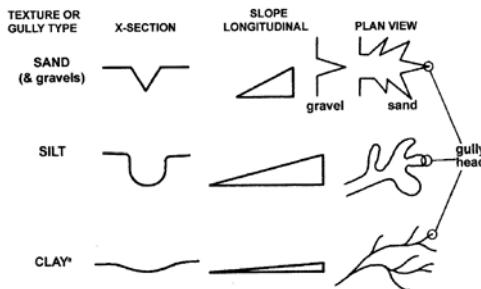
- Trellis** patterns, with short parallel and long parallel patterns joining in a central river, indicate tilted, interbedded, sedimentary bedrock.
- Radial**: Seen on cone-like hills such as volcanoes.
- Rectangular**: flat lying, jointed, sedimentary bedrock





## ④ Gully Erosion

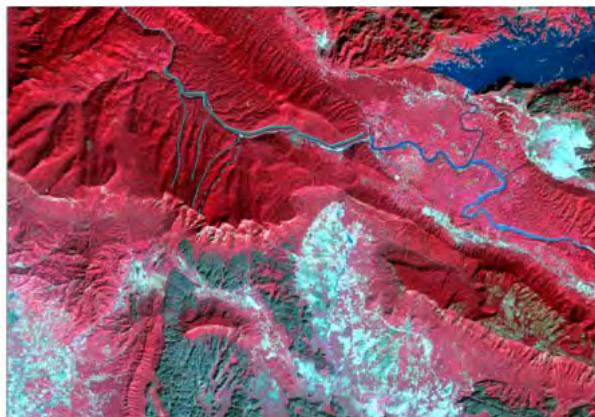
Gully erosion analysis gives another clue to soil texture. To analyse gully features look at the head of the gully, the place where water would start to flow. Gully patterns are best described in terms of the peaks of the soil texture triangle, i.e. sand, silt, and clay.



## ⑤ Boundary Characteristic

This is the outline of the landform as seen on a RS image showing landform characteristic of the area.

LANDFORM	OUTLINE
DRUMLIN	bullet - shape
ESKER	snake - like
ALLUVIAL FAN	fan - like
TERRACE	stepped



1. Interpret topography and draw boundaries of flat area and mountainous terrain.
2. Interpret and draw drainage pattern.
3. Interpret and draw boundaries of land cover/forest types.
4. How these factors are correlated ?



# Results of a Field Survey at the Phou Khao Khouay National Park

March 7, 2015



KOKUSAI KOGYO CO., LTD. ASIA AIR SURVEY CO., LTD.



Mitsuru NASU, Ph.D.

Forest Remote Sensing



## 1. Location of the Survey Area

- Phou Khao Khouay National Park



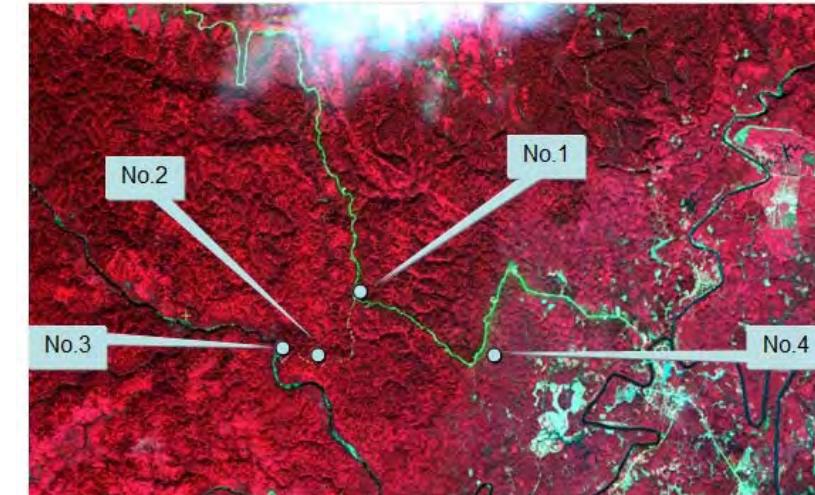
(Landsat-8 acquired on 29 January, 2015)



## Topographic Map



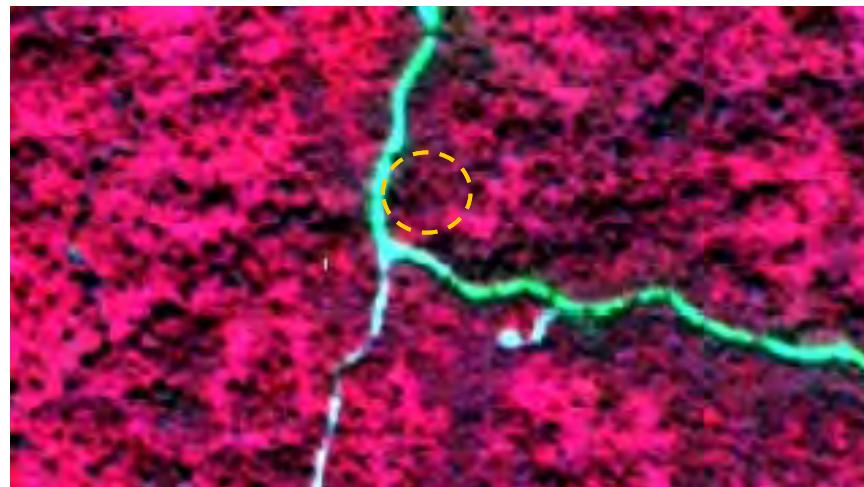
## Survey Plots on RaidEye Image



RapidEye Image (RGB=Band532)



## No.1 Survey point



RapidEye Imagery (RGB=Band532)

DOF/FIPD

KOKUSAI KOGYO CO.,LTD. ASIA AIR SURVEY CO.,LTD.



No.1 Survey Point

DOF/FIPD

KOKUSAI KOGYO CO.,LTD. ASIA AIR SURVEY CO.,LTD.



## No.1 Survey Point



DOF/FIPD

KOKUSAI KOGYO CO.,LTD. ASIA AIR SURVEY CO.,LTD.



## No.1 Survey Point



Trees in dense bamboo.

DOF/FIPD

KOKUSAI KOGYO CO.,LTD. ASIA AIR SURVEY CO.,LTD.



## No.1 Survey Point



Understory is covered by dense bamboo (height: 5 m)

DOF/FIPD

KOKUSAI KOGYO CO.,LTD. ASIA AIR SURVEY CO.,LTD.



## No.1 Survey Point



+ Surface soil contains silt.

DOF/FIPD

KOKUSAI KOGYO CO.,LTD. ASIA AIR SURVEY CO.,LTD.



## No.1 Survey Point



+ In bamboo forest (height is about 5 m).

DOF/FIPD

KOKUSAI KOGYO CO.,LTD. ASIA AIR SURVEY CO.,LTD.



## No.1 Survey Point



Remaining logging evidence

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KOKUSAI KOGYO CO.,LTD. ASIA AIR SURVEY CO.,LTD.



## No.1 Survey Point



DOF/FIPD

KOKUSAI KOGYO CO.,LTD. ASIA AIR SURVEY CO.,LTD.



## No.1 Survey Point



Some trees in the DD family forest.  
Height: 25 m (highest), DBH: 40 – 45 cm

DOF/FIPD

KOKUSAI KOGYO CO.,LTD. ASIA AIR SURVEY CO.,LTD.



## No.1 Survey Point



DOF/FIPD

KOKUSAI KOGYO CO.,LTD. ASIA AIR SURVEY CO.,LTD.



## No.1 Survey Point



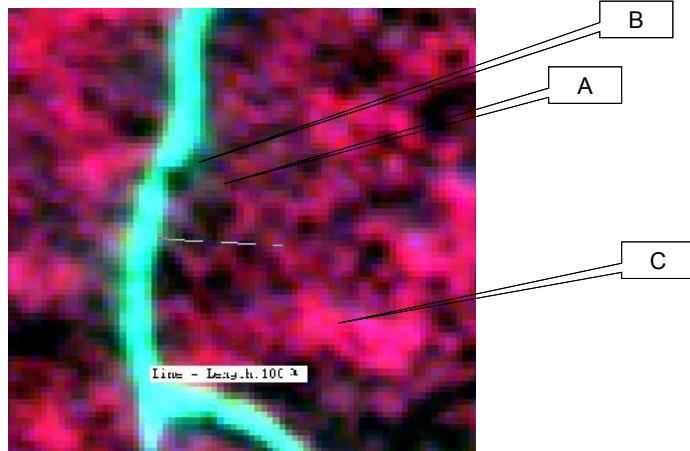
Area of No.1 Survey Point

DOF/FIPD

KOKUSAI KOGYO CO.,LTD. ASIA AIR SURVEY CO.,LTD.



## No.1 Survey Point



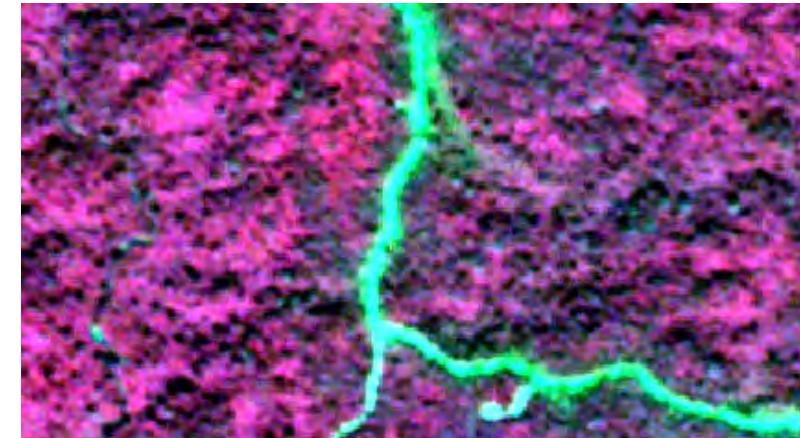
What are A, B, C features on the image ? Why ?  
Draw crown boundaries on the imagery.



KOKUSAI KOGYO CO.,LTD. ASIA AIR SURVEY CO.,LTD.



## No.1 Survey Point



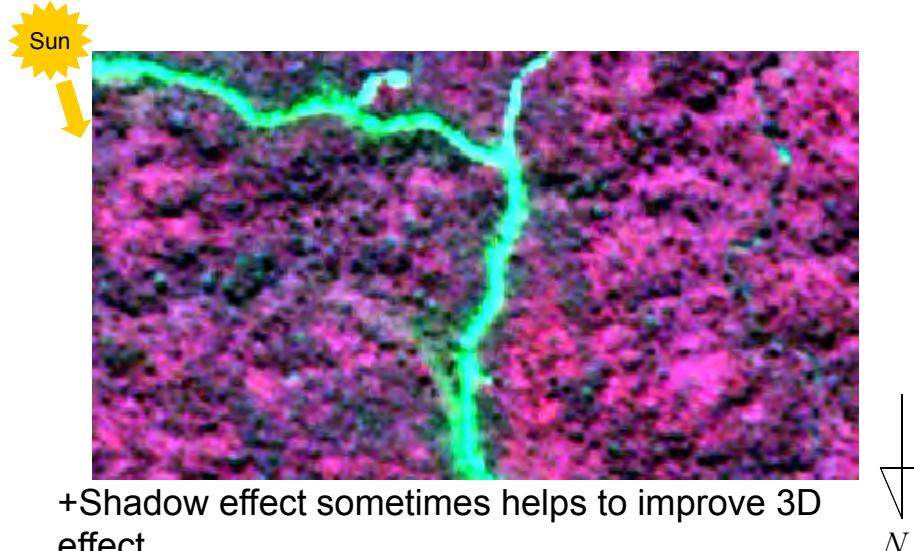
Interpret trees and other features in the forest.



KOKUSAI KOGYO CO.,LTD. ASIA AIR SURVEY CO.,LTD.



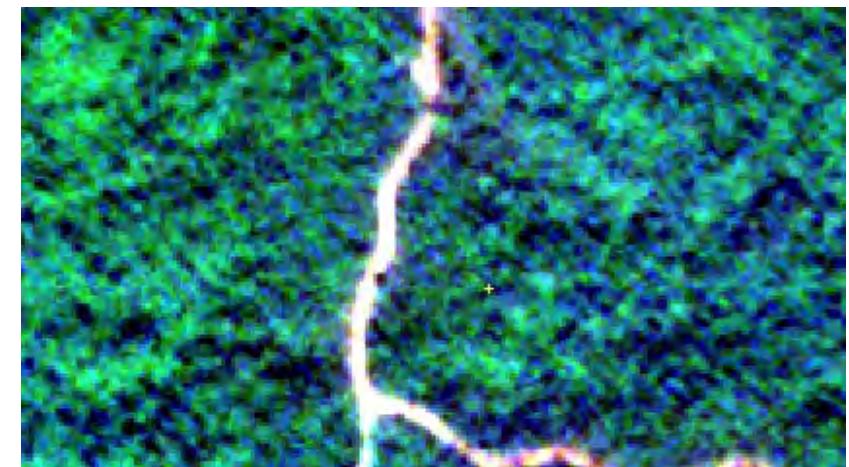
## 180° Rotated Image for Shadow Effect



KOKUSAI KOGYO CO.,LTD. ASIA AIR SURVEY CO.,LTD.



## No.1 Survey Point



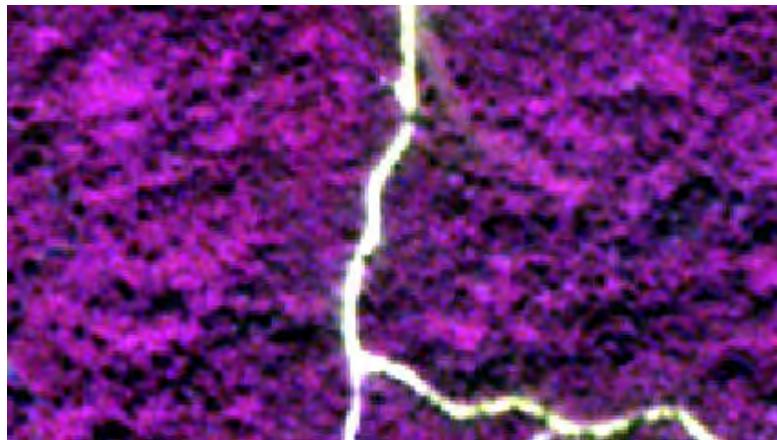
Try to find the composite image the most useful for forest survey.



KOKUSAI KOGYO CO.,LTD. ASIA AIR SURVEY CO.,LTD.



## No.1 Survey Point



RapidEye(RGB=B432)

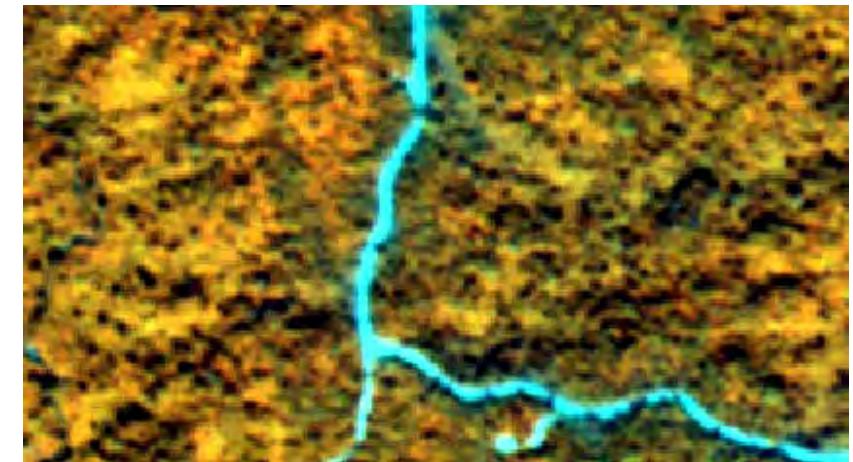
Composite image with RGB=B432 combination.



KOKUSAI KOGYO CO.,LTD. ASIA AIR SURVEY CO.,LTD.



## No.1 Survey Point



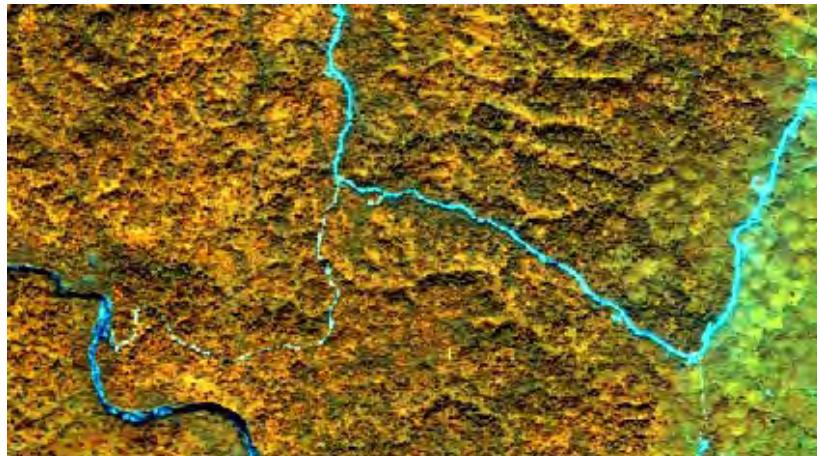
Composite image with RGB=B543 combination. RapidEye(RGB=B543)  
Bamboo and shadows are more discernible !?



KOKUSAI KOGYO CO.,LTD. ASIA AIR SURVEY CO.,LTD.



## No.1,2,3 Survey Point



(Wider view)

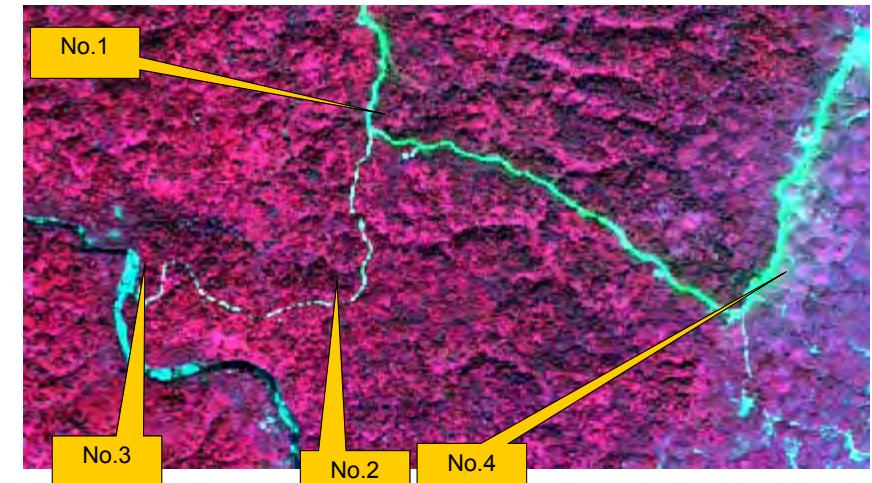
RapidEye(RGB=B543)



KOKUSAI KOGYO CO.,LTD. ASIA AIR SURVEY CO.,LTD.



## No.1,2,3,4 Survey Points



RGB=B532 is still the best combination !?



KOKUSAI KOGYO CO.,LTD. ASIA AIR SURVEY CO.,LTD.

RapidEye(RGB=B532)



## Field Photos (No.2 Survey Point)



DOF/FIPD

KOKUSAI KOGYO CO.,LTD. ASIA AIR SURVEY CO.,LTD.



## No.2 Survey Point



DOF/FIPD

KOKUSAI KOGYO CO.,LTD. ASIA AIR SURVEY CO.,LTD.



## No.2 Survey Point



DOF/FIPD

KOKUSAI KOGYO CO.,LTD. ASIA AIR SURVEY CO.,LTD.



## No.2 Survey Point



DOF/FIPD

KOKUSAI KOGYO CO.,LTD. ASIA AIR SURVEY CO.,LTD.



## No.2 Survey Point



Some sandstone Rocks

DOF/FIPD

KOKUSAI KOGYO CO.,LTD. ASIA AIR SURVEY CO.,LTD.



## No.2 Survey point



More trees in the forest.

DBH: 70 cm, Tree Height: 25 – 30 m

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## No.2 Survey points



Lantern



## No.2 Survey Point



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DOF/FIPD

KOKUSAI KOGYO CO.,LTD. ASIA AIR SURVEY CO.,LTD.

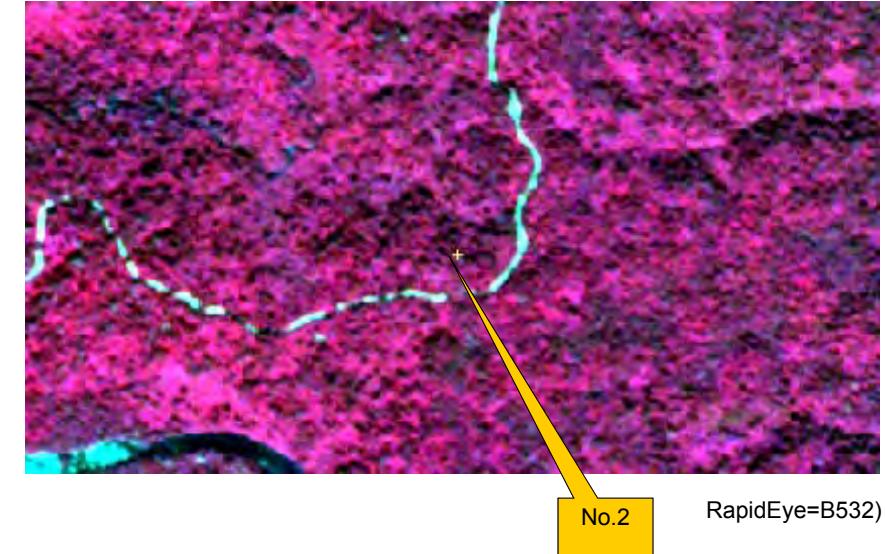
## No.2 Survey Point



DOF/FIPD

KOKUSAI KOGYO CO.,LTD. ASIA AIR SURVEY CO.,LTD.

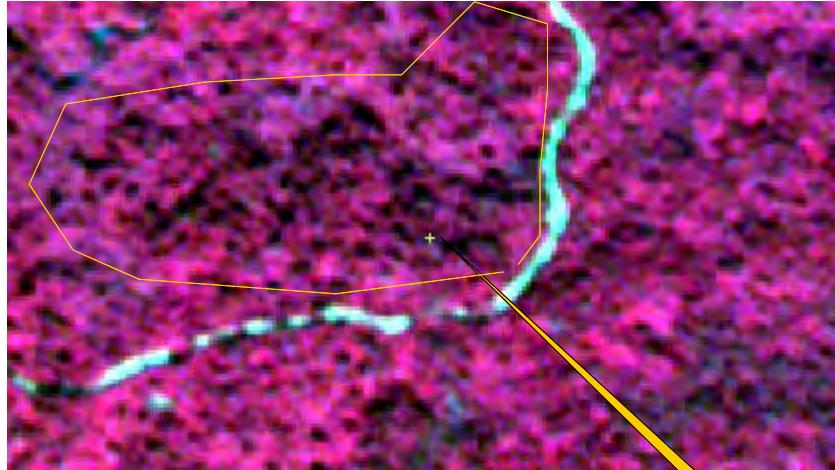
## No.2 Survey Point



DOF/FIPD

KOKUSAI KOGYO CO.,LTD. ASIA AIR SURVEY CO.,LTD.

## No.2 Survey Point

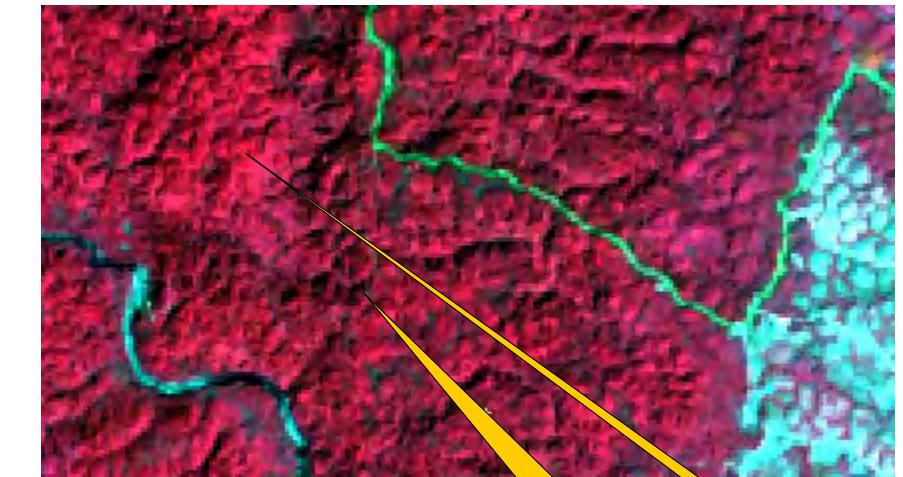


Why area A is darker than other areas ?

