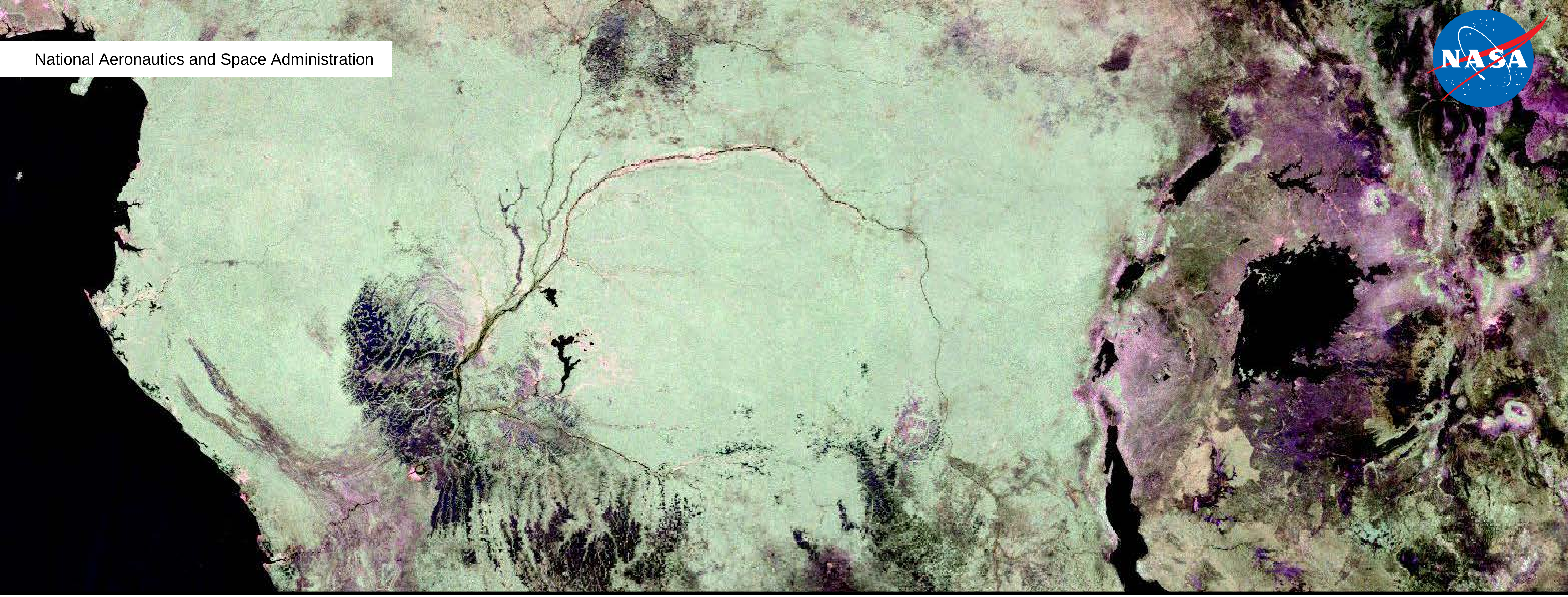
National Aeronautics and Space Administration



SAR for Mapping Land Cover

Erika Podest

7 August 2018

Learning Objectives

By the end of this presentation, you will be able to understand:

- the advantages of SAR over optical systems for mapping land cover and land use change
- the information content in SAR images relevant to land cover characteristics
- the limitations of SAR for mapping land cover
- the optimal sensor parameters for land cover
- how to generate a land cover map from SAR

Advantages and Disadvantages of Radar Over Optical Remote Sensing

Advantages

- Nearly all weather capability
- Day or night capability
- Penetration through the vegetation canopy
- Penetration through the soil
- Minimal atmospheric effects
- Sensitivity to dielectric properties (liquid vs. frozen water)
- Sensitivity to structure

Disadvantages

- Information content is different than optical and sometimes difficult to interpret
- Speckle effects (graininess in the image)
- Effects of topography

Land Cover Mapping: Optical vs Radar

Optical

- Energy reflected by vegetation is dependent on leaf structure, pigmentation, and moisture
- Products are available from visible to infrared wavelengths consisting of several bands of data
- Optical sensors only see surface tops, because the canopy blocks the understory, limiting the inferences of land cover and land use to only when these are correlated well with the characteristics of top layers

Radar

- Microwave energy scattered by vegetation depends on the structure (size, density, orientation), and dielectric properties of the target
- Radar signals are typically only at a single wavelength for each sensor
- The signal can penetrate through the canopy (wavelength dependent), providing information on soil conditions or inundation state.

Joshi et al., Remote Sens. 2016, 8(1), 70; https://doi.org/10.3390/rs8010070

Applications of Radar to Land Cover Mapping and Monitoring

- Mapping forests
- Mapping wetlands
- Mapping biomass
- Monitoring disturbances (e.g., fire, selective logging)
- Monitoring changes (e.g., deforestation, reforestation)

Parameters to Consider for a Land Cover Mapping Study

Radar Parameters

- Wavelength
- Polarizations
- Incidence Angle

Surface Parameters

- Structure
- Dielectric Properties

Radar Parameters: Wavelength

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

Higher Frequency

Shorter Wavelength

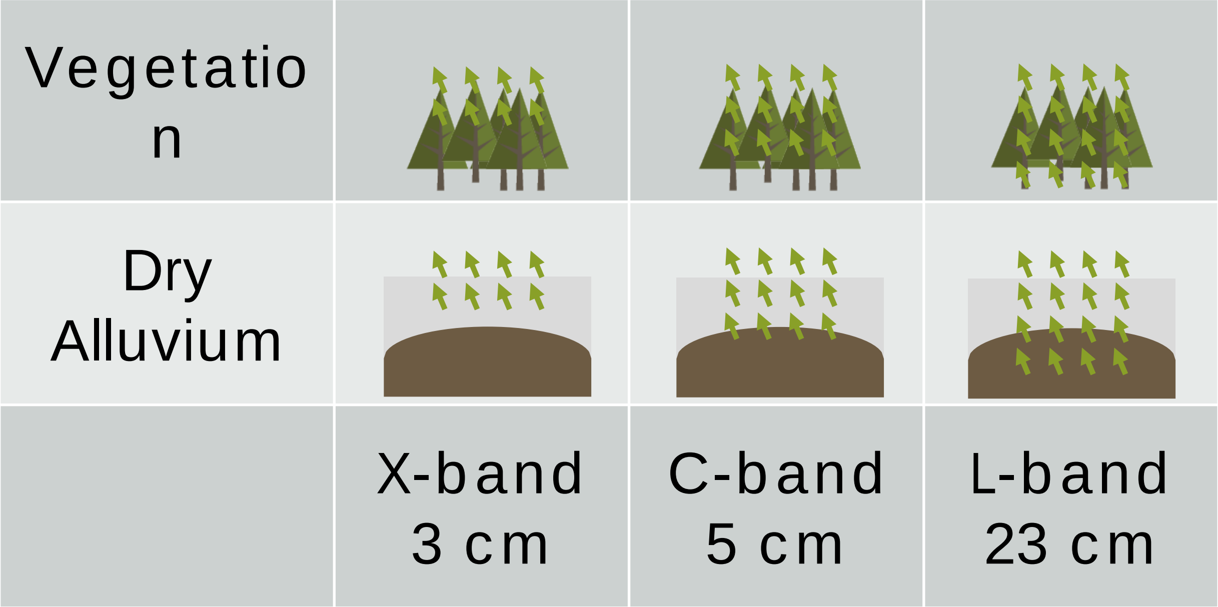
Lower Frequency

Longer Wavelength

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

*wavelengths most frequently used in SAR are in parenthesis

Penetration as a Function of Wavelength



- Penetration is the **primary factor** in wavelength selection
- Generally, the longer the wavelength, the greater the penetration into the target

Frequency Band	Application Example
VHF	foliage & ground penetration, biomass
P-Band	biomass, soil moisture, penetration
L-Band	agriculture, forestry, soil moisture
C-Band	ocean, agriculture
X-band	agriculture, ocean, high resolution radar
Ku-Band	glaciology (snow cover mapping)
Ka-Band	high resolution radar

