ENGO 697

Remote Sensing Systems and Advanced Analytics

session 2

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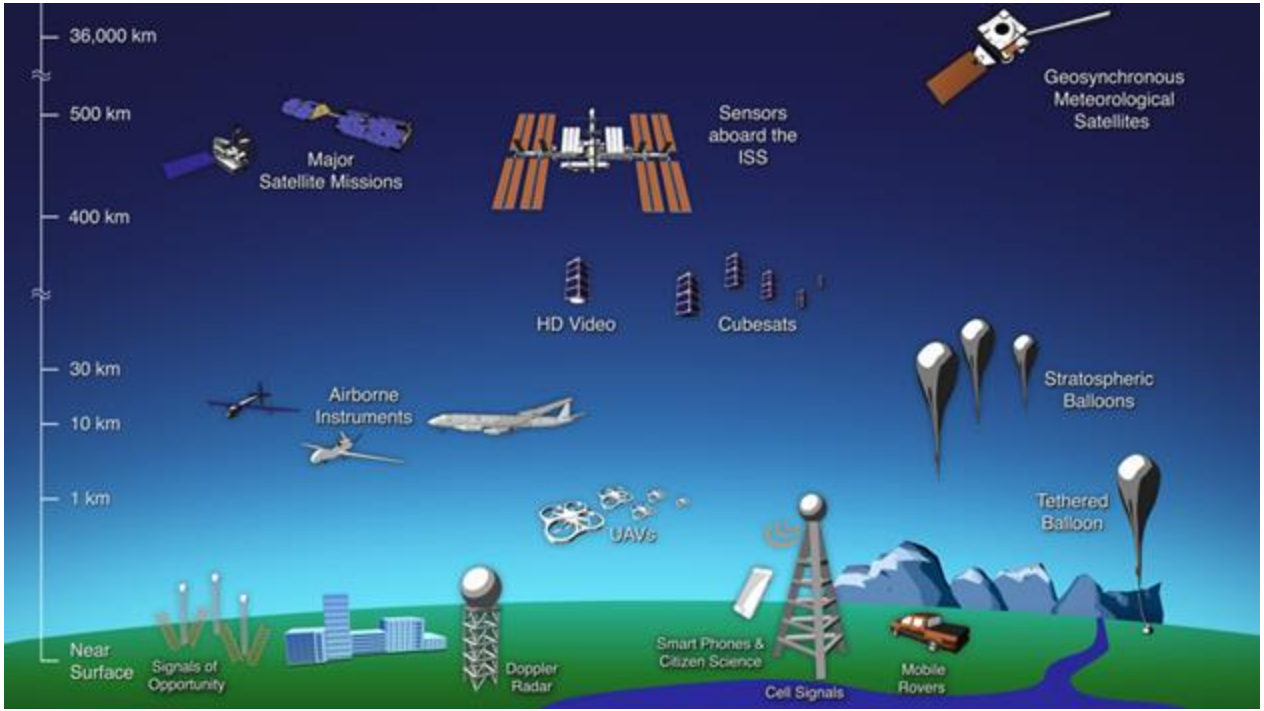
Outline

- ➔ Remote Sensing Sensors
- ➔ Satellite Orbits
- ➔ Imaging modes
- ➔ Resolutions
- ➔ Data preprocessing
- ➔ Questions

Remote Sensing - Sensors



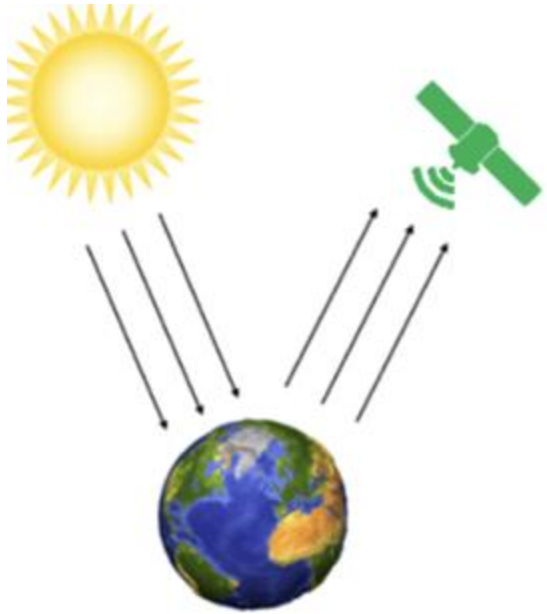
- ➔ ***Sensors*** (Landsat, Sentinel-1/2, Radarsat series, prisma)
- ➔ ***Satellite Orbits*** (geostationary, sun-synchronous)
- ➔ ***Imaging mode*** (point-scan, line-scan, snapshot, non-imaging, etc.)
- ➔ ***Resolution*** (spatial, spectral, temporal, radiometric)
- ➔ ***Platforms*** (ground, UAV, airplane, satellite)

Images from NASA

Learn some concepts followed by a guessing game

- I will define and illustrate key concepts, e.g.,
  - ➔ Passive vs. active,
  - ➔ Microwave vs. optical
  - ➔ RGB vs. hyperspectral
- You (as groups) will do a assign labels to sensors in real-world examples
  - ➔ Talk with your group mates
  - ➔ discuss out an answer for the question
  - ➔ Venture a guess
- Together, we will summarize the examples in the game

Passive sensors vs. Active sensors



Passive Remote Sensing

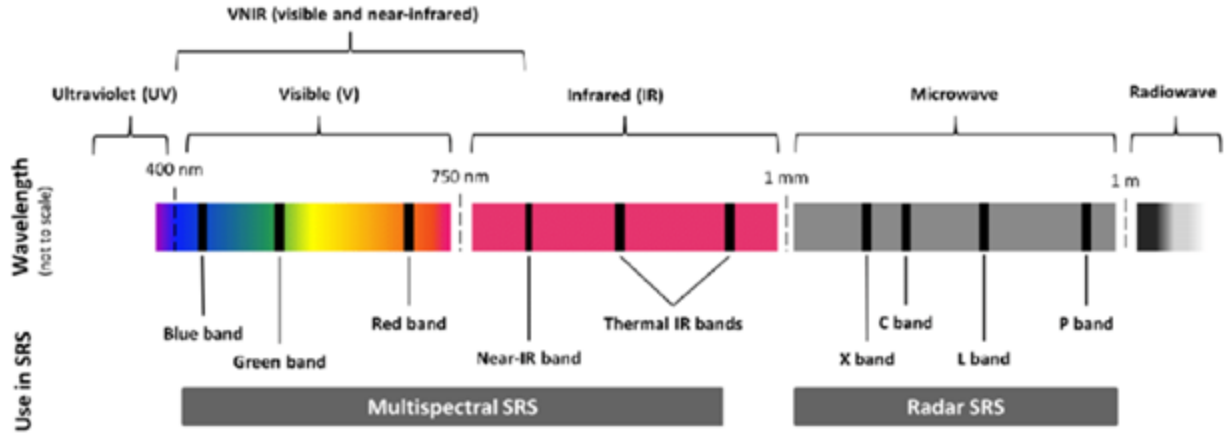
Active Remote Sensing

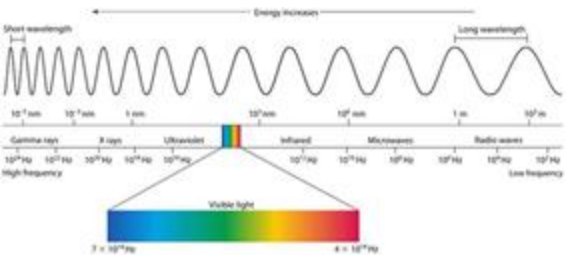
Image from Lopez Ornelas, Maria F. 2016

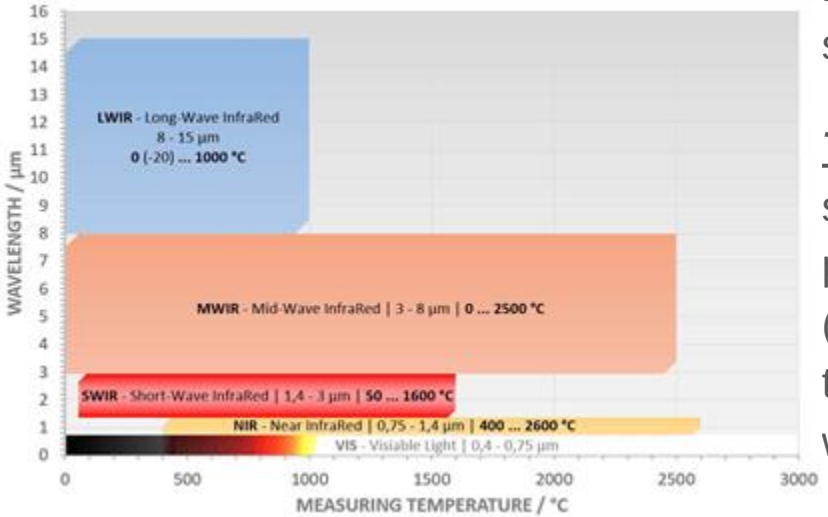
Passive sensors rely on external light sources (e.g., the Sun, or the light bulb) to emit signal (electromagnetic or sound waves) to illuminate the targets.

Active sensors emit signals themselves to illuminate the targets and do not rely on external sources.

Visible Sensors vs. Microwave sensors







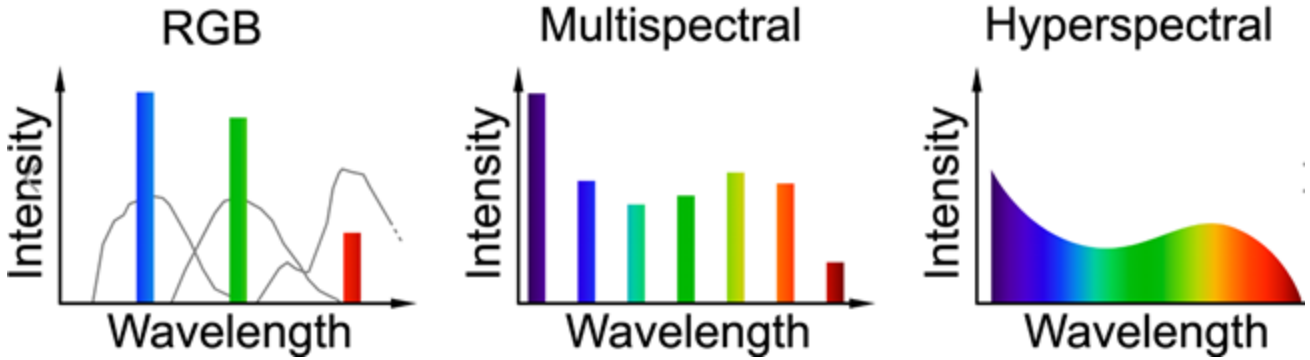
Images from descarteslabs.com and Pettorelli N et. al. 2014

Visible sensors record signal at visible portion of spectrum (400 nm-750nm)

Microwave sensors record signal at microwave portion of the spectrum (1mm-1m).

