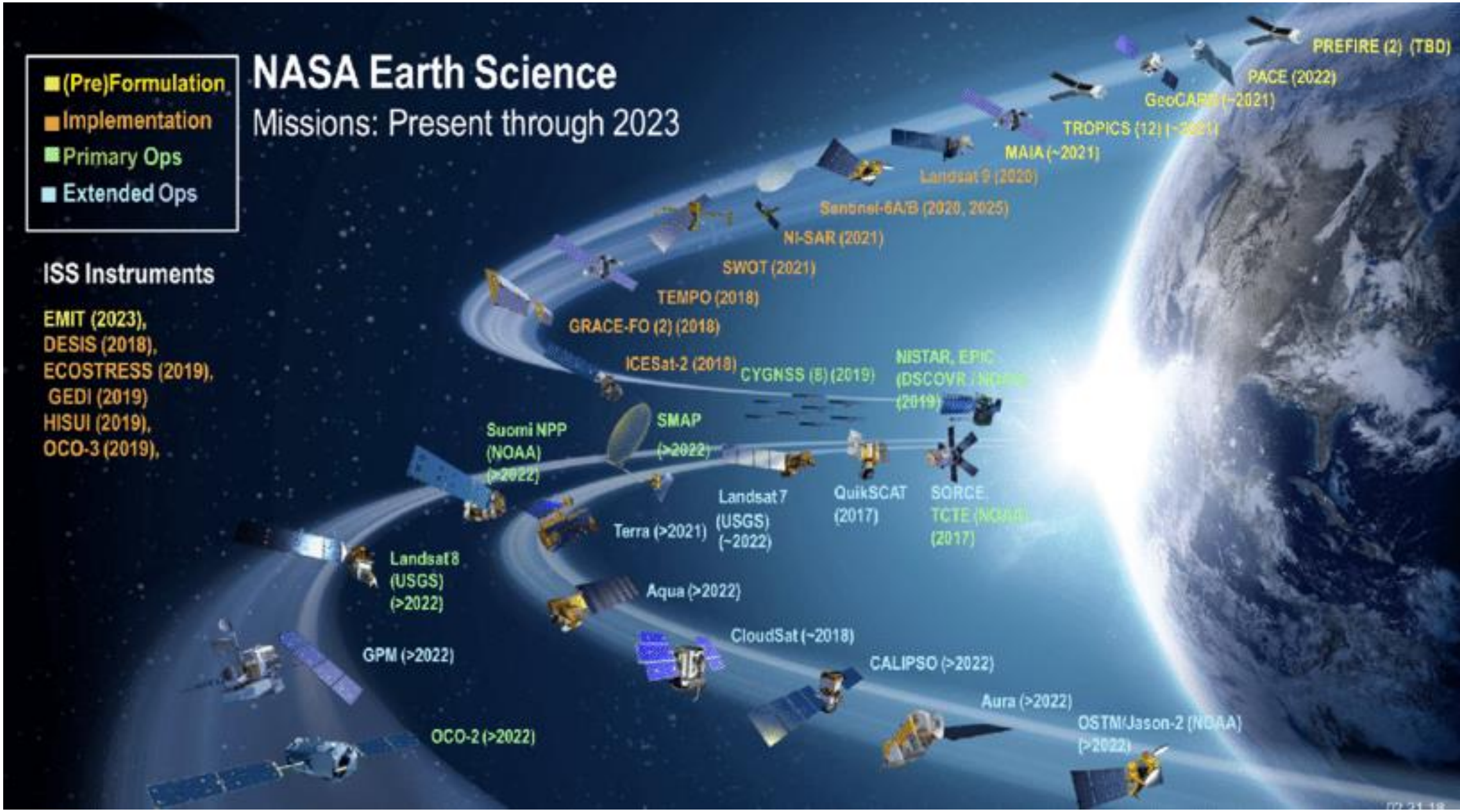
Remote Sensing Passive and Active

Dr. Polyanna da Conceição Bispo
polyanna.bispo@manchester.ac.uk

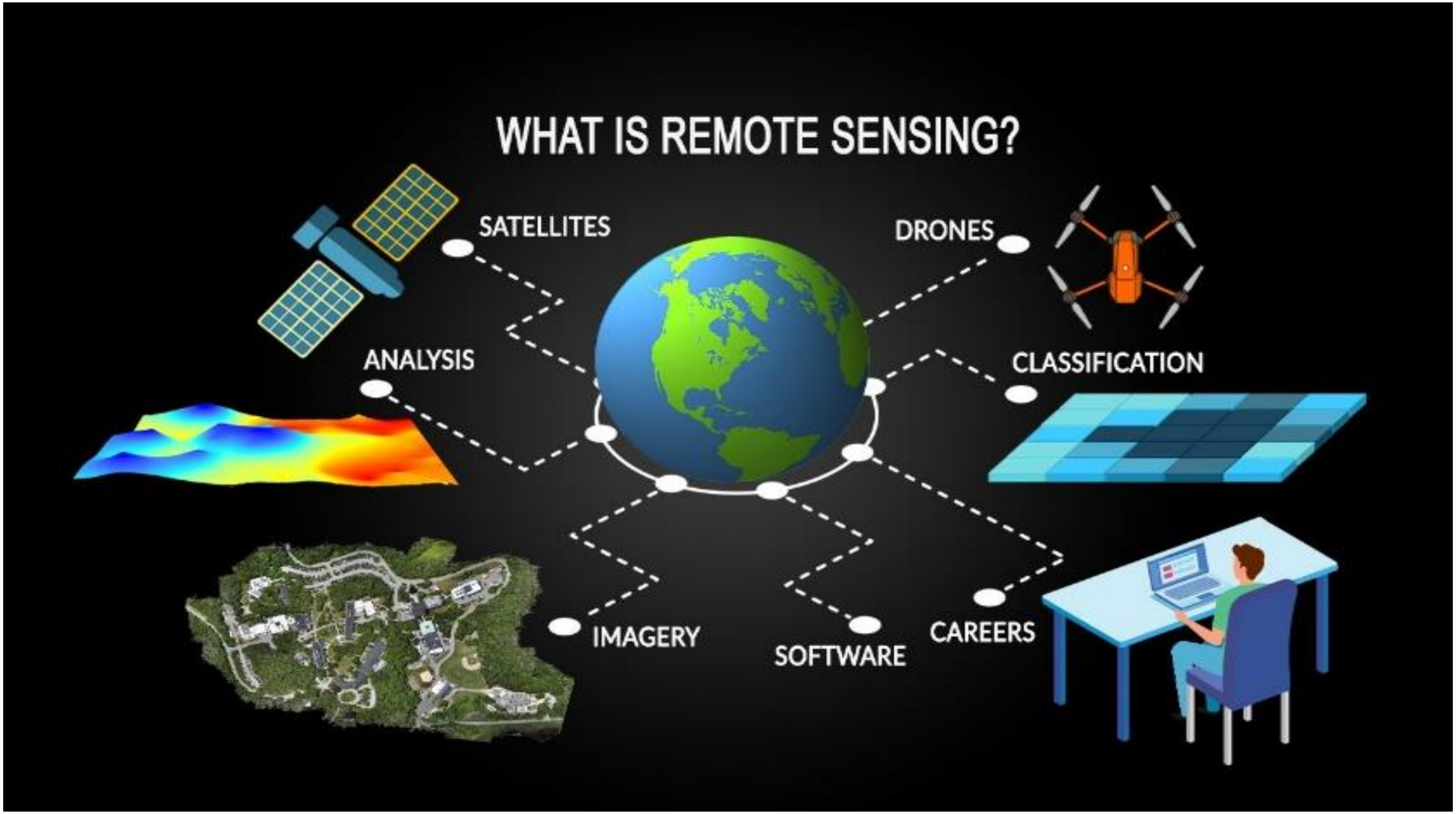

(Pre)Formulation
Implementation
Primary Ops
Extended Ops
NASA Earth Science
Missions: Present through 2023
ISS Instruments
EMIT (2023),
DESIS (2018),
ECOSTRESS (2019),
GEDI (2019)
HISUI (2019),
OCO-3 (2019),
PREFIRE (2) (TBD)
PACE (2022)
GeoCA (~2021)
TROPICS (12)
MAIA (~2021)
Landsat 9 (2020)
Sentinel-6A/B (2020, 2025)
NI-SAR (2021)
SWOT (2021)
TEMPO (2018)
GRACE-FO (2) (2018)
ICESat-2 (2018)
CYGNSS (8) (2019)
NISTAR, EPIC
(DSCOVR
(2019)
SMAP
(>2022)
Suomi NPP
(NOAA)
(>2022)
Landsat 7
(USGS)
(~2022)
QuikSCAT
(2017)
SORCE,
TCTE
(2017)
Terra (>2021)
Landsat 8
(USGS)
(>2022)
Aqua (>2022)
CloudSat (~2018)
CALIPSO (>2022)
GPM (>2022)
Aura (>2022)
OSTM/Jason-2
(>2022)
OCO-2 (>2022)

Intent Learning Outcomes

- Remote Sensing Passive and Active
- What SAR is
- Main characteristics of SAR
- Main SAR Parameters

Short overview on remote sensing

- **Remote Sensing** is "tool"/science of obtaining information about objects or areas from a distance, typically from aircraft or satellites.



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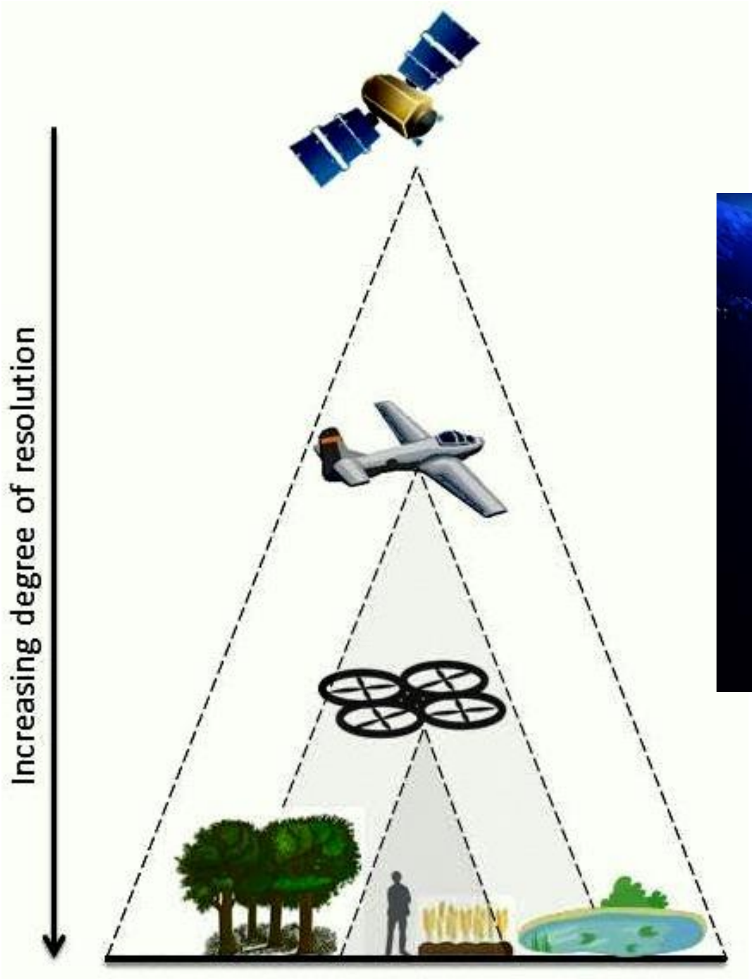
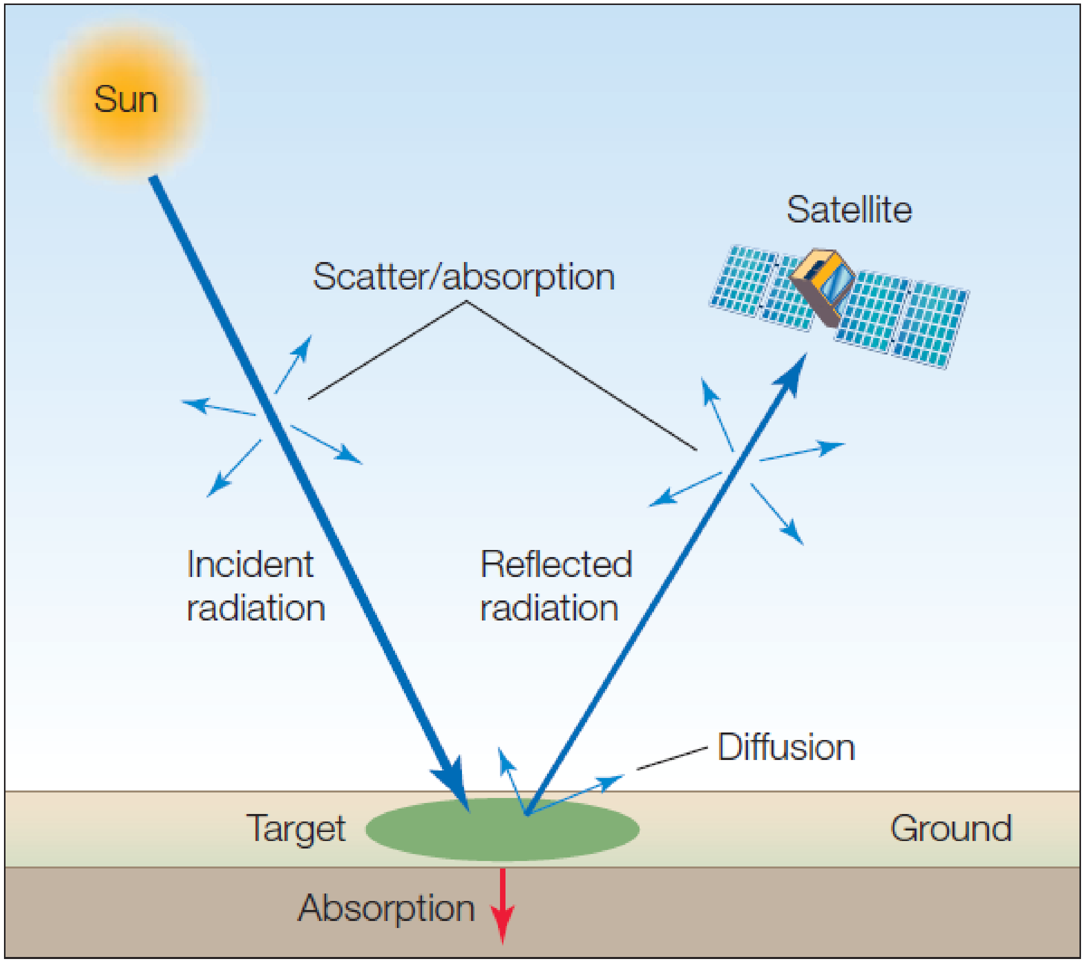


Short overview on remote sensing



How passive remote sensing works

Short overview on remote sensing

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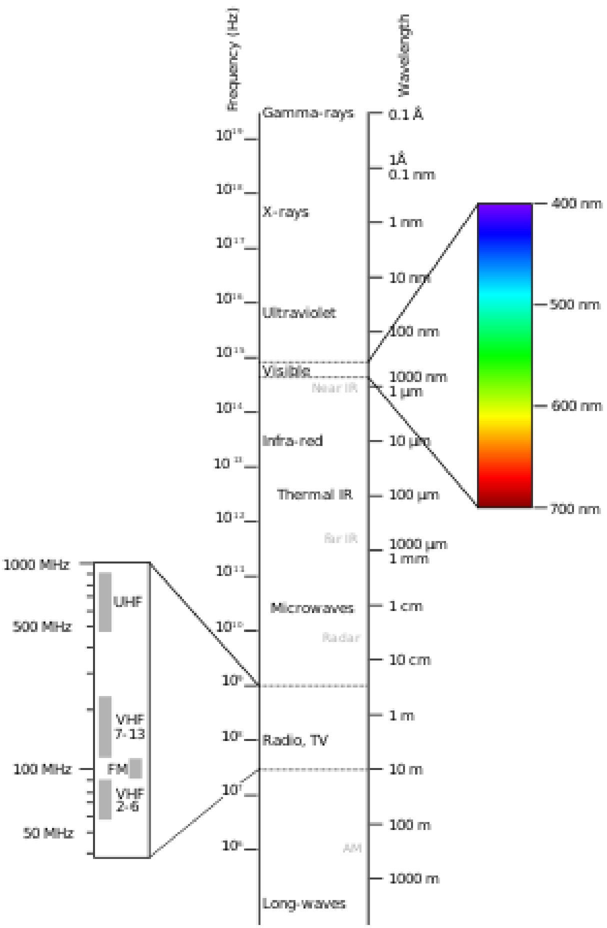
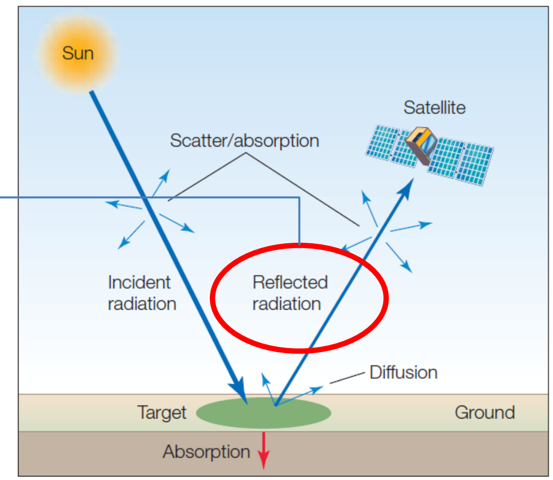
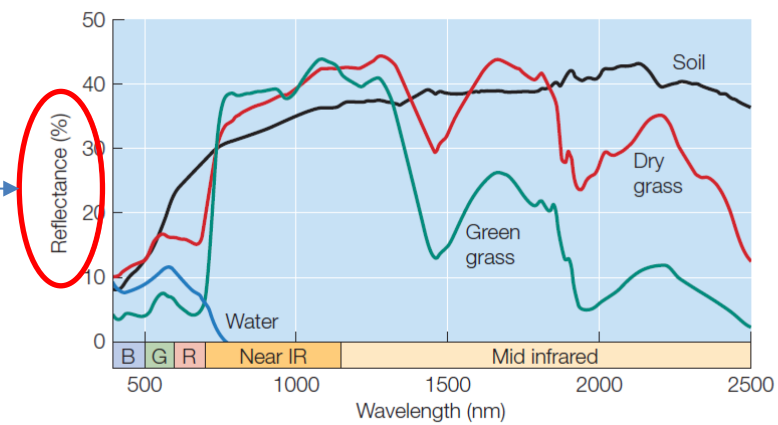
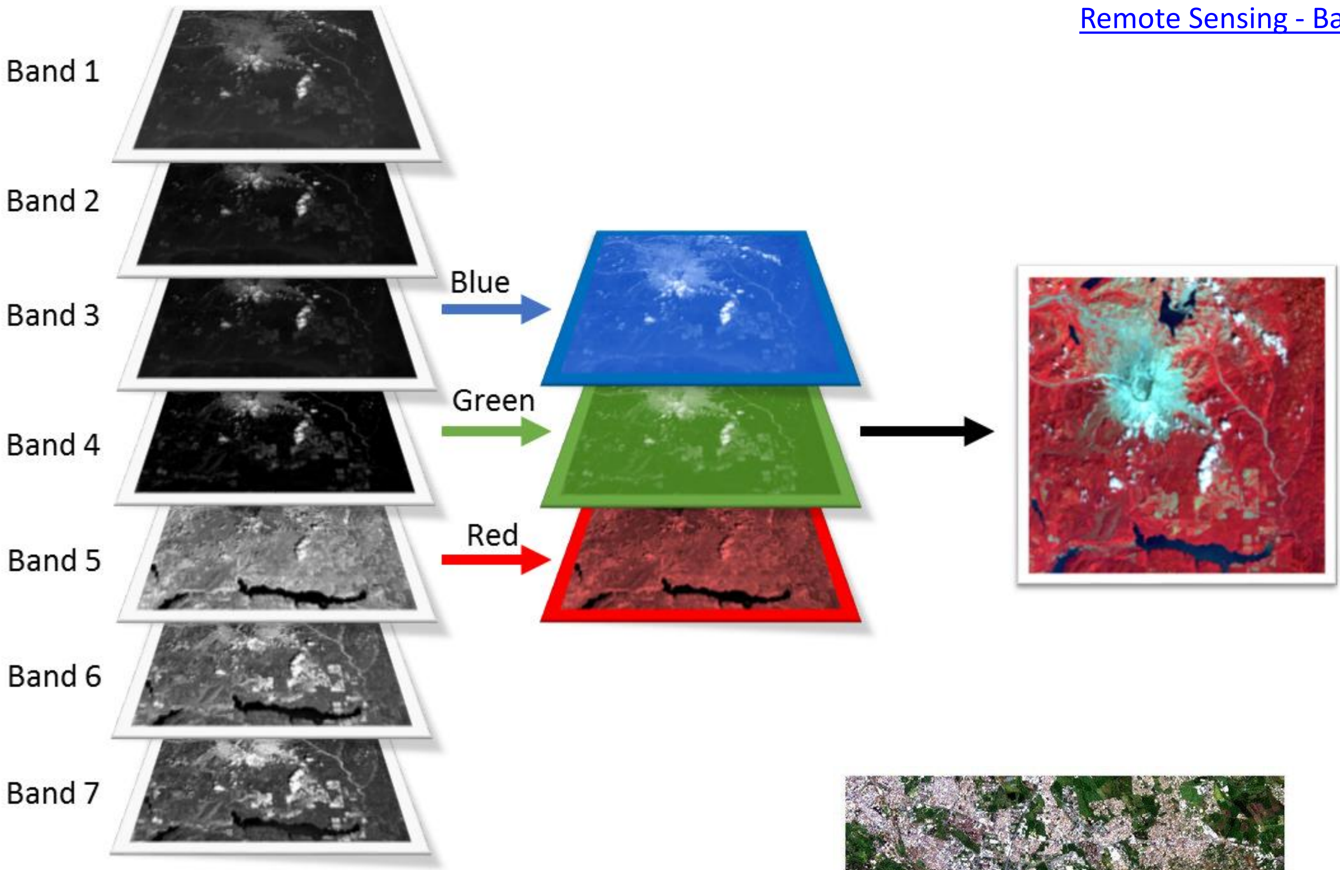


