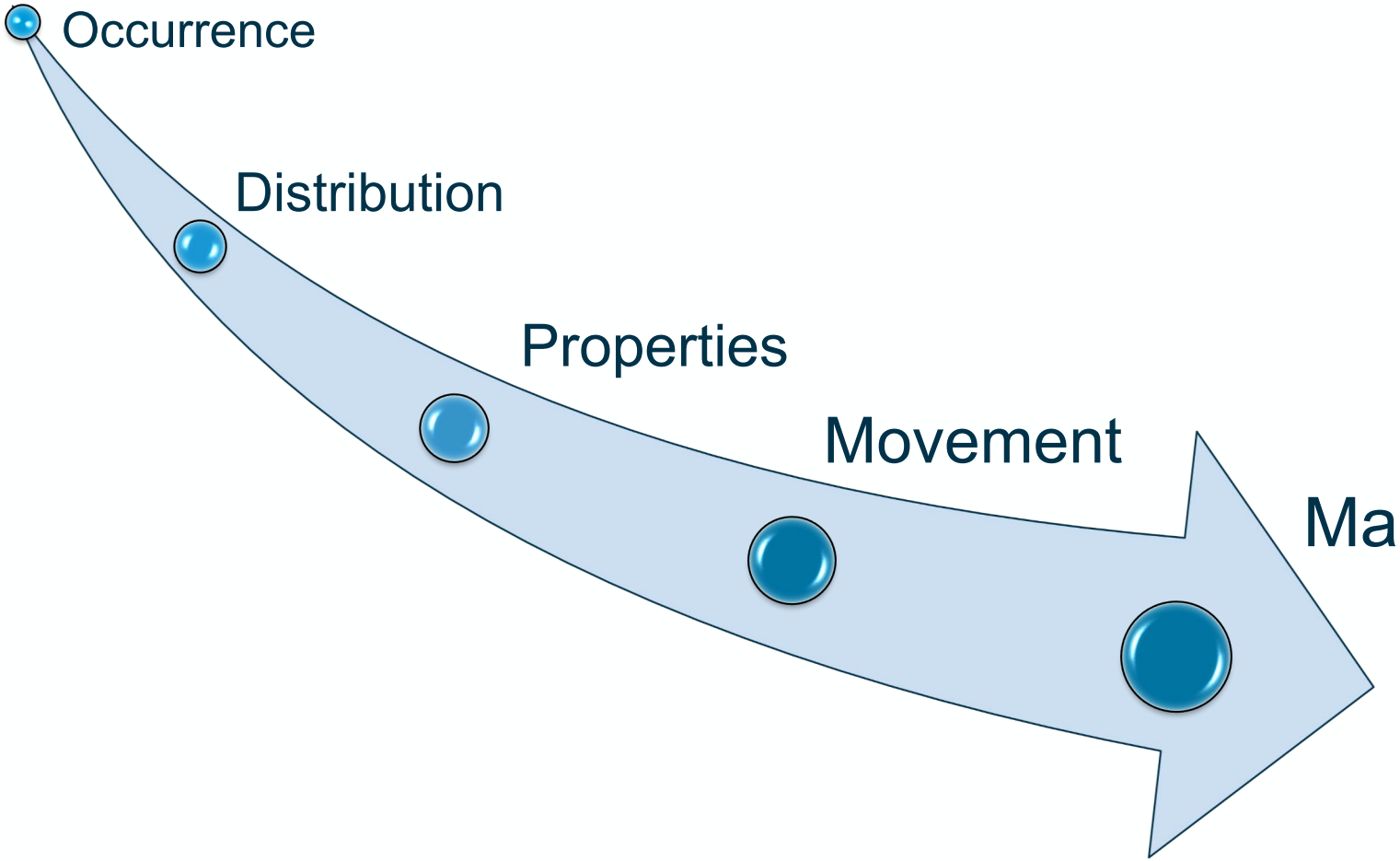
Introduction to SAR RS for Water and Hazards

Maya Ilieva

25 September 2023

Hydrology

Hydrology is the scientific study of the water on Earth and its:

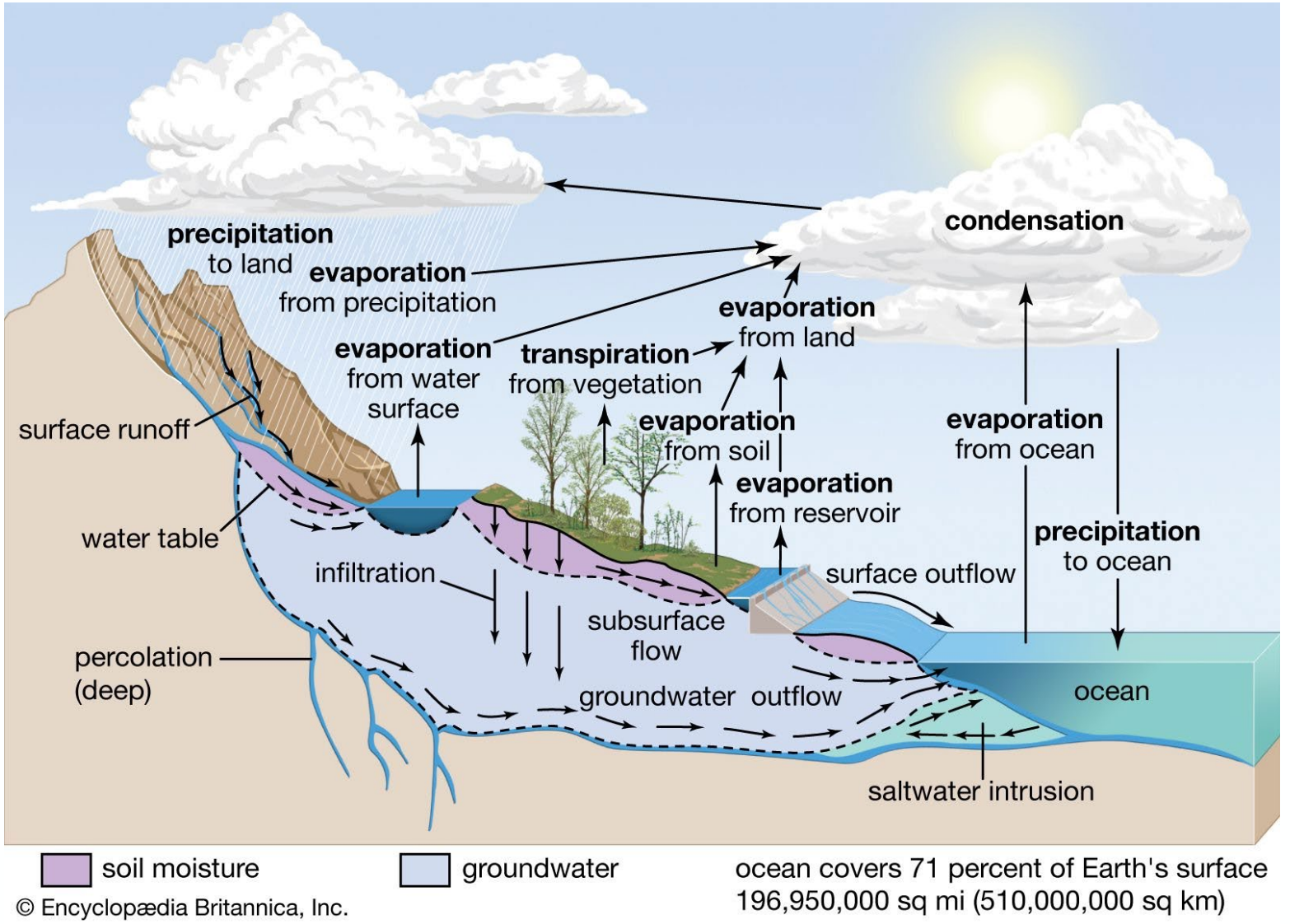


including the water cycle, water resources, and drainage basin sustainability.

Hydrologic cycle

The hydrologic cycle demonstrates the transfer of the water between:

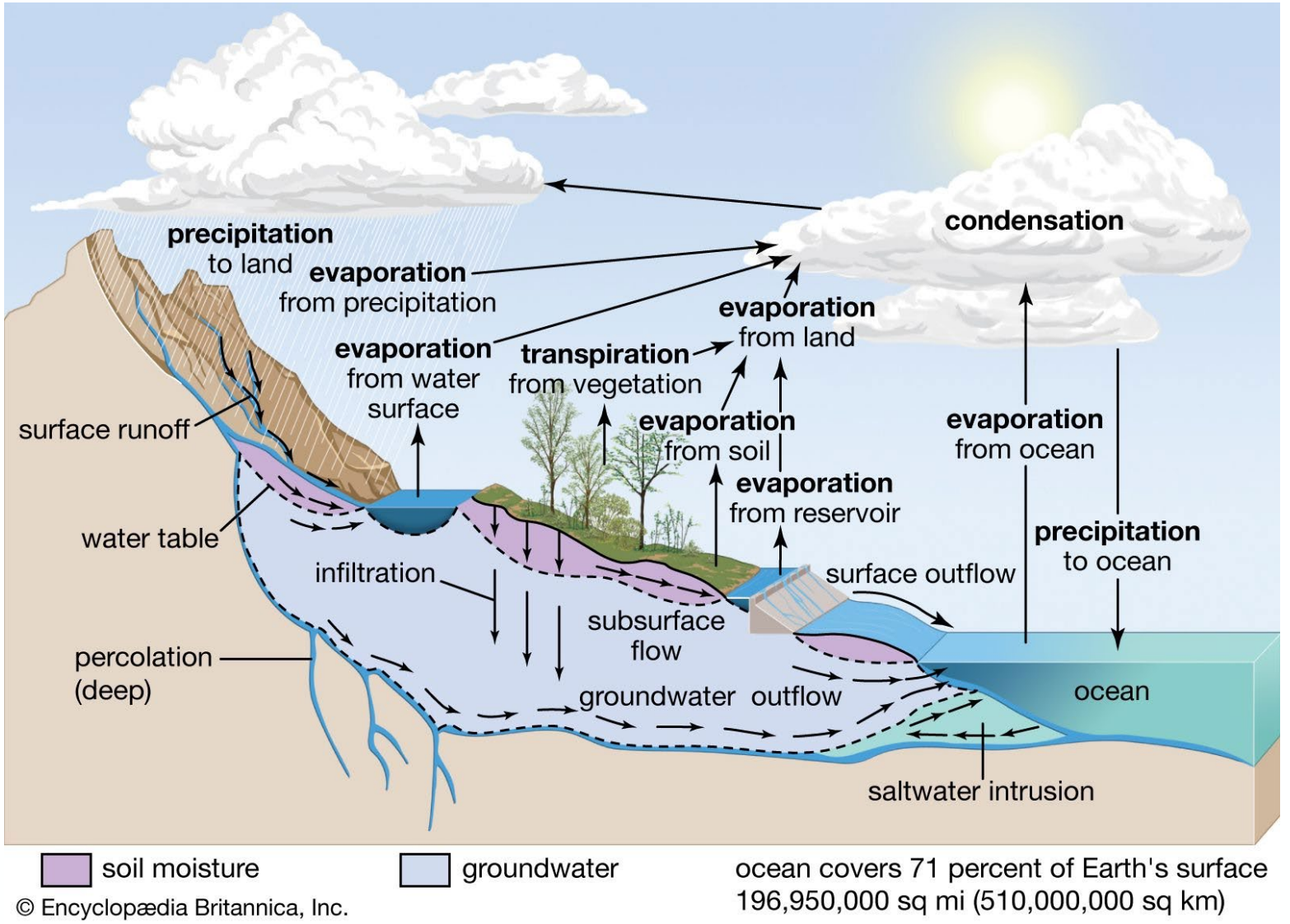
- the land surface
- the ocean and
- the atmosphere



Hydrologic cycle

The hydrologic cycle demonstrates the transfer of the water between:

- **the land surface**
- the ocean and
- the atmosphere



Hydrology

Hydrology is the scientific study of the

- occurrence,
  - distribution,
    - properties,
      - movement and
        - management

of the water on Earth and other planets.

“Remote sensing provides an avenue for observing hydrological variables and extremes over large areas and can facilitate an understanding of hydrological processes and phenomena”

(Frontiers in Remote Sensing, 2023).

Hydrological Variables

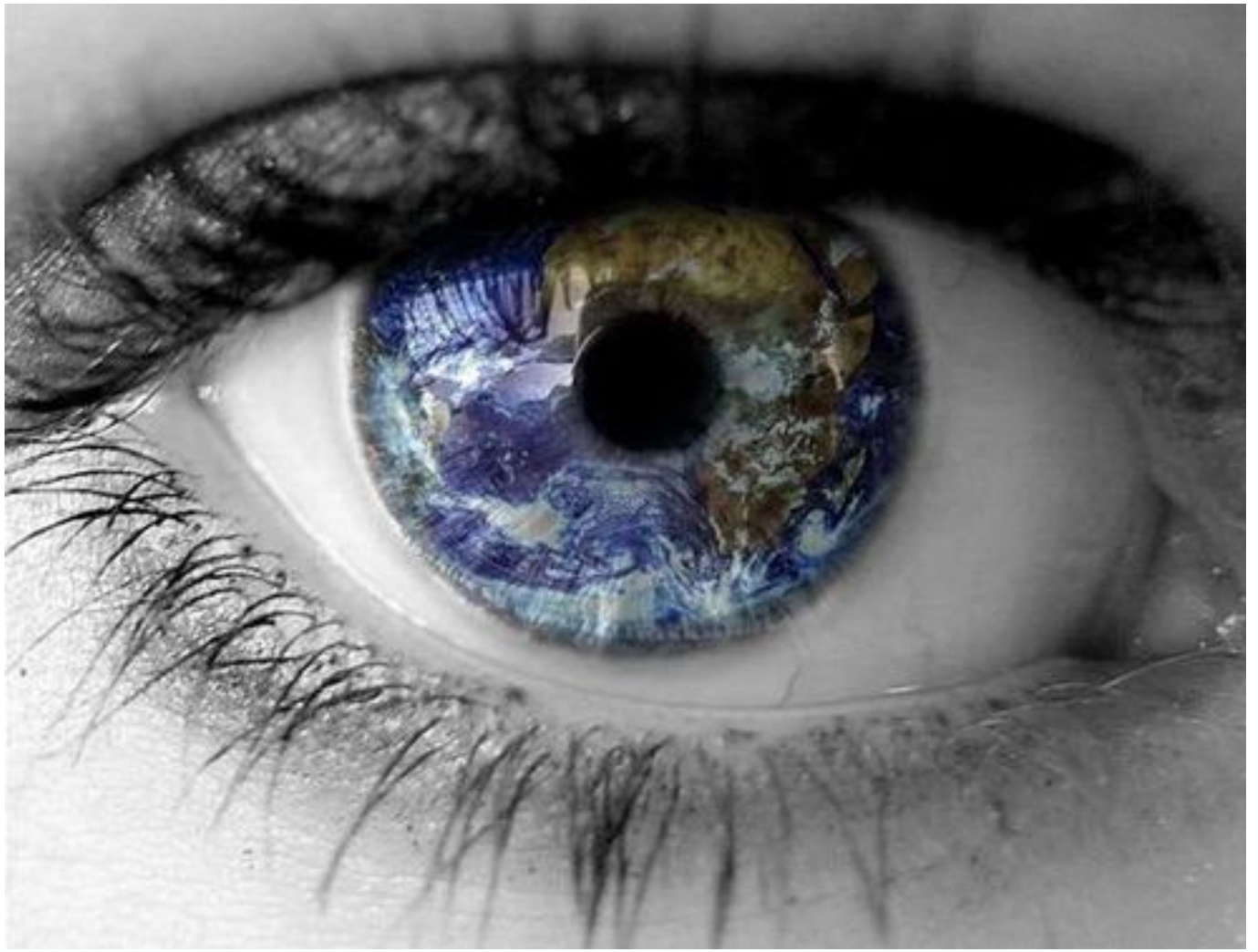
- Surface water hydrology
- Soil moisture
- Evapotranspiration
- Irrigation
- Water quality
- Precipitation
- Snow & Ice
- Groundwater hydrology

Hydrological Extremes

- Flood
- Drought

Remote sensing

Remote sensing (RS) is the technology for obtaining information from a distance without a direct physical contact with the observed object, area or phenomenon.

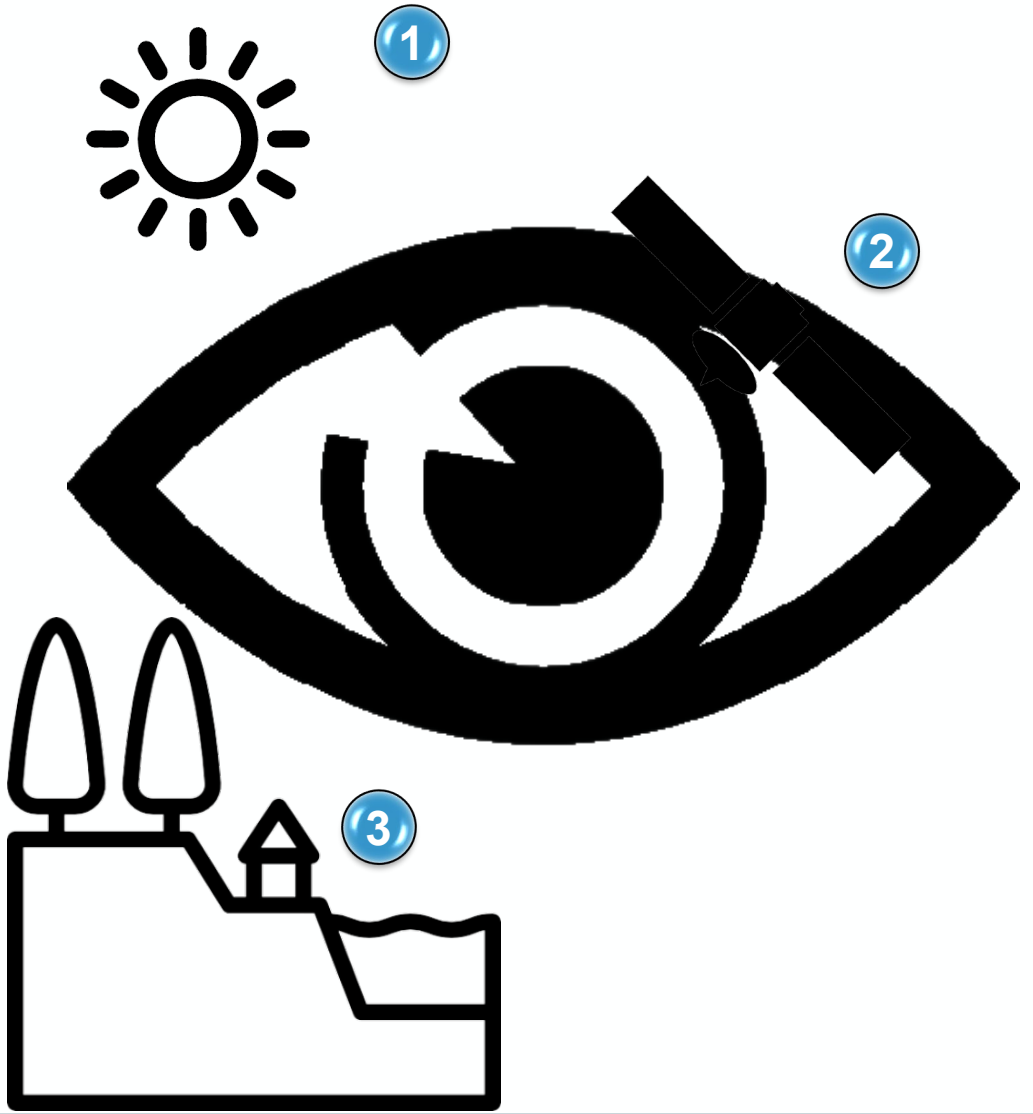


Remote sensing

Remote sensing (RS) is the technology for obtaining information from a distance without a direct physical contact with the observed object, area or phenomenon.

