

Image processing for Earth Observation

Earth observation sensors

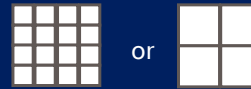
Devis TUIA

EPFL, fall semester 2025

How do I choose the “right” data?

Relevant questions to ask beforehand:

What spatial resolution do I need?



Am I interested at detecting, identifying or characterizing?



Where is my area of interest?



What time/frequency characterizes the process under study?



What accuracy do I need or what inaccuracy is acceptable?



To be considered about data price:

Prices for available products differ considerably, mainly as a function of resolution. \$\$\$

Suppliers apply very different minimum order sizes and constraints.



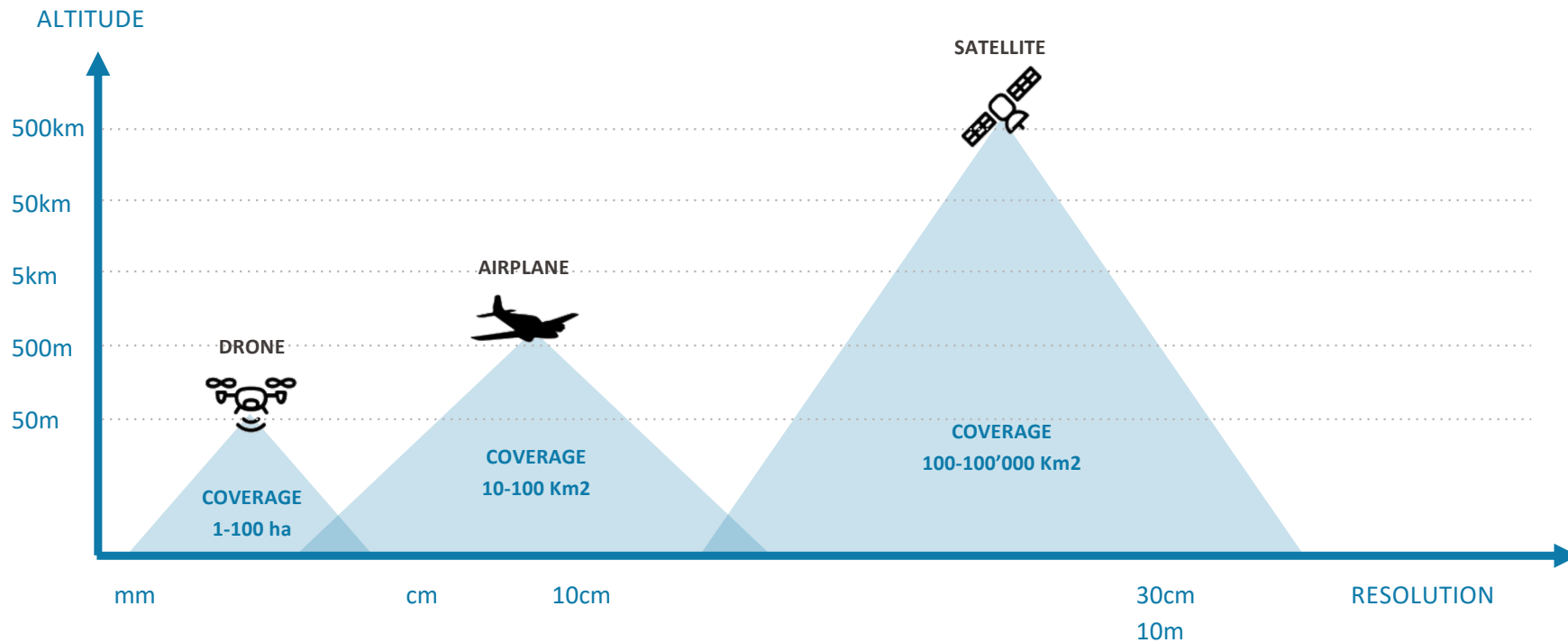
How do I choose the “right” data?

- We will have a look at the different sensor types available
 - Satellite platforms and constellations
 - Passive vs. Active
 - Panchromatic, Multispectral, Hyperspectral
 - SAR, LiDAR

- They all have their advantages related to specific applications
 - Scientific campaigns, production applications
 - Long time series, one-time assessment
 - Accurate measurement of surfaces, detection vs. identification, etc..

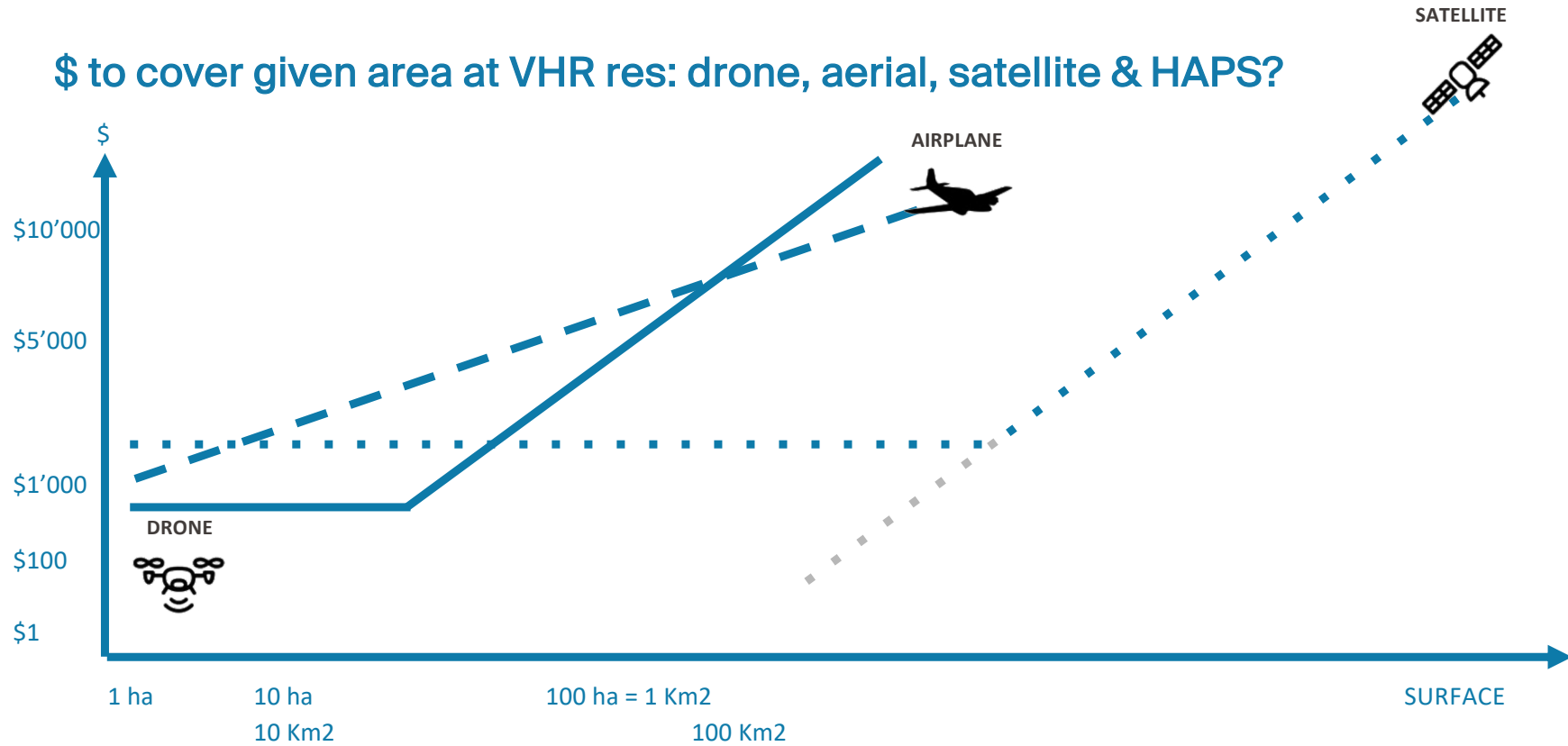
How do I choose the “right” data?

Altitude vs. resolution and coverage for drones, aerial, satellite



How do I choose the “right” data?