DOF/FIPD

KOKUSAI KOGYO CO.,LTD. ASIA AIR SURVEY CO.,LTD.

## Comparison with Landsat-8 Imagery

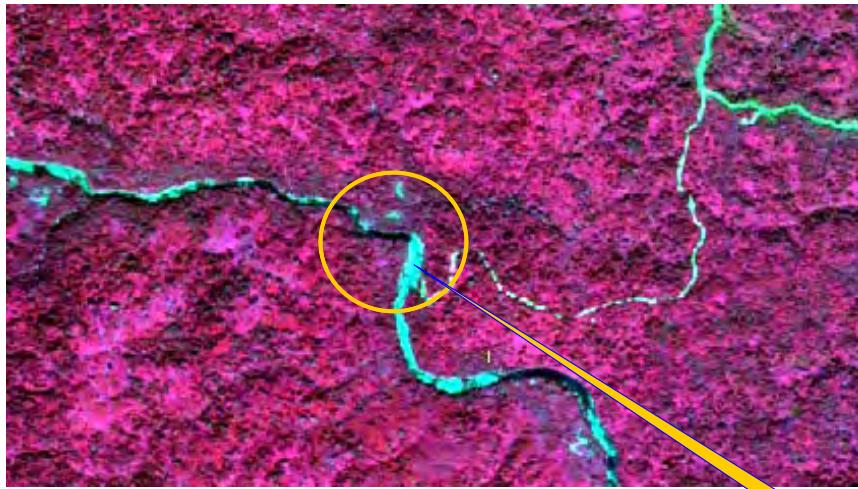
Why area A is lighter ?  
Find the slope direction.

DOF/FIPD

KOKUSAI KOGYO CO.,LTD. ASIA AIR SURVEY CO.,LTD.



## No.3 Survey Point



No.3 Survey Point near river and camping area.

No.3

DOF/FIPD

KOKUSAI KOGYO CO.,LTD. ASIA AIR SURVEY CO.,LTD.



## No.3 Survey Point



KOKUSAI KOGYO CO.,LTD. ASIA AIR SURVEY CO.,LTD.



## No.3 Survey Point

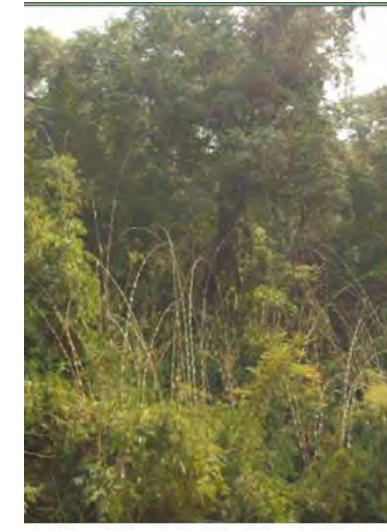


DOF/FIPD

KOKUSAI KOGYO CO.,LTD. ASIA AIR SURVEY CO.,LTD.



## No.3 Survey Point



No. 3 point area

DOF/FIPD

KOKUSAI KOGYO CO.,LTD. ASIA AIR SURVEY CO.,LTD.



## No. 3 point area



DOF/FIPD

KOKUSAI KOGYO CO.,LTD. ASIA AIR SURVEY CO.,LTD.



## No.3 Survey Point

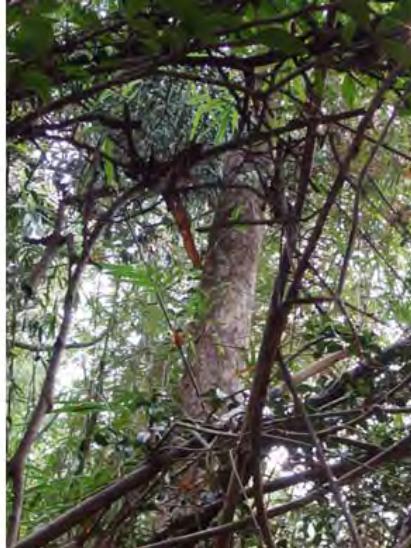


DOF/FIPD

KOKUSAI KOGYO CO.,LTD. ASIA AIR SURVEY CO.,LTD.



## No.3 Survey Point



DOF/FIPD

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## Around No.3 Survey Point



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## Direction of Up-stream



Up-stream (North) direction

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## Around No.3 Survey Point



West-ward

DOF/FIPD

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## Around No.3 Survey Point



Photo taken toward down-stream of the river

DOF/FIPD

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## No.3 Survey Point



East-ward

DOF/FIPD

KOKUSAI KOGYO CO.,LTD. ASIA AIR SURVEY CO.,LTD.



## No.3 Survey Point



DOF/FIPD

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## Near No.3 Survey Point



West-direction

DOF/FIPD

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## Fall



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## Around No.3 Survey Point



Inter-bedded Sandstone Rock

DOF/FIPD

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## Geology



DOF/FIPD

KOKUSAI KOGYO CO.,LTD. ASIA AIR SURVEY CO.,LTD.



## Geology



DOF/FIPD

KOKUSAI KOGYO CO.,LTD. ASIA AIR SURVEY CO.,LTD.



## Trees (No.3 Survey Point)



DOF/FIPD

KOKUSAI KOGYO CO.,LTD. ASIA AIR SURVEY CO.,LTD.

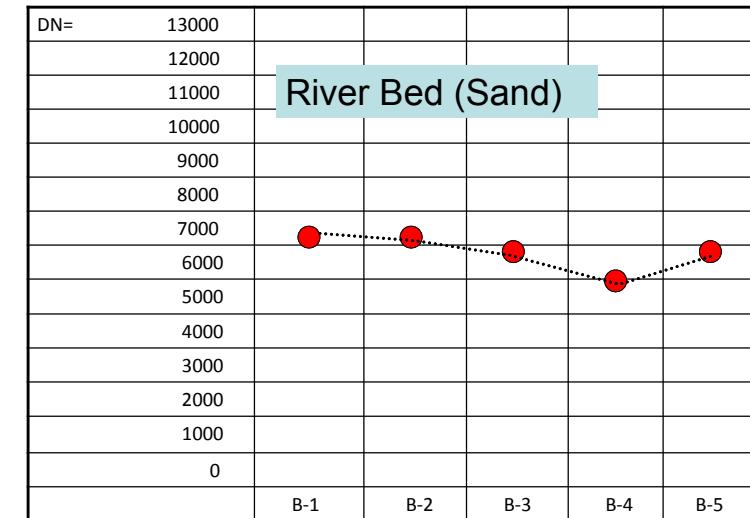
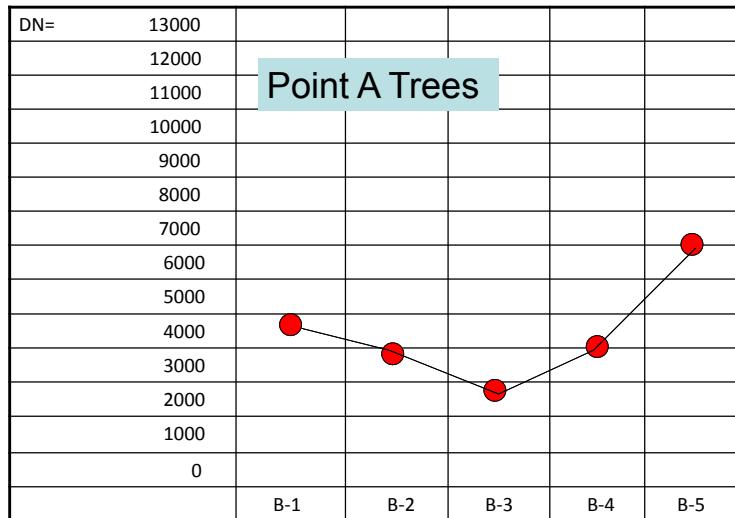
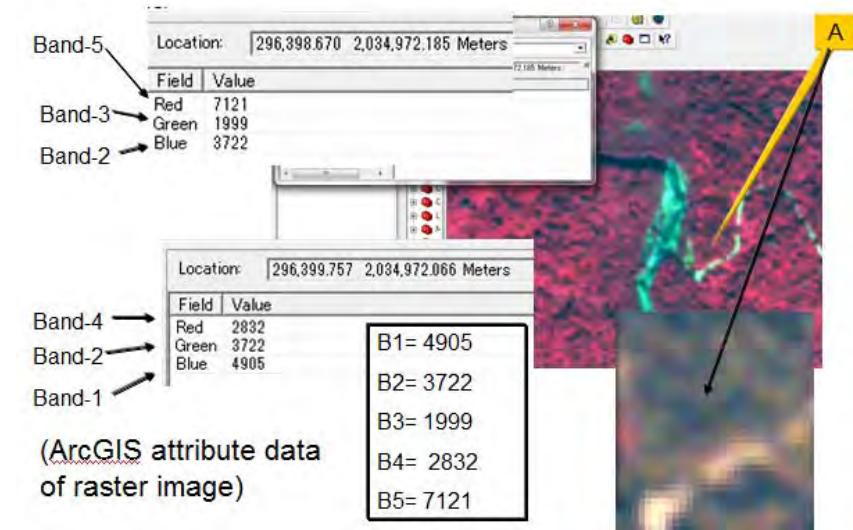
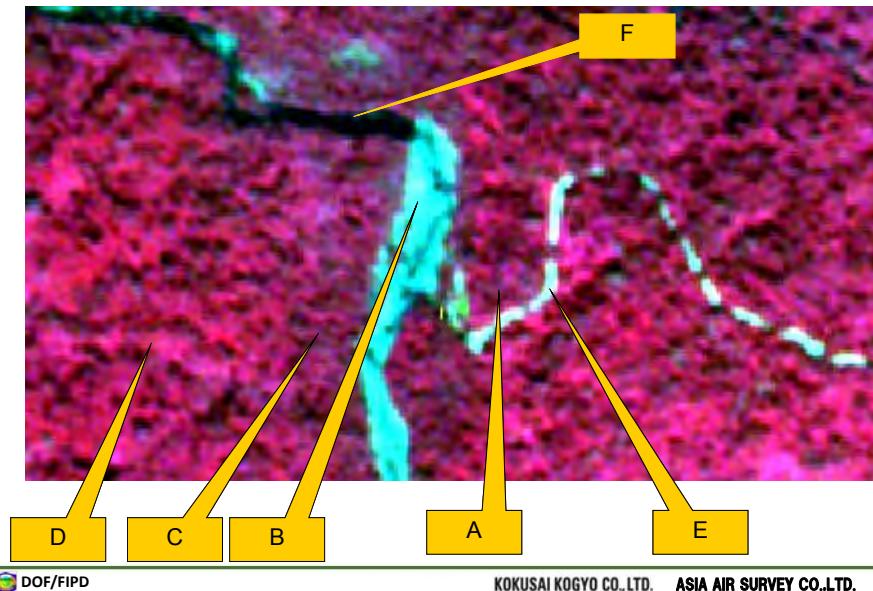


## Trees (No.3 Survey Point)



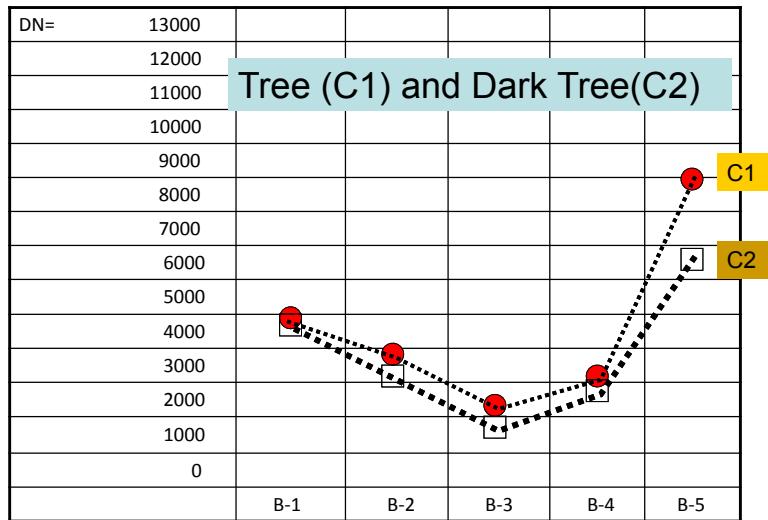
DOF/FIPD

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## Spectral Data (DN) of Feature C1 & C2

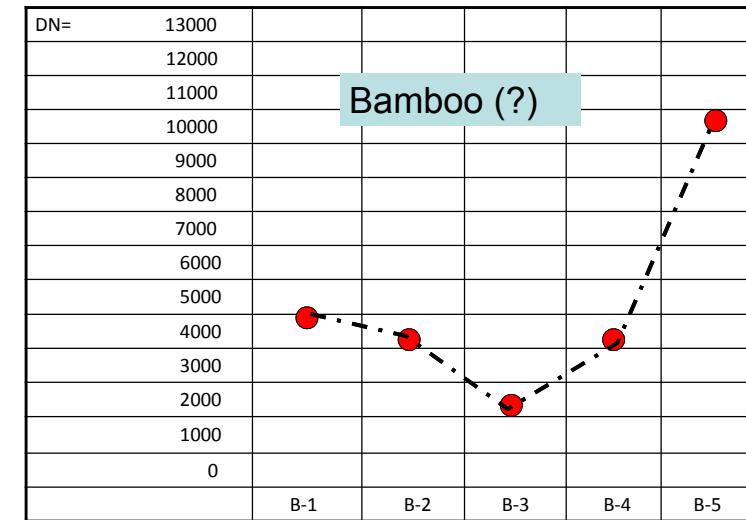


DOF/FIPD

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## Spectral Data (DN) of Feature D

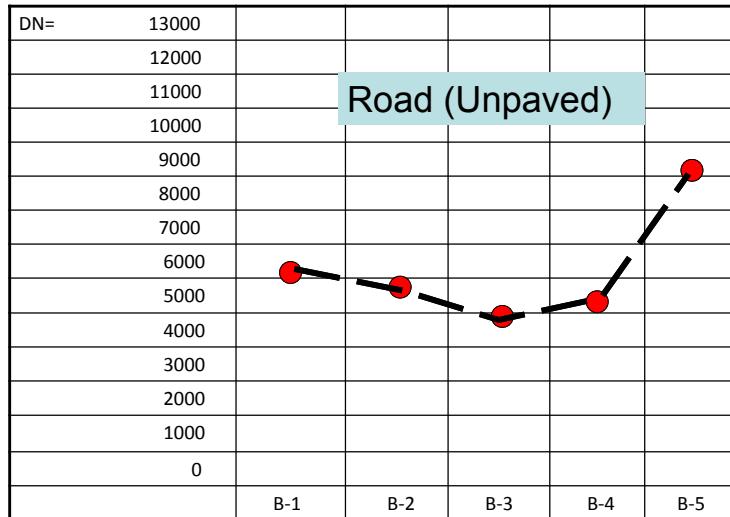


DOF/FIPD

KOKUSAI KOGYO CO.,LTD. ASIA AIR SURVEY CO.,LTD.



## Spectral Data (DN) of Feature E

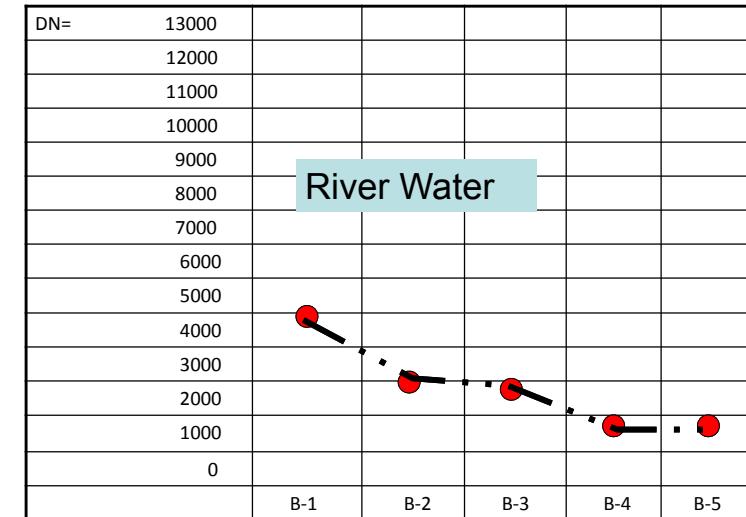


DOF/FIPD

KOKUSAI KOGYO CO.,LTD. ASIA AIR SURVEY CO.,LTD.

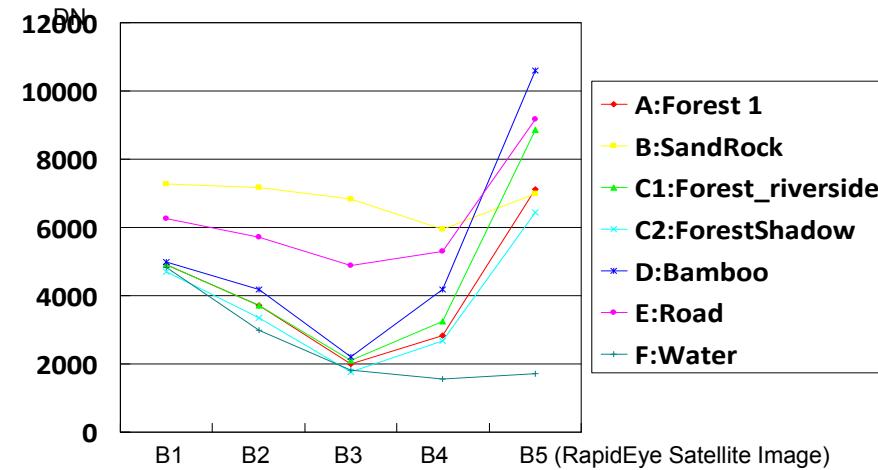


## Spectral Data (DN) of Feature F



DOF/FIPD

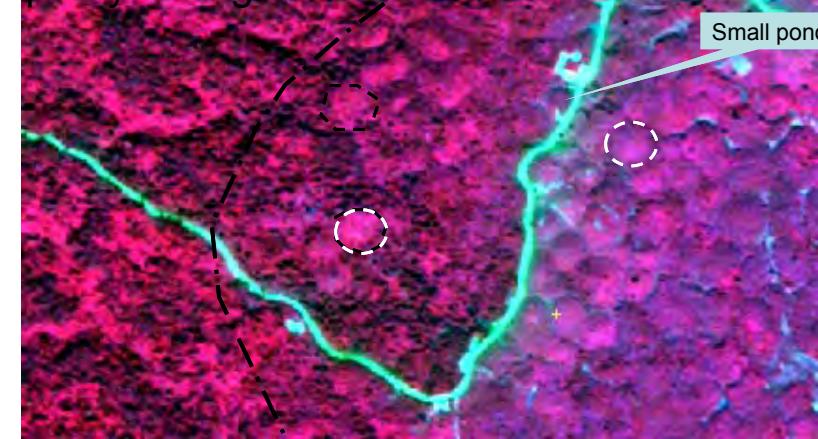
KOKUSAI KOGYO CO.,LTD. ASIA AIR SURVEY CO.,LTD.



+ Bamboo shows high reflectance. + Forest 1, Forest\_riverside, and its ForestShadow show similar shape of curves. + High DN values in B1(blue band) shows high effect of the atmospheric noise. (Path radiance)



## RapidEye Image



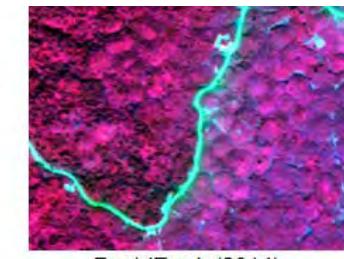
No. 4 area shows quite different land use/land cover and colors.



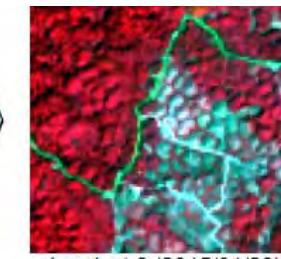
## No.4 Survey point



+Topography with many small hills covered by the silt soil  
+Possibly, flood plain or lakebed sediments in geological age



RapidEye b (2014)



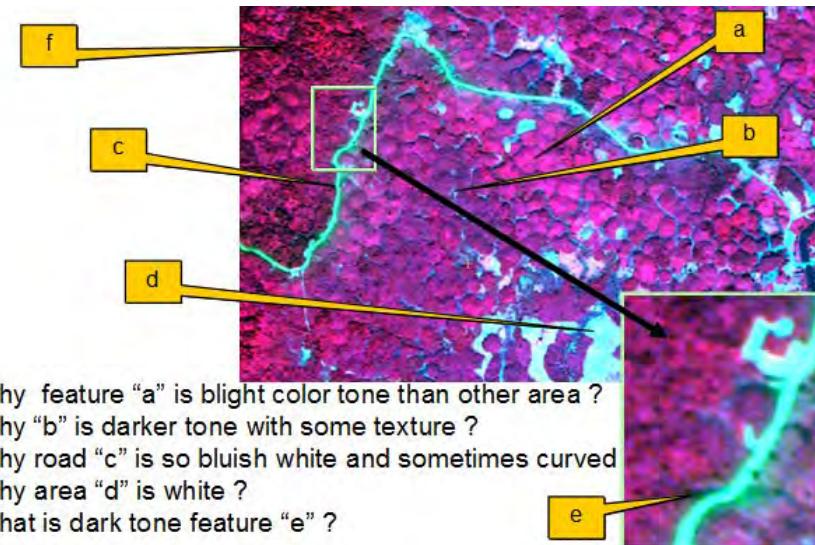
Landsat-8 (2015/01/29)



+ Now, converted to rubber plantation



## Photo Interpretation Keys



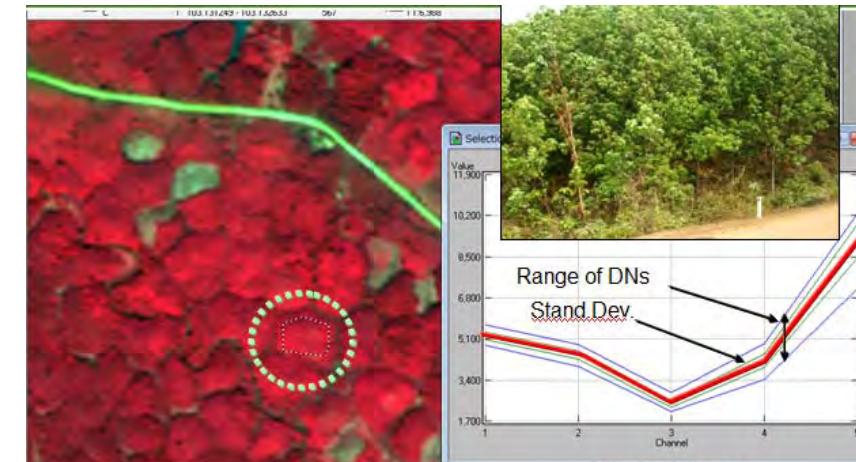
## No.4 Survey Point Area



## No.4 Survey Point Area



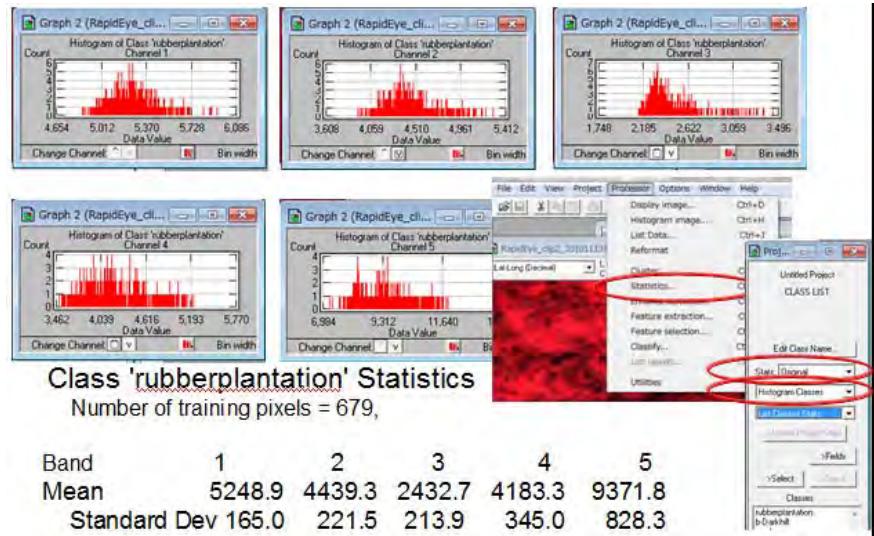
## Spectral Data (DN) of Feature "a"



Rubber Plantation (?)



