esa space solutions | Copernicus Academy | ÚSTAV GEOGRAFIE Prírodovedecká fakulta UPJŠ v Košiciach

4. SAR remote sensing for forestry

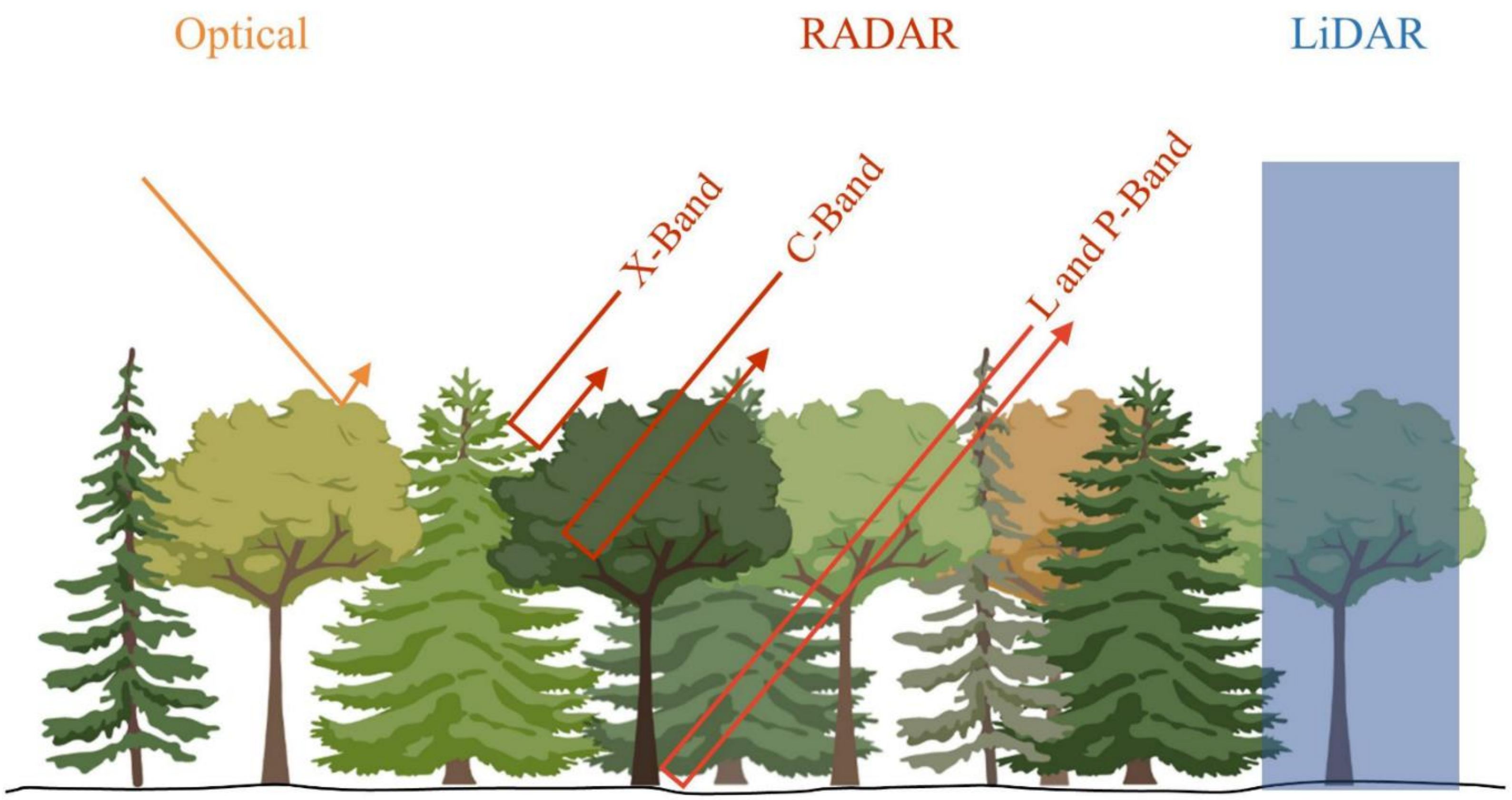
Parameters to Consider for a Forestry Mapping

Radar Parameters

- Wavelength
- Polarizations
- Incidence Angle

Surface Parameters

- Structure
- Dielectric



https://appliedsciences.nasa.gov/sites/default/files/2020-11/SAR_Part1.pdf, https://www.mdpi.com/1999-4907/14/6/1086

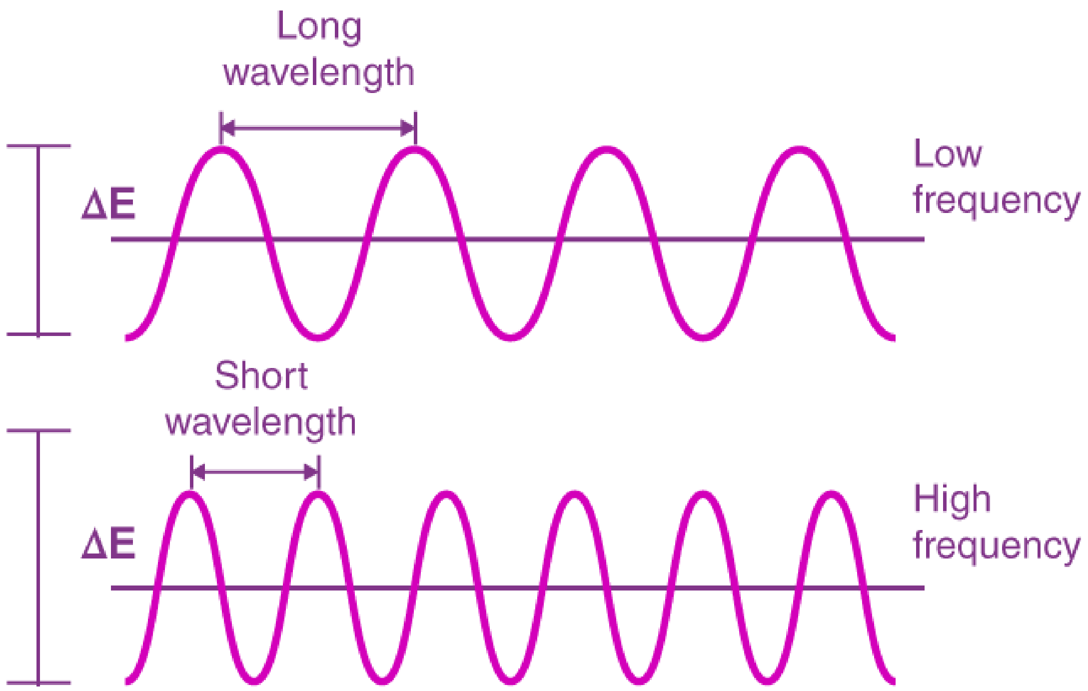
Radar Parameters to Consider for a Forestry Mapping

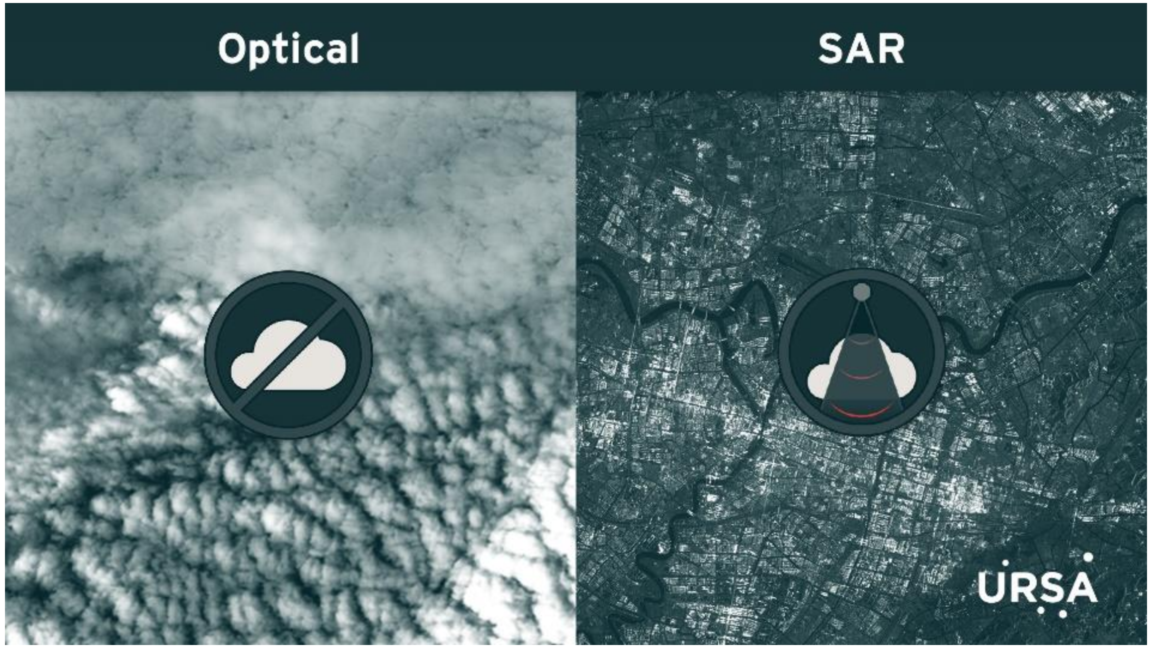
Frequency and Wavelenght

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

Active remote sensing sensors generate EM-waves

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





Source: https://cdn1.byjus.com/wp-content/uploads/2023/03/Relation-Between-Frequency-And-Wavelength.png