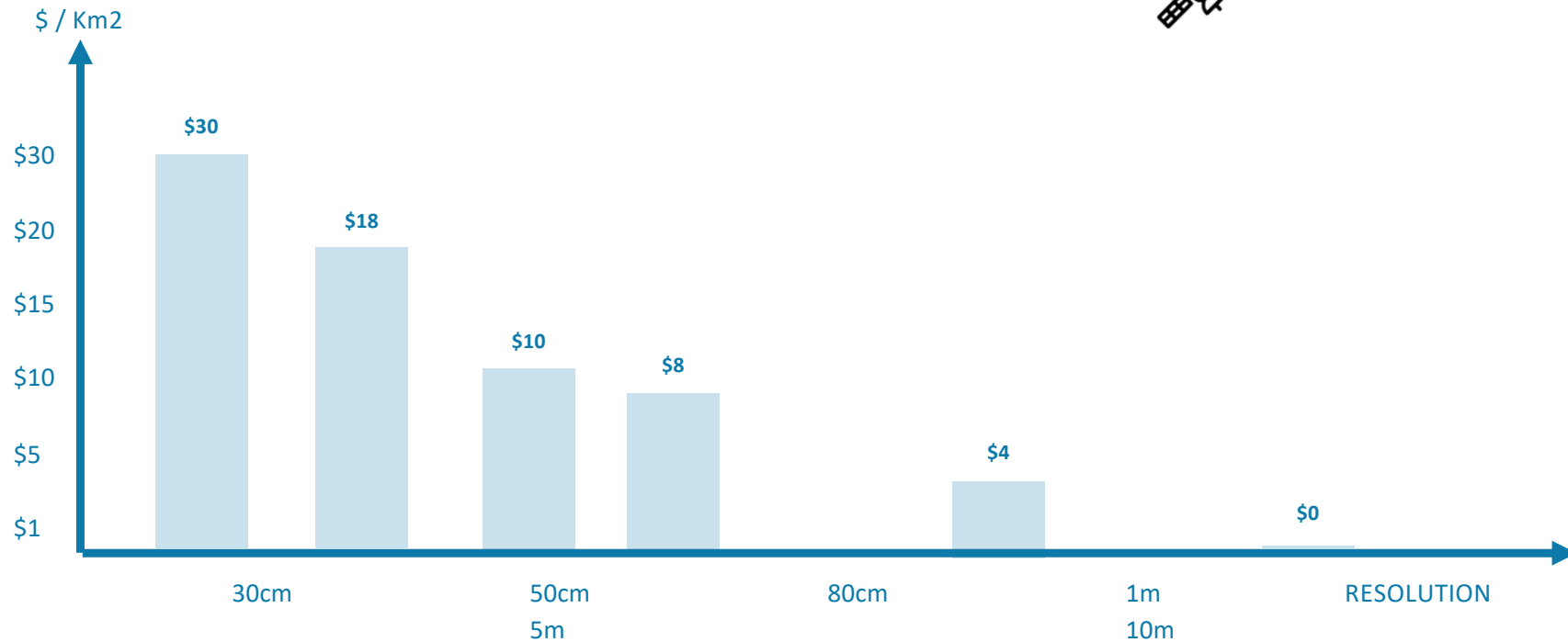
\$ to cover given area at VHR res: drone, aerial, satellite & HAPS?



How do I choose the “right” data?

\$ / Km2 for different satellite image resolutions

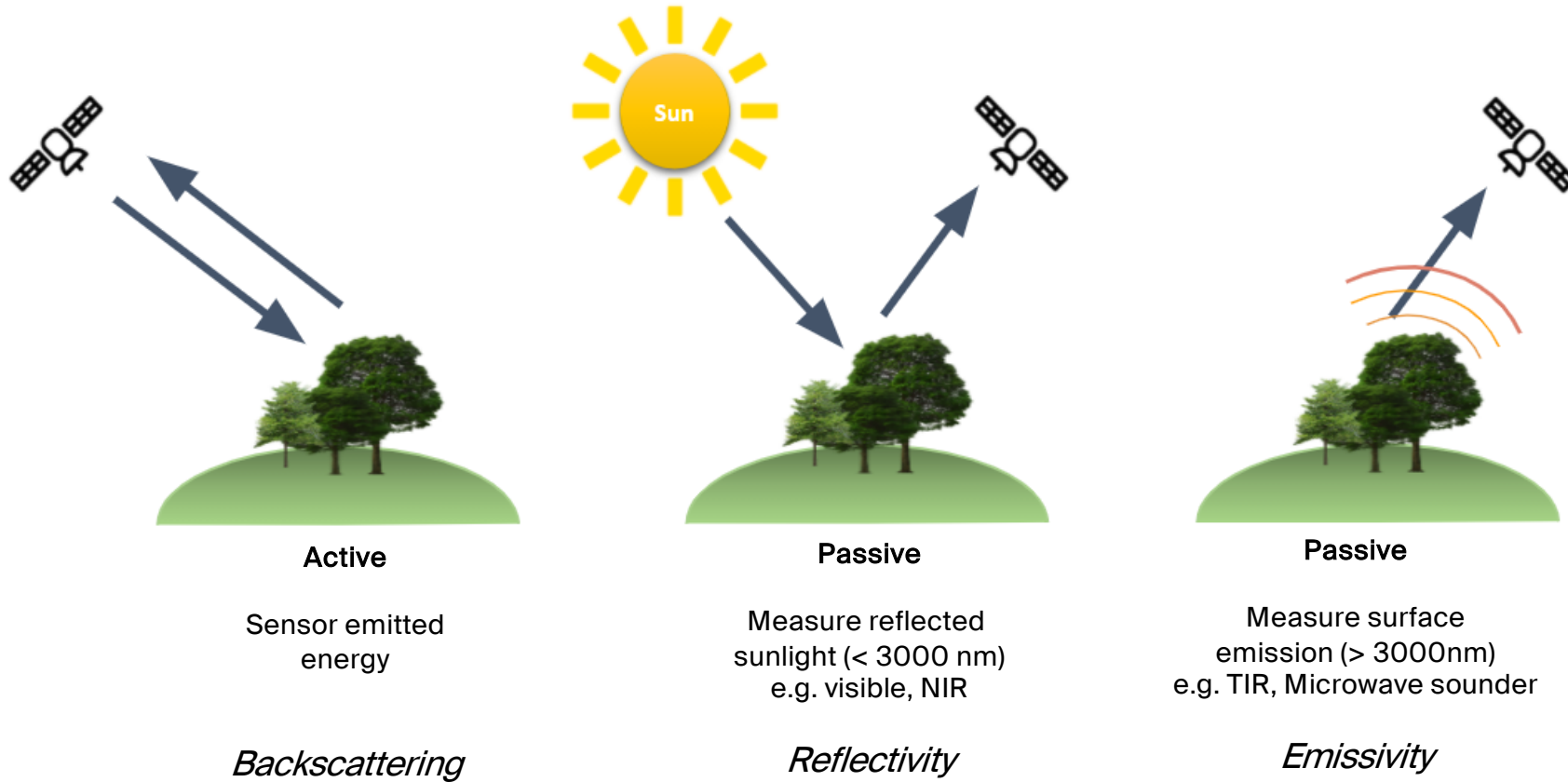
SATELLITE



Note: this is an approximation about 2020 stauts and about archive data

Slide courtesy: F. de Morsier, 2021

Earth observation: Active vs. Passive sensors



Active

Sensor emitted energy

Backscattering

Passive

Measure reflected sunlight (< 3000 nm)
e.g. visible, NIR

Reflectivity

Passive

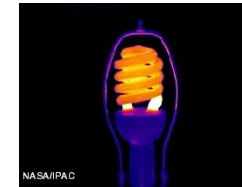
Measure surface emission (> 3000nm)
e.g. TIR, Microwave sounder

Emissivity

Earth observation: Active vs. Passive sensors

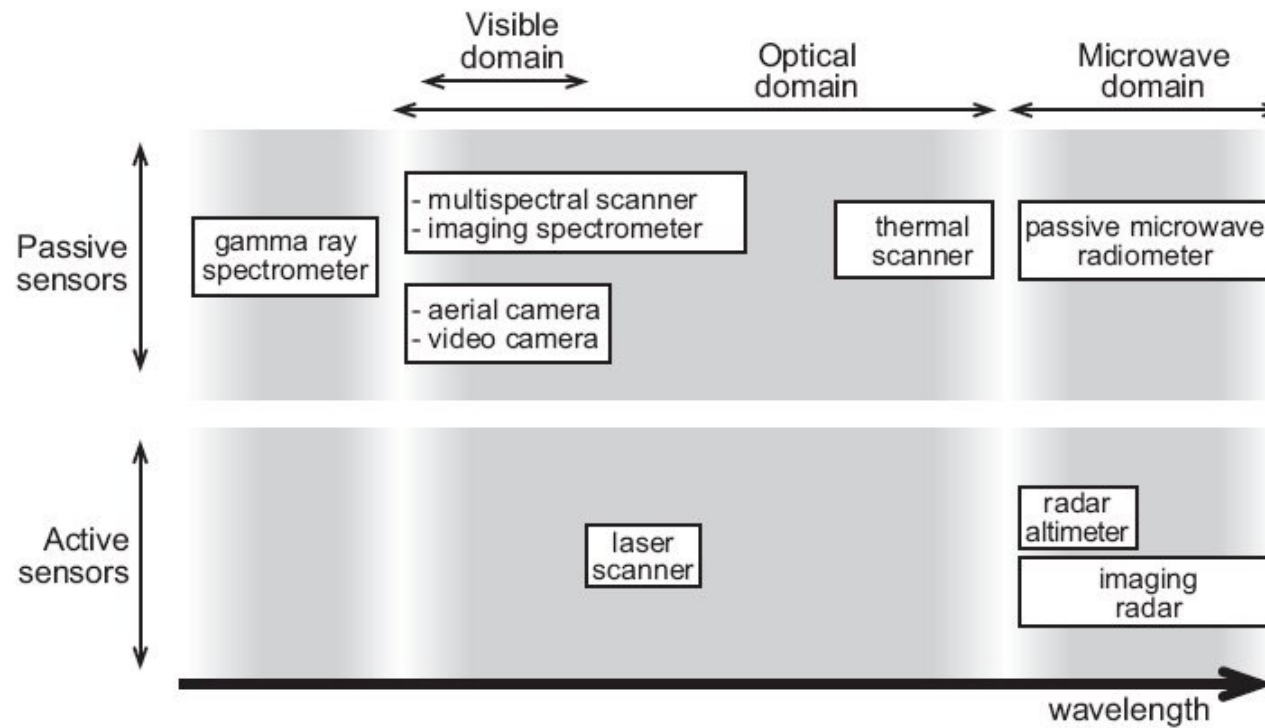
- A passive sensor measures naturally available energy

- Reflectivity: Sunlight (< 3000 nm)
- Emissivity: Emission in the thermal infrared (> 3000 nm)