## Variations of DN Values for Different Bands

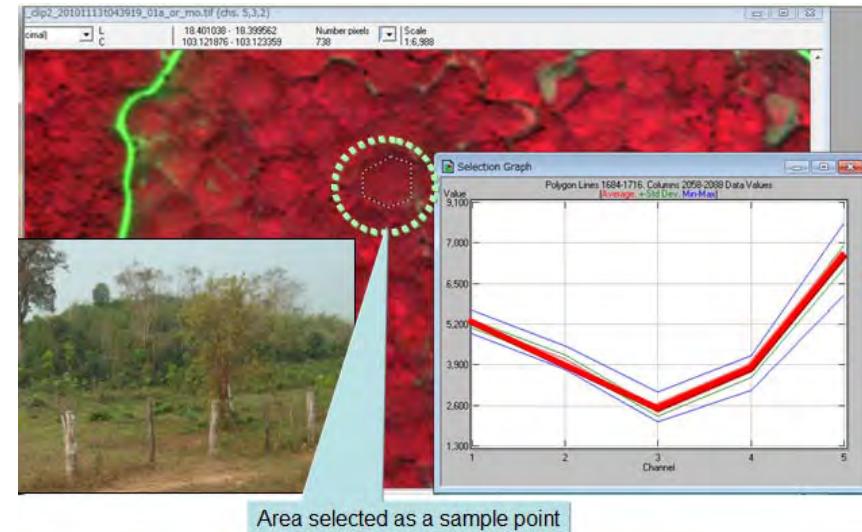


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## Spectral Data (DN) of Feature “b”



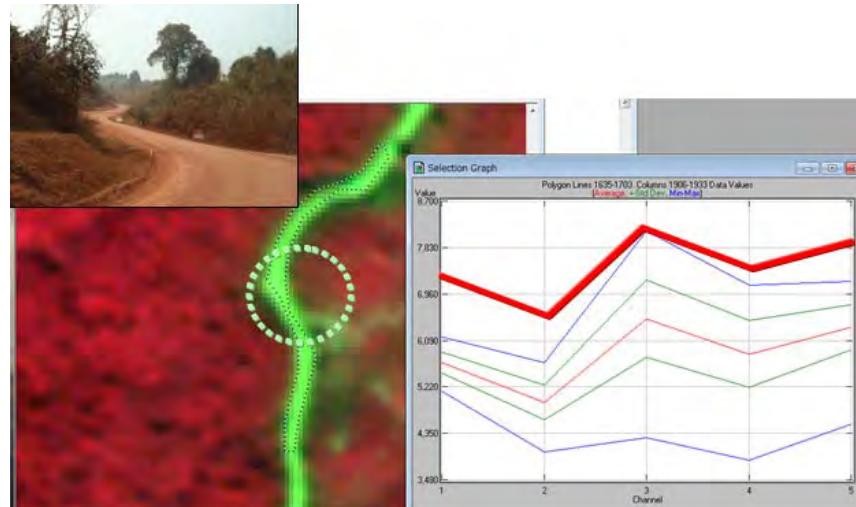
Area selected as a sample point

DOF/FIPD

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## Spectral Data (DN) of Feature “c”

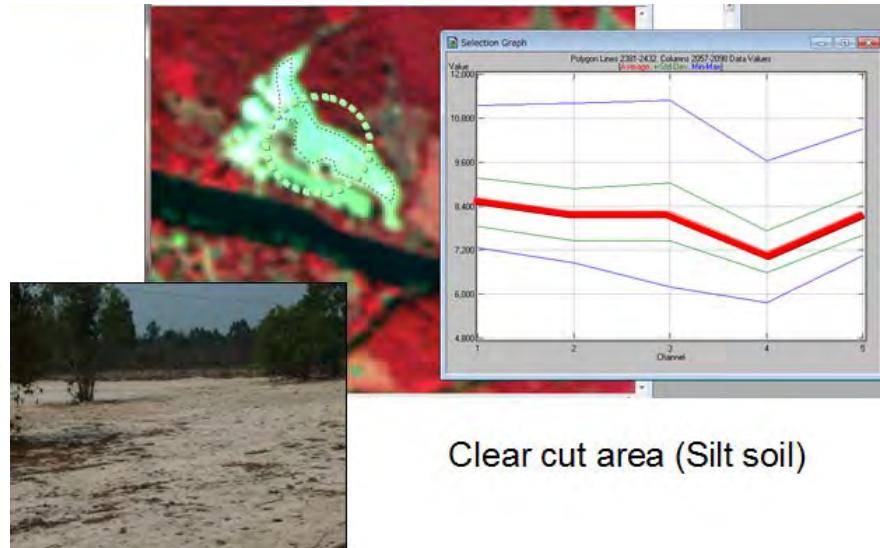


DOF/FIPD

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## Spectral Data (DN) of Feature “d”

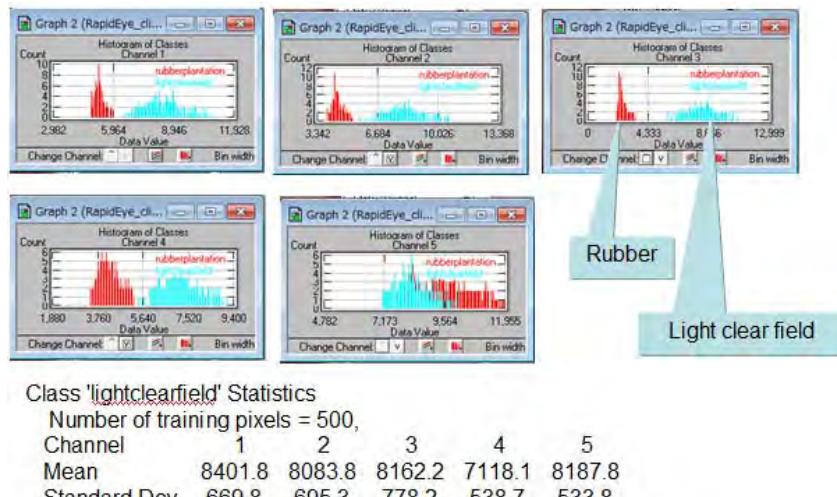


DOF/FIPD

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## Histogram of “d”



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## Spectral Data (DN) of Feature “e”

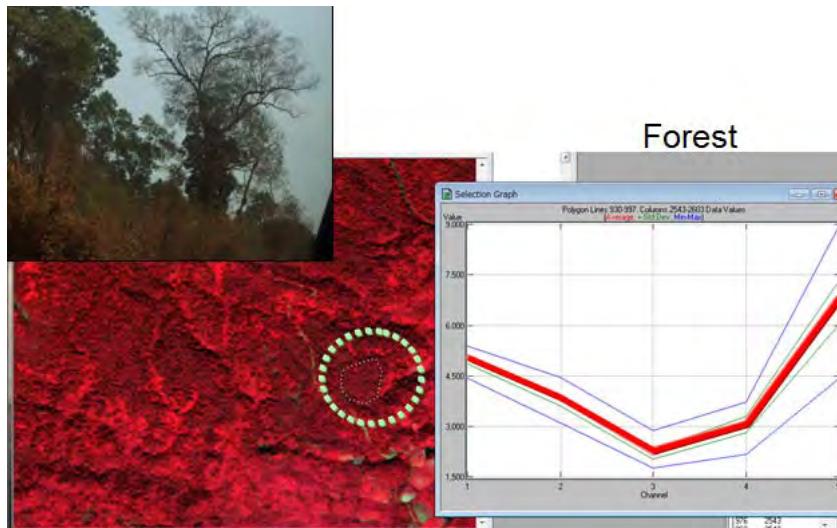


DOF/FIPD

KOKUSAI KOGYO CO.,LTD. ASIA AIR SURVEY CO.,LTD.



## Spectral Data (DN) of Feature “f”

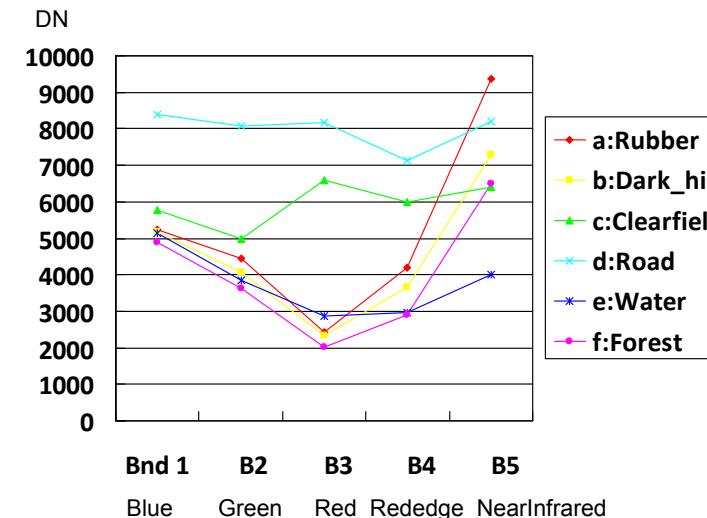


DOF/FIPD

KOKUSAI KOGYO CO.,LTD. ASIA AIR SURVEY CO.,LTD.



## RapidEye Spectral Characteristics Curves



DOF/FIPD

KOKUSAI KOGYO CO.,LTD. ASIA AIR SURVEY CO.,LTD.

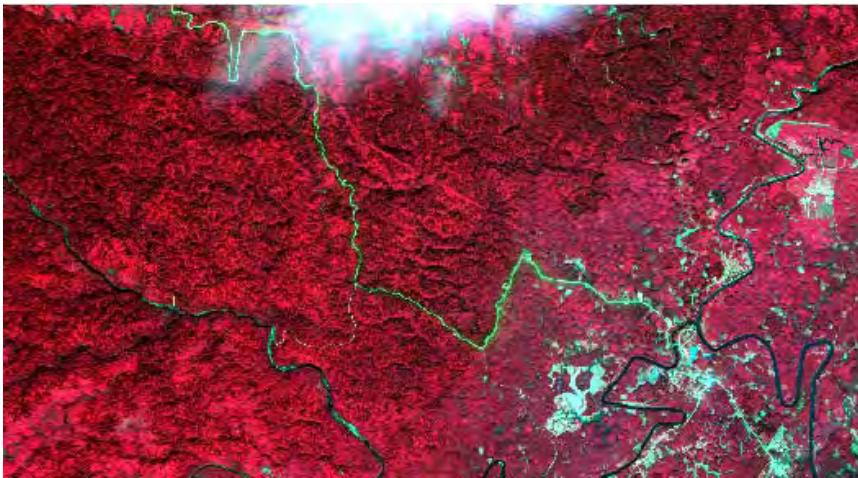


Photo interpret topography and land use/land cover of whole area of this scene.

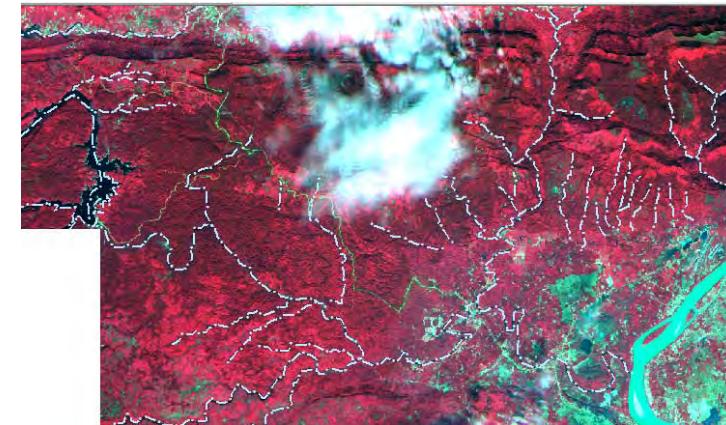


Photo interpret topography and land use/land cover of whole area of this scene.

## Results of the Field Survey

■ What kinds of information we did we get by  
the field survey ?

- 1)
- 2)
- 3)
- 4)
- 5)



# Analyses of Multitemporal Remote Sensing Imageries

- Case Study at South Savannakhet Production Forest -



March 11, 2015



KOKUSAI KOGYO CO.,LTD. ASIA AIR SURVEY CO.,LTD.



Mitsuru NASU, Ph.D.

Forest Remote Sensing

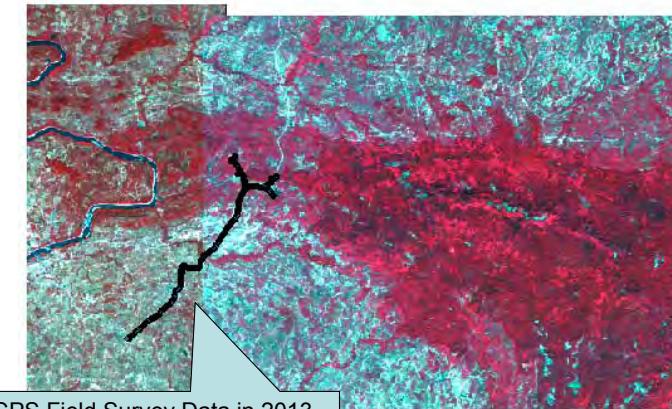


Location



## 1. Location of the Survey Area

- Xebanghieang Sub\_FMA, Xongkhon District FMA, Savannakhet Province



GPS Field Survey Data in 2013

(RapidEye, Acquired in 2010/10 and 2010/12)

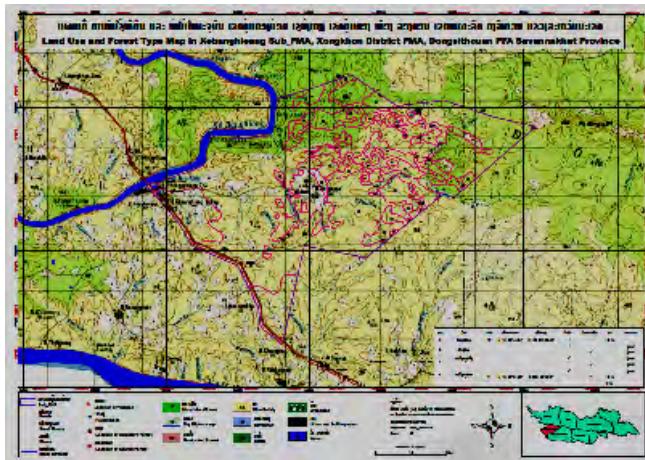


KOKUSAI KOGYO CO.,LTD. ASIA AIR SURVEY CO.,LTD.

2



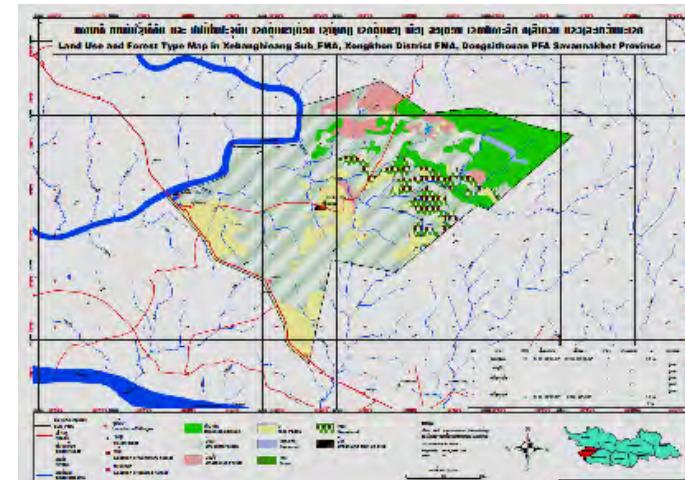
## Topography, Land Use and Forest Type Map



Savannakhet Production Forest Area (Xebanghieang Sub\_FMA)



## Land Use and Forest Type Map



Xebanghieang Sub\_FMA, Savannakhet



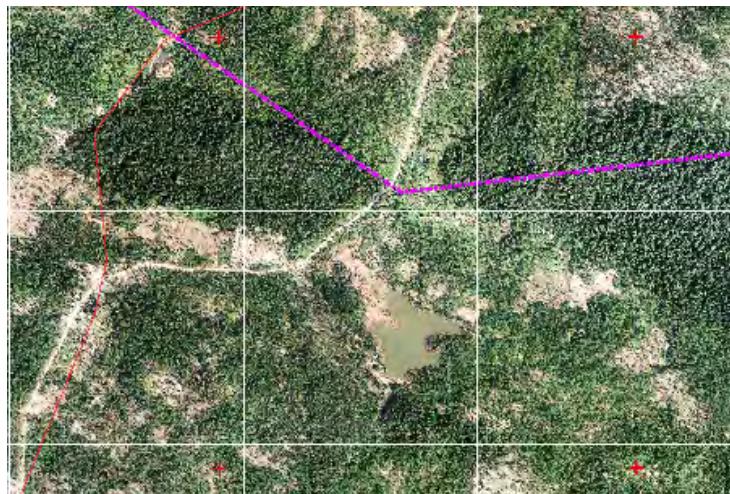
KOKUSAI KOGYO CO.,LTD. ASIA AIR SURVEY CO.,LTD.

3



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4

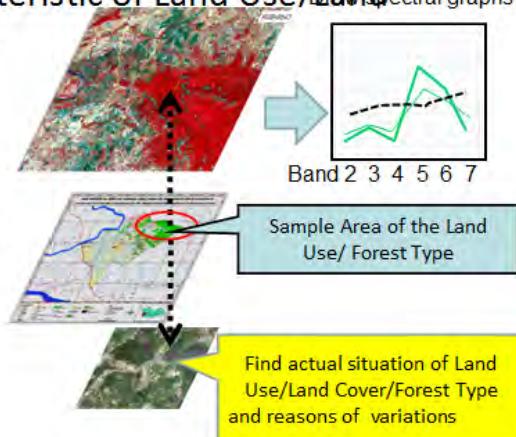


Xebanghieang Sub\_FMA



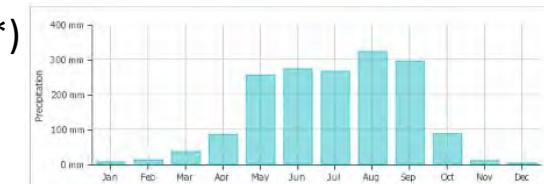
■ Multi-temporal and Multi-sensor Analysis of Spectral Characteristic of Land Use/Land Cover Features

Landsat 8 OLI Image:  
(Multi-temporal Data)

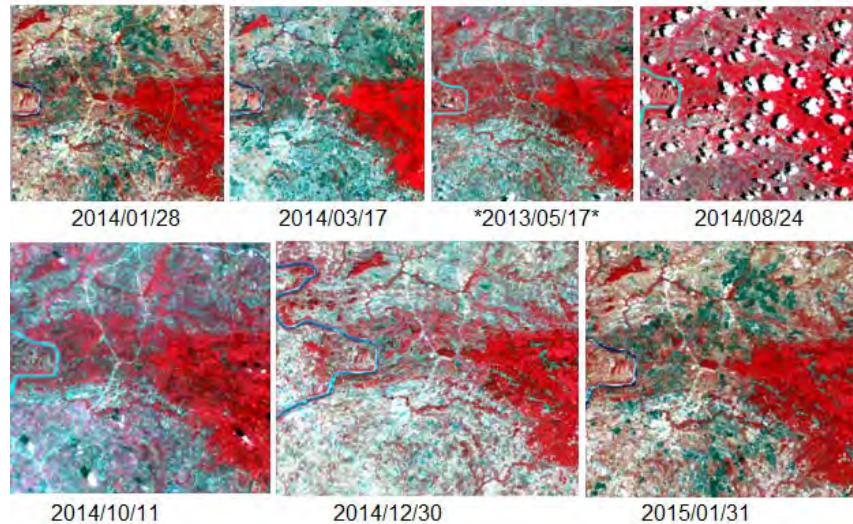


■ Multi-temporal RapidEye and Landsat-8 Images

- Xebanghieang Sub\_FMA, Savannakhet
  - 2014/01/28
  - 2014/03/17
  - 2013/05/17(\*\*\*)
  - 2014/08/24
  - 2014/10/11
  - 2014/12/30
  - 2015/01/31



## jica Color IR Composite Landsat8 Images (RGB=Band543,Savannakhet)

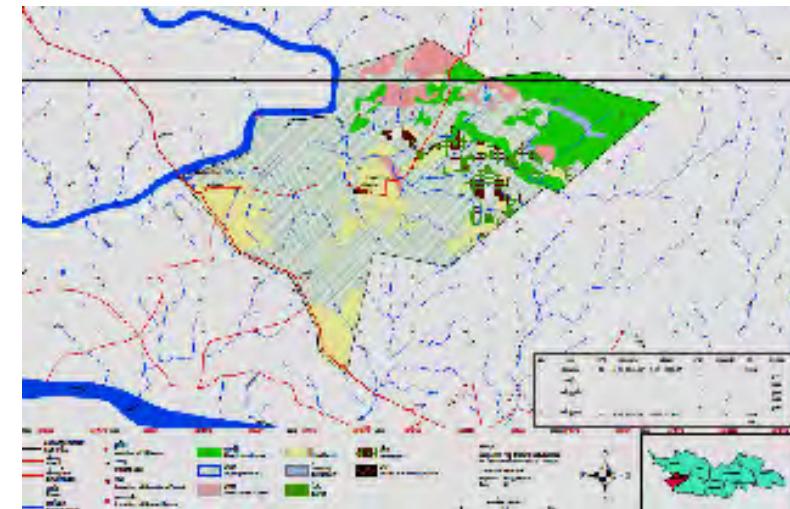


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## jica Forest Map



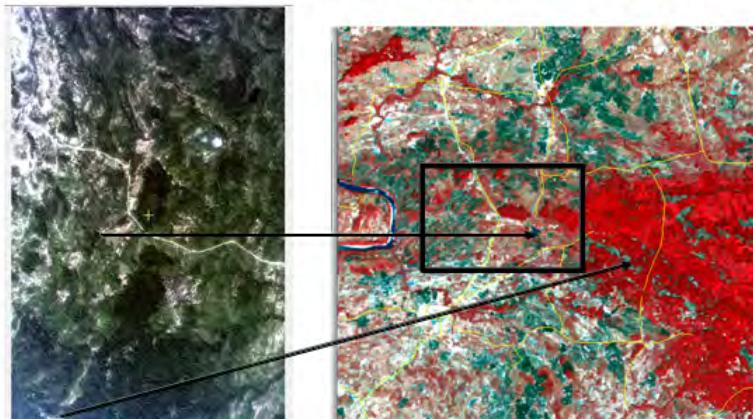
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## jica Registration of Aerial Photo on Landsat8 Image

Georeference and Rectification of Aerial Photos to Landsat 8 Image (UTM48N Coordinate System)

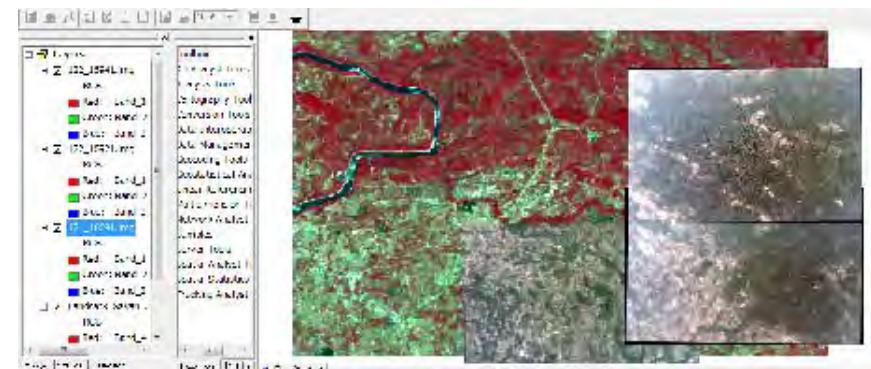


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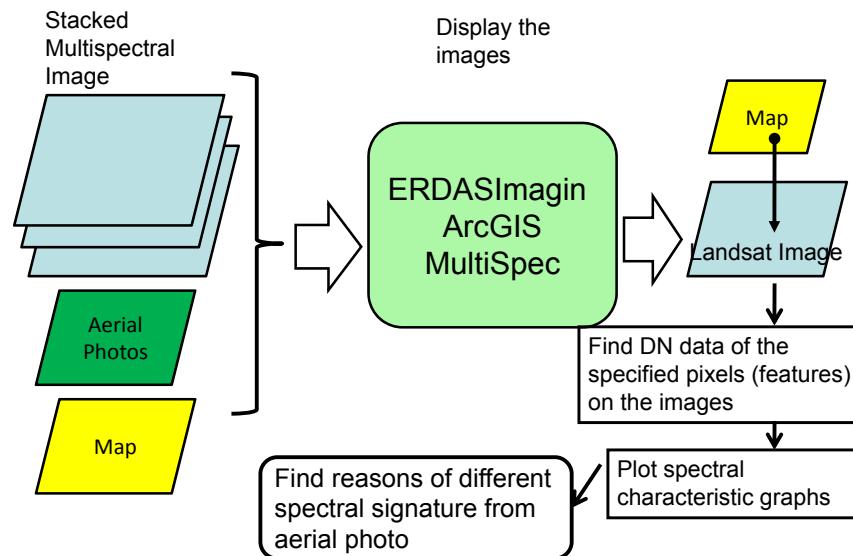
## jica Overlay Images

After the georeference, the aerial photos are rectified for overlaying.



