INTRODUCTION TO SATELLITE REMOTE SENSING

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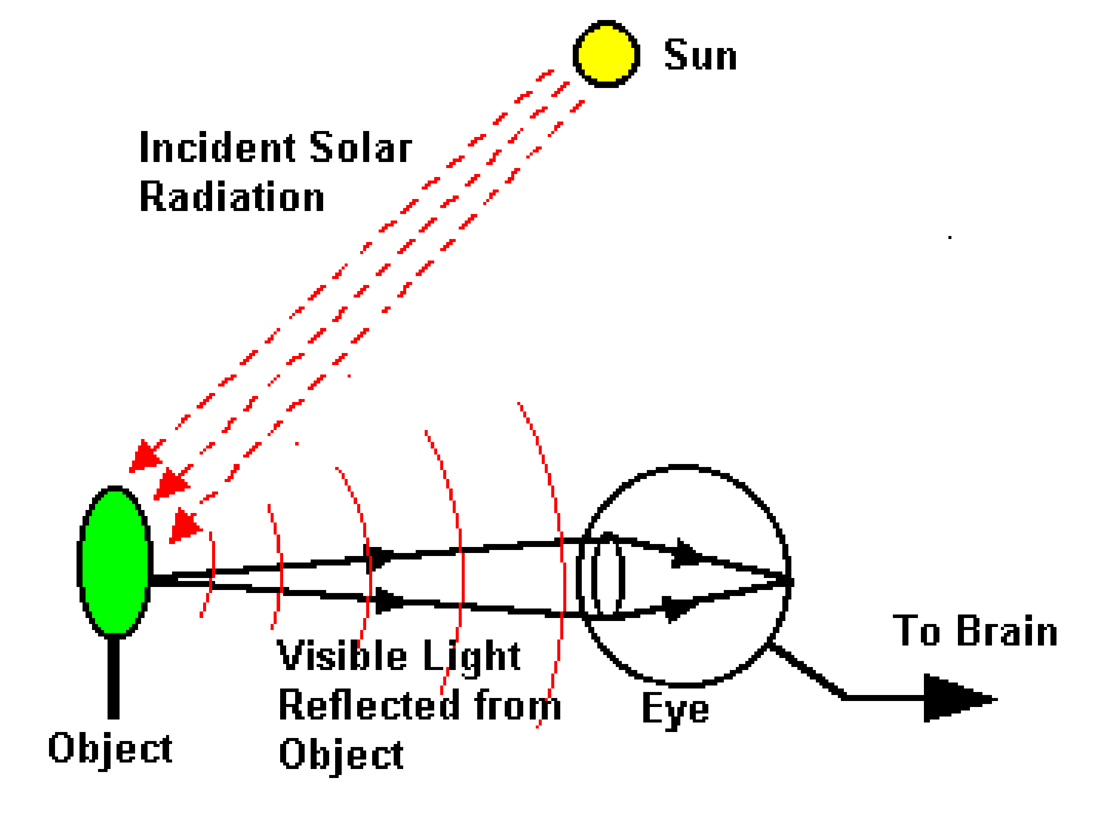
What is "Remote Sensing"?

Remote (*adj.*) far away in space;
Sense (*verb*) perceive by a sense or senses;
(of a machine or similar device) detect.
(Compact Oxford English Dictionary)

Remote Sensing = Sensing or detecting (by a human or a machine) some objects or events at far away locations.



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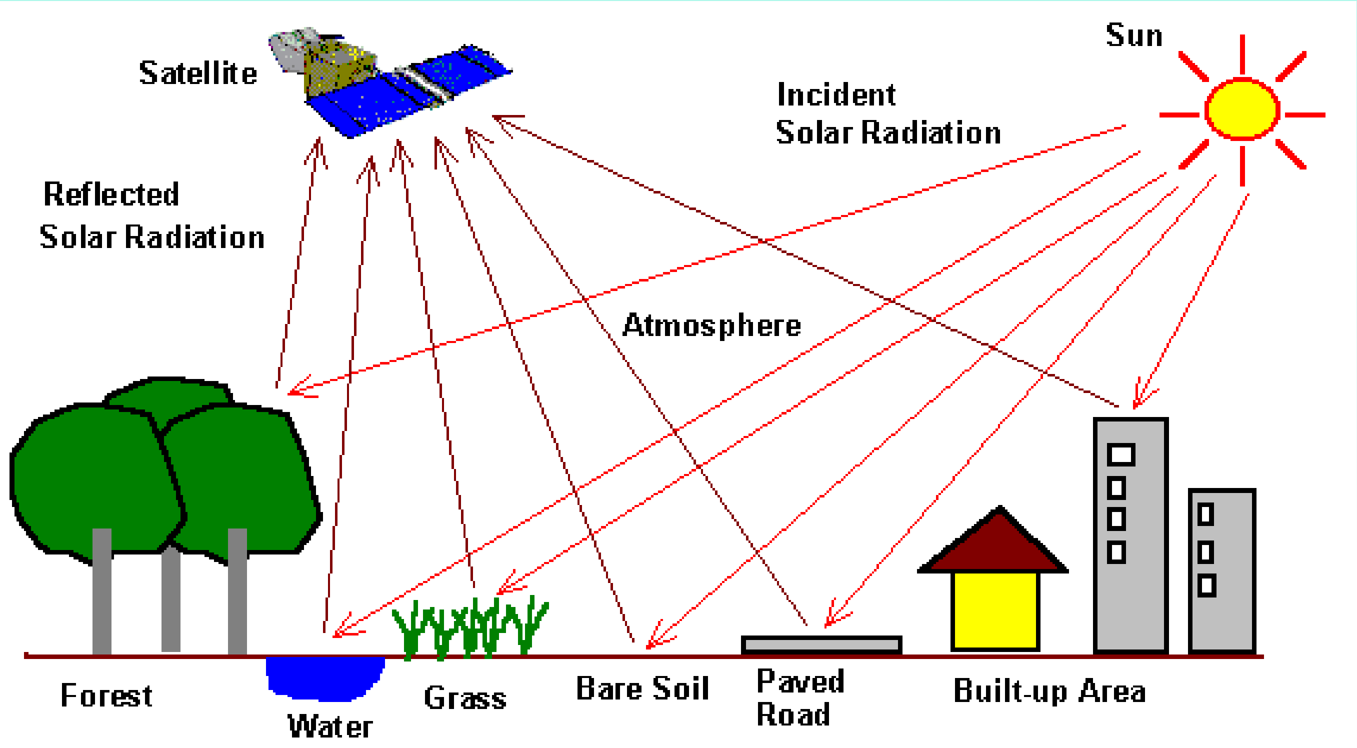
What is "Remote Sensing"?

In this Workshop, we are mainly concerned with **observation** of the **Earth**'s **environment** (atmosphere, land and ocean) from **space**, using **sensors** carried by earth-**orbit**ing **satellites**. (Note the highlighted keywords.)



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The Blue Marble

Photograph of the Earth taken from space, at about 29000 km from the Earth's surface

Apollo 17, on the way to the Moon
1972-12-07
10:39 UTC

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Some questions to ponder about?

- What is a satellite?
- How do we sense / observe the Earth from space?
- What information can we gather from a satellite image?
- How do we utilize satellite images / data to improve life on Earth?

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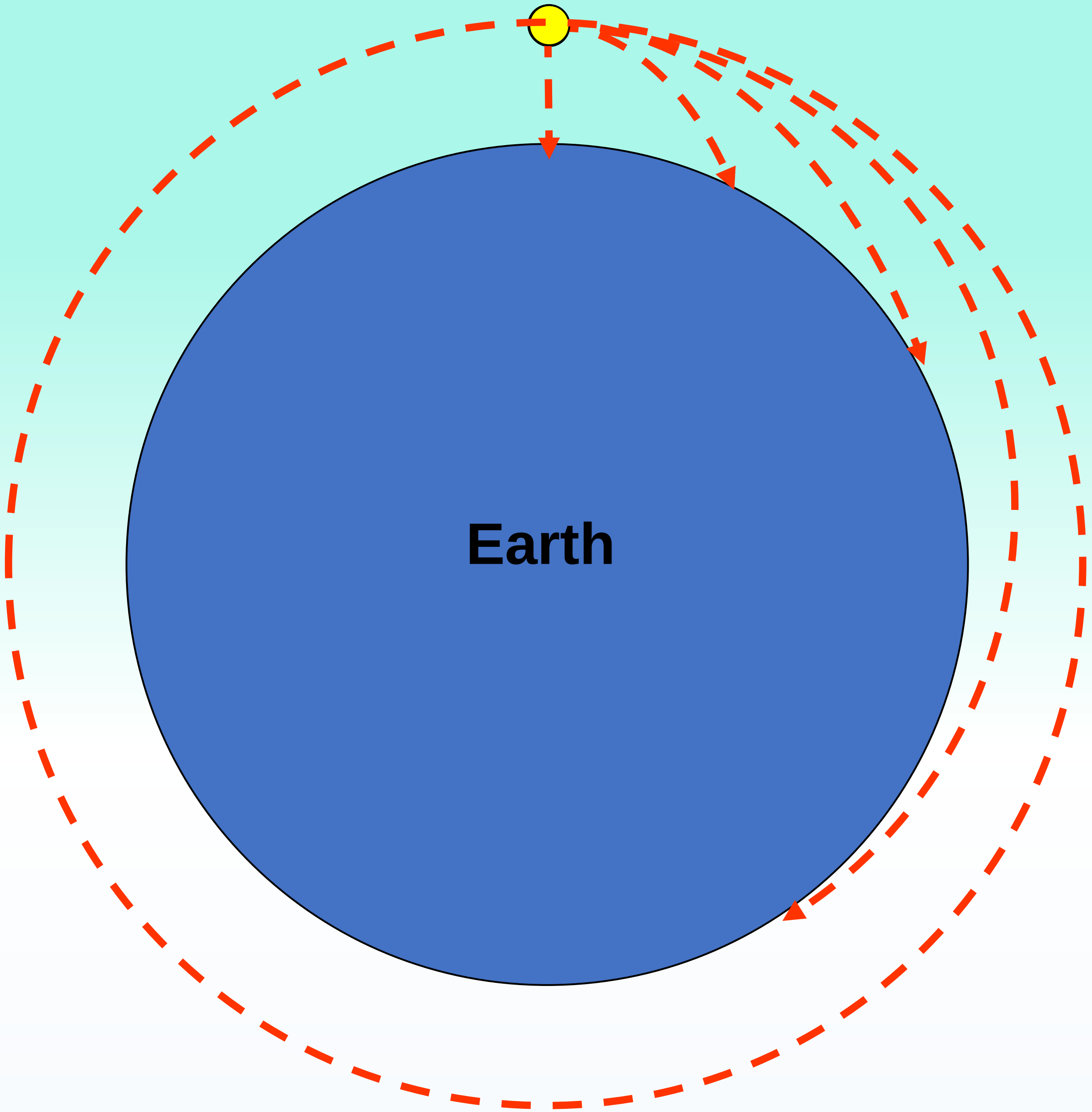
What is a satellite?



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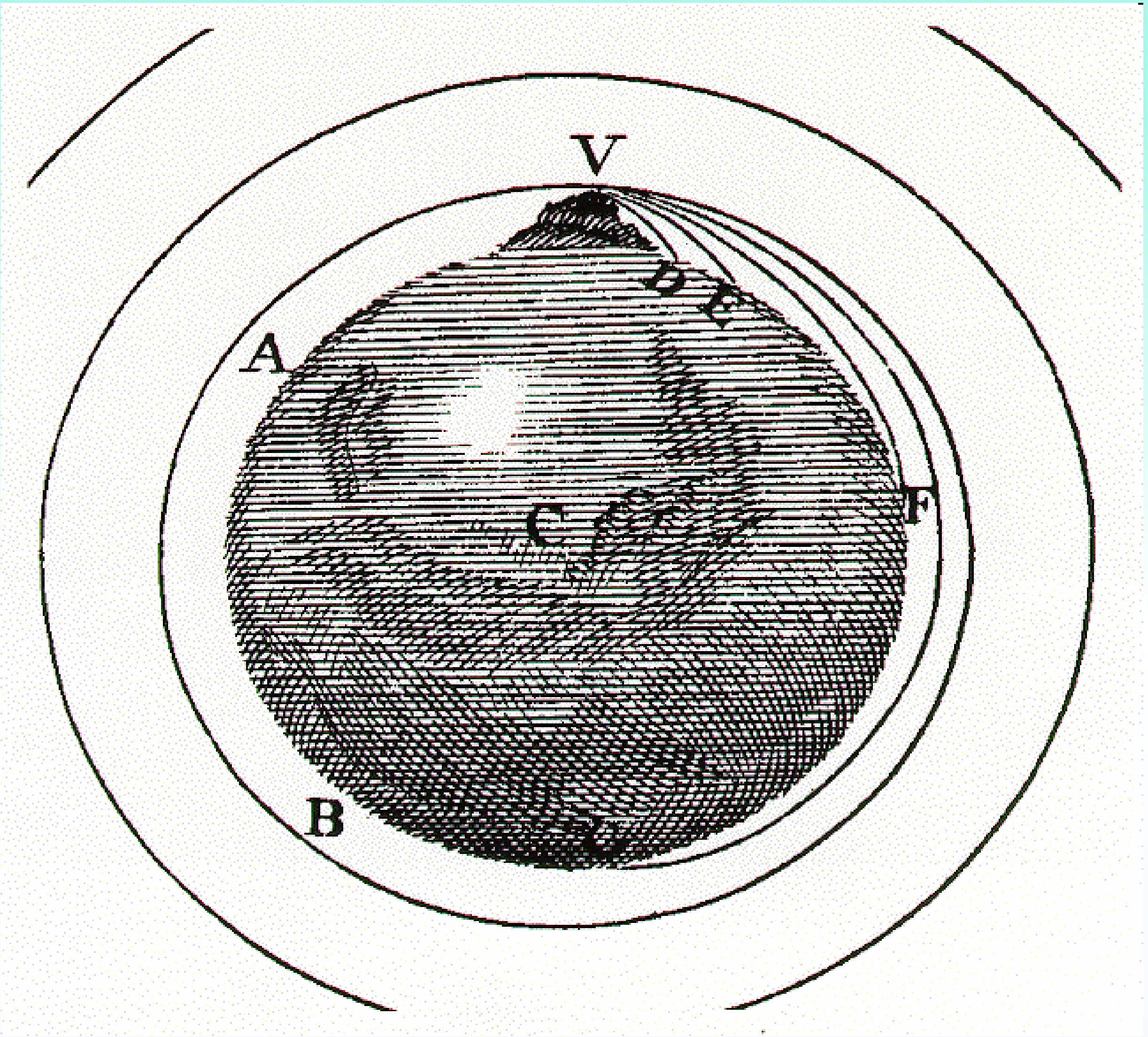
An illustration from Issac Newton, *Philosophiæ Naturalis Principia Mathematica* (The Mathematical Principles of Natural Philosophy), 1687



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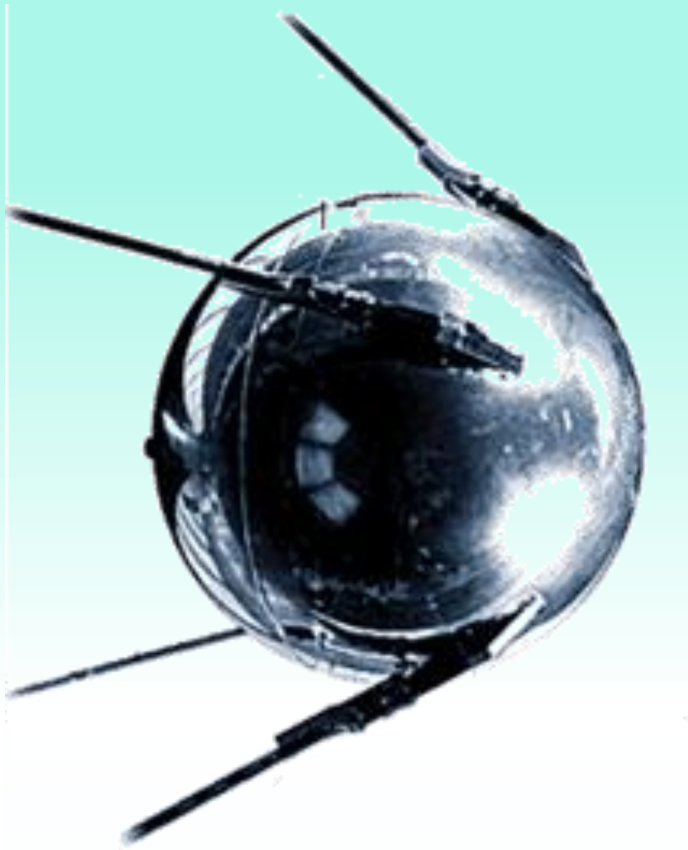
Sputnik 1 – The first artificial satellite



Sputnik 1
October 4, 1957

- Launched 4 October 1957 by the Soviet Union, first artificial satellite of the Earth
- Size: 56 cm diameter
- Shape: Spherical
- Mass: 83.6 kg
- Orbit parameters:
  - Perigee (nearest distance from earth surface): 215 km
  - Apogee (furthest from earth surface): 939 km
  - Orbital inclination: 65.1 degrees
  - Orbital period: 96.2 minutes

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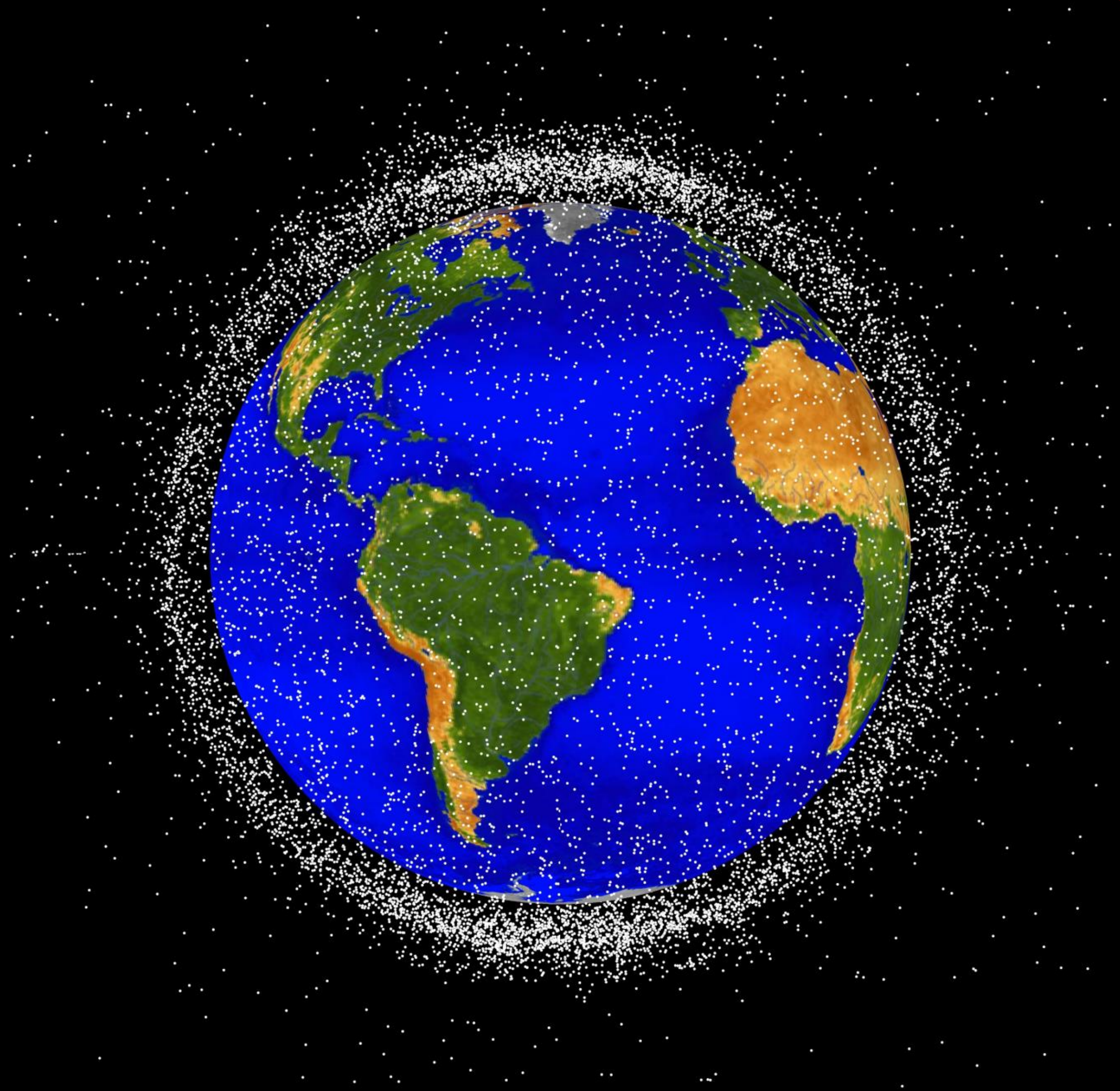
There are now thousands of satellites orbiting the Earth



A computer-generated image of objects in low Earth orbit (below 2000 km) that are currently being tracked by NASA. Approximately 95% of the objects are orbital debris, i.e., not functional satellites.

Image Credit: NASA ODPO

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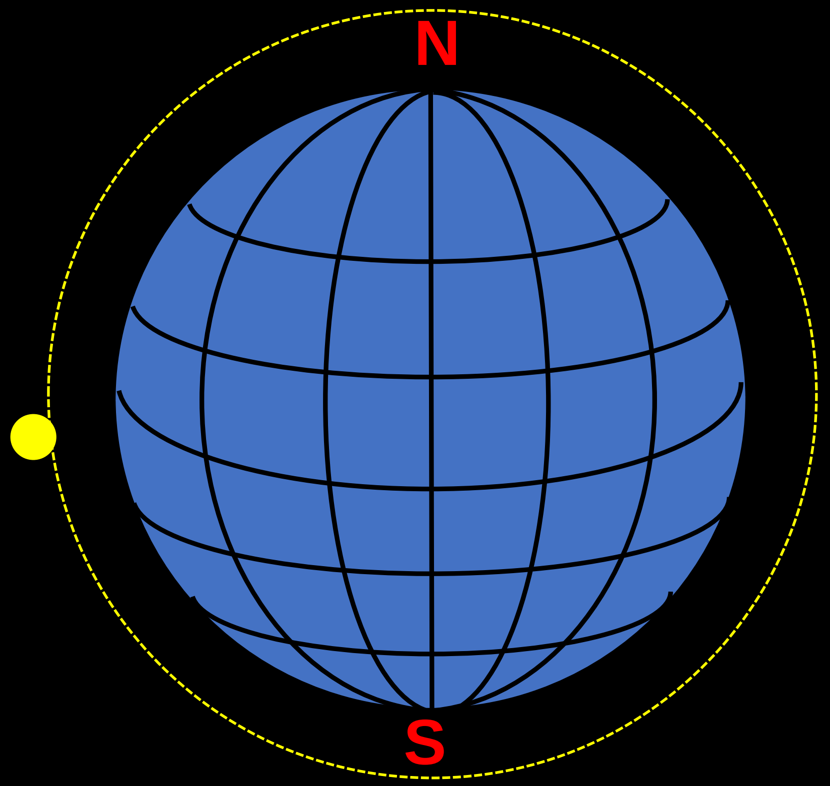
Polar Orbit



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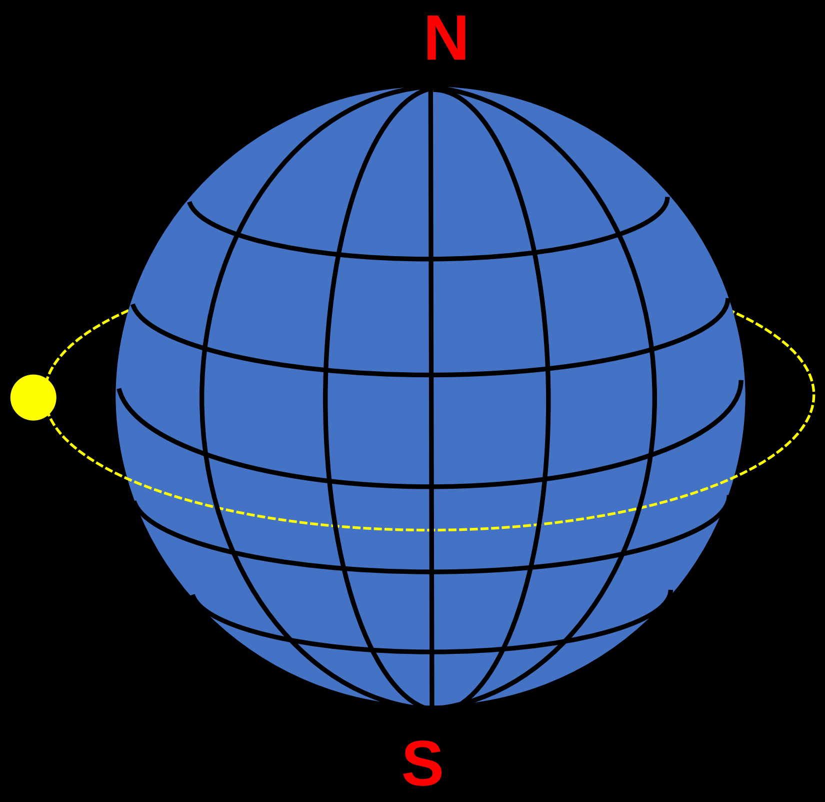
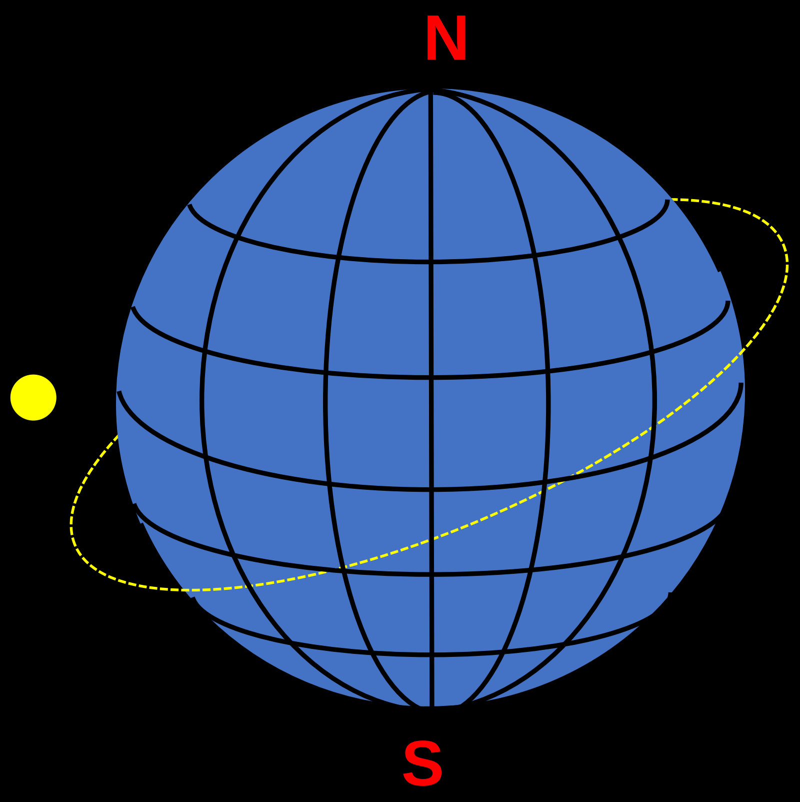
Equatorial Orbit



Inclined Orbit



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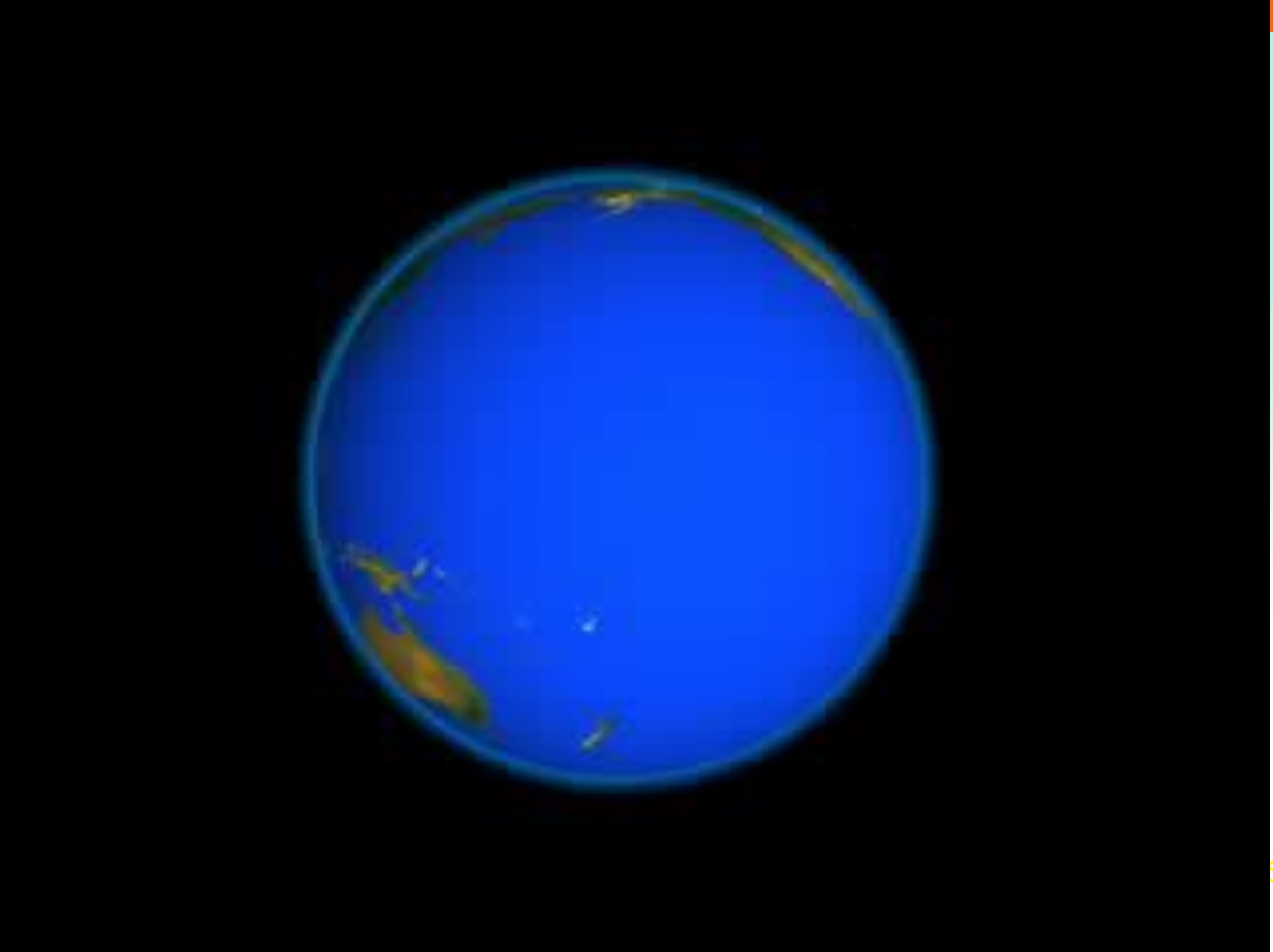

Animation of a low-earth orbit satellite

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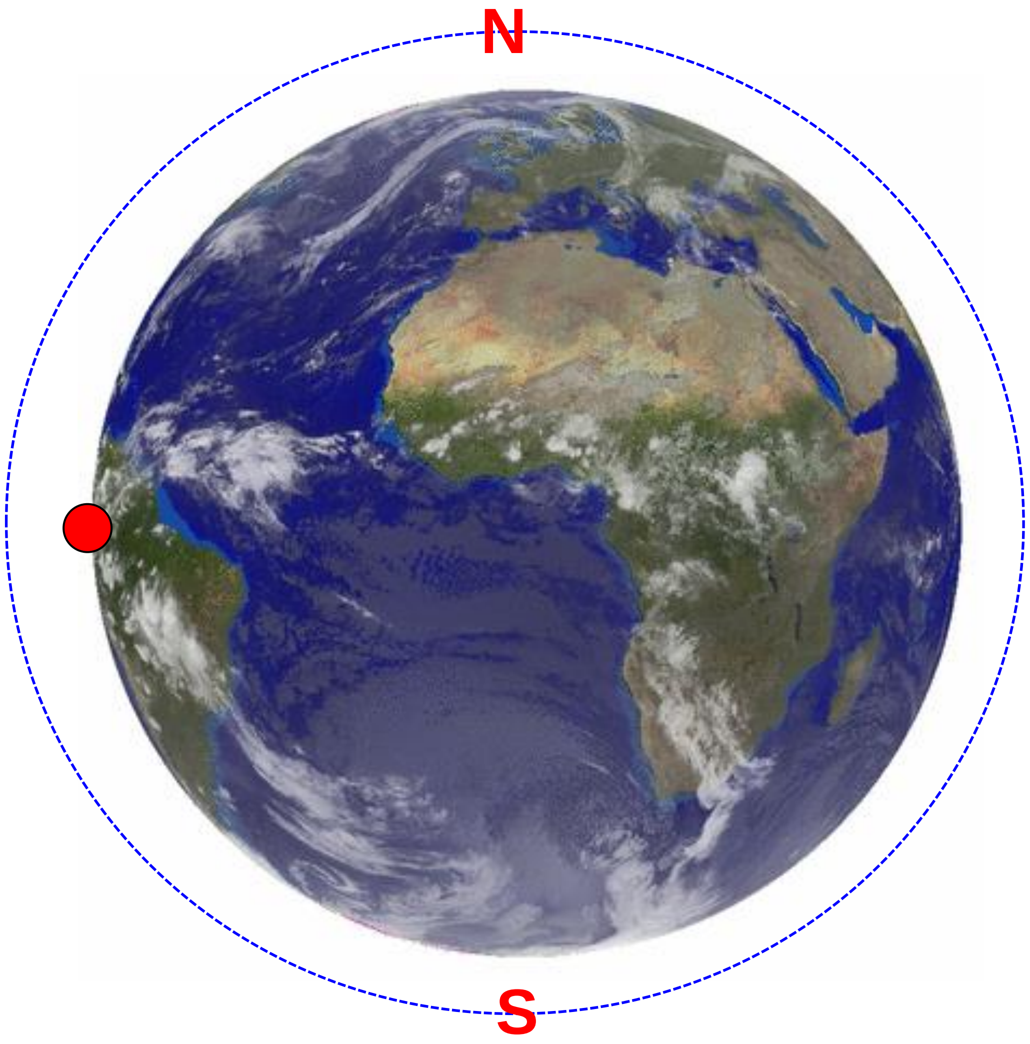
Why doesn't a satellite fall down to Earth?

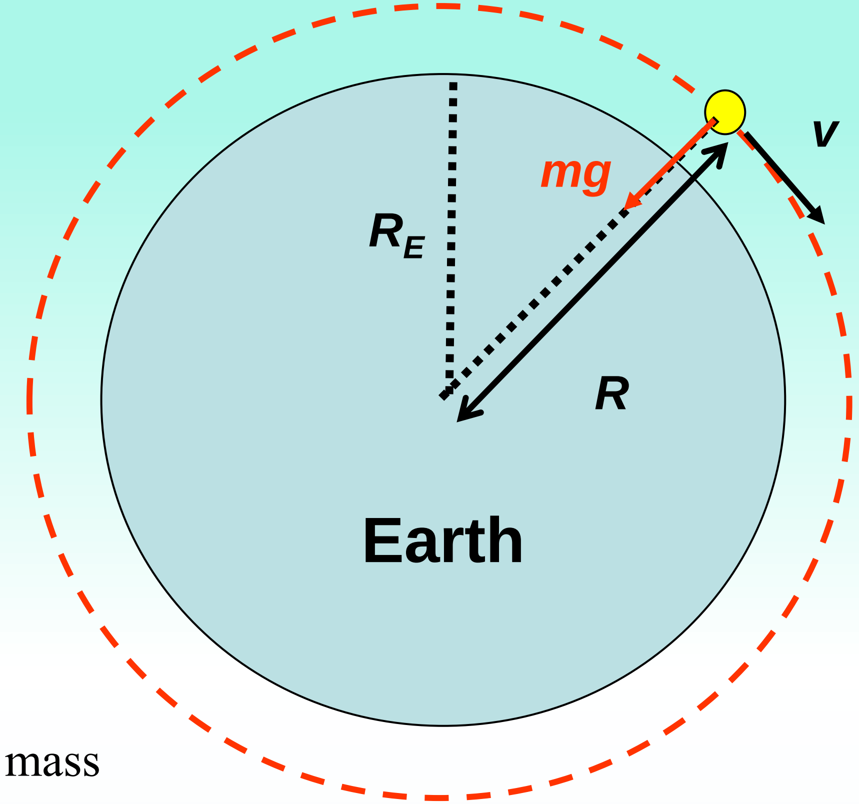


It is falling !!!

The satellite is moving forward at the same time as it is falling, and the earth is not flat.

If the satellite's speed is just right, it follows the curvature of the earth as it falls and never hits the earth surface.

Why doesn't a satellite fall down to Earth?



