Building Capacity to Use Earth Observations in Addressing Environmental Challenges in Bhutan

Day 3 – Land Cover Mapping with SAR and Optical Remote Sensing Data

Objectives

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

- Identify the unique information content from SAR data relevant to land cover mapping
- Identify the unique information content from optical data relevant to land cover mapping
- Identify the advantages and disadvantages of SAR and optical data for land cover mapping

Outline

- SAR for land cover mapping
- Optical for land cover mapping
- Demonstration:
  - Create a land cover map using SAR data only, optical data only, and combined optical and radar

Land Cover Mapping with SAR

Parameters to Consider for a Land Cover Mapping Study

Radar Parameters:

- Wavelength
- Polarizations
- Incidence Angle

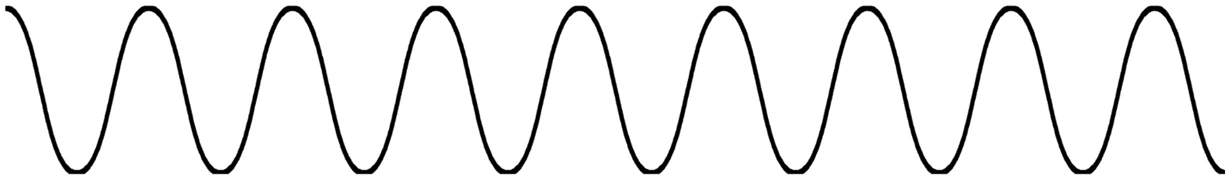
Surface Parameters:

- Structure
- Dielectric

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 (ν), 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 (**5.0**)	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 parentheses.

Penetration as a Function of Wavelength

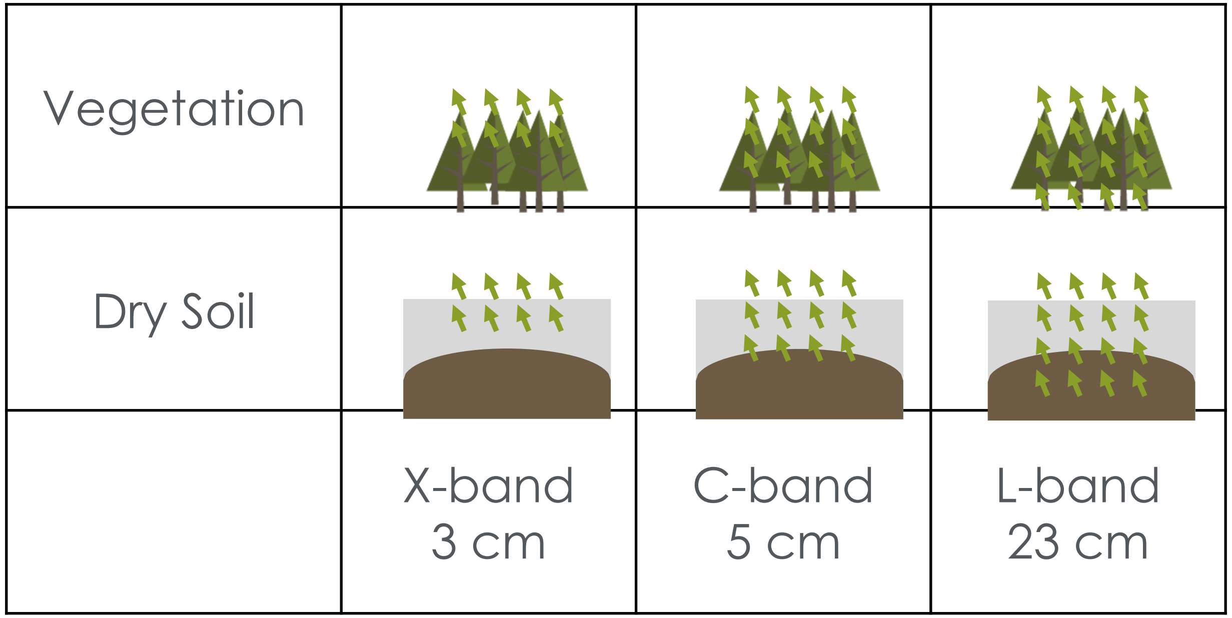


Image (left) based on ESA Radar Course 2; Table (right) Credit: DLR

- 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

Example: Radar Signal Penetration into Vegetation

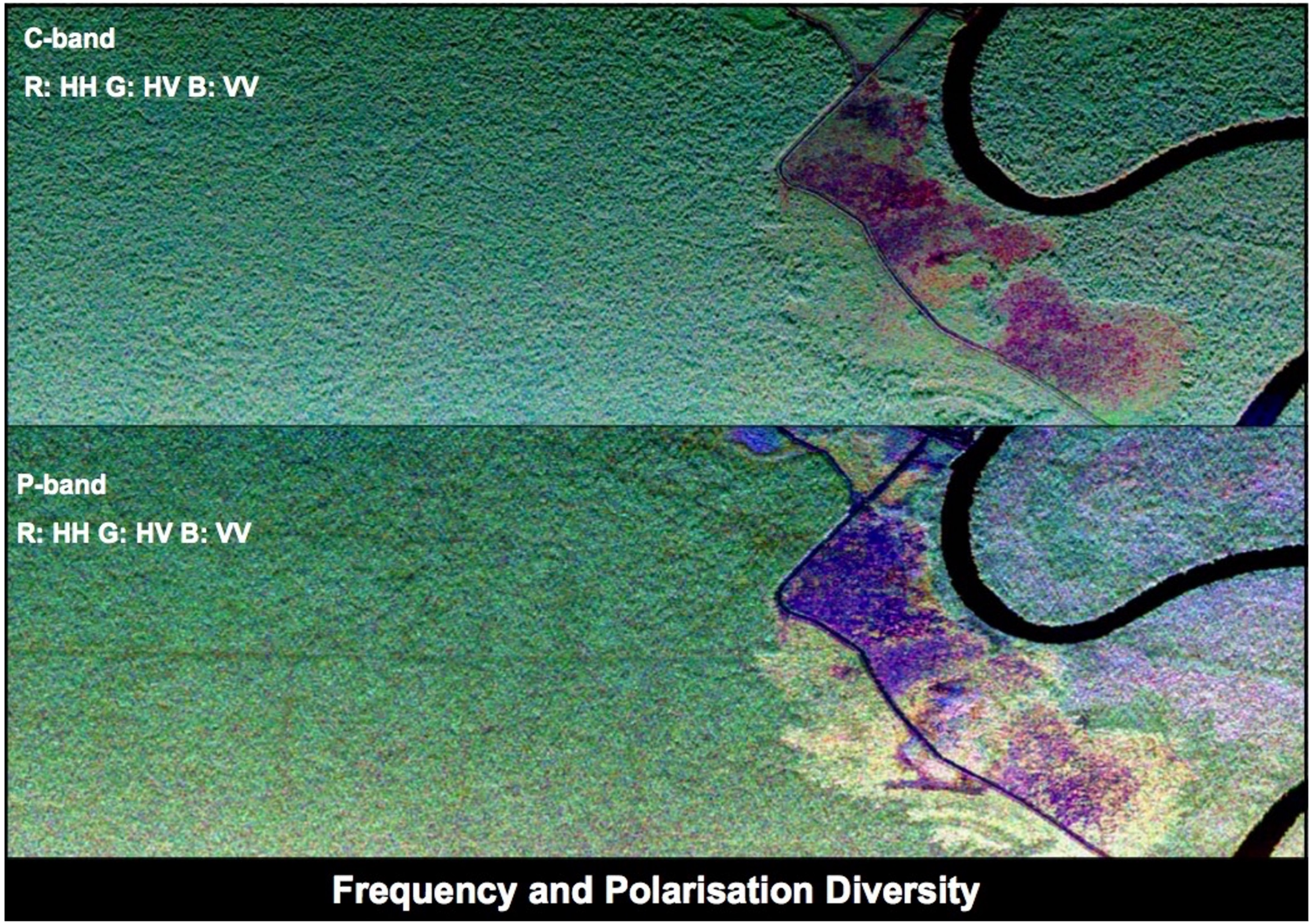


Image Credit: A. Moreira - ESA

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.

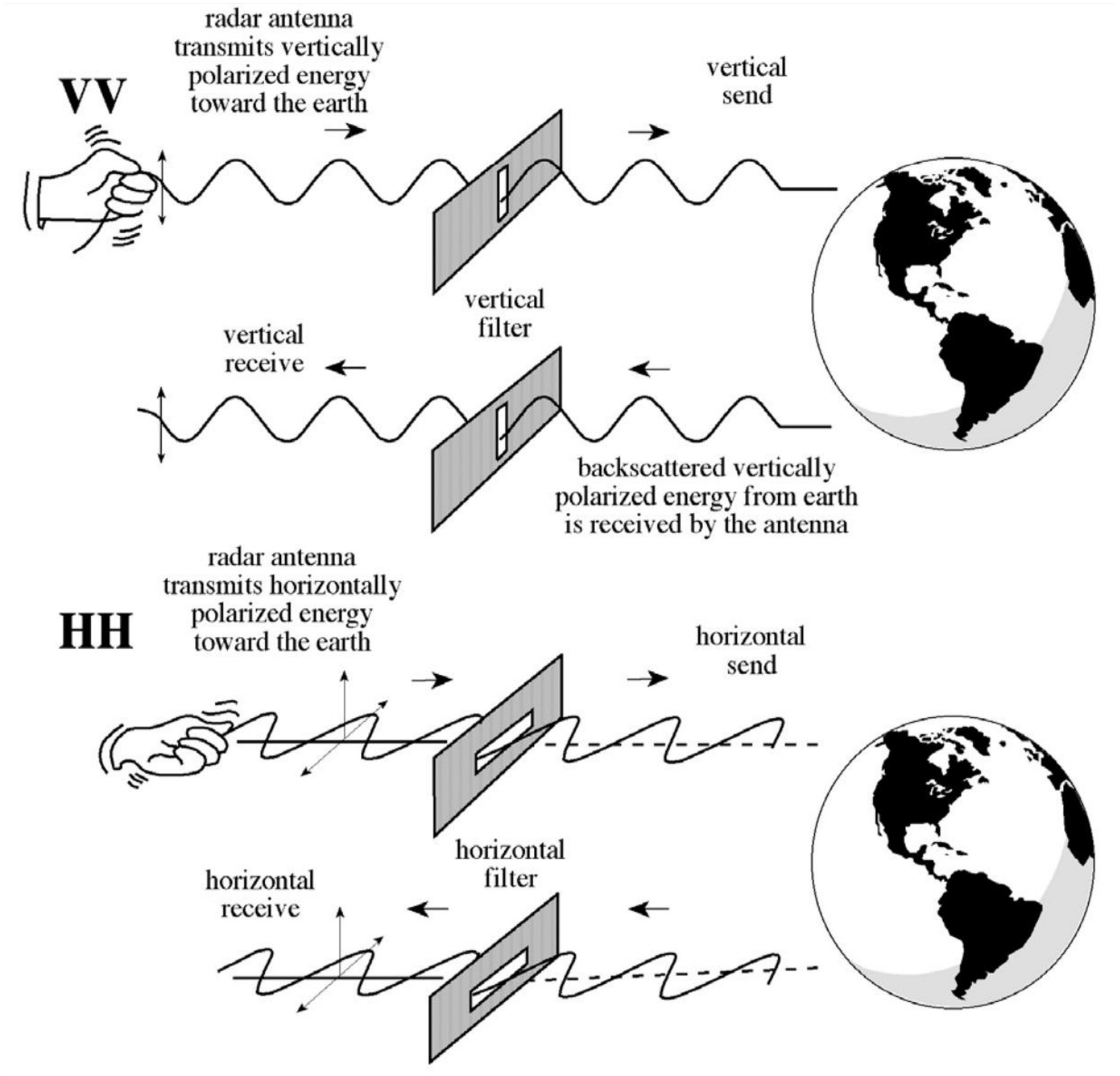


Image Credit: J.R. Jensen, 2000, Remote Sensing of the Environment

Example of Multiple Polarizations for Vegetation Studies

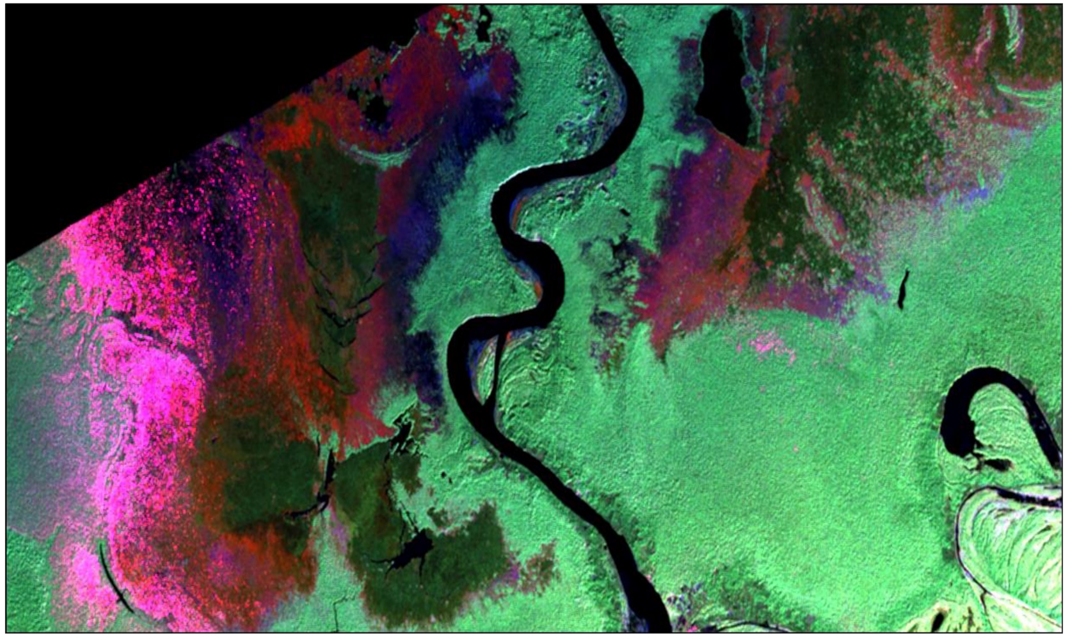
Pacaya-Samiria Forest Reserve in Peru

Images from UAVSAR (HH, HV, VV)

Example of Multiple Polarizations for Vegetation Studies

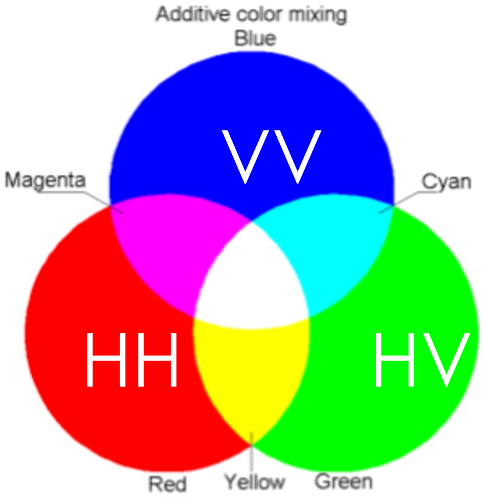
Pacaya-Samiria Forest Reserve in Peru

Images from UAVSAR (HH, HV, VV)



Img Layer 1	*Img Layer 2*	*Img Layer 3*	*Resultant*
Blue	Green	Red	Color
Tonal Change on Image			
White	Black	Black	Blue
Black	White	Black	Green
Black	Black	White	Red
White	White	Black	Cyan
White	Black	White	Magenta
Black	White	White	Yellow
No Tonal Change on Image			
White	White	White	White
Black	Black	Black	Black
Grey	Grey	Grey	Grey

