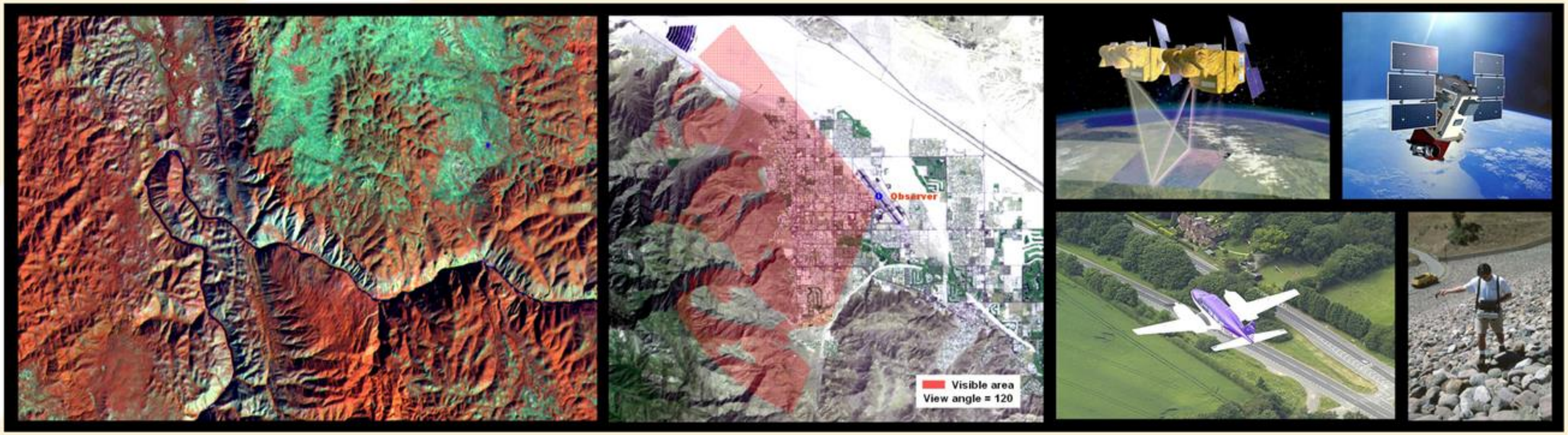
Division of Spatial Information Science
Graduate School of Life and Environmental Sciences
University of Tsukuba

Fundamentals of Remote Sensing and its Applications in GIS



VLM (Visual Learning Material), Read Less, Learn More .....

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Preface

Remote Sensing data is one of the primary data sources in GIS analysis. The objective of this material is to provide fundamentals of Remote Sensing technology and its applications in Geographical Information Systems to undergraduate students and the one who wants to study about Remote Sensing technology by visually (Read less learn more).

However, Remote Sensing technology had been well established for several decades and still booming. Handling and interpretation of remote sensing data will never be easy. It requires additional practical works and digital image processing knowledge. It is impossible to cover all topics in here. So, here I provide additional learning information and other online resources which were listed in Appendix A for further interested students.

I hope you'll enjoy it

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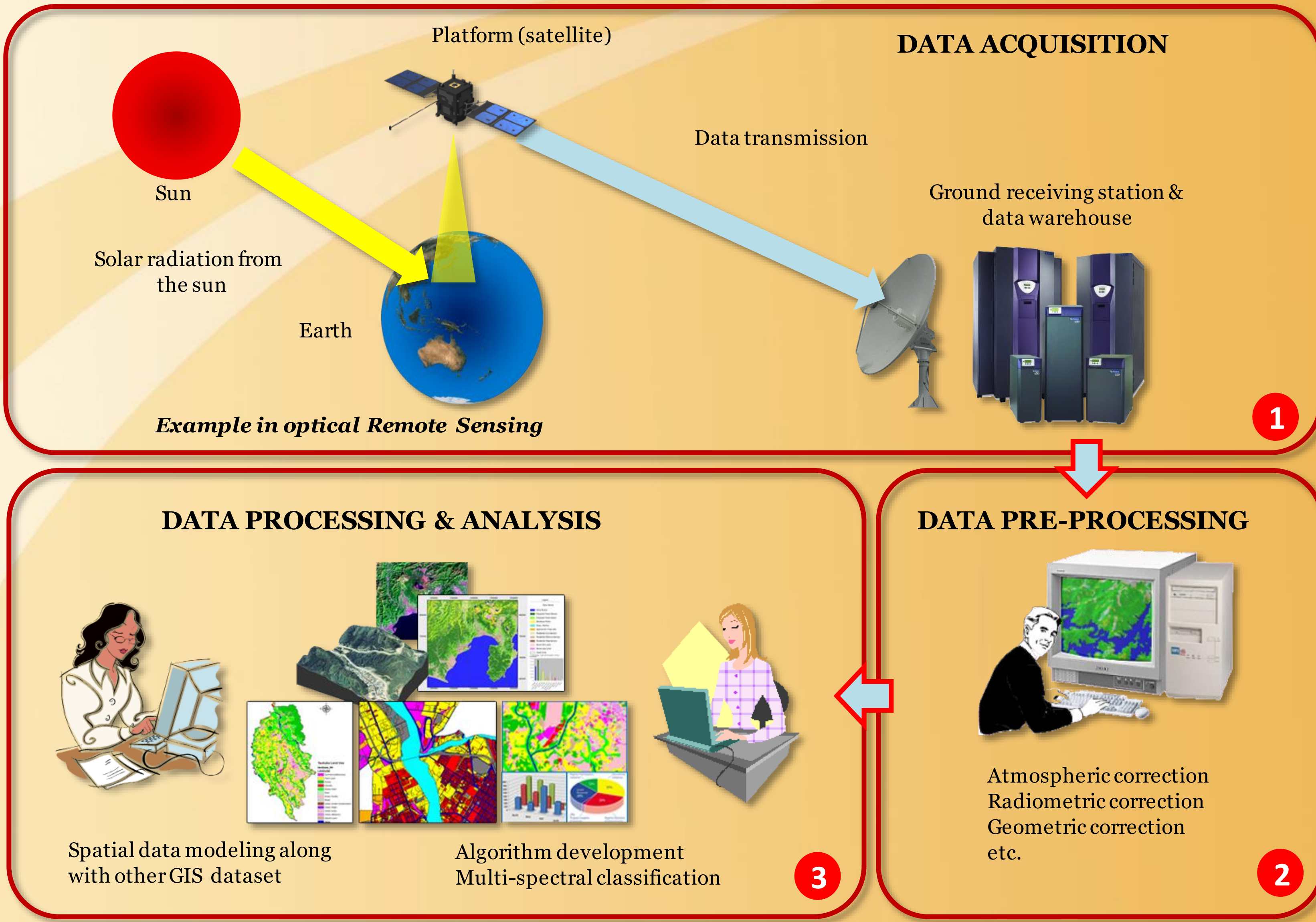
1. Remote Sensing Overview

1.1 Definition

What is Remote Sensing? If you are reading this sentence, now you are doing Remote Sensing. In fact, any information acquired from the object without touching is Remote Sensing. Following is a scientific definition of Remote Sensing.

The **science of acquiring information about the earth** using instruments which are remote to the earth's surface, usually from aircraft or satellites. Instruments may use visible light, infrared or radar to obtain data. Remote sensing offers the ability to observe and collect data for large areas relatively quickly, and is an important source of data for GIS. (Source: digimap)

1.2 Remote Sensing and GIS Work Flow



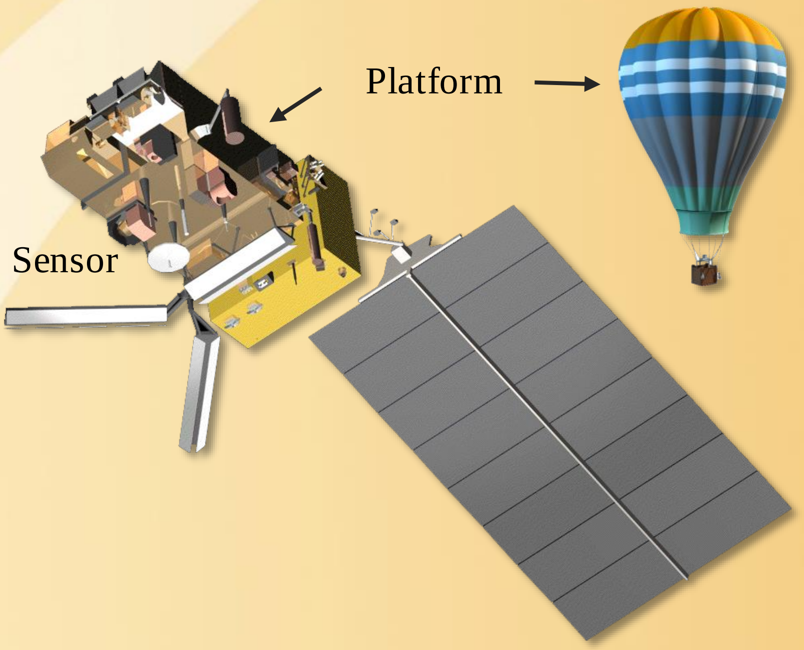
1.3 Components in Remote Sensing

Platform

The vehicle which carries a sensor. i.e. satellite, aircraft, balloon, etc...

Sensors

Device that receives electromagnetic radiation and converts it into a signal that can be recorded and displayed as either numerical data or an image.



One platform can carry more than one sensor. For example:

Platform Name	Sensor Name
Landsat TM	Thematic Mapper (Passive: Optical sensor)
Landsat ETM	Enhanced Thematic Mapper (Passive: Optical sensor)
ALOS	PRISM (Passive: Optical sensor) AVNIR-2 (Passive: Optical sensor) PALSAR (Active: Microwave sensor)

1.4 Types of Remote Sensing

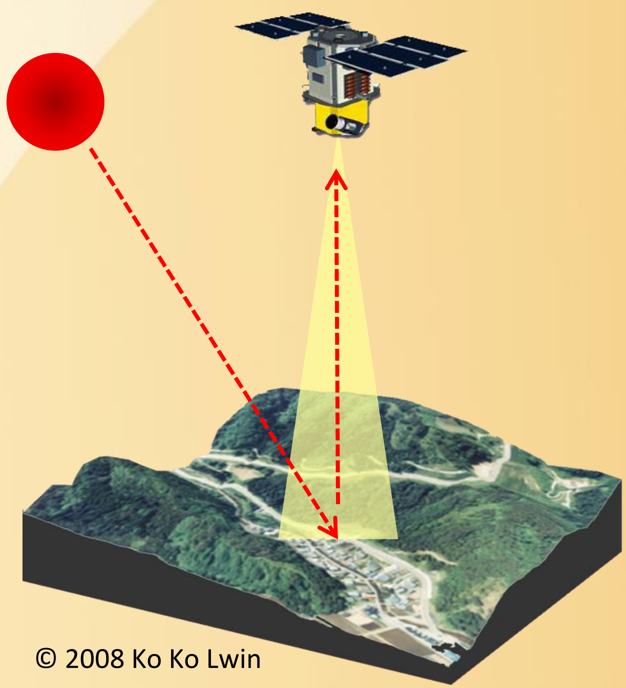
Passive Remote Sensing and Active Remote Sensing

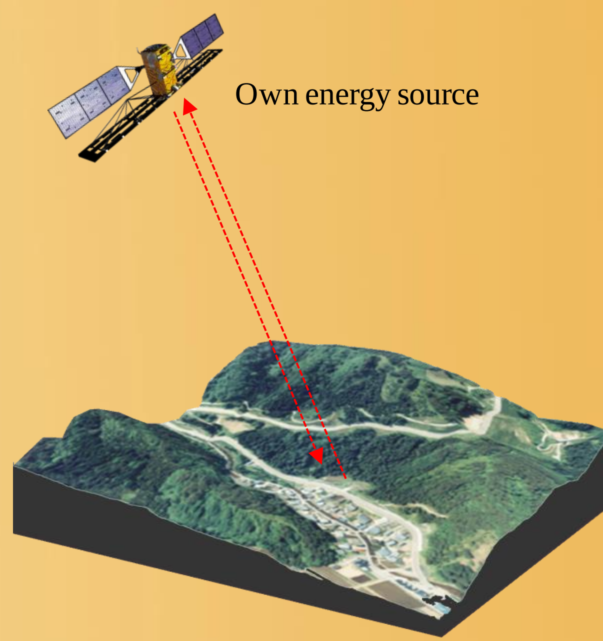
Passive Remote Sensing

Remote sensing of energy naturally reflected or radiated from the terrain.

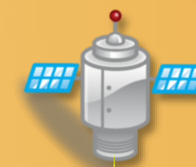
Active Remote Sensing

Remote sensing methods that provide their own source of electromagnetic radiation to illuminate the terrain. Radar is one example.





1.5 Multistage Remote Sensing Data Collection



Satellite based remote sensing

Advantages: Less geometric errors (platform is stable)

Disadvantages: Need to wait a time for certain event

Fixed spatial resolution

Aerial surveying

Advantages: Acquire any times any events

Variable spatial resolution by changing flight altitude and camera focal length

Disadvantages: High geometric errors; require sophisticated geometric correction model

Costly for specific area, specific purpose

Ground based remote sensing GBRS or Low Altitude Remote Sensing

Scientific experiment purposes

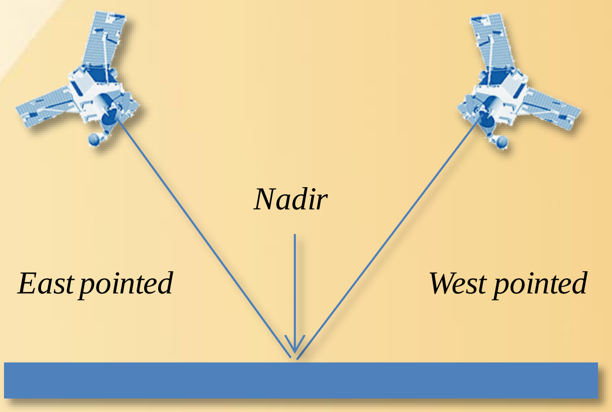
(e.g. study about canopy, soil contamination, etc.)

1.6 Stereo Pair Remote Sensing Data Collection

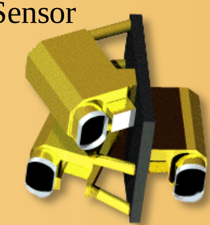
Some satellites capable to acquire stereo pair images that can be achieved when two images of the same area are acquired on different days from different orbits, one taken East of the other (i.e., East or West of the nadir). For this to occur, there must be significant differences in the inclination angles.

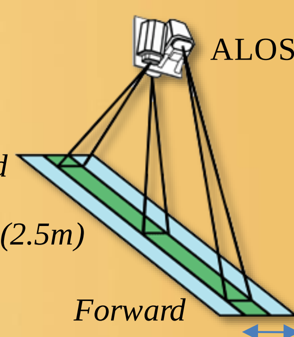
Stereo Pair Images

- Different days from different orbits
  e.g. IKONOS's pointing system
- Onboard two or more inclined sensors
  e.g. SPOT5, ALOS PRISM (Panchromatic Remote-sensing Instrument for Stereo Mapping)



ALOS PRISM Sensor





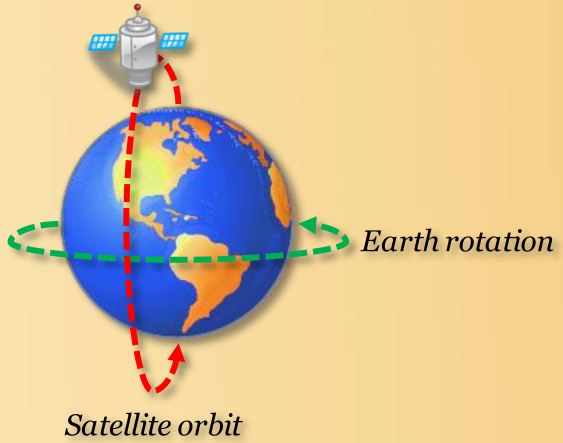
DEM Digital Elevation Model can be generated from stereo pair images by using Photogrammetric technology.

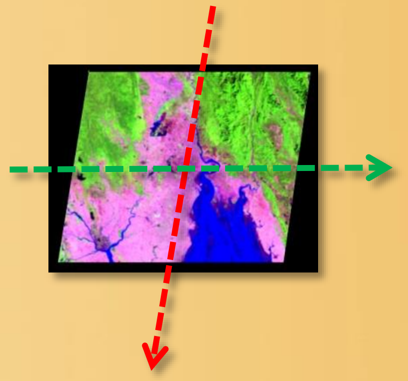
1.7 Types and Uses of Satellites

Types of satellites can be classified by their orbit characteristics.

Type 1: Low Earth Orbits/Satellites: Normally used in spy satellite (Military purposes)

Type 2: Sun-synchronous Orbits/Satellites: a polar orbit where the satellite always crosses the Equator at the same local solar time. Most of the earth resources satellites are sun-synchronous orbit.

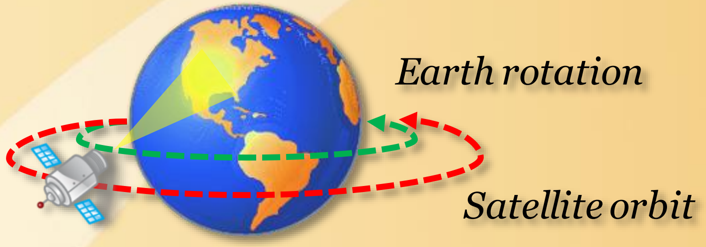


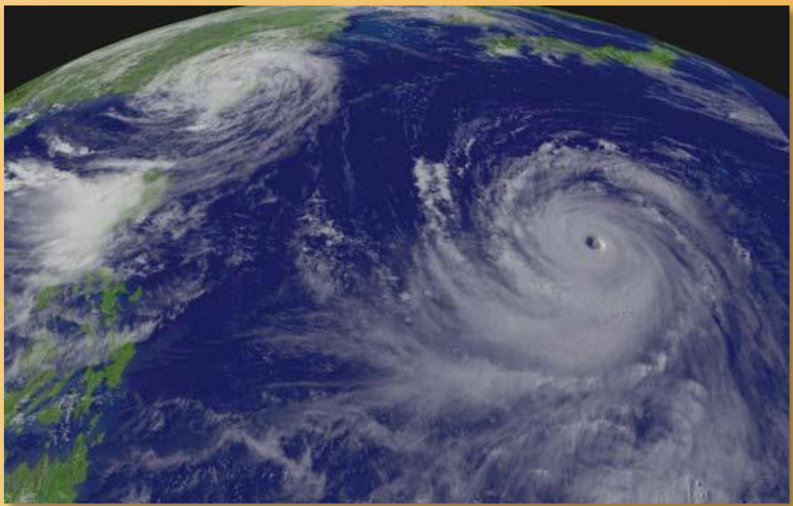


Examples

Landsat TM/ETM
SPOT
ALOS
IKONOS
QuickBird

Type 3: Geostationary Orbits/Satellites: Satellites at very high altitudes, which view the same portion of the Earth's surface at all times. Especially used in metrological applications.