The gravitational attraction of the earth on the satellite provides the centripetal force required to keep the satellite in orbit.

$$\frac{mv^2}{R} = mg$$

Centripetal Force

Gravitational Attraction

m = satellite's mass

g = gravitational field strength

R = satellite's distance from Earth's centre

v = satellite's orbital speed

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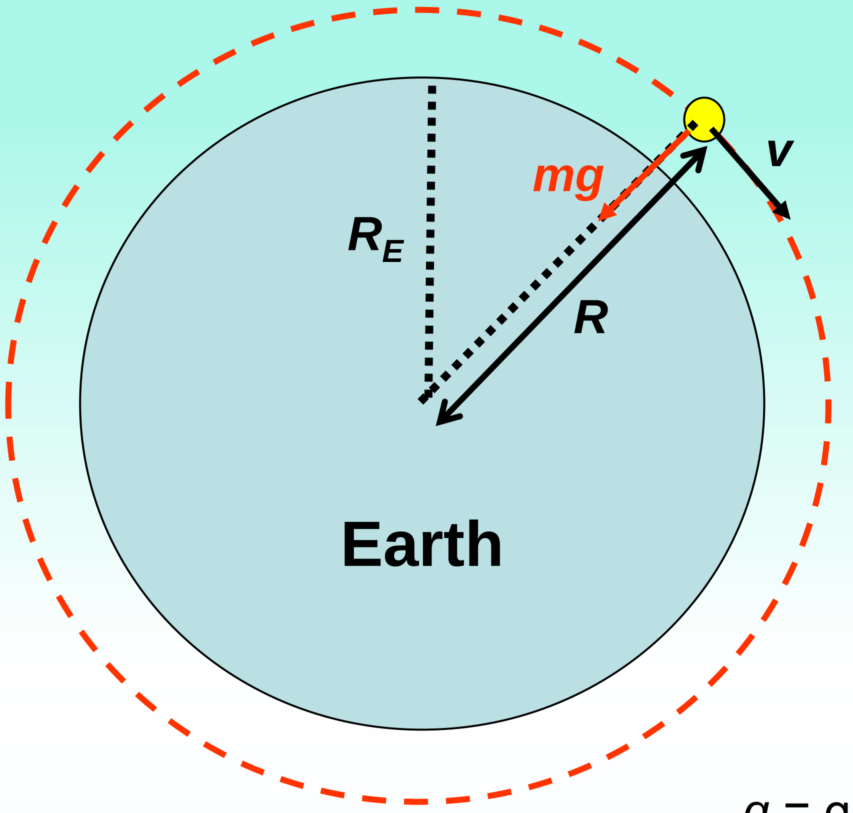
How fast does a satellite move in its orbit?



$$\cancel{m}g = \frac{\cancel{m}v^2}{R}$$

$$v^2 = gR$$

$$v = \sqrt{gR}$$

The gravitational strength g is inversely proportional to the square of the distance from the Earth's centre

$$g = g_0\left(\frac{R_E}{R}\right)^2$$

g = gravitational strength at satellite's orbit
g_0 = *gravitational strength at earth's surface*
R = satellite's orbital radius
R_E = Earth's radius

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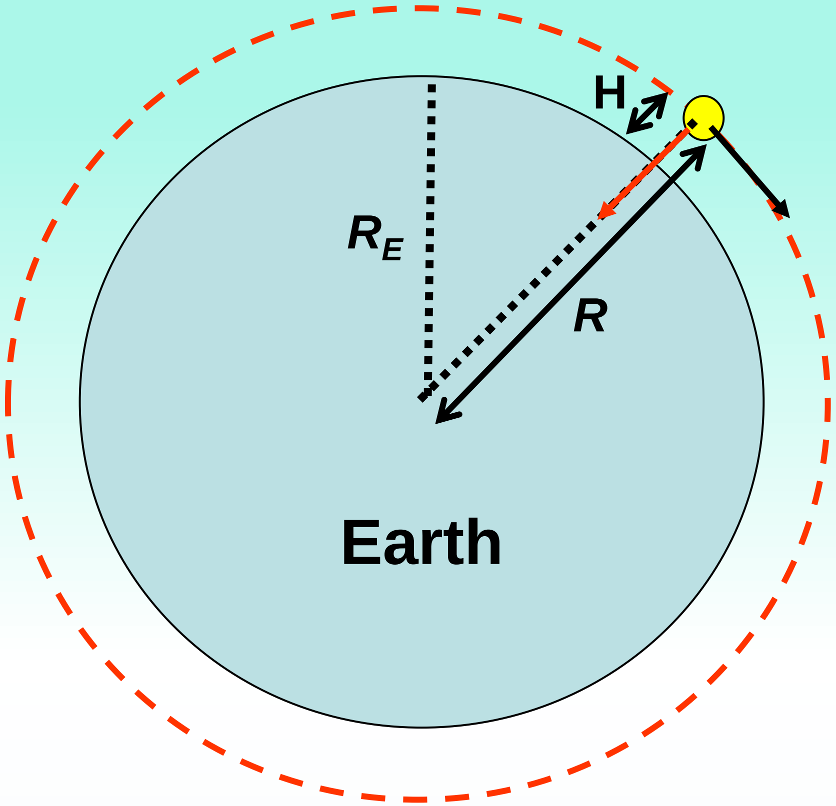
How fast does a satellite move in its orbit?

$$v = \sqrt{gR}$$



Eg. Near to earth's surface,

$R = R_E = 6371$ km, $g = 9.82$ ms^{-2}

$v = 7910$ m/s

E.g. Satellite altitude, H = 750 km
$R = R_E + H = 7121$ km = 7121000 m

Earth's gravitational field strength at surface,
$g_0 = 9.82$ ms^{-2}
Gravitational field strength at orbit altitude,
$g = g_0(R_E/R)^2 = 7.86$ ms^{-2}

Satellite orbital speed,
$v = \sqrt{(7.86 \times 7121000)} = 7481$ ms^{-1}

The orbital speed is approximately 7.5 km per second for a low-earth-orbit (LEO) satellite

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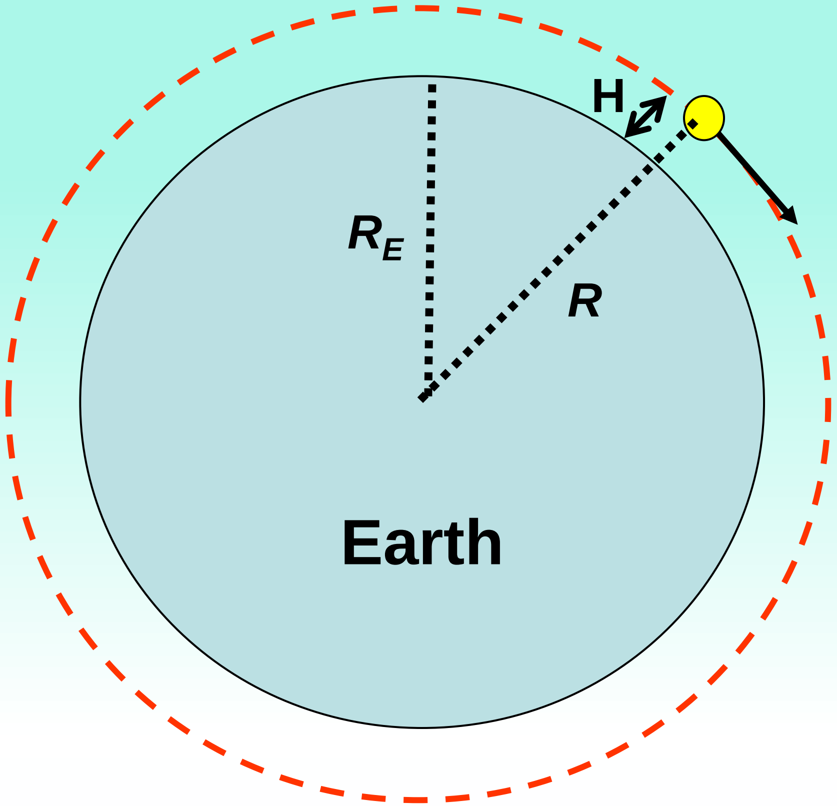
How long does it take for a satellite to travel round the Earth?



E.g. for the previous example,

H = 750 km

R = 7121km

v = 7481 ms^{-2}

Circumference of the orbit = $2\pi R$

= 44743 km = 44743000 m

Orbital Period = time required to complete one orbit

T = $2\pi R$ / v = 5980 s = 99 min 40 s

It takes about 100 min. for a low-earth-orbit satellite to complete one orbit around the earth.

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Speed comparison

Automobile 200 km/h = 55 m/s

Jet plane 900 km/h = 250 m/s

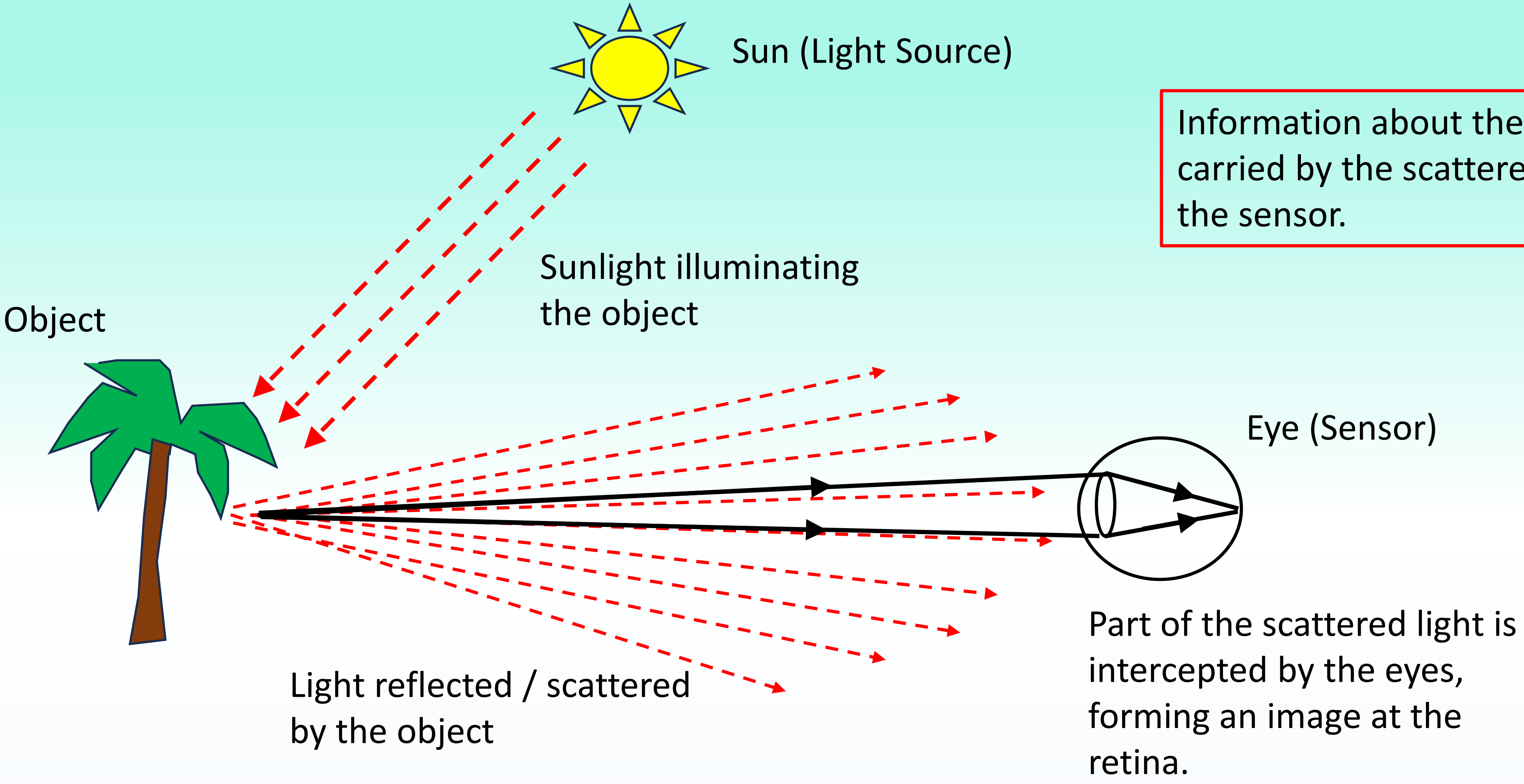
Bullet 3000 km/h = 833 m/s

LEO Satellite 27000 km/h = 7500 m/s

Speed of sound in air ≈ 340 m/s

How do we sense / observe the Earth from space?

Example: Our visual system



Information about the object is carried by the scattered light to the sensor.

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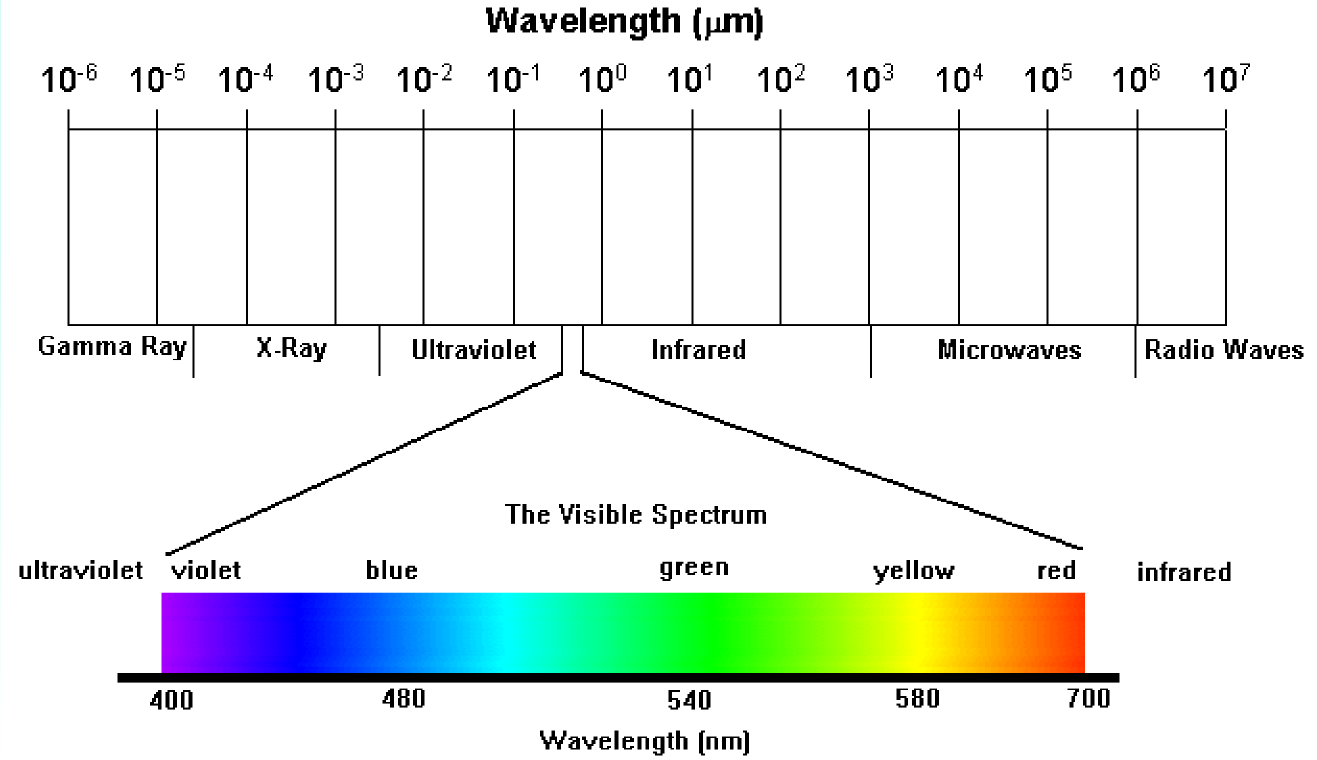
Electromagnetic Spectrum



The electromagnetic spectrum can be divided into several wavelength (frequency) regions, among which only a narrow band from about 400 to 700 nm is visible to the human eyes. Note that there is no sharp boundary between these regions. The boundaries shown in the above figures are approximate and there are overlaps between the adjacent regions.

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Visible and Infrared Bands

- **Visible Light: 400 nm to 700 nm**
  - **Blue: 400 – 500 nm**
  - **Green: 500 – 600 nm**
  - **Red: 600 – 700 nm**
- **Infrared: 0.7 to 300 µm**
  - **Near Infrared (NIR): 0.7 to 1.5 µm.**
  - **Short-Wave Infrared (SWIR): 1.5 to 3 µm.**

Solar Spectral Region

(Reflection of Sunlight from Earth's Surface)

- **Mid-Wave Infrared (MWIR): 3 to 8 µm.**
- **Long Wave Infrared (LWIR): 8 to 15 µm.**
- **Far Infrared (FIR): longer than 15 µm.**

Thermal Emissive Region

(Infrared Emission from Earth's surface)

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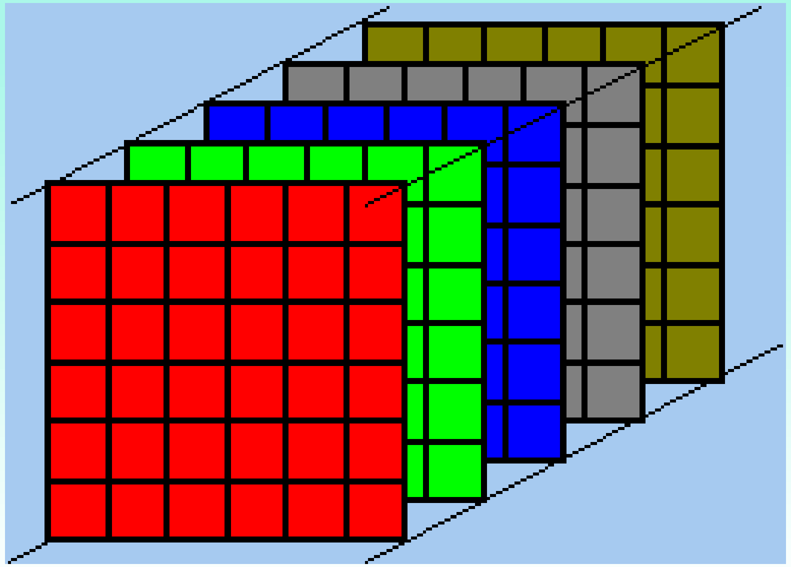
Multispectral Image



A multispectral image consists of a few image layers stacked together. Each layer represents an image acquired at a particular spectral band.

For example, a digital camera acquire images in three visible bands: Red, Green and Blue (RGB). In this case, each pixel of a picture has three intensity values corresponding to the three bands.

Satellite sensors usually acquire images in many more bands, beyond the visible to the NIR, SWIR and also thermal IR bands.

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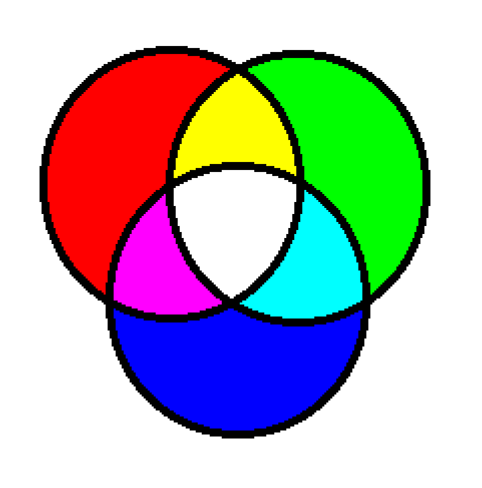
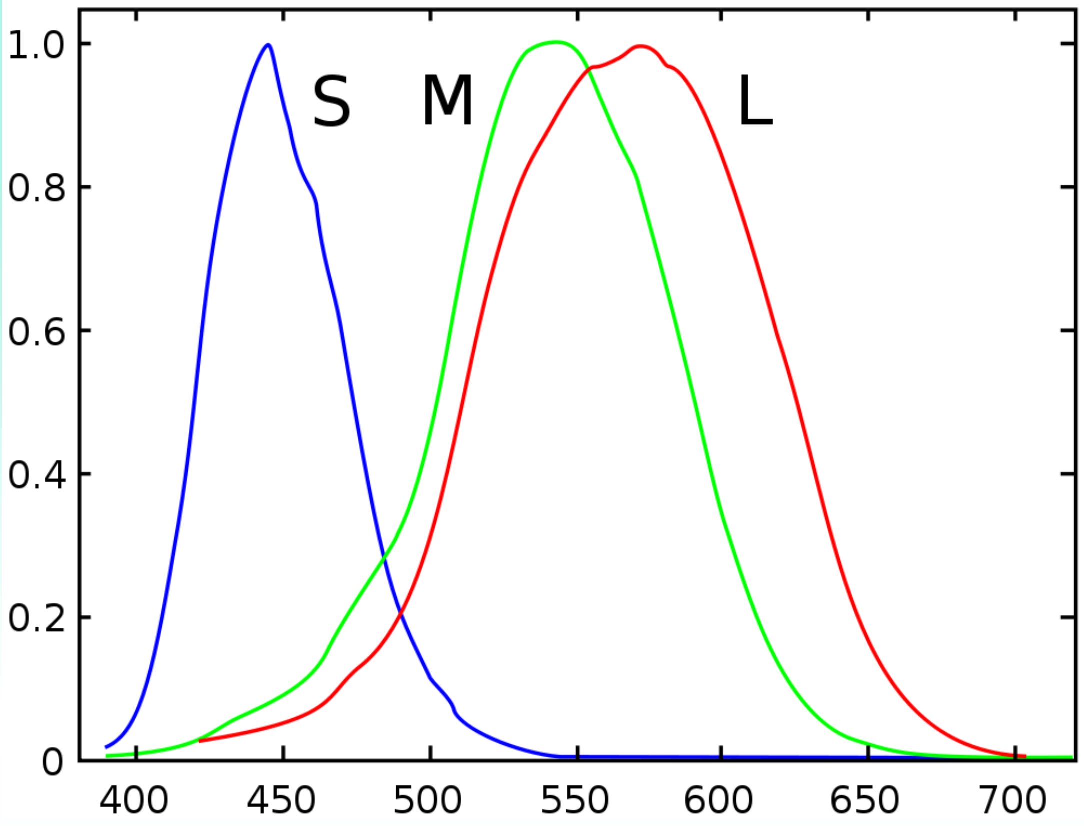
RGB Display Colour Space



- Our eyes have three types of colour sensors (known as the “cones”) and one type of intensity sensor (the “rods”). The cones are sensitive to three spectral regions (Red, Green, Blue).
- Three primary colours (RGB) are sufficient to generate most of the perceivable colours.

A colour display system consists of 3 display channels: R, G and B; each channel displays its respective colour component.

Color sensitivity of cone cells



Normalized typical human cone cell responses (S, M, and L or ‘blue’, ‘green’ and ‘red’ types) to monochromatic spectral stimuli
Source: Wikipedia (Color)

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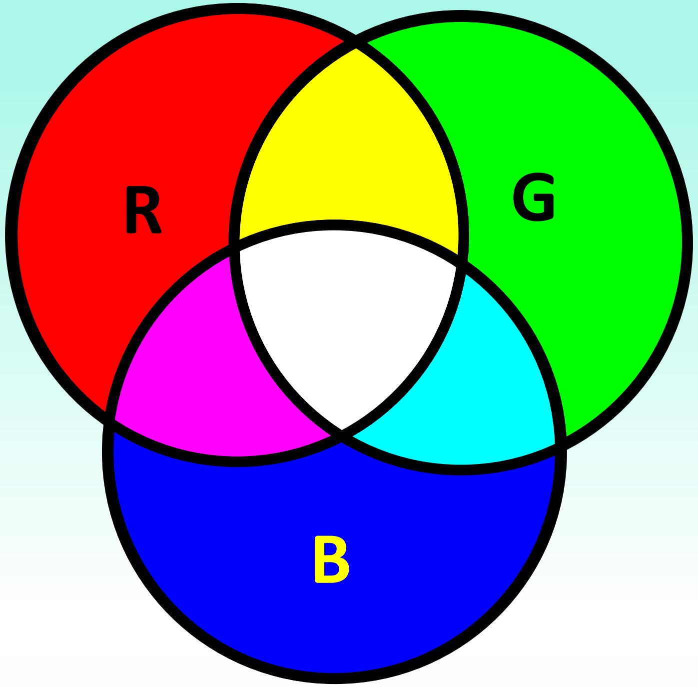
Additive Color Space (RGB)

Primary Colors

Red

Green

Blue



Secondary Colors

Yellow (R + G)

Cyan (G + B)

Magenta (B + R)

White, Grey (R + G + B)

Colour Image

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Colour Image – Red Component

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Colour Image – Green Component

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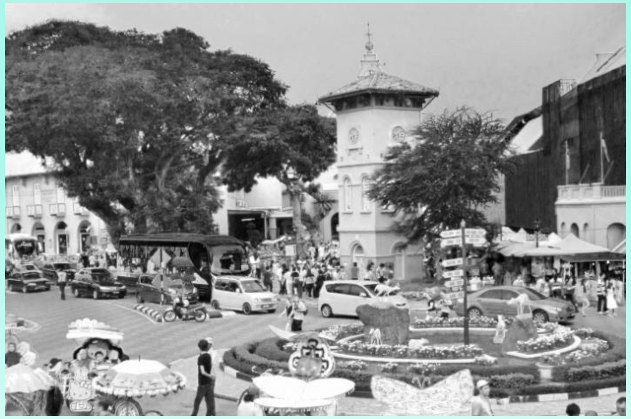
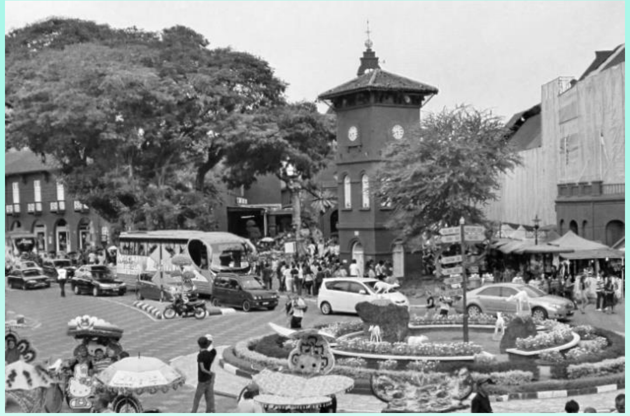
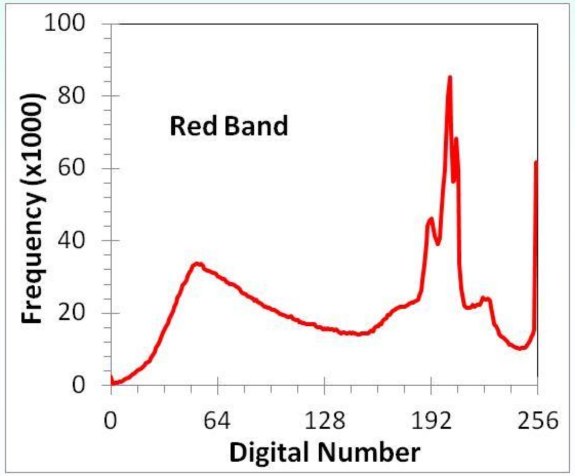
Colour Image – Blue Component

R, G, B components

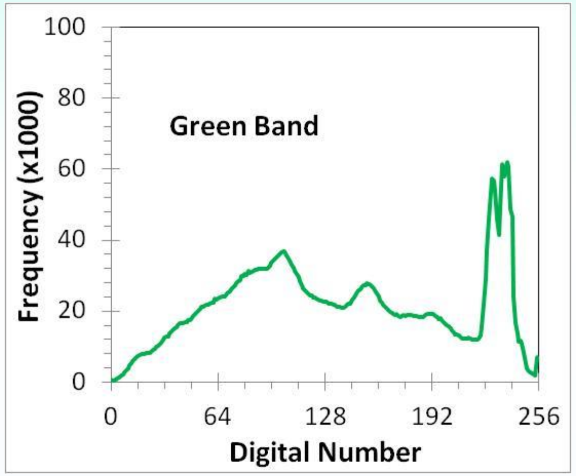




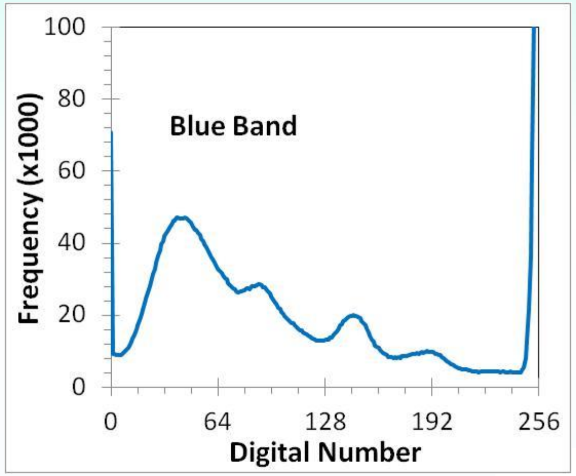
Red Band



Green Band



Blue Band



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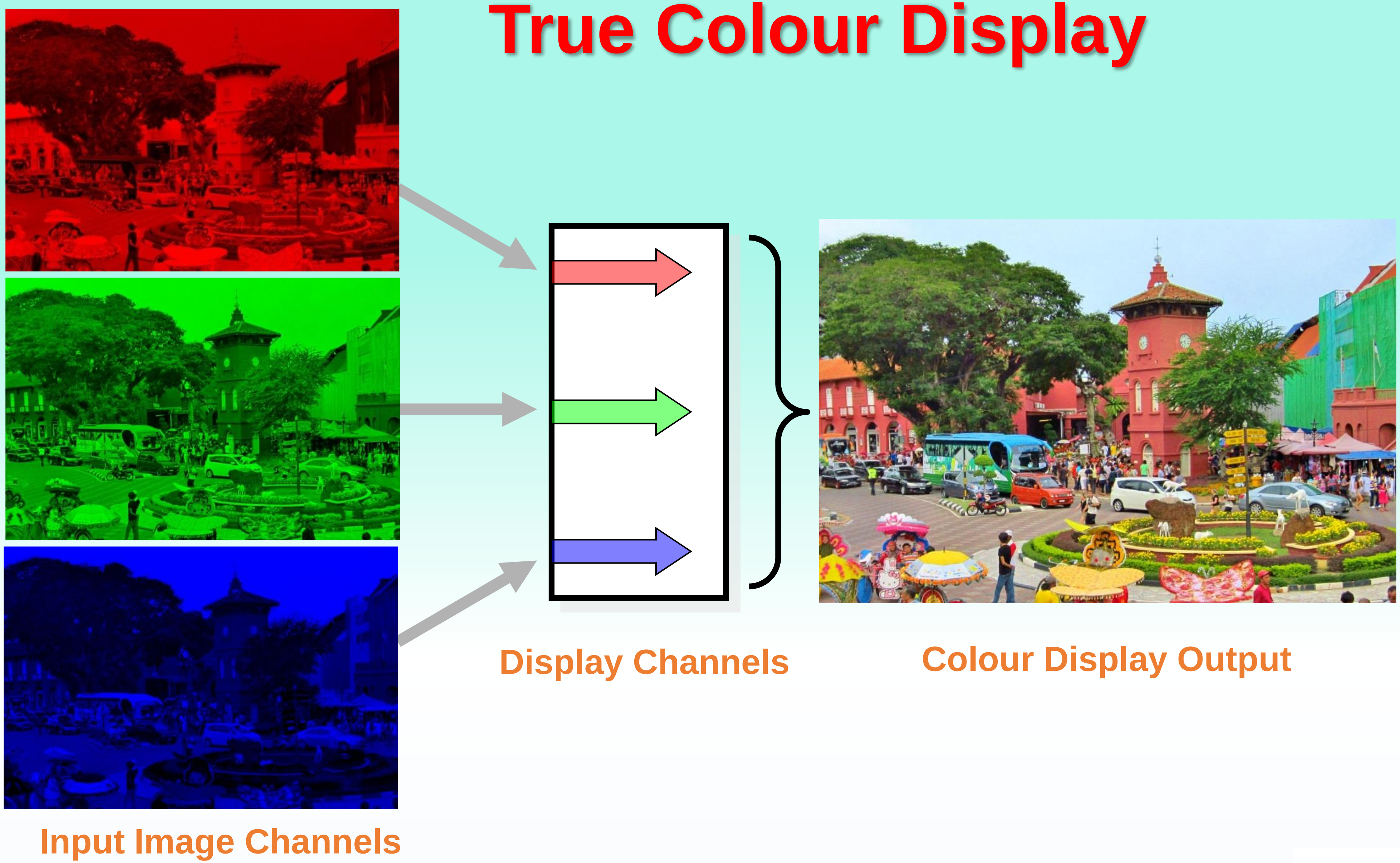
True Colour Display



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But you don't need to always follow the conventional colour display scheme!

False Colour Display

Input Image Channels

Display Channels

Colour Display Output

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Another False Colour Display

Input Image Channels

Display Channels

Colour Display Output

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Different Colour Display Schemes

Spectral Bands	Blue	Green	Red
Display Channels	Blue	Green	Red

Spectral Bands	Red	Blue	Green
Display Channels	Blue	Green	Red

Spectral Bands	Red	Green	Blue
Display Channels	Blue	Green	Red

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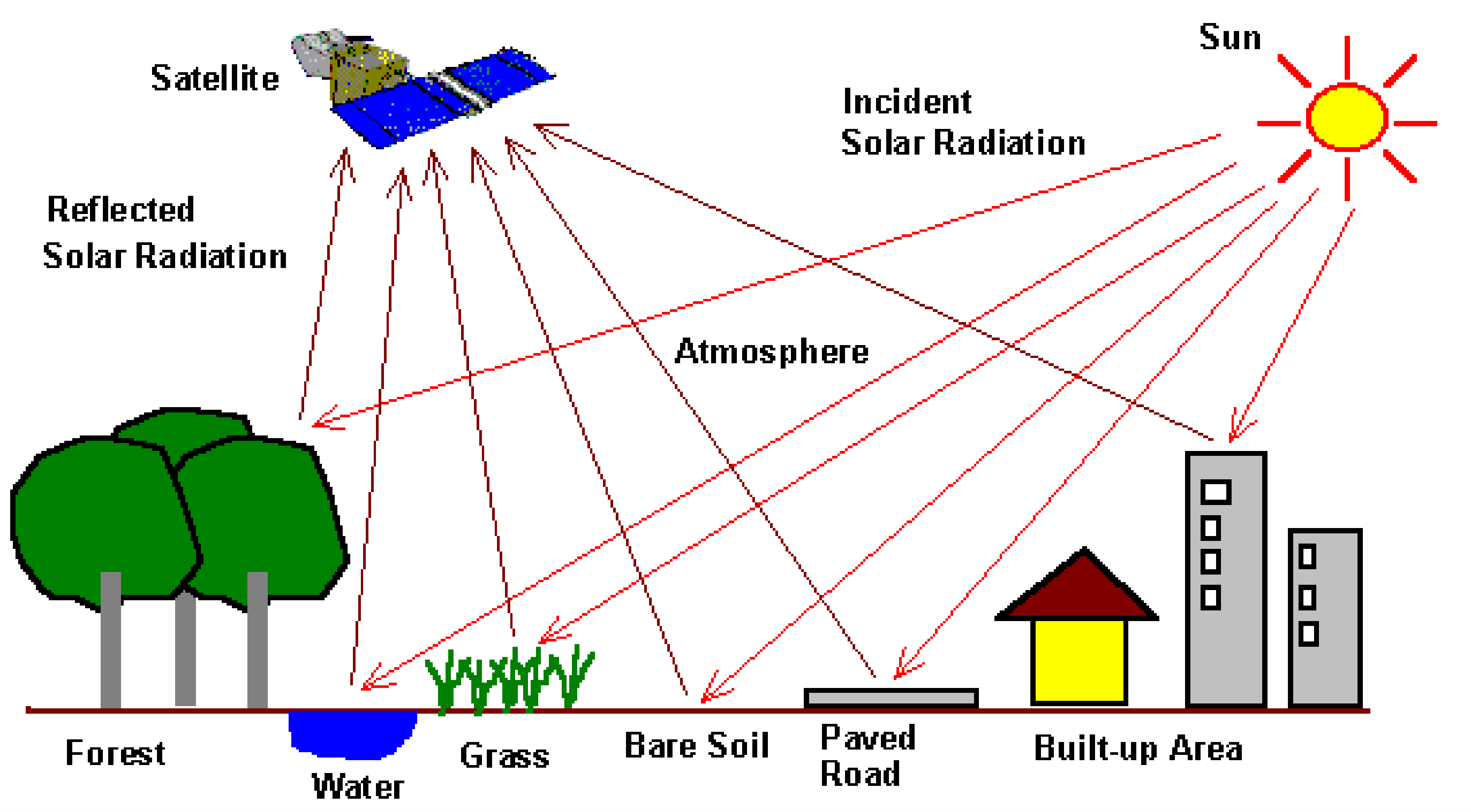
What information can we get from satellite images?

Three main types of remote sensing systems

- Optical Remote Sensing
  - Reflection of sun light from earth's land and ocean surfaces and the atmosphere
  - Visible light – Near Infrared – Shortwave Infrared
- Thermal Remote Sensing
  - Emission of thermal infrared by warm objects
- Microwave Remote Sensing
  - Passive microwave emission
  - Active radar

There are also other types of remote sensing systems, using specialized sensors for specific applications.

Optical Remote Sensing



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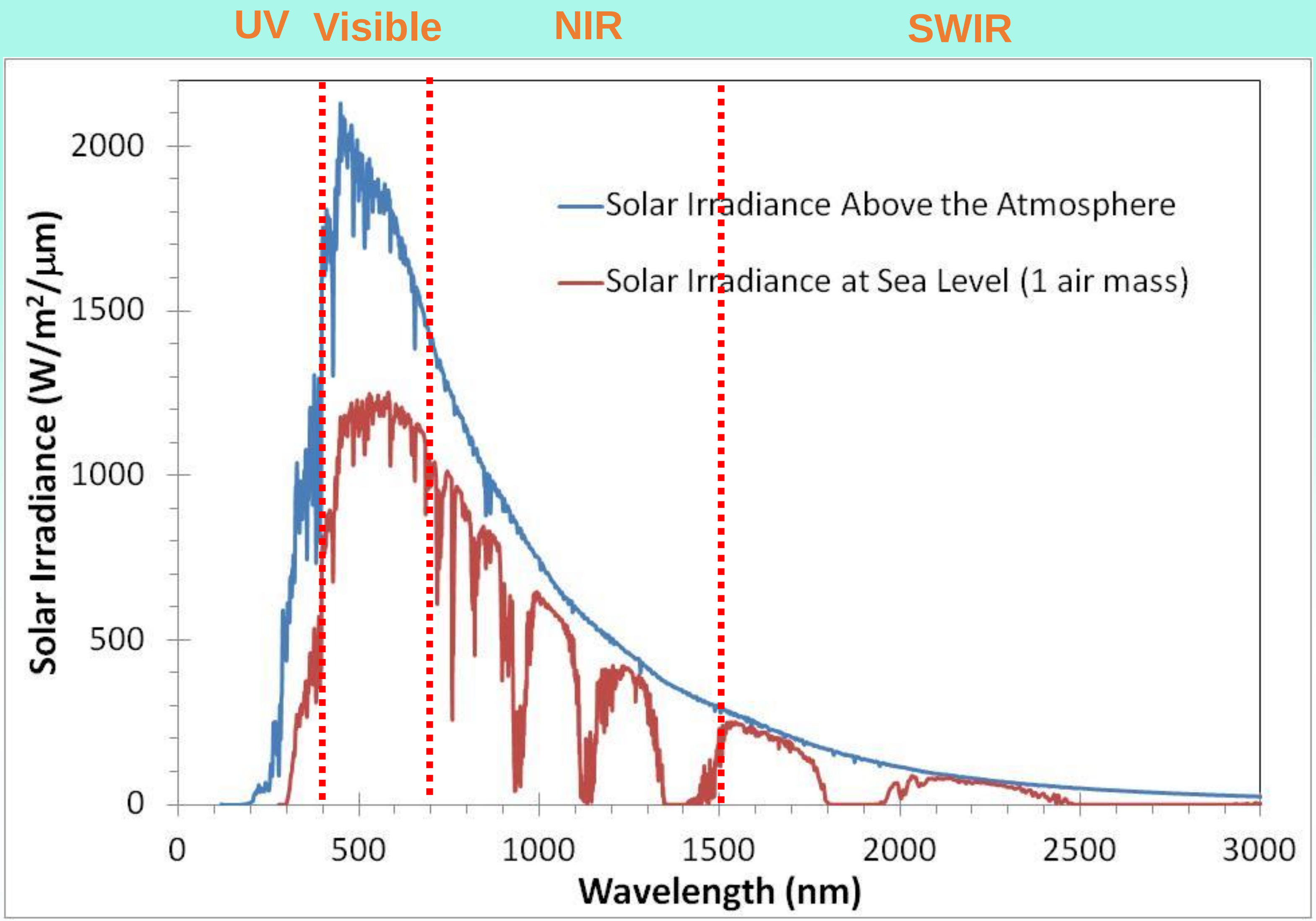
Solar Spectrum



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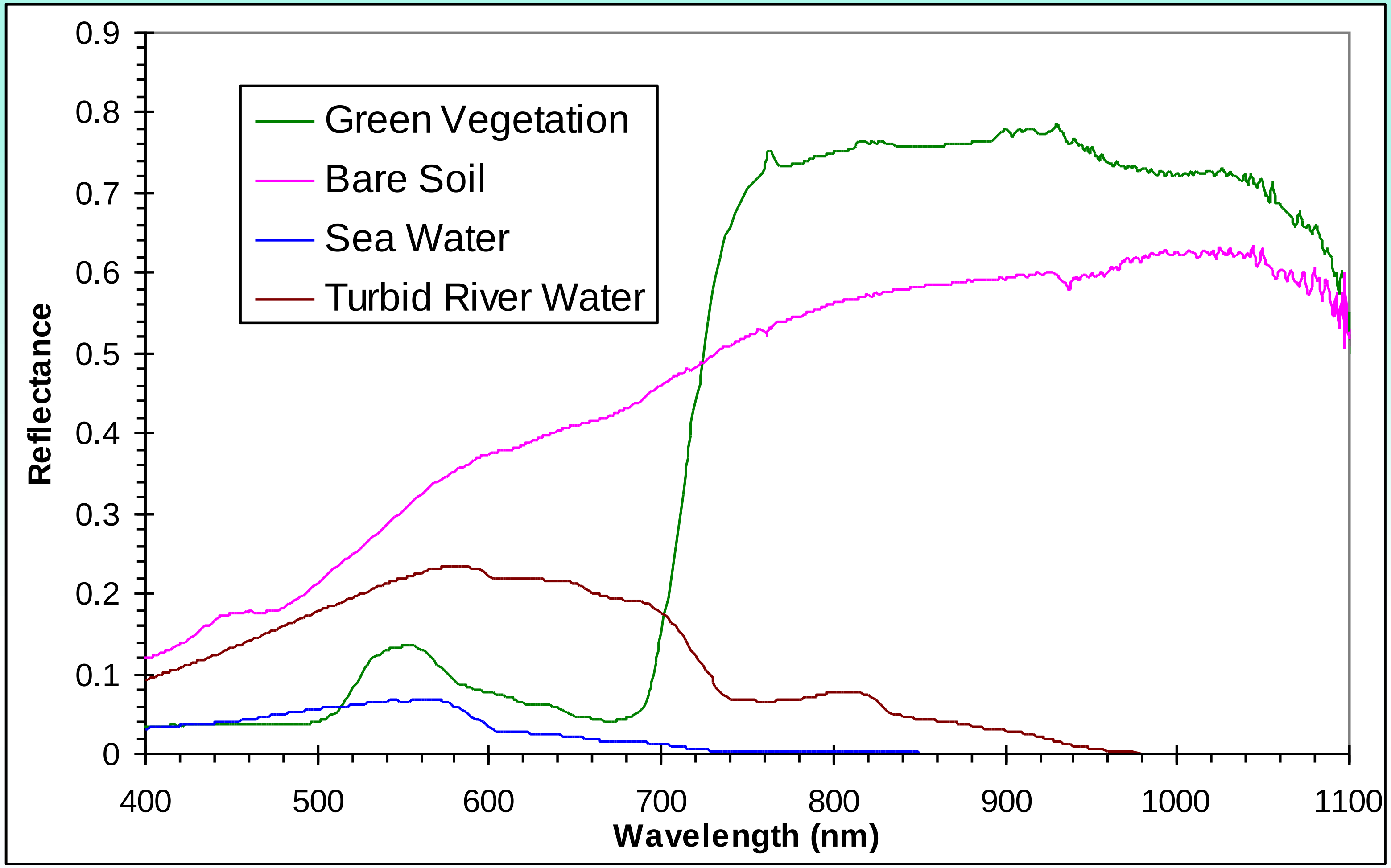
Typical reflectance signatures of some land cover types