RS system consists of:

1) Source of light
2) Sensor
3) Object of interest

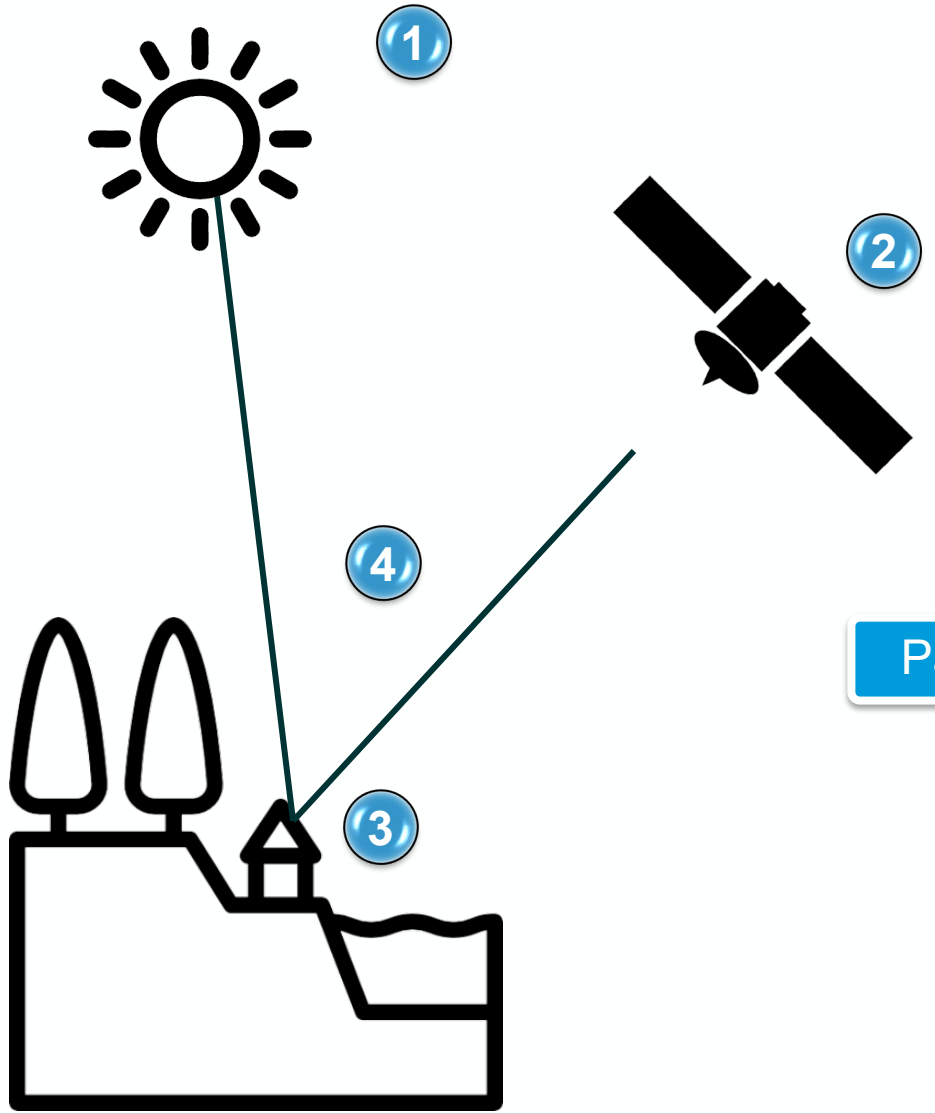


Remote sensing

Remote sensing (RS) is the technology for obtaining information from a distance without a direct physical contact with the observed object, area or phenomenon.

RS system consists of:

1) Source of light
2) Sensor
3) Object of interest - interaction with the object
4) Radiation and atmosphere
5) Recording, preparation and submission of the data
6) System for interpretation and analysis
7) Application



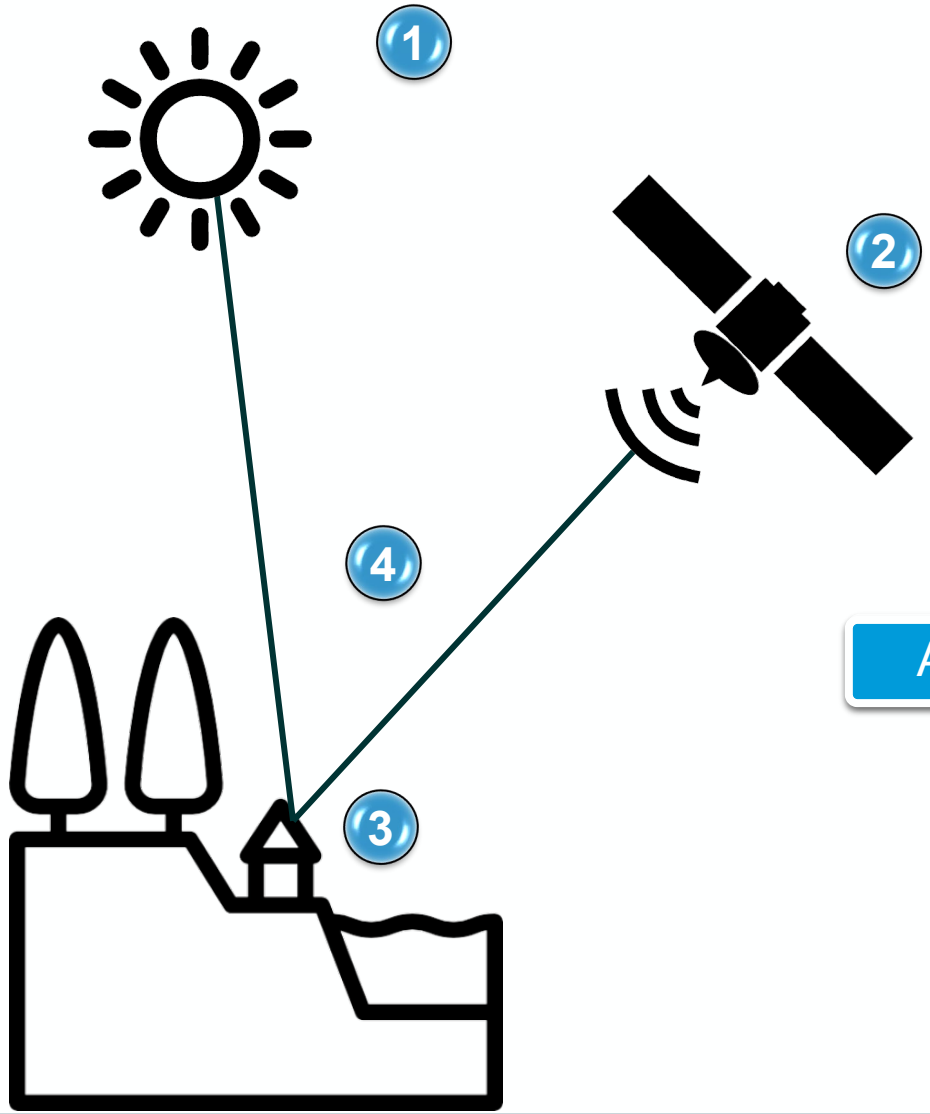
Passive RS

Remote sensing

Remote sensing (RS) is the technology for obtaining information from a distance without a direct physical contact with the observed object, area or phenomenon.

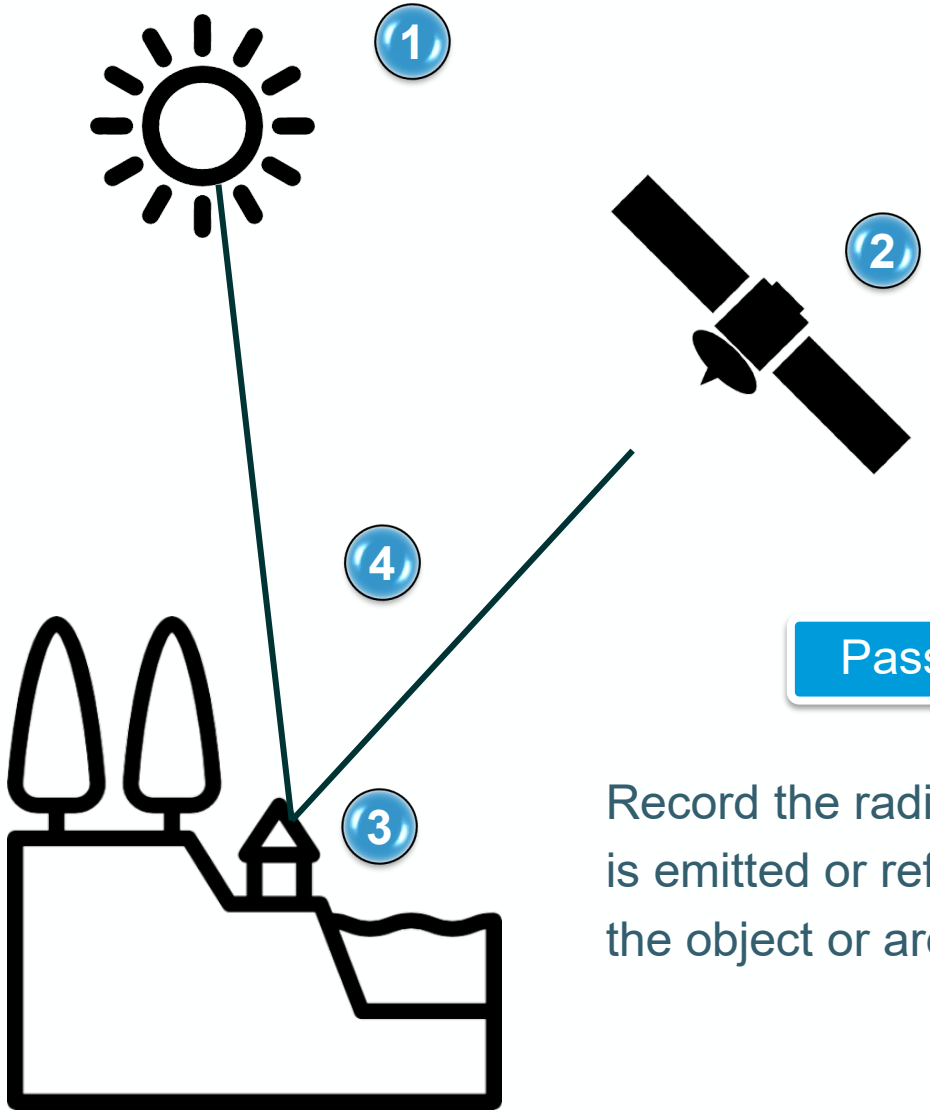
RS system consists of:

1) Source of light (energy)
2) Sensor
3) Object of interest - interaction with the object
4) Radiation and atmosphere
5) Recording, preparation and submission of the data
6) System for interpretation and analysis
7) Application



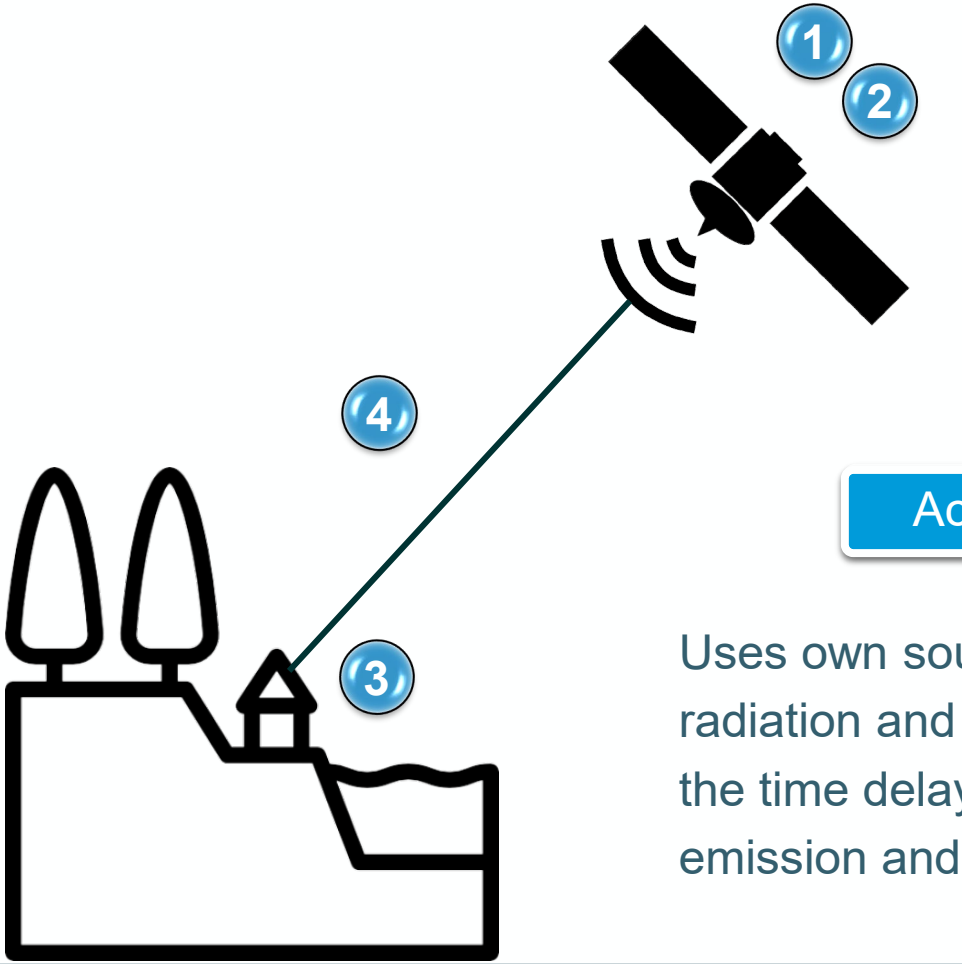
Active RS

Remote sensing



Passive RS

Record the radiation that is emitted or reflected by the object or area.



Active RS

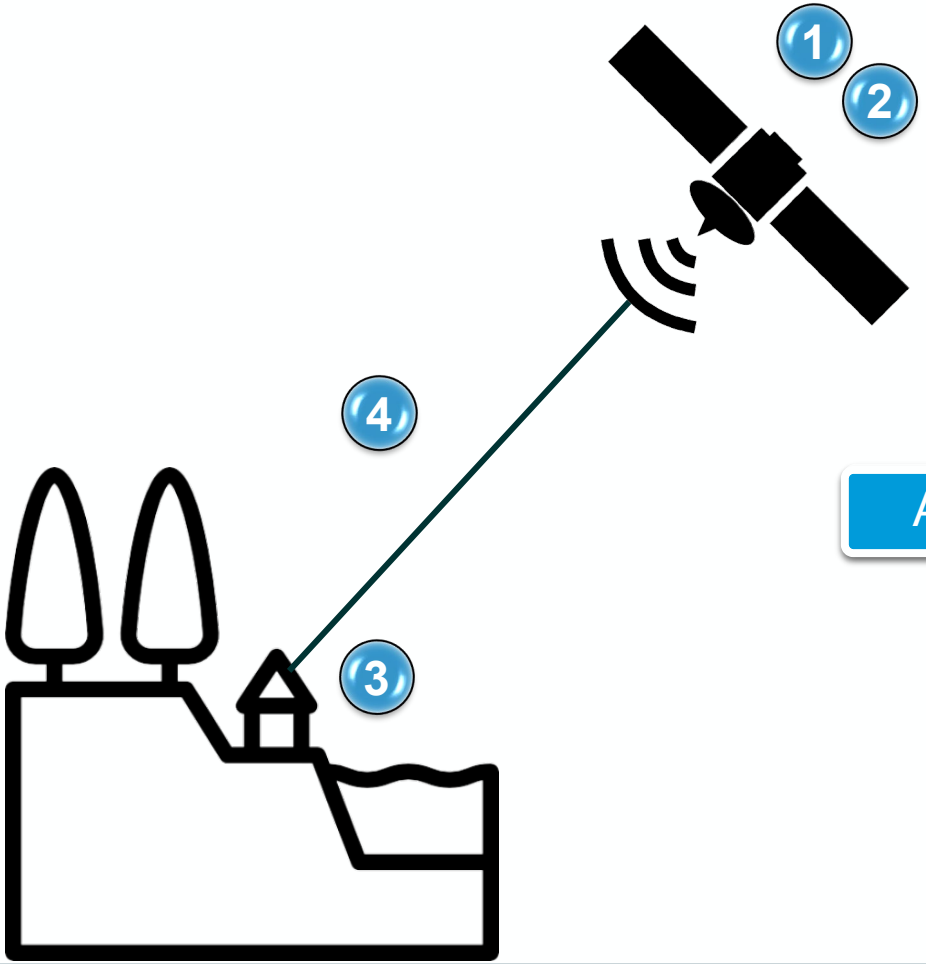
Uses own source of radiation and measures the time delay between emission and return.

Active remote sensing

Remote sensing (RS) is the technology for obtaining information from a distance without a direct physical contact with the observed object, area or phenomenon.

RS system consists of:

1) Source of light (energy)
2) Sensor
3) Object of interest - interaction with the object
4) Radiation and atmosphere
5) Recording, preparation and submission of the data
6) System for interpretation and analysis
7) Application

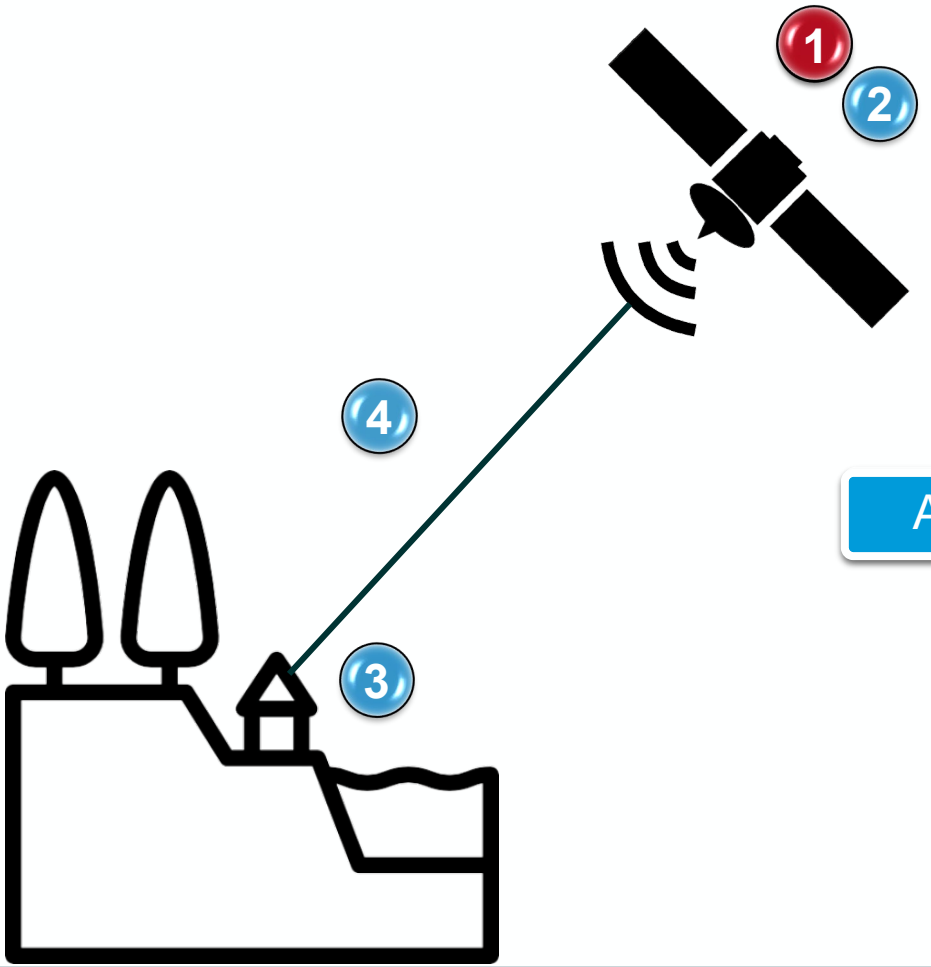


Active remote sensing

Remote sensing (RS) is the technology for obtaining information from a distance without a direct physical contact with the observed object, area or phenomenon.

