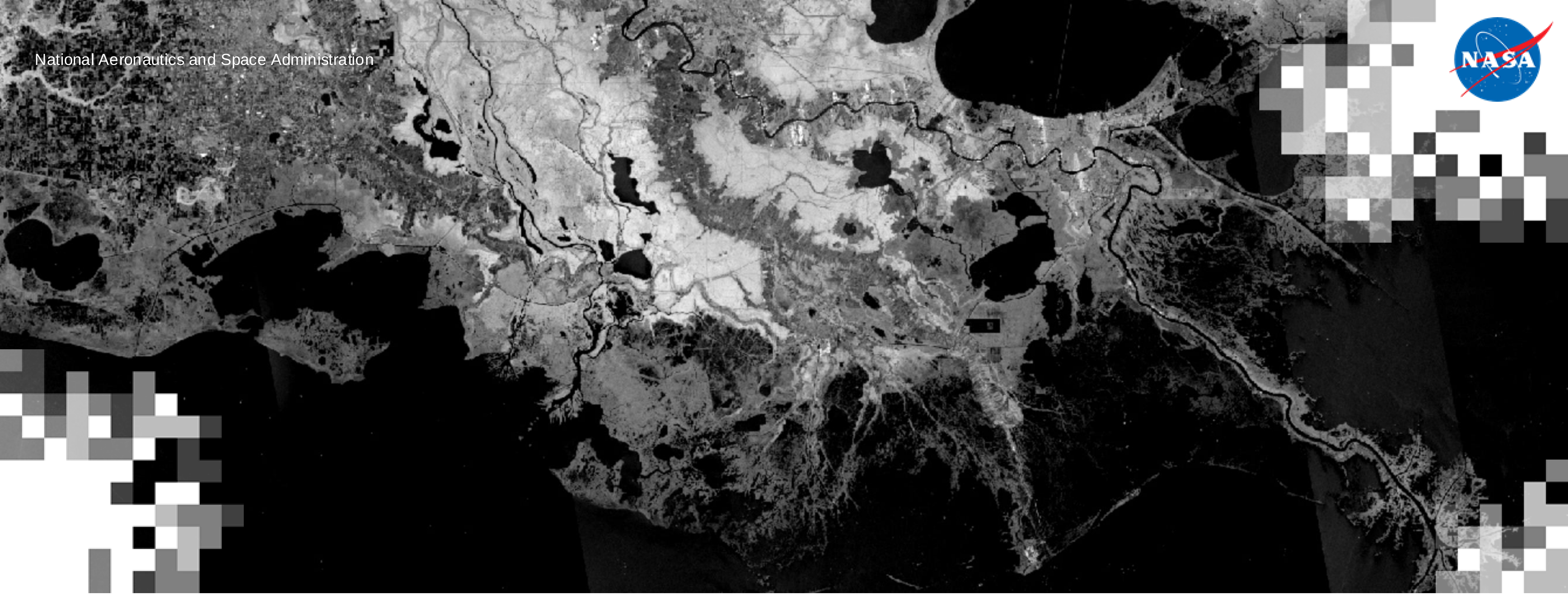
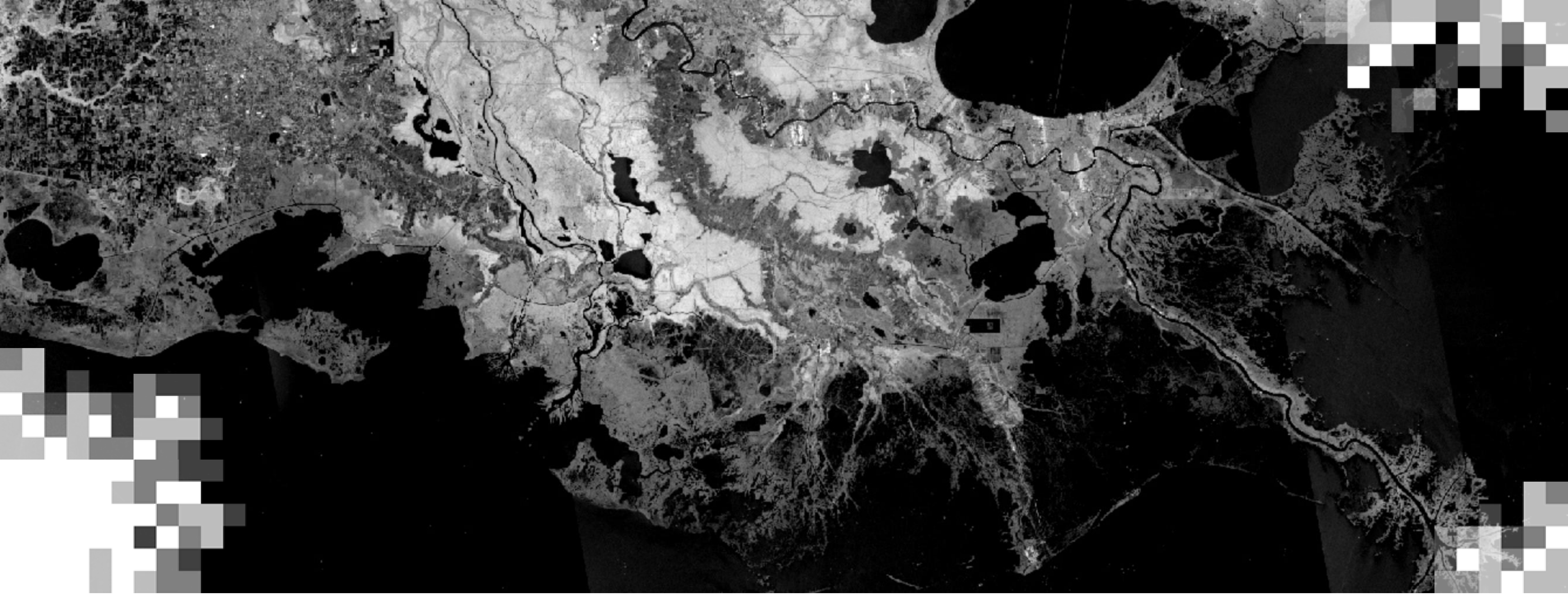


An Introduction to SAR and Its Applications

Part 1: Introduction to Synthetic Aperture Radar (SAR)

Erika Podest, Ph.D. (Jet Propulsion Laboratory, California Institute of Technology)

Nov. 6, 2024



About ARSET

About ARSET

- **ARSET provides accessible, relevant, and cost-free training on remote sensing satellites, sensors, methods, and tools.**

- Trainings include a variety of applications of satellite data and are tailored to audiences with a variety of experience levels.

AGRICULTURE

CLIMATE & RESILIENCE

DISASTERS

ECOLOGICAL CONSERVATION

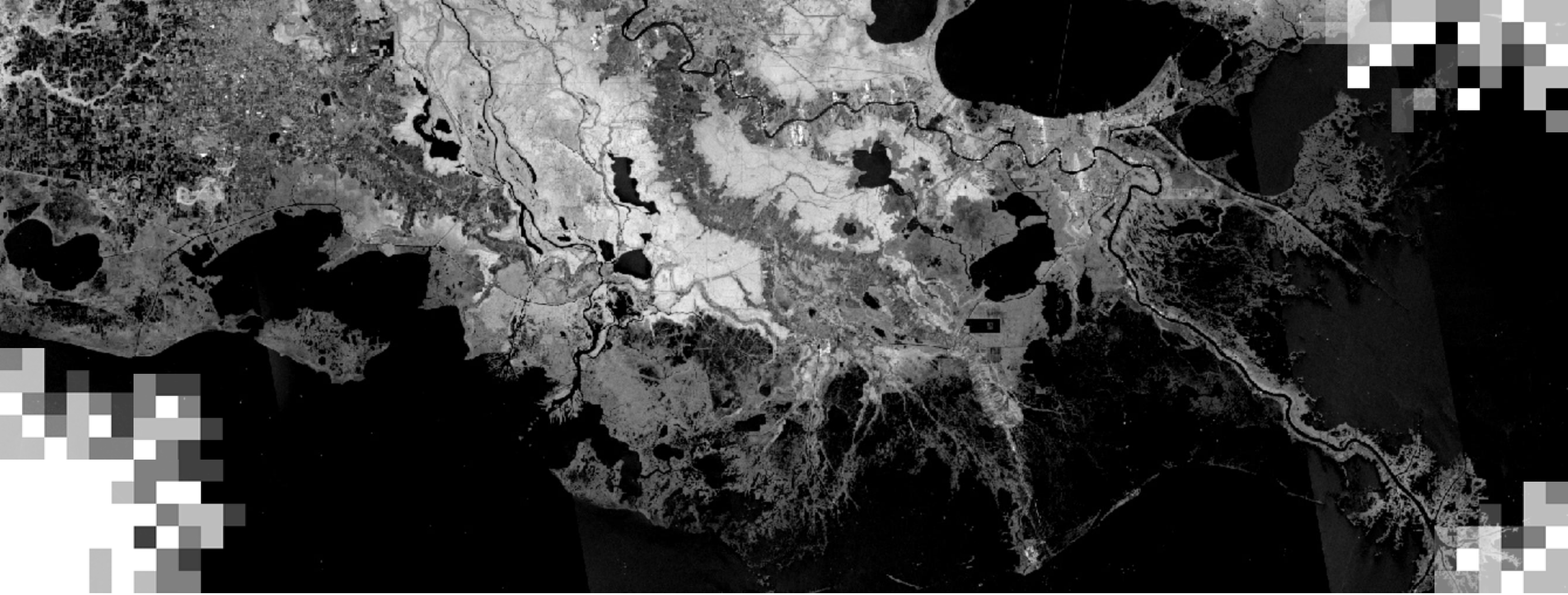
HEALTH & AIR QUALITY

WATER RESOURCES

About ARSET Trainings

- Online or in-person
- Live and instructor-led or asynchronous and self-paced
- Cost-free
- Bilingual and multilingual options
- Only use open-source software and data
- Accommodate differing levels of expertise

- Visit the ARSET website to learn more.



An Introduction to SAR and Its Applications

Overview

Training Outline

Part 1

Introduction to Synthetic Aperture Radar (SAR)

Nov. 6, 2024

Time

Part 2

Introduction to Interferometric SAR (InSAR)

Nov. 13, 2024

Time

Part 3

An Overview of SAR Data Sources and Tools

Nov. 20, 2024

Time

Homework

Opens Nov. 20 – Due Dec. 4 – Posted on the Training Webpage

A certificate of completion will be awarded to those who attend all live sessions and complete the homework assignment by the due date.

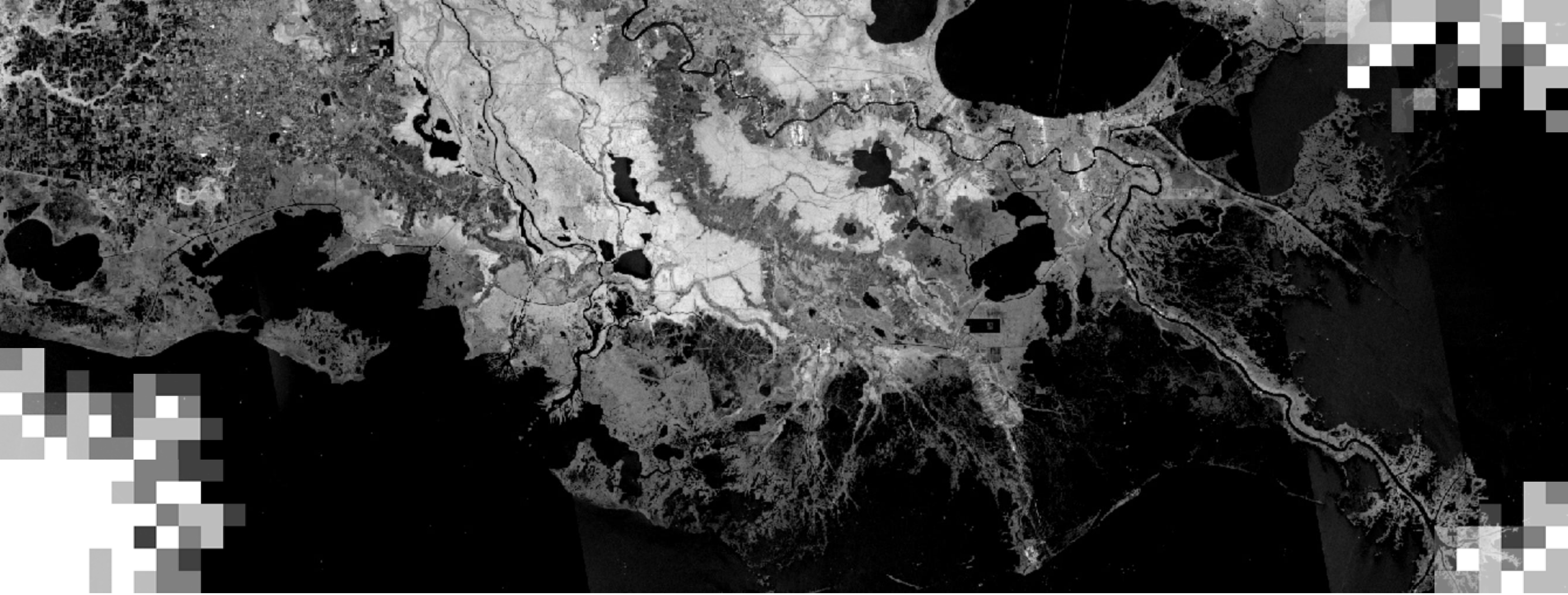
Prerequisites

- Fundamentals of Remote Sensing

Training Learning Objectives

By the end of this training, participants will be able to:

1. Recognize basic features and functionality of Synthetic Aperture Radar (SAR)
2. Evaluate SAR sensor characteristics for addressing different science questions and application areas
3. Interpret the information content in SAR images to distinguish different features (e.g., vegetation, water, inundation) detected by the sensor
4. Evaluate creation of an interferogram through interferometric SAR (InSAR)
5. Interpret an interferogram to measure surface deformation and small movements
6. Compare and contrast the capabilities of historic, current, and upcoming SAR data
7. Access and visualize SAR data for a given location and time



An Introduction to SAR and Its Applications

Part 1: Introduction to Synthetic Aperture Radar (SAR)

Session 1 – Trainer

Erika Podest, Ph.D.