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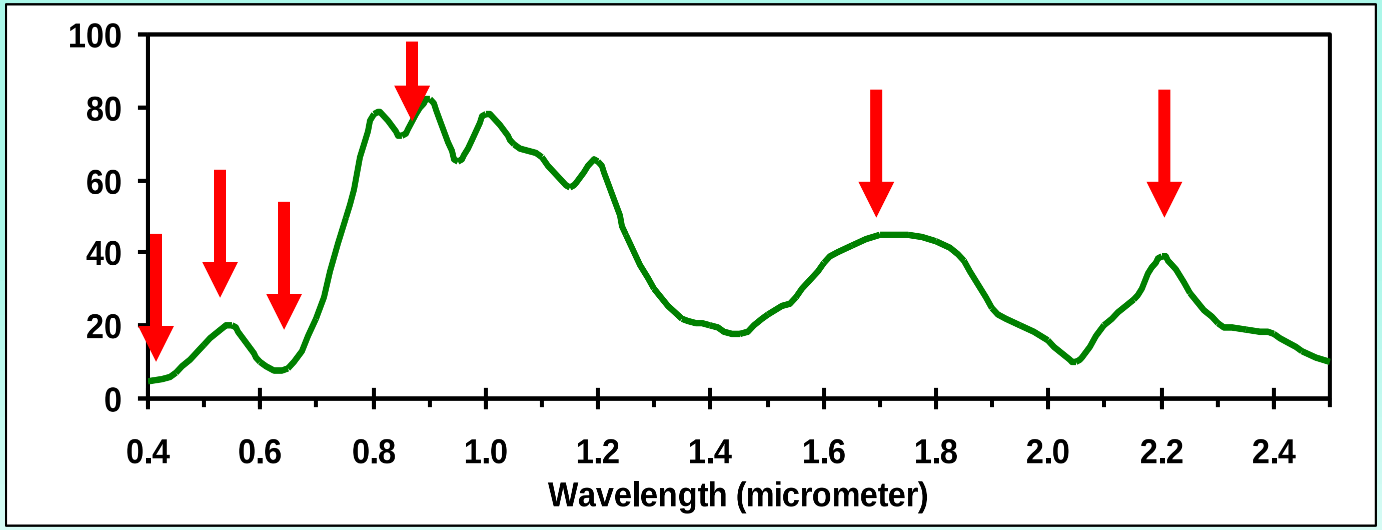
Vegetation Spectral Response



- Blue - Strong absorption by chlorophyll
- Green - Max. reflectance in visible band
  Relatively insensitive to chlorophyll
- Red - Second absorption peak of chlorophyll
- NIR - Strong reflectance due to cellular structure
- SWIR - Sensitive to water content

Landsat 4

Band 1 (Blue)

Grey Scale Display

Landsat 4

Band 2 (Green)

Grey Scale Display

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Landsat 4

Band 3
(Red)

Grey Scale
Display

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Landsat 4

Band 4 (NIR)

Grey Scale Display

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Landsat 4

Band 5
(SWIR
1.6 μm)

Grey Scale
Display

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Landsat 4

Band 7
(SWIR
2.2 μm)

Grey Scale
Display

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Landsat 4

True Color Image

R → Red
G → Green
B → Blue

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Landsat 4

False Color Image

R → NIR
G → Red
B → Green

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Landsat 4

False Color Image

R → SWIR
G → NIR
B → Red

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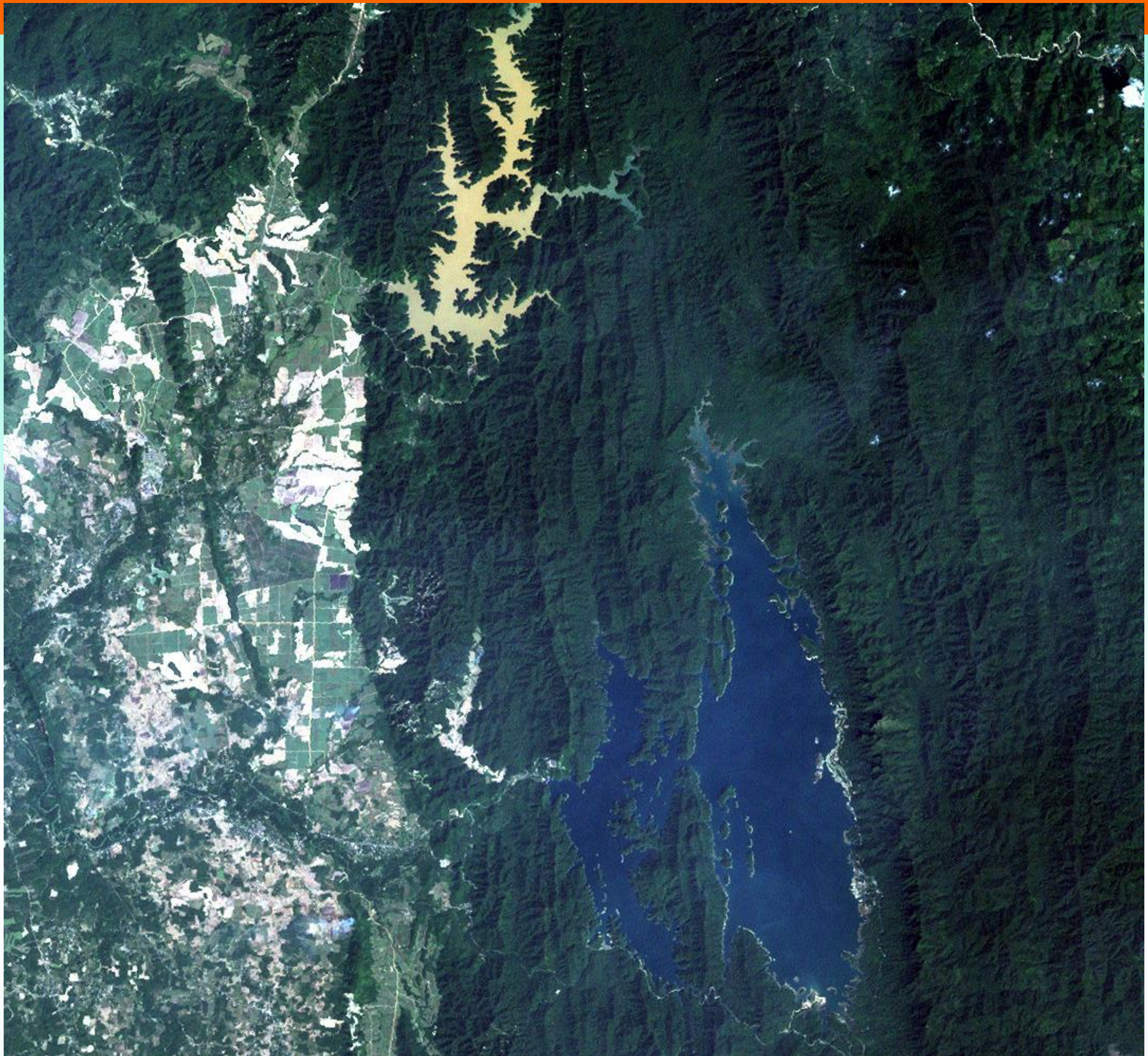

Landsat 7

2002-01-17
Pedu Lake

True Color Image

R → Red
G → Green
B → Blue

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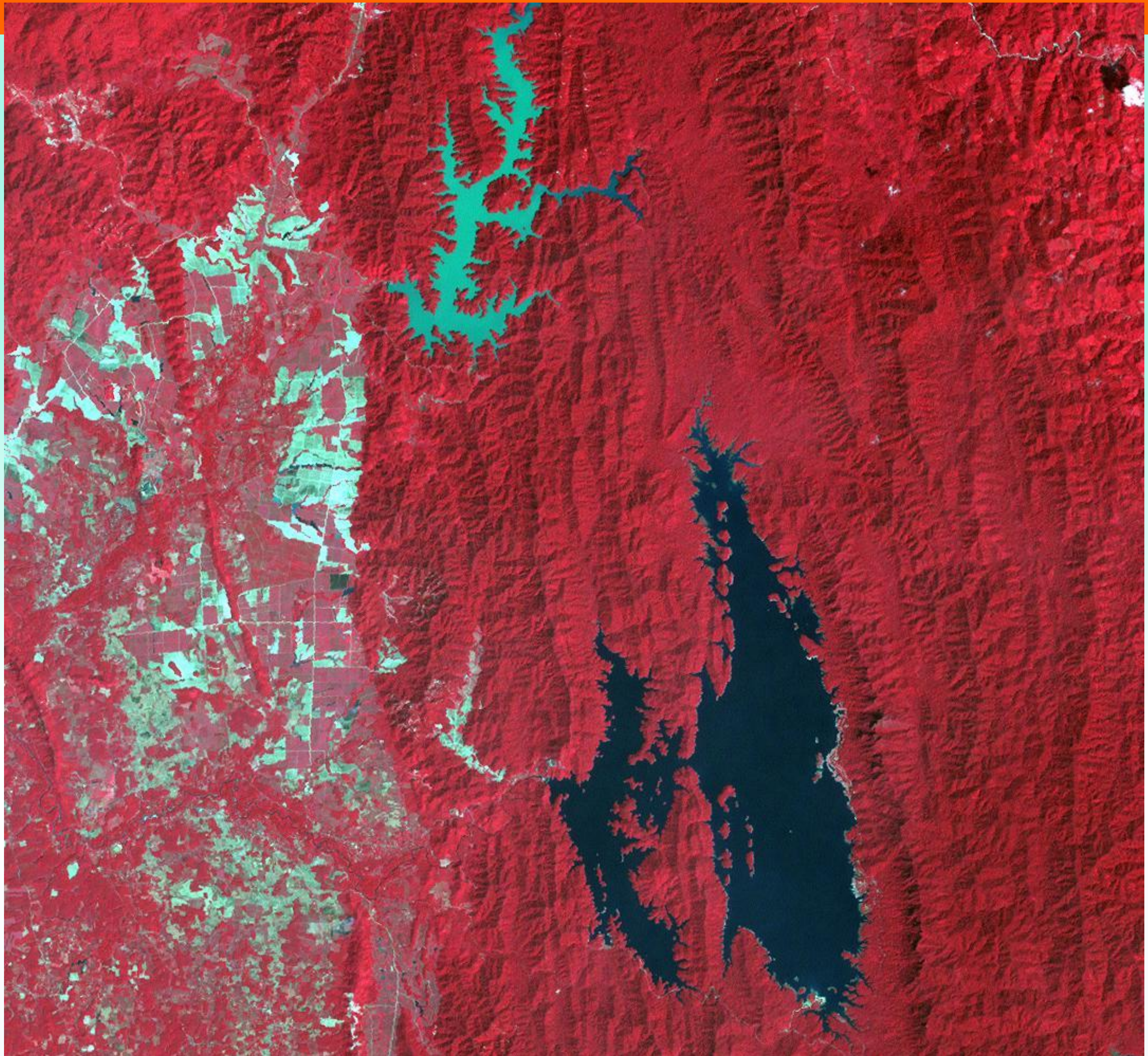

Landsat 7

2002-01-17
Pedu Lake

False Color Image

R → NIR
G → Red
B → Green

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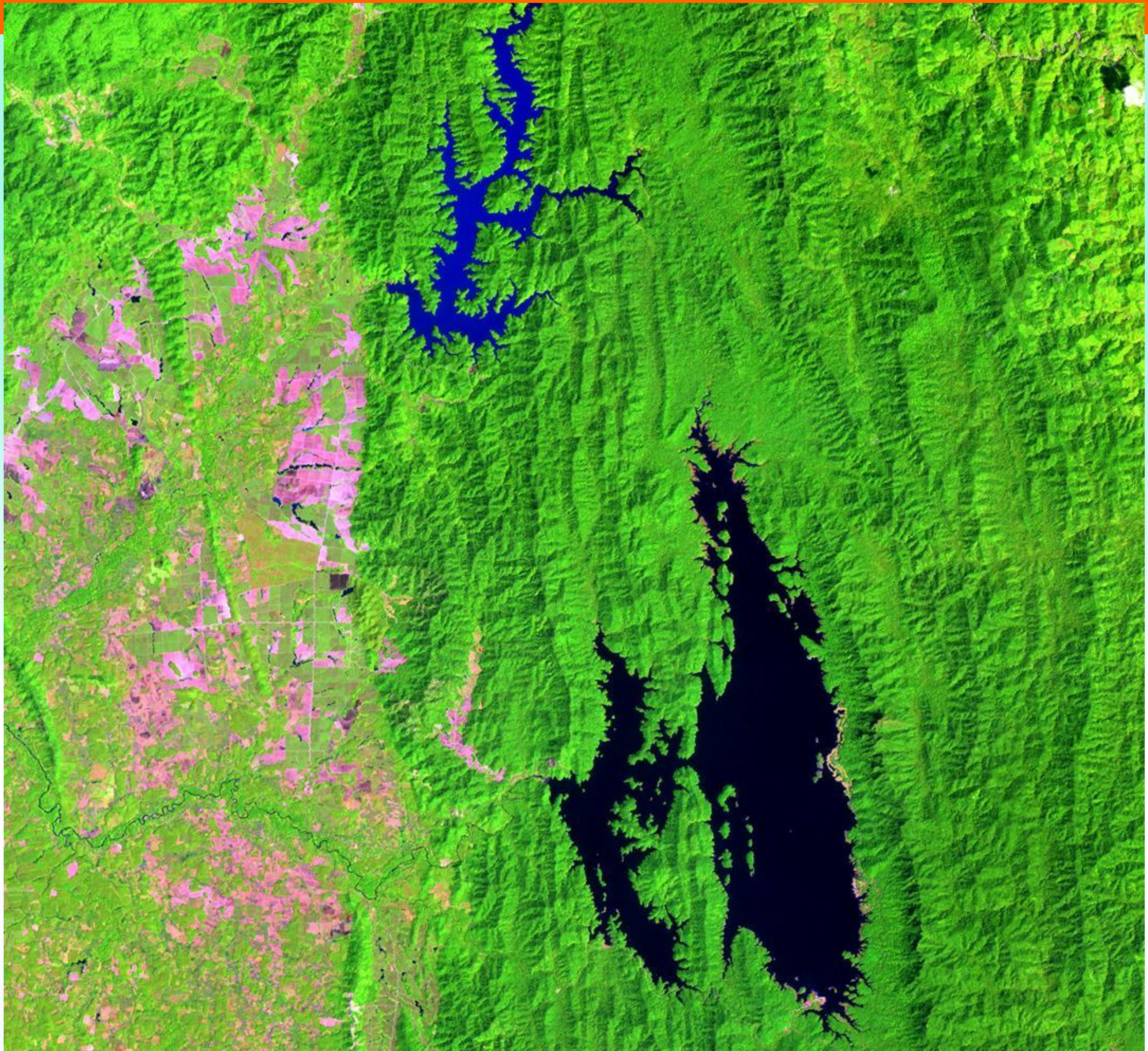

Landsat 7

2002-01-17
Pedu Lake

False Color Image

R → SWIR
G → NIR
B → Red

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Ikonos Image of fire near Kuala Lumpur, 17 Feb 2002, True colour Image

Ikonos Image of fire near Kuala Lumpur, 17 Feb 2002, False colour image (RGB = bands 432)

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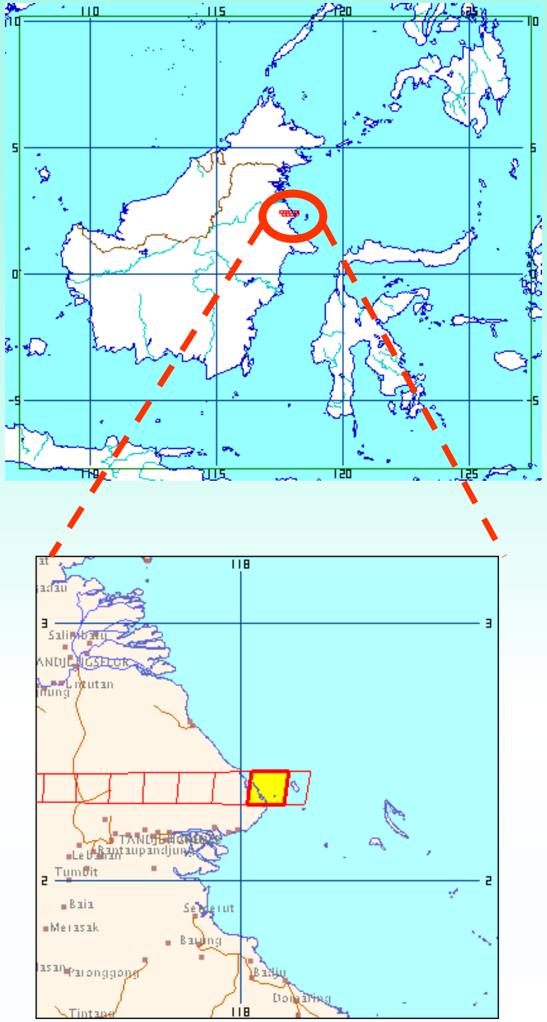
Which areas are under water? which areas are exposed above water?



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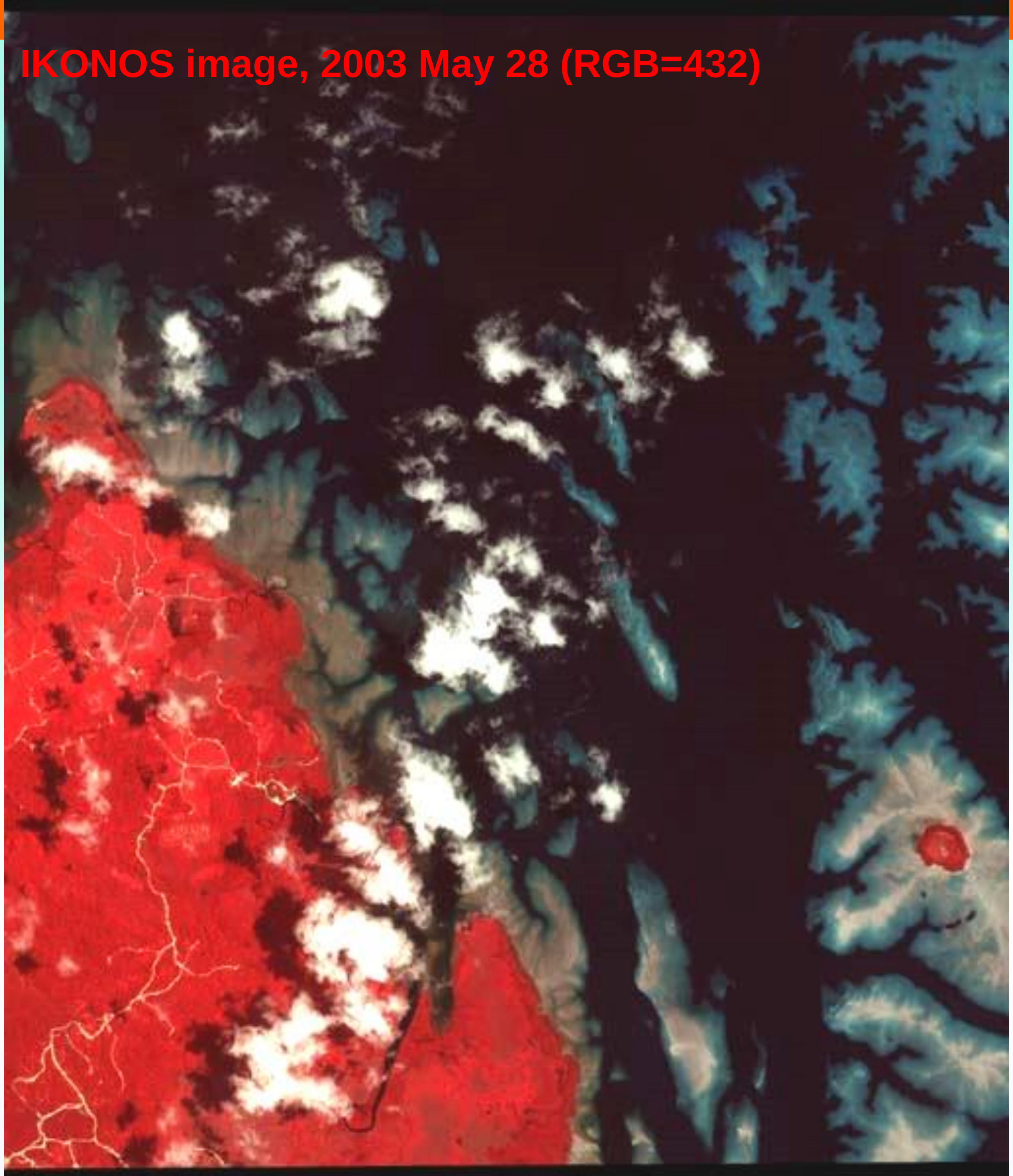
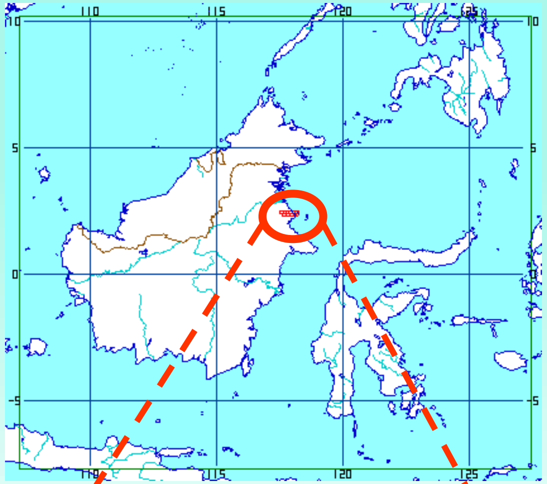
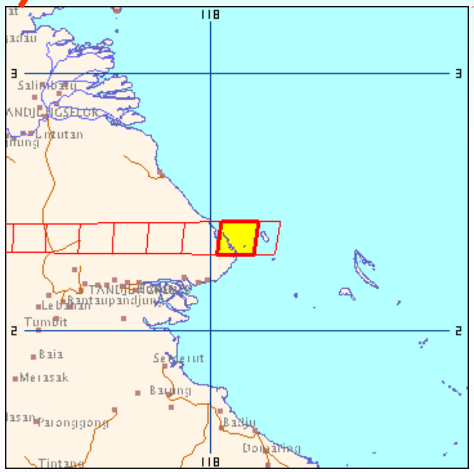


Which areas are under water? which areas are exposed above water?





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Landsat 2001-02-25, Logging tracks, Sarawak (RGB=321)

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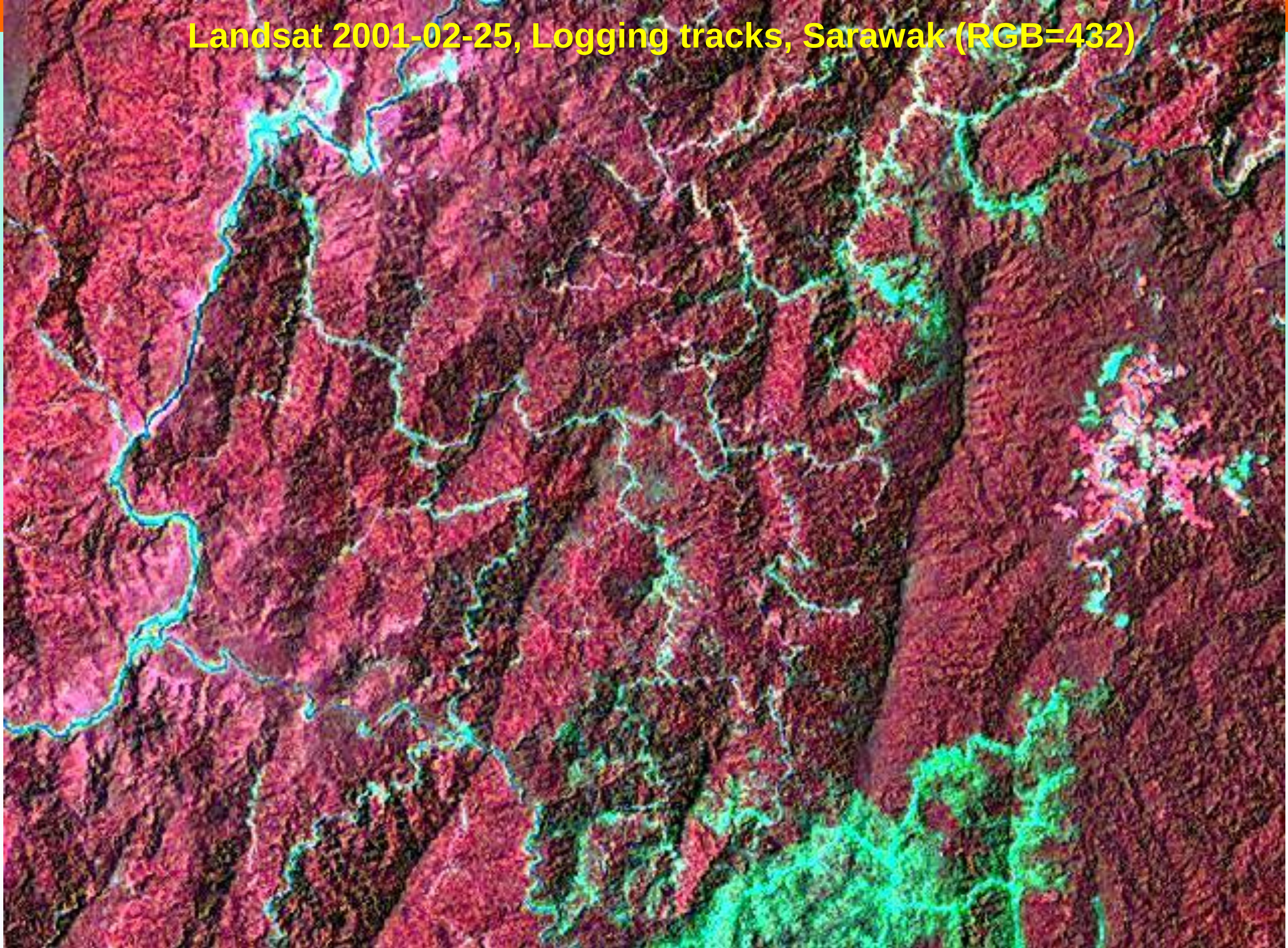
Landsat 2001-02-25, Logging tracks, Sarawak (RGB=432)



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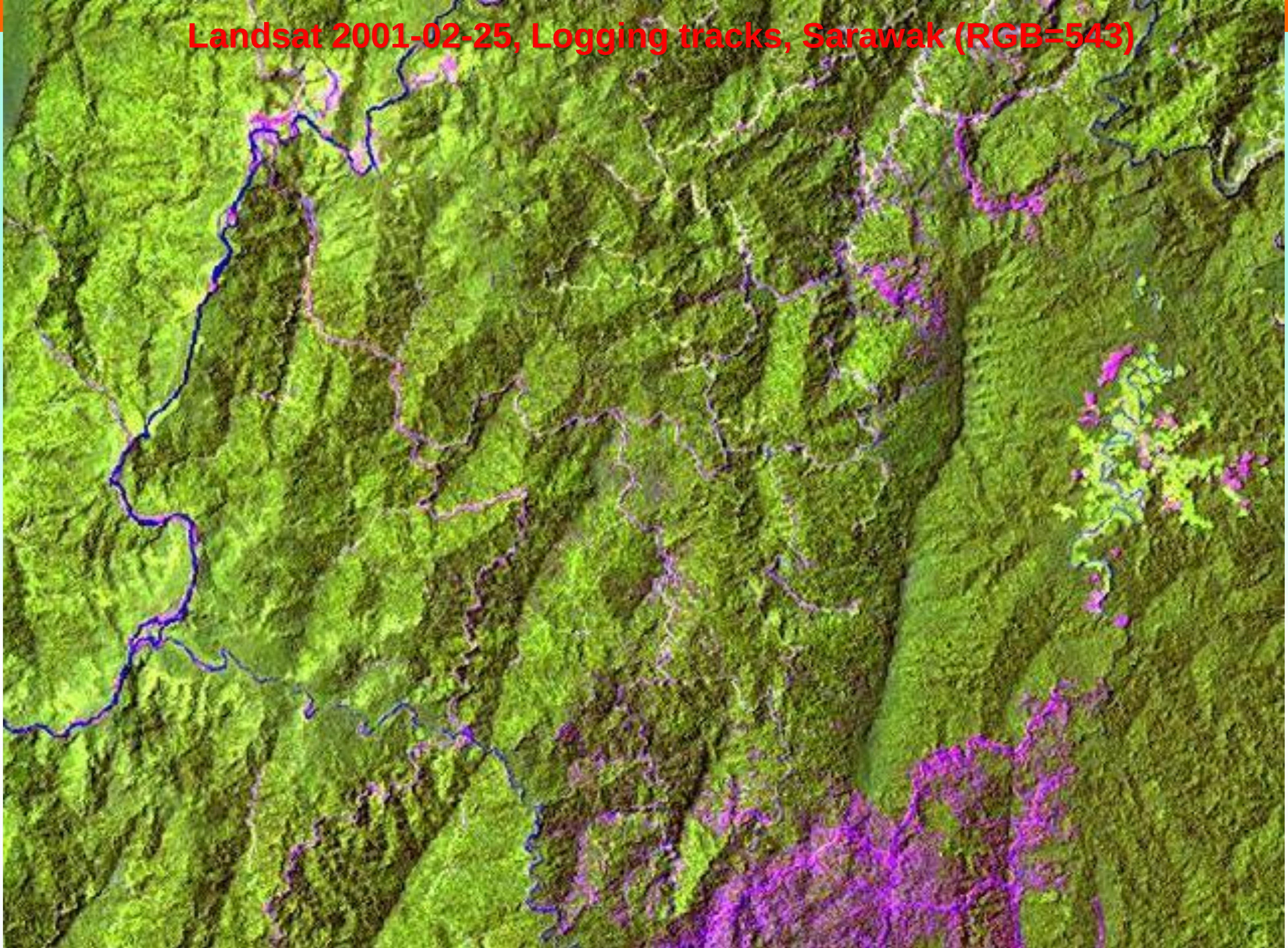
Landsat 2001-02-25, Logging tracks, Sarawak (RGB=543)



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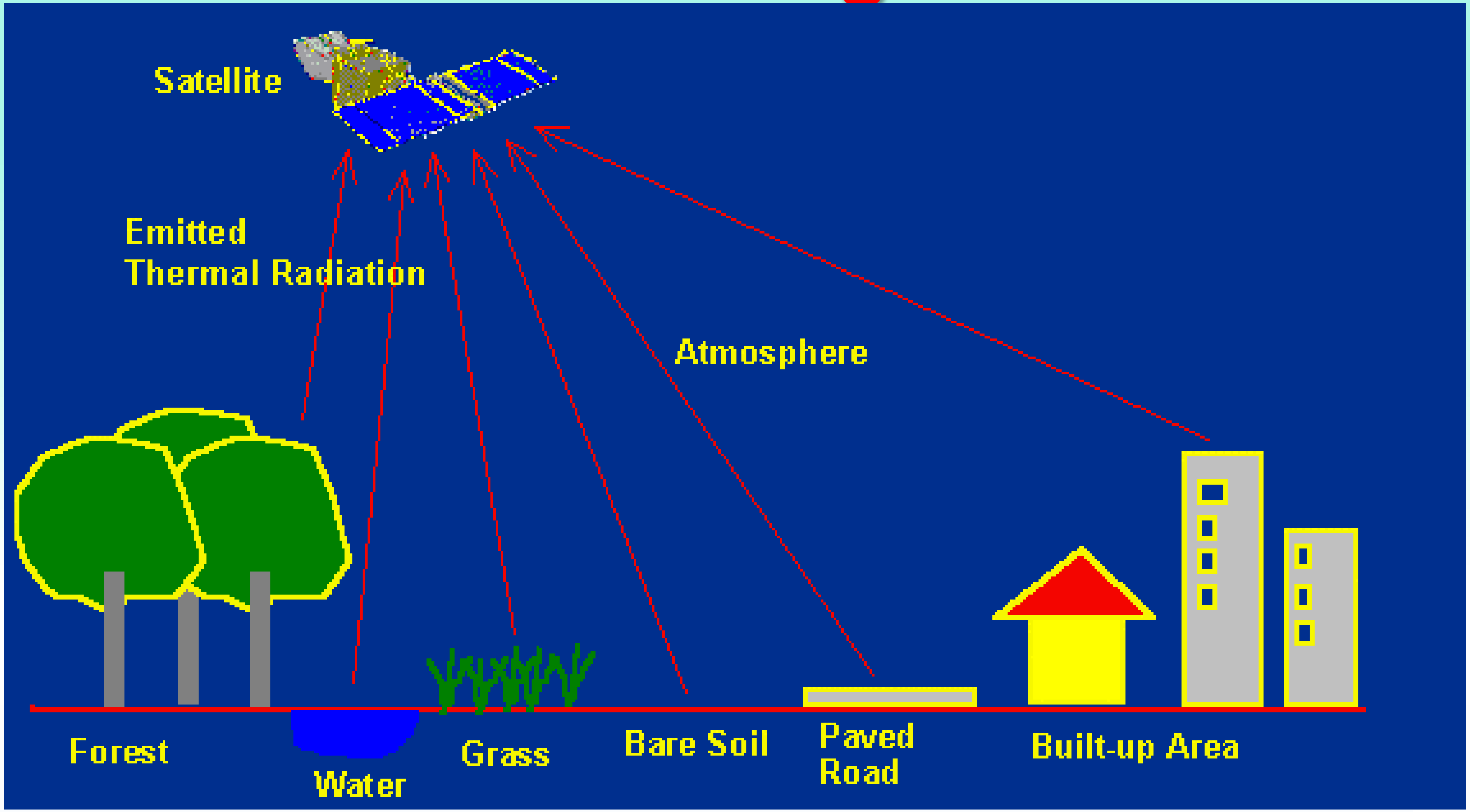
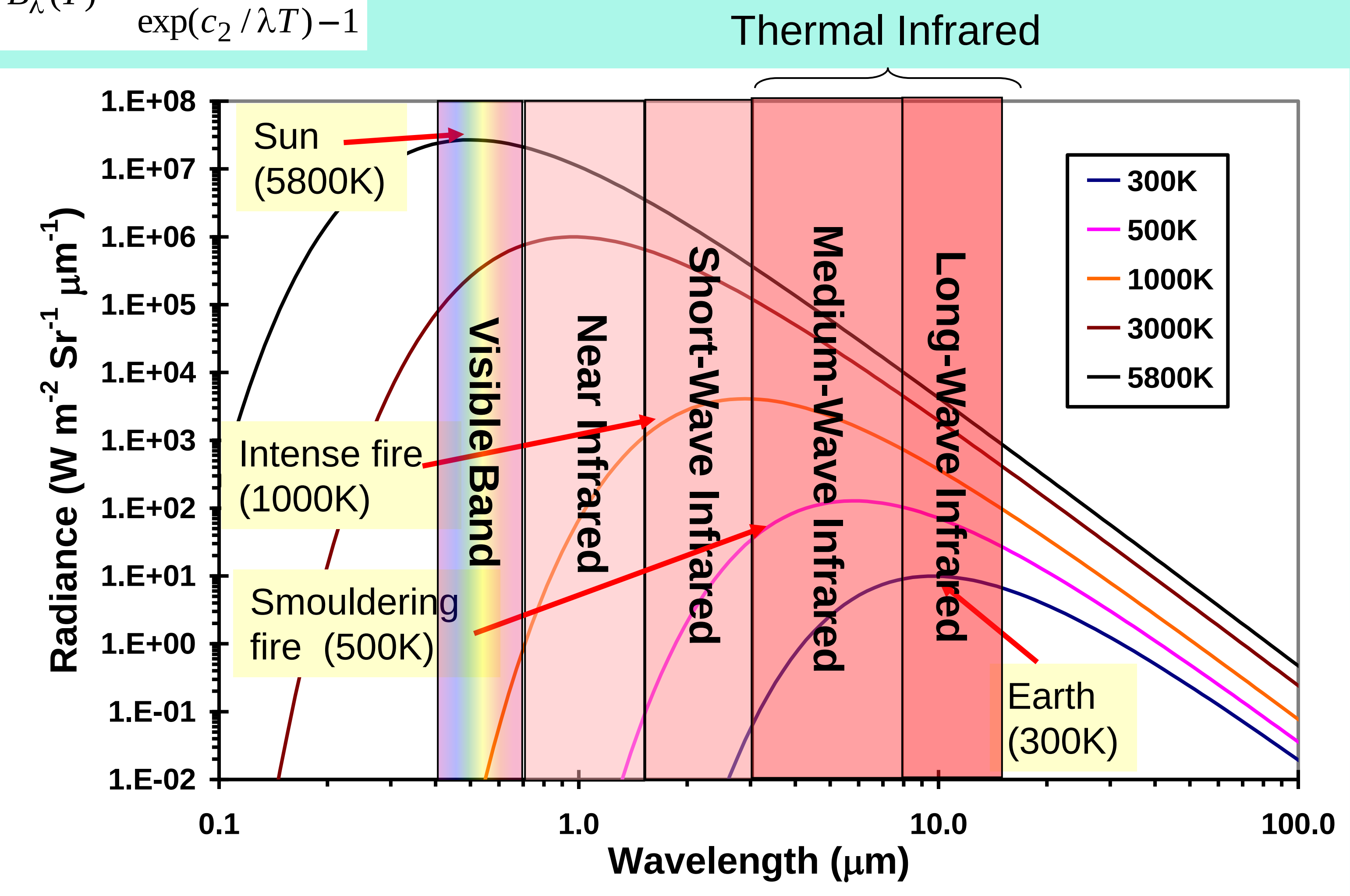
Infrared Remote Sensing



Thermal Emission

$$B_\lambda(T) = \frac{c_1/\lambda^5}{\exp(c_2/\lambda T) - 1}$$



MODIS

Fire hot spots and smoke plumes - Riau, Sumatra

25 June 2005
03:55 UTC

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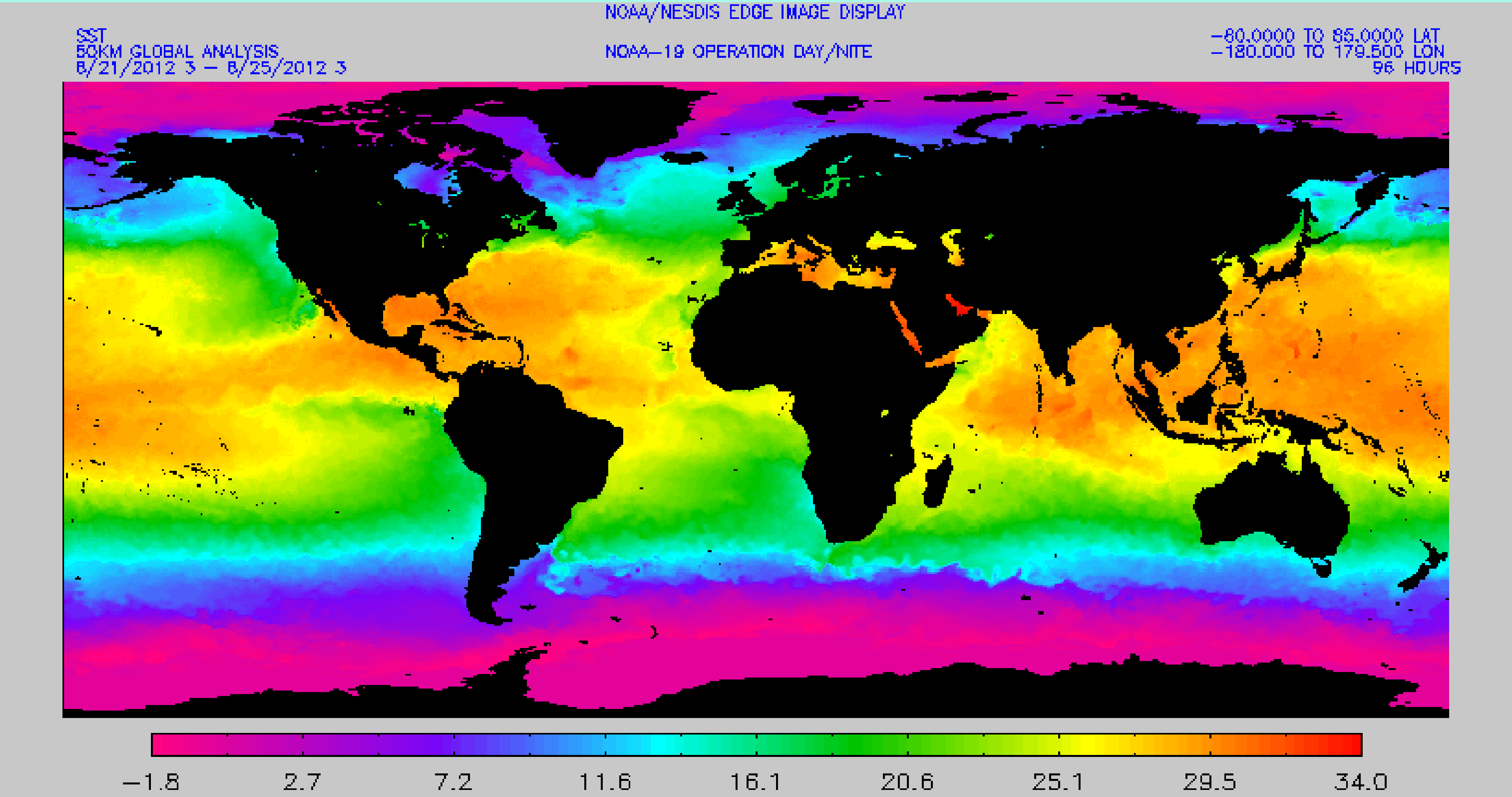
Global Sea Surface Temperature