Radar Parameters to Consider for a Forestry Mapping

Frequency and Wavelenght

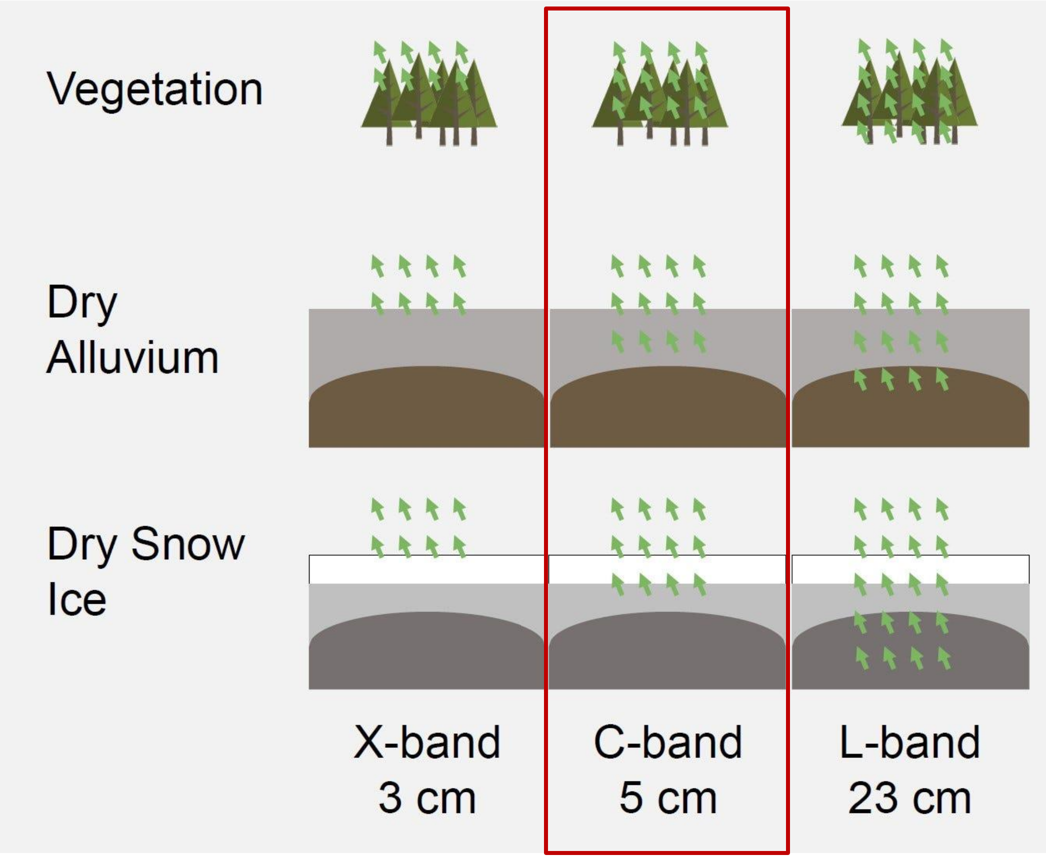
Band	Frequency	Wavelength	Typical Application
Ka	27–40 GHz	1.1–0.8 cm	Rarely used for SAR (airport surveillance)
K	18–27 GHz	1.7–1.1 cm	rarely used (H_2O absorption)
Ku	12–18 GHz	2.4–1.7 cm	rarely used for SAR (satellite altimetry)
X	8–12 GHz	3.8–2.4 cm	High resolution SAR (urban monitoring,; ice and snow, little penetration into vegetation cover; fast coherence decay in vegetated areas)
C	4–8 GHz	7.5–3.8 cm	SAR Workhorse (global mapping; change detection; monitoring of areas with low to moderate penetration; higher coherence); ice, ocean maritime navigation
S	2–4 GHz	15–7.5 cm	Little but increasing use for SAR-based Earth observation; agriculture monitoring (NISAR will carry an S-band channel; expends C-band applications to higher vegetation density)
L	1–2 GHz	30–15 cm	Medium resolution SAR (geophysical monitoring; biomass and vegetation mapping; high penetration, InSAR)
P	0.3–1 GHz	100–30 cm	Biomass. First p-band spaceborne SAR will be launched ~2020; vegetation mapping and assessment. Experimental SAR.

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

Radar Parameters to Consider for a Forestry Mapping

Penetration through vegetation as a Function of Wavelength and dielectric characteristics

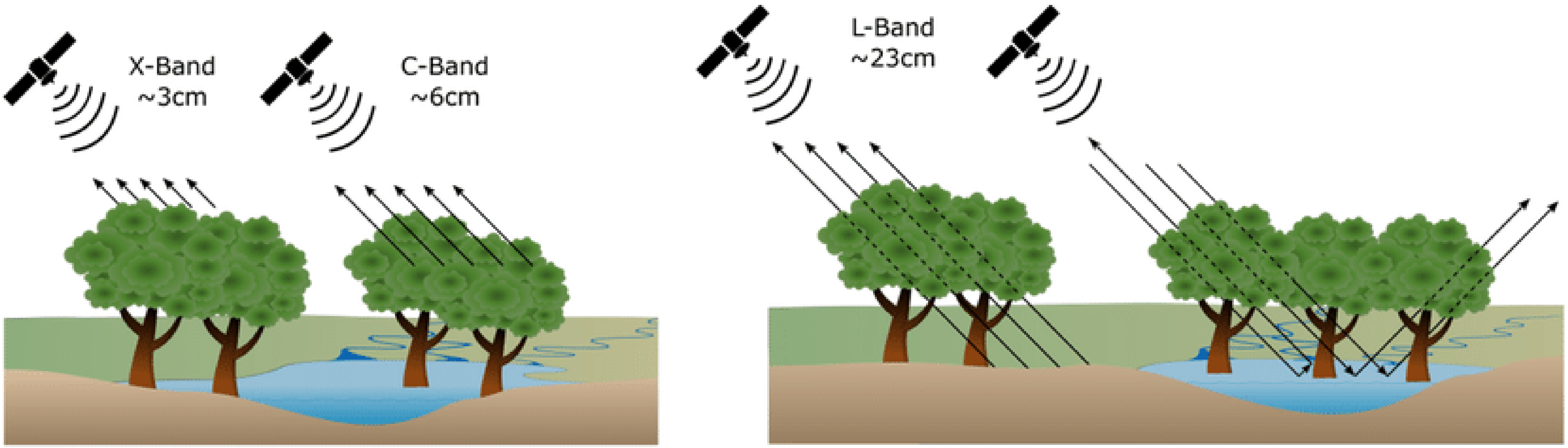
- The penetration depth is depending on **wavelength** and **dielectric characteristics** of objects
- Penetration is the predominant consideration when selecting a wavelength
- Typically, longer wavelengths result in greater penetration into the target



Source:https://medium.com/@preet.balaji20/decoding-synthetic-aperture-radar-sar-remote-sensing-sar-series-part-1-getting-started-d3409eb3b2e3

Radar Parameters to Consider for a Forestry Mapping

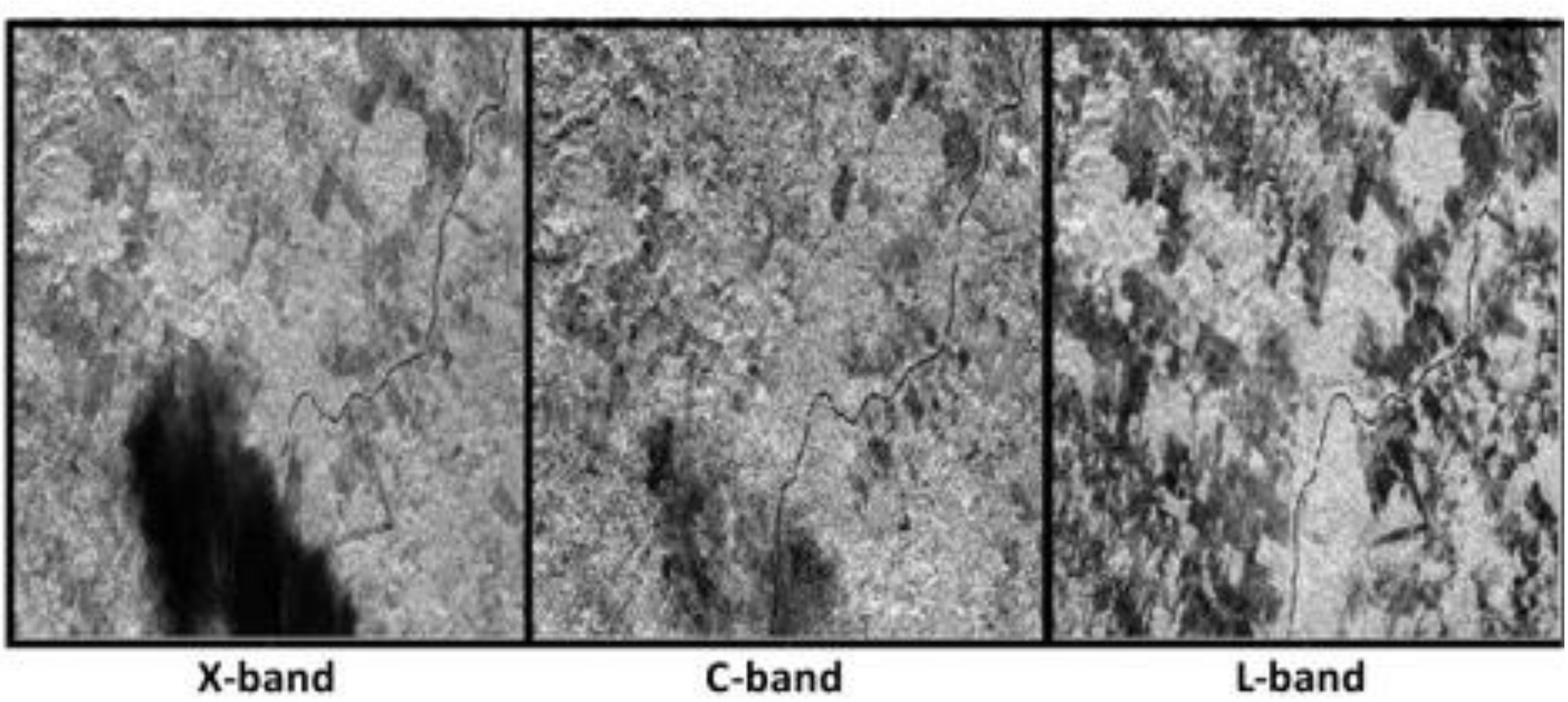
Penetration through vegetation as a Function of Wavelength and dielectric characteristics