Scientist

NASA Jet Propulsion Laboratory

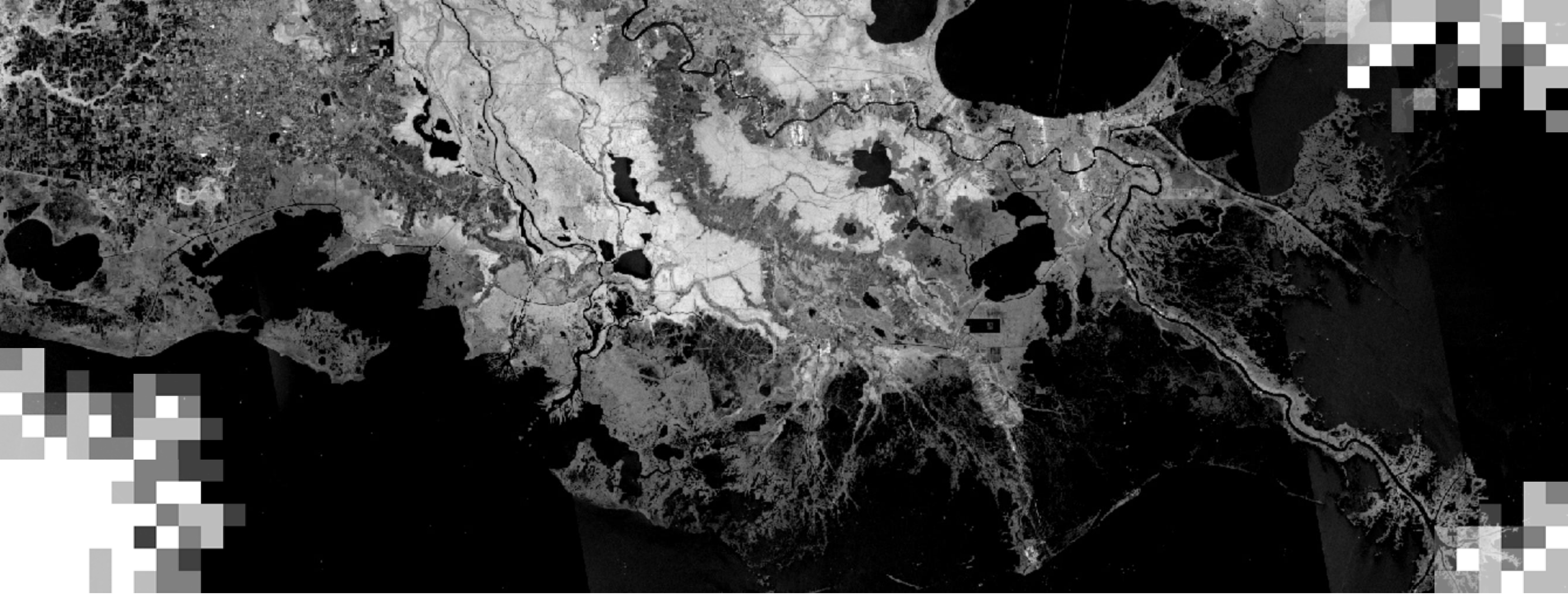
Session 1 Objectives

By the end of Session 1, participants will be able to:

- Identify radar remote sensing signal characteristics
- Recognize how the radar signal interacts with the surface
- Interpret a SAR image to distinguish different features (e.g., vegetation, water, inundation) detected by the sensor
- Identify application areas where different SAR sensors are most applicable

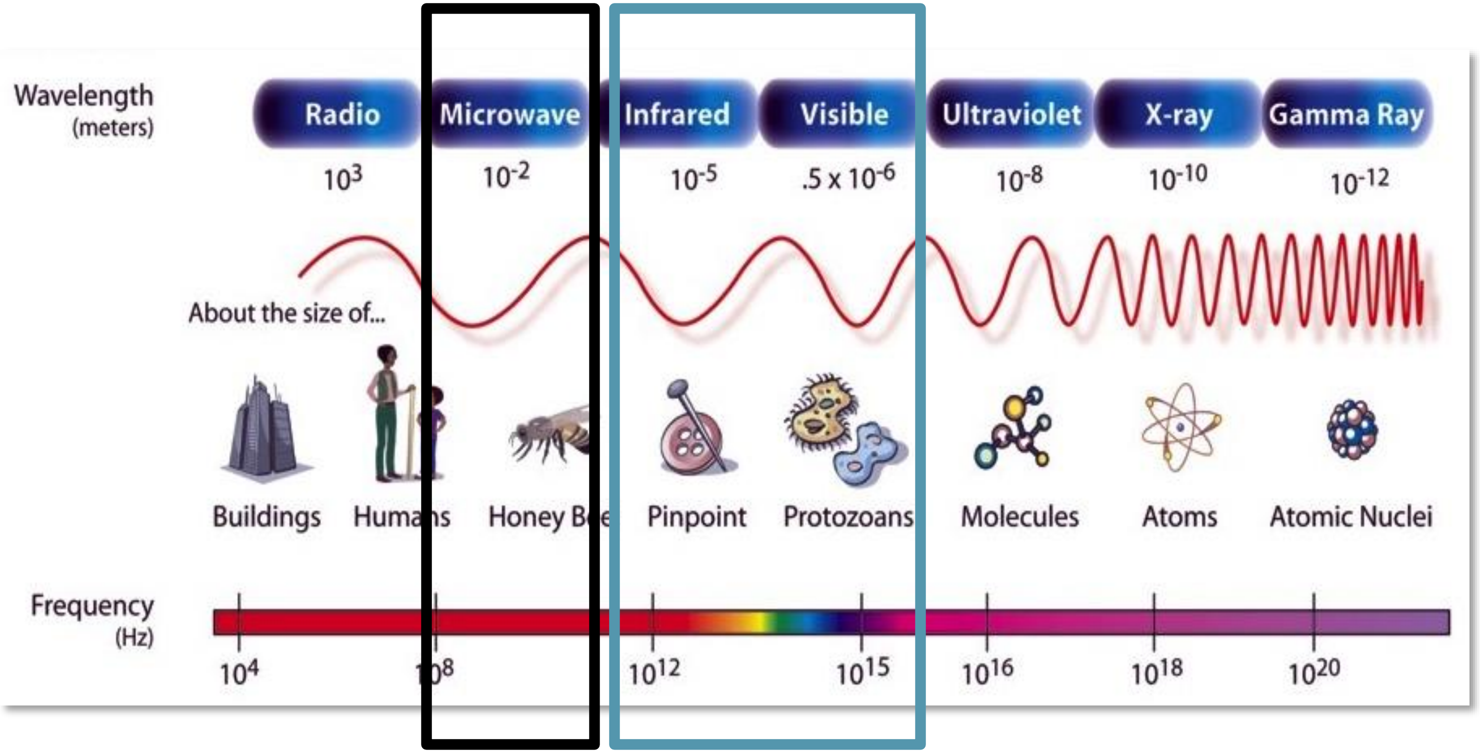
How to Ask Questions

- Please write your questions in the Questions box and we will answer them at the end of the webinar.
- Feel free to enter your questions as we go. We will try to respond all of the questions during the Q&A session after the webinar.
- The remainder of the questions will be answered in the Q&A document, which will be posted to the training website about a week after the training.



Introduction to Synthetic Aperture Radar (SAR): Review of Prerequisites

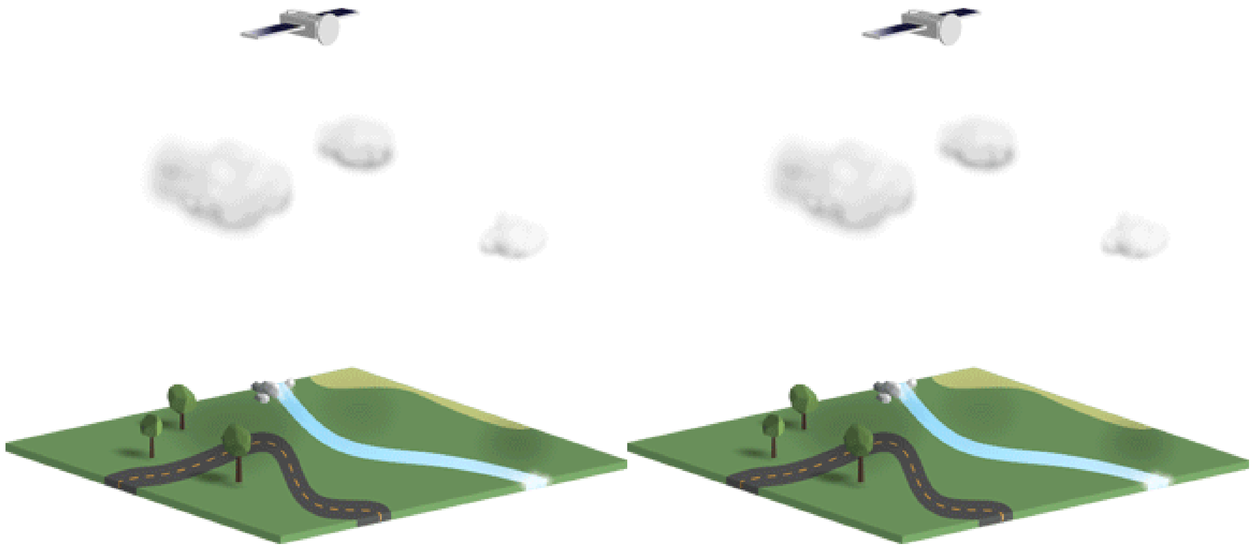
Electromagnetic Radiation for Remote Sensing



Optical Sensors use infrared–visible regions.

- Optical sensors measure reflected solar light and only function in the daytime.
- The surface of the Earth cannot be imaged with visible or infrared sensors when there are clouds.
- Microwaves can penetrate through clouds and vegetation, and can operate in day or night conditions.

Active and Passive Remote Sensing



Passive: Sensors detect only what is emitted from the landscape or is reflected from another source (e.g., light reflected from the sun).

Active: Instruments emit their own signal and the sensor measures what is reflected back. Sonar and radar are examples of active sensors.

Passive Sensors:

- The source of radiant energy arises from natural sources
- e.g., the Sun, Earth, other “hot” bodies

Active Sensors

- Provide their own artificial radiant energy source for illumination
- e.g., **Radar, Synthetic Aperture Radar (SAR)**, LiDAR

Advantages and Disadvantages of Radar Over Optical Remote Sensing

Advantages

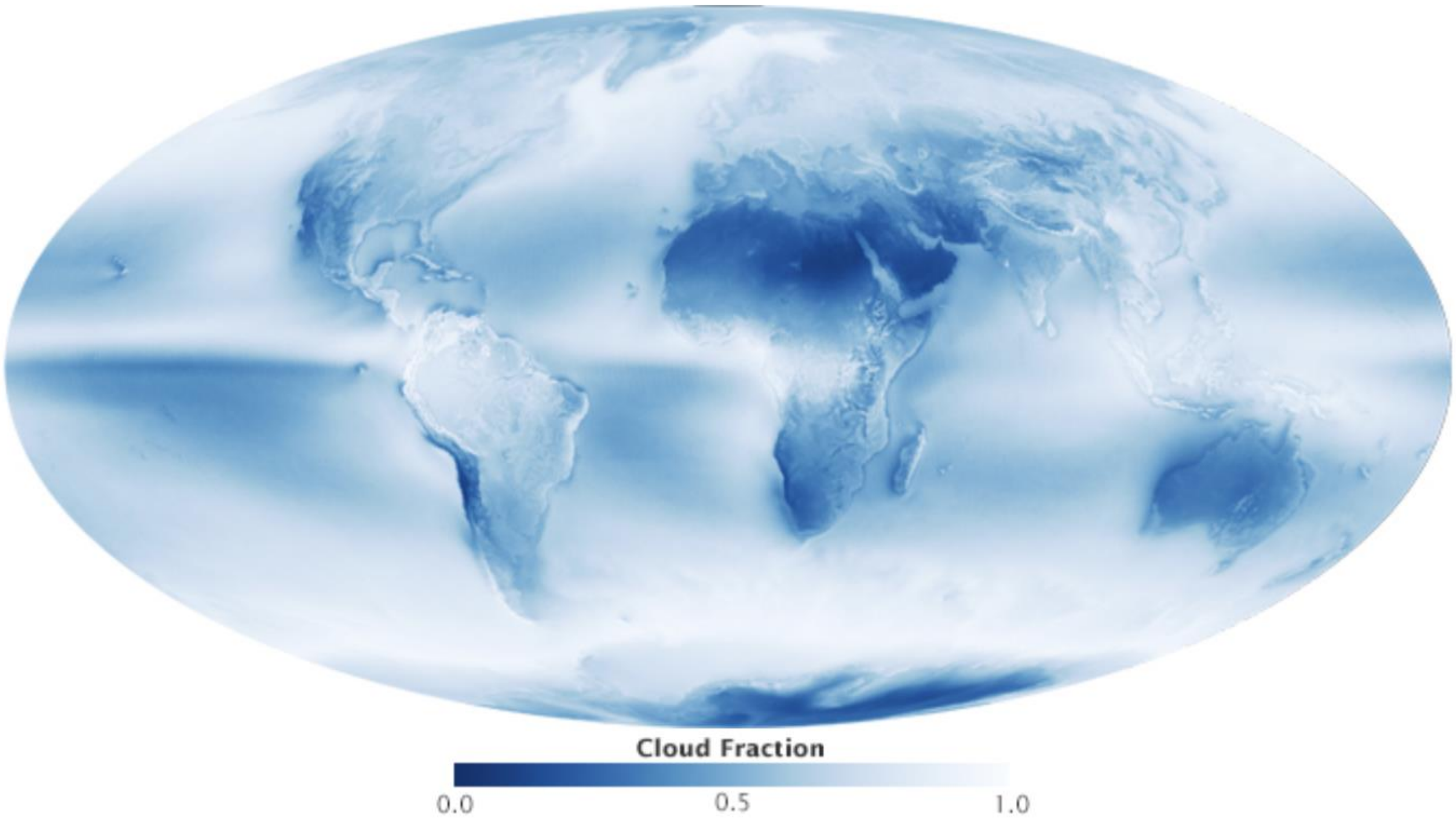
- Nearly all weather capability
- Day or night capability
- Penetration through the vegetation canopy
- Penetration through the soil
- Minimal atmospheric effects
- Sensitivity to dielectric properties (liquid vs. frozen water)
- Sensitivity to structure

Disadvantages

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

Global Cloud Coverage

- Cloud fraction averaged from 2002-2015, compiled using data from MODIS on Aqua.
- Colors range from dark blue (no clouds) to light blue (some clouds) to white (frequent clouds).