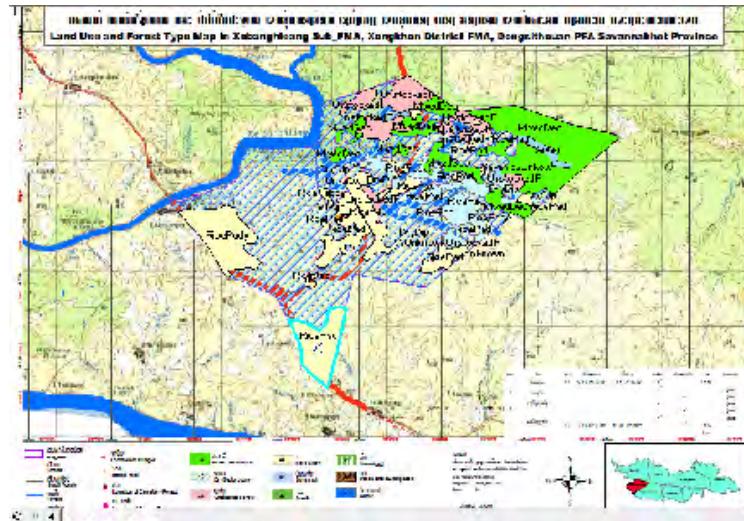
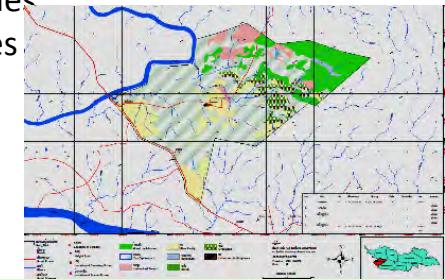
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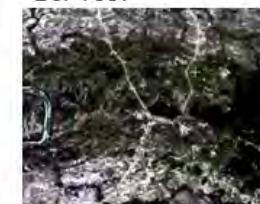
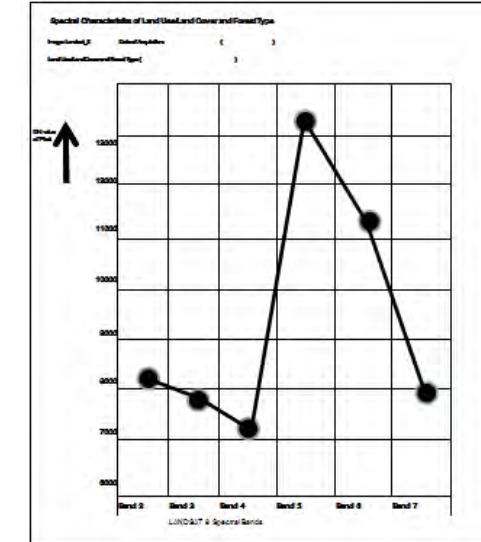
## Features to be specified on the Forest Map and RapidEye and Landsat 8 Images

- (1) 13 Mixed deciduous: 3 samples
- (2) 15 Dry Dipterocarp : 3 samples
- (3) 22 Unstocked Forest : 3 samples
- (4) 41 Rice Paddy : 3 samples
- (5) 31 Savannah : 3 samples
- (6) 61 Water : 3 samples

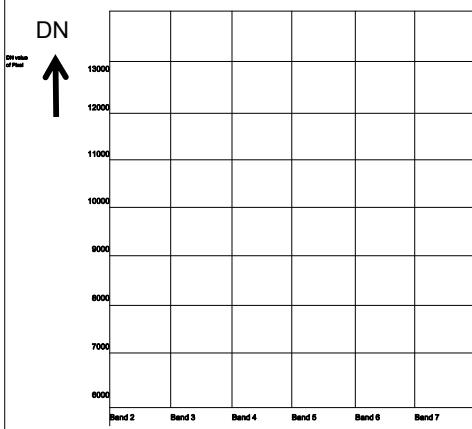


Example:

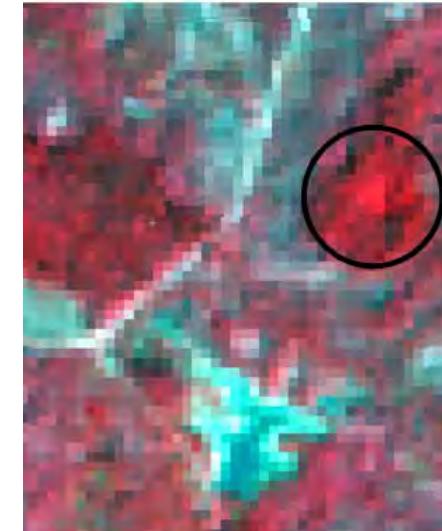
- Savannakhet's DD forest
- 2014/01/28 (Dry winter)
- B1: 8390  
B2: 7837  
B3: 7244  
B4: 133987  
B5: 11279  
B6: 7997



Spectral Characteristics of Land Use/Land Cover and Forest Type  
Image: Landsat 8 Date of Acquisition:  
Land Use/Land Cover and Forest Type:



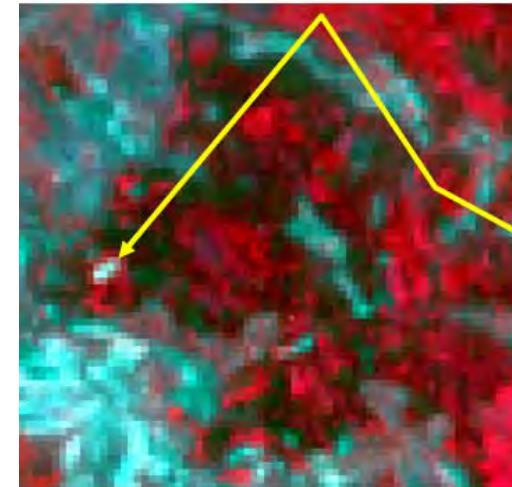
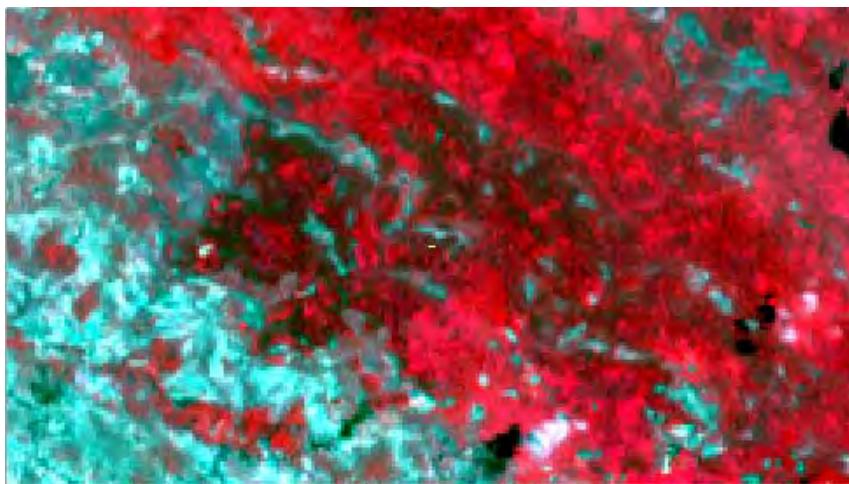
[Remarks]



2013/05/17 Landsat\_8 Image  
(Band 5-4-3)



2013/05/17



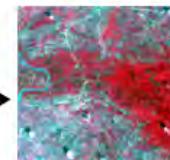
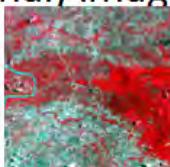
High density canopies



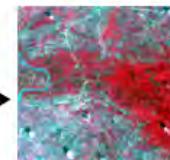
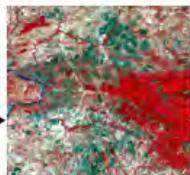
DD ?

Compare similar spectral graphs for multi-temporal (seasonal) images.

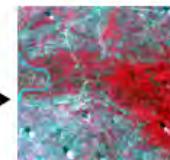
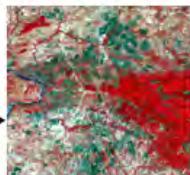
■ 2013/05/17 →



■ 2014/10/11 →



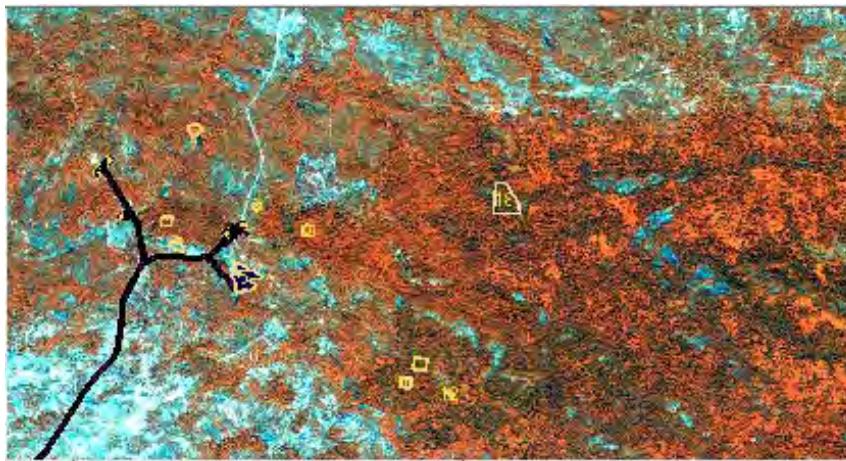
■ 2015/01/31 →



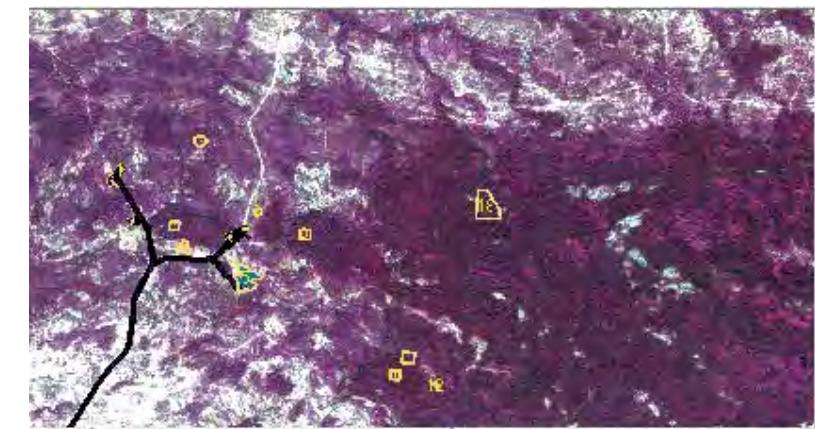
Which image is the best for your forest survey? Why?



RapidEye RGB=B321



RapidEye RGB=B543



RapidEye RGB=B432



## RapidEye Composite Image



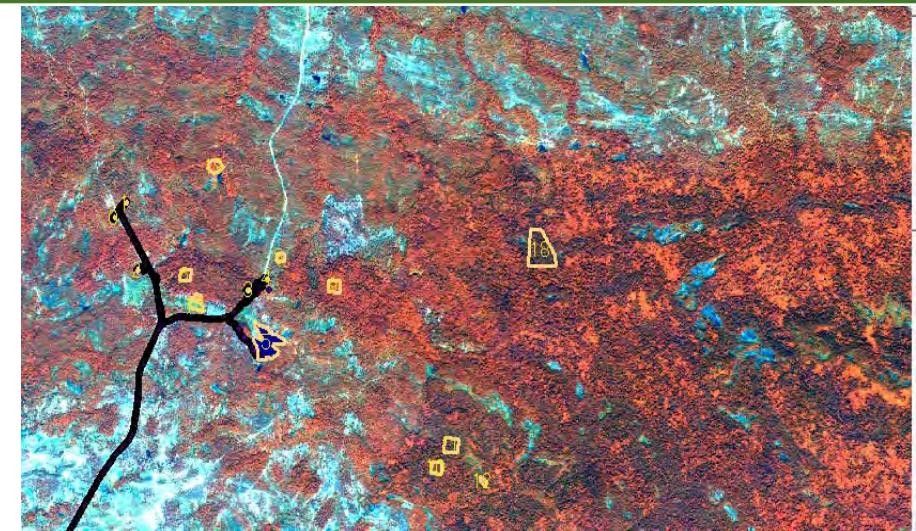
RapidEye RGB=B421

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## RapidEye Composite Image



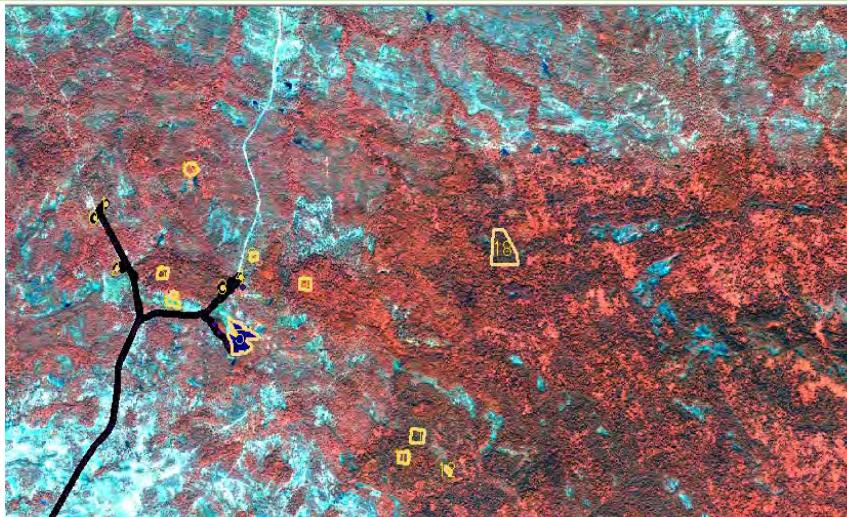
RapidEye RGB=B541

DOF/FIPD

KOKUSAI KOGYO CO.,LTD. ASIA AIR SURVEY CO.,LTD.



## RapidEye Composite Image



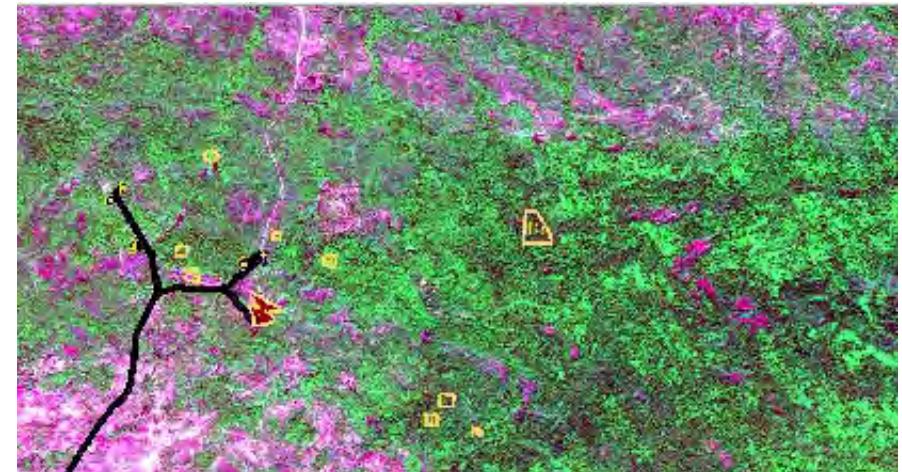
RapidEye RGB=B542

DOF/FIPD

KOKUSAI KOGYO CO.,LTD. ASIA AIR SURVEY CO.,LTD.



## RapidEye Composite Image



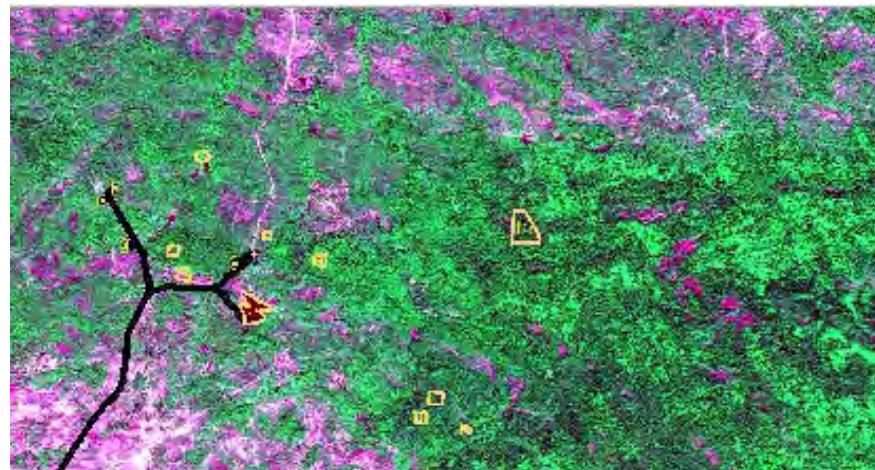
RapidEye RGB=B154

DOF/FIPD

KOKUSAI KOGYO CO.,LTD. ASIA AIR SURVEY CO.,LTD.



## RapidEye Composite Image



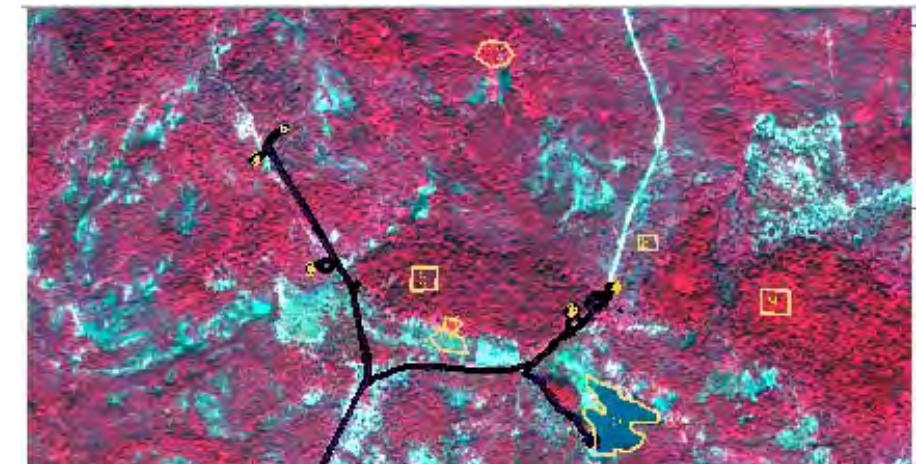
RapidEye RGB=B354

DOF/FIPD

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## RapidEye Composite Image

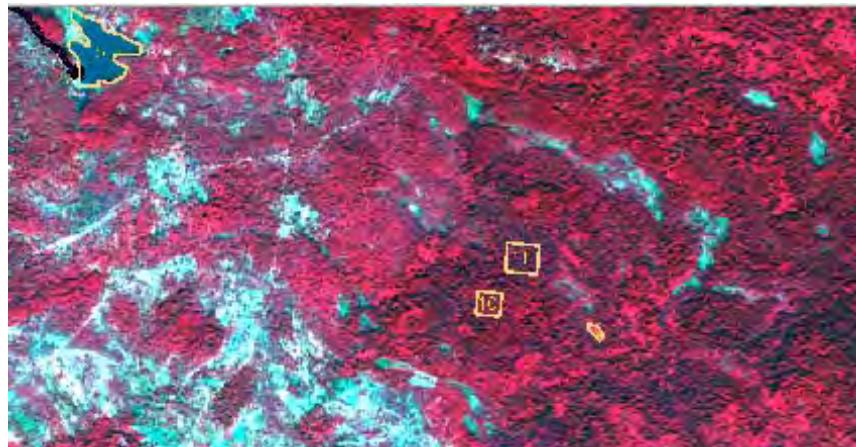


DOF/FIPD

KOKUSAI KOGYO CO.,LTD. ASIA AIR SURVEY CO.,LTD.



## RapidEye Composite Image

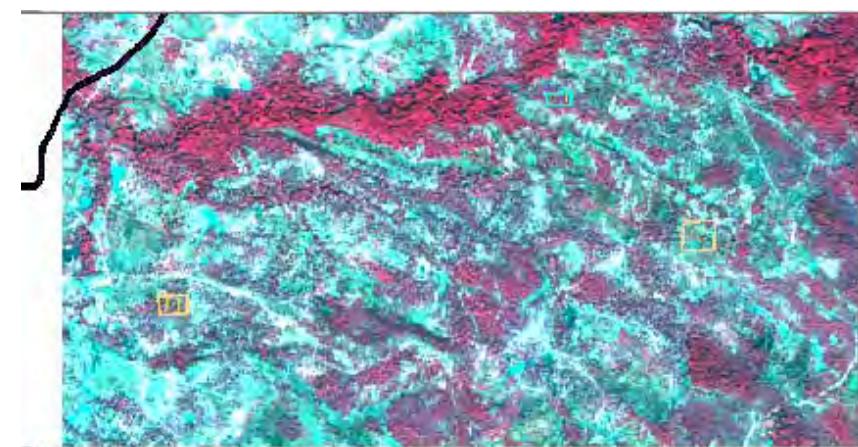


DOF/FIPD

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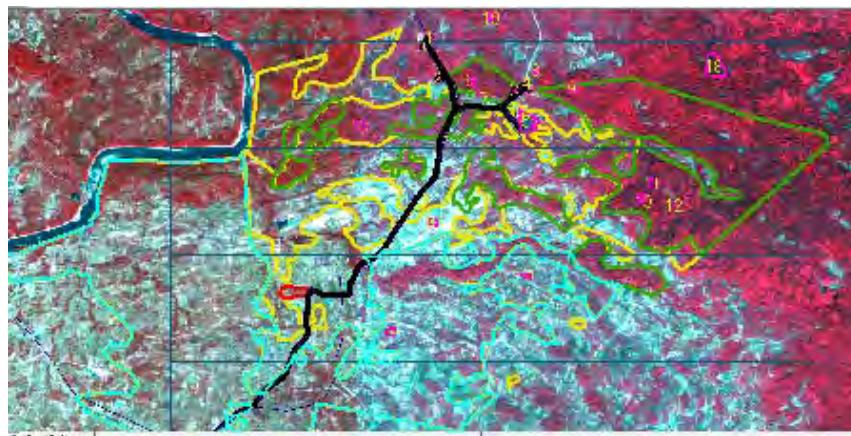


## RapidEye Composite Image



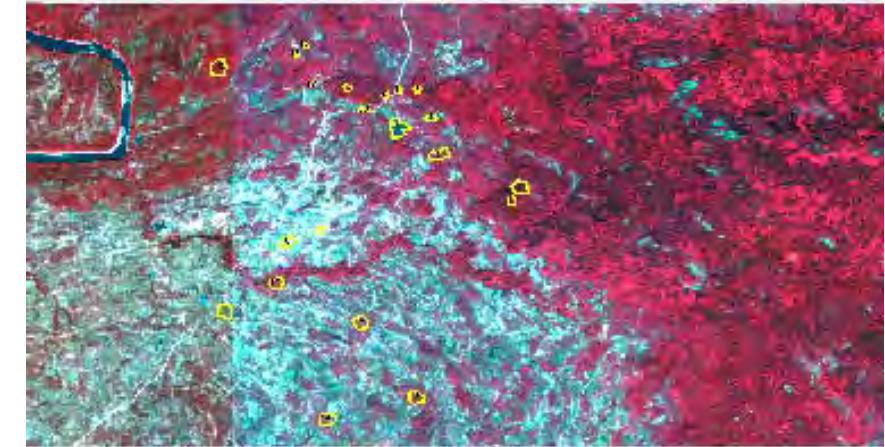
DOF/FIPD

KOKUSAI KOGYO CO.,LTD. ASIA AIR SURVEY CO.,LTD.