21 to 25 August 2012 (96 hours composite image) – NOAA National Climate Data Center

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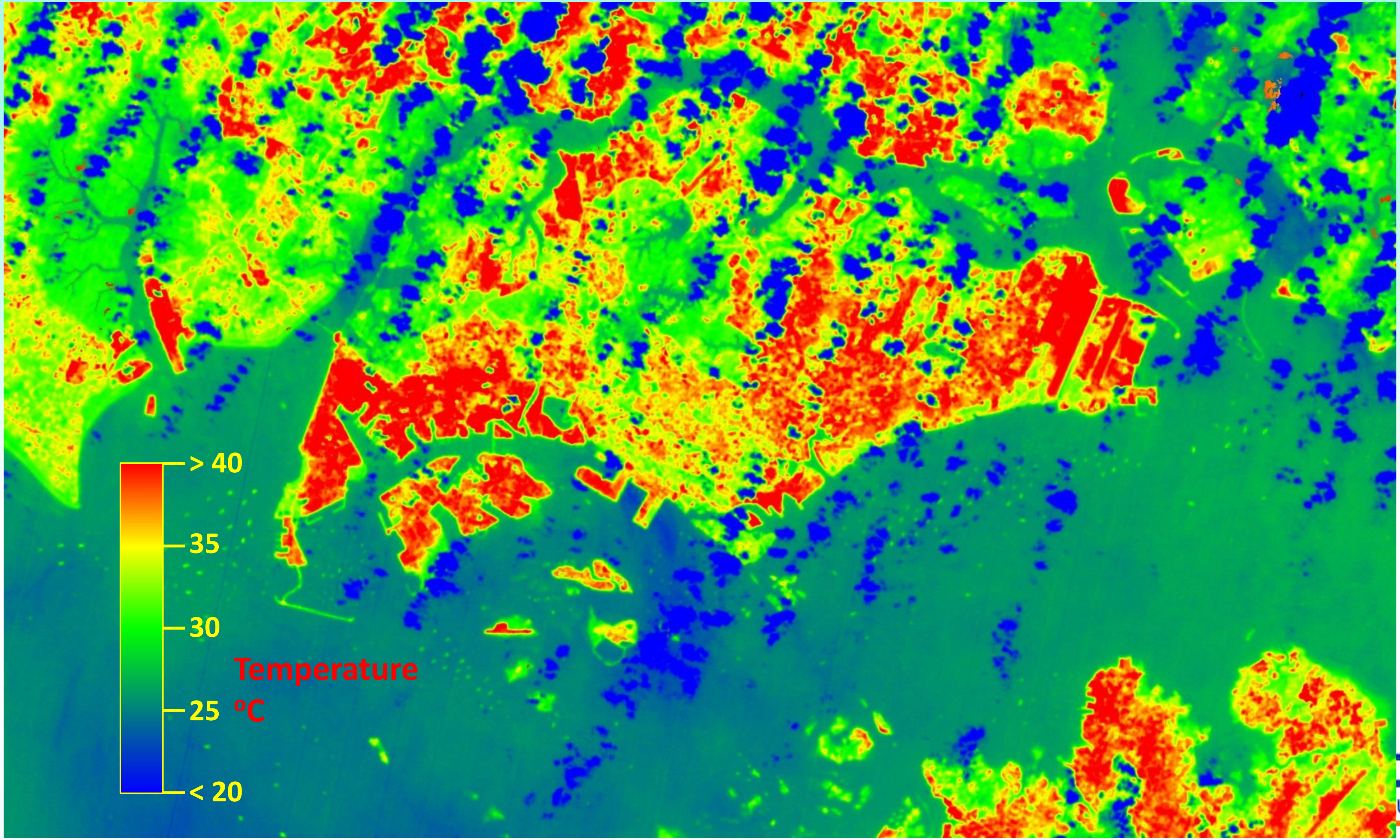
Landsat 8 – Singapore (2014-02-22)
Surface Temperature



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Landsat 8 – Singapore
True Colour Image

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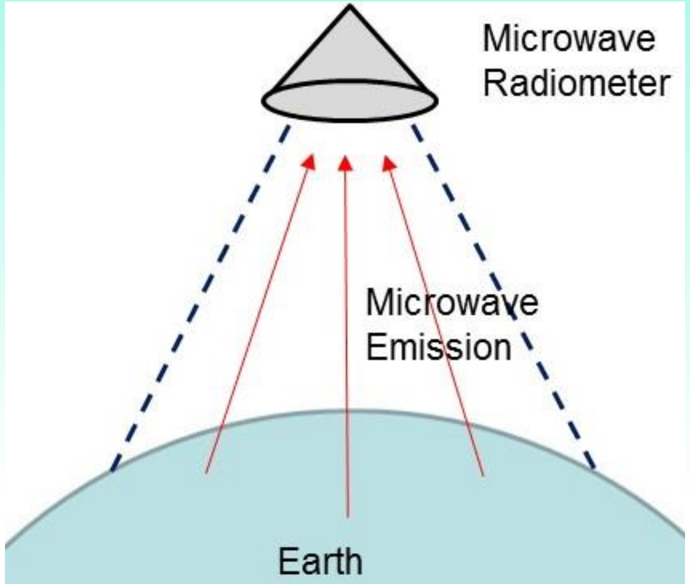
Some Applications of Thermal IR Remote Sensing

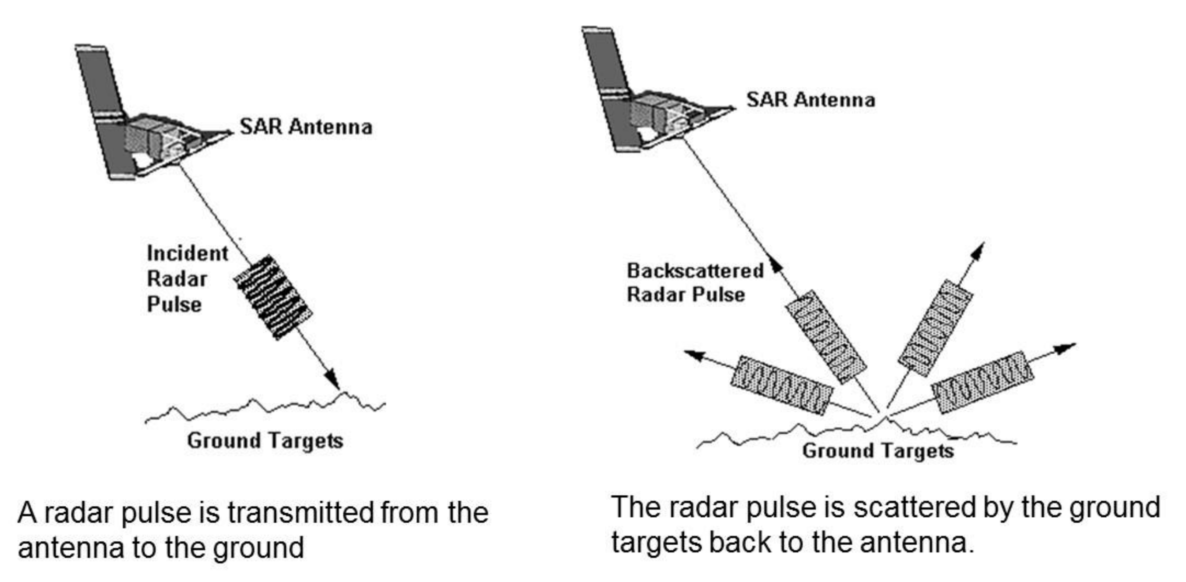
- Sea surface temperature
  - Global warming, El-Nino, La-Nina
- Atmospheric water vapour measurement and mapping
- Forest fires monitoring
- Volcanic activities
- Urban heat island effects

Microwaves Remote Sensing

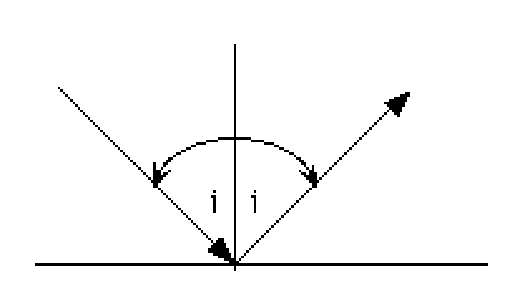
Passive

Active

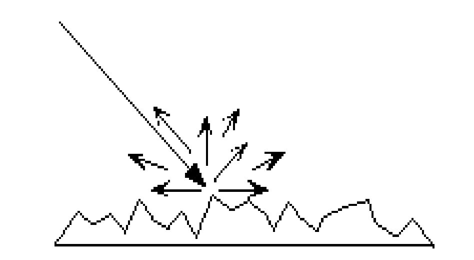




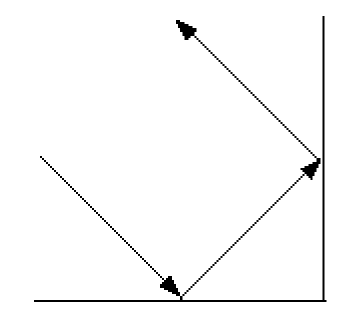
Microwave scattering



A smooth surface acts like a mirror for the incident radar pulse. Most of the incident radar energy is reflected away according to the law of specular reflection, Very little energy is scattered back to the radar sensor. The surface appears dark.



A rough surface reflects the incident radar pulse in all directions. Part of the radar energy is scattered back to the radar sensor. The surface appears bright.



Corner Reflection: When two smooth surfaces form a right angle facing the radar beam, the beam bounces twice off the surfaces and most of the radar energy is reflected back to the radar sensor. The reflector appears very bright.

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A typical SAR scene

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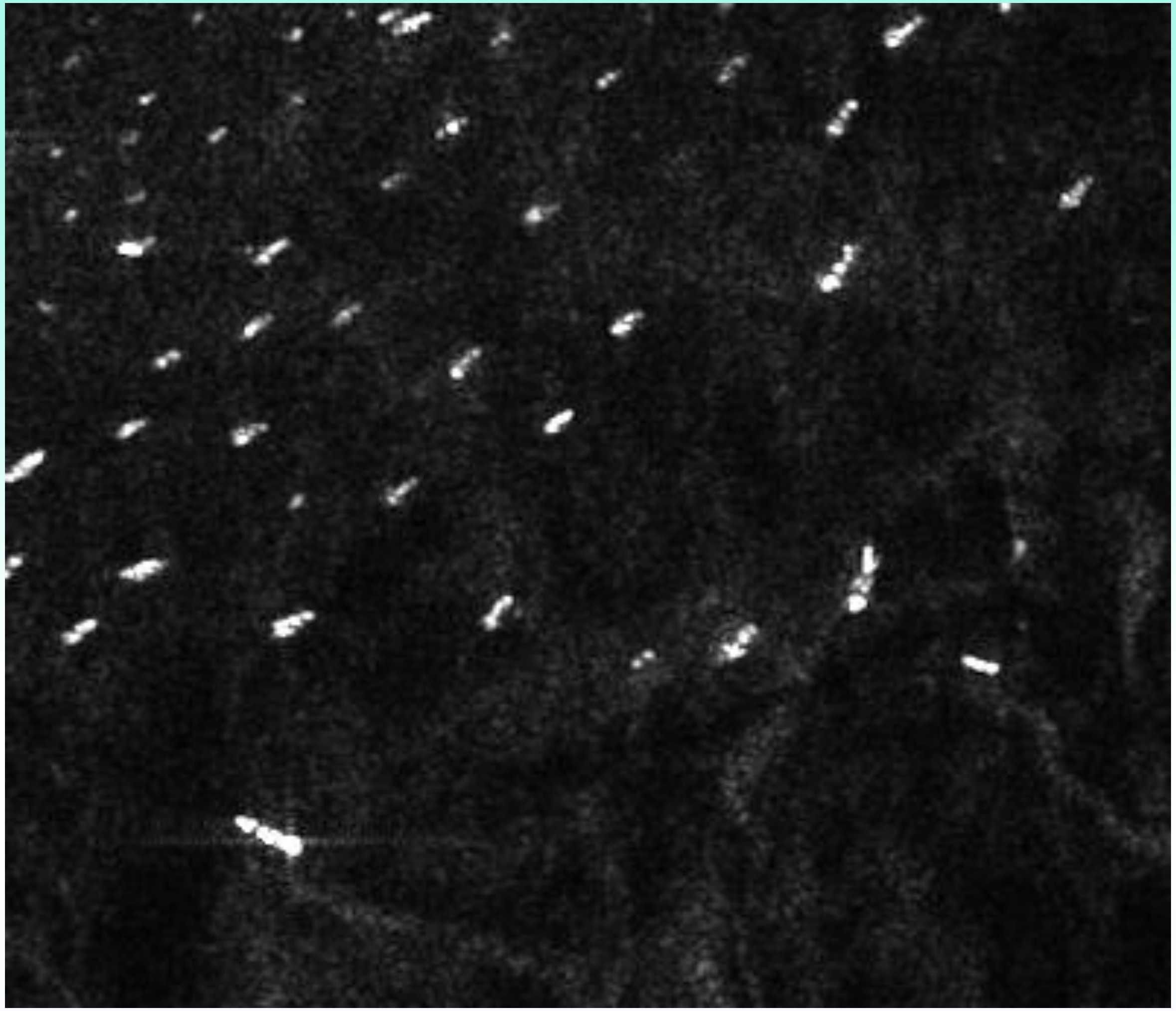
Ships in a SAR image



Ships appear as bright targets against a dark background in this SAR image.

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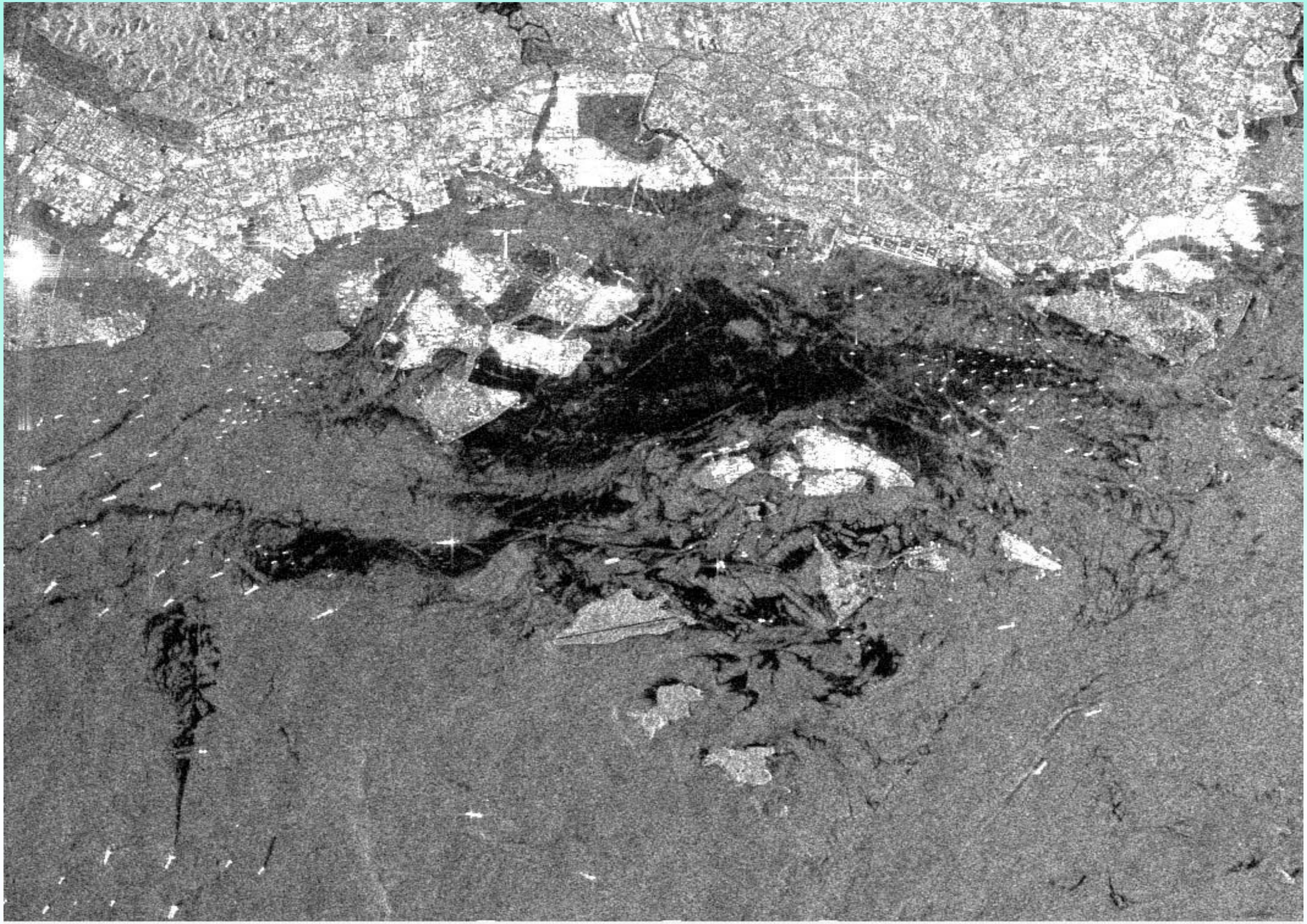

Oil spill from Tanker Song San off west coast of Singapore in August 1996.

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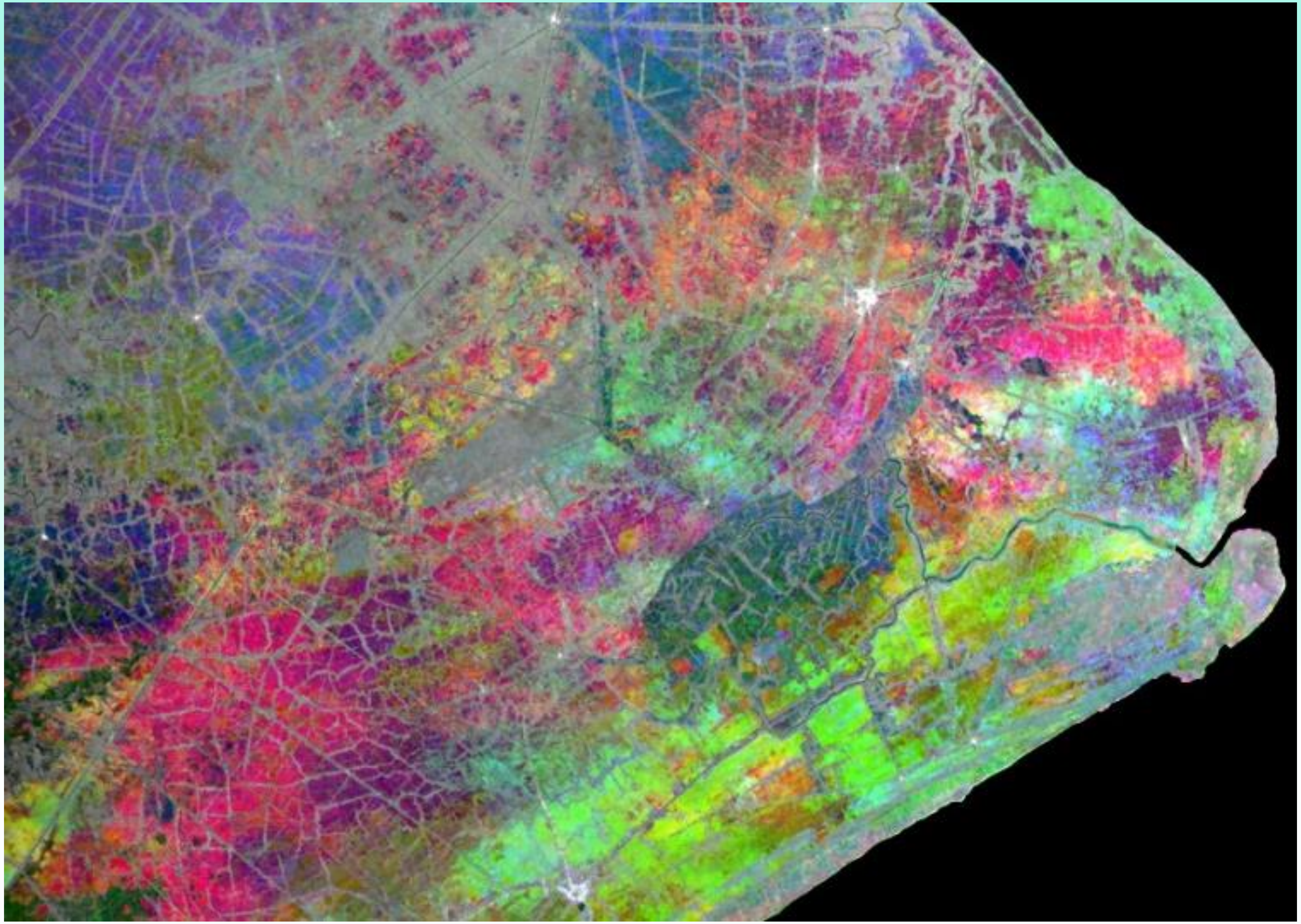

Multitemporal composite SAR image of Mekong Delta, Vietnam

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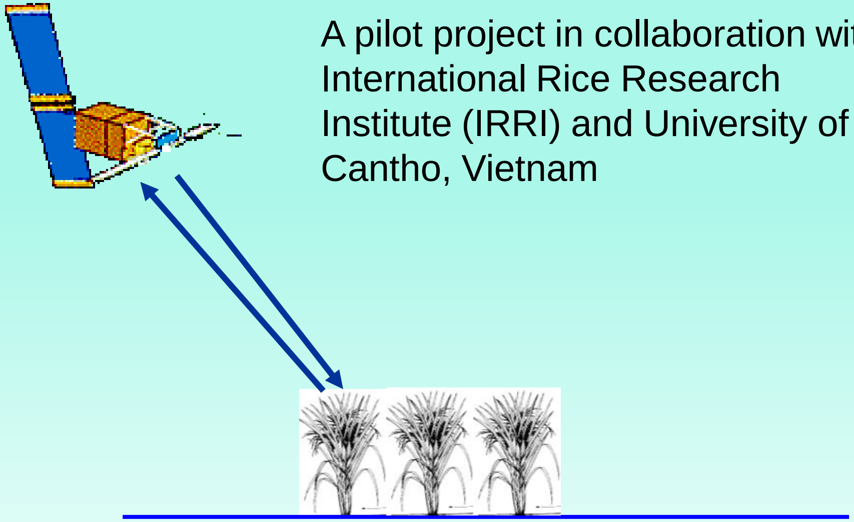
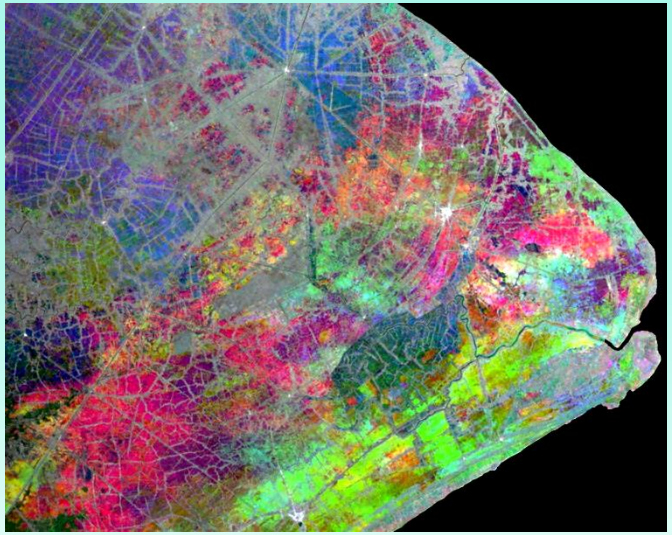
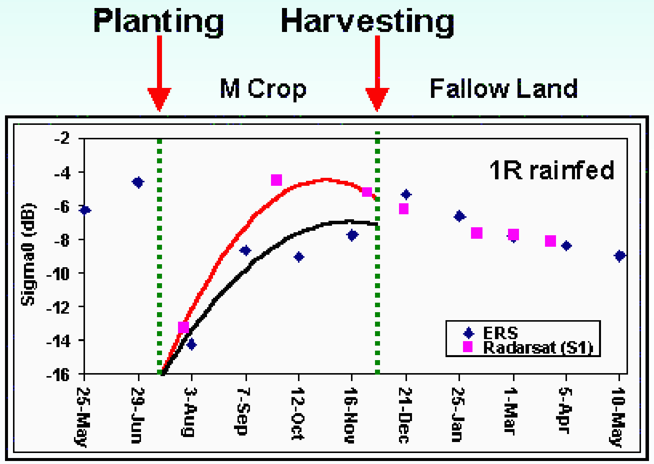
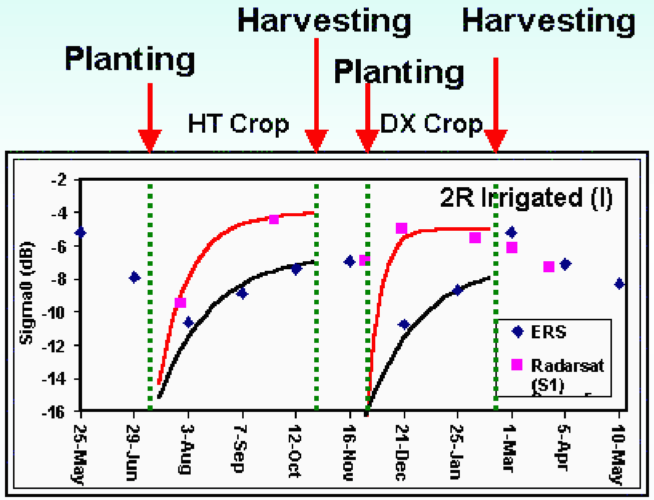
Mapping Rice Crops in Mekong Delta Using ERS Multitemporal Synthetic Aperture Radar Data



A pilot project in collaboration with International Rice Research Institute (IRRI) and University of Cantho, Vietnam







S. C. Liew, S. P. Kam, T. P. Tuong, P. Chen, V. Q. Minh, and H. Lim (1998), **Application of multitemporal ERS-2 synthetic aperture radar in delineating rice cropping systems in the Mekong River Delta, Vietnam**. *IEEE Trans. Geoscience and Remote Sensing*, 36(5) 1412-1420.

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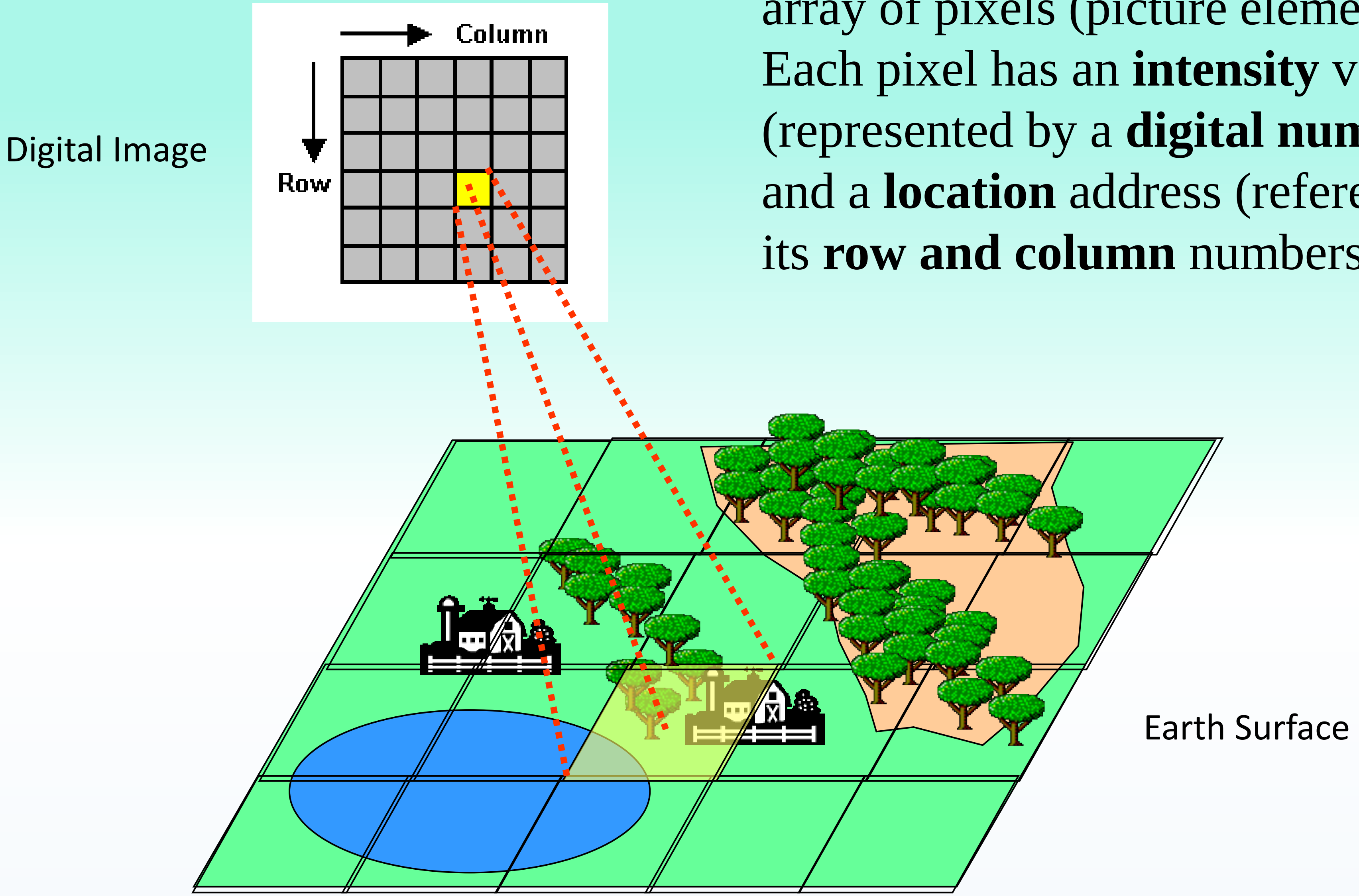
Some Characteristics of Digital Images

Digital Image



A digital image is a two-dimensional array of pixels (picture elements). Each pixel has an **intensity** value (represented by a **digital number**) and a **location** address (referenced by its **row and column** numbers).

Spatial resolution

- The **spatial resolution** of an imaging system refers to the quality of the system in its ability to **resolve fine details**.
- An ideal imaging system should reproduce faithfully all the details of the objects.
- However, due to imperfection of the system and influences of the environment, some details are lost, resulting in “blurring” of the images.

High Resolution → Fine details are preserved in the image

Low Resolution → Fine details lost
Only coarse features remain

An Example: Digitizing a picture at different pixel size

512 pixels

(76.8 cm)

512 pixels (76.8 cm)

Image dimensions:
512 x 512 pixels

Pixel width W is about 1.5 mm at the object plane.

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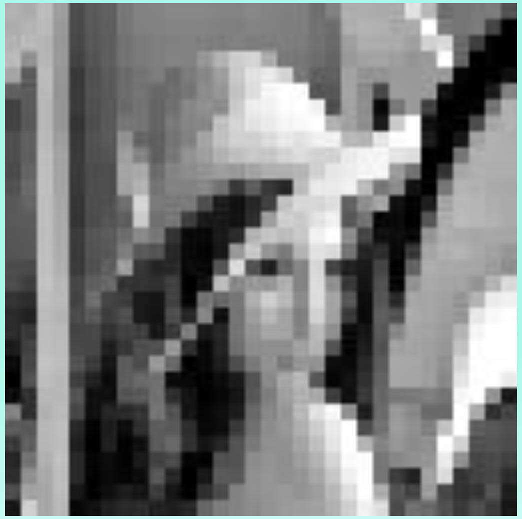
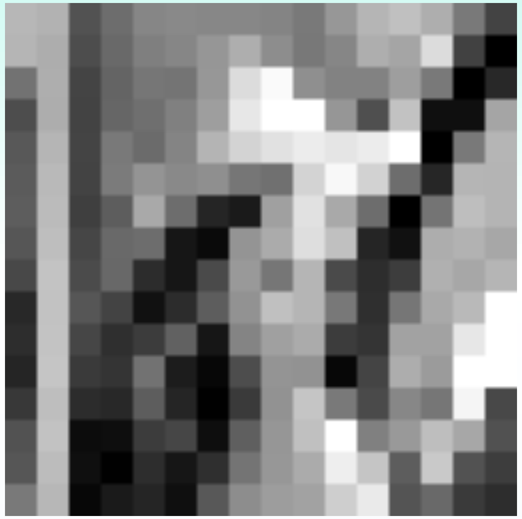
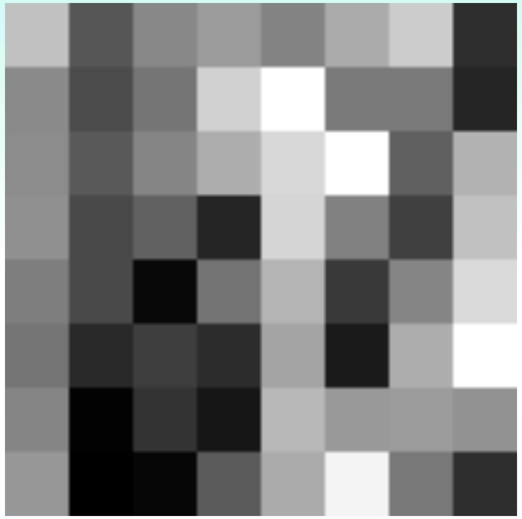
Digitization at increasing pixel width

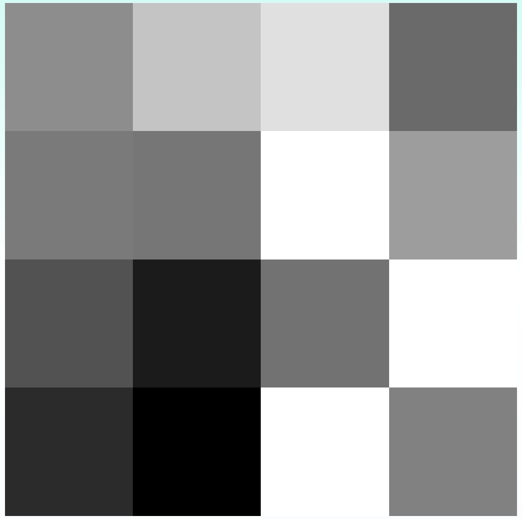

128 x 128 pixels (W=0.6 cm)


64 x 64 pixels (W=1.2 cm)


32 x 32 pixels (W=2.4 cm)


16 x 16 pixels (W=4.8 cm)


8 x 8 pixels (W=9.6 cm)


4 x 4 pixels (W=19.2 cm)

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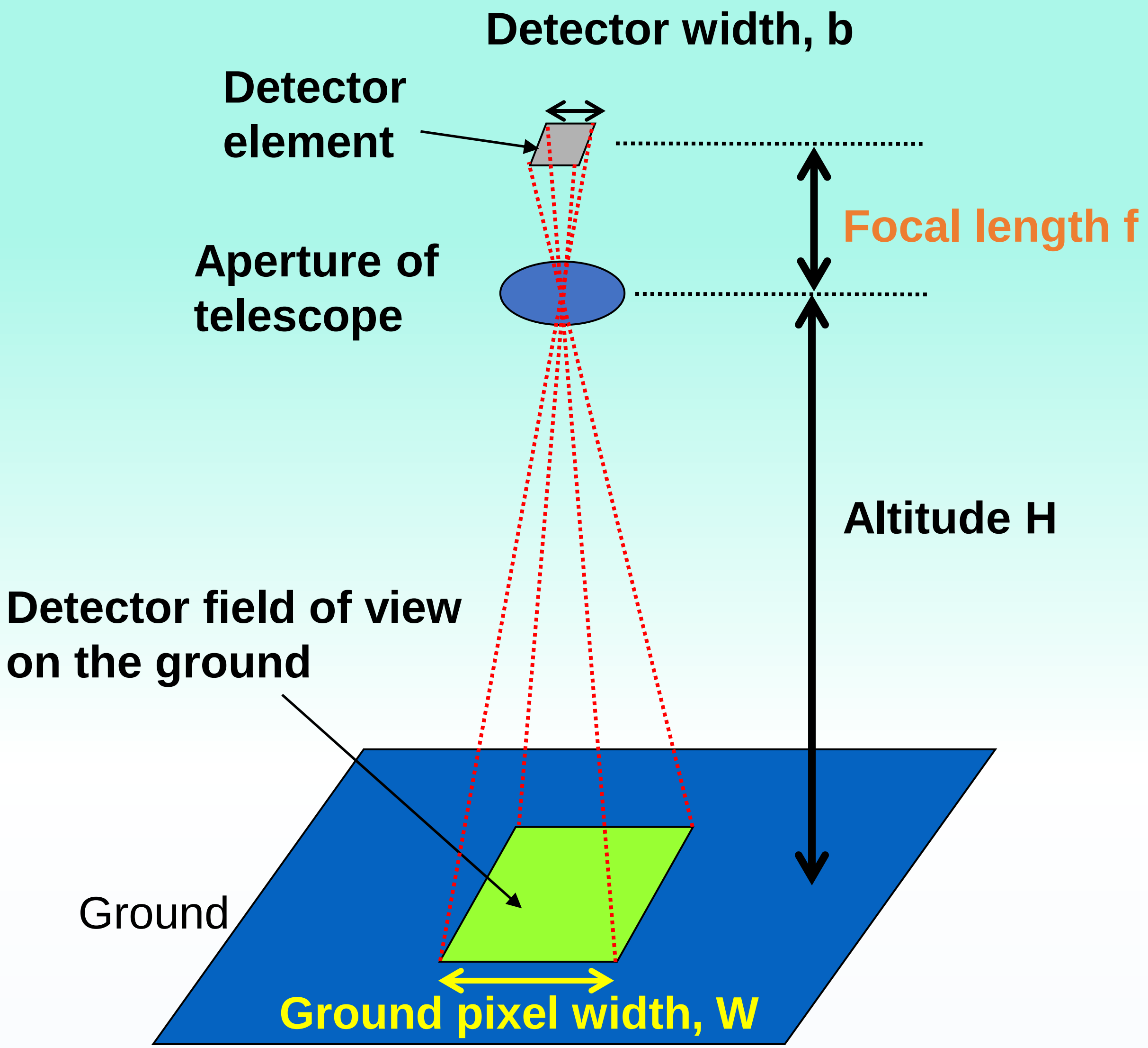
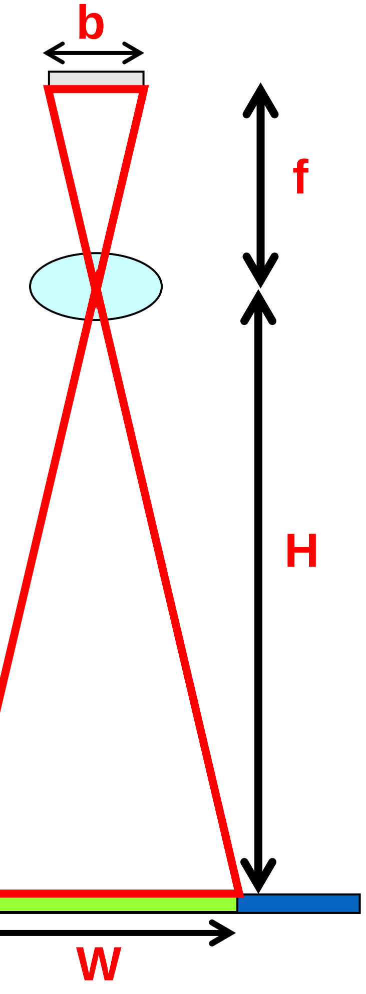
Resolution due to Sampling





$$\frac{W}{H} = \frac{b}{f}$$

$$\boxed{W = \frac{bH}{f}}$$

Ground Pixel Width

Example: Consider the following specifications of a satellite imaging system. What is the ground pixel width?