Image (left) based on ESA Radar Course 2; Table (right) Credit: DLR

Example: Radar Signal Penetration into Vegetation

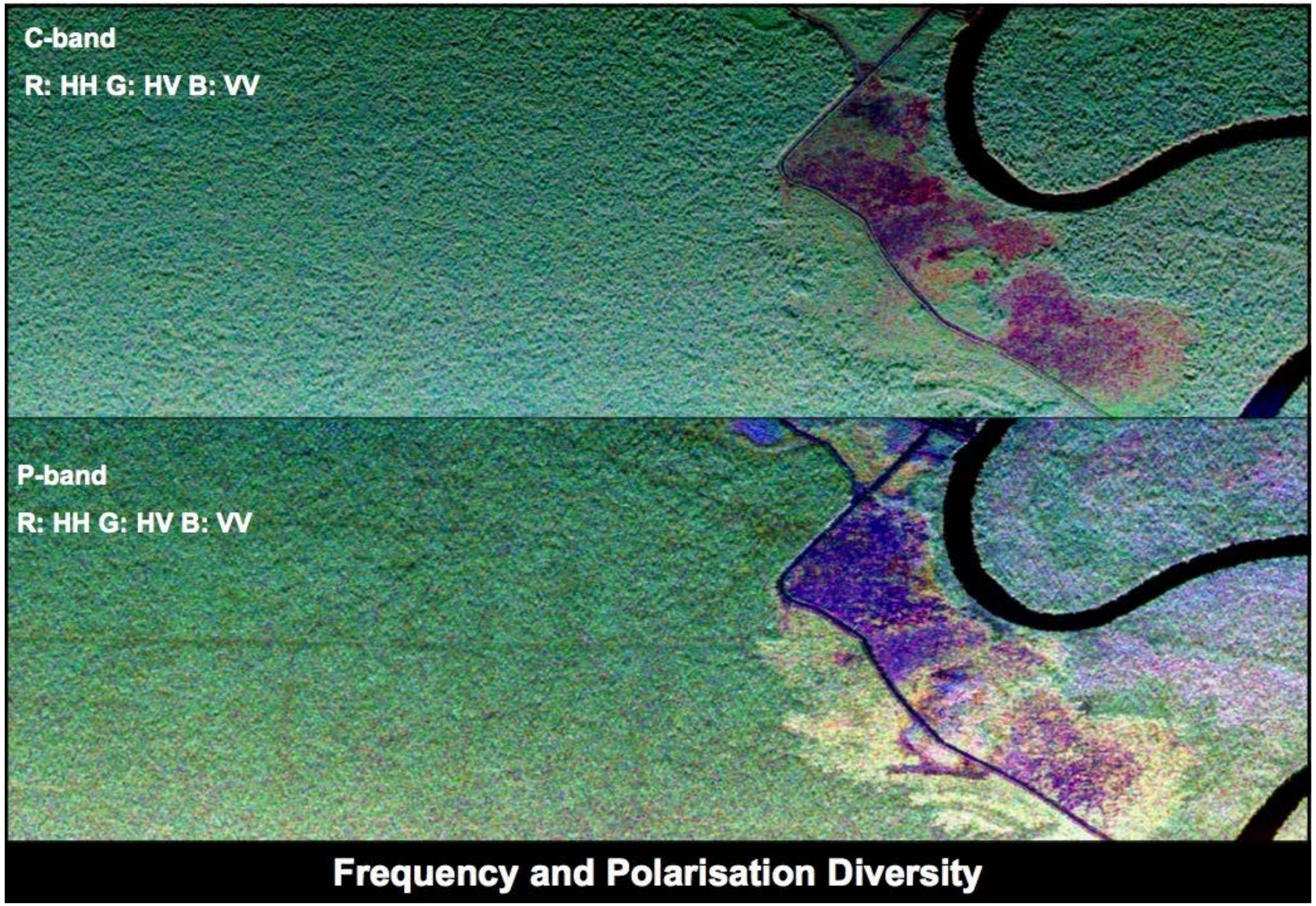


Image Credit: A. Moreira - ESA

Radar Parameters: 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 observed

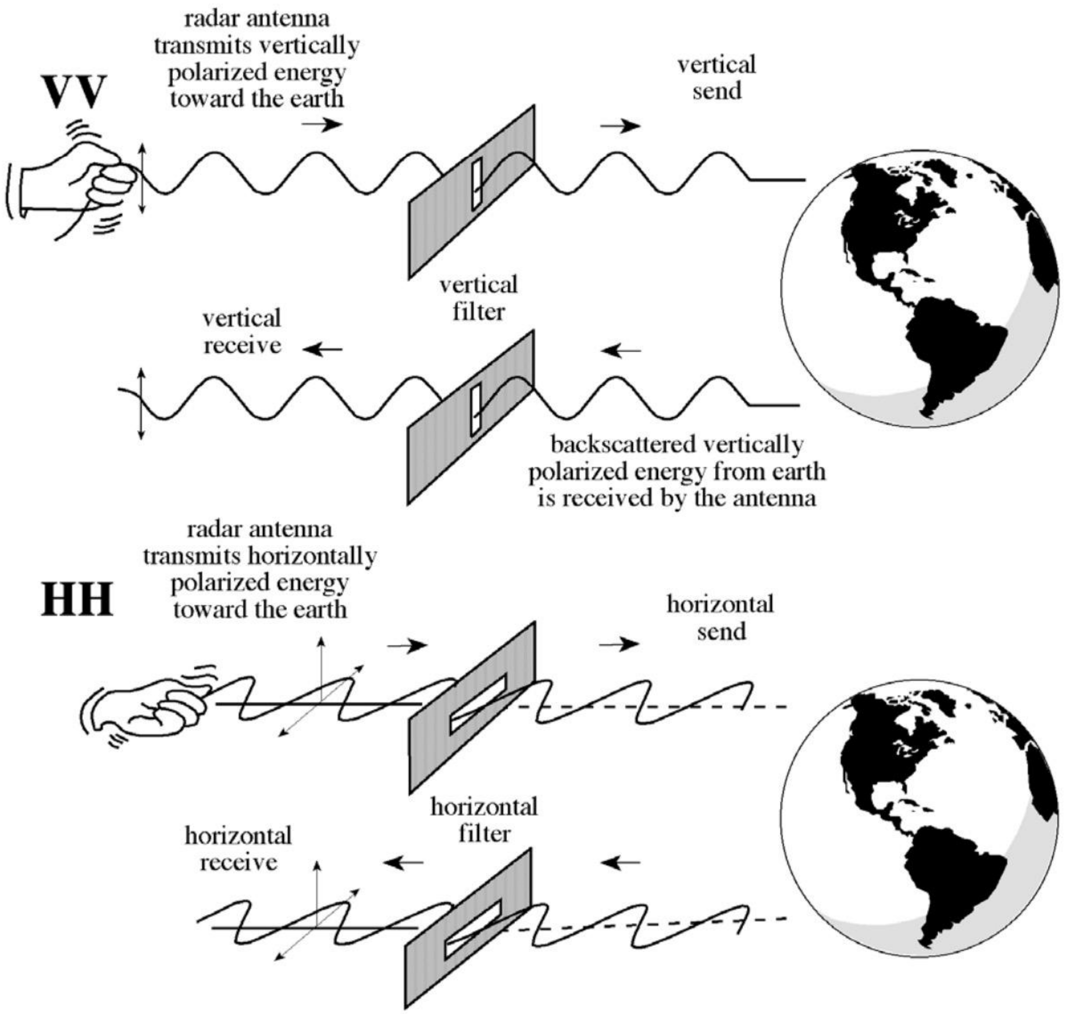


Image Credit: J.R. Jensen, 2000, Remote Sensing of the Environment

Example of Multiple Polarizations for Vegetation Studies