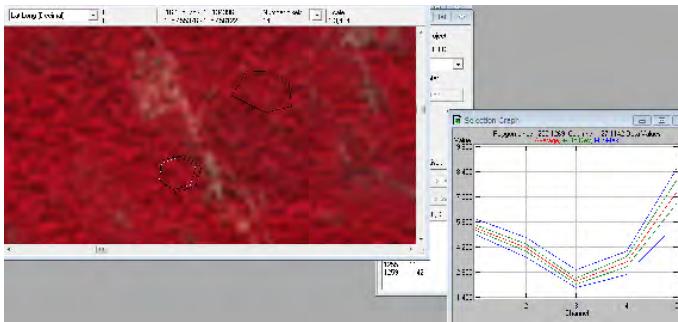
DOF/FIPD

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DOF/FIPD

KOKUSAI KOGYO CO.,LTD. ASIA AIR SURVEY CO.,LTD.

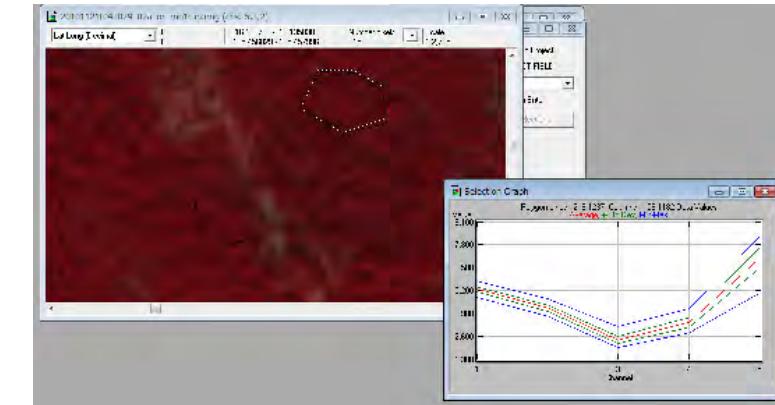
**No. 16 Plot****Class 'No 16' Statistics**

Number of training pixels = 149, Number of training fields = 1

Channel	1	2	3	4	5
Mean	5291.3	4193.3	2310.7	3395.5	7295.9
Standard Deviation	149.5	195.0	160.7	272.3	658.5

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**Class 'Class 17' Statistics**

Number of training pixels = 315, Number of training fields = 1

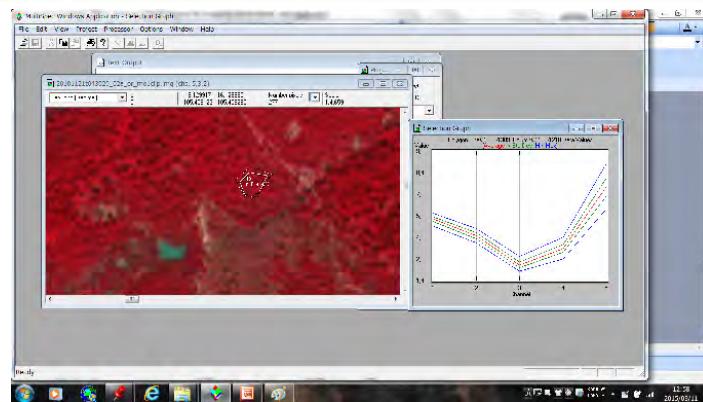
Channel	1	2	3	4	5
Mean	5273.2	4207.8	2386.5	3385.7	7046.3
Standard Deviation	150.4	176.1	199.3	257.9	579.5

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## No.18----Plot 3 (DD)



### Class '18-1' Statistics

Number of training pixels = 169, Number of training fields = 1

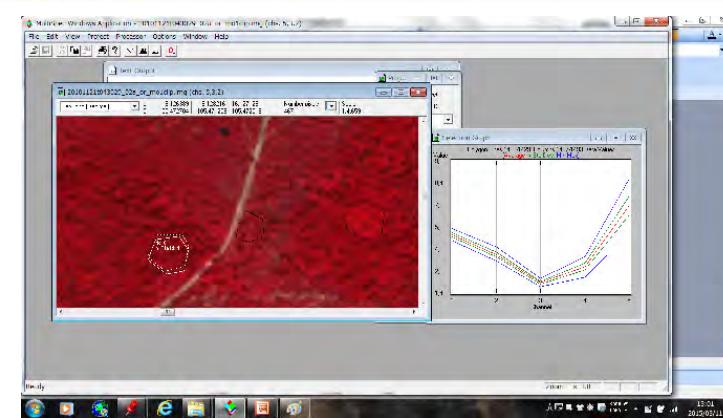
Channel	1	2	3	4	5
Mean	5400.6	4312.4	2412.0	3490.7	7529.9
Standard Deviation	143.0	210.5	205.2	254.4	577.5



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## No.0----Plot 4 (Mixed Deciduous)



### Class 'No-0' Statistics

Number of training pixels = 448, Number of training fields = 1

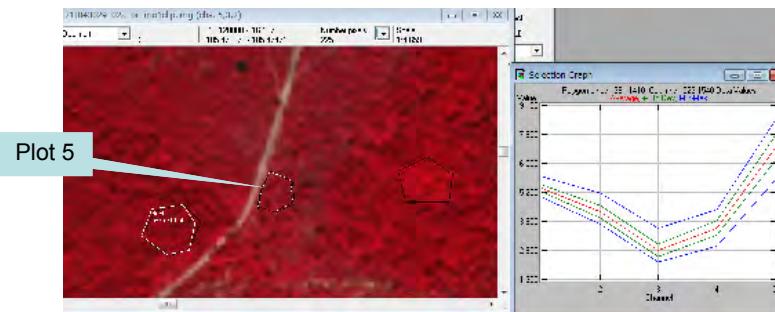
Channel	1	2	3	4	5
Mean	5130.6	3886.9	2086.5	3150.3	7017.2
Standard Deviation	136.9	156.0	101.5	236.4	610.7



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## No.1----Plot 5 (DD)



### Class '1' Statistics

Number of training pixels = 225, Number of training fields = 1

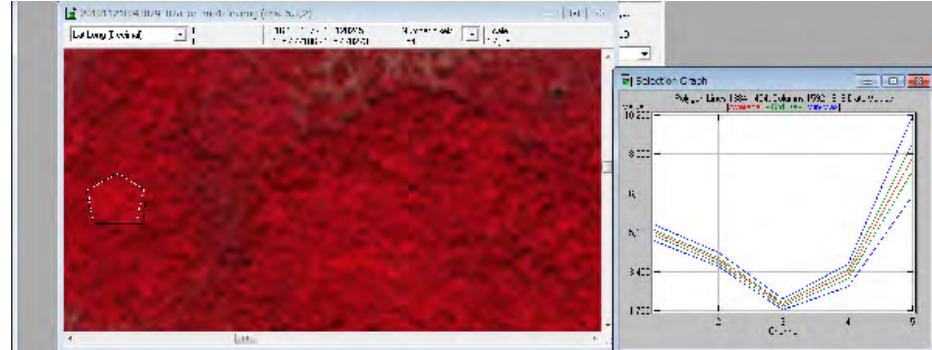
Channel	1	2	3	4	5
Mean	5399.0	4354.3	2612.5	3612.4	7157.9
Standard Deviation	156.7	273.1	289.4	327.0	563.6



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## No.3----Grass land



### Class 'No.3' Statistics

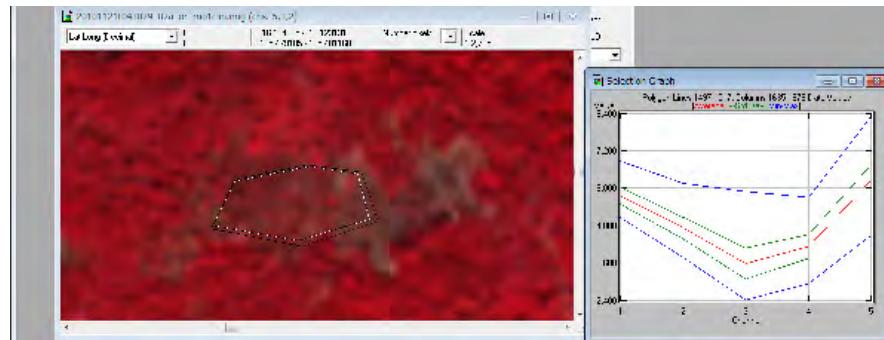
Number of training pixels = 354, Number of training fields = 1

Channel	1	2	3	4	5
Mean	5097.2	3888.7	1968.0	3275.4	8358.5
Standard Deviation	127.1	123.7	82.5	175.4	599.5



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## No.4----Rice Paddy



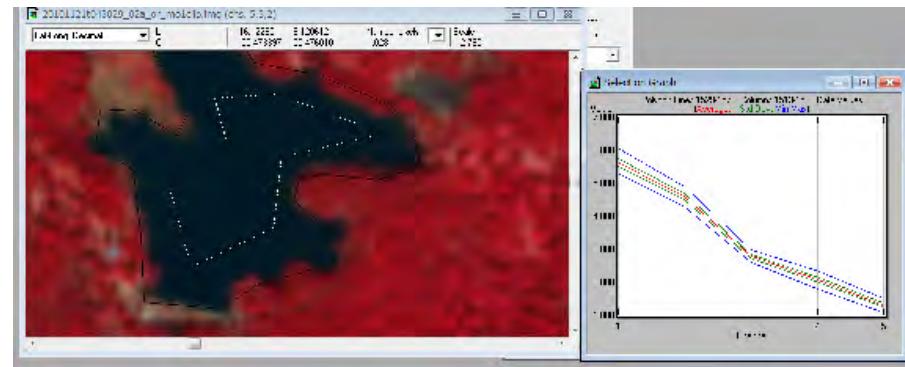
Class 'No.4' Statistics

Number of training pixels = 606, Number of training fields = 1

Channel	1	2	3	4	5
Mean	5761.8	4719.3	3574.7	4138.0	6251.0
Standard Deviation	272.0	342.0	502.1	377.8	500.8



## No.5----Water

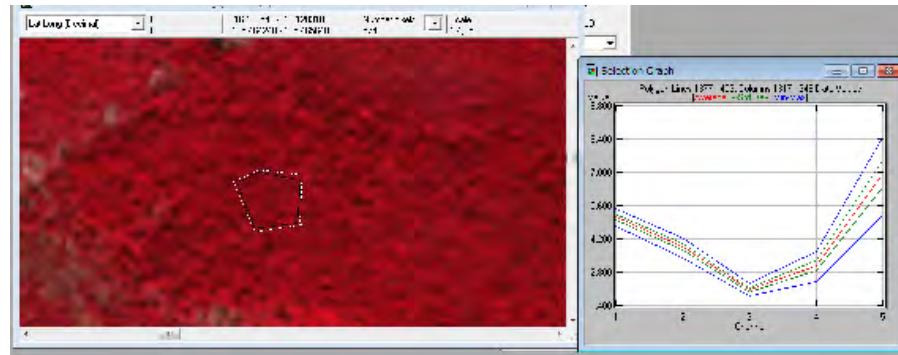


Class 'No.5' Statistics

Number of training pixels = 1028, Number of training fields = 1

Channel	1	2	3	4	5
Mean	5626.6	4580.8	2786.6	2081.9	1301.7
Standard Deviation	120.9	90.3	66.8	77.7	61.6

## No.19---Mixed Deciduous



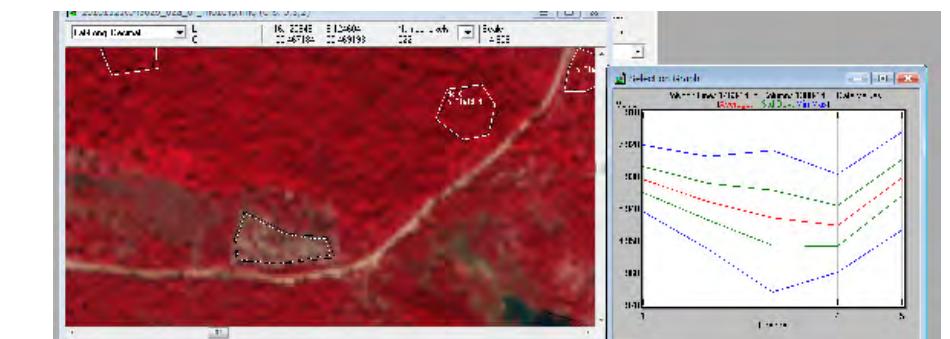
Class 'No.19' Statistics

Number of training pixels = 574, Number of training fields = 1

Channel	1	2	3	4	5
Mean	5135.8	3876.4	2067.0	3090.6	6936.7
Standard Deviation	122.6	137.4	92.0	210.3	568.3



## No.20---Rice Paddy



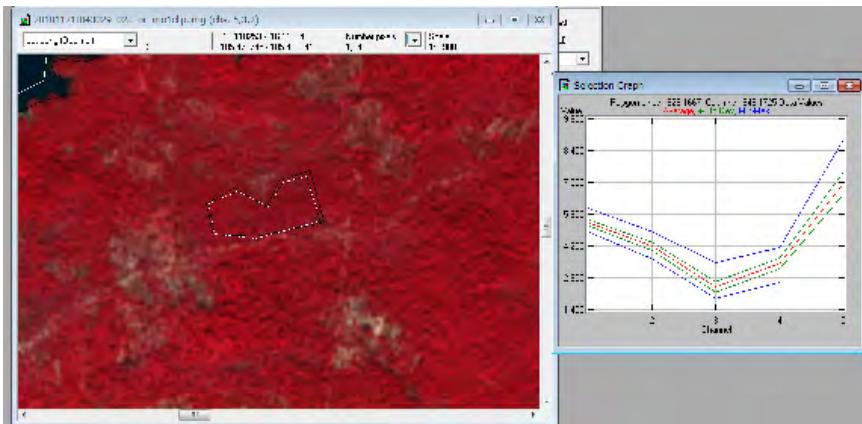
Class 'No 20' Statistics

Number of training pixels = 522, Number of training fields = 1

Channel	1	2	3	4	5
Mean	6850.6	6161.7	5664.4	5427.4	6905.9
Standard Deviation	395.9	573.5	853.7	619.3	562.0



## No.2 ----Mixed Deciduous



Class 'No.2' Statistics

Number of training pixels = 1842, Number of training fields = 1

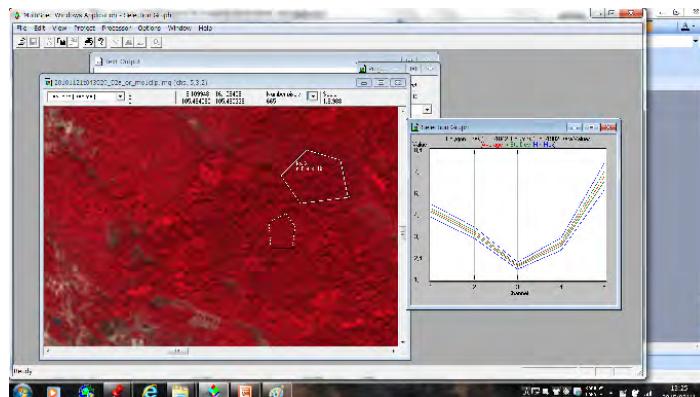
Channel	1	2	3	4	5
Mean	5255.1	4212.7	2424.4	3443.7	6965.9
Standard Deviation	142.5	179.5	227.2	235.4	492.0



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## No.7---Mixed Deciduous (Very Dense)



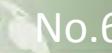
Class 'No.7' Statistics

Number of training pixels = 665, Number of training fields = 1

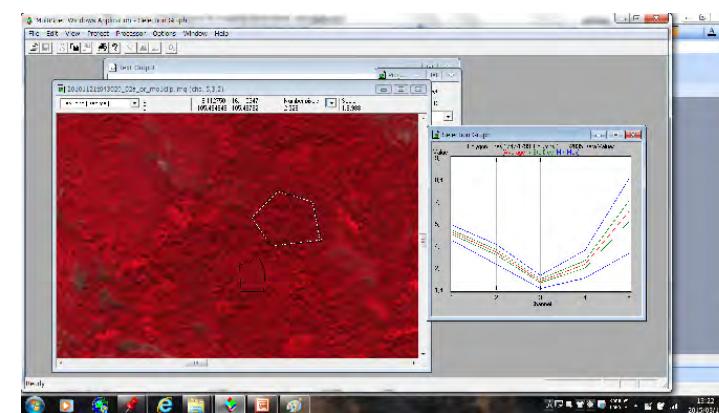
Channel	1	2	3	4	5
Mean	5085.1	3814.9	1982.2	3189.7	6941.6
Standard Deviation	113.3	106.3	67.1	115.3	271.4



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## No.6 ---Mixed Deciduous



Class 'No.6' Statistics

Number of training pixels = 2328, Number of training fields = 1

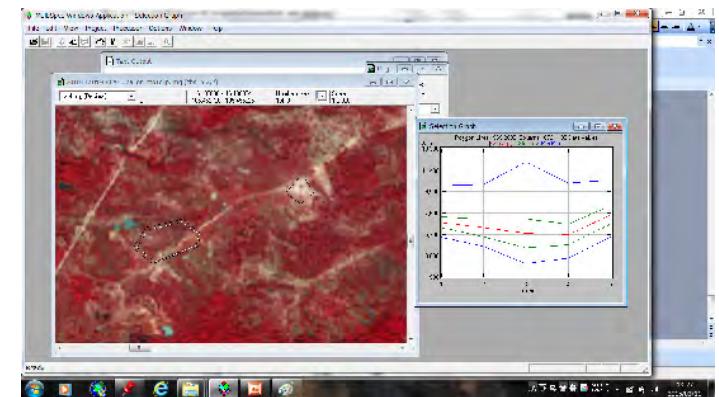
Channel	1	2	3	4	5
Mean	5071.0	3815.0	1990.9	3049.9	6412.2
Standard Deviation	136.5	160.3	110.3	245.4	663.4



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## No.8---Rice Paddy



Class 'No.8' Statistics

Number of training pixels = 1473, Number of training fields = 1

Channel	1	2	3	4	5
Mean	6771.9	6295.2	5792.8	5689.6	7443.8
Standard Deviation	474.7	800.0	1299.9	928.2	812.4

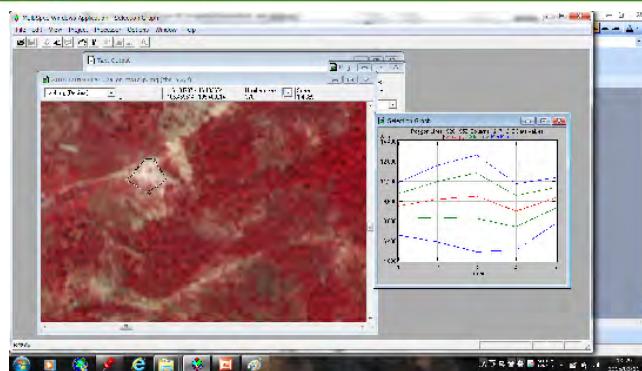


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## No.9---Rice Paddy (very light)



Class 'No.9' Statistics

Original class statistics are listed.

Number of training pixels = 376, Number of training fields = 1

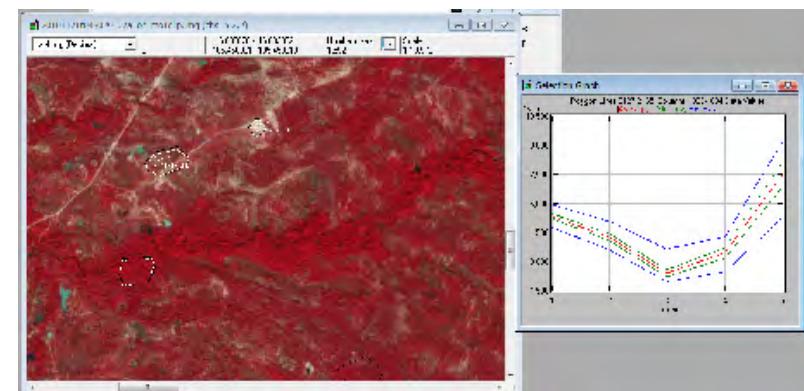
Channel	1	2	3	4	5
Mean	9220.2	9756.1	10055.9	8834.8	9891.4
Standard Deviation	1011.1	1446.1	1865.1	1260.3	844.9



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## No.10 DD (near stream)



Class 'No.10' Statistics

Number of training pixels = 1592, Number of training fields = 1

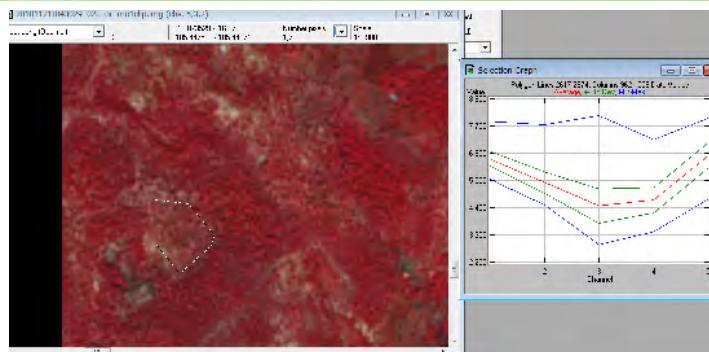
Channel	1	2	3	4	5
Mean	5355.4	4274.7	2415.6	3466.9	7522.2
Standard Deviation	137.5	180.3	172.0	260.5	653.1



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## No.11---Rice Paddy covered by trees?