Telescope diameter, D = 0.7 m
Focal length, f = 10 m
Detector size, b = 12 μm = 1.2×10^{-5} m
Altitude, H = 681 km = 6.81×10^{5} m

The ground pixel width is

$$W = Hb/f$$
$$= (6.81 \times 10^{5} \text{ m}) \times (1.2 \times 10^{-5} \text{ m}) / (10 \text{ m})$$
$$= 0.82 \text{ m}$$

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SATURDAY NOVEMBER 18, 2023

SINCE 1845

INSIGHT
Greening Singapore's power sector | B4-6

The Big Story • Slump in S'pore's key exports continues to ease | A3

Life • Bars raise spirits with striking decor | C1&2

Singapore • Launch of air taxi services put on hold | A16

THE STRAITS TIMES

New approaches to trade policy take time, says PM Lee as US pact stalls

He anticipates more progress in 2024 after Asia-Pacific economic initiative hits roadblock

Bhagyashree Garekar

In his speech in San Francisco on Nov 16, Prime Minister Lee Hsien Loong said the Indo-Pacific Economic Framework for Prosperity should continue to be open, inclusive and flexible, including towards new members. PHOTO: AFP

ANTICIPATING PROGRESS

We look forward to further progress in the negotiations as well as in tangible cooperation next year.

PRIME MINISTER LEE HSIEN LOONG, on the Indo-Pacific Economic Framework for Prosperity.

bhagya@sph.com.sg

SEE THE BIG STORY • A4 & WORLD • A8-9

Demand for skills in digital and care sectors set to grow

Elisha Tushara
Correspondent

Highlights of the Skills Demand for the Future Economy report on display at the Sands Expo and Convention Centre. The report highlights 24 top job skills that are expected to grow in demand. PHOTO: LIANHE ZAOBAO

CONTINUED ON PAGE A2

60 PAGES IN 3 PARTS
$1.20

Can you read this from space?

Is it possible to recognize a human face from an image taken by a satellite from space?

It is rumored that a spy satellite can read the headlines of a newspaper or car license plates. Is this possible?

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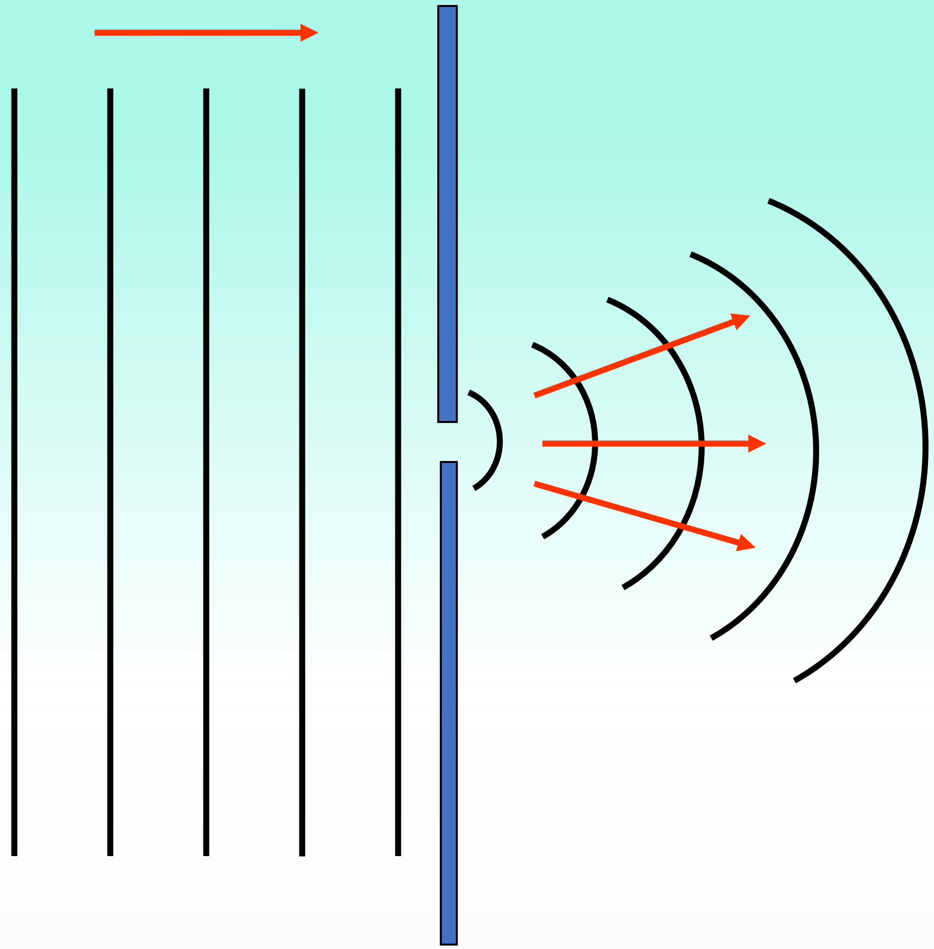
Diffraction of Light



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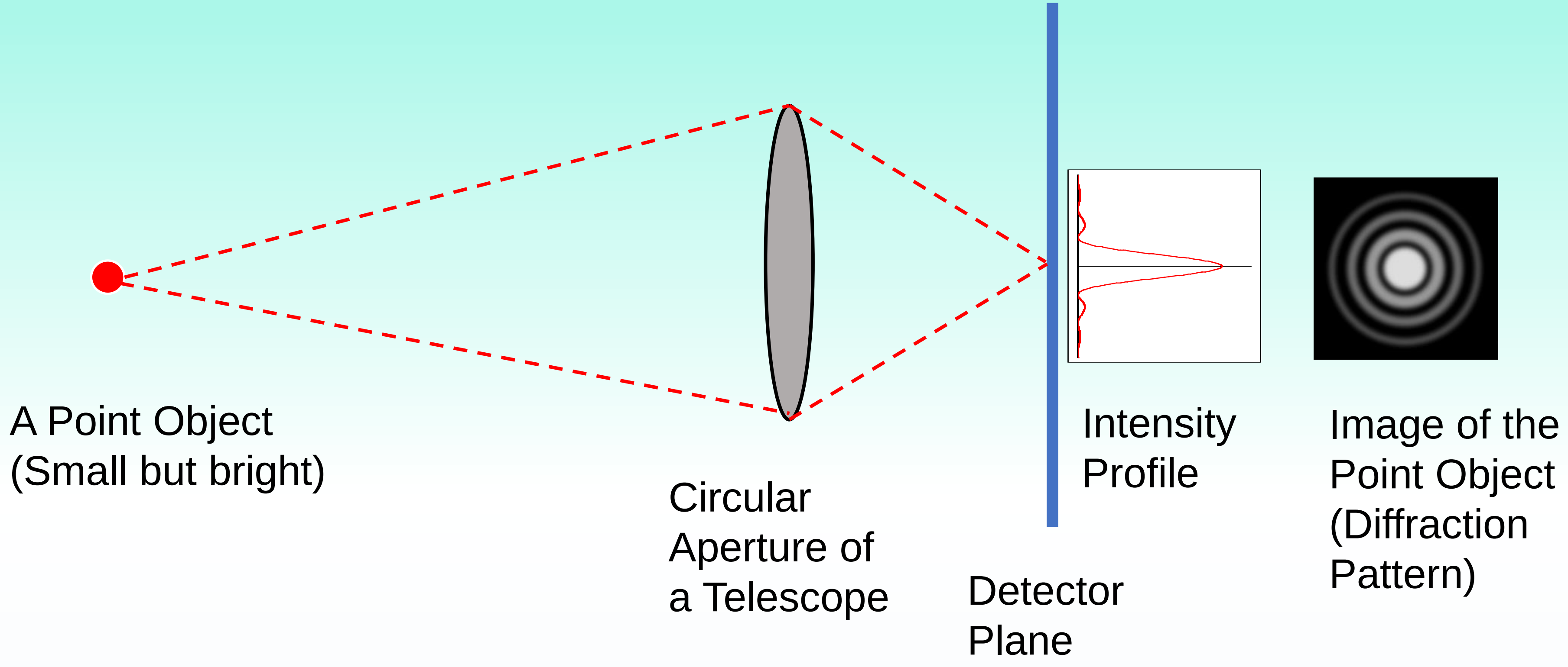
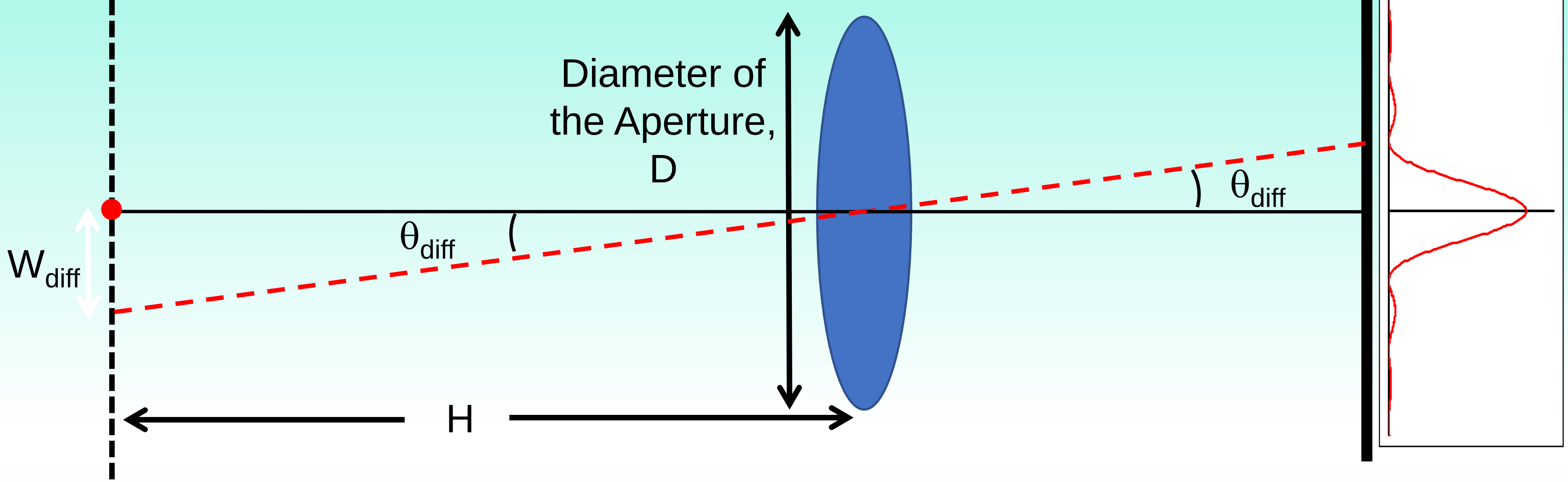
Diffraction pattern



Resolution due to Diffraction

Ground Resolution due to Diffraction

$$W_{diff} = H\theta_{diff} = \frac{1.22\lambda H}{D}$$



$$\text{Diffraction Angle } \theta_{diff} \approx \frac{1.22\lambda}{D}$$

H = Distance of the aperture from the object

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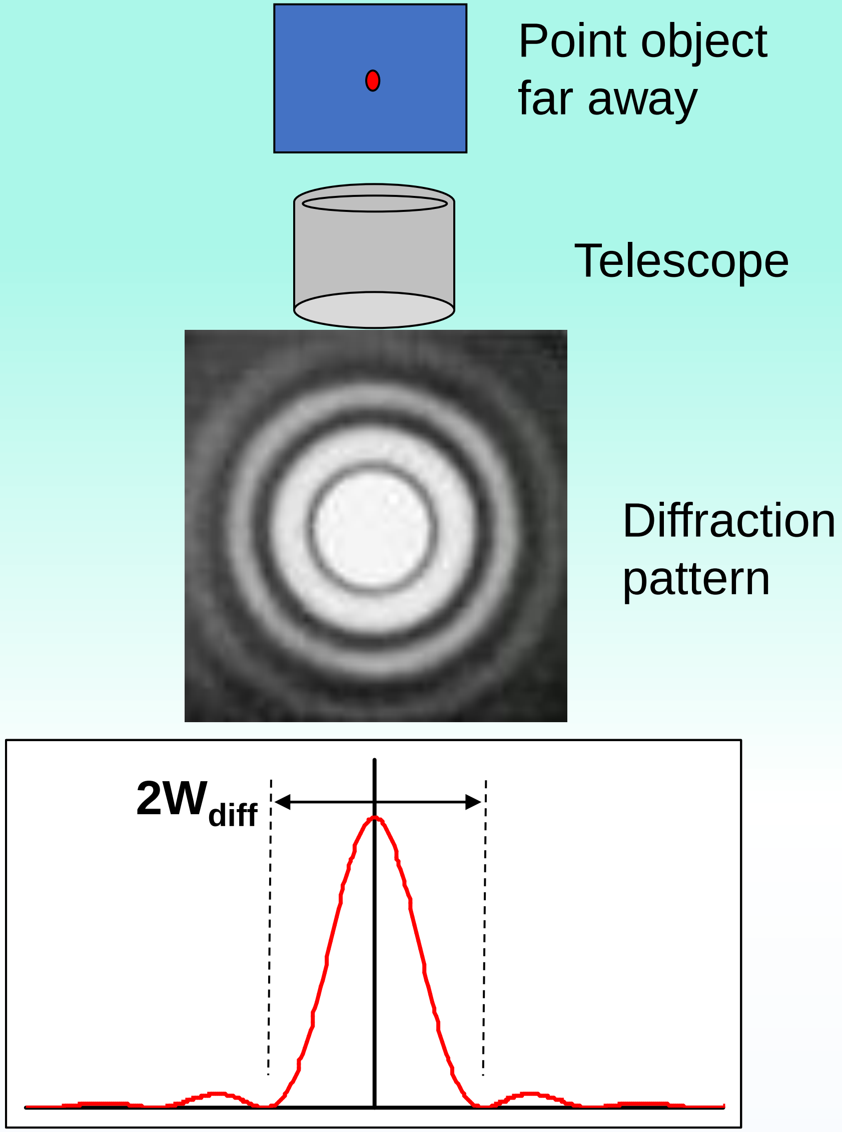
Diffraction Limit of Resolution



The diffraction limit arises from the wave nature of light.

For a telescope with a circular aperture, the ground resolution width due to diffraction is given by the equation

$$W_{diffraction} = \frac{1.22\lambda H}{D}$$

λ is the wavelength of light

H is the altitude of the telescope,

D is the diameter of the telescope aperture.

Diffraction Limit of Resolution

Example: Consider the following specifications of a satellite imaging system. What is the resolution limit imposed by light diffraction?

Telescope diameter, D = 0.7 m
Altitude, H = 681 km = 6.81×10^5 m
Wavelength λ = 500 nm = 5×10^{-7} m

The diffraction limited resolution is

$$W_{diff} = 1.22\lambda H/D$$
$$= 1.22 \times (5 \times 10^{-7}\text{ m}) \times (6.81 \times 10^5\text{ m}) / 0.7\text{ m}$$
$$= 0.59\text{ m}$$

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What is the best resolution achievable for a space-borne camera?

$$W_{diffraction} = \frac{1.22\lambda H}{D}$$

We need a short wavelength, a large aperture and a low altitude.
Assuming, λ = 500 nm, H = 250 km (this is really low for a satellite), and D = 1 m, then

$$\begin{aligned} W_{diffraction} &= \frac{1.22 \times (5 \times 10^{-7}\ \mathrm{m}) \times (2.5 \times 10^{5}\ \mathrm{m})}{1\,\mathrm{m}} \\ &= 0.1525\,\mathrm{m} = 15.25\,\mathrm{cm} \end{aligned}$$

The diffraction limit can be pushed further by using a larger telescope aperture and flying the satellite at a lower altitude. E.g. if D = 2 m and H = 100 km, then $W_{diffraction}$ = 3 cm.

Is this resolution sufficient for face recognition?

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Various types of remote sensing satellites according to their functions

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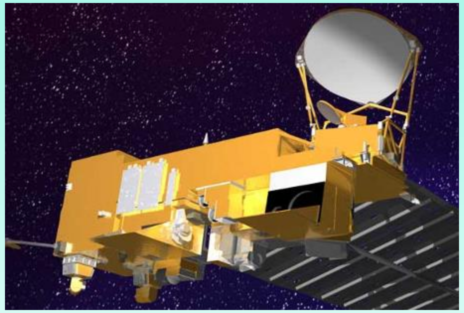
Meteorological / Environmental Satellites

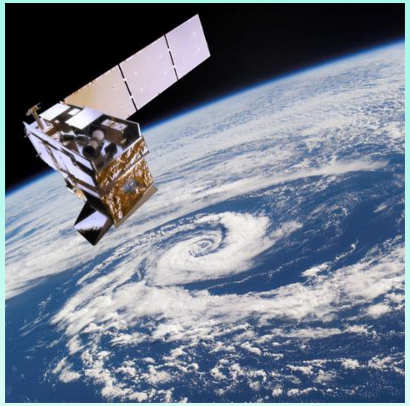
TERRA

AQUA



Moderate Resolution Imaging Spectrometer (MODIS)
Wide coverage (over 2000 km) but low resolution (250 m to 1 km)
36 spectral bands; For observation of land, atmosphere and ocean

Suomi-NPP

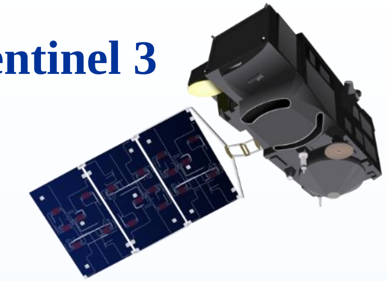


22 bands Visible Infrared Imaging Radiometer Suite (VIIRS)

NOAA-20

Also carries VIIRS, similar to Suomi-NPP

Sentinel 3



21 bands Ocean and Land Color Instrument (OCLI) - Visible-NIR (300 m resolution)
Sea and Land Surface Temperature Radiometer (SLSTR) – Vis-SWIR (500 m), MIR-TIR (1 km)

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Spectral Bands of MODIS (Reflective)

Primary Use	Band No.	Wavelength (nm)	Resolution (km)
Land/Cloud/Aerosols Boundaries	1	620 – 670 (Red)	0.25
	2	841 – 876 (NIR)	0.25
Land/Cloud/Aerosols Properties	3	459 – 479 (Blue)	0.5
	4	545 – 565 (Green)	0.5
	5	1230 – 1250 (SWIR)	0.5
	6	1628 – 1652 (SWIR)	0.5
	7	2105 – 2155 (SWIR)	0.5
Ocean Color/ Phytoplankton/ Biogeochemistry	8	405 - 420	1
	9	438 - 448	1
	10	483 - 493	1
	11	526 - 536	1
	12	546 - 556	1
	13	662 - 672	1
	14	673 - 683	1
	15	743 - 753	1
	16	862 - 877	1
Atmospheric Water Vapor	17	890 - 920	1
	18	931 - 941	1
	19	915 - 965	1

Spectral Bands of MODIS (Emissive)

Primary Use	Band	Wavelength (µm)	Resolution (km)
Surface/Cloud Temperature	20	3.660 - 3.840	1
	21	3.929 - 3.989	1
	22	3.929 - 3.989	1
	23	4.020 - 4.080	1
Atmospheric Temperature	24	4.433 - 4.498	1
	25	4.482 - 4.549	1
Cirrus Clouds Water Vapor	26 (Reflective)	1.360 - 1.390 (SWIR)	1
	27	6.535 - 6.895	1
	28	7.175 - 7.475	1
Cloud Properties	29	8.400 - 8.700	1
Ozone	30	9.580 - 9.880	1
Surface/Cloud Temperature	31	10.780 - 11.280	1
	32	11.770 - 12.270	1
Cloud Top Altitude	33	13.185 - 13.485	1
	34	13.485 - 13.785	1
	35	13.785 - 14.085	1
	36	14.085 - 14.385	1

Typhoon Talim over East China Sea - Terra MODIS 2017-09-14 02:15UT

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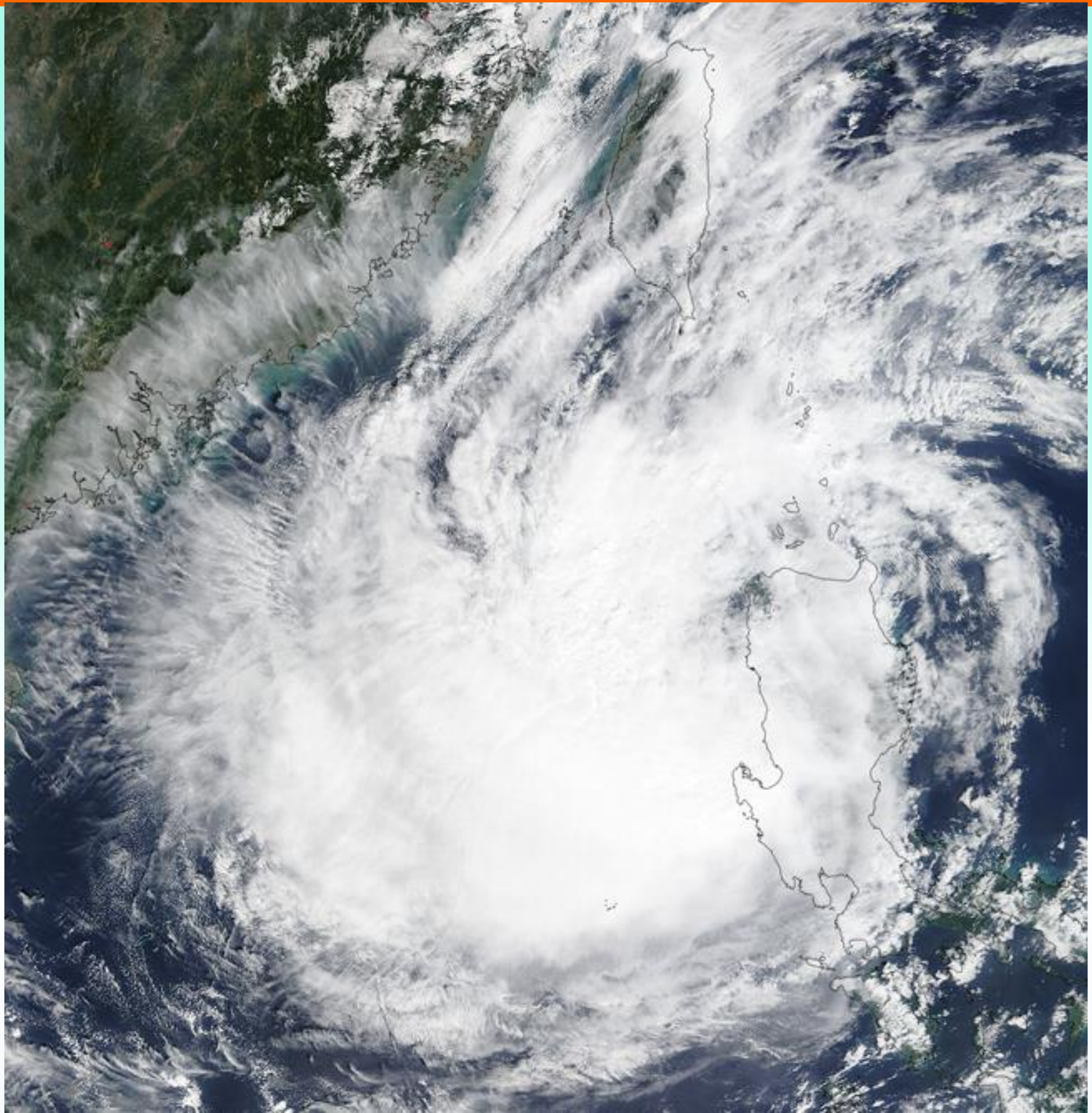

Typhoon Koppu over the Philippines

Terra-MODIS
2015-10-19
03:05 UT

Credit: NASA

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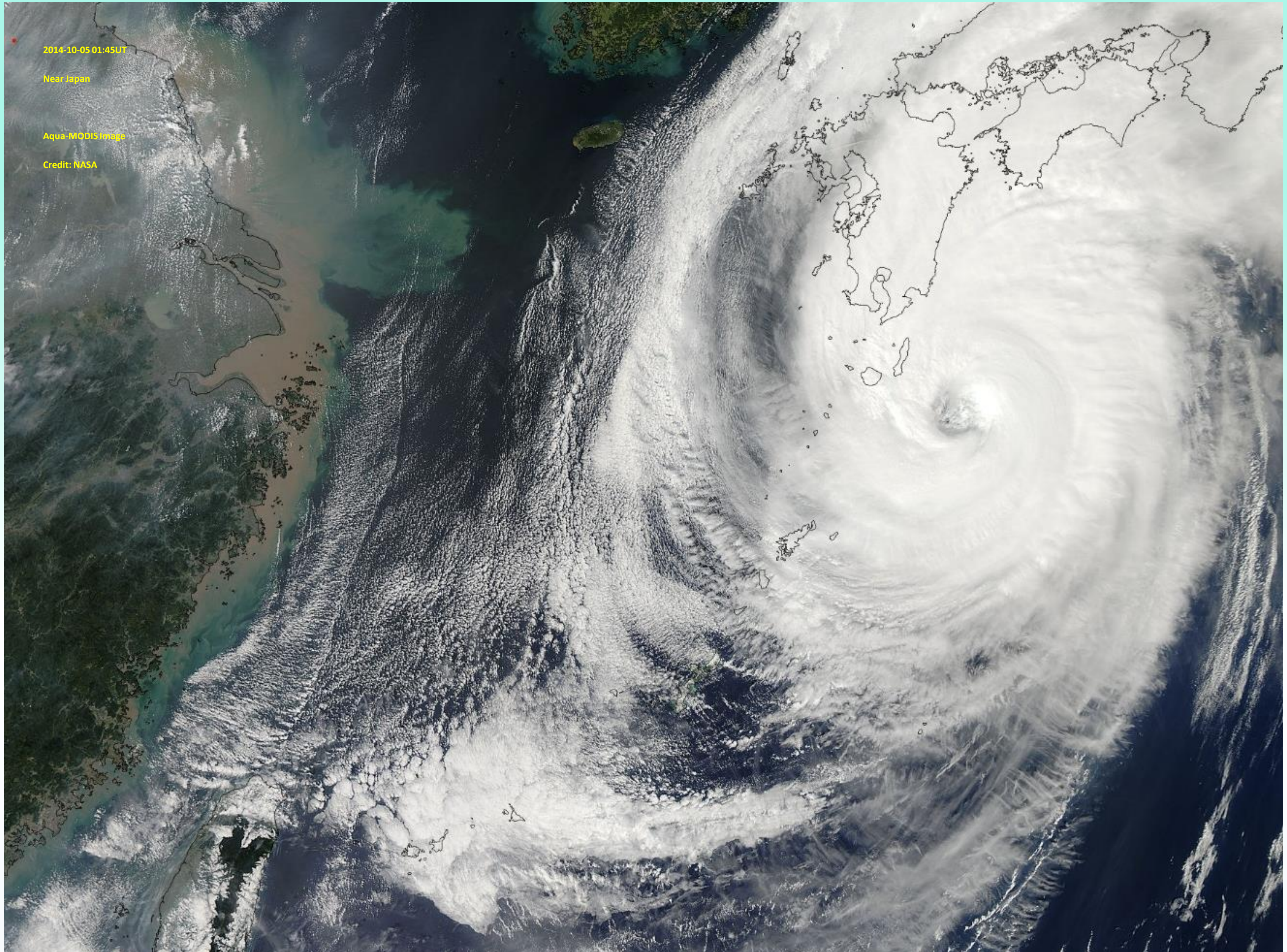
Super Typhoon Phanfone



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MODIS

Fire hot spots and smoke plumes - Riau, Sumatra

25 June 2005
03:55 UTC

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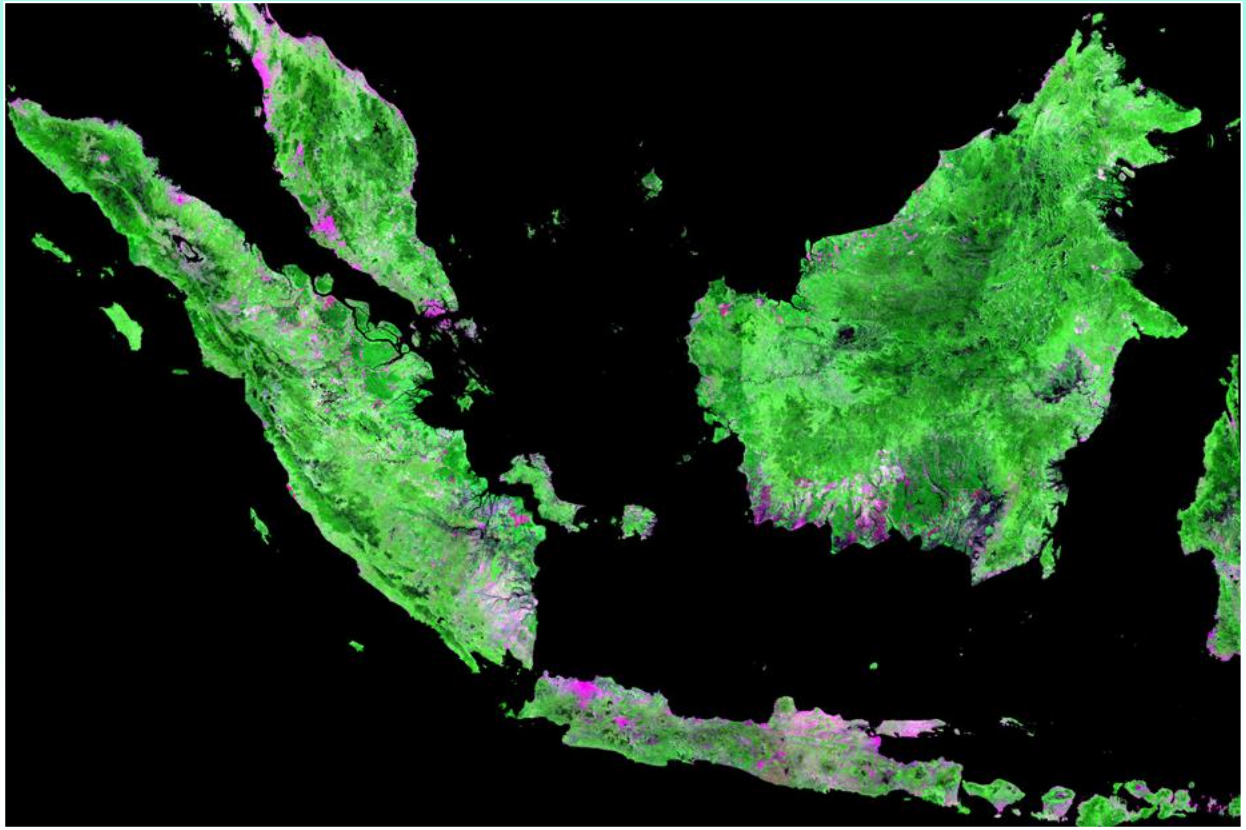
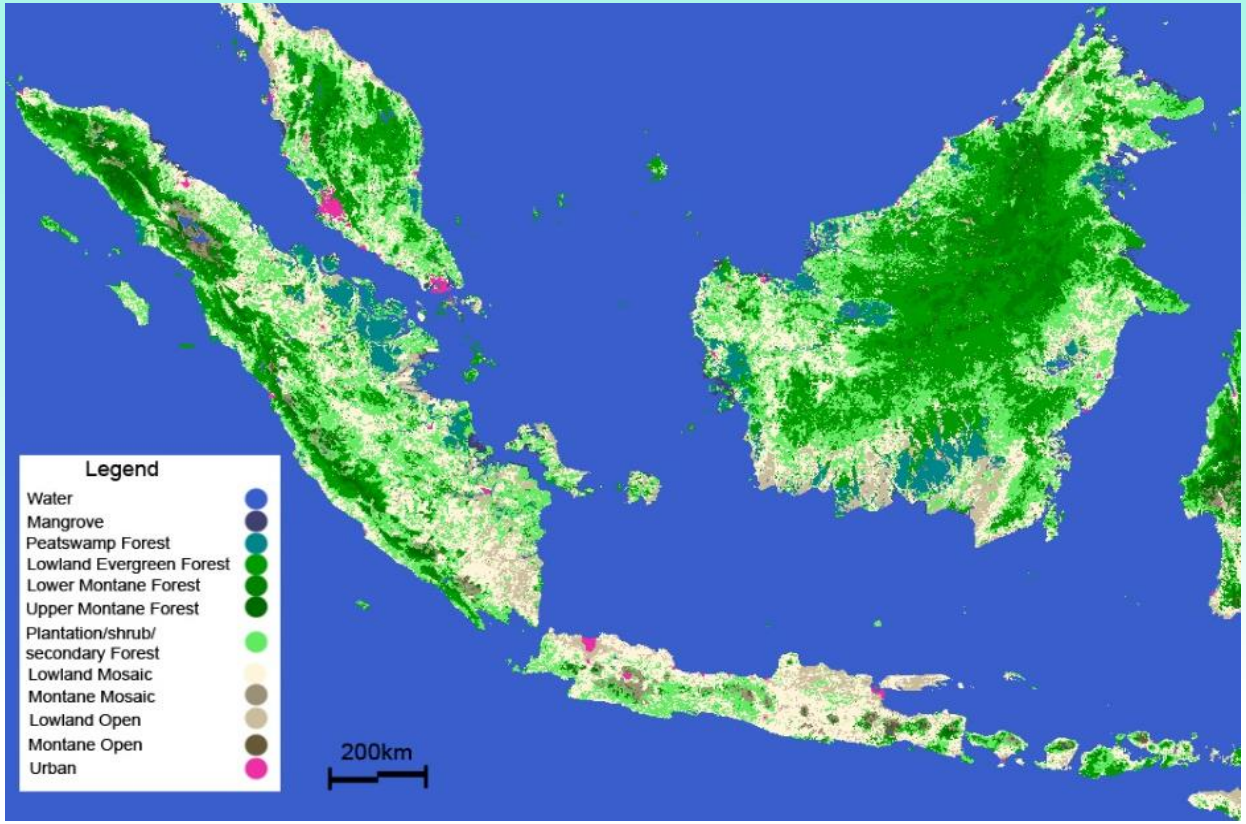
Regional Land Cover Mapping



MODIS 500 m resolution cloud-free mosaic (2005)



Land cover classification map derived from the MODIS images

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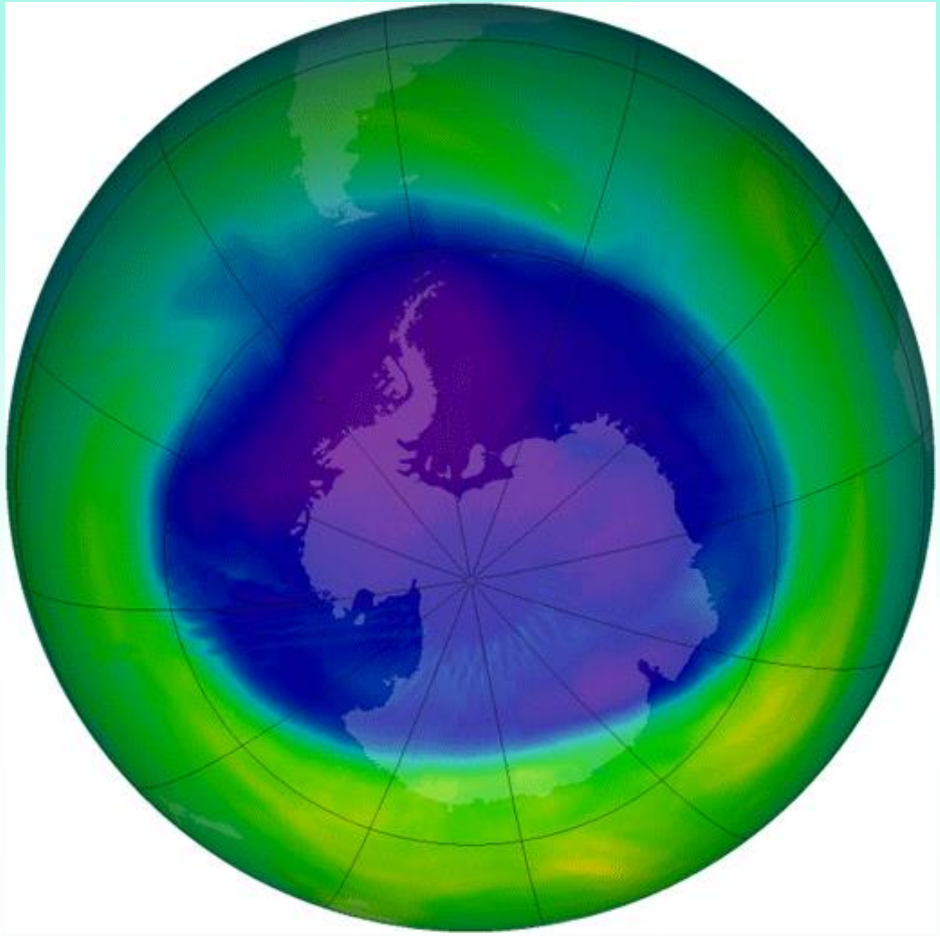
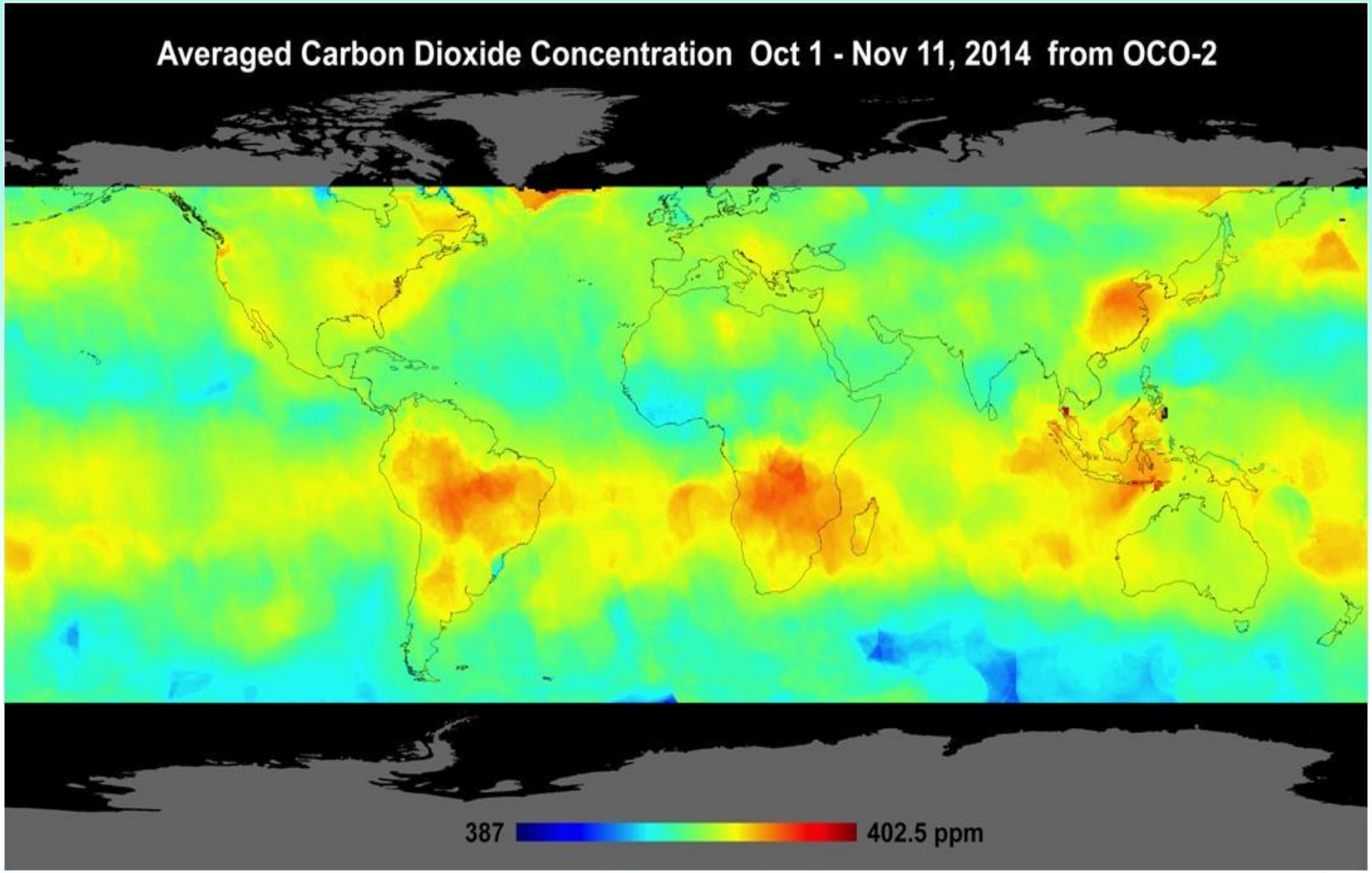
AURA – OMI (Ozone Monitoring Instrument) map of ozone hole over antartica