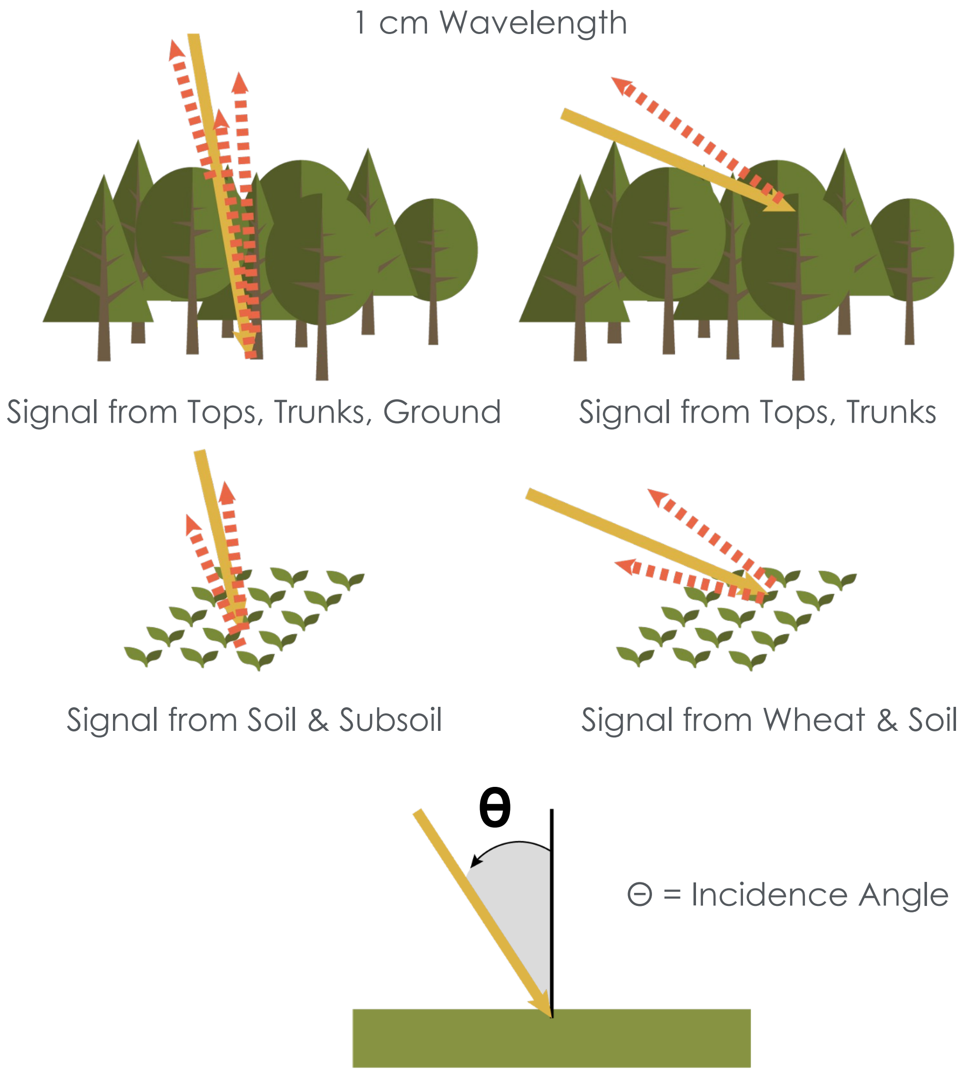
Source: SAR Handbook, Chapter 2 by J. Kellndorfer



Radar Parameters: Incidence Angle

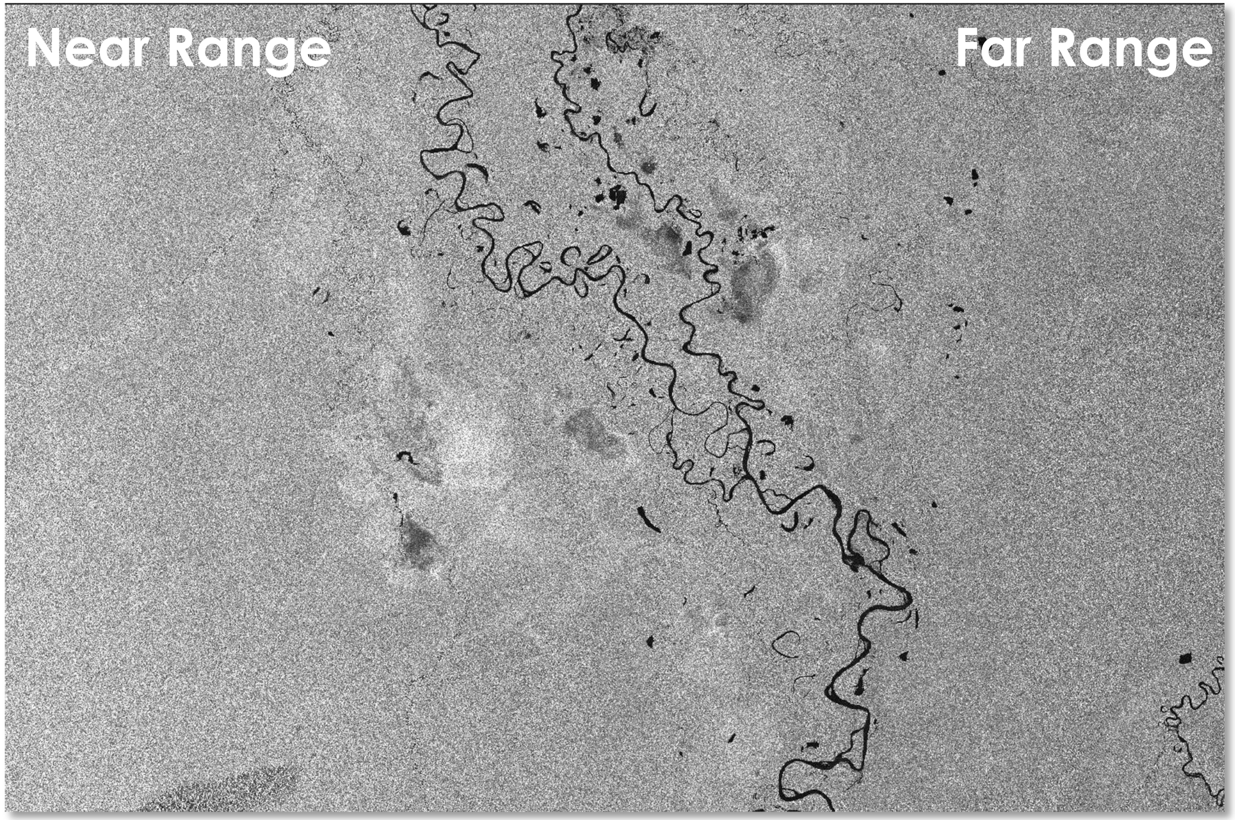
Local Incidence Angle:

- 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

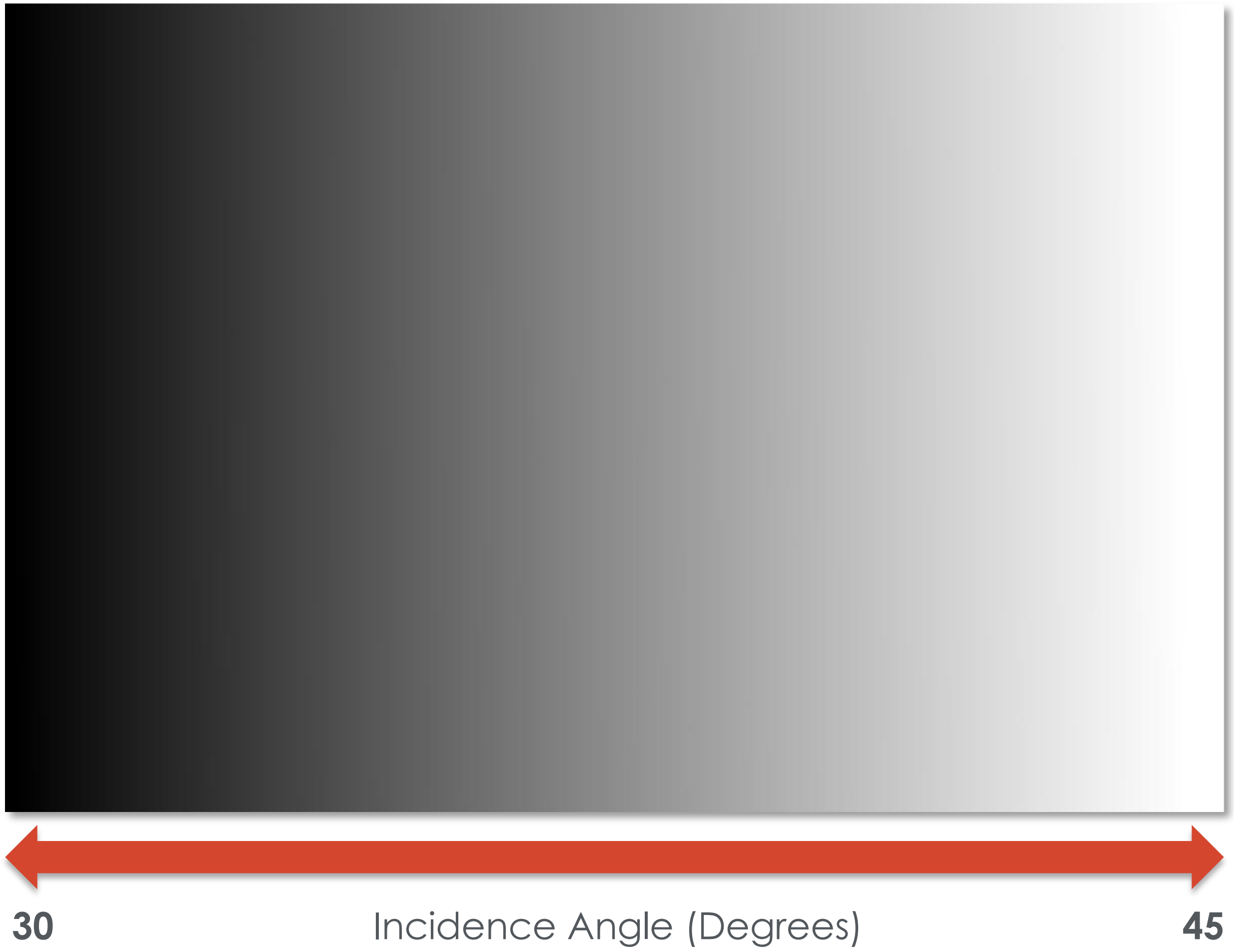


Images Based On: Top: Ulaby et al. (1981a), Bottom: ESA

Effect of Incidence Angle Variation



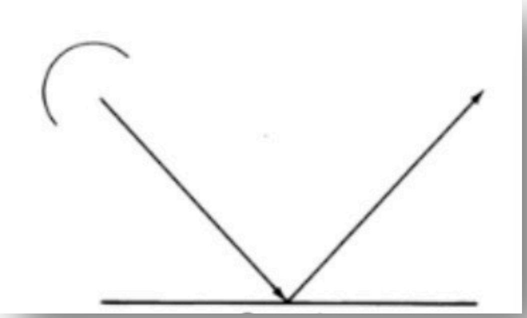
Sentinel-1



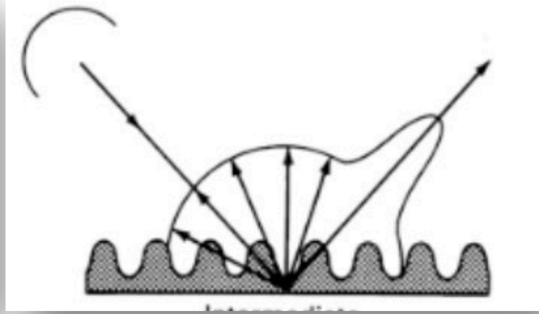
Radar Signal Interaction

- The scale of the surface relative to the wavelength determines how rough or smooth it appears and how bright or dark it will appear on the image.

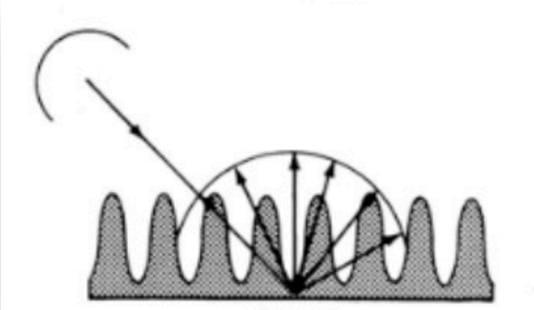
- **Backscattering Mechanisms:**



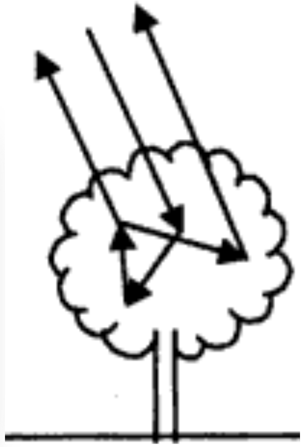
Smooth Surface



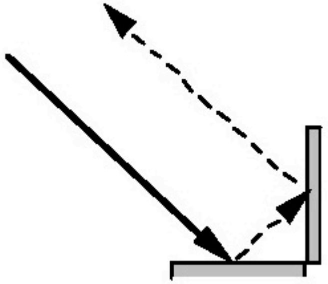
Rough Surface



Rougher Surface



Volume Scattering



Double Bounce

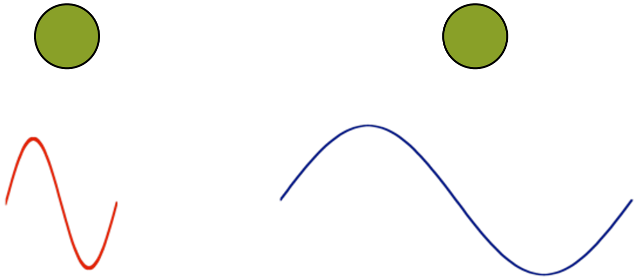
Parameters to Consider for a Land Cover Mapping Study

Radar Parameters:
- Wavelength
- Polarizations
- Incidence Angle

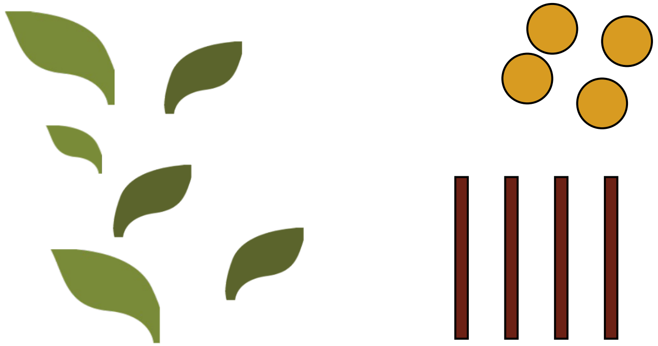
Surface Parameters:
- Structure
- Dielectric