- An active sensor illuminates the target by sending a EM radiation and measuring the return time and intensity
 - Radars (e.g. Synthetic Aperture Radars) → microwaves
 - LiDAR (Light Detection And Ranging) → laser light (typically in NIR)

Earth observation: Active vs. Passive sensors



Passive: aerial photography

- Acquired from aircrafts or drones
- Usually very high spatial resolution (half-meter to few centimeters)
- Usually only R-G-B or NIR-R-G
- Few multispectral cameras (see Micasense or Tetracam which provides several bands)



10



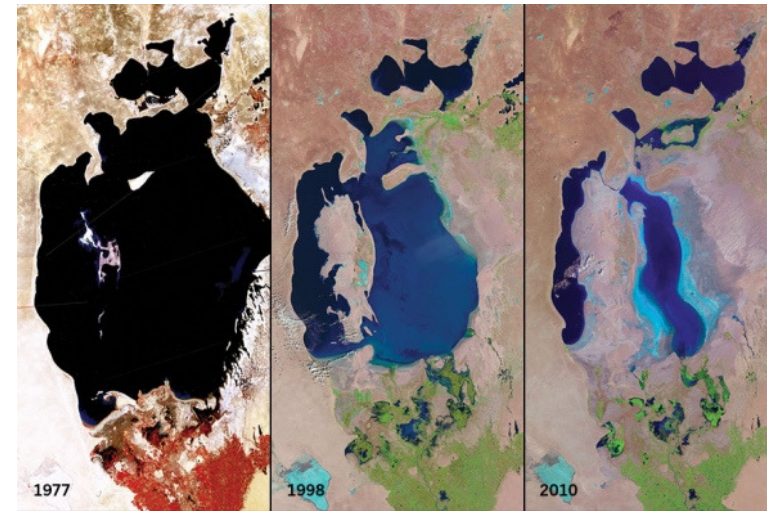
Sunbird uas



Sensefly Ebee

Passive: multispectral

- Term referred to aerial or satellite sensors with less than 20 bands
- Historically governmental missions (Landsat, MODIS, AVIRIS, Sentinel)
- Nowadays many private commercial companies (Airbus, Planet, Digitalglobe, Superview, etc.)
- Resolution varies according to the sensor.



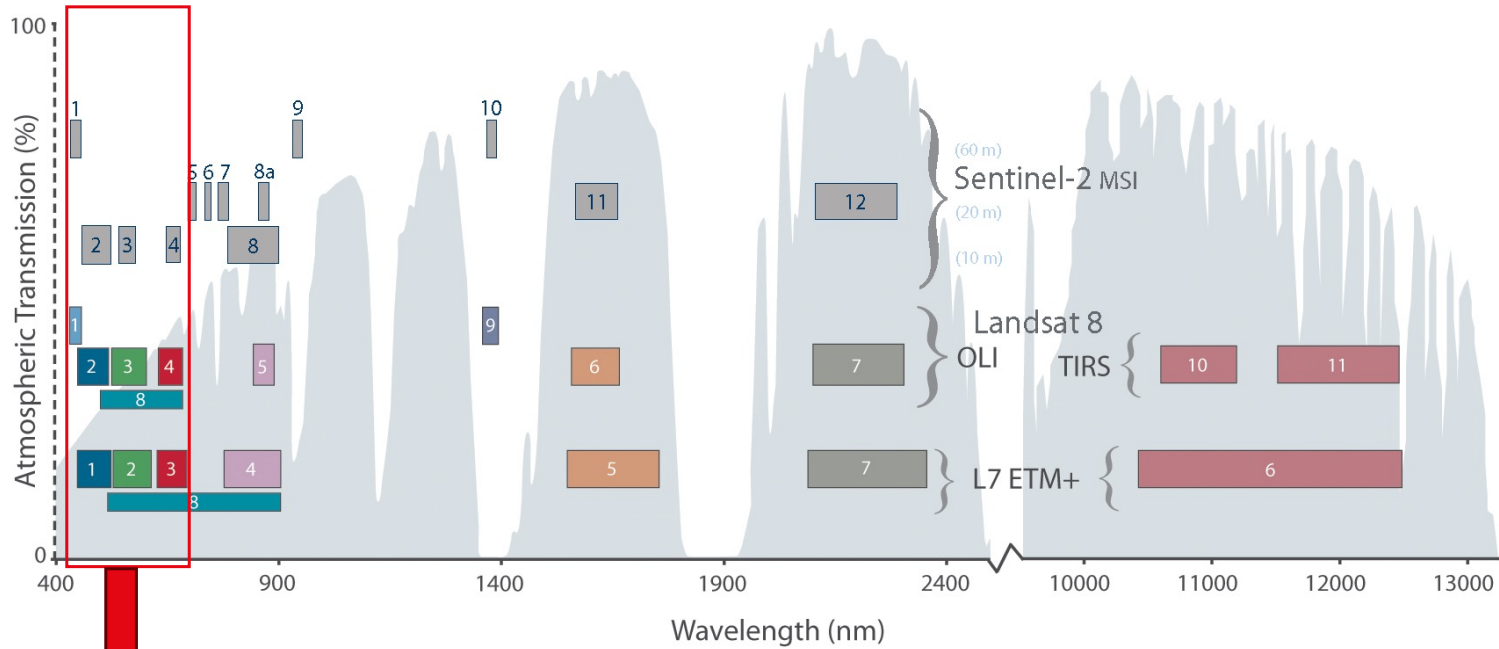
Landsat 2

Landsat 5

<http://visibleearth.nasa.gov/view.php?id=78588>

Landsat 7-8 vs Sentinel-2

Comparison of Landsat 7 and 8 bands with Sentinel-2



IPEO course - Sensors, 9 September 2025

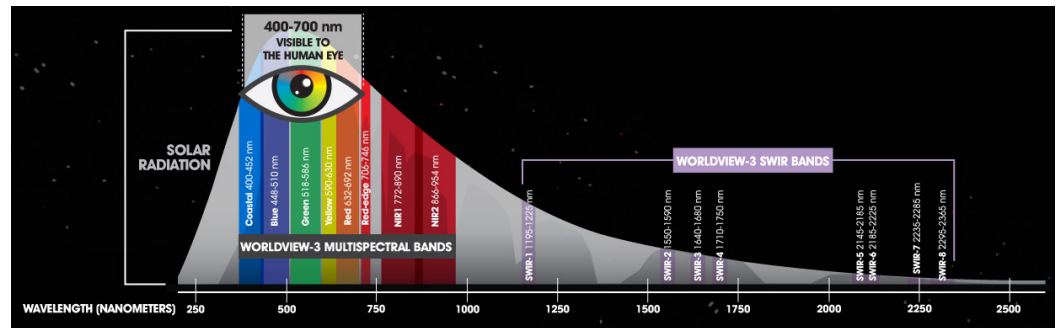
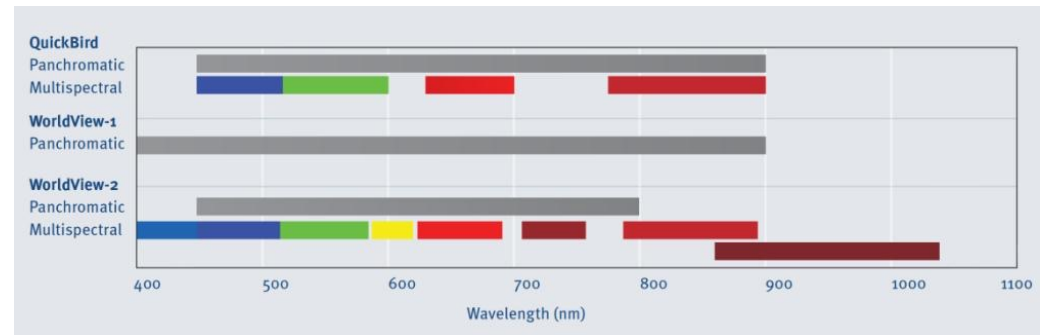
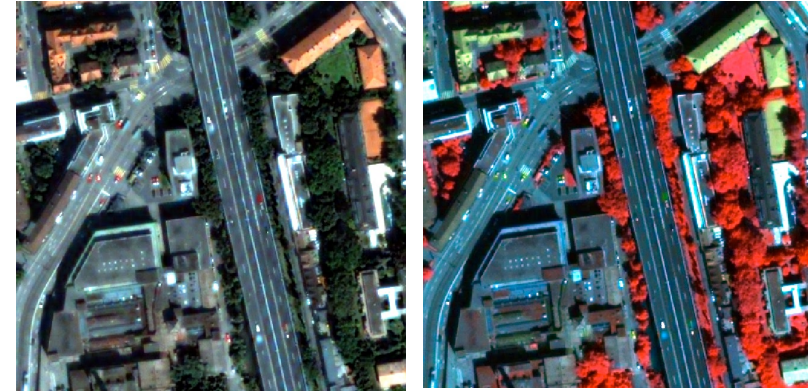


<http://eros.usgs.gov/sentinel-2>

Passive: multispectral

At Very High spatial Resolution (<5m), commercial satellites:

- Pléiades, 4 bands
- SPOT 5/6/7, 4 bands
- QuickBird, 4 bands
- WorldView II, 8 bands
- Worldview III, 16 bands
- Planetscope Doves, 4 bands
- Planet Skysat, 4 bands



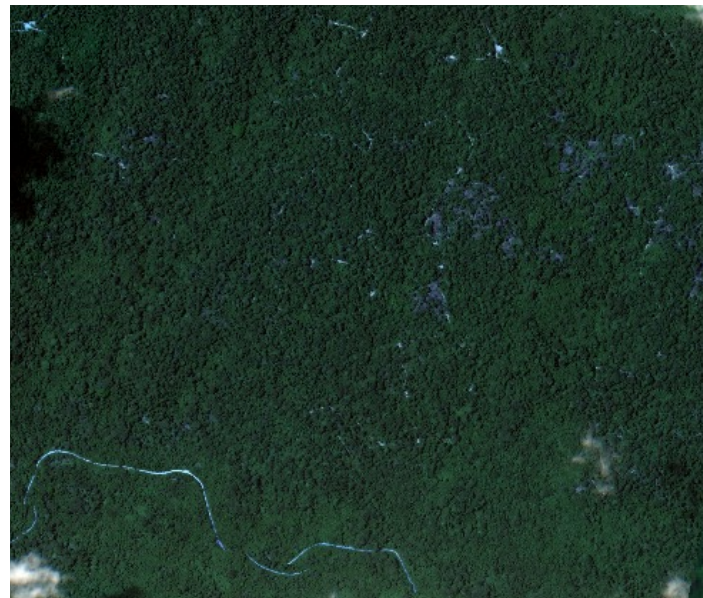
Passive: multispectral

- Two multispectral sensors can have very different characteristics!