Global distribution of CO_2 concentration measured by the OCO-2 satellite



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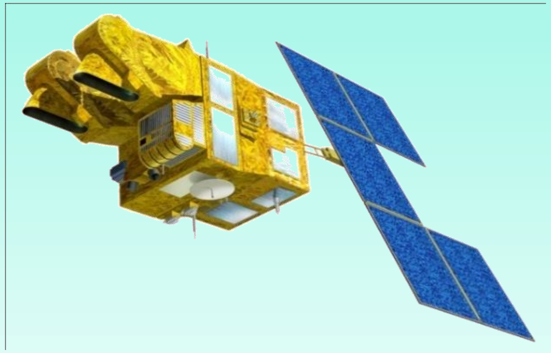
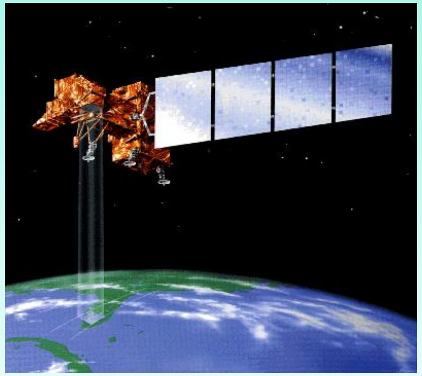
Earth resource satellites

SPOT-5, 6, 7



Landsat-8, 9



Sentinel 2A,B

CBERS-4

Moderate to high resolution (a few m to ~ 100 m)
few spectral bands, usually broad bandwidth;
Swath from tens of km to ~100 km

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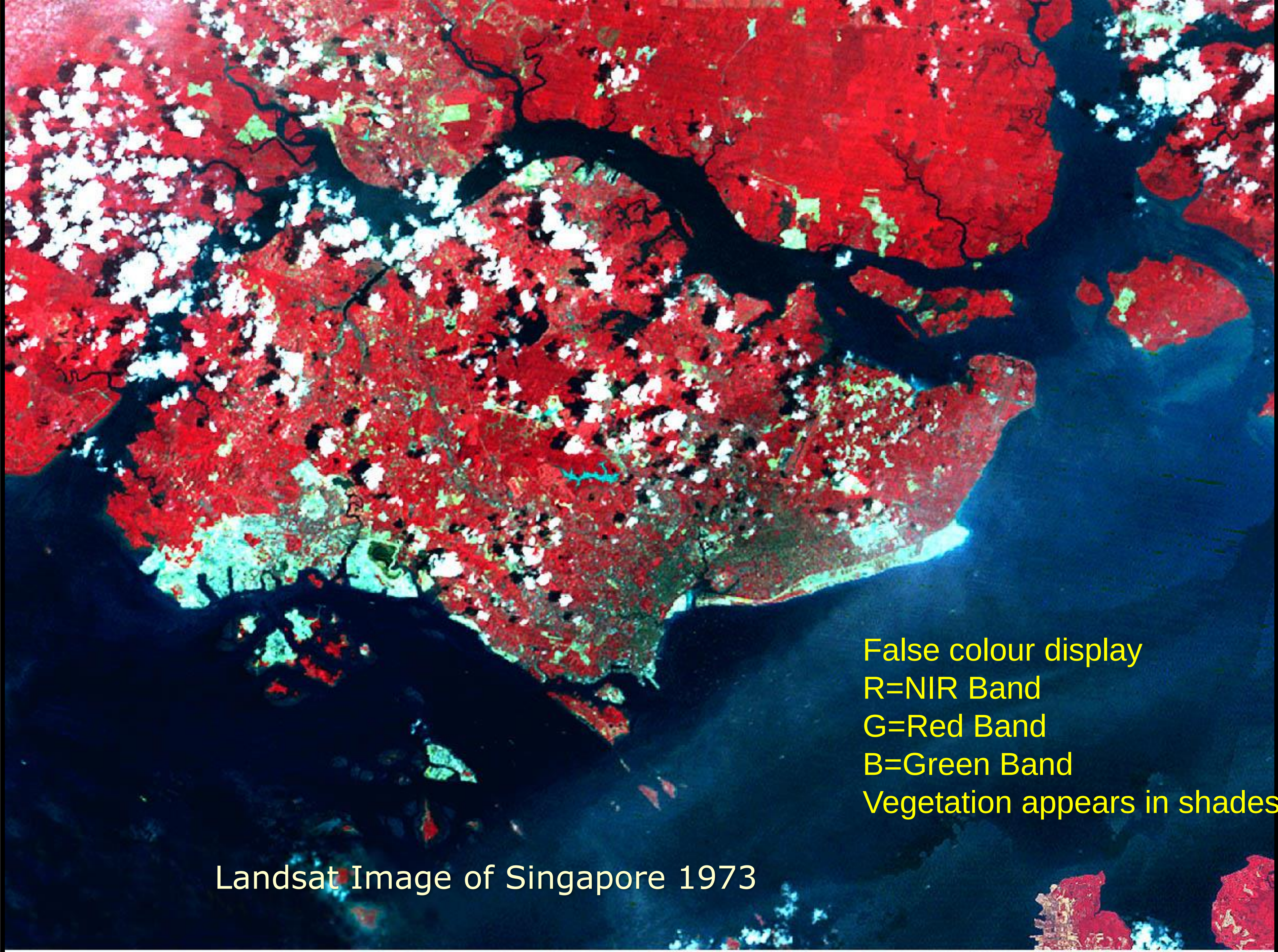
Spectral Bands of Sentinel-2A MSI

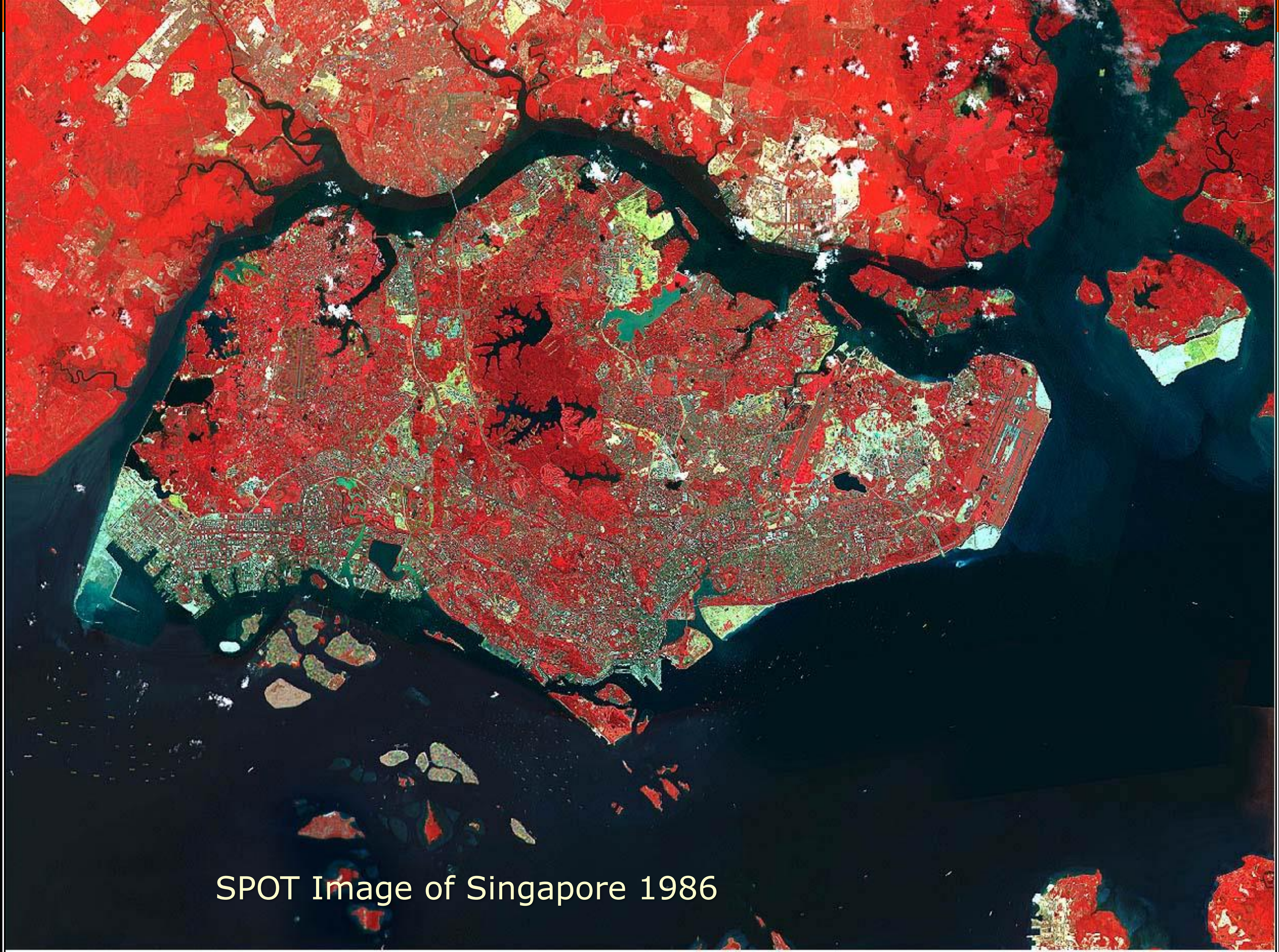
Band number	Spatial Sample Distance (m)	Central wavelength (nm)	Bandwidth (nm)
1	60	443	20
2	10	490	65
3	10	560	35
4	10	665	30
5	20	705	15
6	20	740	15
7	20	783	20
8	10	842	115
8A	20	865	20
9	60	945	20
10	60	1 375	30
11	20	1 610	90
12	20	2 190	180

Spectral Bands of SPOT-5 Satellite

Band No.	Wavelength (μm)	Resolution
1	0.50 - 0.59 (Green)	10 m
2	0.61 - 0.68 (Red)	10 m
3	0.79 - 0.89 (NIR)	10 m
4	1.53 - 1.75 (SWIR)	20 m
--	Panchromatic	5 m and 2.5 m



Landsat Image of Singapore 1973



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SPOT Image of Singapore 1998

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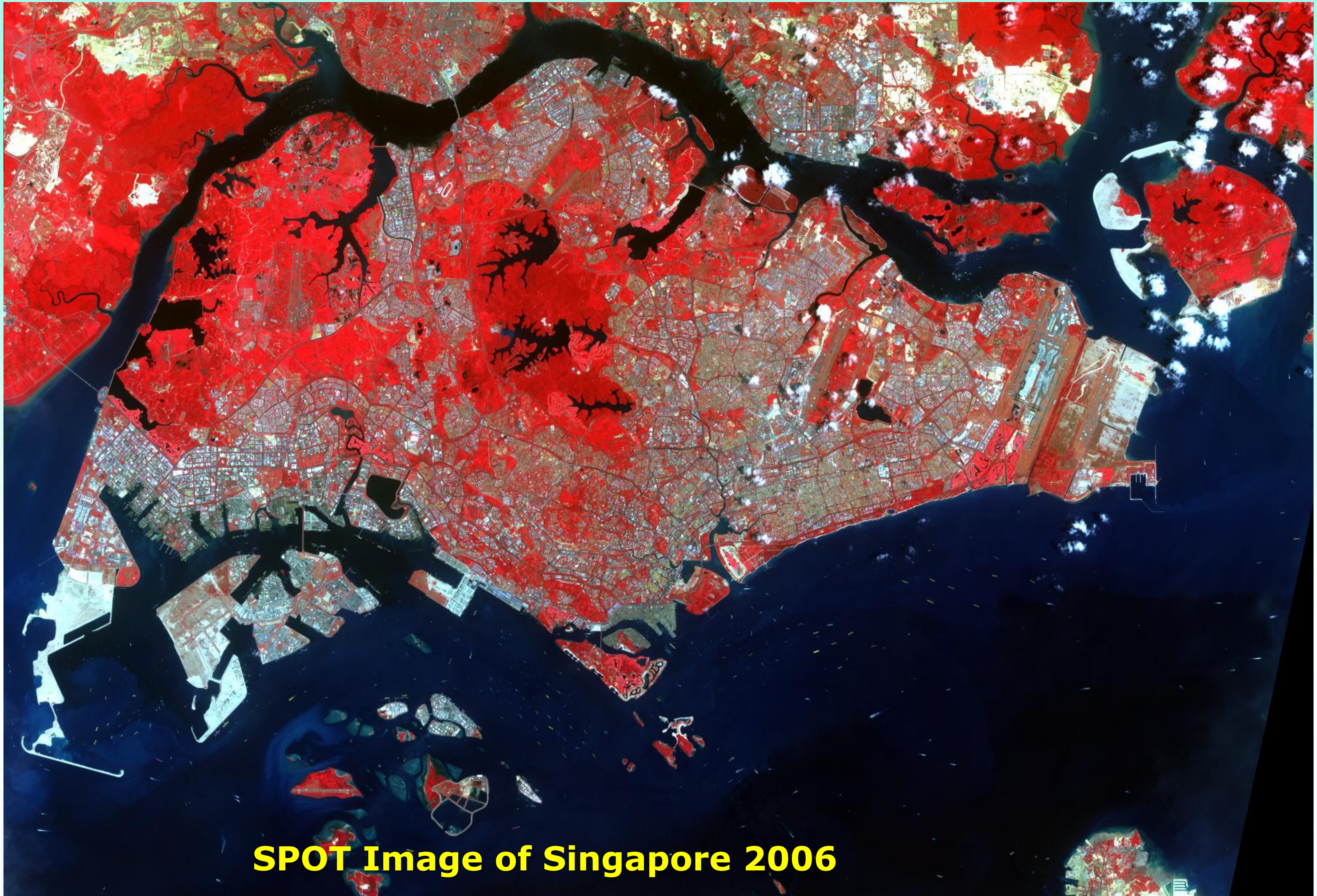

SPOT Image of Singapore 2006

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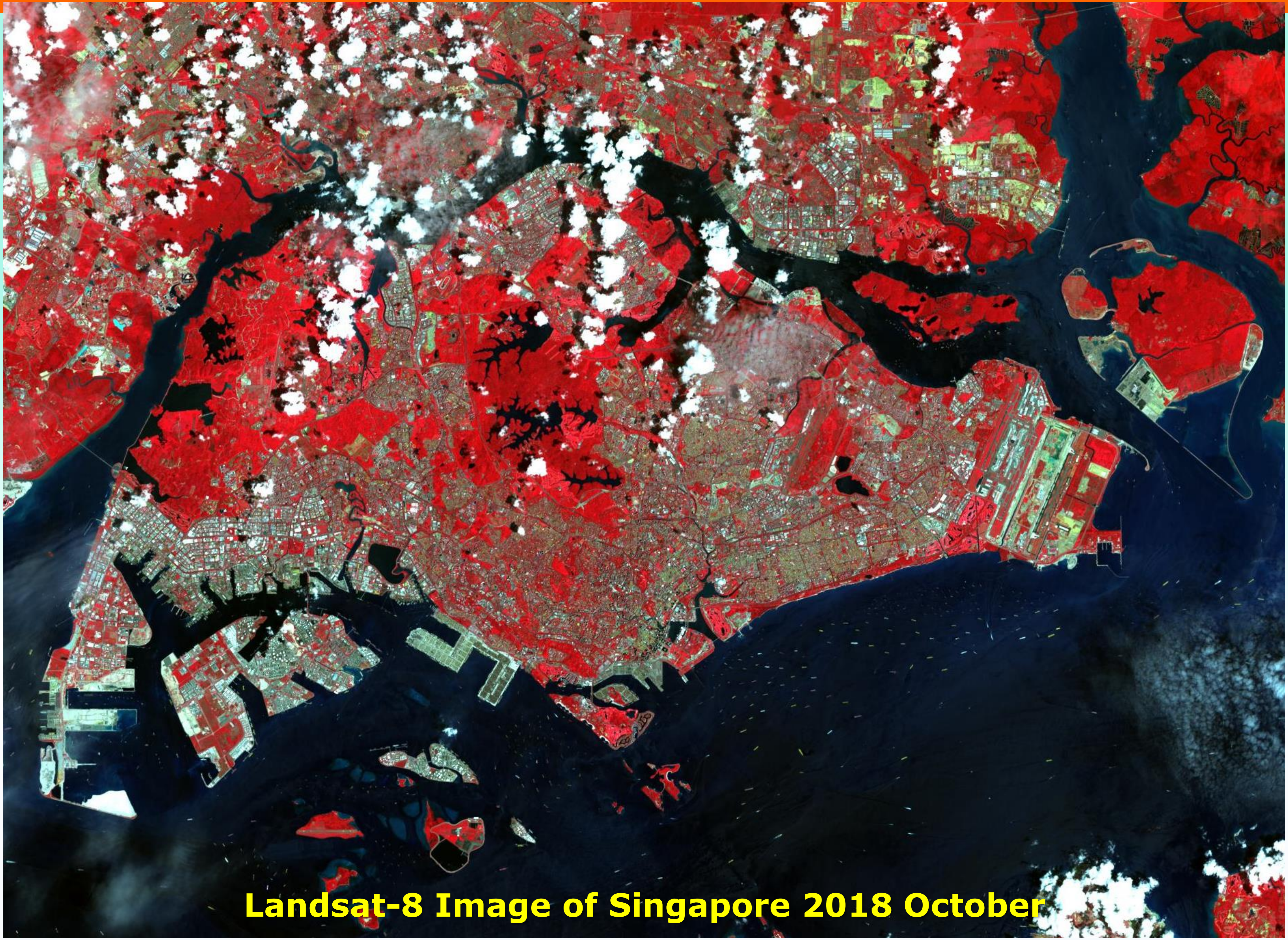

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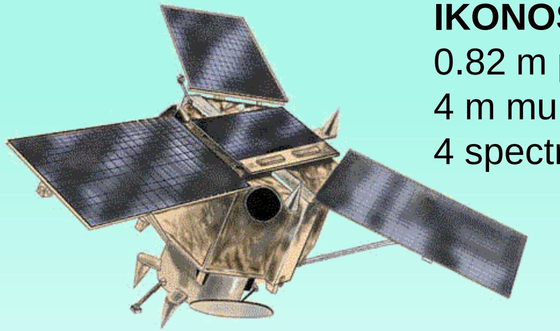
Sub-meter spatial resolution satellites



IKONOS
0.82 m panchromatic
4 m multispectral
4 spectral bands

GeoEye-1
0.41 m panchromatic
1.65 m multispectral
4 spectral bands

WorldView-1
0.50 m panchromatic

WorldView-3
0.31 m panchromatic
1.24 m multispectral VNIR (8 bands)
3.7 m SWIR (8 bands)
30 m CAVIS (12 bands)

WorldView-2
0.46 m panchromatic
1.84 m multispectral
8 spectral bands

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Spectral Bands of IKONOS

Band No.	Wavelength (μm)	Resolution
1	0.40 - 0.52 (Blue)	4 m
2	0.52 - 0.60 (Green)	4 m
3	0.63 - 0.69 (Red)	4 m
4	0.76 - 0.90 (NIR)	4 m
--	Panchromatic	1 m

WorldView-2 Spectral Bands

- B1 “Coastal” (0.40-0.45)
- B2 Blue (0.45 - 0.51)
- B3 Green (0.51 - 0.58)
- B4 Yellow (0.585 – 0.625)
- B5 Red (0.63 – 0.69)
- B6 “Red edge” (0.705 – 0.805)
- B7 NIR1 (0.77 – 0.895)
- B8 NIR2 (0.86 – 1.04)
- Panchromatic

Resolution:
1.84 m multispectral,
0.46 m panchromatic

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GeoEye-1, 0.5-m resolution, 26th Jun 2009
National University of Singapore


IKONOS Image (1-m resolution)

IKONOS, 1-m resolution
Esplanade, Singapore

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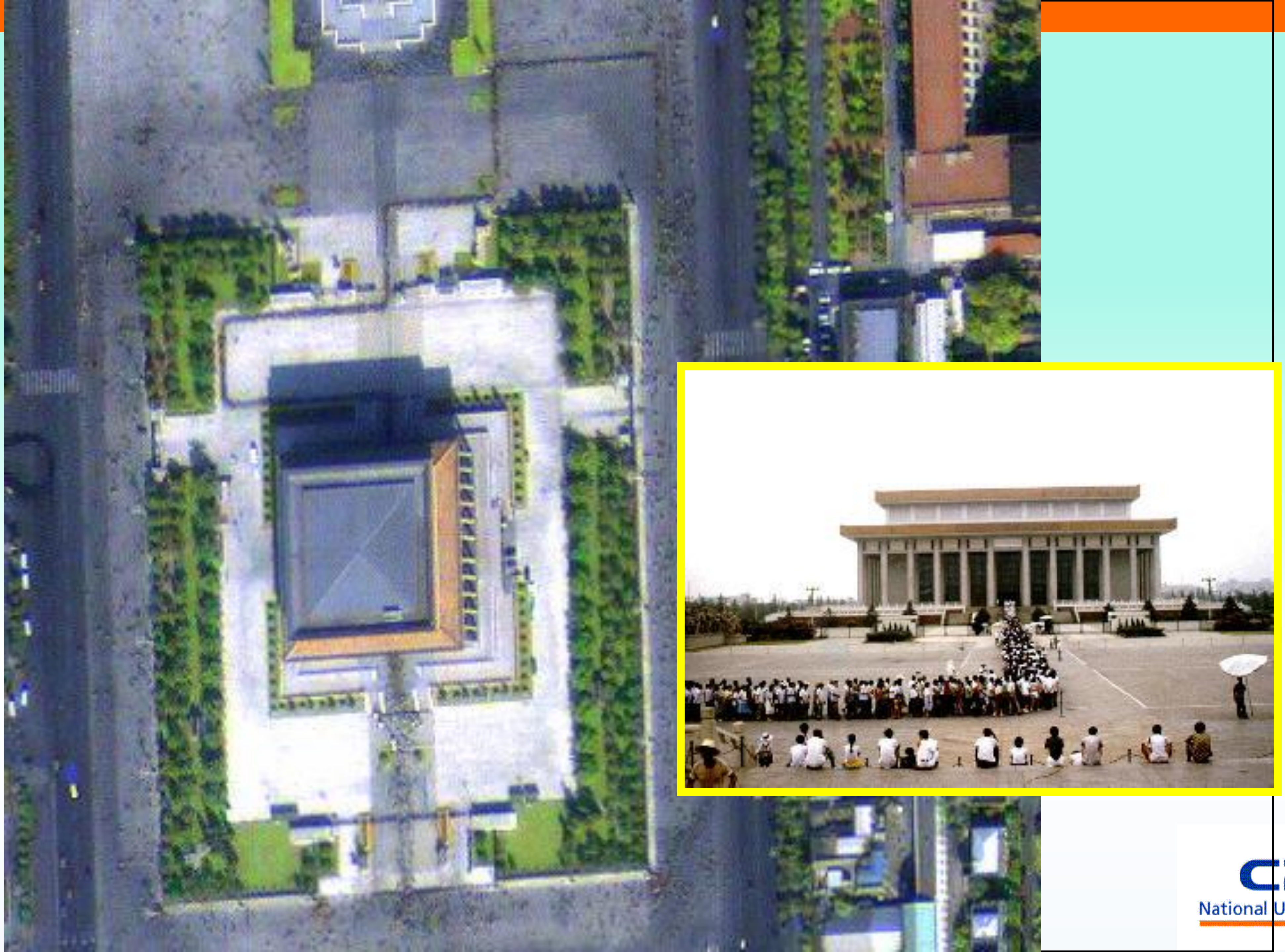
3D Features Extraction and Visualization

Ikonos (1 m resolution) Image of Beijing, 22 October 1999



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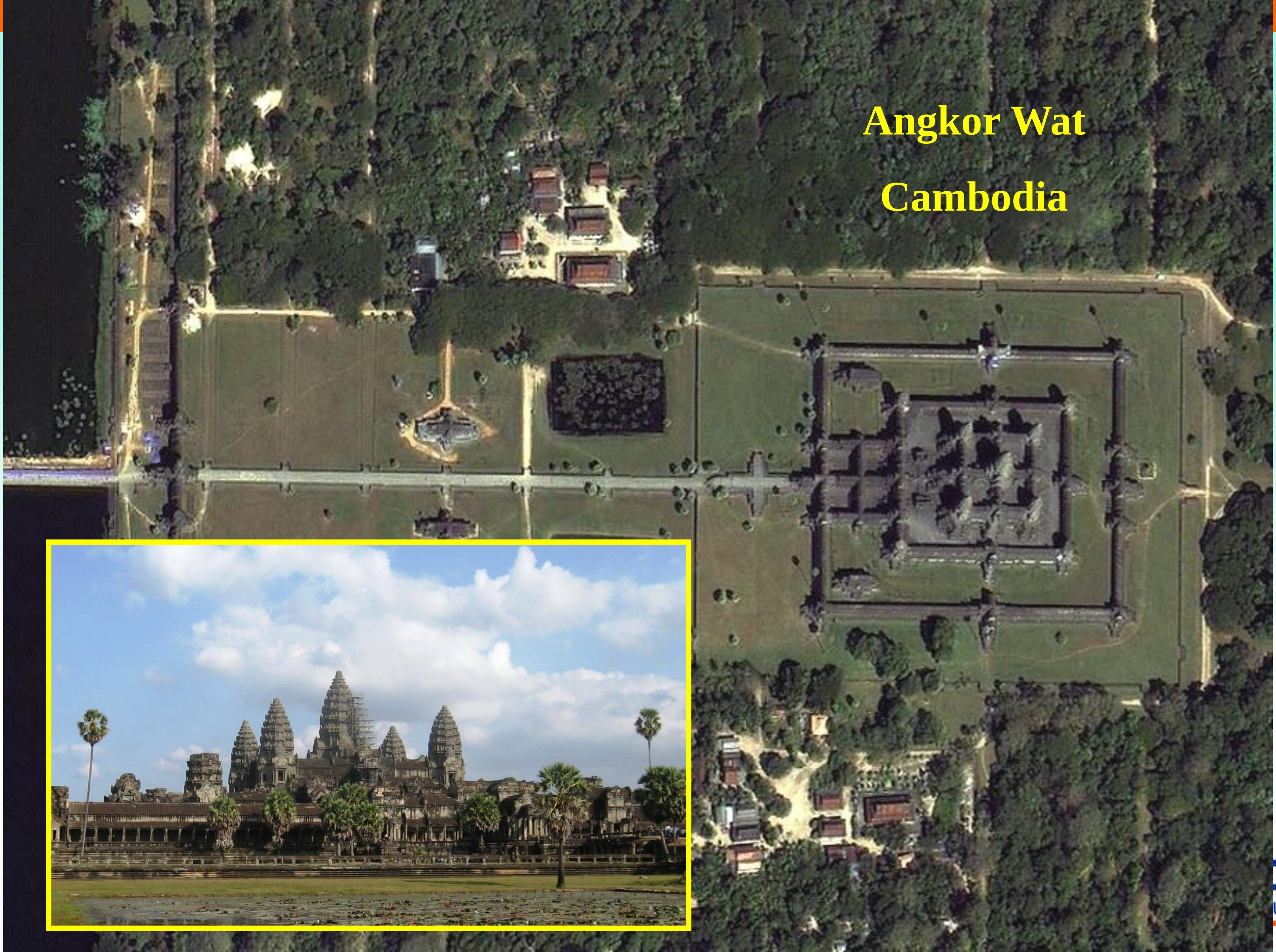
Angkor Wat

Cambodia



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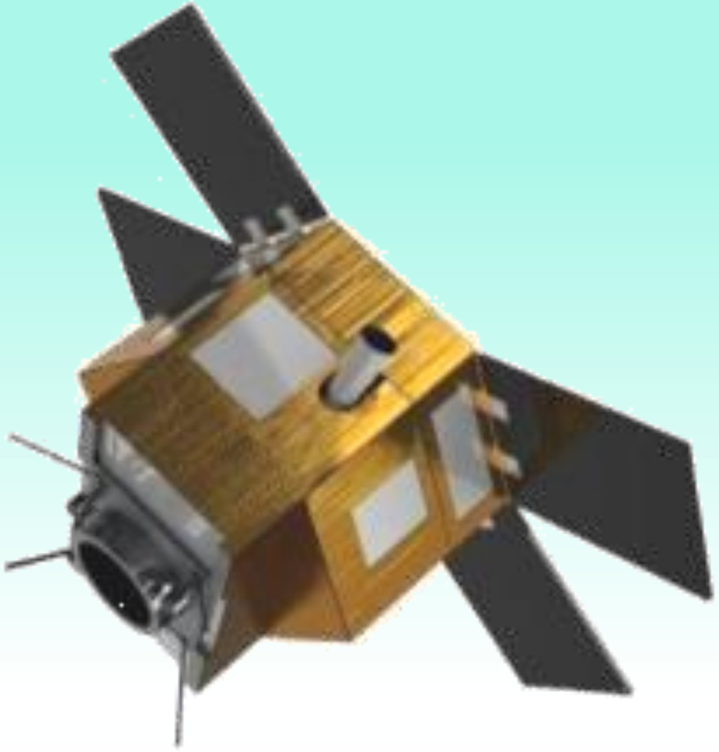
TeLEOS-1

- Launch Date: 16 December 2015
- Designed Life: 5 years
- Orbit: Near Equatorial Orbit (10° to 15° Inclination)
- Orbital height: 550km
- Mass: About 400kg



Imaging & Collection Specifications
- Resolution: 1m nominal at nadir
- Swath width: 12km
- Dynamic Range: 10bits per pixel
- Slew Rate: 2.5 deg/sec

Image Reception and Processing System (Ground Station)
- In-house development of CRISP

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TeLEOS-1 Image
Sentosa Island, Singapore 13 Apr 2016

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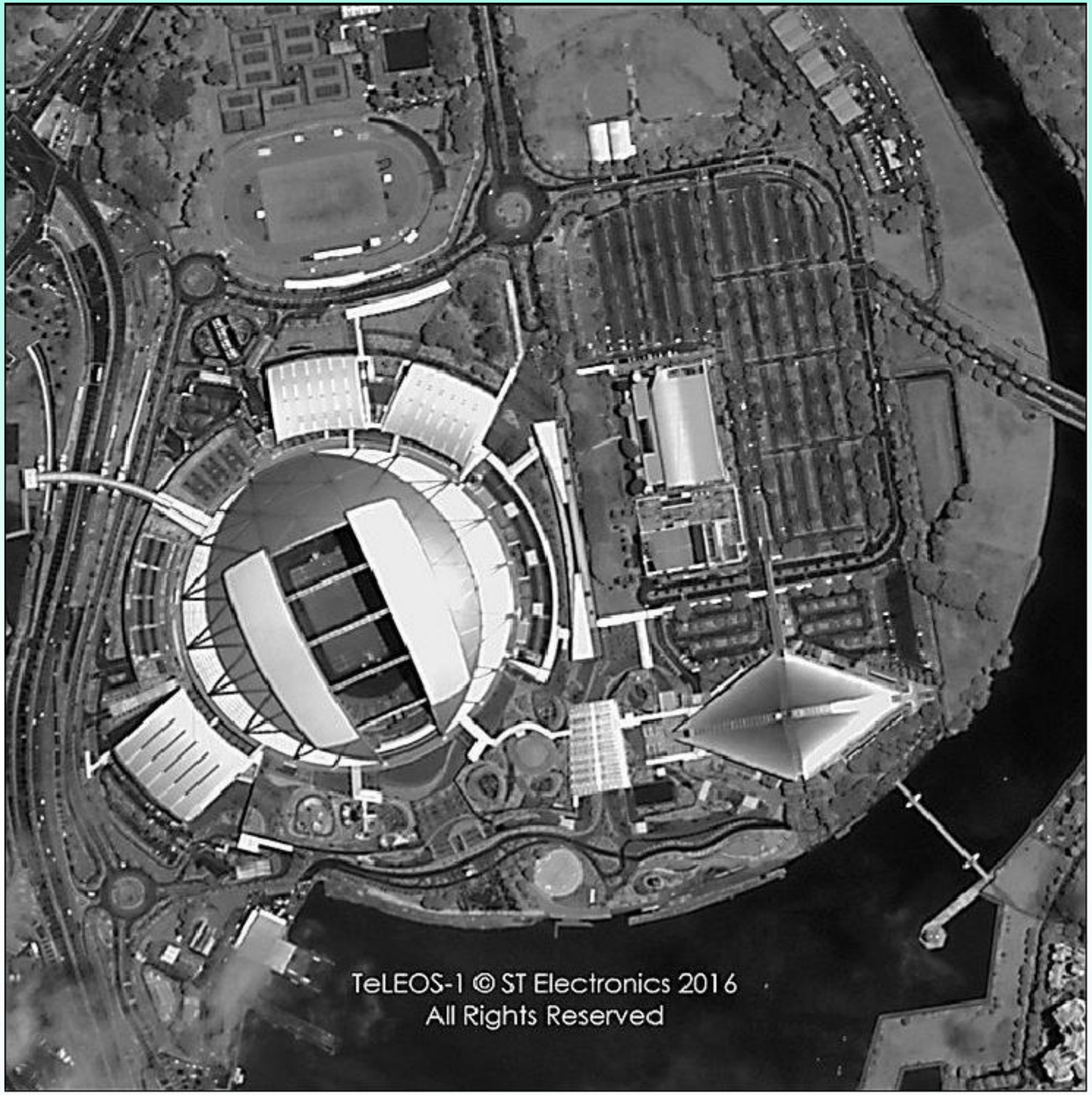

TeLEOS-1 image

Singapore
Sports Hub

23 Jan. 2016

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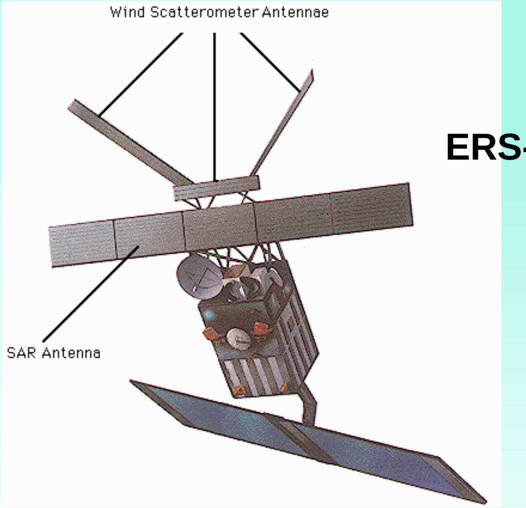
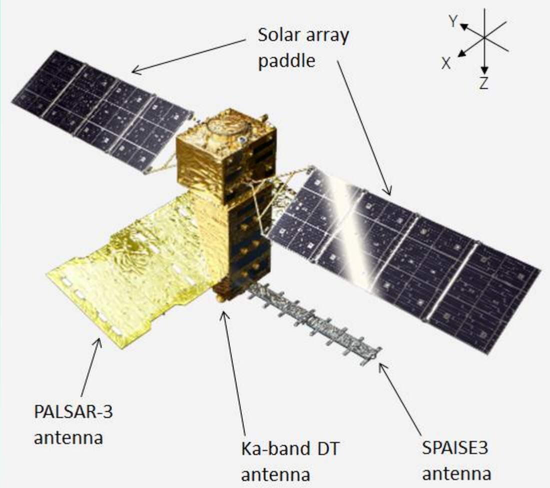
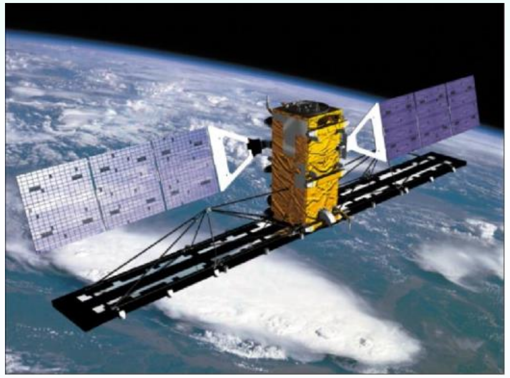
Synthetic Aperture Radar (SAR) Satellites



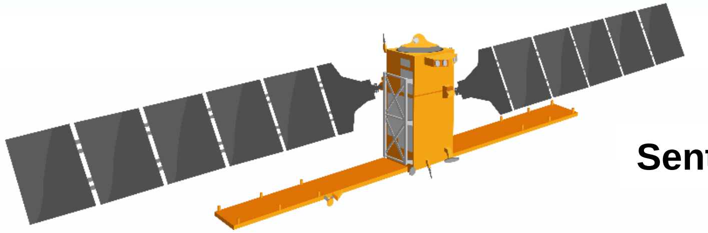
ERS-1,2



ALSO-4



RADARSAT-1,2



Sentinel-1

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Mapping Rice Cropping Systems in Mekong Delta Using Multitemporal Synthetic Aperture Radar Data

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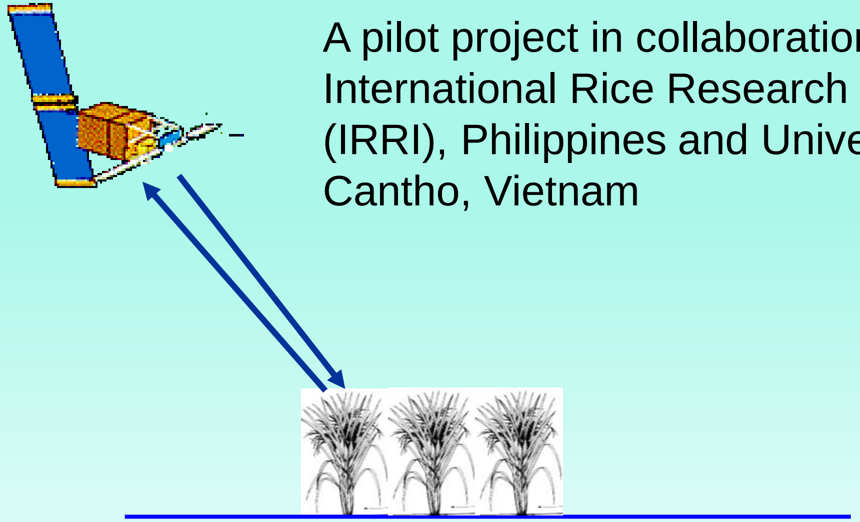
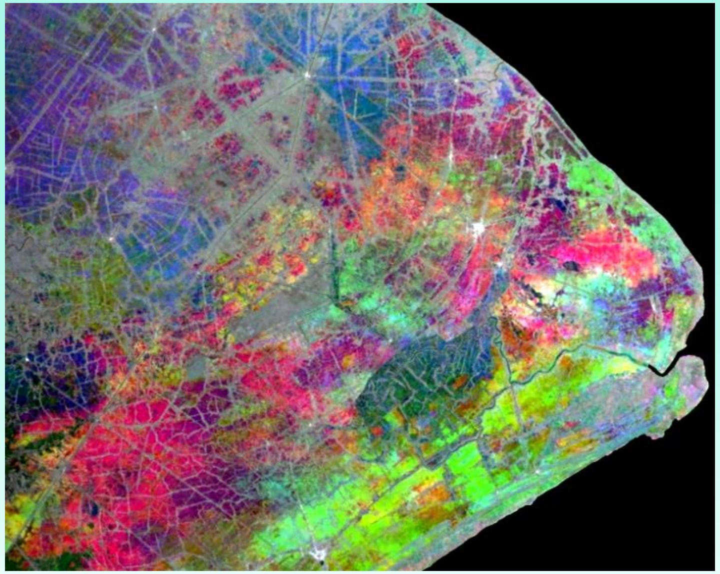
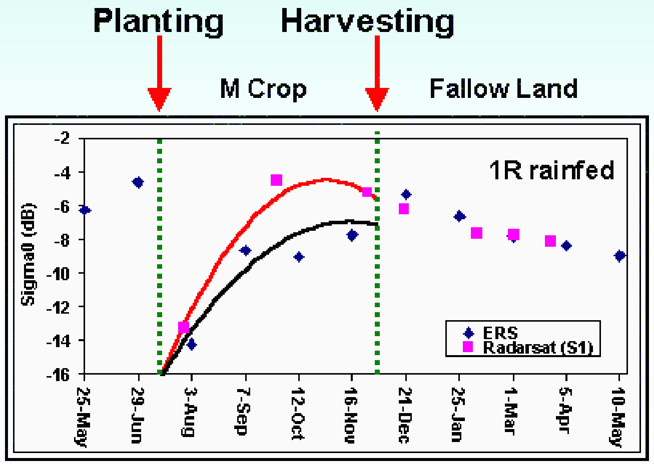
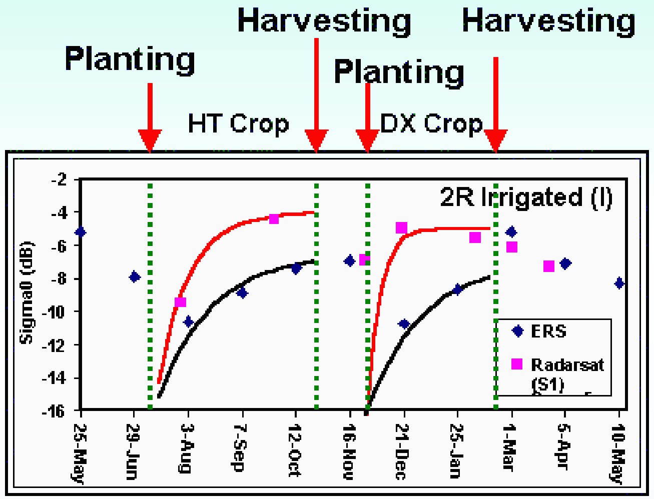
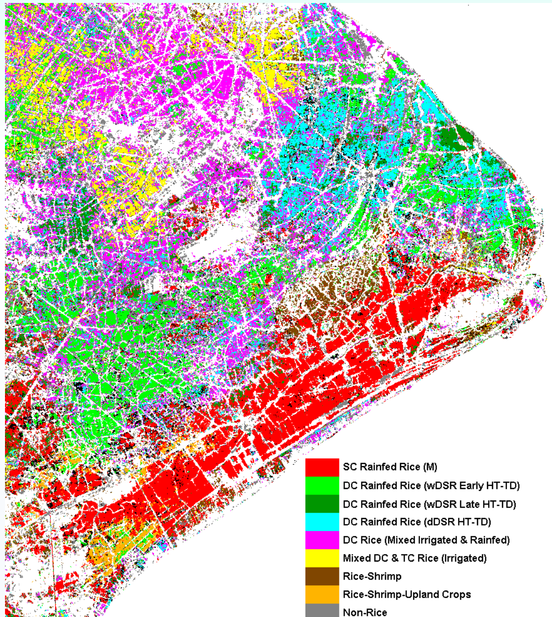