Class 'Class 11' Statistics

Number of training pixels = 1738, Number of training fields = 1

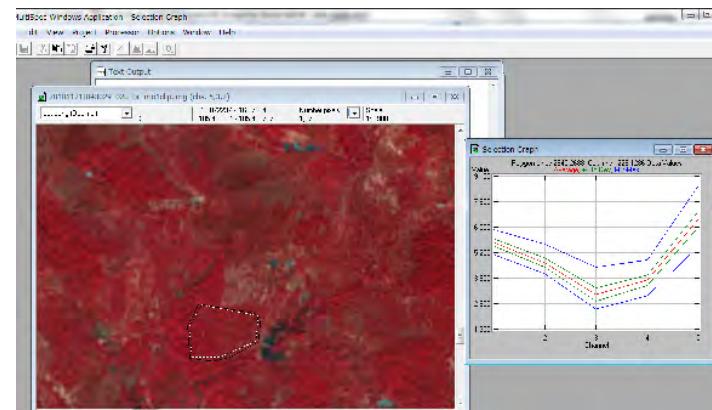
Channel	1	2	3	4	5
Mean	6380.2	5424.9	4478.8	4715.3	6518.4
Standard Deviation	299.8	431.1	683.1	521.7	519.9



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## No.14---DD



Class 'Class 14' Statistics

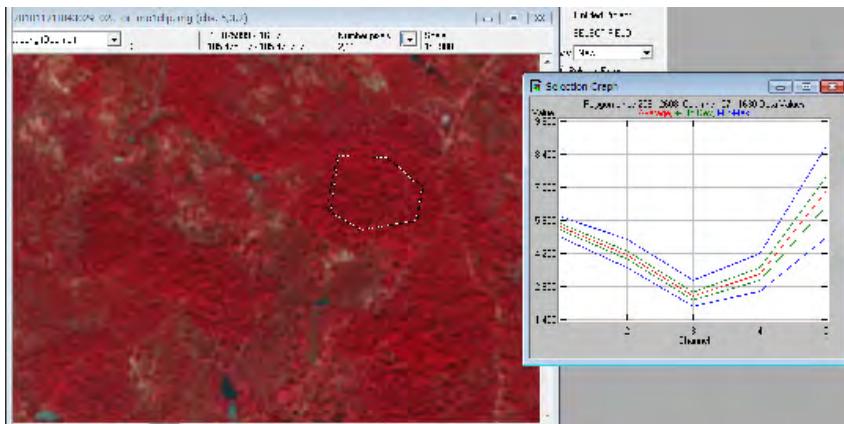
Number of training pixels = 1870, Number of training fields = 1

Channel	1	2	3	4	5
Mean	5731.4	4702.9	3072.7	3816.8	6918.9
Standard Deviation	187.3	226.8	336.1	265.2	400.3



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## No.13—Mixed Deciduous

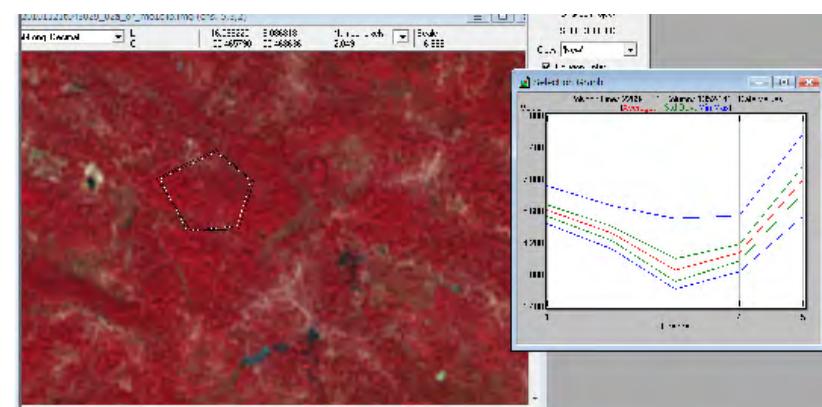


Class 'Class 13' Statistics

Number of training pixels = 2110, Number of training fields = 1

Channel	1	2	3	4	5
Mean	5337.6	4156.8	2418.1	3350.7	6842.3
Standard Deviation	132.5	164.9	154.4	251.6	622.5

## No.12 ---Mixed Deciduous

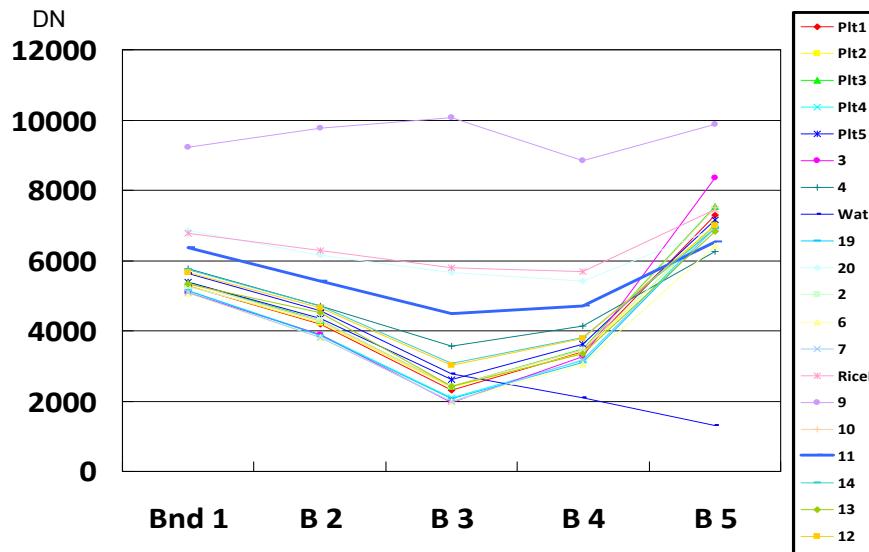


Class 'Class 12' Statistics

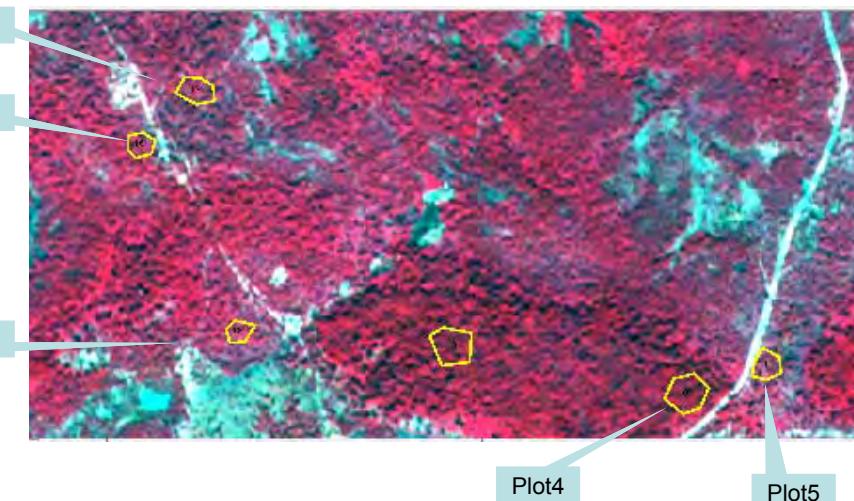
Number of training pixels = 2049, Number of training fields = 1

Channel	1	2	3	4	5
Mean	5646.5	4644.0	3023.6	3778.9	6988.9
Standard Deviation	252.8	313.8	497.4	377.2	583.1

## RapidEye Image---2010/11/13

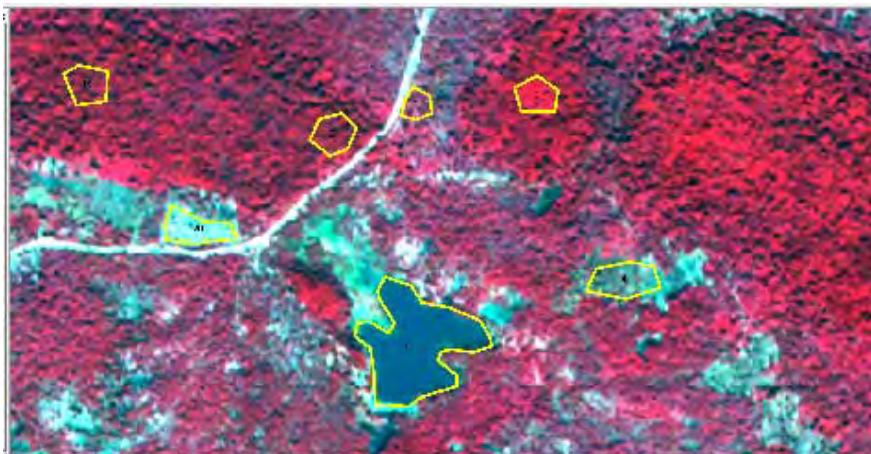


## Sites of Plot Surveys





## RapidEye Image



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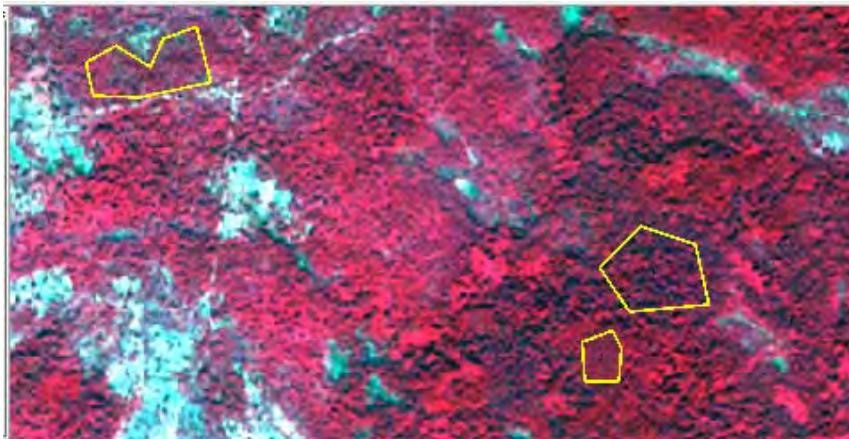


## Aerial Views of Survey Plots



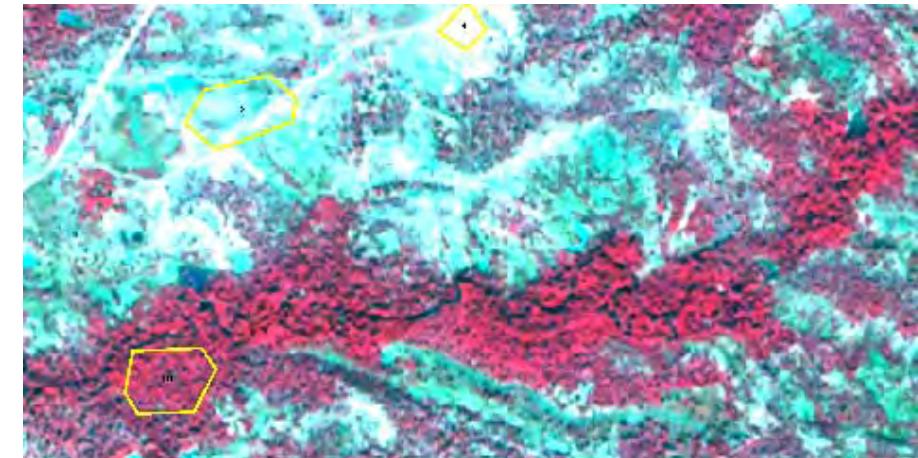
DOF/FIPD

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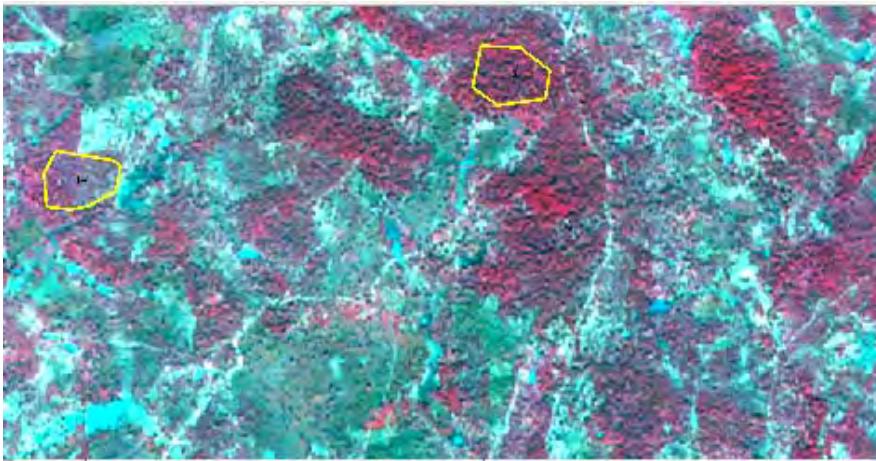
DOF/FIPD

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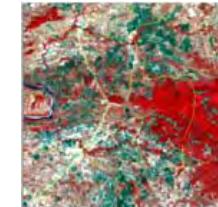
DOF/FIPD

KOKUSAI KOGYO CO.,LTD. ASIA AIR SURVEY CO.,LTD.

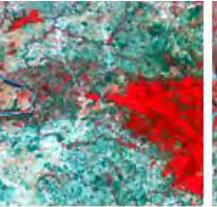


DOF/FIPD

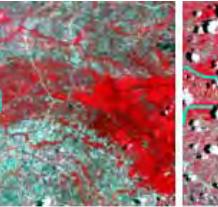
KOKUSAI KOGYO CO.,LTD. ASIA AIR SURVEY CO.,LTD.



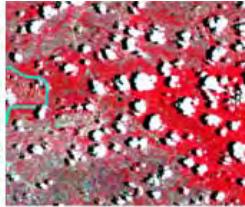
2014/01/28



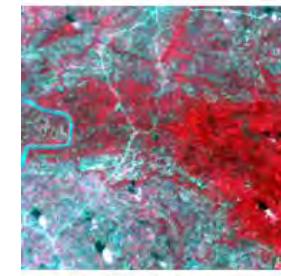
2014/03/17



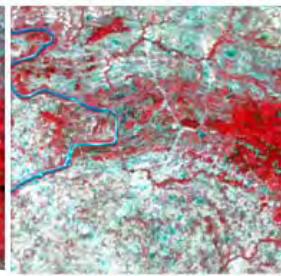
\*2013/05/17\*



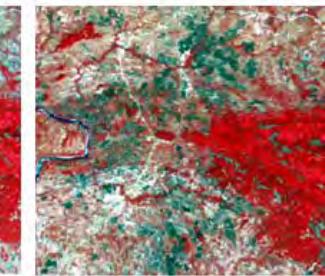
2014/08/24



2014/10/11



2014/12/30



2015/01/31

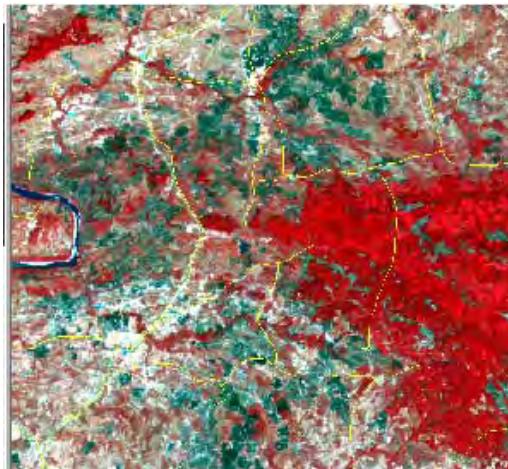
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2014/01/28



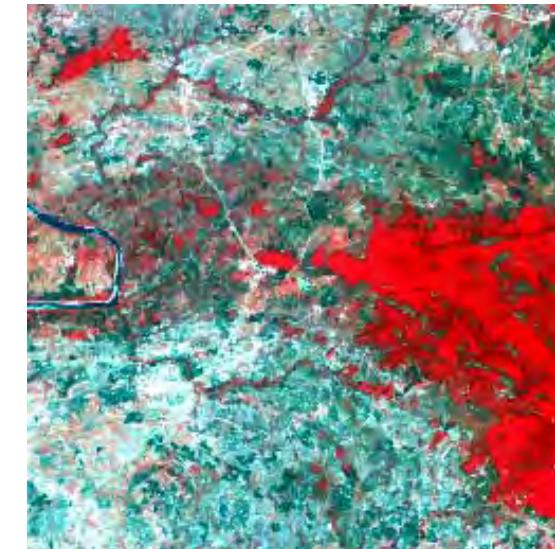
Find and compare the spectral characteristic graphs of various land use/land cover features on the multitemporal images.



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2014/03/17



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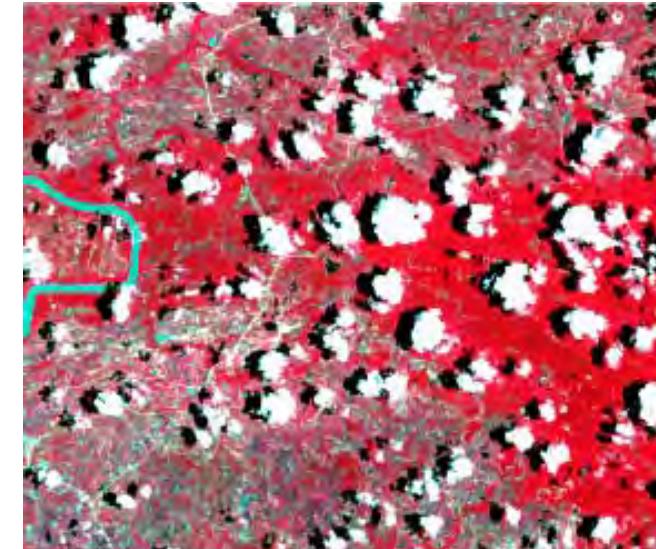
\*2013/05/17\*



DOF/FIPD

KOKUSAI KOGYO CO.,LTD. ASIA AIR SURVEY CO.,LTD.

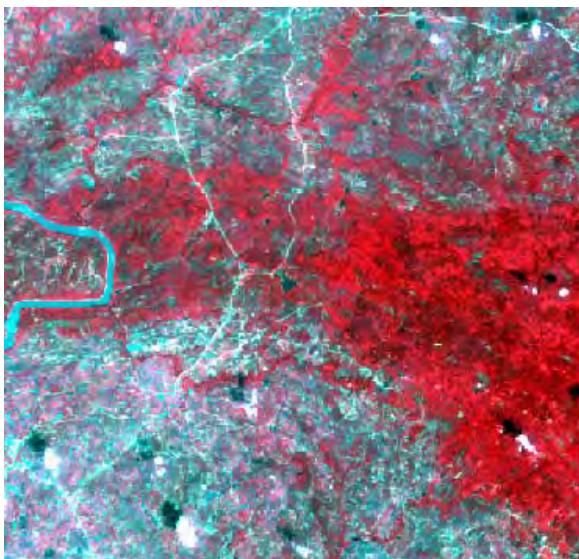
2014/08/24



DOF/FIPD

KOKUSAI KOGYO CO.,LTD. ASIA AIR SURVEY CO.,LTD.

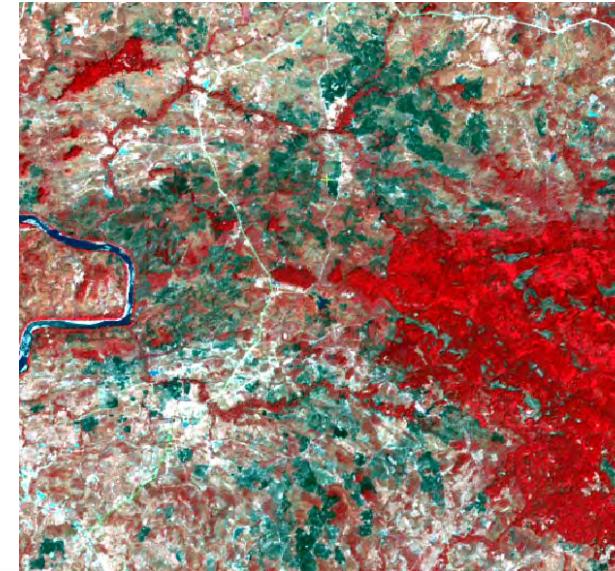
2014/10/11



DOF/FIPD

KOKUSAI KOGYO CO.,LTD. ASIA AIR SURVEY CO.,LTD.

2015/01/31



DOF/FIPD

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# Theory of Remote Sensing

## Part-2

### -NDVI and Related Topics-

Technical Training

March 3rd - 16<sup>st</sup>, 2015



KOKUSAI KOGYO CO.,LTD. ASIA AIR SURVEY CO.,LTD.



Mitsuru NASU, Ph.D.

Forest Remote Sensing

## 7. Understanding Vegetation Indices of Forest and Various Land-Cover Features

Theme to be studied:

-Analyses of NDVI and SVI

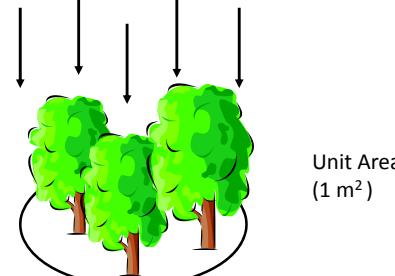
-Vegetation Cover and Land Cover vs. NDVI

-Forest Types vs. NDVI



### [ Definition of Leaf Area Index ]

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



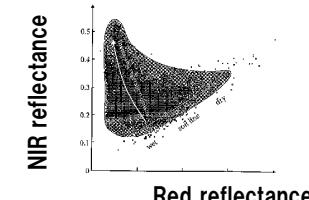
◊ For conifers, that have cylindrical needles, one may consider the projected area of the needles or hemi-surface area of the needles.

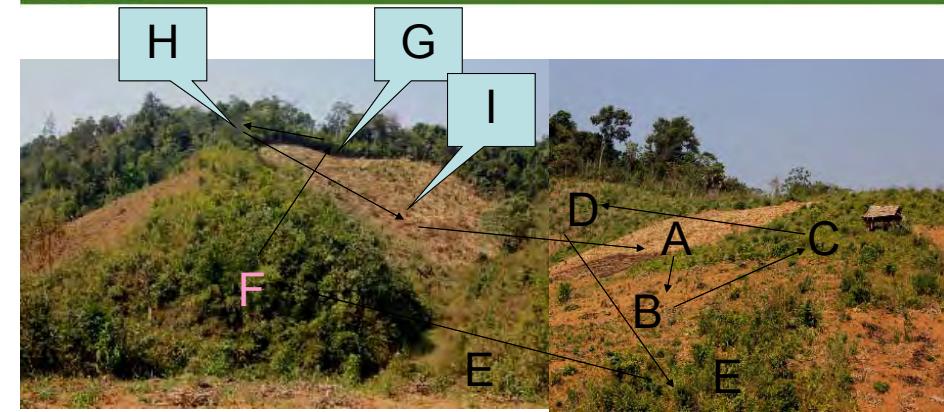
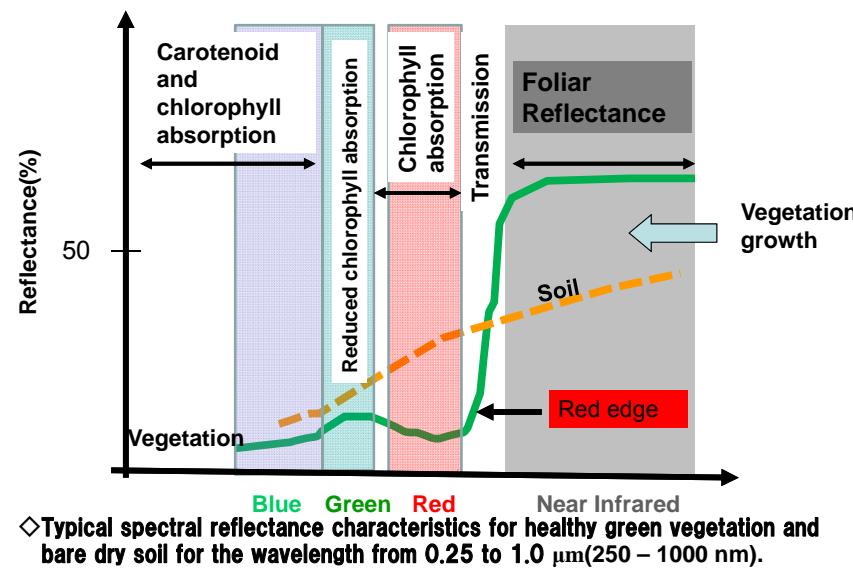
LAI=Technical word in Forestry → Vegetation Index in RS

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

◊ There exists 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.

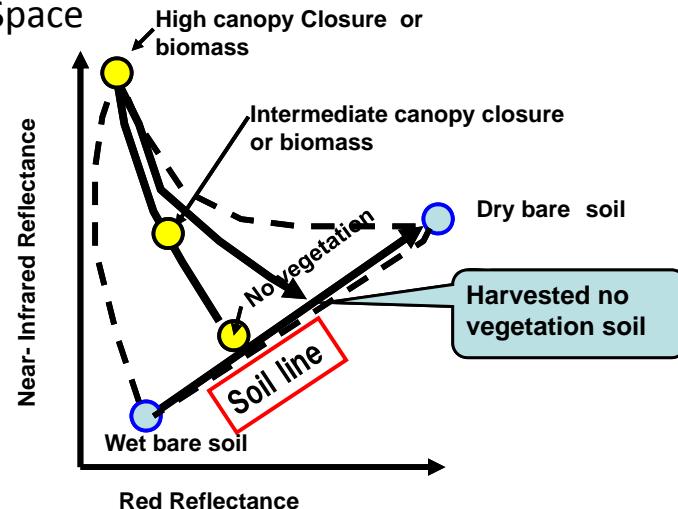




A (bare soil) → B → C → D → E → F → G → H → I (S/B)  
Increase of Amount of Biomass



### Distribution of DNs in Red and Near-infrared Spectral Space



● Simple Ratio:  $SVI = \frac{\rho_{red}}{\rho_{nir}}$ .  
(Simple Vegetation Index)

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

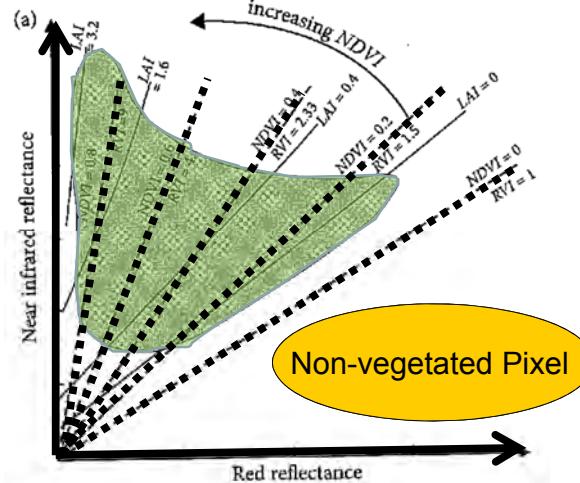
● Enhanced vegetation Index:  $EVI = G \frac{\rho^*_{nir} - \rho^*_{red}}{\rho^*_{nir} + C_1 \rho^*_{red} - C_2 \rho^*_{blue} + L} (1 + L)$ .