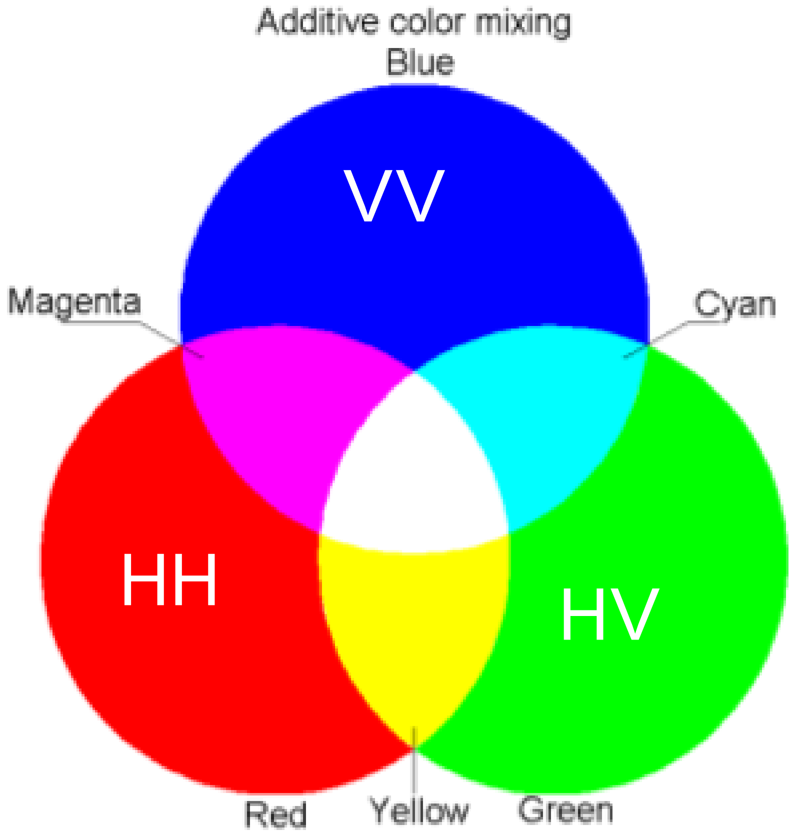
Pacaya-Samiria Forest Reserve in Peru

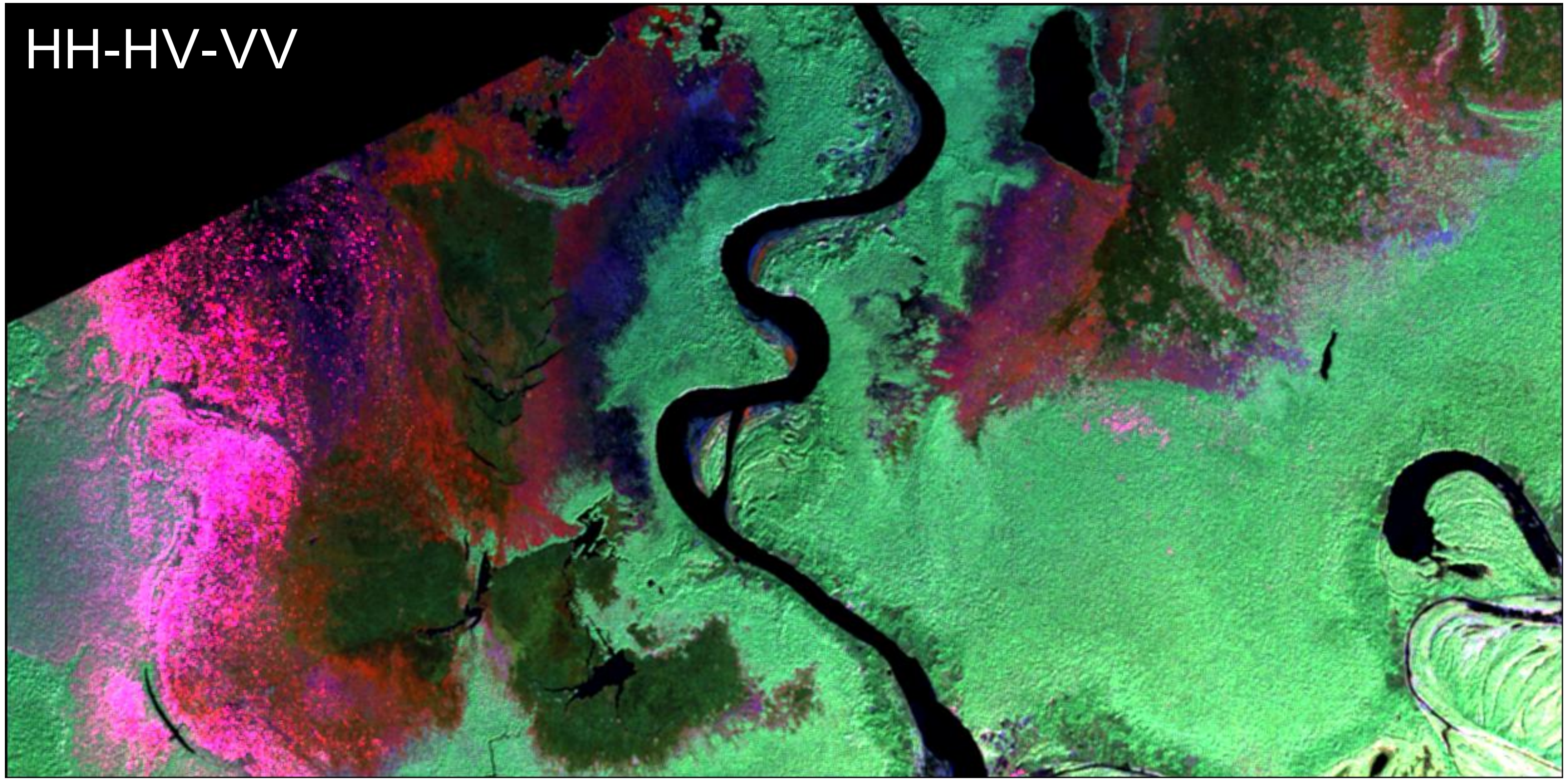
Images from UAVSAR (HH, HV, VV)

Example of Multiple Polarization for Vegetation Studies

Pacaya-Samiria Forest Reserve in Peru

Images from UAVSAR (HH, HV, VV)

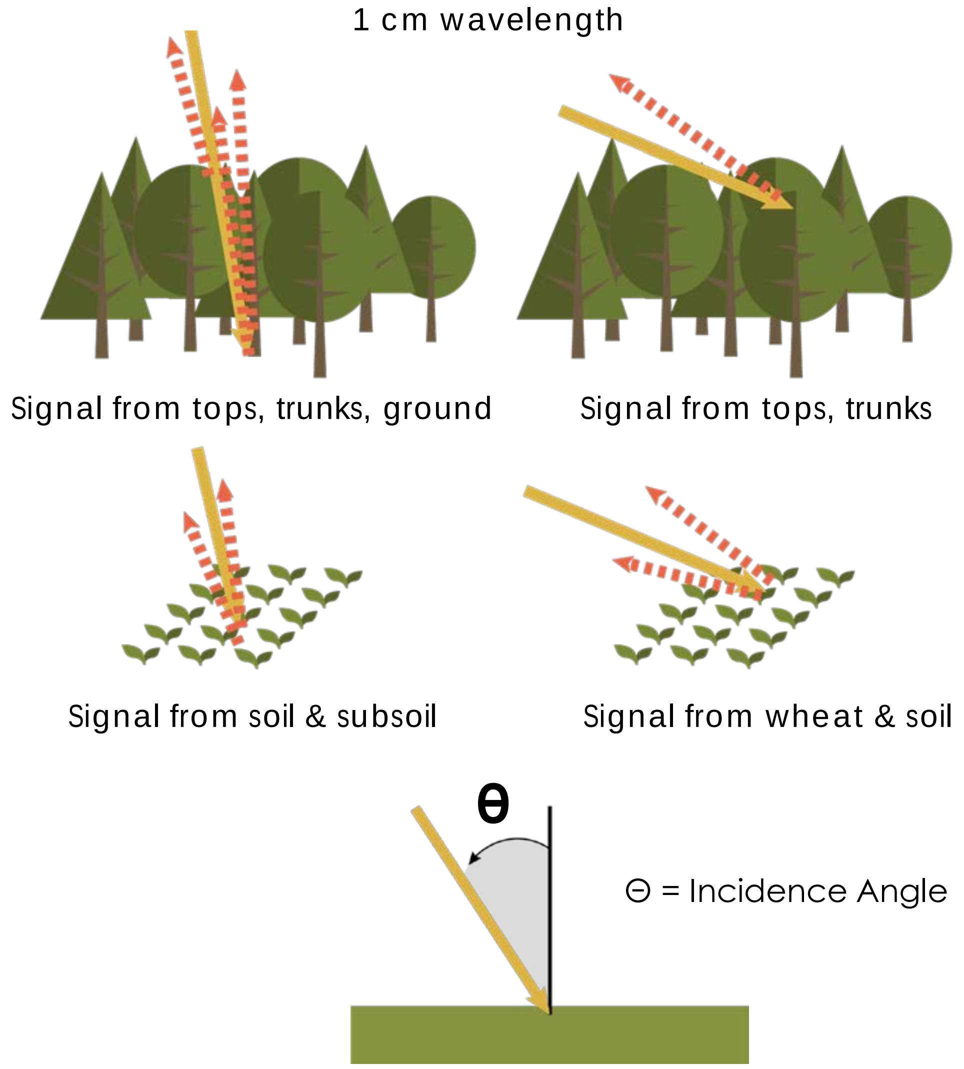




Radar Parameters: Incidence Angle

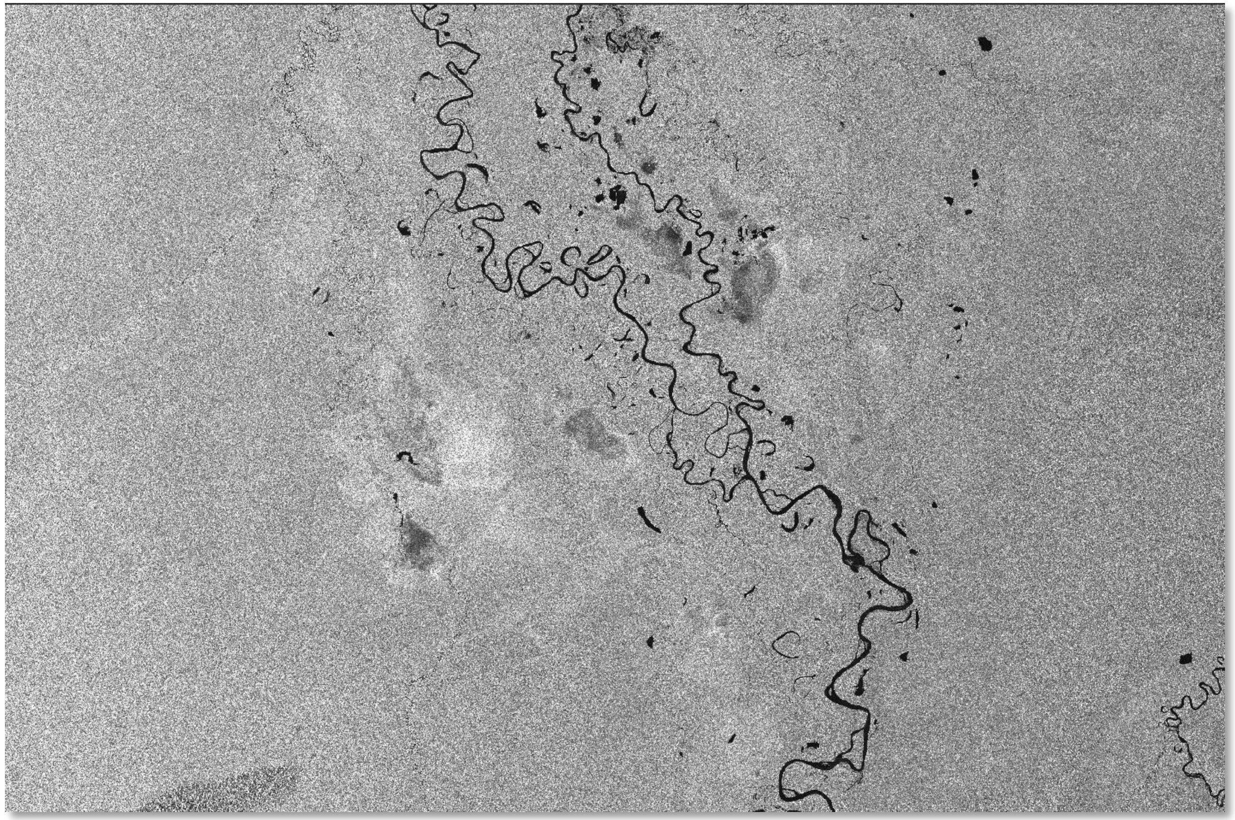
Local Incidence Angle:

- The angle between the direction of illumination of the radar and the Earth's surface plane
- accounts for local inclination of the surface
- influences image brightness
- is dependent on the height of the sensor
- the geometry of an image is different from point to point in the range direction



Images based on: top: Ulaby et al. (1981a), bottom: ESA

Effect of Incidence Angle Variation



Sentinel-1

Parameters to Consider for a Land Cover Mapping Study

Radar Parameters

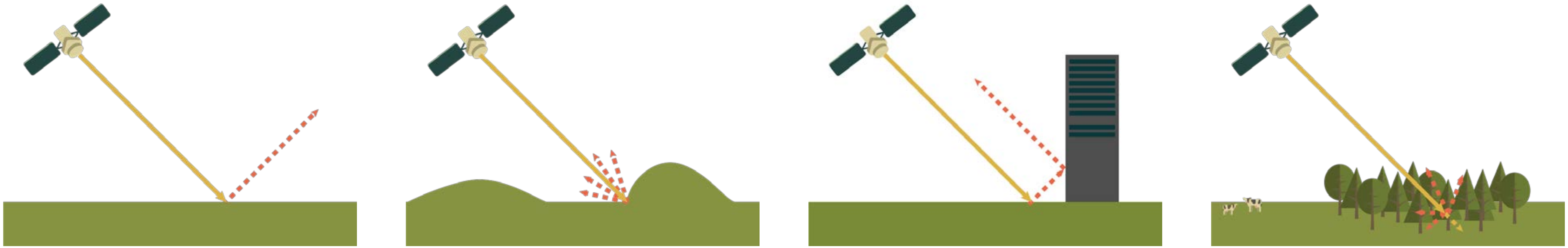
- Wavelength
- Polarizations
- Incidence Angle

Surface Parameters

- Structure
- Dielectric Properties

Radar Signal Interaction

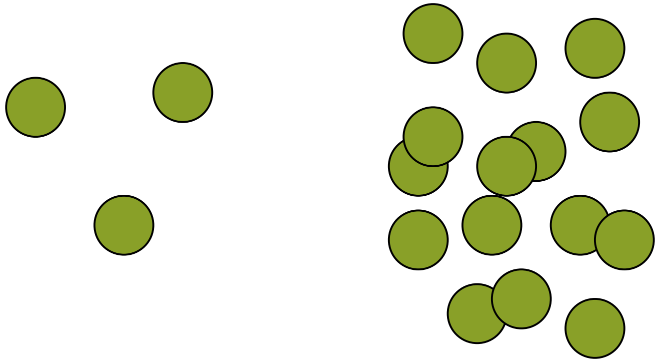
- The scale of the surface relative to the wavelength determine how rough or smooth they appear and how bright or dark they will appear on the image
- Backscattering Mechanisms:



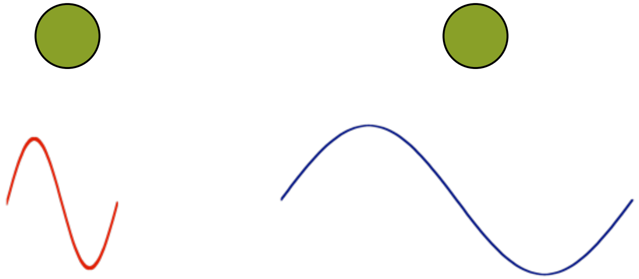
Smooth Surface | Rough Surface | Double Bounce | Vegetation

Surface Parameters Related to Structure

Density



Size Relative to Wavelength



Size & Orientation

Size in Relation to Wavelength

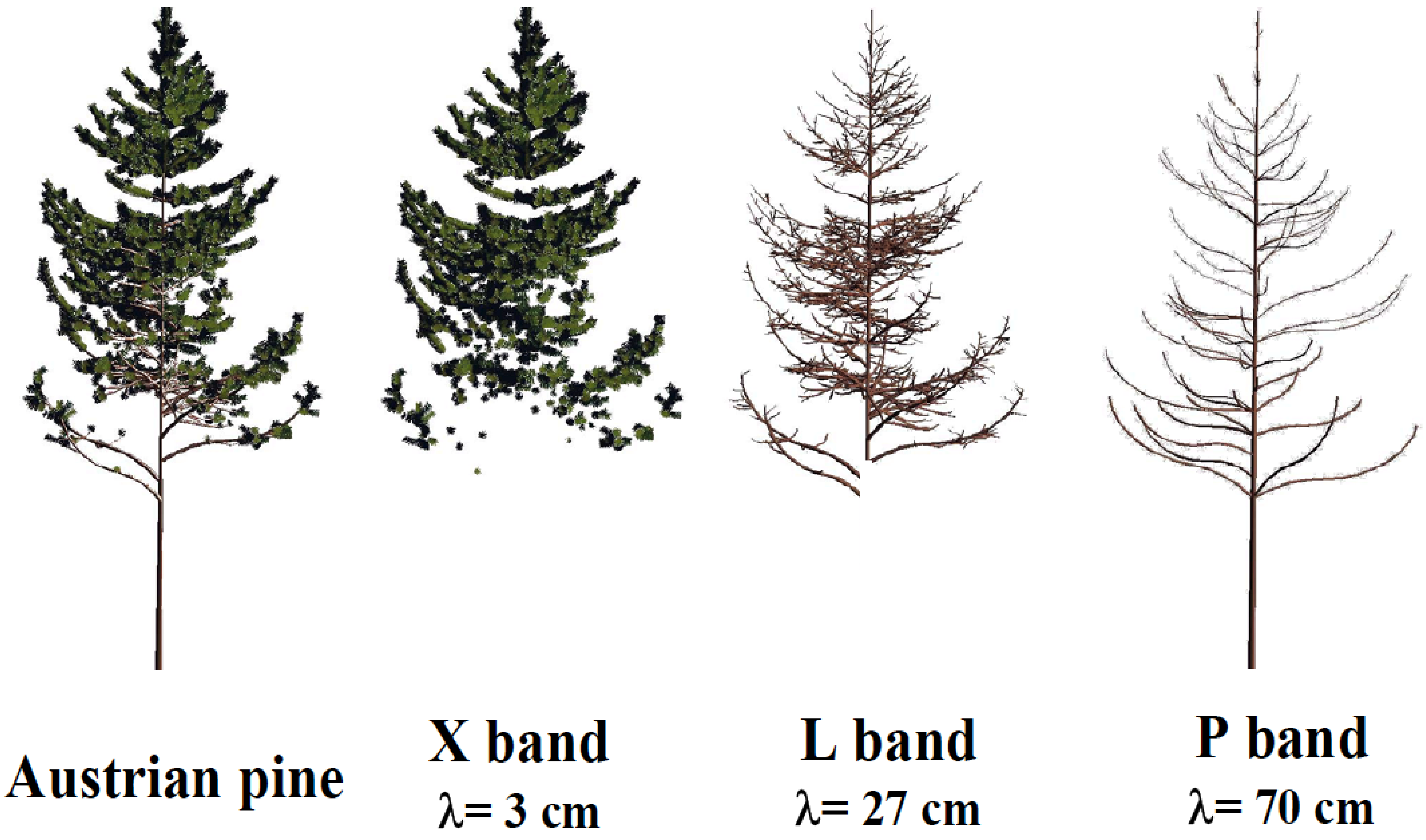
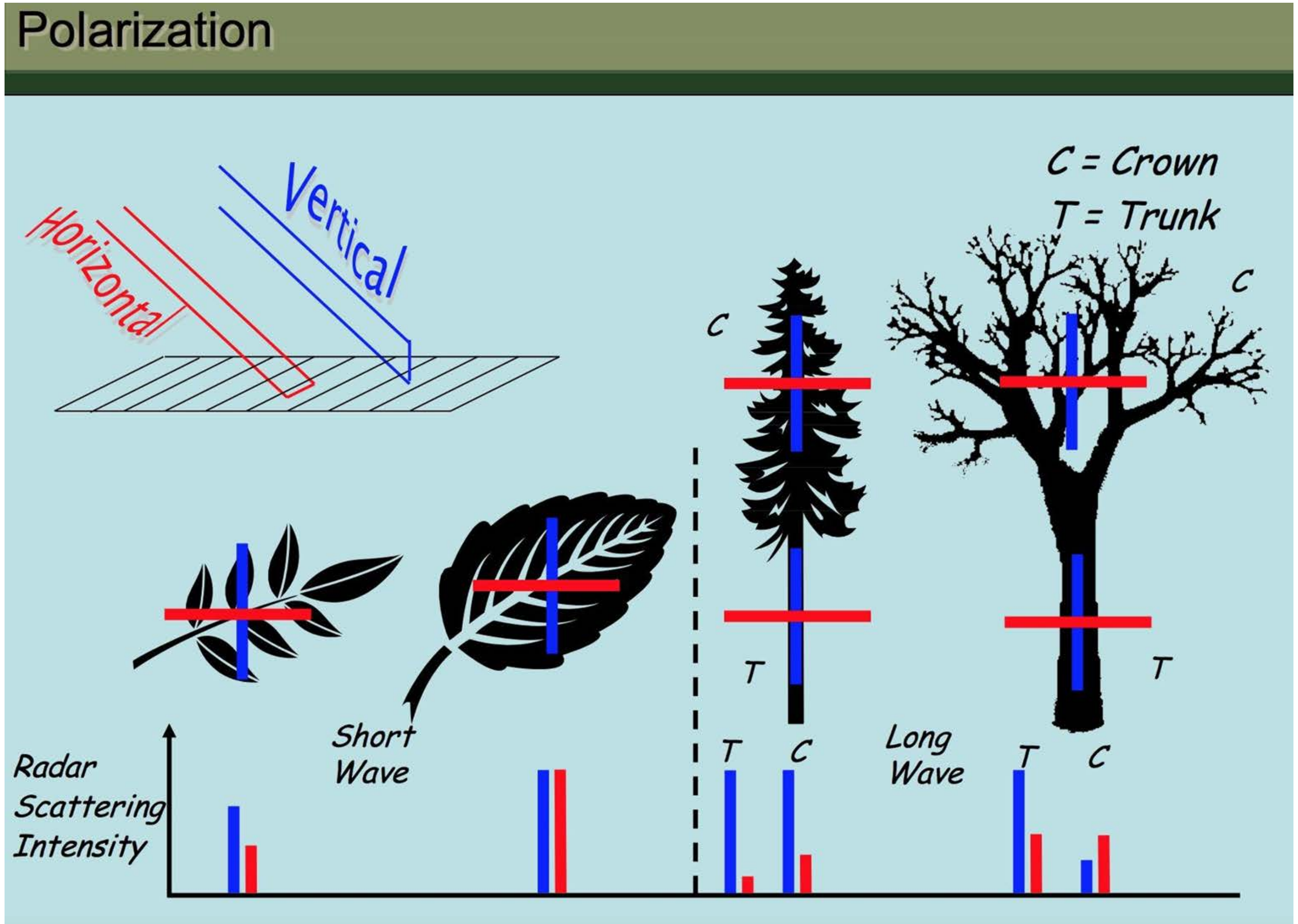