Source:https://medium.com/@preet.balaji20/decoding-synthetic-aperture-radar-sar-remote-sensing-sar-series-part-1-getting-started-d3409eb3b2e3

Radar Parameters to Consider for a Forestry Mapping

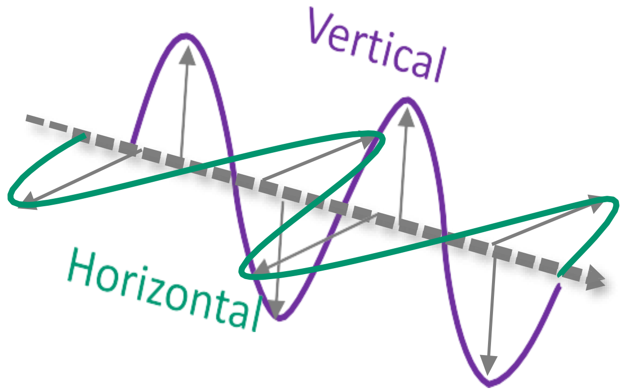
Penetration through vegetation as a Function of Wavelength and dielectric characteristics



Source: https://ars.els-cdn.com/content/image/3-s2.0-B9781785481598500013-f01-25-9781785481598.jpg

Radar Parameters to Consider for a Forestry Mapping

Polarisation



The radar signal is polarised:

Radar: ***transmits*** a EMW in a given polarization
measures the backscattered wave contribution in a given polarization

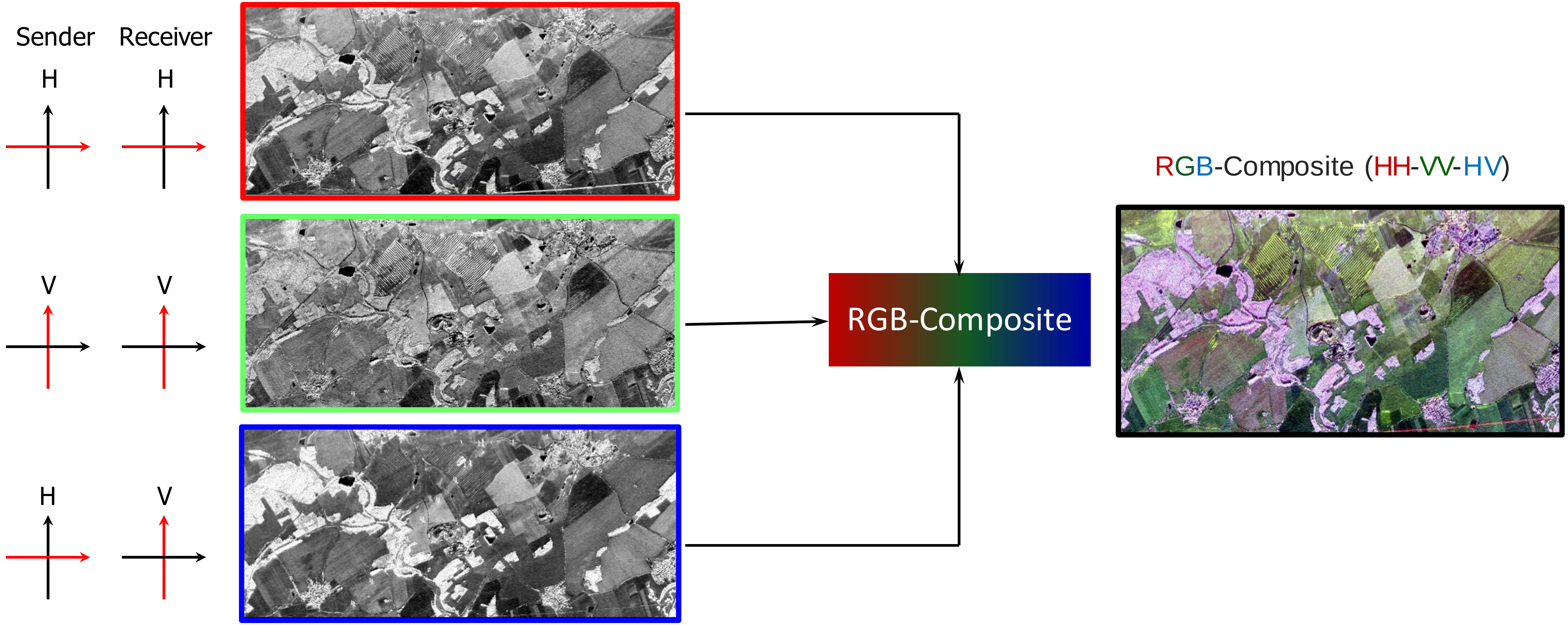
The four combinations of SAR data polarizations:

- **HH**: Horizontal Transmit, HorizontalReceive
- **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 observed object.

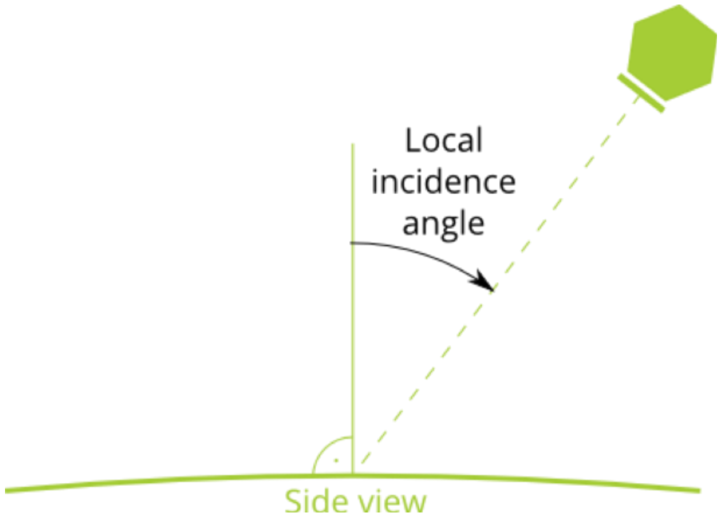
Radar Parameters to Consider for a Forestry Mapping

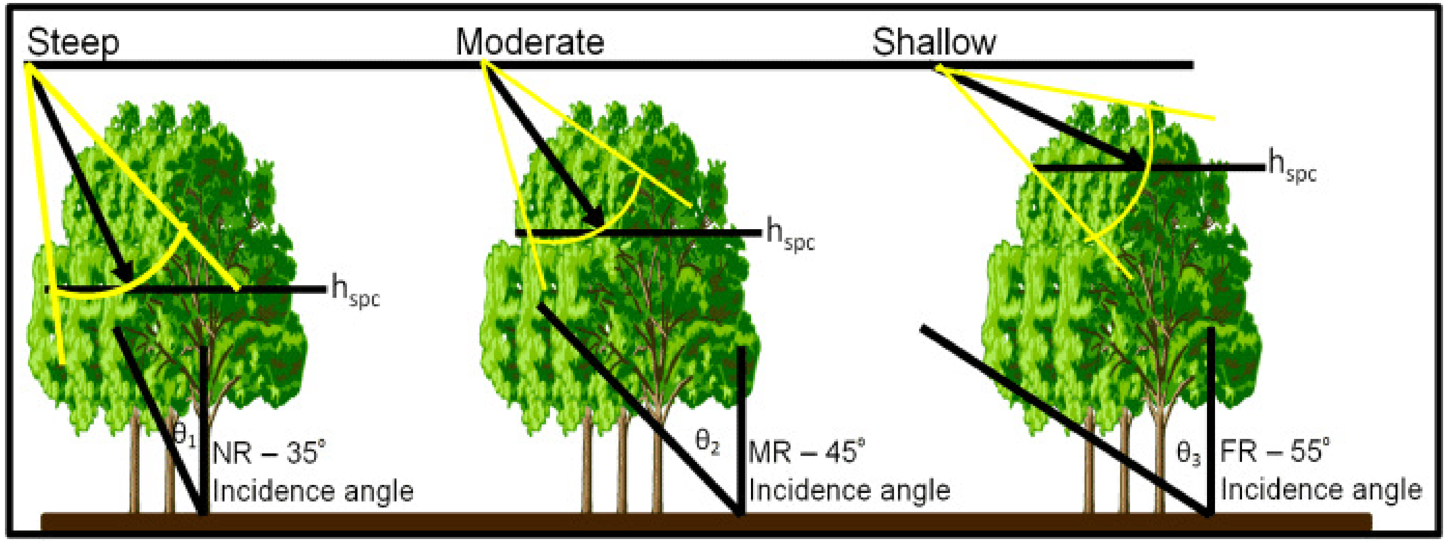
Polarisation – Example of multiple polarisations for vegetation studies



Radar Parameters to Consider for a Forestry Mapping

Incidence angle





Local Incidence Angle:

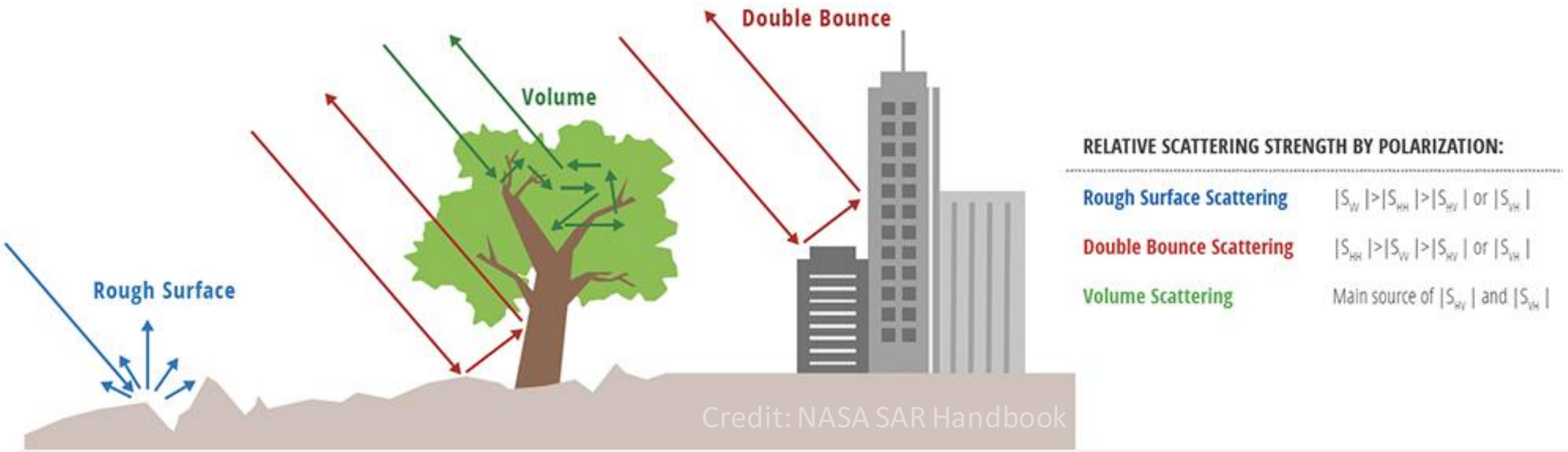
- Refers to the angle formed between the radar illumination direction and the Earth's surface
- Takes into consideration the local slope of the terrain
- Affects the brightness of the image
- Determined by the sensor's altitude
- Results in varying geometric configurations across different points in the image's range direction

Source: https://isprs-archives.copernicus.org/articles/XXXIX-B7/91/2012/

Radar Parameters to Consider for a Forestry Mapping

Signal interacton

Analyzing the signal intensity from these various polarizations provides insights into the composition of the observed surface, as it relates to the following types of scattering:

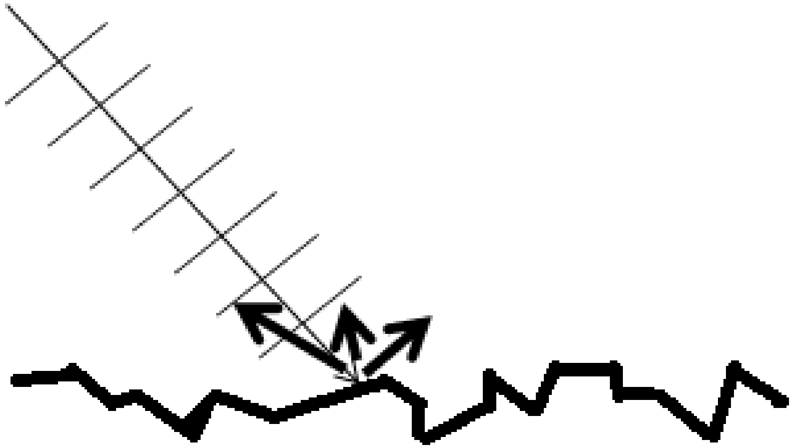


Rough surface scattering	• most sensitive to VV scattering • caused f.e. by bare soil or water
Volume scattering	• most sensitive to cross-polarized data like VH or HV • scattering by the leaves and branches
Double bounce	• most sensitive to an HH polarized signal • caused by buildings, tree trunks, or inundated vegetation

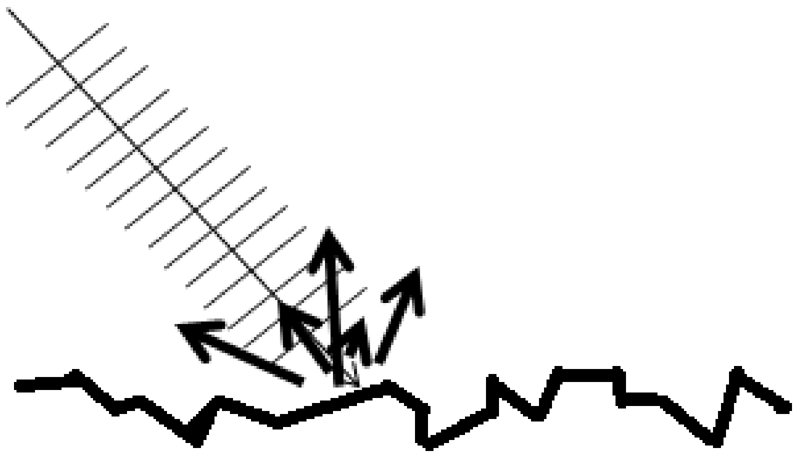
Radar Parameters to Consider for a Forestry Mapping

Radar backscaterring

- The intensity of backscattered energy typically increases with surface roughness