Sentinel 2 (RGB), 10m



Planet SkySat, 0.8m

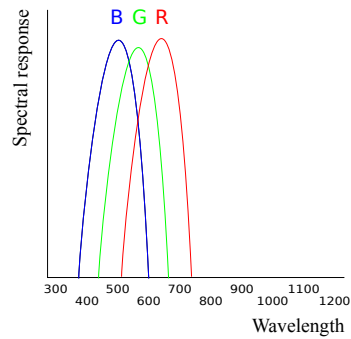


Spectral resolution: multi- vs. hyperspectral

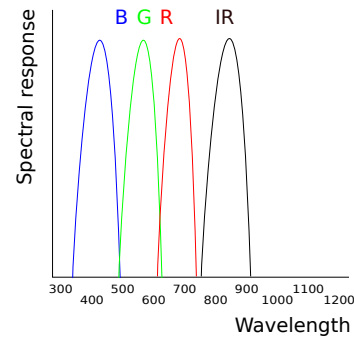
- The differences are mainly in terms of resolution and availability
- Multispectral sensors typically
 - Have 4-10 bands
 - Provide high to very high resolution (30m to ~2m)
 - Are commercially available
- Hyperspectral sensors
 - provide between tens and hundreds bands
 - Provide medium (satellite) to high (airborne) resolution

Spectral resolution: multi- vs. hyperspectral

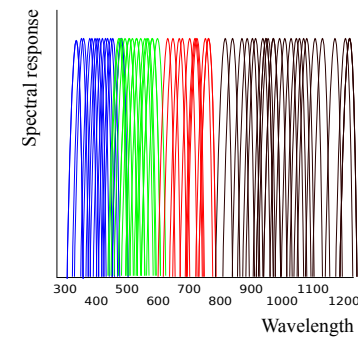
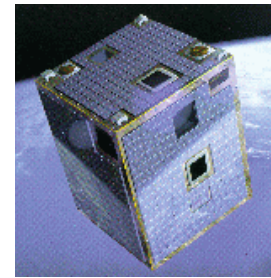
Digital camera



Multispectral

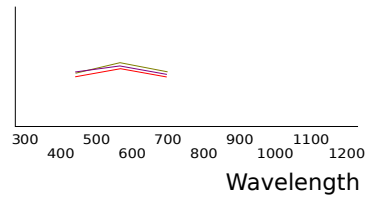


Hyperspectral

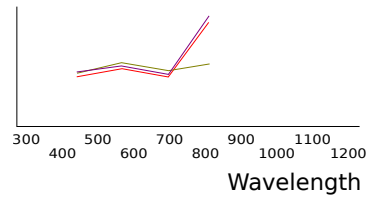


Spectral resolution: multi- vs. hyperspectral

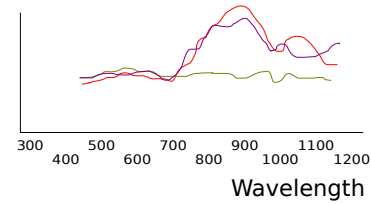
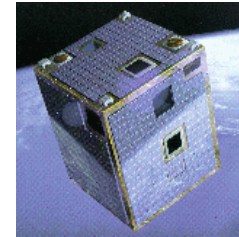
Digital camera



Multispectral

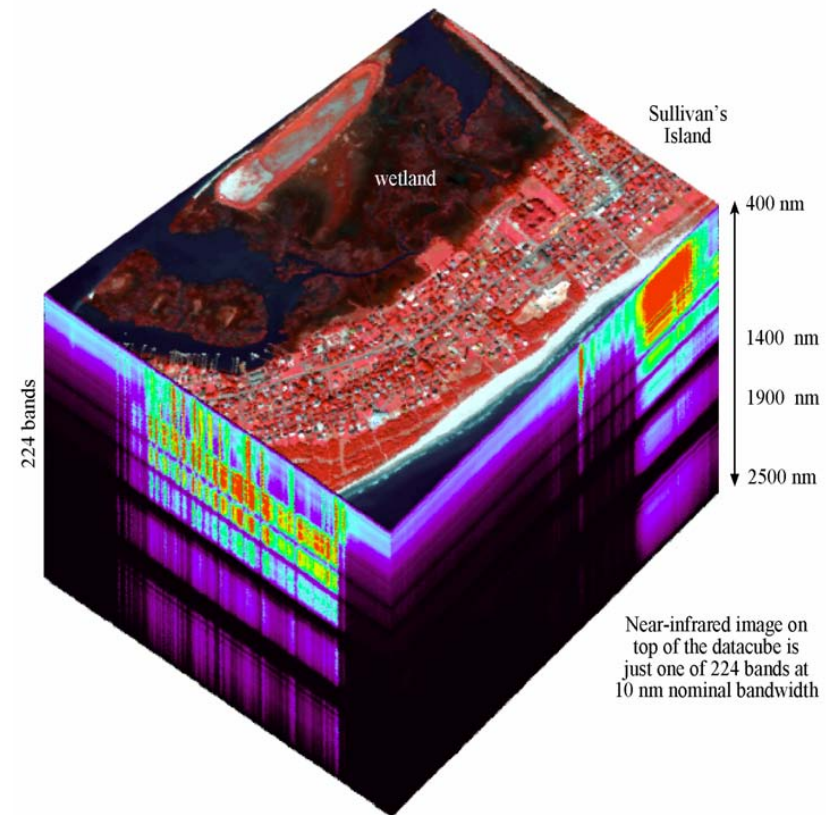


Hyperspectral



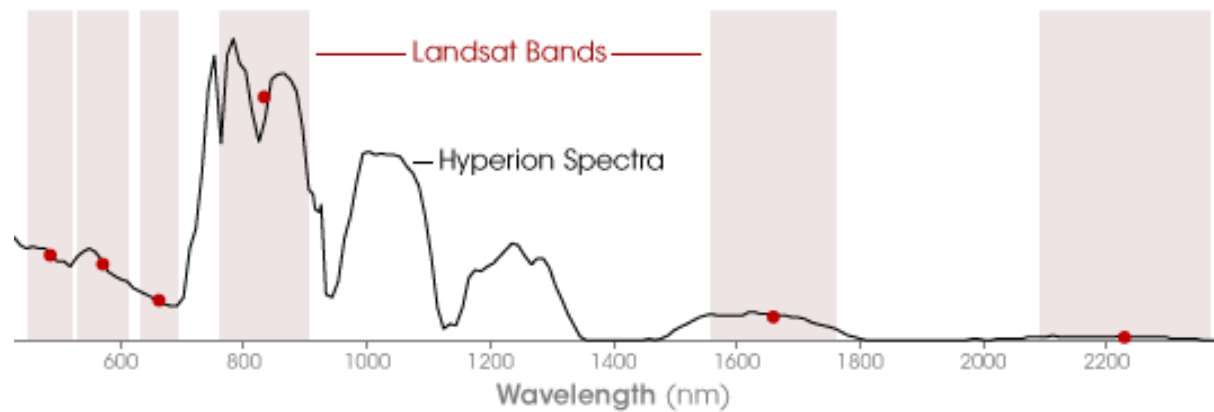
Passive: hyperspectral

- Also called imaging spectrometers
- High number of narrow bands
- Provide a whole precise spectral signature per pixel