Surface Parameters Related to Structure

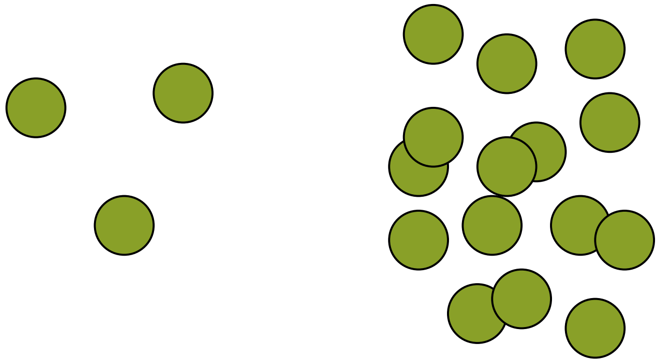
Size Relative to Wavelength



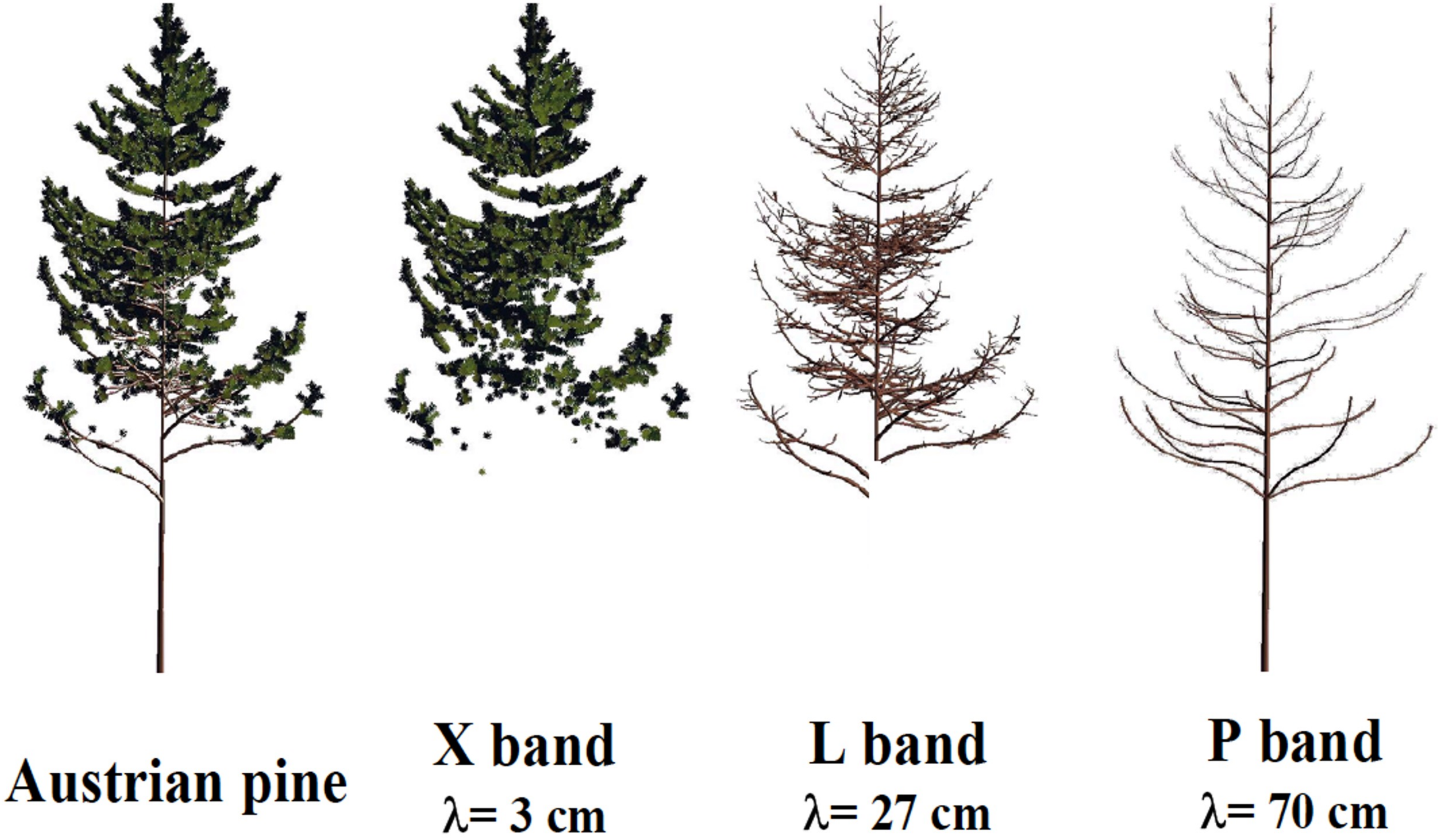
Size & Orientation



Density

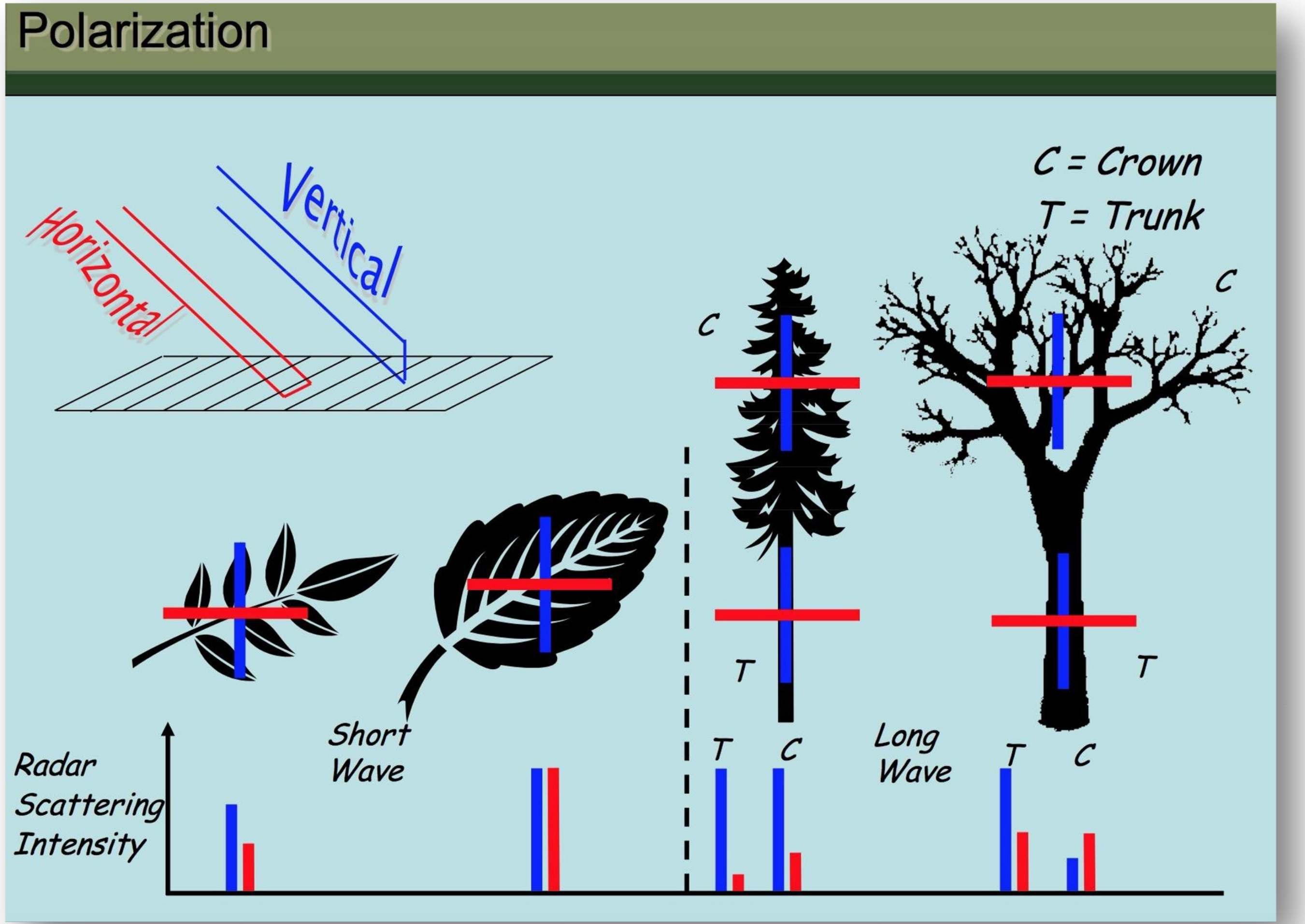


Size Relative to Wavelength



Source: Thuy le Toan

Size and Orientation



RELATIVE SCATTERING STRENGTH BY POLARIZATION:

Rough Surface Scattering	$\|S_{VV}\| > \|S_{HH}\| > \|S_{HV}\|$ or $\|S_{VH}\|$
Double Bounce Scattering	$\|S_{HH}\| > \|S_{VV}\| > \|S_{HV}\|$ or $\|S_{VH}\|$
Volume Scattering	Main source of $\|S_{HV}\|$ and $\|S_{VH}\|$

Source: SAR Handbook

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

Vegetation Density

The denser the vegetation, the less likely for the signal to penetrate through the canopy. This is a function of wavelength.

- Saturation Problem - The signal saturates at a certain biomass level, which is wavelength dependent.

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

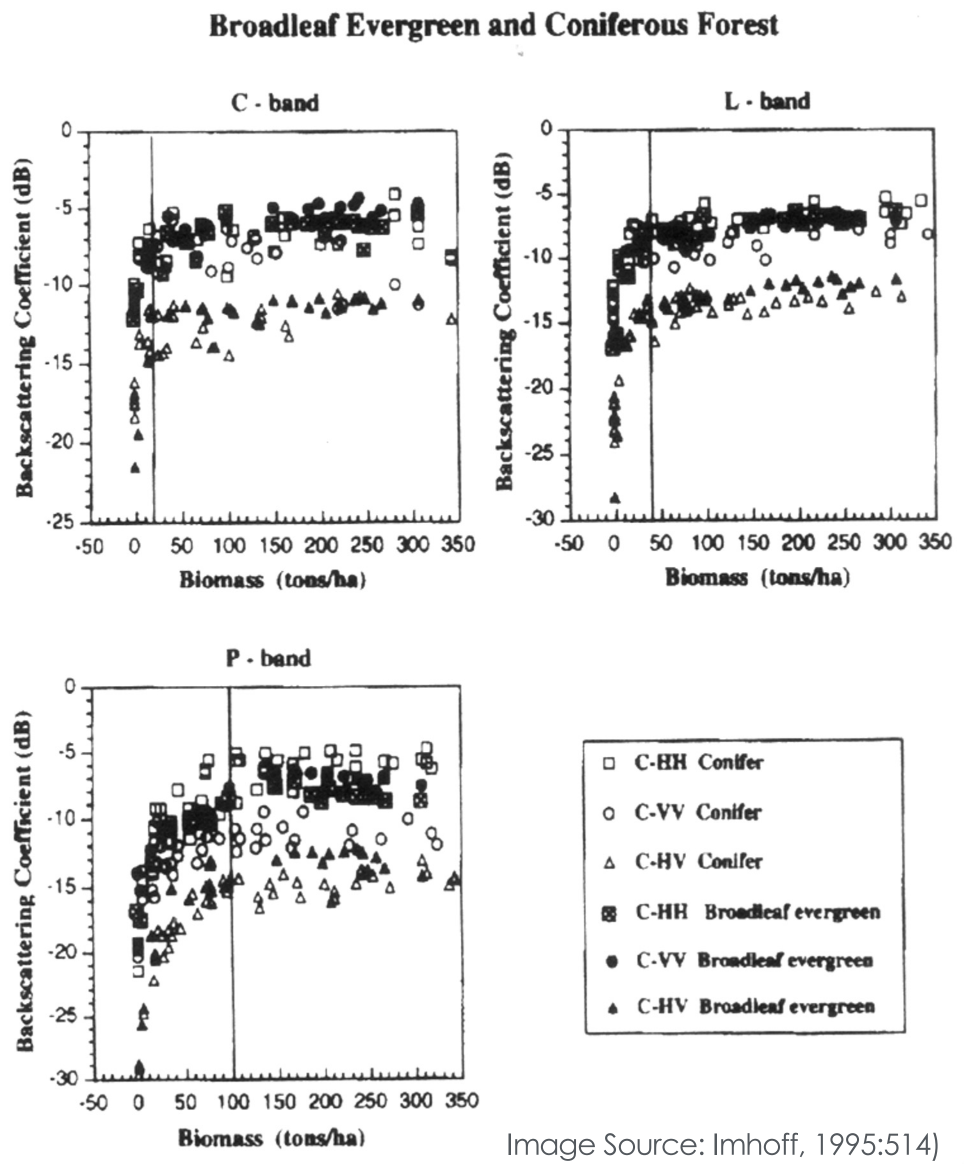
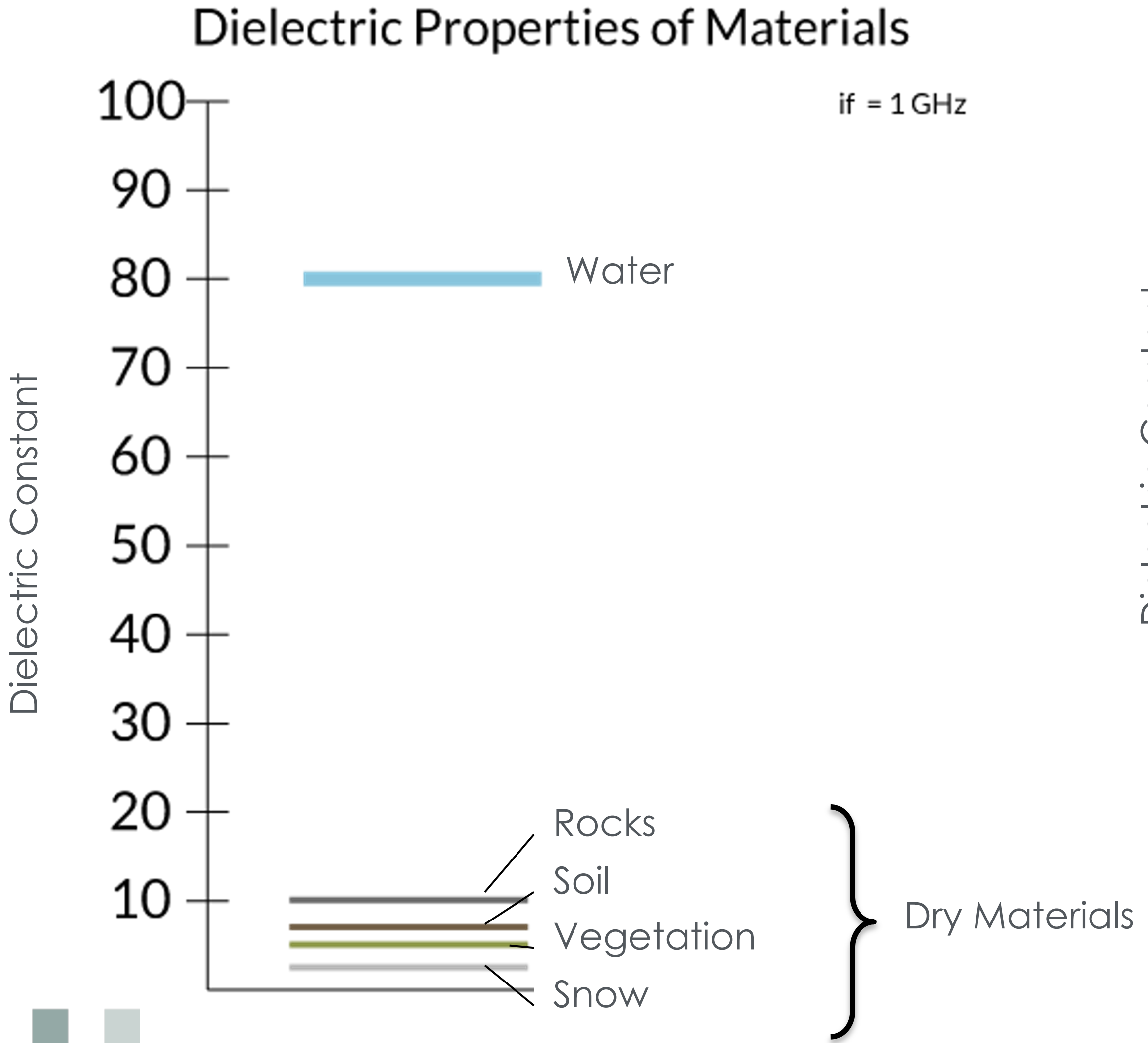
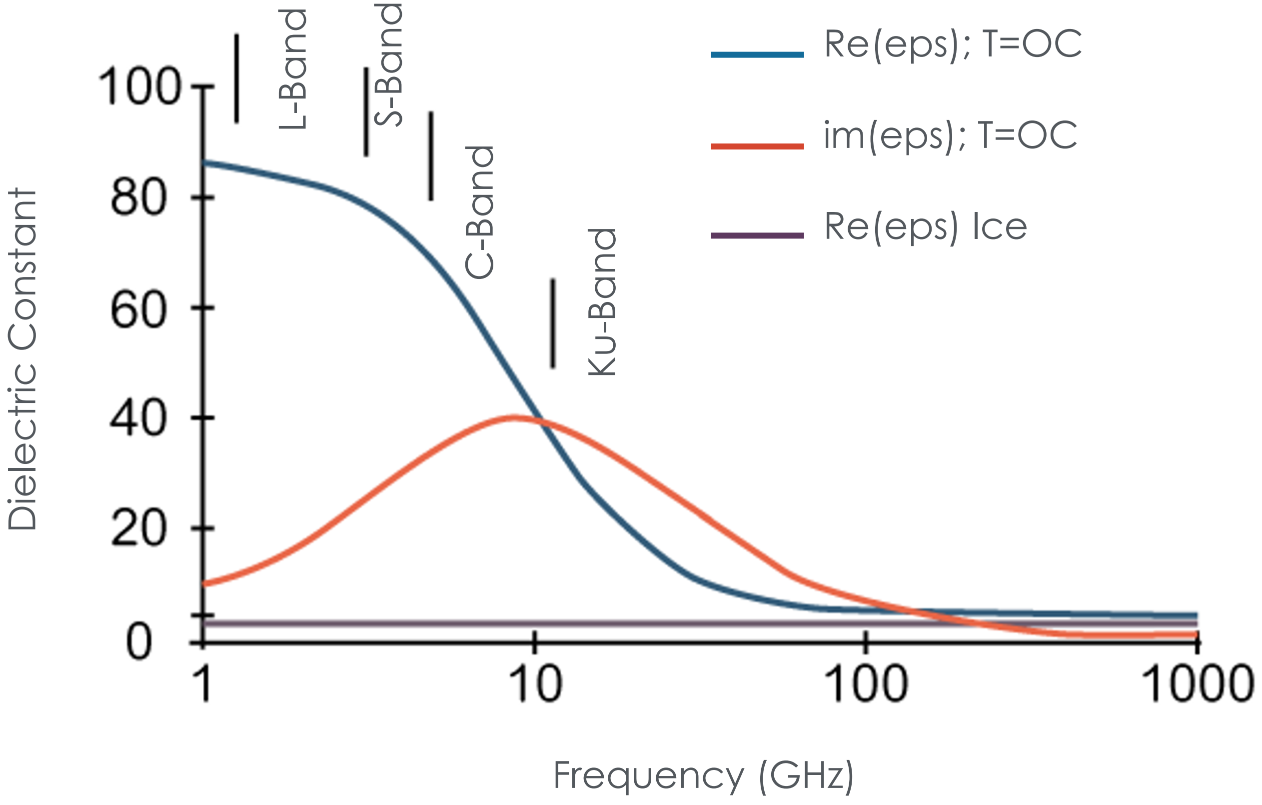