Thermal sensors record signal at thermal infrared portion of spectrum (mostly 3-15um, due to temperature range and water absorption)

RGB sensors vs. Multi/Hyperspectral Sensors



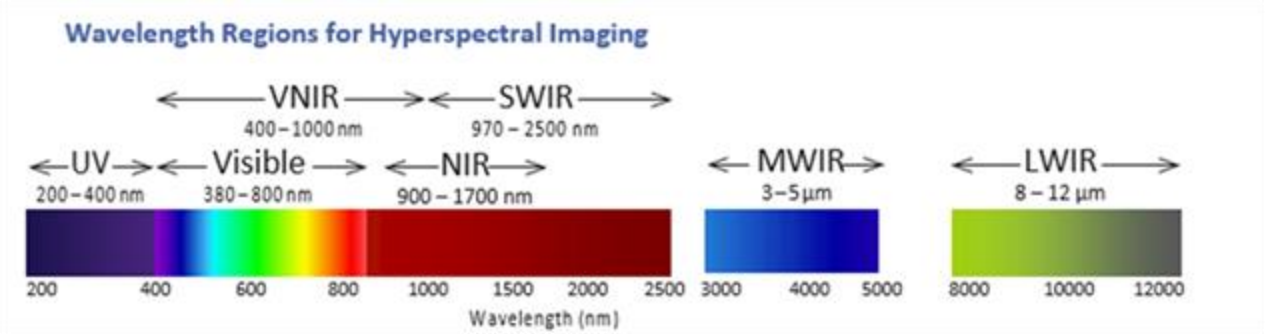


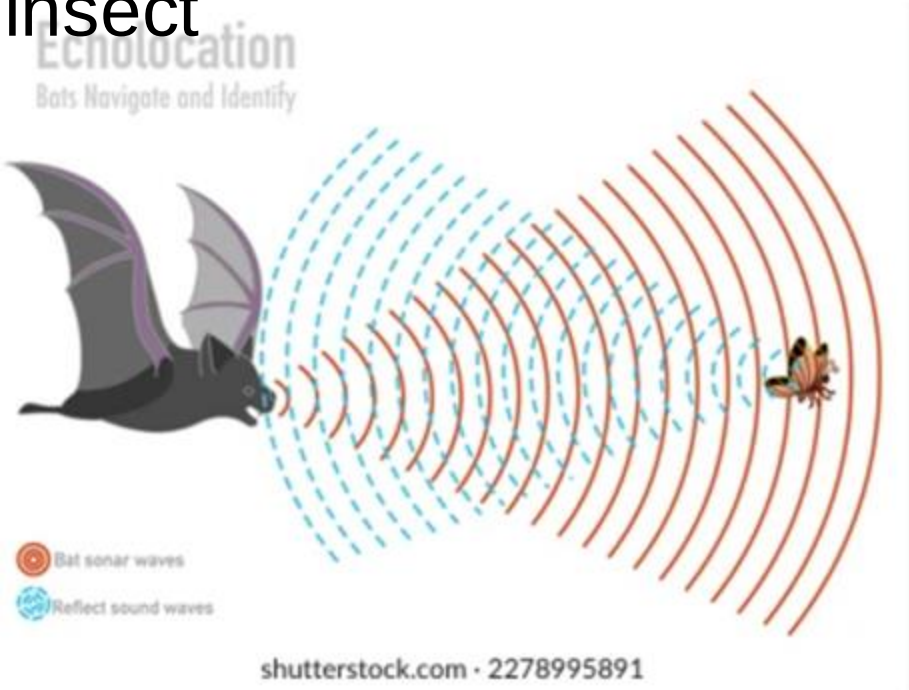
Image from wiki.tum.de and middletonspectral.com

RGB sensors have only three visible channels (i.e., R, G, B).

Multispectral sensors have more than 3 channels at VNIR and SWIR portions of the spectrum (400nm-2500nm).

Hyperspectral sensors typically have hundreds of continuous channels at VNIR and SWIR portions of the spectrum (400nm-2500nm)

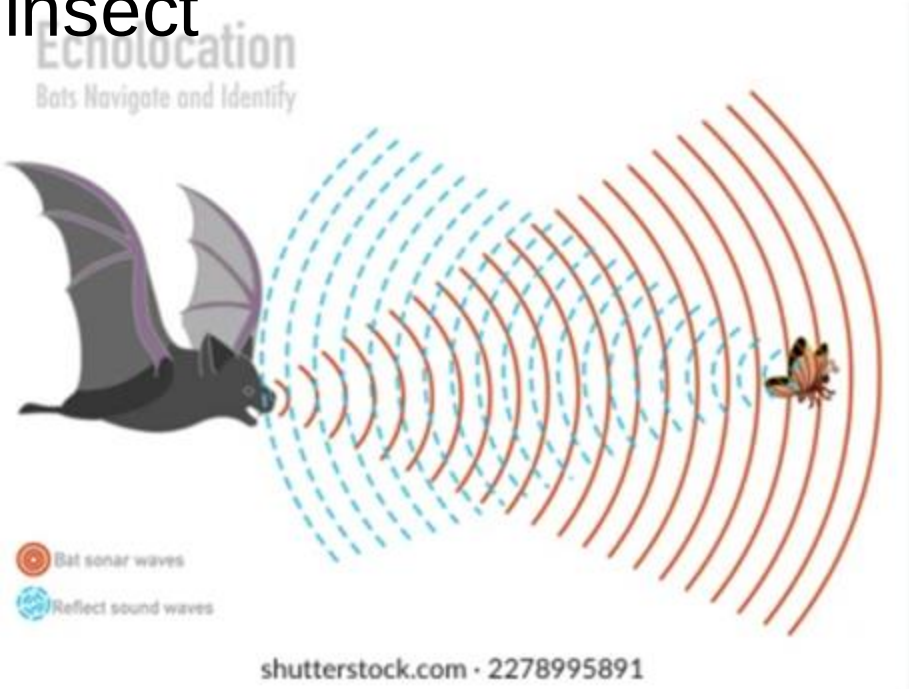
1. A bat uses high-frequency ultrasound to detect insect



Active or passive? or neither?

Microwave or visible? Or neither?

1. Bats use high-frequency ultrasound to detect insect



Active or passive? Active

Microwave or visible? Neither, not applicable, because Bats use ultrasound which is not electromagnetic wave

Ultrasound - Mechanical wave/energy to create particle displacement, need medium (e.g., air, water) to propagate, sensitive to distance and internal structure, e.g., medical imaging, sonar for underwater mapping

EM waves - Electric and magnetic energy, Do not need medium (through vacuum), sensitive to physical/chemical properties of objects, e.g., hyperspectral imaging of crop biochemical properties

2. Humans use eyes to see the world

1. Active or passive? Or neither?

2. Visible or microwave? Or neither?

3. RGB or hyperspectral? Or neither?

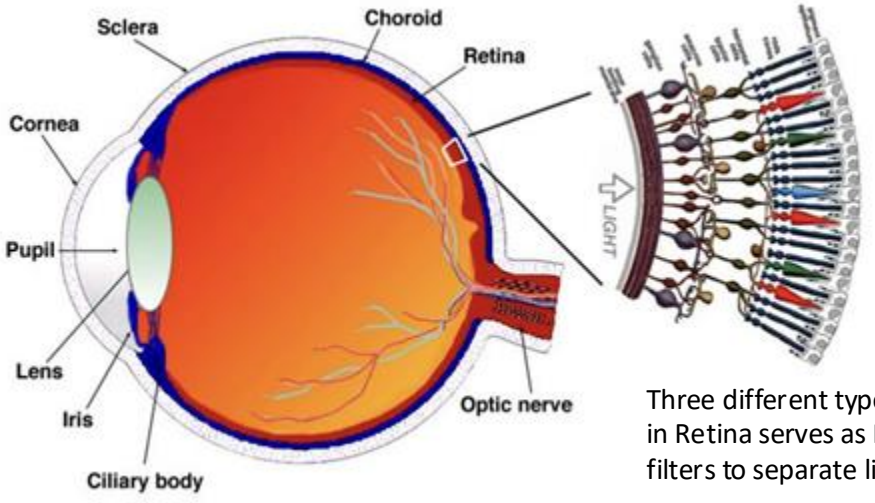
Image from campaignlive.com

2. Humans use eyes to see the world

1. Active or passive? passive

2. Visible or microwave? Visible

3. RGB or hyperspectral? RGB



Three different types of Cones in Retina serves as R, G, B filters to separate light

Pictures from campaignlive.com, courses.cs.washington.edu

3. Thermal imaging is used to detect wild animals at night

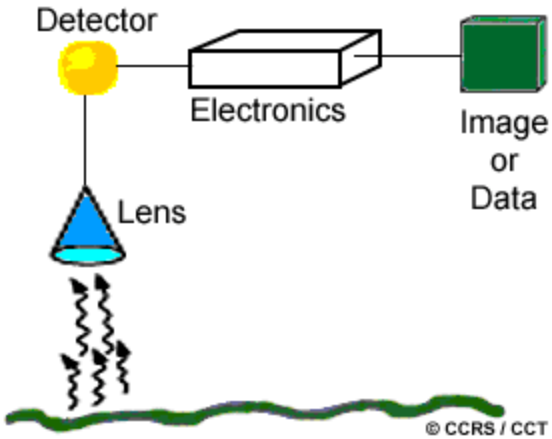
Active or passive? Or neither

Visible or microwave? Or neither

Multispectral or hyperspectral? Or neither

Image from butlerandland.com, ametek-land.com

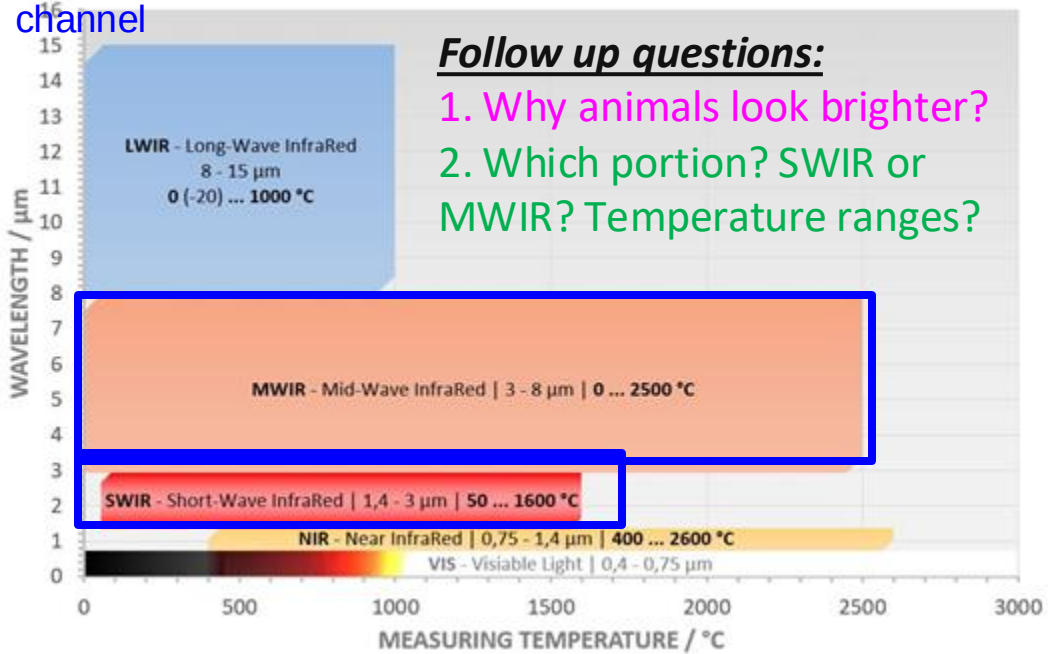
3. Thermal imaging is used to detect wild animals at night



Active or passive? passive

Visible or microwave? Neither, it is thermal infrared, i.e., MWIR + LWIR

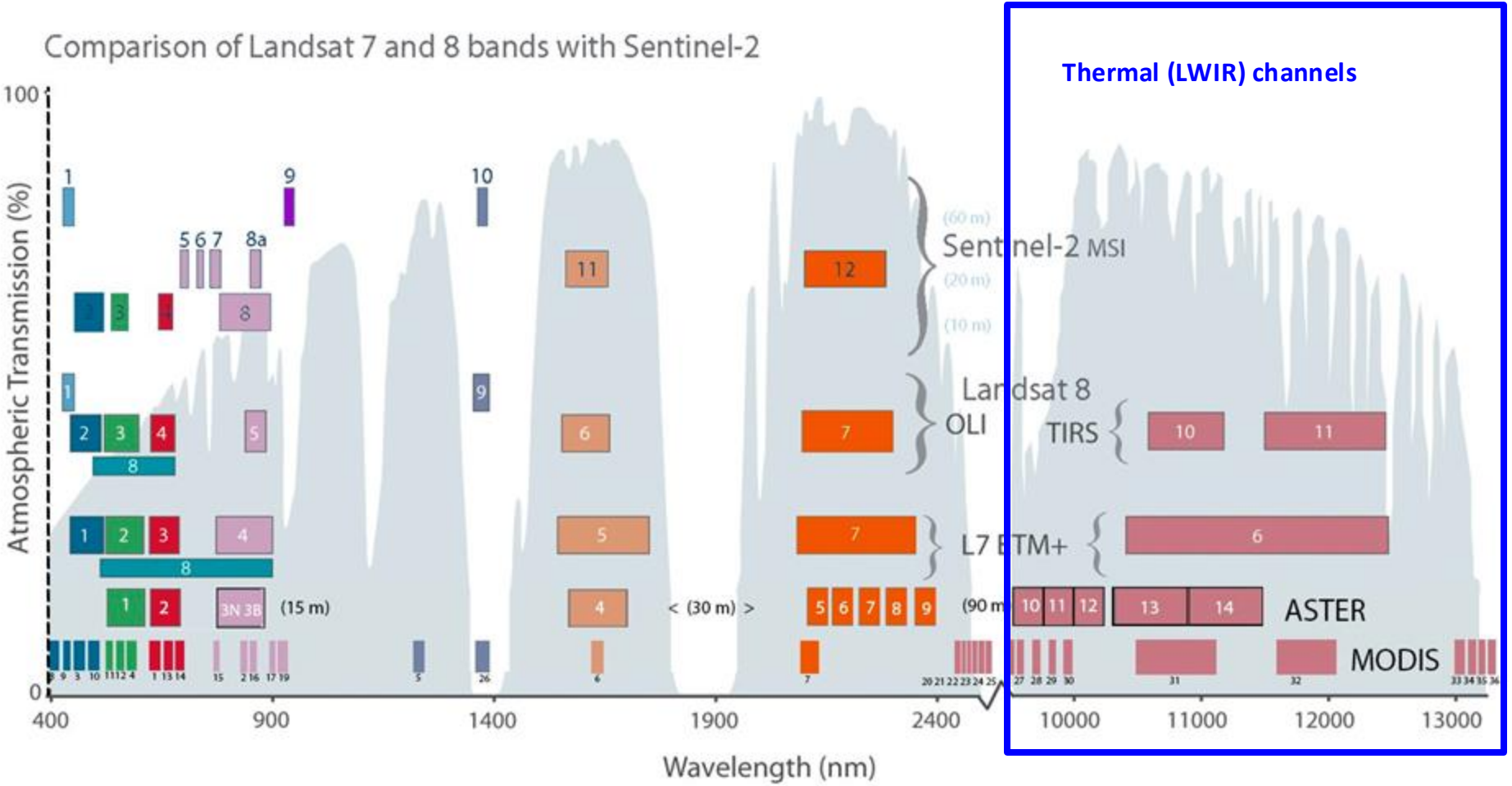
Multispectral or hyperspectral? Neither, this image has just 1 channel



