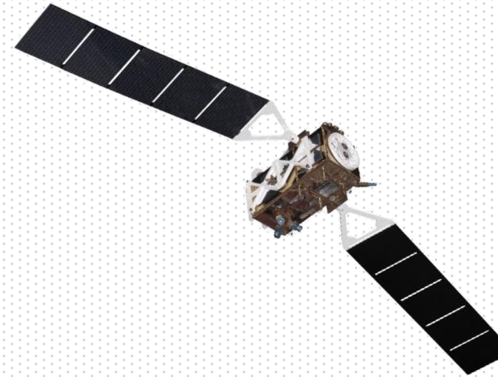
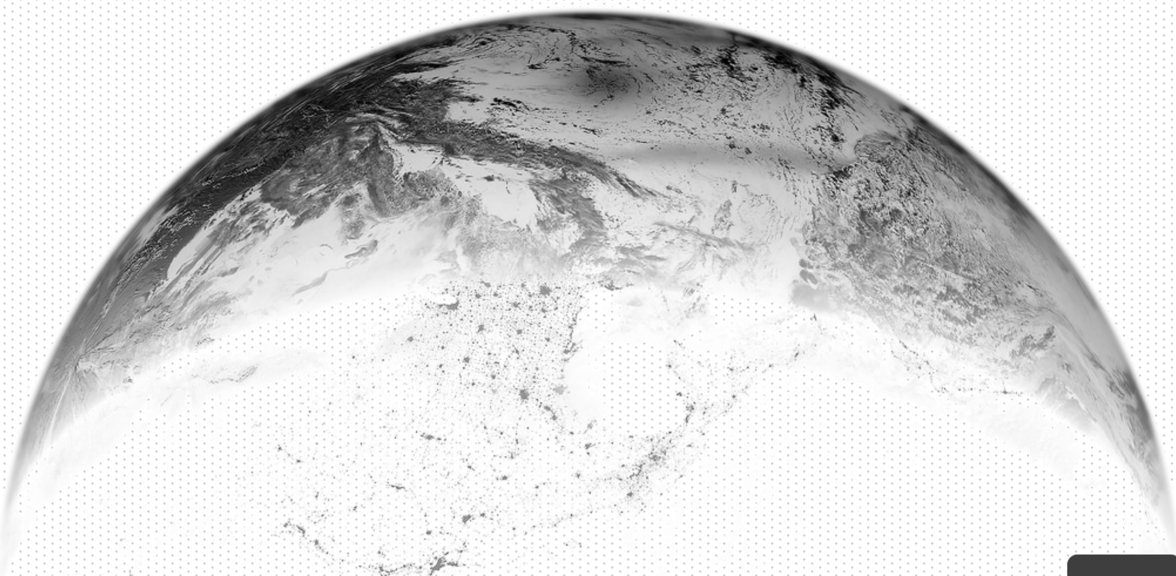


Radar Remote Sensing

Introduction into SAR measurements, data characteristics & challenges



Nesrin Salepci (nesrin.salepci@uni-jena.de), Christian Thiel
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eo college

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UNIVERSITÄT
JENA

Friedrich-Schiller-University Jena, Germany

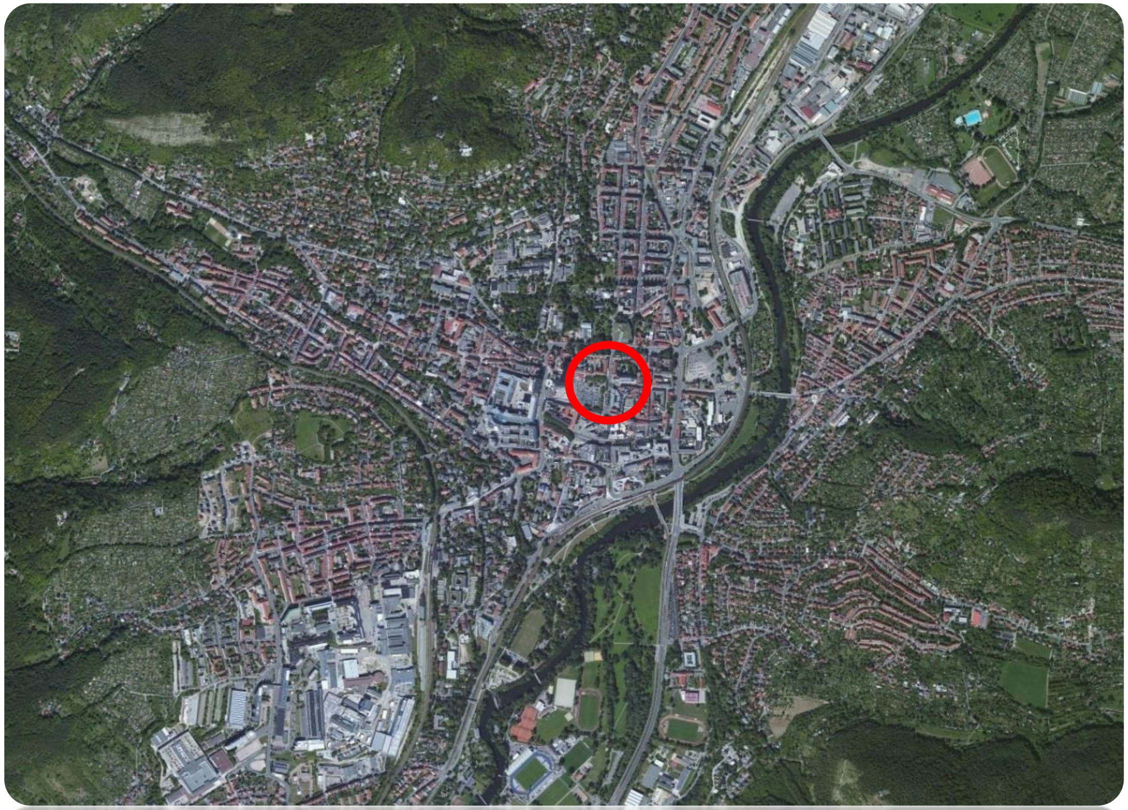
Dept. of Earth Observation

Basic Research
- E.g. SAR coherence & Forestry

Applied Earth Observation
- E.g. landcover mapping using multitemporal SAR data

Project Coordination
- Coordination of many international projects

Education
- BSc Geography
- MSc Geoinformatics
- Various PhD Projects
- SAR-EDU



Outline

- What is Remote Sensing/Earth Observation?
- Active Radar Remote Sensing
  - Electromagnetic spectrum : Why microwaves?
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  - Imaging geometry of radar systems
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  - SAR resolution cell
  - Effects of SAR imaging geometry
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  - SAR measurements
  - Speckle Effect
  - Spaceborne SAR systems
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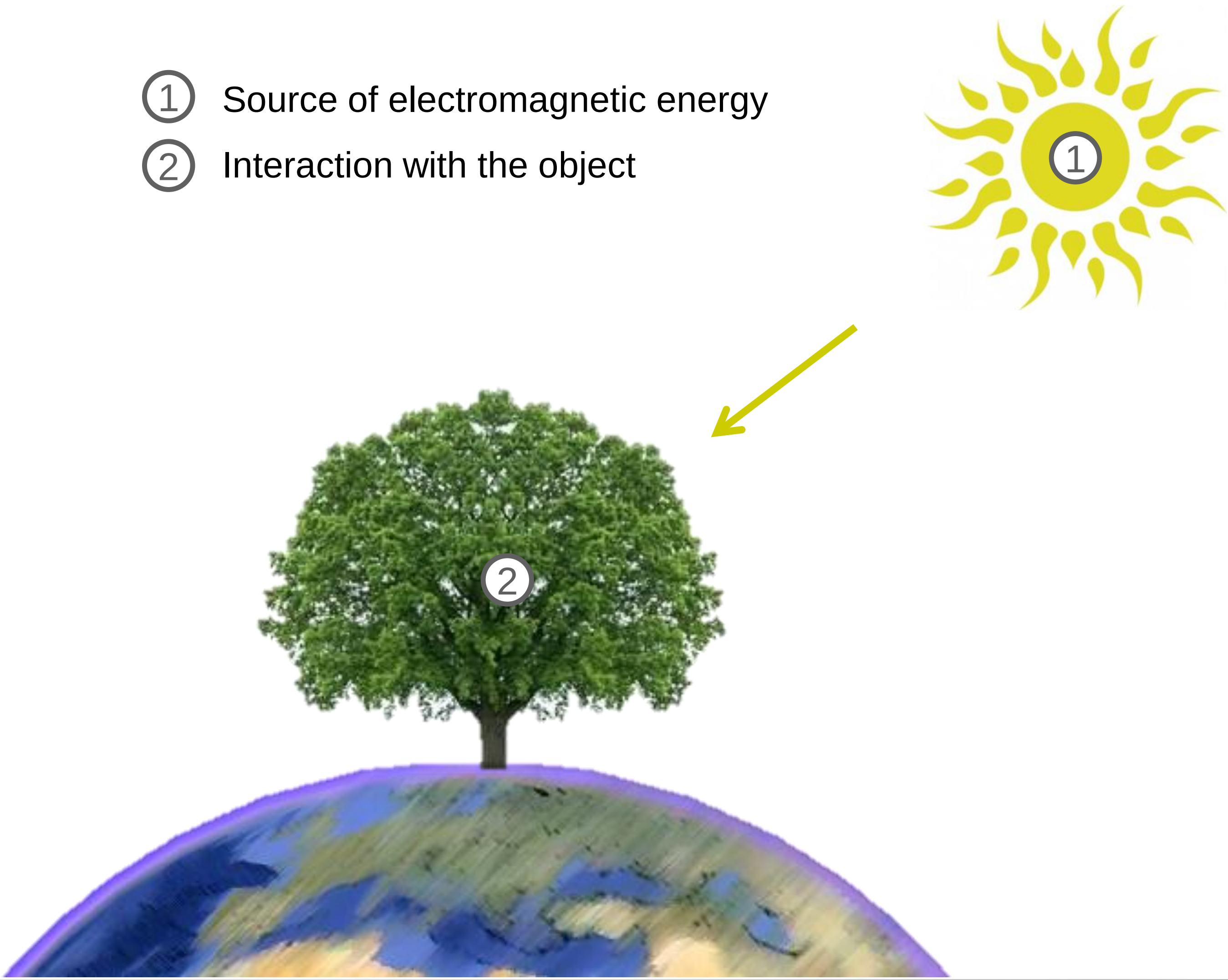
What is Remote Sensing/Earth Observation?

- ***Remote sensing (RS)***, also called earth observation, refers to ***obtaining information*** about objects or areas at the Earth's surface ***without being in direct contact*** with the object or area.

http://freeda.files.wordpress.com/2007/10/sv003.jpg

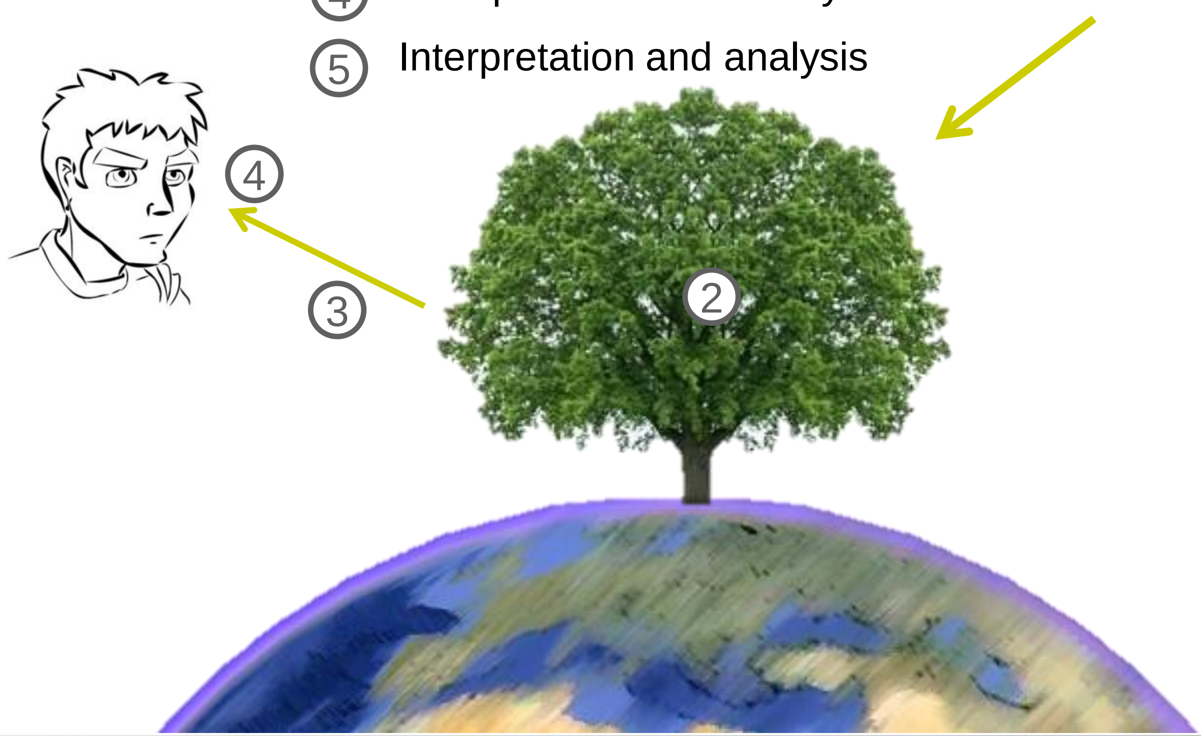
Components of the remote sensing process

1 Source of electromagnetic energy
2 Interaction with the object



Components of the remote sensing process

1. Source of electromagnetic energy
2. Interaction with the object
3. Radiation back to sensor
4. Reception of radiation by sensor
5. Interpretation and analysis



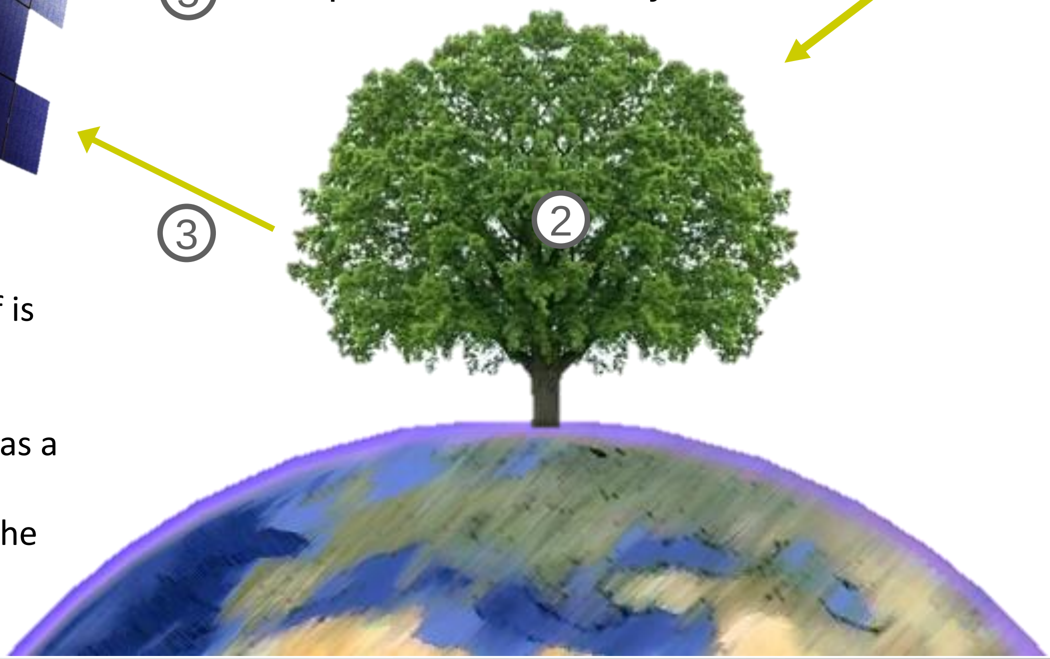
Components of the remote sensing process

1. Source of electromagnetic energy
2. Interaction with the object
3. Radiation back to sensor
4. Reception of radiation by sensor
5. Interpretation and analysis

5

SPOT 5
Optical satellite
visible part of the spectrum

3

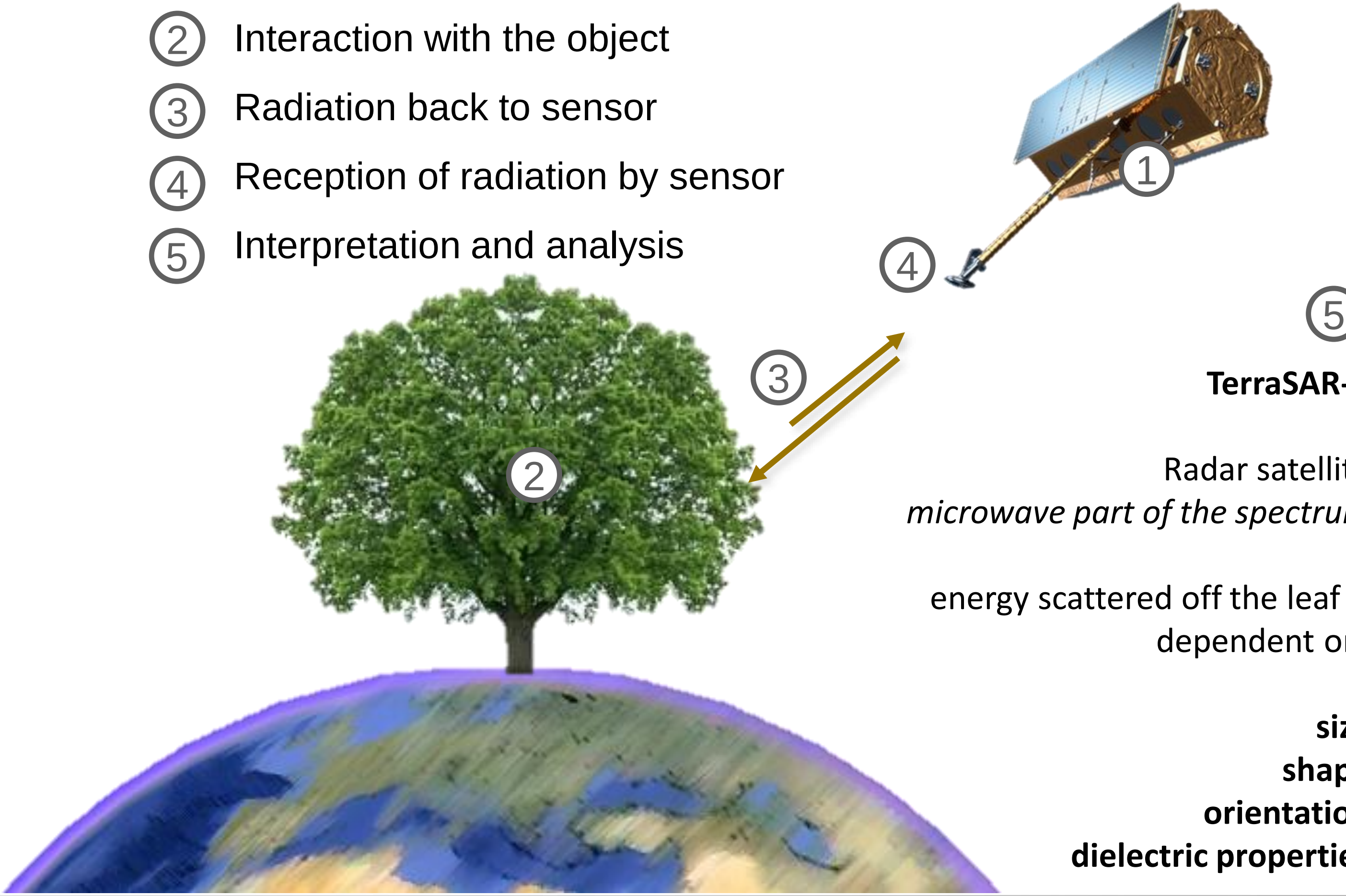


energy scattered off the leaf is dependent on:

The “**greenness**” of the leaf as a function of the amount of chlorophyll, which absorbs the energy that is needed for photosynthesis

Components of the remote sensing process

1. Source of electromagnetic energy
2. Interaction with the object
3. Radiation back to sensor
4. Reception of radiation by sensor
5. Interpretation and analysis



TerraSAR-X

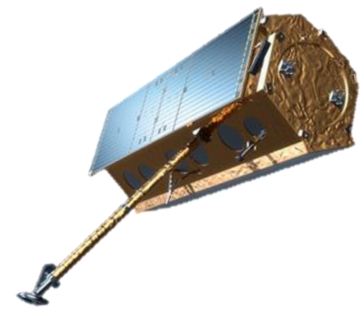
Radar satellite
microwave part of the spectrum

energy scattered off the leaf is dependent on:

size
shape
orientation
dielectric properties

Source of electromagnetic energy

SPOT 5
(optical satellite)



TerraSAR-X
(radar satellite)

Further Examples:

Non-imaging: radiometer, magnetic sensor
Imaging: cameras, optical mechanical scanner, spectrometer, radiometer

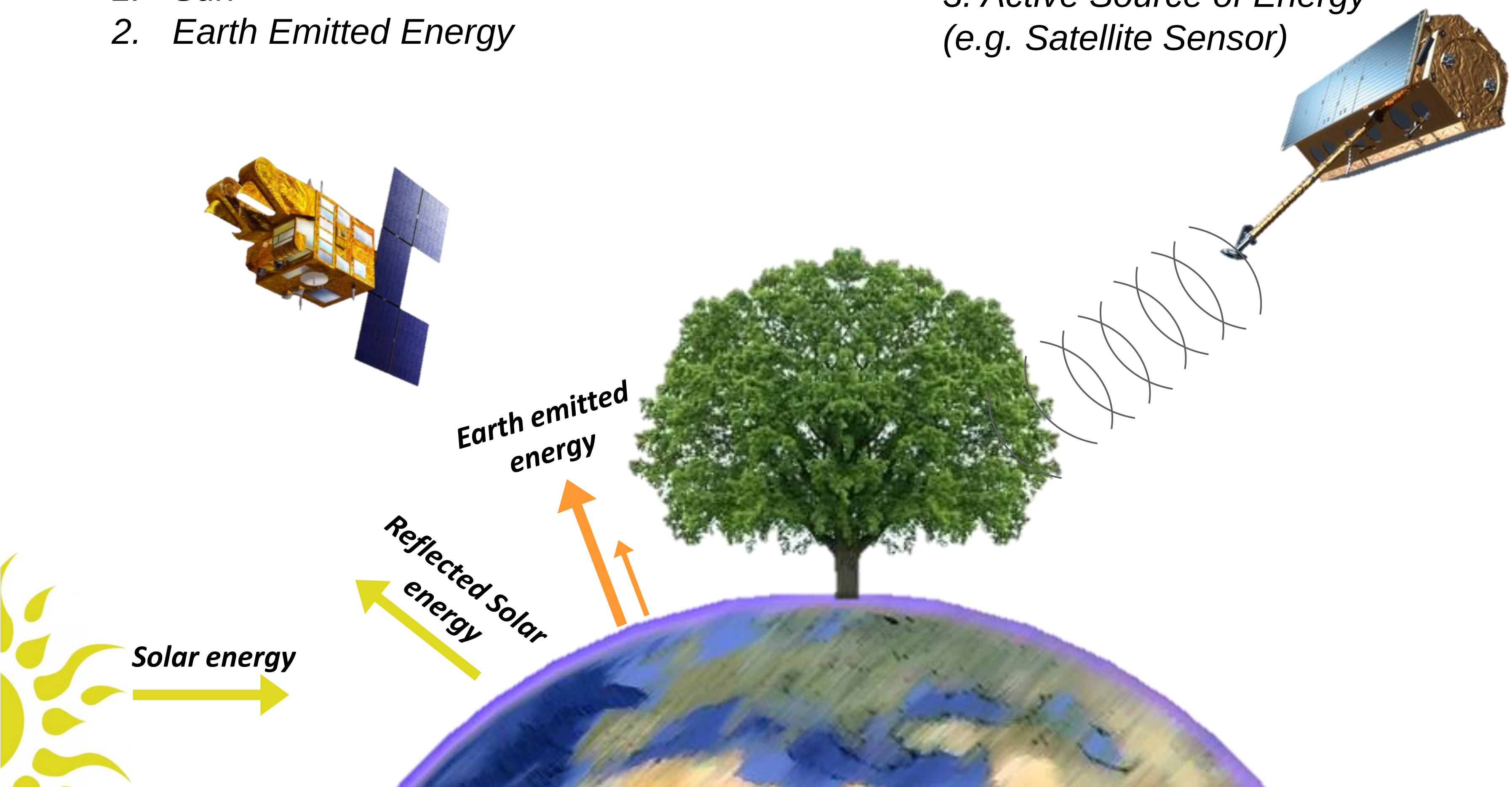
Further Examples:

Non-imaging: radiometer, altimeter, laser
Imaging: Real Aperture Radar, Synthetic Aperture Radar