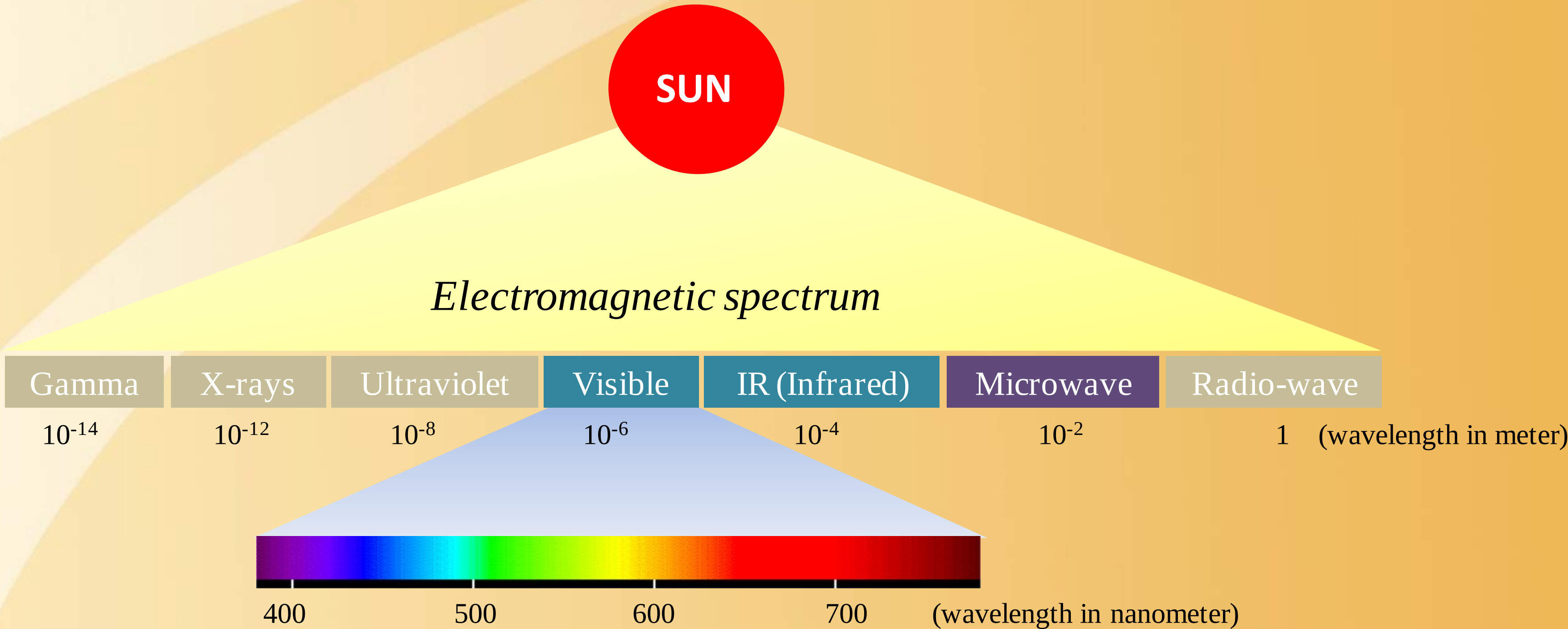




- *Fixed position on specific location*
- *Same speed as earth rotation speed*
- *Wide area coverage*
- *Especially designed for weather monitoring*

2. Remote Sensing Data Acquisition

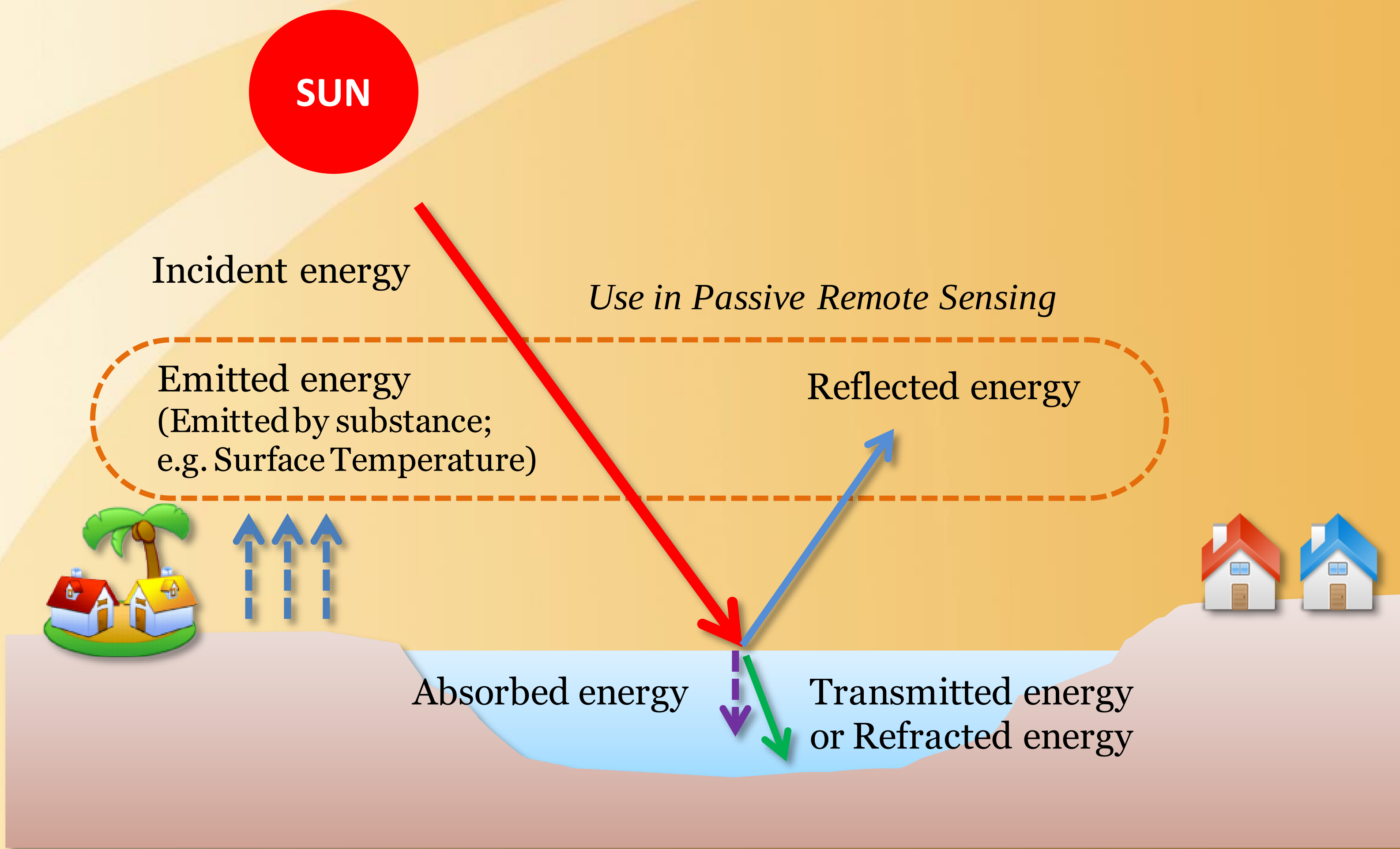
2.1 Electromagnetic Waves Used in Remote Sensing



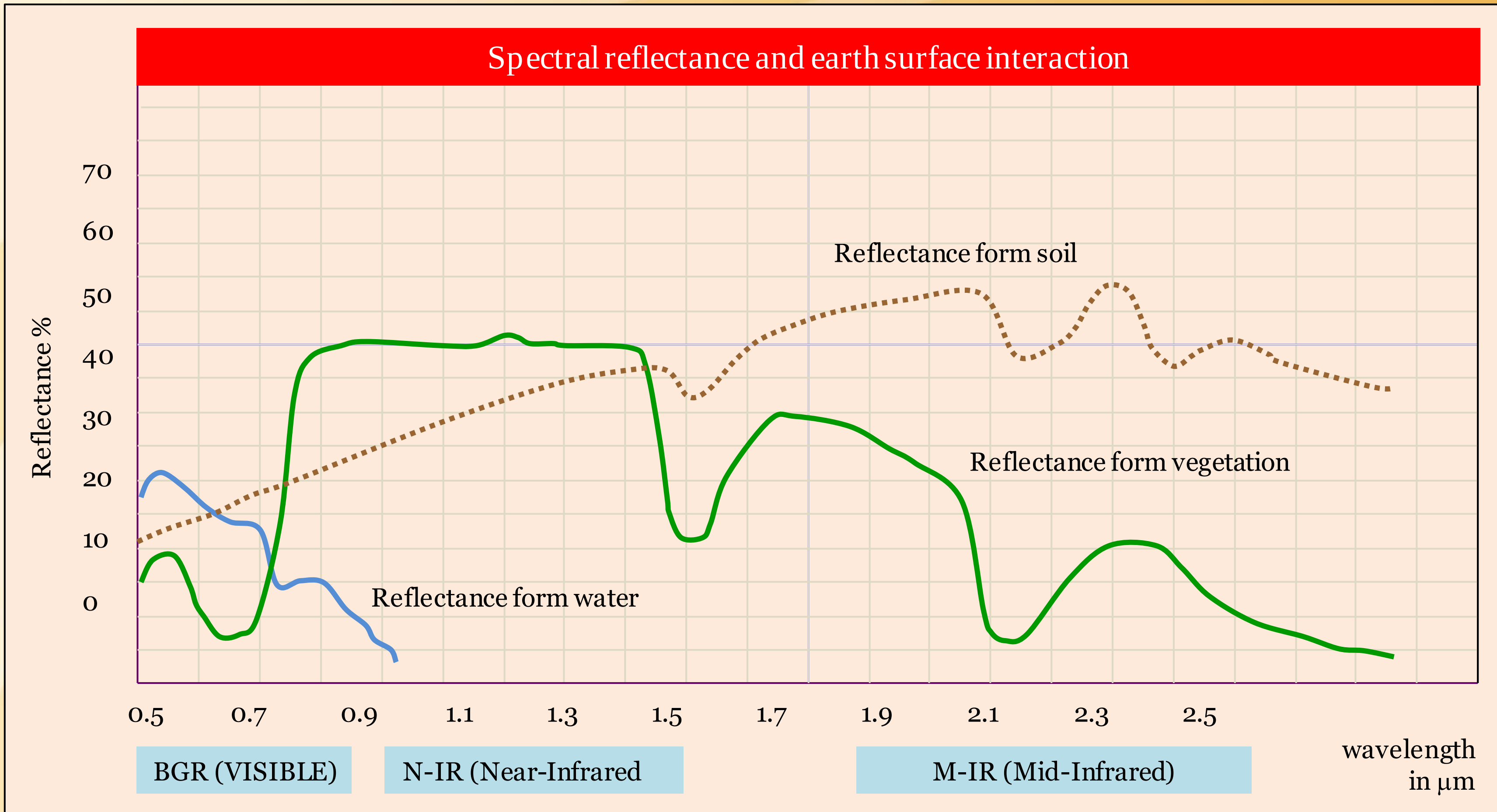
Optical remote sensing (Passive Remote Sensing)

Microwave remote sensing (Active Remote Sensing)

2.2 Properties of Electromagnetic Waves



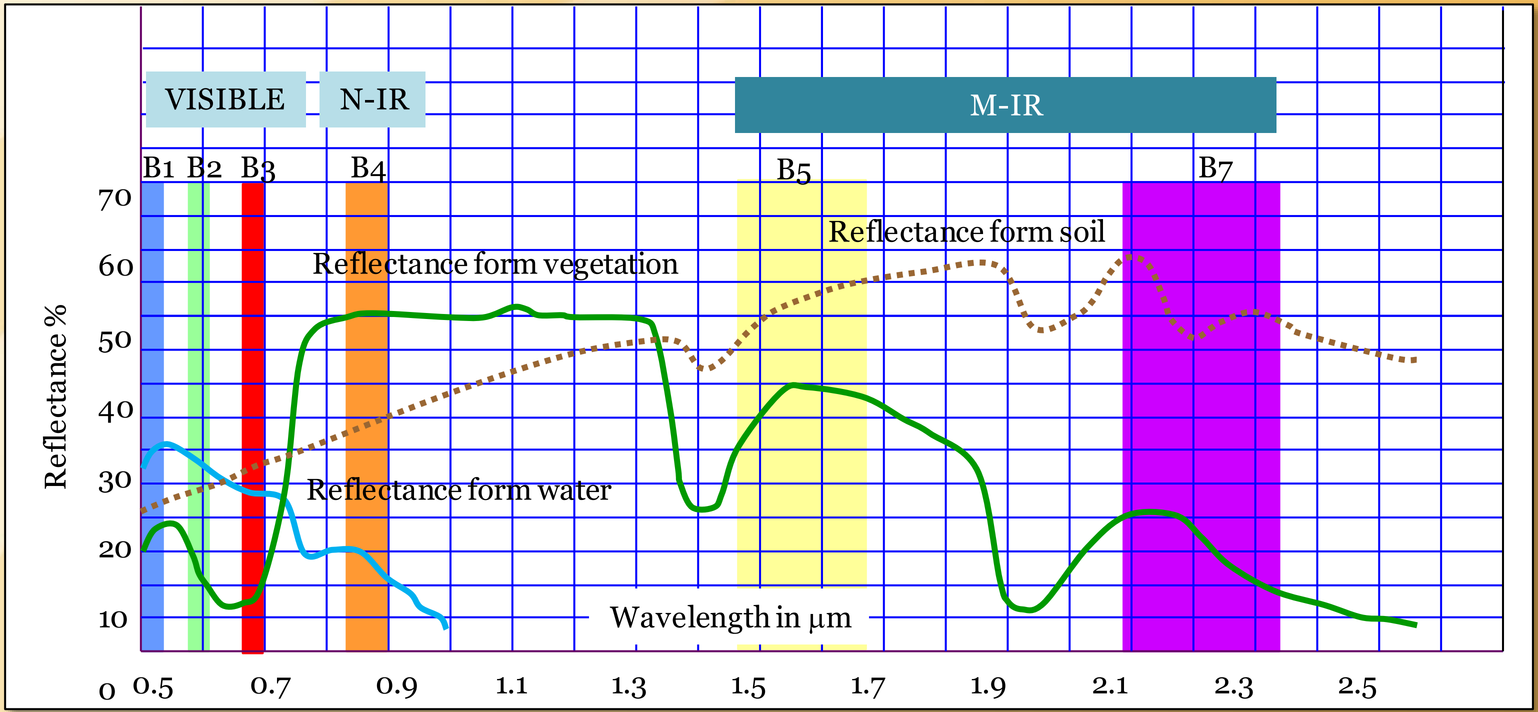
2.3 Spectral Reflectance and Earth Surface Interaction

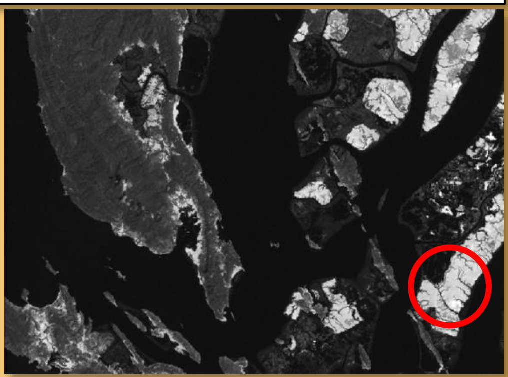


Surface category	Low reflectance	High reflectance
Water	N-IR (Near -Infrared)	Blue (Visible)
Vegetation	M-IR (Mid-Infrared)	N-IR (Near-Infrared)
Soil	Blue (Visible)	M-IR (Mid-Infrared)

2.4 Multi-spectral Remote Sensing Data (Image)

- Composed with more than one spectral band and each band represents specific wavelength
- Example in Landsat TM (Total 7 bands, Band 6 Thermal band omitted in here)



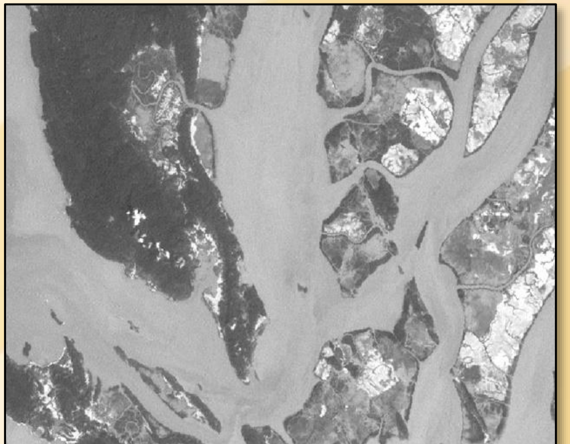


TM Band 1: High reflectance in water **TM Band 4**: High reflectance in vegetation **TM Band 7**: High reflectance in bare land (soil)

2.4 Multi-spectral Remote Sensing Data (Image) (Continued)

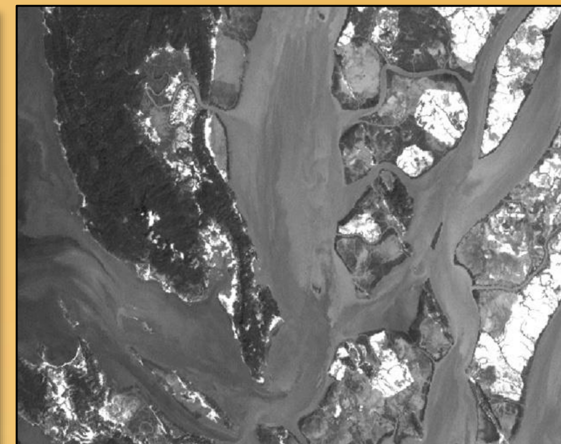
Example in Landsat TM/ETM (Band 6 omitted)

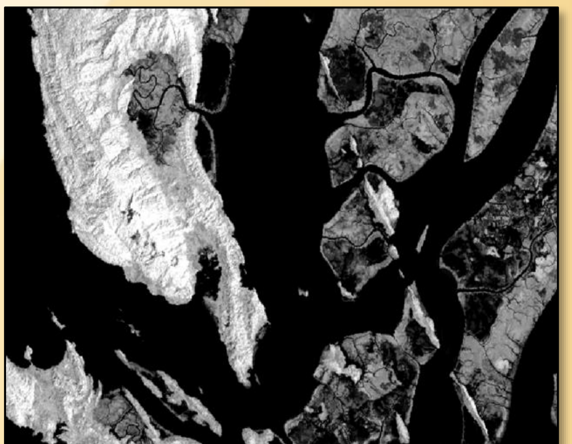
Band 1 : Blue (0.450 ~ 0.515 μm)