Spectral resolution: multi- vs. hyperspectral

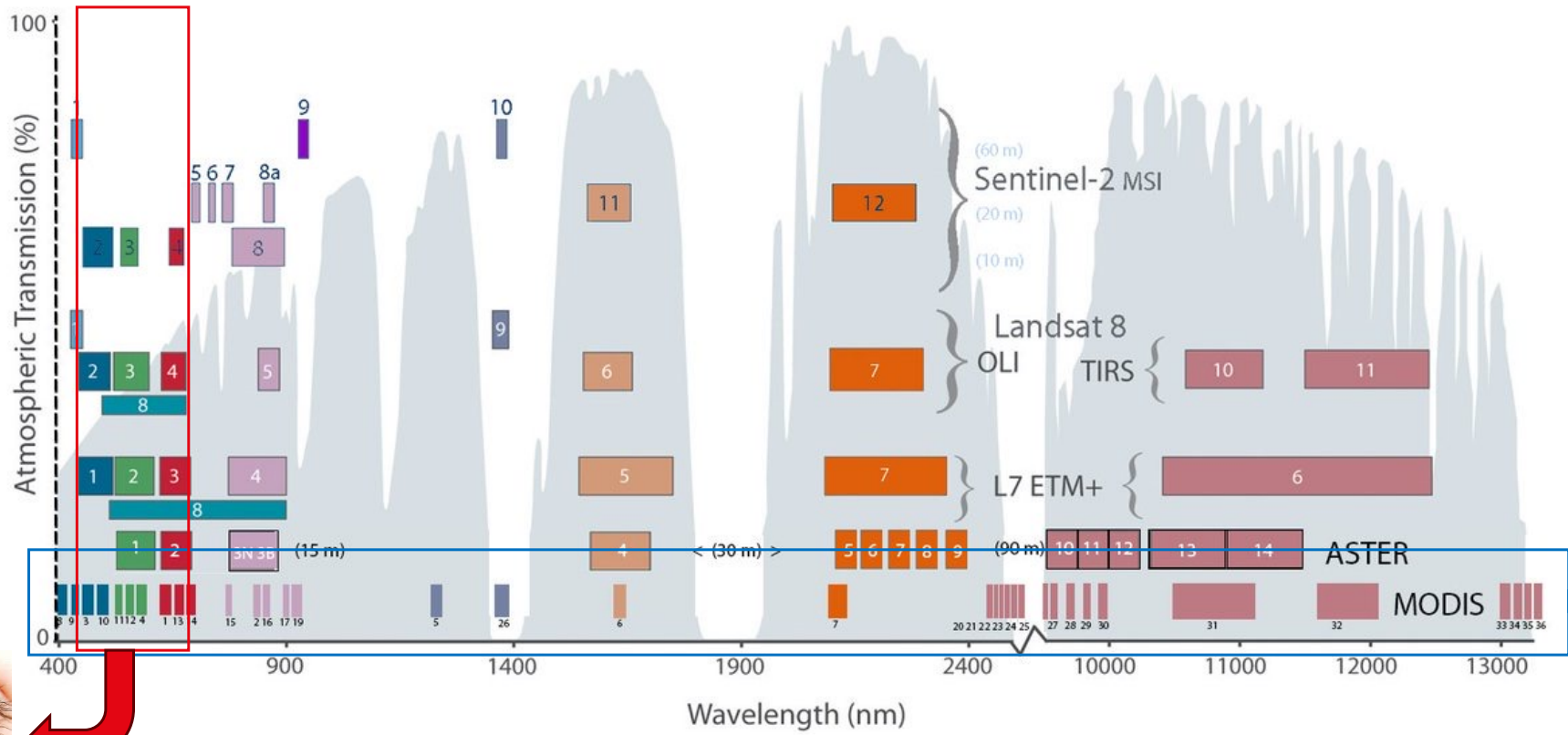
- band values from Landsat (multispectral)
- spectrum retrieved by Hyperion (hyperspec.)



earthobservatory.nasa.gov

Hyperspectral: MODIS vs. multispectral

Comparison of Landsat 7 and 8 bands with Sentinel-2 and MODIS sensor onboard Terra & Aqua satellites



course - Sensors, 9 September 2025



Hyperspectral

Hyperspectral: AVIRIS

- Airborne Visible Infrared Imaging Spectrometer
- First successful airborne hyperspectral experiment from NASA
- 400nm-2500nm in 224 bands (10 nm interval)

Hyperspectral: AVIRIS - Kennedy space center

Band 5 (448nm) - B



Band 10 (497 nm) - G



Band 30 (675nm) - R



Band 40 (771nm) - NIR



Band 100 (1473nm) - NIR



Band 130 (1772nm) - SWIR (starting)



Hyperspectral: AVIRIS – Fire in Brazil

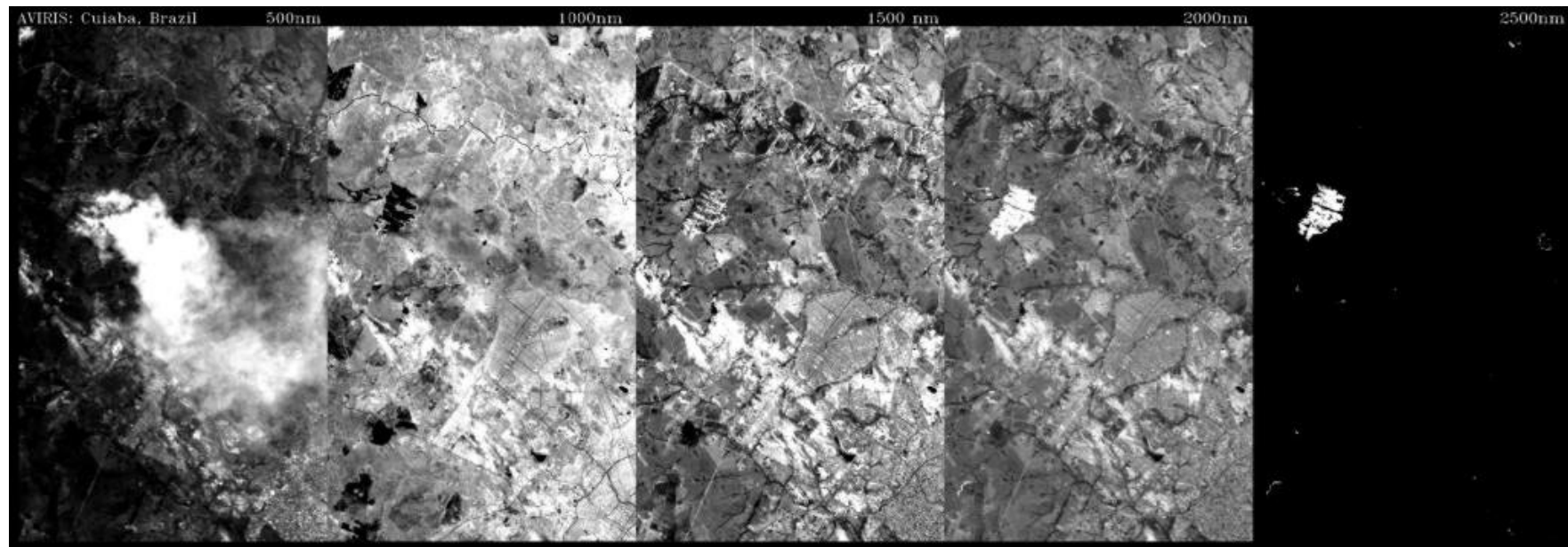
500nm

1000 nm

1500 nm

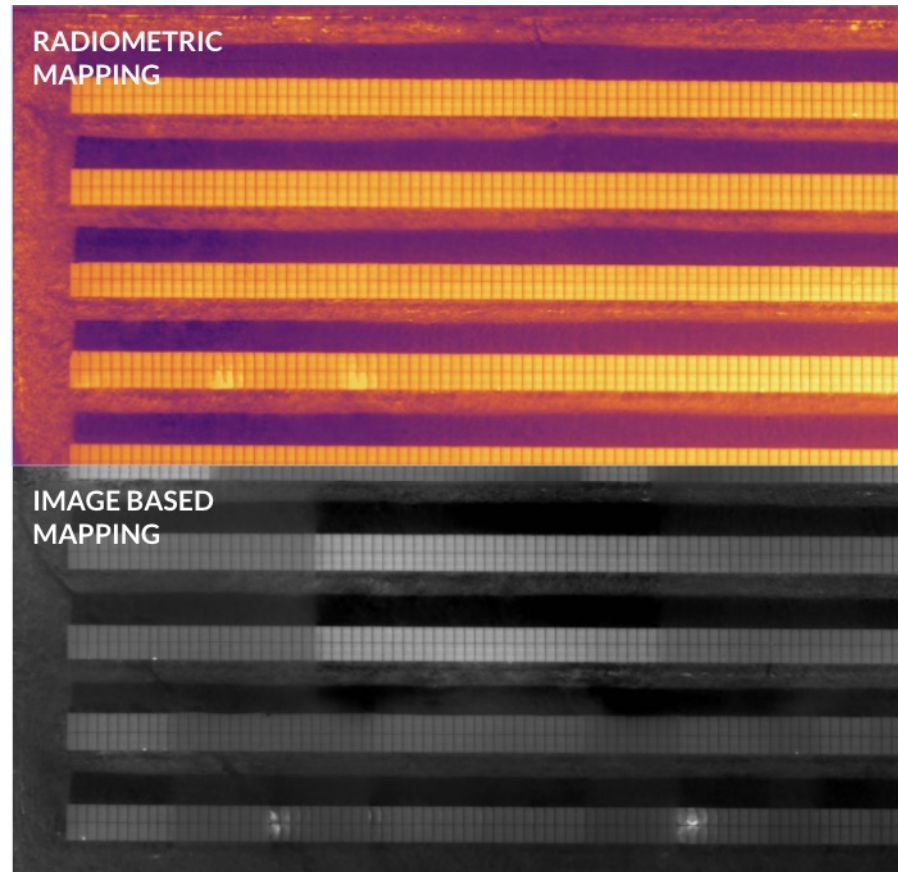
2000 nm

2500 nm



Source: Geog.ucsb.edu

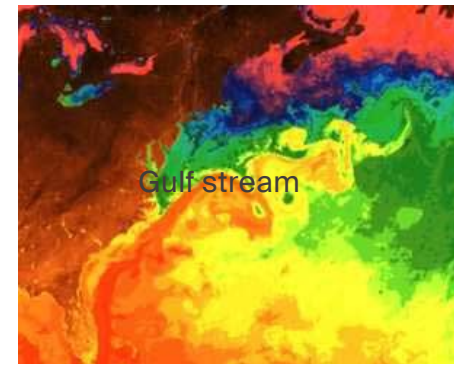
Passive: Thermal



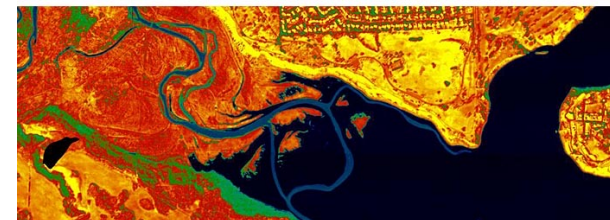
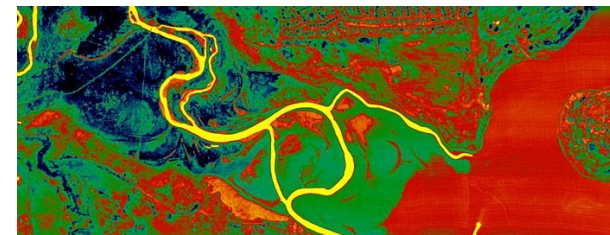
<https://support.dronedeploy.com/docs/thermal-mapping>