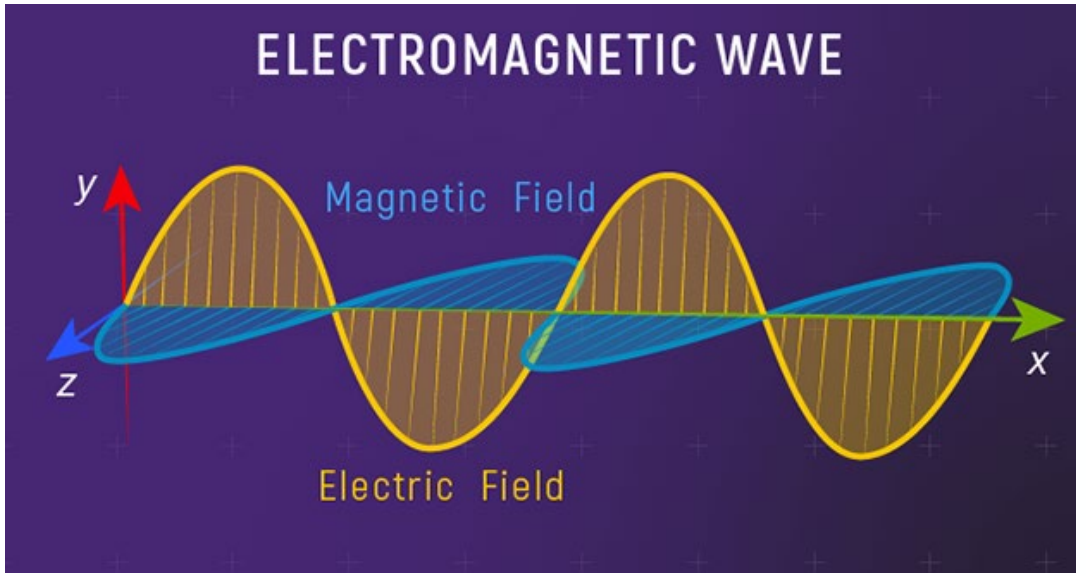
RS system consists of:

1) **Source of light (energy)**
2) Sensor
3) Object of interest - interaction with the object
4) Radiation and atmosphere
5) Recording, preparation and submission of the data
6) System for interpretation and analysis
7) Application

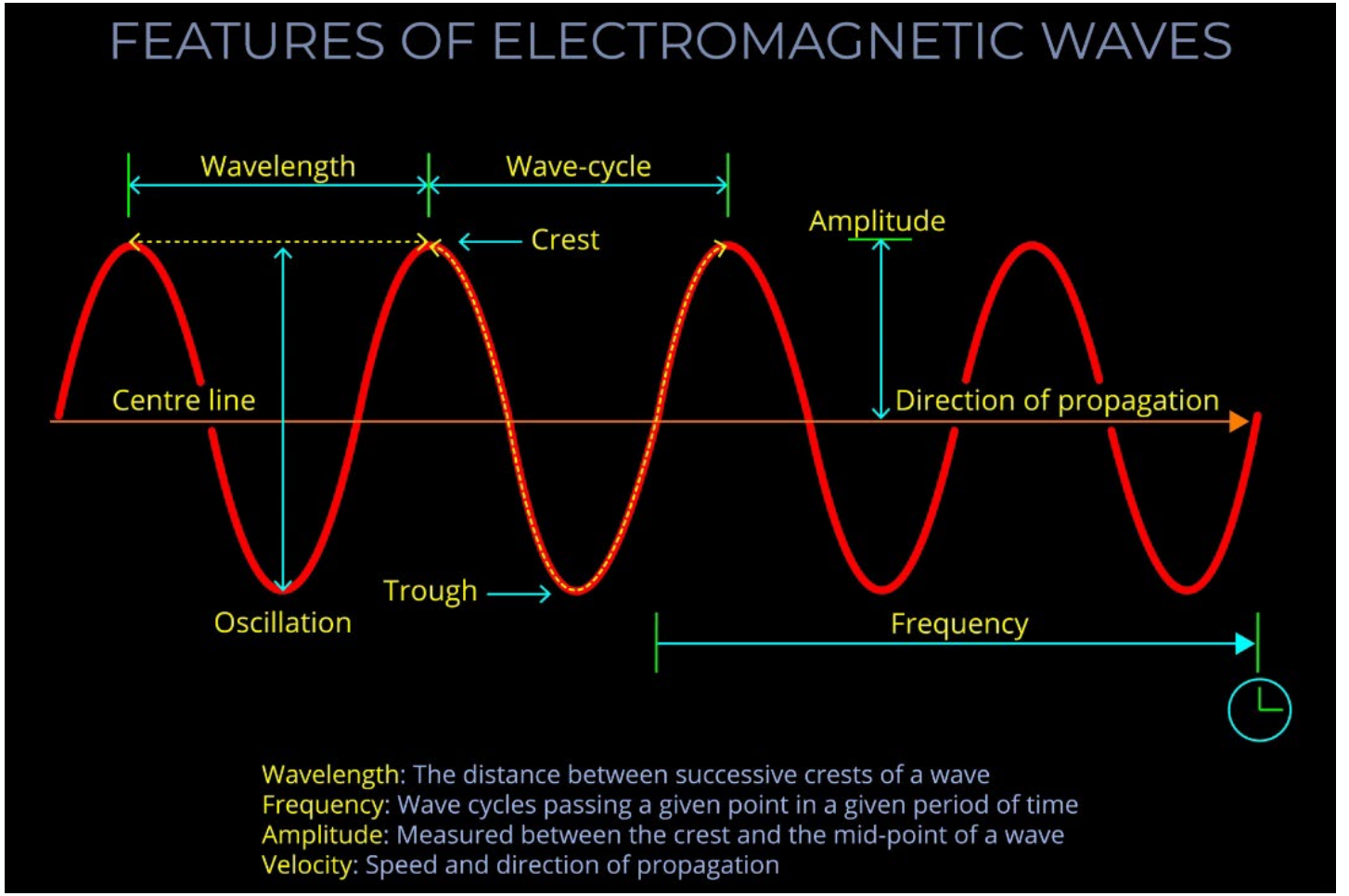


Source of Light – electromagnetic (EM) radiation

Electromagnetic radiation is the flow of energy at the speed of light through free space or a medium in the form of oscillating perpendicular to each other electric and magnetic fields.



© NASA, ESA, Leah Hustak (STScI)

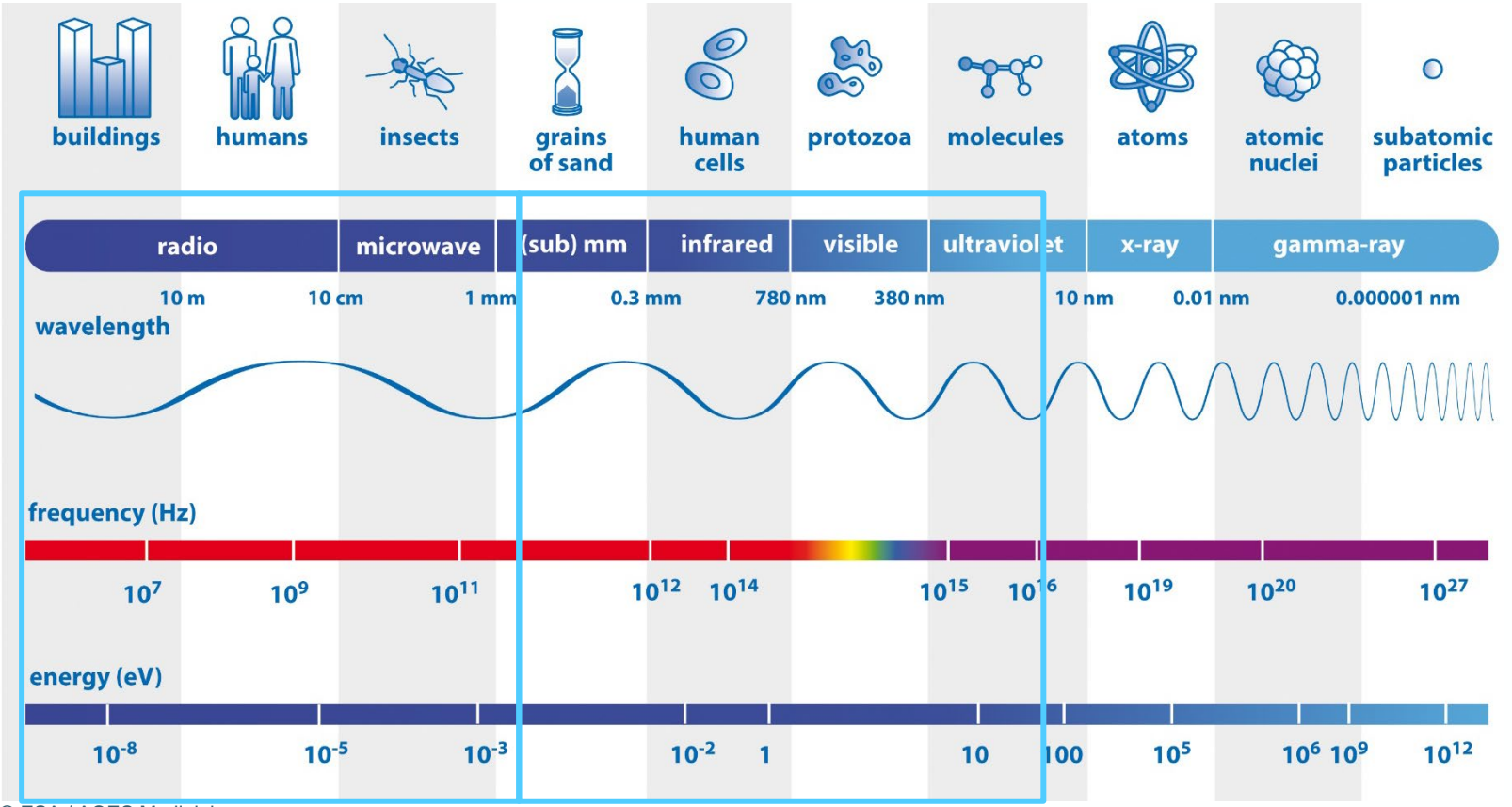


Electromagnetic spectrum

EM radiation is classified into seven classes (regions, types or **bands**) according to wavelength:

Solar illumination comes from the thermonuclear reaction within the Sun and the spectrum that reaches the Earth is within the portion of the infrared, visible and ultraviolet EM radiation, between 100 nm and 1mm.

Dedicated active air and space-borne radar systems use transmitter of EM radio or microwaves, a transmitting antenna and receiving antenna.



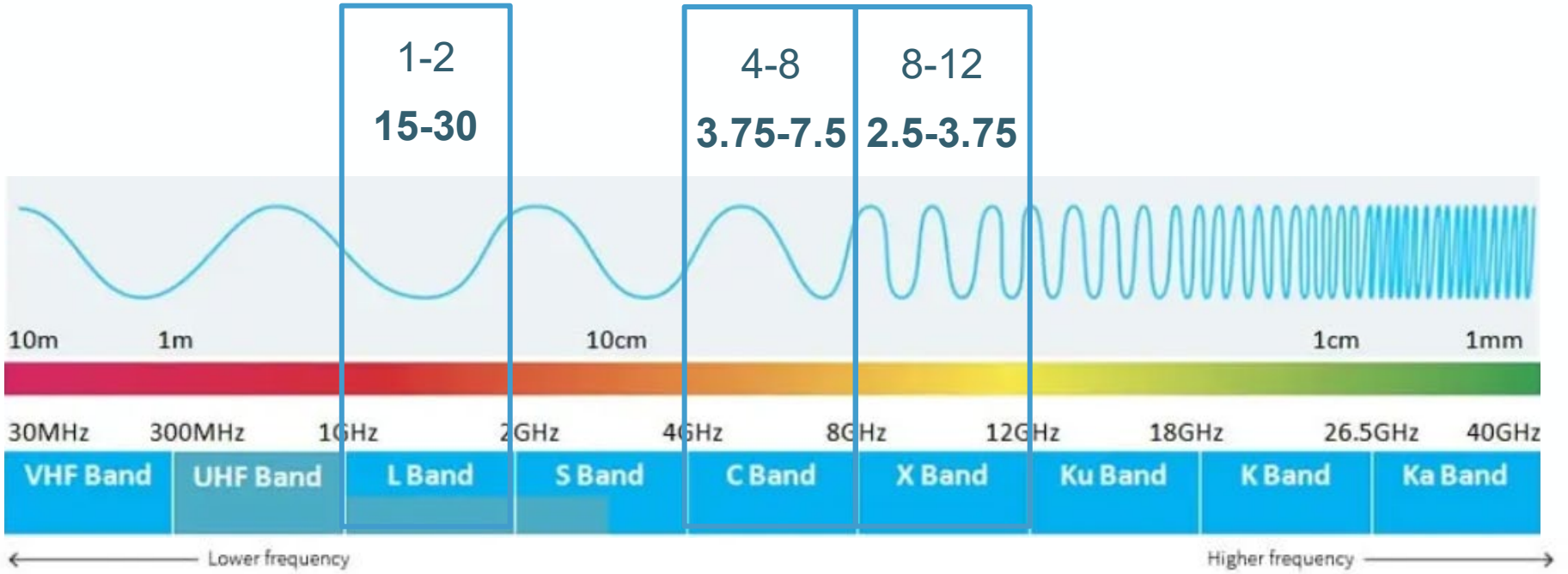
$$c = \lambda f$$

λ – wavelength (m), f – frequency (cycles per second, Hz), c – speed of light (3×10^8 m/s)

Microwave EM

Frequency range (GHz)

Wavelength range (cm)



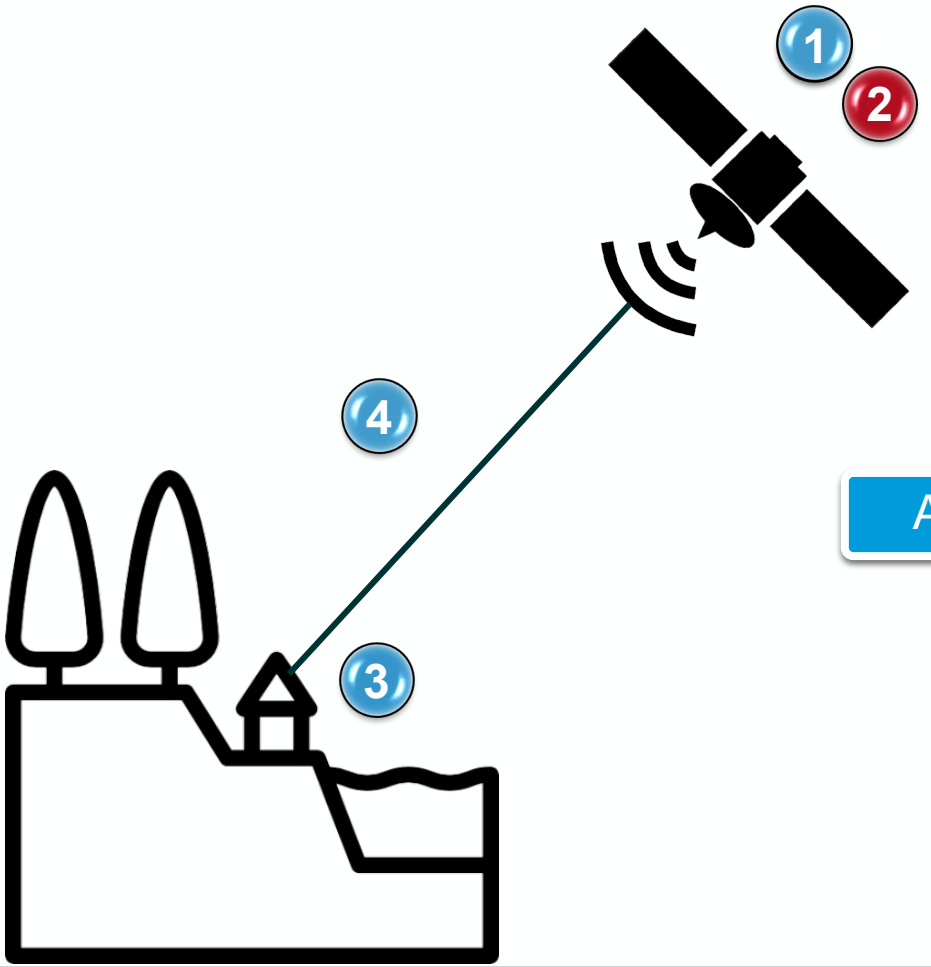
Smaller	Bandwidth	Larger
Larger	Antenna size	Smaller
Less	Attenuation (susceptibility to rain fade or other interference)	More

Active remote sensing

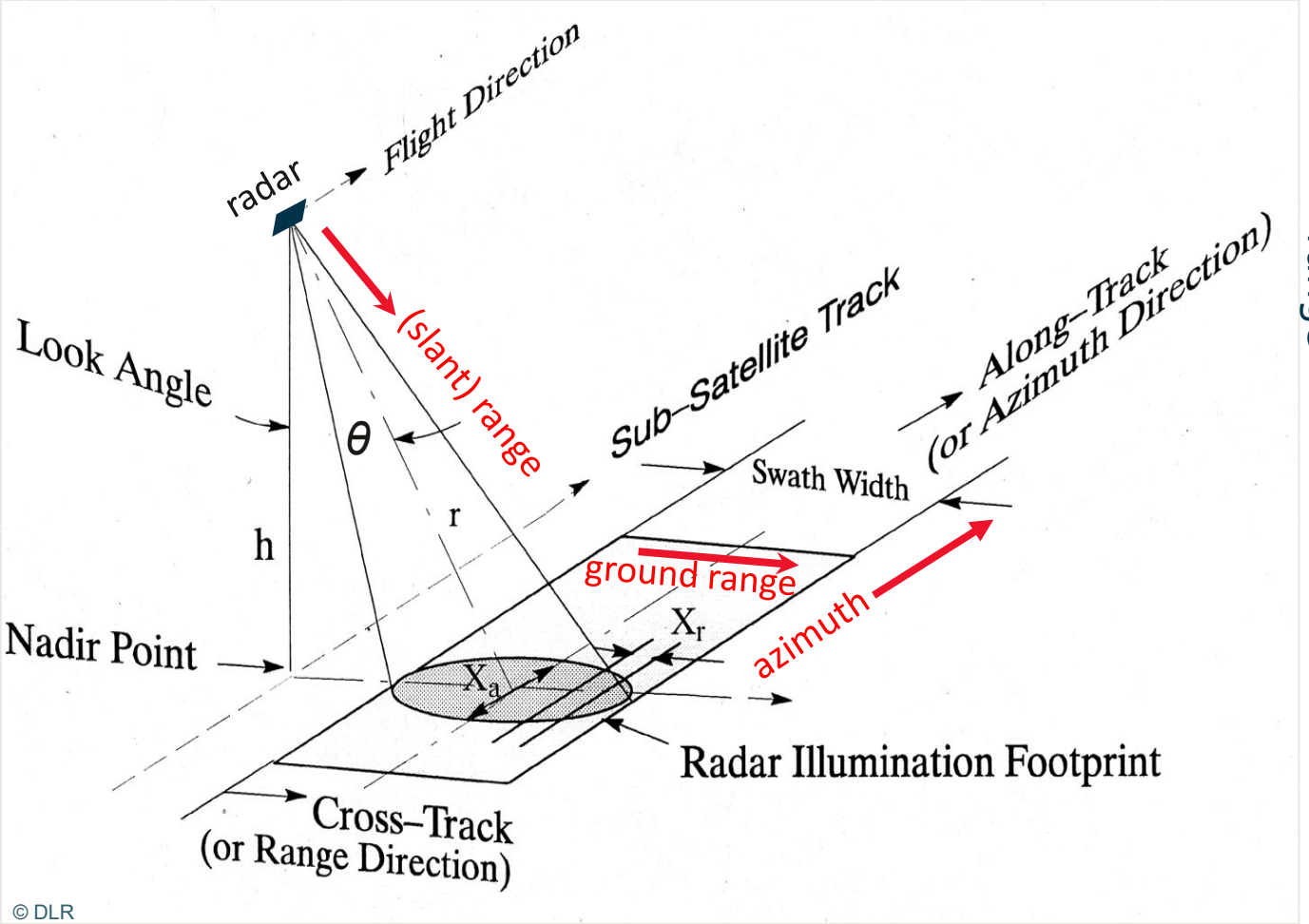
Remote sensing (RS) is the technology for obtaining information from a distance without a direct physical contact with the observed object, area or phenomenon.