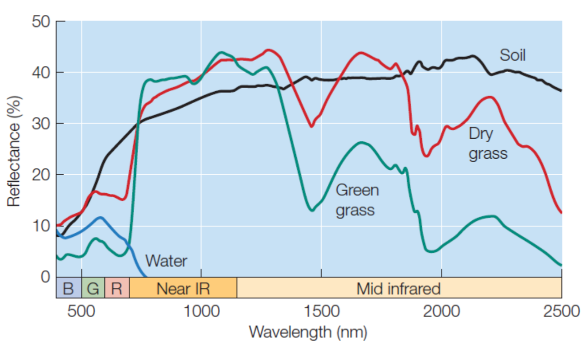


How passive remote sensing works



[Remote Sensing - Band Combinations - YouTube](https://www.youtube.com)





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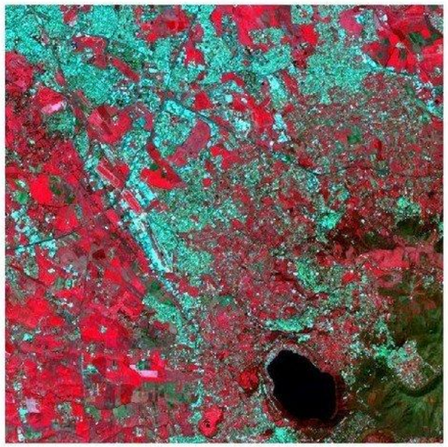


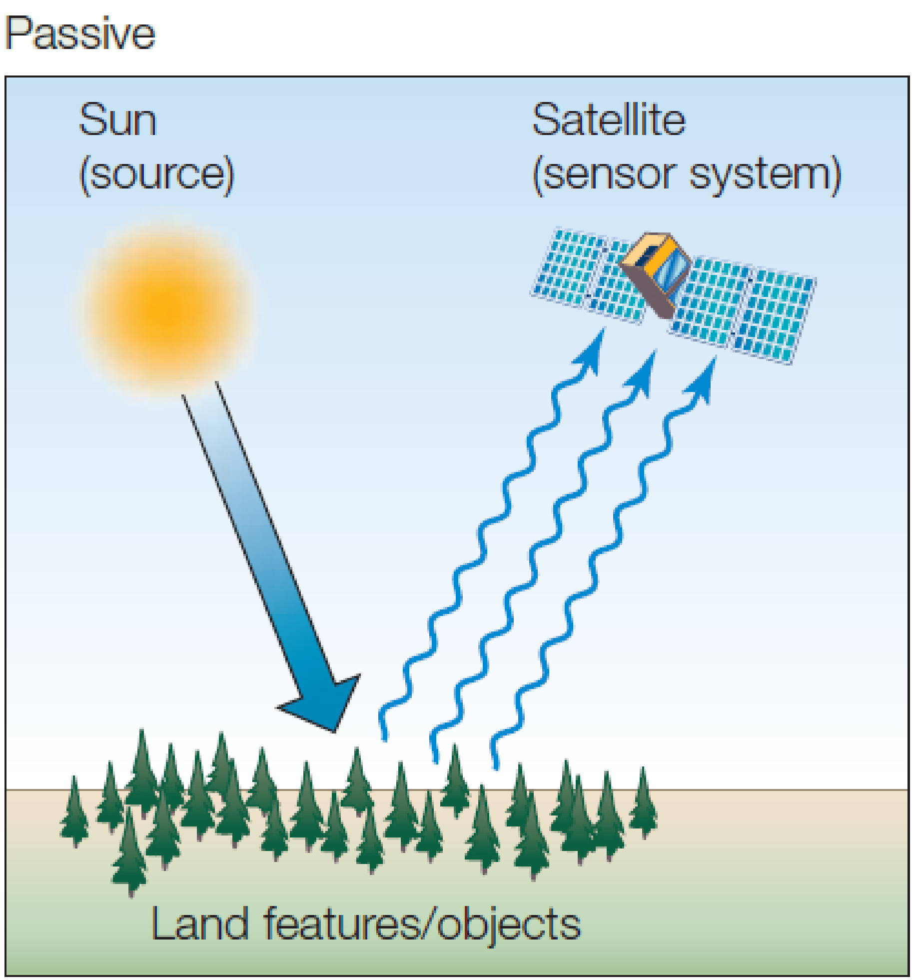
RGB = 543

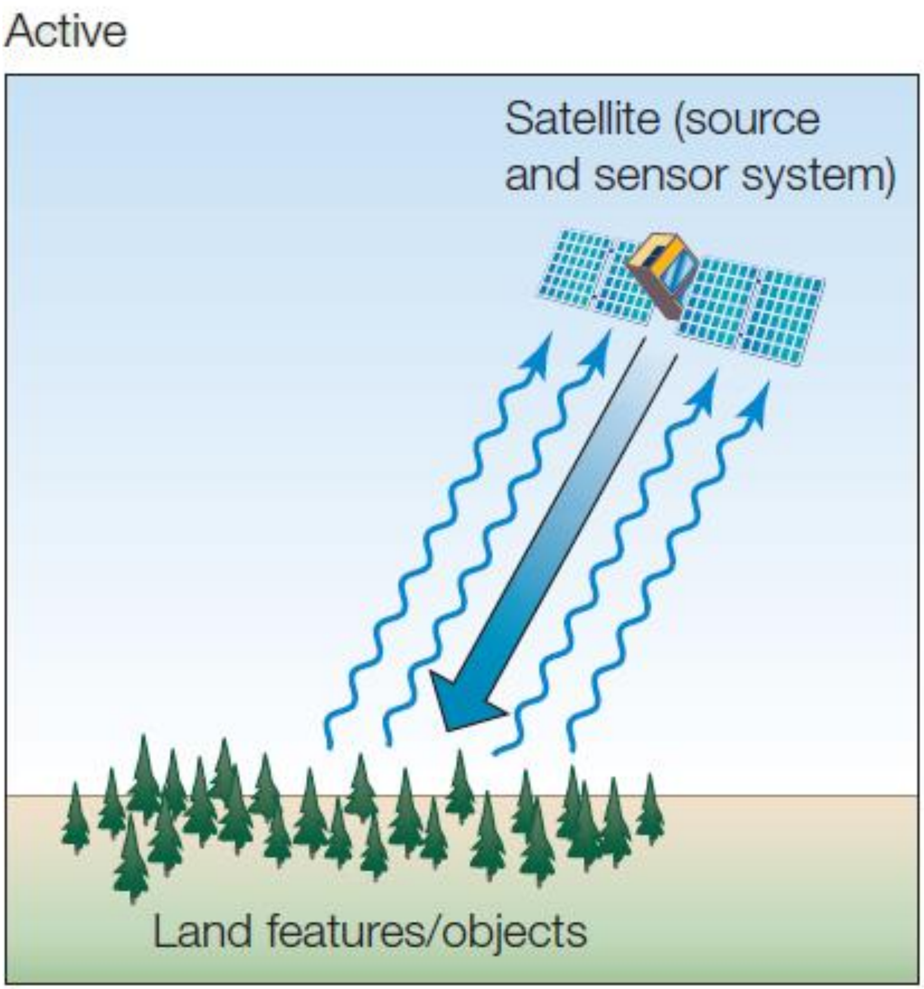
3. Brief Introduction to Remote Sensing — Semi-Automatic Classification Plugin 5.3.6.1 documentation (semiautomaticclassificationmanual-v5.readthedocs.io)

Remote Sensing Passive and Active

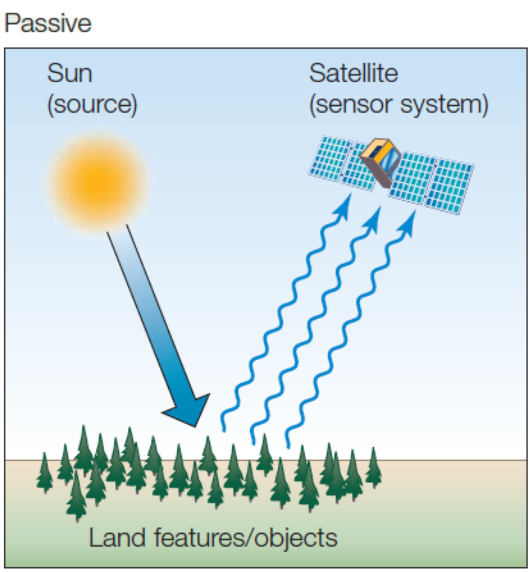
Optical

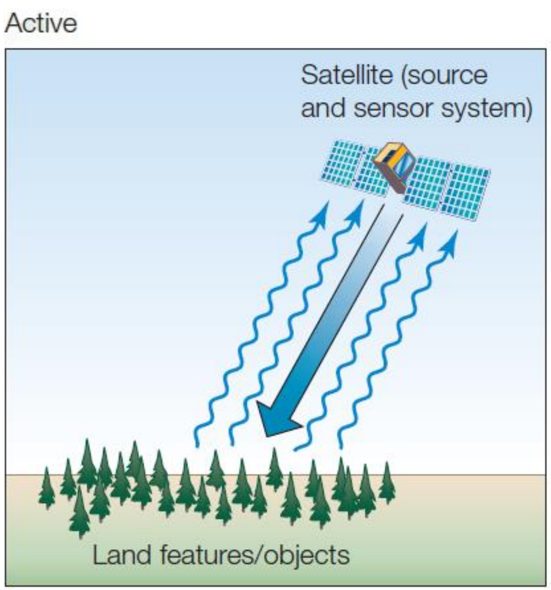
RADAR





Optical	SAR
Images acquired during the day	Images acquired day/night
Quality of the image dependent of the atmosphere and weather conditions	Quality of images independent of the weather and atmospheric conditions
Sensitive to chemical and biophysical characteristics of the target	Sensitive to water content (dielectric constant), geometric and structural characteristics of the target





General comparison between optical and SAR

What is SAR?

SAR (Synthetic Aperture RADAR) is a type of active data collection where a sensor produces its own energy and then records the amount of that energy reflected back after interacting with the Earth.

While optical imagery is similar to interpreting a photograph, SAR data require a different way of thinking in that the signal is instead responsive to surface characteristics like structure and moisture.

How does SAR Work?

Synthetic aperture radar is a way of creating an image using radio waves. The radio waves used in SAR typically range from approximately 3 cm up to a few meters in wavelength, which is much longer than the wavelength of visible light, used in making optical images. These wavelengths fall within the microwave part of the spectrum in the figure below.

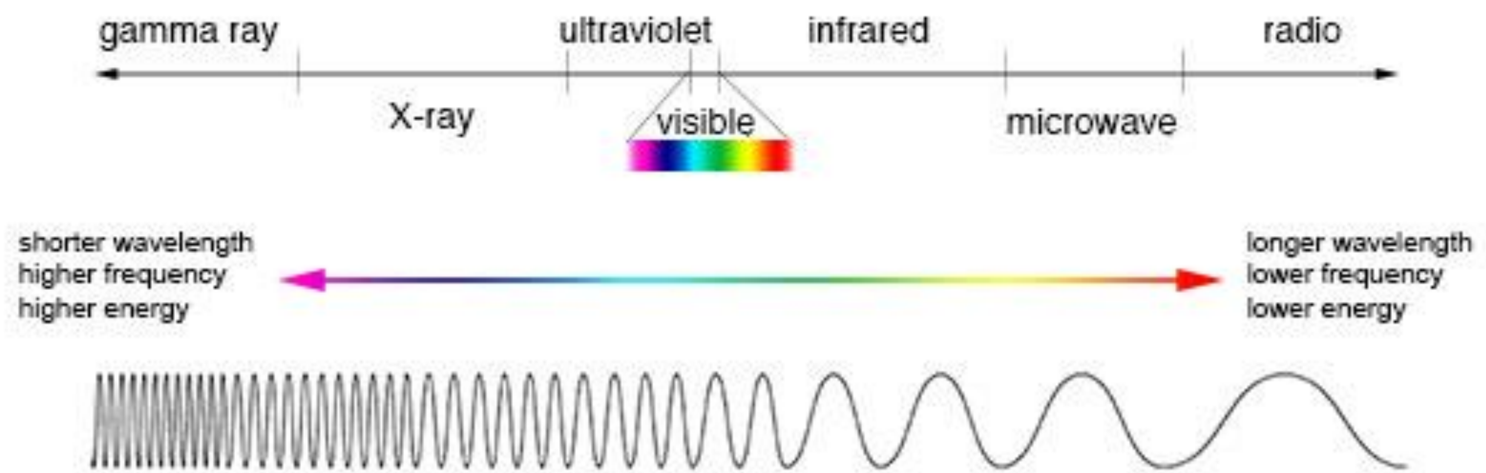
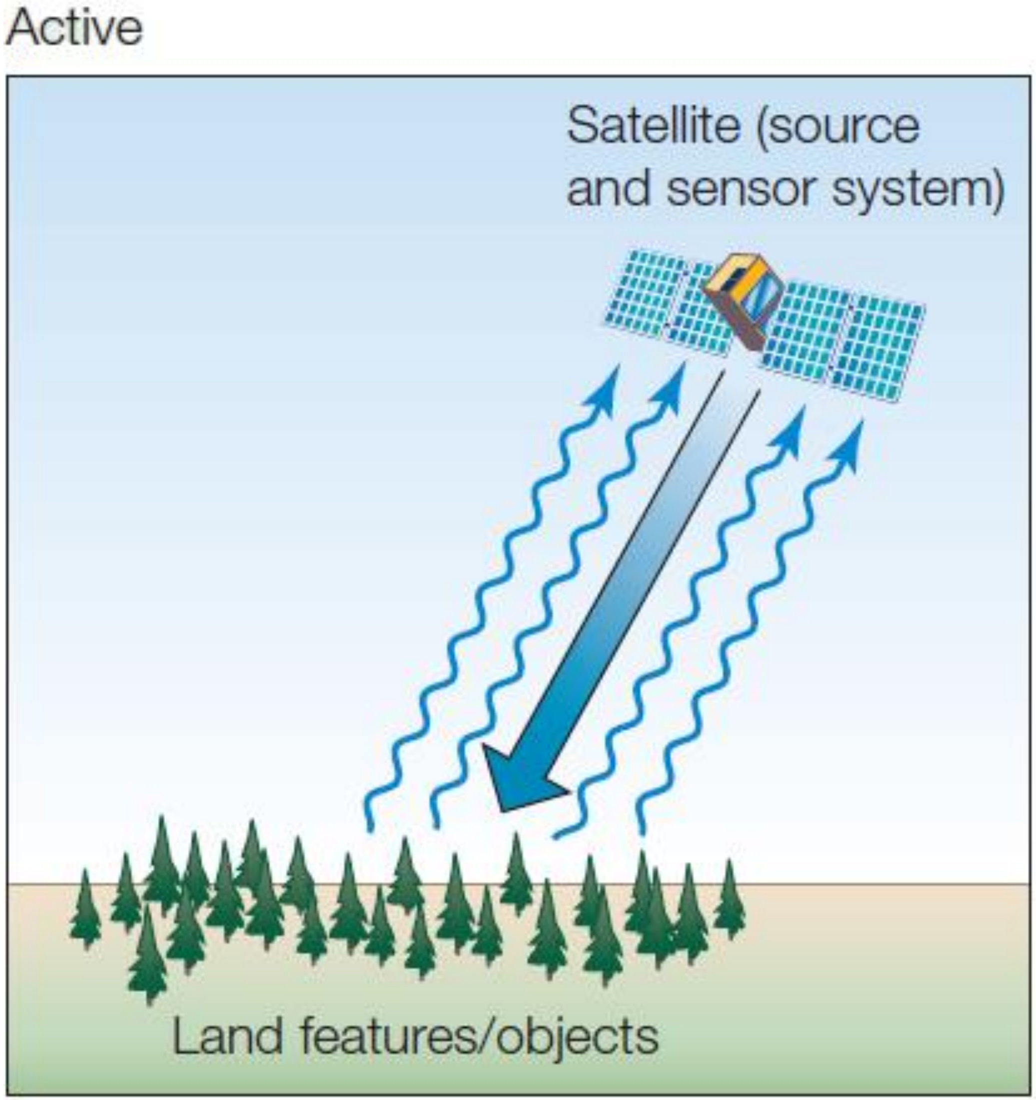
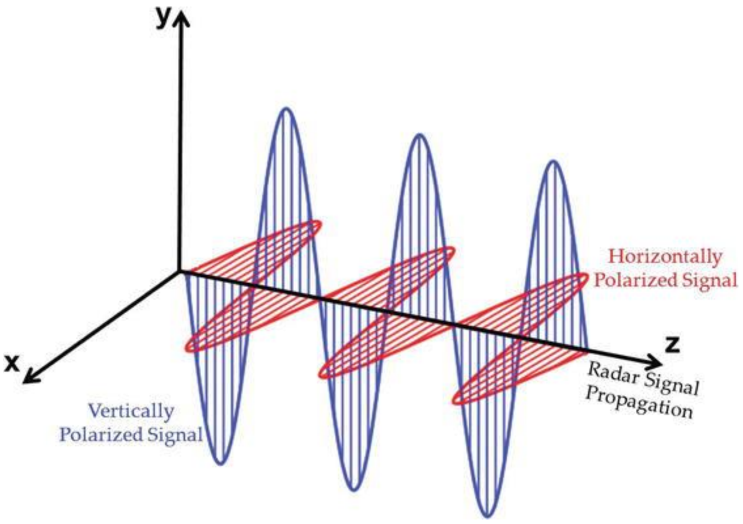


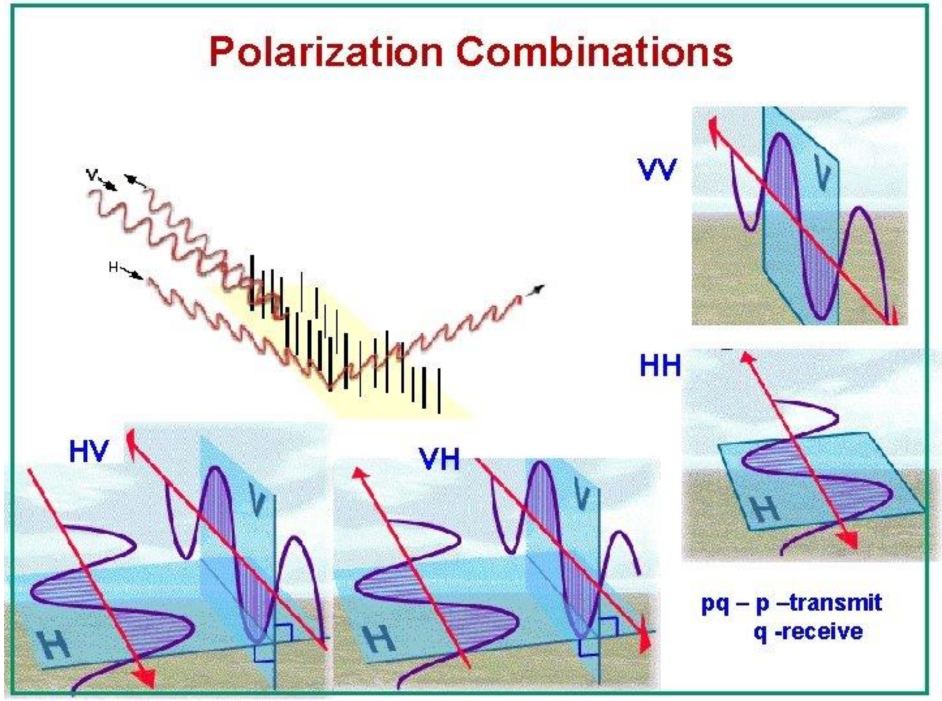
Figure 1. Comparison of wavelength, frequency, and energy for the electromagnetic spectrum. (Credit: NASA's Imagine the Universe)