Follow up questions:

1. Why animals look brighter?
2. Which portion? SWIR or MWIR? Temperature ranges?

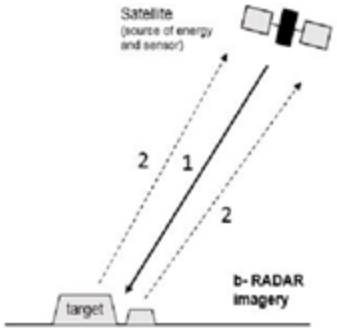
Image from butlerandland.com, ametek-land.com, natural-resources.canada.ca

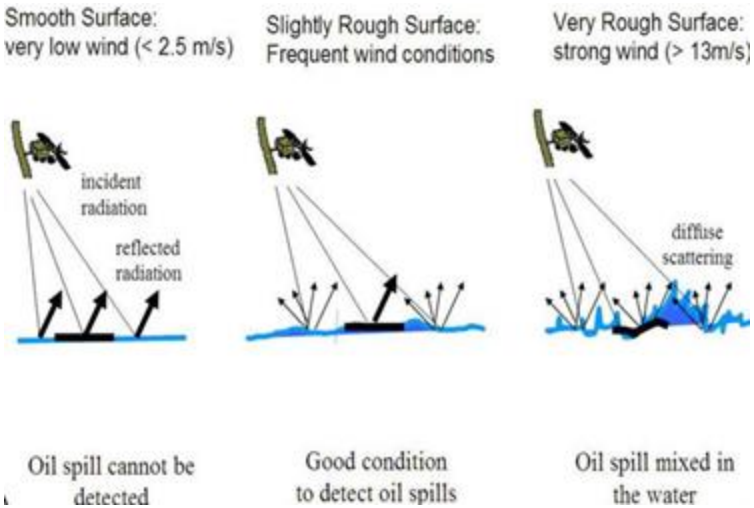


Many satellite sensors have thermal bands (LWIR), low spatial resolution, *military reconnaissance, wildfire detection, urban temperature mapping*

Images from USGS

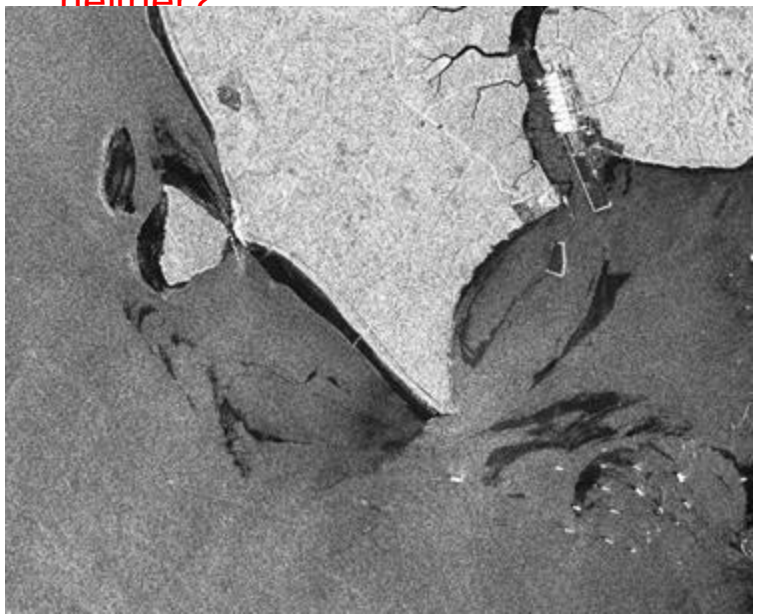
4. Synthetic aperture radar (SAR) is used to detect marine oil spills from ships





Active or passive? Or neither?

Visible or microwave? Or neither?



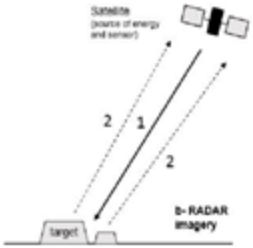
Images from gisgeography.com, markelowitz.com

4. Synthetic aperture radar (SAR) is used to detect marine oil spills

Benefits:

(1) does not rely the Sun to provide illumination, so it can work day and night, 24 hours a day

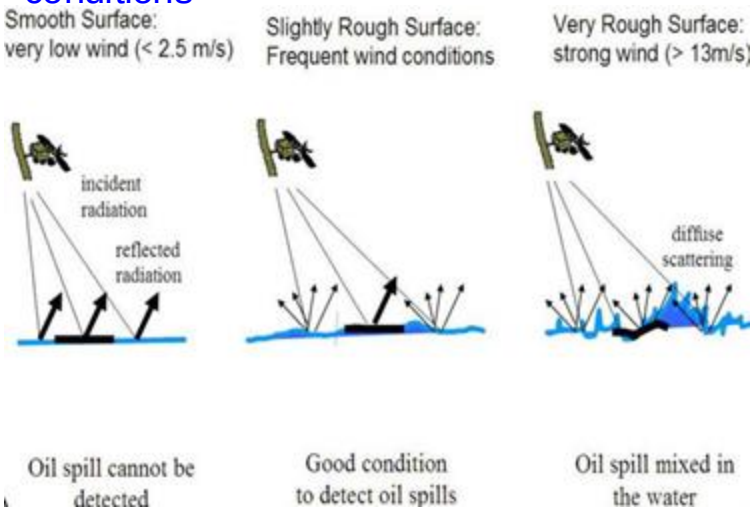
(2) Microwave can penetrate cloud, can work independently of weather conditions

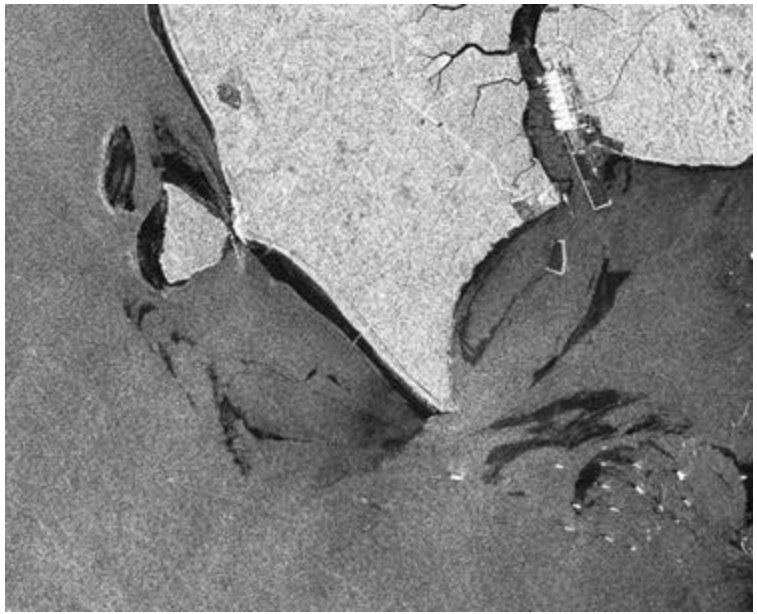


Active or passive? Active

Visible or microwave? Microwave

Why do oil spills look dark on SAR image?





Images from gisgeography.com, markelowitz.com

5. Maxar Introduces 15 cm HD images in 2020: The Highest Clarity From Commercial Satellite Imagery

Active or passive? Or neither

Visible or microwave? Or neither

RGB or Hyperspectral? Or neither

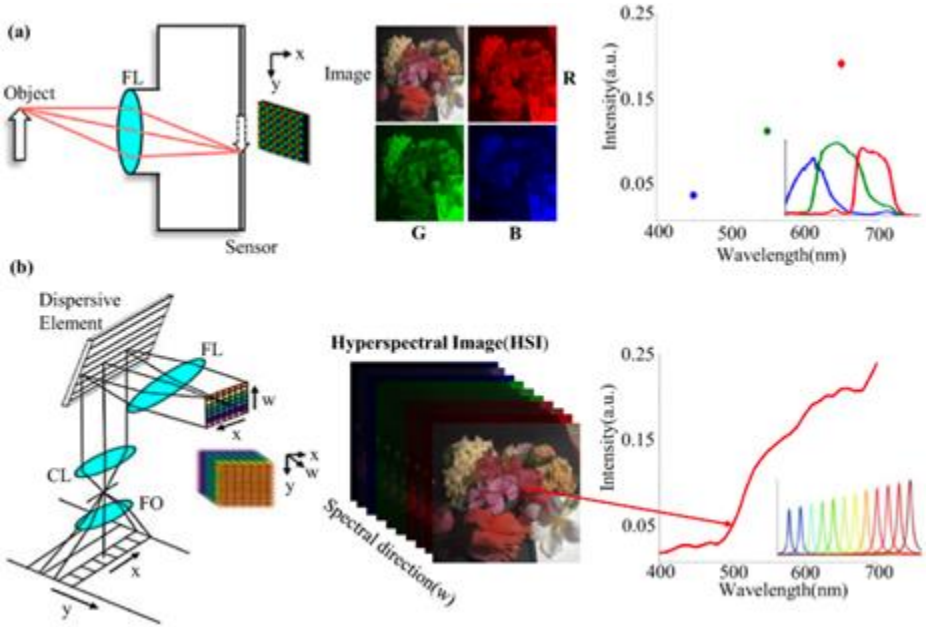
Images from blog.maxar.com

5. Maxar Introducing 15 cm HD: The Highest Clarity From Commercial Satellite Imagery

Active or passive? passive

Visible or microwave? visible

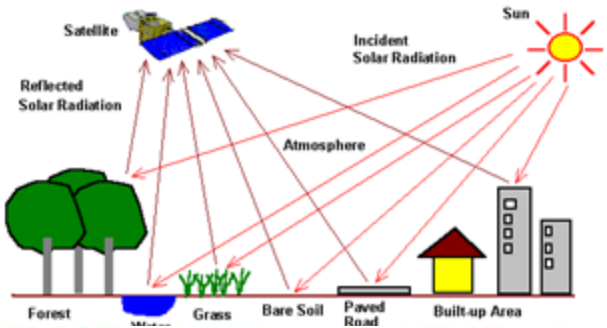
RGB or Hyperspectral? RGB



Is it possible for 15cm Maxar camera to have hundreds of hyperspectral channels?