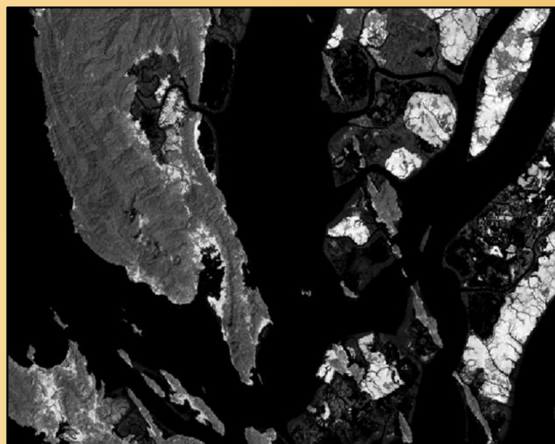
Band 2 : Green (0.525 ~ 0.605 μm)

Band 3 : Red (0.630 ~ 0.690 μm)

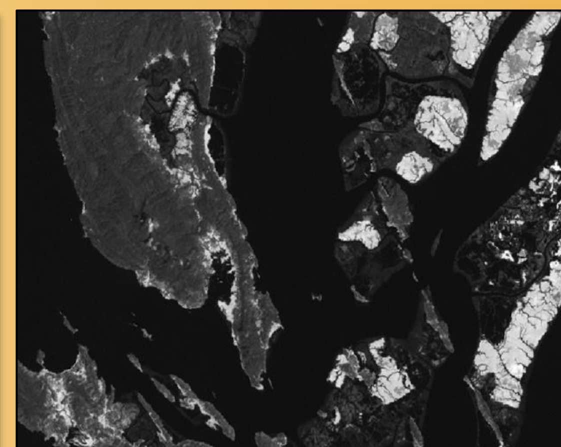




Band 4 : Near-Infrared(0.750 ~ 0.900 μm)



Band 5 : Mid-Infrared (1.550 ~ 1.750 μm)



Band 7 : Mid-Infrared (2.090 ~ 2.350 μm)

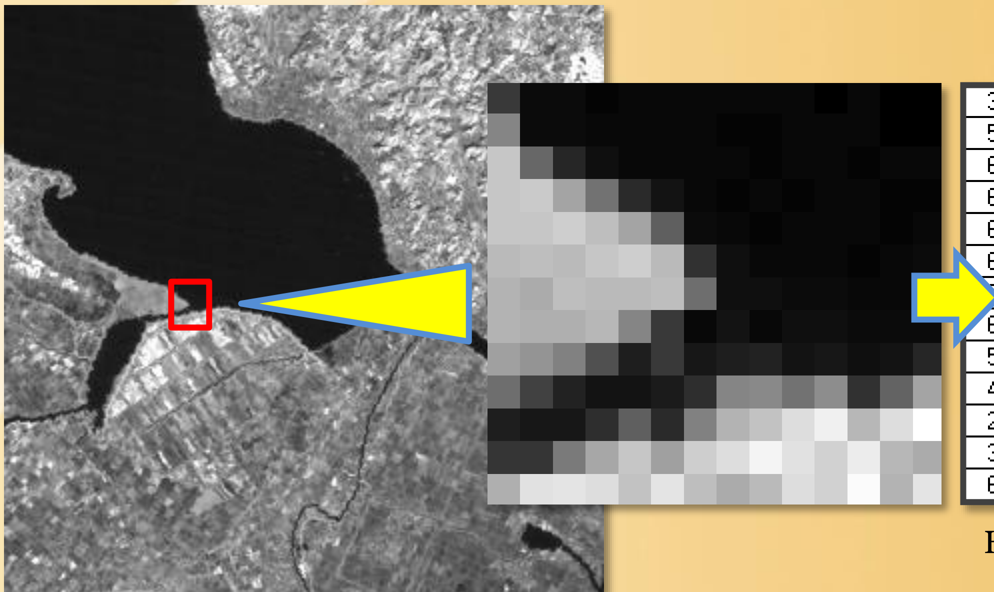
2.5 Spectral Properties and Principal Applications

Example in Landsat TM/ETM

Band	Wavelength (μm)	Principal applications
B-1	0.45 - 0.52 (Blue)	This band is useful for mapping coastal water areas, differentiating between soil and vegetation, forest type mapping, and detecting cultural features.
B-2	0.52 - 0.60 (Green)	This band corresponds to the green reflectance of healthy vegetation. Also useful for cultural feature identification.
B-3	0.63 - 0.69 (Red)	This band is useful for discriminating between many plant species. It is also useful for determining soil boundary and geological boundary delineations as well as cultural features.
B-4	0.76 - 0.90 (Near-Infrared)	This band is especially responsive to the amount of vegetation biomass present in a scene. It is useful for crop identification and emphasizes soil/crop and land/water contrasts.
B-5	1.55 - 1.75 (Mid-Infrared)	This band is sensitive to the amount of water in plants, which is useful in crop drought studies and in plant health analyses. This is also one of the few bands that can be used to discriminate between clouds, snow, and ice.
B-6	10.4 - 12.5 (Thermal Infrared)	This band is useful for vegetation and crop stress detection, heat intensity, insecticide applications, and for locating thermal pollution. It can also be used to locate geothermal activity.
B-7	2.08 - 2.35 (Mid-Infrared)	This band is important for the discrimination of geologic rock type and soil boundaries, as well as soil and vegetation moisture content.

2.6 Spectral Reflectance to DN (Digital Number)

In fact, remote sensing data is converting of spectral reflectance value to digital number (DN) known as a pixel. Each spectral wavelength represents as a single layer in remote sensing data called “Band” or “Channel”. The more bands or channels present, the more spectral properties in remote sensing data.

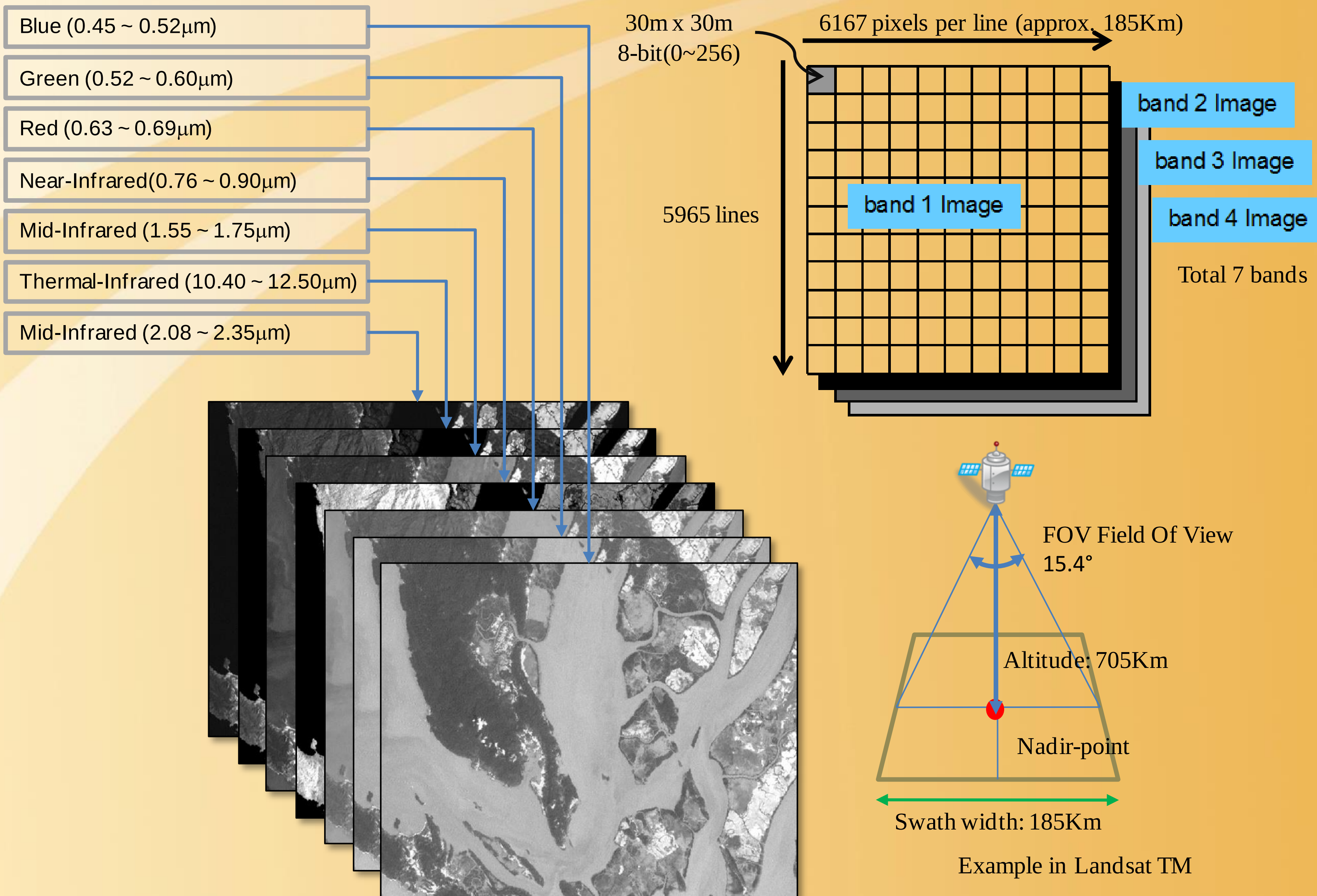


Low DN → Darker

31	19	19	17	18	18	18	18	18	18	16	18	16	16
51	19	19	18	18	18	18	17	17	18	18	18	16	16
68	43	26	20	18	18	18	18	17	18	18	17	18	18
68	69	59	46	27	21	18	17	18	17	18	18	17	17
68	68	70	66	59	41	19	18	17	18	18	18	17	18
65	66	65	68	70	65	29	20	18	18	18	17	18	19
63	61	66	65	65	66	45	20	20	19	19	19	18	19
63	62	62	64	51	31	18	21	18	20	20	19	19	19
58	55	50	37	24	31	22	24	25	21	22	20	21	26
45	33	25	21	21	23	28	51	52	46	53	29	42	59
24	22	22	28	41	27	50	63	67	74	79	64	74	83
30	30	48	60	68	58	70	74	80	75	71	78	64	61
62	75	76	74	67	76	66	61	65	74	71	82	63	76

High DN → Brighter

2.7 Structure of Remote Sensing Data *(Example in Landsat TM)*



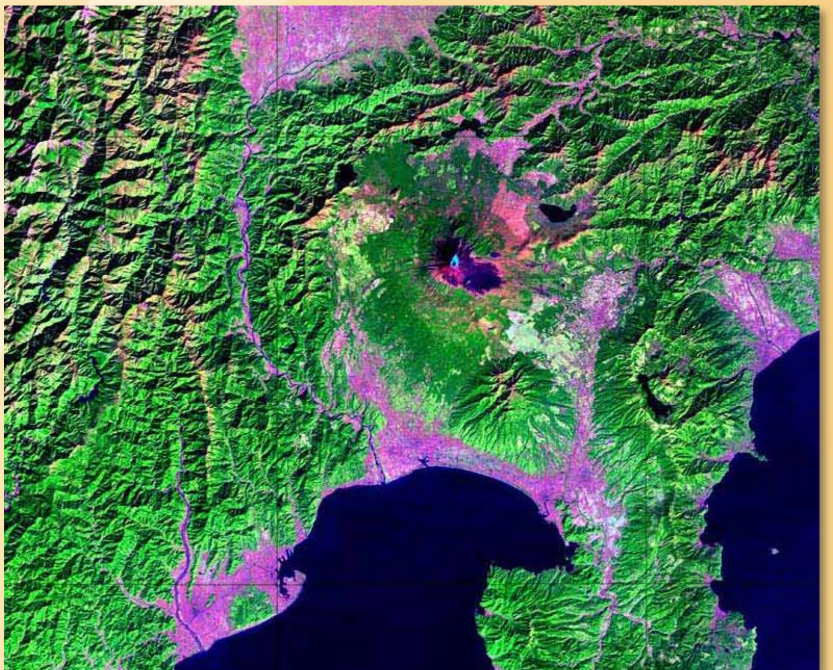
Example in Landsat TM

2.8 Resolutions in Remote Sensing

There are four types of resolutions in Remote Sensing.

(a) Spatial Resolution: The detail discernible in an image is dependent on the spatial resolution of the sensor and refers to the size of the smallest possible feature that can be detected.

Example: Landsat TM Spatial resolution 30mx30m, QuickBird 67cm x 67cm

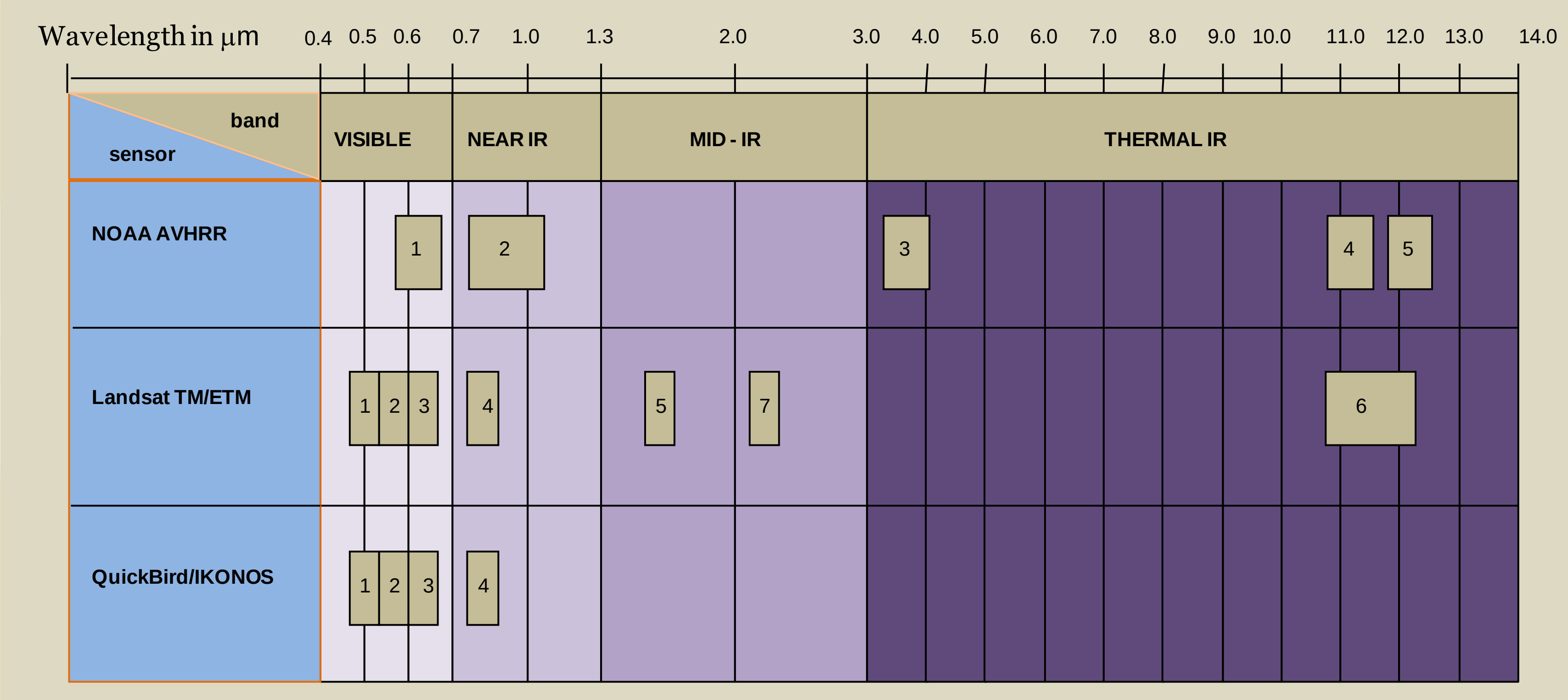


Landsat TM 30m x 30m

QuickBird 67cm x 67cm

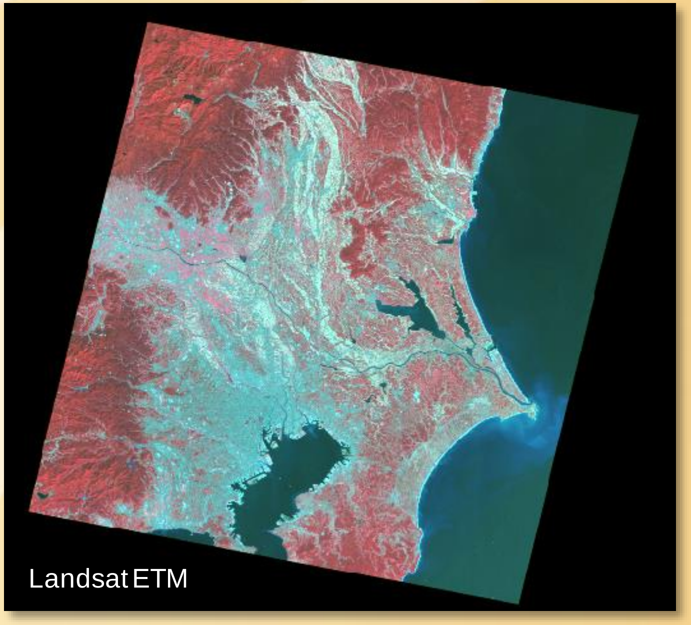
(b) Spectral Resolution: Spectral resolution describes the ability of a sensor to define fine wavelength intervals. The finer the spectral resolution, the narrower the wavelength range for a particular channel or band.

Example: Landsat TM has 7 Bands, QuickBird/IKONOS Multispectral has 4 Bands, etc.

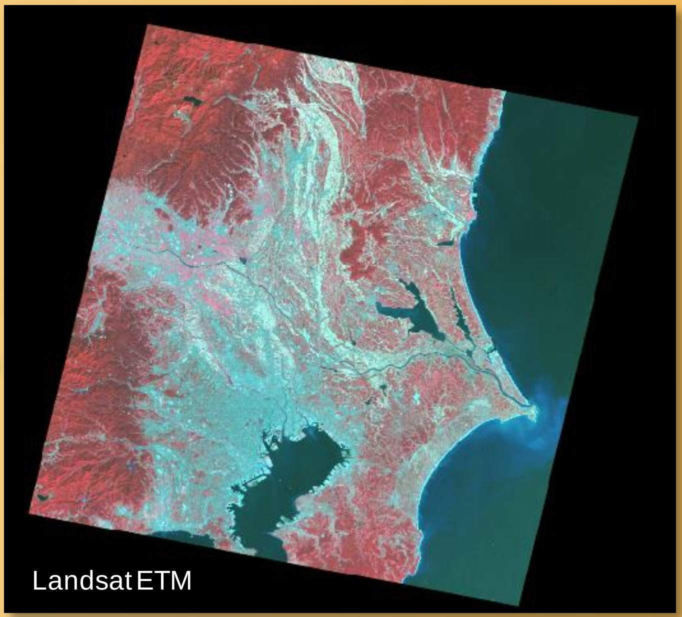


(c) Temporal Resolution: Also important to consider in a remote sensing system, refers to the length of time it takes for a satellite to complete one entire orbit cycle. The revisit period of a satellite sensor is usually several days except Geostationary satellites.