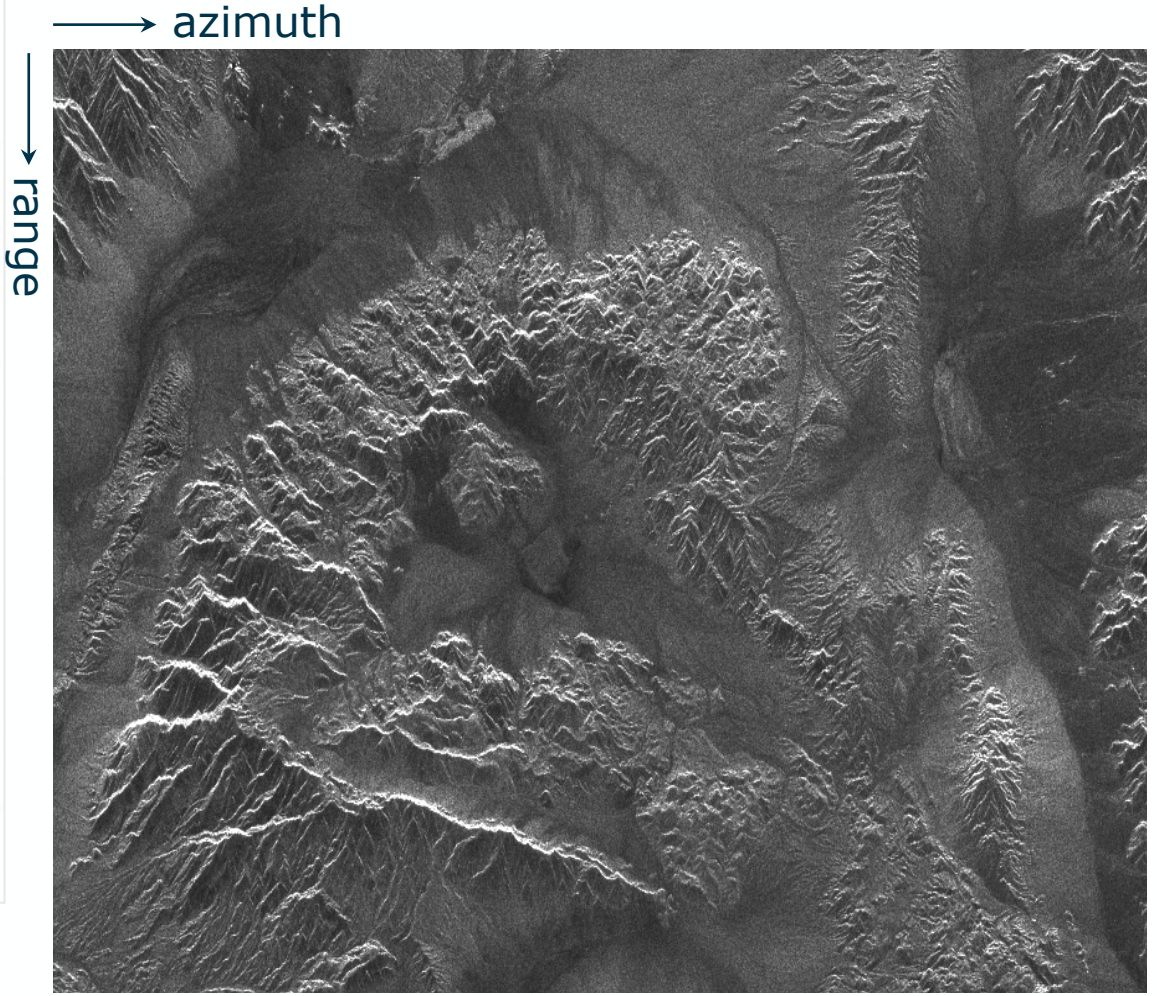
RS system consists of:

1) Source of light (energy)
2) **Sensor – satellite antenna**
3) Object of interest - interaction with the object
4) Radiation and atmosphere
5) Recording, preparation and submission of the data
6) Interpretation and analysis
7) Application



Active Radar Remote Sensing – Imaging geometry



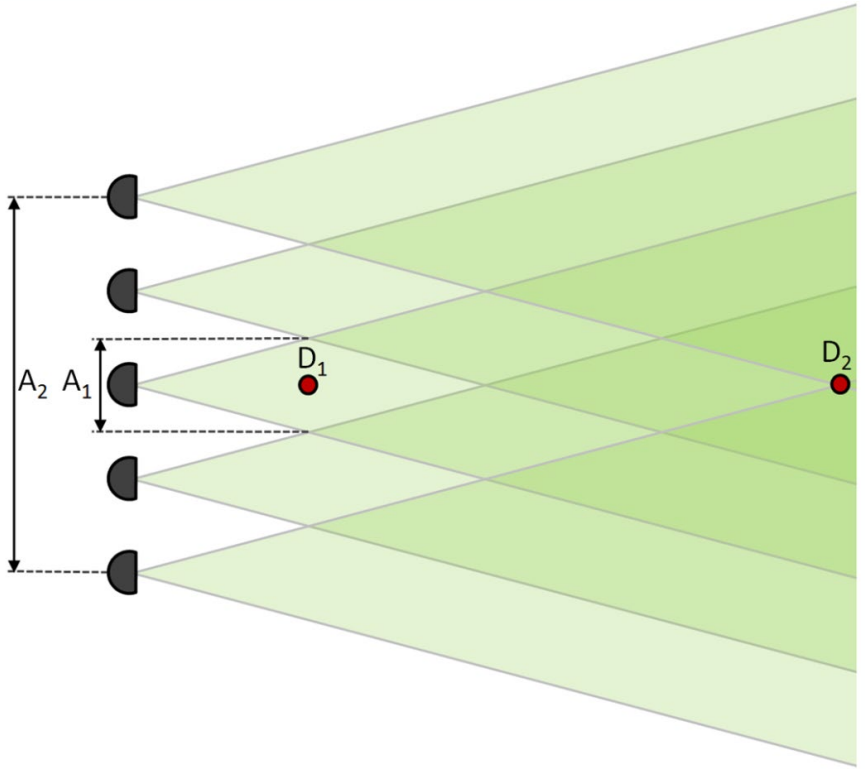


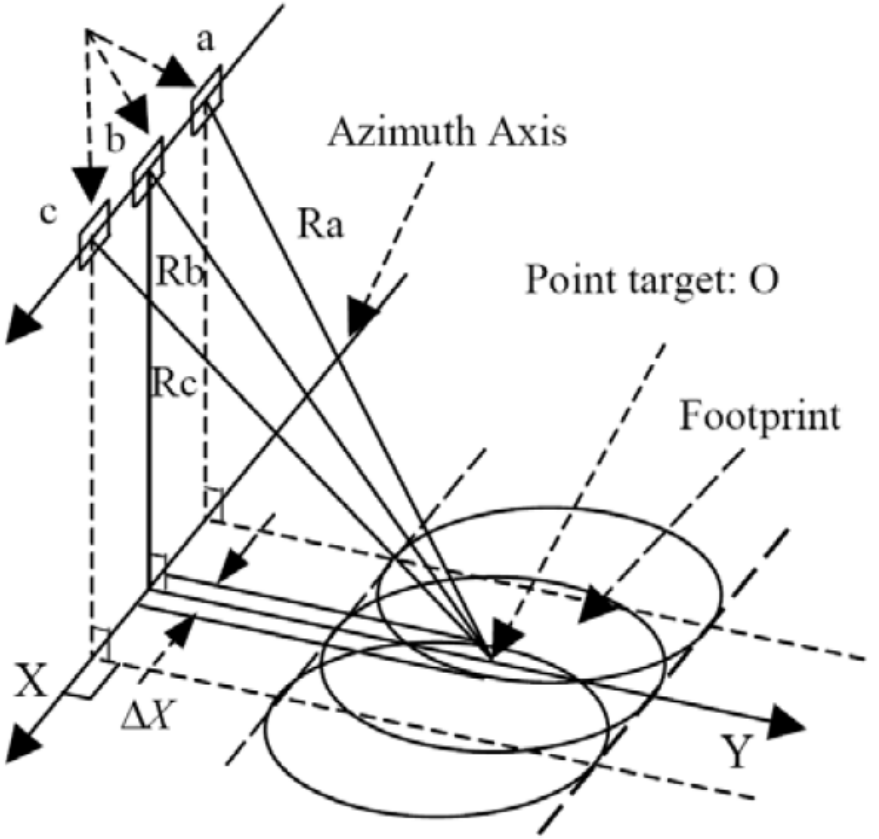
- side-looking geometry

Synthetic Aperture Radar (SAR)

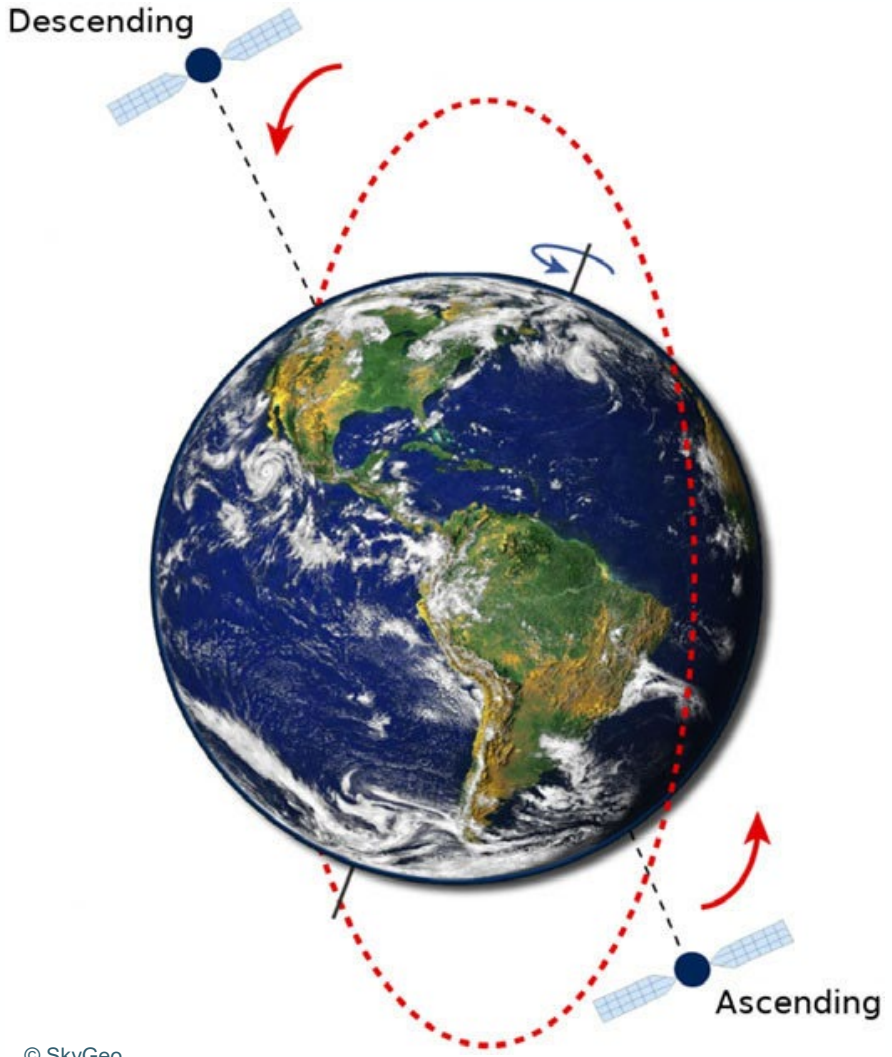
Larger antenna -> better resolution!

Solution: Simulate the equivalent of a large antenna by combining data from a series of radar pulses emitted and received by a smaller antenna while it is in motion.

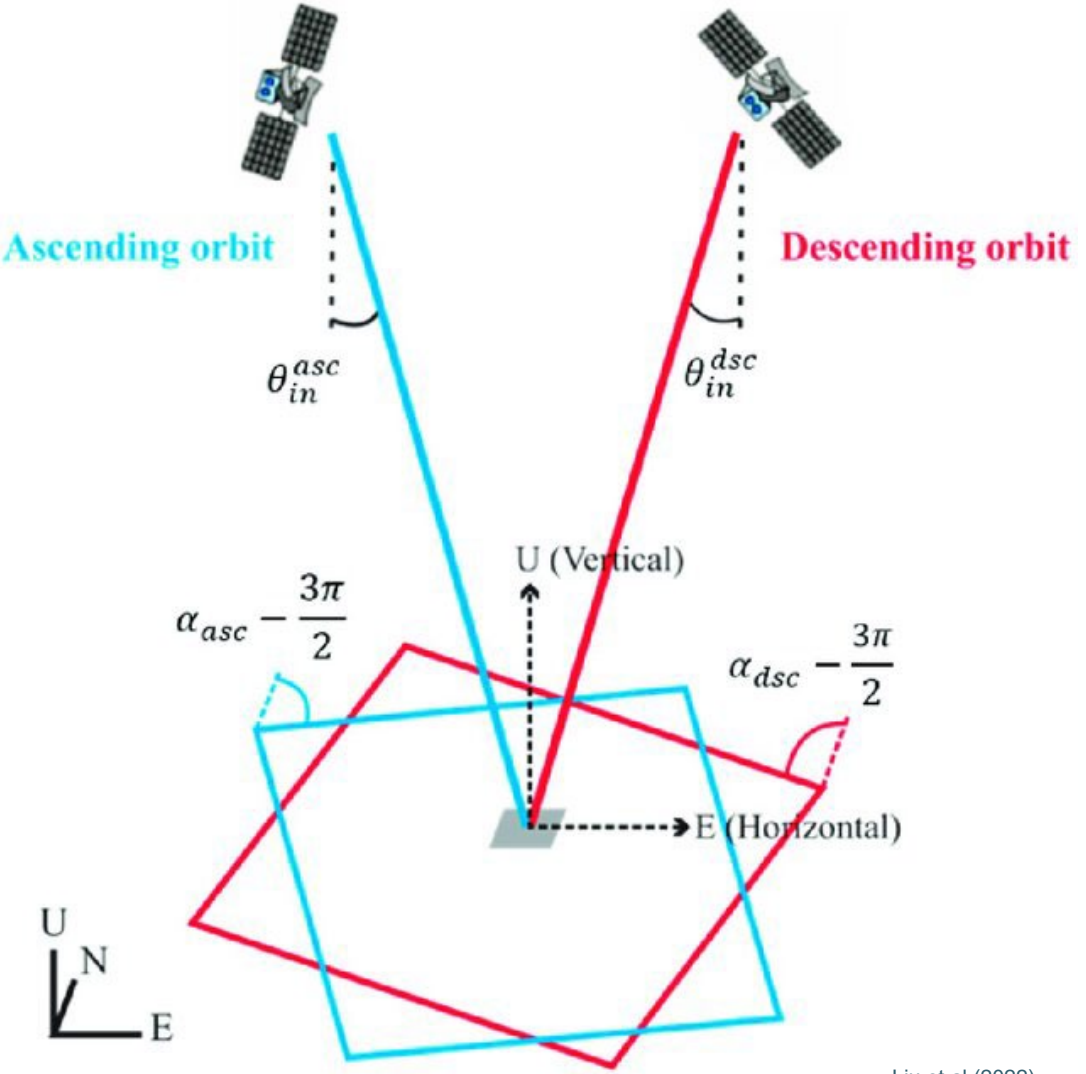




SAR satellite orbit

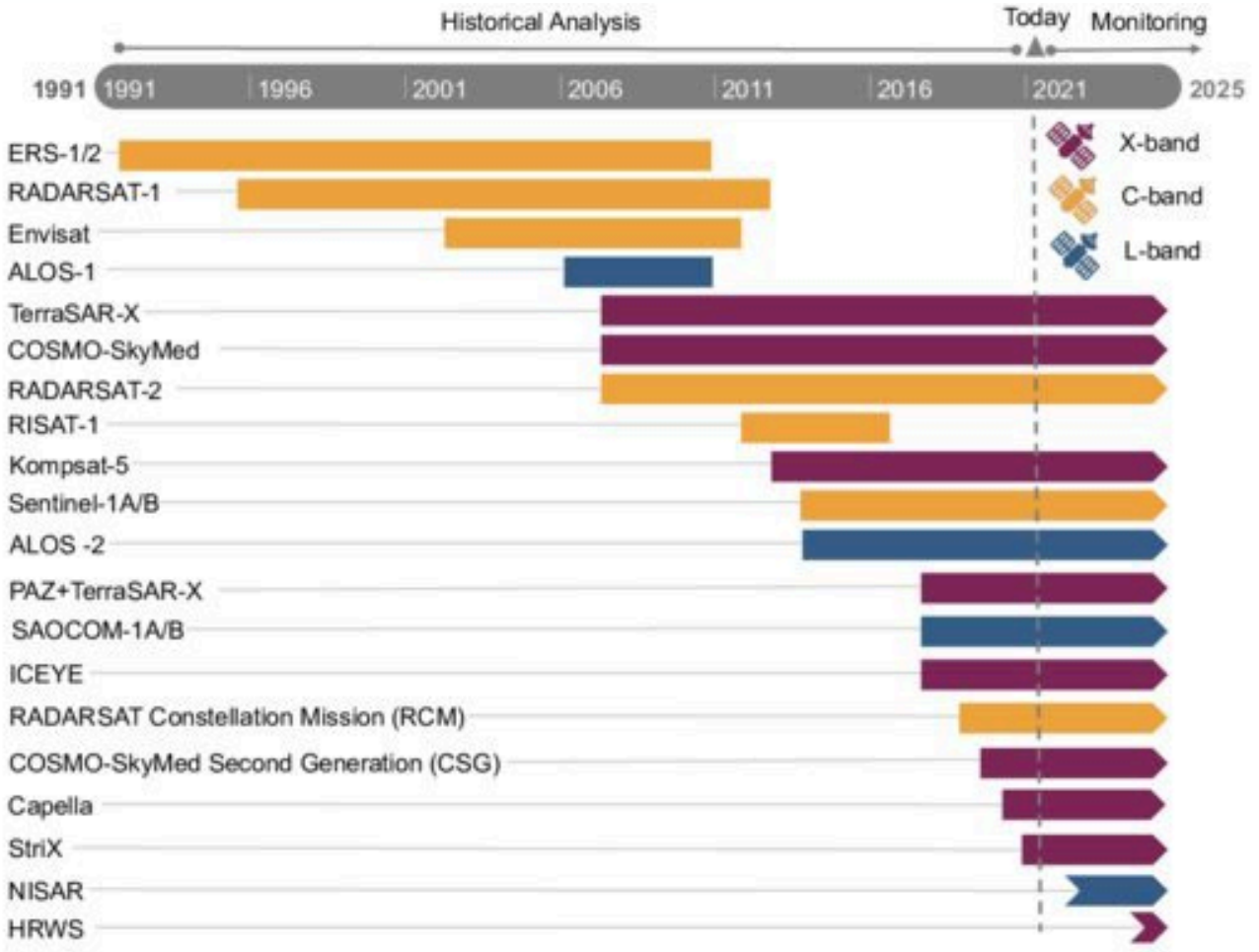


© SkyGeo



Liu et al (2022)

SAR satellite missions



	Revisit time (days)	Resolution (metre)
ERS-1/2	35	28
RADARSAT-1	24	9
Envisat	35	28
ALOS-1	46	10
TerraSAR-X	11	0.3
COSMO-SkyMed	16 (1)	0.5
RADARSAT-2	24	1.6
RISAT-1	25	1
Kompsat-5	28	1
Sentinel-1A/B	12 (6)	5
ALOS -2	14	1
PAZ+TerraSAR-X	11 (4)	1
SAOCOM-1A/B	16 (8)	3
ICEYE	<1	0.4
RADARSAT Constellation Mission (RCM)	12 (4)	1
COSMO-SkyMed Second Generation (CSG)	16 (8)	0.5
Capella	<1	0.3
StriX	1	1
NISAR	12	3
HRWS	-	0.25

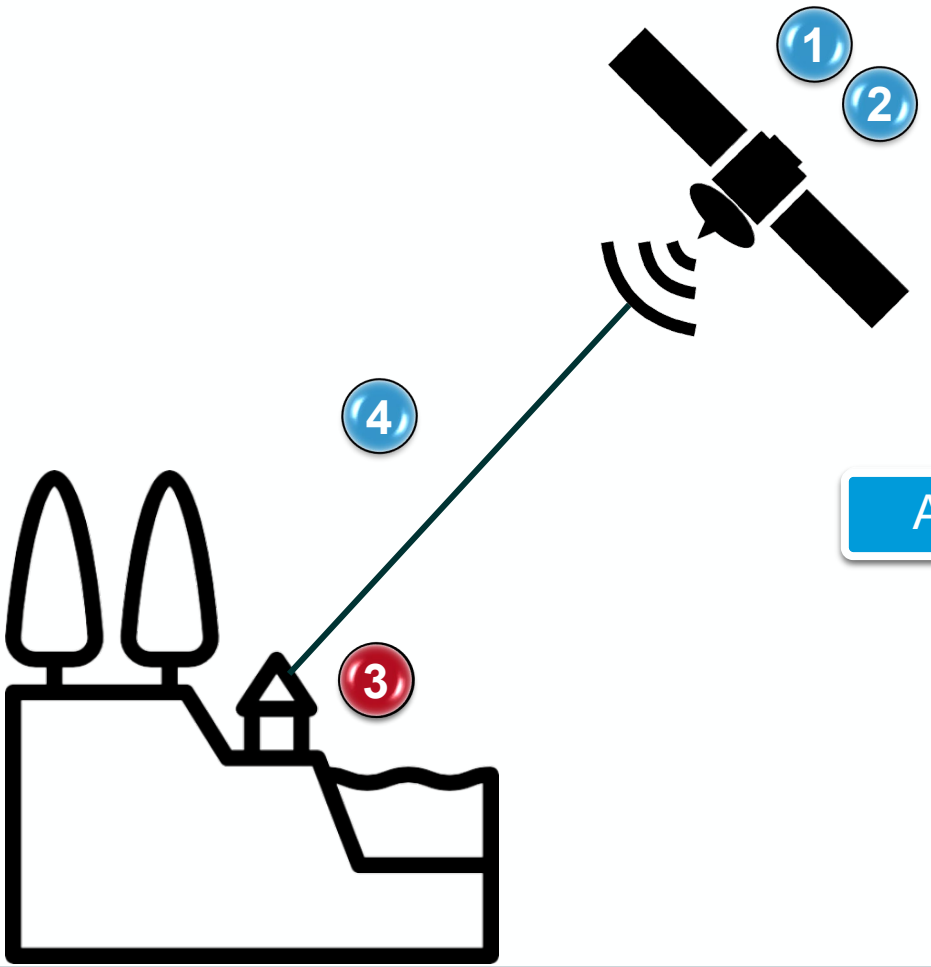
Macchiarulo et al. (2021)

Active remote sensing

Remote sensing (RS) is the technology for obtaining information from a distance without a direct physical contact with the observed object, area or phenomenon.