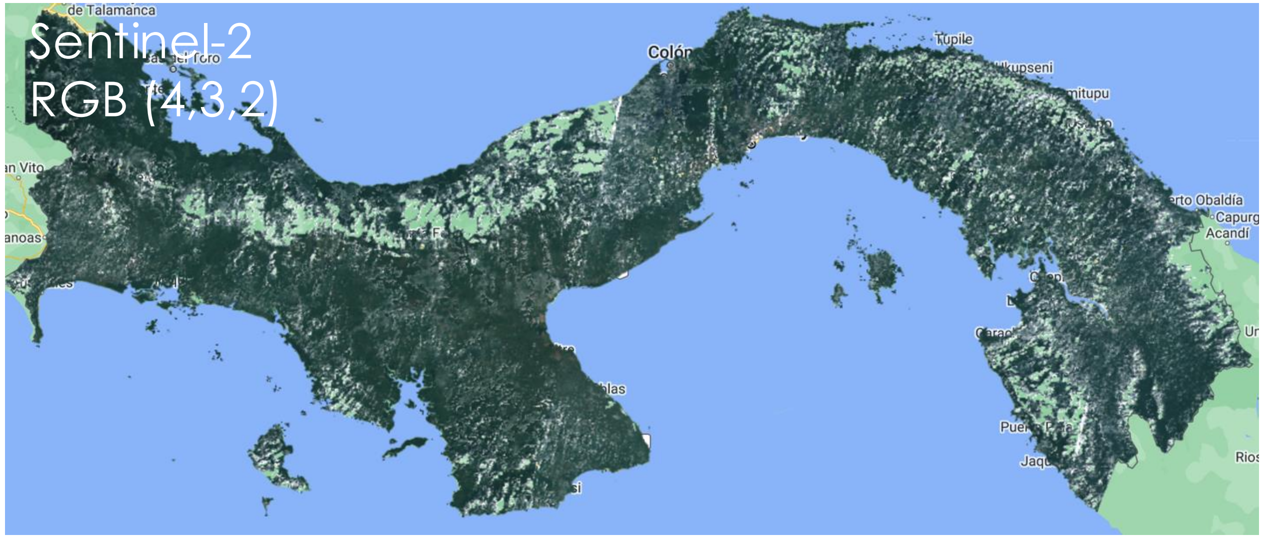


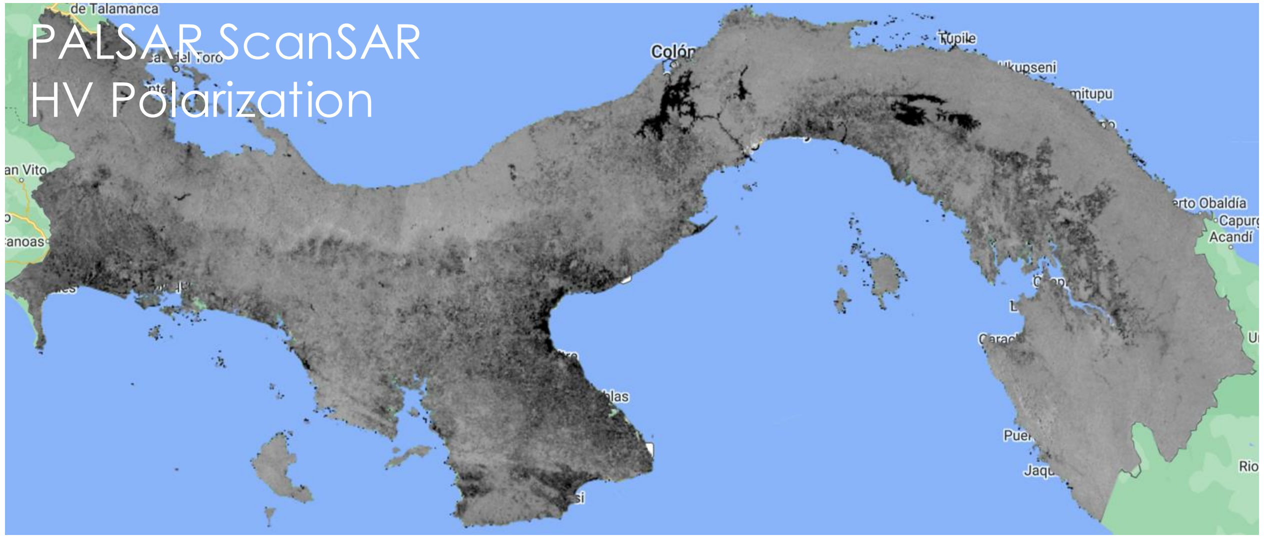
Source: NASA Earth Observatory

Optical vs. Radar

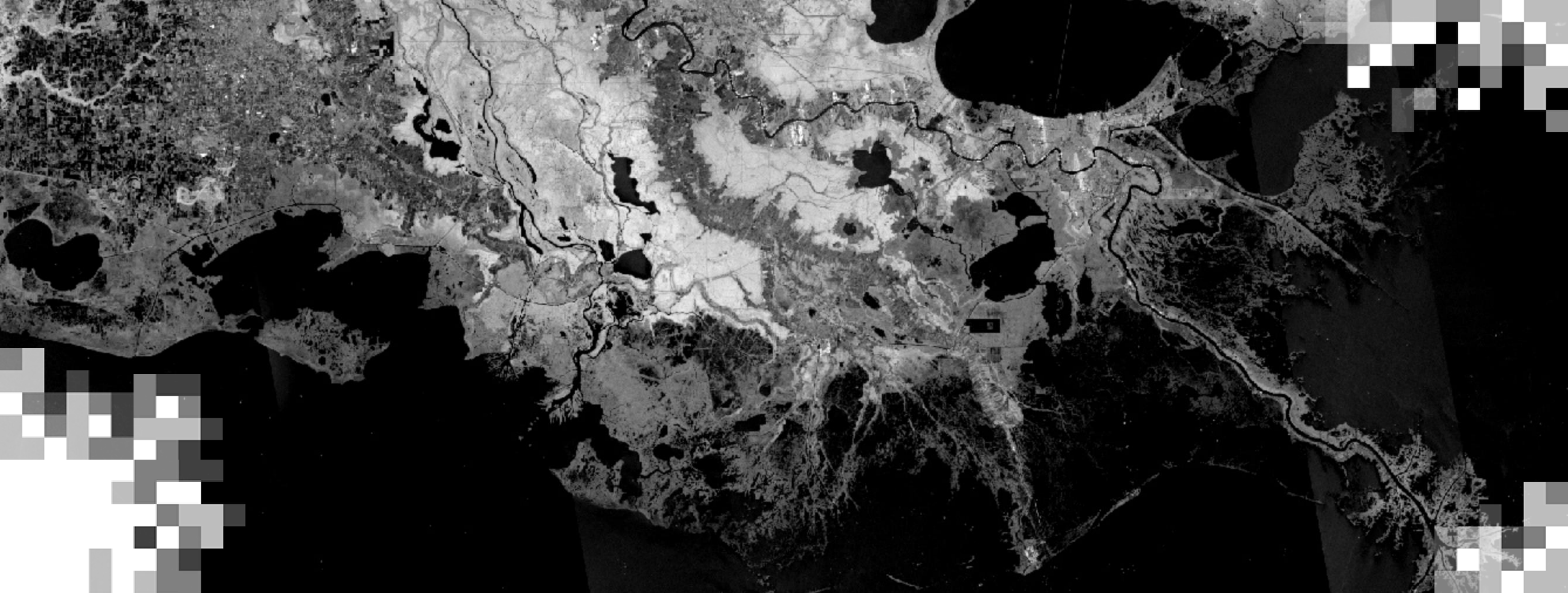
- The country of Panama is situated in the tropics, where clouds are prevalent, particularly during the rainy season.
- In the optical image composite at the top, areas covered by clouds have been masked out.
- The bottom SAR image composite, on the other hand, displays data for the entire country.

Panama: Nov. 1-30, 2019



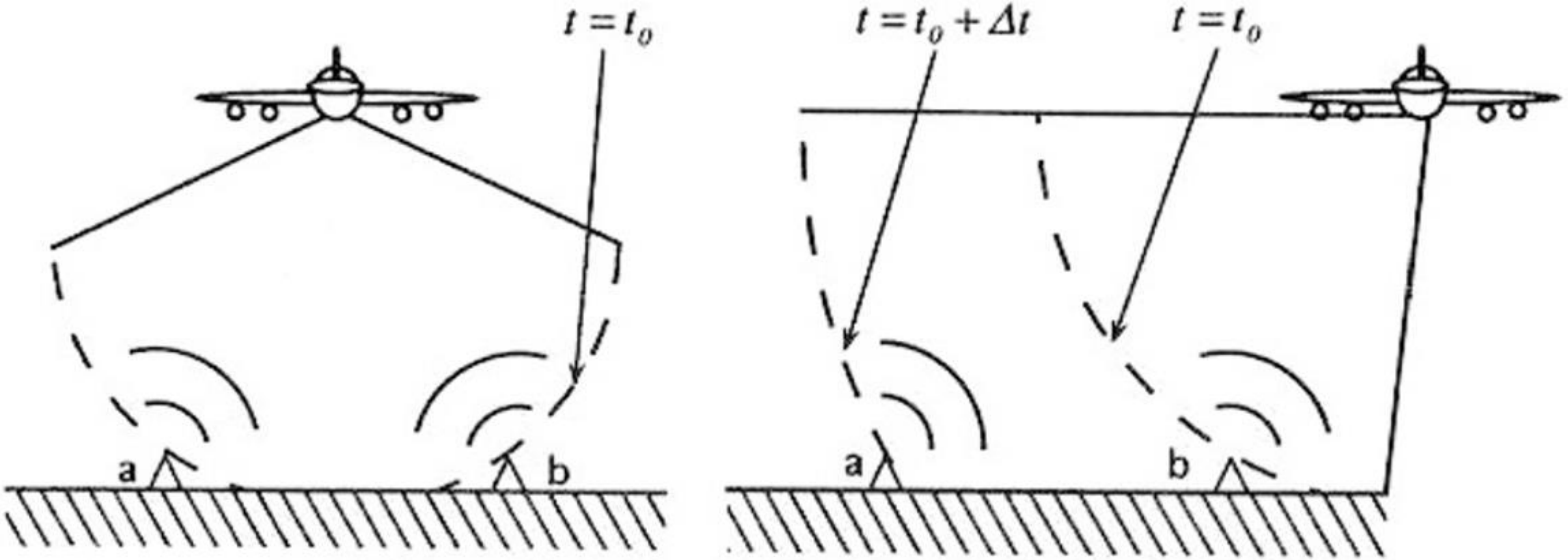


Source: Sentinel-2 and PALSAR ScanSAR from GEE



Radar Image Formation

Down-Looking vs. Side-Looking Radar



Side-Looking Radar

- Each pixel in the radar image represents a complex quantity of the energy that was reflected back to the satellite.
- The magnitude of each pixel represents the intensity of the reflected echo.

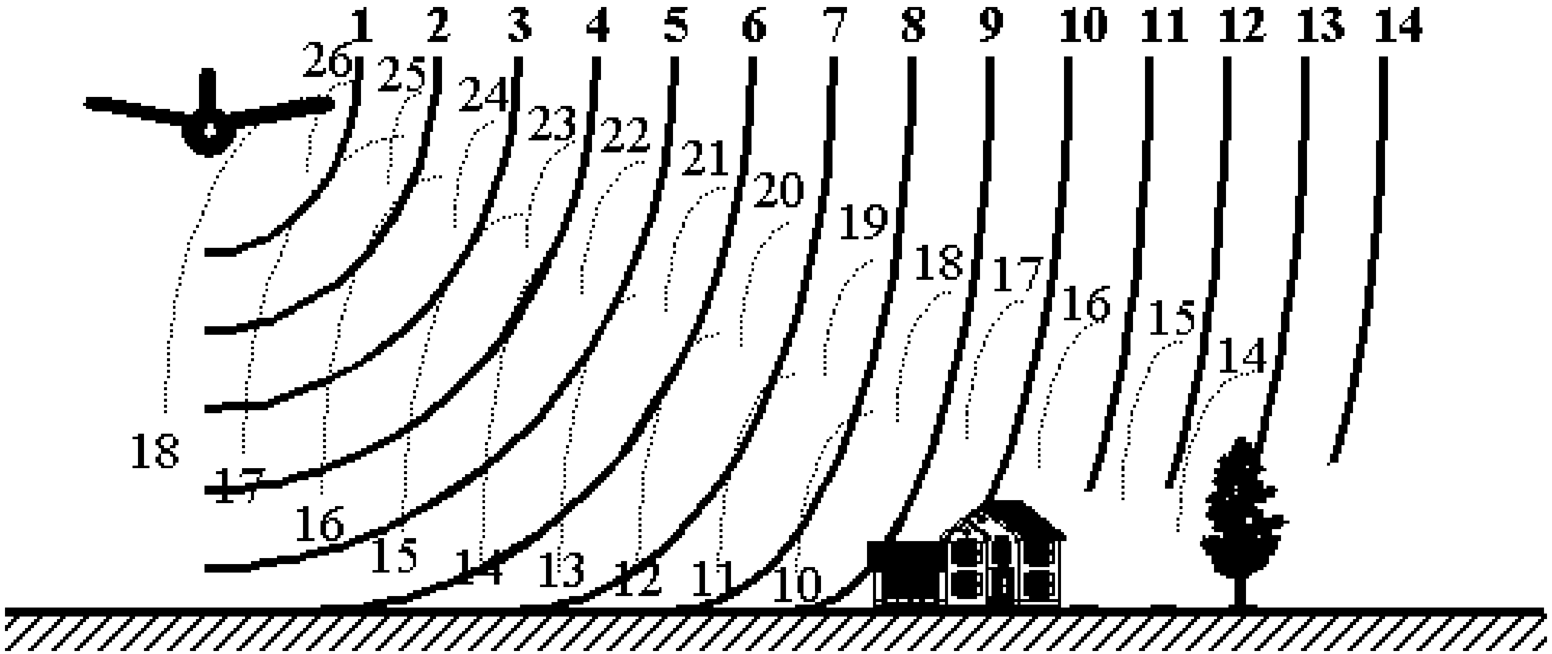


Image Credit: Lillesand and Kiefer, 1994

Radar Geometry

Slant Range Distance

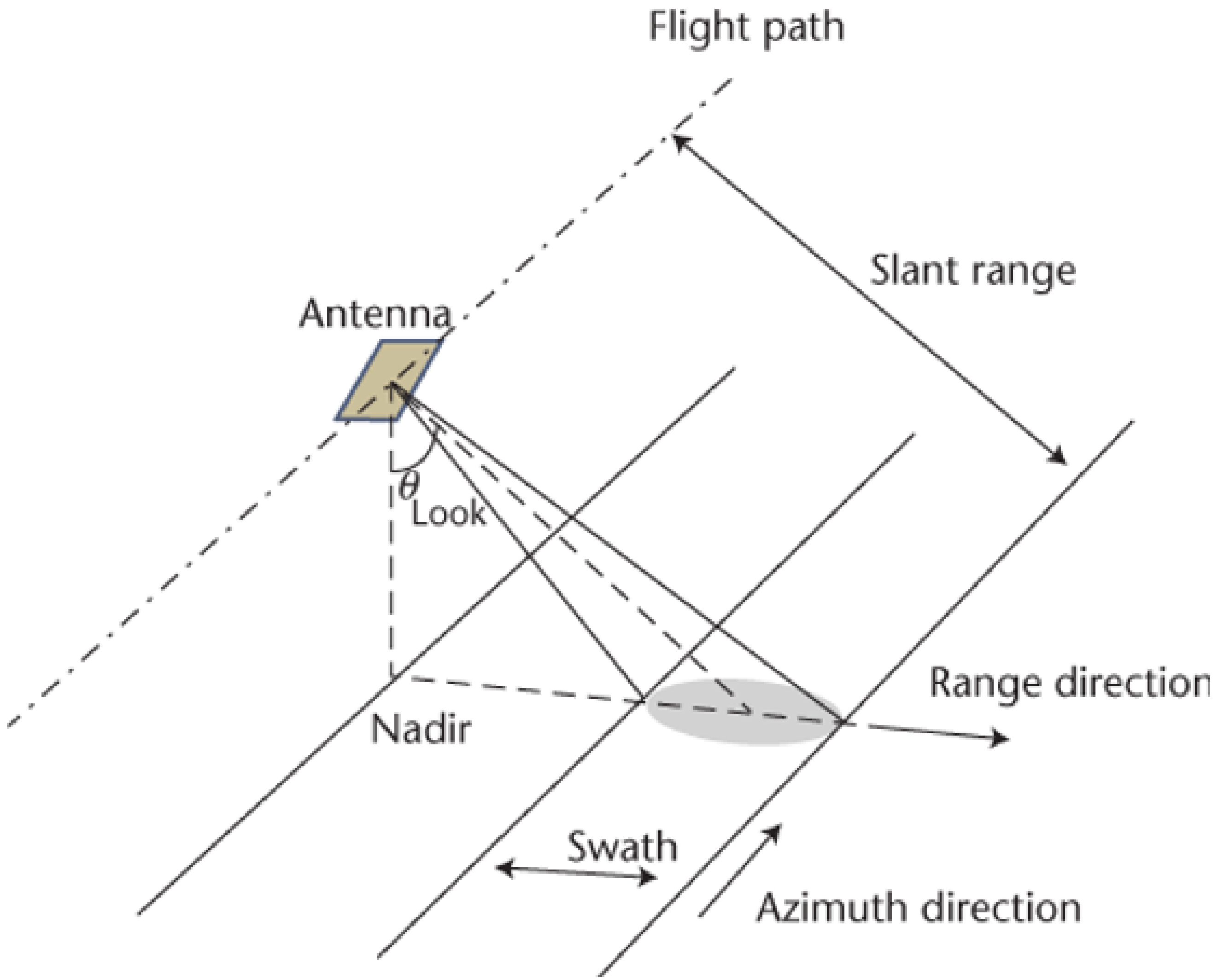
- The direct distance between the sensor and the target

Range Direction (Across Track)

- The direction perpendicular to the motion of the radar sensor

Azimuth Direction (Along Track)

- The direction parallel to the motion of the radar platform as it moves over the target area



Range Resolution

Range Resolution (Across Track)

- **Pulse Length:** The duration of the transmitted pulse.
- **Range resolution** depends on the length of the pulse (shorter pulses results in higher resolutions).
- If pulses are shortened, transmitted amplitude must be increased to maintain same total power in the pulse.
- Use range pulse compression by frequency modulation.