The surface appears smooth to long wavelength
=> Backscattering is low

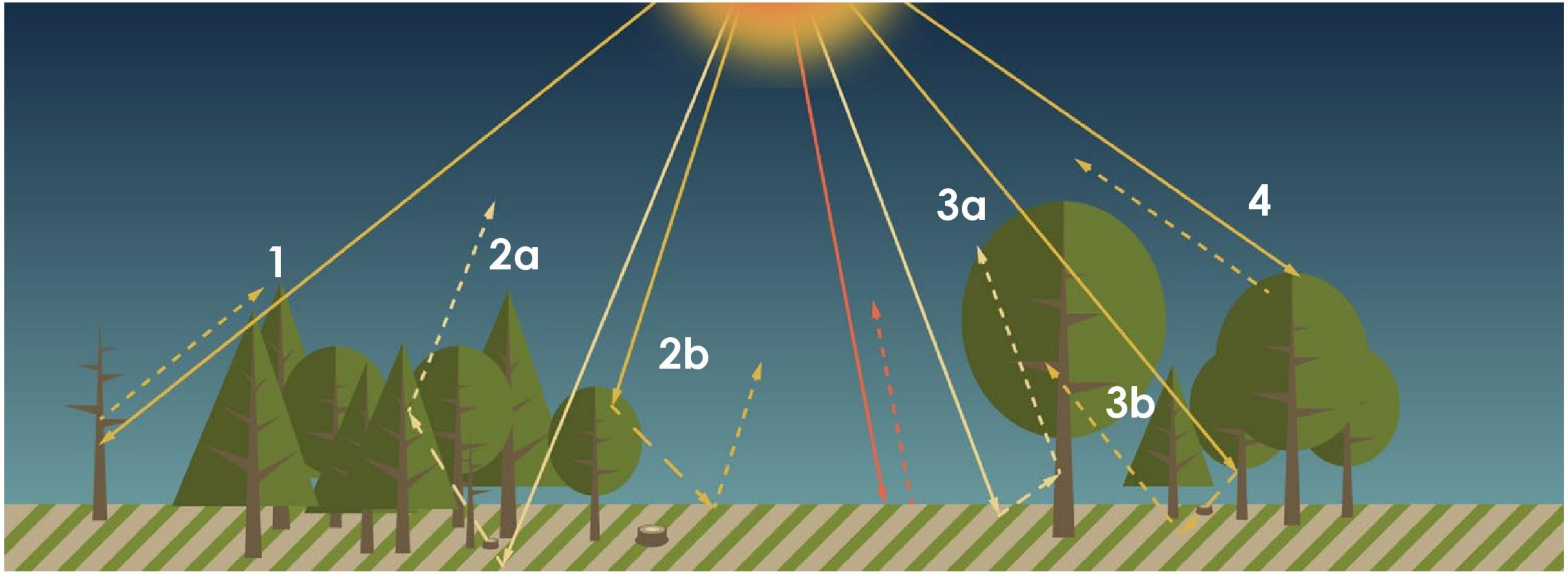


The surface appears rough to shorter wavelength
=> Backscattering increases

https://appliedsciences.nasa.gov/sites/default/files/2020-11/SAR_Part3.pdf

Radar Parameters to Consider for a Forestry Mapping

Radar backscaterring in Forests

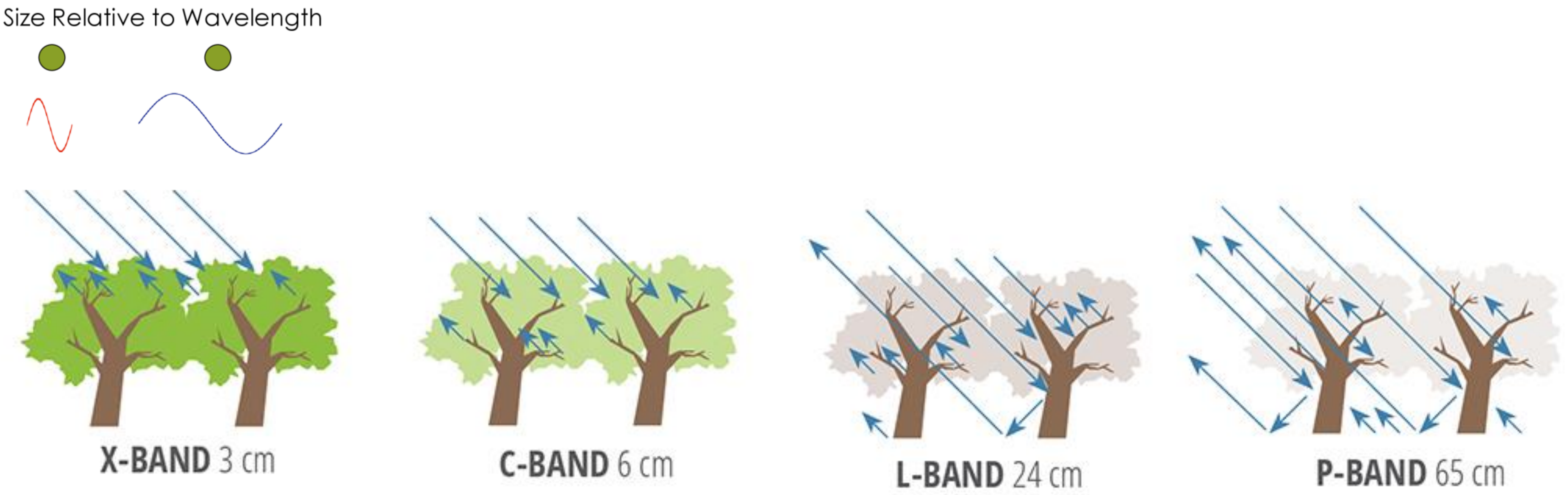


Dominant backscattering sources in forests: (1) direct scattering from tree trunks, (2a) ground-crown scattering, (2b) crown-ground scattering, (3a) ground-trunk scattering, (3b) trunk-ground scattering, (4) crown volume scattering.

https://appliedsciences.nasa.gov/sites/default/files/2020-11/SAR_Part3.pdf

Surface Parameters to Consider for a Forestry Mapping

Structure

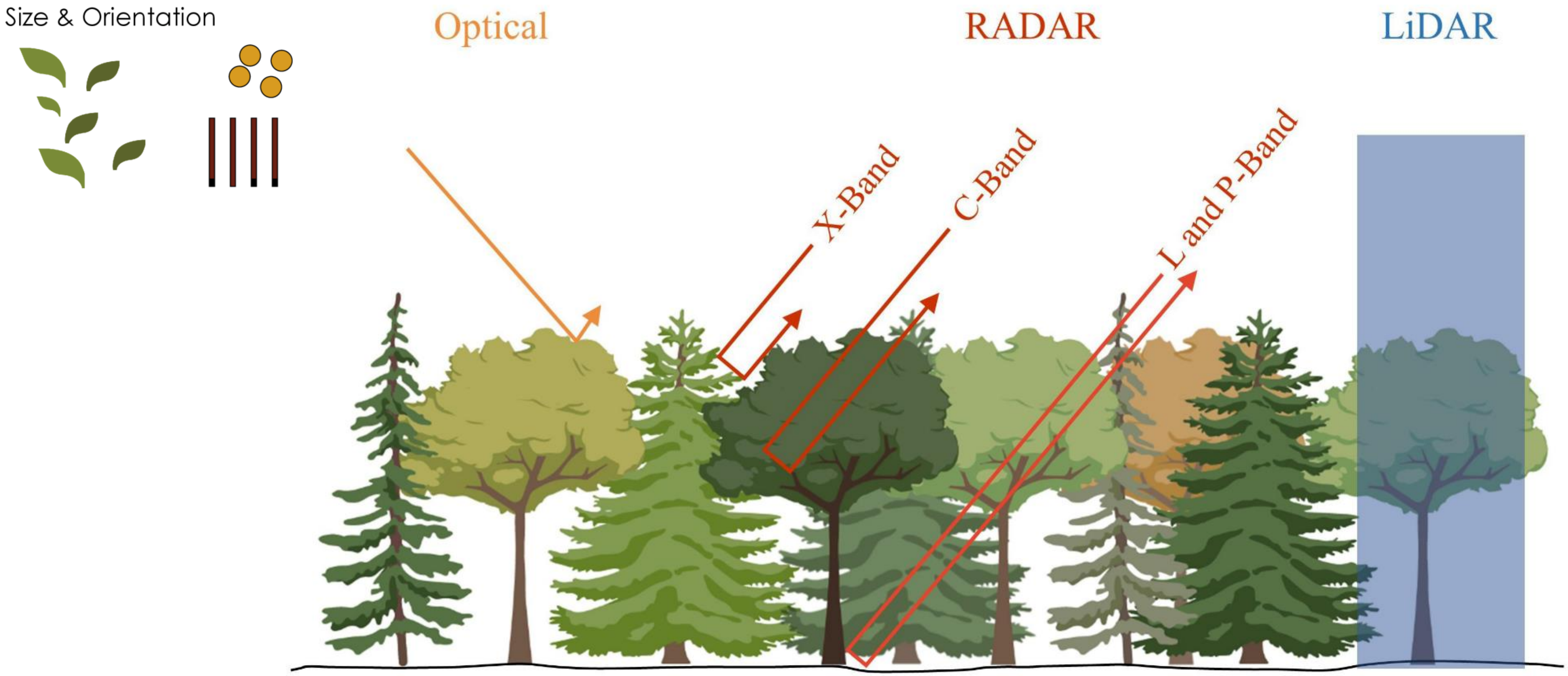


- **P-band SAR**: provide information for forest biomass and height estimations
- **L-band SAR**: forest cover and change monitoring using dual polarization (cross-pol most sensitive to forest structure (e.g. JERS-1, ALOS PALSAR)
- **C-band**: dense time-series for accurate detection of forest cover change
- **X-band**: application in forest degradation assessment and forest height estimation (e.g. using TanDEM-X)

https://appliedsciences.nasa.gov/sites/default/files/2020-11/SAR_Part1.pdf

Surface Parameters to Consider for a Forestry Mapping

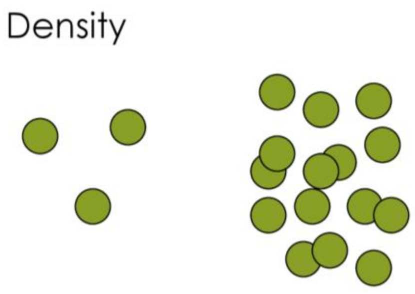
Structure



https://appliedsciences.nasa.gov/sites/default/files/2020-11/SAR_Part1.pdf, https://www.mdpi.com/1999-4907/14/6/1086

Surface Parameters to Consider for a Forestry Mapping

Structure



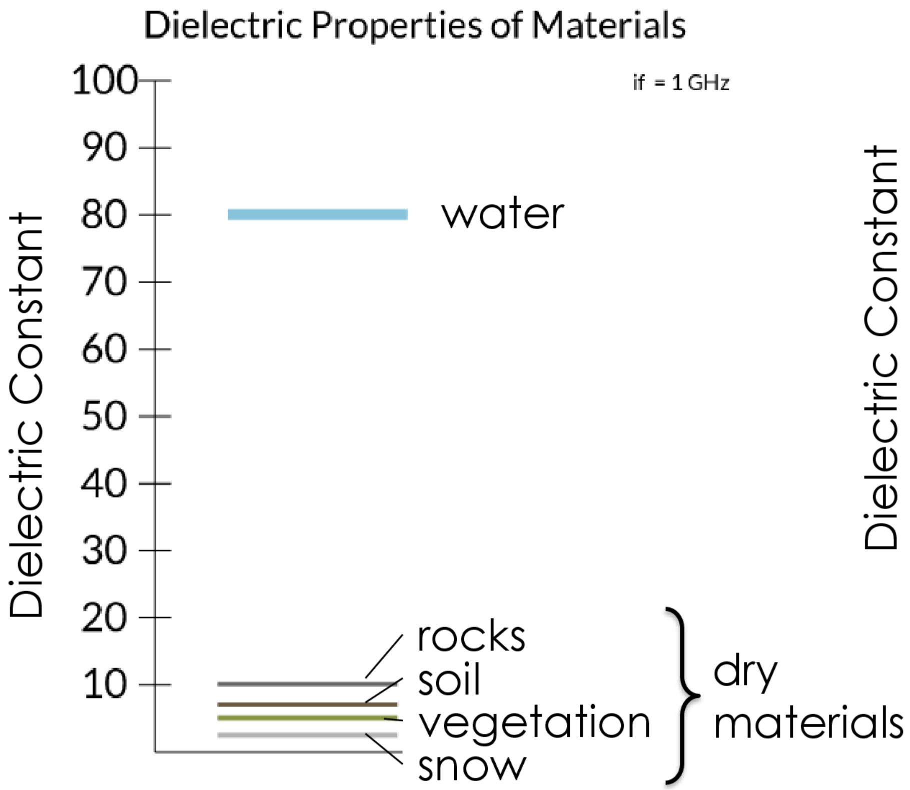
- The more dense the vegetation, the lower the probability of signal penetration through the canopy (influenced by wavelength)
- Saturation issue - the signal reaches a maximum level at a specific biomass threshold, which varies according to wavelength:
  - C-band ≈ 20 tons/ha (2 kg/m2)
  - L-band ≈ 40 tons/ha (4 kg/m2)
  - P-band ≈ 100 tons/ha (10 kg/m2)