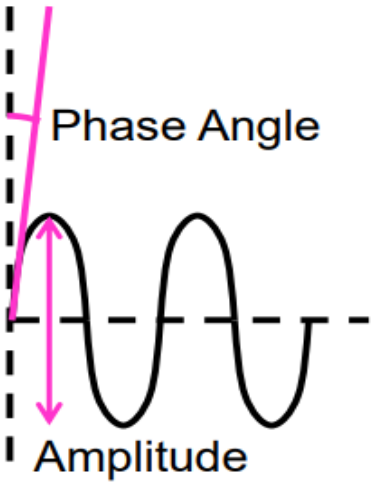
RS system consists of:

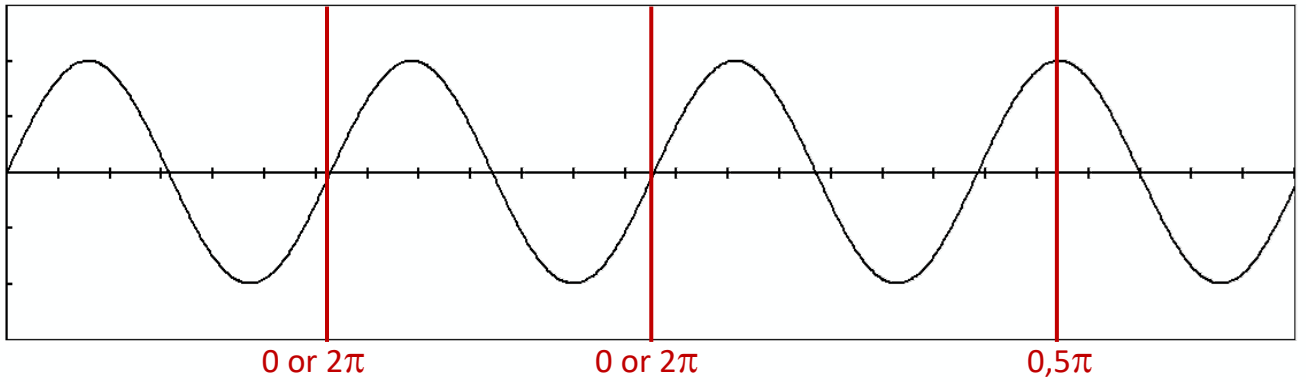
1) Source of light (energy)
2) Sensor
3) **Object of interest - <u>interaction with the object</u>**
4) Radiation and atmosphere
5) Recording, preparation and submission of the data
6) System for interpretation and analysis
7) Application



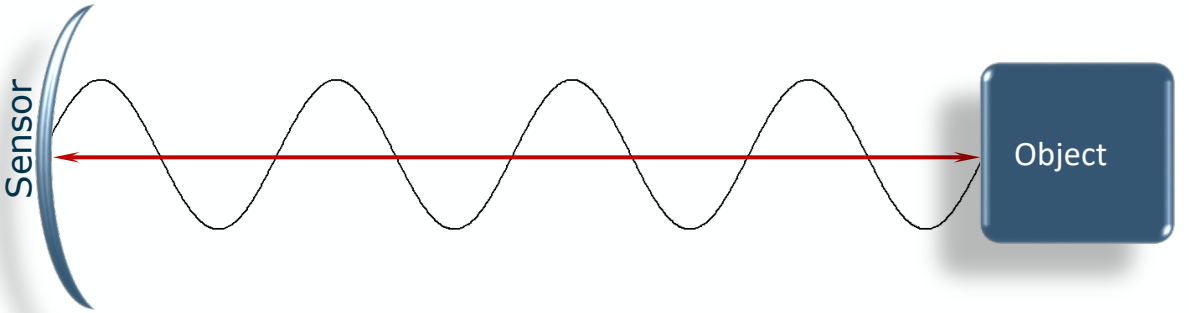
SAR signal – phase

1. Phase [0, 2π] - Property of a periodic phenomenon (electromagnetic wave) referred to an arbitrary origin.

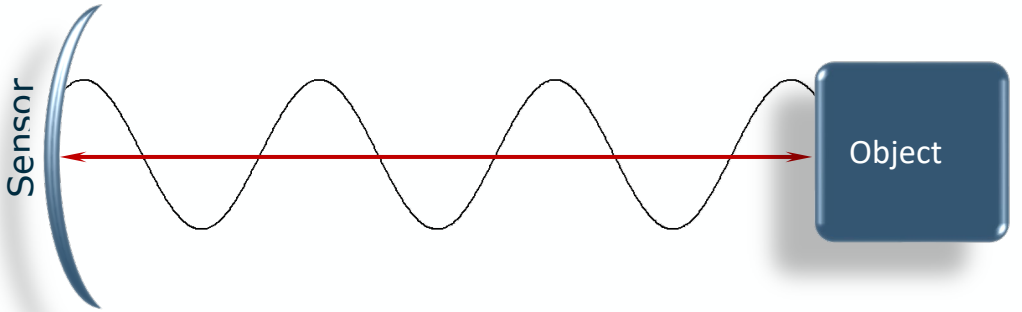




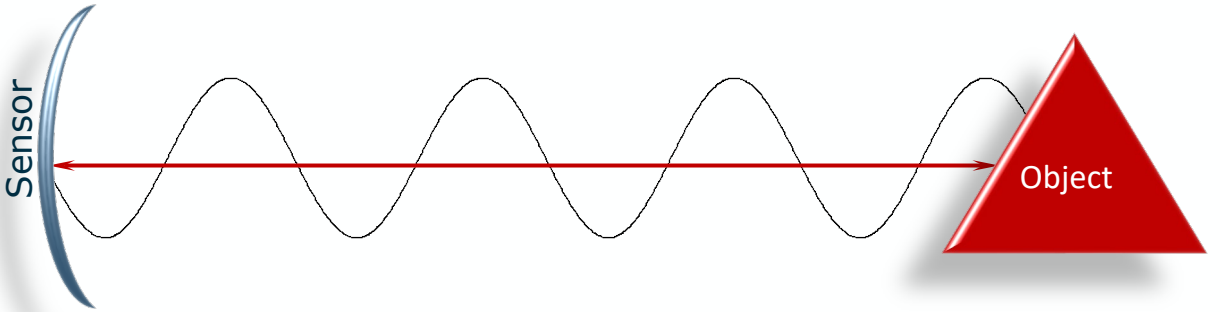
SAR signal – interaction with the object



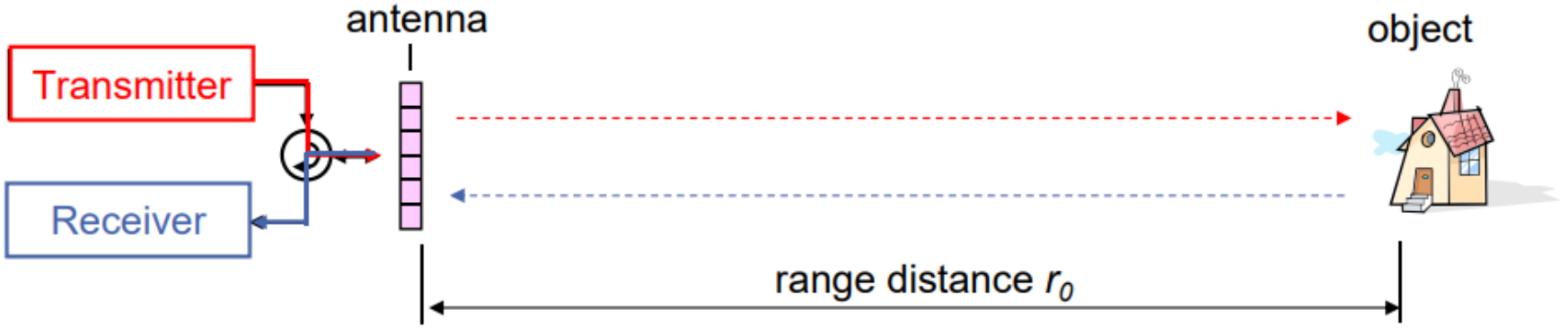
Depends on the distance between the sensor and the target:

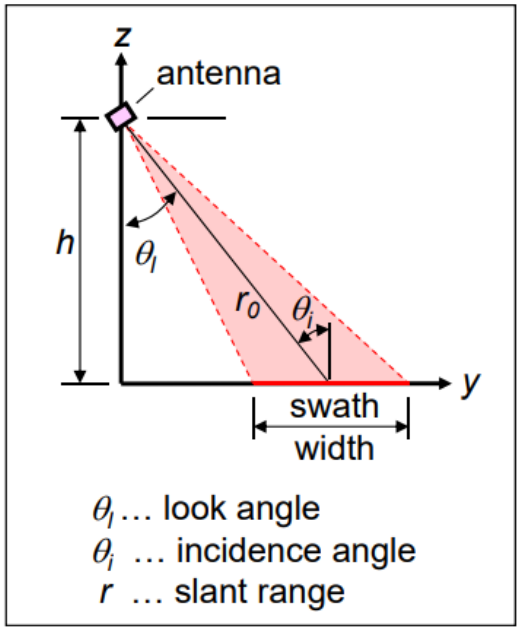


Depends on the characteristics of the target:



SAR signal - measurement principle



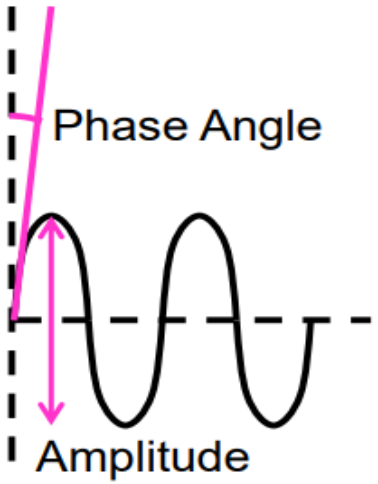


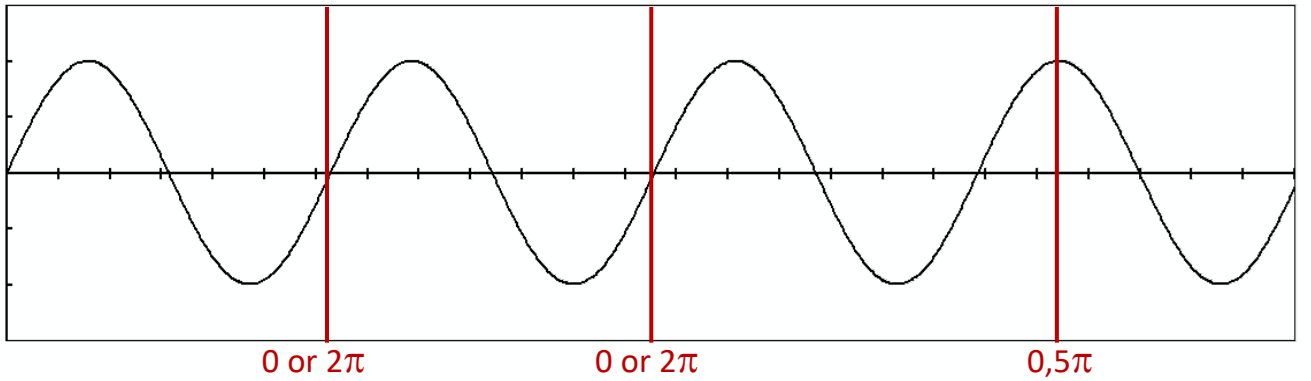
- Time delay for the received signal: $t_d = \frac{2 \cdot r_0}{c_0}$

- Incidence angle: $\cos\theta_l \approx \frac{h}{r_o}$

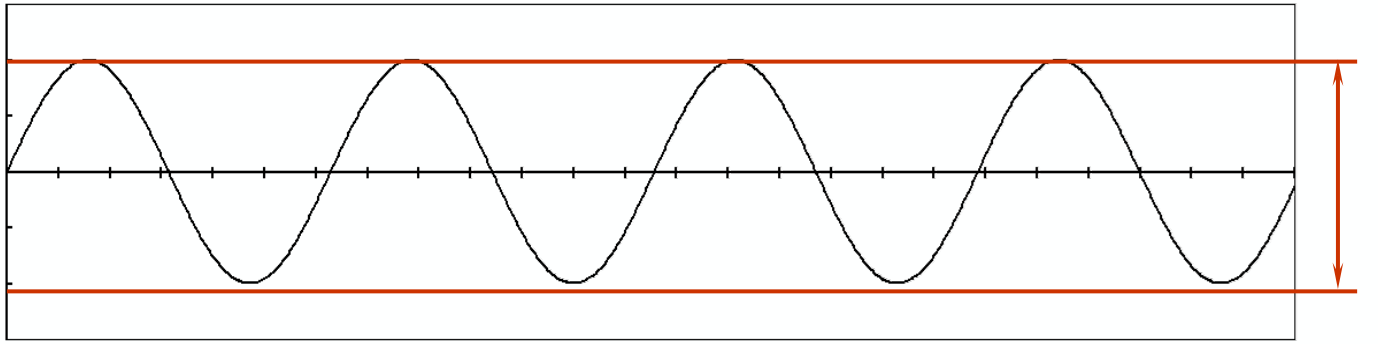
SAR signal – phase and amplidute

1. Phase [0, 2π] - Property of a periodic phenomenon (electromagnetic wave) referred to an arbitrary origin.

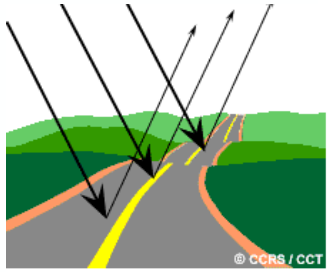




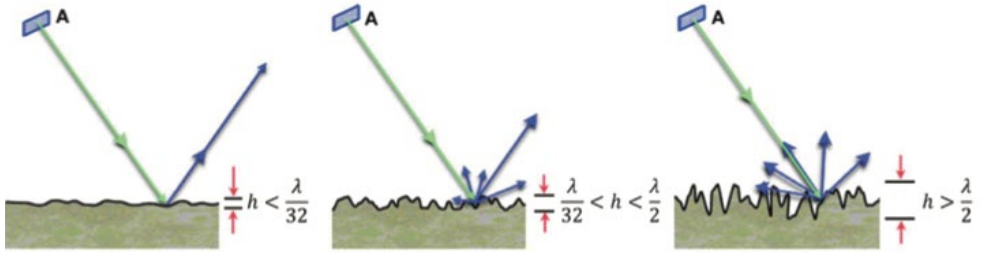
2. Amplitude - Measure of the strength of a signal, in this context the height of the electromagnetic wave.