Source of electromagnetic energy

1. *Sun*
2. *Earth Emitted Energy*

3. Active Source of Energy (e.g. Satellite Sensor)



Passive and Active Remote Sensing

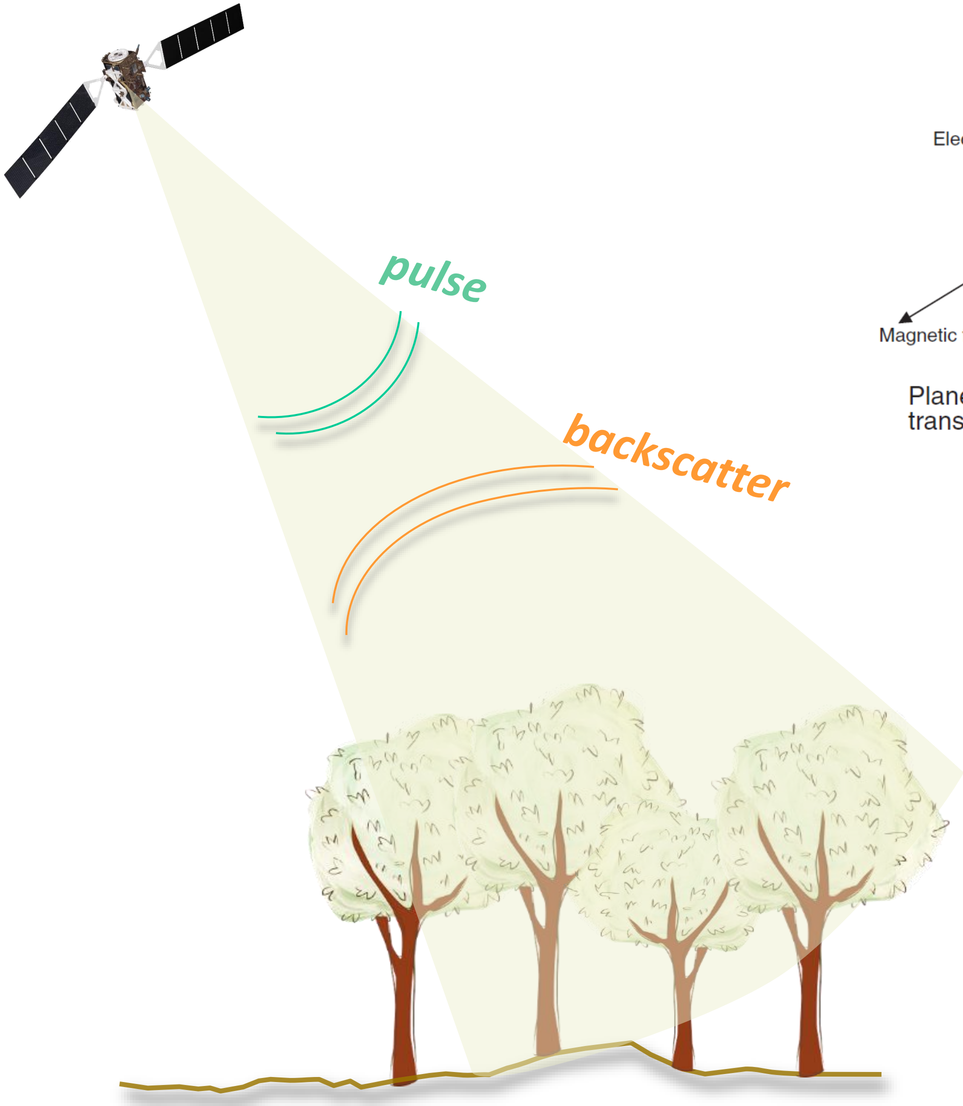
Passive remote sensing systems:

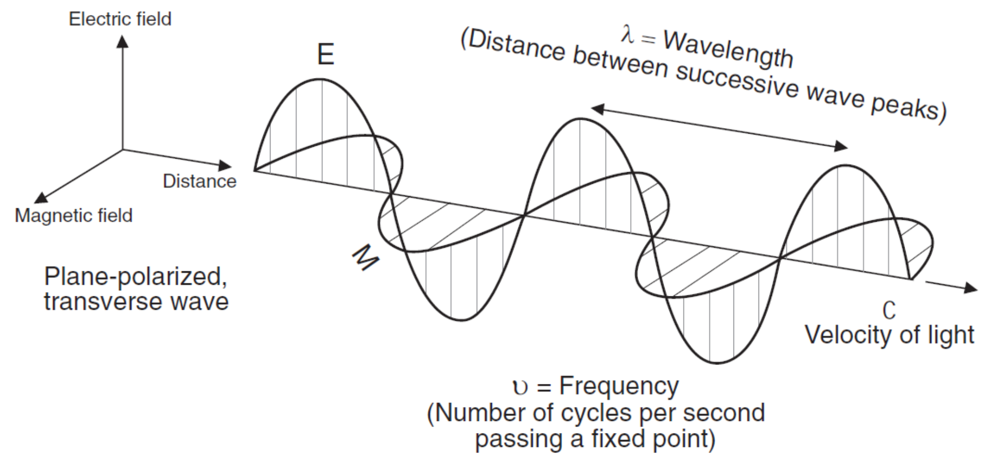
- Detect the **reflected** or **emitted** EM radiation from natural sources
- **Some of the images represent reflected solar radiation in the visible and the near infrared regions of the EM spectrum**
- **others are the measurements of the energy emitted by the earth surface itself i.e. in the thermal infrared wavelength region**

Active remote sensing systems:

- Detect **reflected responses** from objects irradiated by **artificially-generated energy** sources
- **energy is transmitted from the remote sensing platform**
- **measurement of relative return from the earth's surface**

Radar remote sensing & electromagnetic wave





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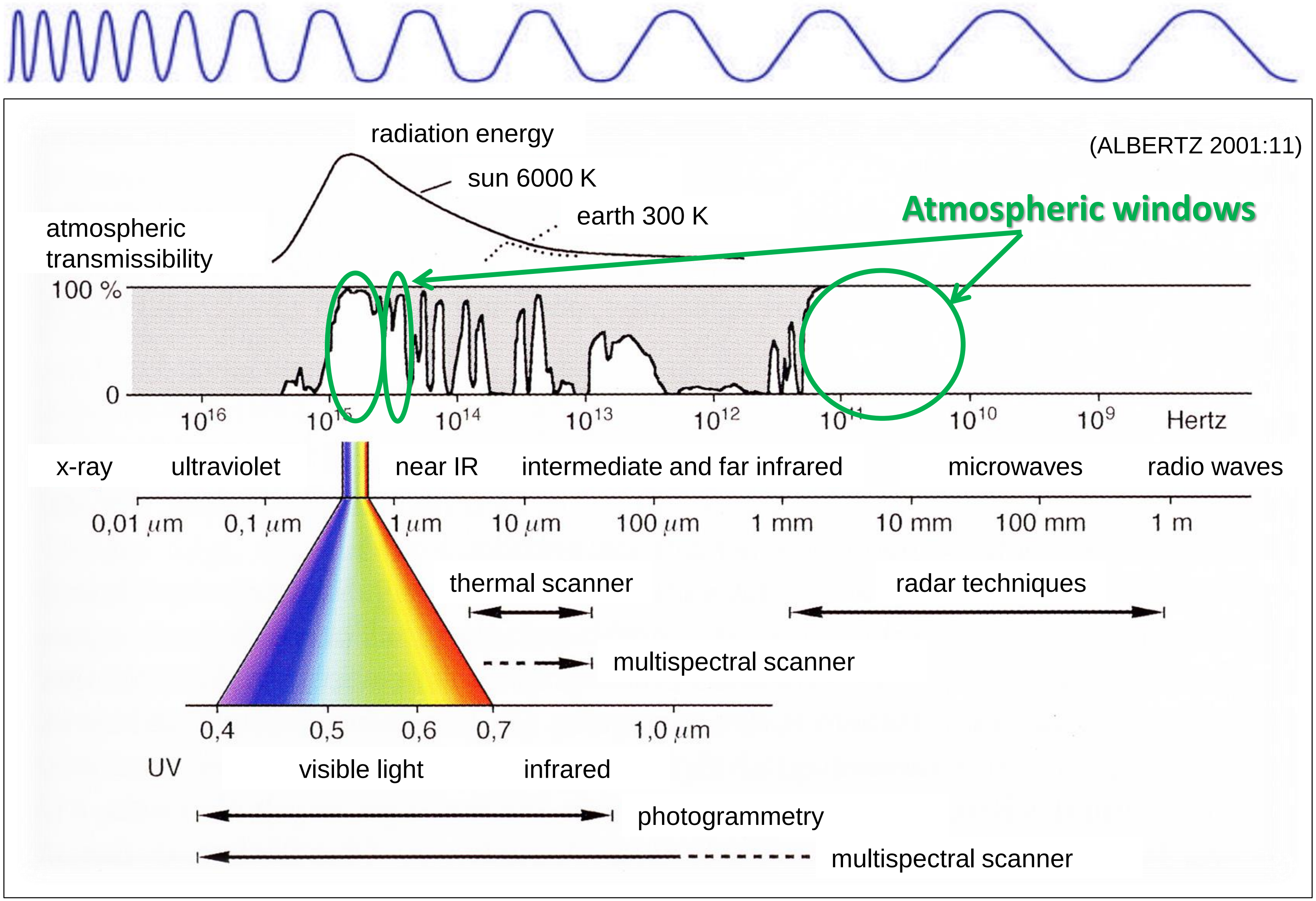
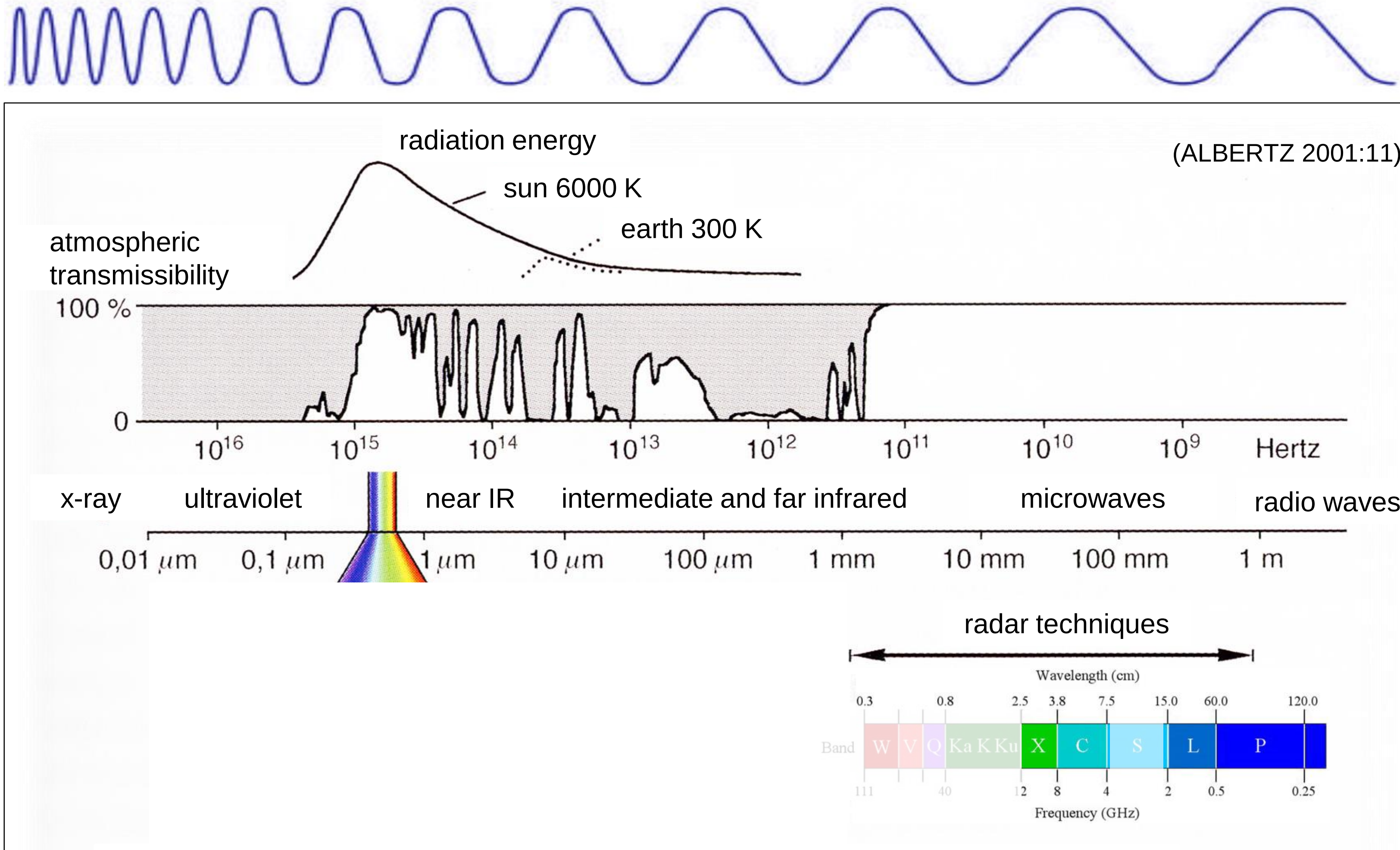
electromagnetic spectrum



electromagnetic spectrum



SAR systems: X,C,L & P bands

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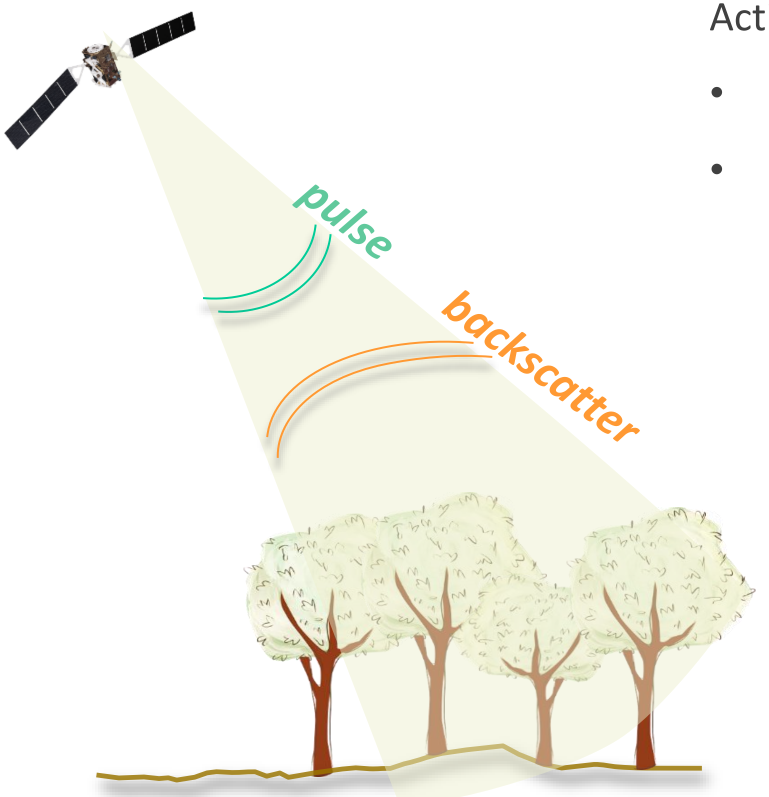
Active Radar Remote Sensing

Basic characteristics of radar systems/SAR sensors

- **active** $\Rightarrow$ **independent of sun illumination**



Active remote sensing sensors generate EM-waves

- no sunlight required night time acquisitions possible
- no problems due to bad illumination

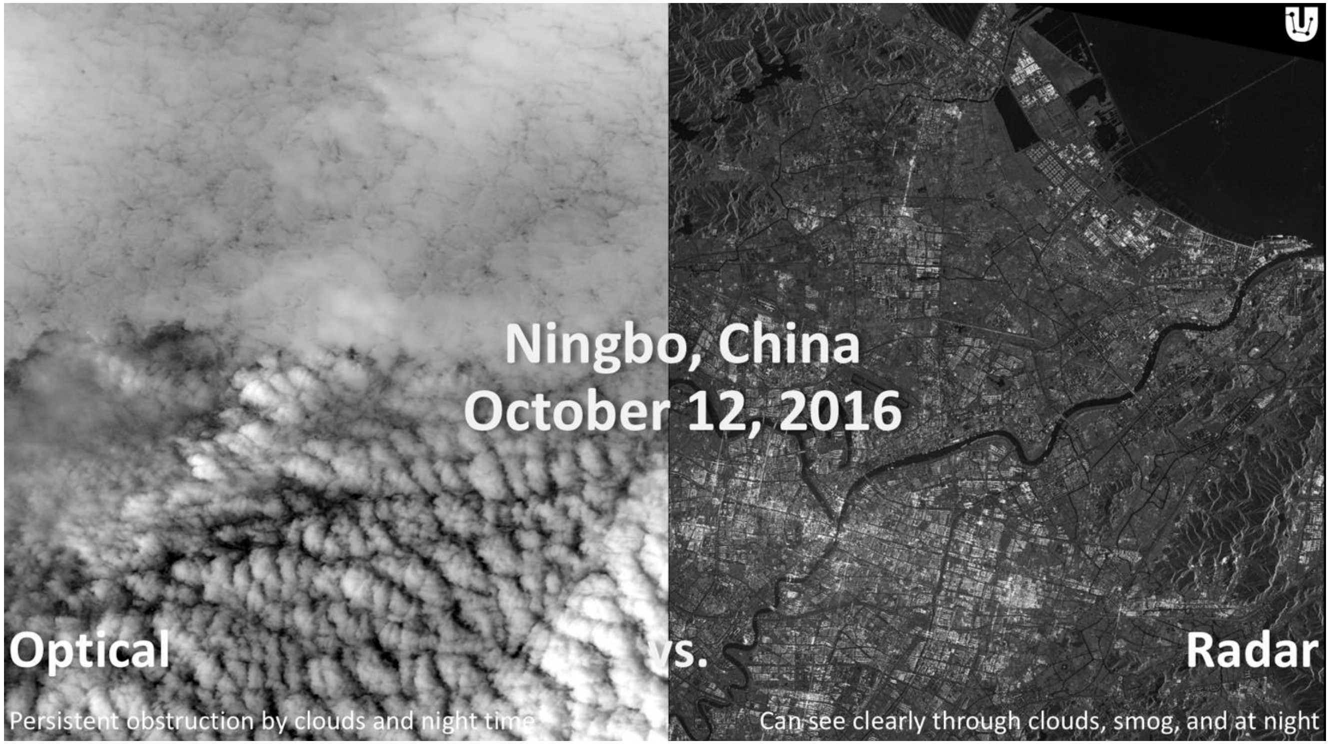
Active Radar Remote Sensing

Basic characteristics of radar systems/SAR sensors

- active $\Rightarrow$ independent of sun illumination
- **microwave** $\Rightarrow$ **penetrates into/through objects**

  clouds and (partially) canopy, soil, snow

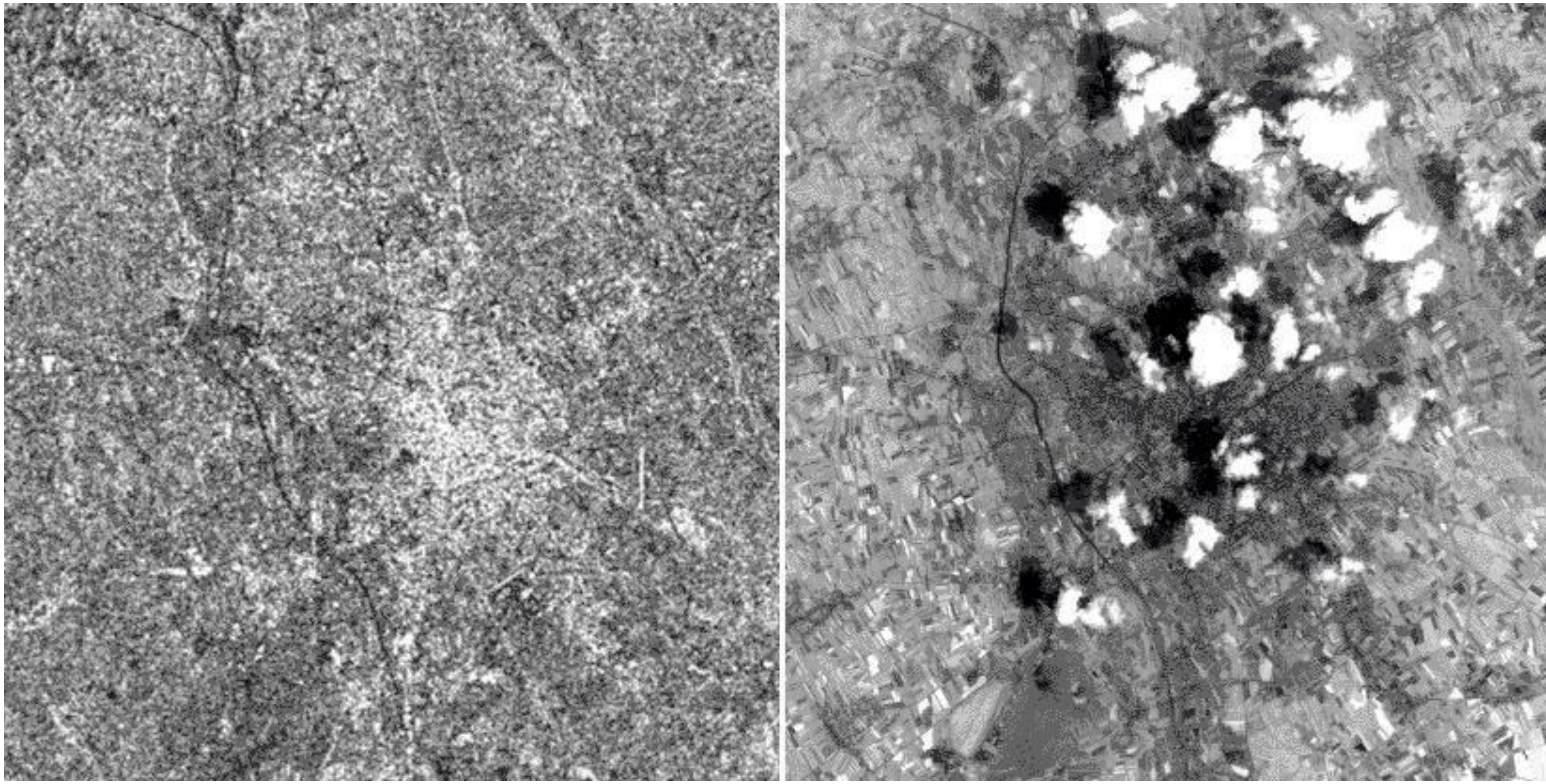
  (almost) no problems with clouds, dust, fog. Sensing of „hidden“ objects



https://ubique.americangeo.org/company-and-not-for-profit-spotlights/ursa-space-systems/

Active Radar Remote Sensing

Characteristics / Example all weather

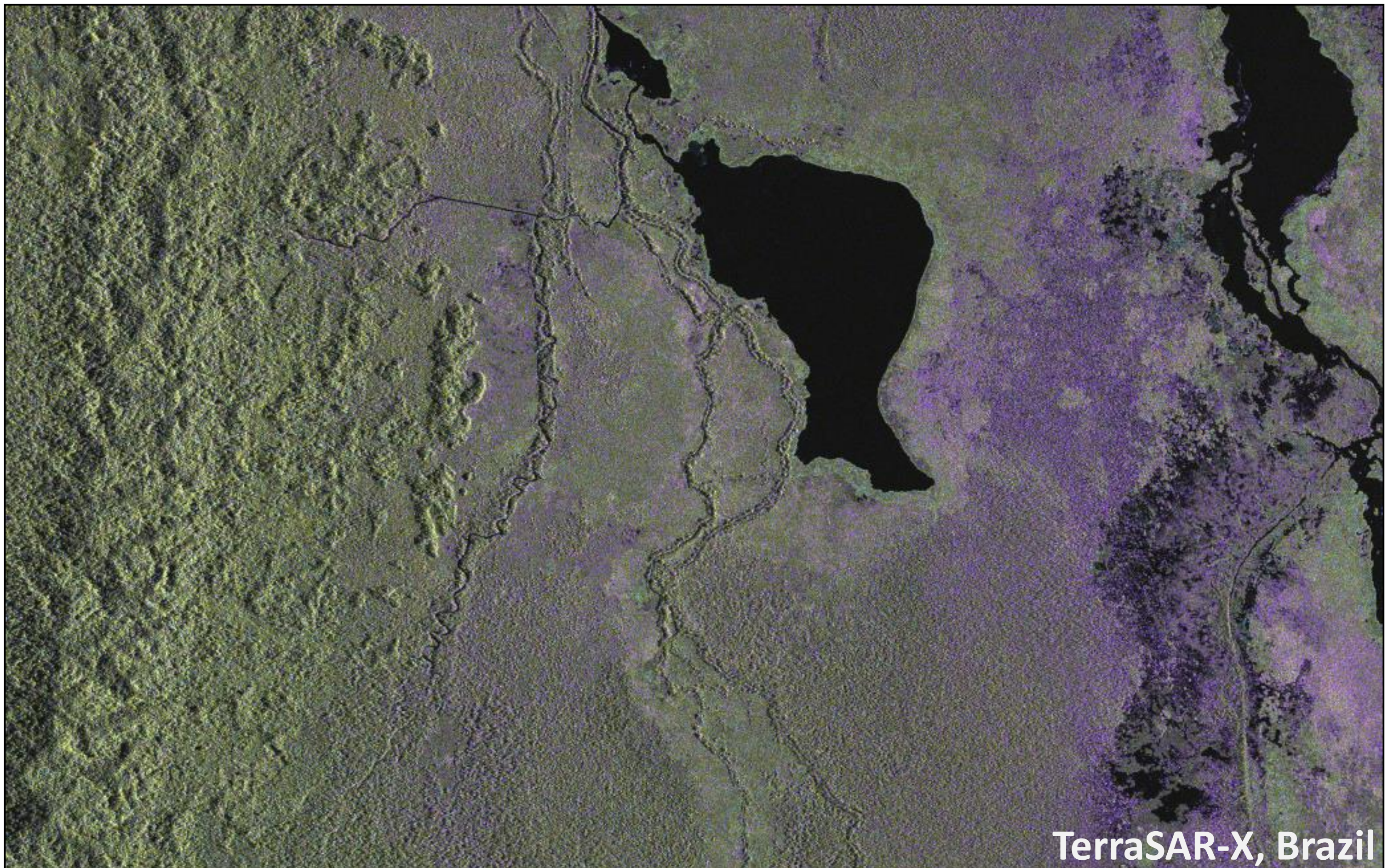


These images were acquired over the city of Udine, northeastern Italy, by ERS-1 on the 4th of July 1993 at 9.59 a.m. (GMT) and Landsat-5 on the same date at 9.14 a.m. (GMT) respectively. The clouds that are clearly visible in the optical image, are not appearing in the SAR image.