Image Credit: Thuy le Toan

Size and Orientation



Source: Walker, W. *Introduction to Radar Remote Sensing for Vegetation Mapping and Monitoring*

Density

- Saturation Problem
- Data/Instrument
  - NASA/JPL polarimetric AIRSAR operating at C-, L-, and P-band
  - Incidence angle 40°-50 °

- C-band ≈ 20 tons/ha (2 kg/m2)
- L-band ≈ 40 tons/ha (4 kg/m2)
- P-band ≈ 100 tons/ha (10 kg/m2)

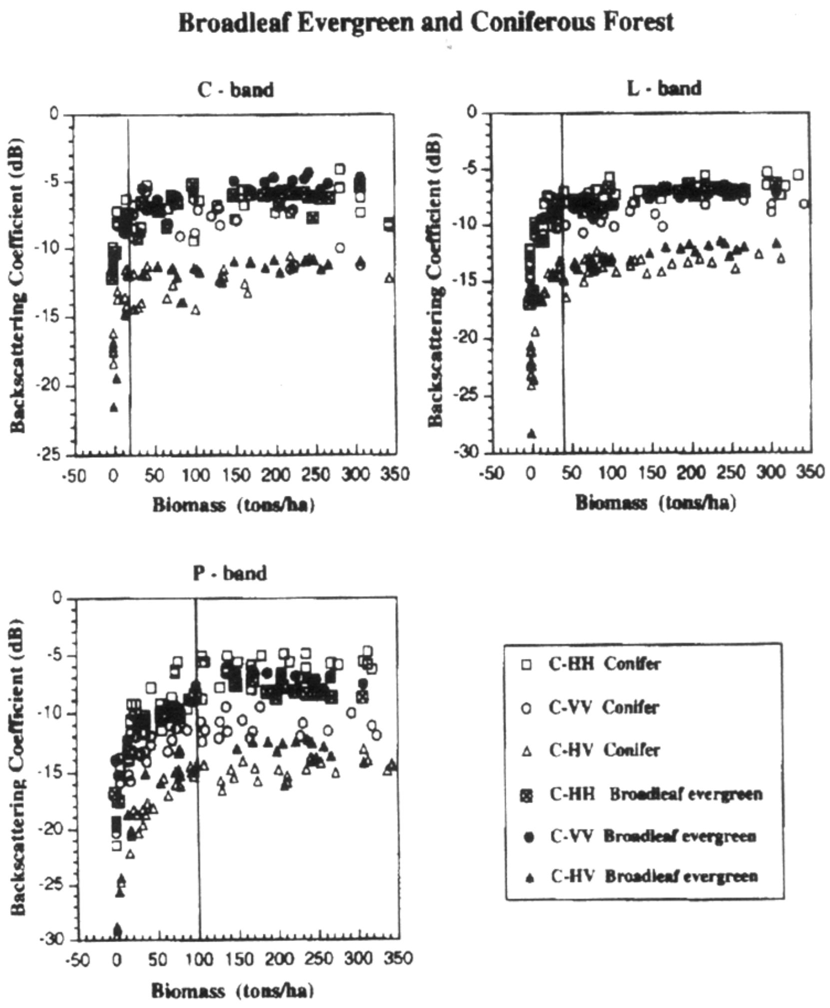
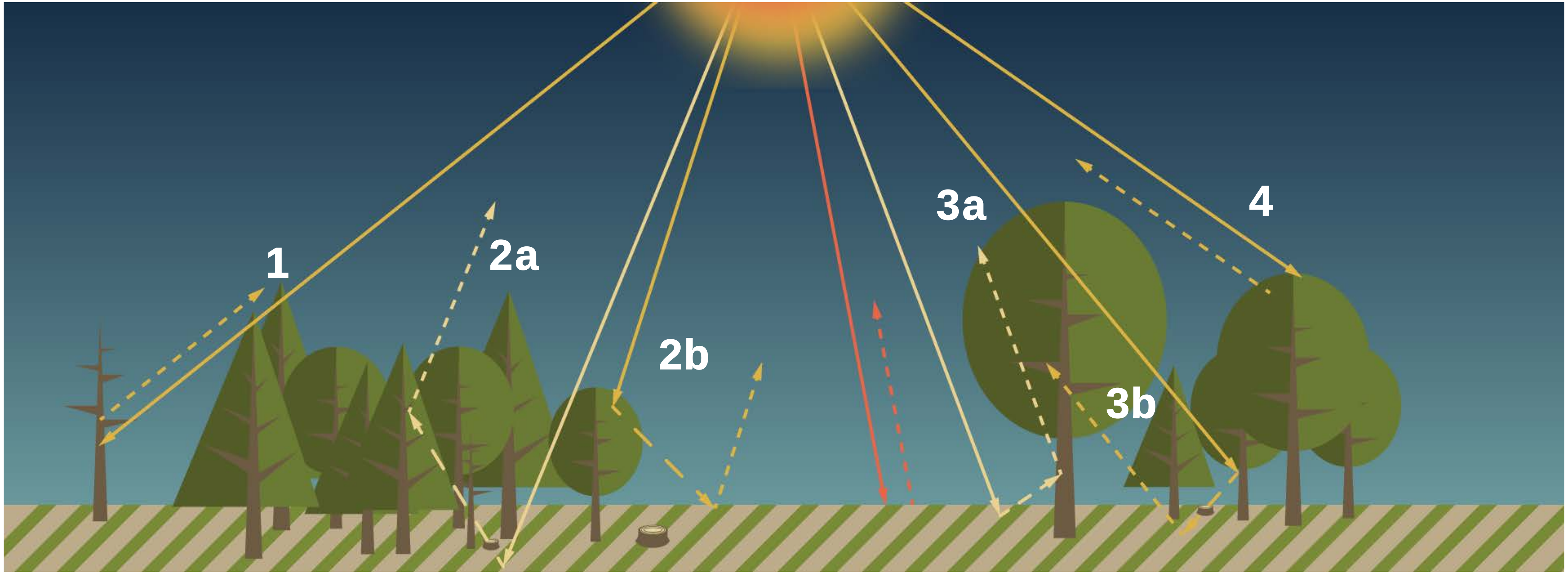