$\rho$ : reflectance of light (DN value of a pixel)

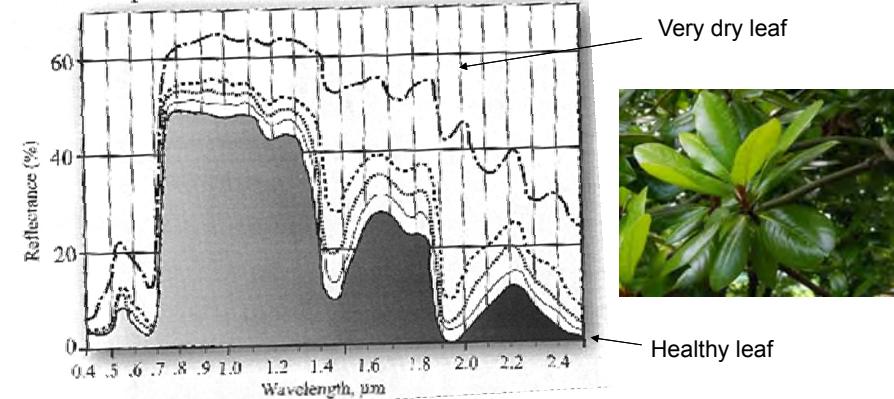


Equal NDVI, equal RVI(=SVI), and equal LAI(Leaf-Area Index)

Lines (These are actually very similar figures.)



### 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.



Investigating relationships between Landsat ETM+ sensor data and leaf area index in a boreal conifer forest (paper on RSE 78)

Lars Eklundh\*, Lars Harrie, Andres Kuusk.

Remote Sensing of Environment 78 (2001) 239– 251

- 1) The theoretical reflectance response to LAI changes investigated using a forest canopy reflectance model in order to simulate stand reflectances in the Landsat ETM+ wavelength bands.
- 2) The response to changes in LAI is strongest in the visible wavelength bands, particularly Red band, whereas only weak response is noted in the NIR band and for some vegetation indices [simple ratio (SR) and NDVI].
- 3) Modelled reflectances are influenced by various other factors, particularly ground reflectance and leaf biochemical properties.



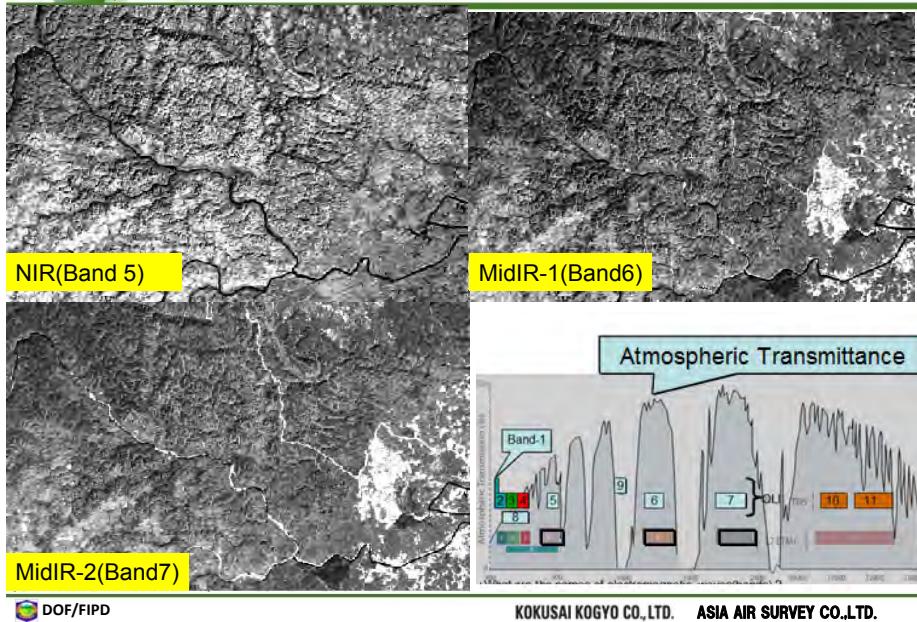
4) Observed reflectances from the Landsat ETM+ sensor have been compared with reflectance modelling results and with field-based LAI estimates.

5) Statistical relationships between LAI and observed ETM+ reflectances are strongest in Mid-IR 2 band.

[Landsat ETM+ Spectral Bands]

1	0.45–0.52 μm	30m
2	0.52–0.60 μm	30m
3	0.63–0.69 μm	30m
4	0.76–0.90 μm	30m
5	1.55–1.75 μm	30m
6	10.4–12.5 μm	60m
7	2.08–2.35 μm	30m
8	0.50–0.90 μm	15m

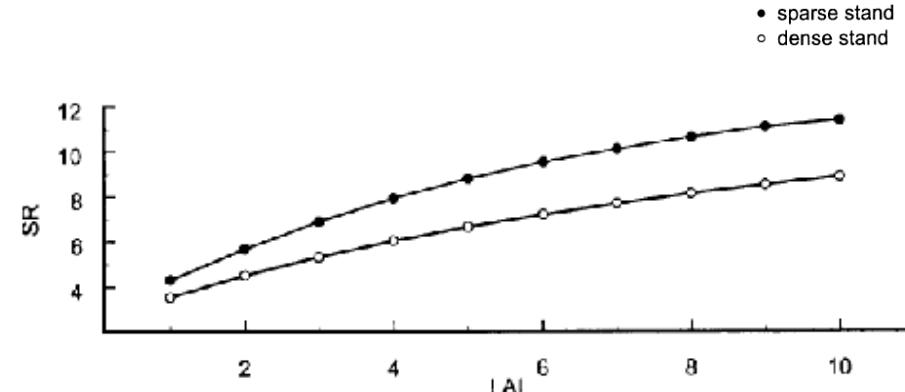
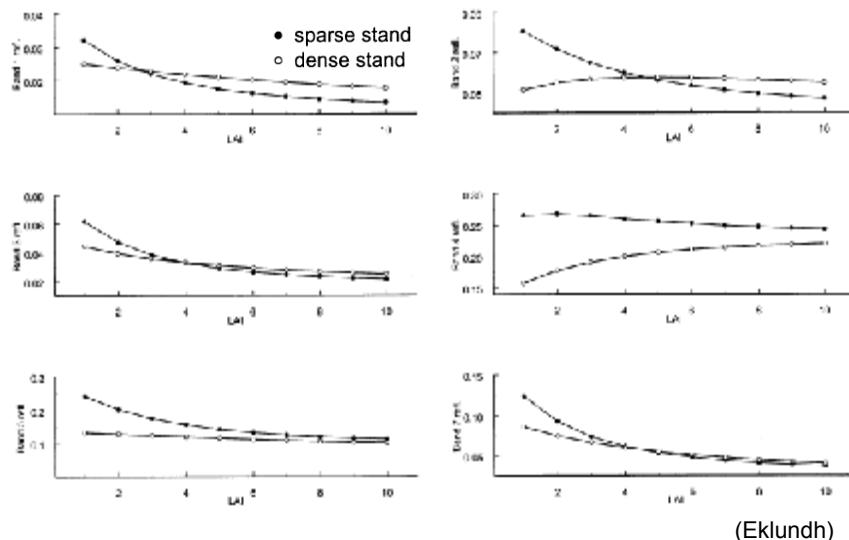
RGB=B432



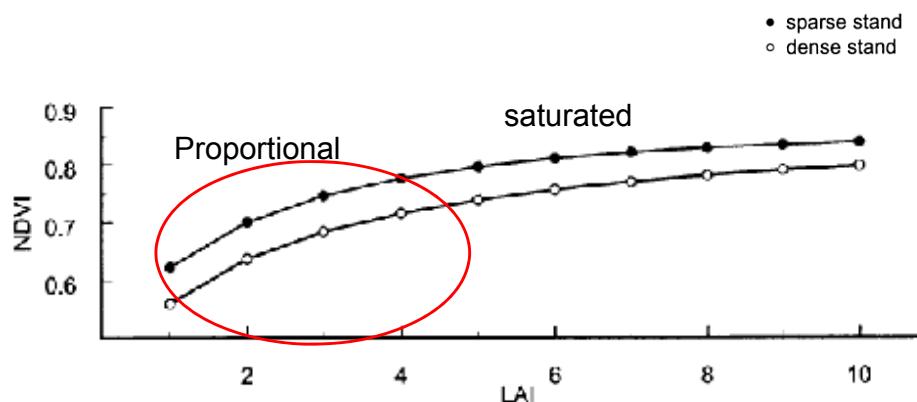
Parameters in the ETM+ optical channels for two different pine stands (sparse and dense) to which the forest canopy reflectance model is most sensitive. (Eklundh, et.al.)

	Blue (B1)	Green (B2)	Red (B3)	Near IR (B4)	Mid-IR1 (B5)	Mid-IR2 (B6)
Stand 1 (sparse)	ground reflectance	ground reflectance	sun angle	ground reflectance	ground reflectance	sun angle
Stand 2 (dense)	Leaf refractive index	chlorophyll	Leaf structure	tree height	leaf water	LAI

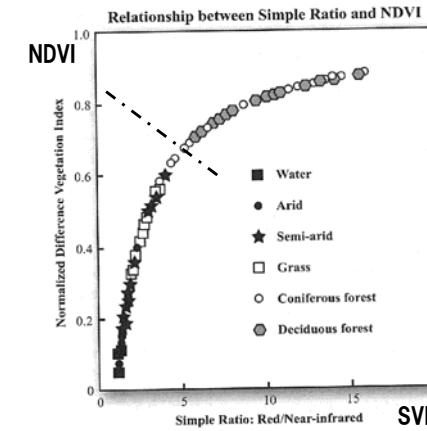
LAI=Leaf Area Index



(Eklundh)



+Sparse area have better correlation than that's of the dense stand.  
(Eklundh)



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

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

(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.



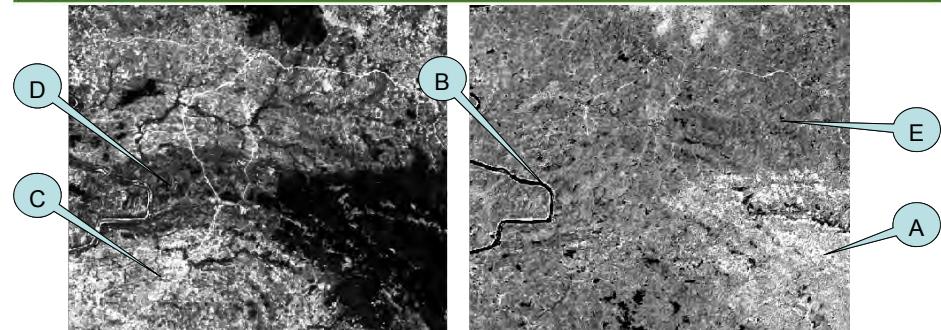
- ◇Much of the light reflected from a canopy has undergone more than one reflection. Thus, the overall reflectance of a dense canopy is usually substantially less than the reflectance measured for a single leaf. → Dense forest → Darker
- ◇As leaf-area index decreases, the canopy reflectance tends to that of the underlying soil.

◇Radiation becomes enriched in the near-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 the solar angle.

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

(Albedo=Total reflectance of light)



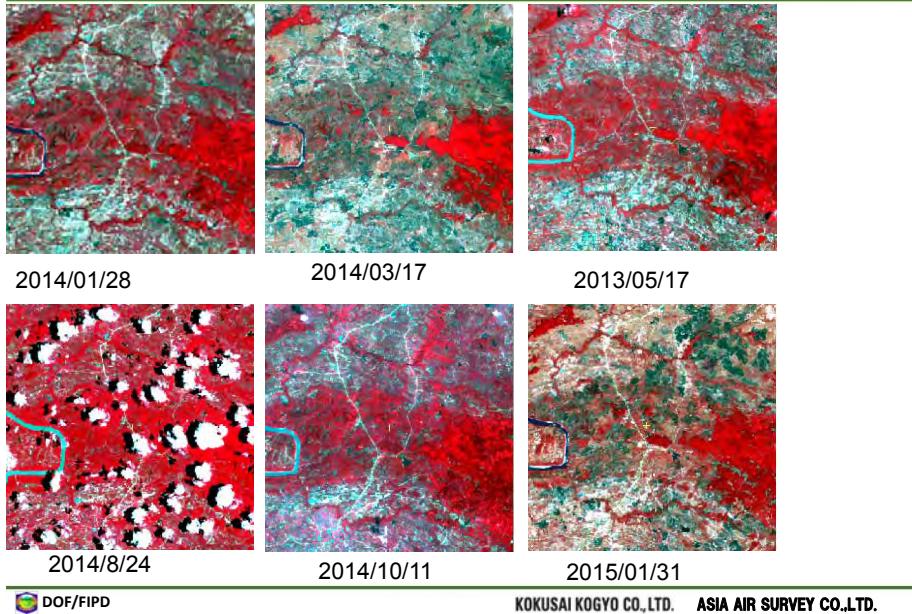
Red Color Band (Band 4)

Near Infrared Band (Band 5)

Which features (define) have high, medium and low radiation (reflectance) of red and near LR lights ?

Band	A( )	B( )	C( )	D( )	E( )
4(Red)					
5(NIR)					

## jica Multi-temporal Landsat\_8 Images of S. Savannakhet



## jica Landsat\_8 Data Analyses of NDVI & SVI

Obtain and Compare NDVI and SVI Data for Savannakhet Landsat\_8 Images:

- 2014/03/17 → (file: )
- 2013/05/17 (file: )
- 2014/08/24 (file: )
- 2014/10/11 (file: )
- 2015/01/31 (file: )

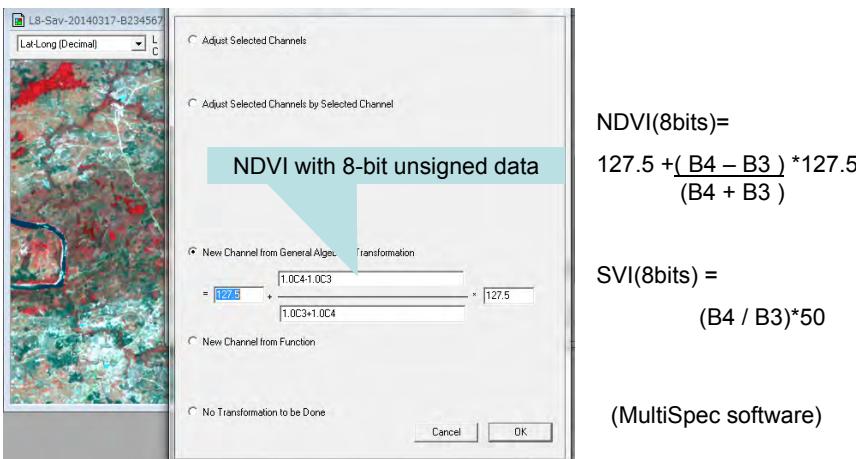
(Use ArcGIS raster data processing functions)

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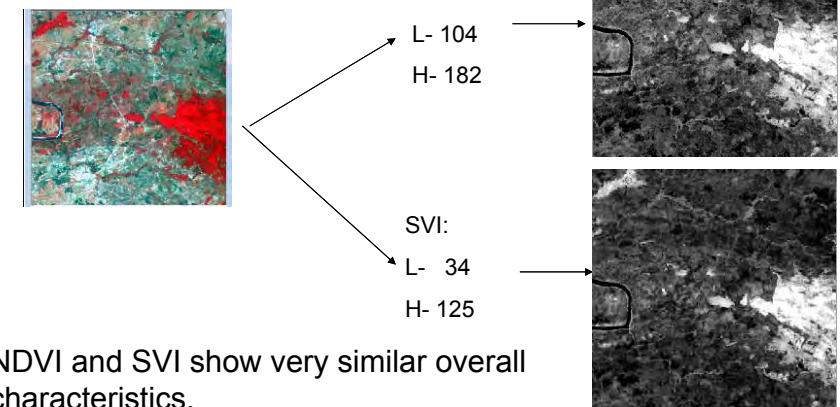
## jica NDVI and SVI (Simple Vegetation Index)

### Computations of NDVI and SVI



## jica Actual NDVI and SVI (End of Dry Season)

Savannakhet Landsat\_8 Images:  
 2014/03/17



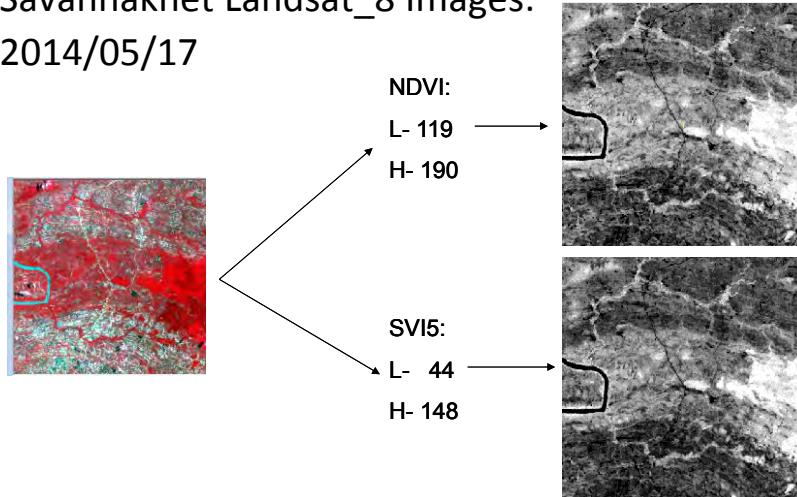
DOF/FIPD

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## Actual NDVI and SVI ( Beginning of Rainy Season)

- Savannakhet Landsat\_8 Images:
- 2014/05/17



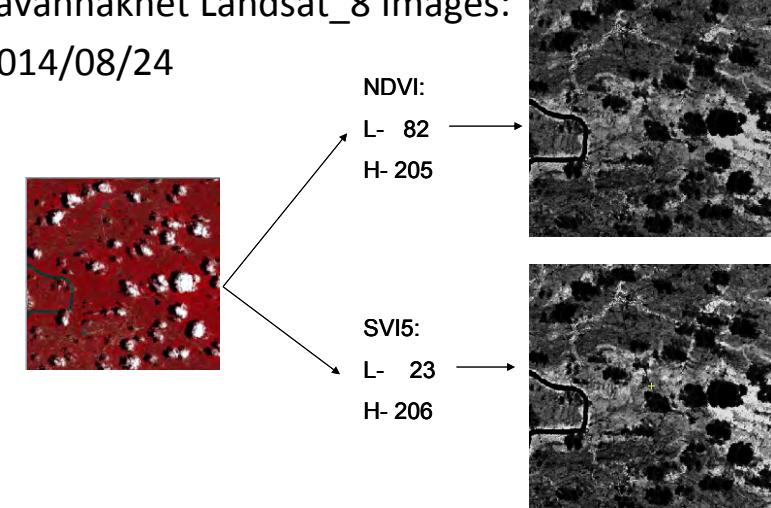
DOF/FIPD

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## Actual NDVI and SVI ( Middle of Rainy Season)

- Savannakhet Landsat\_8 Images:
- 2014/08/24



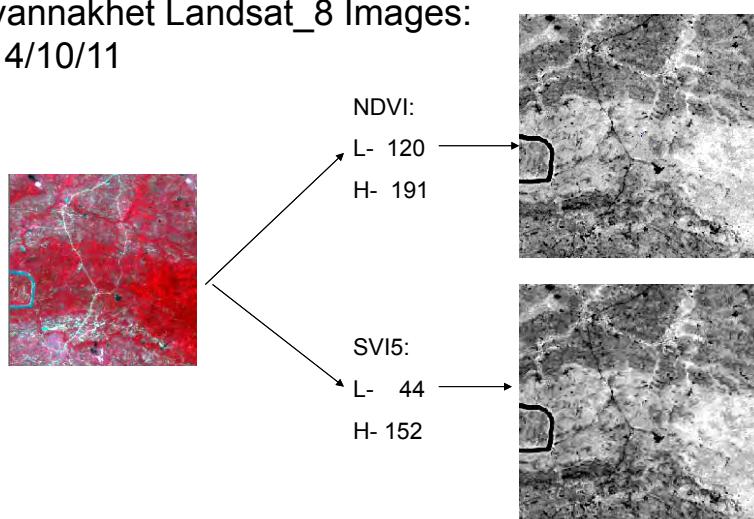
DOF/FIPD

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## Actual NDVI and SVI ( Beginning of Dry Season)

- Savannakhet Landsat\_8 Images:
- 2014/10/11



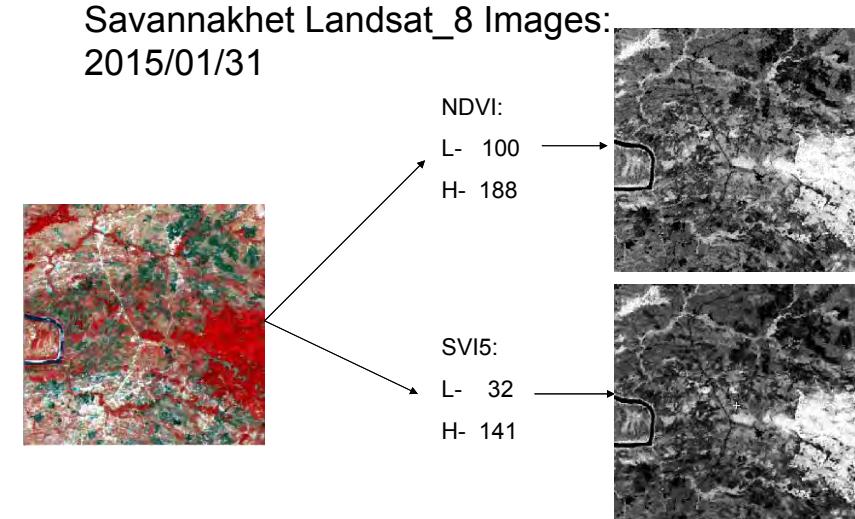
DOF/FIPD

KOKUSAI KOGYO CO.,LTD. ASIA AIR SURVEY CO.,LTD.



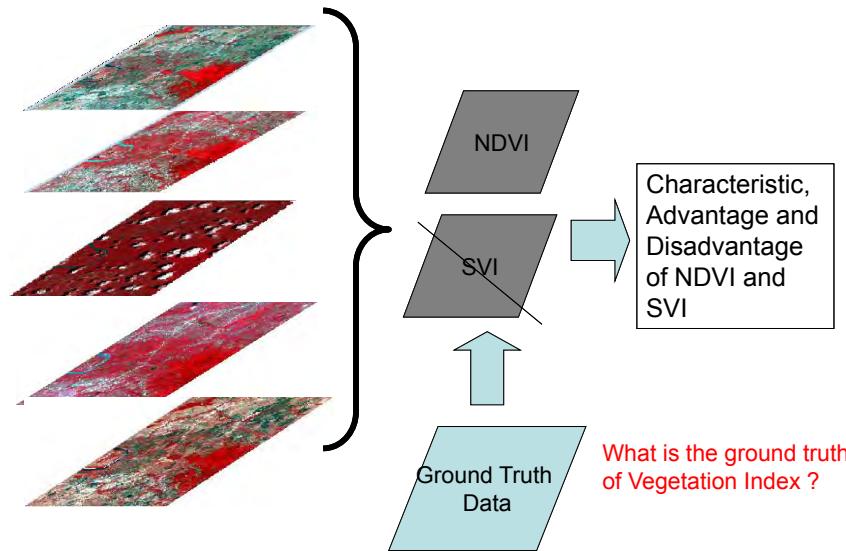
## Actual NDVI and SVI ( Middle of Dry Season)

- Savannakhet Landsat\_8 Images:
- 2015/01/31



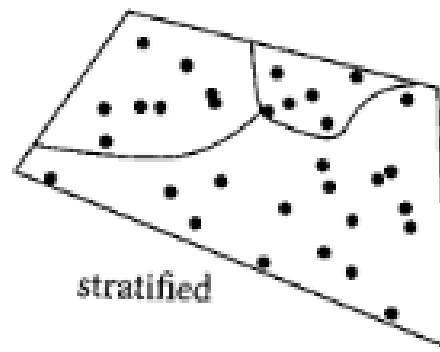
DOF/FIPD

KOKUSAI KOGYO CO.,LTD. ASIA AIR SURVEY CO.,LTD.