Active Radar Remote Sensing

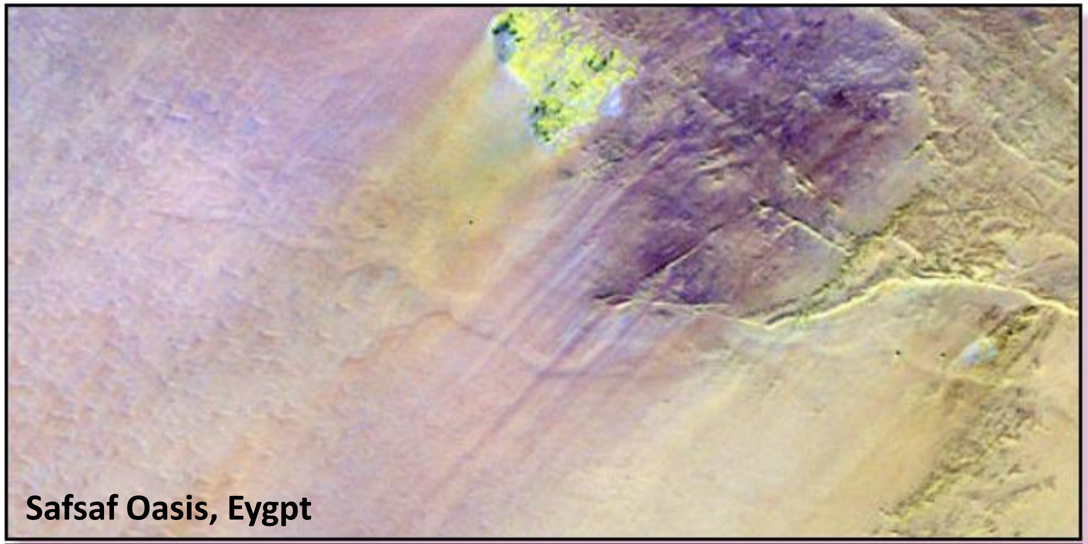
Characteristics / Example all weather

Cloud cover is a big problem in remote sensing of moist tropics

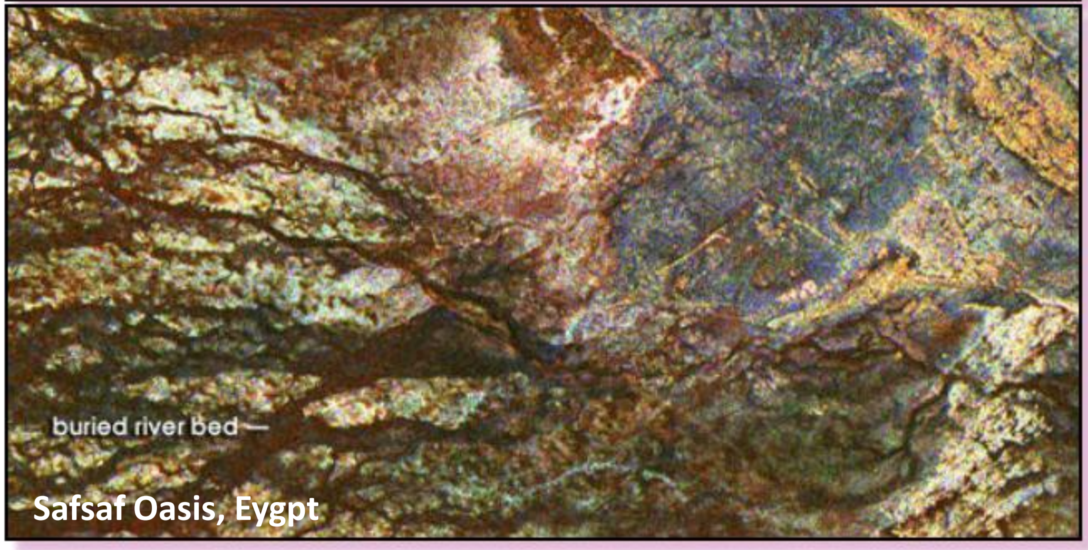


Active Radar Remote Sensing

Characteristics / penetration through sand



Landsat Thematic Mapper
shows the desert’s surface



SIR-C/X-SAR
shows what the landscape might look like if stripped bare of sand

Active Radar Remote Sensing

Advantages / Example all weather

- active ⇒ independent of sun illumination
- **microwave ⇒ penetrates into/through objects**

The penetration depth is depending on **wavelength** and **dielectric characteristics** of objects

wavelengths: **X-band: 3 cm**
C-band: 6 cm
L-band: 23 cm

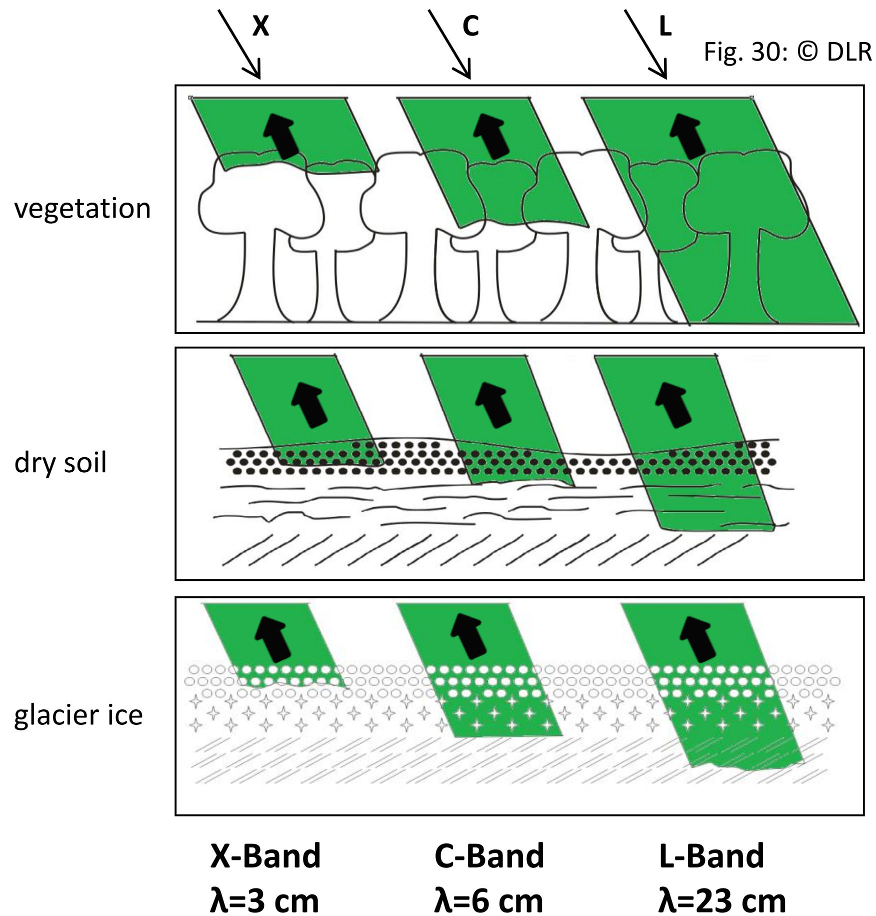
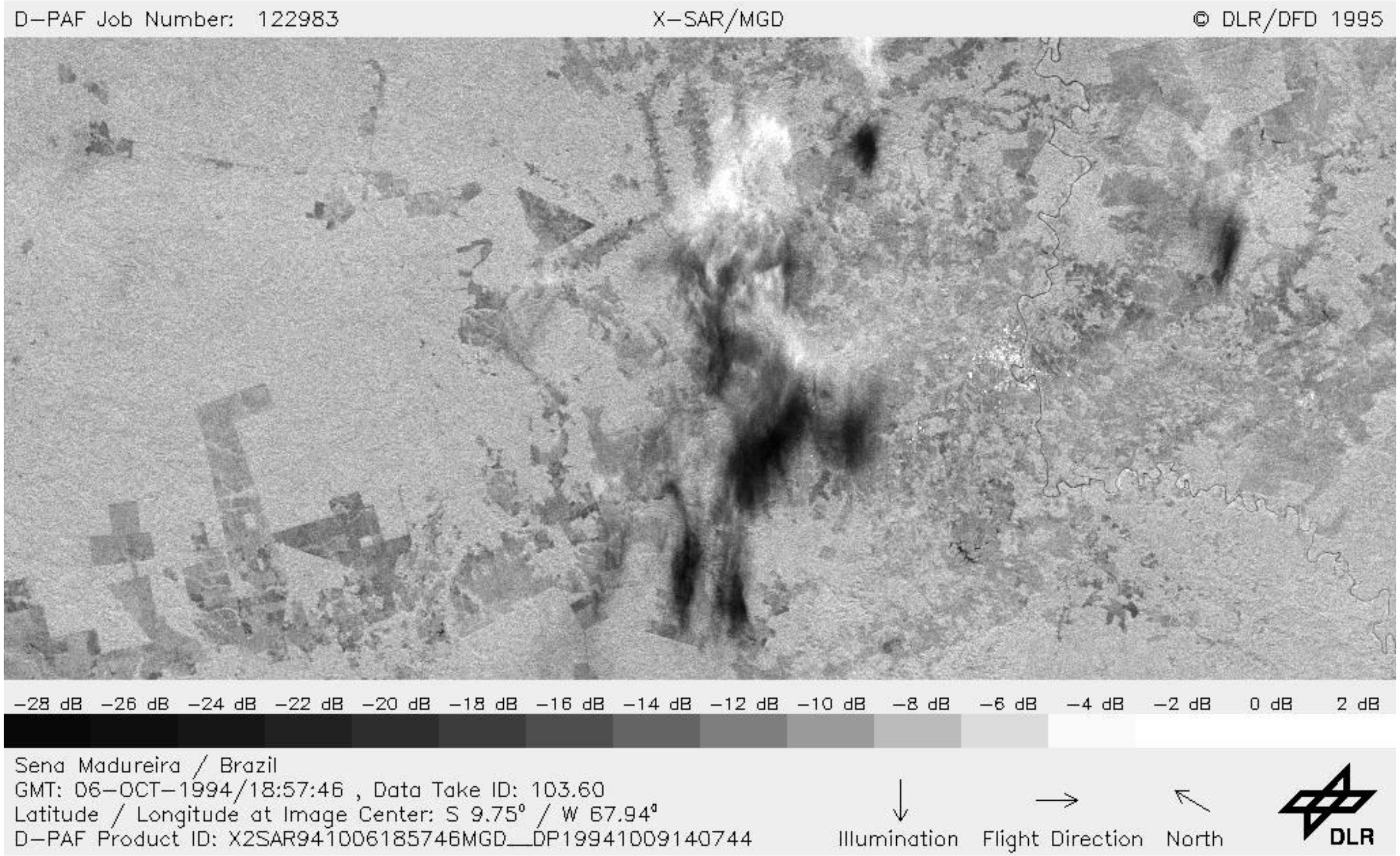


Fig. 30: © DLR

Heavy Clouds and Rain Cells in X-Band SAR Images

→ Only visible at short wavelengths and extreme conditions

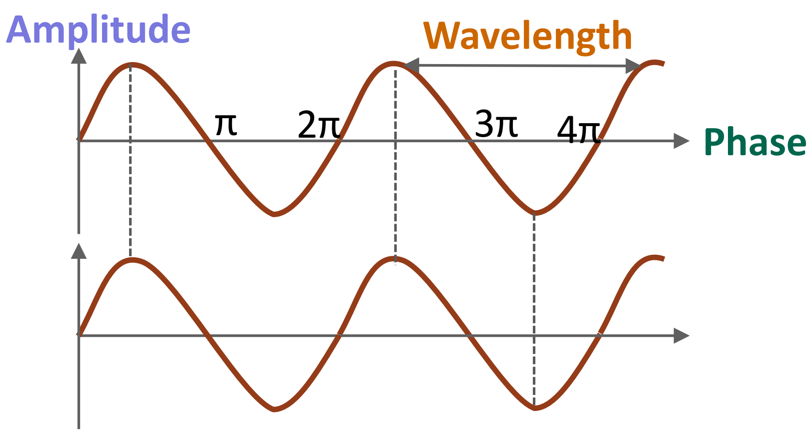


Active Radar Remote Sensing

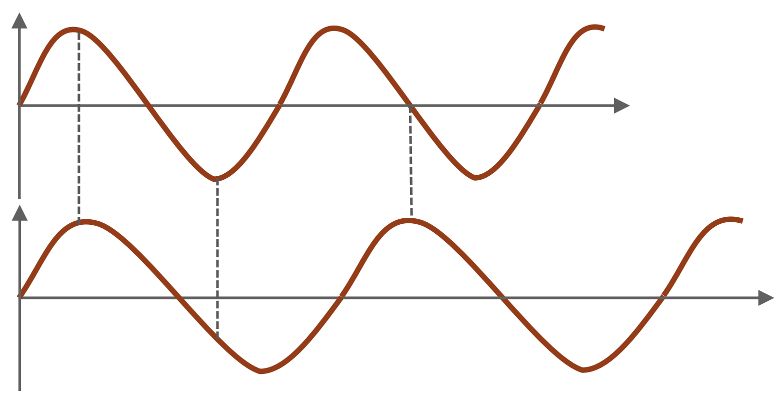
Basic characteristics of radar systems/SAR sensors

- active ⇒ independent of sun illumination
- microwave ⇒ penetrates into/through objects
- **coherent ⇒ interferometry, speckle**

> ➢ Microwaves used for Earth Observation are **coherent waves**!!!
> ➢ Waves maintaining a constant phase with respect to each other are coherent



coherent

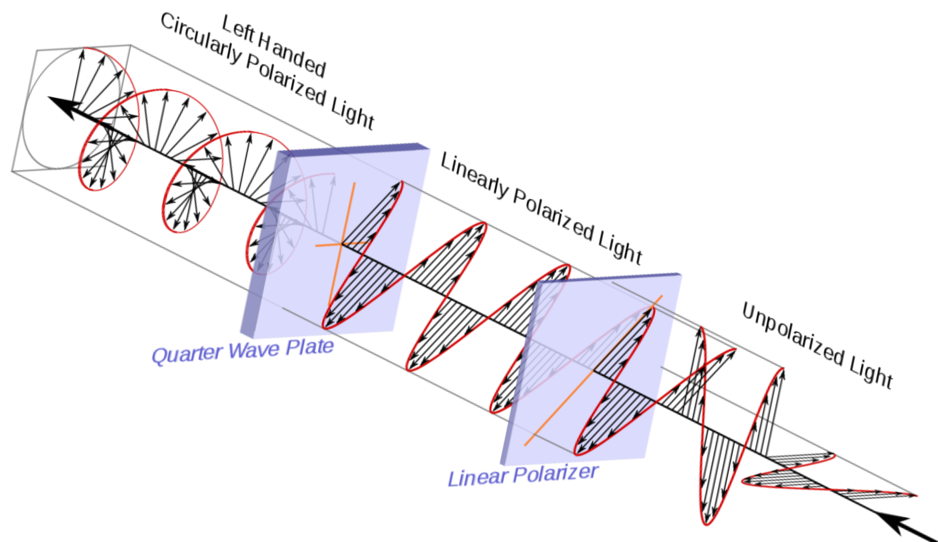


not coherent

Active Radar Remote Sensing

Basic characteristics of radar systems/SAR sensors

- active ⇒ independent of sun illumination
- microwave ⇒ penetrates into/through objects
- coherent ⇒ interferometry, speckle
- **polarization ⇒ can be exploited**



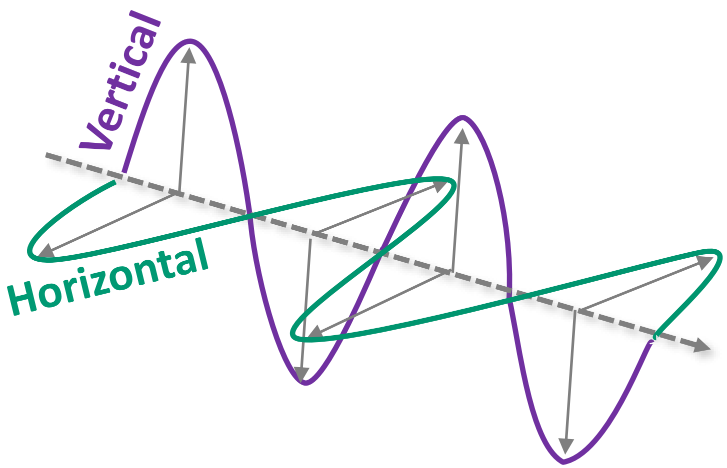
Polarization of the electromagnetic waves refers to the **direction of electric field.**

©http://www.wikipedia.org

Active Radar Remote Sensing

Basic characteristics of radar systems/SAR sensors

- active $\Rightarrow$ independent of sun illumination
- microwave $\Rightarrow$ penetrates into/through objects
- coherent $\Rightarrow$ interferometry, speckle
- **polarization $\Rightarrow$ can be exploited**



Microwave sensors emit signals in horizontal (**H**) or vertical (**V**) polarizations.

<u>The four combinations of SAR data polarizations:</u>

HH: The emitted and backscattered signals have horizontal polarization

HV: The emitted signal has horizontal polarization, and the backscattered signal has vertical polarization.

VH: The emitted signal has vertical polarization, and the backscattered signal has horizontal polarization.

VV: Both emitted and reflected signals have vertical polarization

Active Radar Remote Sensing

Basic characteristics of radar systems/SAR sensors

- active ⇒ independent of sun illumination
- microwave ⇒ penetrates into/through objects
- coherent ⇒ interferometry, speckle
- polarization ⇒ can be exploited
- **spatial resolution: space-borne: 0.5 m - 100 m** (Sentinel-1: ≈10 m, TerraSAR-X: ≈1 m)
  air-borne: > 0.2 m

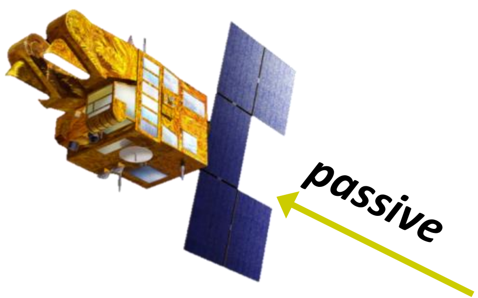
Active Radar Remote Sensing

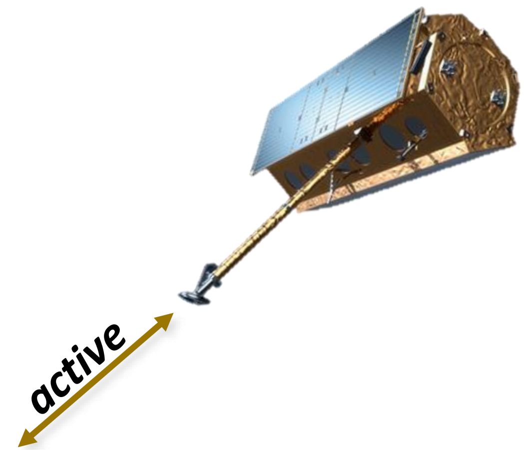
Basic characteristics of radar systems/SAR sensors

- active ⇒ independent of sun illumination
- microwave ⇒ penetrates into/through objects
- coherent ⇒ interferometry, speckle
- polarization ⇒ can be exploited
- spatial resolution ⇒ space-borne: 0.5 m - 100 m (Sentinel-1: ≈10 m, TerraSAR-X: ≈1 m)
  air-borne: > 0.2 m
- **backscatter** ⇒ is the reflection of signals back to the direction from which they came.

Magnitude and characteristics of backscatter depend on **geometric** & **dielectric** properties of objects

Interaction with the object





SPOT 5
Optical satellite
visible part of the spectrum

energy scattered off the leaf is dependent on:

The "**greenness**" of the leaf as a function of the amount of chlorophyll, which absorbs the energy that is needed for photosynthesis

TerraSAR-X
Radar satellite
microwave part of the spectrum

energy scattered off the leaf is dependent on:

size
shape
orientation
dielectric properties

Synthetic Aperture Radar image, X-Band, VV, E-SAR, Weisseritz, Germany 2007

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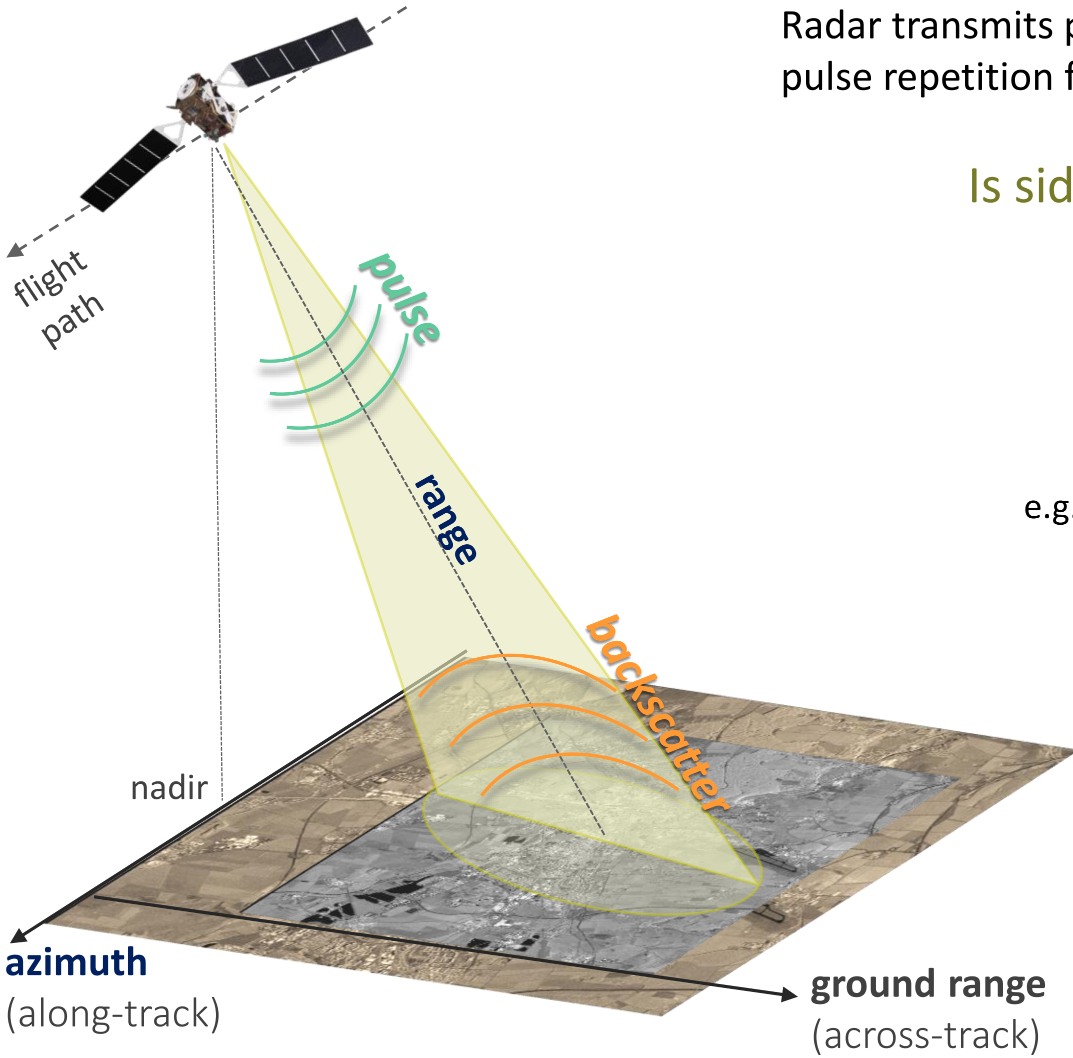
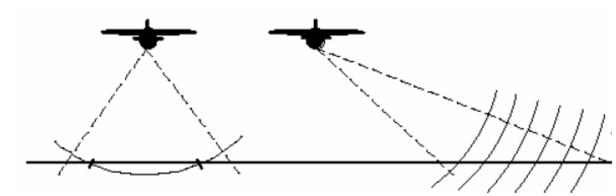
Radar Remote Sensing

Side looking imaging geometry



Radar transmits pulses and receives echoes at the rate of the pulse repetition frequency: *PRF* $\cong$ 1000 - 4000 Hz

Is side looking really necessary?

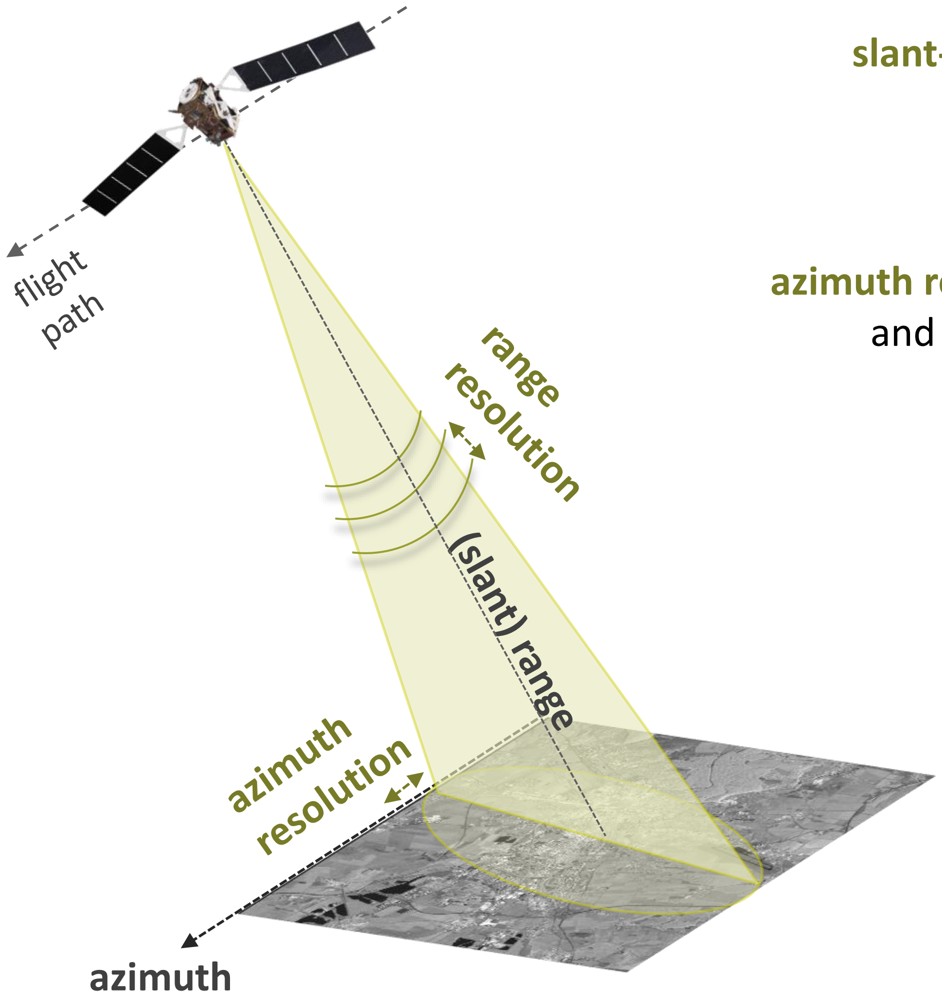


Nadir looking,
e.g. aerial photography

Side looking,
e.g. SLAR, SAR

range: scanning in the look direction at the speed of light

azimuth: scanning in flight direction at the speed of the sensor



slant-range resolution depends on the **bandwidth of the system**

azimuth resolution is a function of the **antenna length** and **sensor height** over the Earth's surface!