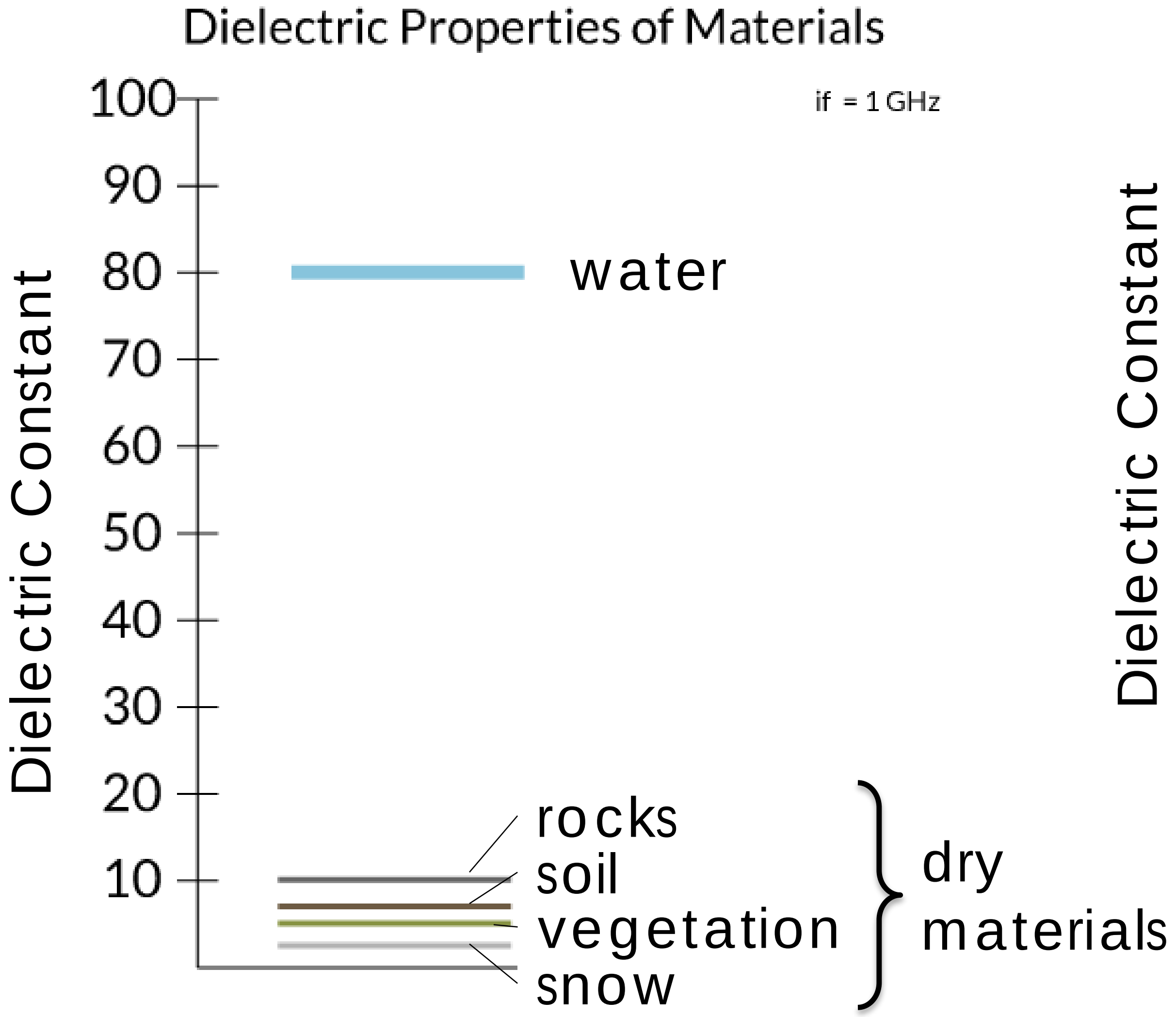
Image Source: Imhoff, 1995:514)