Passive: Thermal hyperspectral scanners

- Usually scan frequencies in atmospheric windows of thermal infrared
 - (3000-5000 nm)
 - (9000-14000 nm)
- Measure the radiation emitted by a body
 - => thermal reflections
 - =/= body temperature!
- Multiple bands can allow to deduce body temperature
- Applications:
 - Water surface temperature
 - Cloud detection and characterization



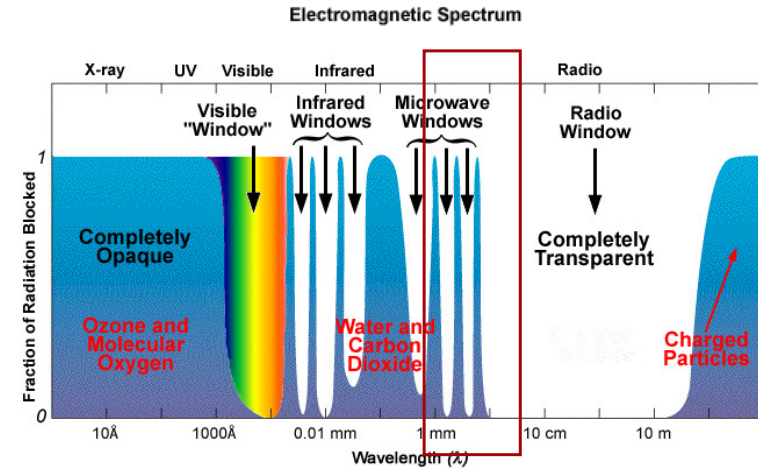
NOAA ocean explorer



TASI airborne images (4am, 2pm)

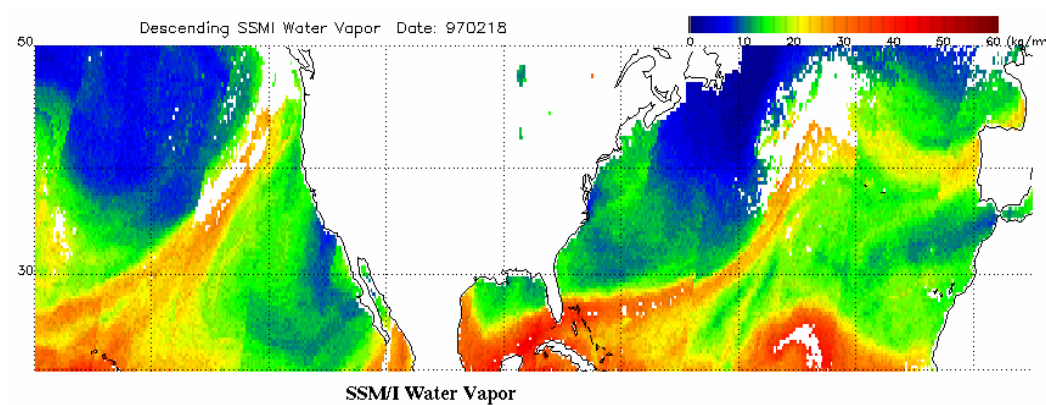
Passive: microwave radiometer

- Consider energy emitted at wavelengths from millimeters to centimeters
- Usually mounted on meteorological satellites
- Used to study
 - Air temperature;
 - Sea surface temperature;
 - Soil moisture;
 - Water vapour.



©The COMET Program

Source: cimss.ssec.wisc.edu



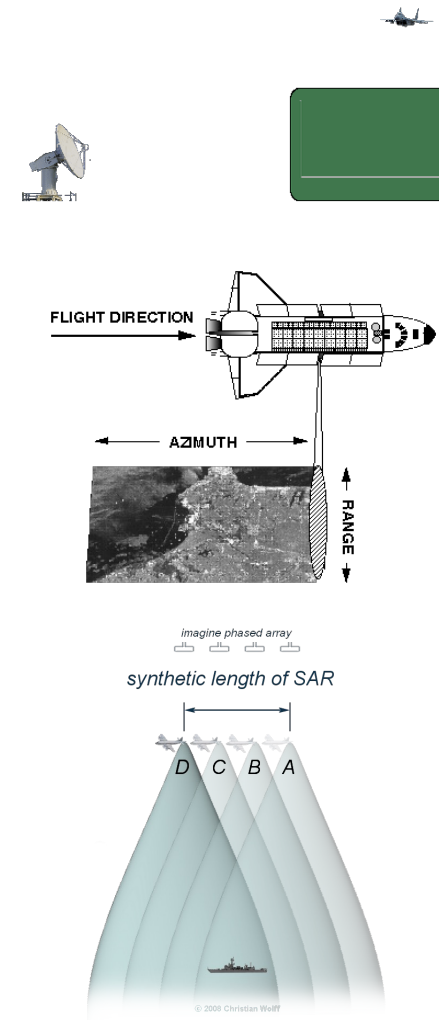
SSM/I Water Vapor

Active: SAR

- Synthetic Aperture Radar
 - Emit microwave pulses and record return time after hitting the ground

- Radar:
 - Travel time => converted to distance
 - The narrower the width of the wave, the higher the resolution of the range

- Synthetic Aperture:
 - Antenna length defines the resolution in the azimuth direction
 - Increase spatial resolution by simulating a huge antenna

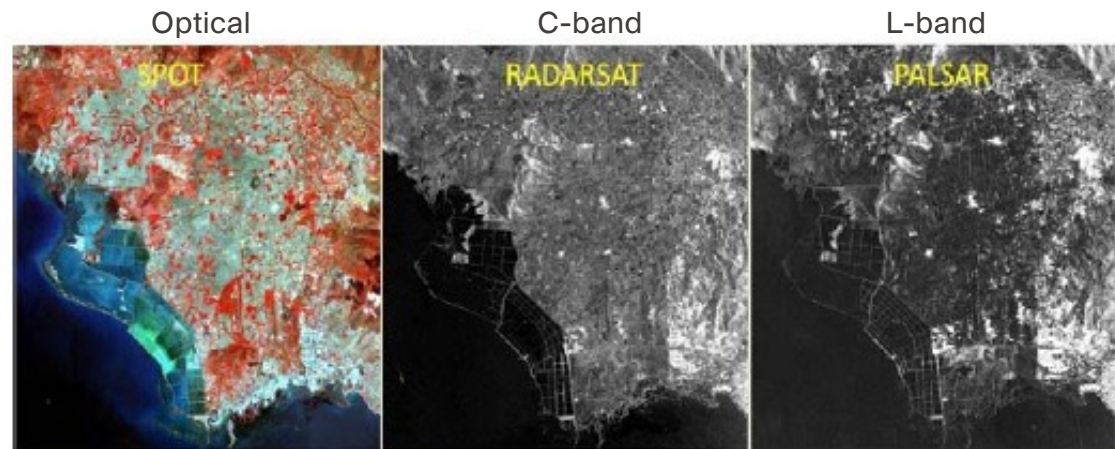


Source: <http://southport.jpl.nasa.gov/desc/>

Source: <http://www.radartutorial.eu>

Active: SAR - Wavelength of the radar bands

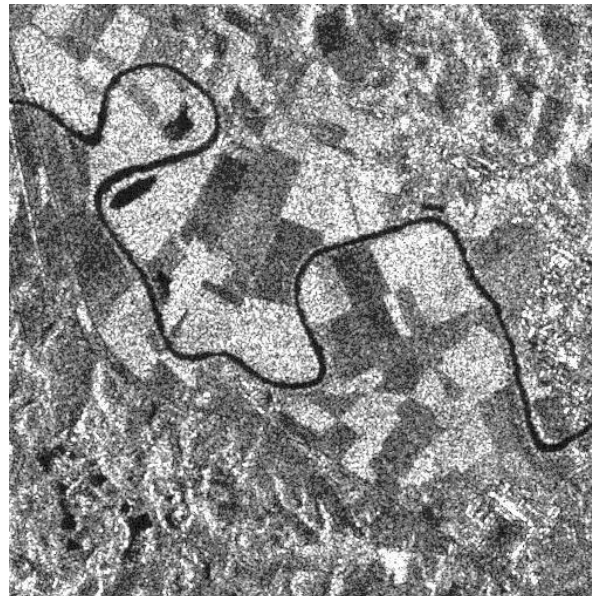
- **L** band: more than 15 cm
Medium range meteorological applications (e.g. rainfall measurements)
- **S** band: 7.5 to 15 cm.
- **C** band: 3.75 to 7.5 cm.
Sea ice surveillance. No atmosphere contamination in rains
- **X** band: 2.4 to 3.75 cm.
High resolution radars, mapping and surveillance