Example: Landsat TM 16 days, SPOT 26 days, etc.



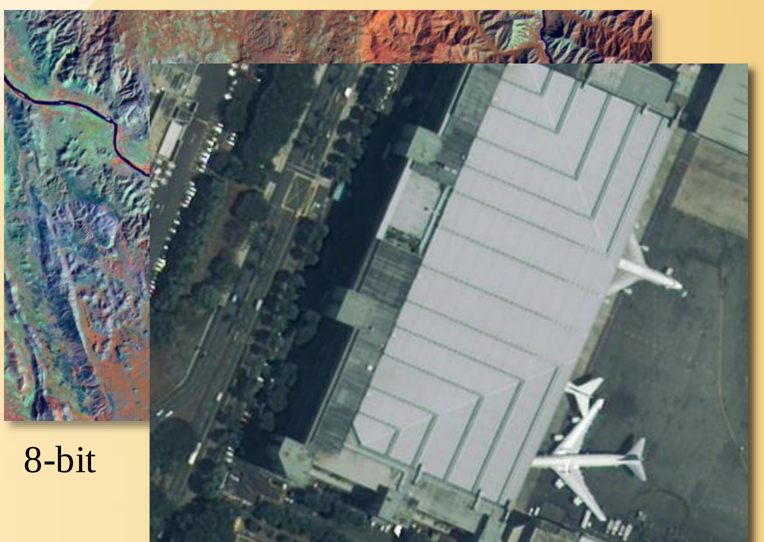
16 days for next orbit at same place



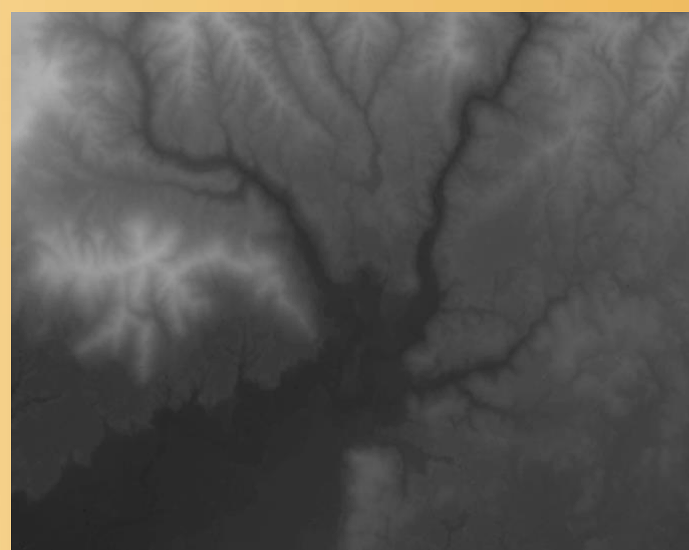
(d) Radiometric Resolution: The radiometric resolution of an imaging system describes its ability to discriminate very slight differences in energy.
The finer the radiometric resolution of a sensor, the more sensitive it is to detecting small differences in reflected or emitted energy.

Example: Landsat TM 8 bits, SPOT 8 bits, IKONOS 11 bits. However, most computer programs do not support 11-bit, so it will convert to 16-bit.

8-bit : 2^8 = maximum 256 color levels or DN values (commonly used)
16-bit : 2^{16} = maximum 65536 color levels or DN values (especially used in elevation data, e.g. DEM, DSM, DTM, etc.)



8-bit



16-bit

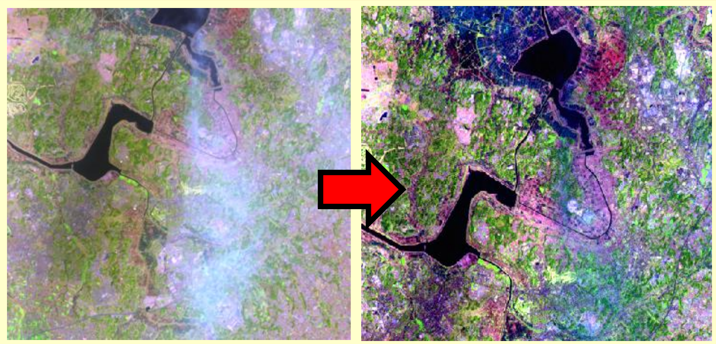
3. Remote Sensing Data Processing and Analysis

3.1 Remote Sensing Data Pre-processing

(a) Atmospheric correction
(b) Radiometric correction
(c) Geometric correction

However, most remote sensing data can be acquired or purchased atmospheric, radio metric and geometric corrected data.
Here, we will introduce briefly.

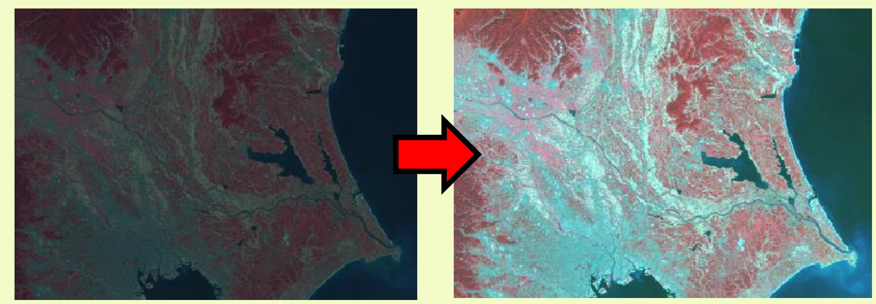
(a) Atmospheric correction



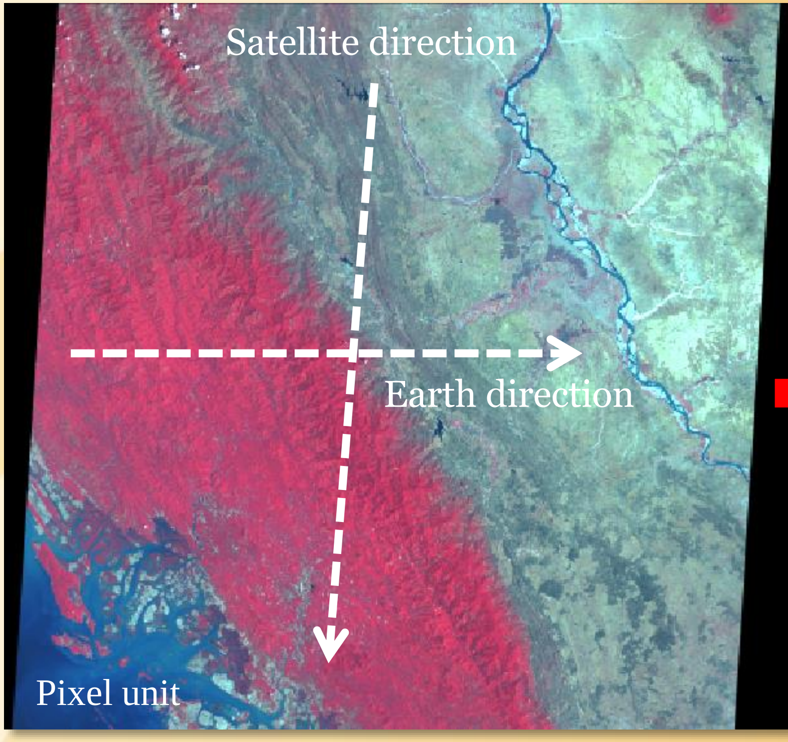
Haze reducing

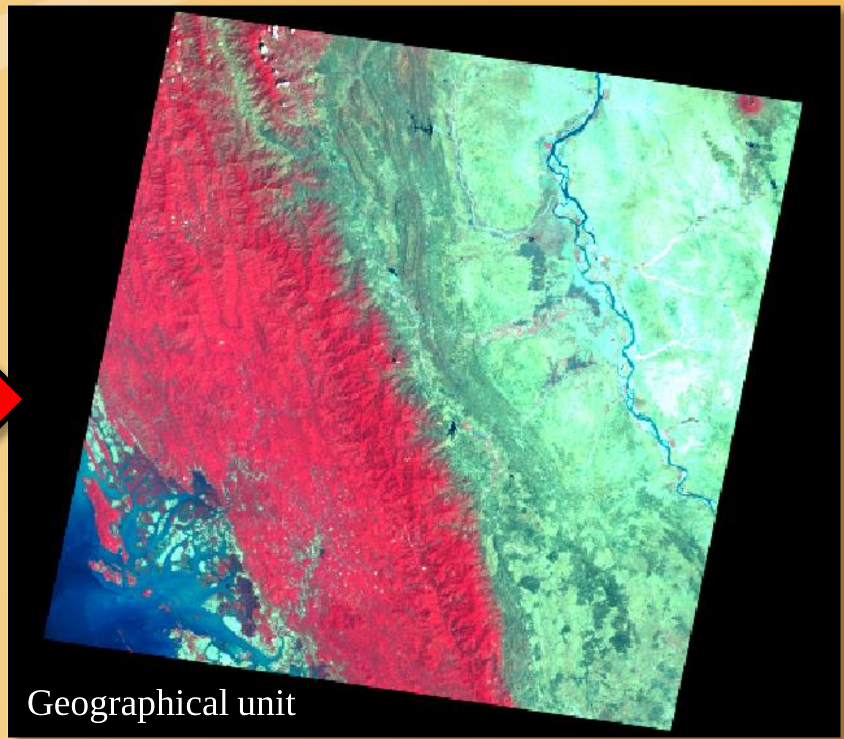
Small haze can be removed in Landsat TM/ETM.
But not clouds. Because B4 (IR) can penetrate the haze.

(b) Radiometric correction



(c) Geometric correction





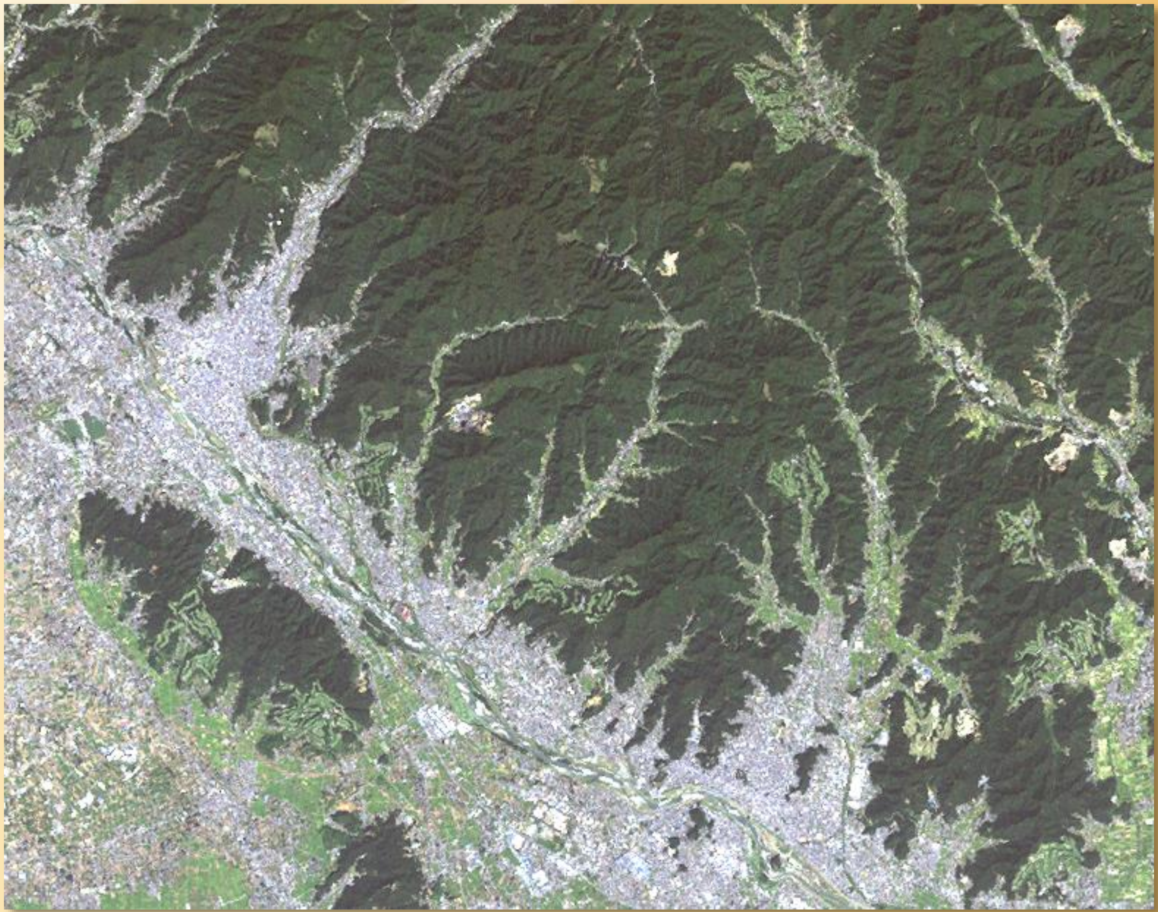
Geometric distortion due to Earth rotation.

Methods of Geometric correction

1. Using satellite header file (satellite onboard GPS)
2. Image to image registration
3. Image to map registration
4. Manually entered GCPs (Ground Control Points)

3.2 Visual Interpretation (Band combination)

First step interpretation and to distinguish various land covers into different colors



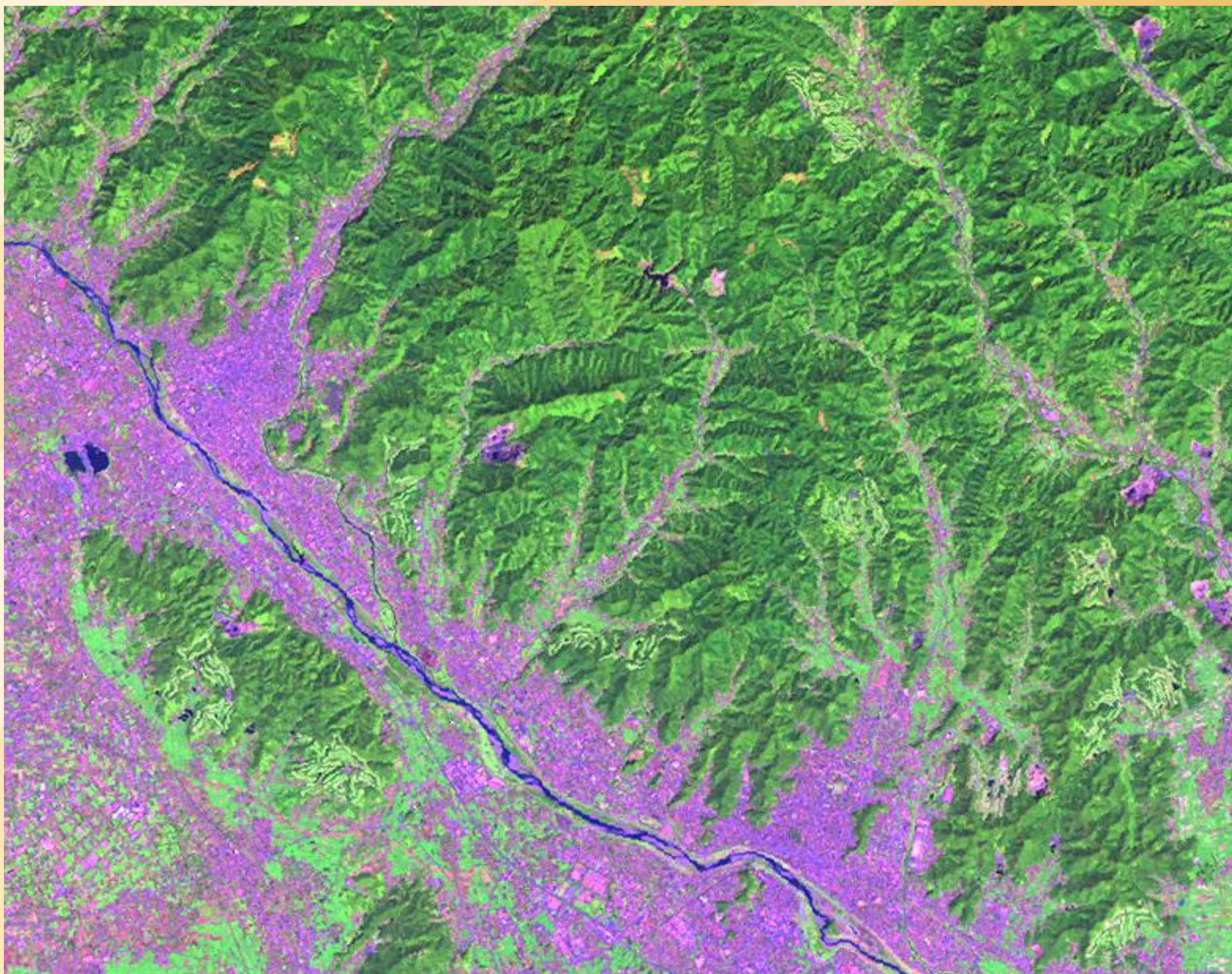
Landsat TM5 Tokyo (Ashikaga, Isezaki)

Example:

RGB 321 in Landsat TM/ETM gives natural color. Assign band 3 to red channel, band 2 to green channel and band 1 to blue channel in computer display.

To see landscape in realistic view.