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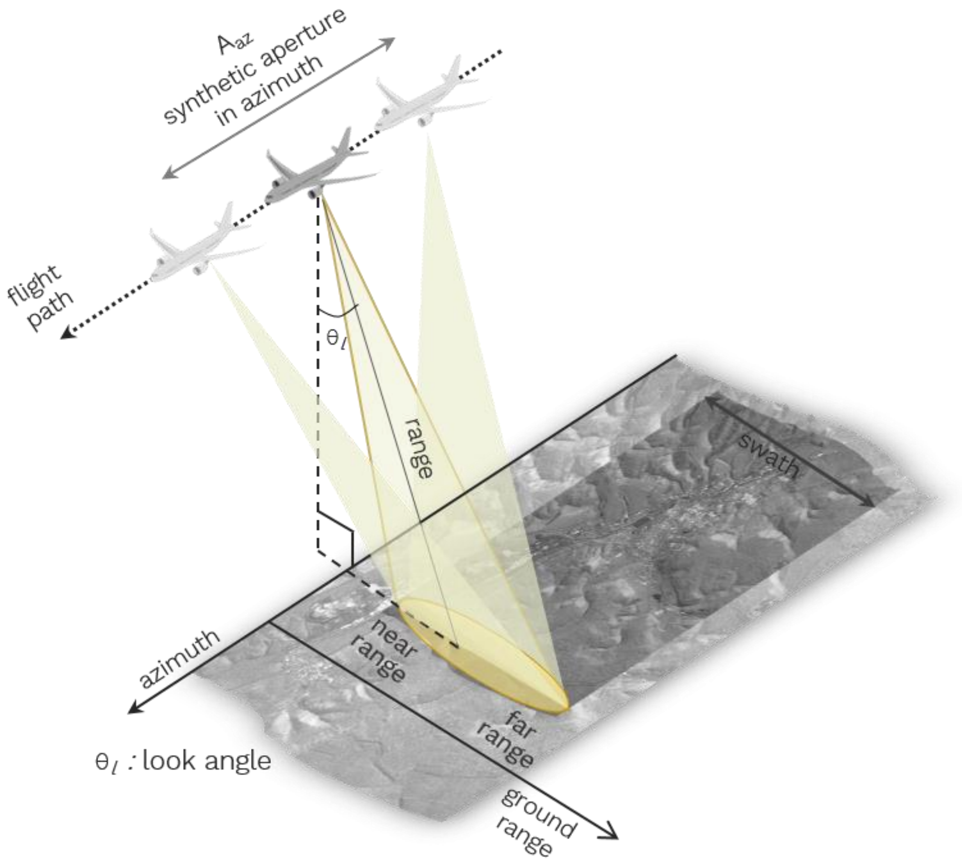
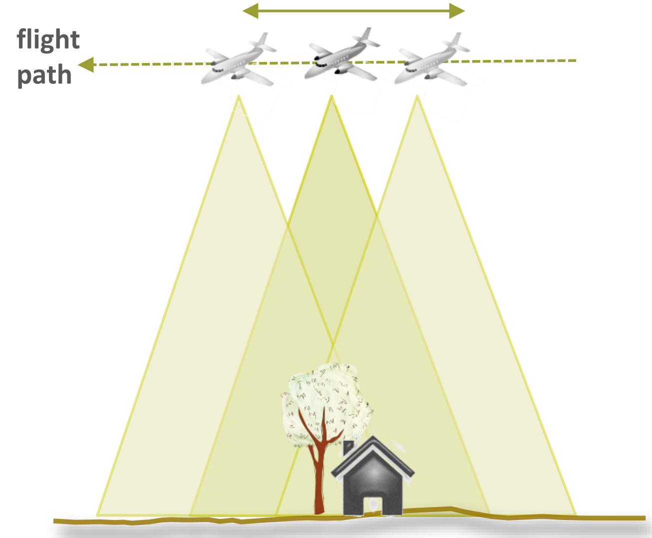
Synthetic Aperture Radar (SAR)

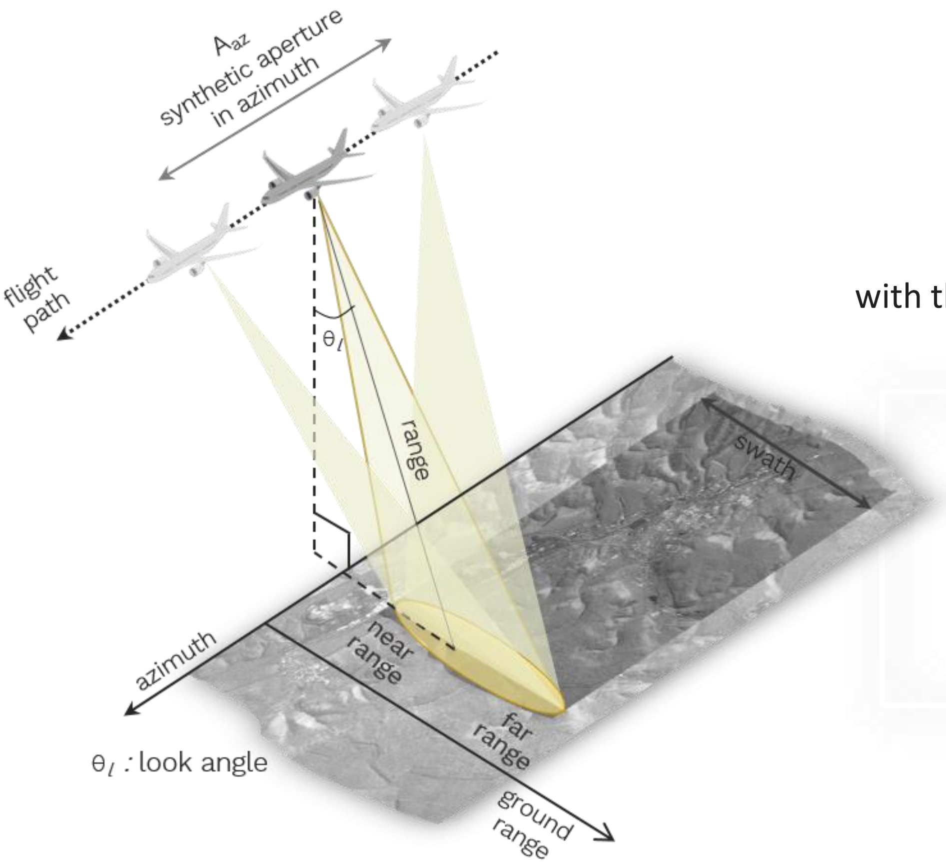
The key factor that is utilized in SAR is to synthesize a much longer antenna in azimuth direction by making use of the motion of the SAR sensor in order to achieve finer resolution.





Side view

Synthetic Aperture Radar (SAR) – azimuth resolution

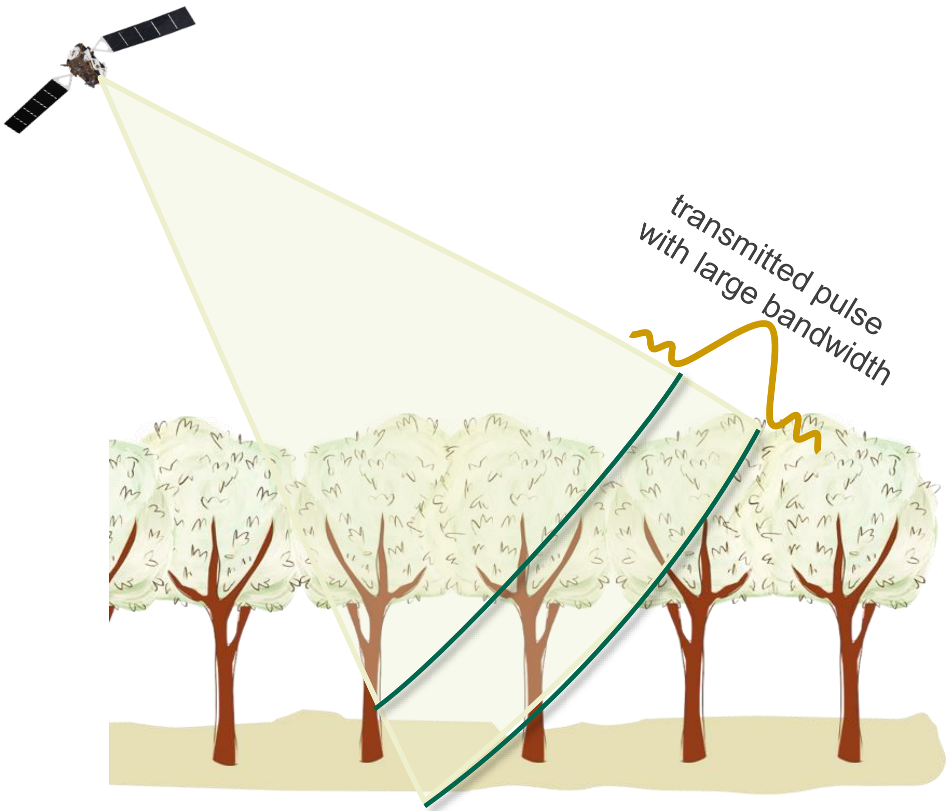


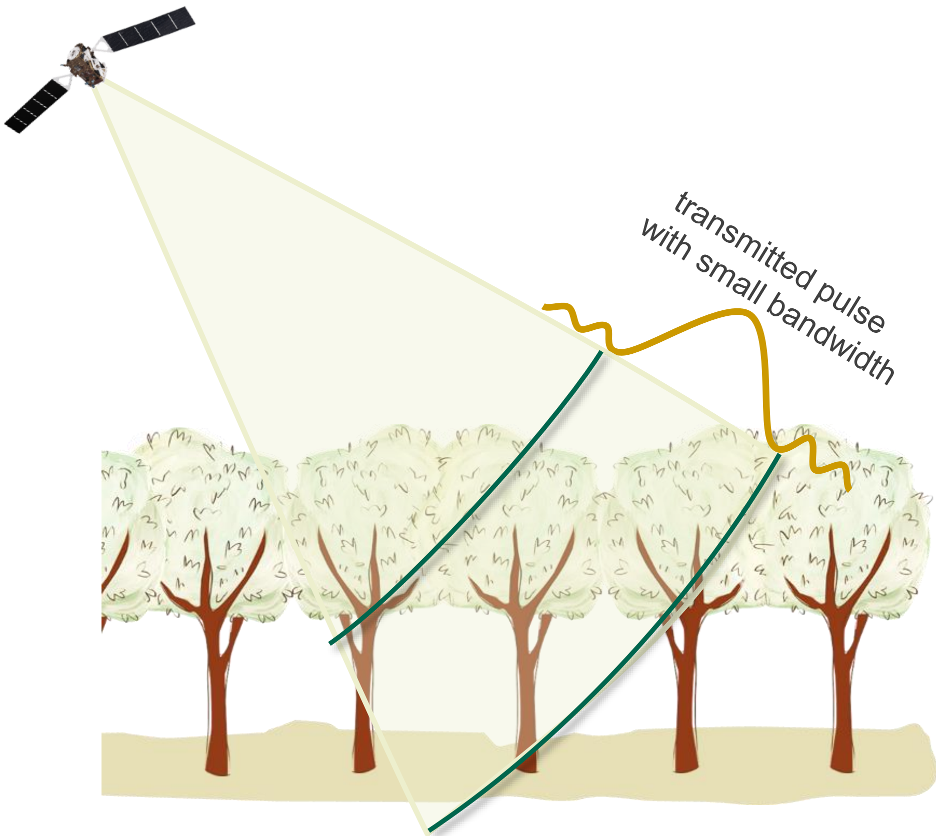
with the azimuth resolution being a function of the aperture in azimuth

Azimuth resolution $\delta_{az} = \frac{\lambda r_0}{2A_{az}}$

λ : carrier wavelength
r_0 : range distance
A_{az} : azimuth aperture

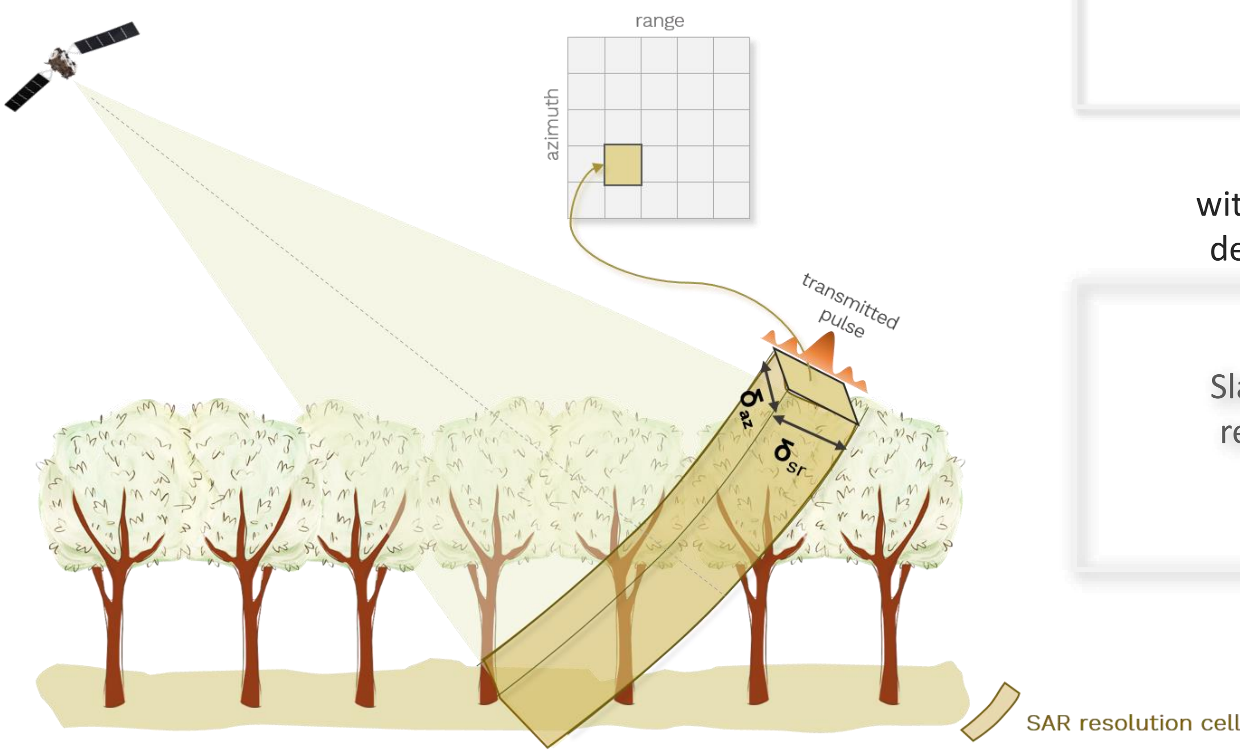
Synthetic Aperture Radar (SAR) – range resolution





Synthetic Aperture Radar (SAR) – resolution cell

A SAR pixel = sum of all contributions within the resolution cell



with the azimuth resolution being a function of the aperture in azimuth

Azimuth resolution

$$\delta_{az} = \frac{\lambda r_0}{2A_{az}}$$

λ : carrier wavelength
r_0 : range distance
A_{az} : azimuth aperture

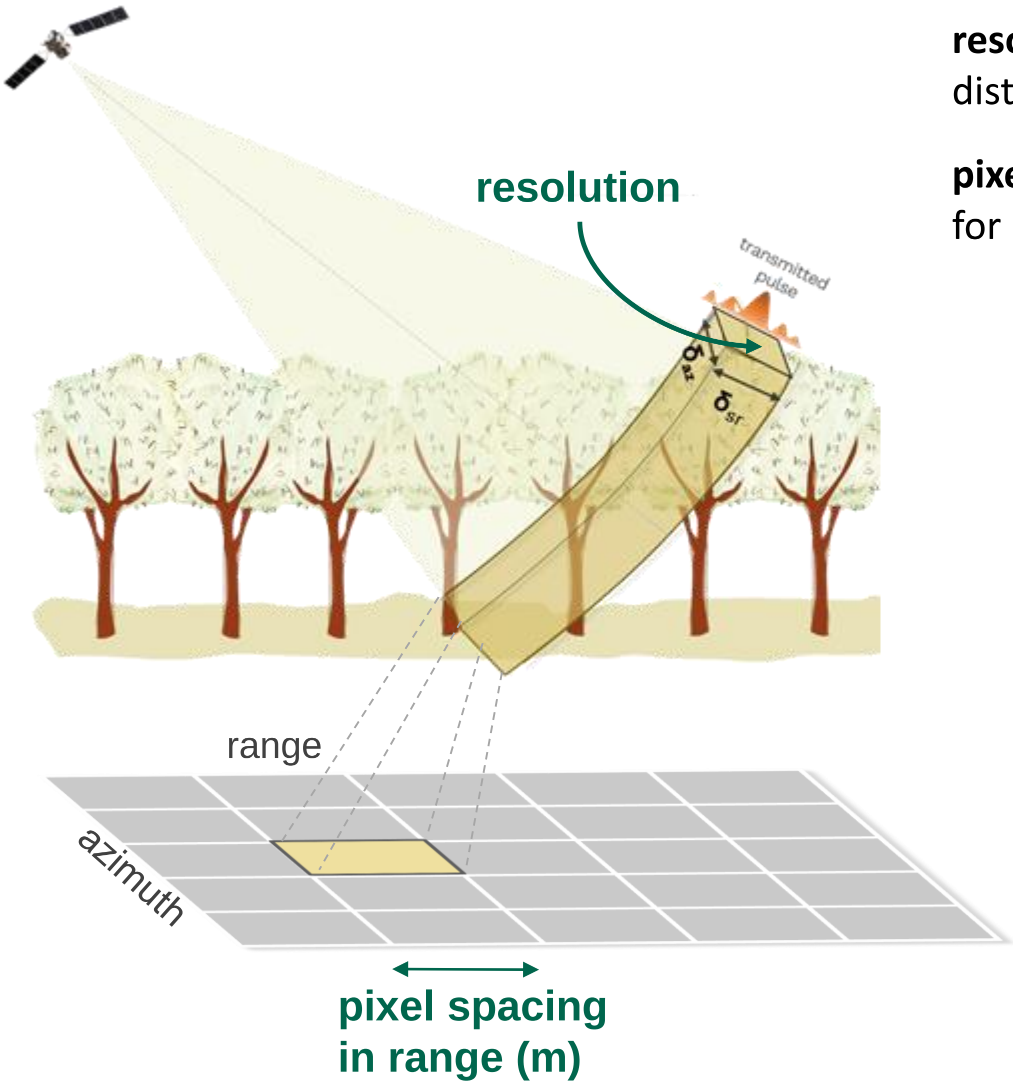
with the slant-range resolution depending on the bandwidth

Slant-range resolution

$$\delta_{sr} = \frac{c}{2W}$$

c : speed of light
W : pulse bandwidth

resolution vs. pixel spacing



resolution is a measure of the system's ability to distinguish between adjacent targets

pixel spacing represents the distance on the ground for a pixel in the range and azimuth directions

Acquisition resolution of Sentinel 1 Level-1 SLC

Mode	Resolution rg x az	Pixel spacing rg x az
SM	1.7x4.3 m to 3.6x4.9 m	1.5x3.6 m to 3.1x4.1 m
IW	2.7x22 m to 3.5x22 m	2.3x14.1 m
EW	7.9x43 m to 15x43 m	5.9x19.9 m
WV	2.0x4.8 m and 3.1x4.8 m	1.7x4.1 m and 2.7x4.1 m

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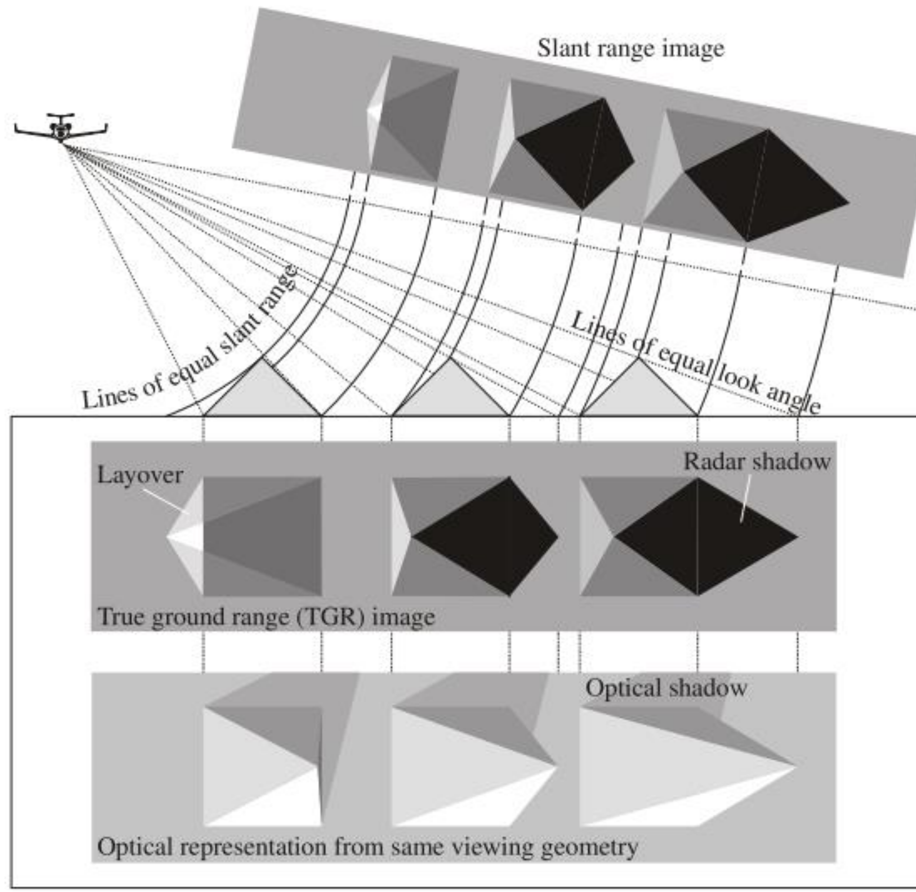
Geometric Effects in SAR images

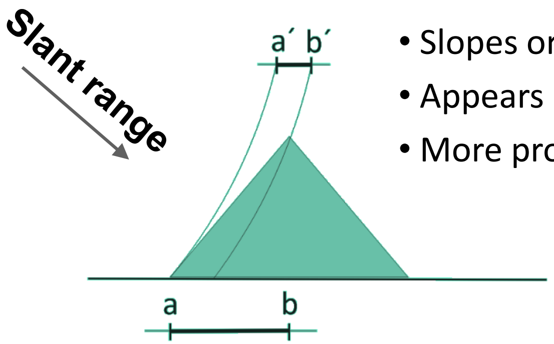
Effects of side-looking geometry

→ The mapping of a radar image is contrary to the intuitive mapping of an optical image

→ Side looking geometry of SAR systems cause some typical geometric effects

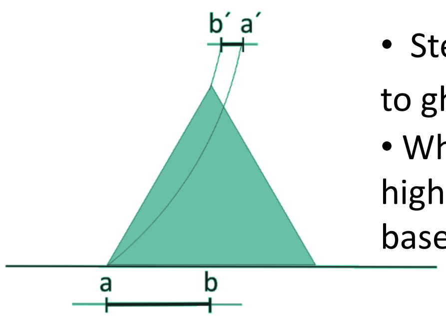
- Controlled by:
  - ❖ Incidence angle
  - ❖ Topography
- The effects are:
  - ❖ Foreshortening
  - ❖ Layover
  - ❖ Radar shadow





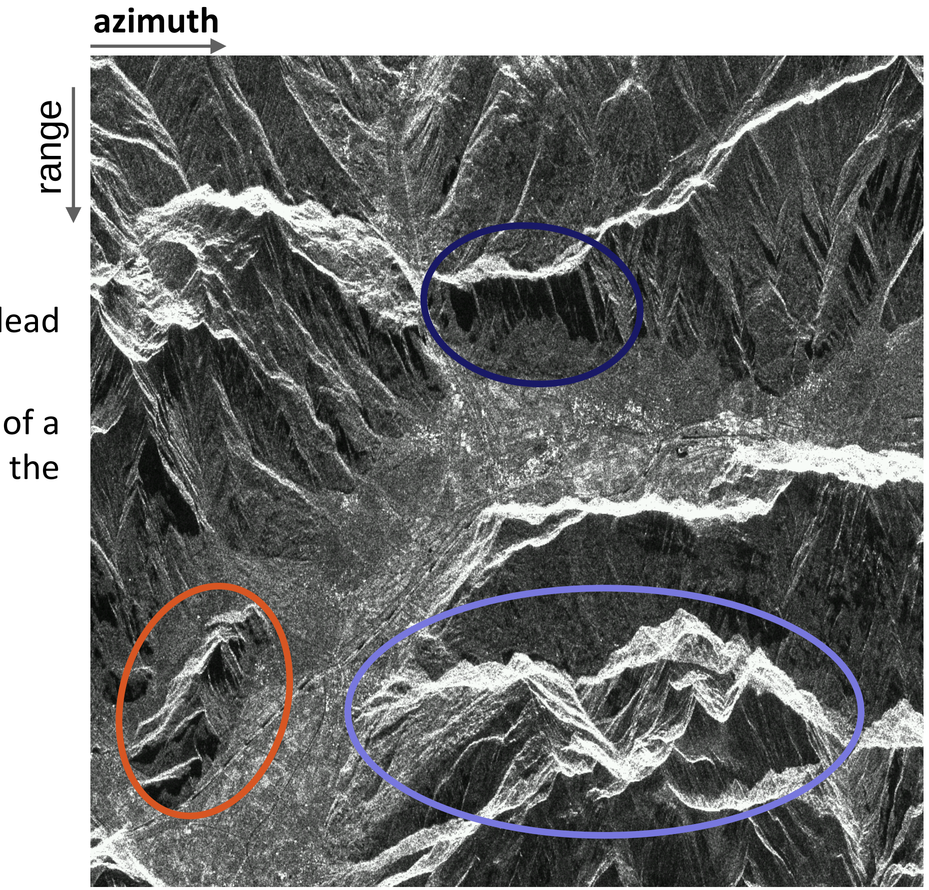
Foreshortening

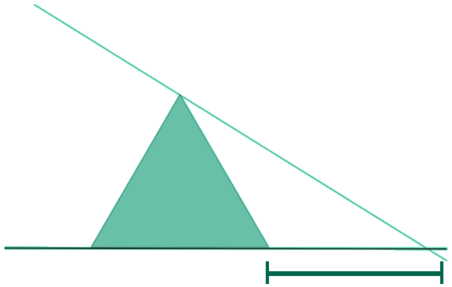
- Slopes oriented to the SAR appear compressed (Distance between a and b is shortened)
- Appears as very bright area
- More pronounced in near range (small incidence angle) than in far range (high incidence angles)