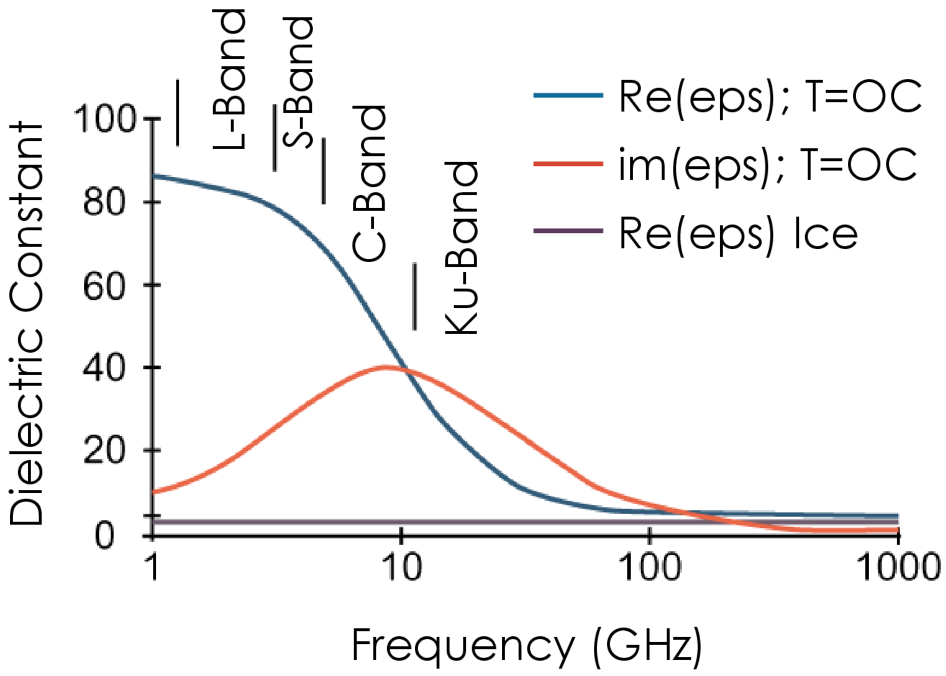
→ Combination of different polarizations can improve biomass estimates

https://www.civilsdaily.com/wp-content/uploads/2017/01/classification-dense.png

Surface Parameters to Consider for a Forestry Mapping

Dielectric constant



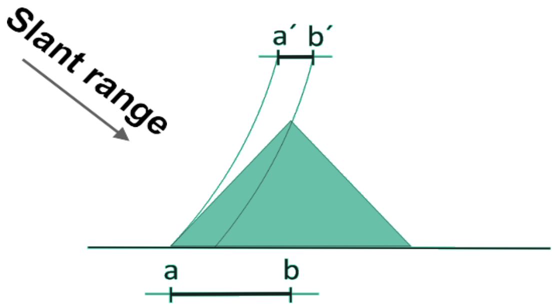


Source: https://appliedsciences.nasa.gov/sites/default/files/2020-11/SAR_Part1.pdf

Surface Parameters to Consider for a Forestry Mapping

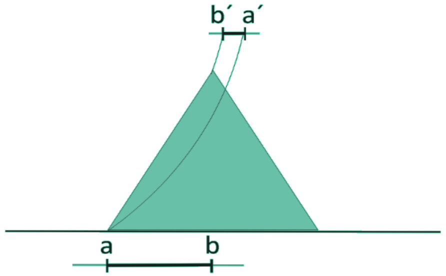
Geometric Effects

Foreshortening



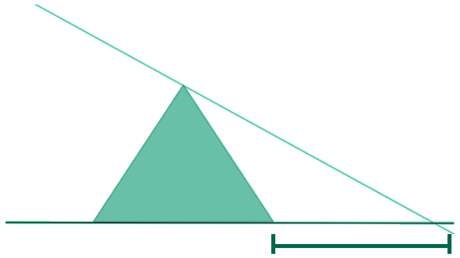
- Slopes oriented to the SAR appear compressed (Distance between a and b is shortened)
- Appears as very bright area
- More pronounced in near range (small incidence angle) than in far range (high incidence angles)

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)