3.2 Visual Interpretation (Band combination) *continued*



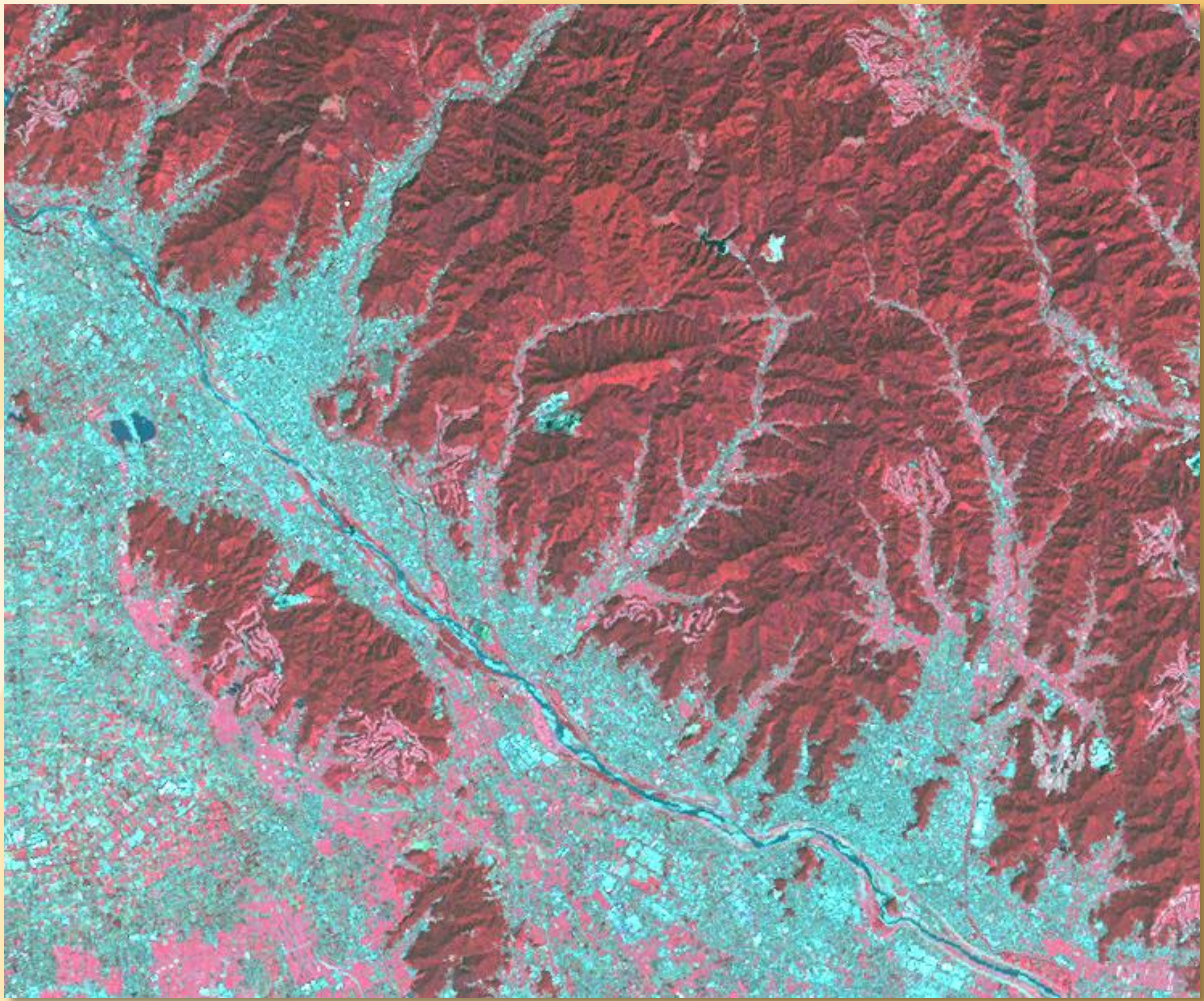
Landsat TM5 Tokyo (Ashikaga, Isezaki)

Example:

RGB 543 in Landsat TM/ETM gives false color. Assign band 5 to red channel, band 4 to green channel and band 3 to blue channel in computer display.

To discriminate between soil, vegetation and water.

3.2 Visual Interpretation (Band combination) *continued*



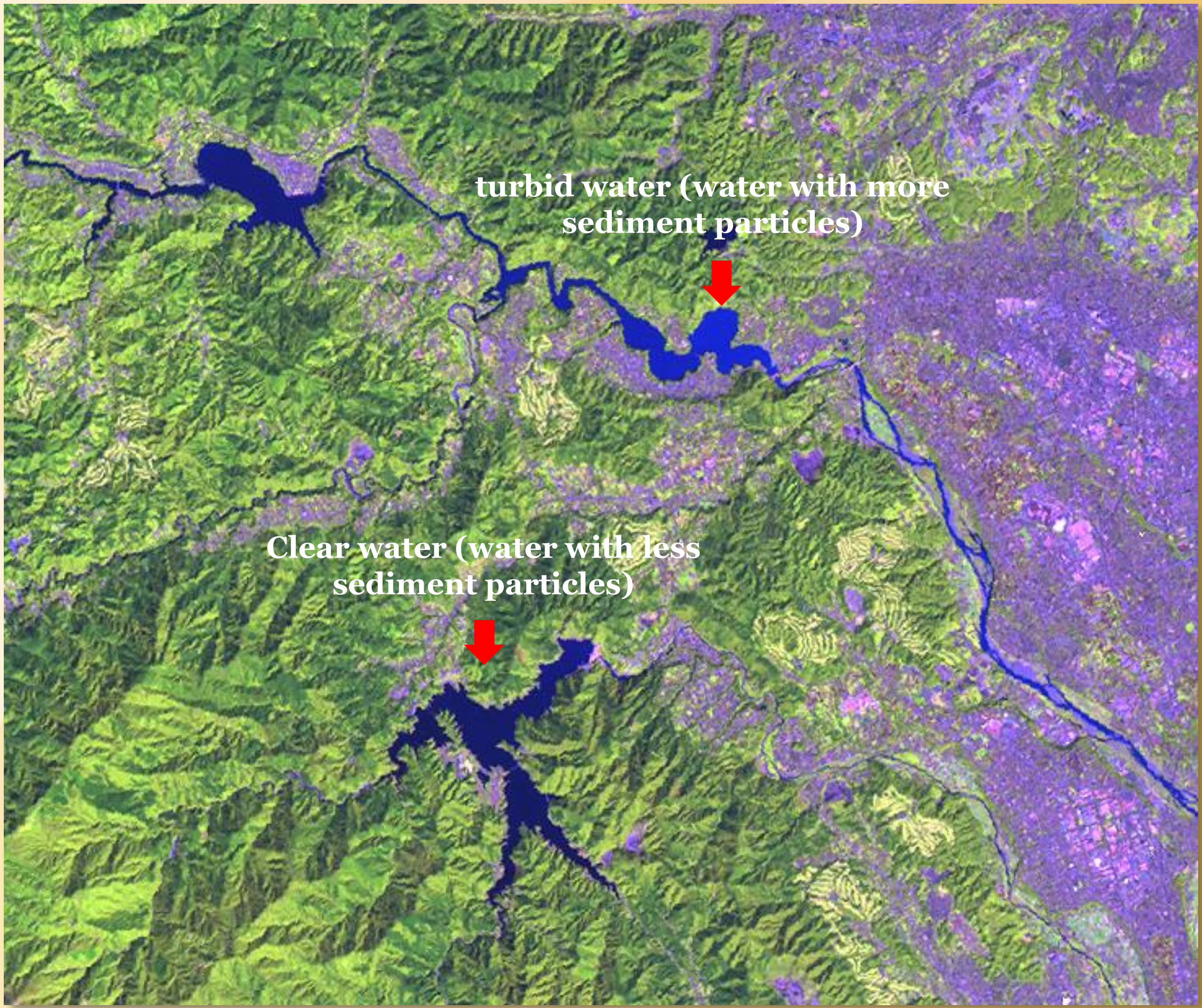
Landsat TM5 Tokyo (Ashikaga, Isezaki)

Example:

RGB 432 in Landsat TM/ETM gives false color. Assign band 4 to red channel, band 3 to green channel and band 2 to blue channel in computer display.

To determine vegetation stress and vigor.

3.2 Visual Interpretation (Band combination) *continued*



Landsat TM5 Tokyo (Hachioji)

Example:

RGB 541 in Landsat TM/ETM gives false color. Assign band 5 to red channel, band 4 to green channel and band 1 to blue channel in computer display.

To assess water quality. Turbid water gives bright blue and clear water gives dark blue.

3.3 Apply Algorithms

We can manipulate between bands (playing with DN Digital Numbers) and extract meaningful information.

(a) NDVI (Normalized Difference Vegetation Index)

Perhaps, well known and useful algorithm is NDVI (Normalized Difference Vegetation Index). Vegetation is low reflectance in Red band and high reflectance in Infrared band. By normalizing this two bands, we can measure vegetation stress and vigor.

General formula	NDVI = (Infrared – Red) / (Infrared + Red) The value is between +1 (vigor) ~ -1 (stress)
NOAA AVHRR	NDVI = (B2 – B1) / (B2 + B1)
Landsat TM/ETM	NDVI = (B4 – B3) / (B4 + B3)
IKONOS/QuickBird	NDVI = (B4 – B3) / (B4 + B3)

(b) NBR (Normalized Burn Ratio)

Landsat TM/ETM NBR = (B4 – B7) / (B4 + B7)

These two bands provide the best contrast between photosynthetically healthy and burned vegetation (Howard et al. 2002).

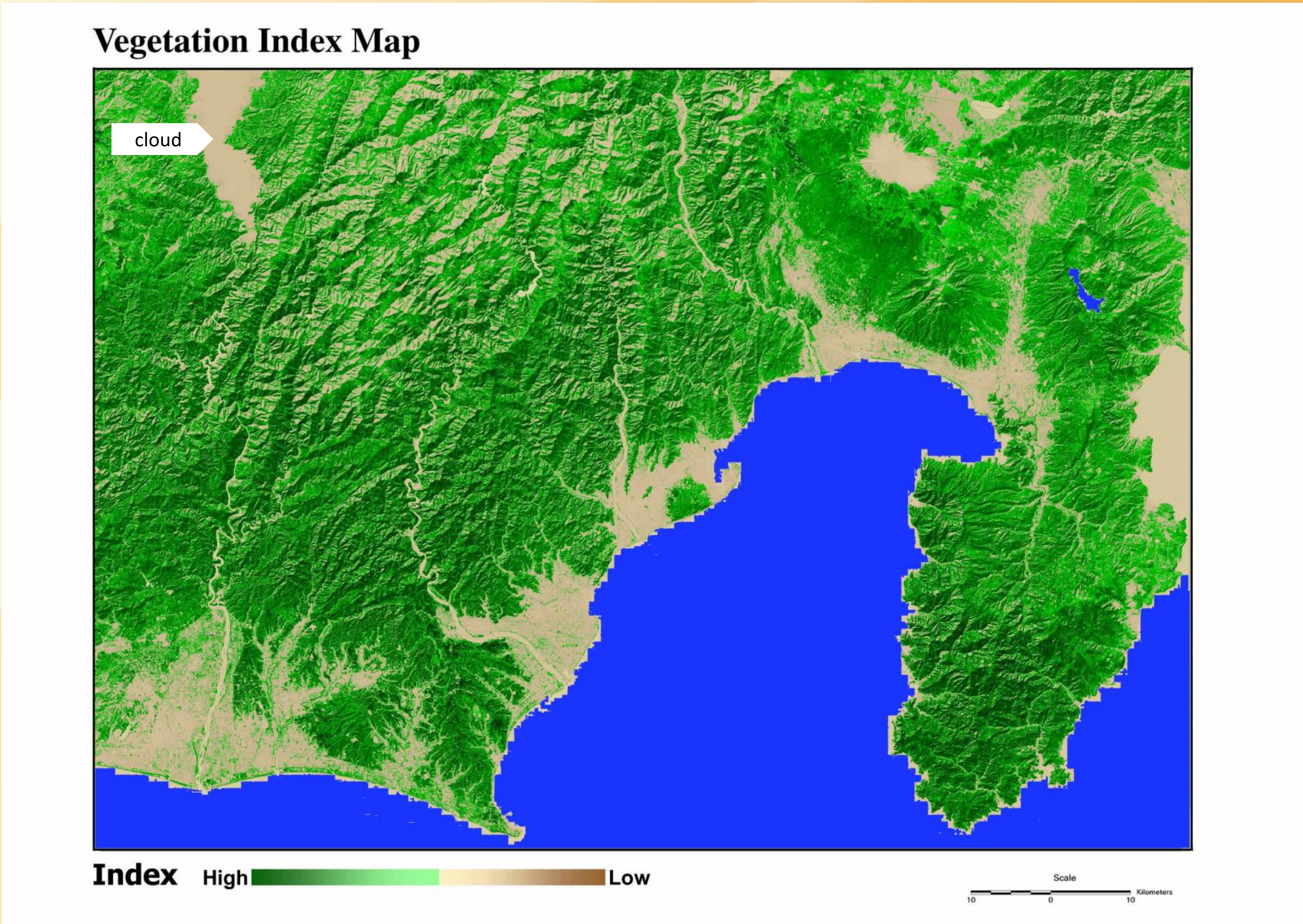
3.3 Apply Algorithms *(continued)*

Landsat TM5 Tokyo (Hanno)

Example:

Vegetation index (NDVI) stretched to 8-bit.

3.3 Apply Algorithms *(continued)*



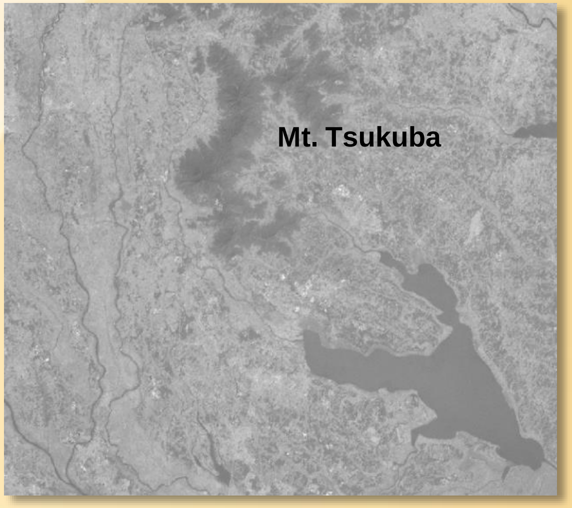
3.3 Apply Algorithms *(continued)*

(c) Surface Temperature

Some satellites carry thermal sensors. For example, Landsat TM/ETM, NOAA AVHRR ASTER, MODIS, etc.

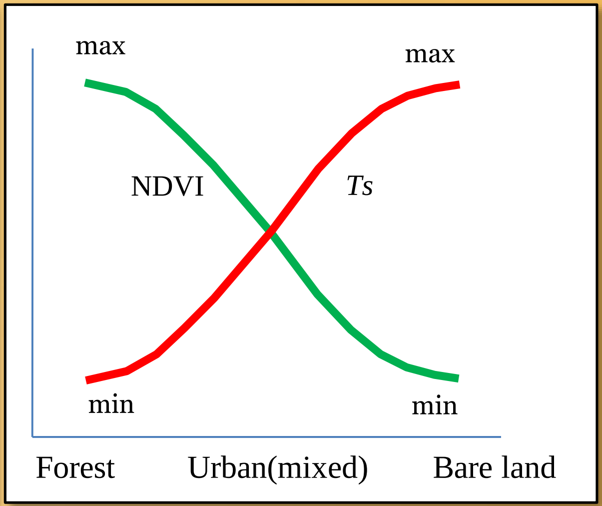
Thermal band records thermal emissive from the land surface objects. This band is good to study between surface temperature (*Ts*) and other land covers. For example, some researchers use surface temperature an NDVI to classify the land use land cover.

Thermal band spatial resolution is normally coarser than other bands because temperature does not change very well within the small area. Example: Landsat ETM thermal band spatial resolution is 60m compares to other bands (30m).



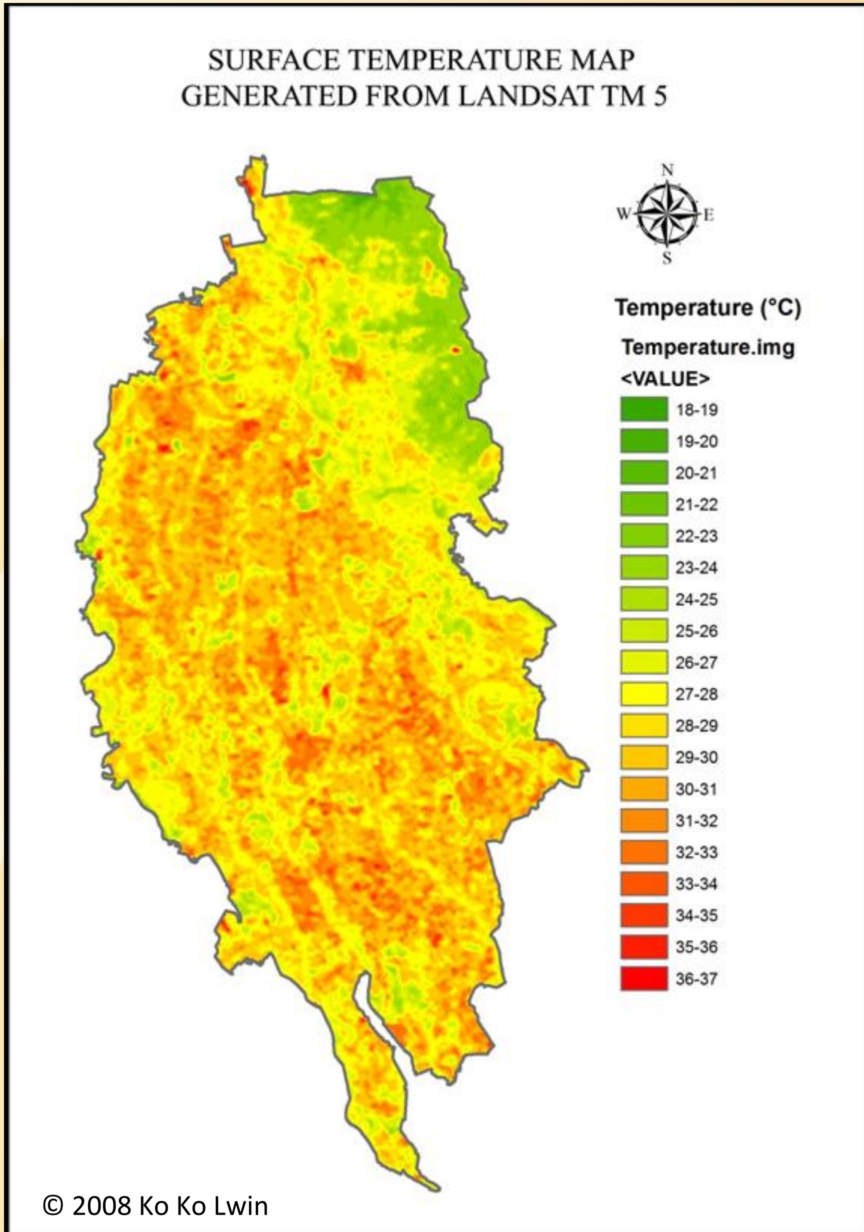
Landsat ETM Thermal Band 6 (Low gain)

Landsat ETM Thermal Band 6 (High gain)



NDVI vs. Ts

3.3 Apply Algorithms *(continued)*



Step1. Conversion of the Digital Number (DN) to Spectral Radiance (L)

L = LMIN + (LMAX - LMIN) * DN / 255
Where
L = Spectral radiance
LMIN = 1.238 (Spectral radiance of DN value 1)
LMAX = 15.600 (Spectral radiance of DN value 255)
DN = Digital Number

Step2. Conversion of Spectral Radiance to Temperature in Kelvin

$$T_B = \frac{K_2}{\ln\left(\frac{K_1}{L}+1\right)}$$

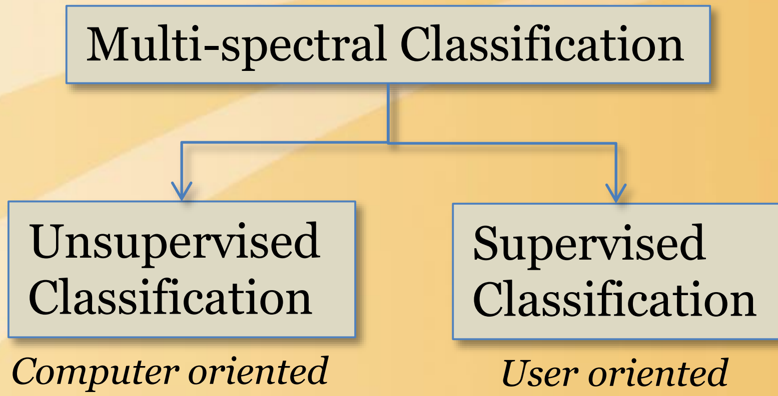
Where
K_1= Calibration Constant 1 (607.76)
K_2 = Calibration Constant 2 (1260.56)
T_B = Surface Temperature

Step3. Conversion of Kelvin to Celsius

$T_B = T_B - 273$

Tsukuba City surface temperature map generated from Landsat TM5 satellite acquired by 1987-05-21, 11:00AM Local Time (JST)

3.4 Multi-spectral Classification



<u>Multi-spectral Classification</u>

The process of assigning individual pixels of an image to categories, generally on the basis of spectral reflectance characteristics. Two kinds of multi-spectral classifications.