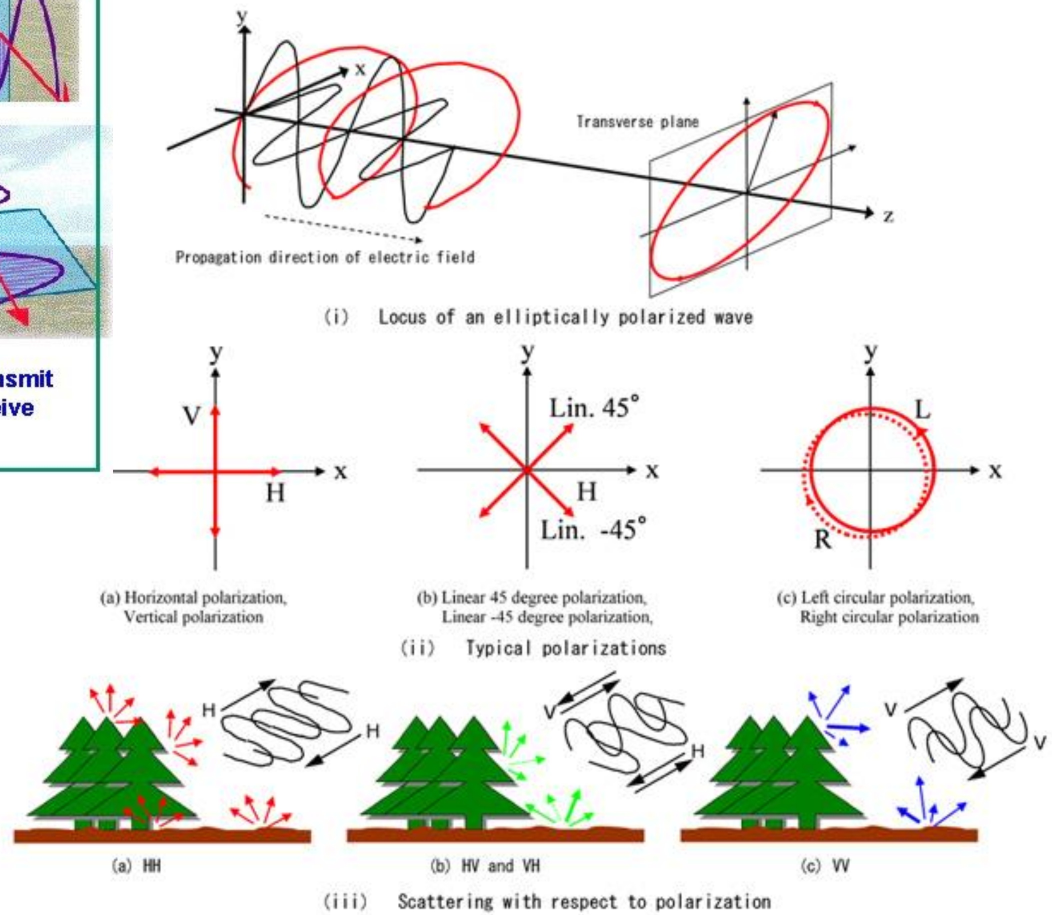
Remote Sensing Active



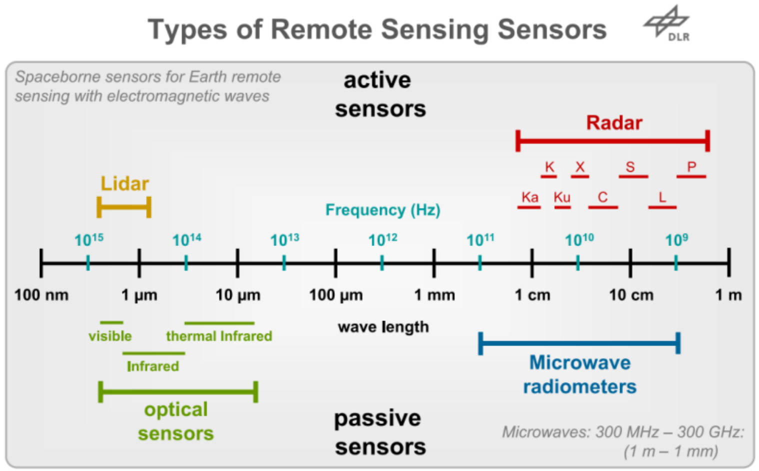


SAR polarization





Polarimetric observation by PALSAR (jaxa.jp)

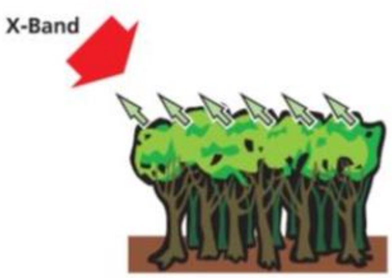


SAR wavelengths and different capabilities of penetration on the target

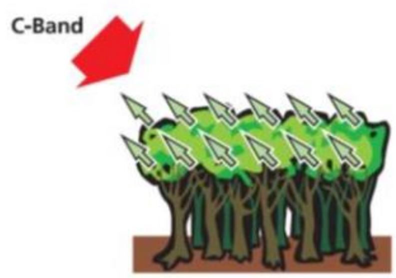
TanDEM-X

Sentinel 1

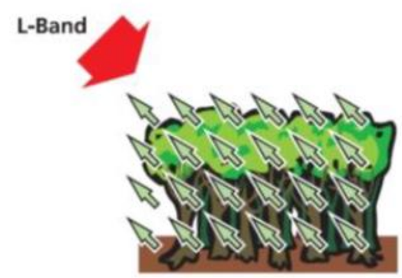
ALOS - PALSAR 2



X band (~3 cm)



C band (~6 cm)

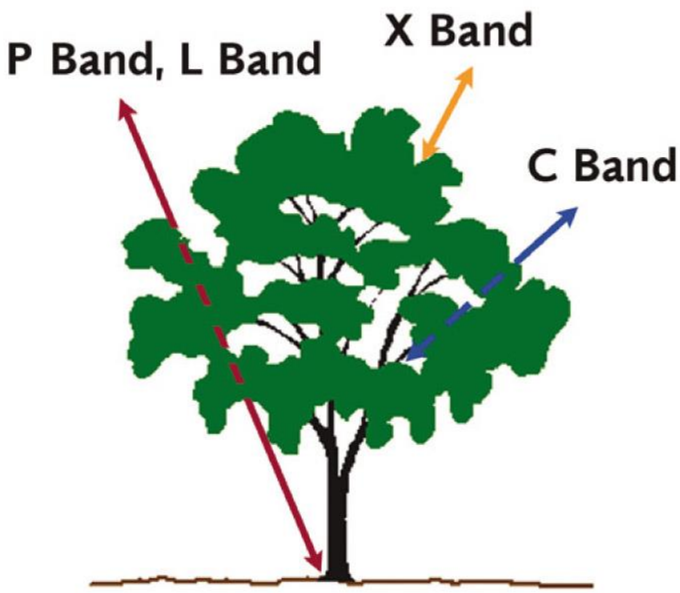


L band (~ 25 cm)

https://www.youtube.com/watch?v=em41MxplcDc

Frequency and Wavelength of Commonly Used Radar Remote Sensing Bands

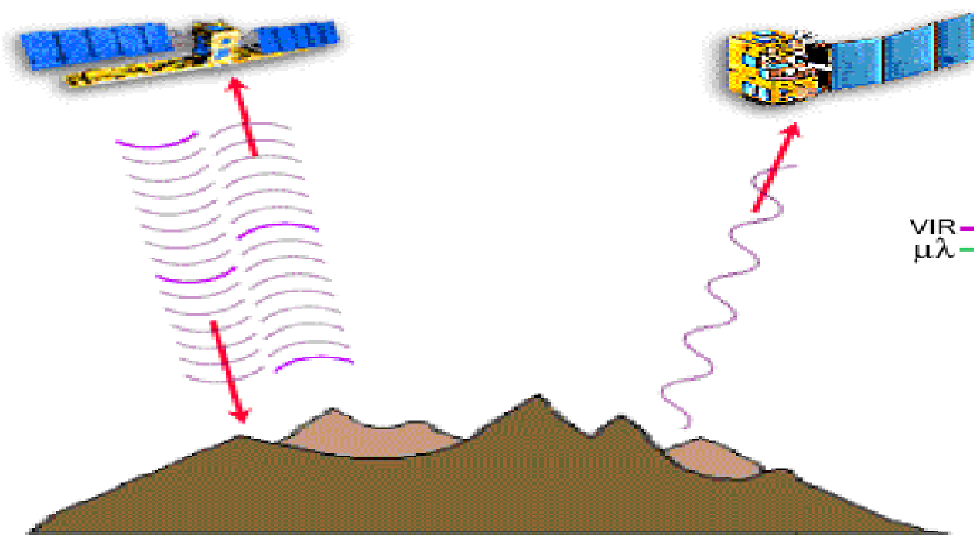
Band	Frequency	Wavelength	Key Characteristics
X Band	12.5-8 GHz	2.4-3.75 cm	Widely used for military reconnaissance, mapping and surveillance (TerraSAR-X, TanDEM-X, COSMO-SkyMed)
C Band	8-4 GHz	3.75-7.5 cm	Penetration capability of vegetation or solids is limited and restricted to the top layers. Useful for sea-ice surveillance (RADARSAT, ERS-1).
S Band	4-2 GHz	7.5-15 cm	Used for medium-range meteorological applications—e.g., rainfall measurement, airport surveillance
L Band	2-1 GHz	15-30 cm	Penetrates vegetation to support observation applications over vegetated surfaces and for monitoring ice sheet and glacier dynamics (ALOS PALSAR)
P Band	1-0.3 GHz	30-100 cm	To date only used for research and experimental applications. Significant penetration capabilities regarding vegetation canopy (key element for estimating vegetation biomass), sea ice, soil, glaciers.

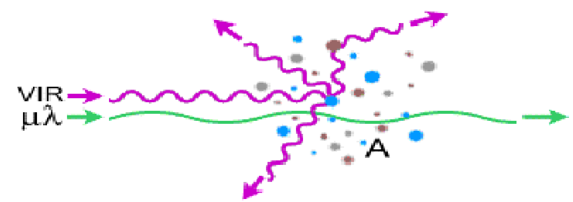


Discover the Benefits of Radar Imaging « Earth Imaging Journal: Remote Sensing, Satellite Images, Satellite Imagery (eijournal.com)

SAR Concept

- A radar transmits electromagnetic waves in form of pulses and records the echoes scattered back by objects encountered by the waves along their path.
- The echoes are a modified version of the transmitted pulse. Depending on the object scattering back the pulses, the echoes recorded by the radar are different (more or less energy, particular phase value etc.).
- Radar can always acquire, i.e. it does not suffer from cloud cover, fog and day-night cycle



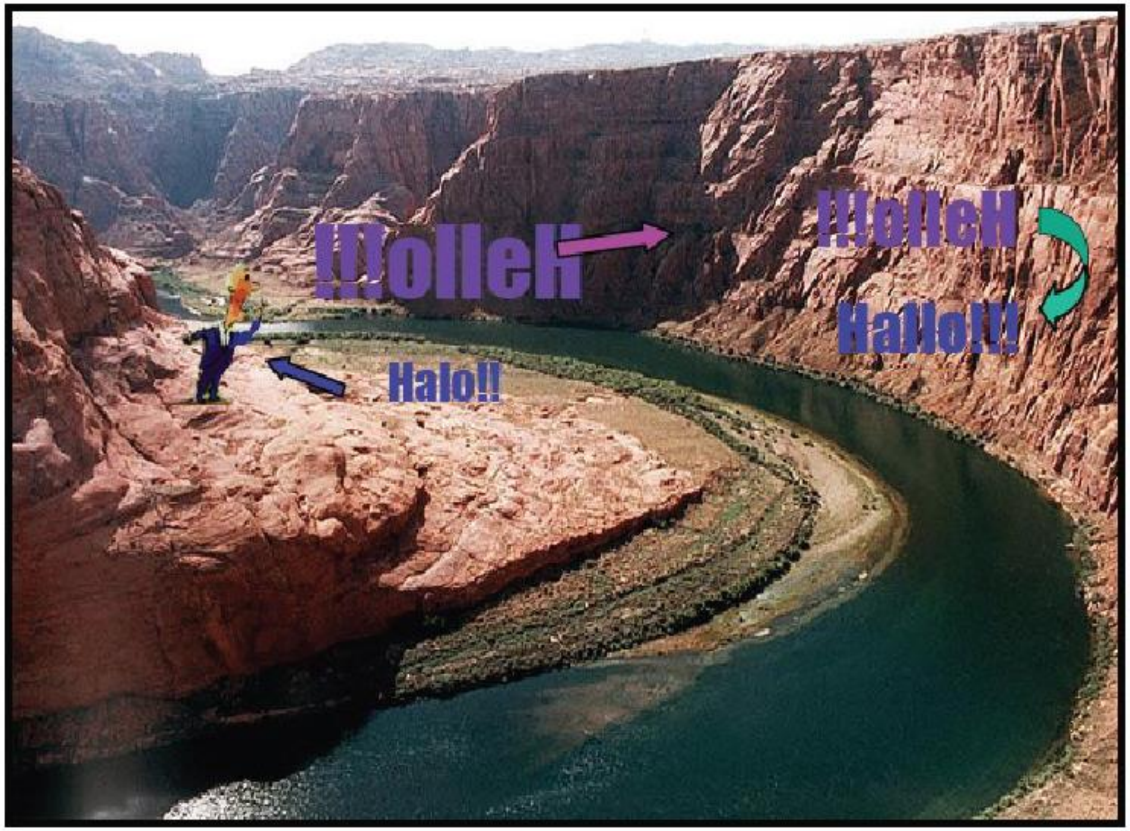


INQUA

Source: https://eo4society.esa.int/wp-content/uploads/2020/08/SAR-Intro_IParcharidis_2017.pdf

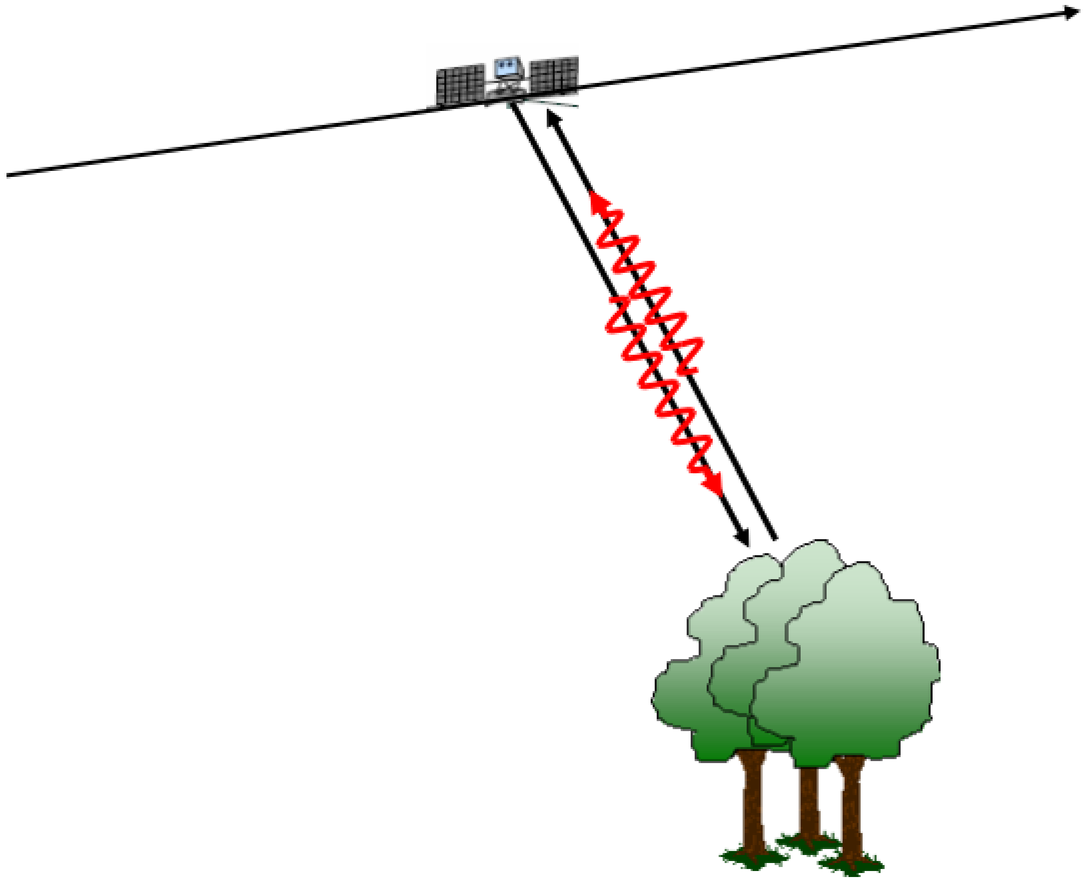
SAR Concept

- Imagine you are in the Grand Canyon and you shout. The cliffs will reflect the sound wave. After some time you will hear an echo, which is not exactly the same compared to what you shouted. This is the “principle” of a RADAR!



Source: https://eo4society.esa.int/wp-content/uploads/2020/08/SAR-Intro_IParcharidis_2017.pdf

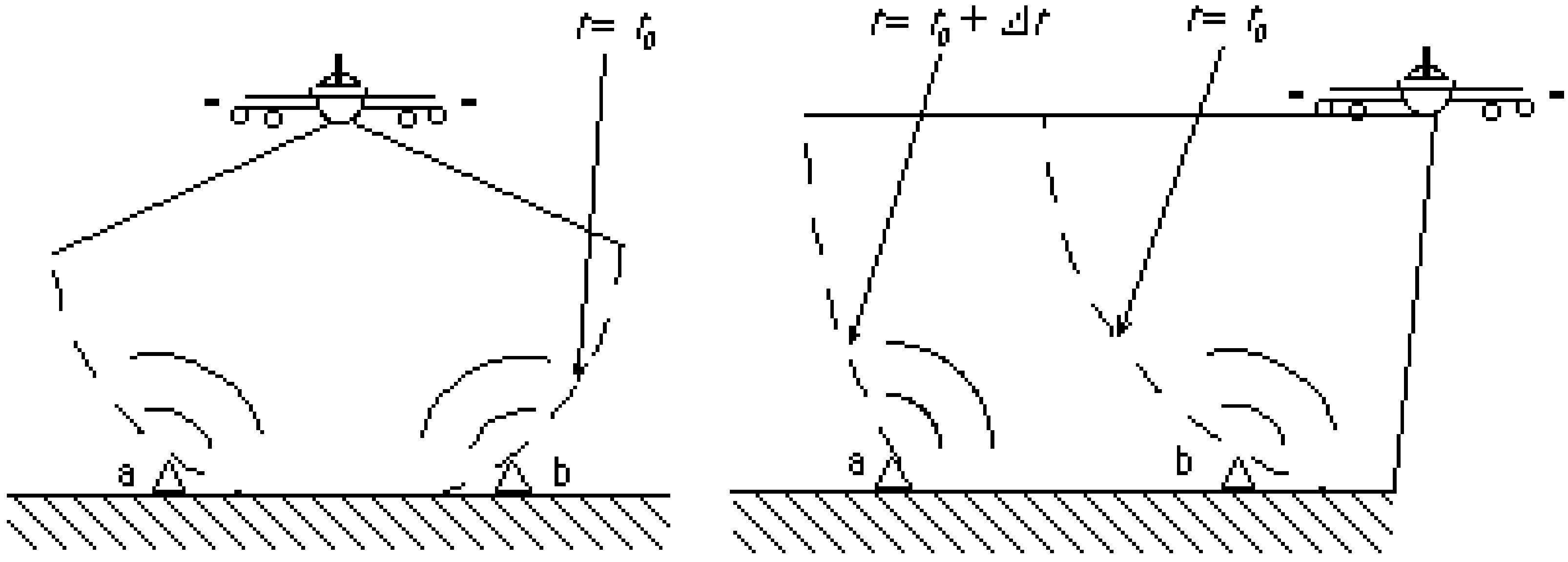
SAR Concept



Active system: day and night operations

Source: Thuy Le Toan, Introduction to SAR: ESA Advanced course in land remote sensing (2010)

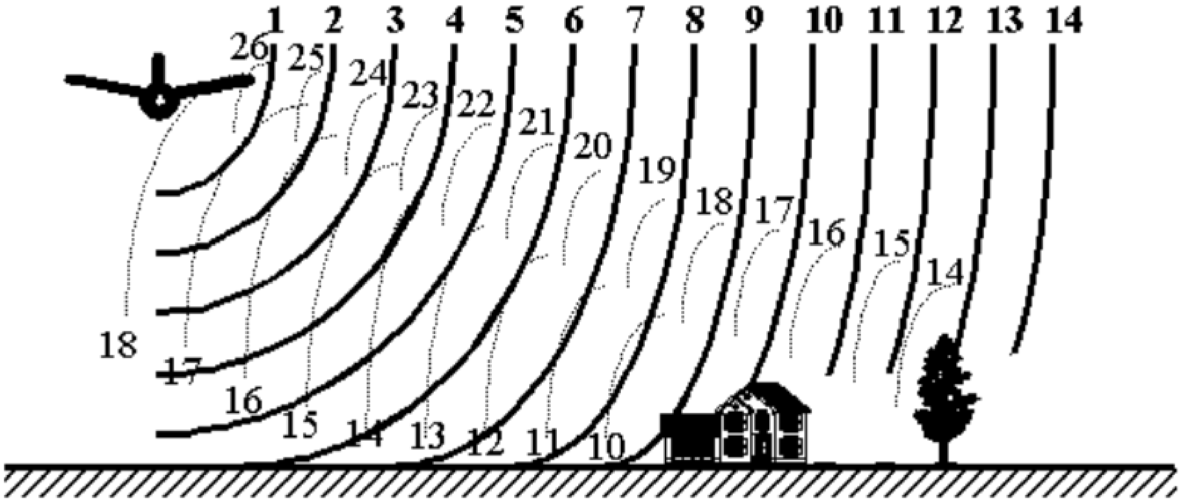
Basic concepts:
Down Looking vs. Side Looking Radar



(a) (b)