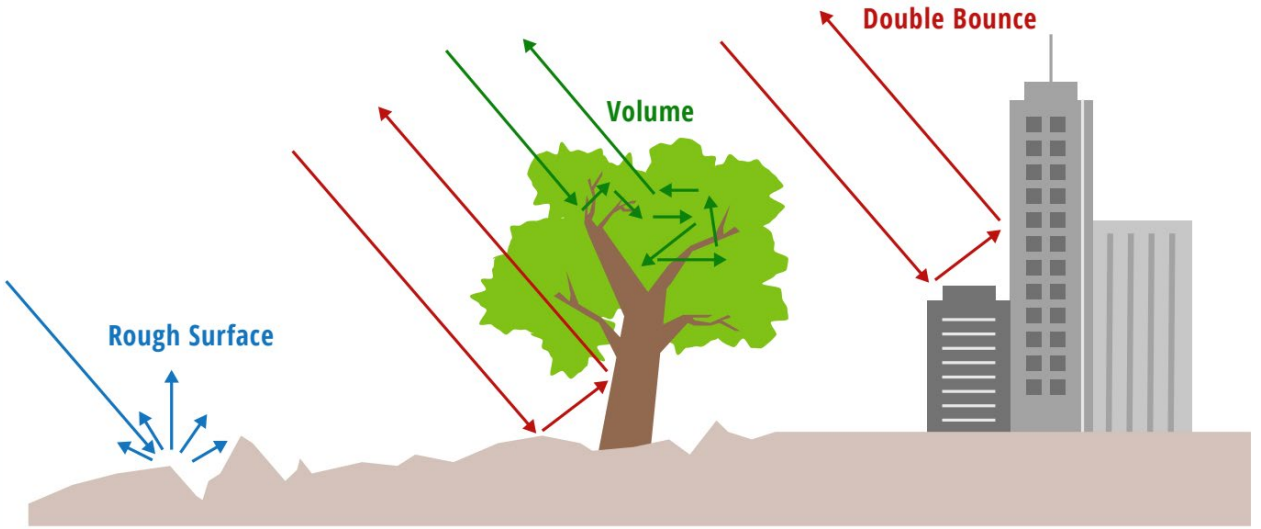


SAR signal – interaction with the object

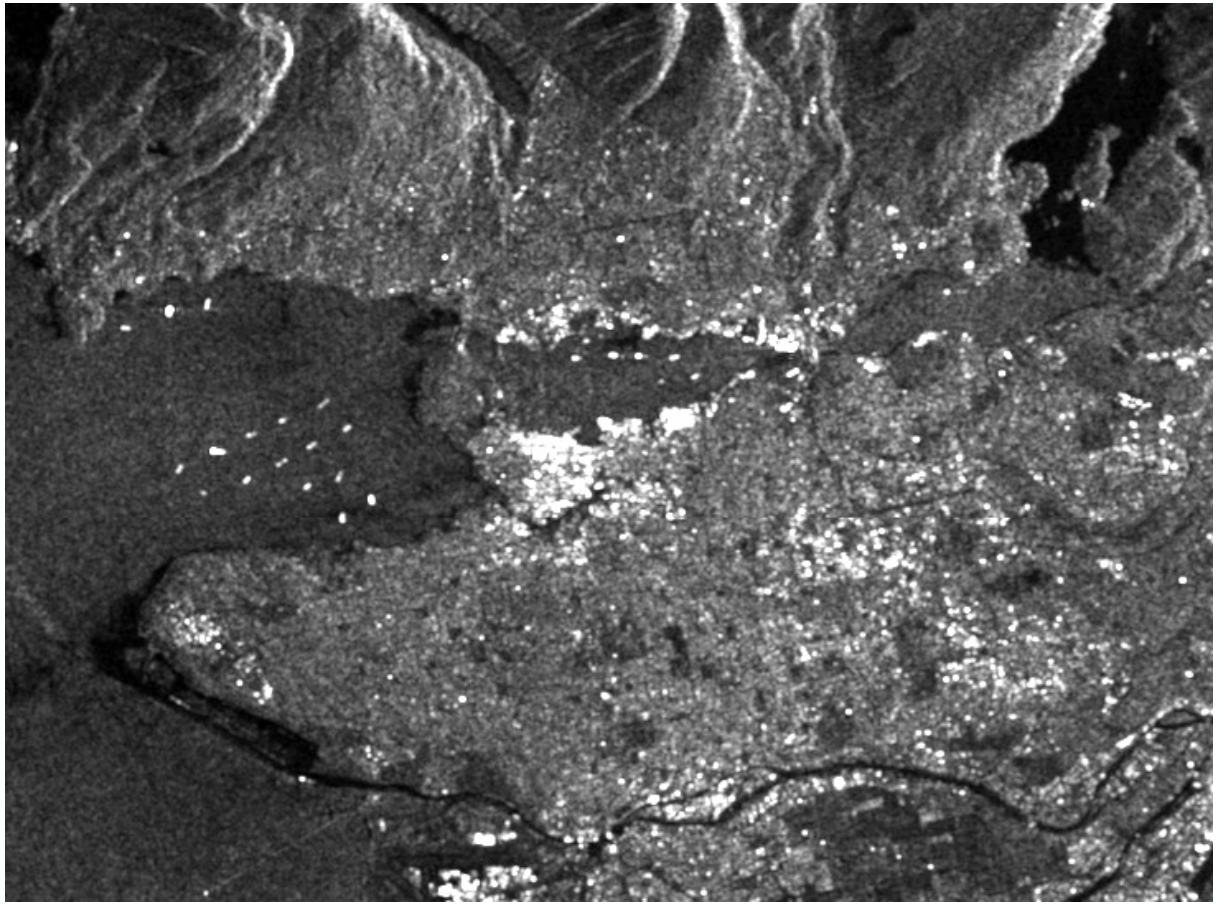


Specular reflection



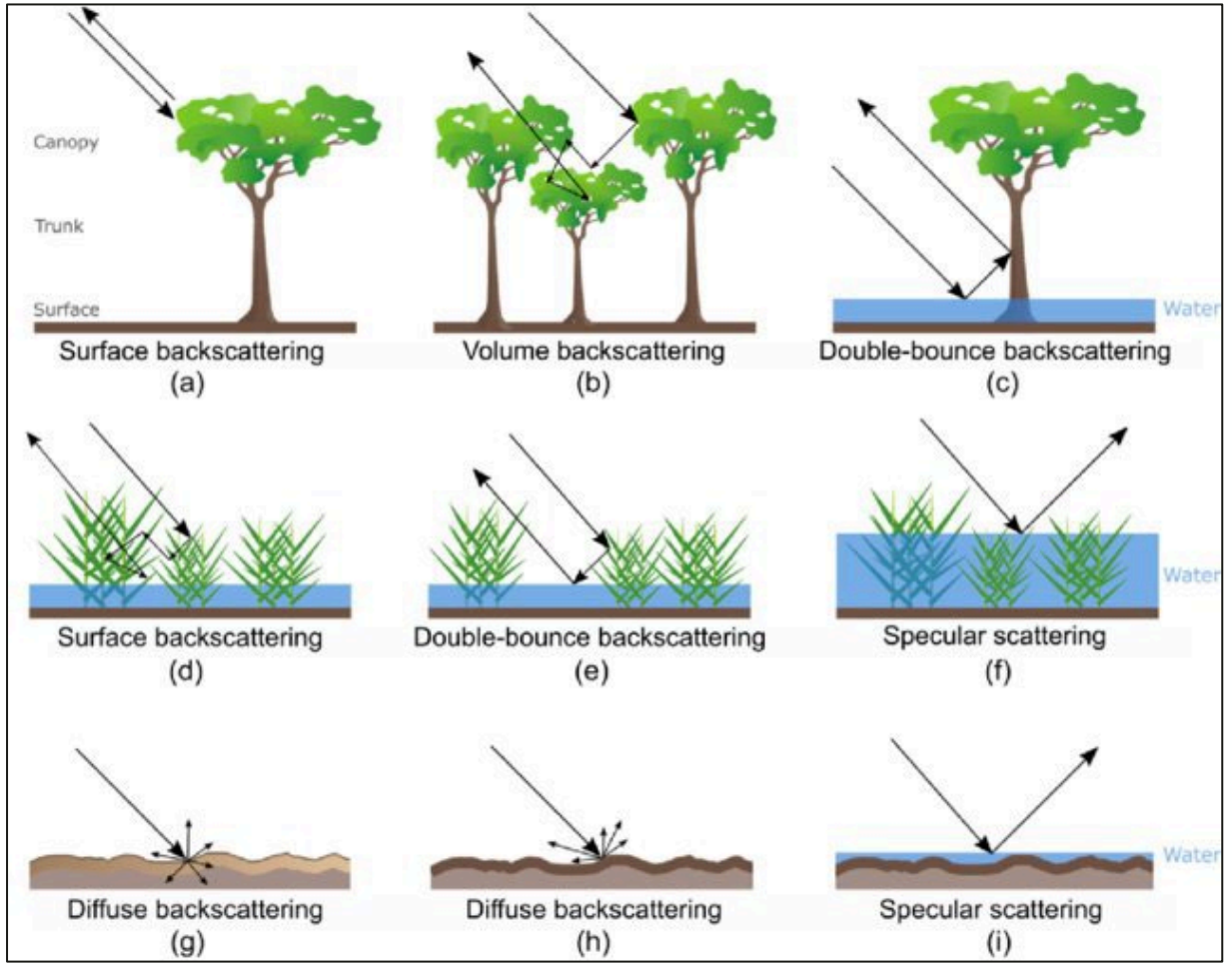


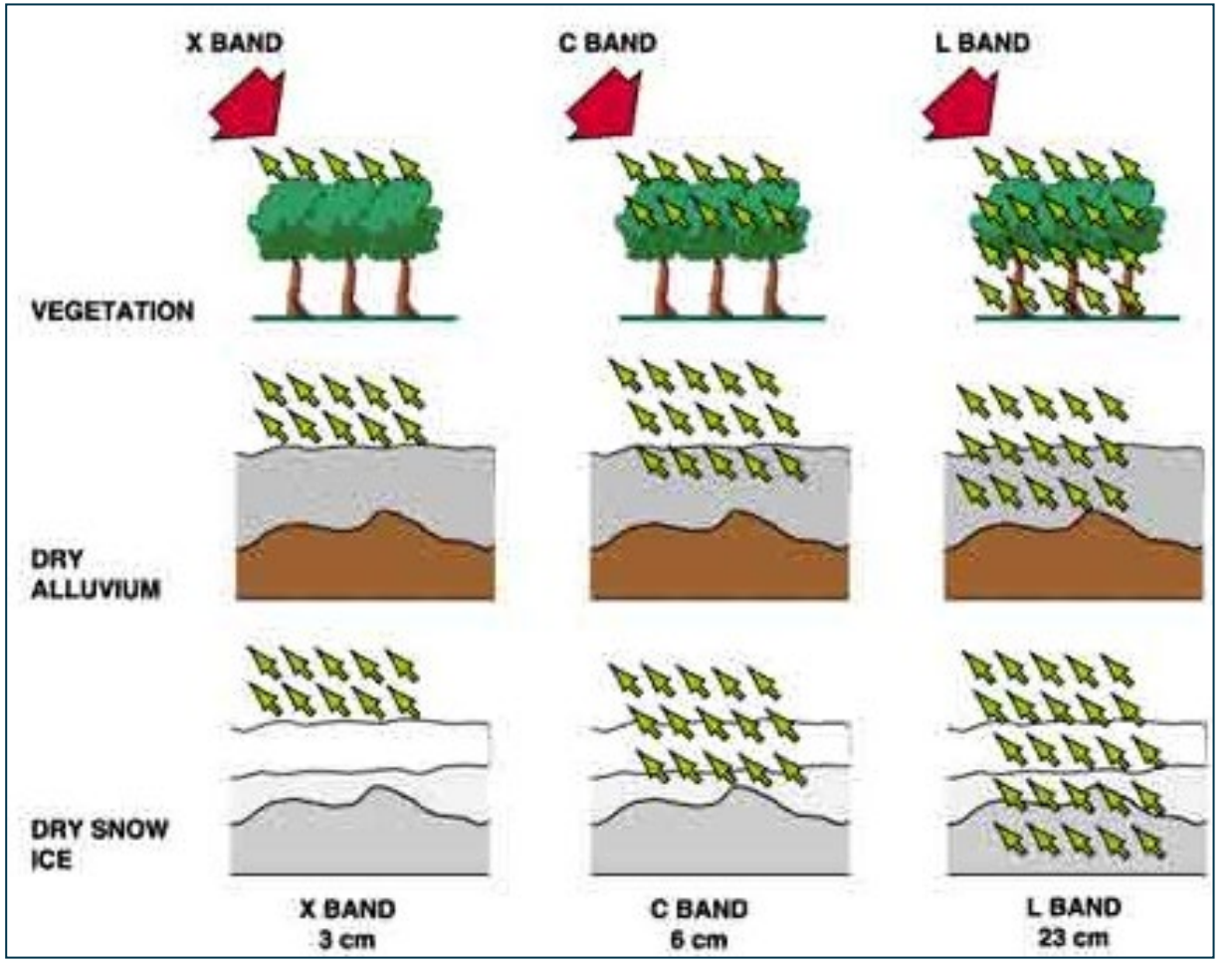
© ASF/Meyer



© DLR

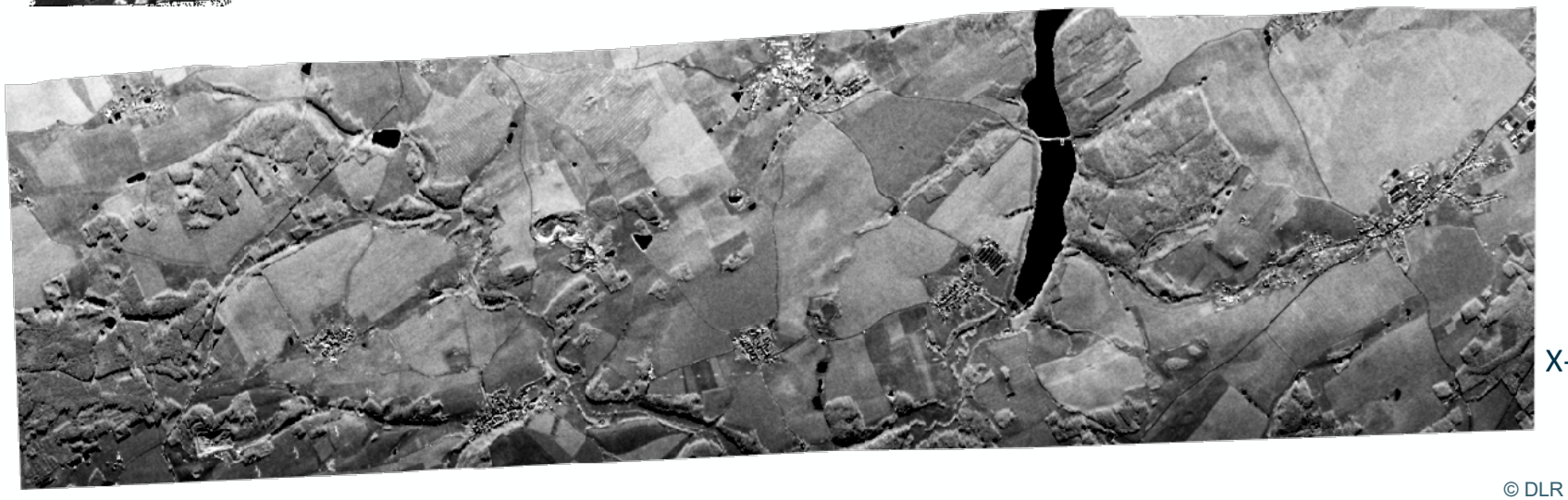
SAR signal – interaction with the object