<u>Unsupervised Classification</u>

Digital information extraction technique in which the computer assigns pixels to categories with no instructions from the operator. Also known as Isodata Classification.

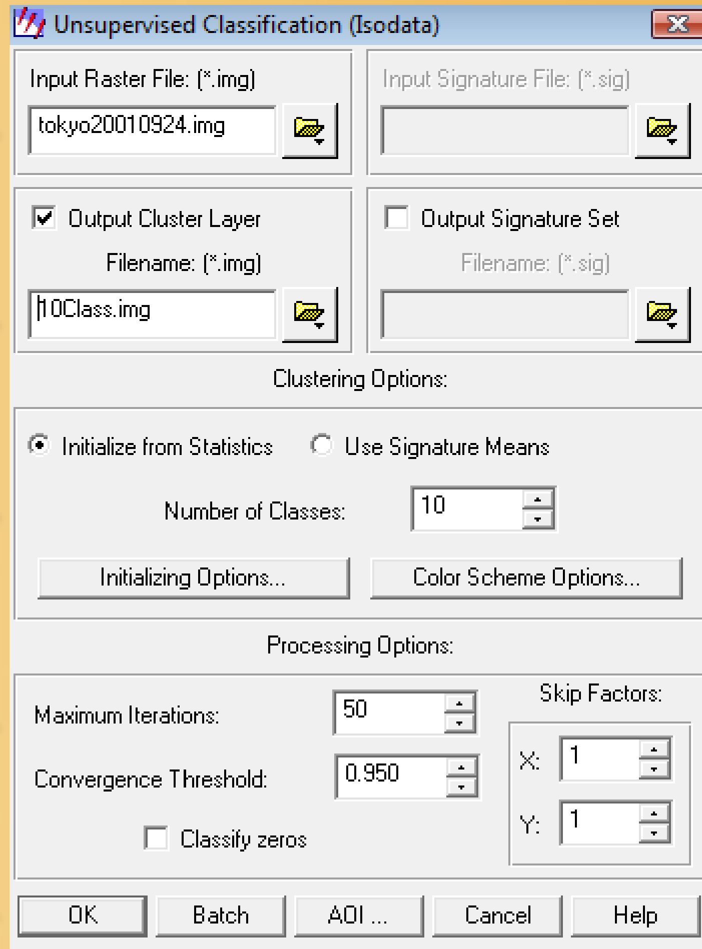
<u>Supervised Classification</u>

Digital-information extraction technique in which the operator provides training-site information that the computer uses to assign pixels to categories.

3.4 Multi-spectral Classification *(continued)*

<u>Unsupervised Classification (ERDAS Imagine Approach)</u>

1. Insert classify image
2. Give out put file name
3. Set numbers of classes
4. Set Maximum iteration
5. Click OK to start to classify



Unsupervised classification is sometime use to know general clustered information from the image.

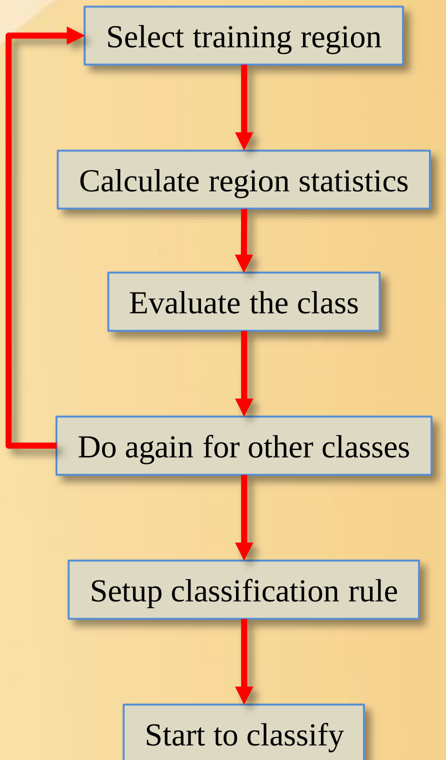
3.4 Multi-spectral classification *(continued)*

Supervised Classification (ERDAS Imagine Approach)

Signature:
Any characteristic or series of characteristics by which a material or object may be recognized in an image, photo, or data set.

Workflow

Signature collection steps



Draw polygon on an image

Compare signature statistics with other classes
-Avoid overlapping each other (signature separation)

Evaluate the selected class (pre-view)

Do again for other land use classes same as above

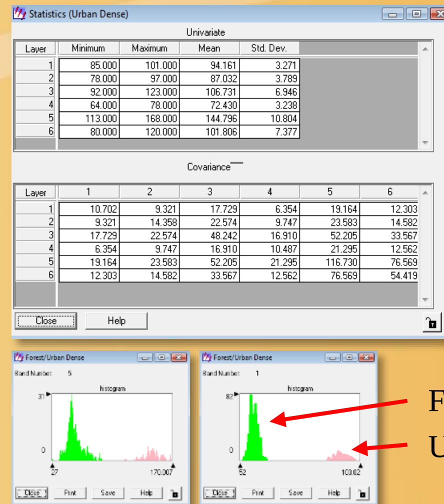
Setup classification rule
(e.g. Maximum Likelihood Classifier)

Start to classify an image

Step 1 : Select training region

Training region or signature   Signature Collection Tool

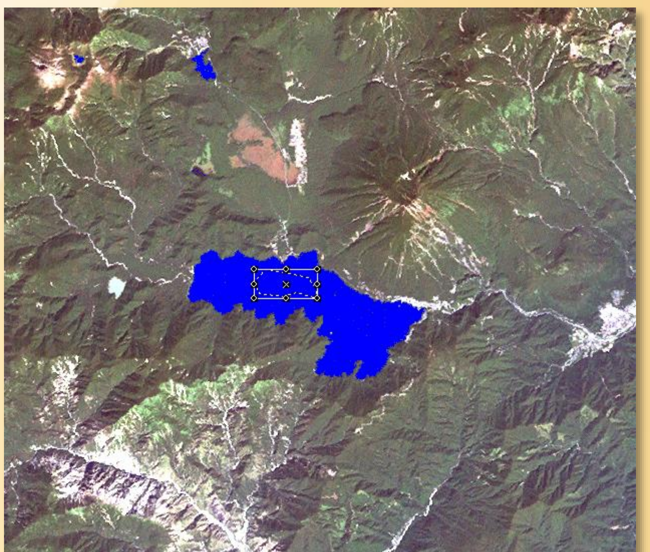
Step 2: Calculate region statistics



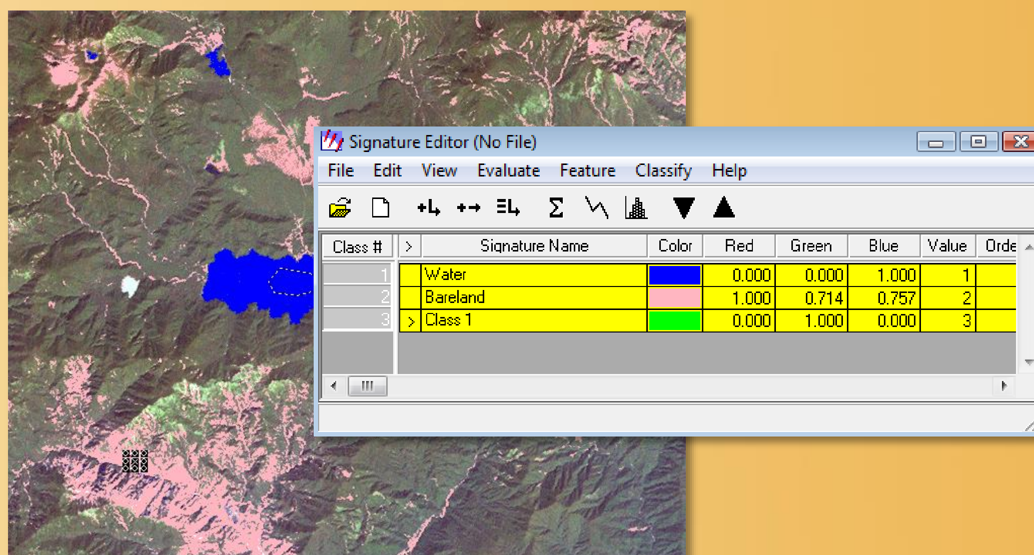
Forest

Urban Dense

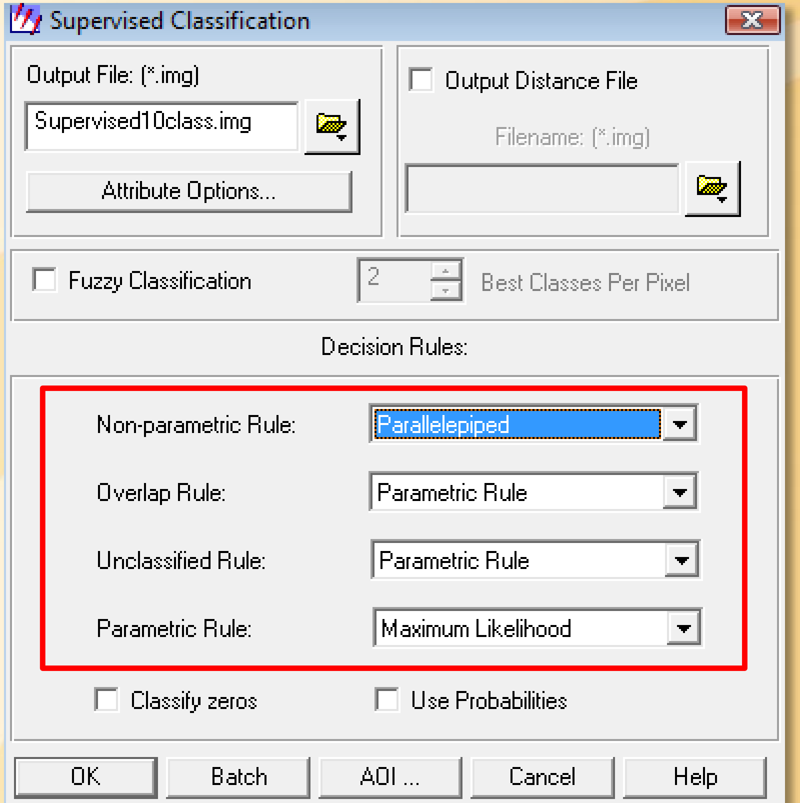
Step 3: Evaluate the class



Step 4: Do for other classes

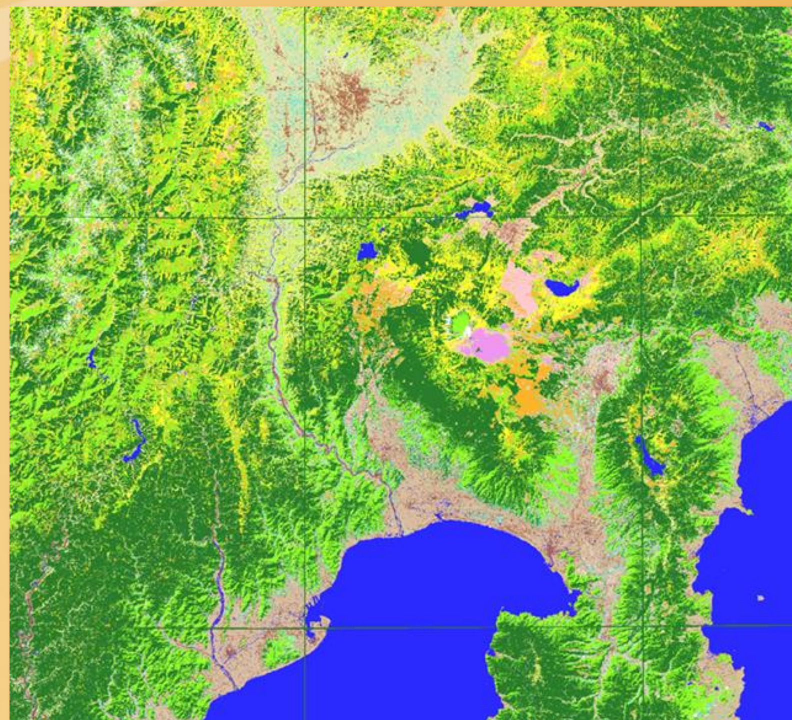


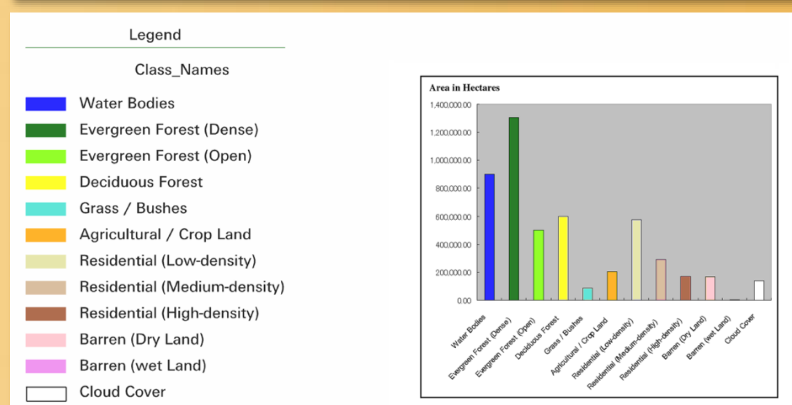
Step 5: Setup classification rule



Land use land cover is commonly used in spatial data modeling processes such as Hydrological Modeling, Soil Erosion and Land Degradation, Monitoring of Deforestation Process, Land Use Changes, etc.

Step 6: Start to classify

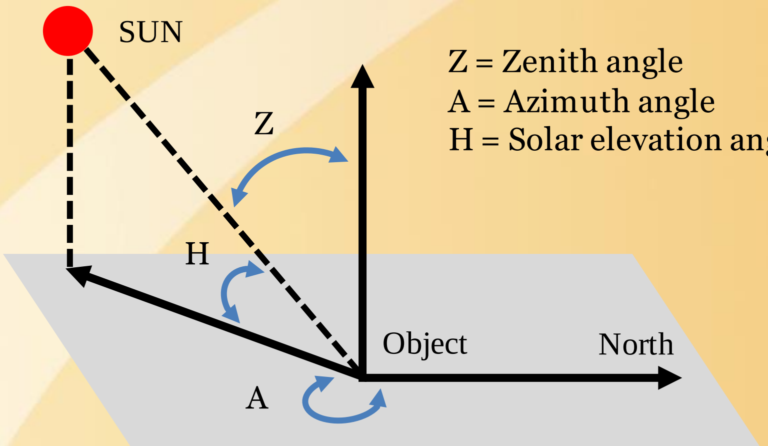


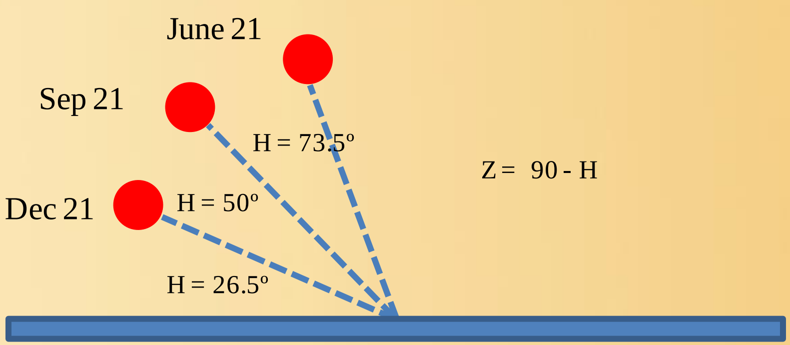


3.5 Scene Selection Criteria for Multi-spectral Classification

Scene should be:

1. Cloud free (if possible)
2. Plants growing season
3. Low solar zenith angle period

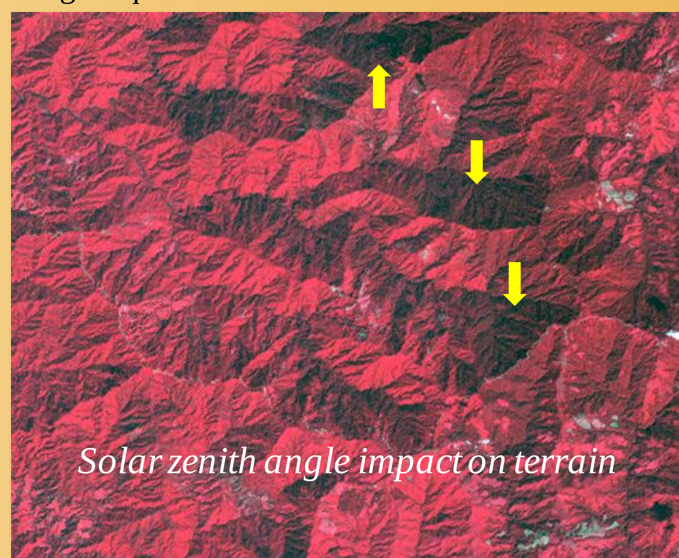




Normally effected in high rise mountain area and require additional "*Topographic Normalization*" process.