Basic Concepts: Side Looking Radar

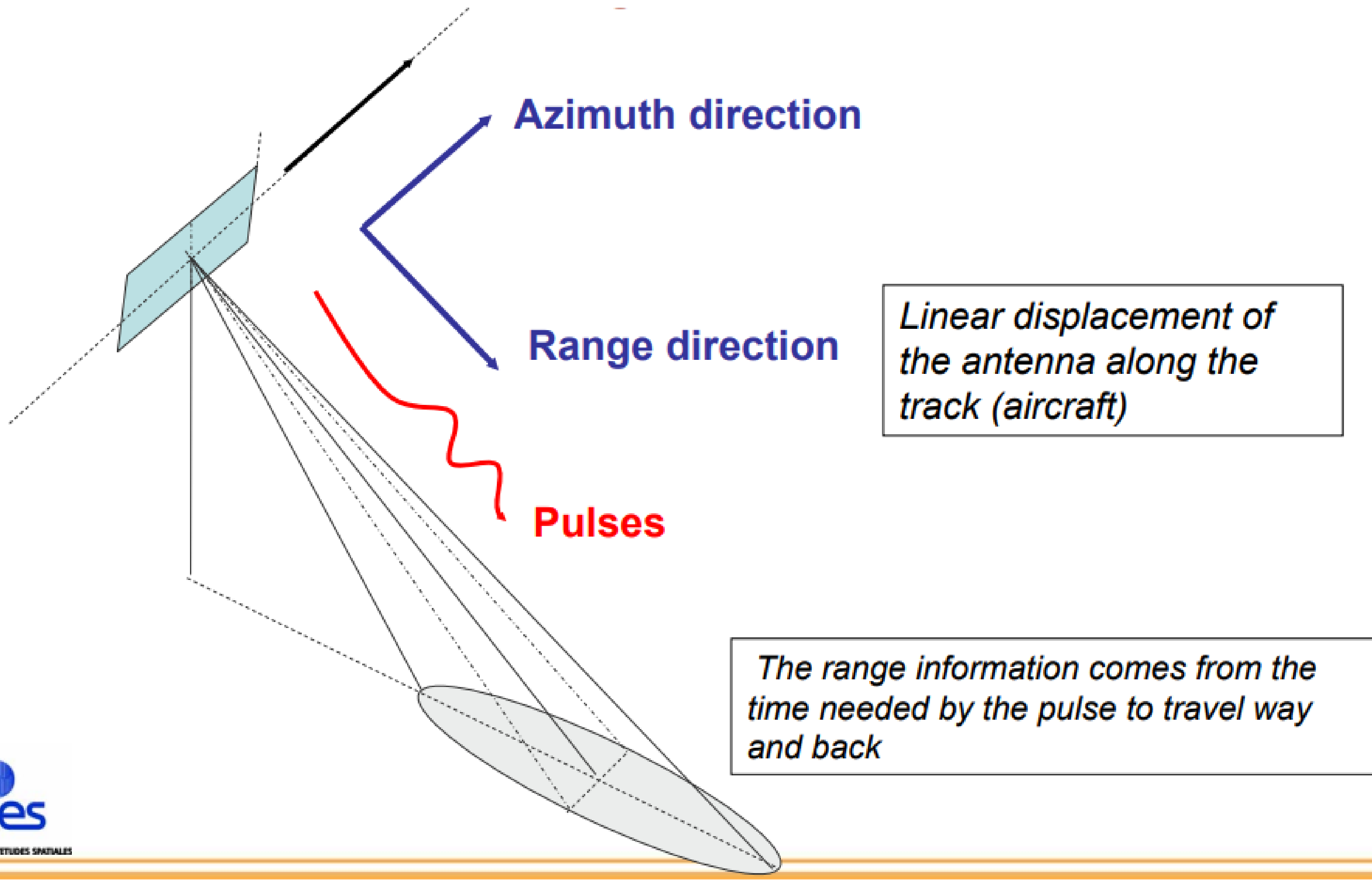
- Each pixel in the radar image represents a complex quantity of the energy that was reflected back to the satellite
- The magnitude of each pixel represents the intensity of the reflected echo



Credit: Paul Messina, CUNY NY, after Drury 1990, Lillesand and Kiefer, 1994

Source: Erika Podest, Basics of SAR: NASA-ARSET Applied Remote Sensing Training

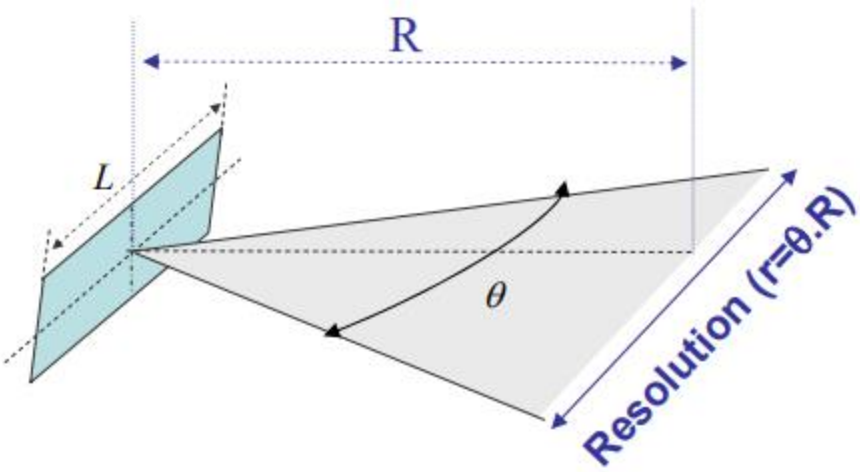
Side Looking Airborne Radar

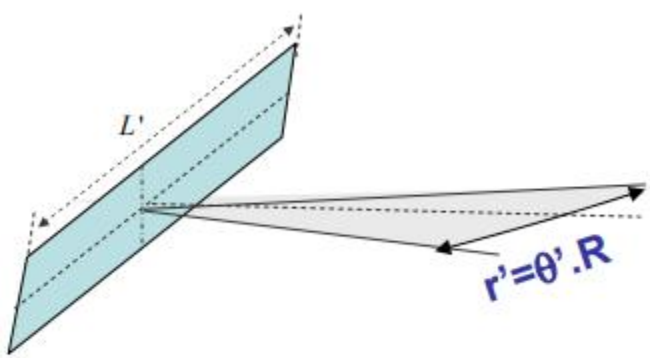


CENTRE NATIONAL D'ETUDES SPATIALES

Source: Thuy Le Toan, Introduction to SAR: ESA Advanced course in land remote sensing (2010)

Antenna scattering





$$\theta = \frac{\lambda}{L}$$

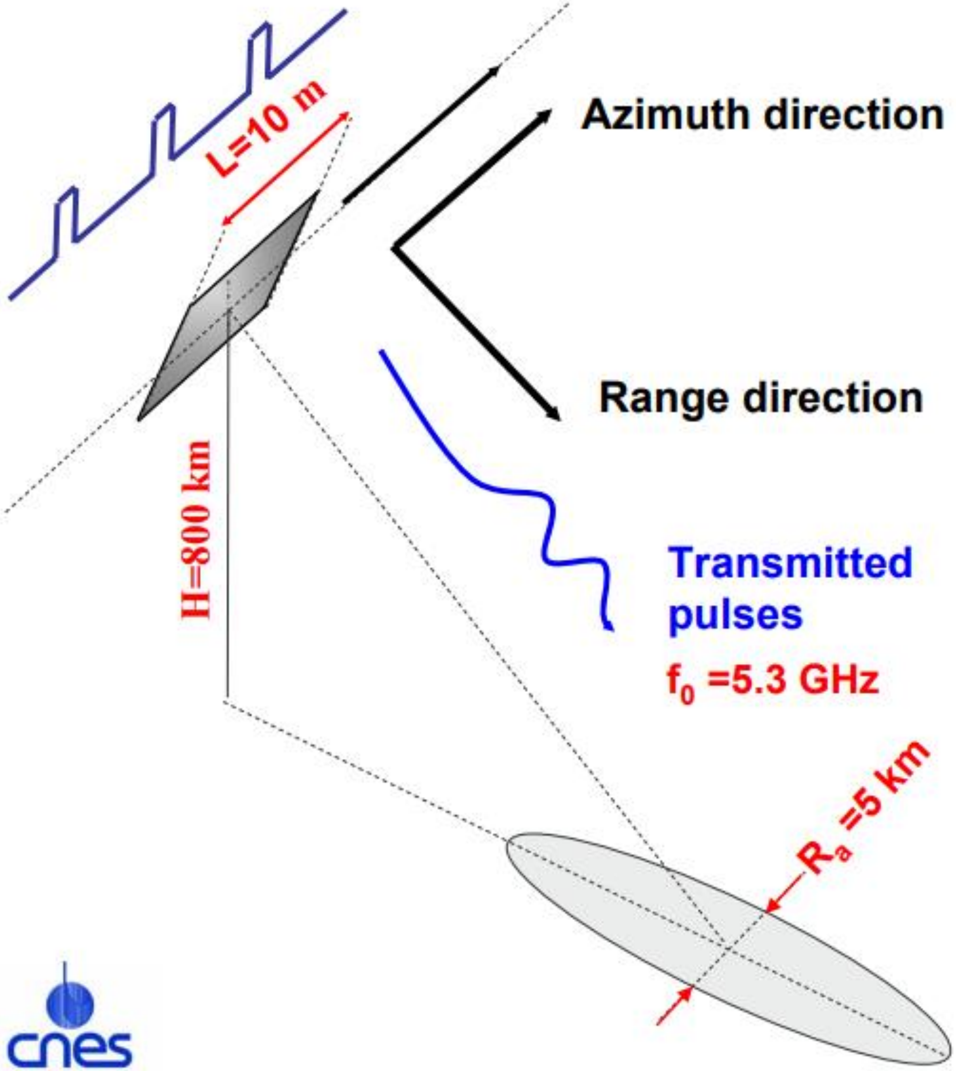
- λ: Wavelength
- θ: Angular aperture (horizontal plane)
- L: Antenna length (horizontal direction)

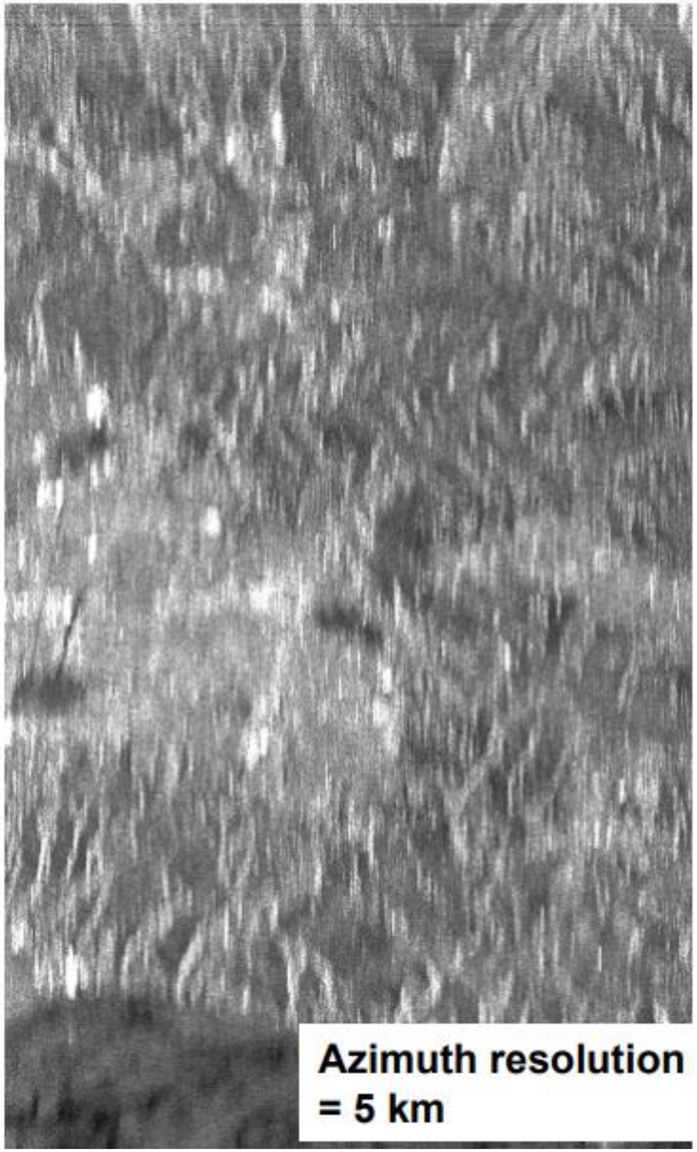
The larger the antenna, the narrower the aperture (finer resolution)

$$Ra = \frac{\lambda R}{L}$$

<u>Numerical example:</u>
L ≈ 10m, R ≈ 1000 km (spaceborne radar), λ ≈ 5 cm (C band) ➔ **resolution ≈ 5 km**

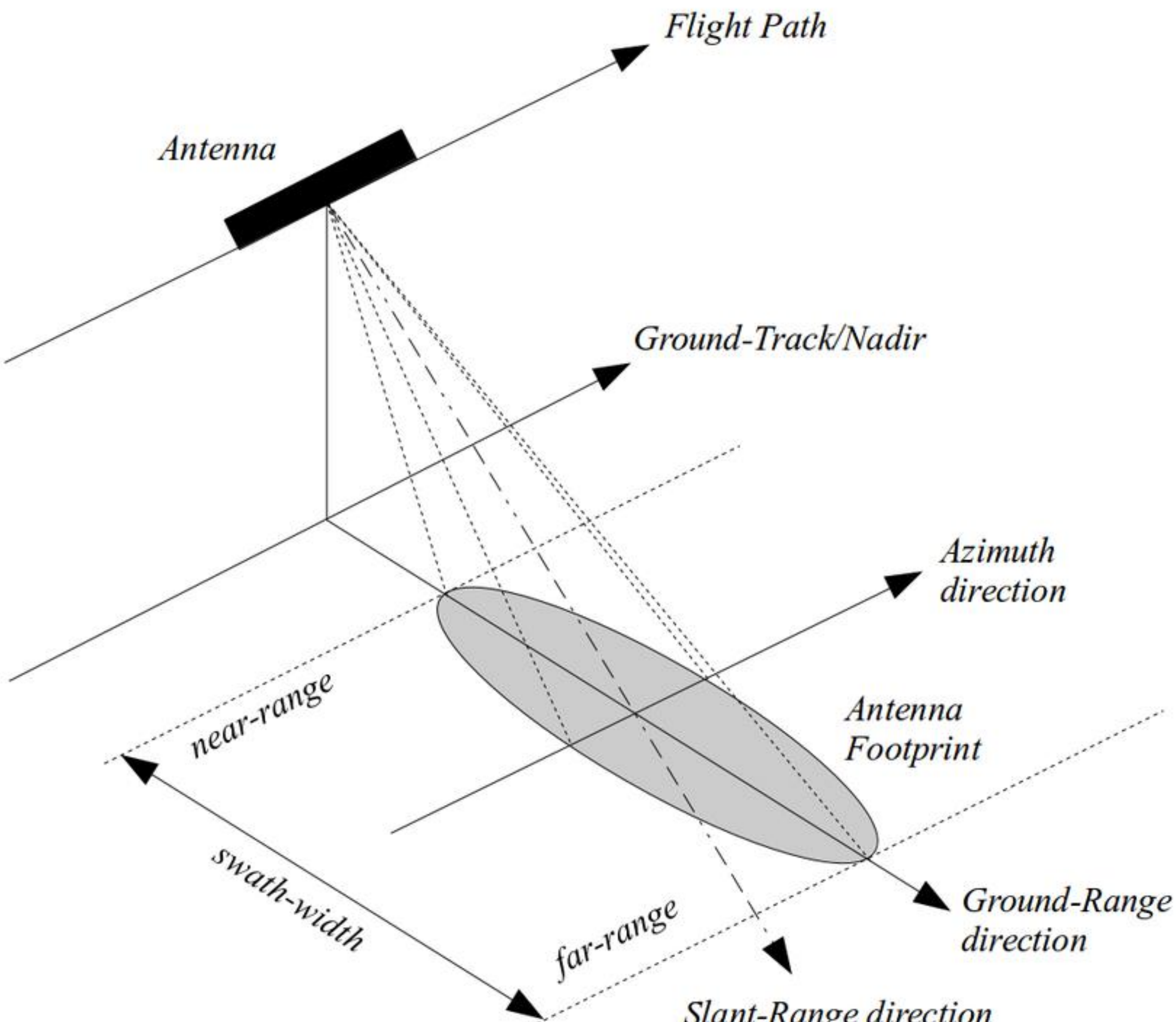
Source: Thuy Le Toan, Introduction to SAR: ESA Advanced course in land remote sensing (2010)

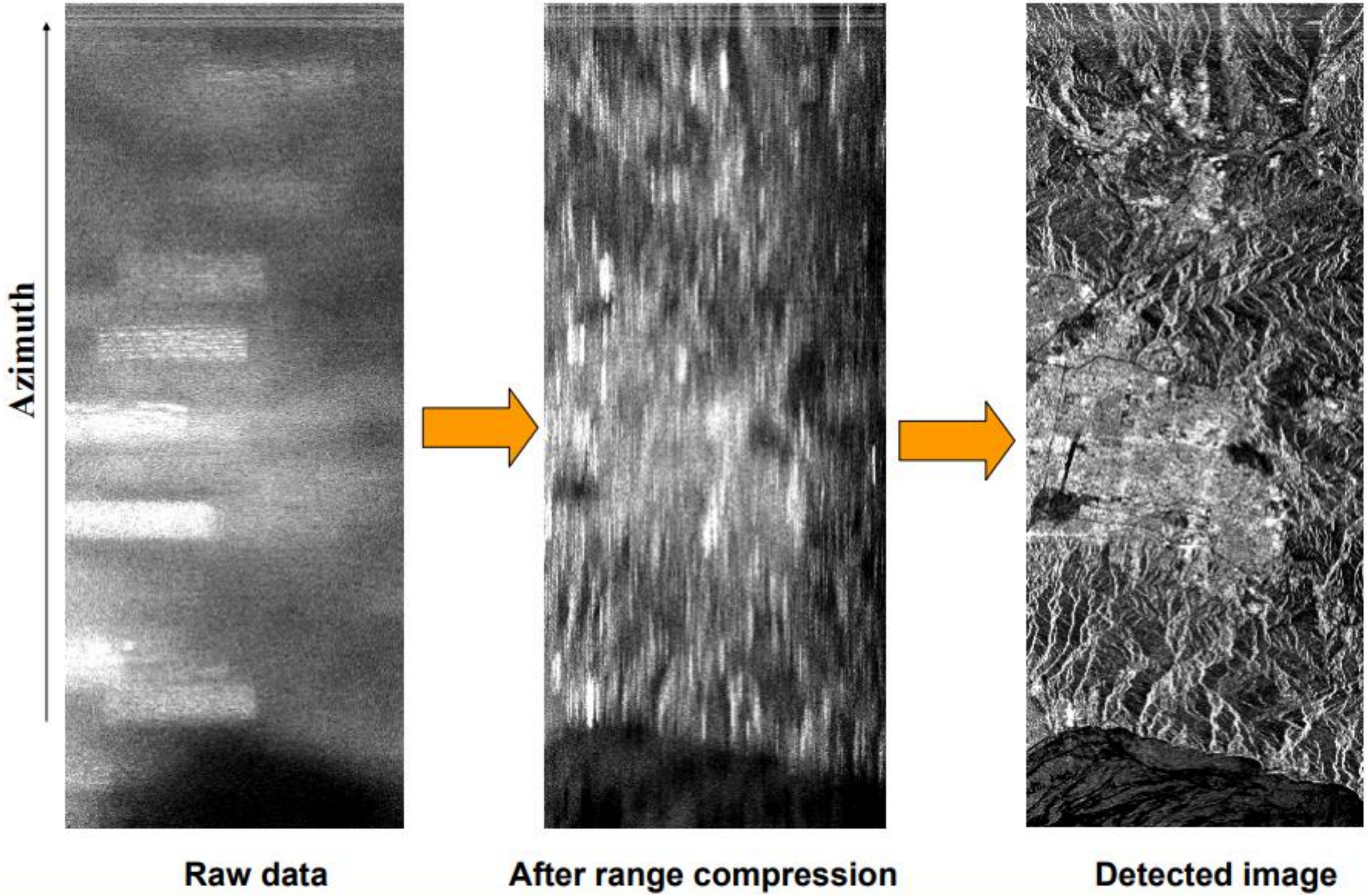




Source: Thuy Le Toan, Introduction to SAR: ESA Advanced course in land remote sensing (2010)

SYNTHETIC APERTURE RADAR SENSORS





Source: Thuy Le Toan, Introduction to SAR: ESA Advanced course in land remote sensing (2010)

Synthetic Aperture Radar (SAR)