Impact of the frequency

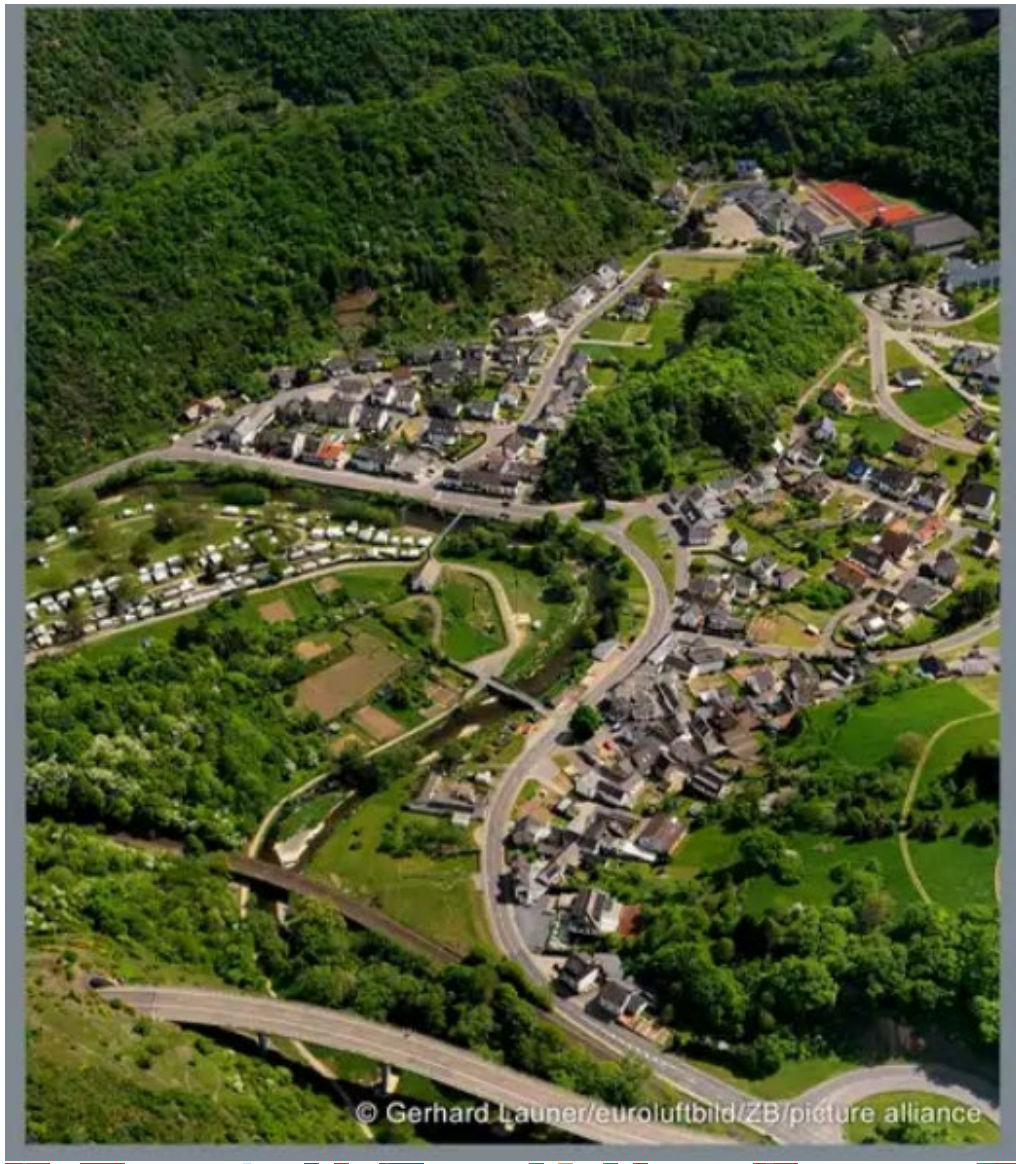
L-band



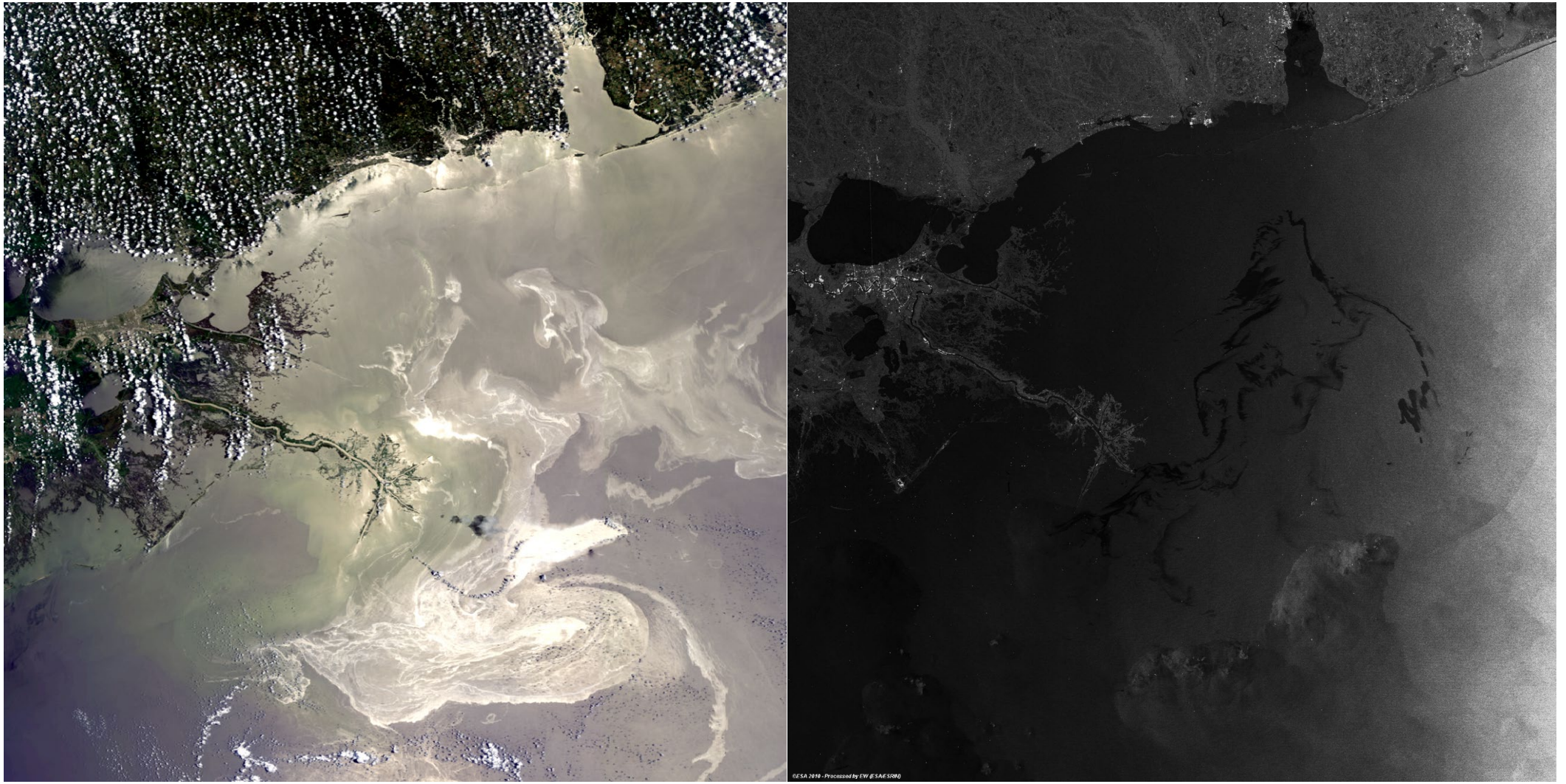
X-band

© DLR

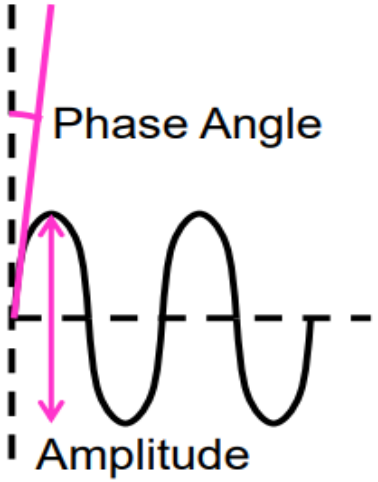
Germany 2021 flood



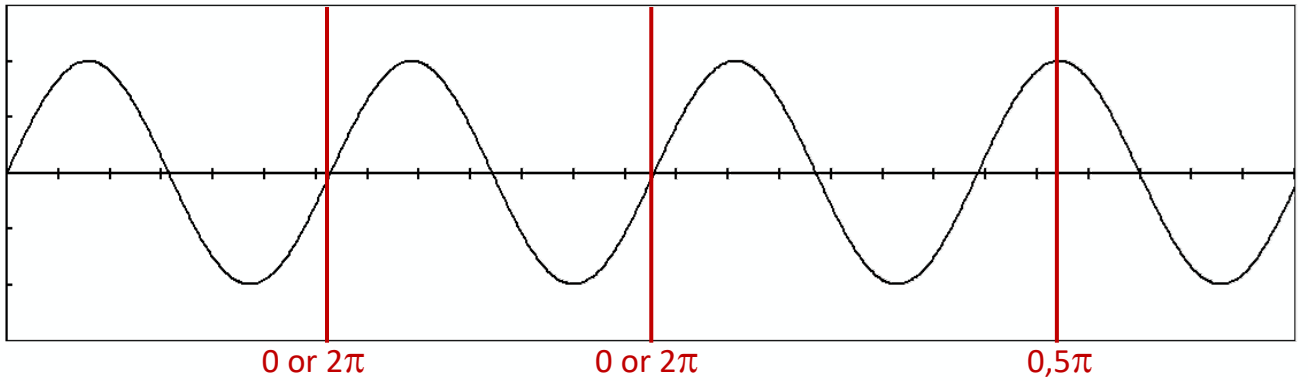
Mexico 2010 oil spill



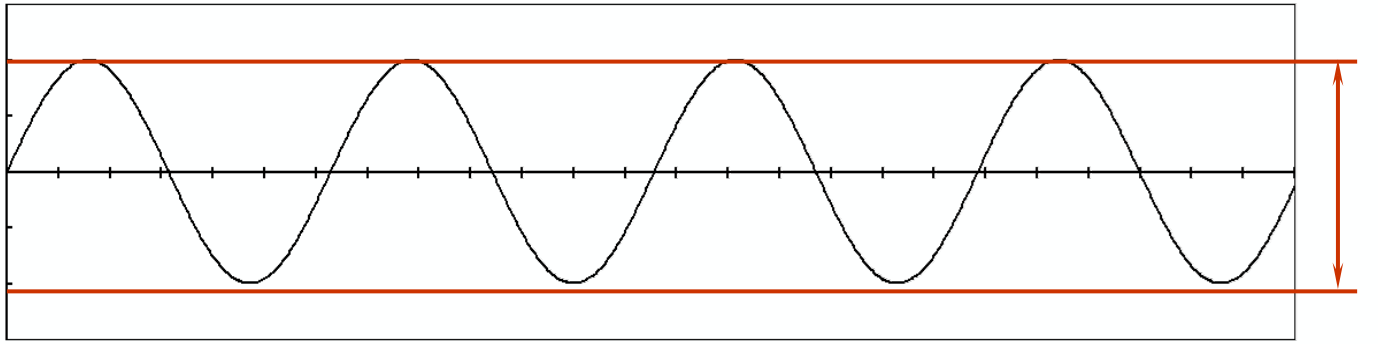
SAR signal – phase and amplidute



1. Phase [0, 2π] - Property of a periodic phenomenon (electromagnetic wave) referred to an arbitrary origin.



2. Amplitude - Measure of the strength of a signal, in this context the height of the electromagnetic wave.



SAR signal

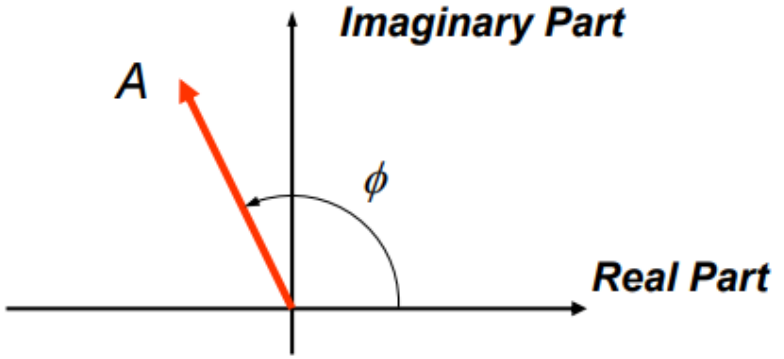
complex representation: $A \cdot \cos(2\pi f_0 t + \phi) \rightarrow A \cdot \exp[j\,(2\pi f_0 t + \phi)]$

after demodulation: $A \cdot \exp[j \cdot \phi]$

amplitude: A

intensity, power: A^2

phase: ϕ

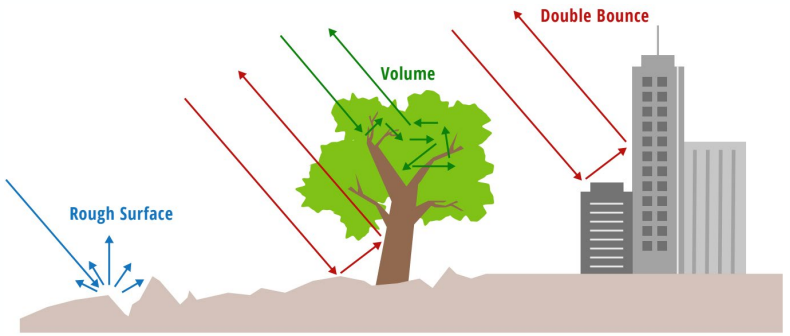


Every pixel of a complex SAR image consists of a real and an imaginary part, i.e. it is a phasor and contains amplitude and phase information.

amplitude information $\rightarrow$ *backscattering coefficient* σ_o

$$\text{phase information} = -\frac{4.\pi}{\lambda}.r + \phi_{object}$$

Backscattering Coefficient



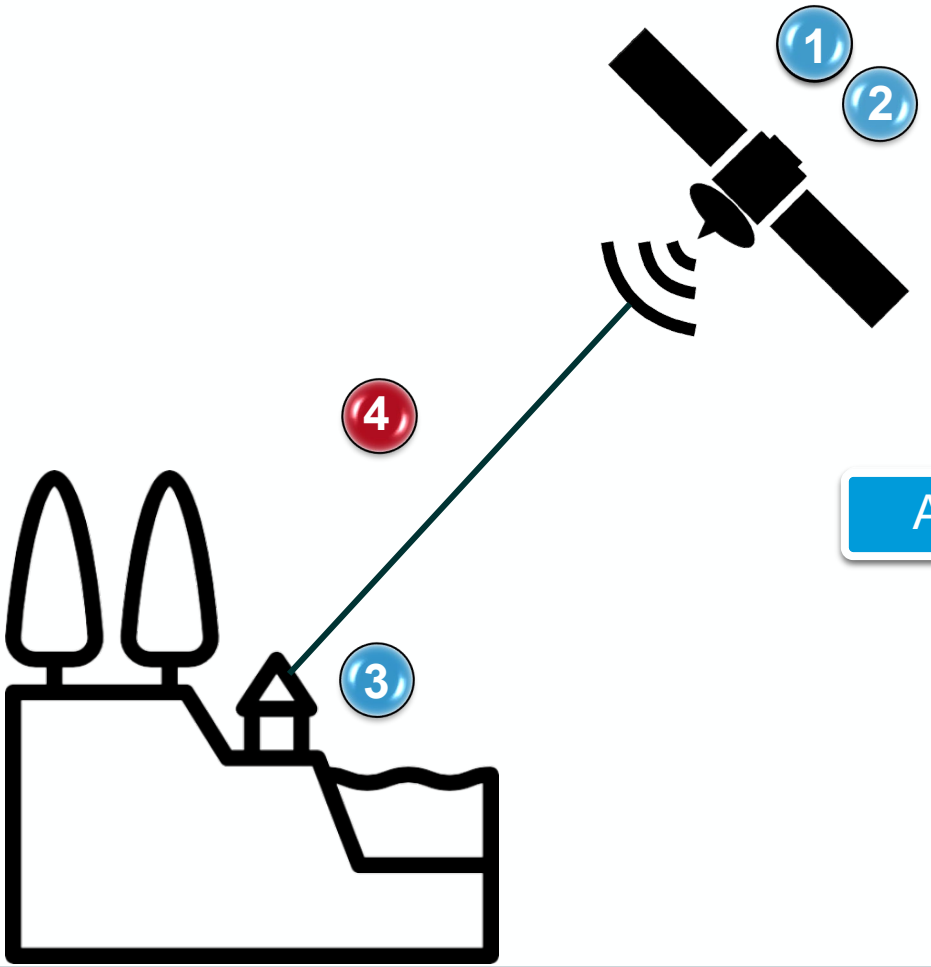
Levels of Radar backscatter	Typical scenario
Very high backscatter (above -5 dB)	→ Man-Made objects (urban) → Terrain Slopes towards radar → very rough surface → radar looking very steep
High backscatter (-10 dB to 0 dB)	→ rough surface → dense vegetation (forest)
Moderate backscatter (-20 to -10 dB)	→ medium level of vegetation → agricultural crops → moderately rough surfaces
Low backscatter (below -20 dB)	→ smooth surface → calm water → road → very dry soil (sand)

Active remote sensing

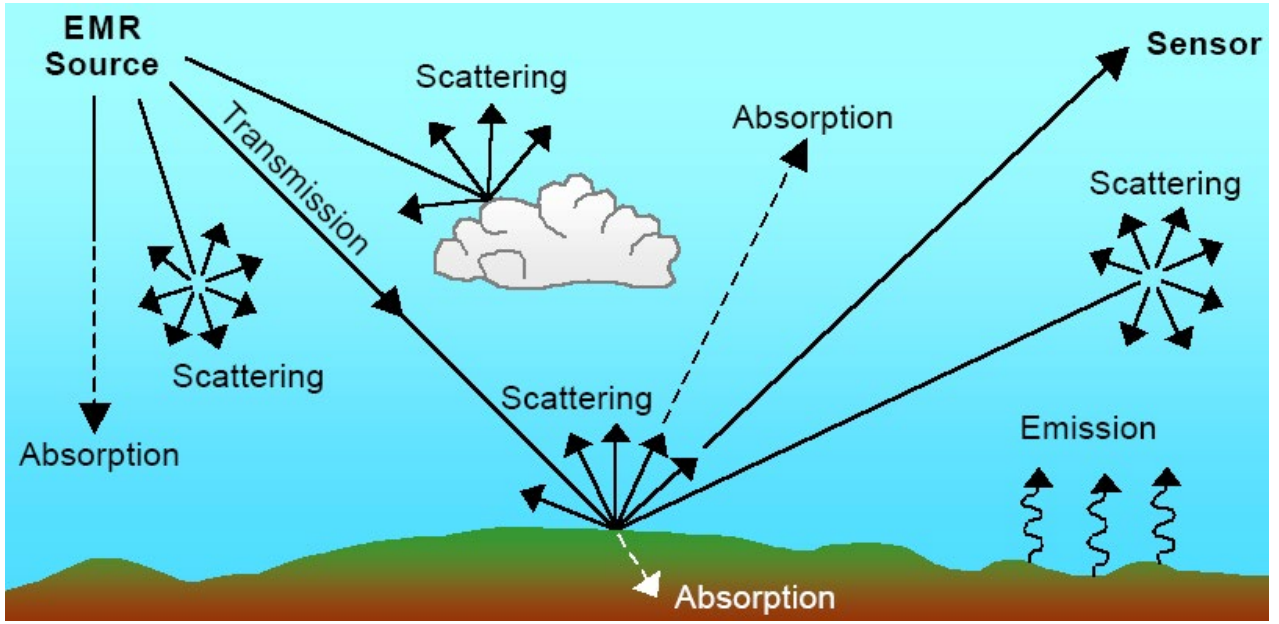
Remote sensing (RS) is the technology for obtaining information from a distance without a direct physical contact with the observed object, area or phenomenon.

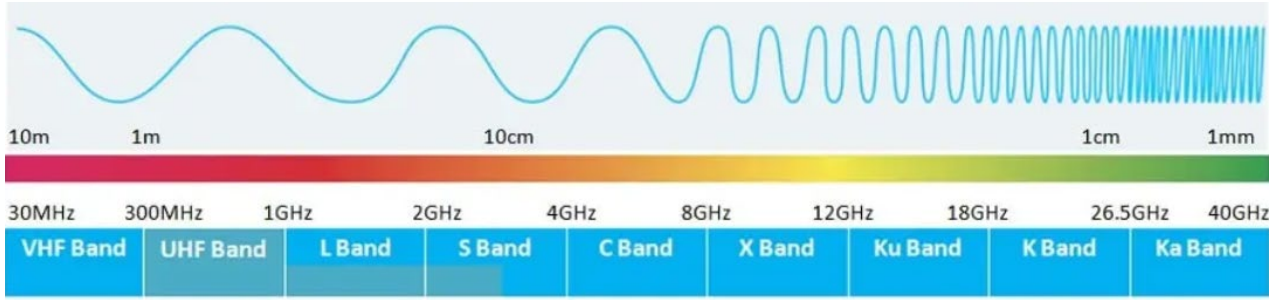
RS system consists of:

1) Source of light (energy)
2) Sensor – satellite antenna
3) Object of interest - interaction with the object
4) **Radiation and atmosphere**
5) Recording, preparation and submission of the data
6) Interpretation and analysis
7) Application

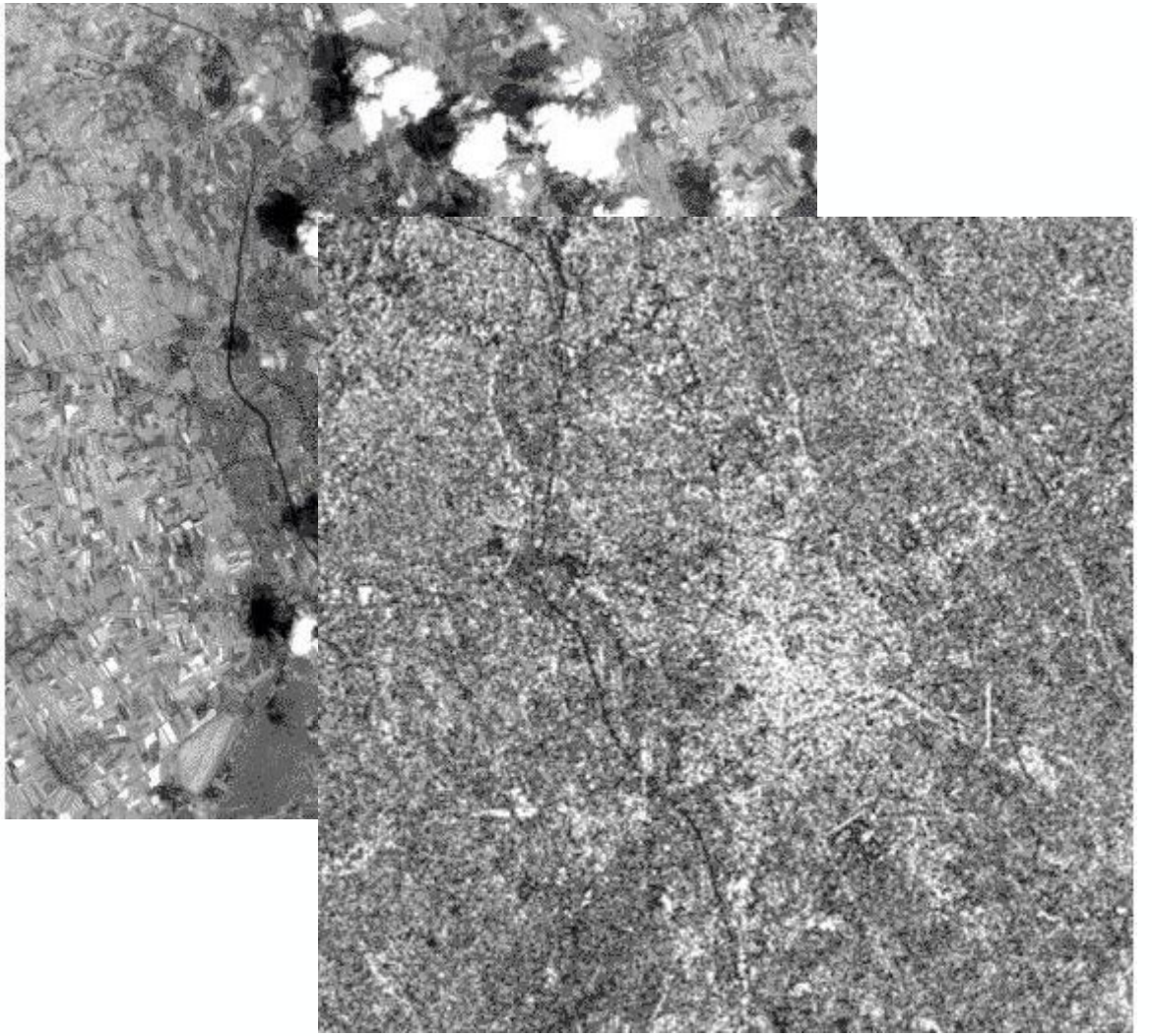


Interaction with atmosphere





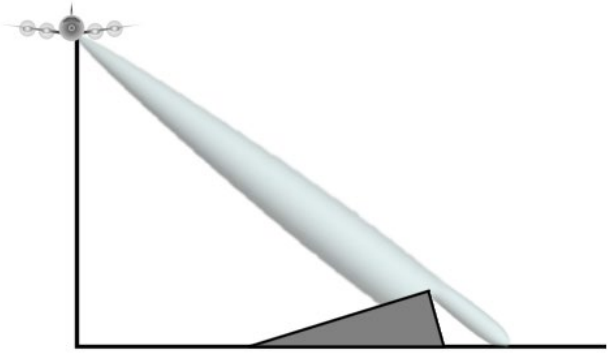
© ESA / AOES Medialab



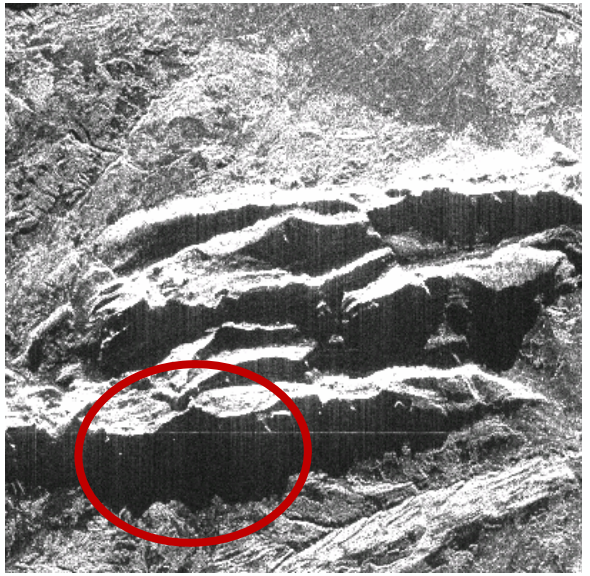
© DLR

Limitations because of the geometry

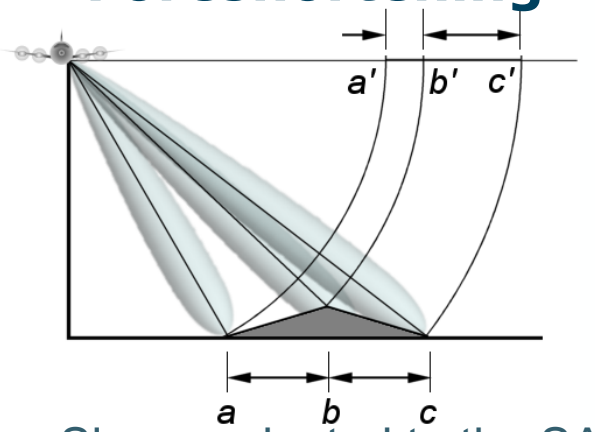
Shadowing



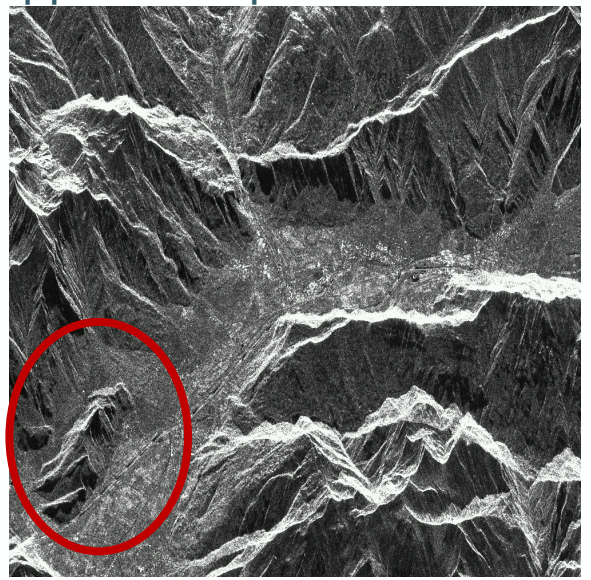
Steep slopes oriented away from the SAR return no signal.