Images from blog.maxar.com, nature.com

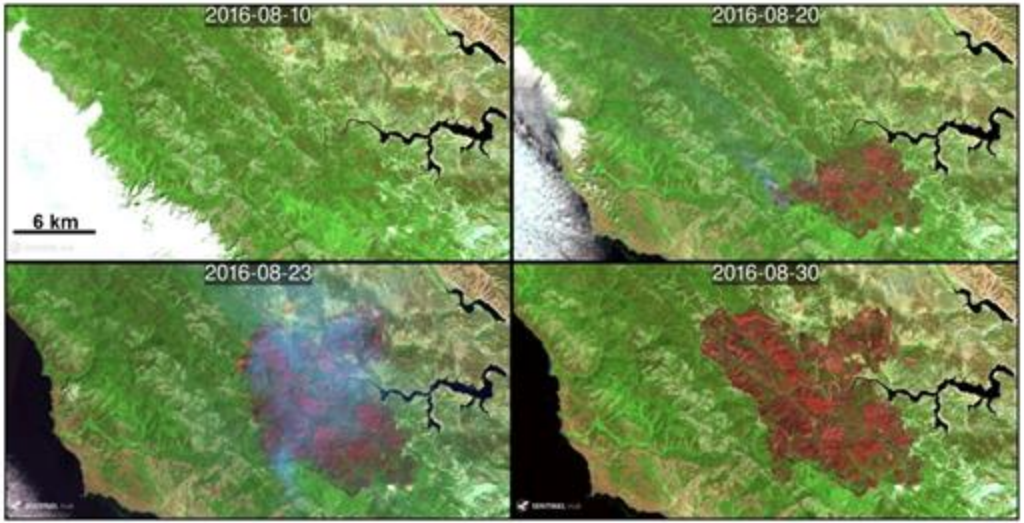
6. Sentinel-2 images are used to monitor wildfire by mapping burned areas

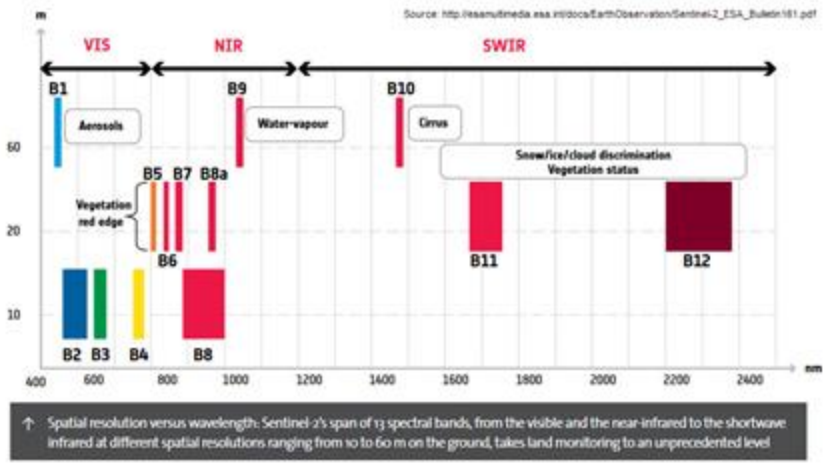


Active or passive? Or neither

Visible or microwave? Or neither

RGB or Hyperspectral? Or neither





RGB color composite of bands SWIR/NIR/Red = 12/8A/4)

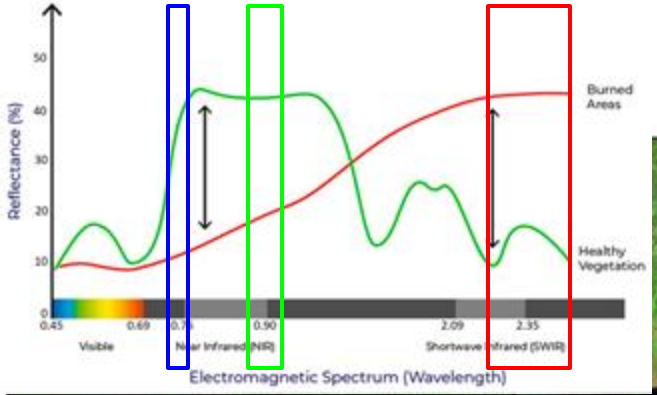
Images from crisp.nus.edu.sg, labo.obs-mip.fr

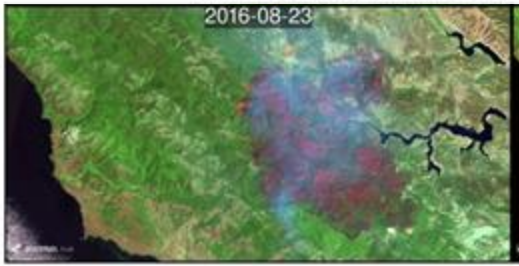
6. Sentinel-2 images are used to monitor wildfire by mapping burned areas

Why burned area looks very red on this image? Burned area -> no vegetation -> dry soil?

Why vegetation looks very green on this image? B8A -> 950nm -> near infrared -> mostly reflected by healthy plants

What is the bluish area on 2016-08-23 image?



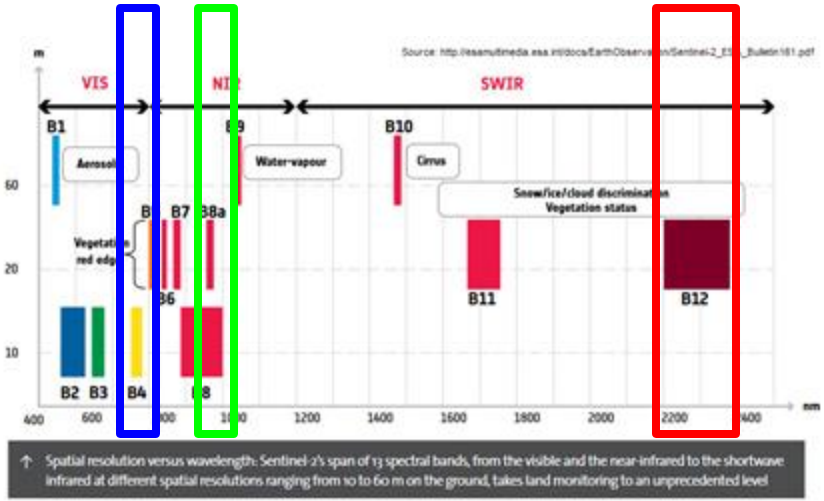


RGB color composite of bands SWIR/NIR/Red = 12/8A/4)

Active or passive? passive

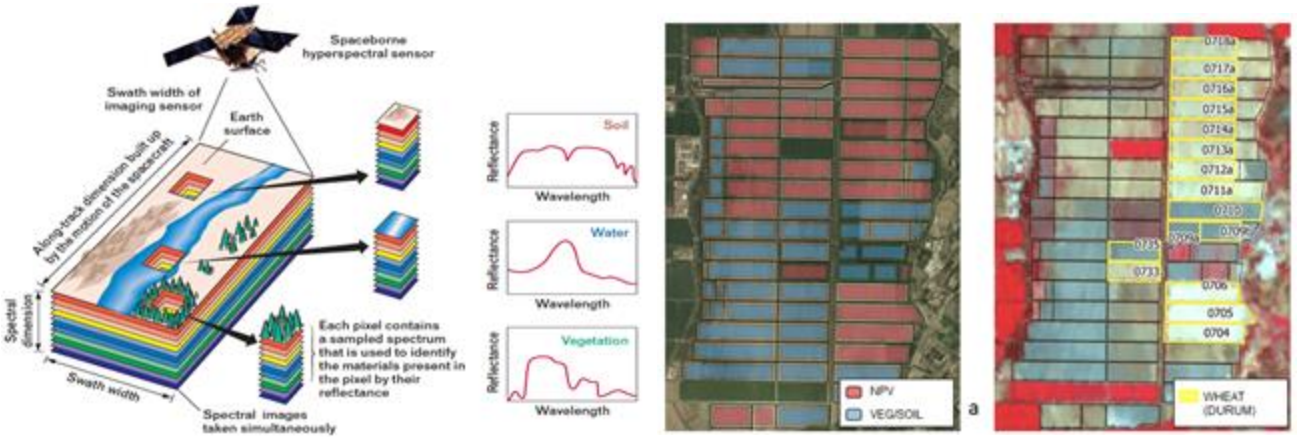
Visible or microwave? Neither, it covers not only Visible, NIR and SWIR

RGB or Hyperspectral? Neither, it is multispectral



Images from crisp.nus.edu.sg, labo.obs-mip.fr, Alcaras, Emanuele, et al. 2022

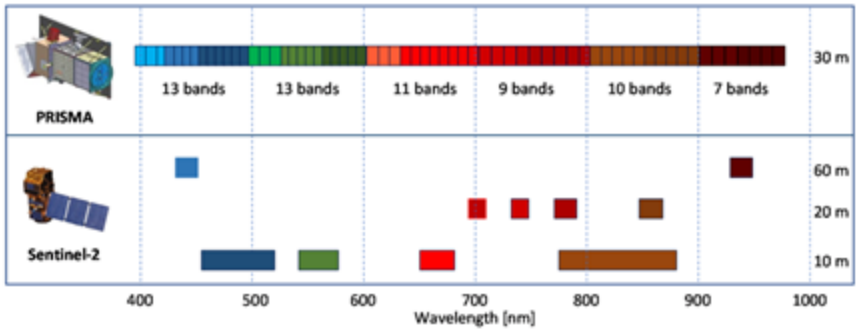
7. Images from PRISMA (launched by ISA on March 22, 2019) is used to map non-photosynthetic vegetation for crop degradation assessment



Active or passive? Or neither?

Visible or microwave? Or neither?

RGB or hyperspectral? Or neither?



PRISMA data will be important for supporting the following key applications:

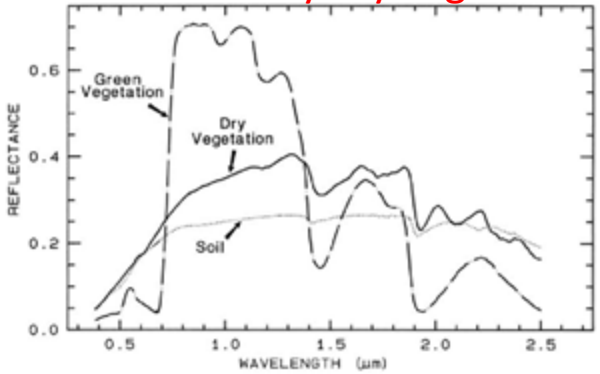
- ***Agricolture and Forests***
- ***Land use***
- ***Inland and Coastal water***
- ***Risk Management***
  (es. volcanic, fires, oil spill, hydrology, etc..)
- ***Atmosphere and Climate***
- ***Geology***
- ***Soil***
- ***Urban Areas***
- ...

- PRISMA P/L operates with a Pushbroom scanning concept.
- It records the radiation reflected from the Earth surface (spectral cubes) in 400nm – 2505nm spectral window
  - PAN range
  - 240 bands in VNIR / SWIR (partial overlap)
  - High spectral Resolution (much better of 14 nm)

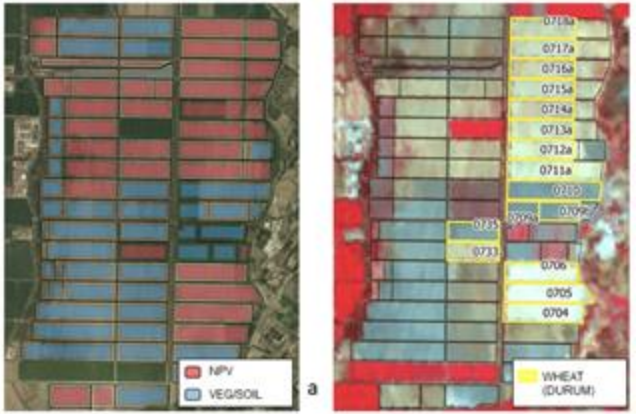
Images from markelowitz.com, Pepe, Monica, et al. (2020), Niroumand-Jadidi, M. (2020)

7. Images from PRISMA (launched by ISA on March 22, 2019) is used to map non-photosynthetic vegetation for crop degradation assessment

Why hyperspectral image can better identify dry vegetation?