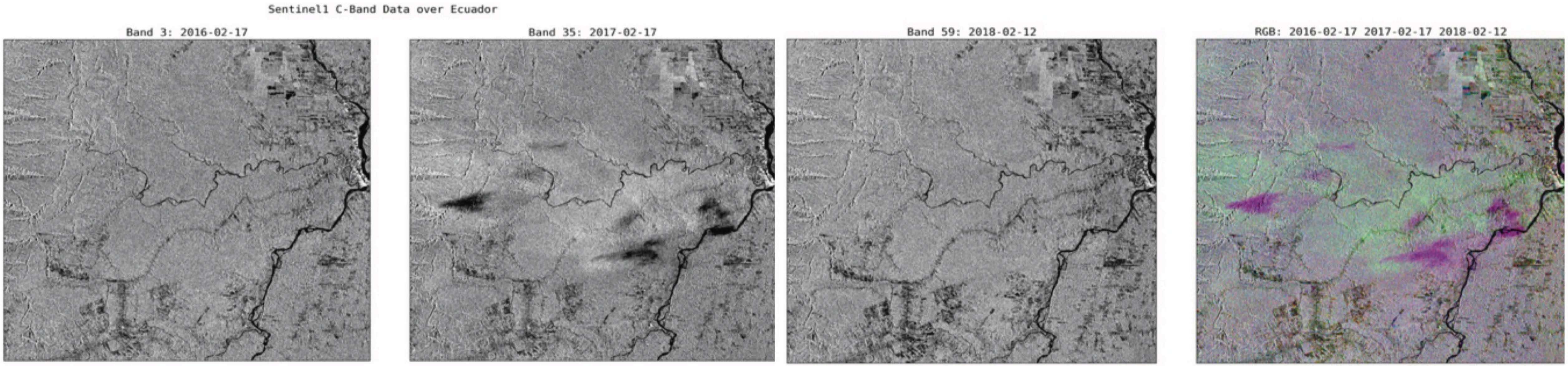
Image Source: Imhoff, 1995:514)

Surface Parameters: Dielectric Constant



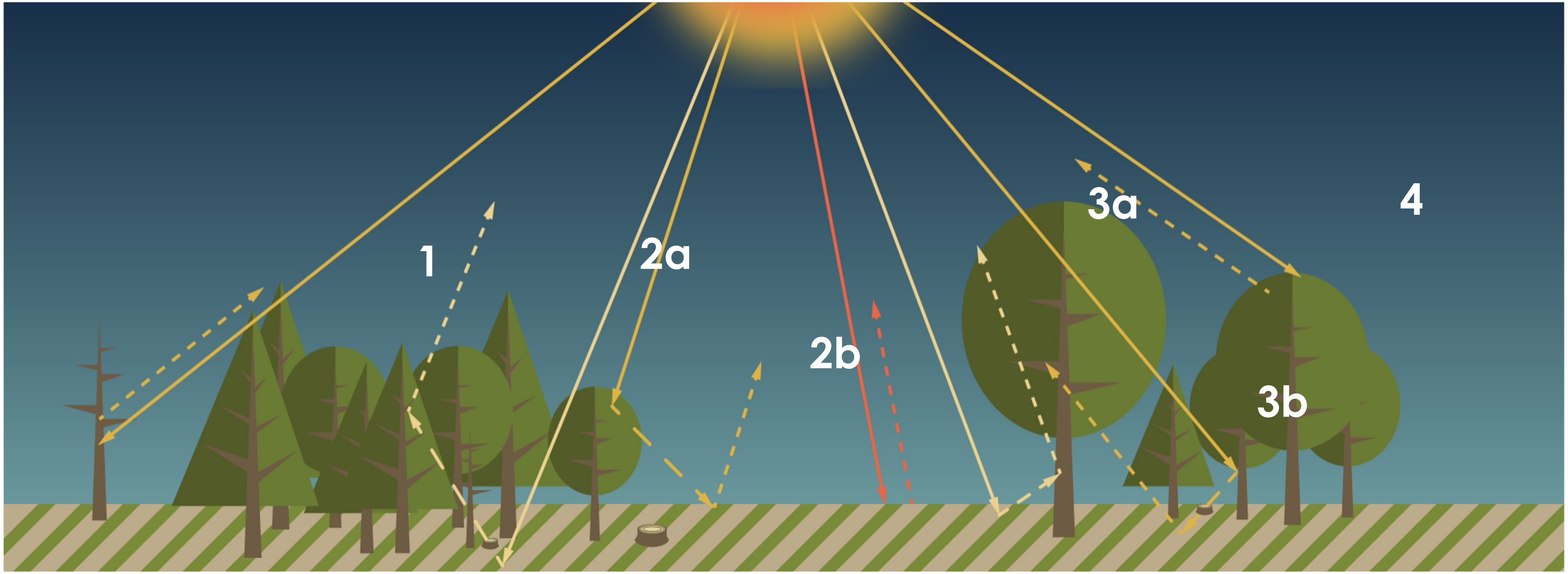


Rain Event and an Increase in Surface Moisture



Source: SAR Handbook, Chapter 2 by Josef Kellndorfer

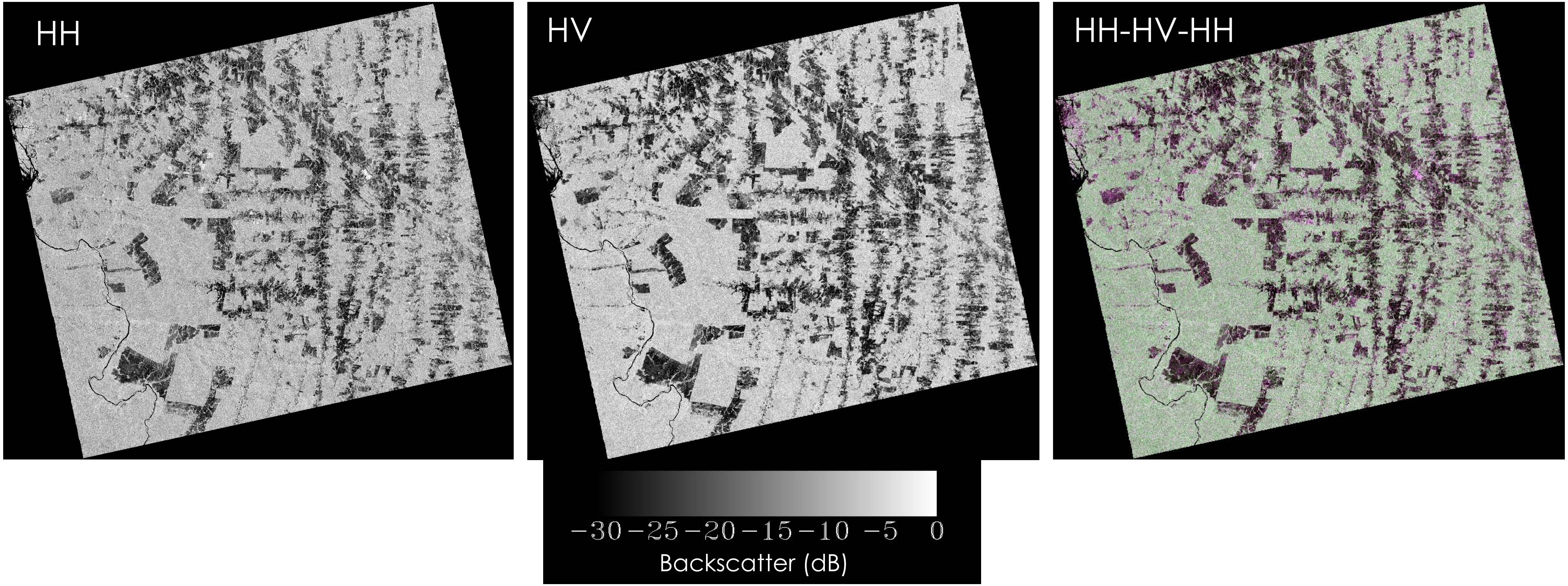
Radar Backscattering in Forests



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.

SAR Characteristics in Forested and Deforested Areas

ALOS PALSAR Near Altamira, Brazil; Dec. 12, 2010



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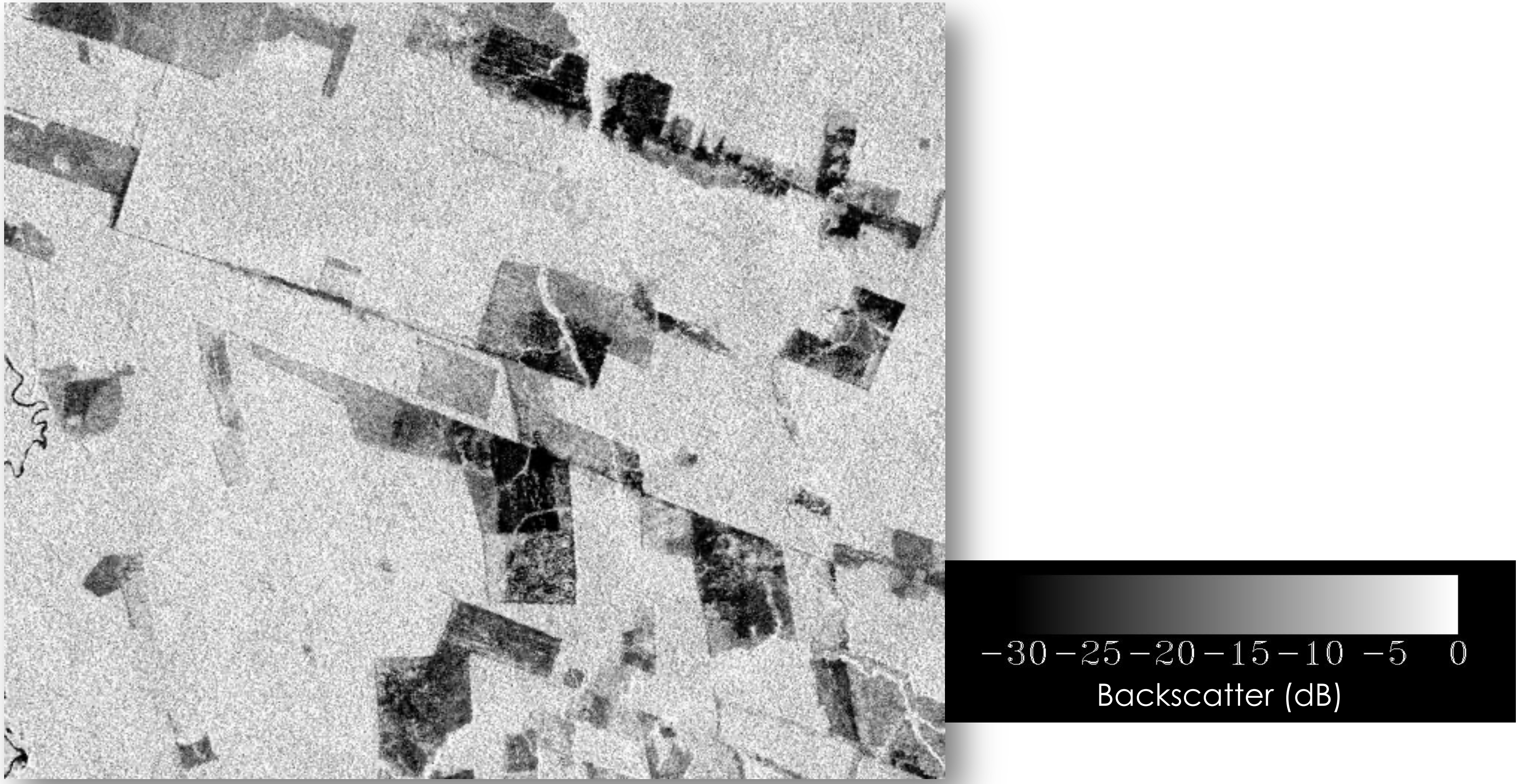
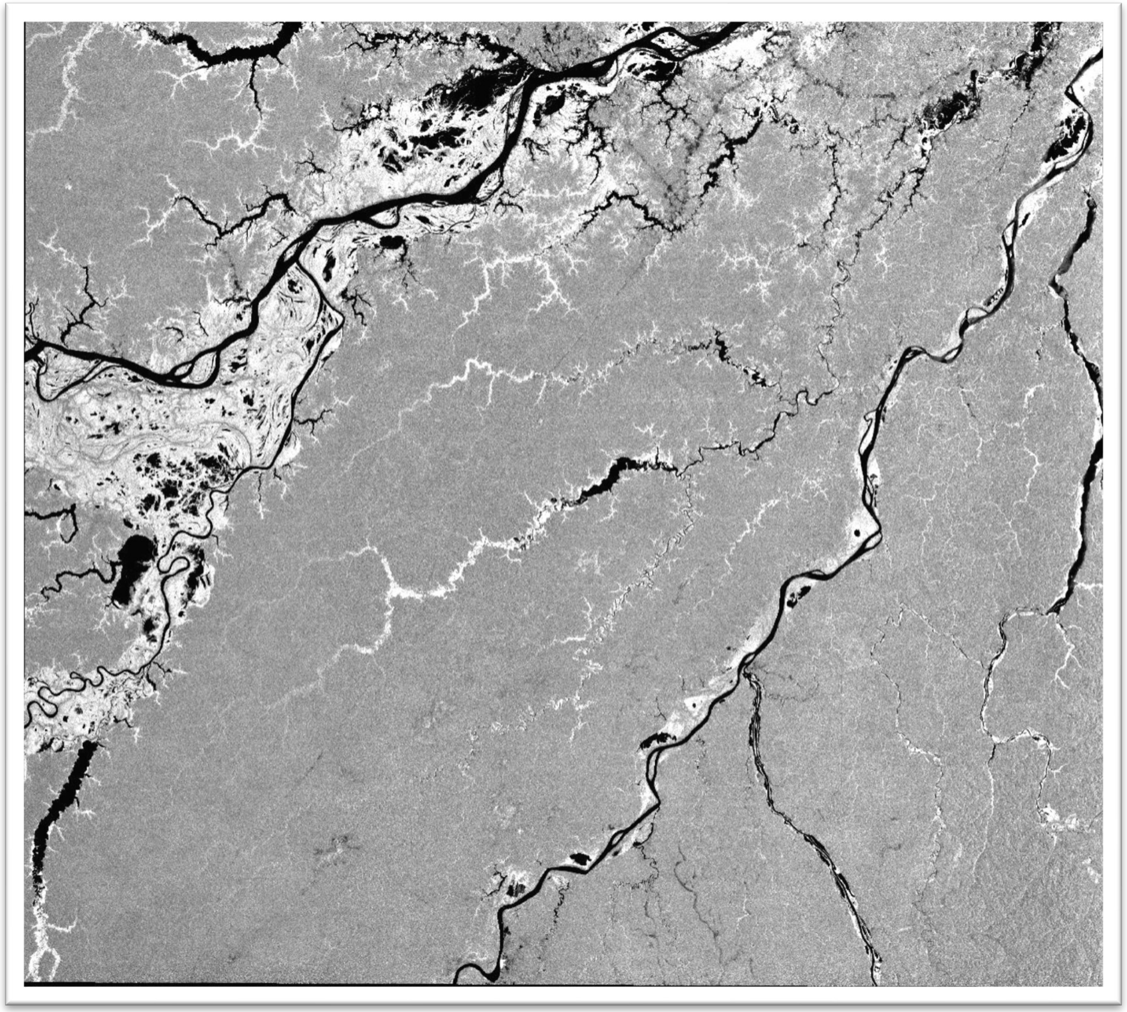