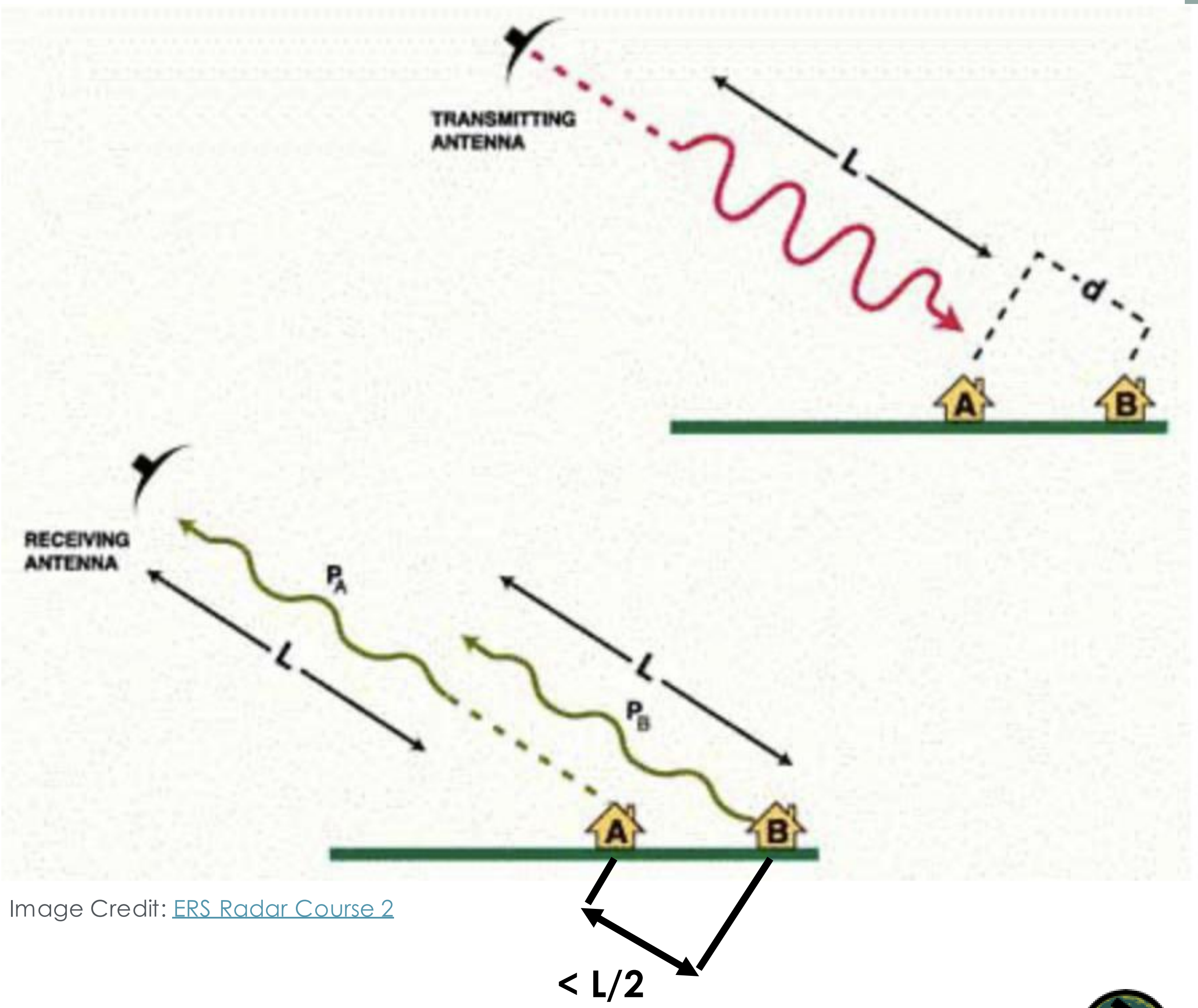


Image Credit: ERS Radar Course 2

Slant Range Resolution vs. Ground Range Resolution

Ground Range

- Distance between the satellite ground track and the target

Incidence Angle

- Angle between line of sight of the radar and the vertical to the terrain

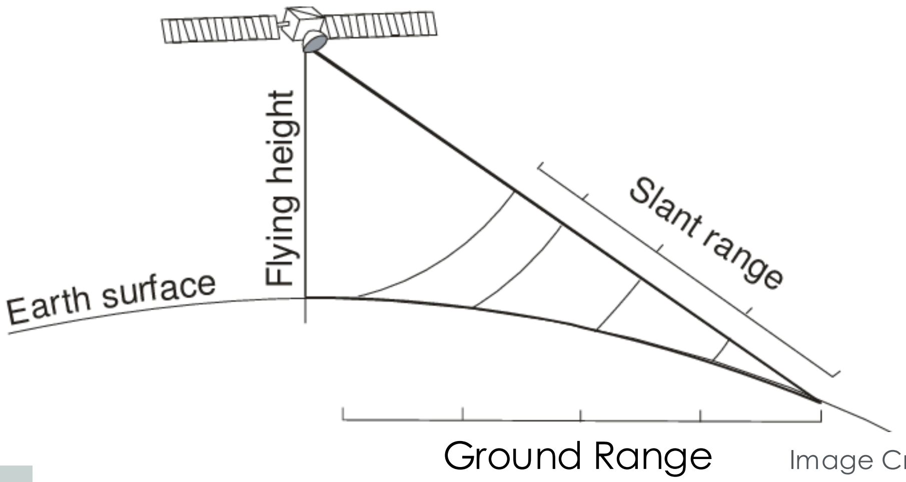
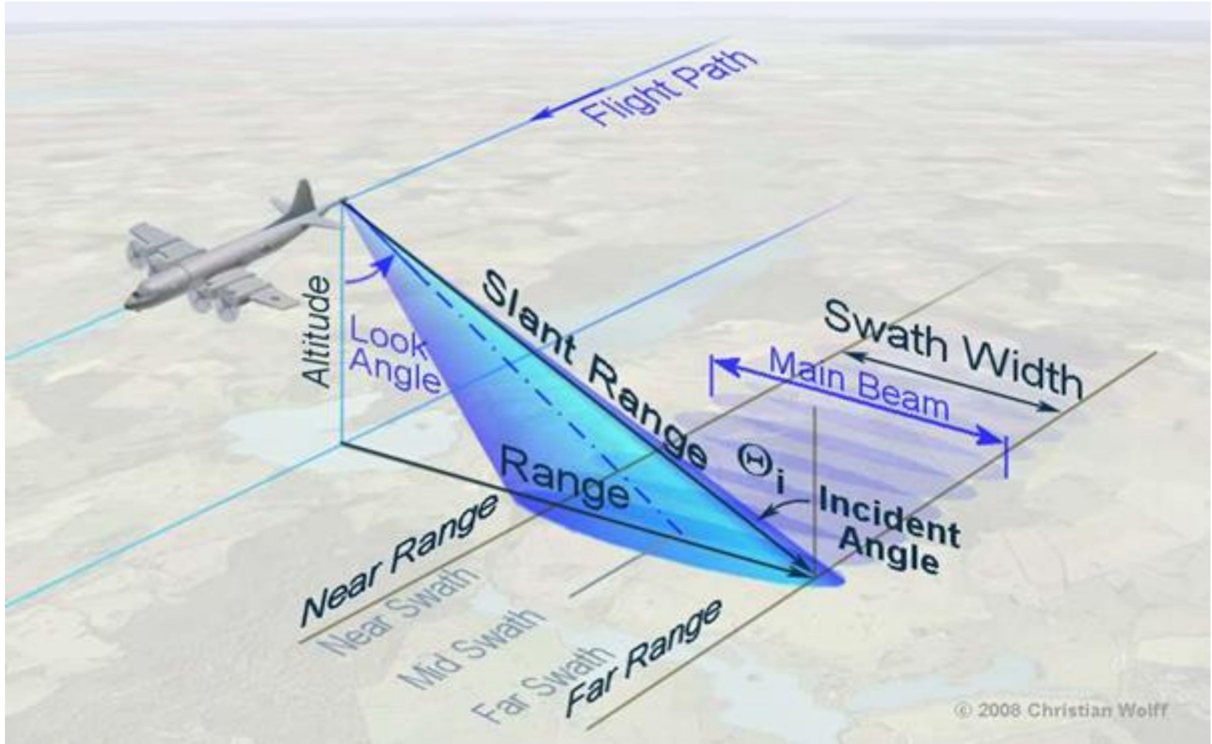


Image Credit: Silva et al., 2006



Azimuth Resolution

Azimuth Resolution (Along Track)

- Resolution of an imaging radar system in the azimuth direction is determined by the angular beamwidth and the slant-range.
- The beamwidth of the antenna is directly proportional to the wavelength of the transmitted pulse and inversely proportional to the length of the antenna (or aperture).

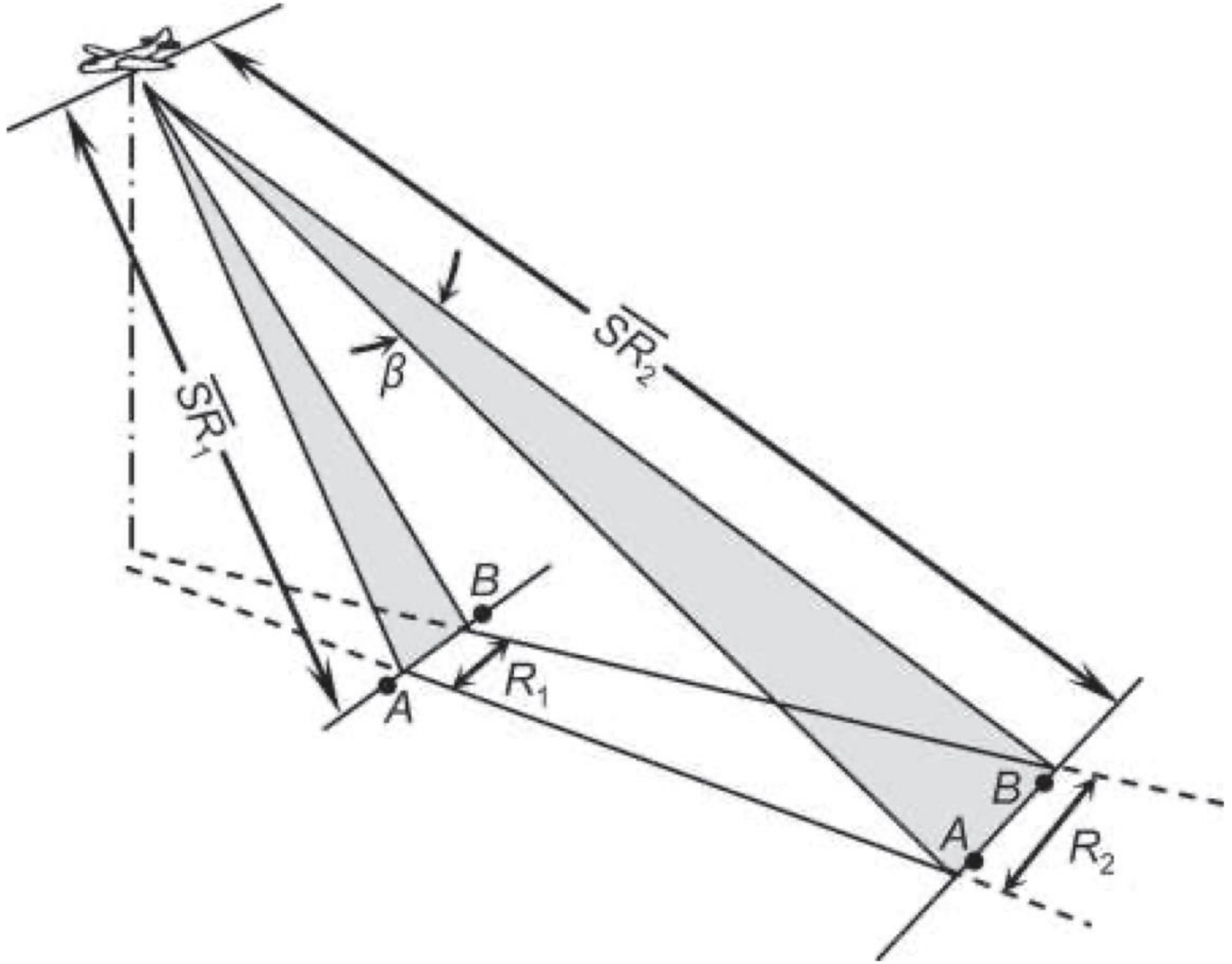


Image Credit: Lillesand and Kiefer, 7th Edition

Synthetic Aperture Radar

Azimuth Resolution (Along Track)

- It is difficult to have long antennas in space, but one can be synthesized by using the movement of the satellite to simulate a very long antenna.