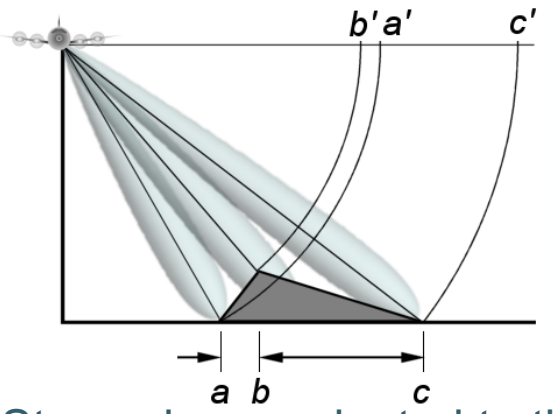
Foreshortening



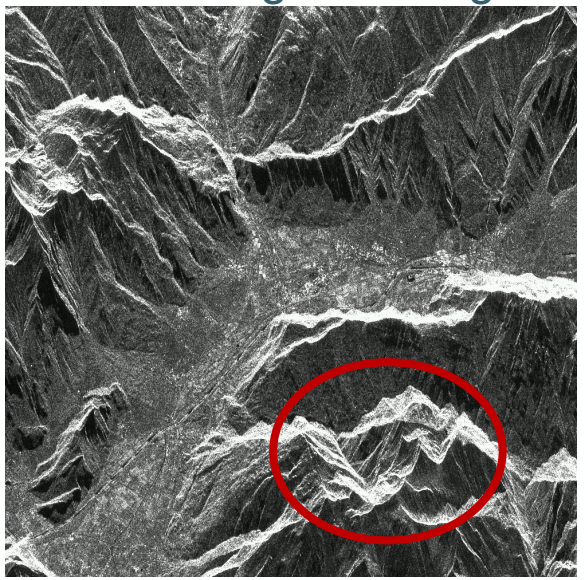
Slopes oriented to the SAR appear compressed.



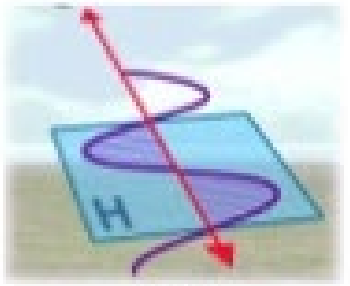
Layover



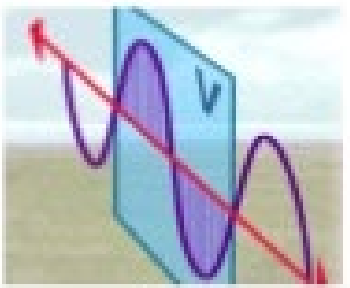
Steep slopes oriented to the SAR lead to ghost images.



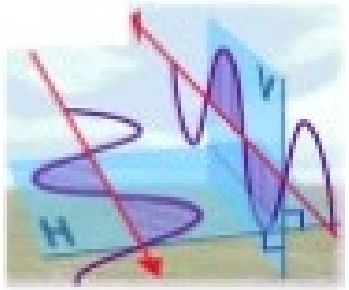
Polarization



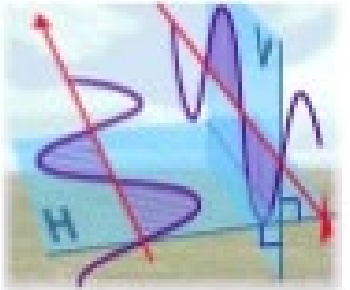
HH



VV



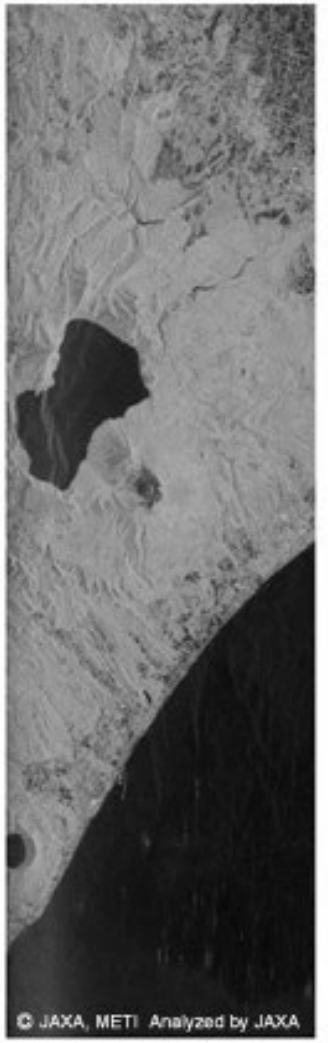
HV



VH

(a) HH (b) HV and VH (c) VV

HH



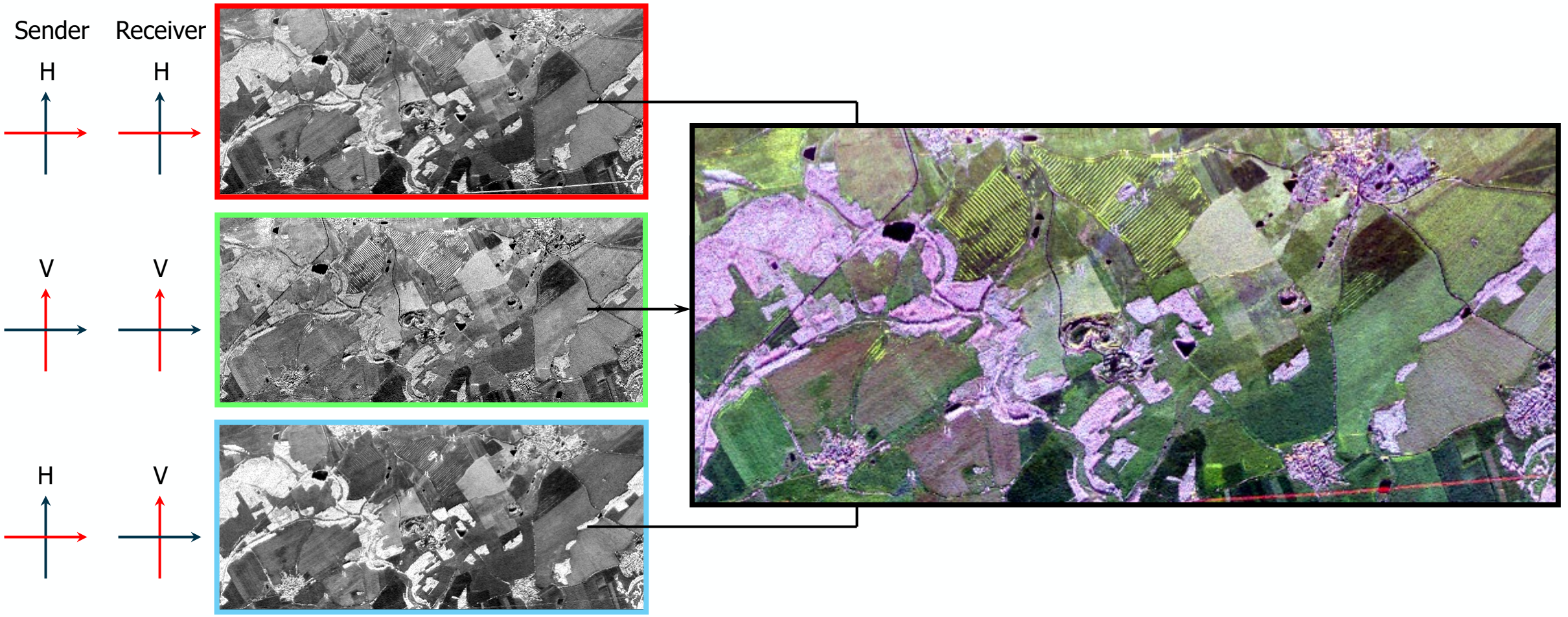
HV

VV

HH, HV, VV

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

Polarization and RGB-Composite



Polarization and RGB-Composite

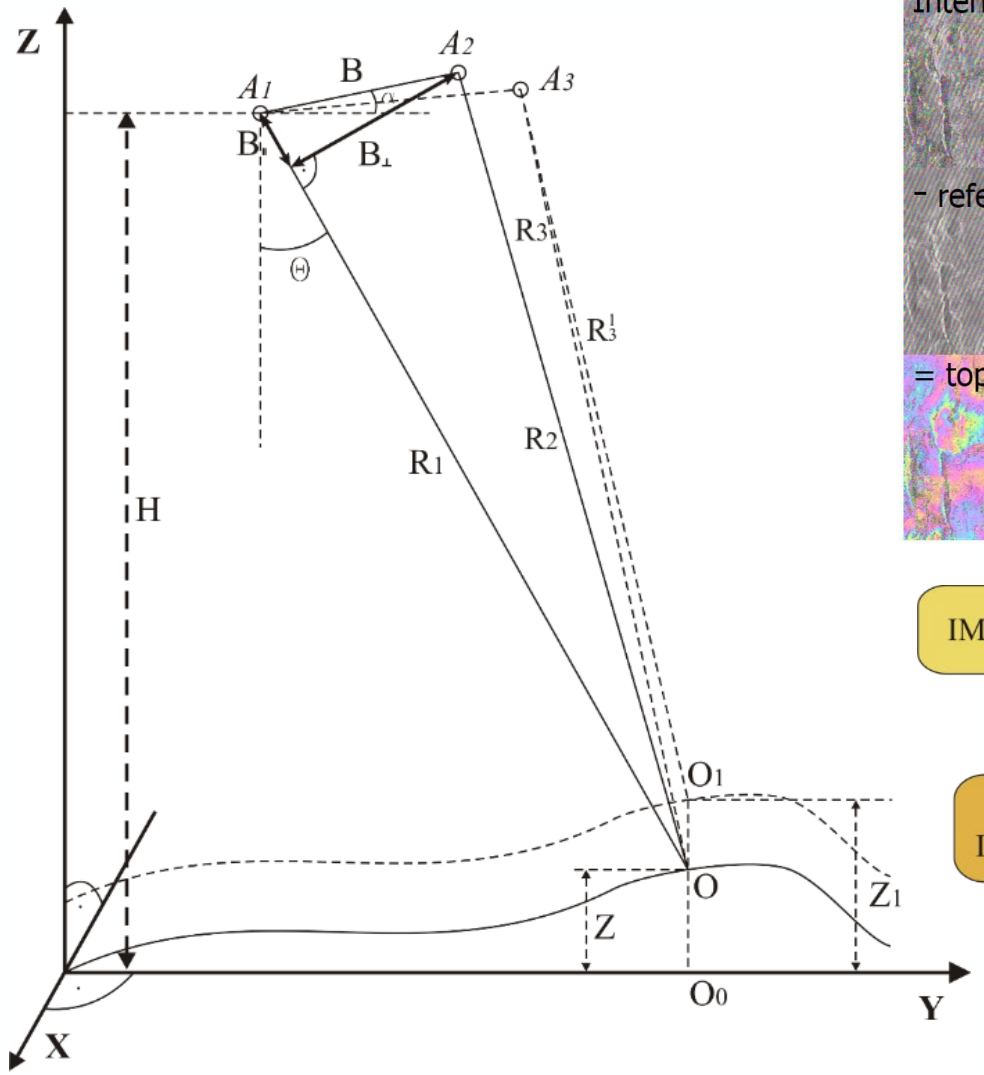
HH

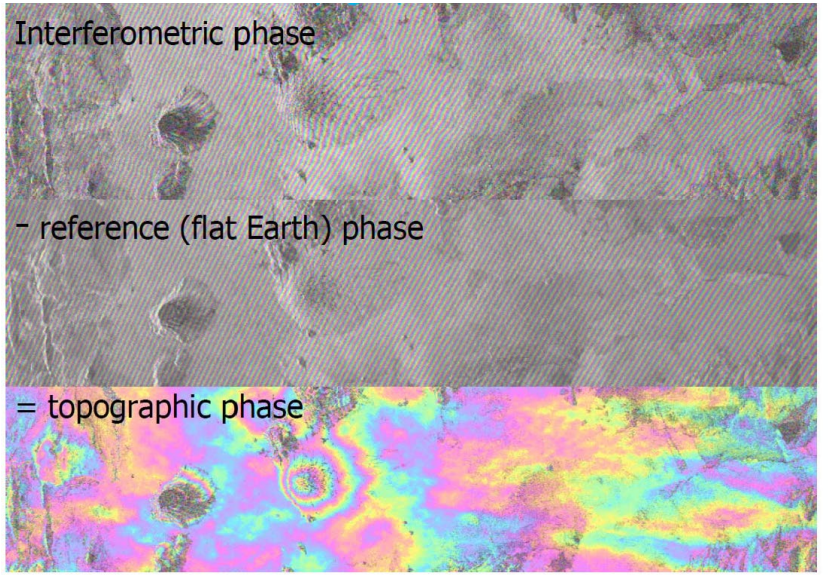
VV

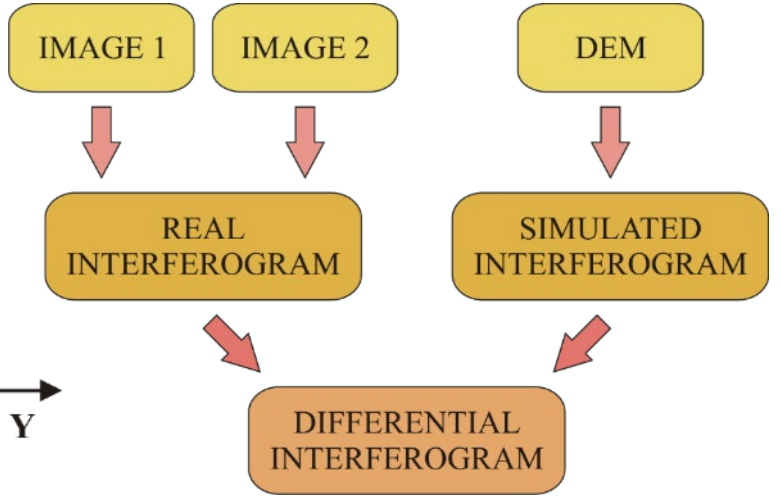
HV

RGB

Interferometric Synthetic Aperture Radar (InSAR) and Differential InSAR (DInSAR)





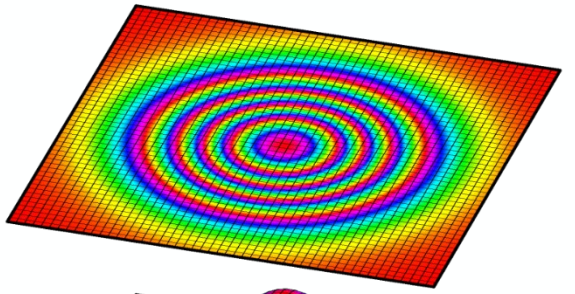


Interferometric Phase

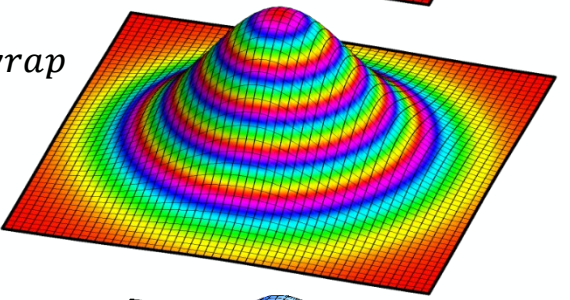
$$\phi_{diff} = \frac{4\pi}{\lambda}\Delta r_{diff}$$

$$\Delta\phi = \phi_{topo} + \phi_{diff}$$

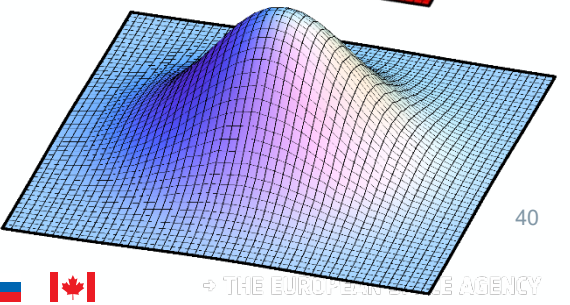
ϕ_{int}



ϕ_{unwrap}



Δr



Hydrology and Hazards - Floods

Emilia Romagna region, Italy, May 18, 2023

Megala Kalyvia, Greece, September 9, 2023

Khyber Pakhtunkhwa province

© Abdul Majeed/AFP via Getty Images

Stahovica, Slovenia, A

Derna, Lybia, September 12, 2023

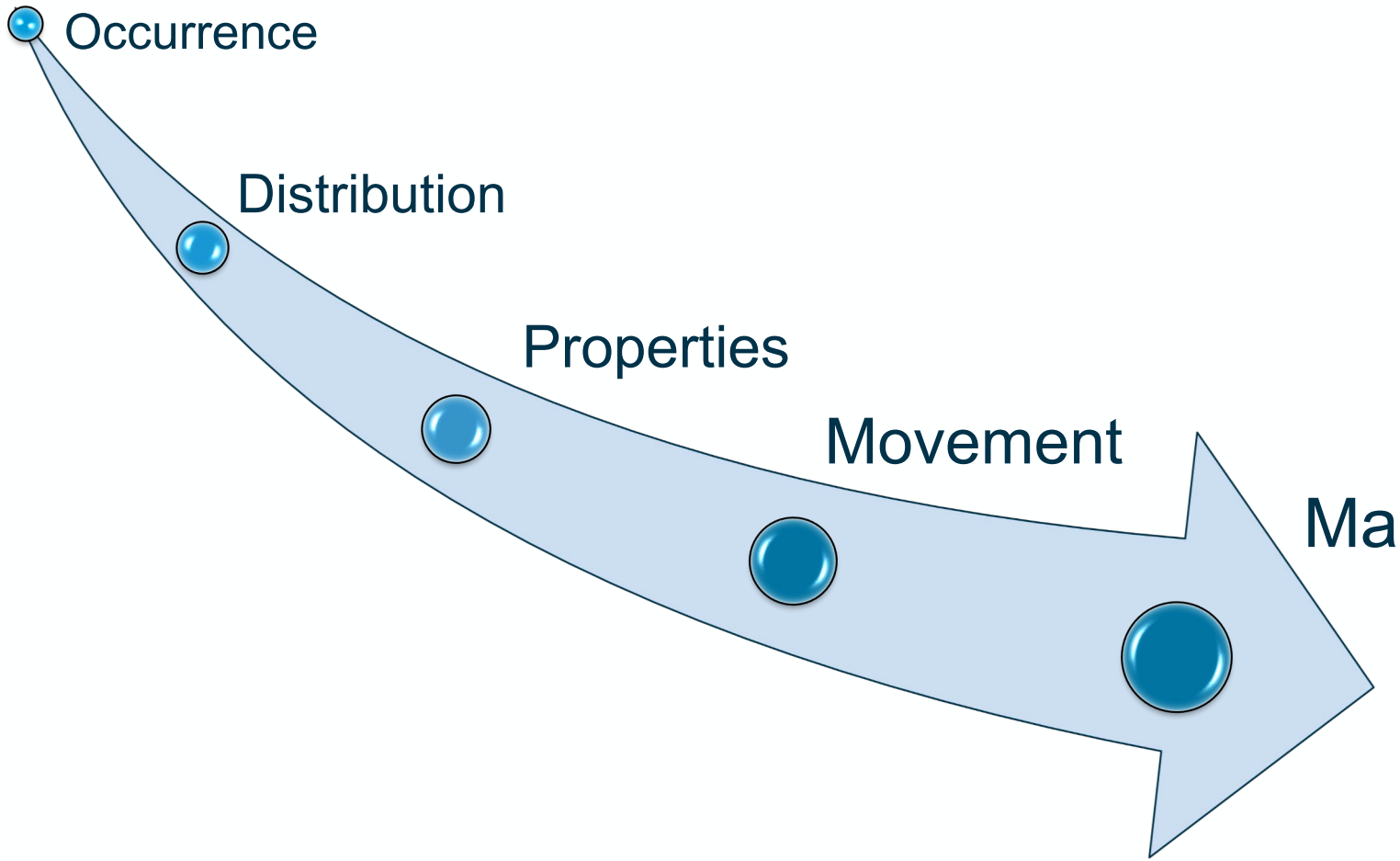
© Jamal Alkomaty/AP Photo

Hydrology and Hazards – Floods -> Landslides

Albula, Switzerland, June 16, 2023

Hydrology and RS SAR

Hydrology is the scientific study of the water on Earth and its:



including the water cycle, water resources, and drainage basin sustainability.

Thank you for the attention!

maya.ilieva@upwr.edu.pl