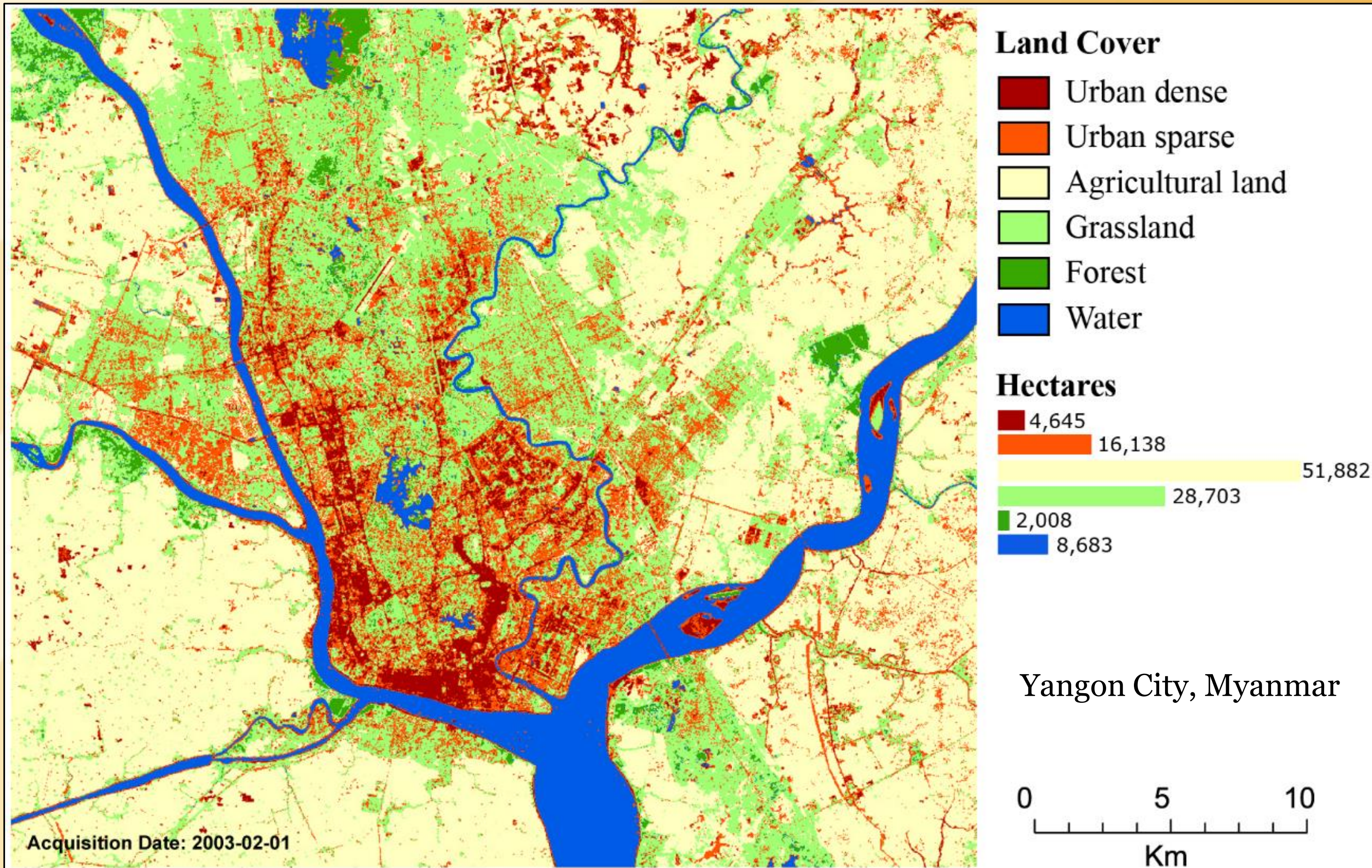
Image acquired in June

Image acquired in November



Part II: Remote Sensing Data Applications in GIS

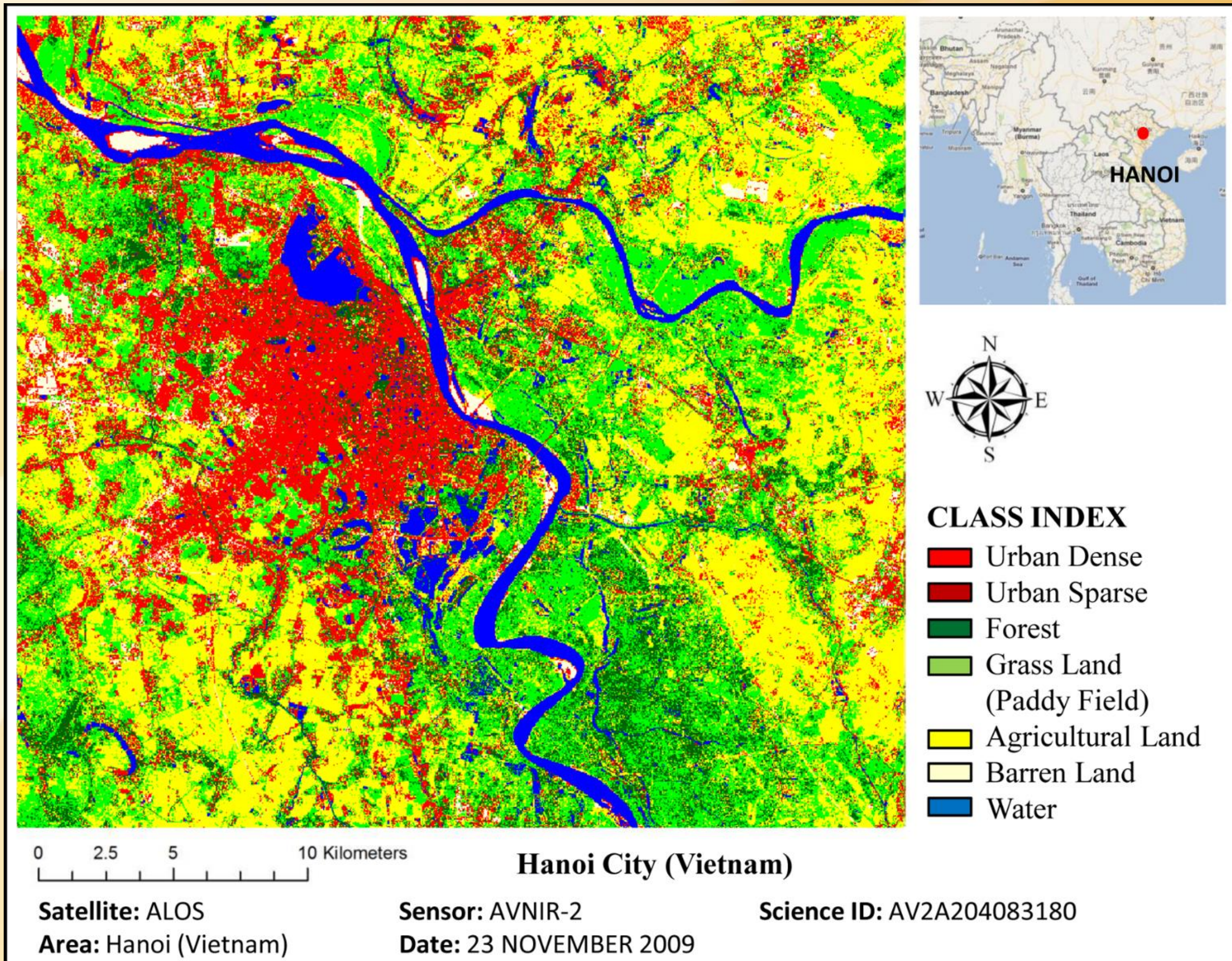
4.1 Land Cover Classification from Landsat ETM+



Land cover classification form Landsat ETM++

Source: Lwin, K. K. and Murayama, Y. (2013), Evaluation of land cover classification based on multispectral versus pansharpened Landsat ETM+ imagery, ***GIScience and Remote Sensing***, 50, 458-472.

4.2 Land Cover Classification from ALOS AVNIR-2



Land cover classification form ALOS AVNIR-2

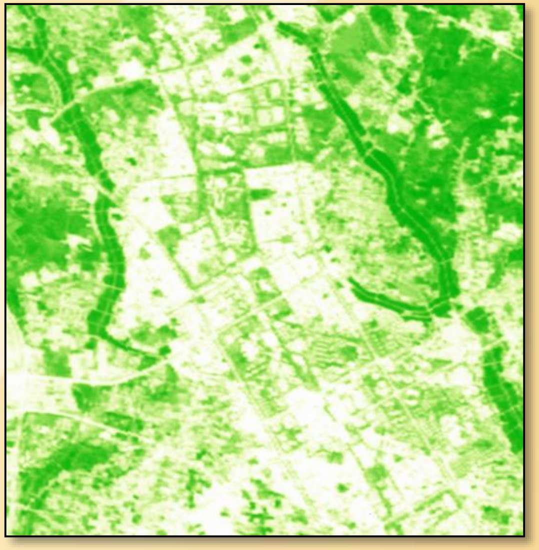
Source: Lwin, K. K. and Murayama, Y., (2011), Mapping the human settlement of South East Asia cities using ALOS AVNIR-2, ***Tsukuba Geoenvironmental Sciences***, 7: 13-17.

4.3 Urban Greenness (Eco-friendly Walk Score Calculator)

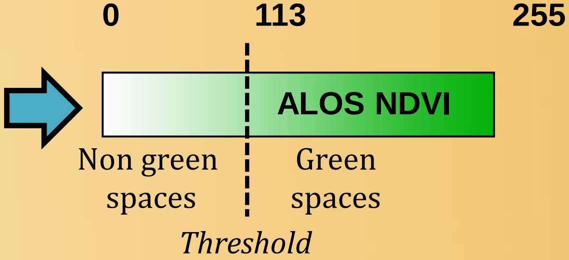
Web based interactive eco-friendly walk score calculator for Tsukuba City.

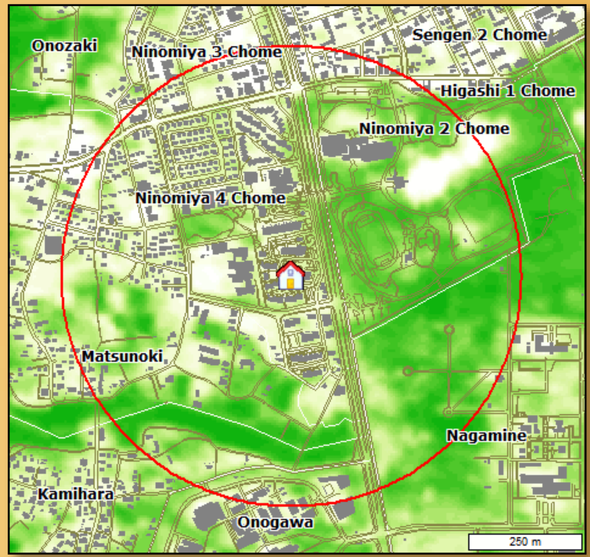
Eco-friendly Walk Score measures the degree of greenness (green density) by user defined geographic patterns based on Normalized Different Vegetation Index (NDVI).

NDVI was calculated from Advanced Land Observation Satellite ALOS AVNIR-2 sensor (ground resolution at 10m).



Green spaces:
Forest, paddy fields and grass lands
Non Green Spaces:
Bare lands, water surface, roads and building footprints



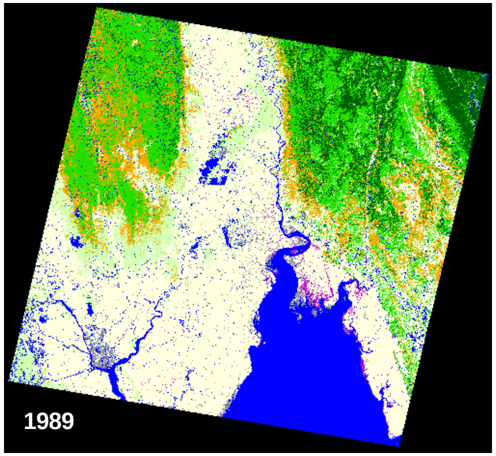



```
Search Radius: 500.06 m
Search Area: 78.56 Ha
Greenness Score: 55
```

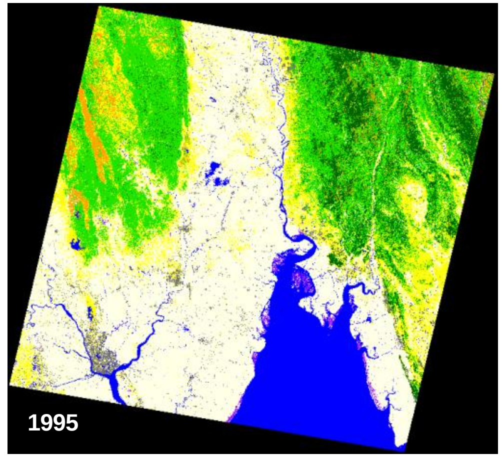
Choosing a Place to Live with GIS Project Homepage
Eco-friendly Walk Score Calculator for Tsukuba City
http://land.geo.tsukuba.ac.jp/ecowalk/default.aspx

Source: Lwin, K. K., & Murayama, Y., (2011), Modelling of Urban Green Space Walkability: Eco-friendly Walk Score Calculator, ***Computers, Environment and Urban Systems***, 35(5):408-420.

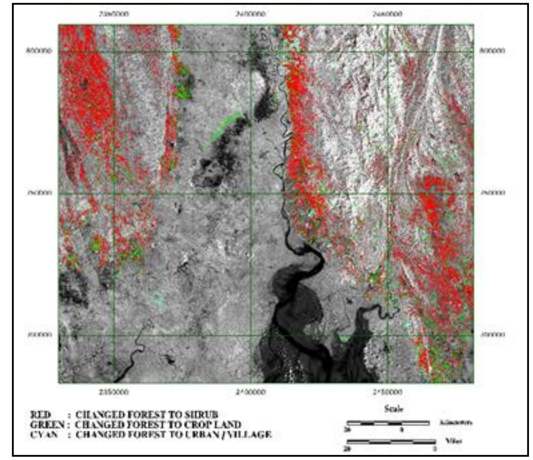
4.4 Monitoring of Deforestation Process



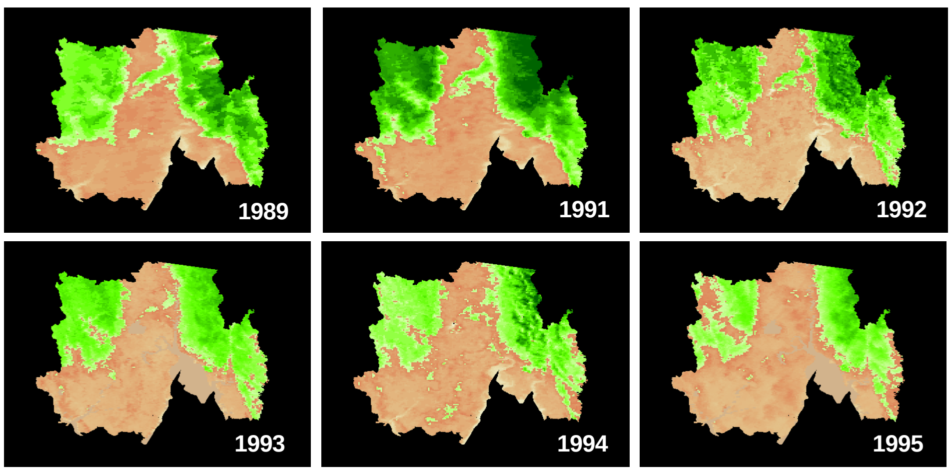
1988 Land use map

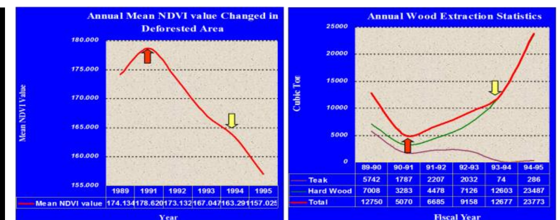


1995 Land use map



Deforested areas

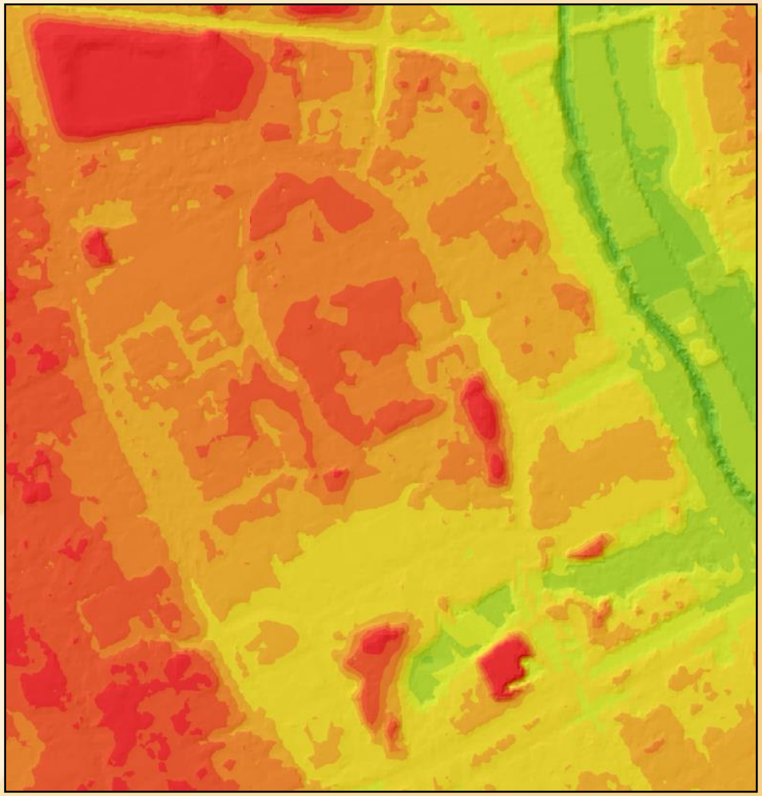




Monitoring of annual deforestation process using Landsat TM and NOAA AVHRR 10-day composite NDVI images (case study in Myanmar).

Source: Lwin, K. K. and Shibasaki, R., (1998), Monitoring and Analysis of Deforestation Process Using Remote Sensing and GIS: A Case Study of Myanmar, in: ***19th Asian Conference on Remote Sensing (ACRS)***, Manila, Philippines.