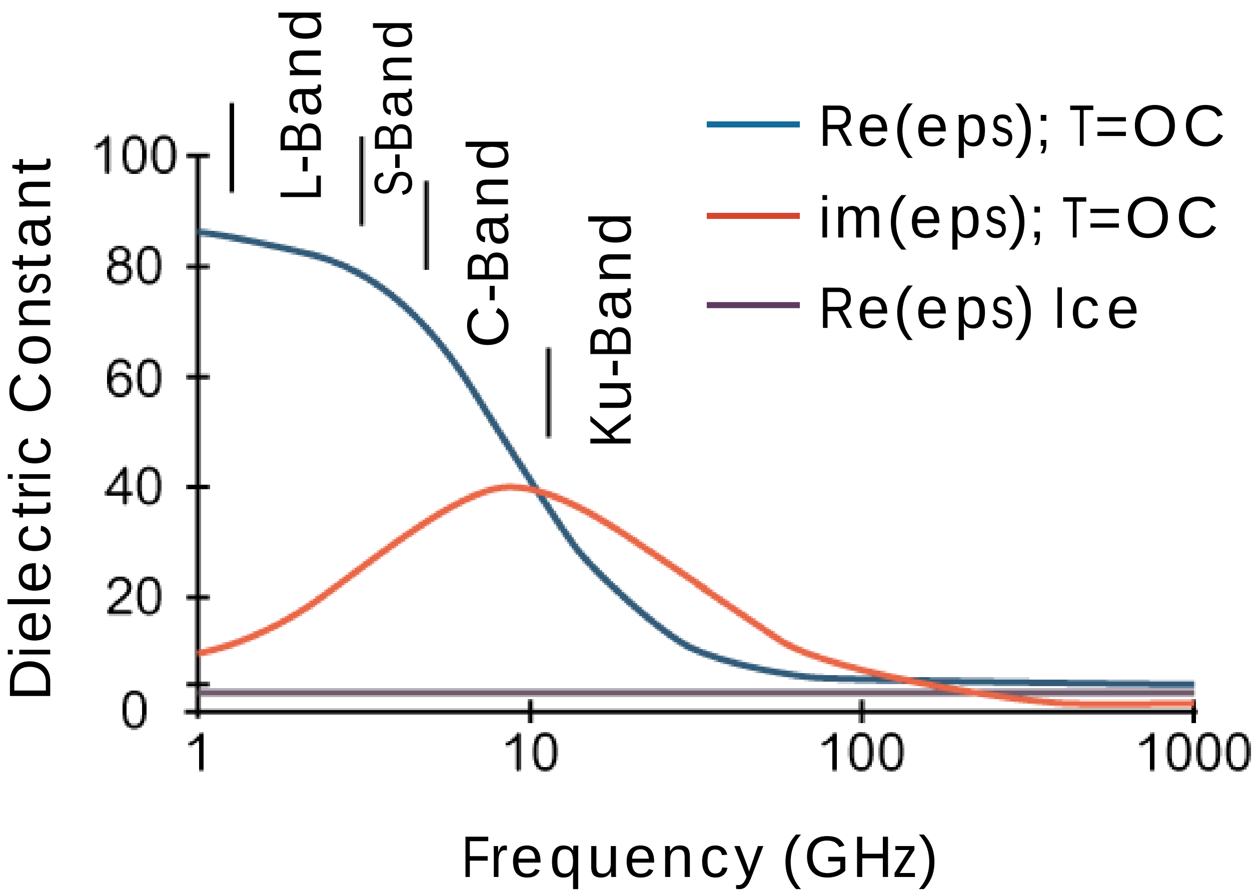
Radar Backscattering in Forests



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

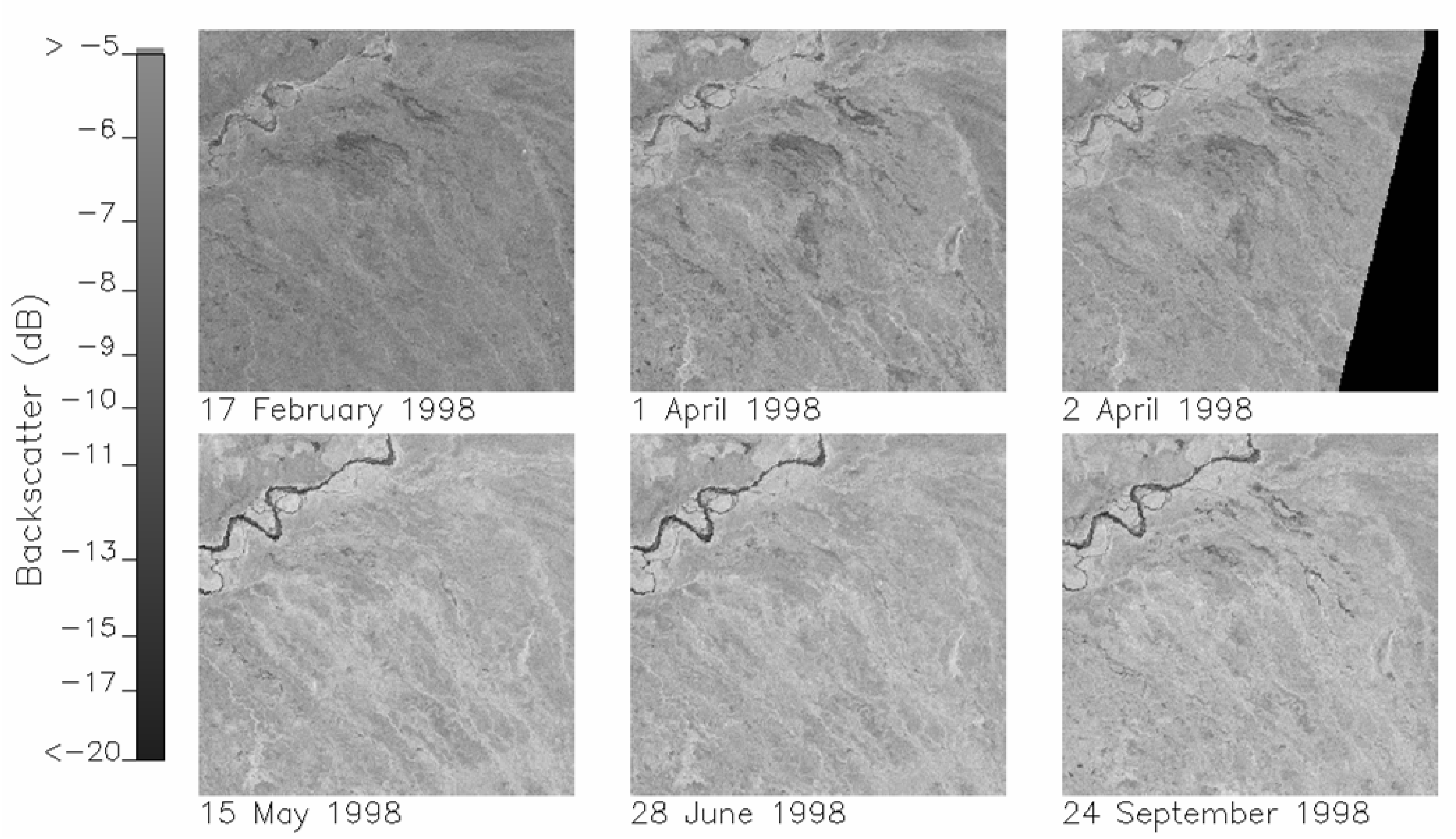
Surface Parameters: Dielectric Constant





Dielectric Properties of the Surface

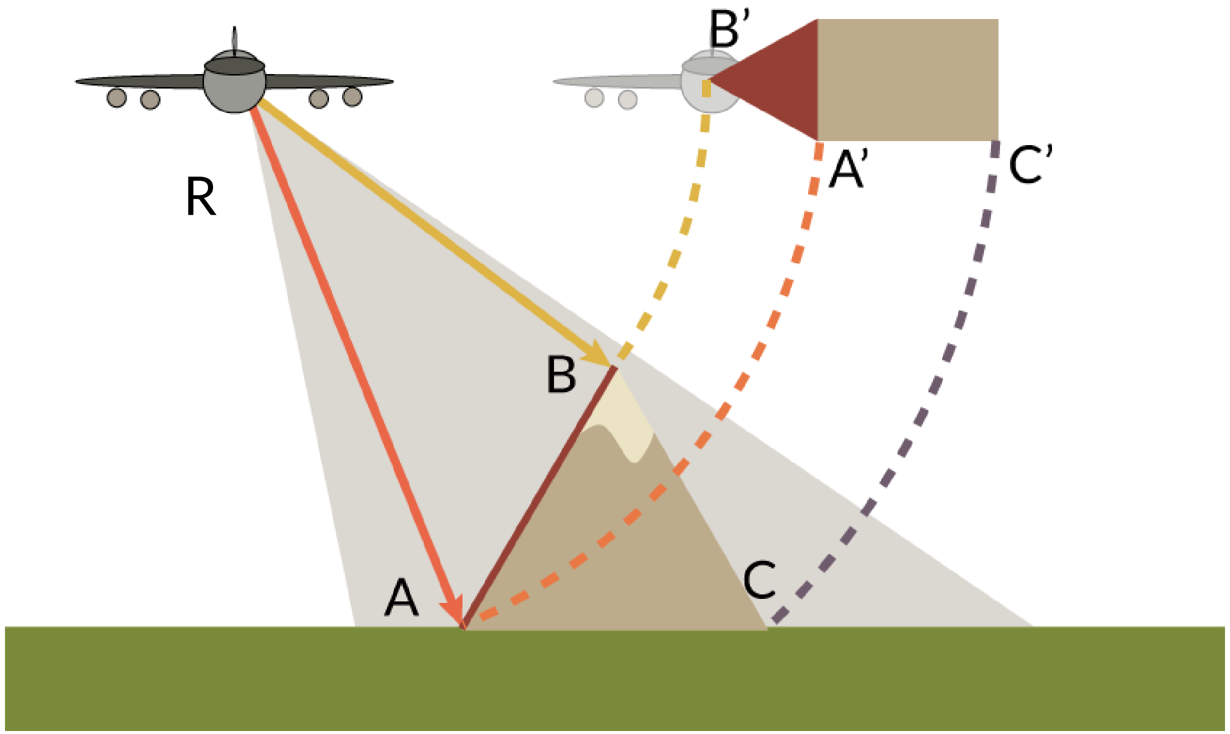
- During the land surface freeze/thaw transition there is a change in dielectric properties of the surface
- This causes a notable increase in backscatter



Geometric Distortion

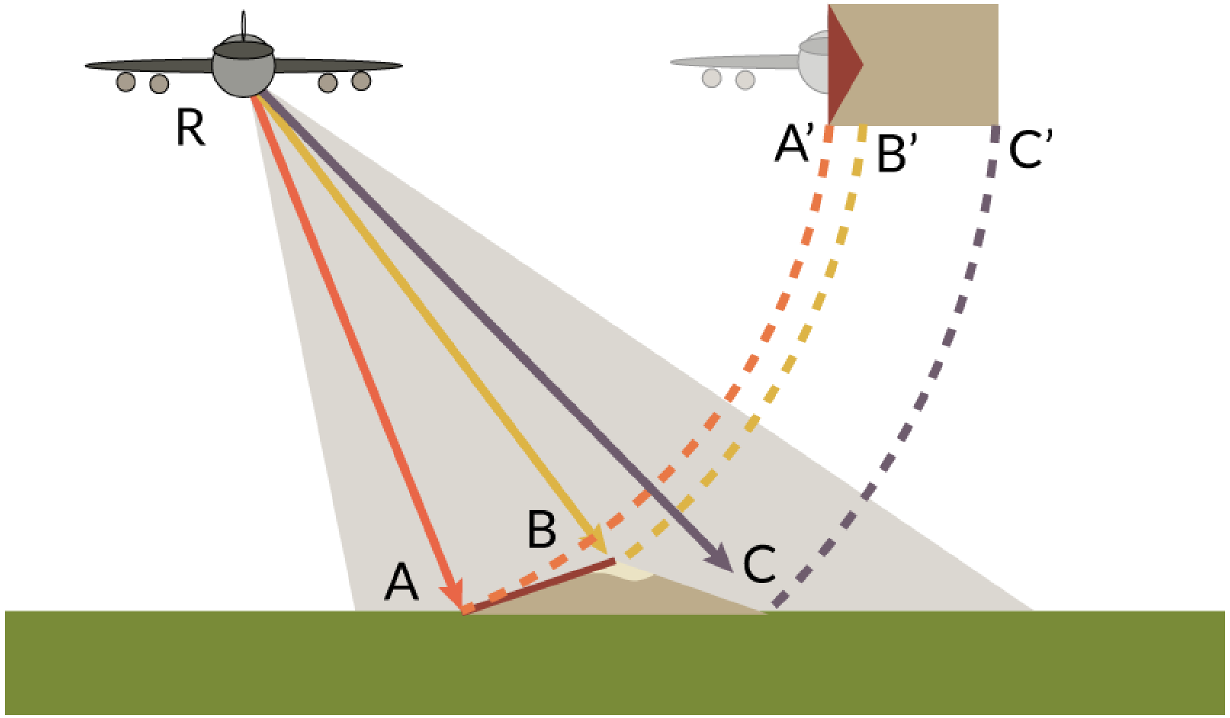
Layover

AB = BC
A'B' < B'C'
RA > RB
RA' > RB'



Foreshortening

RA < RB < RC
AB = BC
A'B' < B'C'



Images based on NRC images

Shadow

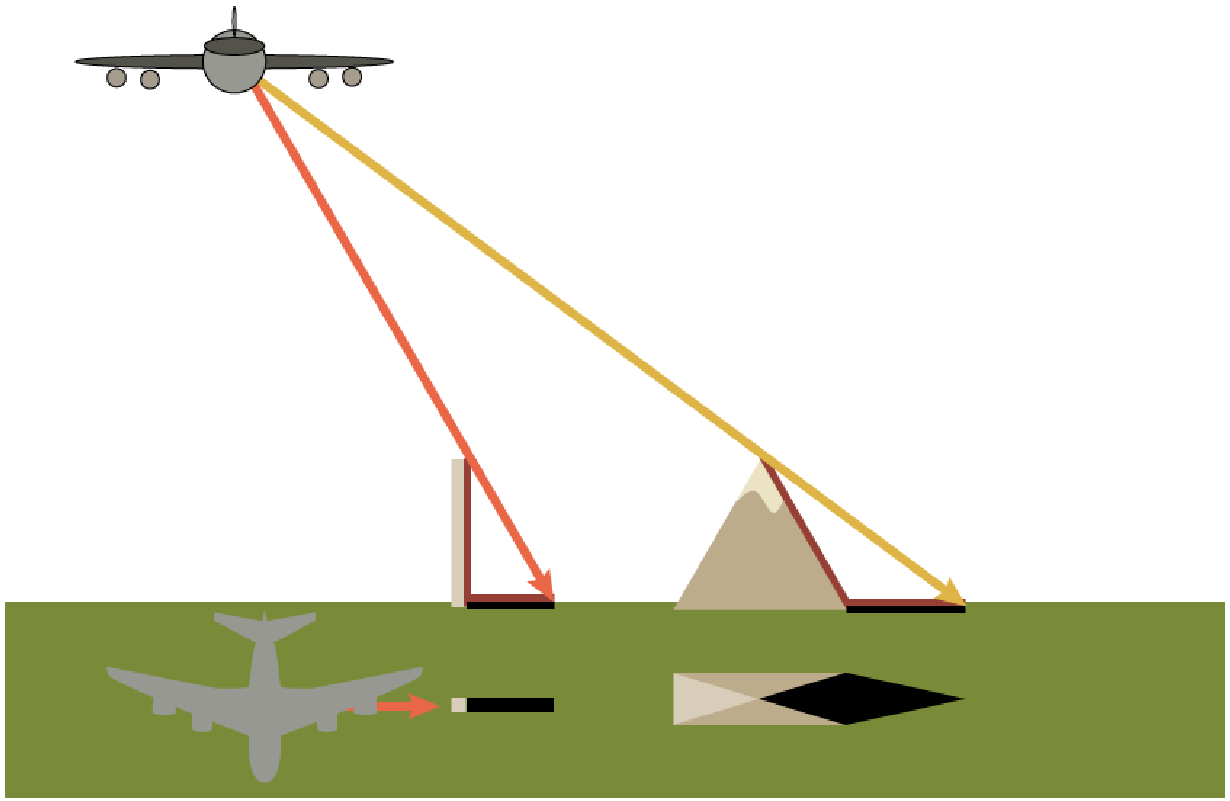


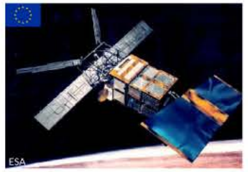
Image (left) based on NRC

Radar Data from Different Satellites

Legacy:

SeaSAT
1978

ERS 1/2
1991-2011



ENVISAT
2002-2012

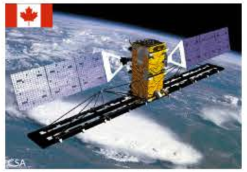
ALOS-1
2002-2012

Radarsat-1
1995-2013

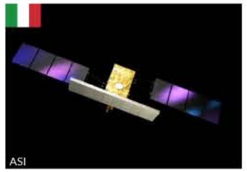
Current:

TanDEM-X
2007

Radarsat-2
2007



COSMO-SkyMed
2007



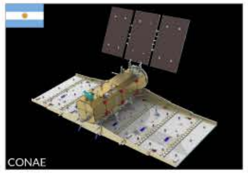
ALOS-2
2014

Sentinel-1
2014

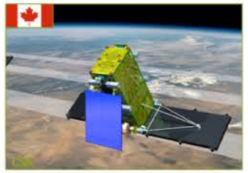
PAZ SAR
2018

Future:

SAOCOM
2018

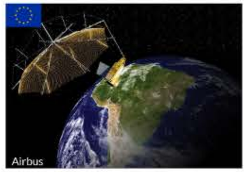


RCM
2018



NISAR
2021

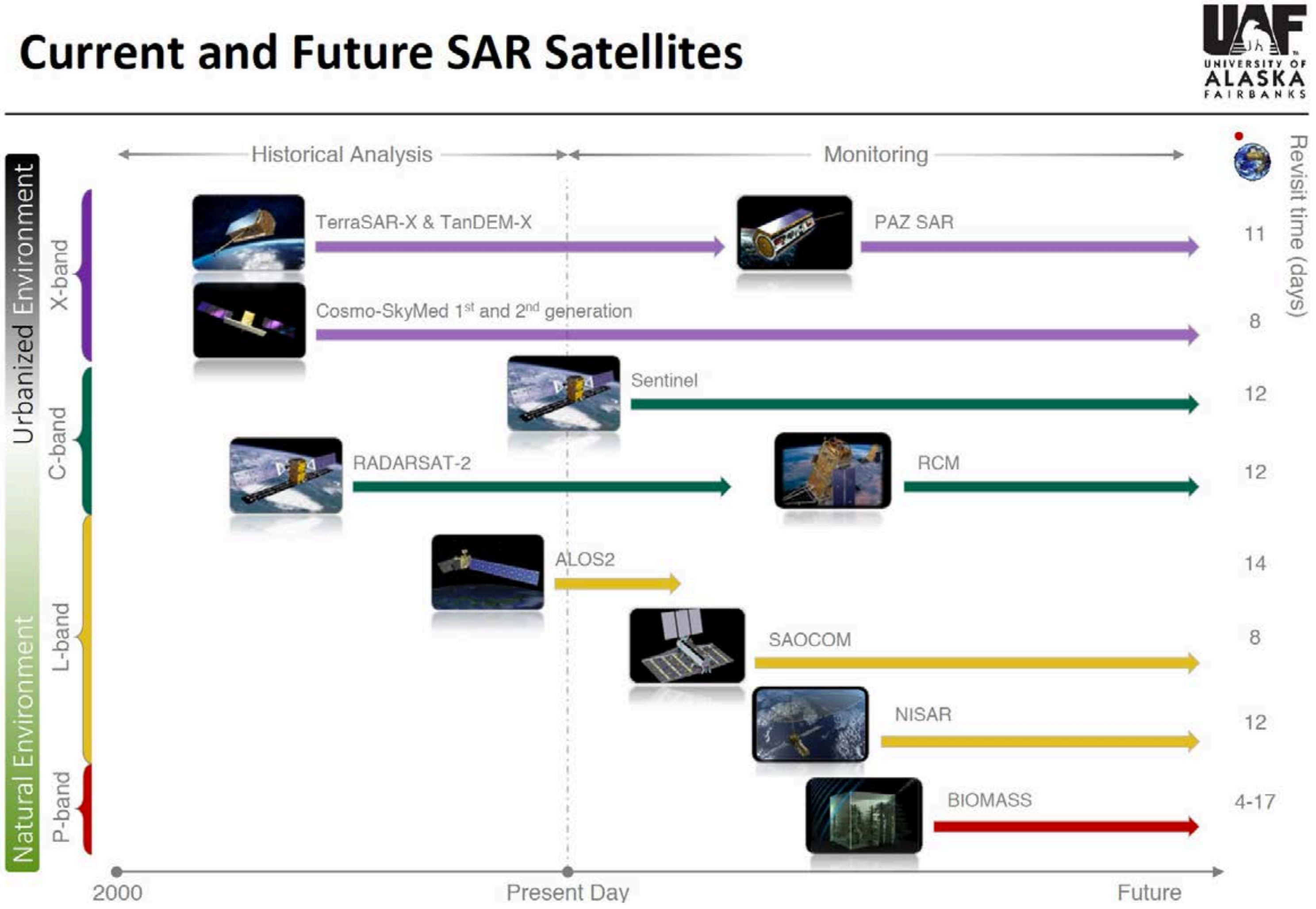
Biomass
2021



freely accessible

Credit: Franz Meyer, University of Alaska, Fairbanks

Current and Future SAR Satellites



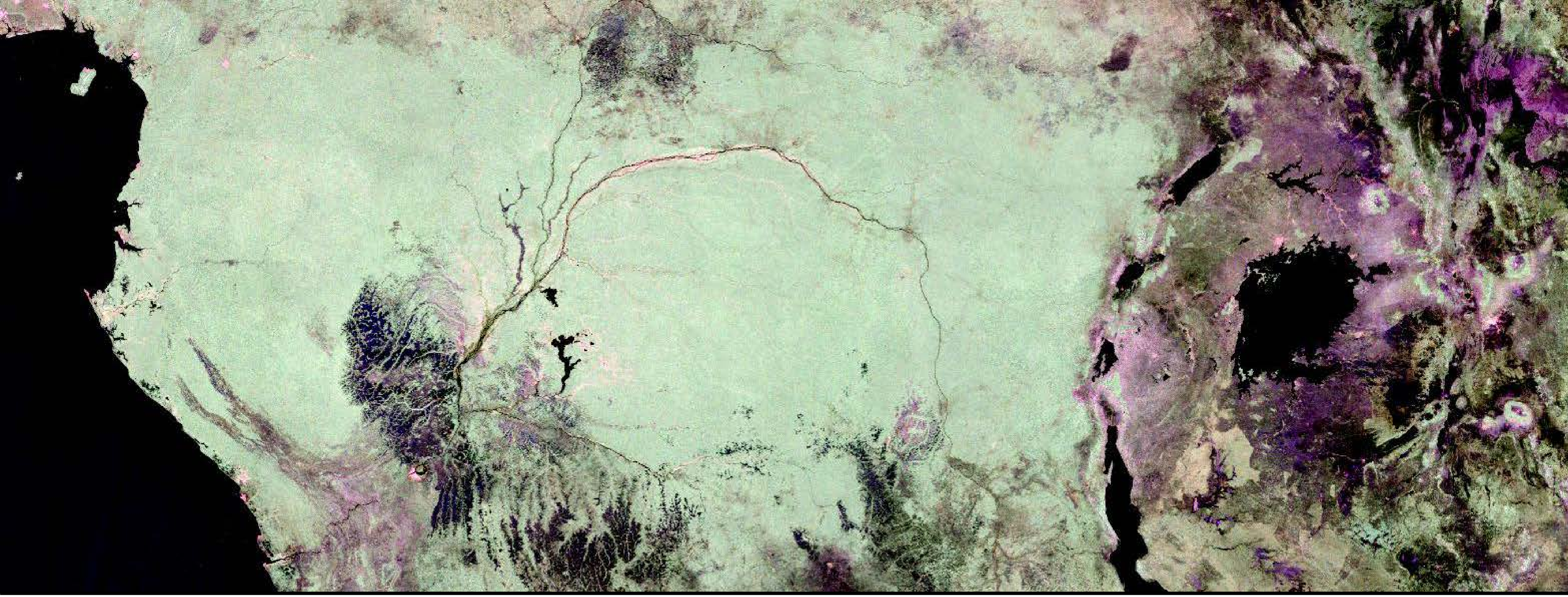
Courtesy: A. Ferretti, TRE: modified version

NASA-ISRO SAR Mission (NISAR)

- High spatial resolution with frequent revisit time
- Earliest baseline launch date: 2021
- Dual frequency L- and S-band SAR
  - L-band SAR from NASA and S-band SAR from ISRO
- 3 years science operations (5+ years consumables)
- All science data will be made available free and open

NISAR Characteristic:	Would Enable:
L-band (24 cm wavelength)	Low temporal decorrelation and foliage penetration
S-band (12 cm wavelength)	Sensitivity to light vegetation
SweepSAR technique with Imaging Swath >240 km	Global data collection
Polarimetry (Single/Dual/Quad)	Surface characterization and biomass estimation
12-day exact repeat	Rapid Sampling
3-10 meters mode-dependent SAR resolution	Small-scale observations
3 years since operations (5 years consumables)	Time-series analysis
Pointing control < 273 arcseconds	Deformation interferometry
Orbit control < 500 meters	Deformation interferometry
>30% observation duty cycle	Complete land/ice coverage
Left/Right pointing capability	Polar coverage, North and South
Noise Equivalent Sigma Zero ≤ -23 db	Surface characterization of smooth surfaces

Courtesy: Paul Rosen (JPL)



Hands-on Exercise

Sentinel-1 Toolbox

- A free and open source software developed by ESA for processing and analyzing radar images from Sentinel-1 and other satellites
- It can be accessed through the following site: http://step.esa.int/main/download/
- It includes the following tools
  - Calibration
  - Speckle noise
  - Terrain correction
  - Mosaic production
  - Polarimetry
  - Interferometry
  - Classification