Layover

- Steep slopes oriented to the SAR lead to ghost images
- When radar beam reaches the top of a high feature (b) before it reaches the base (a)



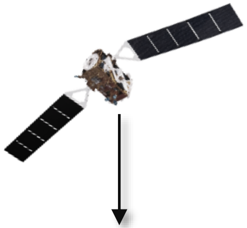


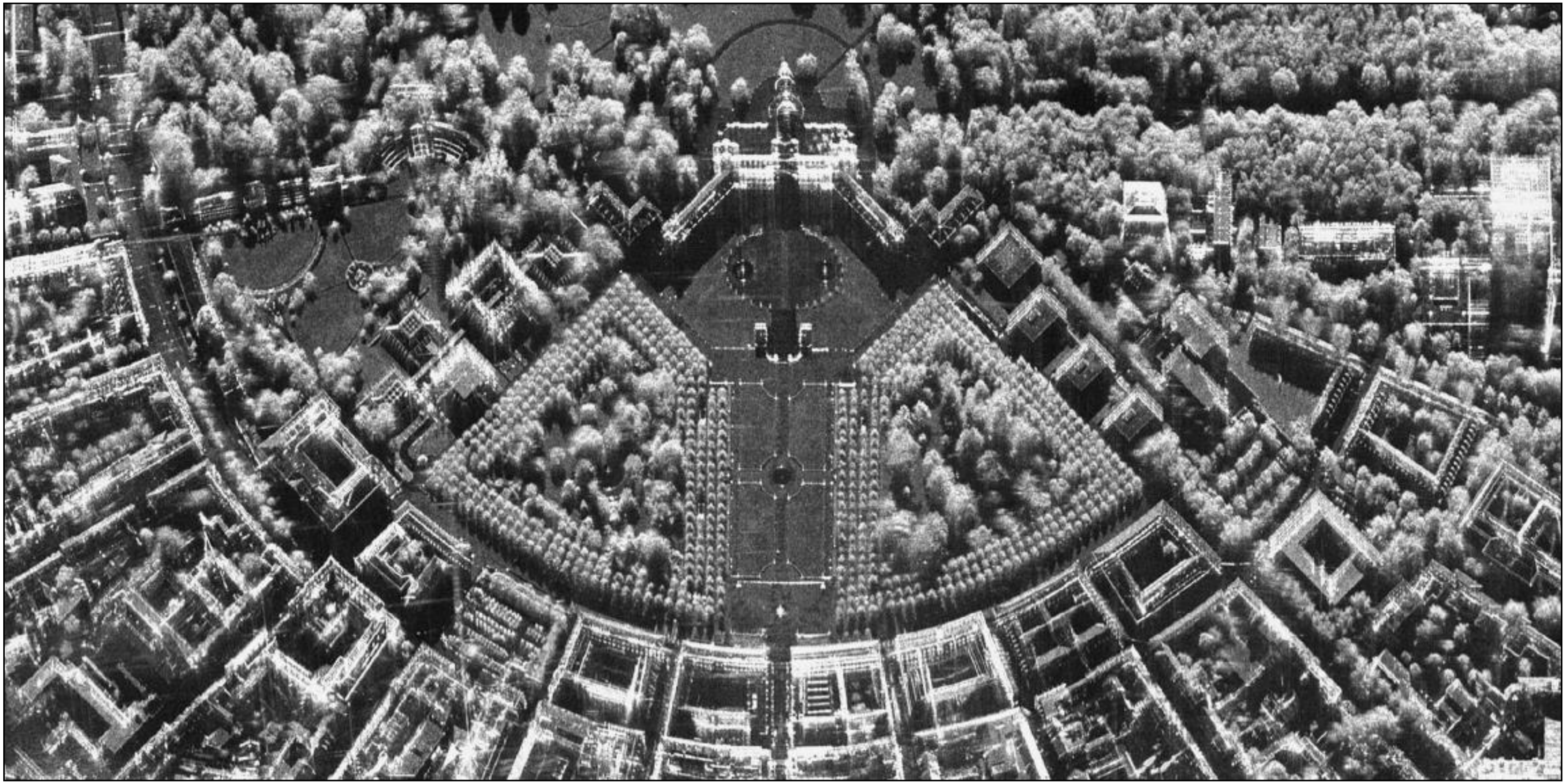
Radar shadow

- Steep slopes oriented away from the SAR return no signal
- No signals can be transmitted to this area (as it is blocked by the slope)
- Thus no signals can be scattered back from these areas
- Appears as black area in the image

SAR Data Example

Effects of side-looking geometry

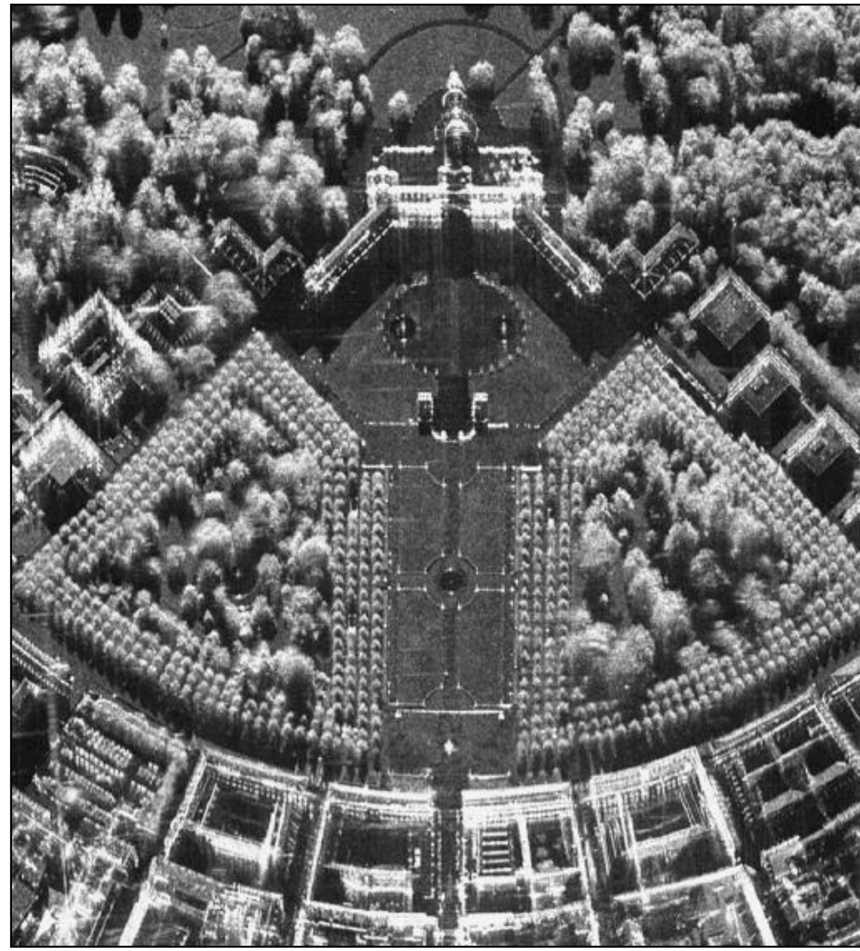




Andreas R. Brenner and Ludwig Roessing, Radar Imaging of Urban Areas by Means of Very High-Resolution SAR and Interferometric SAR, IEEE TRANSACTIONS ON GEOSCIENCE AND REMOTE SENSING, VOL. 46, NO. 10, OCTOBER 2008 (X-band)

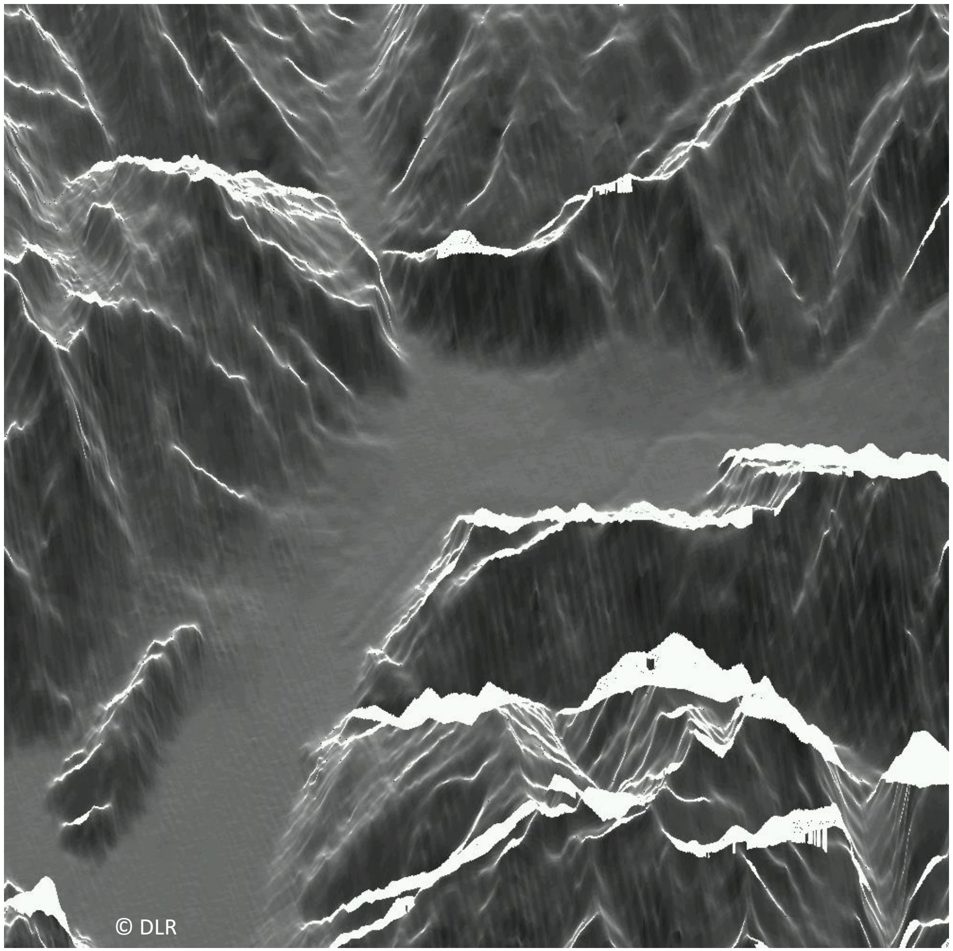
SAR Data Examples

GoogleMaps



Layover Mask Computed from DEM

100m DEM



simulated ERS-Image
white: lay-over & foreshortening

Outline

- What is Remote Sensing/Earth Observation?
- Active Radar Remote Sensing
  - Electromagnetic spectrum : Why microwaves?
  - Basic characteristics of radar systems
  - Imaging geometry of radar systems
- SAR Remote Sensing
  - SAR resolution cell
  - Effects of SAR imaging geometry
  - Influences on radar backscatter
  - SAR measurements
  - Speckle Effect
  - Spaceborne SAR systems
- Summary

Influences on radar backscatter

- The properties of the microwaves that were scattered back from Earth's surface depends on a number of parameters:

Radar Backscatter

System Parameters

- wavelength / frequency
- polarization
- Incidence angle
- resolution

Target Parameters

- dielectric constant
- surface roughness
- 3-D distribution of scatterers & scattering mechanisms
- local slope & orientation

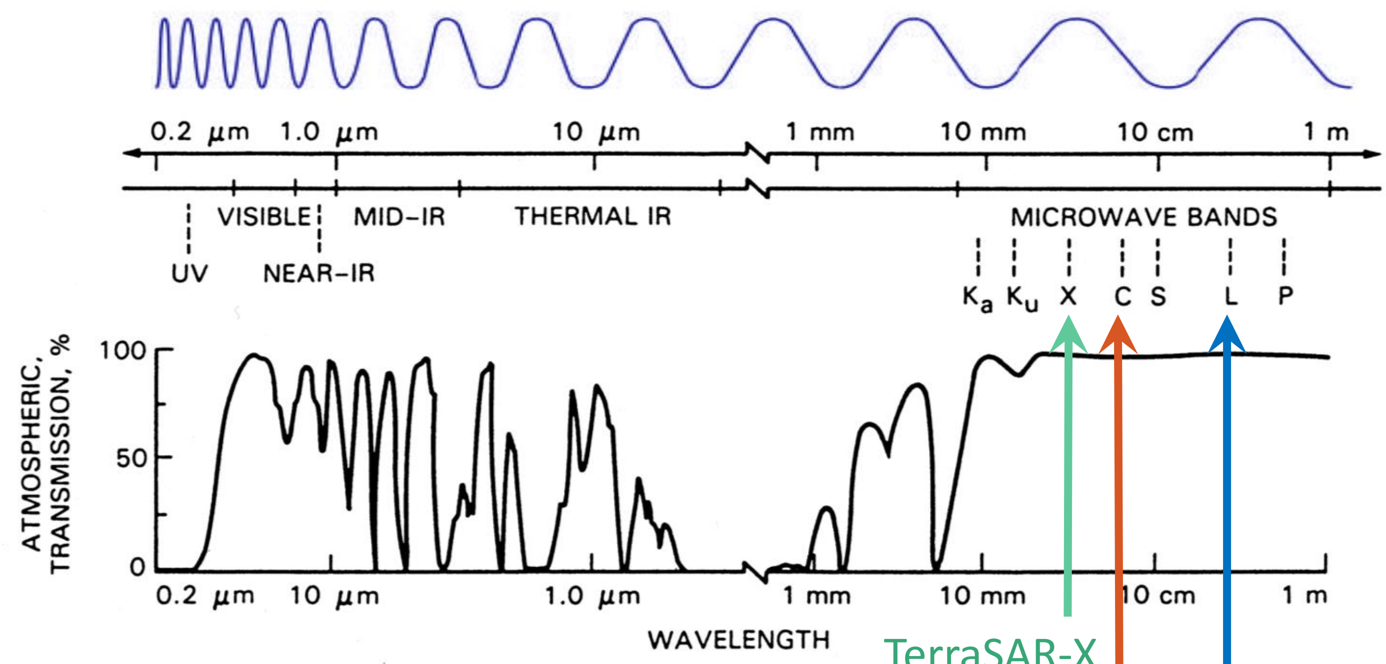
Influences on radar backscatter

System parameters : Wavelength/Frequency

Radar Backscatter

System Parameters
- wavelength / frequency
- polarization
- Incidence angle
- resolution

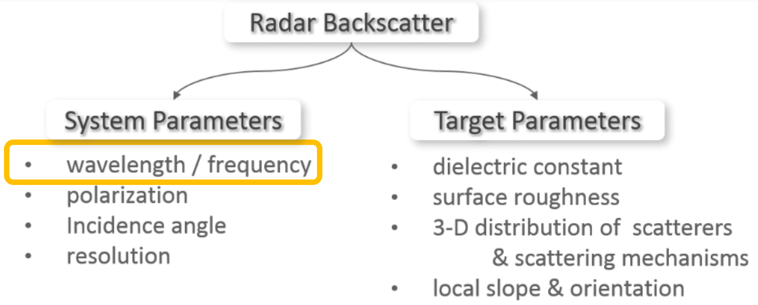
Target Parameters
- dielectric constant
- surface roughness
- 3-D distribution of scatterers & scattering mechanisms
- local slope & orientation



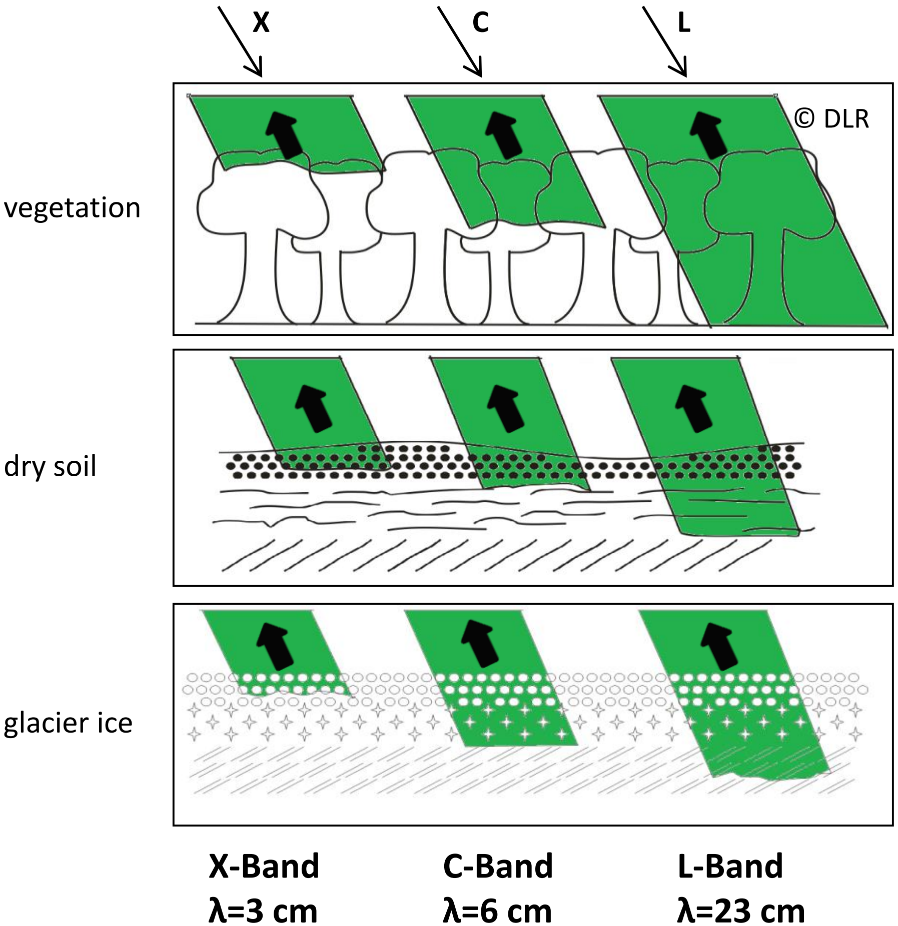
Radar bands and transmission of Radar through the atmosphere (WICKS 2006:o.S.).

Influences on radar backscatter

System parameters : Wavelength/Frequency



Penetration of Microwaves



Influences on radar backscatter

System parameters : Wavelength/Frequency

Radar Backscatter

System Parameters
- wavelength / frequency
- polarization
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- resolution

Target Parameters
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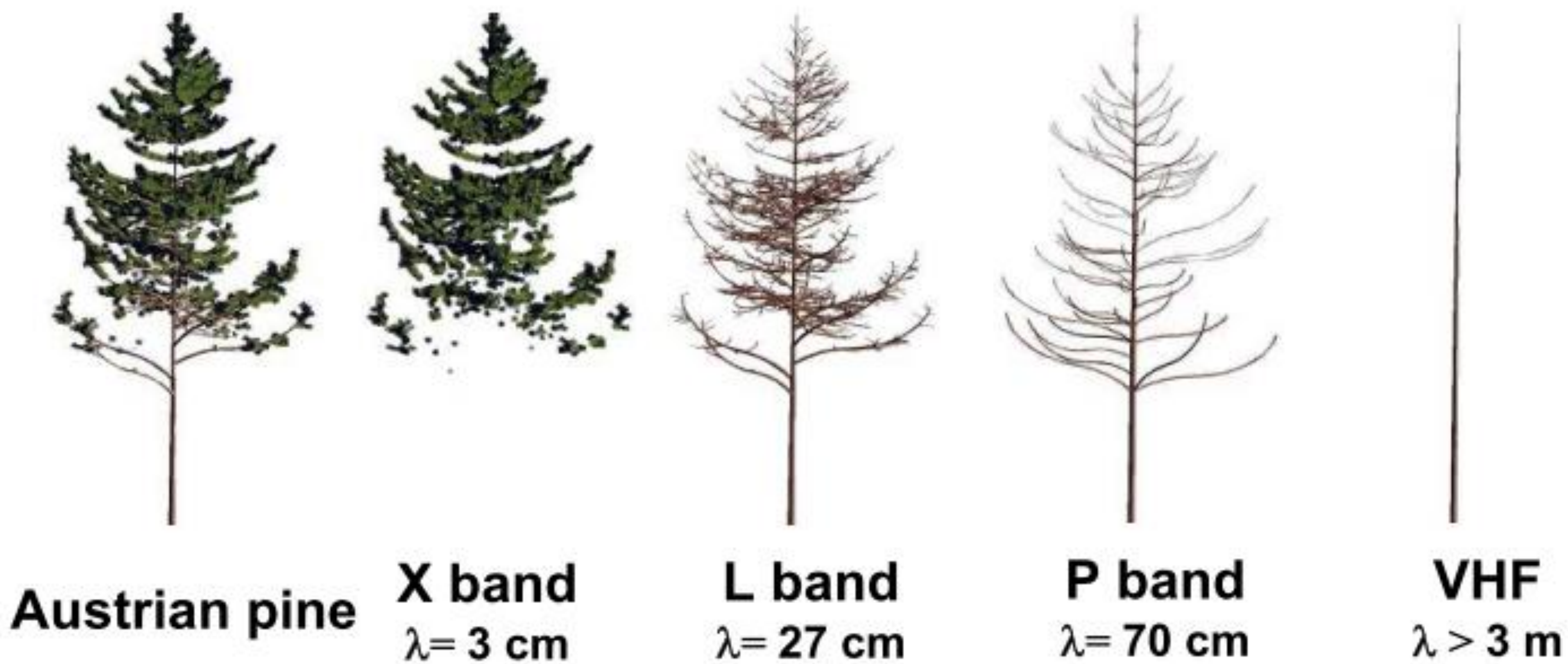
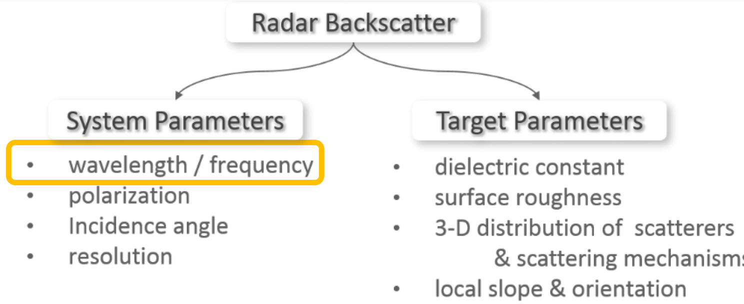


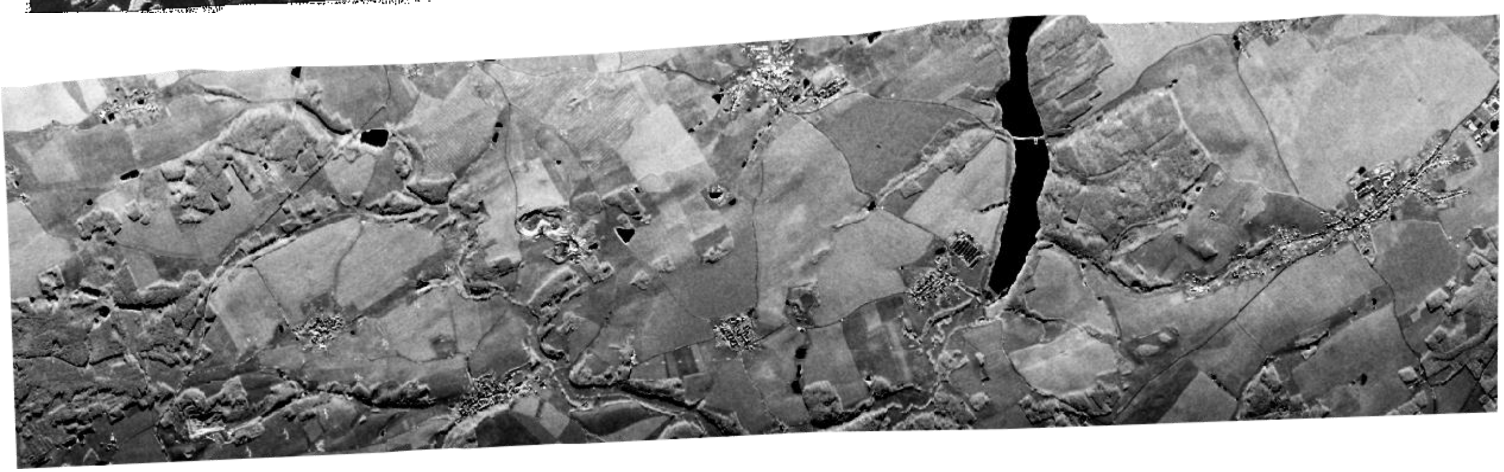
LE TOAN

Influences on radar backscatter

System parameters : Wavelength/Frequency



L-band



X-band

Influences on radar backscatter

System parameters : Polarization

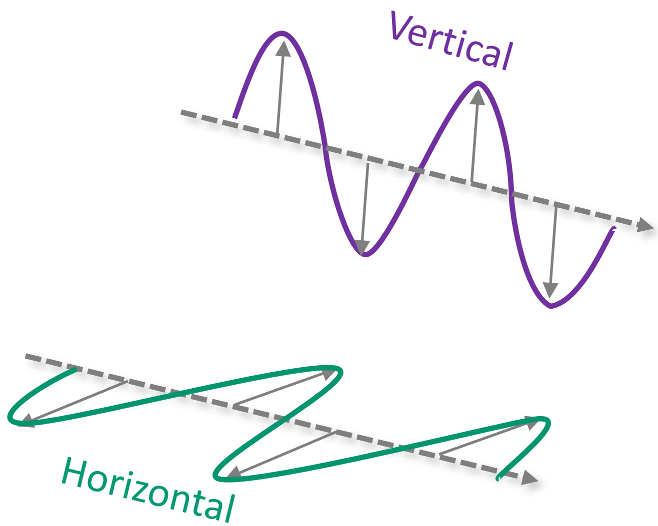
Radar Backscatter

System Parameters

- wavelength / frequency
- polarization
- Incidence angle
- resolution

Target Parameters

- dielectric constant
- surface roughness
- 3-D distribution of scatterers & scattering mechanisms
- local slope & orientation