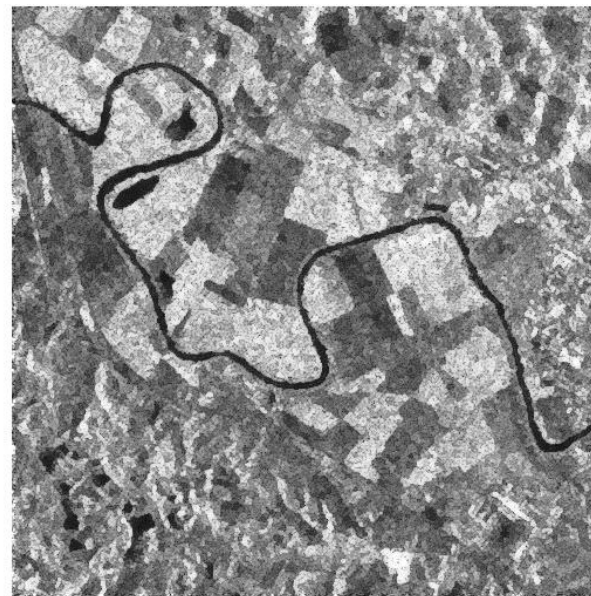
Active: SAR is not optical imaging !

- There is a noise effect called speckle

Not filtered

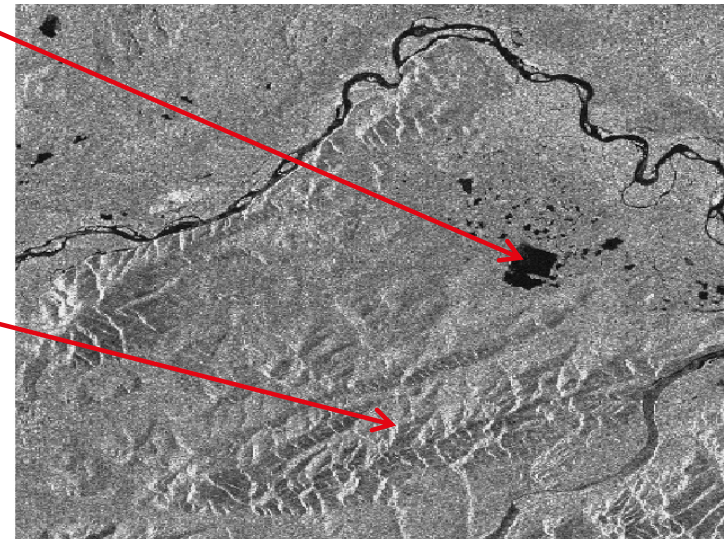


"Despeckled"



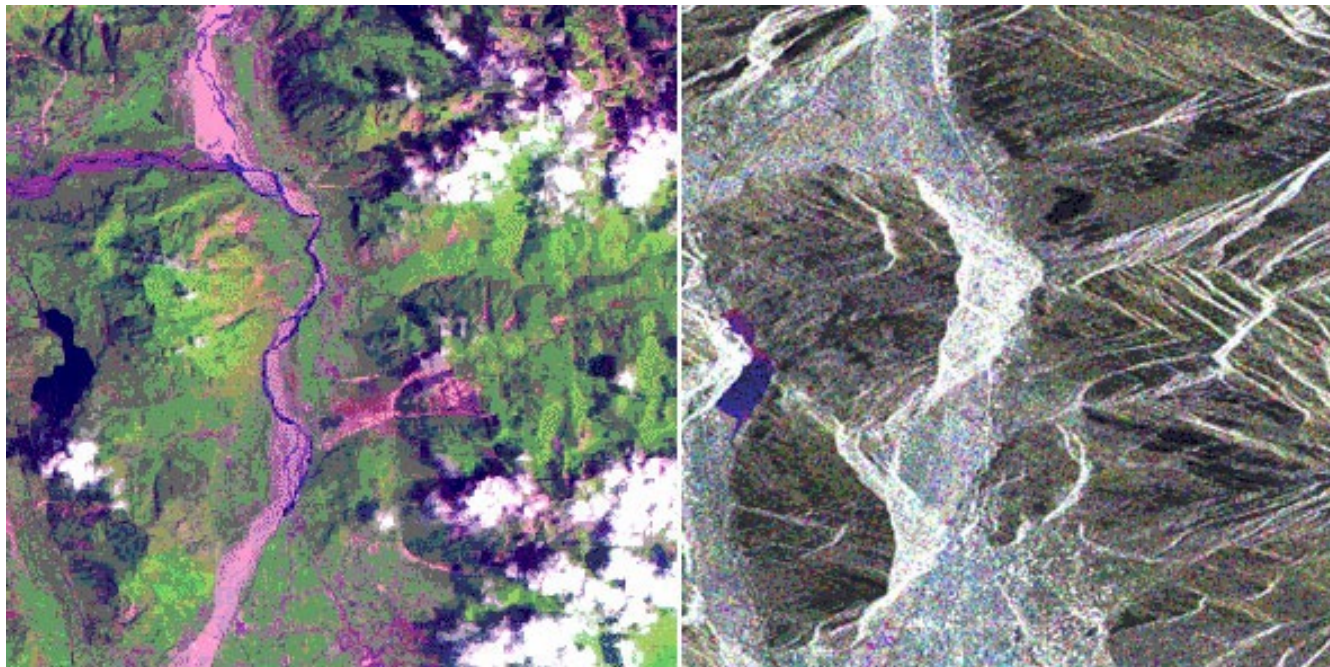
Active: SAR is not optical imaging !

- SAR is an image reconstructed from pulse echos
- It depicts how the particle interacts with the surface and returns to the antenna, not how light is reflected.
- A few features
 - Water is black, as beams do not return
 - Mountains are bright in the looking direction (many beams bounce back)
 - Shadowing effect behind vertical structures



Active: SAR specific effects: layover, shadows..

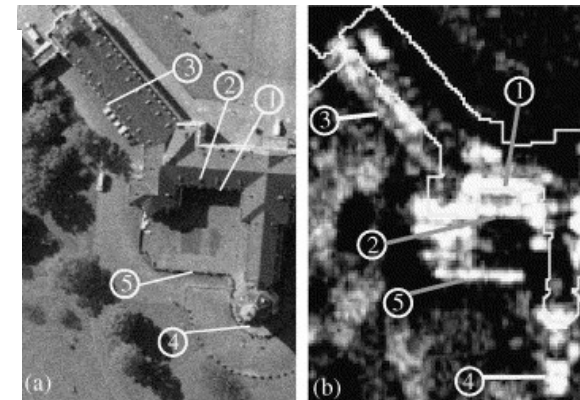
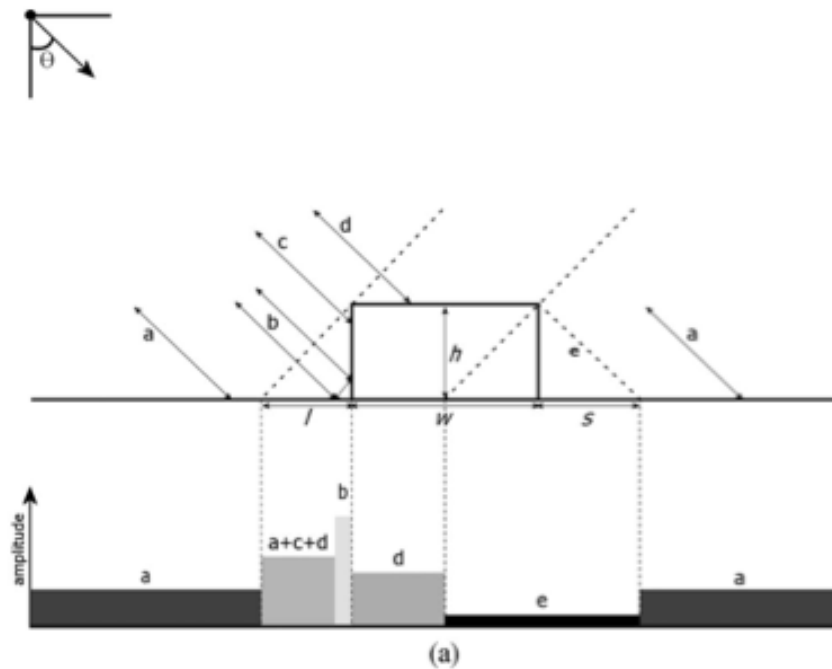
- The layover effect: may seem minimal, but...



Source: <http://earth.esa.int/>

Active: SAR is not optical imaging !