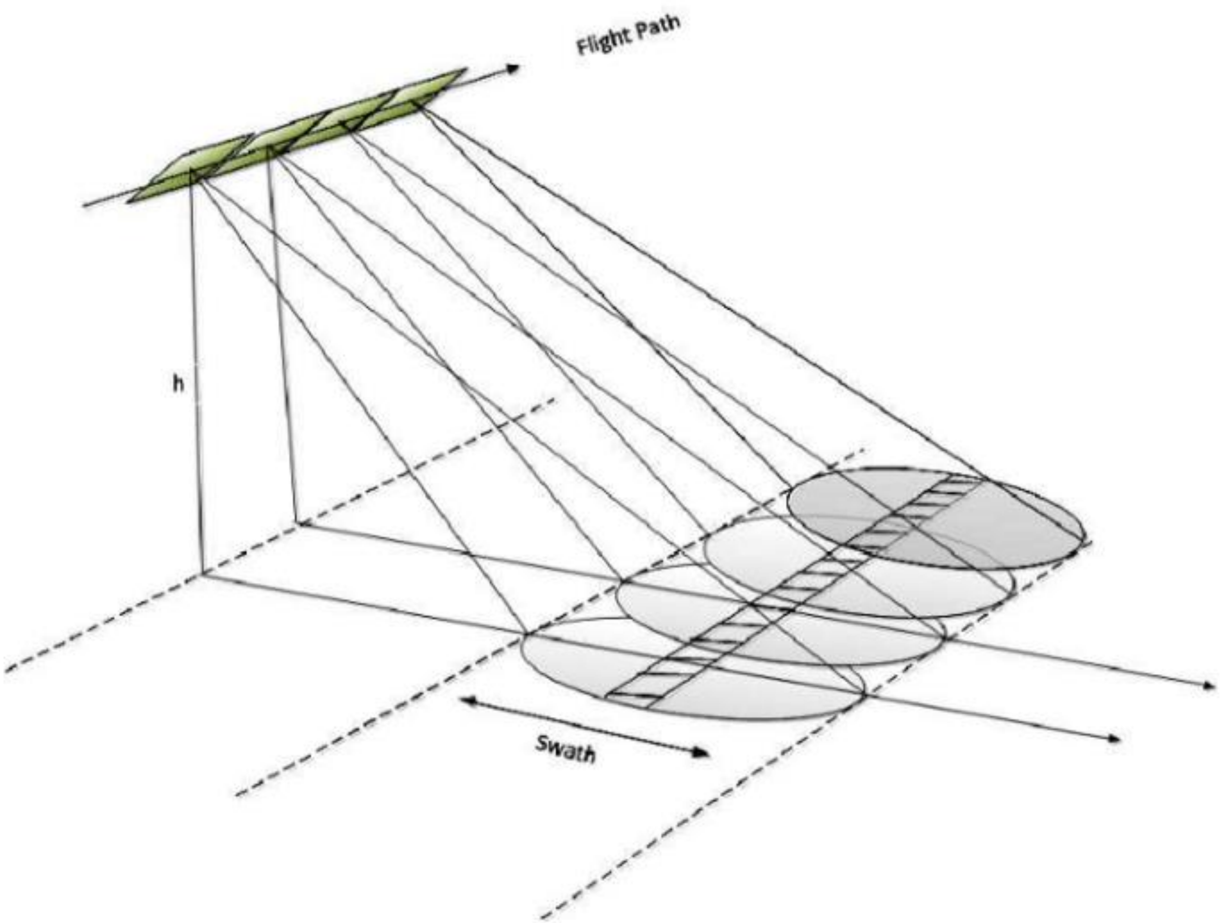
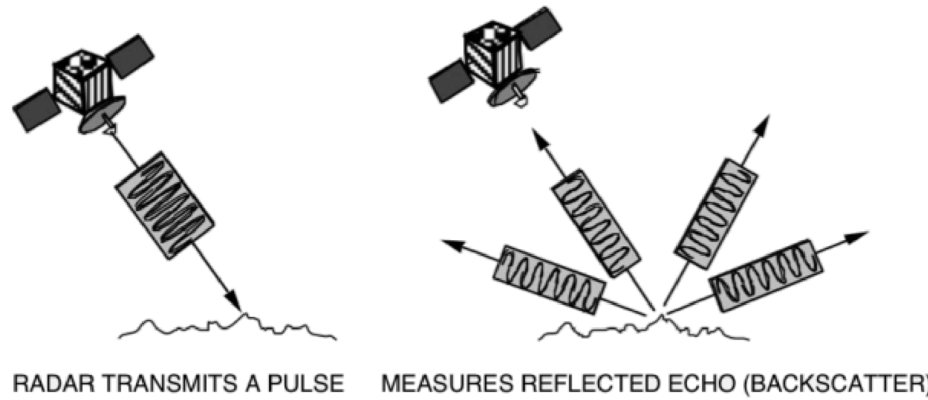


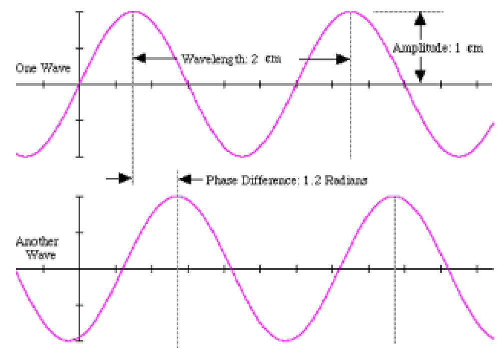
Figure 3. Synthetic Aperture Generation (Credit: NASA)

[NISAR Imaging Animation - YouTube]

Review of Radar Image Formation

- Radar can measure amplitude (the strength of the reflected echo) and phase (the position of a point in time on a waveform cycle)
- Radar can only measure the part of the echo reflected back towards the antenna (**backscatter**)
- Radar pulses travel at the speed of light





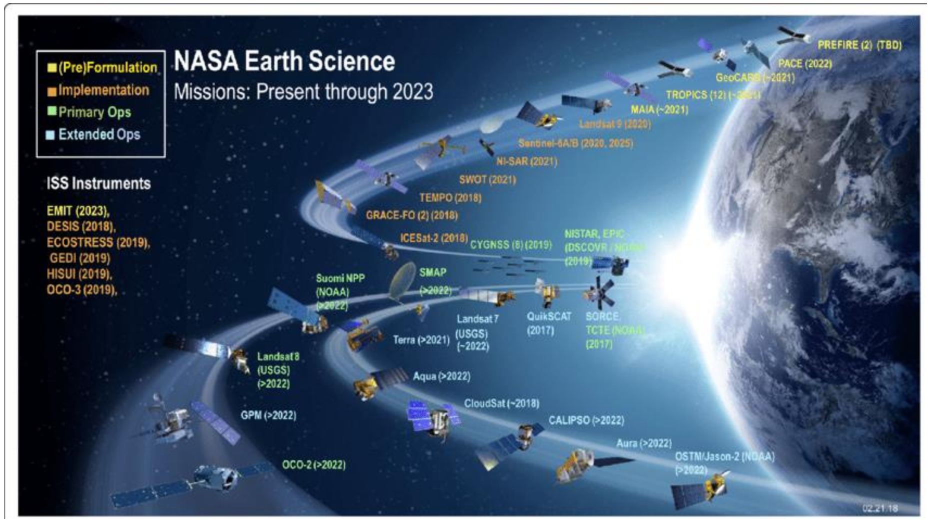
- The strength of the reflected echo is the **backscattering coefficient** (sigma naught) and is expressed in decibels (dB)

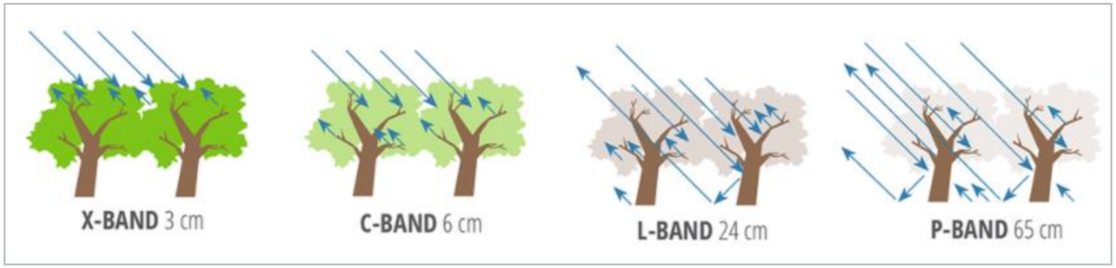
Source: Erika Podest, Basics of SAR: NASA-ARSET Applied Remote Sensing Training

Spaceborne SARs

Year	Satellite	Band	Inc.Angle	Polarization
1978	SEASAT (USA)	L (1.3 GHz)	23°	HH
1981	SIR-A (USA)	L (1.3 GHz)	50°	HH
1984	SIR-B (USA)	L (1.3 GHz)	15°-65°	HH
1991	ERS-1 (Europe)	C (5.3 GHz)	23°	VV
1991	ALMAZ-1 (USSR)	S (3.0 GHz)	30°-60°	HH
1992	JERS-1 (Japan)	L (1.3 GHz)	39°	HH
1994	SIR-C/X-SAR (USA, Germany)	L (1.3 GHz), C (5.3 GHz), X (9.6 GHz)	15°-55°	HH, HV, VV, VH (SIR-C), VV (X-SAR)
1995	ERS-2 (Europe)	C (5.3 GHz)	23°	VV
1995	Radarsat-1 (Canada)	C (5.3 GHz)	20°-50°	HH
2000	SRTM (USA, Germany)	C (5.3 GHz), X (9.6 GHz)	54°	HH, VV (C), VV (X)
2002	ENVISAT (Europe)	C (5.3 GHz)	15°-45°	HH, HV, VV, VH
2006	ALOS-1 (Japan)	L (1.3 GHz)	8°-60°	HH, HV, VV, VH
2007	TerraSAR-X (Germany)	X (9.7 GHz)	15°-60°	HH, HV, VV, VH
2007	Radarsat-2 (Canada)	C (5.3 GHz)	10°-60°	HH, HV, VV, VH
200710	COSMO-SkyMed 1-4 (Italy)	X (9.6 GHz)	20°-59°	HH, HV, VV, VH
2010	TanDEM-X (Germany)	X (9.7 GHz)	15°-60°	HH, HV, VV, VH
2014	ALOS-2 (Japan)	L (1.3 GHz)	8°-70°	HH, HV, VV, VH
2014	Sentinel-1A (Europe)	C (5.4 GHz)	20°-45°	HH/HV, VV/VH

Gade, M., 2015, October. Synthetic aperture radar applications in coastal waters. In *Proceedings of the 12th International Conference on the Mediterranean Coastal Environment MEDCOAST held* (pp. 6-10).





Sensitivity of SAR measurements to forest structure and penetration into the canopy at different wavelengths used for airborne or spaceborne remote sensing observations of the land surface. Credit: NASA SAR Handbook.

[Introduction to Sentinel 1: SAR(Synthetic-Aperture Radar) Data | by Albert Um | Medium]

Main SAR characteristics

Advantages

- All weather capability (small sensitivity to clouds, light rain)
- Day and night operation (independence of sun illumination)
- No effects of atmospheric constituents (multitemporal analysis)
- Sensitivity to dielectric properties (water content , biomass, ice)
- Sensitivity to surface roughness (ocean wind speed)
- Accurate measurements of distance (interferometry)
- Sensitivity to man made objects
- Sensitivity to target structure (use of polarimetry)
- Subsurface and volume penetration

Introduction_to_SAR.pdf (europa.eu)

Source: Thuy Le Toan, Introduction to SAR: ESA Advanced course in land remote sensing (2010)

Main SAR characteristics

Disadvantages

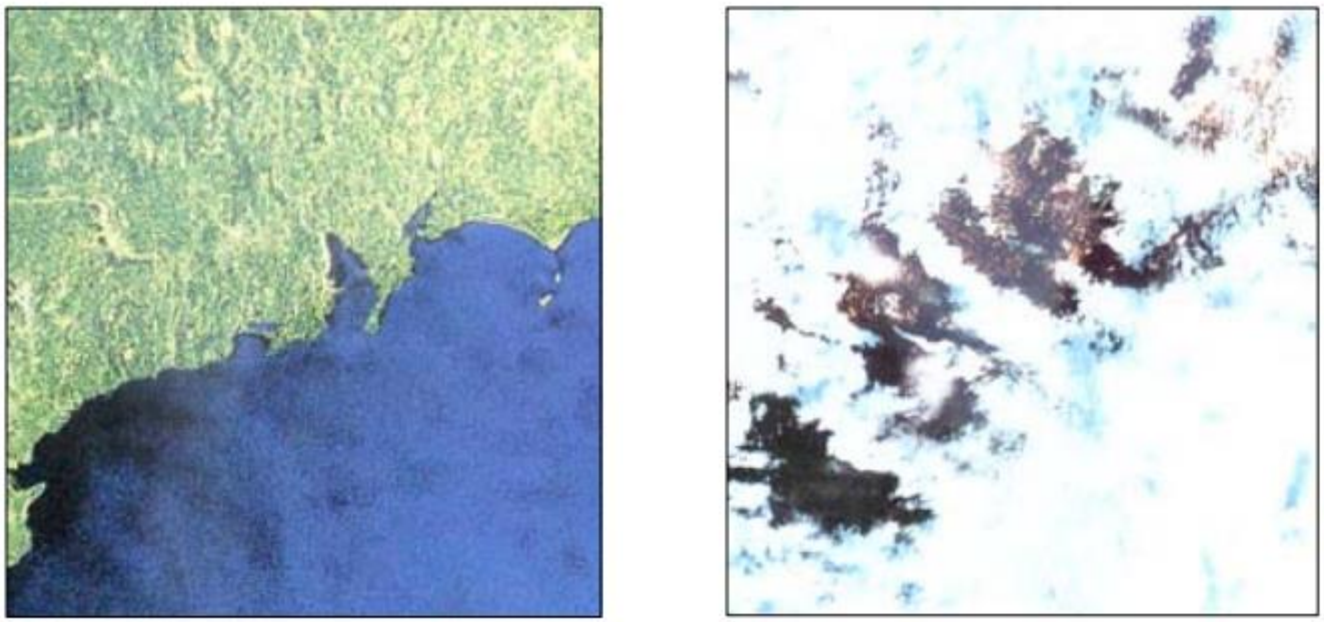
- Complex interactions (difficulty in understanding, complex processing)
- Speckle effects (difficulty in visual interpretation)
- Topographic effects
- Effect of surface roughness

Introduction_to_SAR.pdf (europa.eu)

Source: Thuy Le Toan, Introduction to SAR: ESA Advanced course in land remote sensing (2010)

All-weather system

- An ‘all-weather’imaging system
- A microwaves system: cloud penetrating capabilities



ERS-1 SAR, 11.25 a.m. LANDSAT TM, 9.45 a.m.
Ireland, 09/08/1991

Introduction_to_SAR.pdf (europa.eu)

Source: Thuy Le Toan, Introduction to SAR: ESA Advanced course in land remote sensing (2010)

Effect of surface roughness – Internal waves

ERS Images (C band, 23°, VV) in false colors

Gibraltar strait
Image : **90 km x 100 km**

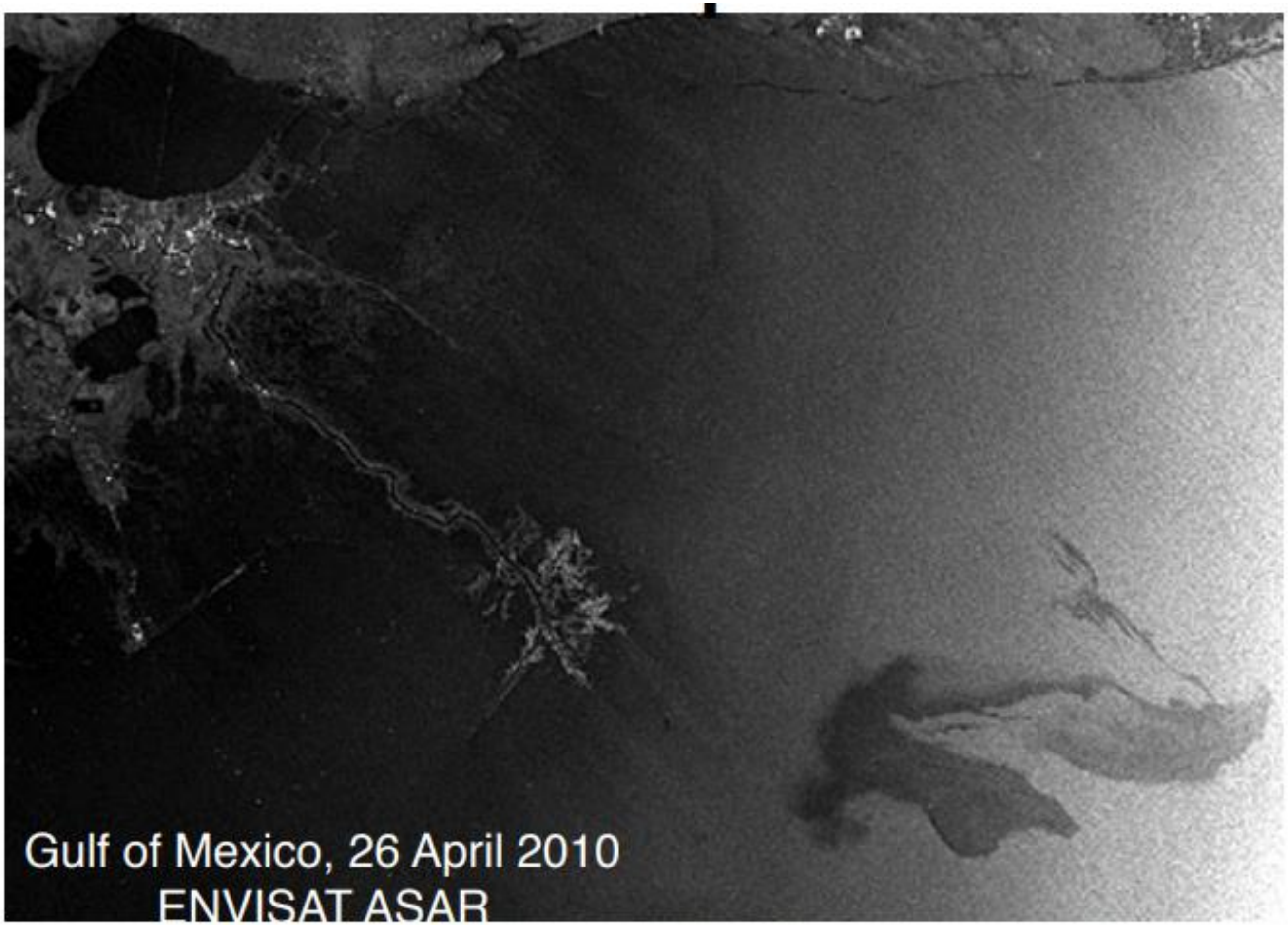
• Internal waves ($l \approx 2$ km)
Origin : difference of salinity between Atlantic Ocean and Mediterranean sea + tide effects

From 'ERS-1 : 500 days in orbit '. Published by the European Space Agency'

Introduction_to_SAR.pdf (europa.eu)

Source: Thuy Le Toan, Introduction to SAR: ESA Advanced course in land remote sensing (2010)

Sensitivity to surface roughness Oil Spill detection



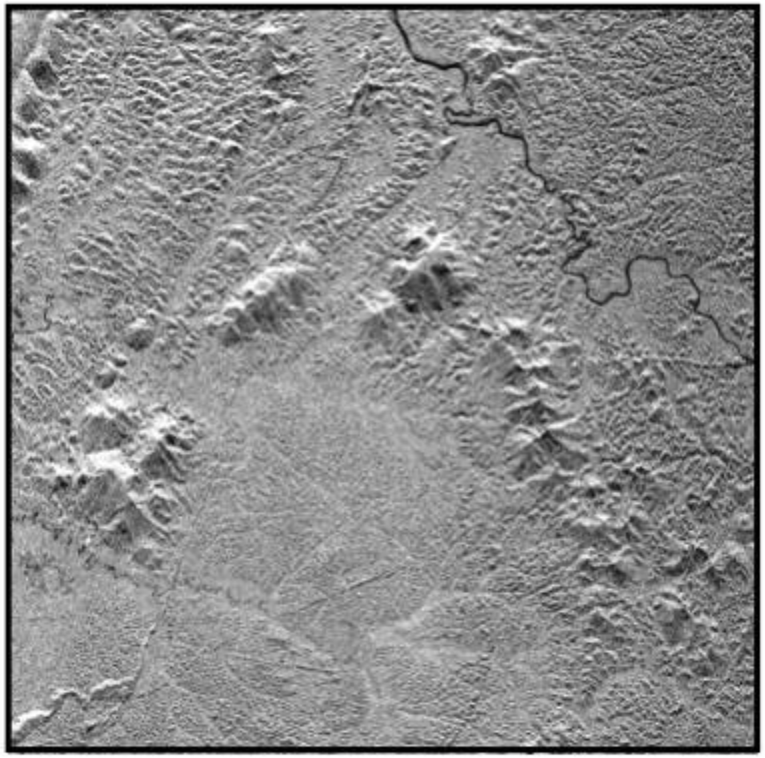
ESA: This Envisat radar image captures the oil that is spilling into the Gulf of Mexico after a drilling rig exploded and sank off the coasts of Louisiana and Mississippi, USA, on 22 April 2010. The oil spill is visible as a dark grey whirl in the bottom right. Envisat acquired this image from its Advanced Synthetic Aperture Radar on 26 April at 15:58 UTC

[Introduction_to_SAR.pdf (europa.eu)](Introduction_to_SAR.pdf)

Source: Thuy Le Toan, Introduction to SAR: ESA Advanced course in land remote sensing (2010)

Topographic effects

Sedimentary basin (Kalimantan, Indonesia)
RADARSAT F4 (C band, ~ 45°, resolution : 8 m)



Tropical forest in French Guyana
ERS (C band, 23°, VV, resolution : 20 m)