Sentinel-2 Band	Center Wavelength	Bandwidth	PRISMA Bands
1-Coastal aerosol	442.3	21	5–8
2-Blue	492.1	66	9–17
3-Green	559	36	20–25
4-Red	665	31	32–35
5-Vegetation red edge	703.8	16	37–39
6-Vegetation red edge	739.1	15	41–42
7-Vegetation red edge	779.7	20	44–46
8-NIR	833	106	47–52
8A-Narrow NIR	864	22	53–54
9-Water vapour	943	21	60–61
10-SWIR-Cirrus	1376.9	30	109–112
11-SWIR	1610.4	94	128–137
12-SWIR	2185.7	185	186–209



Active or passive?
passive

Visible or microwave?
Neither, it has Visible, NIR, SWIR
RGB or hyperspectral?
hyperspectral

Green (healthy) vegetation

non-green (non-photosynthetic) due to disease or dead dry vegetation

bare ground areas

Images from markelowitz.com, Pepe, Monica, et al. (2020), Niroumand-Jadidi, M. (2020), skopplj

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- It records the radiation reflected from the Earth surface (spectral cubes) in 400nm – 2505nm spectral window
  - PAN range
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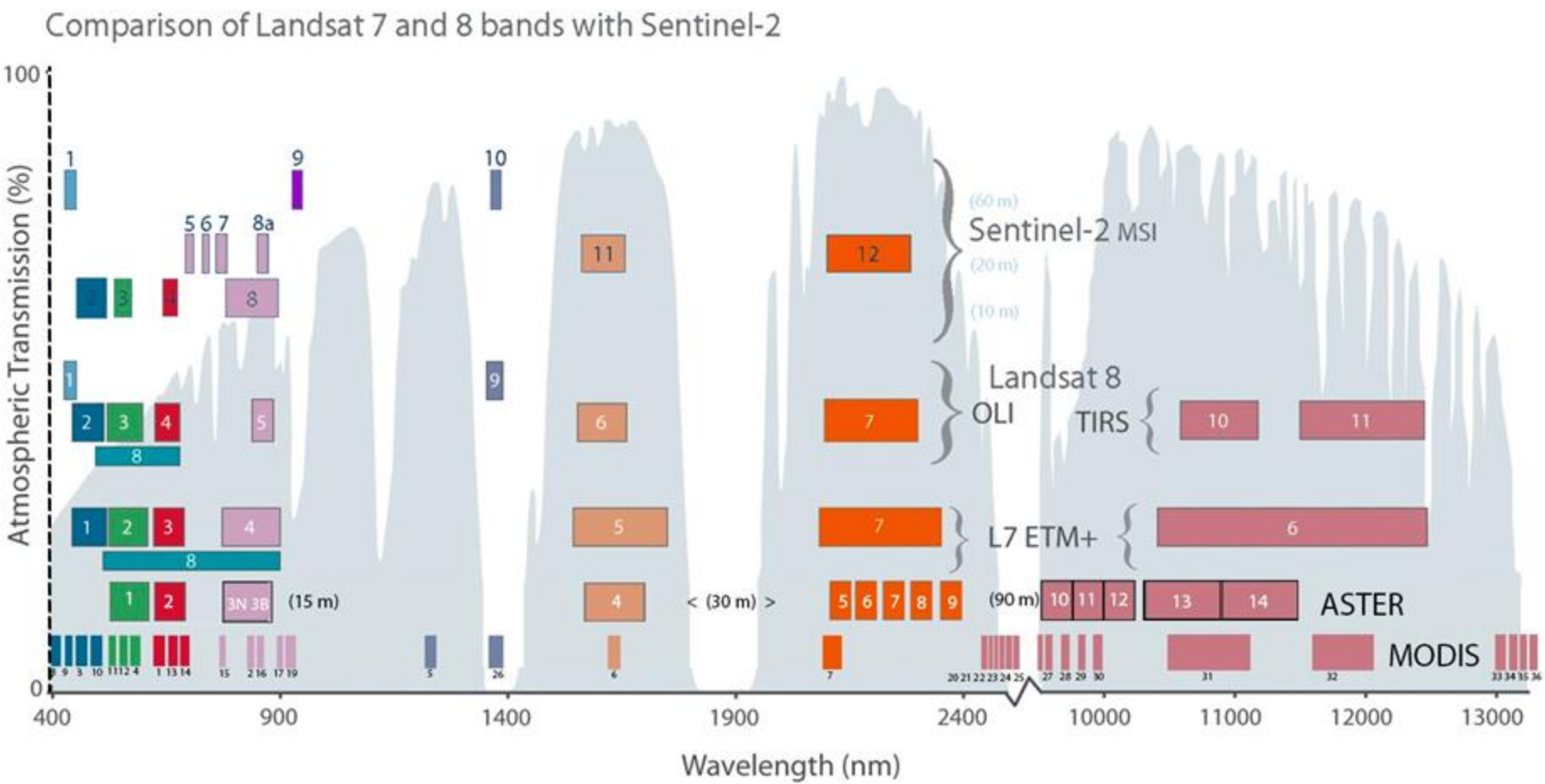
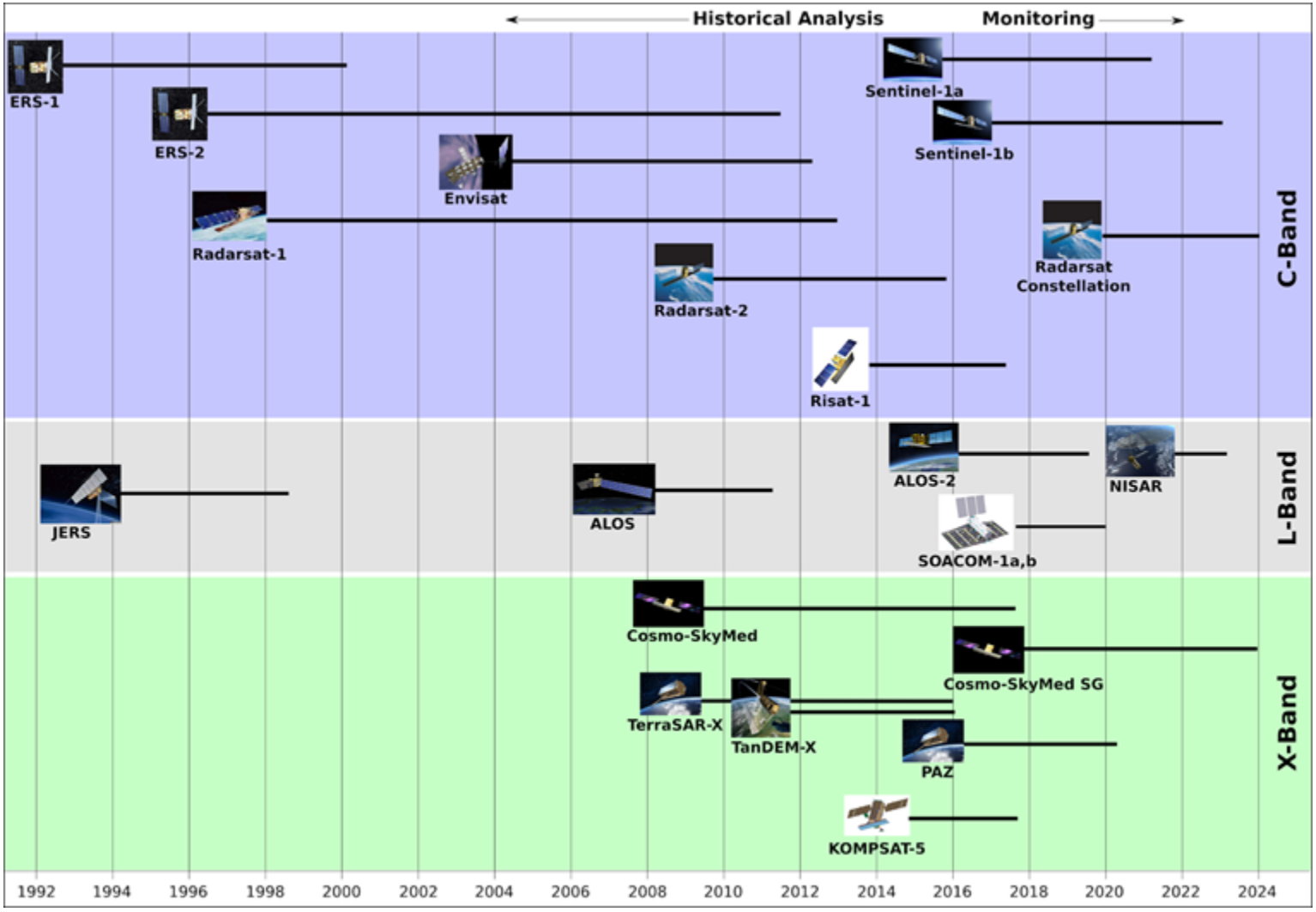
Summary of sensors

	1. Bat	***2.Human eye***	***3.Thermal Imaging***	***4.SAR***	***5.Maxar HD***	***6.Sentinel -2***	***7.PRISMA***
Source of radiation	Active	Passive	Passive	Active	Passive	Passive	Passive
Wavelength	ultrasound	visible	thermal	microwave	visible	visible+NIR +SWIR	visible+NIR +SWIR
Number of channels	1	3 (RGB)	1 or more	1-4	3 (RGB)	13	240



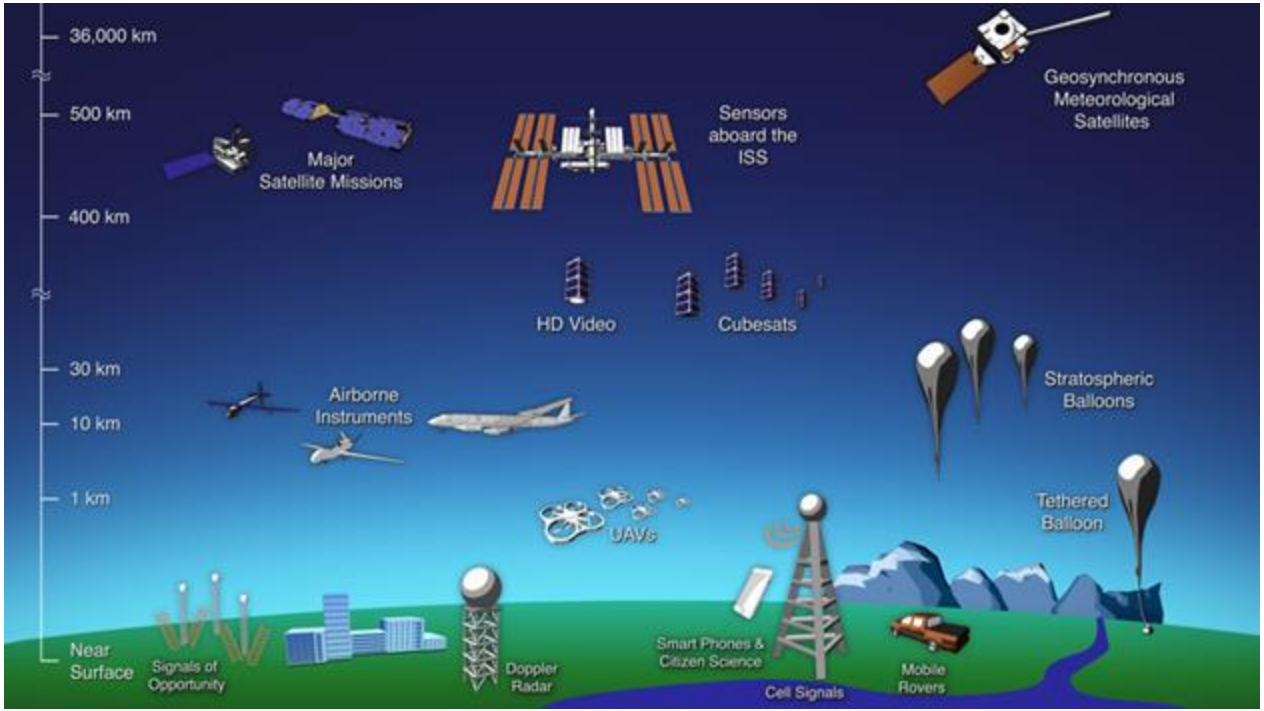
Images from USGS



Summary of historical and ongoing ***SAR*** sensors

From UNAVCO

Orbits



- ➔ ***Sensors*** (Landsat, Sentinel-1/2, Radarsat series, prisma)
- ➔ ***Orbits*** *(geostationary, sun-synchronous)*
- ➔ ***Imaging mode*** (point-scan, line-scan, snapshot, non-imaging, etc.)
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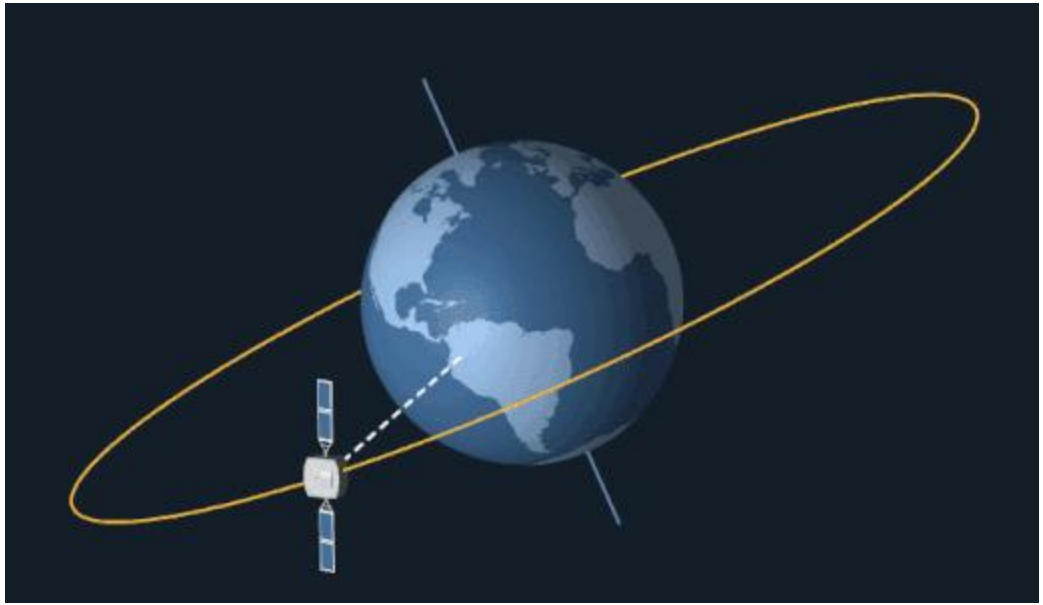
- ➔ ***Platforms*** (ground, UAV, airplane, satellite)