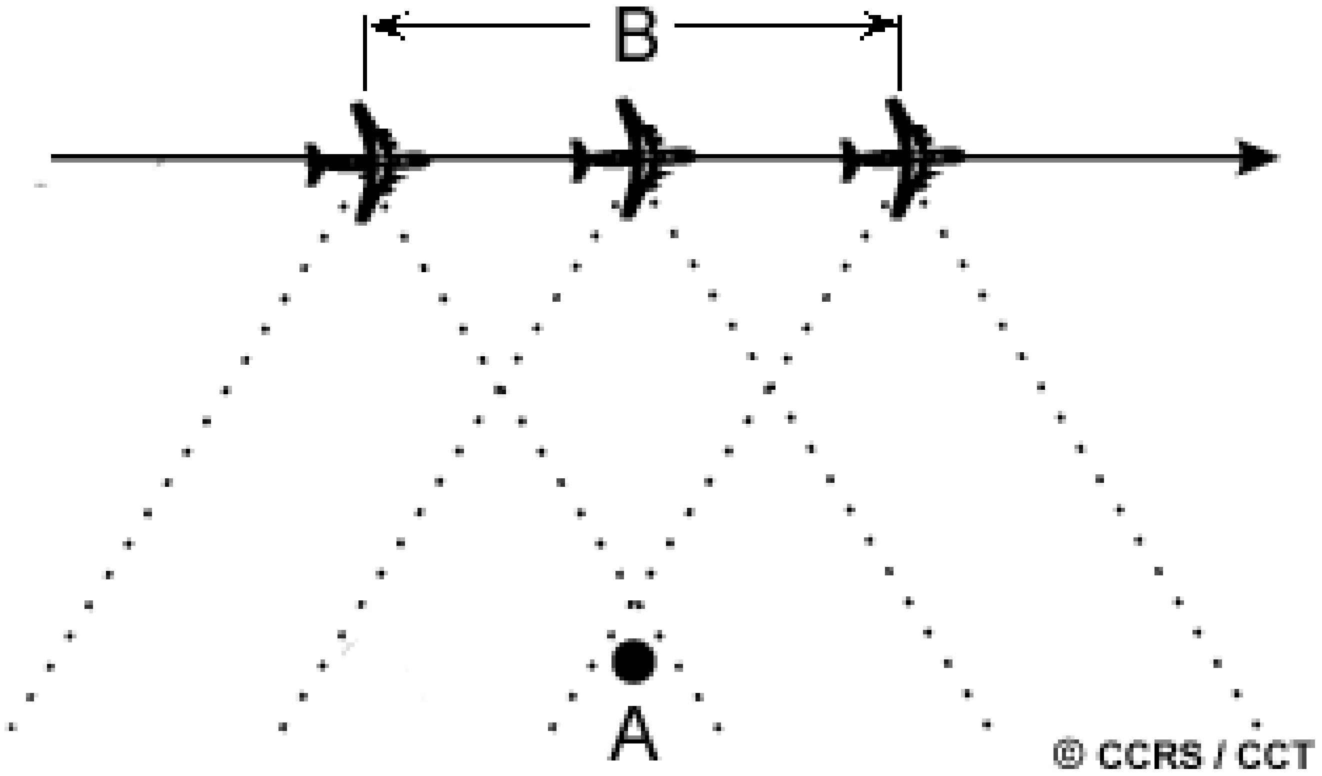
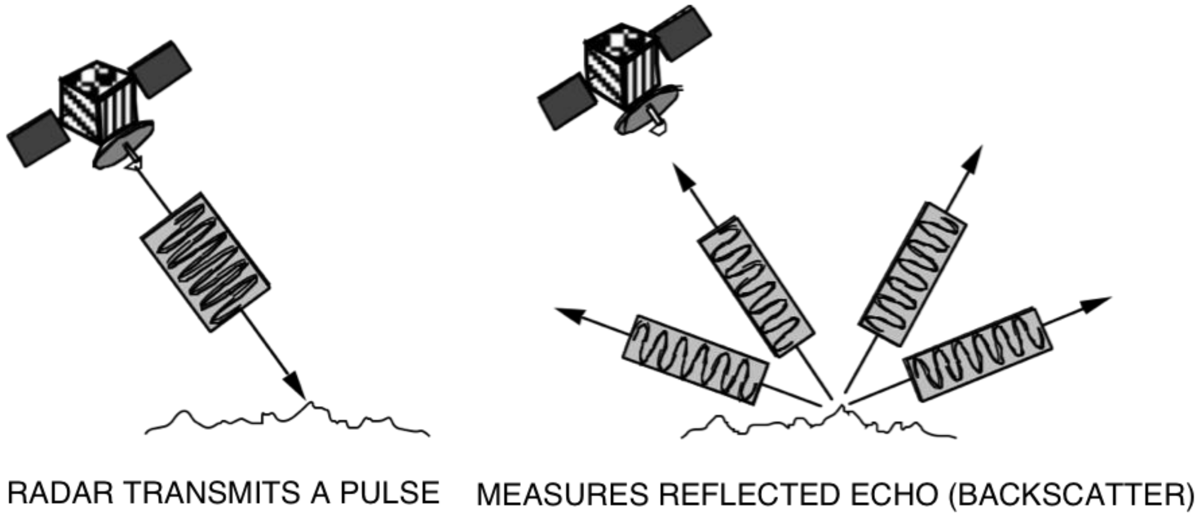
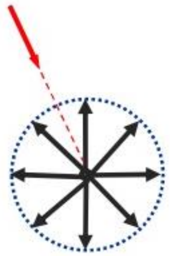


Image Credit: Lillesand and Kiefer, 7th Edition

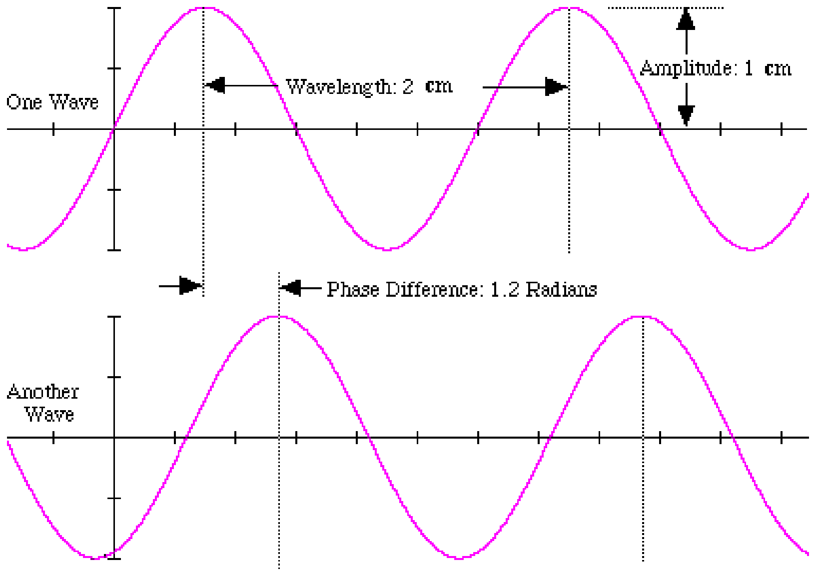
Review of Radar Image Formation

1. Radar can measure amplitude (the strength of the reflected echo) and phase (the position of a point in time on a waveform cycle).
2. Radar can only measure the part of the echo reflected back towards the antenna (backscatter).
3. Radar pulses travel at the speed of light.
4. The strength of the reflected echo is the backscattering coefficient (sigma naught) and is expressed in decibels (dB).

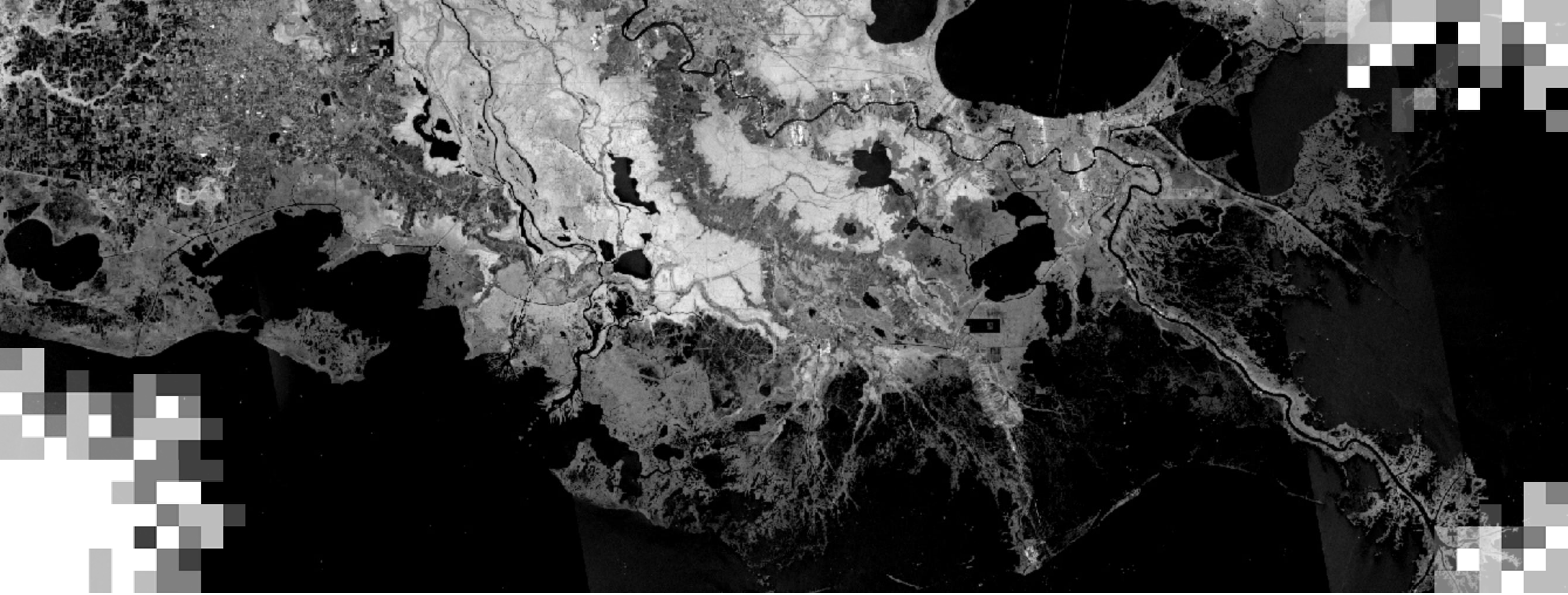




Isotropic scatterer



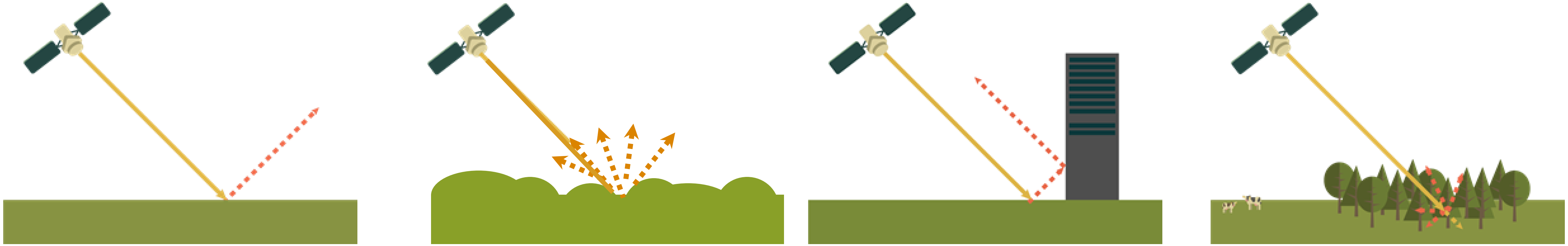
Source: ESA-ASAR Handbook



Radar Backscatter Mechanisms

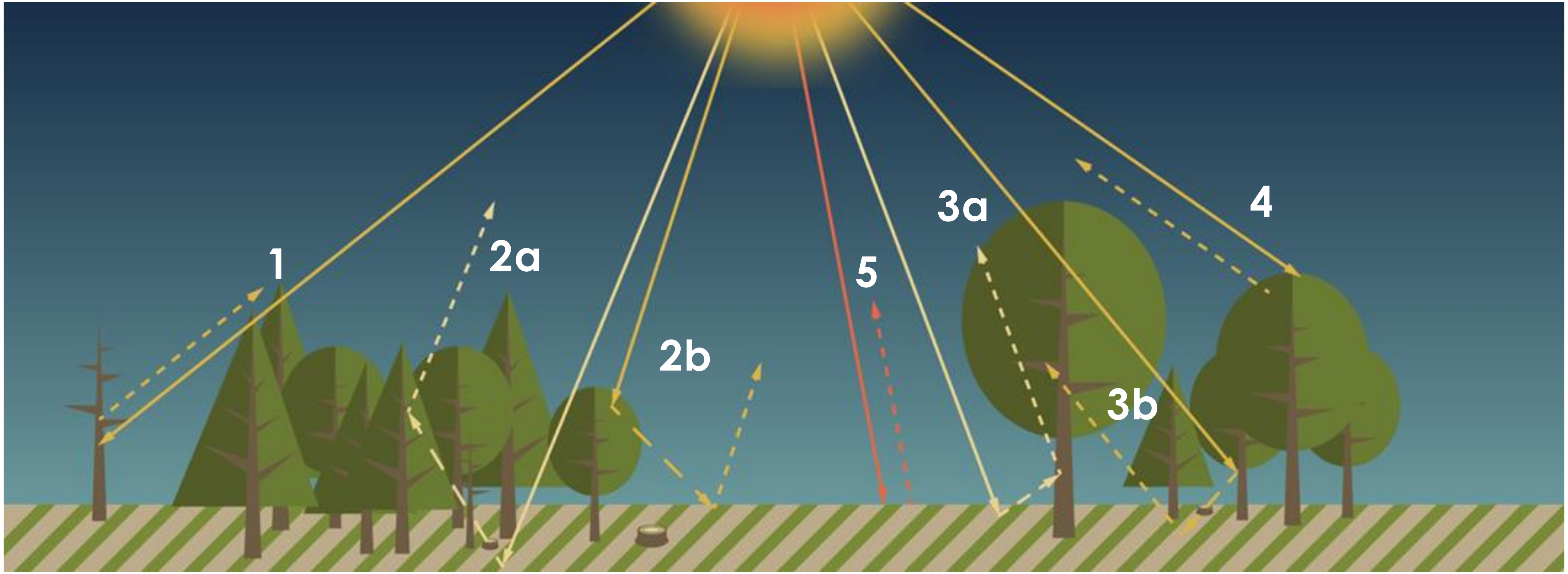
Radar Signal Interaction

- The scale of the surface relative to the wavelength determines how rough or smooth it appears, as well as how bright or dark it will be in the image.
- Backscattering Mechanisms:



Smooth Surface (specular Reflector) | Rough Surface | Double Bounce | Volumetric

Volumetric Scattering: Radar Backscatter in Forests

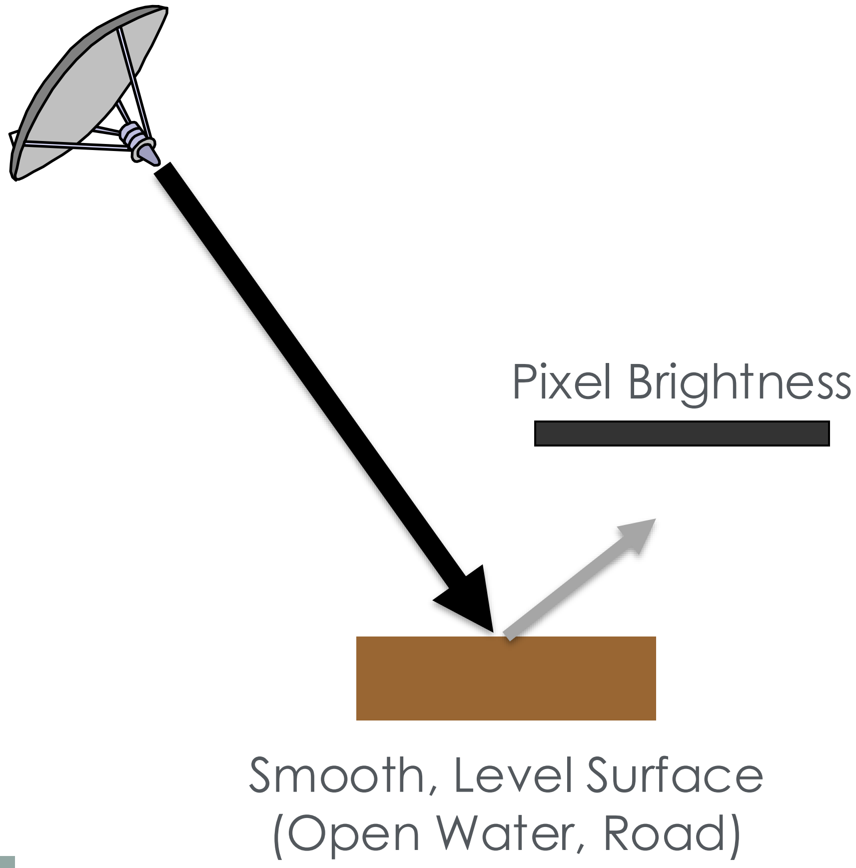


Dominant Backscattering Sources in Forests:

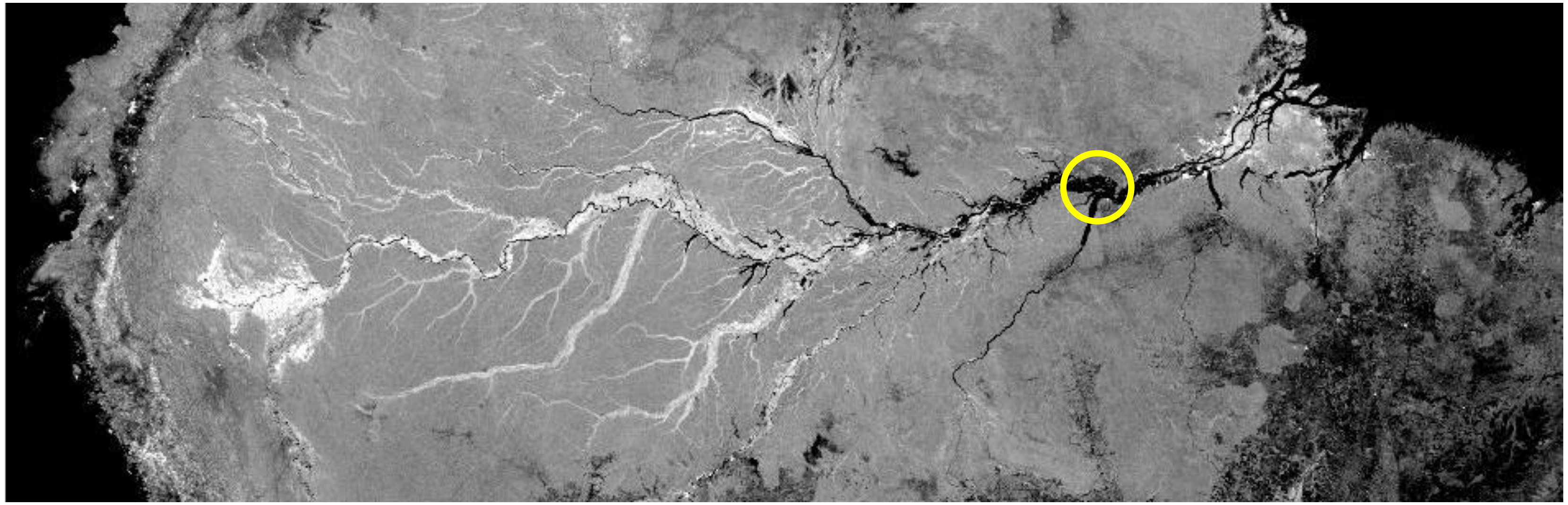
(1) Direct Scattering from the Tree Trunks
(2a) Ground-Crown Scattering
(2b) Crown-Ground Scattering
(3a) Ground-Trunk Scattering
(3b) Trunk-Ground Scattering
(4) Crown Volume Scattering
(5) Direct Scattering from the Soil Surface

Smooth Surface Reflection

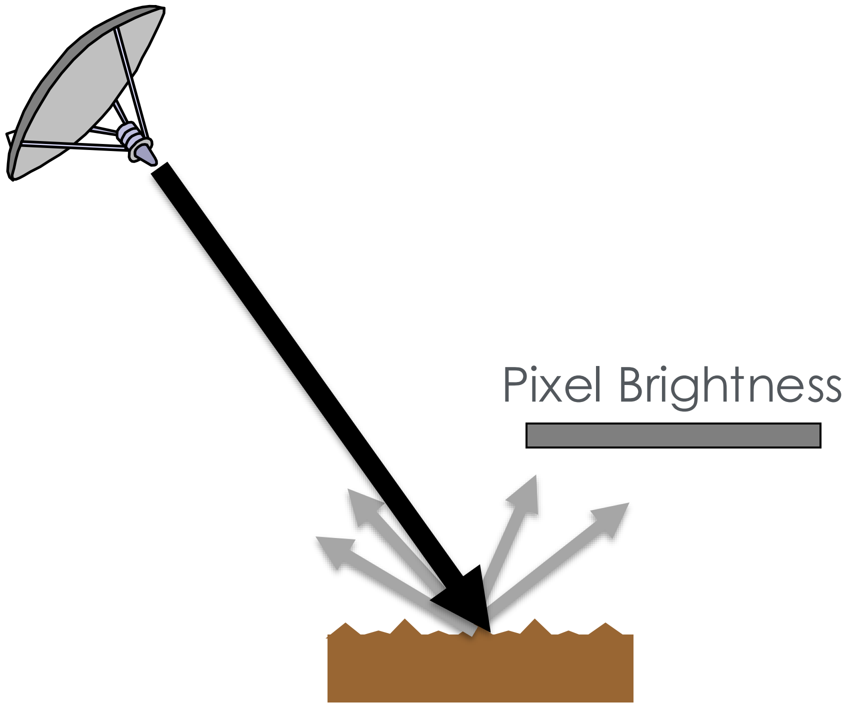
Smooth Surface Reflection (Specular Reflection)



SMAP Radar Mosaic of the Amazon Basin
April 2015 (L-band, HH, 3 km)

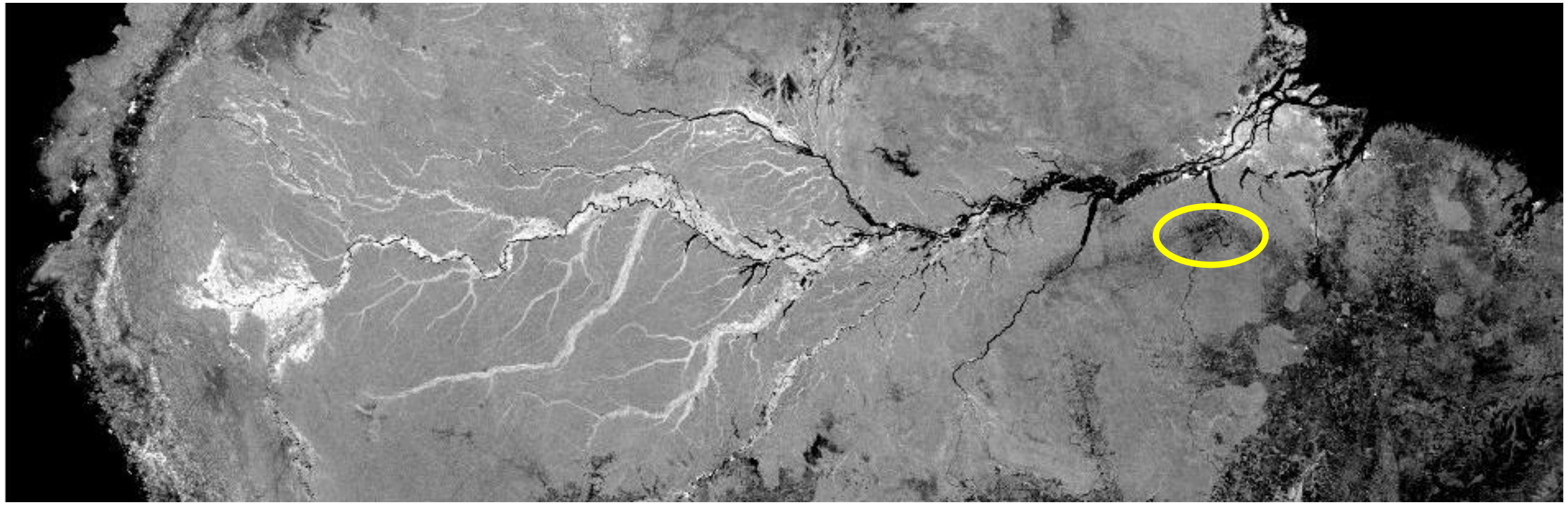


Rough Surface Reflection

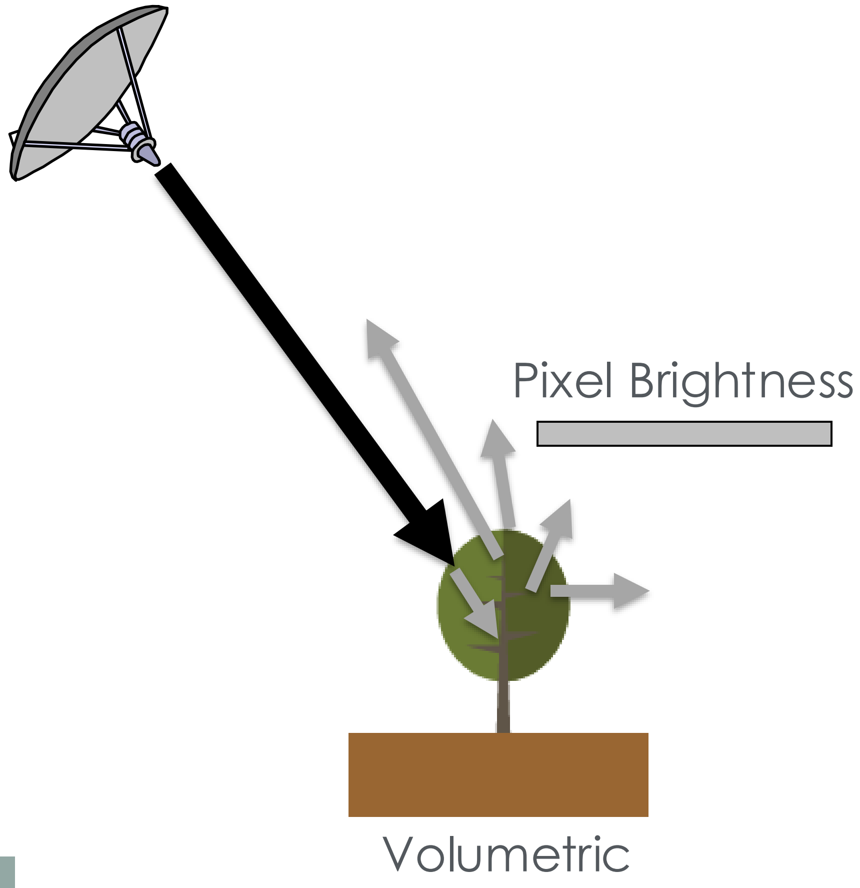


Rough, Bare Surface
(Deforested Areas, Tilled Agricultural Fields)

SMAP Radar Mosaic of the Amazon Basin
April 2015 (L-band, HH, 3 km)



Volume Scattering by Vegetation



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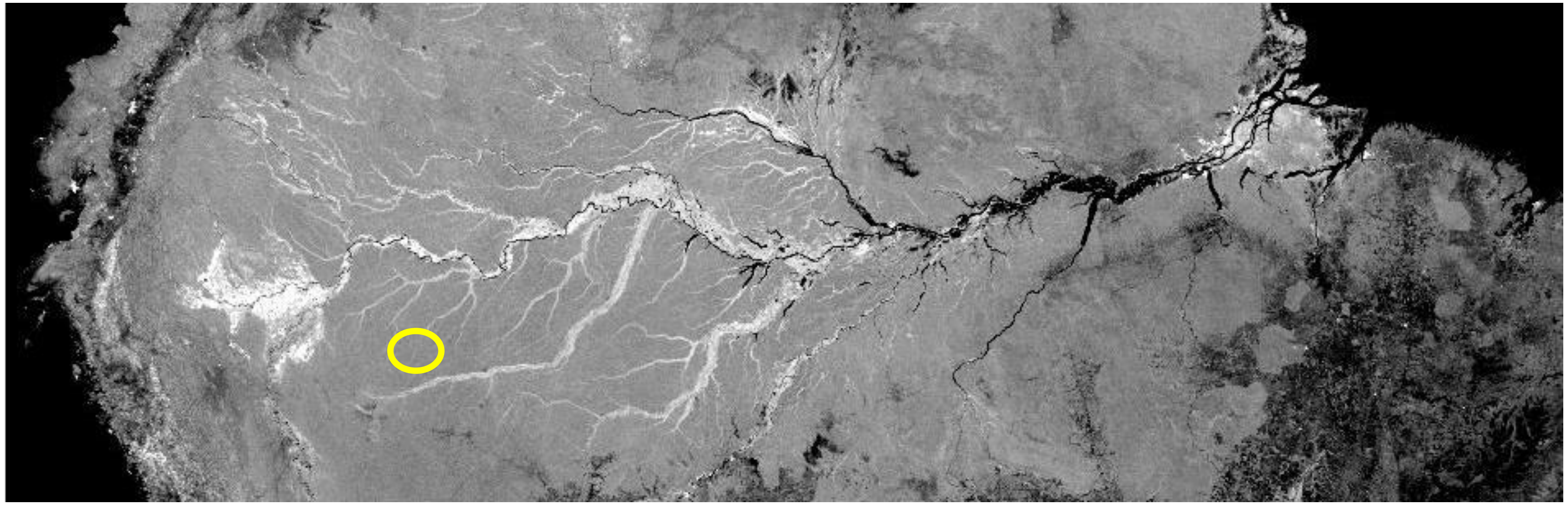
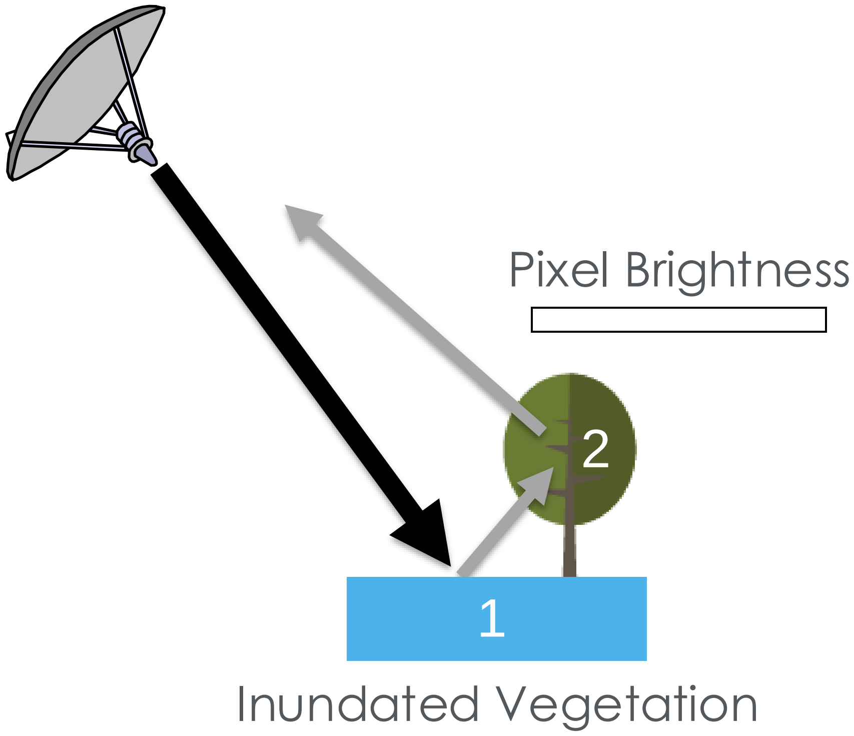