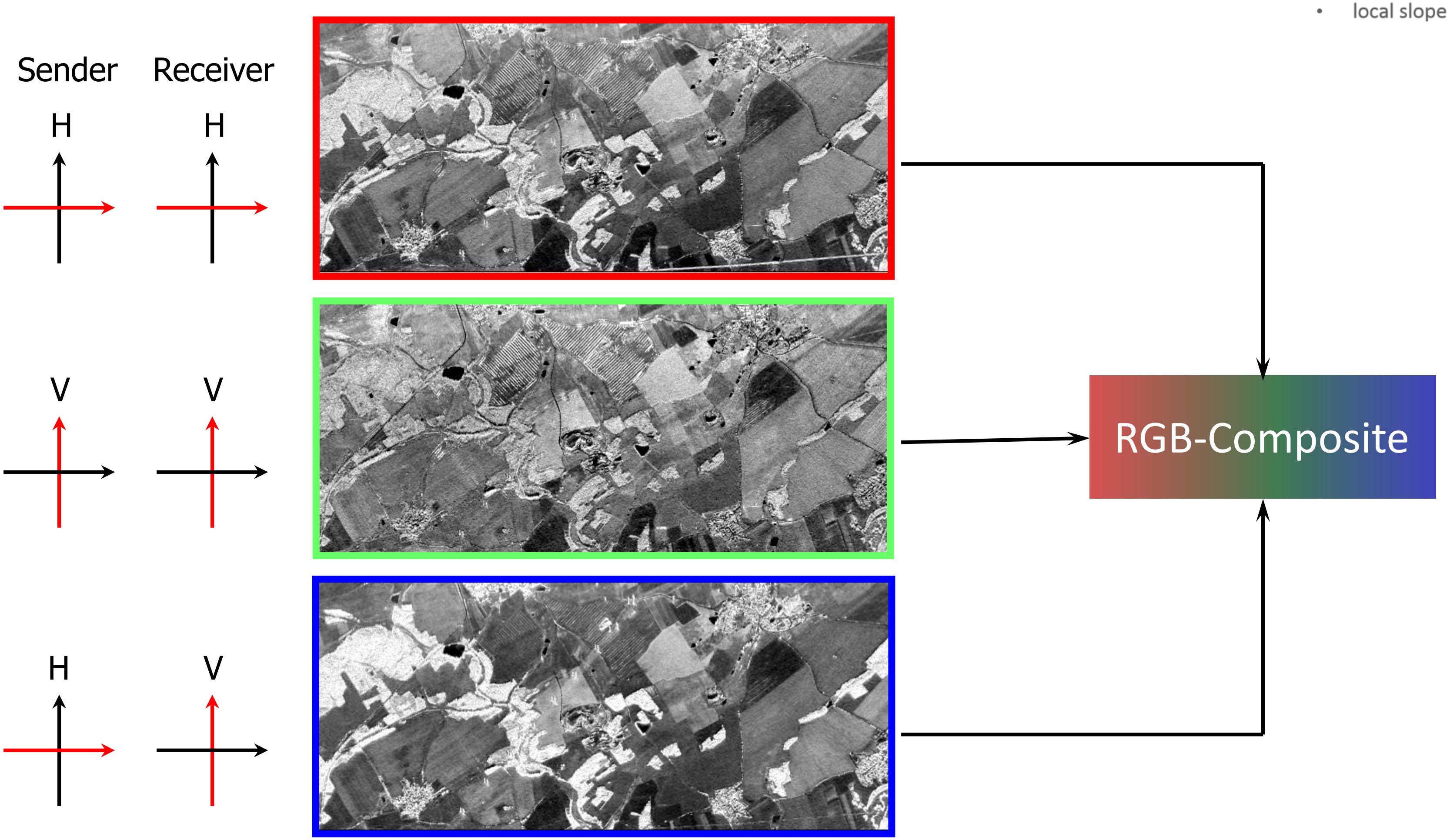
Influences on radar backscatter

System parameters : Polarization

Radar Backscatter

System Parameters
- wavelength / frequency
- polarization
- Incidence angle
- resolution

Target Parameters
- dielectric constant
- surface roughness
- 3-D distribution of scatterers & scattering mechanisms
- local slope & orientation



Influences on radar backscatter

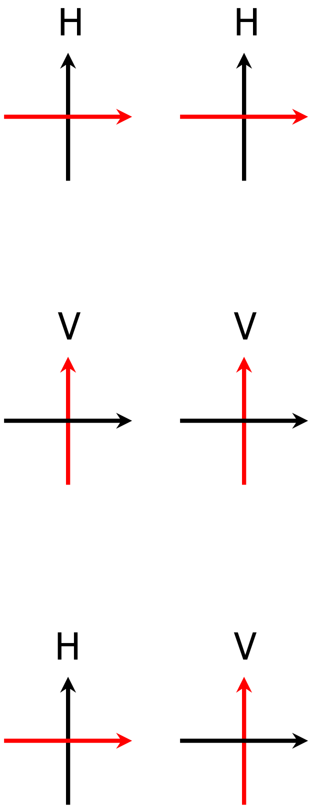
System parameters : Polarization

Radar Backscatter

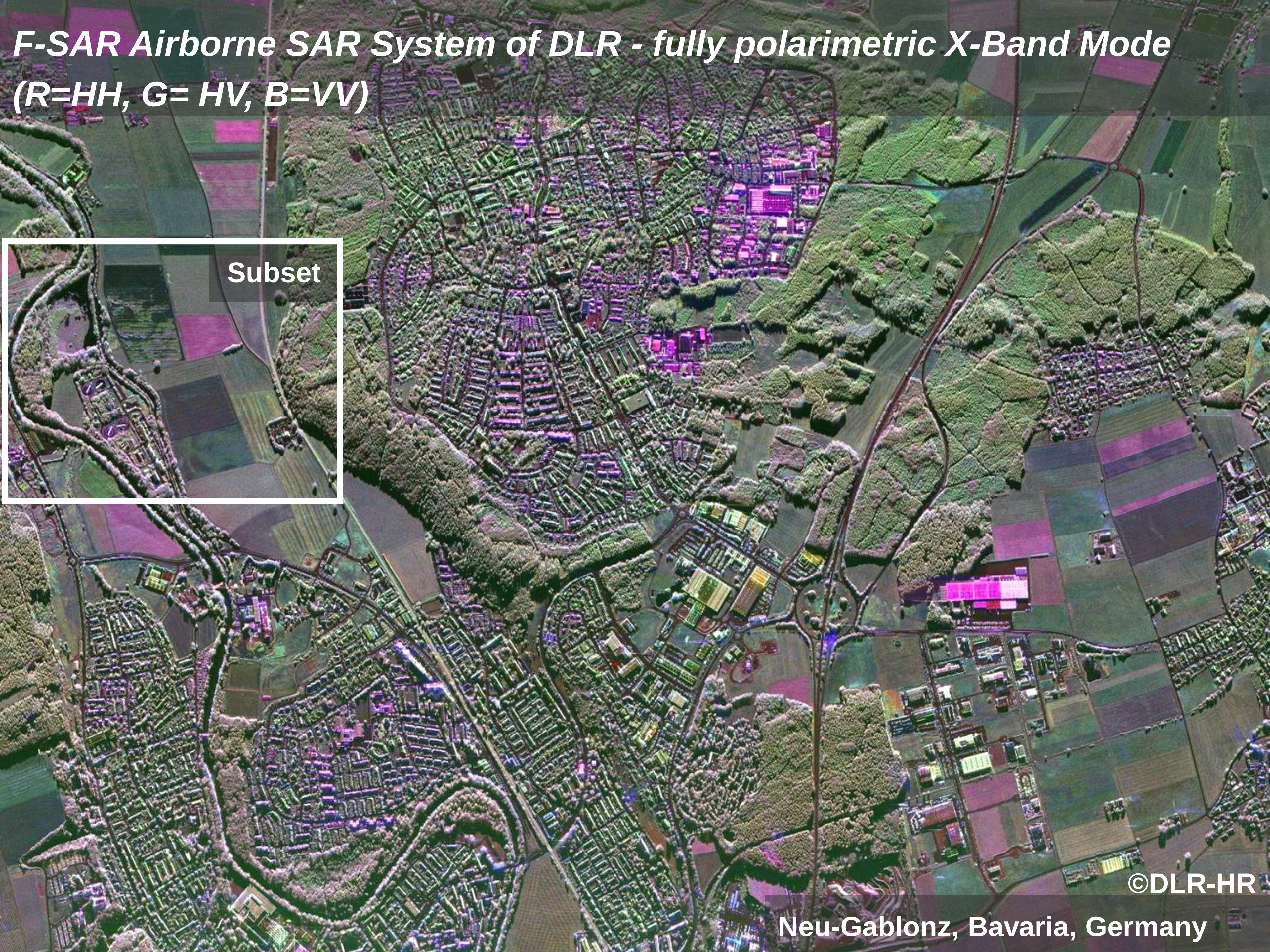
System Parameters
- wavelength / frequency
- polarization
- Incidence angle
- resolution

Target Parameters
- dielectric constant
- surface roughness
- 3-D distribution of scatterers & scattering mechanisms
- local slope & orientation

Sender Receiver



RGB-Composite (HH-VV-HV)

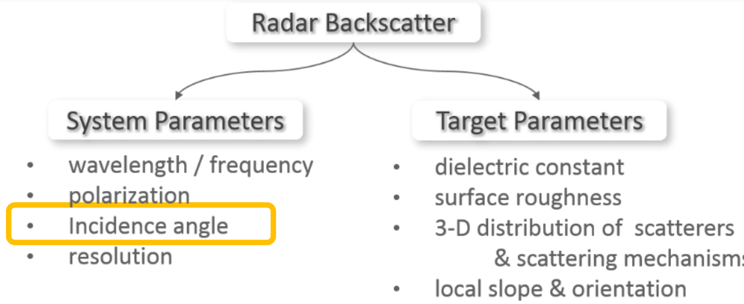

F-SAR Airborne SAR System of DLR - fully polarimetric X-Band Mode
(R=HH, G= HV, B=VV)
Subset
©DLR-HR
Neu-Gablonz, Bavaria, Germany

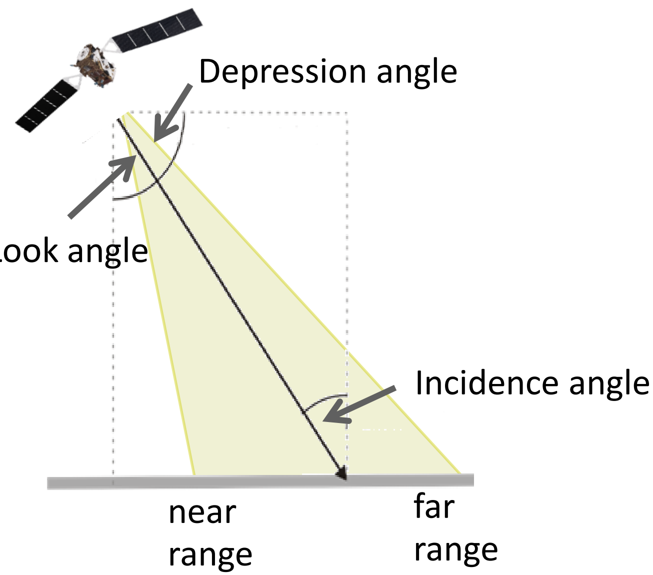
Subset of Neu-Gablonz Area - River, Fields and …
(R=HH, G= HV, B=VV)

… a purification plant

Influences on radar backscatter

System parameters : Incident angle

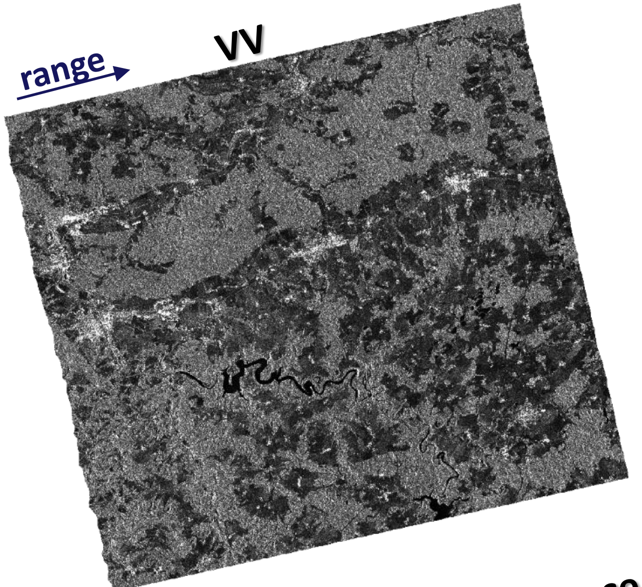




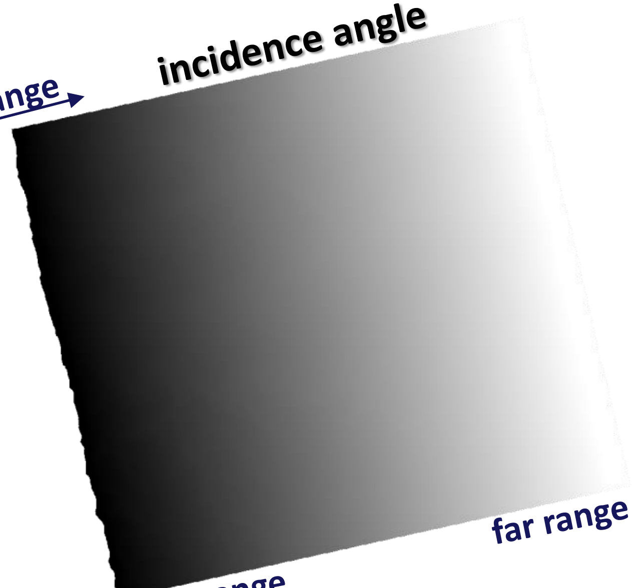
Incidence angle at:
far range **>** near range

- Backscatter decreases with increasing incidence angle (if all other conditions remain constant)

- Magnitude of decrease depends on surface roughness and dielectric properties range VV



range incidence angle



near range far range

Radar Backscatter

System Parameters

- wavelength / frequency
- polarization
- Incidence angle
- resolution

Target Parameters

- dielectric constant
- surface roughness
- 3-D distribution of scatterers & scattering mechanisms
- local slope & orientation

Influences on radar backscatter

System parameters : resolution

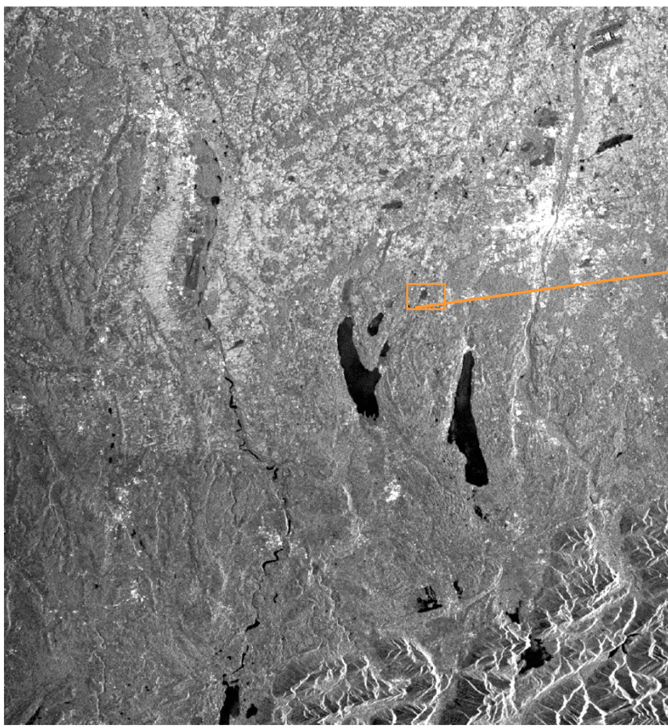
Radar Backscatter

System Parameters

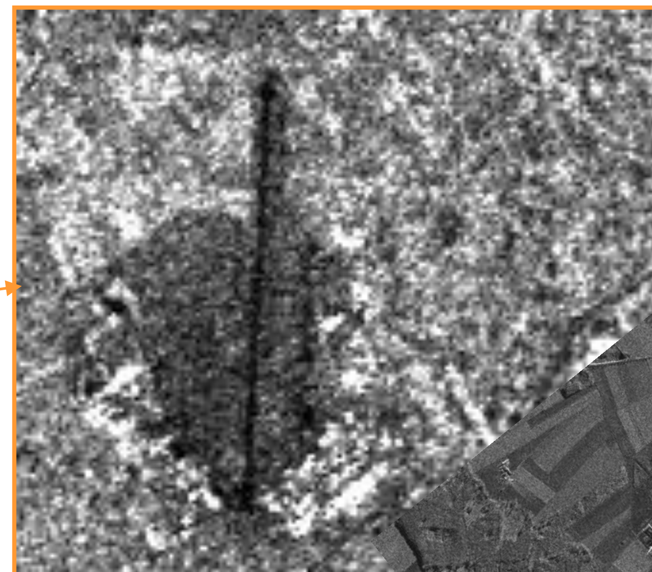
- wavelength / frequency
- polarization
- Incidence angle
- resolution

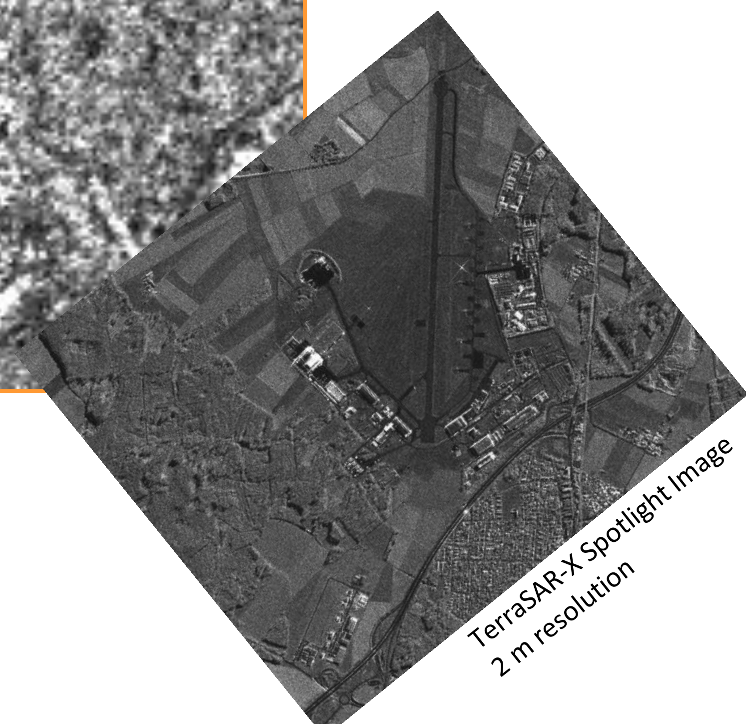
Target Parameters

- dielectric constant
- surface roughness
- 3-D distribution of scatterers & scattering mechanisms
- local slope & orientation



ENVISAT / ASAR IM 2 Oberpfaffenhofen 100 km x 100 km;
25 m resolution (© ESA)





TerraSAR-X Spotlight Image
2 m resolution

Influences on radar backscatter

Target parameters : Dielectric Properties

Radar Backscatter

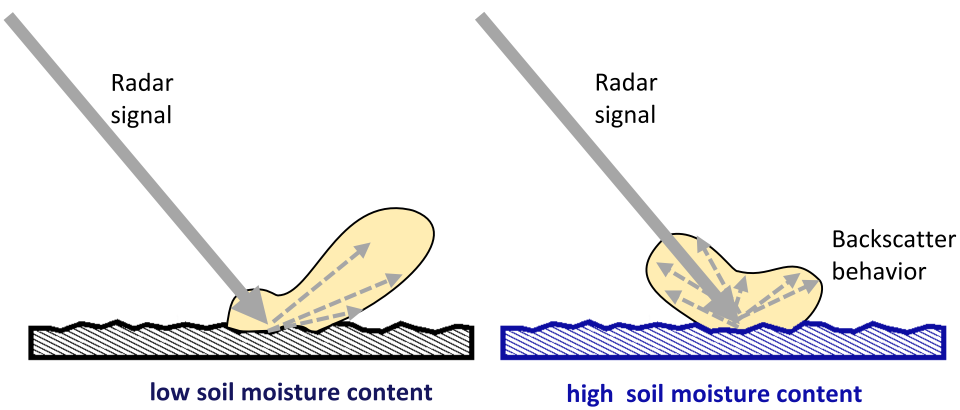
System Parameters
- wavelength / frequency
- polarization
- Incidence angle
- resolution

Target Parameters
- dielectric constant
- surface roughness
- 3-D distribution of scatterers & scattering mechanisms
- local slope & orientation

<u>Determined by dielectric constant ε_r:</u>

- Strongly dependent on **water content** of natural media

- Controls reflection properties of natural media and thus the strength of radar backscatter (higher ε_r -> higher backscatter)



Effect of soil moisture on backscattering behavior

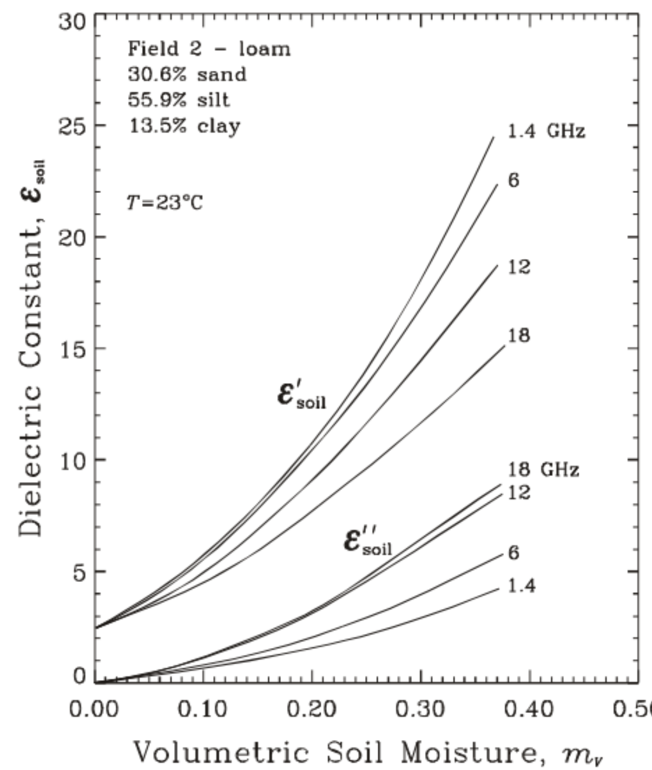


Fig.: Relationship between soil moisture and dielectric constant (Woodhouse, 2006)

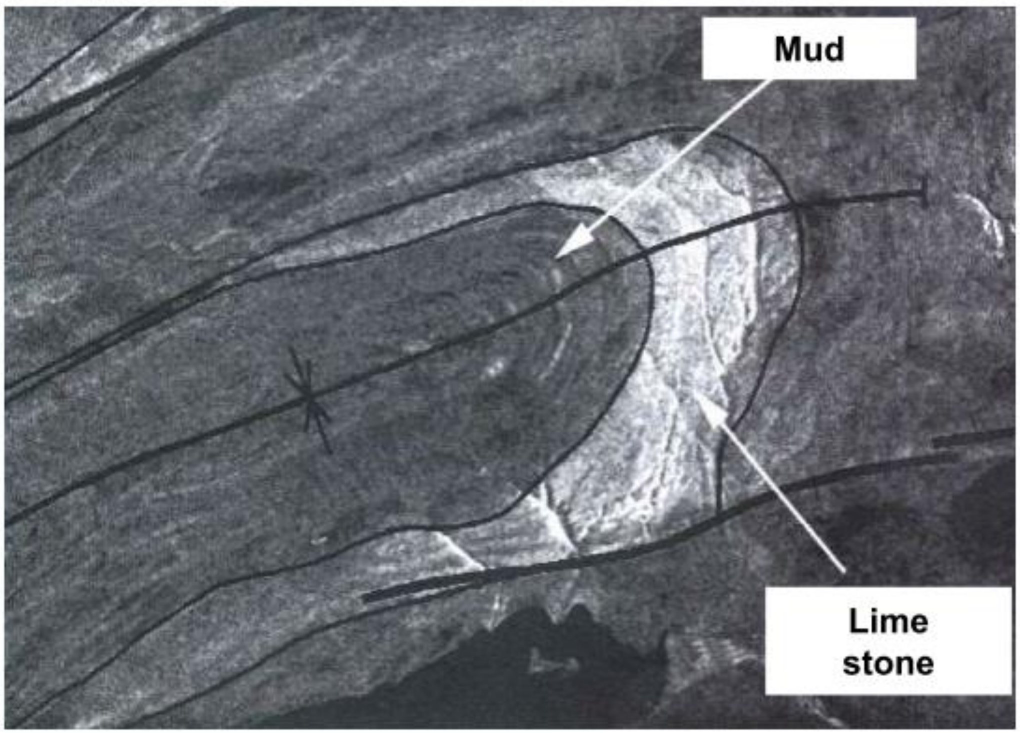
Influences on radar backscatter

Target parameters : Surface Roughness

Radar Backscatter

System Parameters
- wavelength / frequency
- polarization
- Incidence angle
- resolution

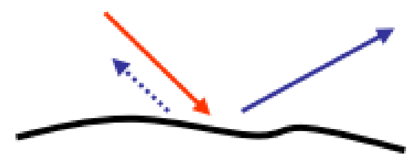
Target Parameters
- dielectric constant
- surface roughness
- 3-D distribution of scatterers & scattering mechanisms
- local slope & orientation



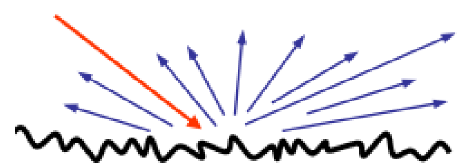
Radarsat, C-band, HH

Bathirst Island, Canada

mud, smooth surface, low radar backscatter



Lime stone, rough surface, high radar backscatter



Influences on radar backscatter

Target parameters : Scattering Mechanisms

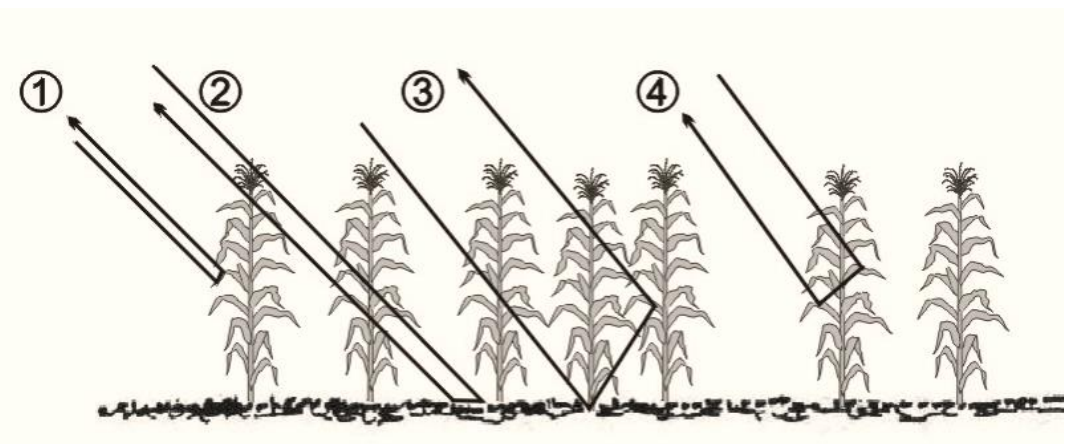
Radar Backscatter

System Parameters
- wavelength / frequency
- polarization
- Incidence angle
- resolution

Target Parameters
- dielectric constant
- surface roughness
- 3-D distribution of scatterers & scattering mechanisms
- local slope & orientation

The backscattered signal results from:

- surface scattering
- volume scattering
- multiple volume-surface scattering (double-bounce)



1) direct backscattering from plants
2) direct backscattering from underlying soil
3) multiple scattering between plants and soil
4) multiple scattering between plants,
5) leaves, stalks ect.