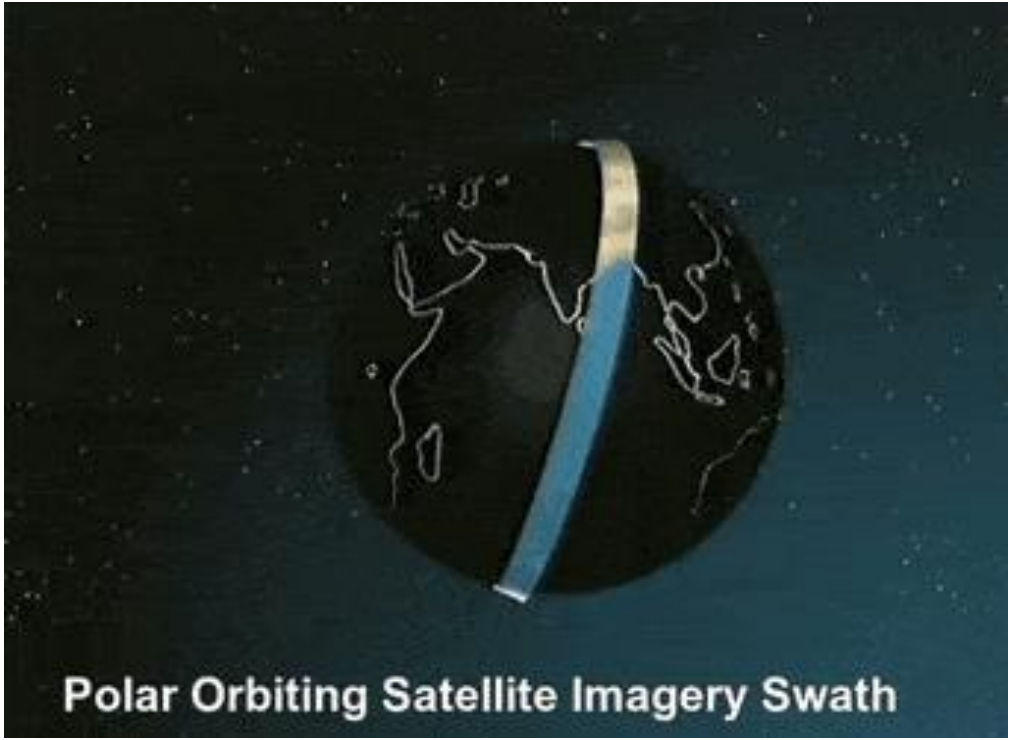
Images from NASA

Geostationary Orbit



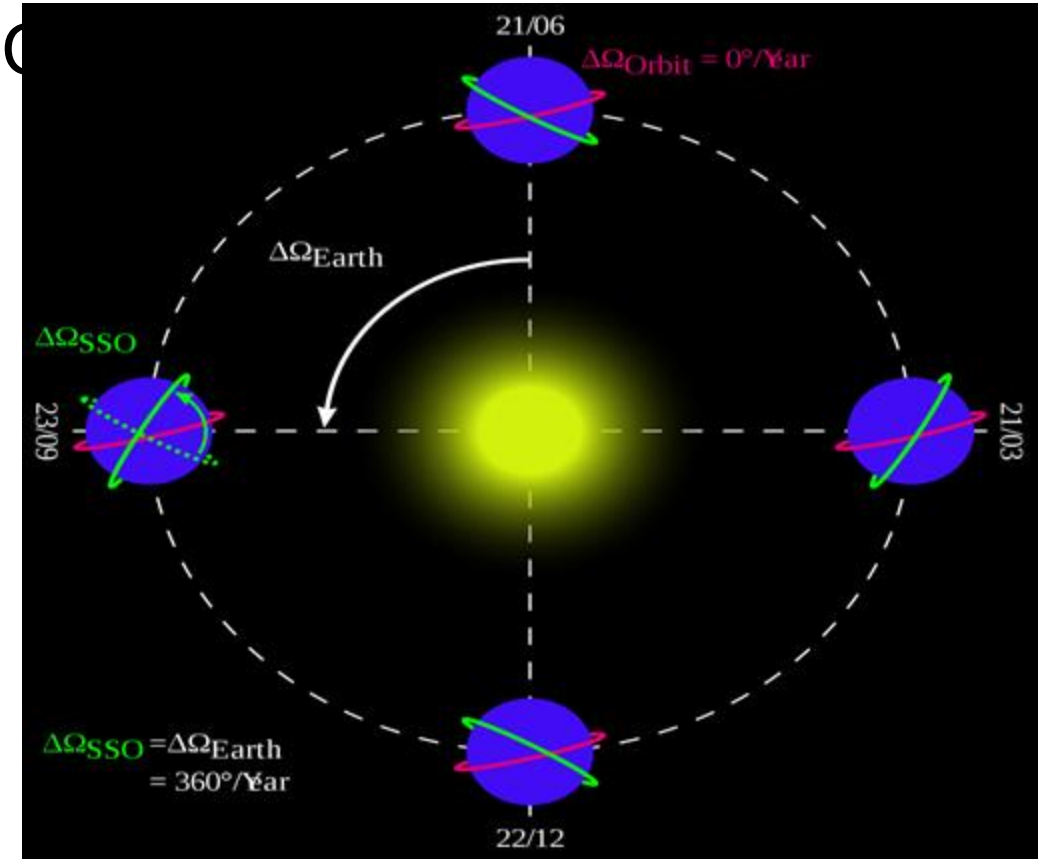
- Satellites circle the Earth around the Equator at the same rate as the Earth spins, so that they can keep monitoring the same region. But, it has trouble monitoring the polar regions.
- Satellites are very high above (e.g., 35,000km above), so that they can see very large area (e.g., whole hemisphere), but with low spatial resolution.
- This orbit is mainly used for communication and large-scale phenomena monitoring, such as hurricanes

Polar Orbit



- Satellites circle the Earth around the Polar regions as the Earth spins underneath it, so that they can sea nearly every part of the Earth.
- Satellites are relatively low (e.g., 200 km - 1000 km vs. 35,000km), so that they have high spatial resolution, but with narrow swath coverage.
- This orbit is mainly used for Earth mapping.

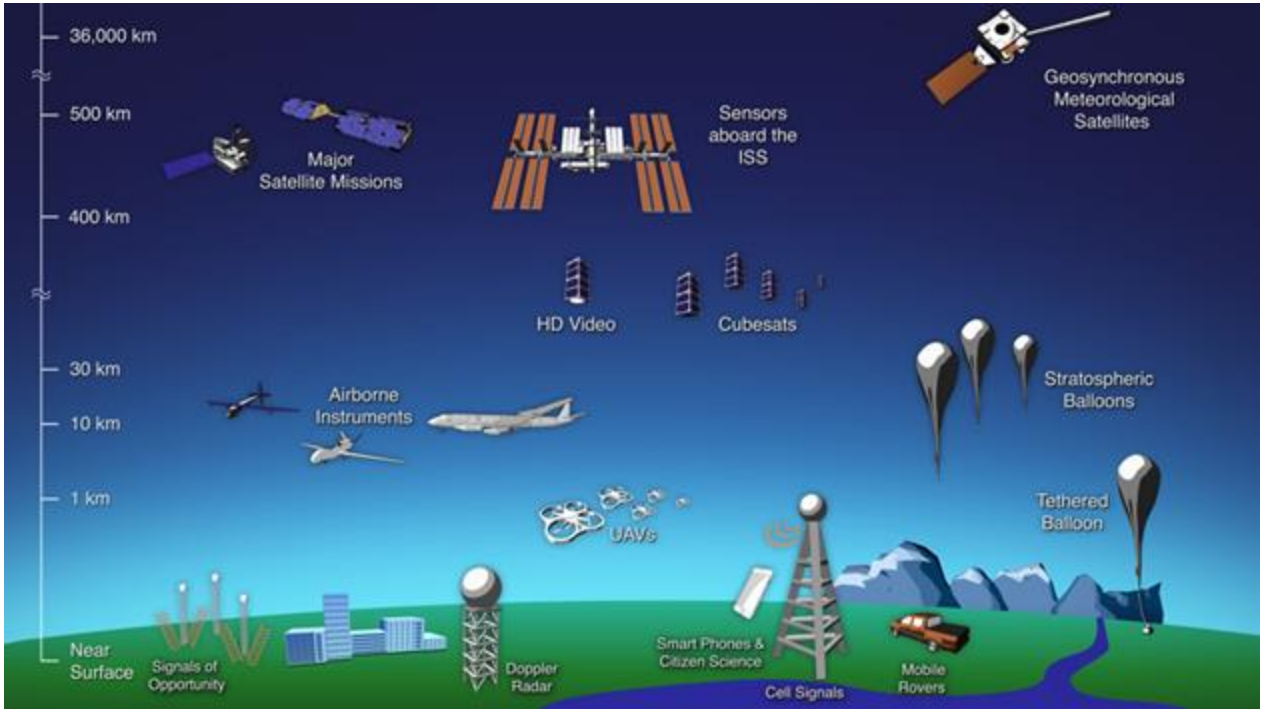
Sun Synchronous
O



- Sun synchronous orbit is a particular type of polar orbit where successive orbital pass occurs at the same local time of the day. It requires changing the orientation of the orbit during the year.
- Satellites are relatively low (e.g., 700 km - 800 km), so that it takes a short period of time, e.g., 100 minutes to finish one orbit, and 50 minutes to finish the Sun side orbit, during wich local time of the day does not vary greatly.
- Optical sensors work best at the Sun side of the orbit, whereas long wave radiation sensors work best at dark side of the orbit.

Diagram showing the orientation of a Sun-synchronous orbit (green) at four points in the year. A non-Sun-synchronous orbit (magenta) is also shown for reference. Dates are shown in white: day/month.