Double Bounce



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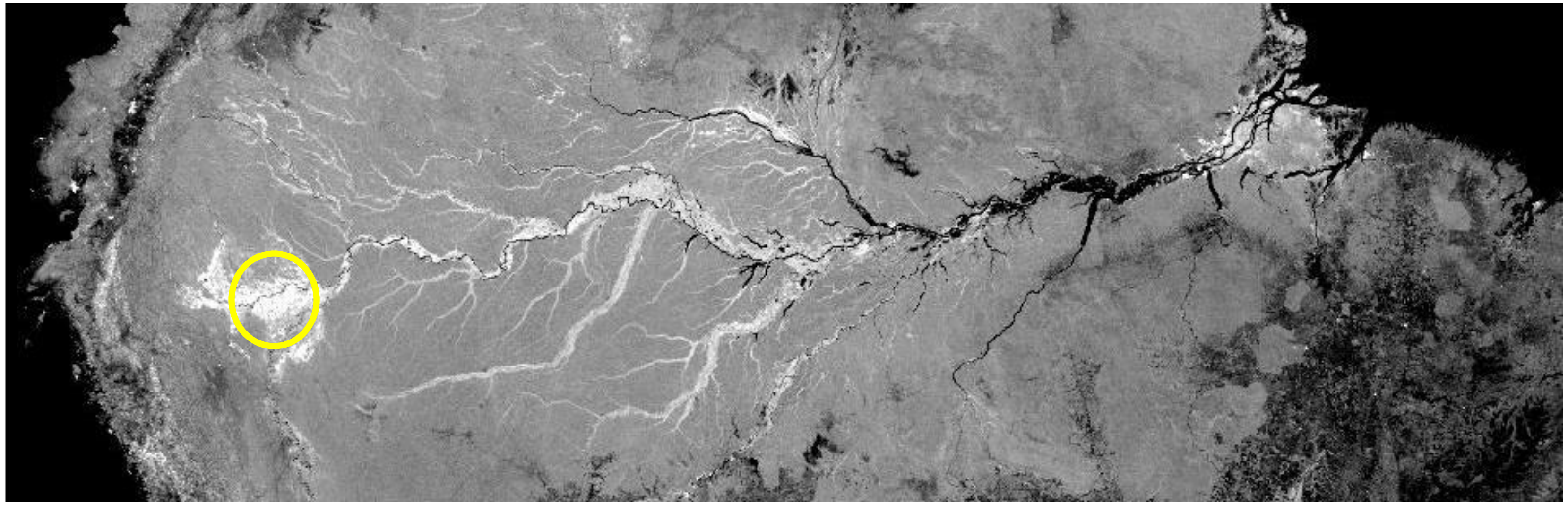
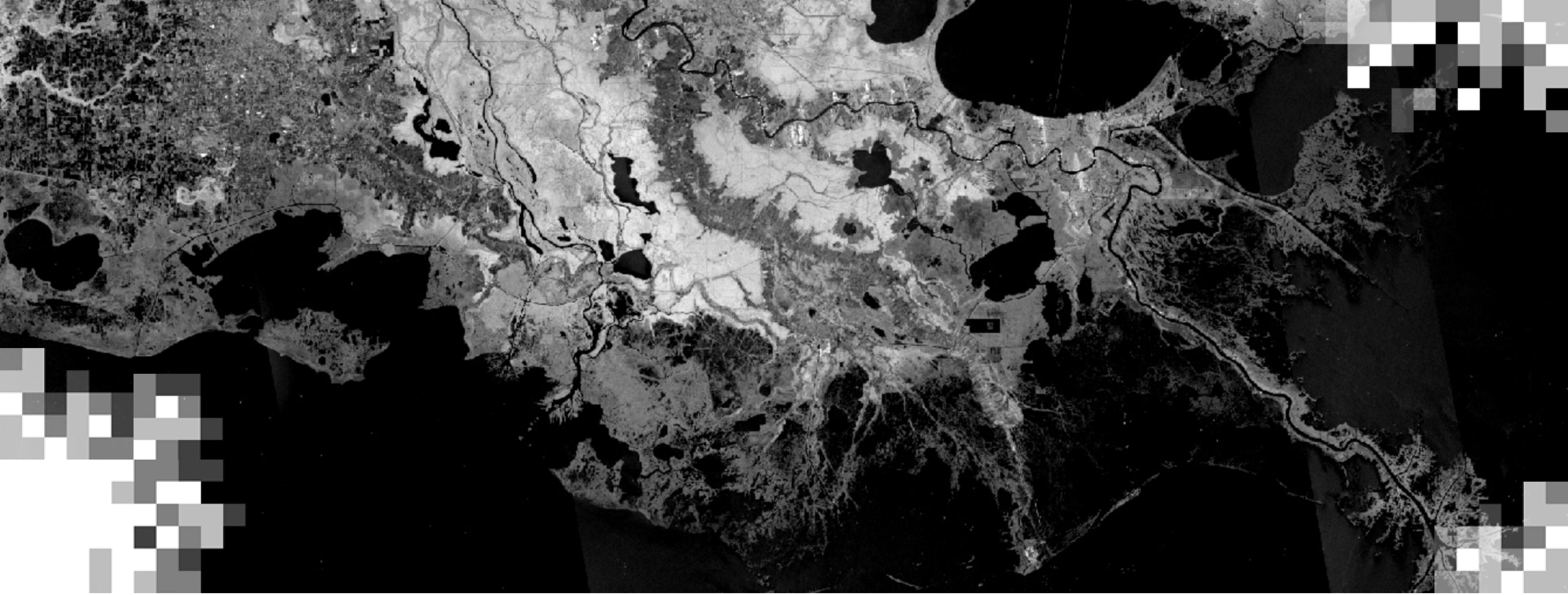




Radar Parameters that Influence the Signal

Radar Parameters to Consider for a Study

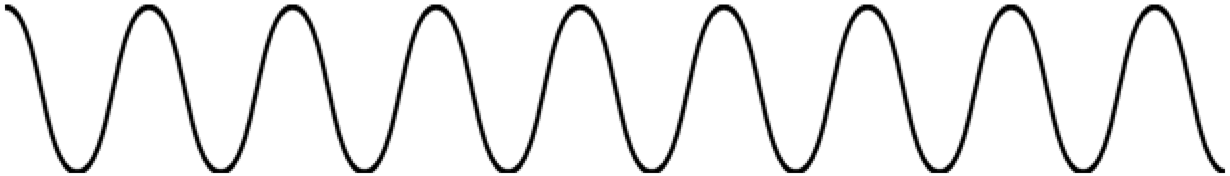
- Wavelength
- Polarization
- Incidence Angle

Radar Parameters: Wavelength

$$\lambda = \frac{c}{v}$$

c = speed of light ($3x10^8$ m/s)
λ = wavelength (m)
v = frequency (cycles per second, Hz)

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 parentheses.

Signal Penetration as a Function of Wavelength

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

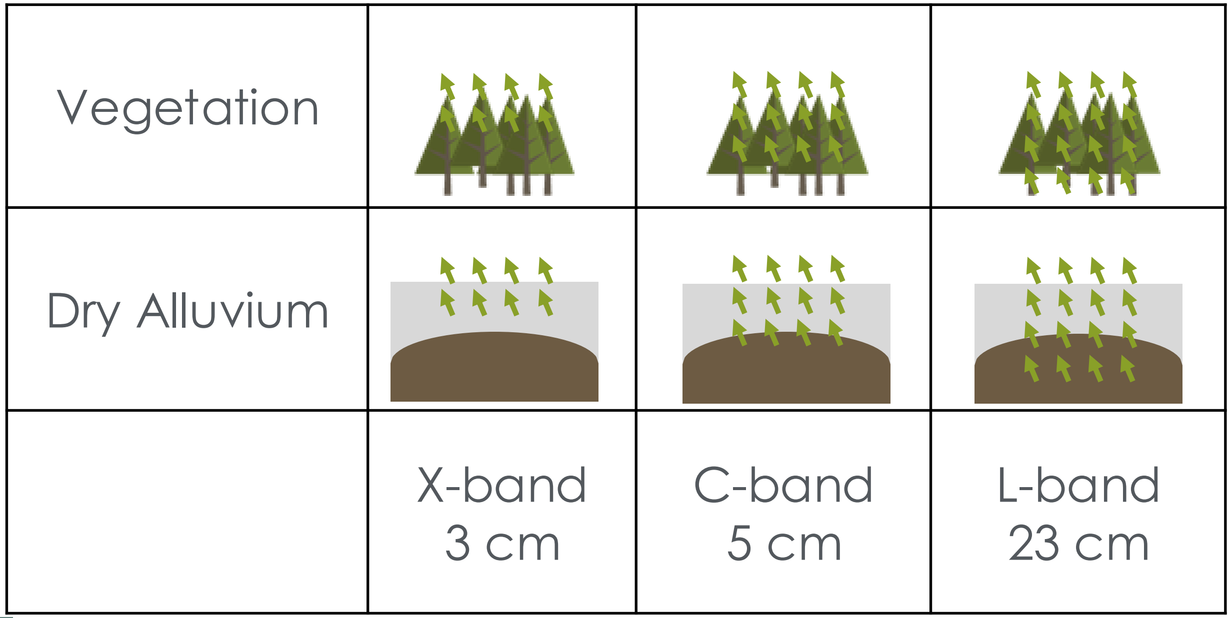
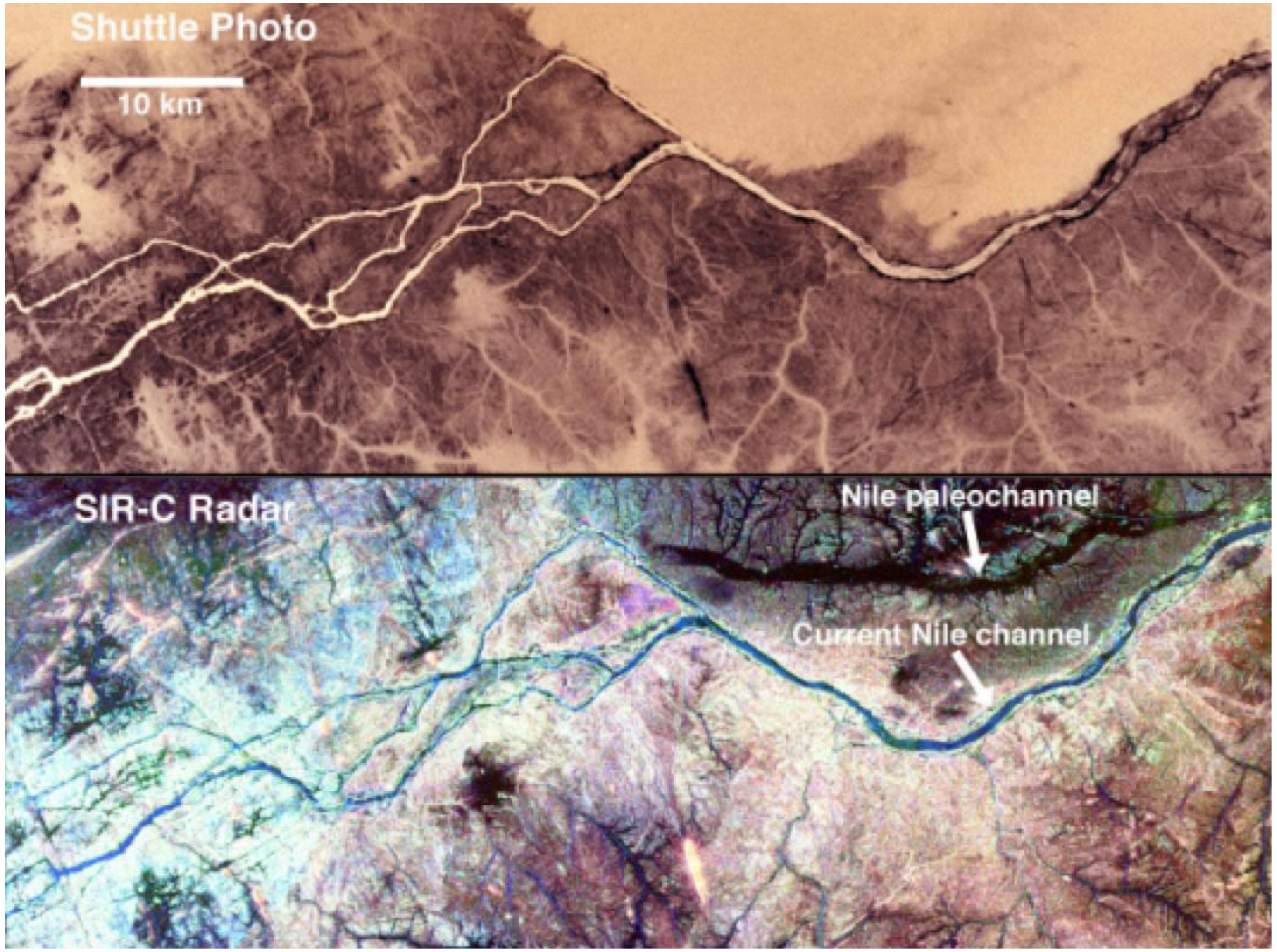


Image Based On ESA Radar Course 2

Frequency Band	Application Example
VHF	foliage & ground penetration, biomass
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: Signal Penetration into Dry Soils