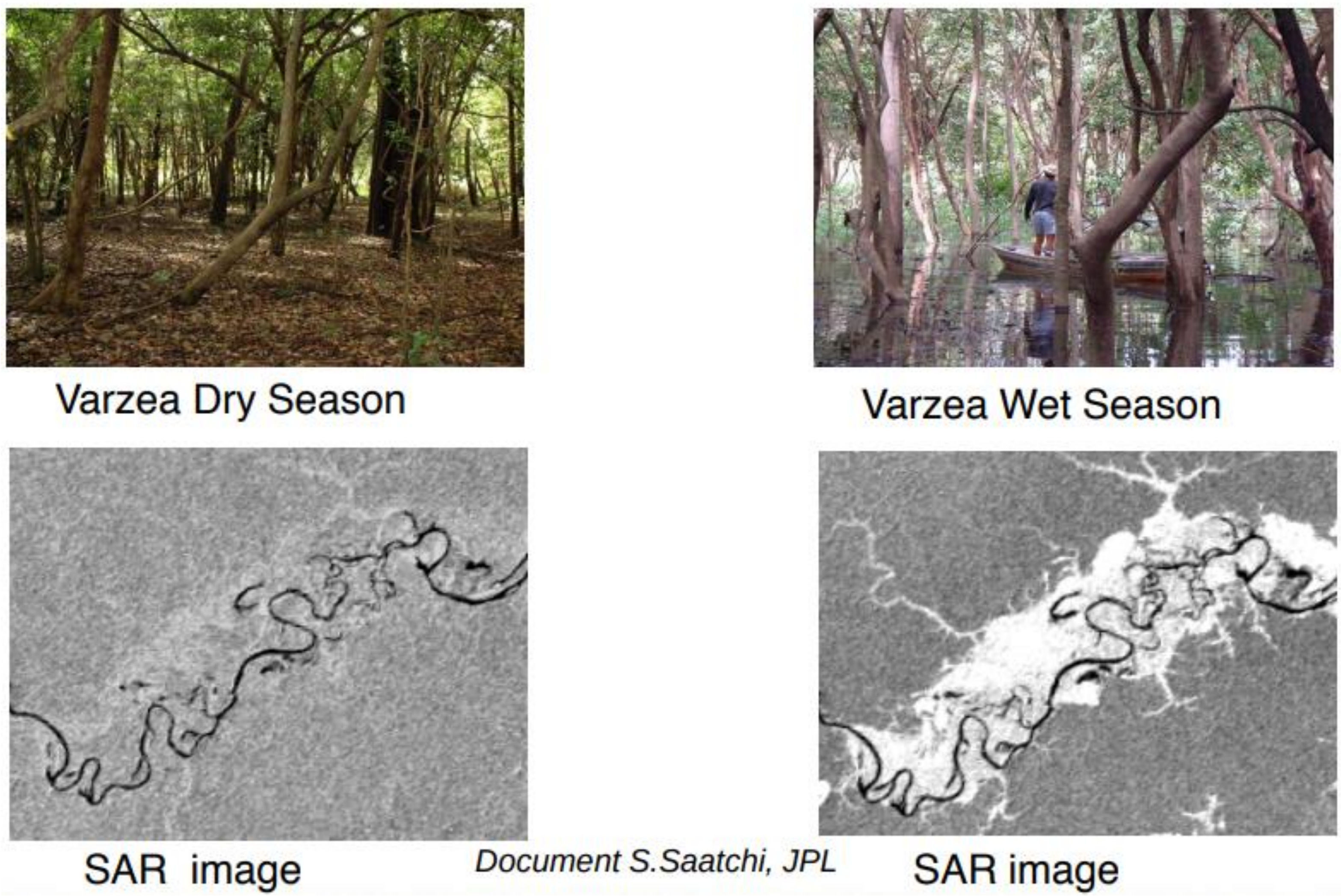
- *The SAR side looking makes it extremely sensible to the relief, even under vegetation cover in tropical forests.*

cnes
CENTRE NATIONAL D'ETUDES SPATIALES

Introduction_to_SAR.pdf (europa.eu)

Source: Thuy Le Toan, Introduction to SAR: ESA Advanced course in land remote sensing (2010)

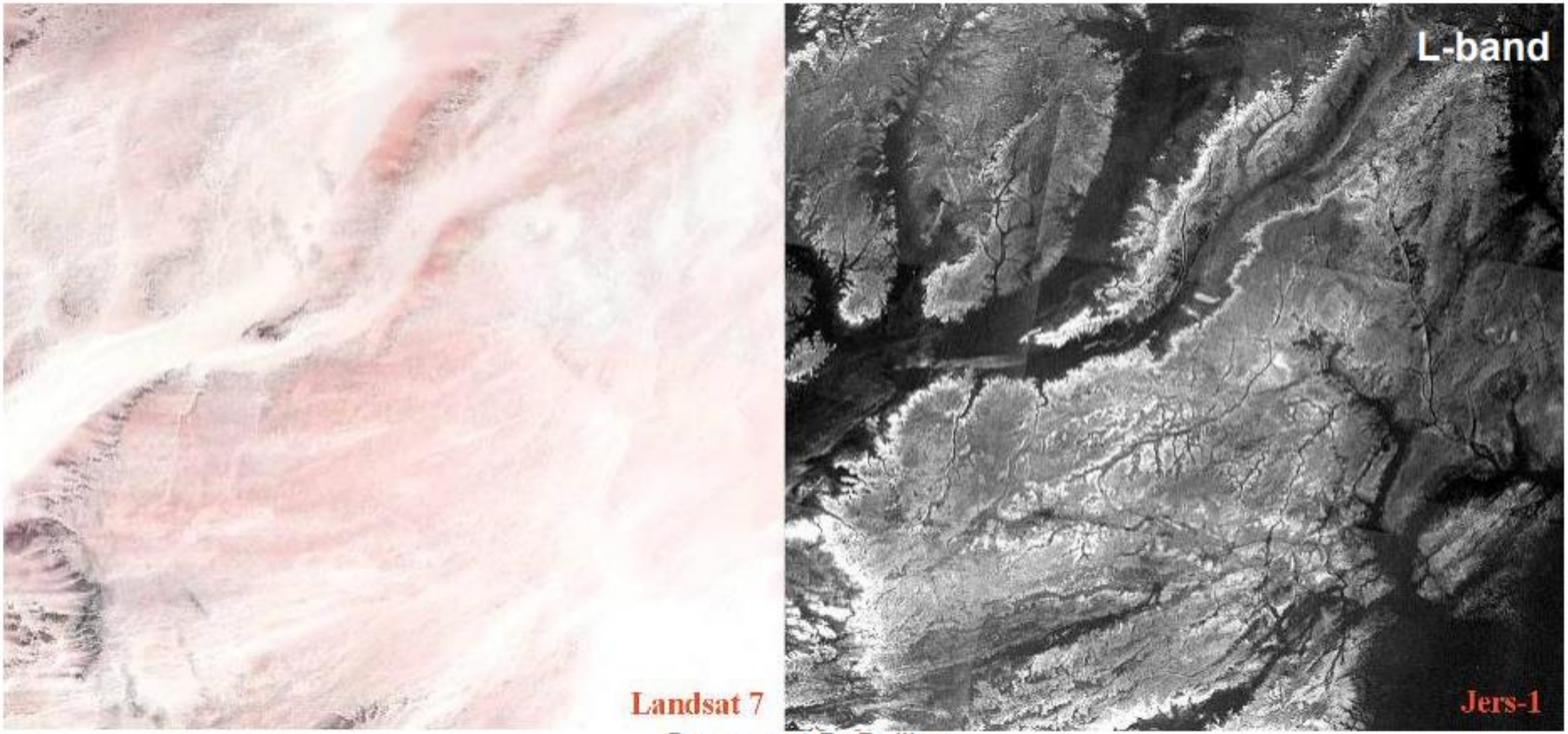
Sub-canopy penetration



[Introduction_to_SAR.pdf (europa.eu)](Introduction_to_SAR.pdf)

Source: Thuy Le Toan, Introduction to SAR: ESA Advanced course in land remote sensing (2010)

Surface penetration



Document P. Paillou

Microsoft PowerPoint - D1La1-sar-basics-LeToan.ppt (esa.int)

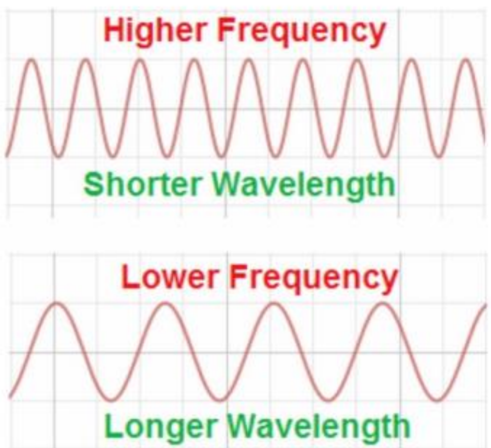
Source: Thuy Le Toan, Introduction to SAR: ESA Advanced course in land remote sensing (2010)

Main SAR parameters

- Wavelength
- Polarization
- Incidence Angle

Wavelength

$$\text{Wavelength} = \frac{\text{Speed of light}}{\text{frequency}}$$



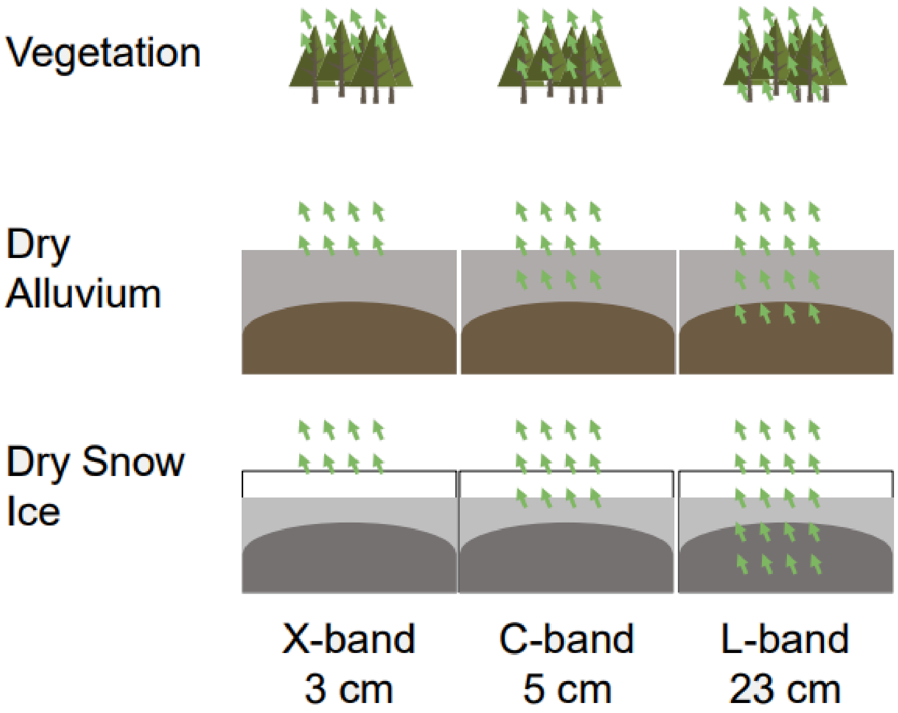
Band designation*	Wavelength (λ), cm	Frequency (ν), GH$_z$ (10^9 cycles · sec^{-1})
Ka (0.86 cm)	0.8 to 1.1	40.0 to 26.5
K	1.1 to 1.7	26.5 to 18.0
Ku	1.7 to 2.4	18.0 to 12.5
X (3.0 cm, 3.2 cm)	2.4 to 3.8	12.5 to 8.0
C (6.0)	3.8 to 7.5	8.0 to 4.0
S	7.5 to 15.0	4.0 to 2.0
L (23.5 cm, 25 cm)	15.0 to 30.0	2.0 to 1.0
P (68 cm)	30.0 to 100.0	1.0 to 0.3

* Wavelengths most frequently used in SAR are in parenthesis

- Penetration is the primary factor in wavelength selection
- Penetration through the forest canopy or into the soil is greater with longer wavelengths

Source: Erika Podest, Basics of SAR: NASA-ARSET Applied Remote Sensing Training

Penetration as a Function of Wavelength



- Waves can penetrate into vegetation and (in dry conditions) soil
- Generally, the longer the wavelength, the stronger the penetration into the target

Image based on ESA Radar Course 2

Source: Erika Podest, Basics of SAR: NASA-ARSET Applied Remote Sensing Training

Example: Radar Signal Penetration into Dry Soils

- Different satellite images over southwest Libya
- The arrows indicate possible fluvial systems

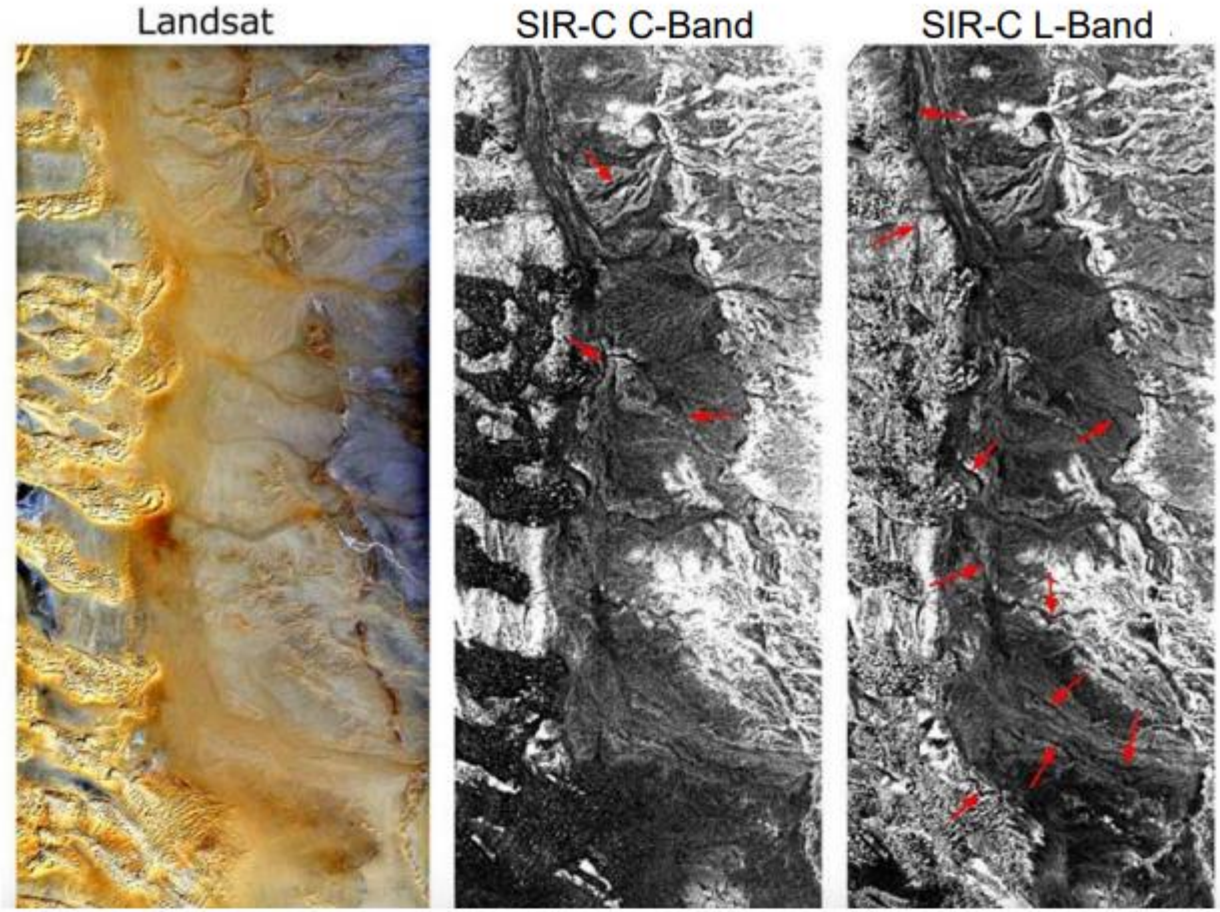


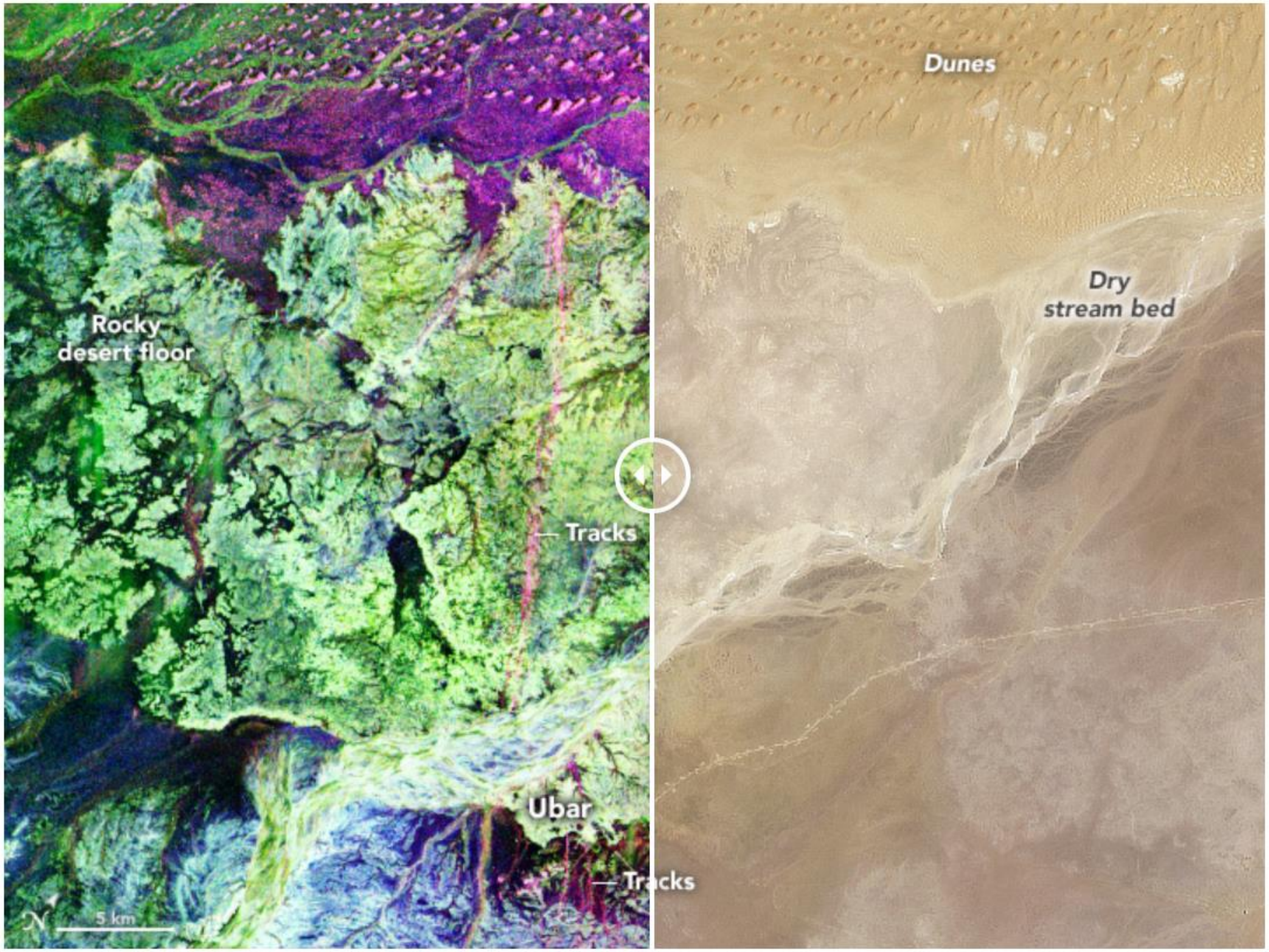
Image Credit: A Perego

[NASA ARSET: Basics of Synthetic Aperture Radar (SAR), Session 1/4 – YouTube]() (min 16:35 -20:45)

Source: Erika Podest, Basics of SAR: NASA-ARSET Applied Remote Sensing Training

Wavelength

https://earthobservatory.nasa.gov/images/90847/secrets-beneath-the-sand



Source: https://www.earthdata.nasa.gov/learn/backgrounders/what-is-sar

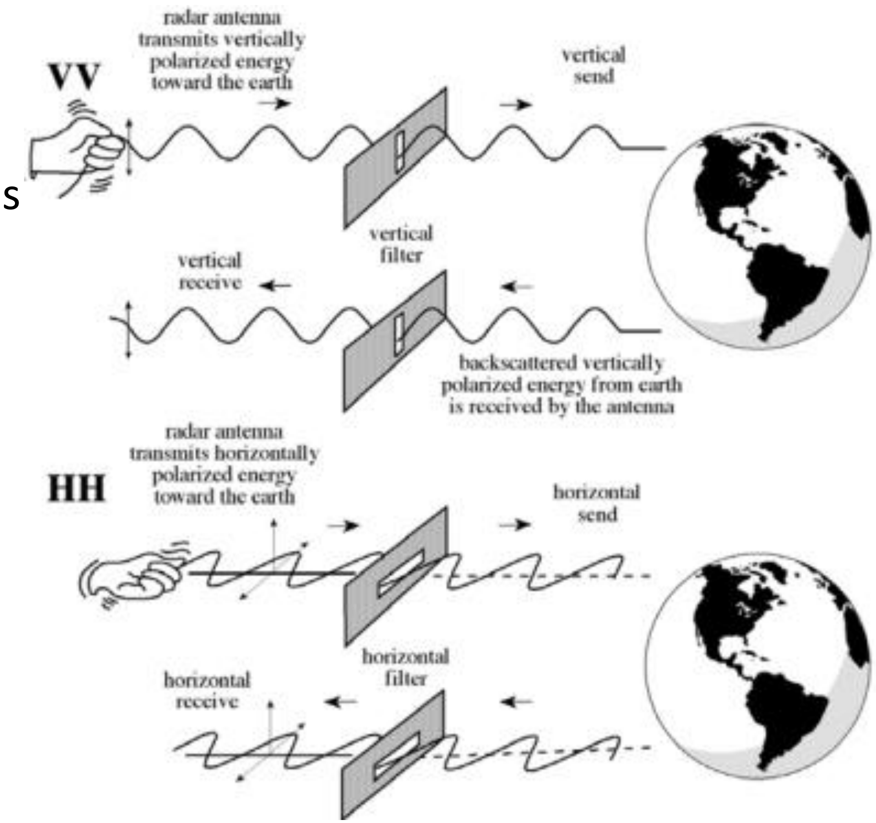
Polarization

- The radar signal is polarized
- The polarizations are usually controlled between H and V:

– HH: Horizontal Transmit, Horizontal Receive
– HV: Horizontal Transmit, Vertical Receive
– VH: Vertical Transmit, Horizontal Receive
– VV: Vertical Transmit, Vertical Receive

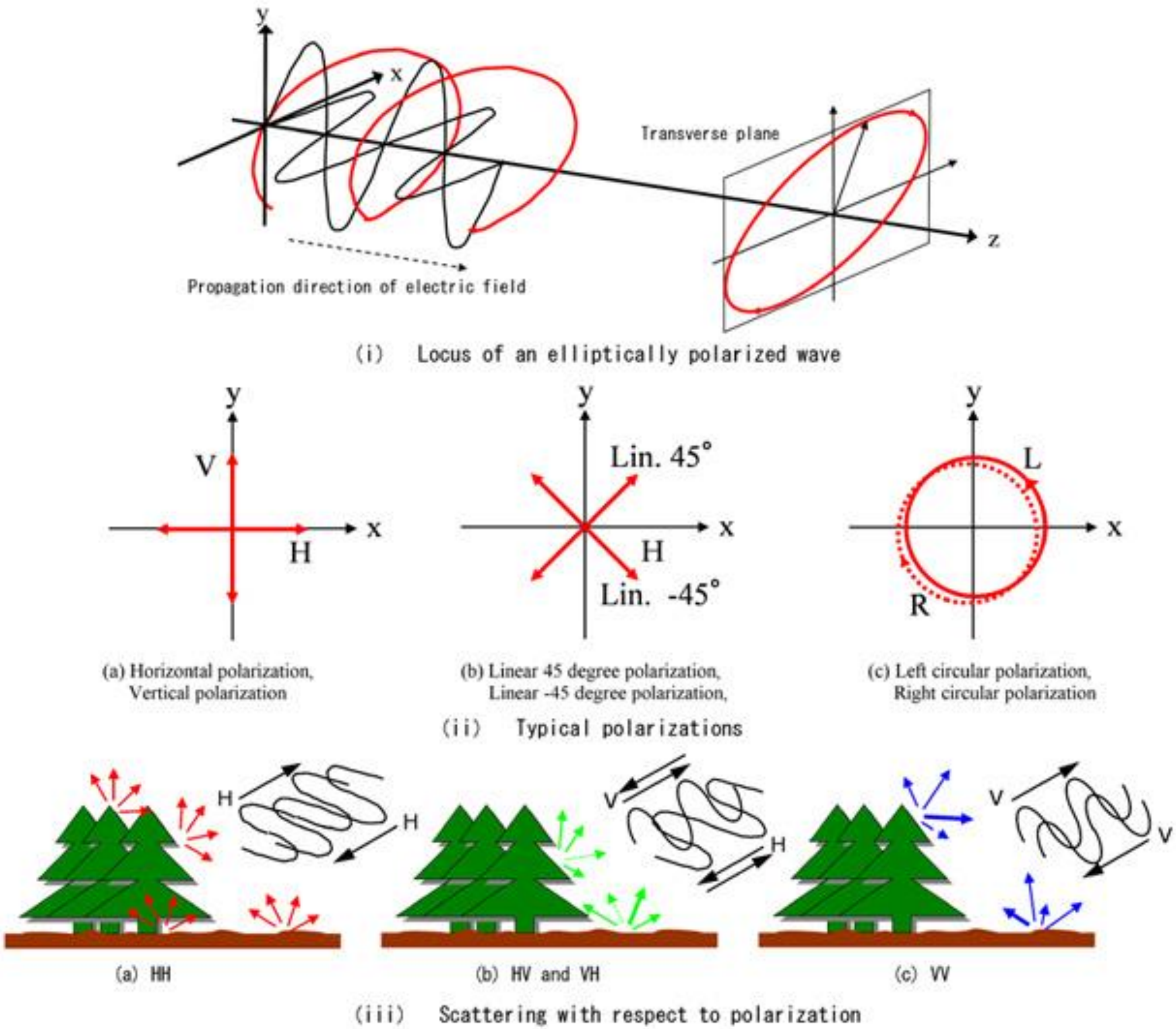
• Quad-Pol Mode: when all four polarizations are measured

- Different polarizations can determine physical
- properties of the object observe



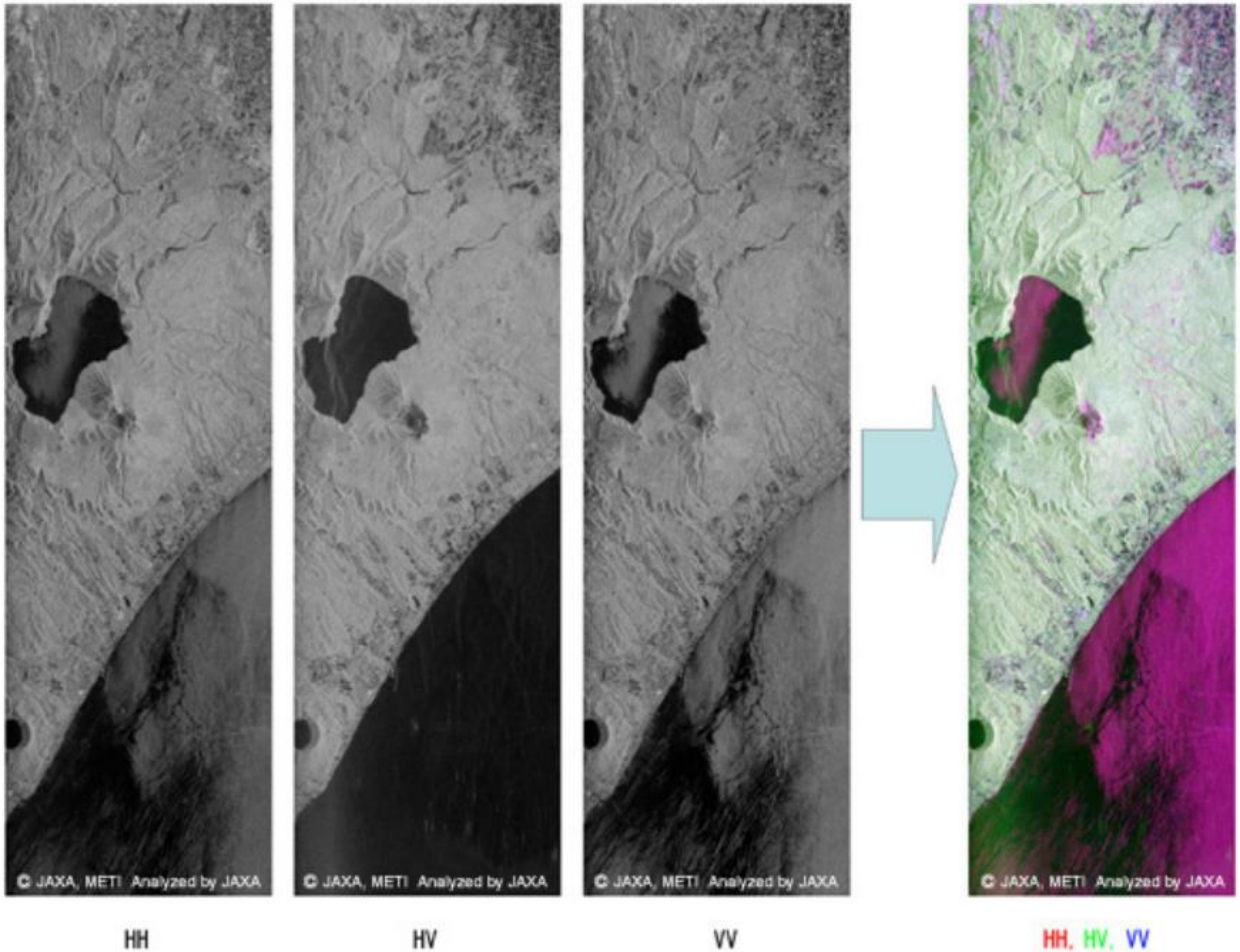
Source: Erika Podest, Basics of SAR: NASA-ARSET Applied Remote Sensing Training

Polarization



Source: https://www.eorc.jaxa.jp/ALOS/en/img_up/pal_polarization.htm

Polarization



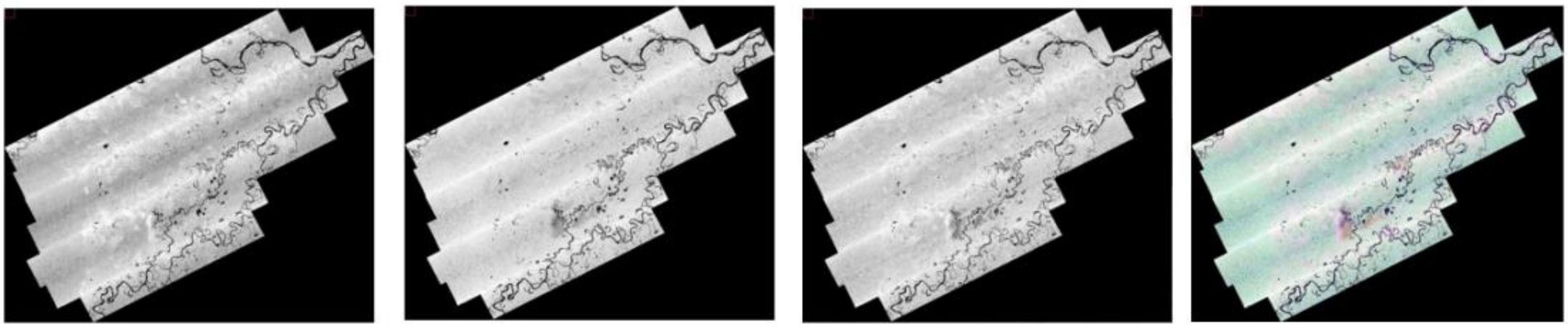
2006/08/19 01:17(UT) ALOS/PALSAR POLARIMETRY

Source: https://www.eorc.jaxa.jp/ALOS/en/img_up/pal_polarization.htm

Example of Multiple Polarizations for Vegetation Studies

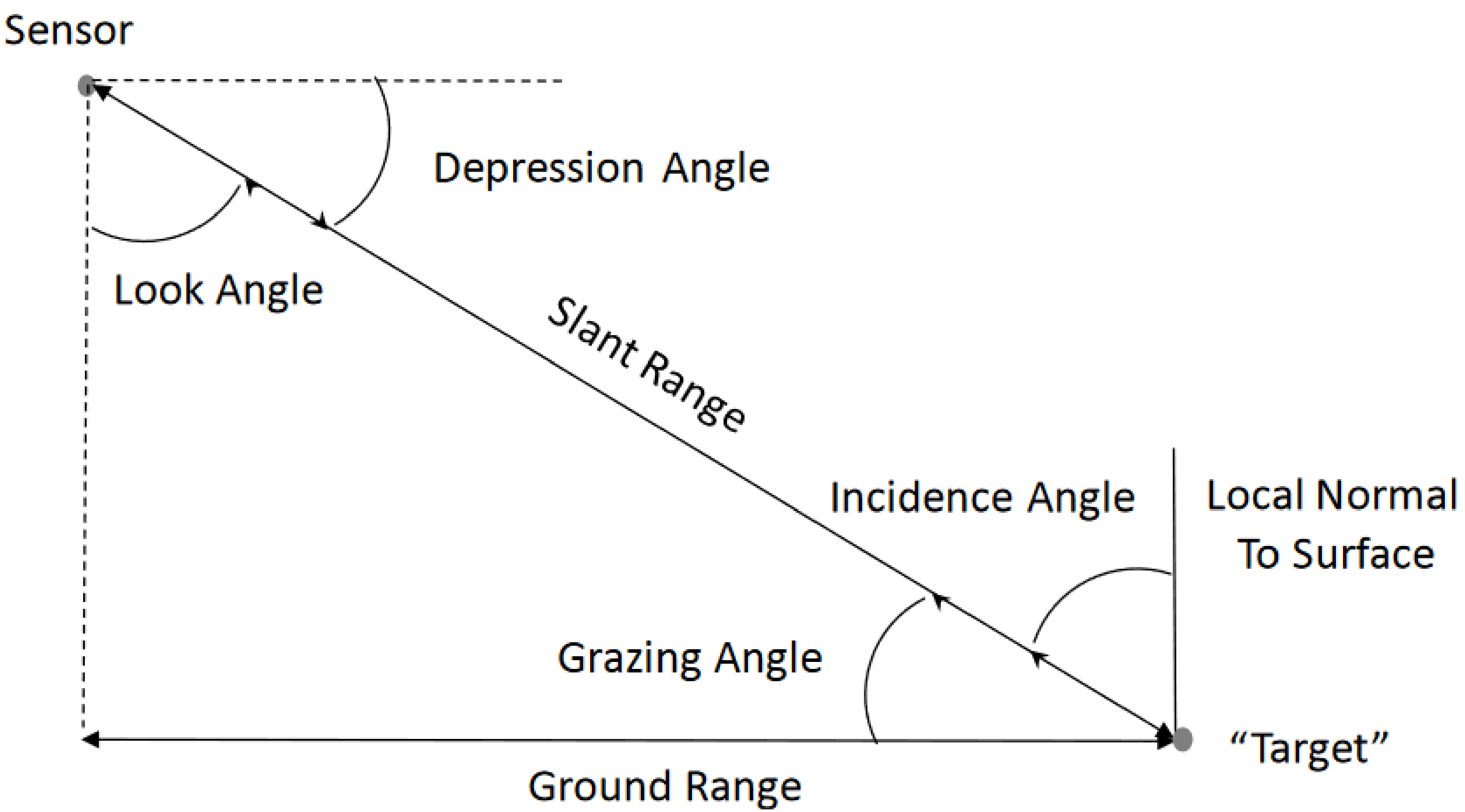
- Pacaya-Samiria Forest Reserve in Peru (2013)

Images from UAVSAR (HH, HV, VV)



Source: Erika Podest, Basics of SAR: NASA-ARSET Applied Remote Sensing Training

Incidence Angle



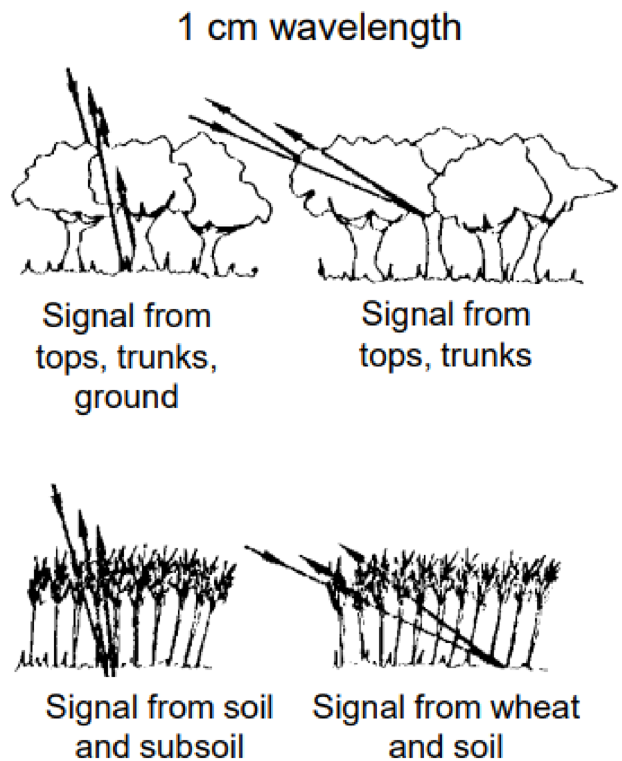
Source: https://descanso.jpl.nasa.gov/SciTechBook/series2/02Chap1_110106_amf.pdf

Incidence Angle

- The angle between the direction of illumination of the radar and the Earth's surface plane
- Depending on the height of the sensor, the incidence angle will change
- This is why the geometry of an image is different from point to point in the range direction
- Local Incidence Angle:

– accounts for local inclination of the surface

– influences image brightness



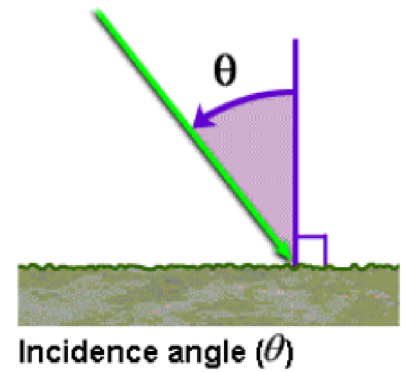
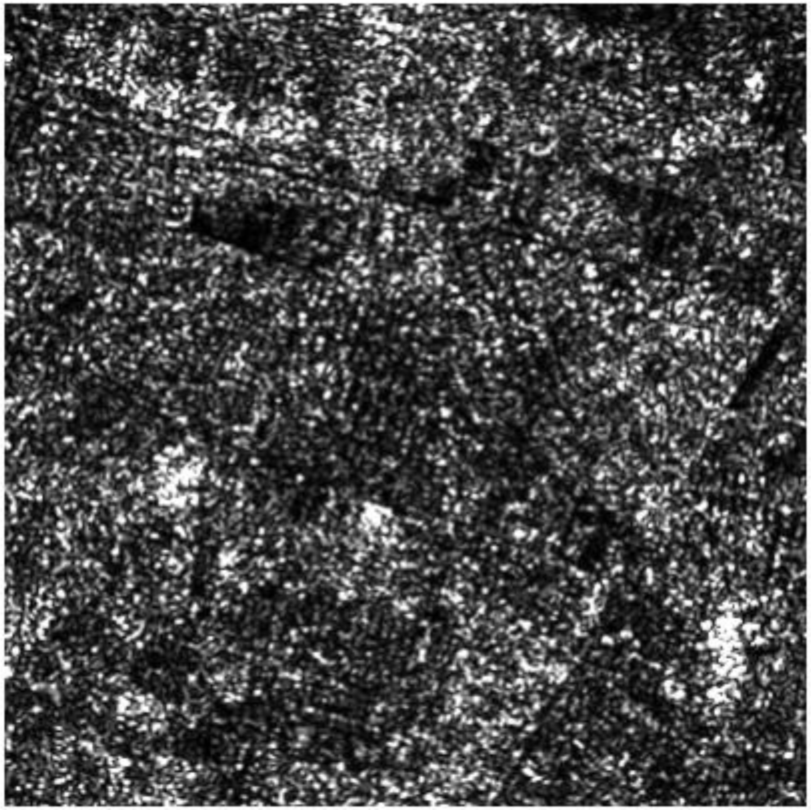


Image Credit: Left: Ulaby et al. (1981a), Right: ESA

Source: Erika Podest, Basics of SAR: NASA-ARSET Applied Remote Sensing Training

Speckle



Example of an intensity image
APP HH image 400 x 400 pixels (of 12.5m)
Gaoyou, Jiangsu province, China, 2004 05 24

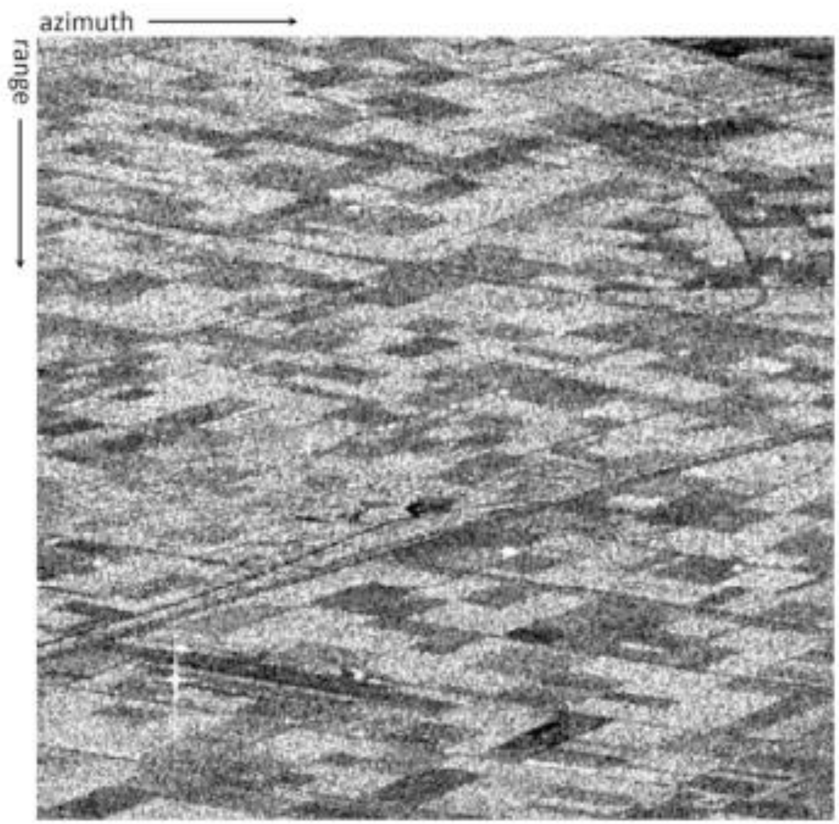
The image is seen as a **picture**.