SAR Characteristics for Inundated Vegetation

PALSAR HV for Rondonia, Brazil



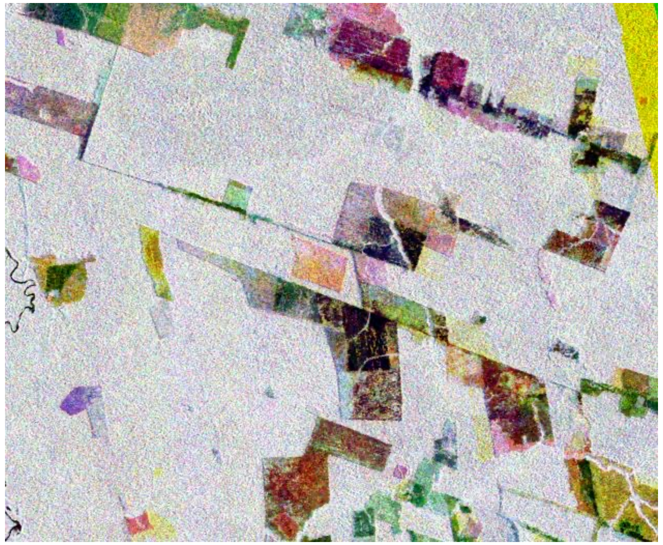
Expected Backscatter for Different Vegetation Scenarios

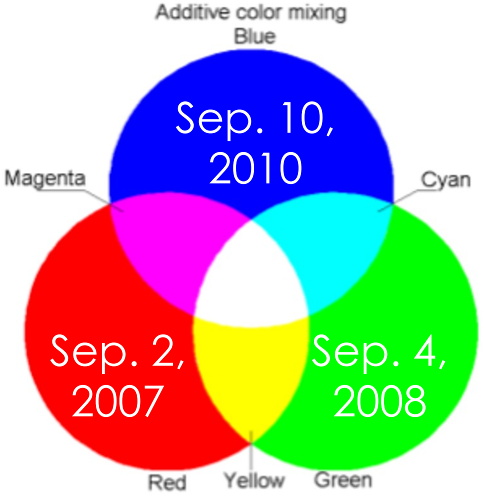
WAVELENGTH	POLARIZATION	RESPONSE BY FOREST TYPE					
		Sparse Forest (dry)	Sparse Forest (flooded)	Degraded Forest (dry)	Degraded Forest (flooded)	Dense Forest (dry)	Dense Forest (flooded)
C-band backscatter (g0)	VV	Medium to high; Depending on the roughness of the forest floor and moisture, there is 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

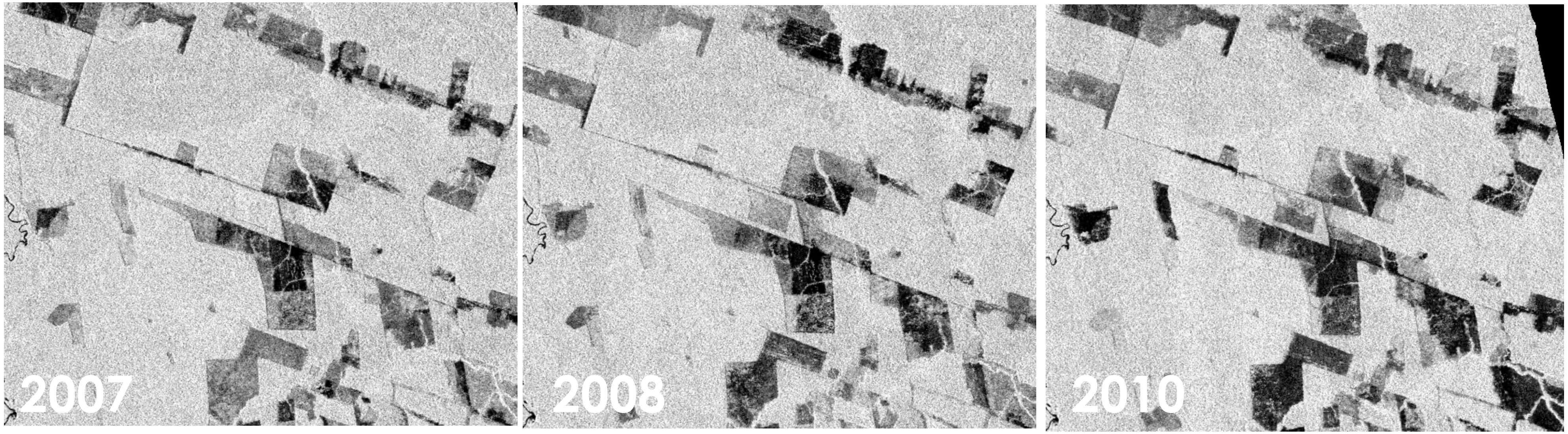
Source: SAR Handbook, Chapter 2 by Josef Kellndorfer

Example of Multiple Dates for Vegetation Studies

PALSAR HV Multi-Temporal RGB for Rondonia, Brazil

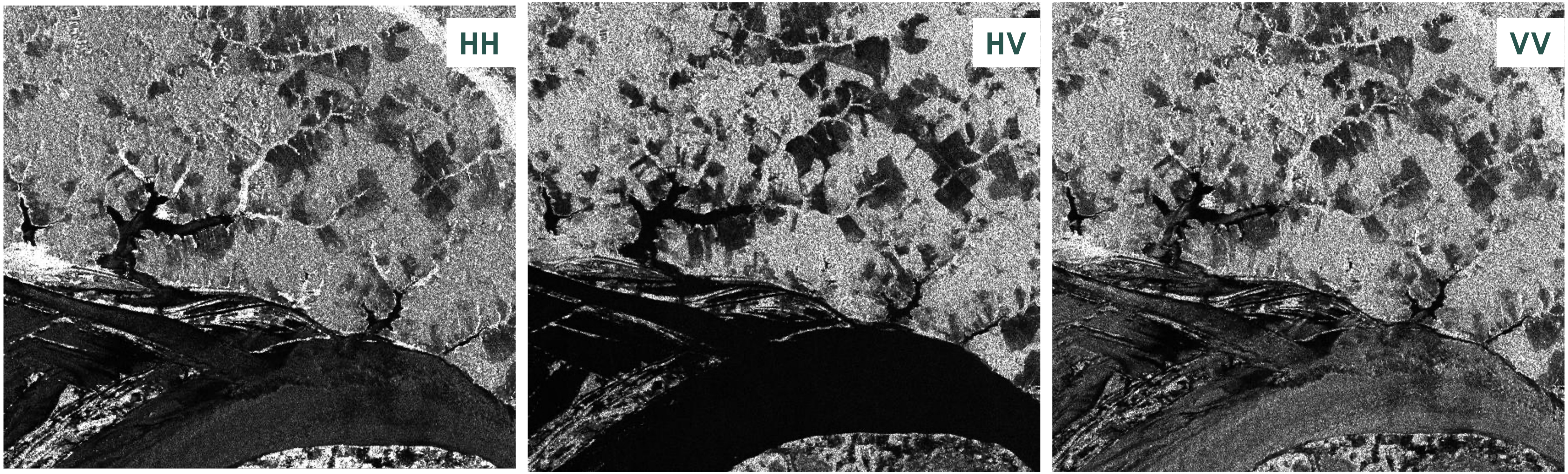






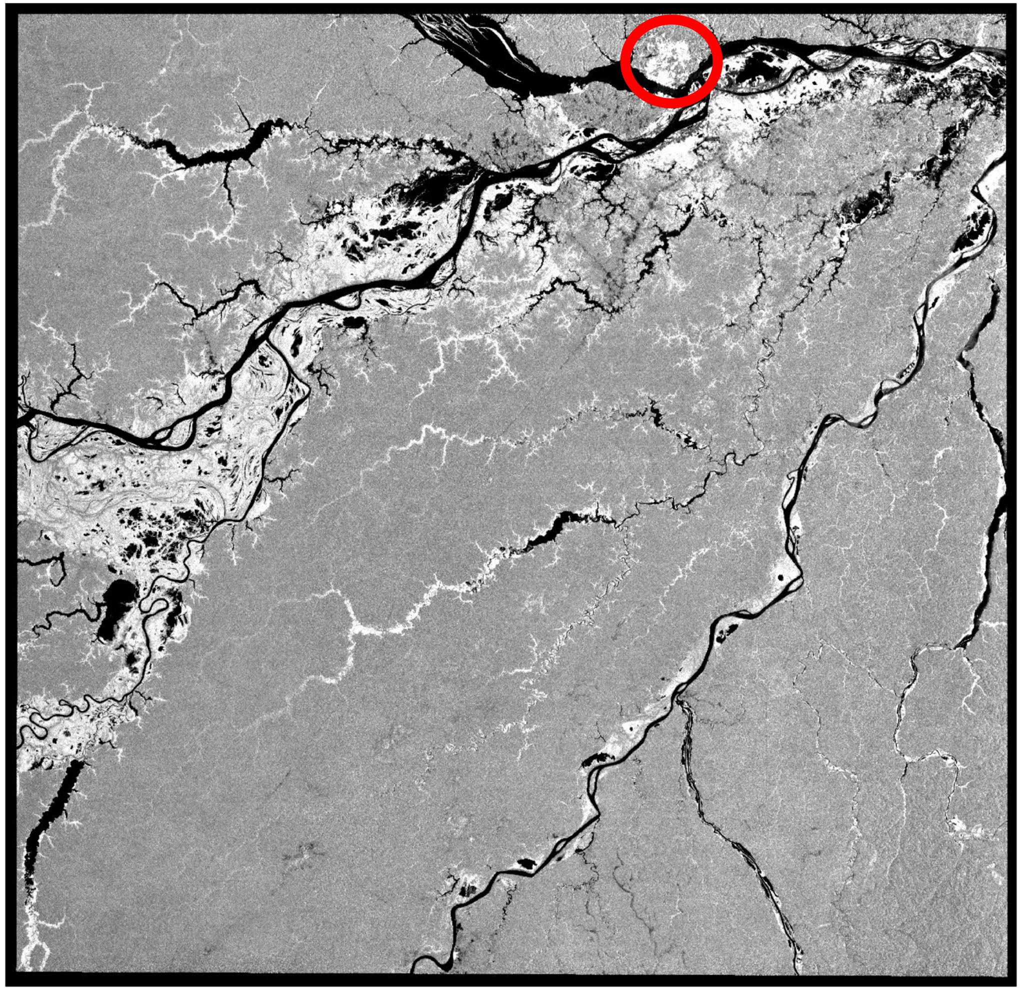
Source of Confusion: Open Water and Low Vegetation