The relative importance of these contributions depend on
- surface roughness
- dielectric properties of the medium

All of these factors depend on
- the radar frequency
- the polarization
- the incidence angle

Influences on radar backscatter

Target parameters : Scattering Mechanisms

Radar Backscatter

System Parameters
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- Incidence angle
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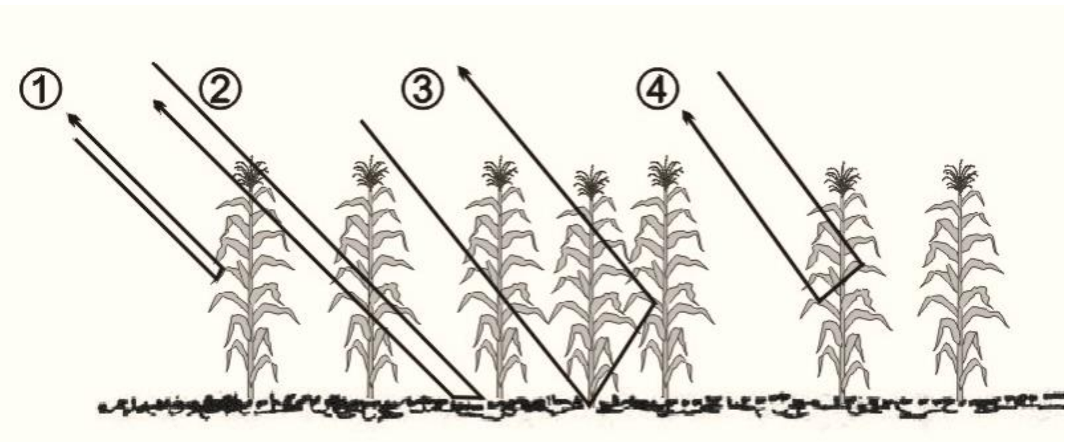
- local slope & orientation



Influences on radar backscatter

Target parameters : local slope & orientation

Radar Backscatter

System Parameters
- wavelength / frequency
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Target Parameters
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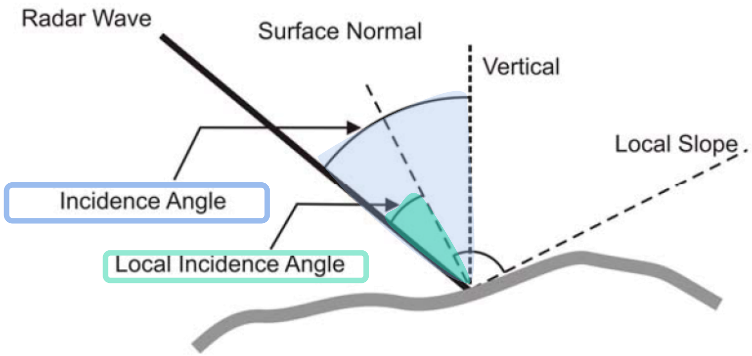

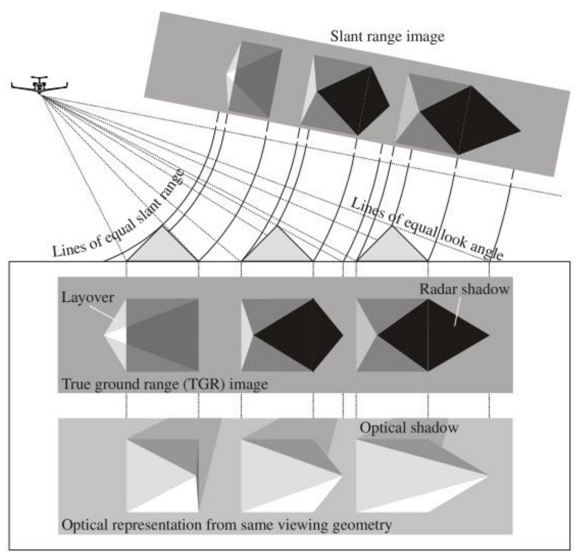

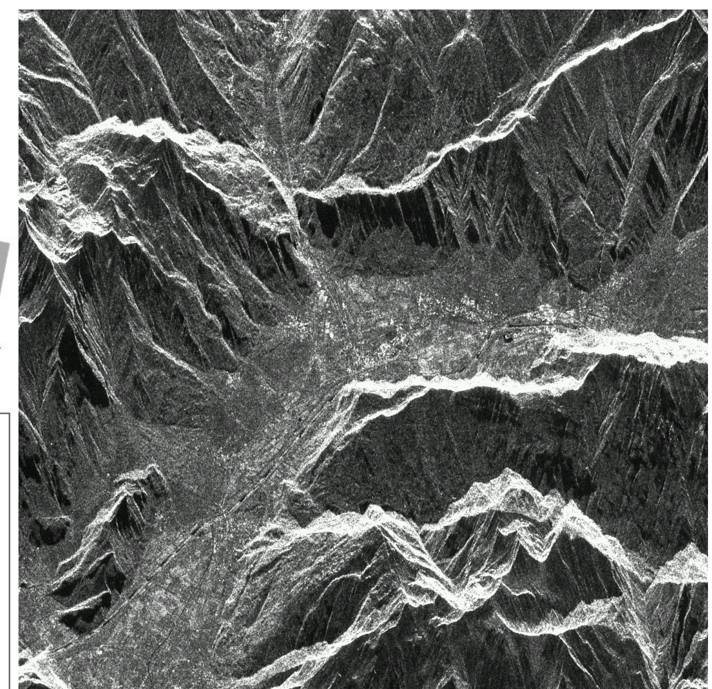

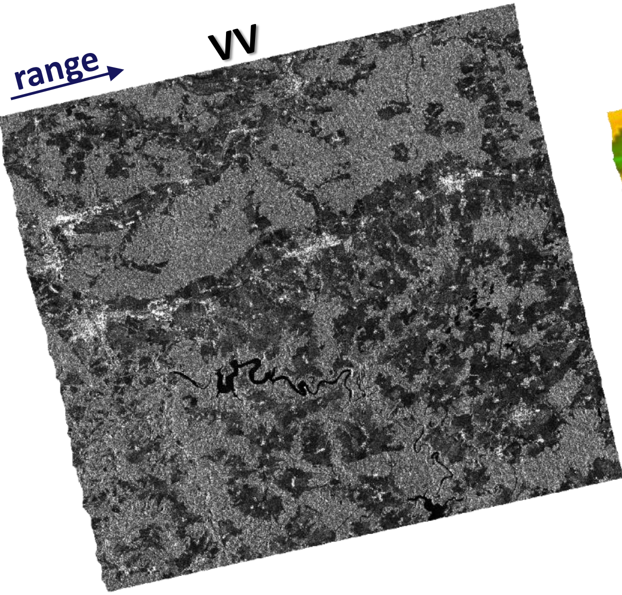

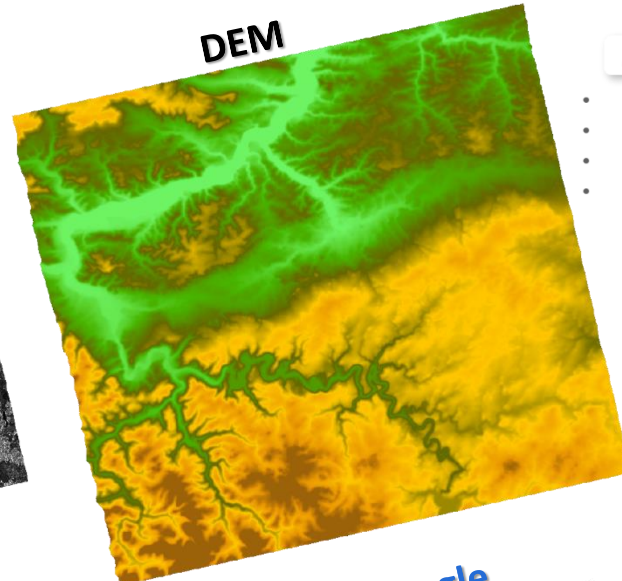

Radar Backscatter

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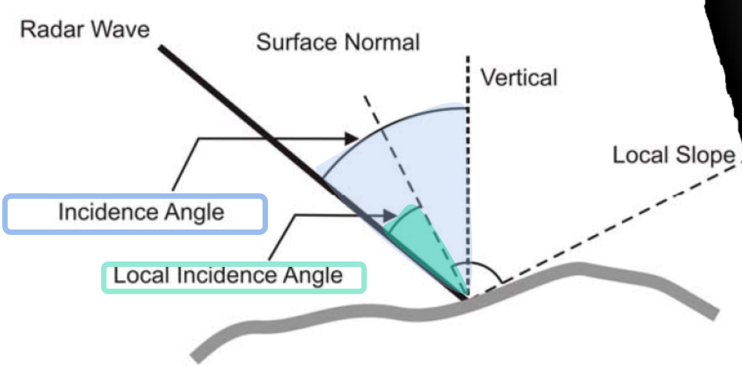

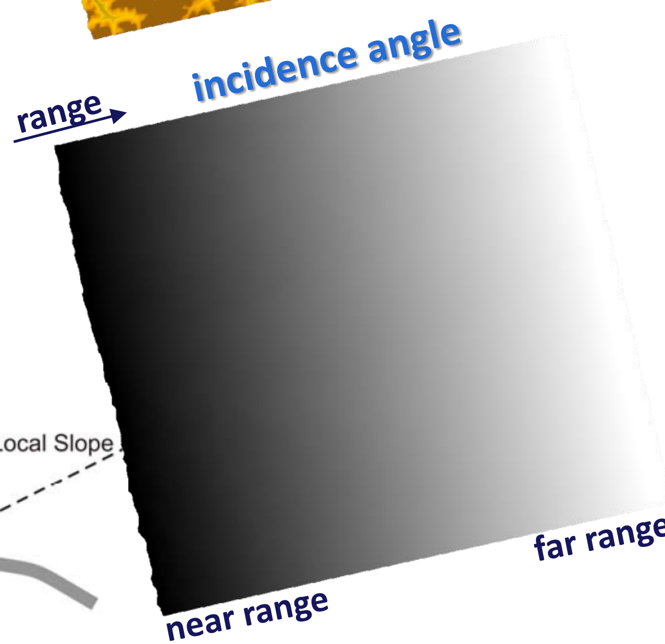

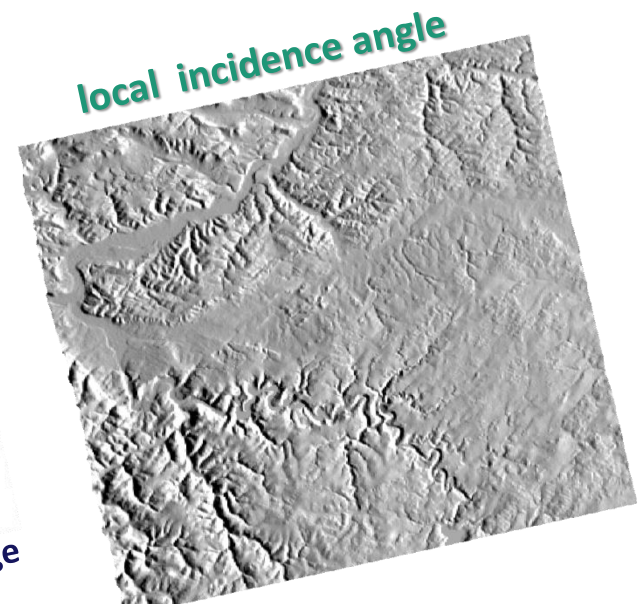

Backscattering Coefficient σ_o

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)*

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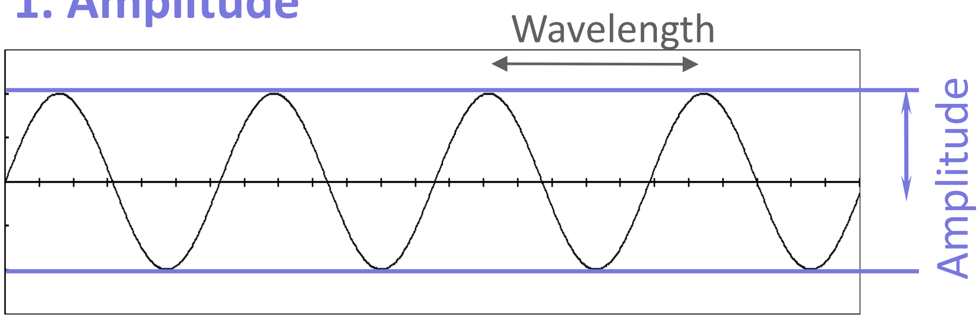
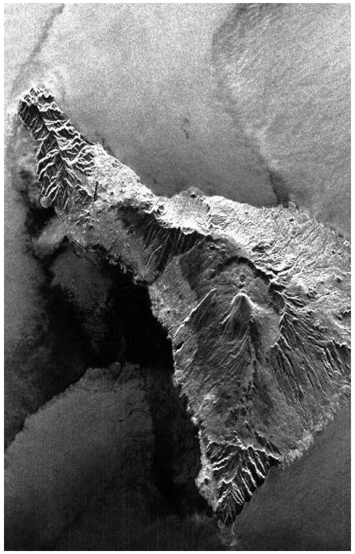
SAR Measurements

1. Amplitude



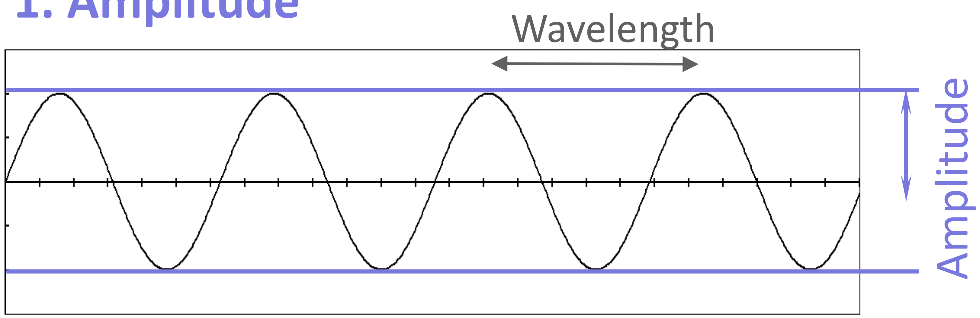


Most commonly used image is the intensity which is: **Intensity = amplitude²**

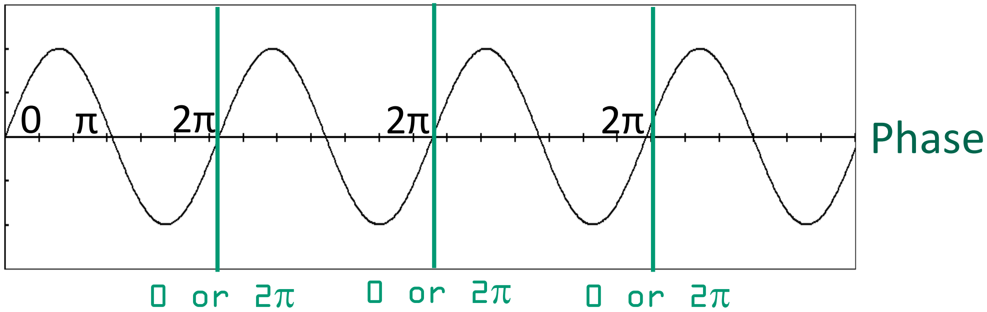
SAR Measurements

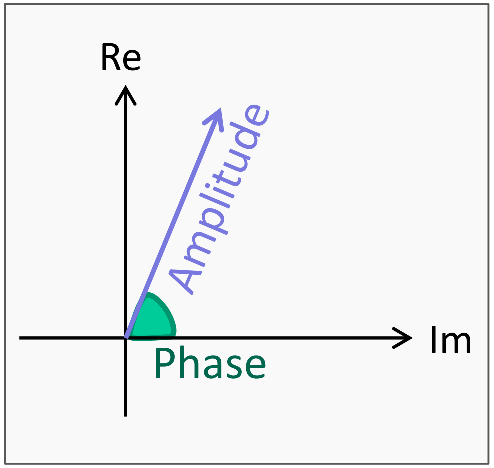
Single look complex (SLC) pixel value is a complex number!

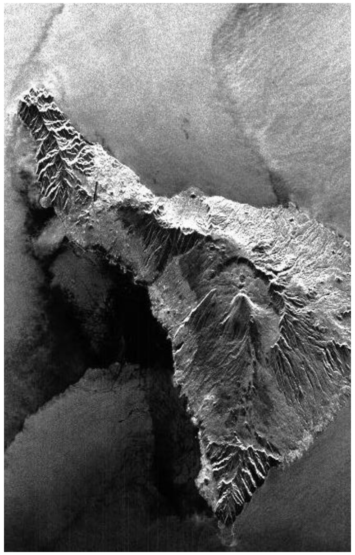
1. Amplitude

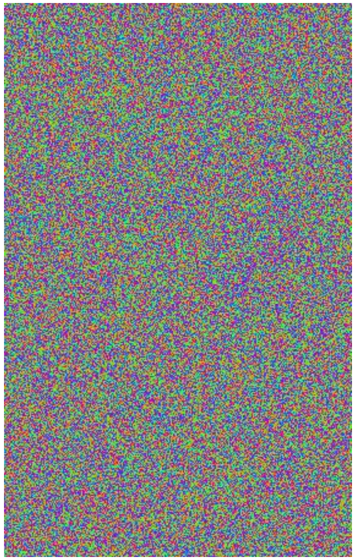


2. Phase [0, 2π]



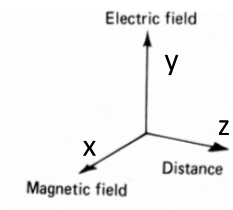


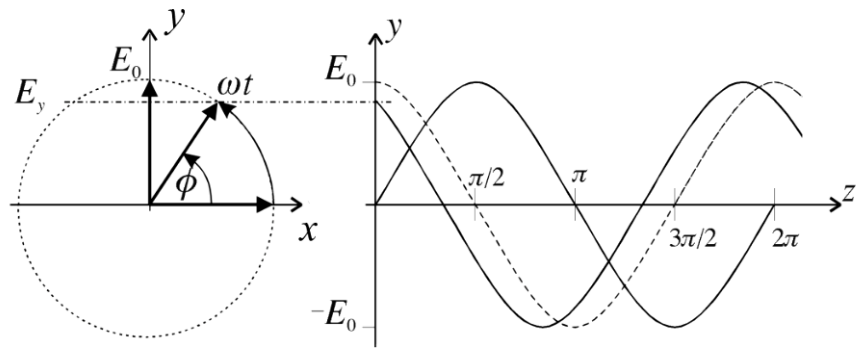




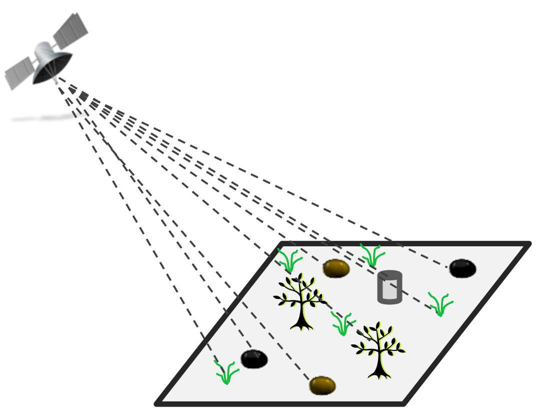
SAR Measurements

Phase is the shift angle between the phase of pulse and echo and relates to the object distance

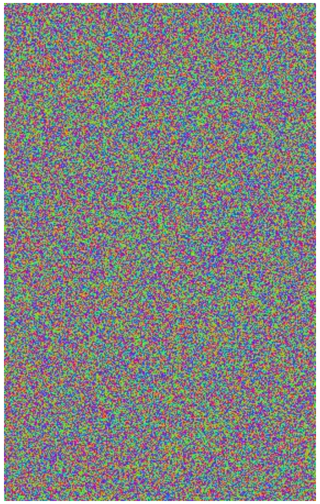




due to contributions from different scatterers in the resolution cell: ***Phase is random for one image***



Resolution cell



Second image of the same area from different sensor positions cancels out the phase contribution introduced by individual scatterers!!

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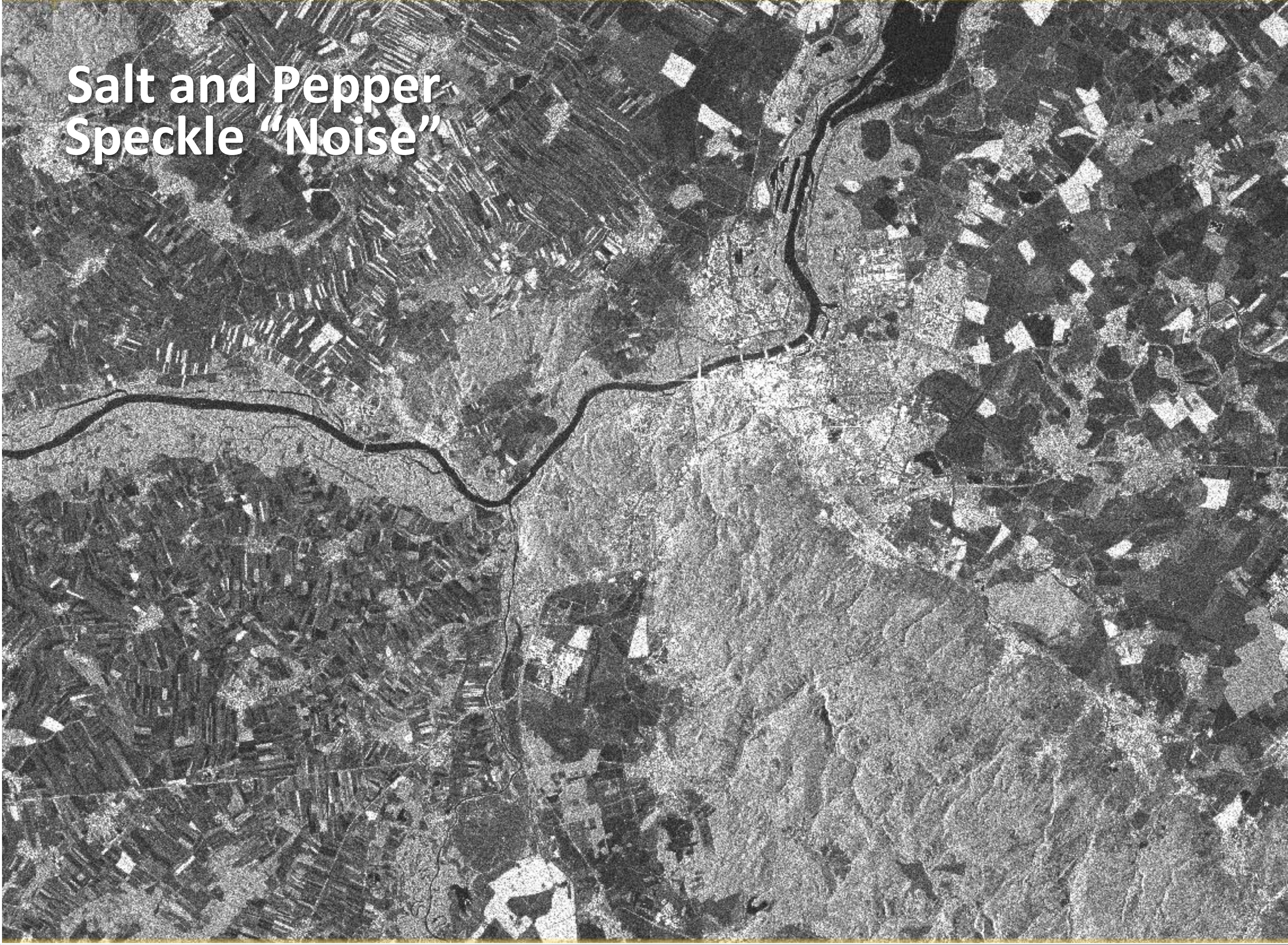
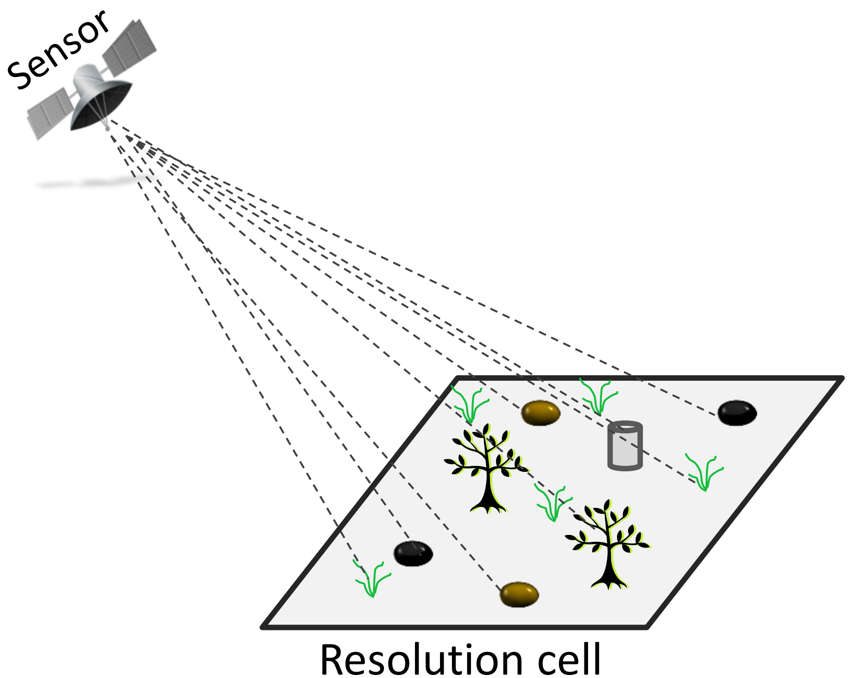
Salt and Pepper Speckle “Noise”