Pixels are **numbers**.

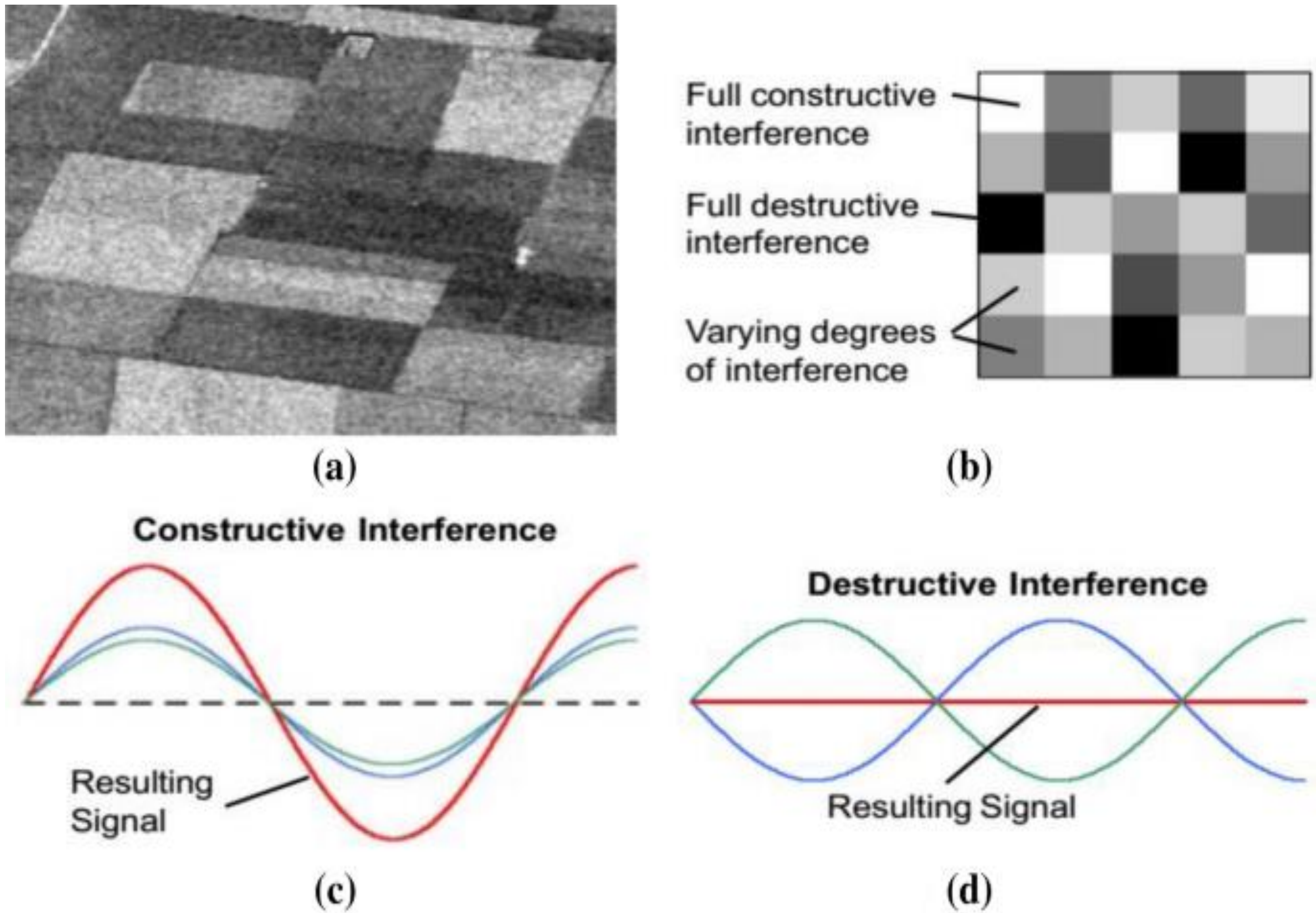
Image is affected by **speckle** noise

Source: Thuy Le Toan, Introduction to SAR: ESA Advanced course in land remote sensing (2010)

SAR images additionally are characterized by a somewhat grainy appearance that resembles "salt and pepper" noise. This noise-like pattern is usually referred to as "speckle."



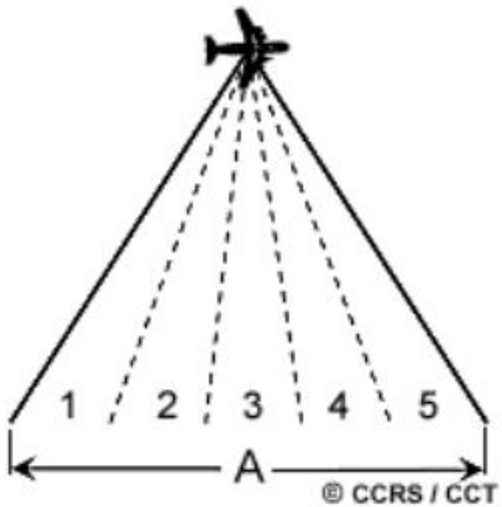
Source: Thuy Le Toan, Introduction to SAR: ESA Advanced course in land remote sensing (2010)

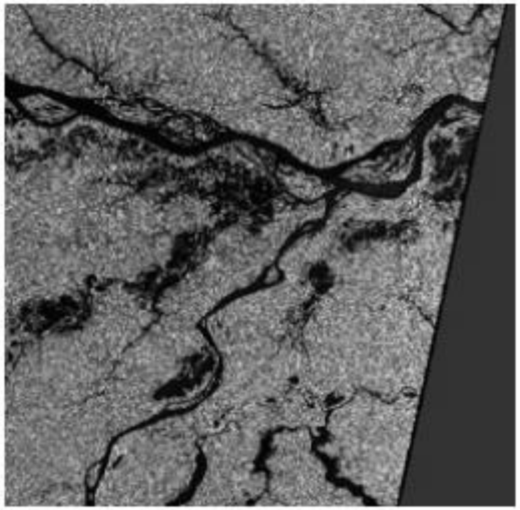


Source: https://link.springer.com/article/10.1007/s11831-021-09548-z

Speckle Reduction: Multilooking

Divides radar beam into several, narrower sub-beams
– e.g. 5 beams on the right
• Each sub-beam is a “look” at the scene
• These “looks” are subject to speckle
• By summing and averaging the different “looks” together,
the amount of speckle will be reduced in the final output
image





Source: Erika Podest, Basics of SAR: NASA-ARSET Applied Remote Sensing Training

Speckle Reduction: Multilooking

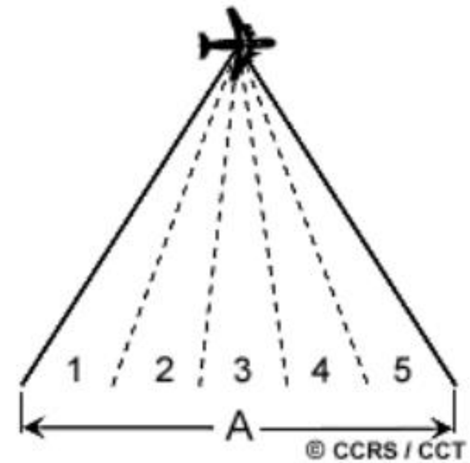
Multi-looking: The process of multi-looking improve the SAR image quality by reducing the speckle and allows us to obtain a square pixel on the output image. Either in range or azimuth direction or in both the directions, subsequent lines are averaged to get a better image.

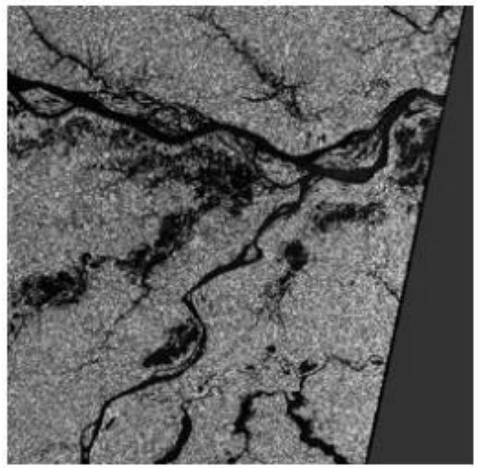
Divides radar beam into several, narrower sub-beams – e.g. 5 beams on the right

• Each sub-beam is a "look" at the scene

• These "looks" are subject to speckle

• By summing and averaging the different "looks" together, the amount of speckle will be reduced in the final output image



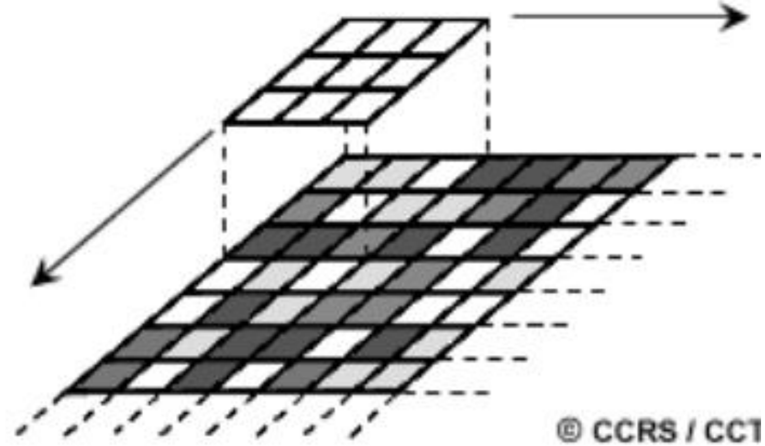


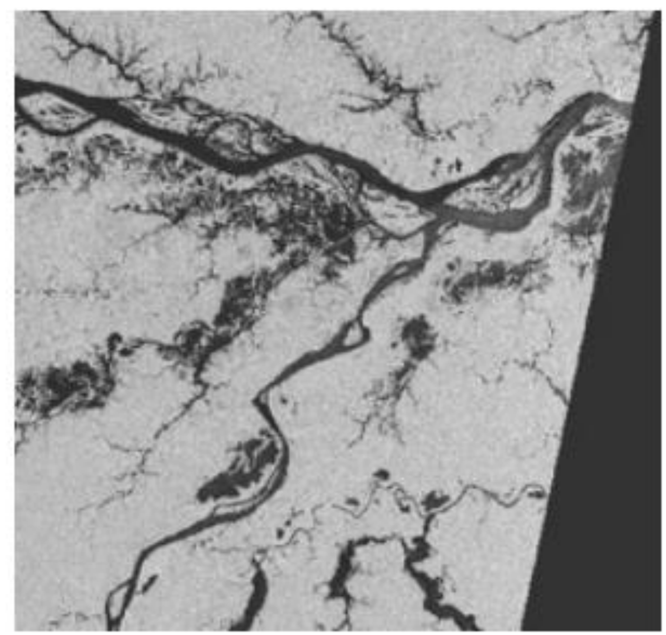
Source: Erika Podest, Basics of SAR: NASA-ARSET Applied Remote Sensing Training

Speckle Reduction: Spatial Filtering

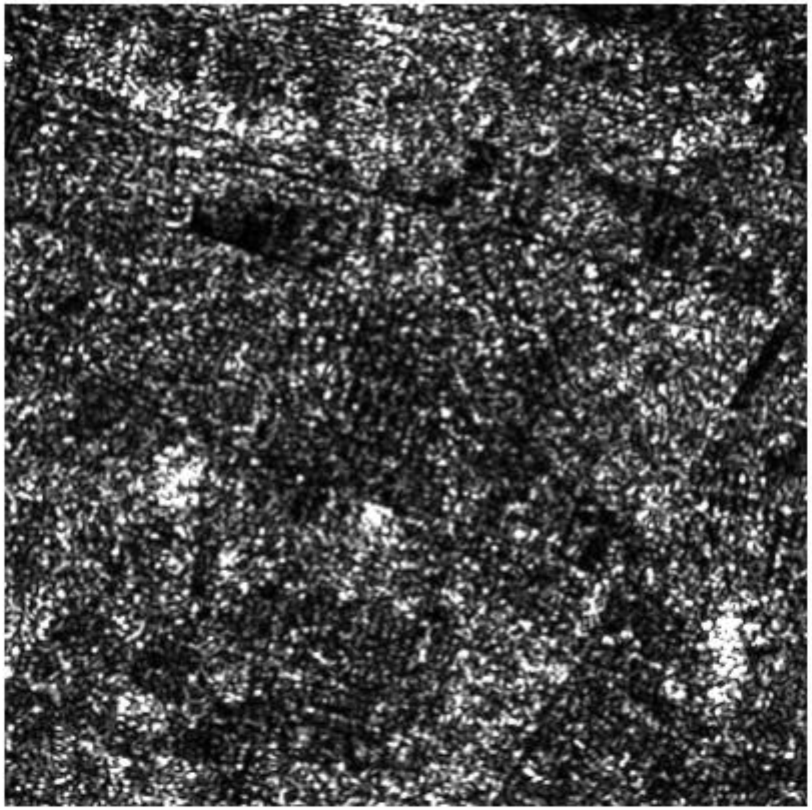
Moving window over each pixel in the image

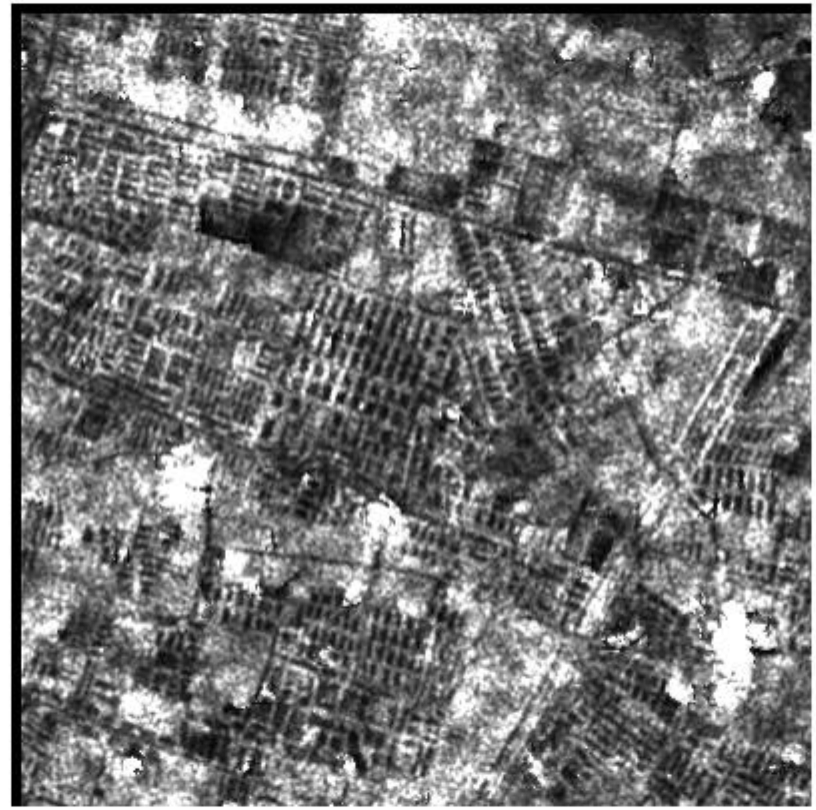
- Applies a mathematical calculation on the pixel values within the window
- The central pixel is replaced with the new value
- The window is moved along the x and y dimensions one pixel at a time
- Reduces visual appearance of speckle and applies a smoothing effect





Source: Erika Podest, Basics of SAR: NASA-ARSET Applied Remote Sensing Training

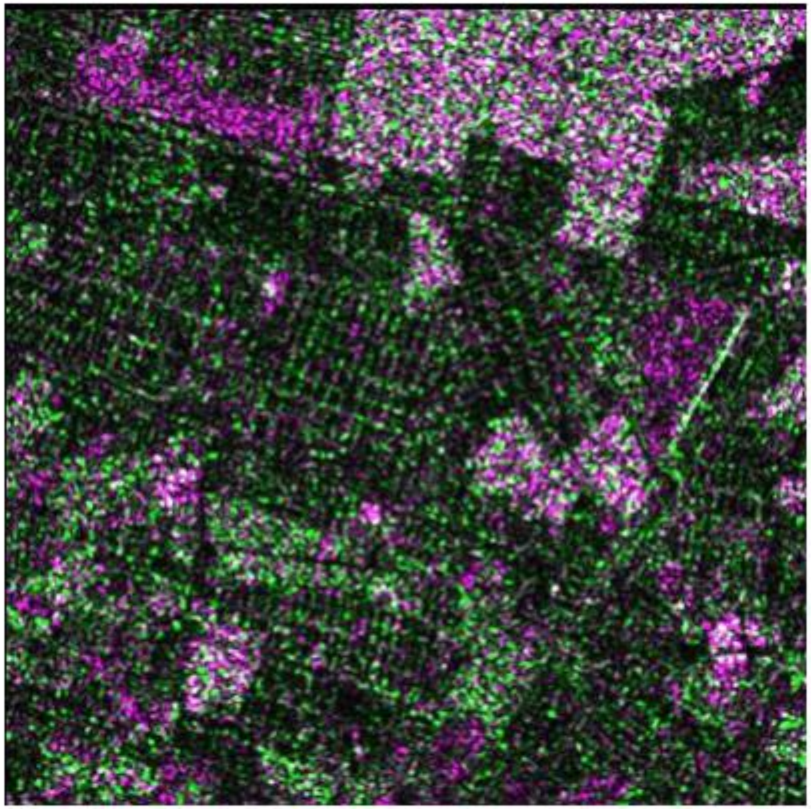




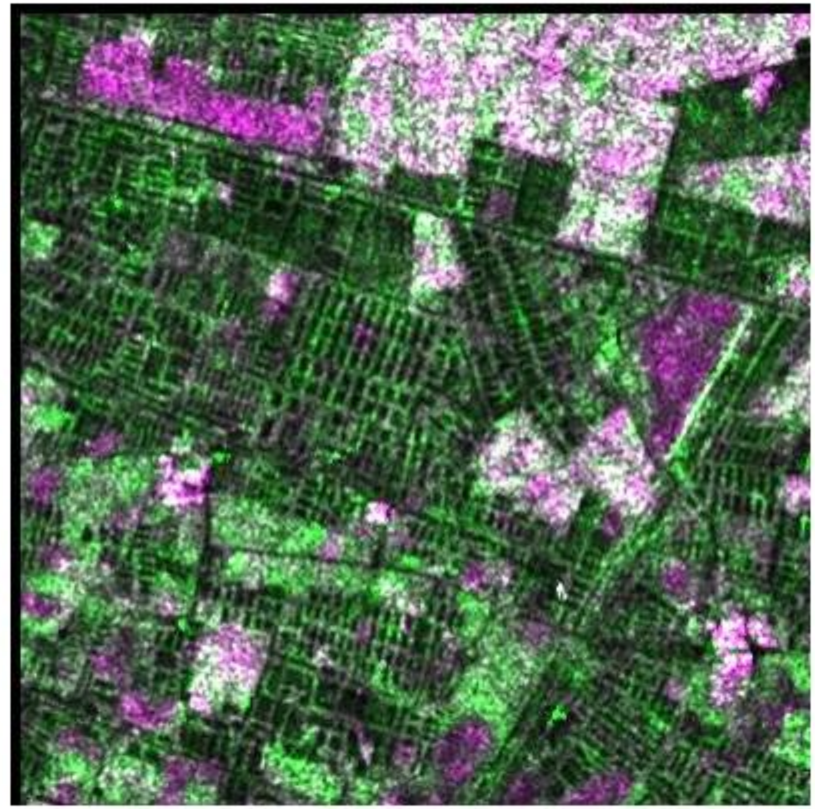
Same image, after speckle filtering

Source: Thuy Le Toan, Introduction to SAR: ESA Advanced course in land remote sensing (2010)

Initial HH and VV images



HH and VV image after filtering



HH (magenta) and VV (green) images
400 x400 pixels
Gaoyou, Jiangsu province
2004 09 06

Source: Thuy Le Toan, Introduction to SAR: ESA Advanced course in land remote sensing (2010)

SAR Main Properties

- High resolution capability (independent of flight altitude)
- Weather independent by selective proper frequency range
- Day/night capability due to own illumination
- Complementary to optical systems
- Polarization signature can be exploited (physical structure, dielectric constant)
- Many areas of application:

- Topography
- Oceanography
- Glaciology
- Geology
- Forestry
- Moving Target Indication (MTI)
- Volcano and Earthquake monitoring
- Environment monitoring
- Military surveillance and reconnaissance

Source: SAR.pdf (man.ac.uk)

Any Questions?

Thank you

Dr. Polyanna da Conceição Bispo
polyanna.bispo@manchester.ac.uk