- Buildings show a very complex structure

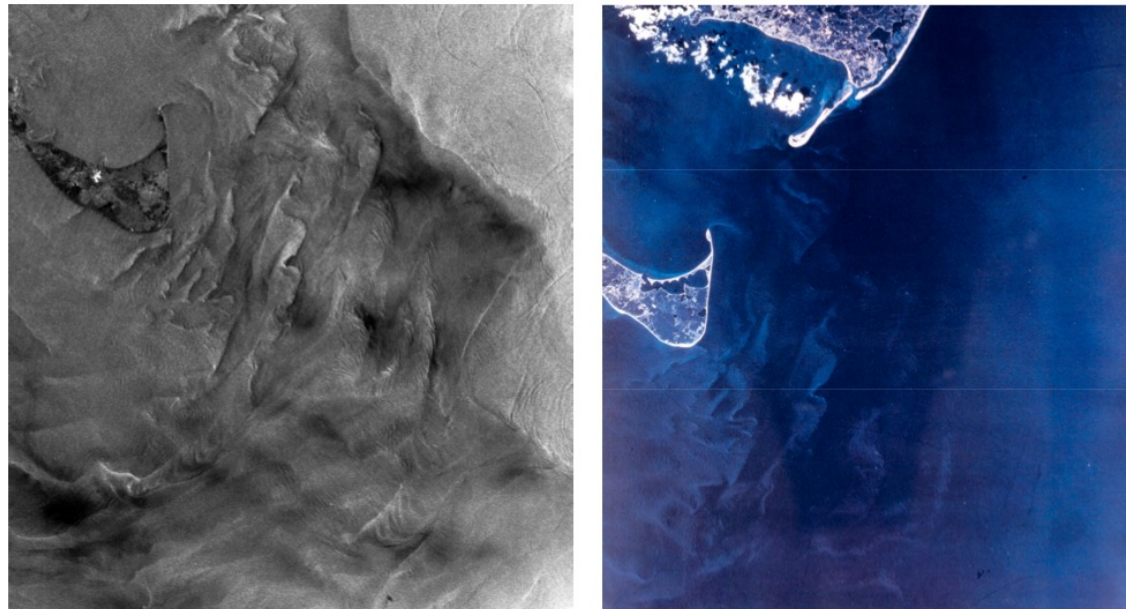


Source: Soergel et al, 2005

Source: Brunner et al, 2010

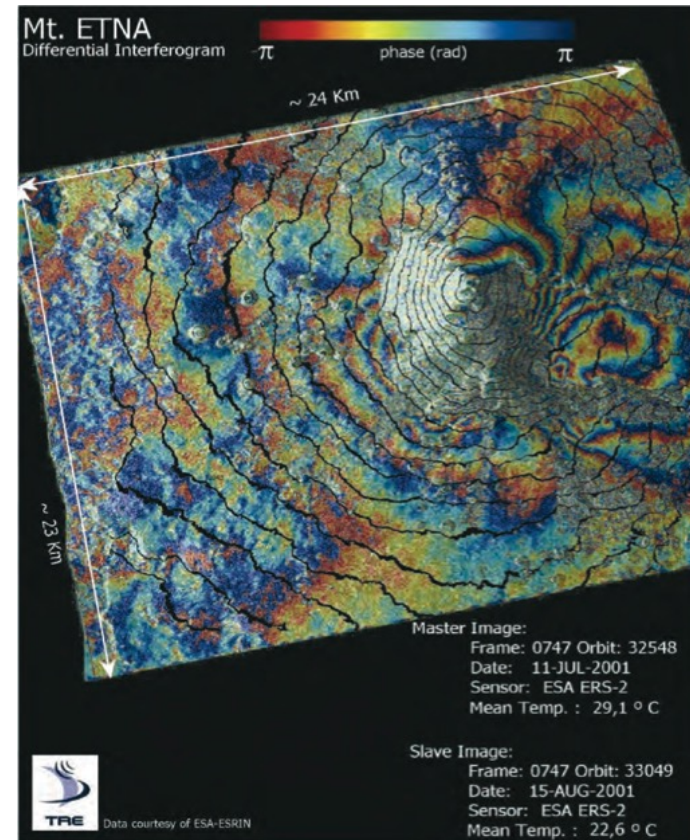
Active: So why using SAR?

- SAR “sees” through clouds (microwaves)
- SAR “sees” at night (active sensor)
- SAR penetrates in the ground (depth proportional to frequency)
- SAR allows to characterize surface roughness



Active: So why using SAR?

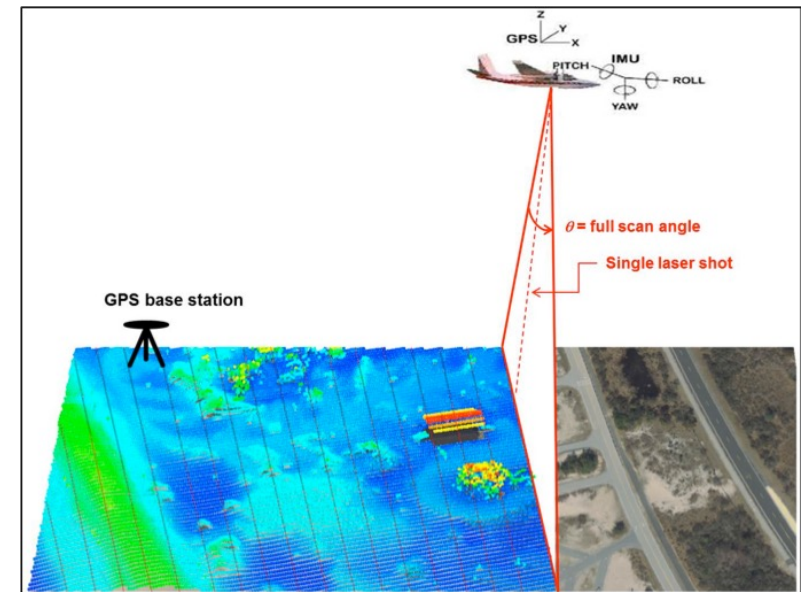
- With two SAR acquisitions, we can measure height displacements of the order of the half of the wavelength.
- In this example (2001 eruption of Mt. Etna), the sensor ERS is used. It has $\lambda = 5.6\text{cm}$, so each fringe (color cycle) is a 2.8cm vertical displacement.
- This is the domain of differential interferometry InSAR (not covered in this course).



Source: <http://www.esa.int/> (InSAR principles)

Active: LiDAR

- Similar to radar: focused laser beams ↔ instead of radio waves
- Travel time -> converted to distances
- Retrieves the 3D coordinates of the object using:
 - Travel time
 - Sensor location
 - Firing angle of the beam
- Requires:
 - Accurate 3D positioning of sensor
 - Accurate positioning of airplane



Source: NOAA 2012

Point clouds examples



Point clouds examples



What's coming next with EO platforms..

- Large constellation of small satellites
 - Several hundreds of satellites
 - Acquiring multiple images / day (hourly)
 - Real-time live video stream from satellite
 - SEN <https://sen.com/>
 - Onboard processing (alert system, detections, etc.)
 - http://www.esa.int/Applications/Observing_the_Earth/Ph-sat/First_Earth_observation_satellite_with_AI_ready_for_launch
- ⇒ Main trend is towards higher frequency of revisit

EO satellites – a selection

Satellite	Launch	Spatial resolution	# of spectral bands	Spectral domain*	Swath	Revisit time	Price
Landsat-8 (OLI)	2013	15 m	1	Pan	185 km	16 days	free
		30 m	5	B, G, R, NIR			
		30 m	3	SWIR			
Terra (ASTER)	1999	15 m	4	B, G, R, NIR	60 km	16 days	
		30 m	6	SWIR			
Sentinel-2A/B (constellation: 2)	2015/ 2017	10 m	4	B, G, R, NIR	290 km	5 days	
		20 m	6	NIR, SWIR			
		60 m	3	B, NIR, SWIR			
Rapideye (constellation: 5)	2003	6.5 m	5	B, G, R, RE, NIR	77 km	1 day	0.95 to 1.3 €/km ²
SPOT-6/SPOT-7 (constellation: 2)	2012/ 2014	1.5 m 6 m	1 4	Pan B, G, R, NIR	60 km	1 day	
Planet - doves (constellation: 149)	2013/ 2017	3.0/3.7 m	4	B, G, R, NIR	24.6 km	1 day**	~0.10 €/km ²
Planet - SkySat (constellation: 7)	2013/ 2016	0.9 m 2.0 m	1 4 (Video option)	Pan B, G, R, NIR	8 km	< 1 day	
OptiSAR[#] (constellation: 8)	2021	1.5x2.5 m	4 (Optical) (not confirmed) 1 (SAR)	B, G, R, NIR (not confirmed) X-Band	5 km	1 day	? not yet available
Pleiades 1A/B (constellation: 2)	2011	0.5 m 2 m	1 4	Pan B, G, R, NIR	20km	1 day	17 €/km ²

* Pan - panchromatic, B - blue, G - green, R - red, RE - red edge, NIR - near infrared, SWIR - shortwave infrared

8 SAR-satellites with X- and L-Band sensors, in tandem mode with 8 optical VHR satellites.

EO satellites – Open list

- Here is an open source collaborative list of Earth Observation satellites initiated by the [Geoawesomeness](#) team:

<https://docs.google.com/spreadsheets/d/1KEODq9f7ej8QiNZug3fY8jKoy5zDXC0gNdPdcOFDjDM/edit#gid=0>

A little sat-exercise

- Form a group of 3 persons
- For next week, prepare a poster for one of the topics you can find at this page: https://docs.google.com/spreadsheets/d/1fKZtfln7095q41-SyqjVwCDG9CEbV_NgucDbYC1PWW8/edit?gid=0#gid=0
- Send the poster on moodle
(name the file “Topic#_YourLastNames.pdf”, max 60Mb).

Deadline: Thursday next week, 12:00

Summing up

- There are MANY sensors around
- You must know your options, so that, according to your needs, you can chose the more suitable
- Always check
 - The **resolution** needed (not the maximal, but the scale of the process under study and the level of characterization required)
 - The **spectral properties** of the problem
 - The **acquisition conditions** (when studying typhoons, optical images will be useless except for observation of top layer of the clouds..)