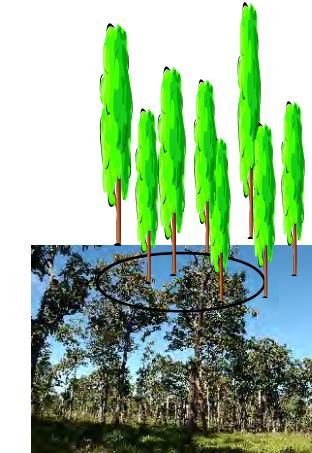


## Ground Truth of Vegetation Index

- Biomass/Unit Area → Field Plot Survey
- Tree Density or Crown Density → Field Plot Survey
- Tree Height → Field Plot Survey
- Total Leaf Area → Field Plot Survey ?
- Etc. Physical measurement ?



Stratified Sampling Scheme



(From Forest Plot Survey in 2013)

Plot Number	Plot Area (ha)	DBH (cm)	Height (m)	Crown Coverage (%)	Biomass (t/ha)	Species
01	0.05	15	10	50	1.5	Croton
02	0.05	15	10	50	1.5	Croton
03	0.05	15	10	50	1.5	Croton
04	0.05	15	10	50	1.5	Croton
05	0.05	15	10	50	1.5	Croton
06	0.05	15	10	50	1.5	Croton
07	0.05	15	10	50	1.5	Croton
08	0.05	15	10	50	1.5	Croton
09	0.05	15	10	50	1.5	Croton
10	0.05	15	10	50	1.5	Croton
11	0.05	15	10	50	1.5	Croton
12	0.05	15	10	50	1.5	Croton
13	0.05	15	10	50	1.5	Croton
14	0.05	15	10	50	1.5	Croton
15	0.05	15	10	50	1.5	Croton
16	0.05	15	10	50	1.5	Croton
17	0.05	15	10	50	1.5	Croton
18	0.05	15	10	50	1.5	Croton
19	0.05	15	10	50	1.5	Croton
20	0.05	15	10	50	1.5	Croton
21	0.05	15	10	50	1.5	Croton
22	0.05	15	10	50	1.5	Croton
23	0.05	15	10	50	1.5	Croton
24	0.05	15	10	50	1.5	Croton
25	0.05	15	10	50	1.5	Croton
26	0.05	15	10	50	1.5	Croton
27	0.05	15	10	50	1.5	Croton
28	0.05	15	10	50	1.5	Croton
29	0.05	15	10	50	1.5	Croton
30	0.05	15	10	50	1.5	Croton
31	0.05	15	10	50	1.5	Croton

(THE STUDY ON THE STRENGTHENING OF METHODOLOGICAL AND TECHNOLOGICAL APPROACHES FOR REDUCING DEFORESTATION AND FOREST DEGRADATION WITHIN THE REDD IMPLEMENTATION FRAMEWORK: APPLICATION IN LAO PDR, April 2012, Asia Air Survey Co.,Ltd.)



## Estimation of the above ground biomass from the field plot survey data:

DBH → Basal Area → B

Tree No.	DBH (cm)	Height (m)	Biomass (t dry matter / tree)
01	45.0	17.91	3.8066
02	25.0	41.20	3.2188
03	11.0	52.0	2.3979
04	12.0	64.0	2.4849
05	30.0	651.0	3.4012
84	14.0	95.0	2.6390
85	26.5	477.0	3.2771
Average	22.1		19.1
Total		31,742.0	kg dry m.
ABD		161.70	t d.m. / ha
BBD		31.00	t d.m. / ha
Living Biomass		192.70	t d.m. / ha
Carbon		96.4	t C / ha



$Y_a = \exp[-2.289 + 2.649 \times \ln(\text{DBH}) - 0.021 \times (\ln(\text{DBH}))^2]$   
 $Y_a$ : Aboveground Biomass (kg dry matter / tree)  
 Application: Tropical trees in general having DBH of 5 to 148 cm in the tropical low land with an annual precipitation of 2,000 to 4,000 mm  
 $BBD = \exp[-1.0587 + 0.8836 \times \ln(\text{ABD})]$   
 $BBD$ : Belowground Biomass (t dry matter / ha)  
 $ABD$ : Aboveground Biomass (t dry matter / ha)

(IPCC Allometry Equations)

## Excel Computation using IPCC Allometry Equation

Tree number	No.	DBH (cm)	IPCC GPG-LULUCF	Allometry Equation		Plot_1	Height(m)	Codes in "Trees of Lao"	Scient Name
				Y <sub>a</sub>	LN(DBH)				
3	01	45.0	1,791.0	3.8066	14.49068	26.0	142		
4	02	25.0	412.0	3.2188	10.36116	24.0	142		
5	03	11.0	52.0	2.3979	5.74990	7.0	123		
6	04	12.0	64.0	2.48491	6.17476	13.0	6		
7	05	30.0	651.0	3.40120	11.56814	15.0	265		
8									
	84	14.0	95.0	2.63906	6.96462	15.0	109		
	85	26.5	477.0	3.27714	10.73968	22.5	142		
	Average	22.1					19.1		
	Total		31,742.0	kg dry m.					
	ABD		161.70	t d.m. / ha					
	BBD		31.00	t d.m. / ha					
	Living Biomass		192.70	t d.m. / ha					
	Carbon		96.4	t C / ha					

IPCC Good Practice Guidance for LULUCF  
Annex 4A.2 Examples of allometric equations for estimating aboveground biomass and belowground biomass of trees

TABLE 4.A.1 ALLOMETRIC EQUATIONS FOR ESTIMATING ABOVEGROUND BIOMASS (KG DRY MATTER PER TREE) OF TROPICAL AND TEMPERATE HARDWOOD AND PINE SPECIES			
Equation	Forest type*	R <sup>2</sup> /sample size	DBH range (cm)
$Y = \exp[-2.289 + 2.649 \times \ln(\text{DBH}) - 0.021 \times (\ln(\text{DBH}))^2]$	Tropical moist broadleaf	0.98226	5 - 148
$Y = 21.297 - 0.953 \times (\text{DBH}) + 0.740 \times (\text{DBH})^2$	Tropical wet broadleaf	0.92176	4 - 112

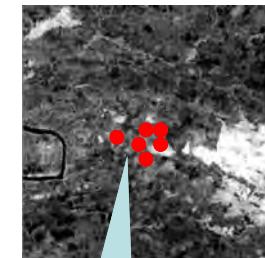
## Living Biomass

- Plot 1 : 192.70 tdm/ha
- Plot 2 : 267.10 tdm/ha
- Plot 3: 359.00 tdm/ha
- Plot 4: 260.30 tdm/ha
- Plot 5: 209.70 tdm/ha
- Plot 6: 137.00 tdm/ha

## Carbon

- 96.4 tC/ha
- 133.6 tC/ha
- 179.5 tC/ha
- 130.2 tC/ha
- 104.9 tC/ha
- 68.5 tC/ha

+Vegetation Indices



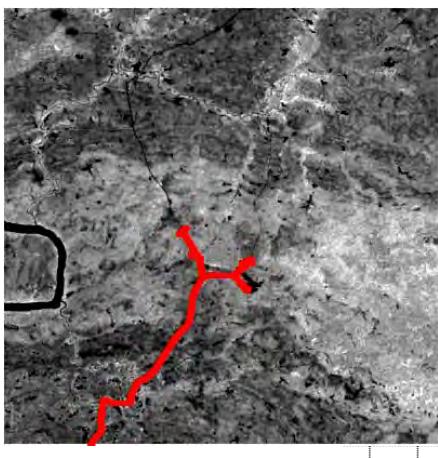
Sample Plots by 2013 field survey

Above Ground Biomass (from Plot Survey Data)

+Crown Cover Rate (from Aerial Photos)

Correlation Analysis

## Value of NDVI (2014/10/11)-Savannakhet

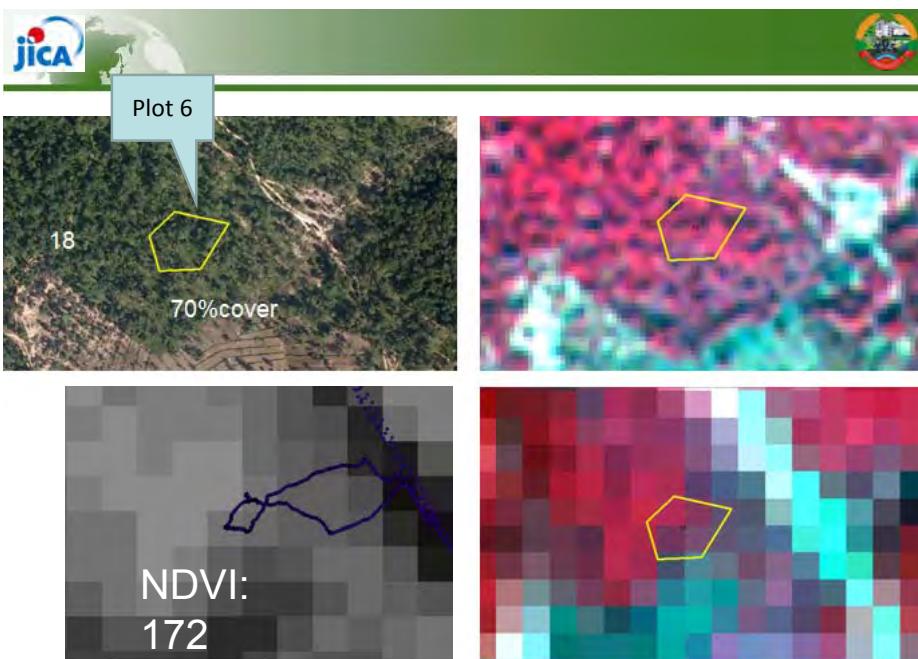


NDVI=121 – 192  
(128<Vegetated Area)



DOF/FIPD

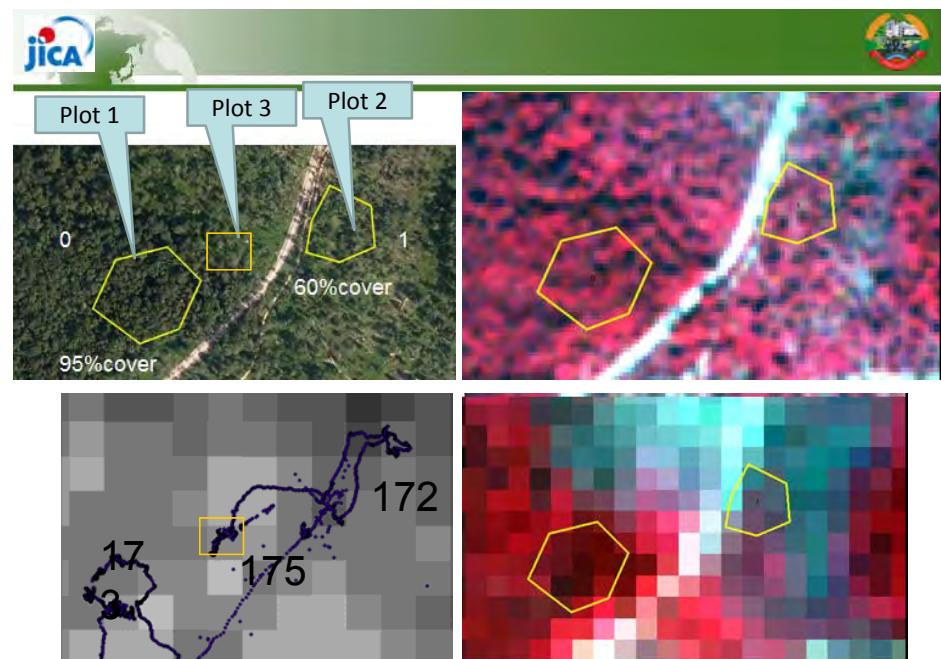
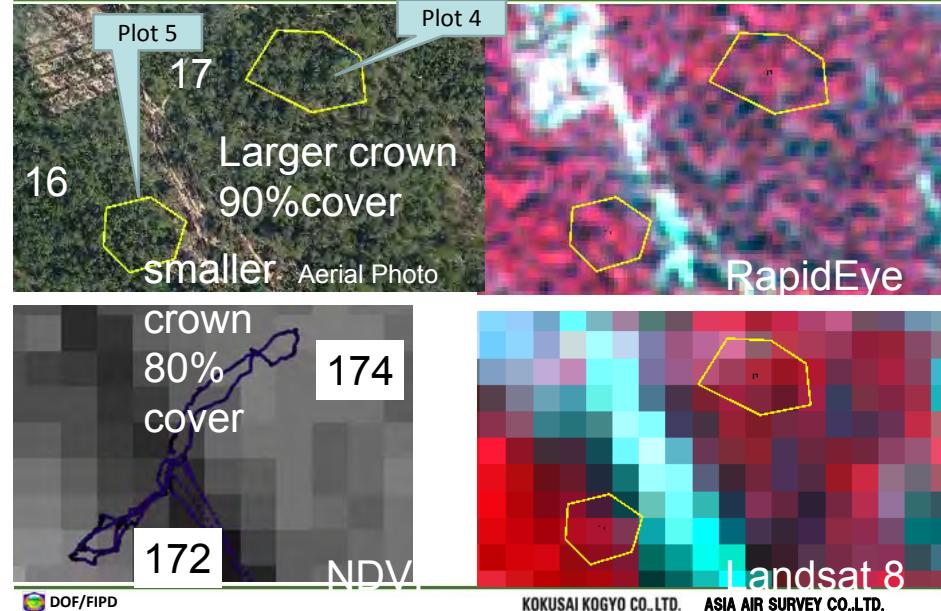
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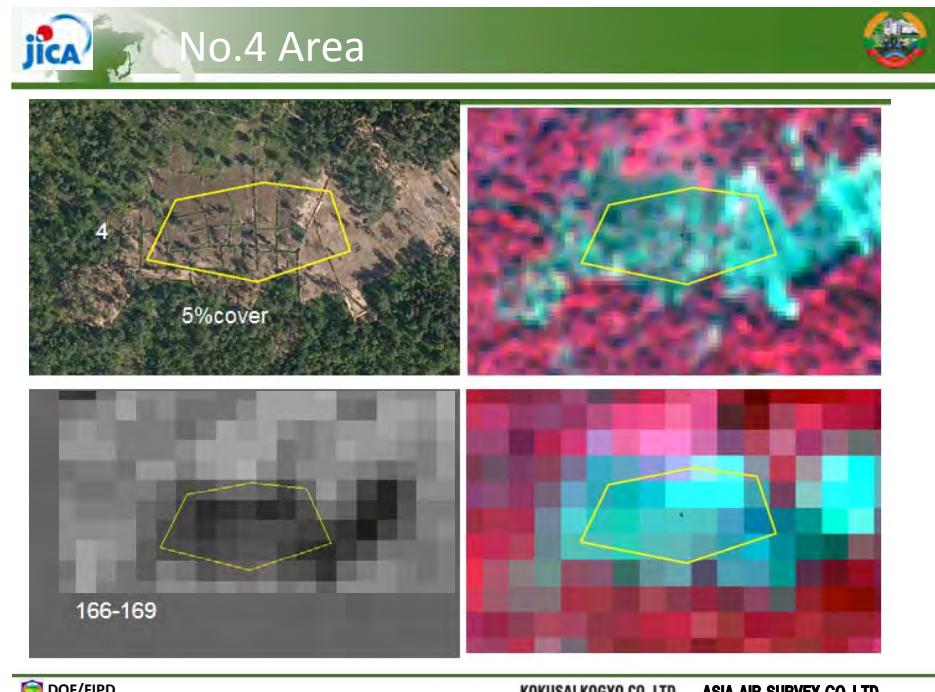
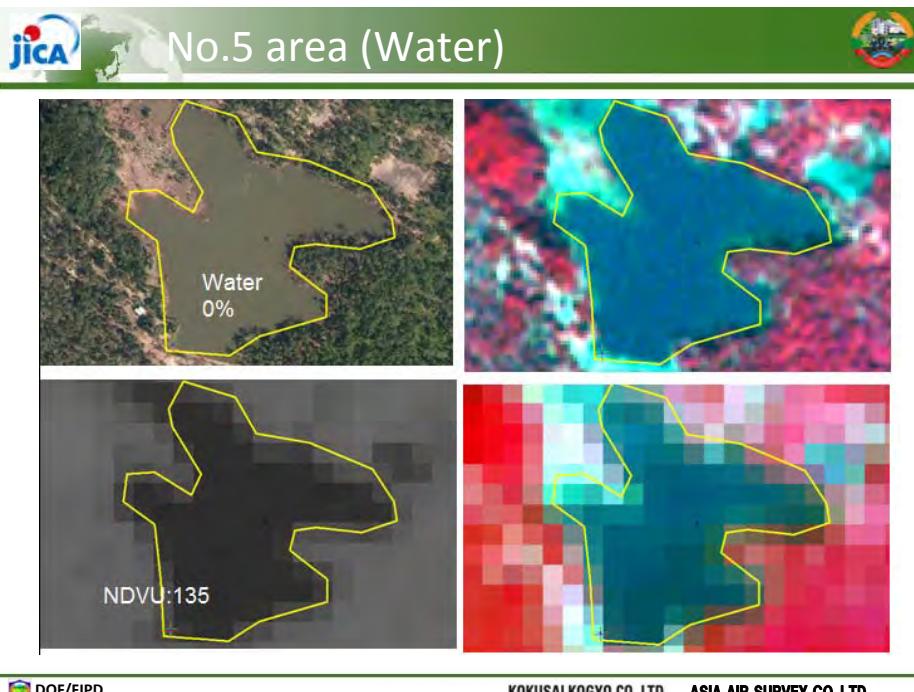
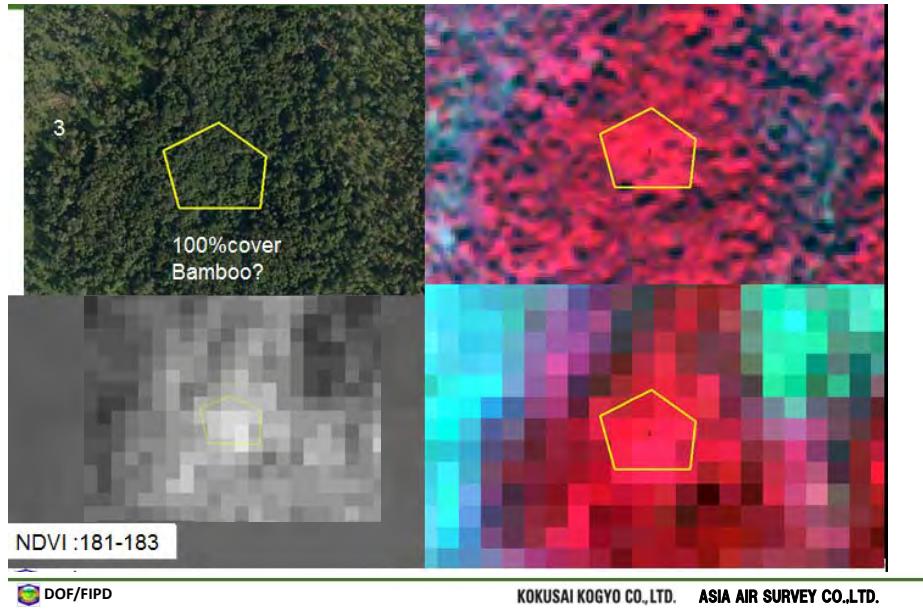


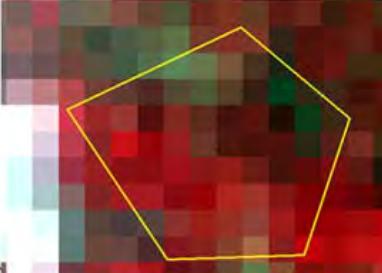
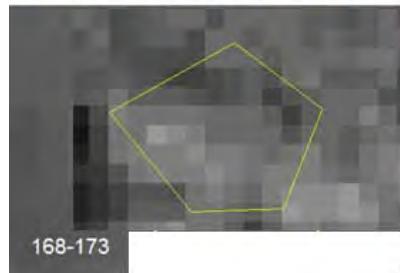
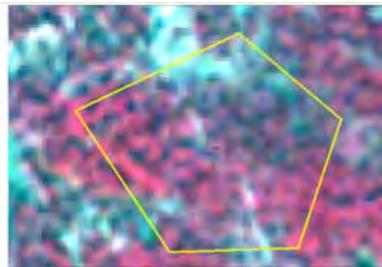
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## Comparison of Images

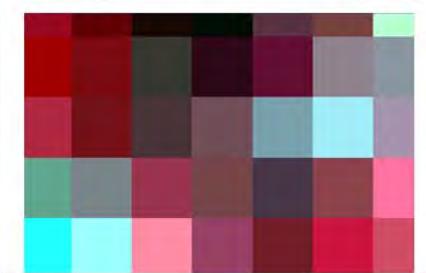
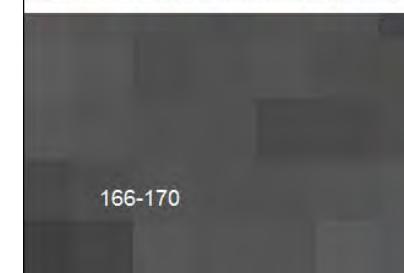






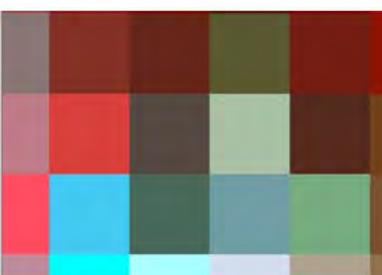
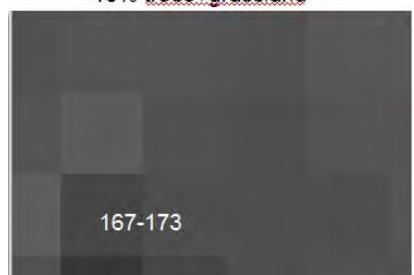
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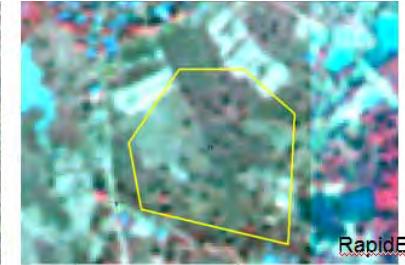
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KOKUSAI KOGYO CO.,LTD. ASIA AIR SURVEY CO.,LTD.



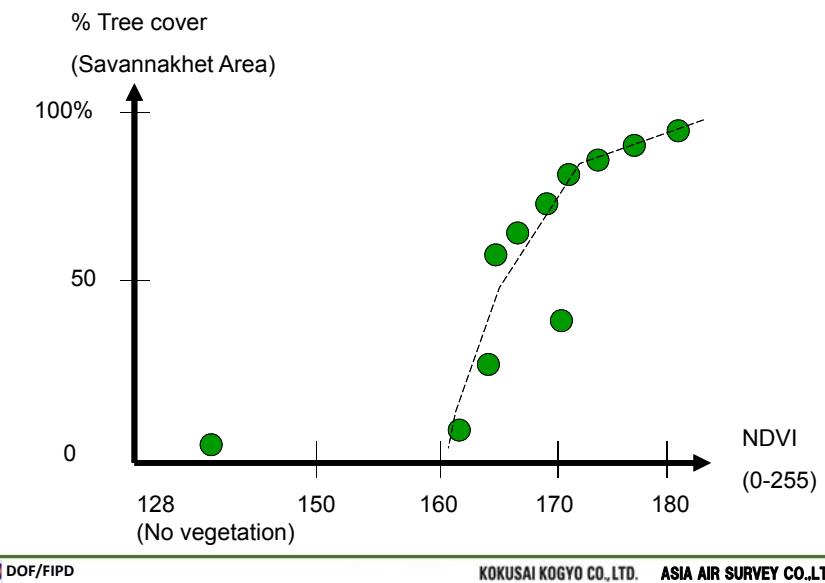
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DOF/FIPD

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	Living Biomass	Carbon	NDVI
Plot 1	192.70 tdm/ha	96.4 tC/ha	173
Plot 2	267.10 tdm/ha	133.6 tC/ha	172
Plot 3	359.00 tdm/ha	179.5 tC/ha	175
Plot 4	260.30 tdm/ha	130.2 tC/ha	174
Plot 5	209.70 tdm/ha	104.9 tC/ha	172
Plot 6	137.00 tdm/ha	68.5 tC/ha	172



Thank you very much !

Khoputyai Rai Rai !

ありがとうございました