Images from PALSAR (L-Band) Near Manaus, Brazil

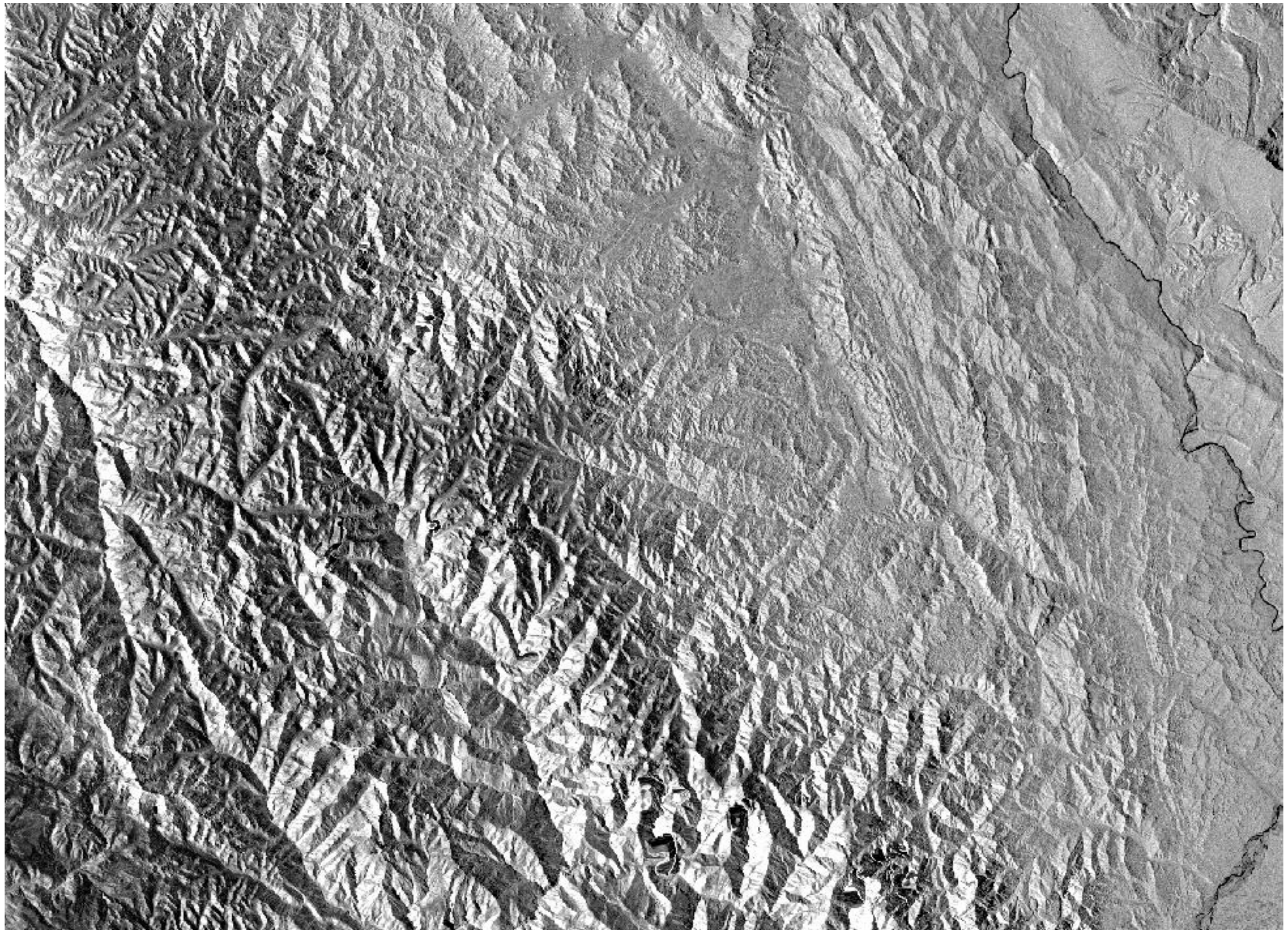


Source of Confusion: Urban Areas and Flooded Areas

Images from PALSAR (L-Band) Near Manaus, Brazil



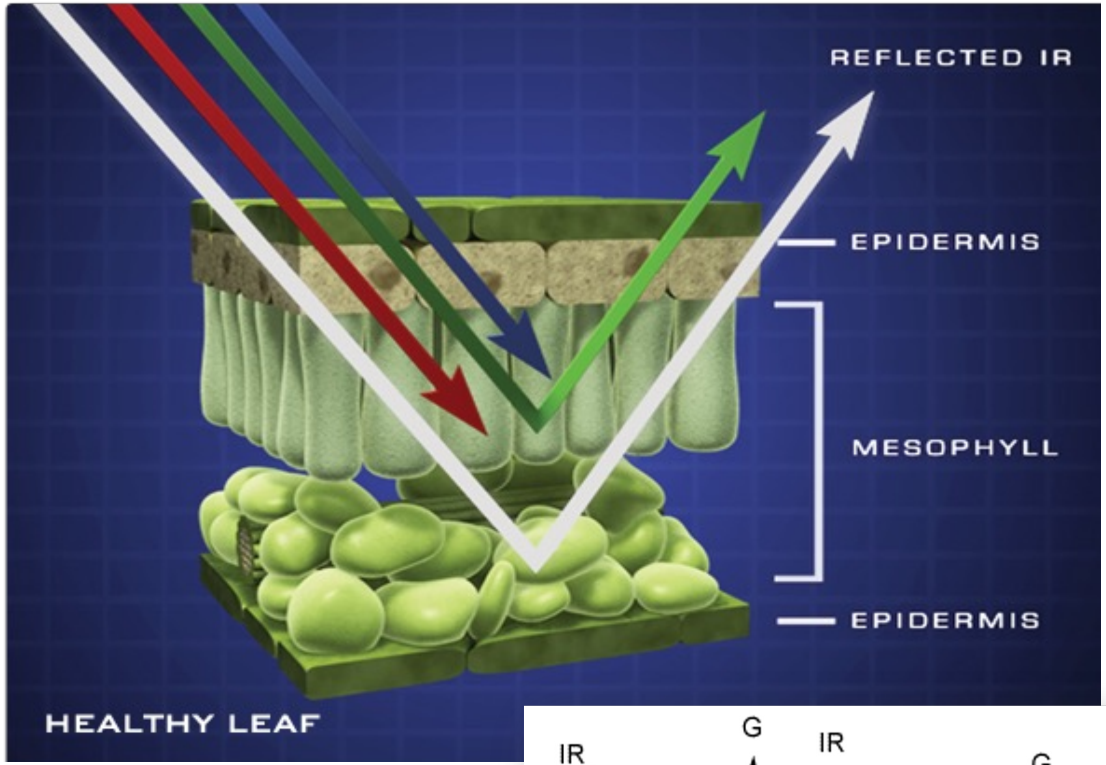
Source of Confusion: Topography and Inundated Vegetation



Land Cover Mapping with Optical Data

Spectral Signatures

- Every surface on Earth reflects and absorbs energy in different ways.
- Spectral signature is the unique way a surface reflects energy.
- We typically characterize spectral signatures in a graph:
  - Percent reflectance on the y-axis
  - Wavelength on the x-axis
- Example: Healthy, green vegetation **absorbs Blue and Red** wavelengths (used by chlorophyll for photosynthesis) and **reflects Green and Infrared**.



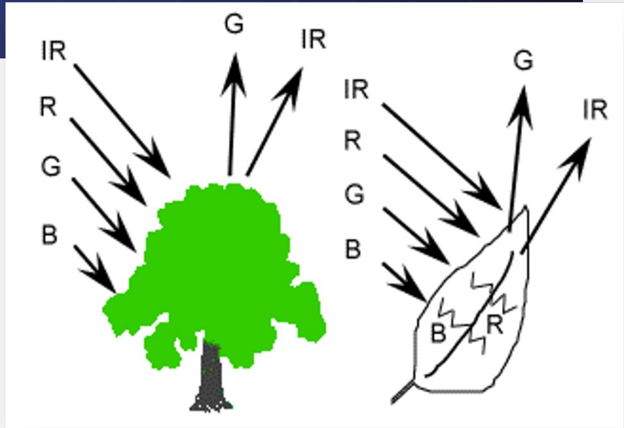
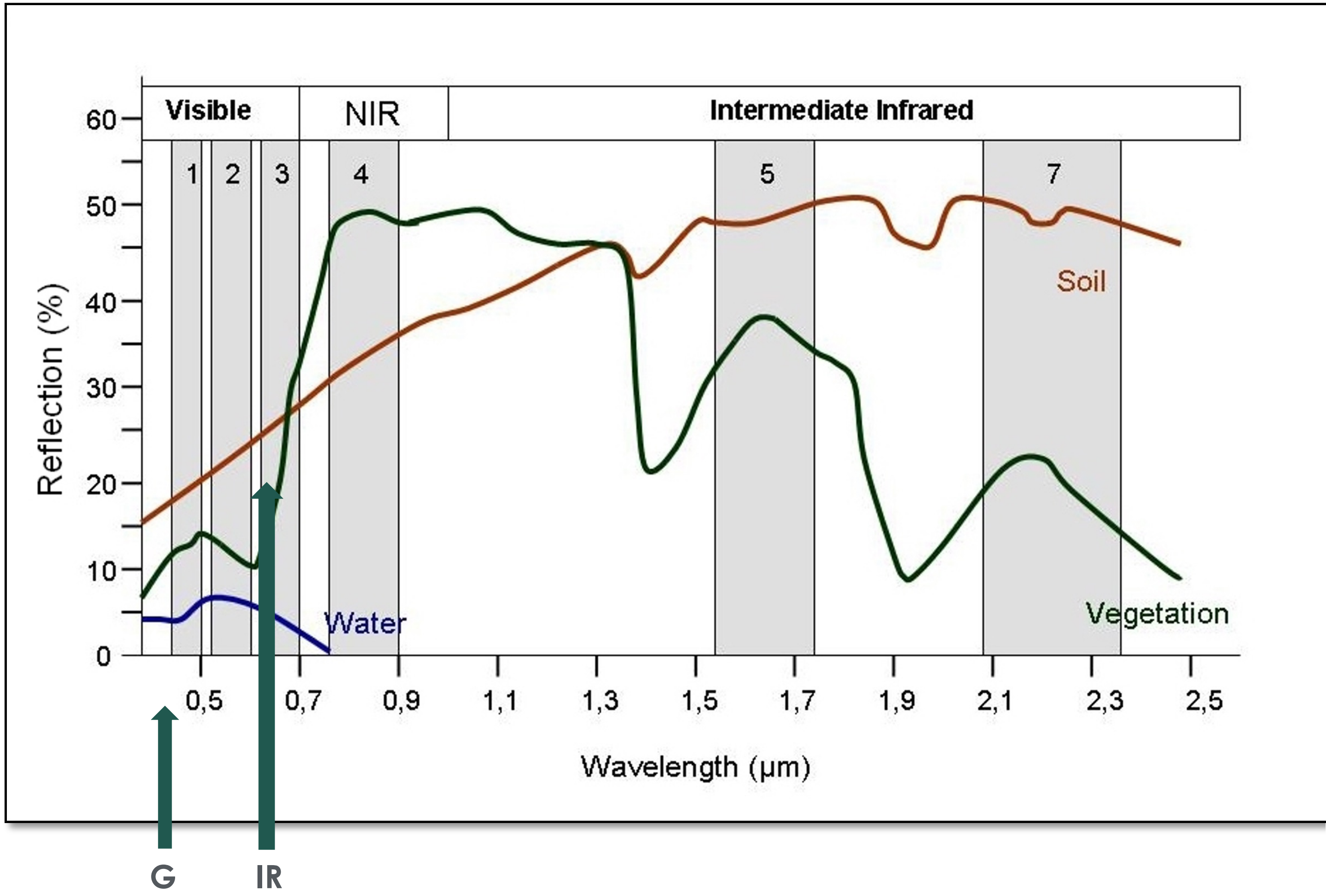


Image Credits: NASA/Jeff Carns & Ginger Butcher

Spectral Signatures

- Different surfaces have different spectral signatures.
- In this example you can see the differences between Water, Vegetation, and Soil signatures.



How Optical Satellites Collect Data

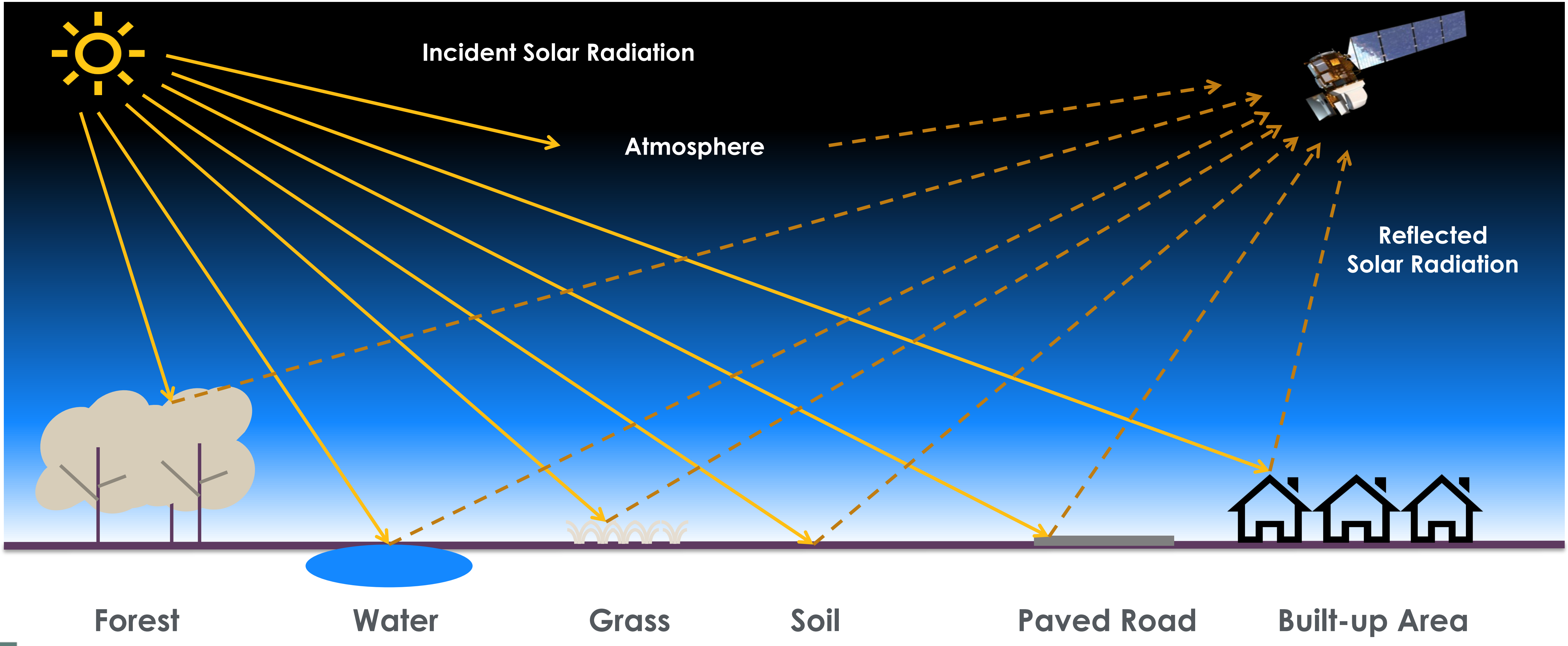
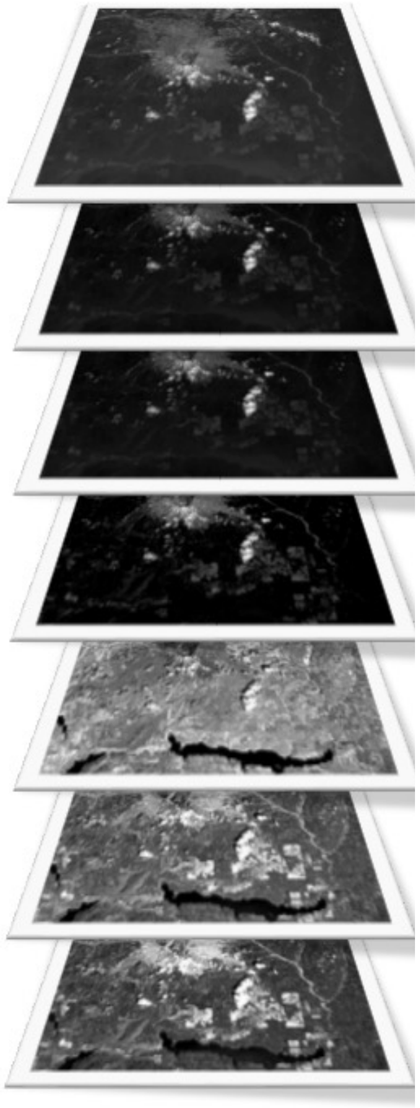


*Image Recreated from Natural Resources Canada image.

Image Bands vs. Color Channels

Band 1
Band 2
Band 3
Band 4
Band 5
Band 6
Band 7

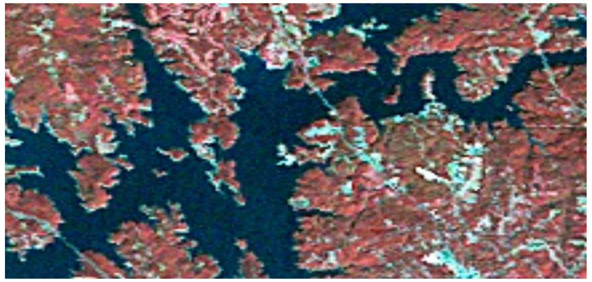


Red Channel	Green Channel	Blue Channel
Red Band	Green Band	Blue Band

True Color

Red Channel	Green Channel	Blue Channel
Near-Infrared Band	Red Band	Green Band

False Color



Red Channel	Green Channel	Blue Channel
Mid-Infrared Band	Near Infrared Band	Green Band

SW Infrared (Vegetation Contrast)

Turning Data Into Information

Optical Image Classification

Spectral Classes

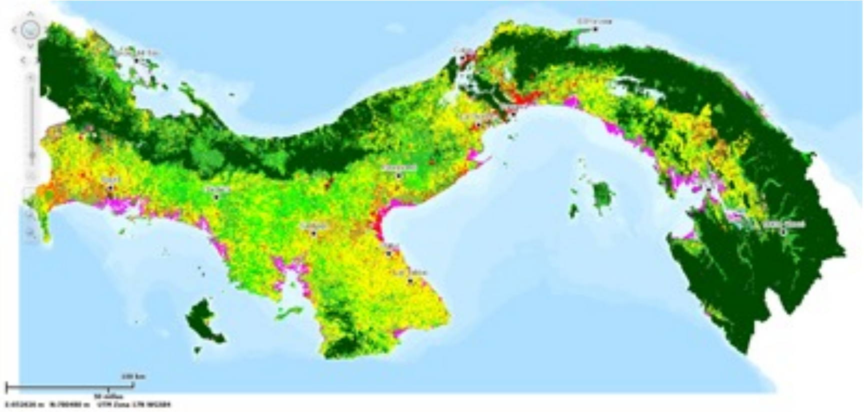
- Groups of pixels that are uniform with respect to their pixel values in several spectral bands.