A pilot project in collaboration with International Rice Research Institute (IRRI), Philippines and University of Cantho, Vietnam



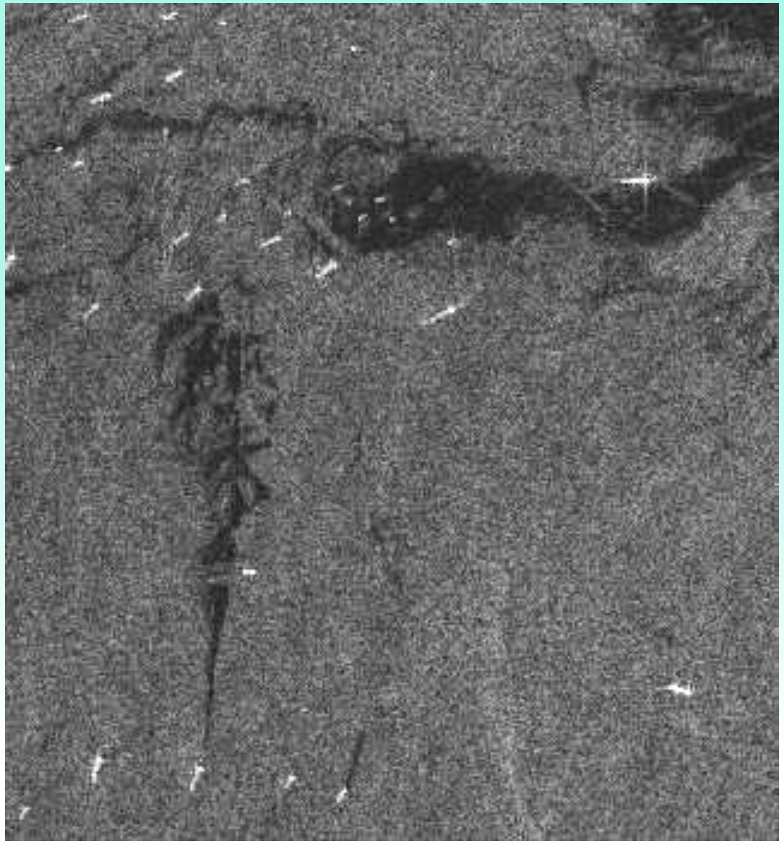


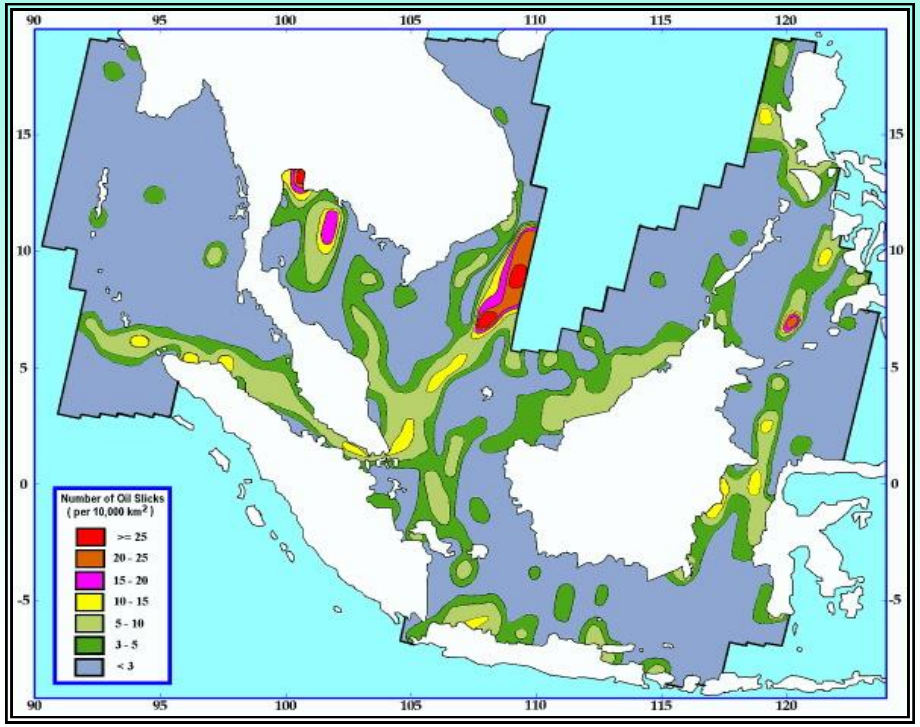


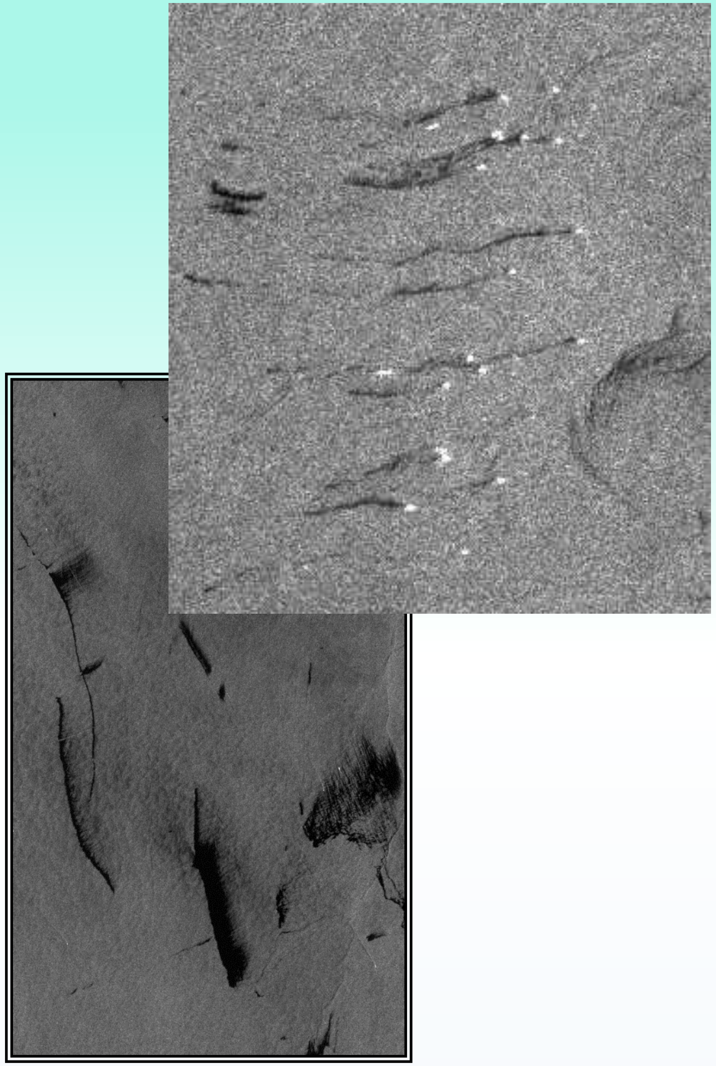


S. C. Liew, S. P. Kam, T. P. Tuong, P. Chen, V. Q. Minh, and H. Lim (1998), **Application of multitemporal ERS-2 synthetic aperture radar in delineating rice cropping systems in the Mekong River Delta, Vietnam**. *IEEE Trans. Geoscience and Remote Sensing*, 36(5) 1412-1420.

Ocean Oil Spills







- Aug 1996: An ERS SAR image clearly identified a ship discharging a plume of oil 5-km long.
- With the ERS image and other evidence, the culprits were convicted in court and fined a total of S$ 1.25 million.

Frequency of Oil Spills from Ships estimated with more than 5000 scenes of ERS SAR images

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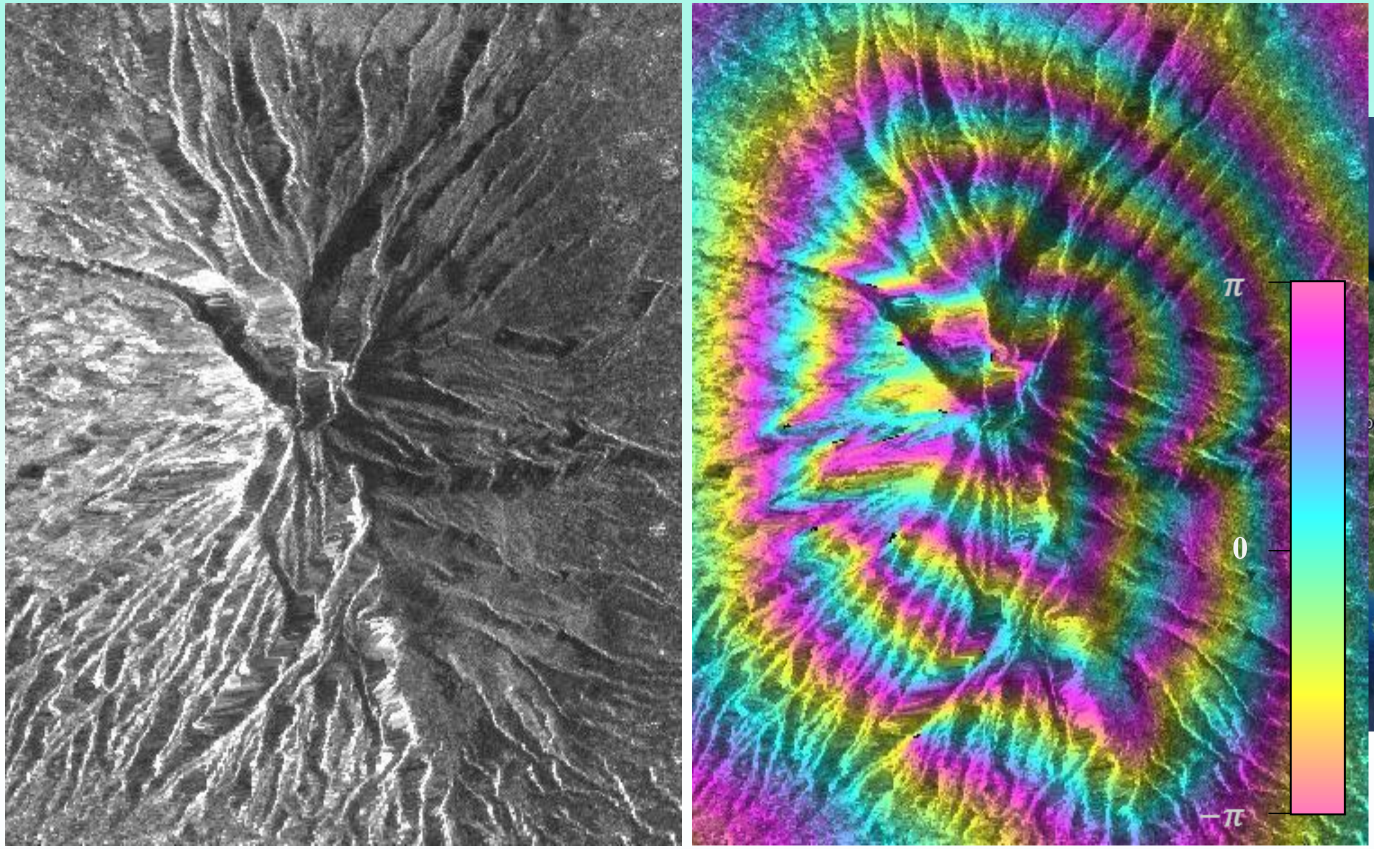
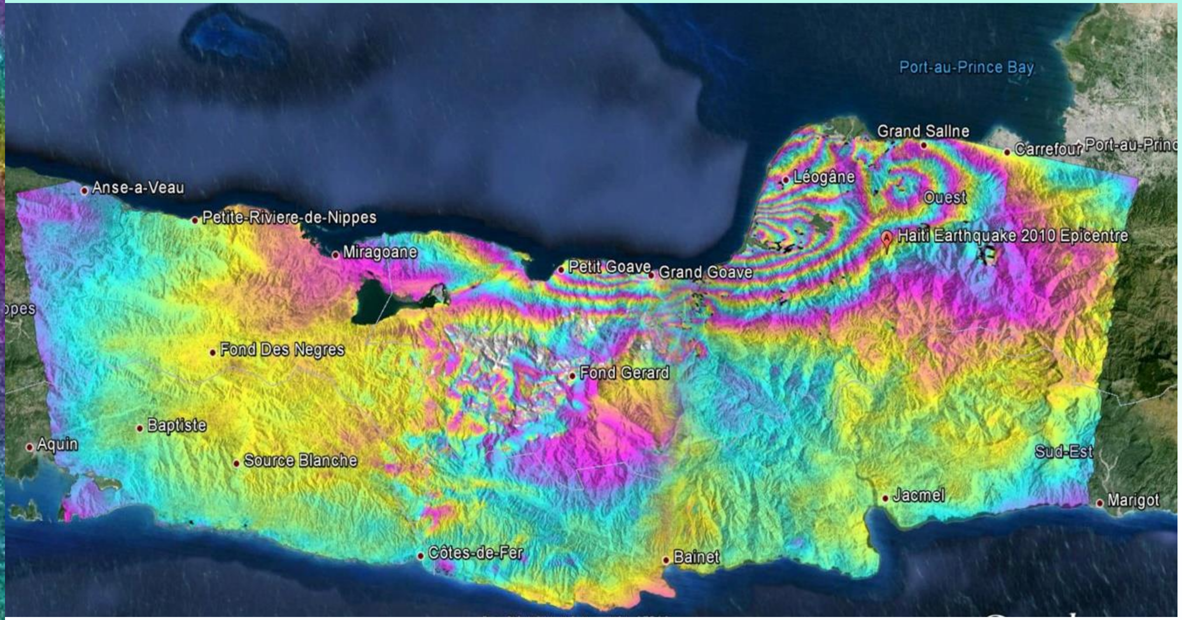
Interferometric SAR



Mt Merapi ALOS-1 Palsar Intensity Image (left), InSAR interferogram (right)



ALOS-1 DInSAR of Haiti Earthquake 2010.
Fringe interval = 24cm

Polarimetric Synthetic Aperture Radar

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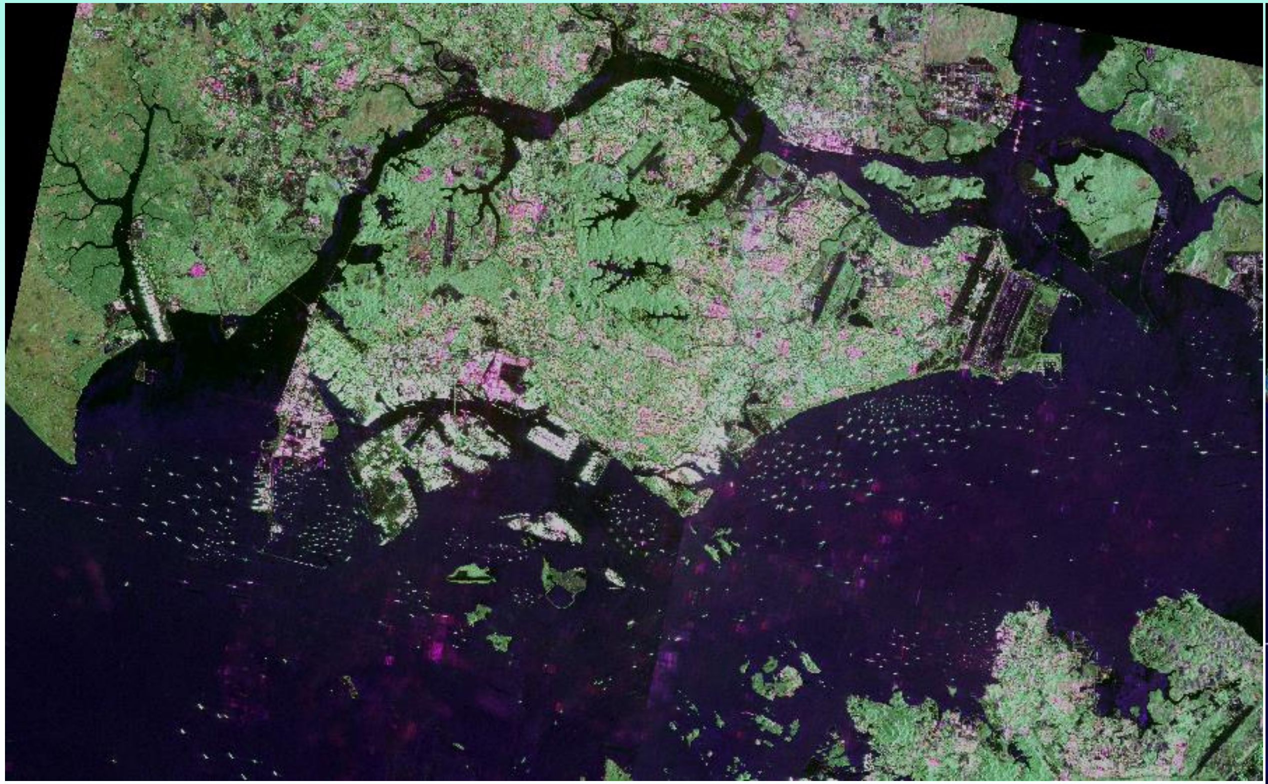
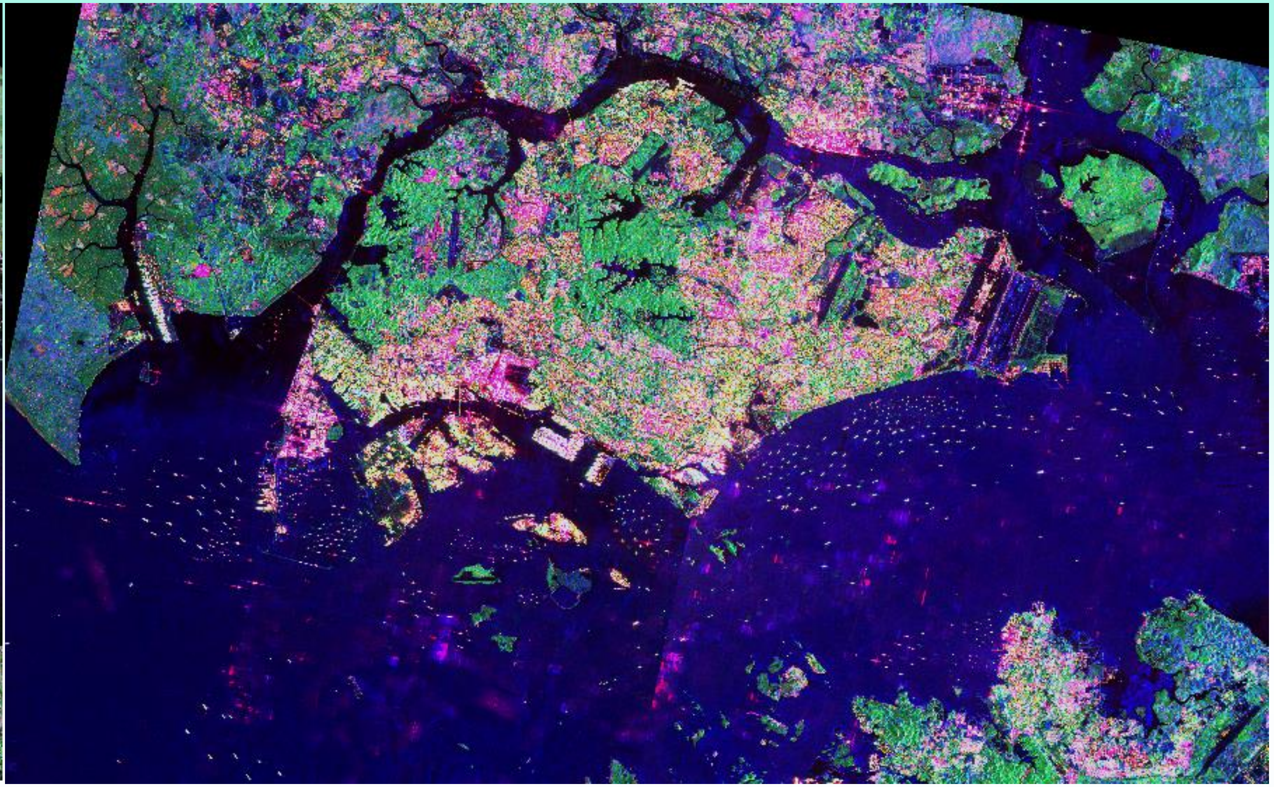
ALOS-2 PALSAR-2
Polarimetric Intensity Image



Red = HH
Green = HV
Blue = VV

ALOS-2 PALSAR-2
Polarimetric Scattering Decomposition Image



Red = Even Bounce
Green = Volume Scattering
Blue = Odd Bounce

Image Interpretation

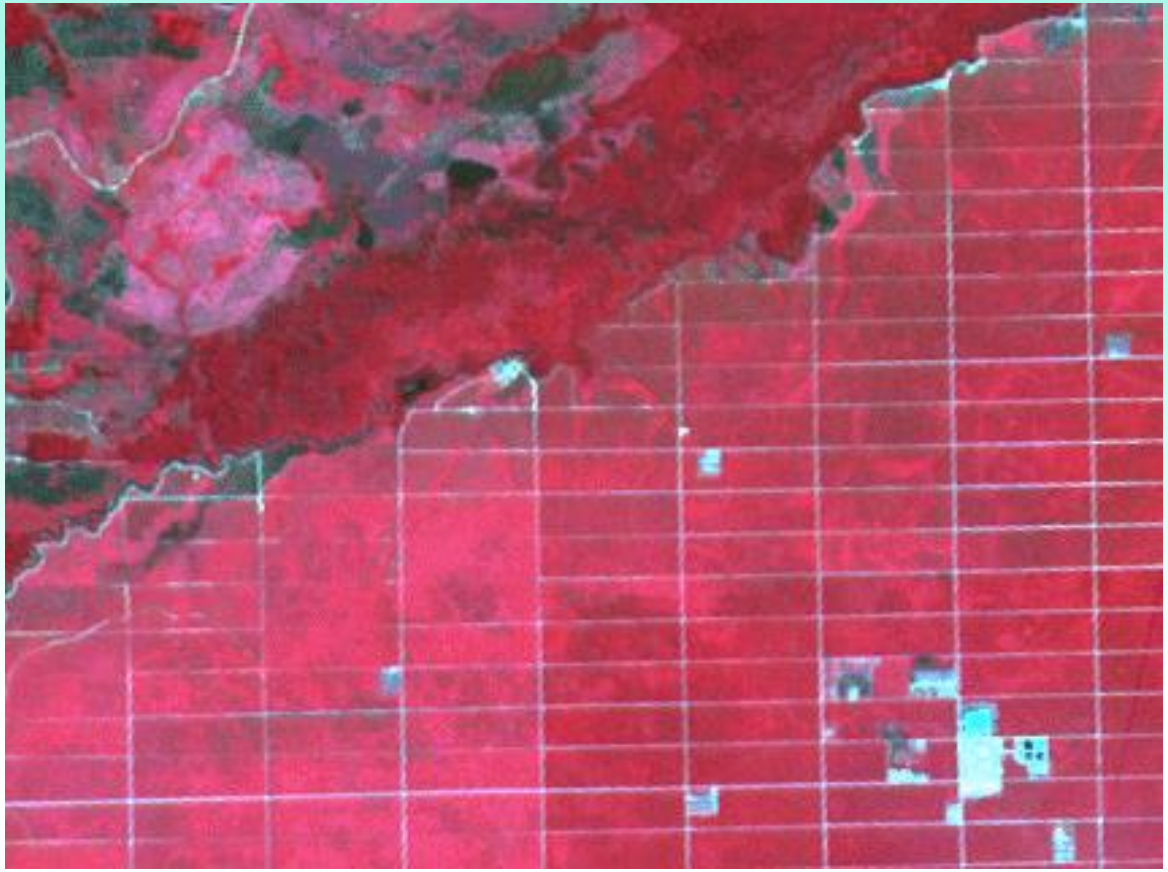
- Radiometric and Spectral Information
  - Brightness and colours
- Spatial and Geometric Information
  - Shape, size and location
- Textural Information
  - heterogeneity, directionality, “patterns”
- Contextual Information
  - Human activities, physical environment, natural phenomena, extreme events, disasters

Use any other information you can gather to help in interpretation.

“Ground Truth” information is always useful.

Domain knowledge is important! The more knowledge you have, the more information you can derive from the image.

Geometric Pattern



SPOT false colour image, RGB=321

Texture

IKONOS
True colour
image

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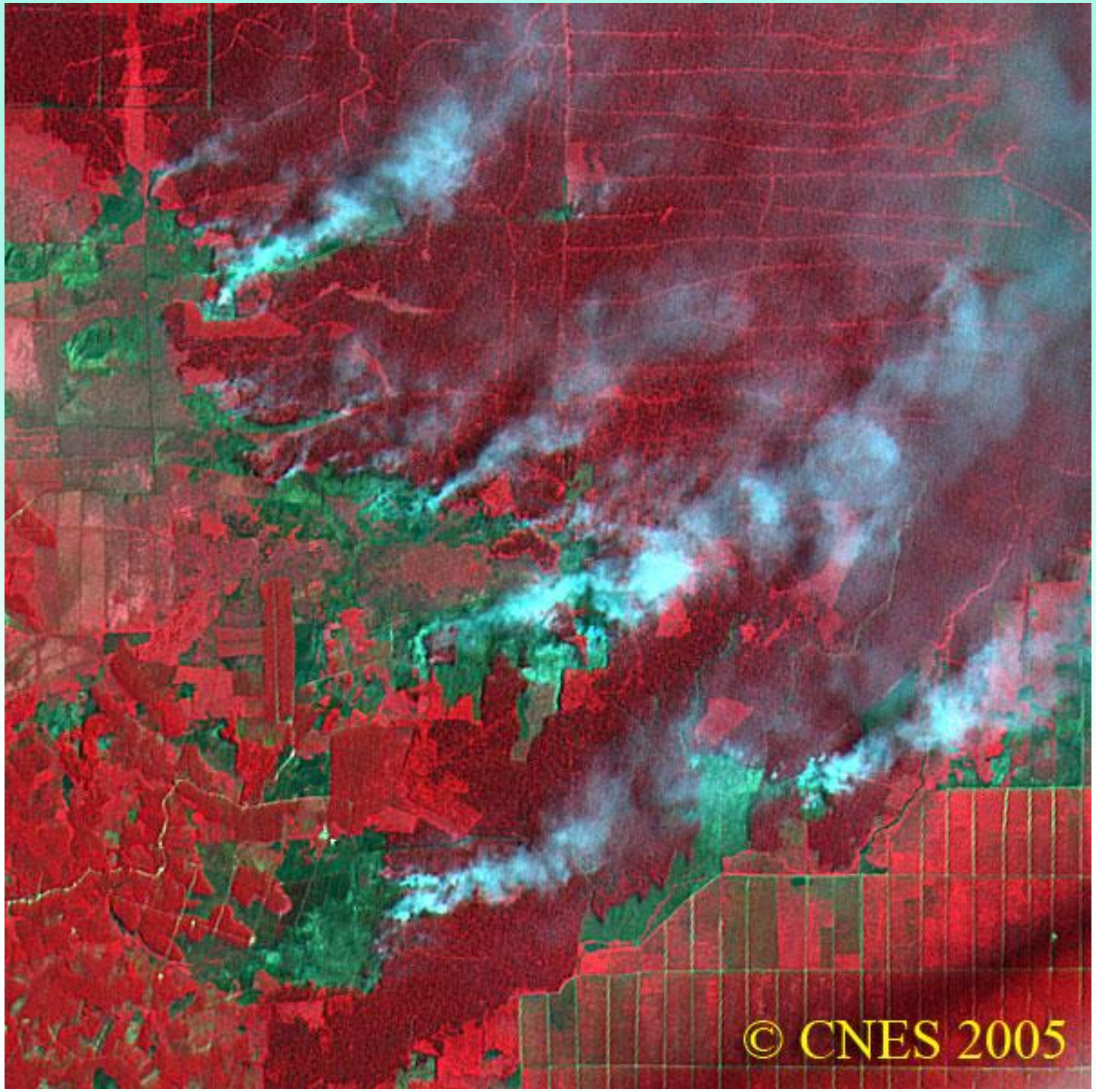
Contextual Information



SPOT
false colour
image,
RGB=321

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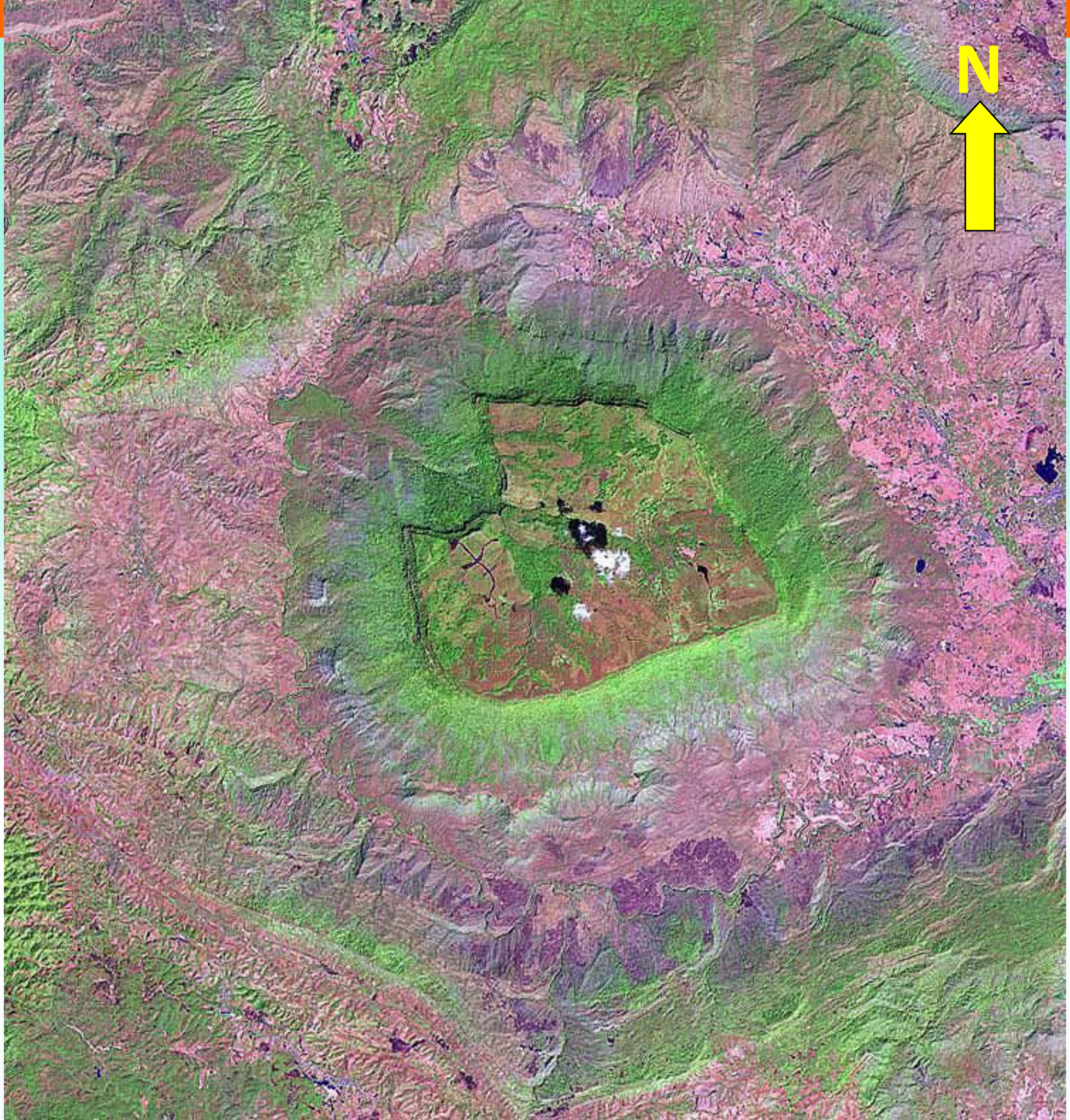
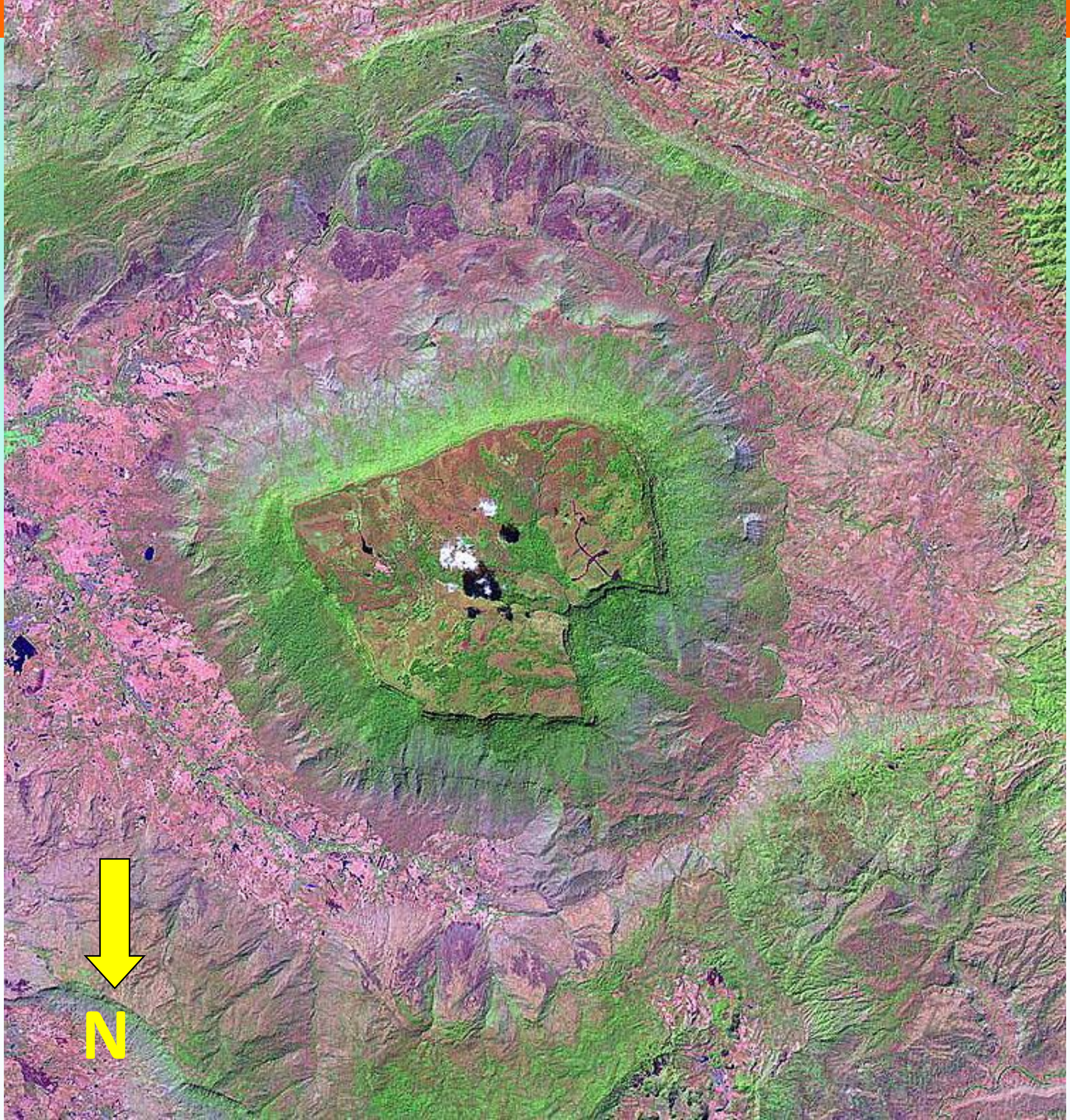


Illumination effect. Sometimes our eyes play tricks on us.

North is up.

Is the heart-shaped structure higher or lower than the surrounding?



Illumination effect.
Sometimes our eyes play tricks on us.

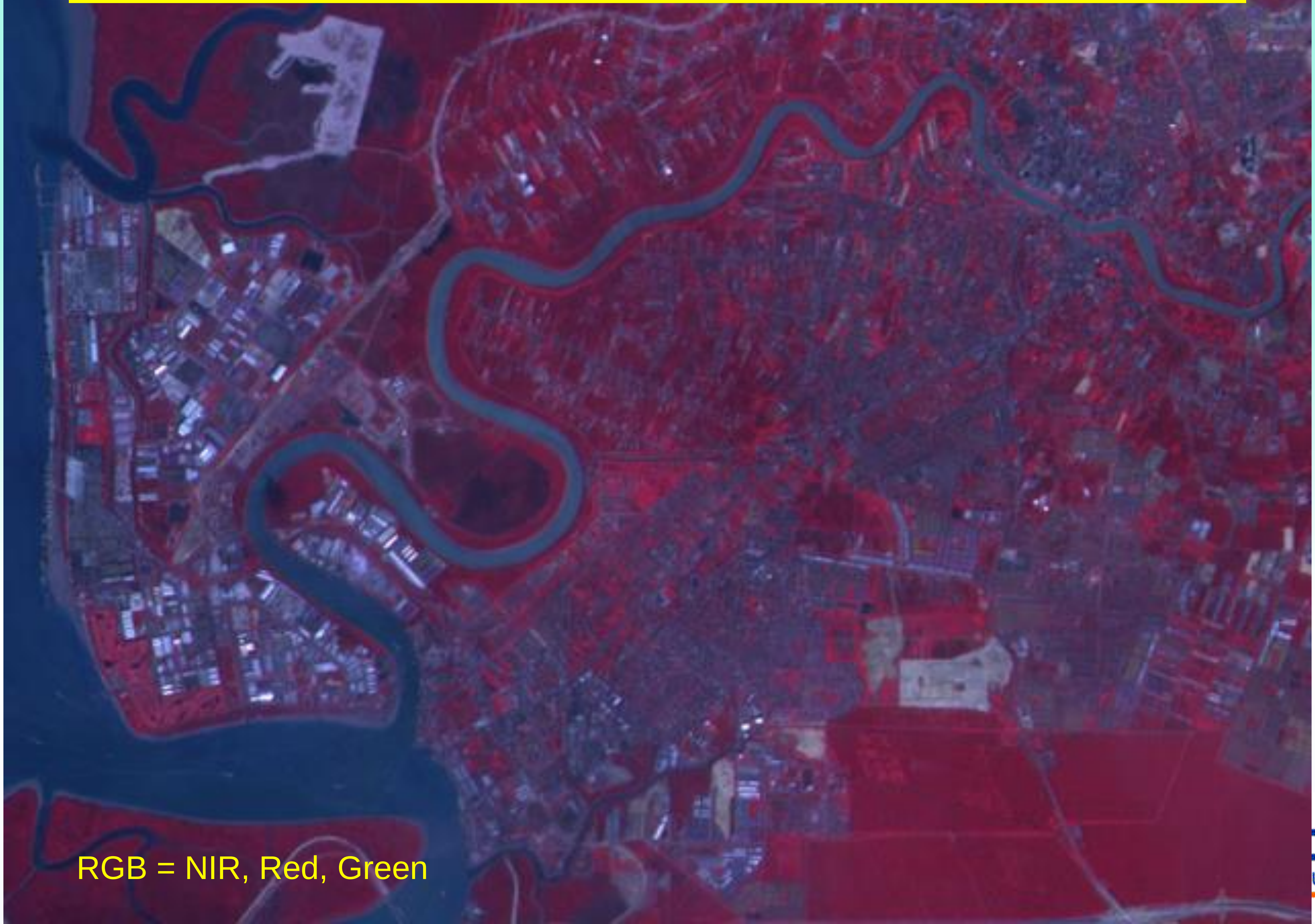
Rotate the image 180 degrees.
Now, North is down.