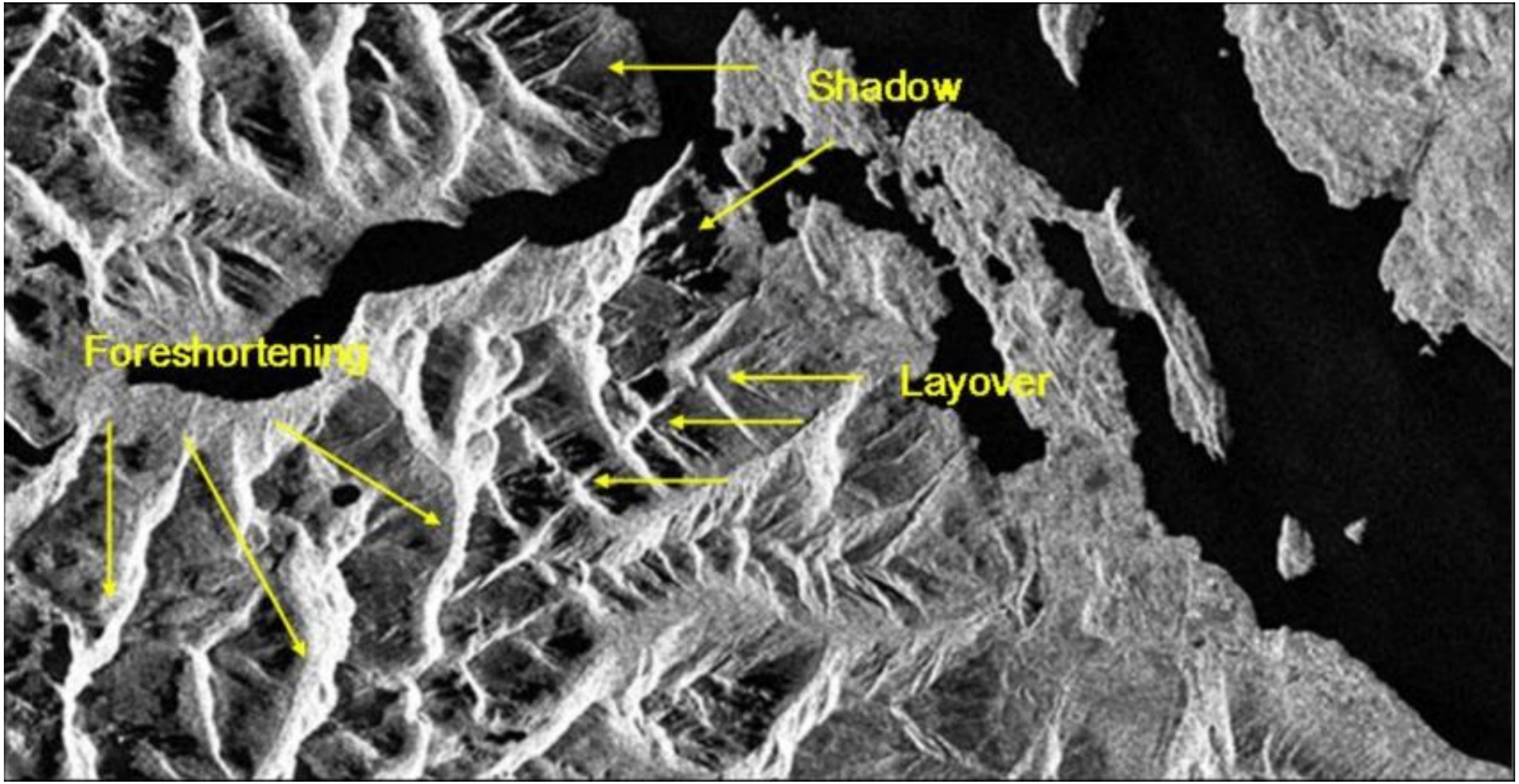
Radar shadow



- 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

Surface Parameters to Consider for a Forestry Mapping

Geometric Effects

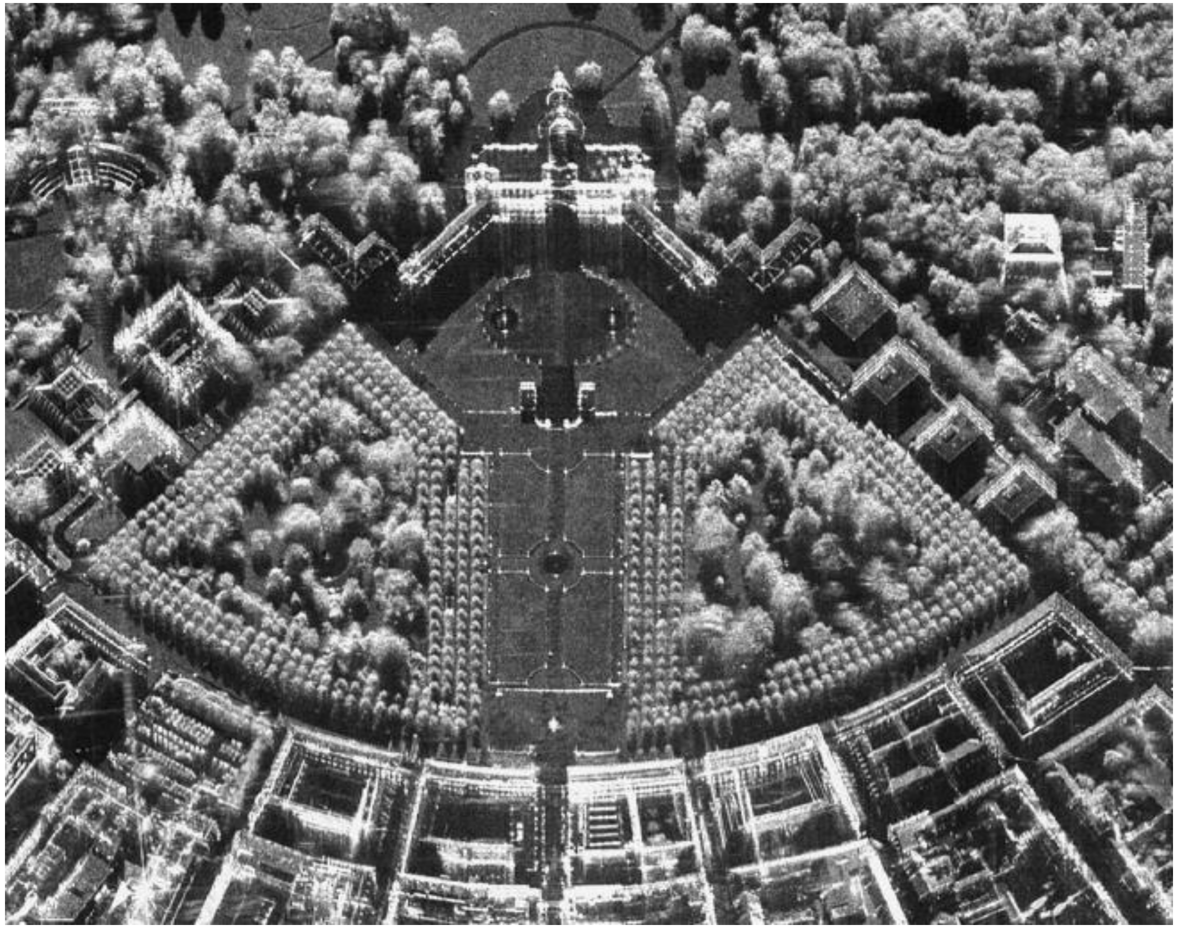


Source: https://www.researchgate.net/profile/M-Lenzano/publication/263124688/figure/fig23/AS:614356547039256@1523485423960/Figura-9-Efectos-de-shadowi-ng-foreshortening-y-layover-en-una-imagen-SAR-de-RADARSAT-1.png

Surface Parameters to Consider for a Forestry Mapping

Geometric effects – side looking

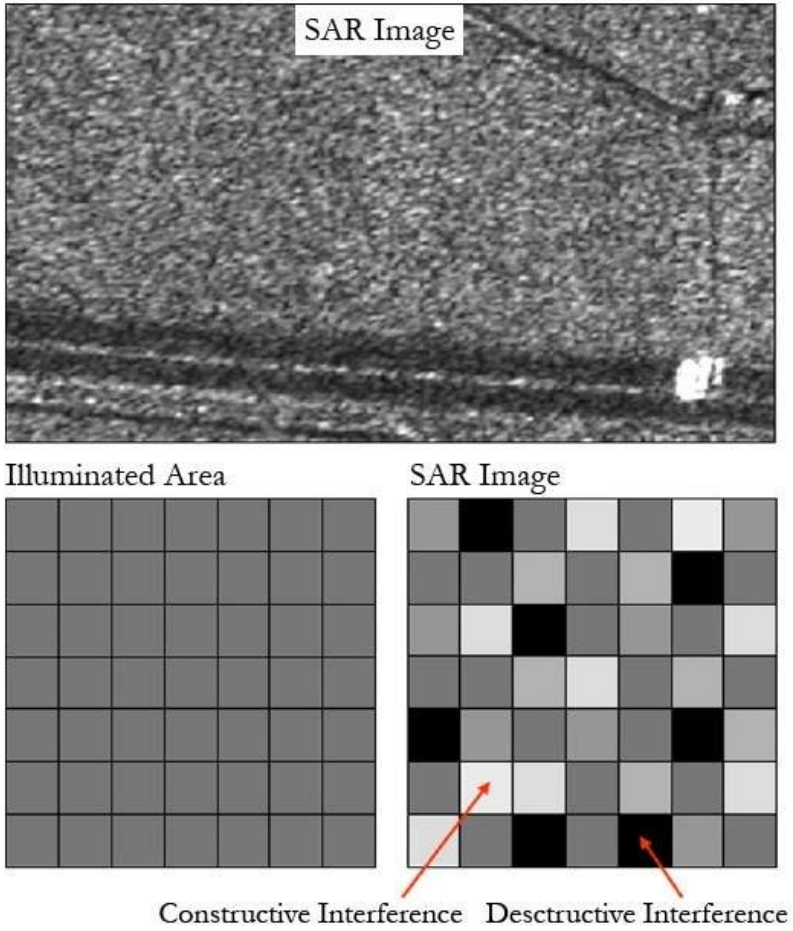
Google maps



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)

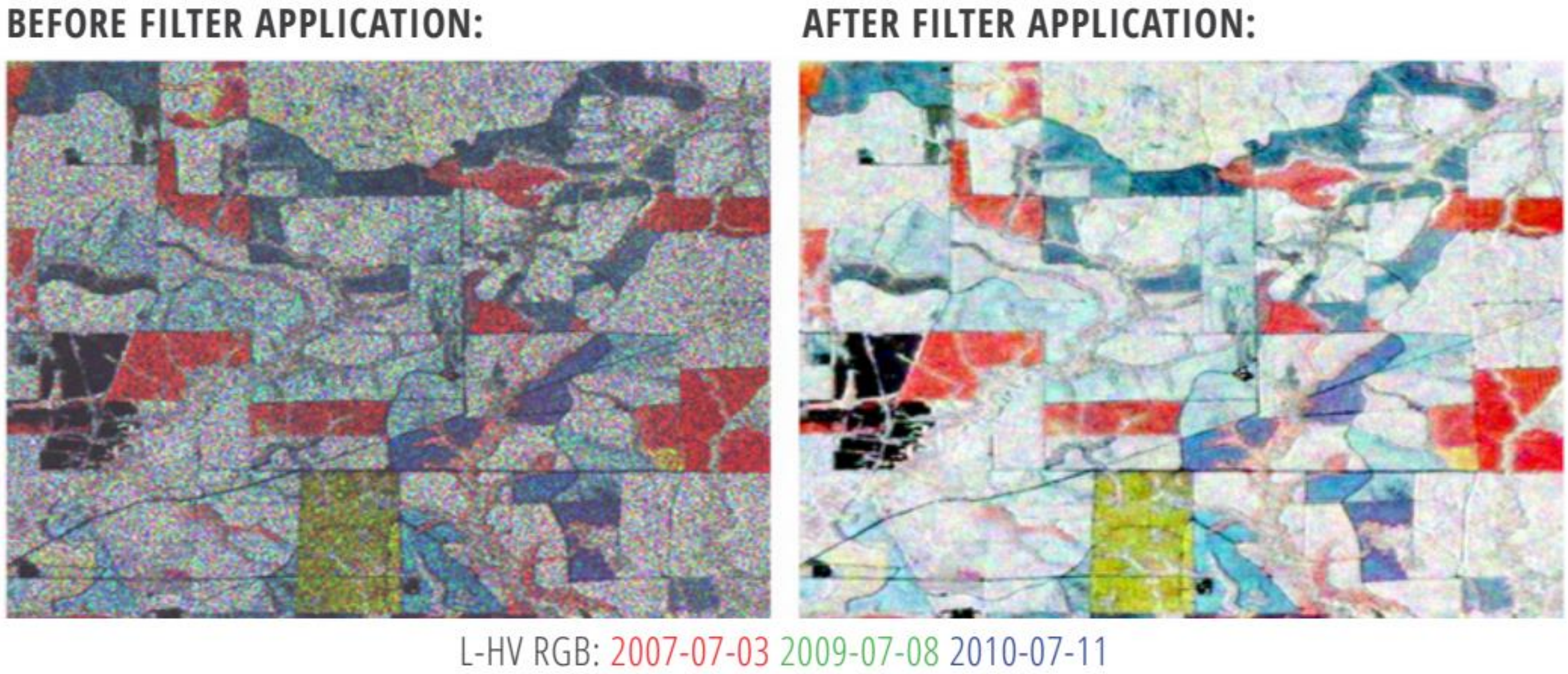
Speckle

- Granular noise that affects radar images, reducing class spectral seperability
- Degrades the quality of SAR image
- Results from random fluctuations in the return signal from an object
- Preprocessing is necessary to filter the images, aiming to minimize information loss - using of moving windows filters



Source:https://www.researchgate.net/publication/225006983_The_Combined_Use_of_Optical_and_SAR_Data_for_Large_Area_Impervious_Surface_Mapping/figures?lo=1

Speckle



Multitemporal speckle flter application on a perfectly co-registered time series data stack of ALOS L-band data over Louisiana, U.S.