Informational Classes

- Categories of interest to users of the data (i.e., water, forest, urban, agriculture, etc.).

Image classification is the process of grouping spectral classes and assigning them informational class names.

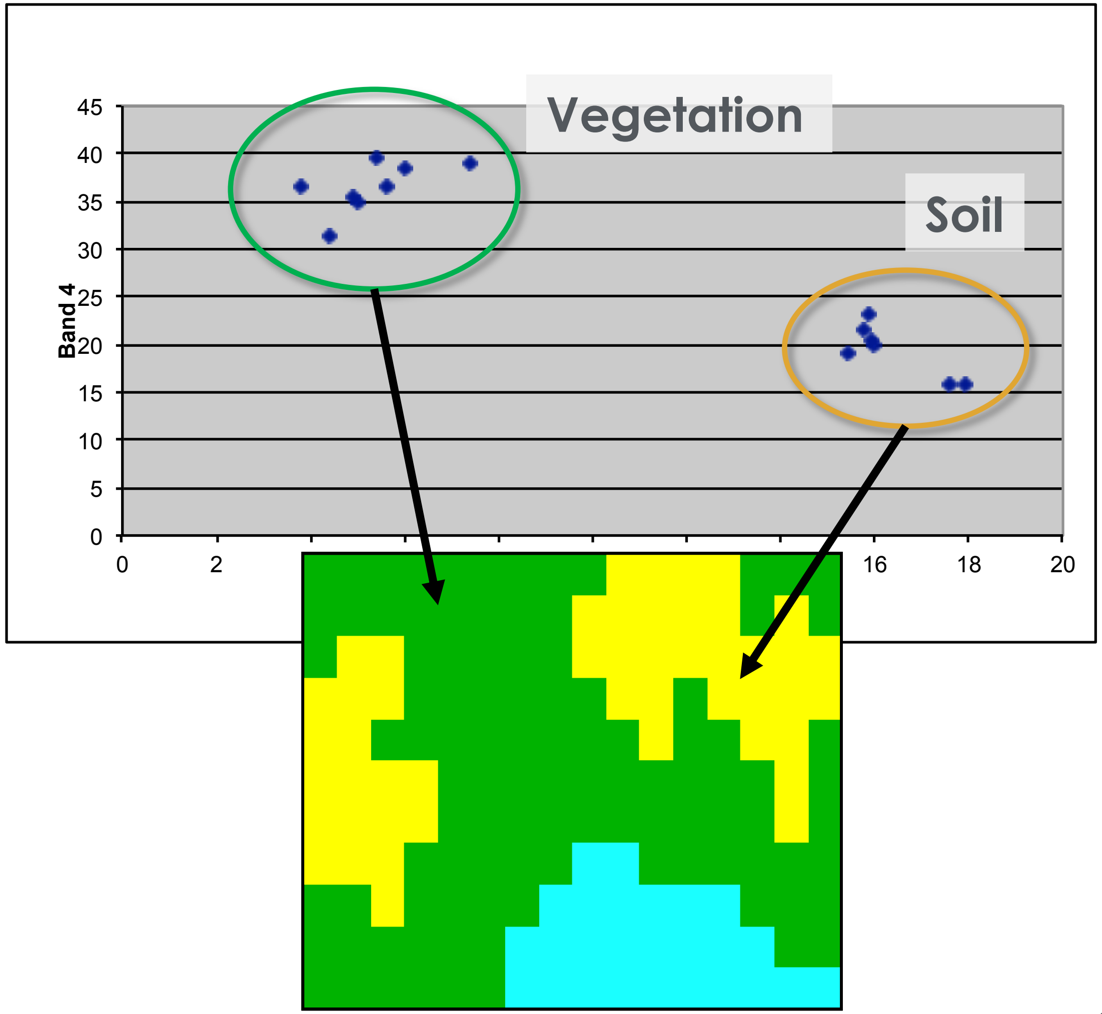
Satellite image of Panama



Land Cover Map of Panama

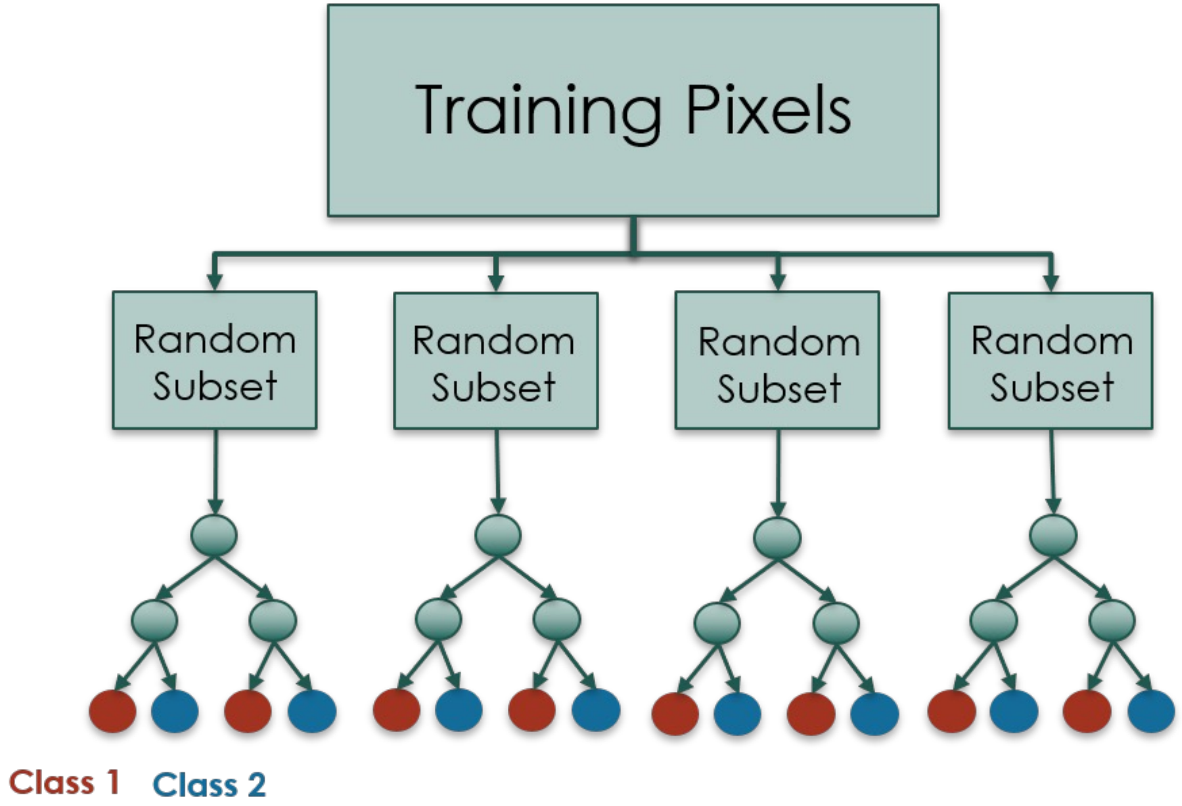
Optical Image Classification

- Requires delineating boundaries of classes in n-dimensional space using class statistics.
- Each group of pixels is characterized by:
  - **Min.**
  - **Max.**
  - **Mean**
  - **Standard Deviation**
- All the pixels in the image that fall within those statistics are given those labels.
- **Supervised** or **Unsupervised**



Random Forest Classification Algorithm

- Example of an ensemble model (combines the results from multiple models; logic → result from a combination will be better than from a single model)
- Supervised Learning
- Random Forest Algorithm takes a random set of training sites (~2/3) and builds multiple decision (classification) trees; remaining ~1/3 training sites used to estimate error and importance of each predictor variable



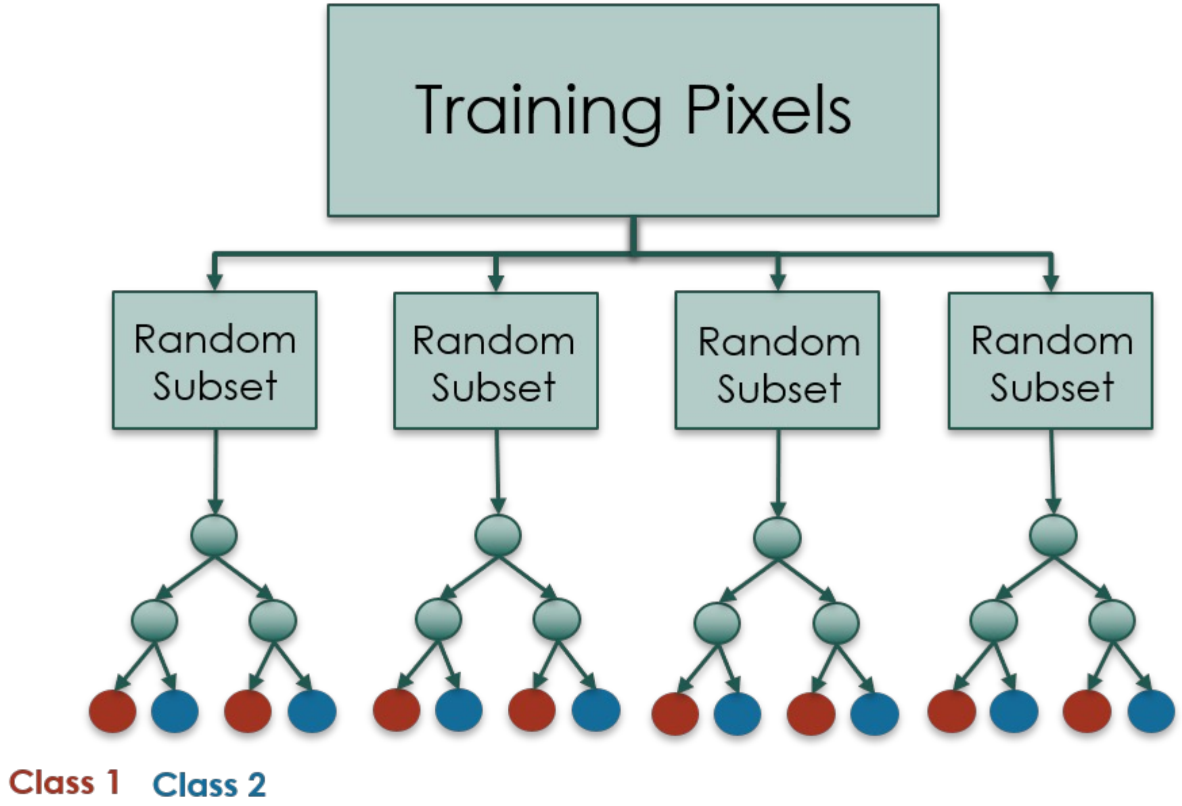
Random Forest Classification Algorithm

Advantages

- No need for pruning
- Overfitting is not a problem
- Not sensitive to outliers in training data
- Easy to parameterize

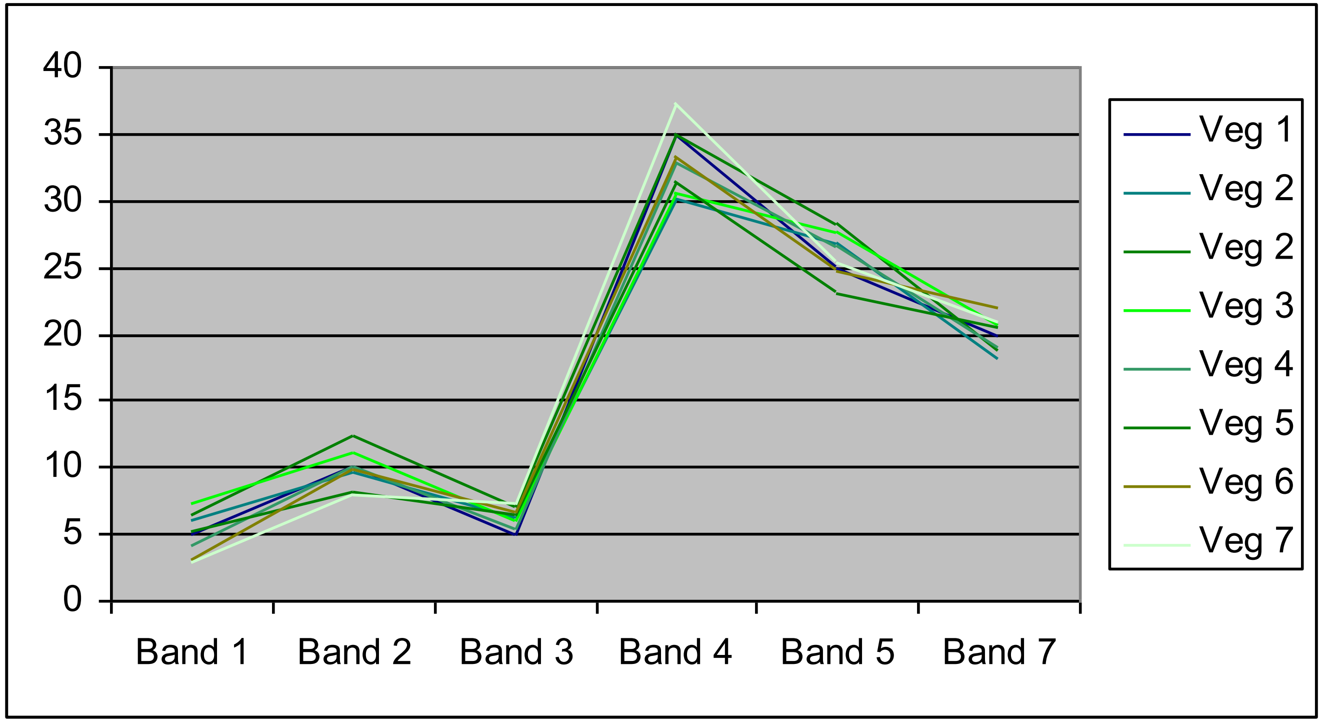
Limitations

- Algorithm cannot predict spectral range beyond training data
- Training data must capture entire spectral range