Imaging Mode



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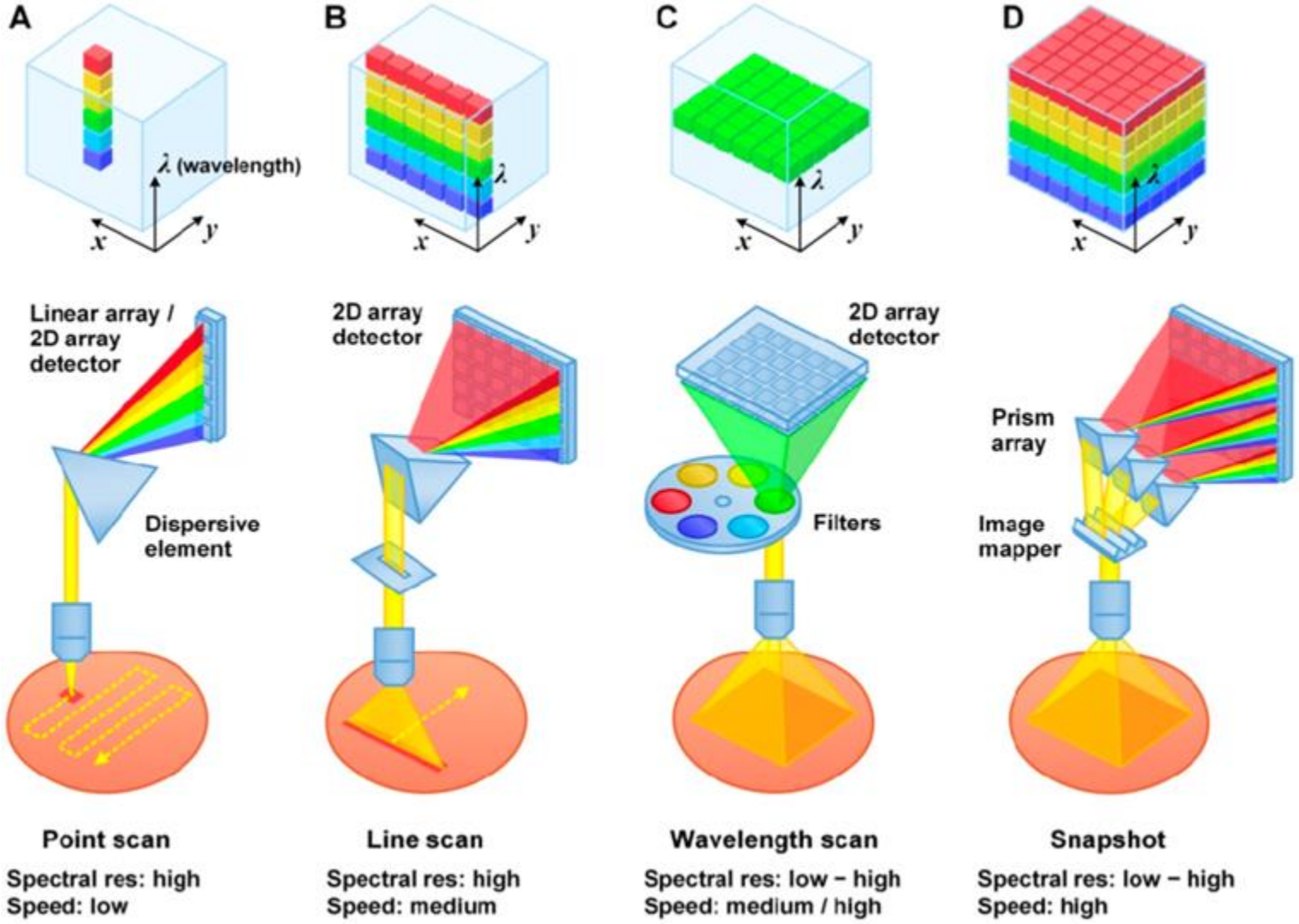
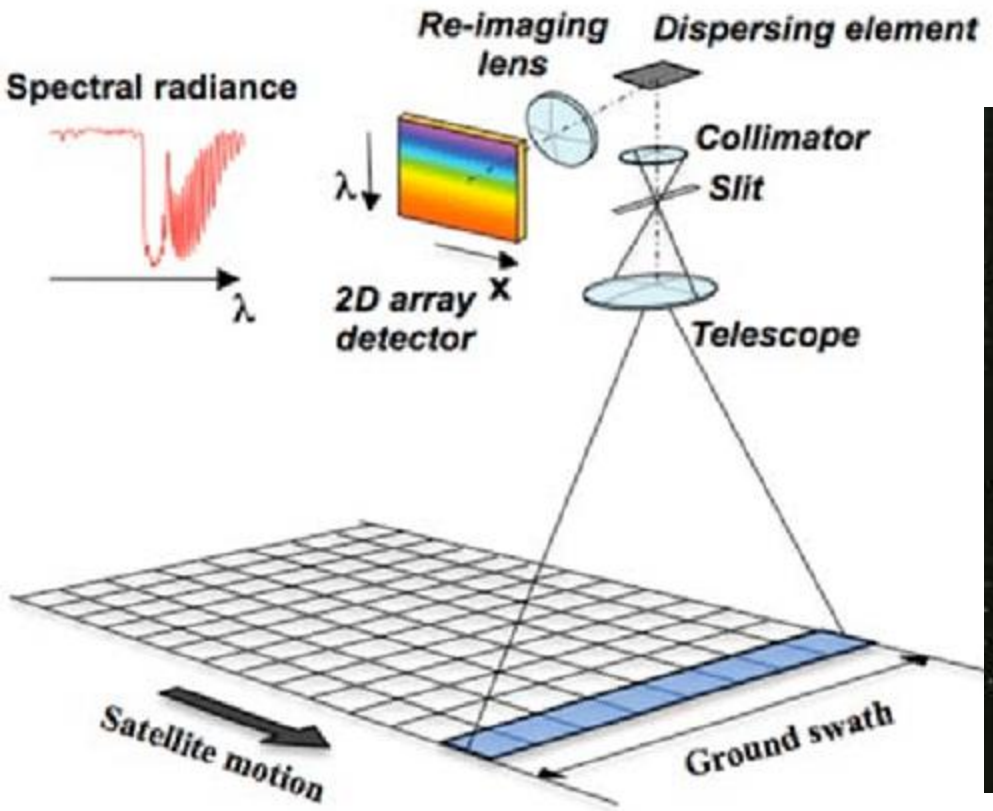
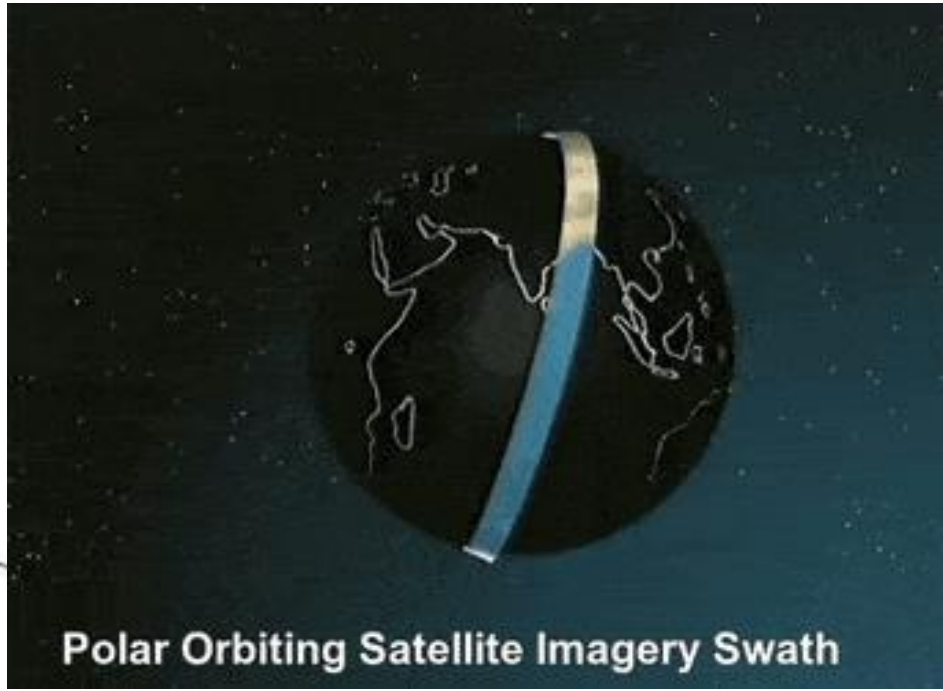
- ***Platforms*** (ground, UAV, airplane, satellite)

Images from NASA

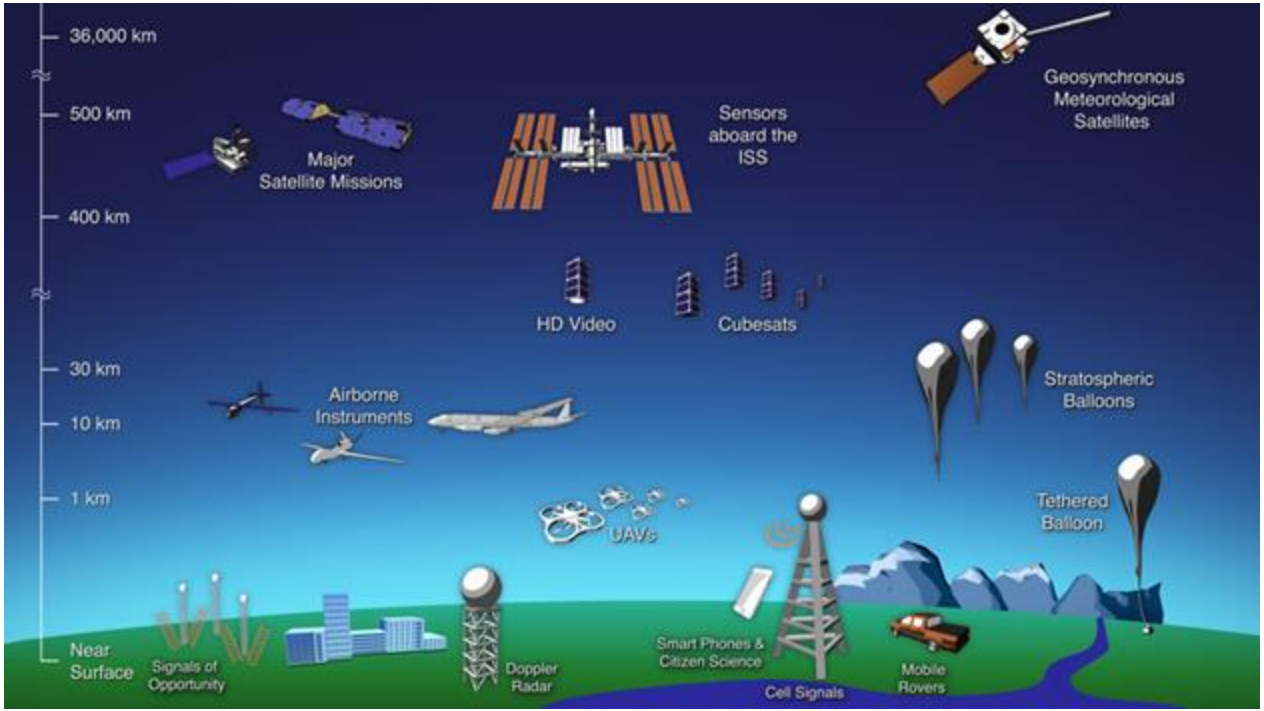

A
B
C
D
λ (wavelength)
x
y
Linear array / 2D array detector
Dispersive element
2D array detector
2D array detector
Filters
Prism array
Image mapper
Point scan
Spectral res: high
Speed: low
Line scan
Spectral res: high
Speed: medium
Wavelength scan
Spectral res: low – high
Speed: medium / high
Snapshot
Spectral res: low – high
Speed: high





Pushbroom imaging approach

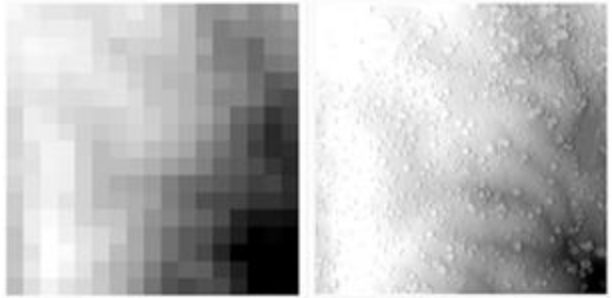
Resolution



- ➔ ***Sensors*** (Landsat, Sentinel-1/2, Radarsat series, prisma)
- ➔ ***Orbits*** (geostationary, sun-synchronous)
- ➔ ***Imaging mode*** (point-scan, line-scan, snapshot, non-imaging, etc.)
- ➔ ***Resolution*** (spatial, spectral, temporal, radiometric)
- ➔ ***Platforms*** (ground, UAV, airplane, satellite)

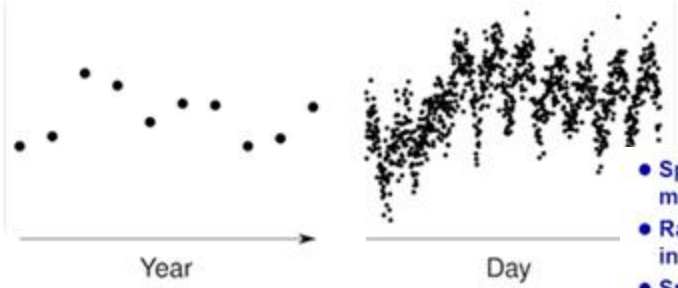
Images from NASA

Spatial resolution



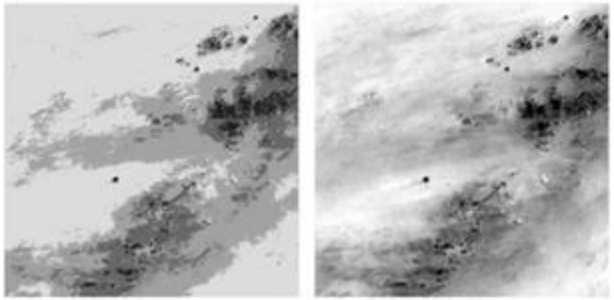
30m pixels 1m pixels

Temporal resolution



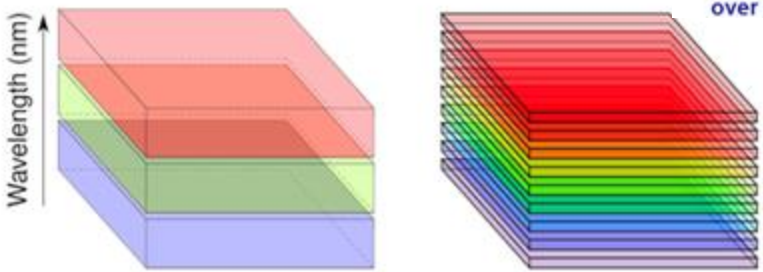
- Spectral resolution = part of the EM spectrum measured
- Radiometric resolution = smallest differences in energy that can be measured
- Spatial resolution = smallest unit-area measured
- Revisit time (temporal resolution) = time between two successive image acquisitions over the same area