Source:https://gis1.servirglobal.net/TrainingMaterials/SAR/Ch3-Content.pdf

SAR for forestry - Applications

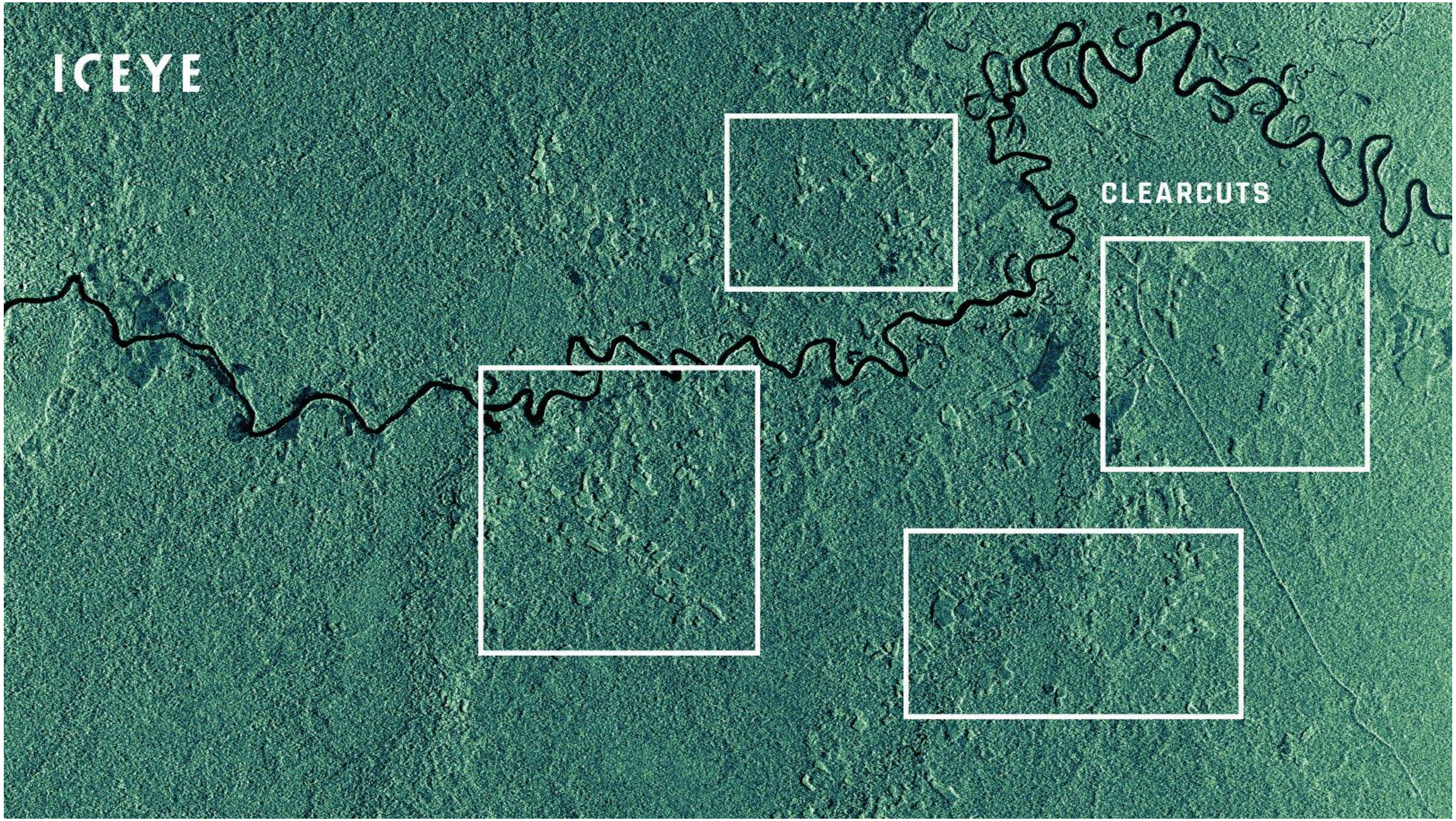
Expected backscatter characteristics for diferent vegetation transition

WAVELENGTH	POLARIZATION	RESPONSE BY FOREST TYPE					
		Sparse Forest (dry)	Sparse Forest (flooded)	Degraded Forest (dry)	Degraded Forest (flooded)	Dense Forest (dry)	Dense Forest (flooded)
C-band backscatter (g0)	VV	Medium to high; Depending on the roughness of the forest floor and moisture, there is lots of variation in this category	Low to medium; Depending on forest density, lots of forward scattering	Medium to high; most scattering from crown	Medium to high; most scattering from crown	Medium to high; most scattering from crown (Can be low in scenarios where absorption dominates and diminishes backscatter)	Medium to high; most scattering from crown (Can be low in scenarios where absorption dominates and diminishes backscatter)
	VH	Medium to high; Depending on the roughness of the forest floor and moisture, there is lots of variation in this category	Low to medium; Depending on forest density, lots of forward scattering	Medium to high; most scattering from crown	Medium to high; most scattering from crown	Medium to high; most scattering from crown (Can be low in scenarios where absorption dominates and diminishes backscatter)	Medium to high; most scattering from crown (Can be low in scenarios where absorption dominates and diminishes backscatter)
	VV/VH Ratio	Medium to high	Medium to high	Medium	Medium	Medium	Medium
L-band backscatter (g0)	HH	Low to medium; lower than dense forest and flooded sparse forest. At steep incidence angles, backscatter can be medium to high	Medium to high, depending on how much double bounce is contributing to the signal	Medium to high	High to very high, double bounce contributes to high backscatter	High to very high; higher than degraded forest, however at very high biomass levels we see saturation and no distinction with degraded forests	High to very high, double bounce contributes to high backscatter
	HV	Low to very low, depending on how dry the soils are	Low to very low. Most scattering is in the forward direction due to specular reflection	Medium to high	Medium to high, no seasonal variation with flooded forest floor	High to very high; volume scattering is dominant – best senstivity to biomass	Medium to high, no seasonal variation with flooded forest floor
	HH/HV Ratio	Medium	High	Medium	High	Medium	High

Source:https://gis1.servirglobal.net/TrainingMaterials/SAR/Ch3-Content.pdf

SAR for forestry - Applications

Detecting clearcuts



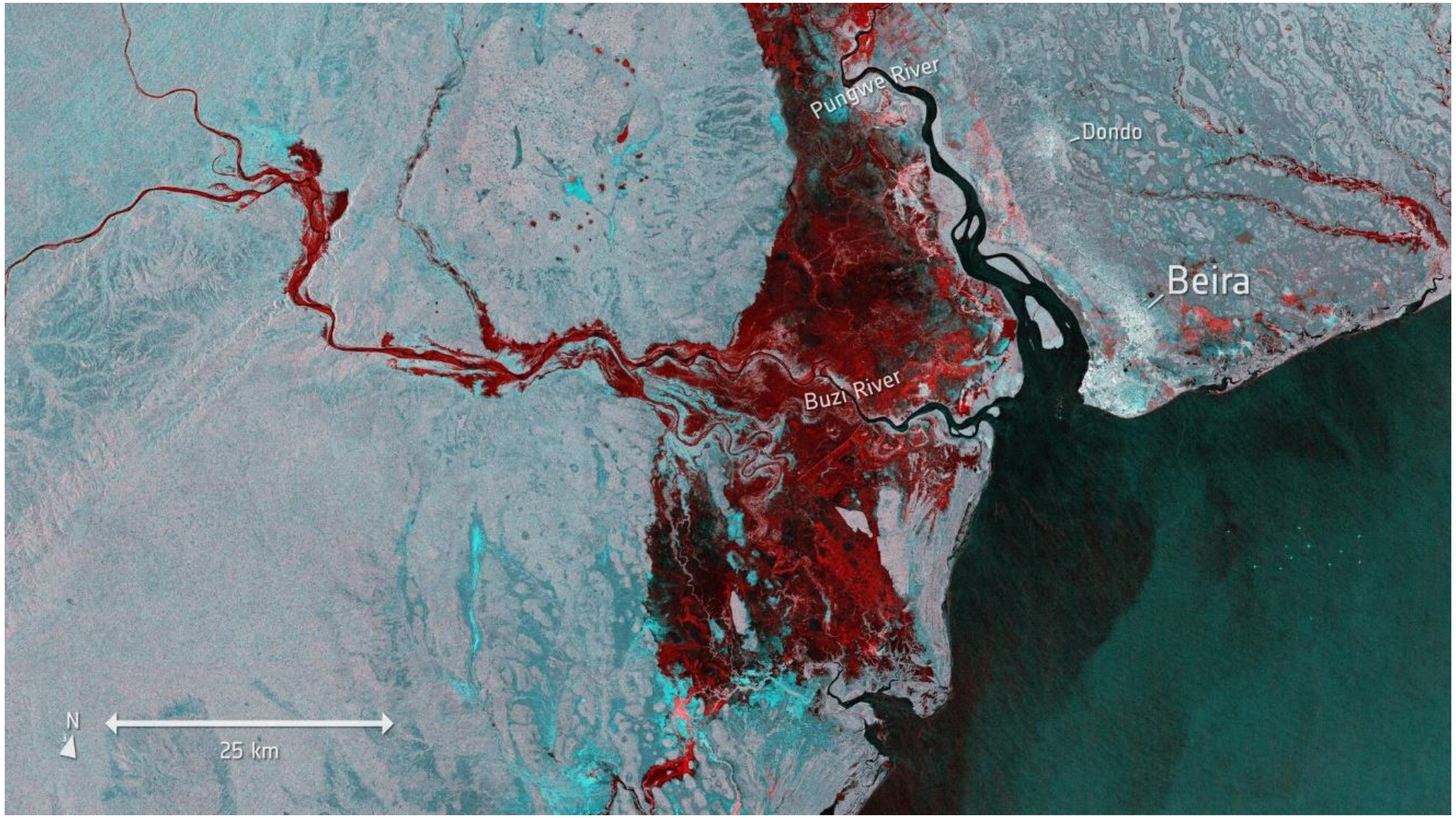
ICEYE SAR satellite Strip image of Masisea District, Peru, west of Area de Conservación Regional Imiría. The image was taken on 9th of April 2020.

For more information, see the tutorial: [4. Forestry with Sentinel-1: Single Image Analysis and Time Se ries to detect forest change using SNAP software]

Source: https://www.iceye.com/hubfs/26618_20200409-Masisea-Peru-deforestation.jpg:

SAR for forestry - Applications

Detecting inundated forests and floods



Floods imaged by Copernicus Sentinel-1
Millions of people in Mozambique, Malawi and Zimbabwe are struggling to cope with the aftermath of what could be the southern hemisphere's worst storm: Cyclone Idai. This image is from Copernicus Sentinel-1 and shows the extent of flooding, depicted in red, around the port town of Beira in Mozambique on 19 March. This mission is also supplying imagery through the Copernicus Emergency Mapping Service to aid relief efforts.

CREDIT: contains modified Copernicus Sentinel data (2019), processed by ESA

Source: https://www.esa.int/ESA_Multimedia/Images/2019/03/Floods_imaged_by_Copernicus_Sentinel-1 esa space solutions

Copernicus Academy

ÚSTAV GEOGRAFIE Prírodovedecká fakulta UPJŠ v Košiciach

Thank you for the attention