Limitations of Optical Data

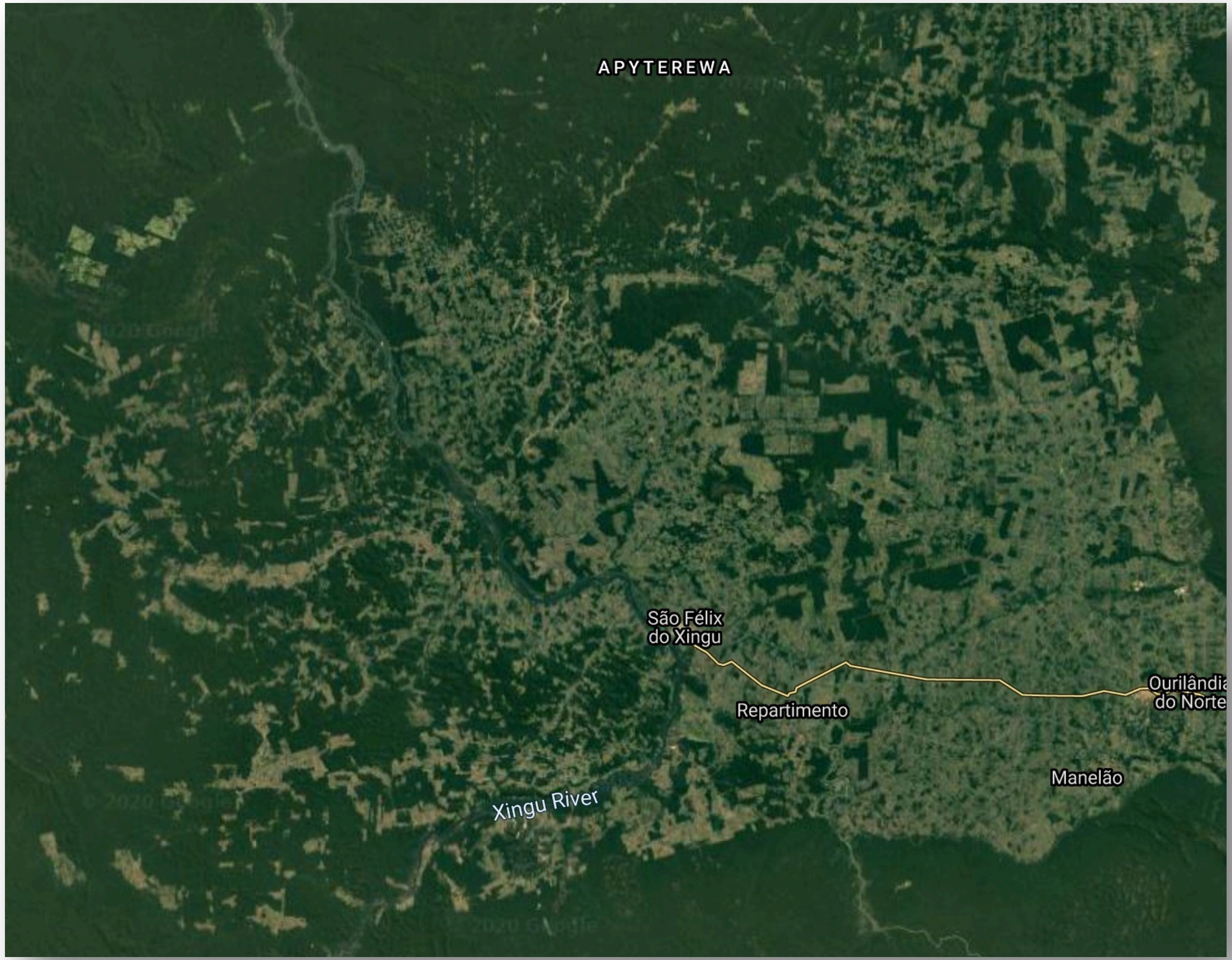
- Spatial resolution is often too coarse (for NASA data) to provide high level of detail on the ground.
- Spectral resolution is often too coarse to distinguish between different vegetation types.
- Does not penetrate clouds and smoke.
- Cannot penetrate forest canopy.



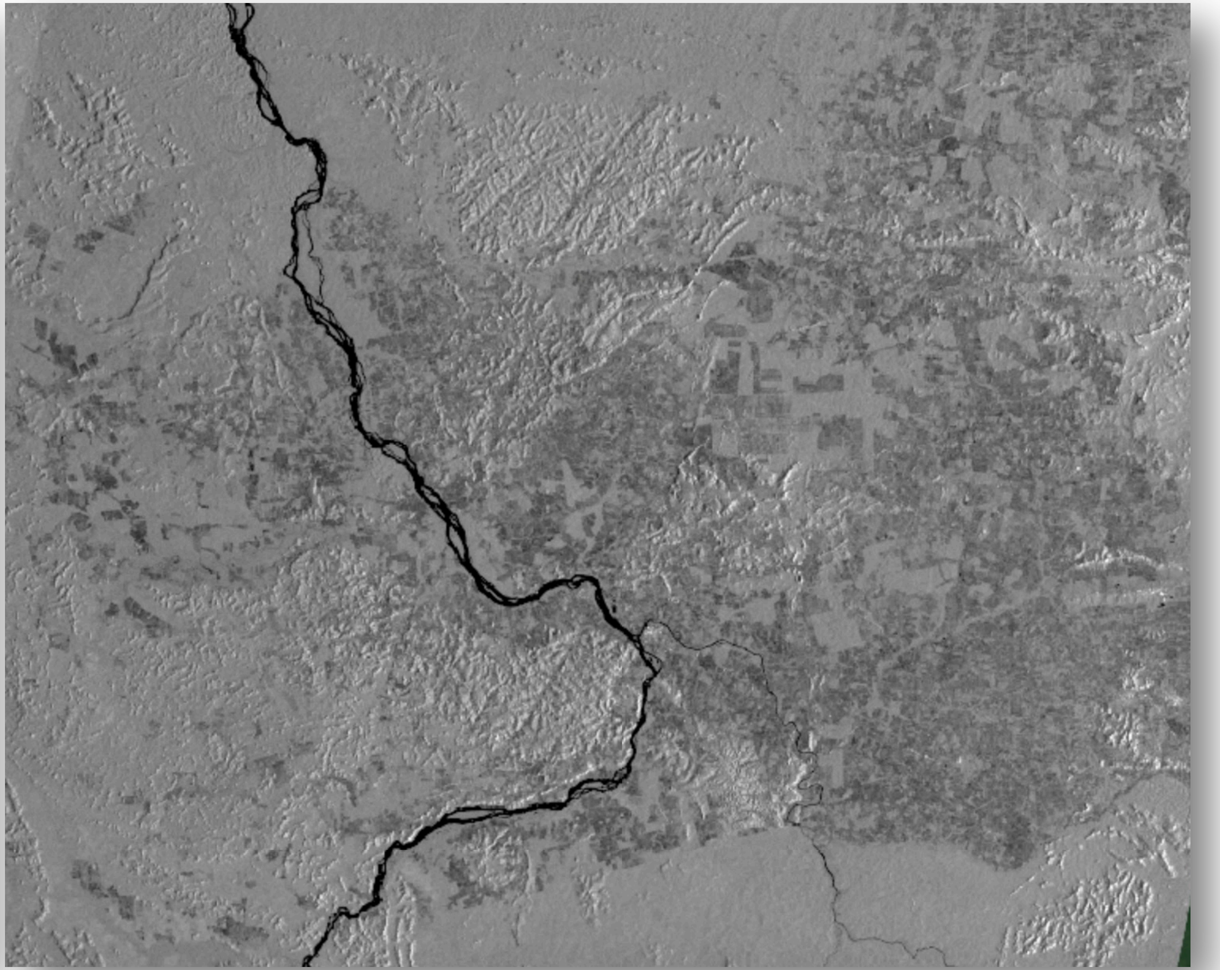
Example of the Spectral Similarities Among Different Vegetation Types

Optical vs. Radar Data Overview

Forest Monitoring with Optical and Radar Data



Landsat (Optical)



Sentinel-1 (SAR)

Land Cover Mapping: Optical vs. Radar

Radar

- Microwave energy scattered by vegetation depends on the structure and moisture/water content of the target.
- Radar data usually consists of 1-2 bands of data.
- The signal can penetrate through the canopy, providing information on soil conditions or inundation state.

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.

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

Advantages and Disadvantages of Radar Over Optical Remote Sensing

Radar Disadvantages

- Information content is different than optical/sometimes difficult to interpret
- Speckle effects (graininess in the image)
- Topographic differences introduce distortions in data

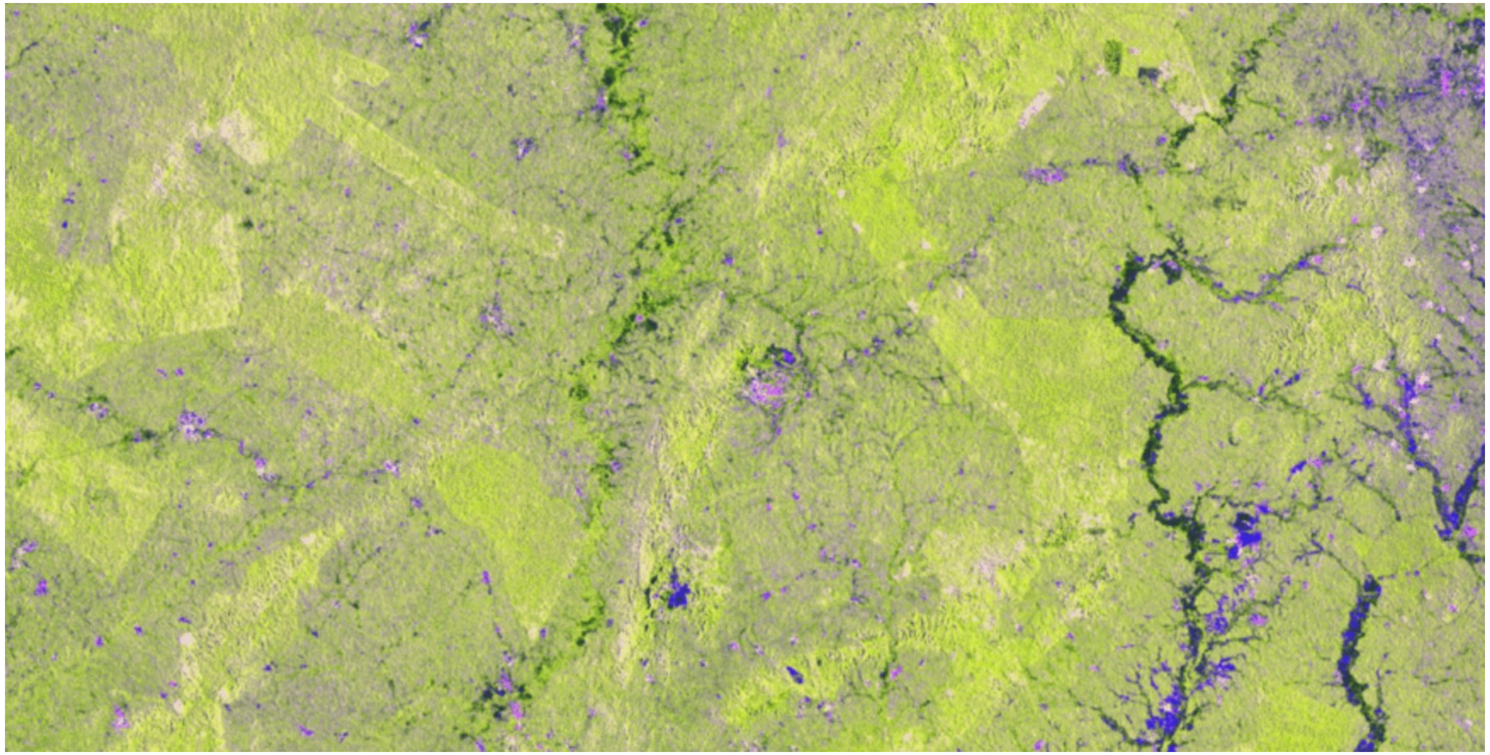
Radar Advantages

- Nearly all-weather capability
- Day or night capability
- Penetration through vegetation canopy
- Penetration through soil
- Minimal atmospheric effects
- Sensitivity to moisture/water content of land surface
- Sensitivity to structure

Applications of Radar for Land Cover

Mapping and Monitoring:

- Forests
- Wetlands
- Biomass
- Disturbances
  - Wildfire
  - Selective Logging
  - Deforestation
  - Reforestation



Identification of vegetation change using Sentinel-1 radar imagery in Ghana.
Image Credit: Satelligence

Benefits to Using Both Radar and Optical Data

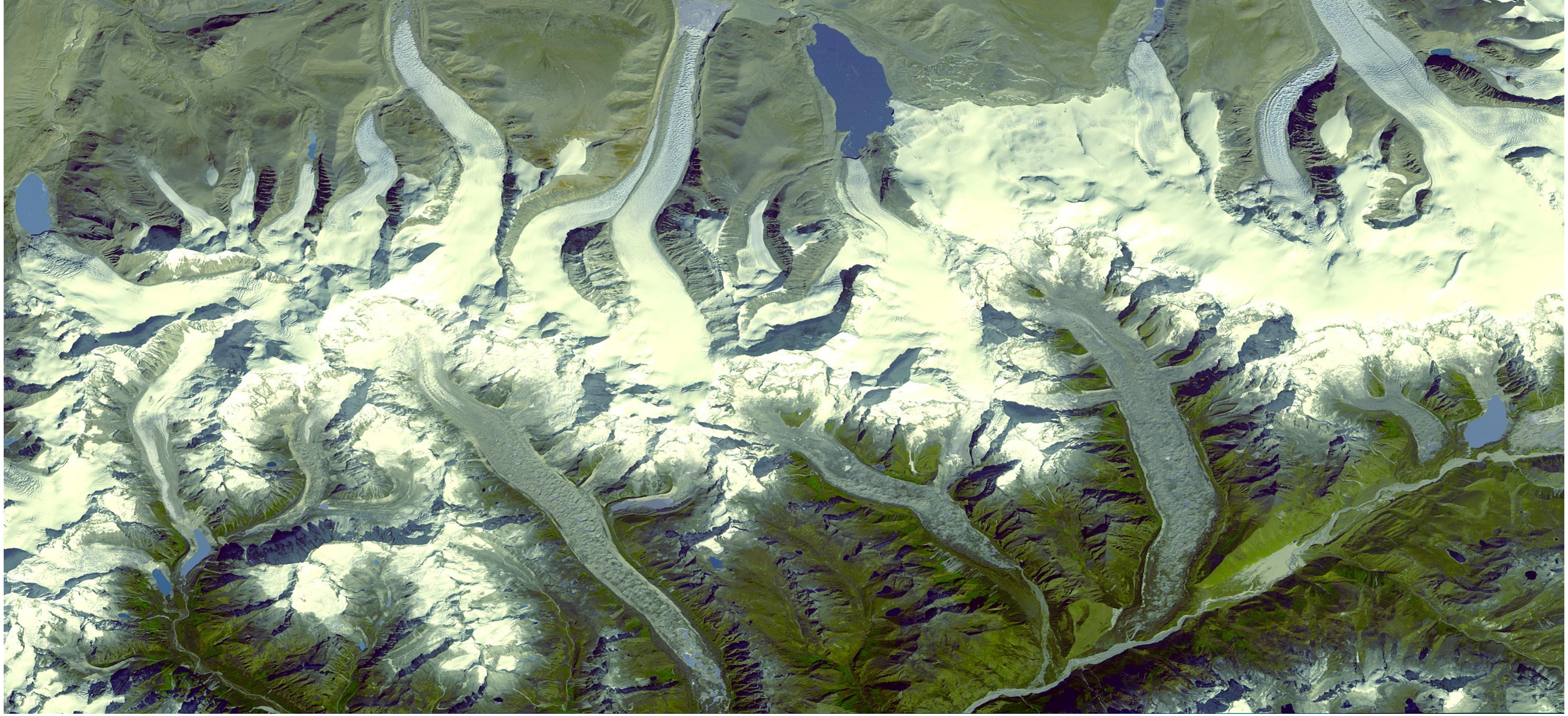
- Improved land cover classification

- Ability to provide more detailed characterization of land changes
  - Broad classes of land cover and change (optical)
  - Land surface roughness and soil moisture (radar)

- Ability to more accurately monitor vegetation health for agricultural purposes, forest disturbances, and land degradation
  - NDVI and/or EVI (optical)
  - Plant structure and volume (radar)

Demonstration:

Create a Land Cover Map with Radar and Optical Data using GEE



Demonstration:

Create a Land Cover Map with Radar and Optical Data Using GEE