Radiometric resolution



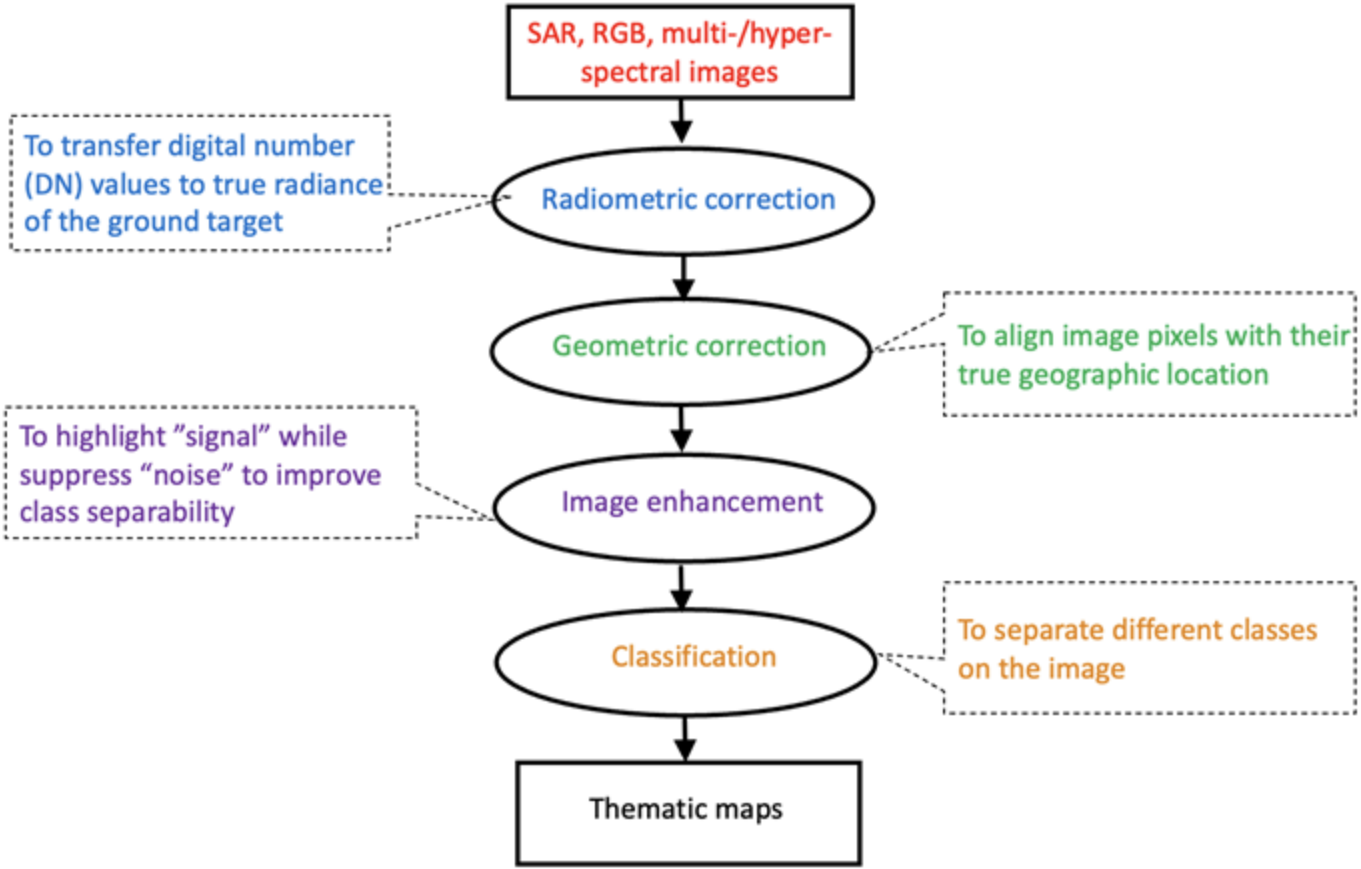
2-bit → (2^2=4 values) 8-bit → (2^8=256 values)

Spectral resolution



3 bands, 120 nm bins 9 bands, 40 nm bins

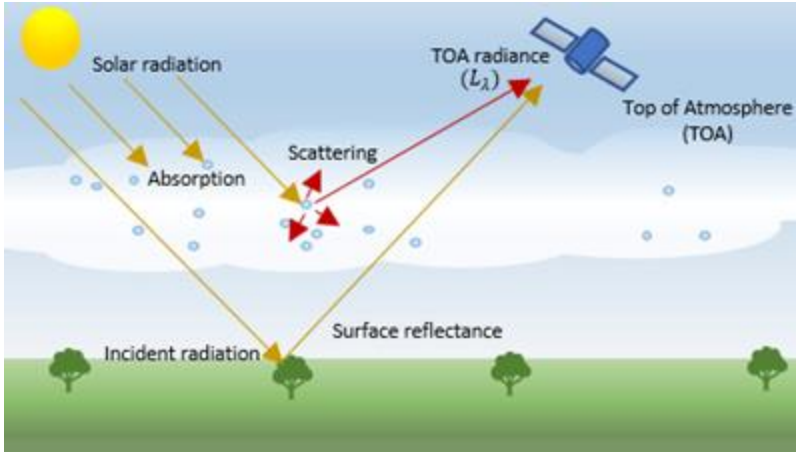
Remote Sensing Image Classification Pipeline

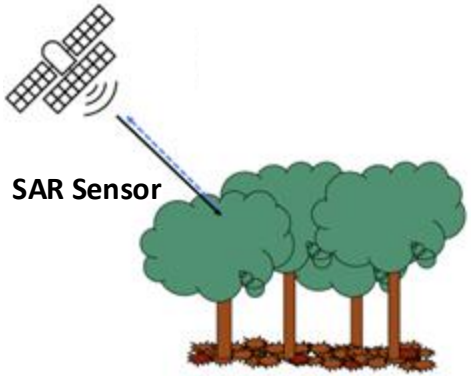


Radiometric correction

Does SAR sensor image require the same radiometric correction process?

Optical sensor






The aerial image before haze removal (b) The aerial image after haze removal (a)

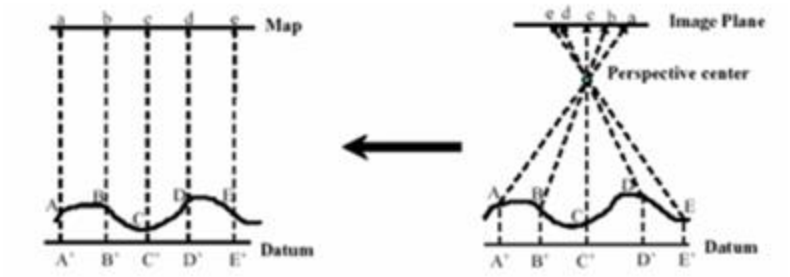
➔ ***Radiometric correction*** to transfer digital number (DN) value into true ground target relectance.

- The *sensed DN value is influenced by different factors*, e.g., Sun elevation/distance, atmosphere scattering, sensor noise/response, sensor viewing geometry
- *Correction methods/steps*: Sun angle correction, DN to radiance correction, Haze removal
- Remote sensing radiometric correction can be performed using some software tools, such as PCI geomatica

Images from de.mathworks.com

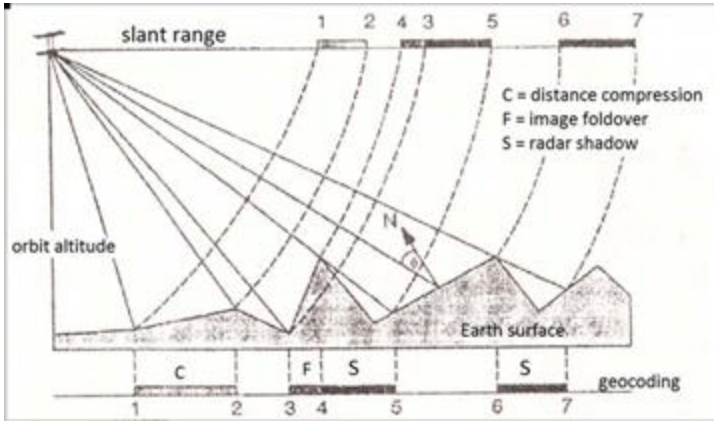
Geometric correction

Does SAR image has the same type of geometric distortions?



- Orthogonal projection.
- Uniform scale.
- No relief displacement.

- Perspective projection.
- Non-uniform scale.
- Relief displacement.

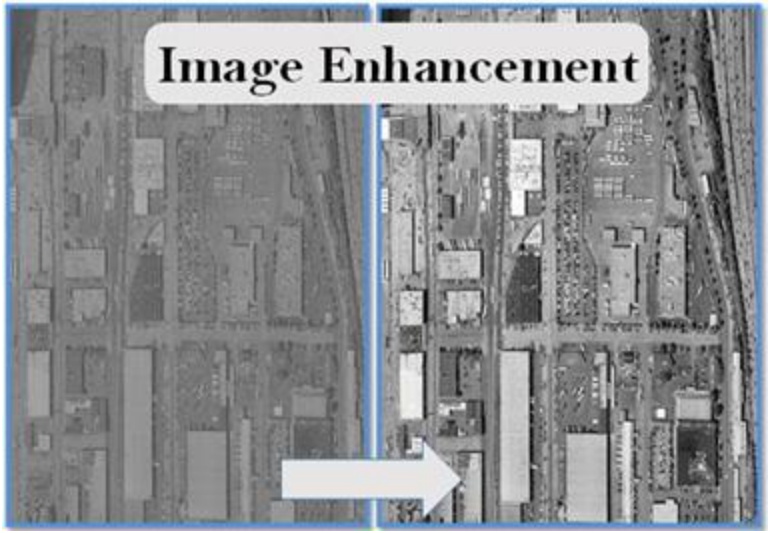


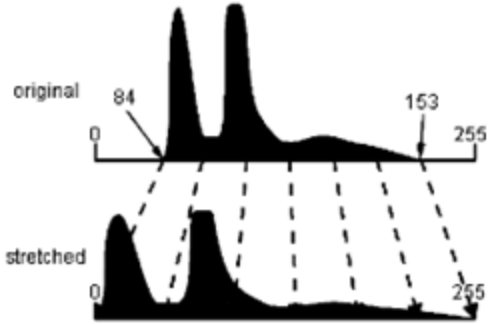
Images from geospatialworld.net

➔ ***Geometric correction:*** align image pixels with their true geographic positions.

- geometric distortions in remote sensing systems, e.g., optical camera and SAR
- Ground control point (GCP) and image registration
- Orthorectification and georeferencing
- Quality assessment
- Remote sensing image geometric correction can be achieved by some software tools, such as PCI Geomatica, and SNAP

Image enhancement





Images from igntu.ac.in/

➔ ***Image enhancement*** - To highlight ”signal” while suppress “noise” to improve class separability

- Histogram analysis and stretching
- Spatial filtering methods, e.g., mean, median, adaptive filtering, denoising, etc.
- Multi-/hyper-spectral feature extraction, e.g., vegetation indices, color composition, PCA, etc.
- Remote sensing image enhancement can be achieved using some software tools, such as PCI Geomatica and ENVI

Image classification

Remote sensing images (***data***) -> thematic maps (***information***)

➔ ***Image classification*** - To transfer remote sensing images into thematic maps

- Supervised classification methods, e.g., Maximum likelihood, SVM, RF, neural networks, CNN
- Unsupervised classification, e.g., k-means, gaussian mixture model
- Object-based image classification
- ML and AI models
- Accuracy assessment

Image credit: Jong-Min Yeom

Questions?