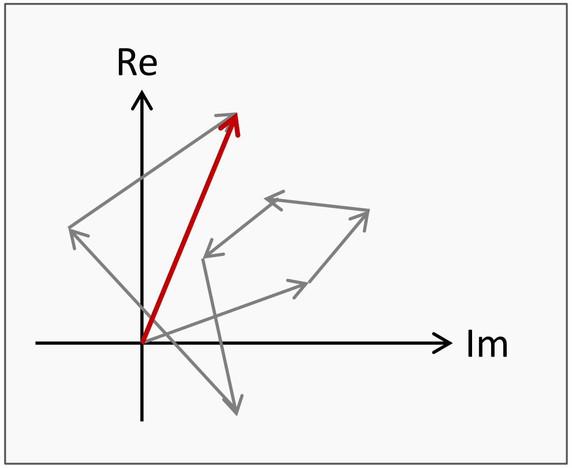
Backscatter value of a pixel

- Resolution cells are made up of many scatterers with different phases



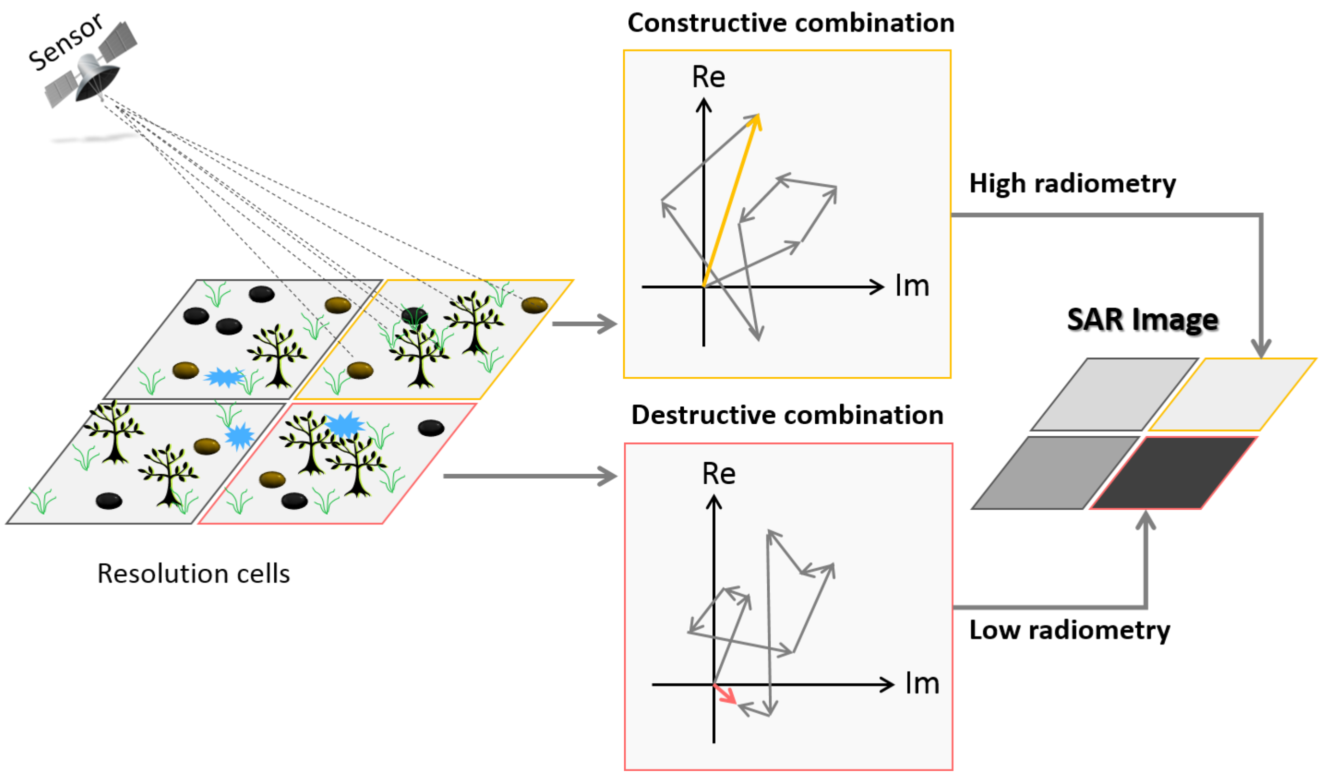
after Sarti (2011)

- Every grey vector corresponds to a scatterer in the resolution cell
- Resultant value of the pixel (red vector) is the coherent sum of all those individual contributions



Coherent sum of all the contributions (red vector)

Backscatter value of a pixel

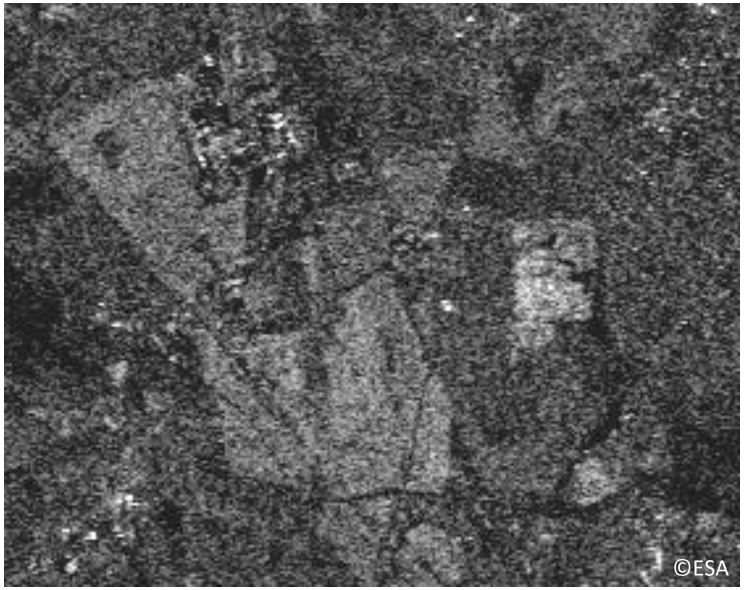


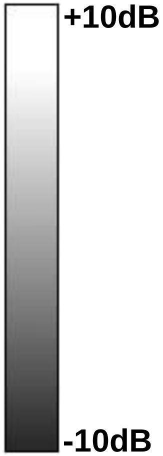
Speckle Reduction by spatial filtering

original SAR image
SAR data © AeroSensing GmbH

speckle filtered
Bayesian algorithm

Speckle Reduction by temporal multilooking (ERS)





5 spatial looks
20 x 20 m ground resolution
2 dB radiometric resolution

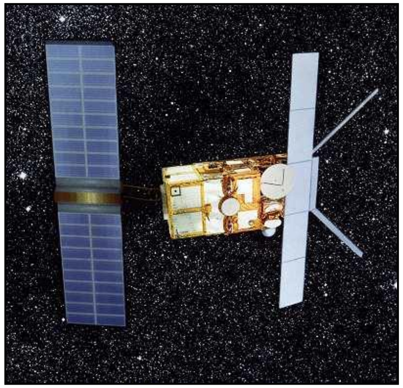
320 spatio-temporal looks
20 x 20 m ground resolution
0.3 dB radiometric resolution

Outline

- What is Remote Sensing/Earth Observation?
- Active Radar Remote Sensing
  - Electromagnetic spectrum : Why microwaves?
  - Basic characteristics of radar systems
  - Imaging geometry of radar systems
- SAR Remote Sensing
  - SAR resolution cell
  - Effects of SAR imaging geometry
  - Influences on radar backscatter
  - SAR measurements
  - Speckle Effect
  - Spaceborne SAR systems
- Summary

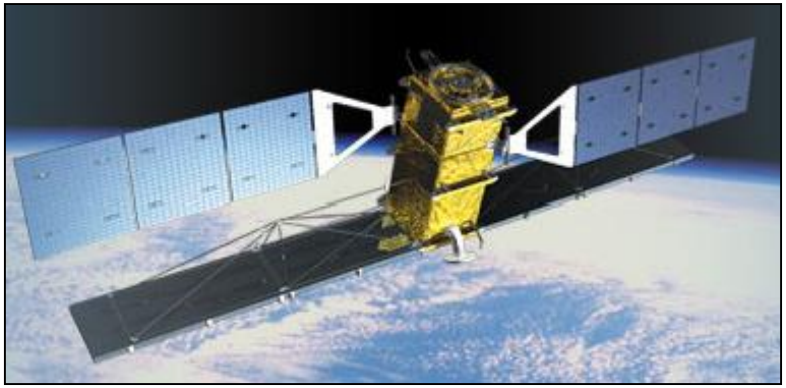
Active Radar Remote Sensing

Examples of satellite based radar sensors



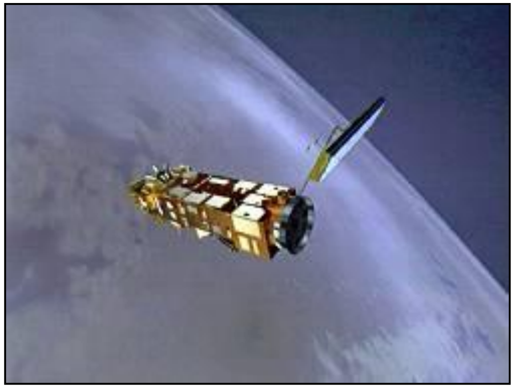
ERS-1, 2

JERS-1

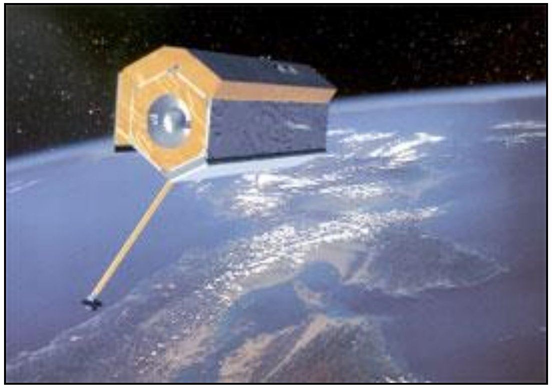


Radarsat 1, 2

ALOS (PALSAR)



Envisat (ASAR)



TerraSAR-X

Active Radar Remote Sensing

Examples of satellite based radar sensors

Sentinel-1 is the first of the Copernicus Programme satellite constellation conducted by the European Space Agency (ESA)

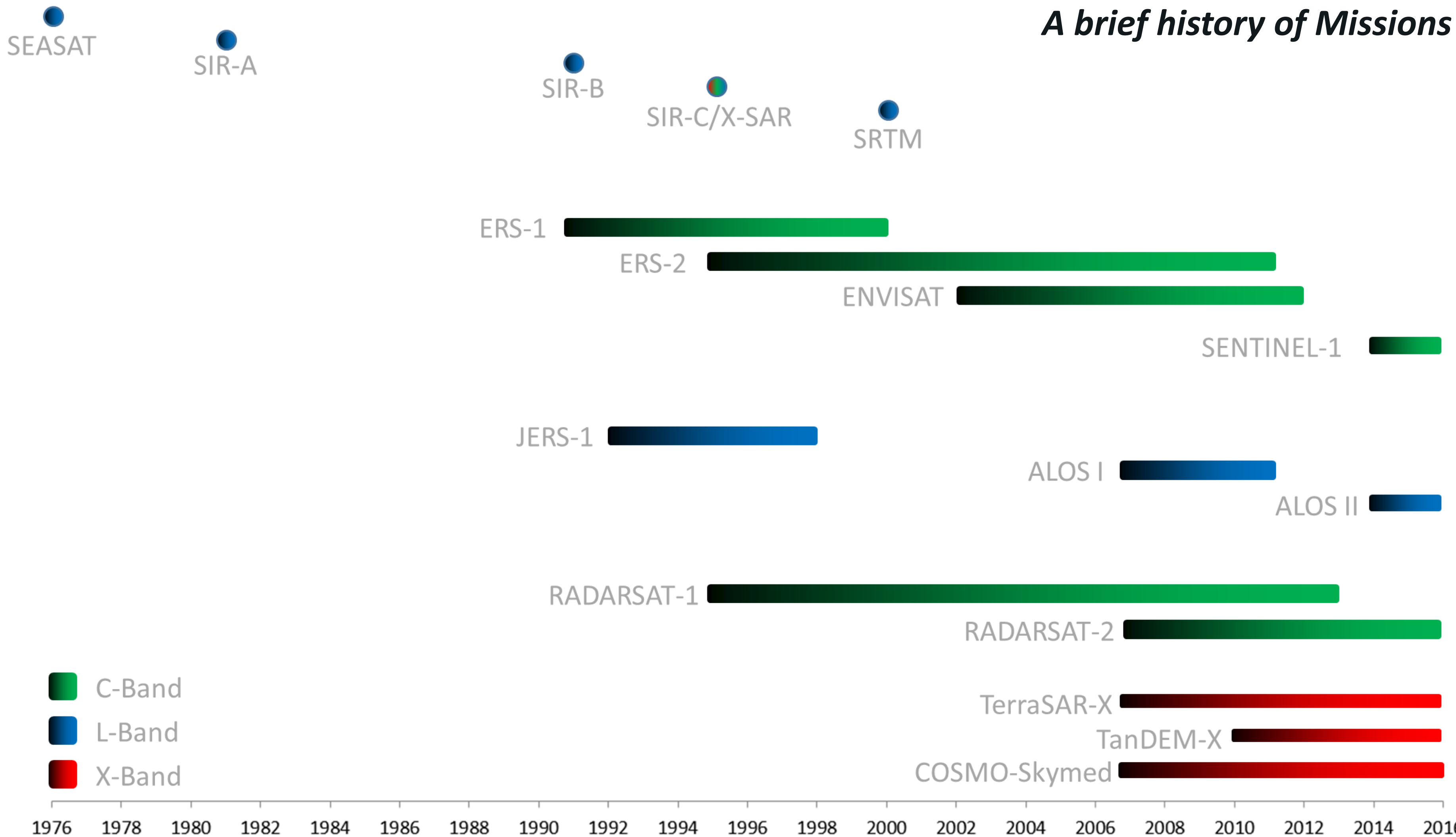
Sentinel-1A

Based on a constellation of two satellites, the Sentinel-1 mission is developed for continuation of the C-band SAR data flow provided by its predecessor ERS and Envisat.

The constellation of 2 satellite provides revisit cycle of six days!!!

Active Radar Remote Sensing

A brief history of Missions



Spaceborne SARs

satellite	owner	band	resolution	look angle	swath	lifetime
ERS-1	ESA	C	25 m	23°	100 km	1991-2000
ERS-2	ESA	C	25 m	23°	100 km	1995-2012
Radarsat-1	Canada	C	10 m - 100 m	20°- 59°	50 - 500 km	1995-2013
ENVISAT	ESA	C	25 m - 1 km	15°- 40°	100 - 400 km	2002-2012
ALOS	Japan	L	10 m -100 m	35°- 41°	70 - 360 km	2006-2011
Cosmo	Italy	X	ca. 1 m - 16 m	…	…	2007-
TerraSAR-X & TanDEM-X	Germany	X	1 m - 16 m	15°- 60°	10 - 100 km	2007/2010-
Radarsat-2	Canada	C	3 m - 100 m	15°- 59°	10 - 500 km	2007-
ALOS-2	Japan	L	3 m – 100 m	8°-70°	25 – 350 km	2014-
Sentinel-1	ESA	C	5 m – 50 m	20°-46°	20 - 400 km	2014-

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Active Radar Remote Sensing

Advantages

- ***all weather*** capability (small sensitivity of clouds, light rain)
- ***day and night*** operation (independence of sun illumination, active instruments, they have their own source of energy)
- ***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 penetration*** (the longer the wavelength, the higher the transmission through a medium)

Active Radar Remote Sensing

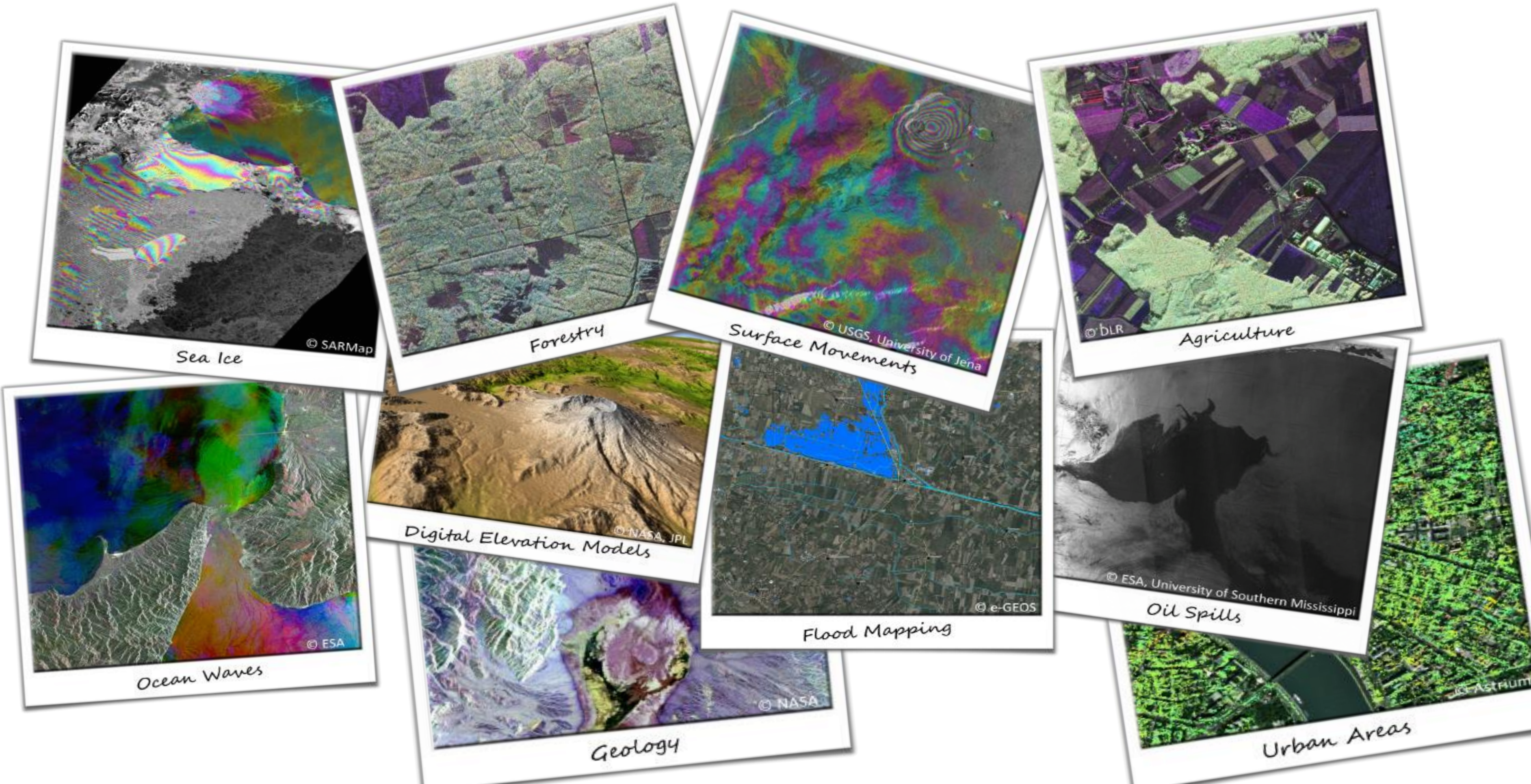
Inconvenients

- ***complex*** interactions (difficulty in understanding, complex processing)
- ***speckle*** (difficulty in visual interpretation)
- ***topographic effects***
- etc.

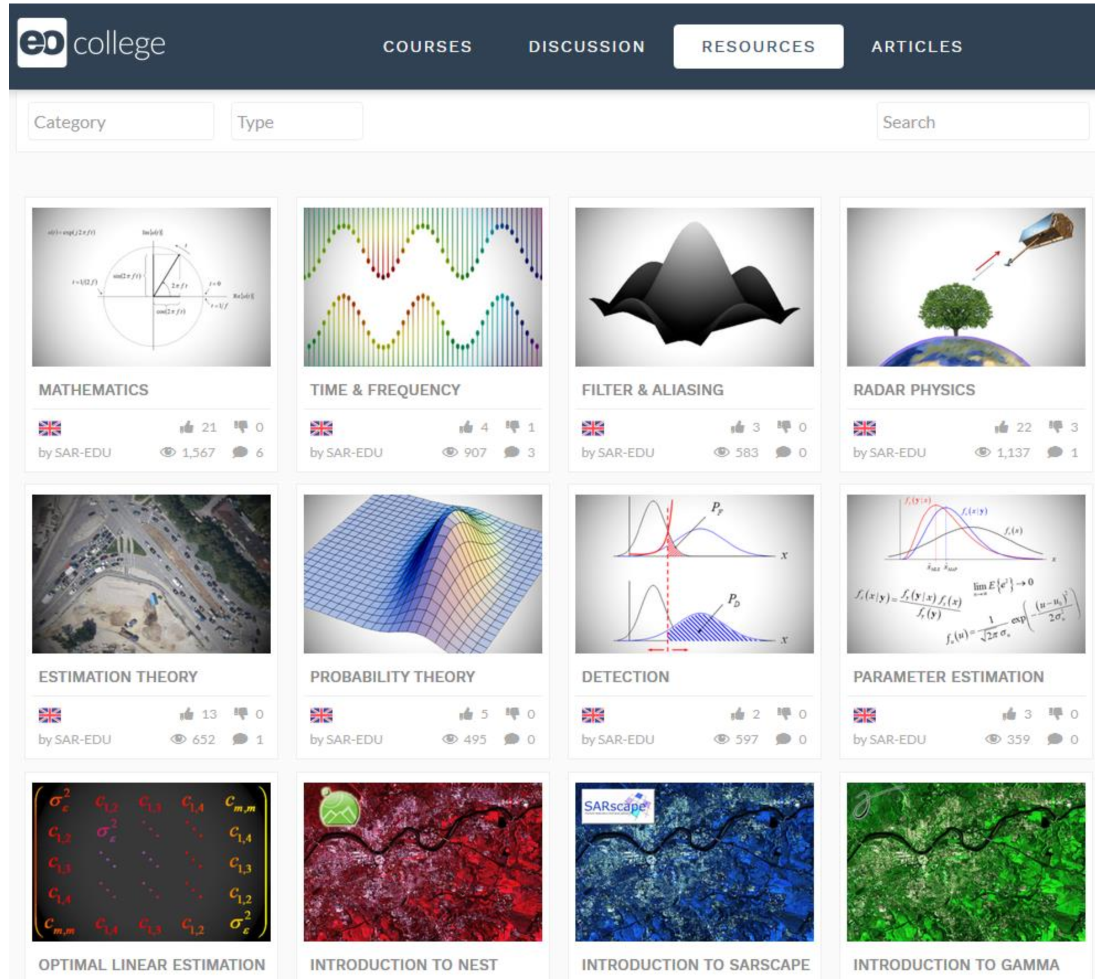
Summary

Applications of radar remote sensing systems

SAR's ability to pass relatively unaffected through clouds, illuminate the Earth's surface with its own signals, and precisely measure distances makes it especially useful for variety of applications:



Hi, welcome to the **EO college.**
Your hub to learn Earth observation.
Here you can discuss with the EO



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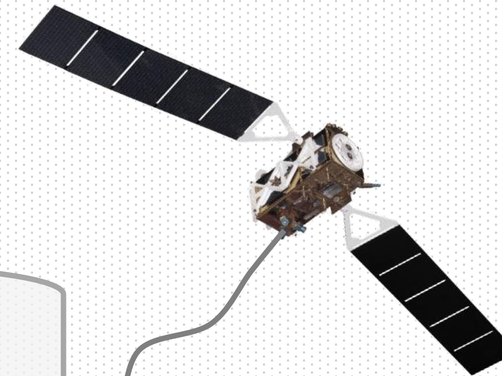
Thank you



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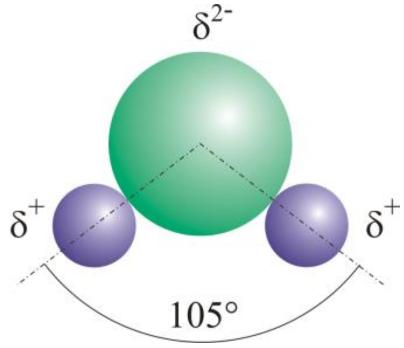
Water and Microwaves

- Water molecules (H_2O) act like a electric dipoles



Water molecule
[E. Generalic, https://glossary.periodni.com/glossary.php?en=water]

Compass
[Source:openclipart.org]

- H_2O shows strong orientational polarization if electromagnetic field is applied