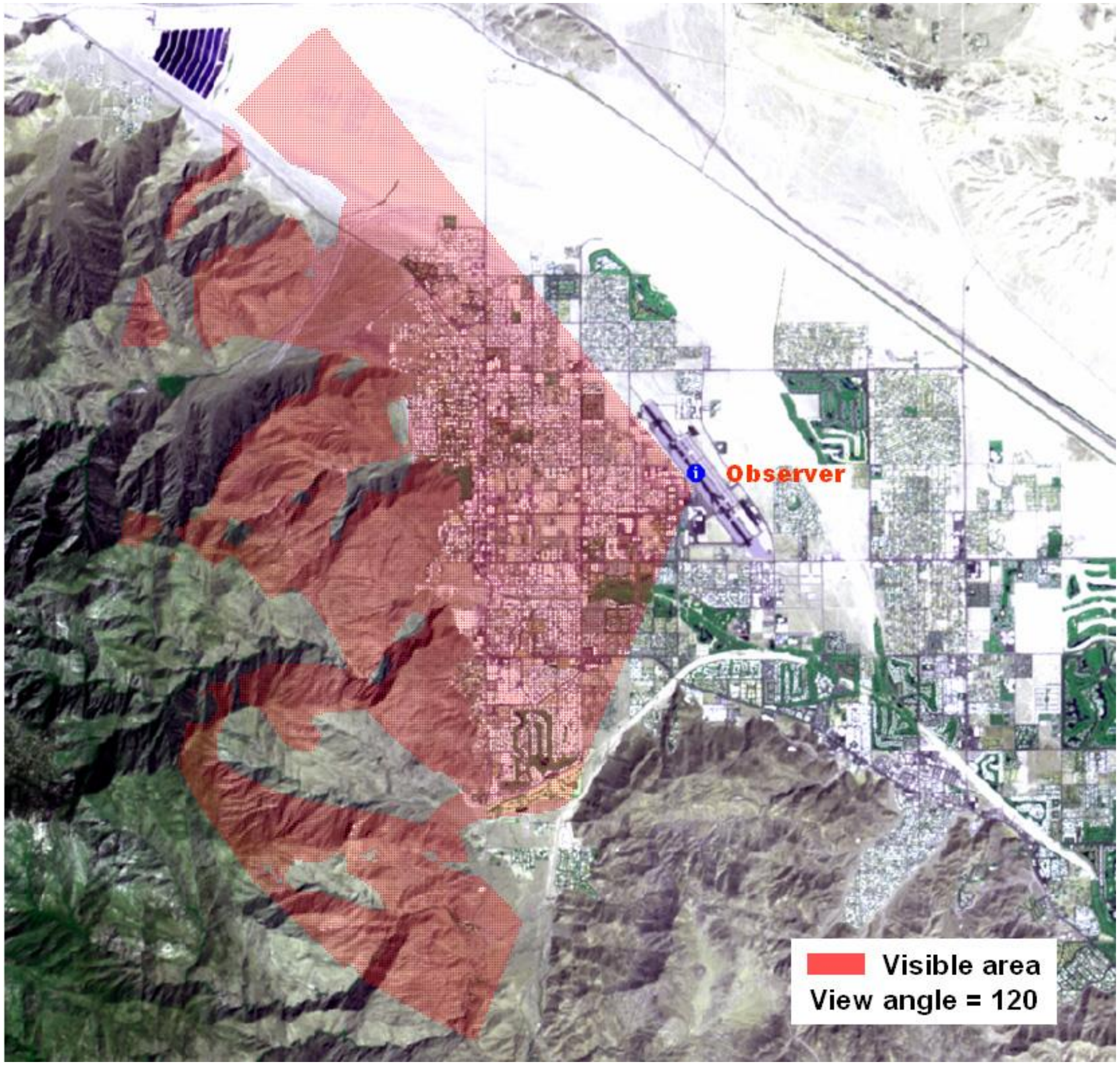
4.5 Surface Steepness Measurement from LIDAR

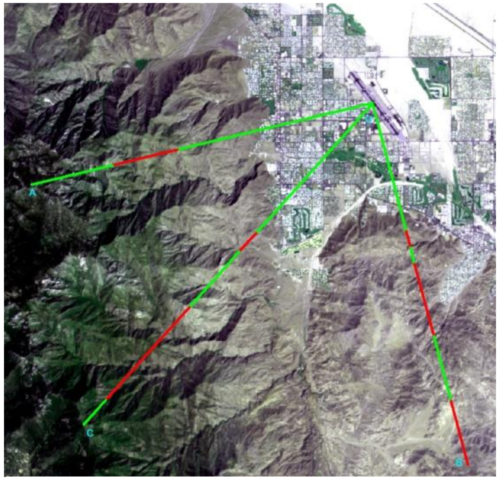


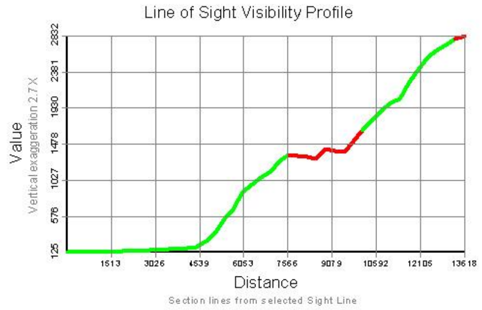
DTM and DSM generation form LIDAR data to measure terrain height and surface height (from sea level).
DTM = Digital Terrain Model
DSM = Digital Surface Model

Source: Lwin, K. K., Zhou, Y. and Murayama, Y., (2013), Identification of Bicycle Lanes Steepness from LIDAR Data, ***Tsukuba Geoenvironmental Sciences***, 8: 9-15.

4.6 Viewshed Analysis and Resort Site Selection

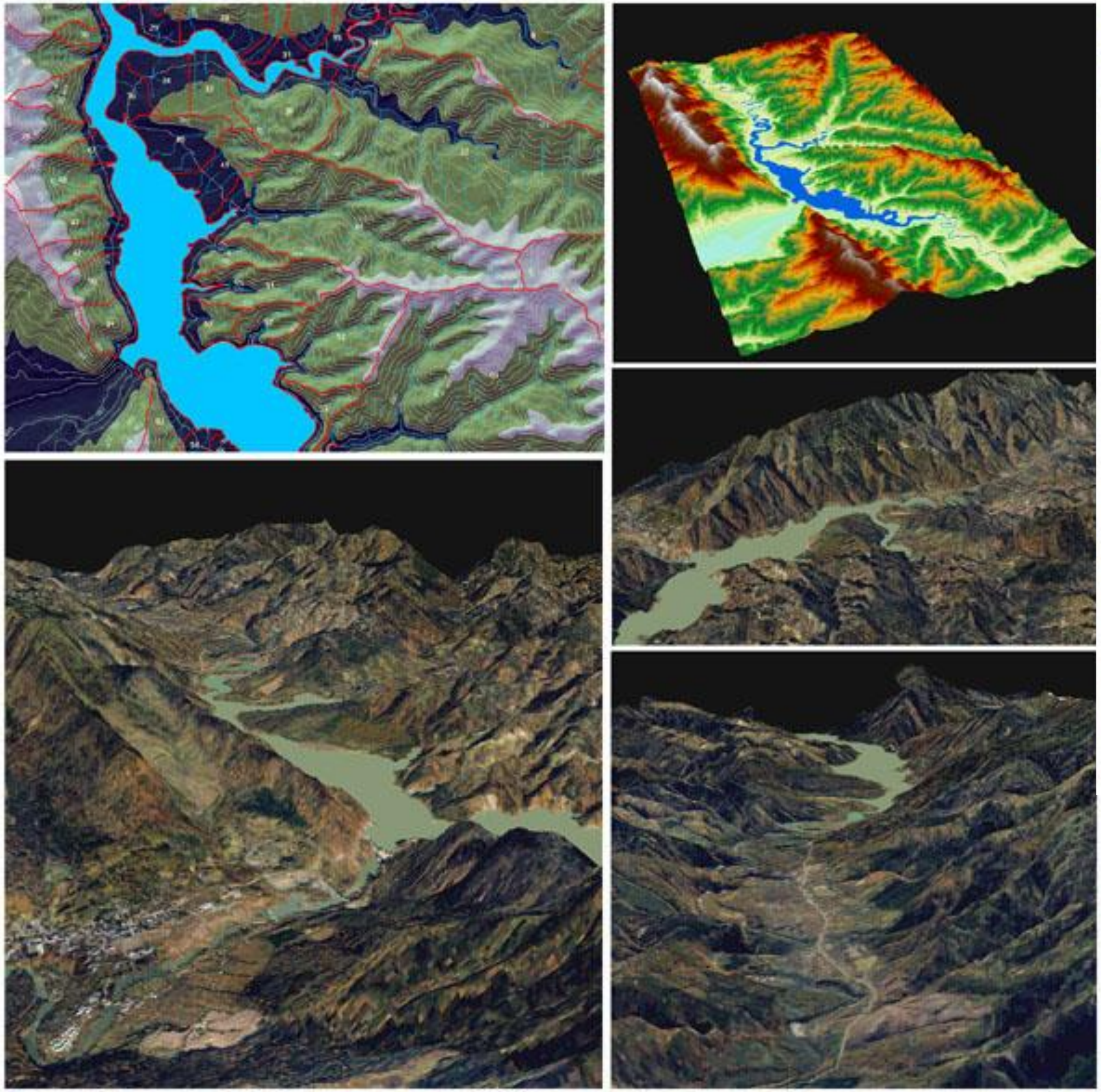






Viewshed and line of sight analysis based on DEM (Digital Elevation Model) and Aerial Photos for resort site selection. (Data source: ERDAS imagine)

4.7 Watershed and Environmental Impact Assessment



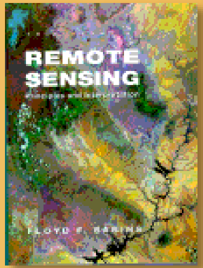
Watershed and environmental impact assessment. Aerial photos orthorectification, mosaicking and watershed delineated from DEM.

Appendix A Remote Sensing Learning Resources

BOOKS

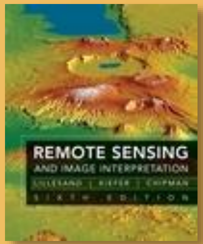
Beginners

Remote Sensing: Principles and Interpretations (Hardcover)
by Floyd F. Sabins (Author)



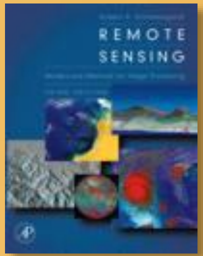
Intermediate

Remote Sensing and Image Interpretation (Hardcover)
by Thomas M. Lillesand (Author), Ralph W. Kiefer (Author), Jonathan W. Chipman (Author)



Advanced

The one who wants to develop own image processing algorithms…
Remote Sensing, Third Edition: Models and Methods for Image Processing (Hardcover) by Robert A. Schowengerdt (Author)



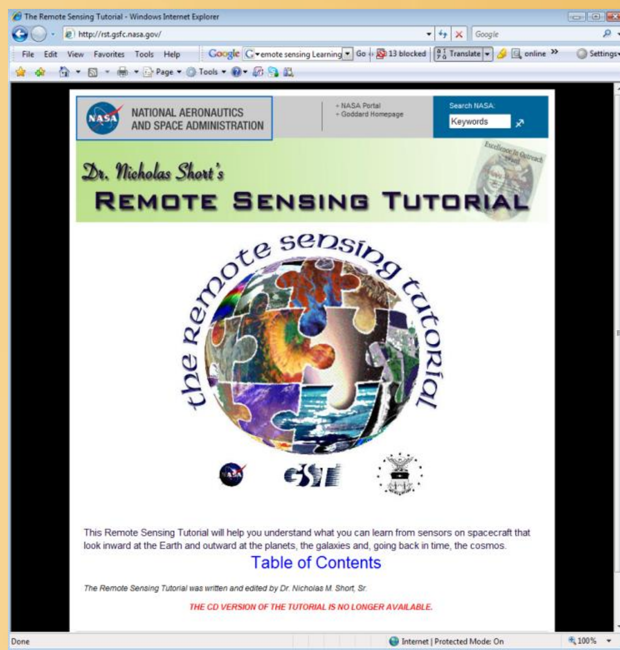
Appendix A Remote Sensing Learning Resources *(continued)*

Online Learning

CCRS Canada Centre for Remote Sensing
http://landmap.mimas.ac.uk/ipc/ccrs/fundam_e.html

NASA Remote Sensing Tutorial
http://rst.gsfc.nasa.gov/

TELSAT, Belgium
http://eoedu.belspo.be/en/guide/index.htm



Appendix B Remote Sensing Data Resources

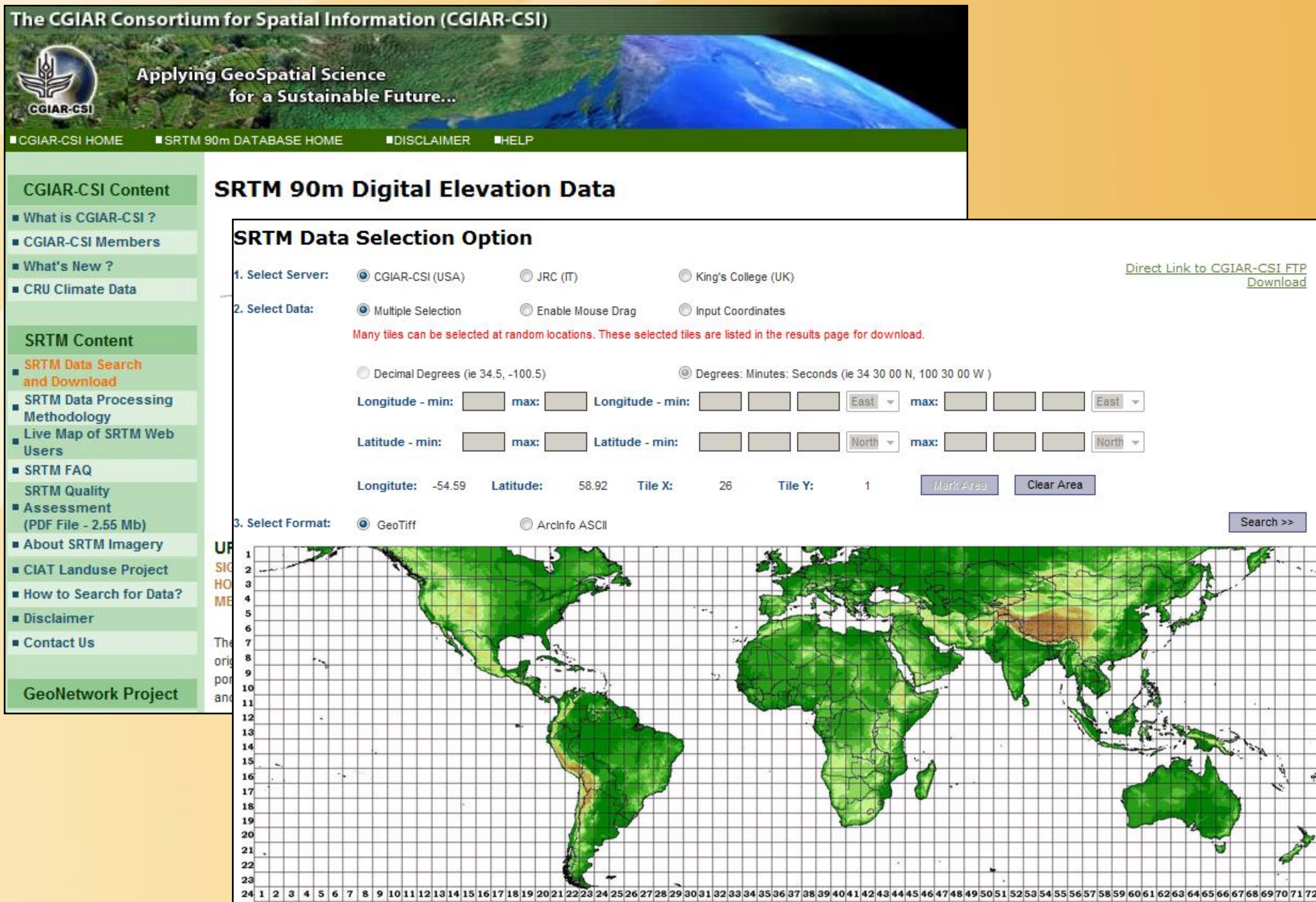
The GLCF is a center for land cover science with a focus on research using Remotely sensed satellite data and products to assess land cover change for local to global systems.

http://www.landcover.org/index.shtml ; http://www.landsat.org/ (Free)

Appendix B Remote Sensing Data Resources *(continued)*

SRTM 90m Digital Elevation Data (Free)

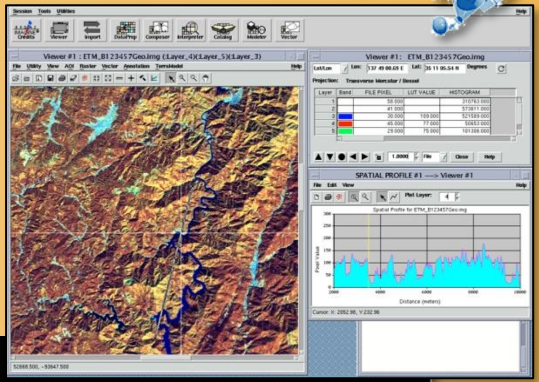
http://srtm.csi.cgiar.org/



Appendix C Remote Sensing Software Resources

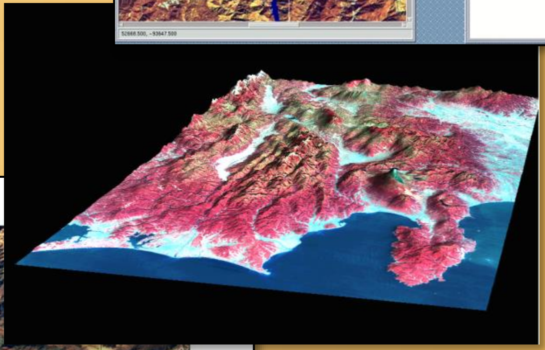
Freeware

MultiSpec (A Multispectral Image Data Analysis System)
http://cobweb.ecn.purdue.edu/~biehl/MultiSpec/

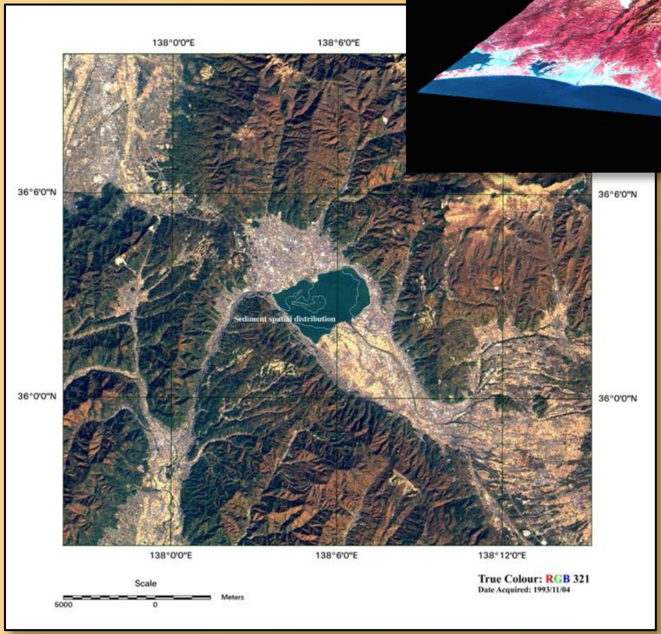


Commercial

ERDAS Imagine
http://gi.leica-geosystems.com/LGISub1x33x0.aspx



PCI Geomatics
http://www.pcigeomatics.com/



ENVI
http://rsinc.com/envi/

ER Mapper
http://www.ermapper.com/

IDRISI
http://www.clarklabs.org/