Is the heart-shaped structure higher or lower than the surrounding?

Some techniques in image processing and extracting information from satellite images

- Radiometric enhancement
  - Contrast stretching
- Algebraic operations
  - Band ratioing, vegetation index, moisture index, chlorophyll indices, etc.
- Classification
- Modeling
  - Physics-based models
  - Statistical models
  - Machine learning models

Example: Before contrast enhancement



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After contrast enhancement

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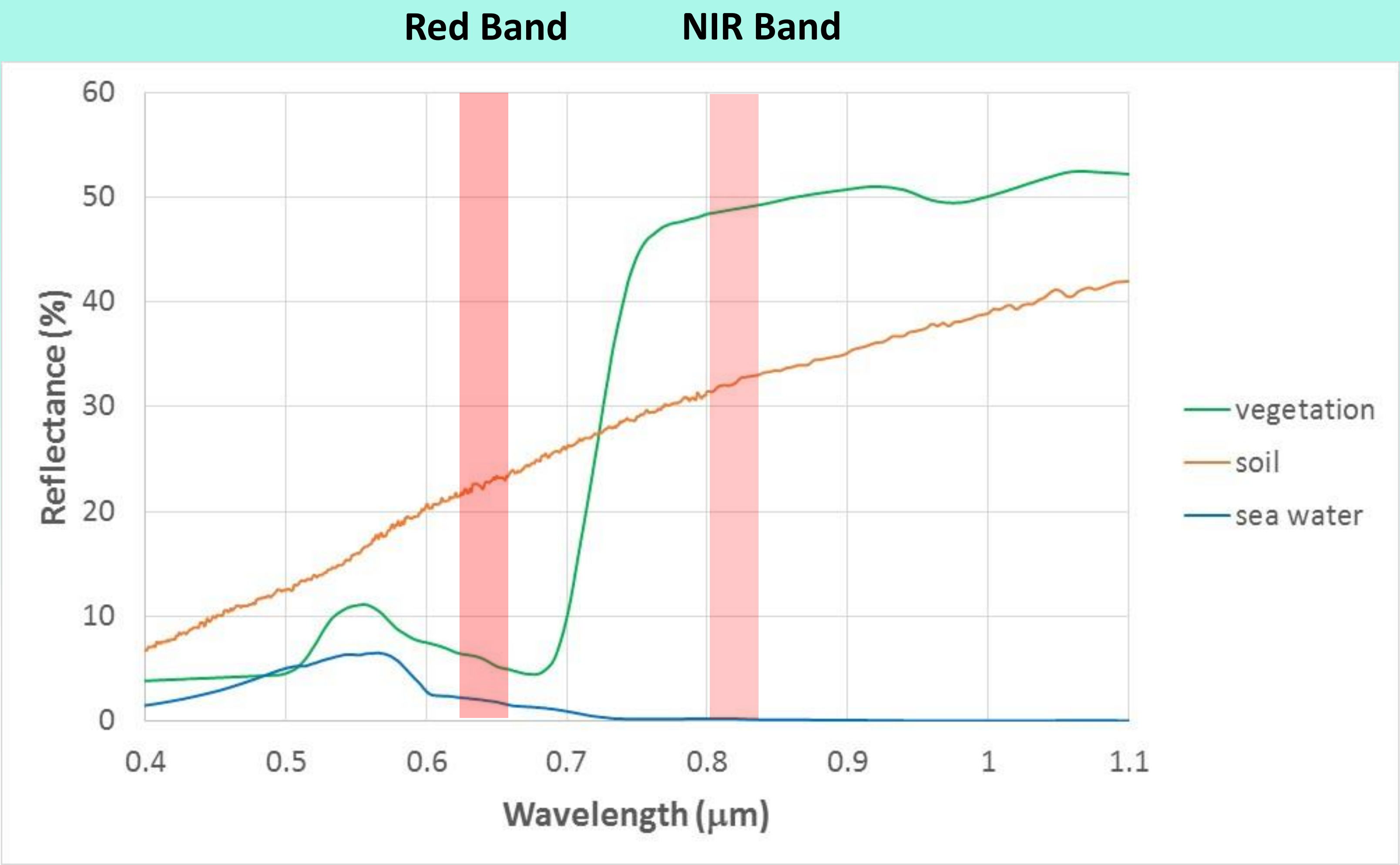
Vegetation Index



Ratio Vegetation Index

$RVI = R_{NIR}/R_{Red}$

Normalized Differece Vegetation Index

$NDVI = (R_{NIR} - R_{red})/(R_{NIR} + R_{red})$

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Satellite image

RGB = NIR, Red, Green

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NDVI

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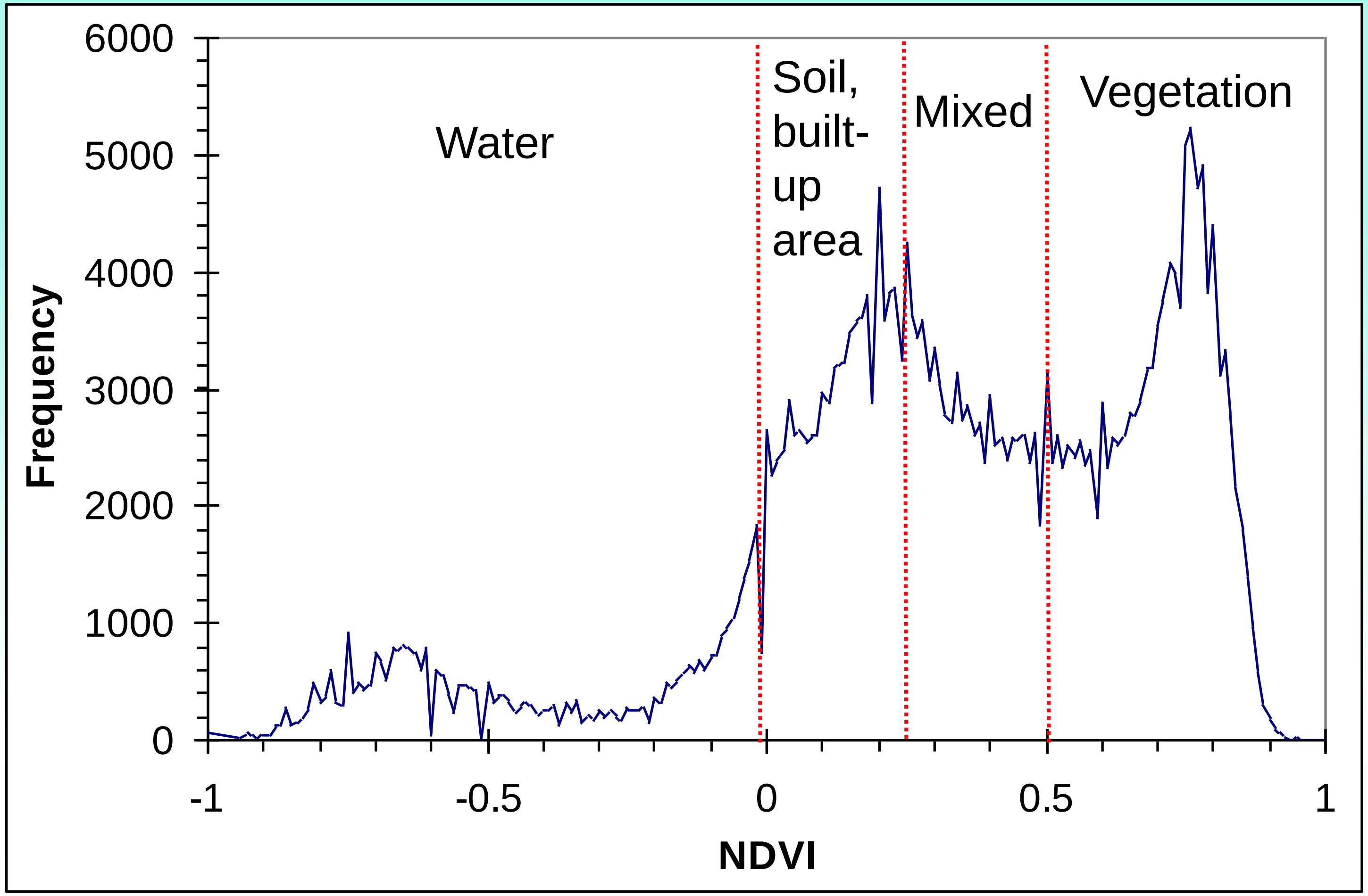
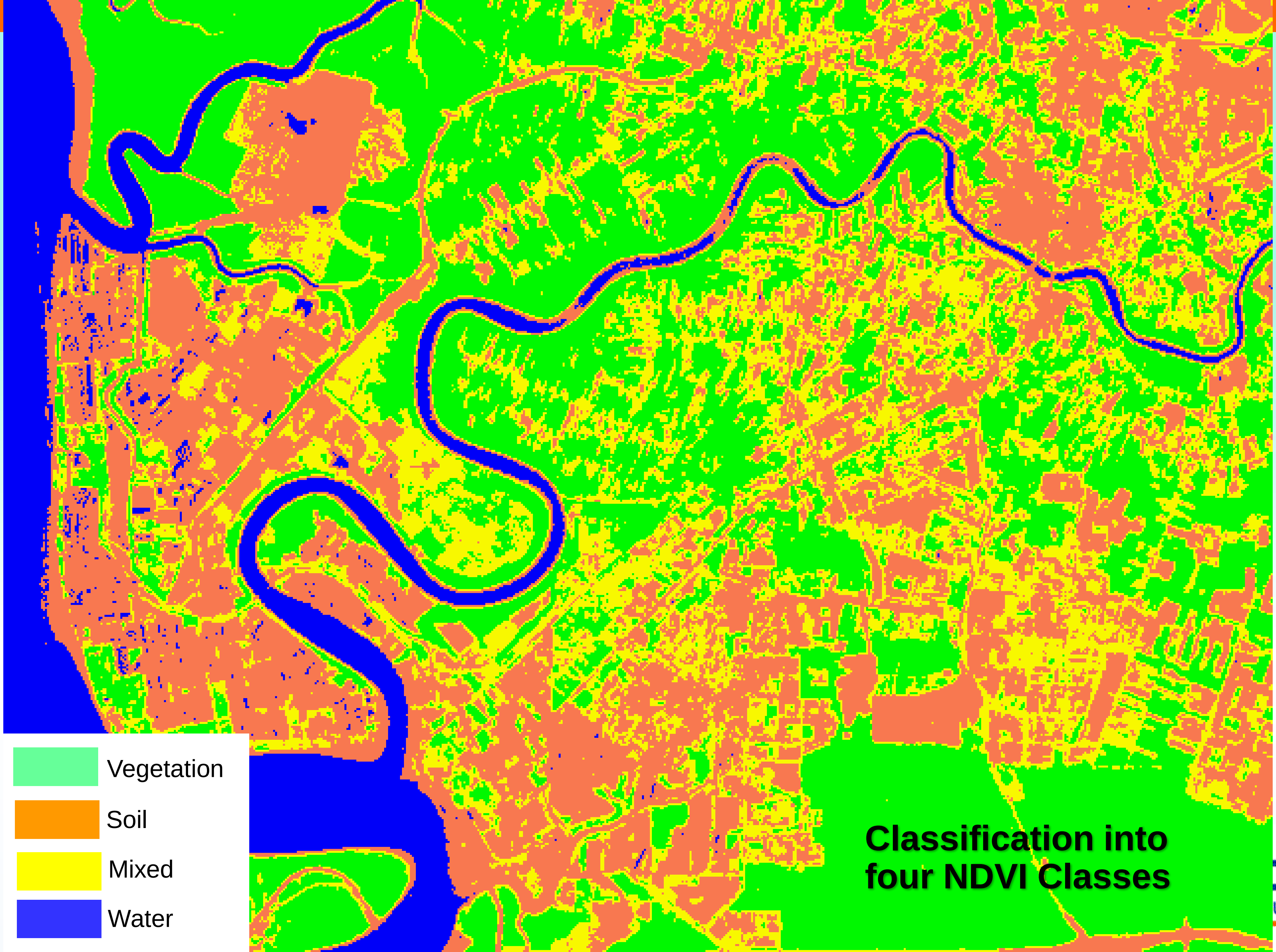
NDVI Histogram



NDVI can be used for classification into broad land cover classes



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Mapping Mangrove Area

Landsat 7 ETM+ Image
(RGB=543)

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Mapping Mangrove Area

Landsat 7 ETM+ Image
(NDVI)

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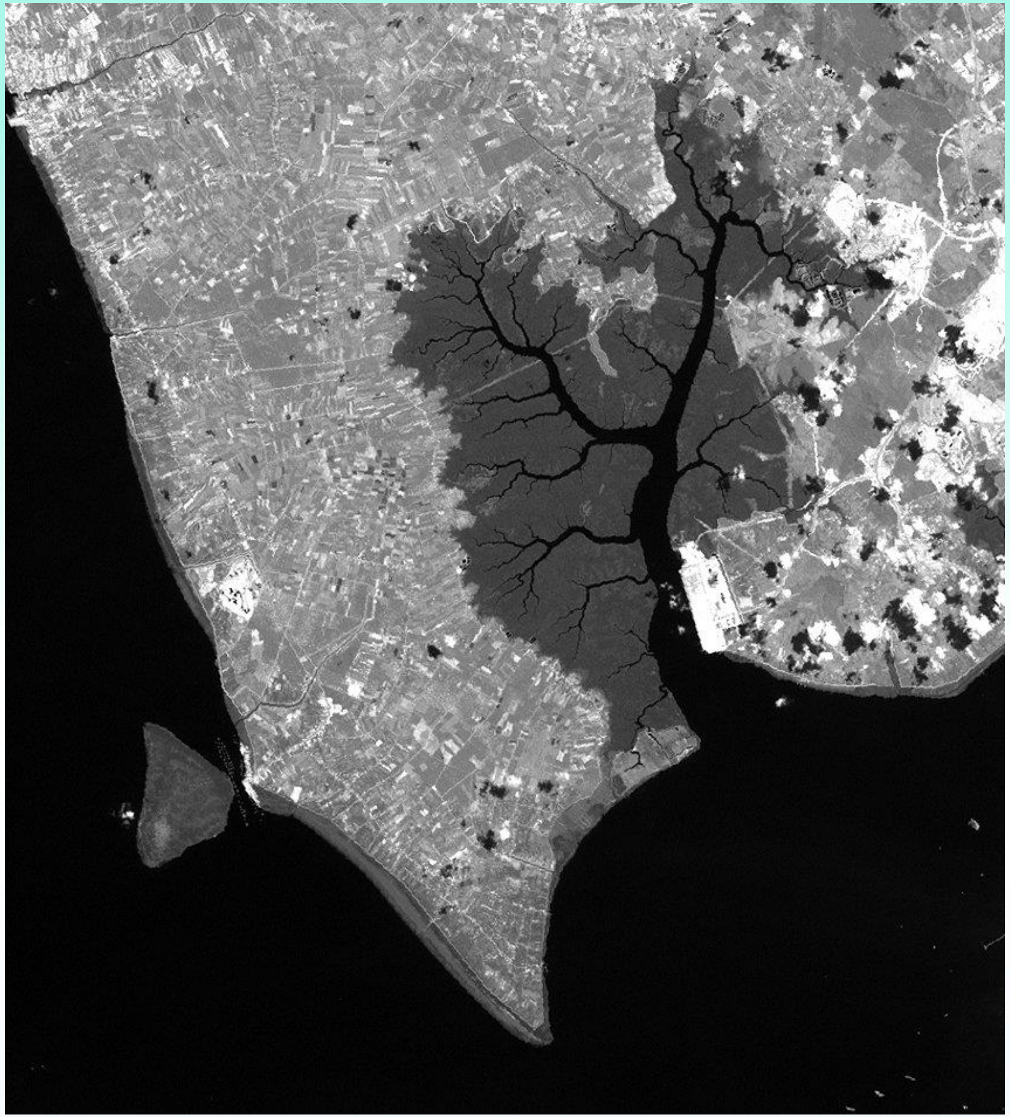
Mapping Mangrove Area



Landsat 7 ETM+ Image
(Band 5 SWIR)

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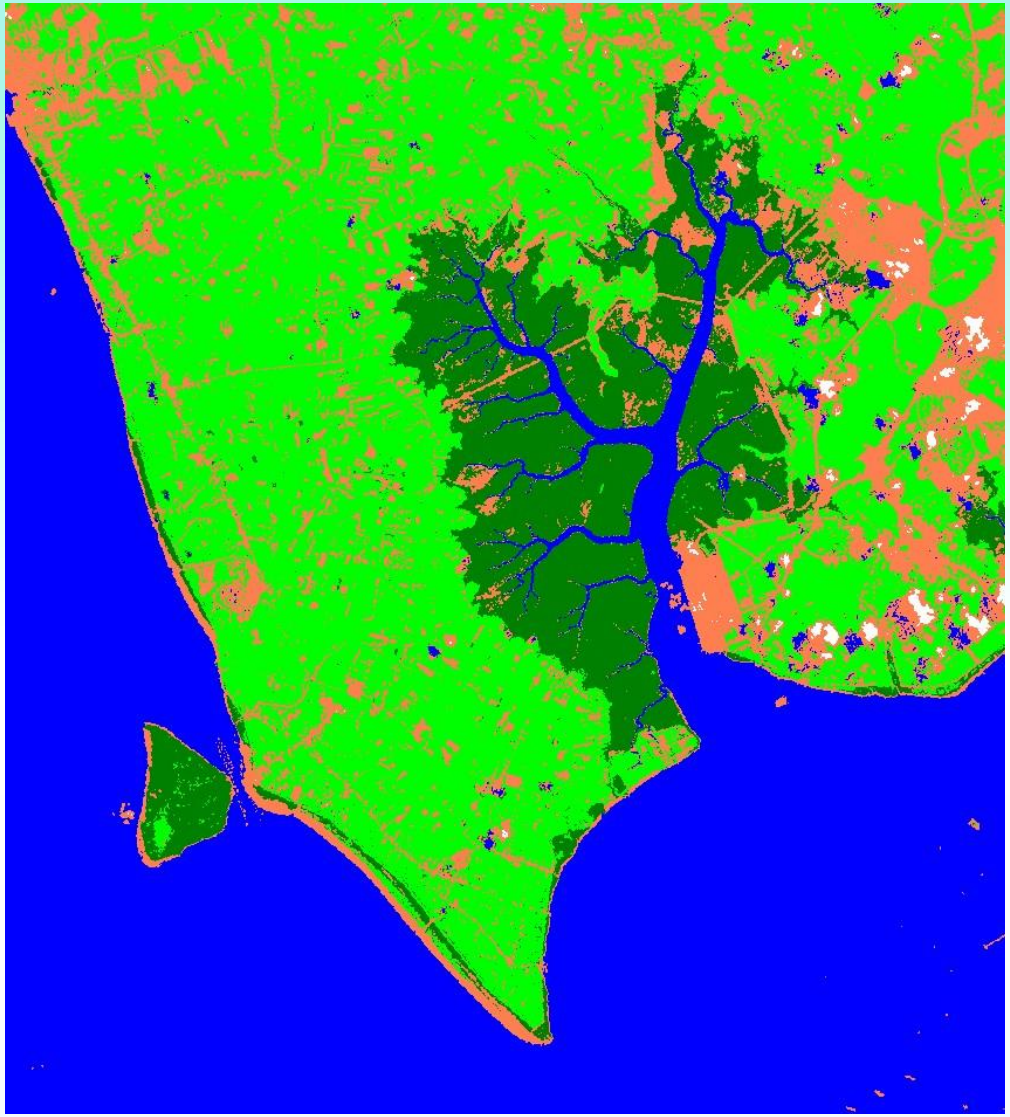
Mapping Mangrove Area



Mangrove Map derived from Landsat 7 ETM+ Image

Water

Non-vegetation

Mangrove

Non-mangrove vegetation

Mangrove Area delineated by thresholding on NDVI to select vegetation (green areas) and then on Band 5 (SWIR) to select moist vegetation (Dark green areas).

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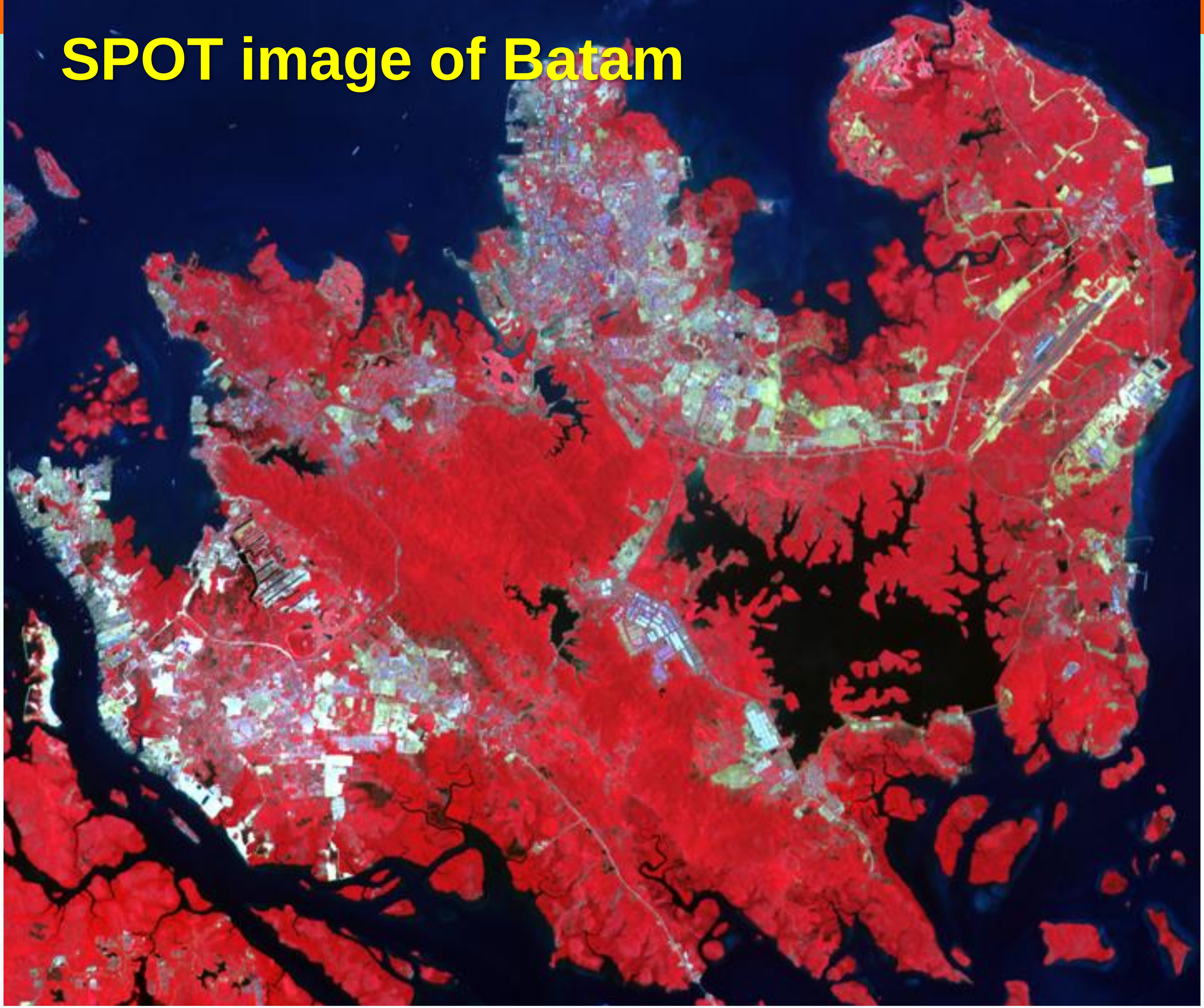

Land cover / Land Use Classification

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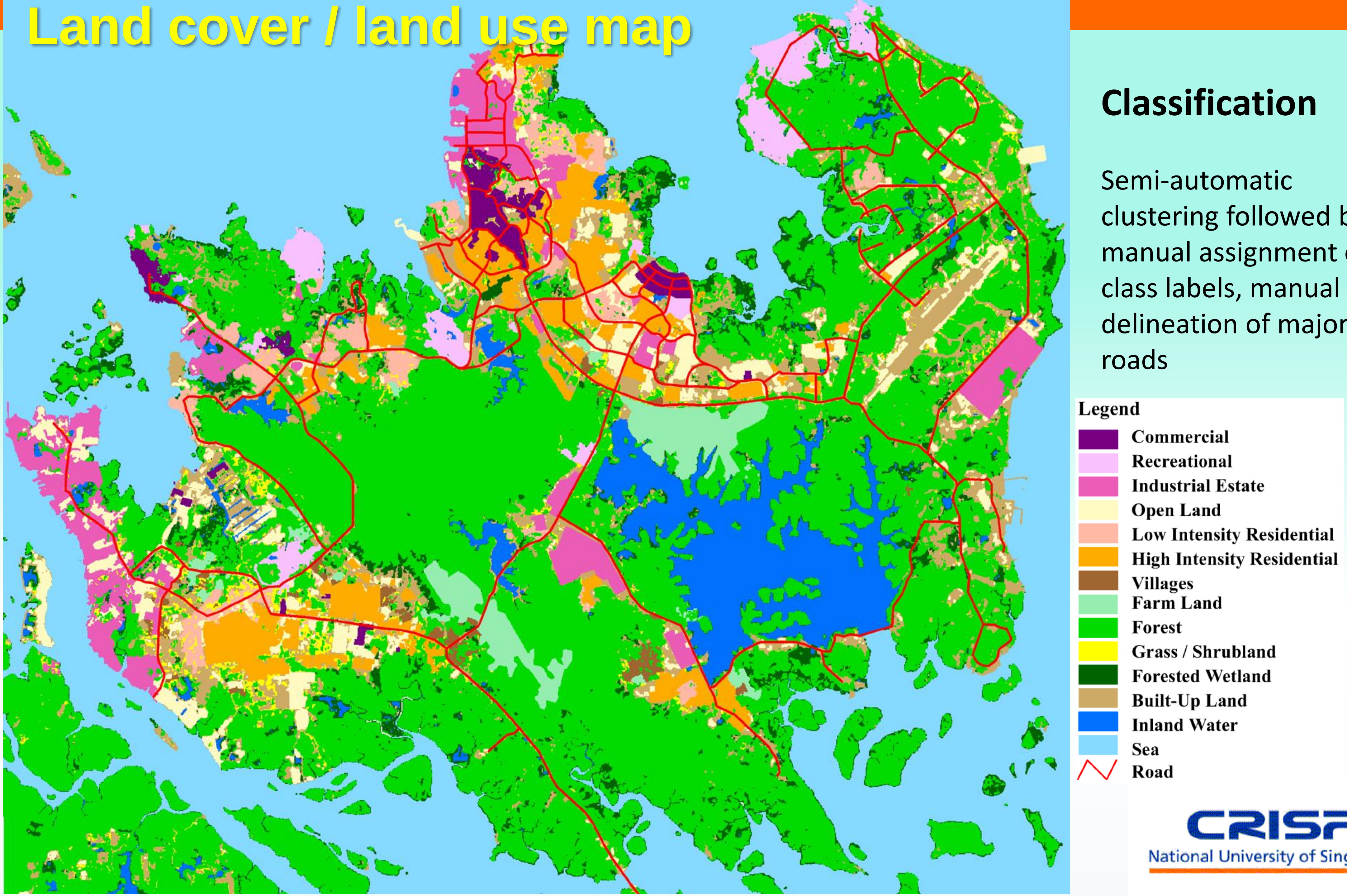
Land cover / land use map



Classification

Semi-automatic clustering followed by manual assignment of class labels, manual delineation of major roads

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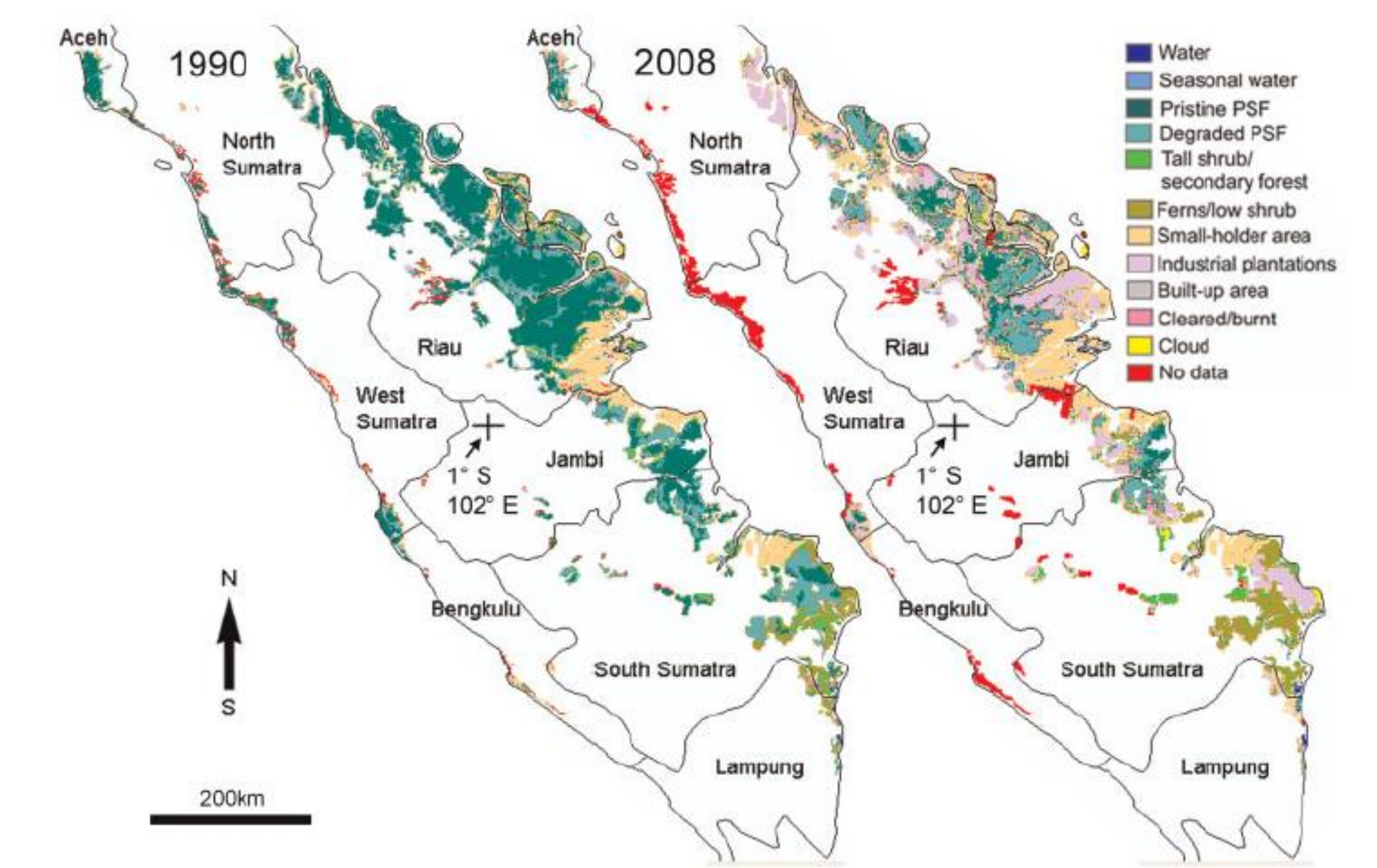
Land cover change in peatlands of Sumatra 1990 – 2008



From: Miettinen and Liew, Land degradation & development 21: 285–296 (2010)

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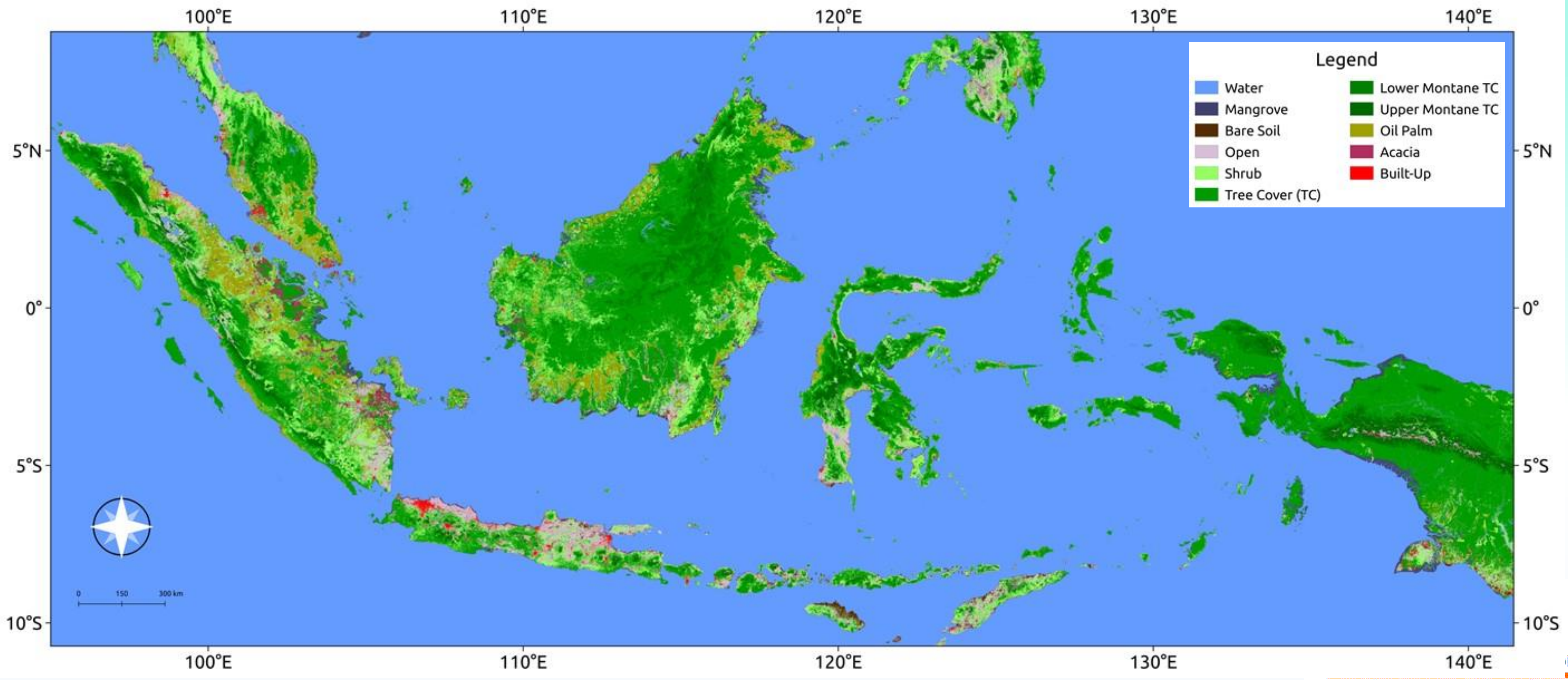
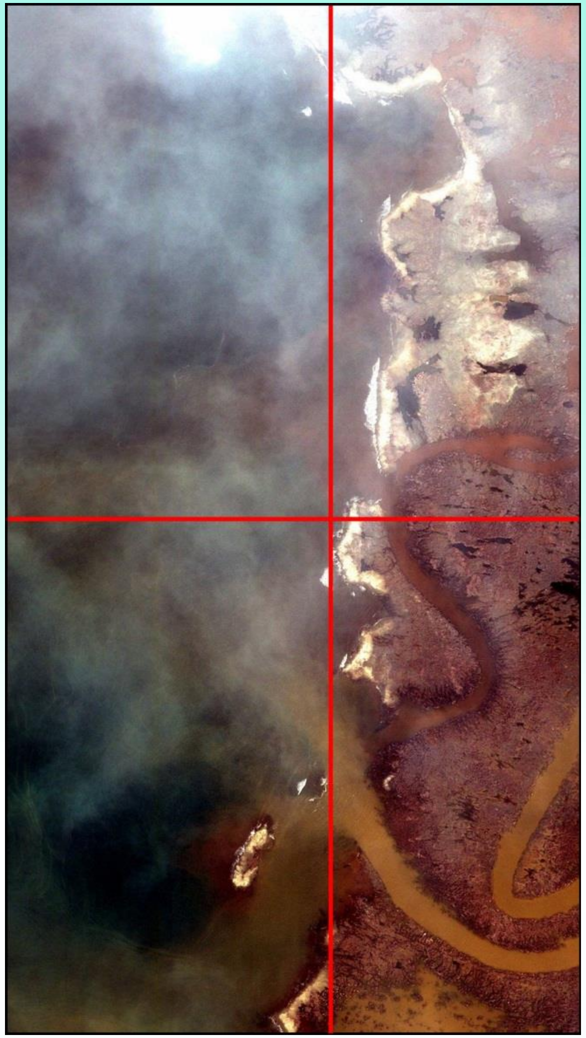
Southeast Asia Land Cover map 2020 (30m resolution)
Automatic Classification by Machine Learning

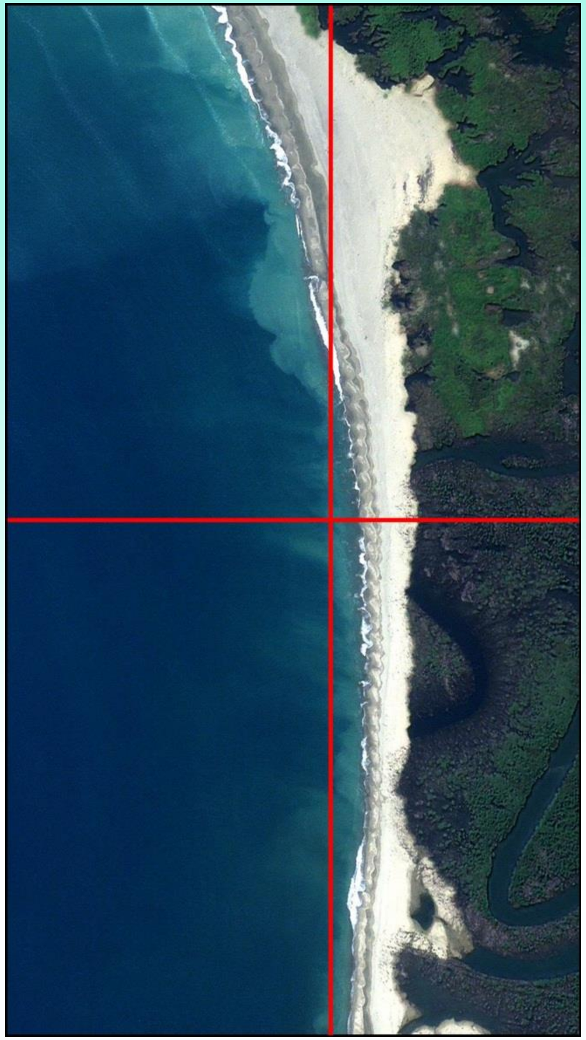


Change Detection: Aceh Coast – Recovery after the 2004 Indian Ocean Tsunami

Pre-tsunami



Tsunami



13 months Post-tsunami

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End of Lecture 1

Thank you

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