Example: Signal Penetration into Vegetation

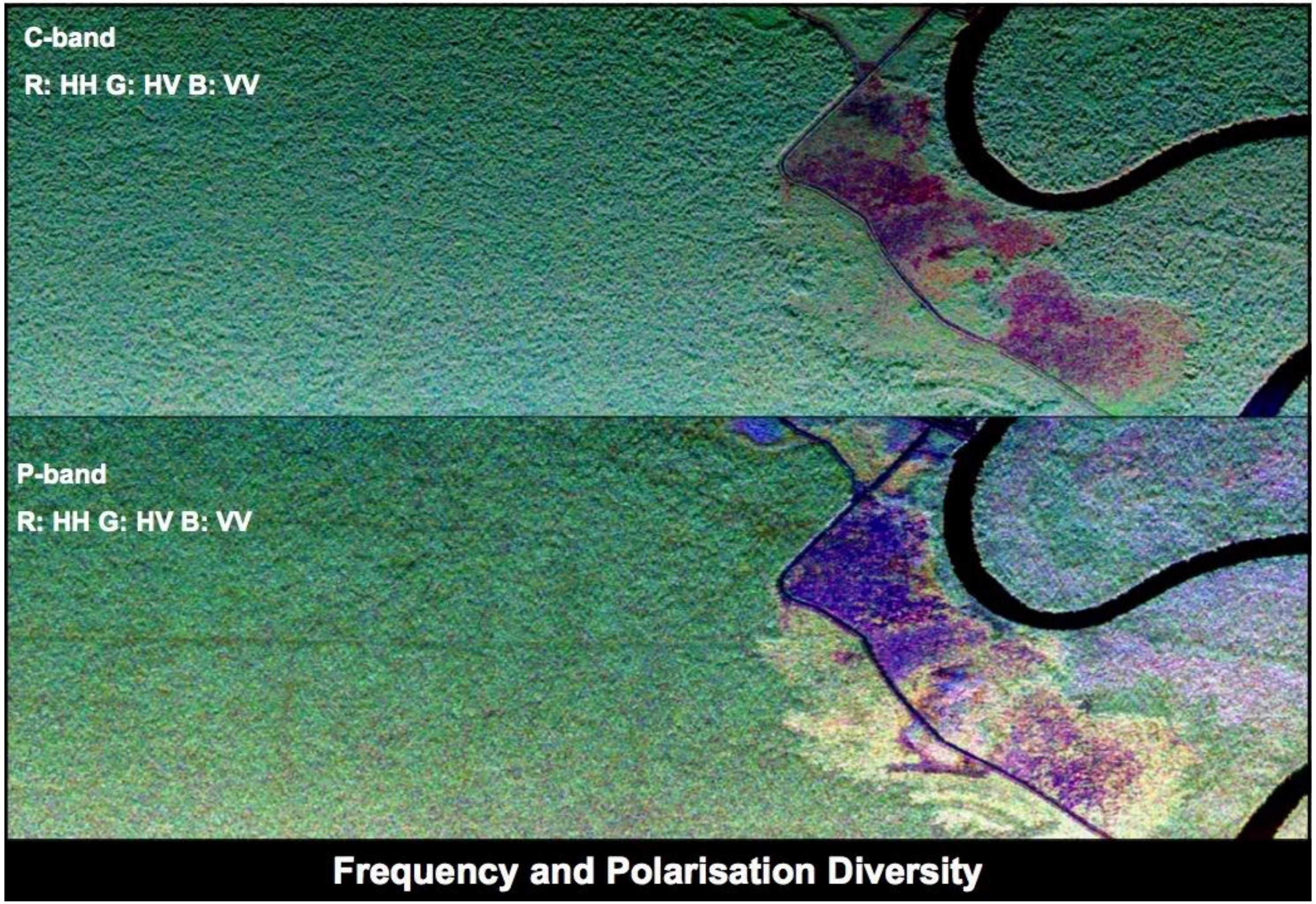
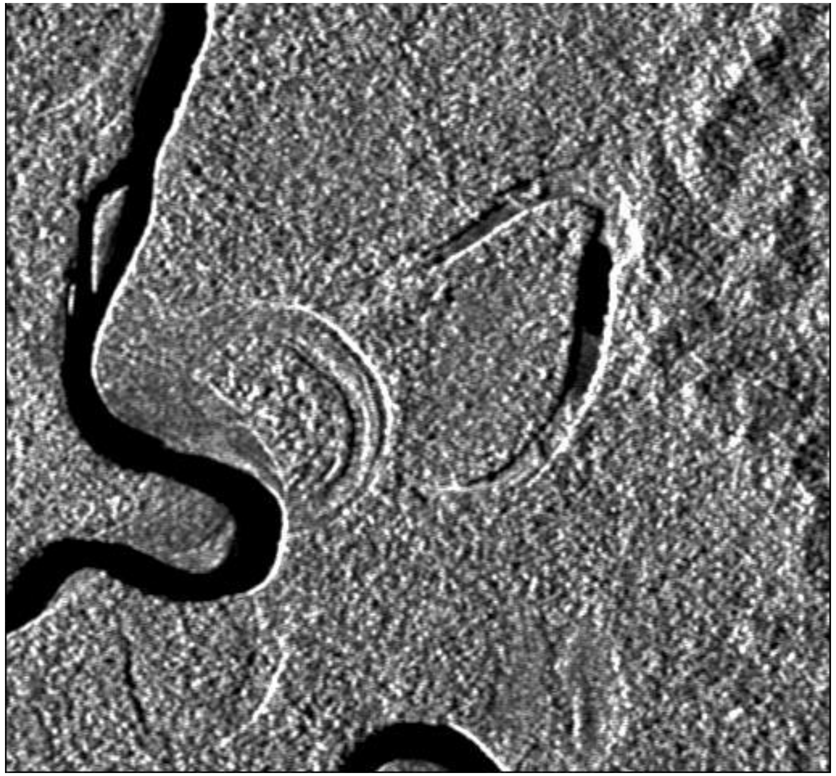


Image Credit: A Moreira (ESA)

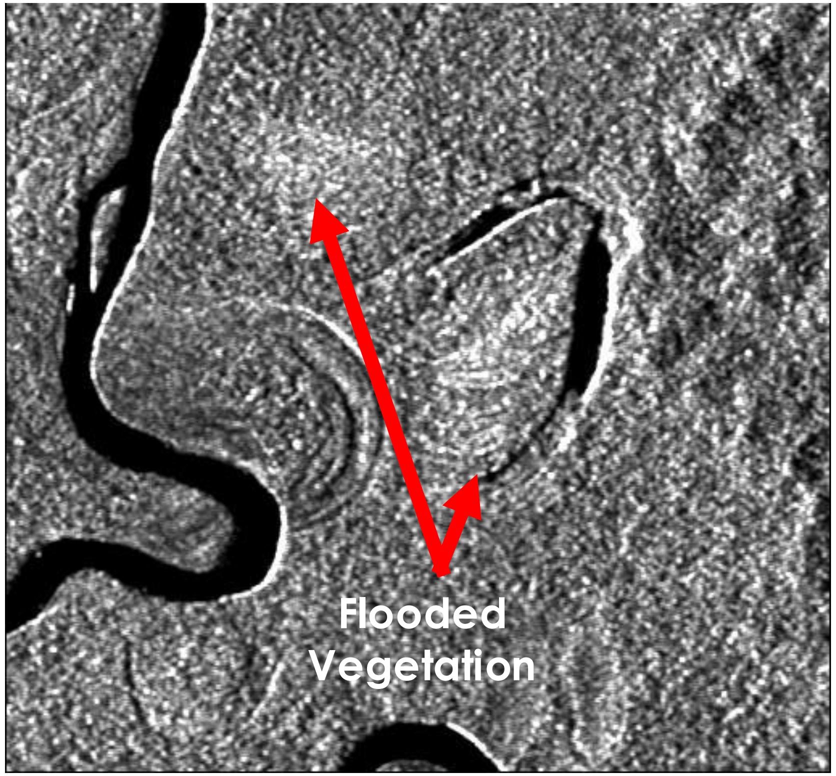
Example: Signal Penetration into Inundated Vegetation

Multi-frequency AIRSAR Data in Manu National Park, Peru

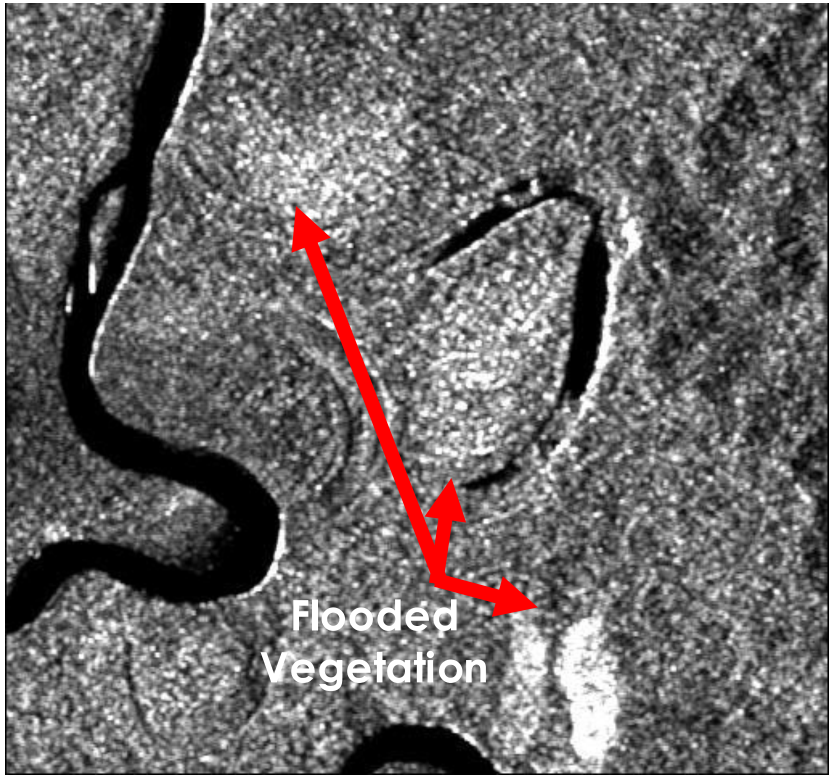
C-Band



L-Band



P-Band



Radar Parameter: Polarization

- **Polarization:** The orientation of the electric field of the electromagnetic wave.
- The polarizations are usually controlled between **H** and **V**:
  - HH: Horizontal Transmit, Horizontal Receive
  - VV: Vertical Transmit, Vertical Receive
  - HV: Horizontal Transmit, Vertical Receive
  - VH: Vertical Transmit, Horizontal Receive

- **Quad-Pol Mode:** When all four polarizations are measured.
- Different polarizations can determine physical properties of the object observed.

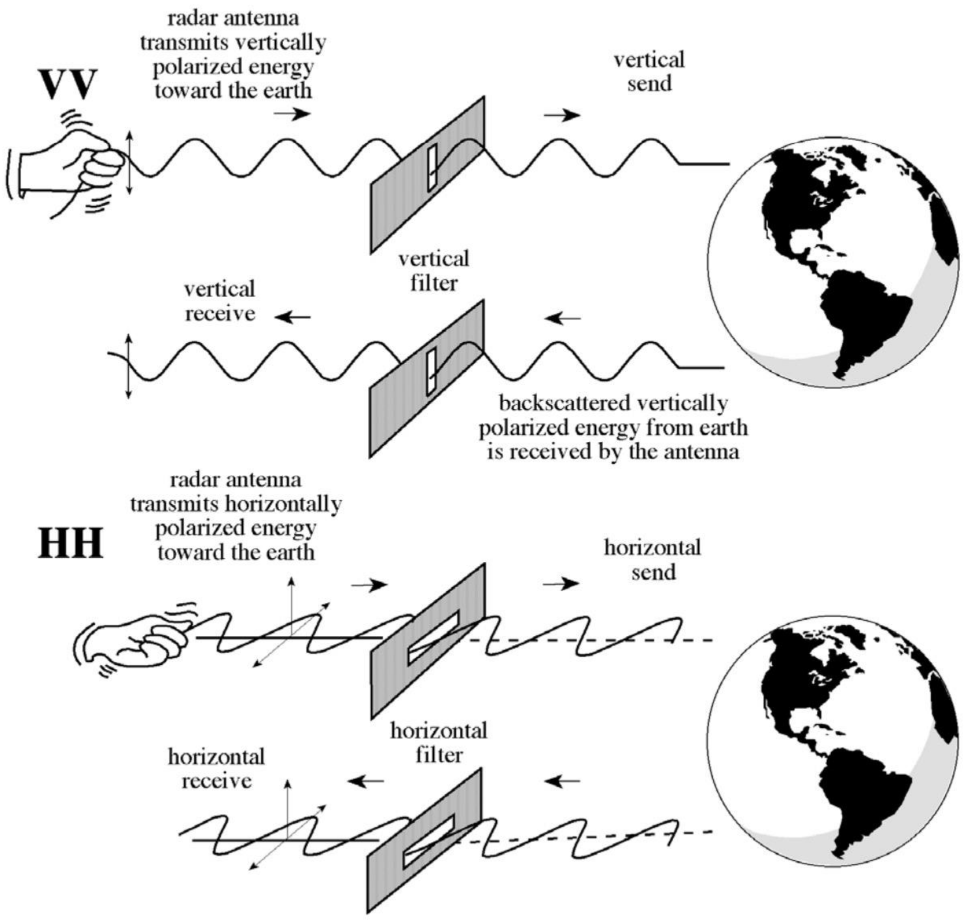
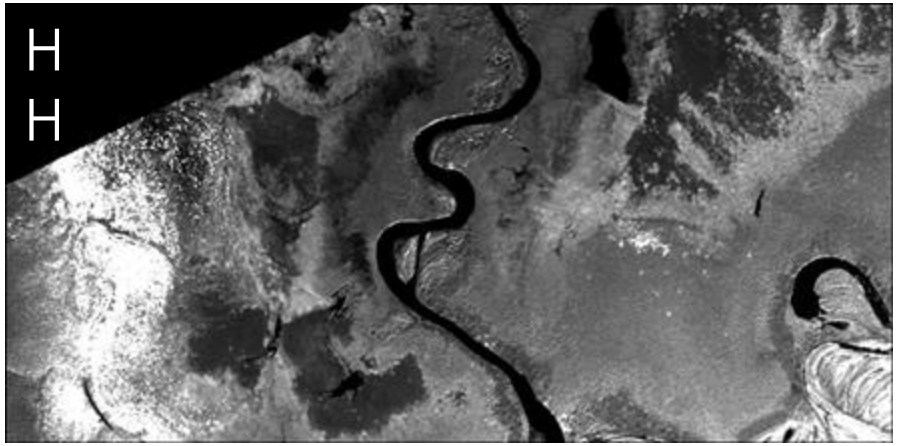


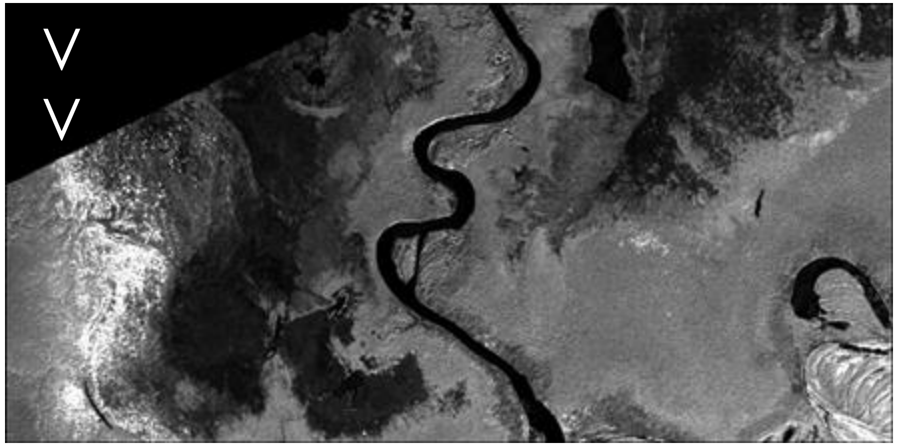
Image Credit: J.R. Jensen, 2000. Remote Sensing of the Environment

Example of Multiple Polarizations for Vegetation Studies

Pacaya-Samiria Forest Reserve in Peru

Images from UAVSAR (HH, HV, VV)

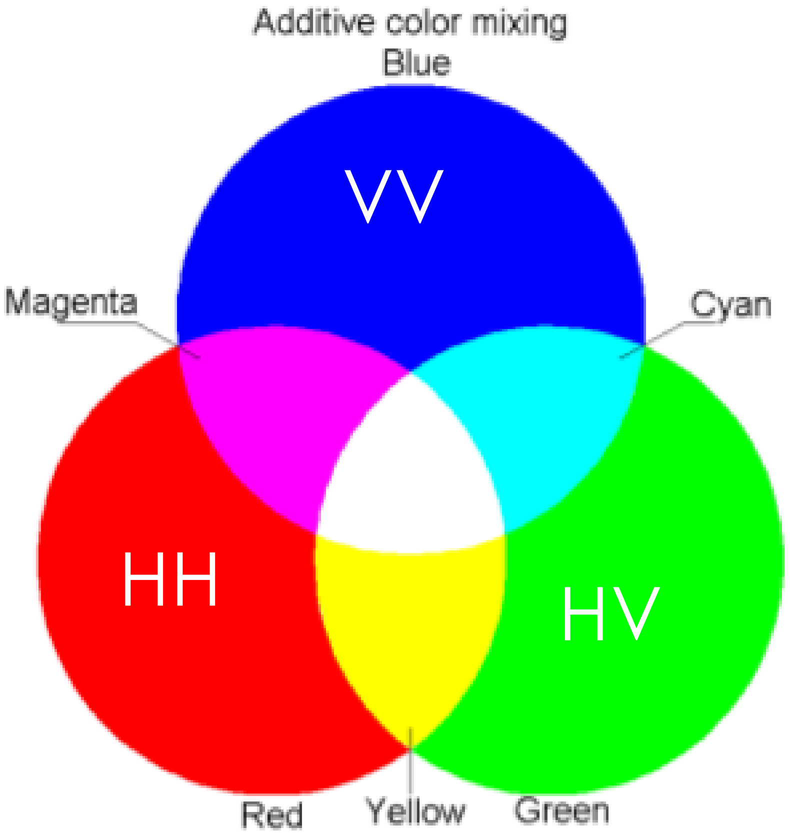


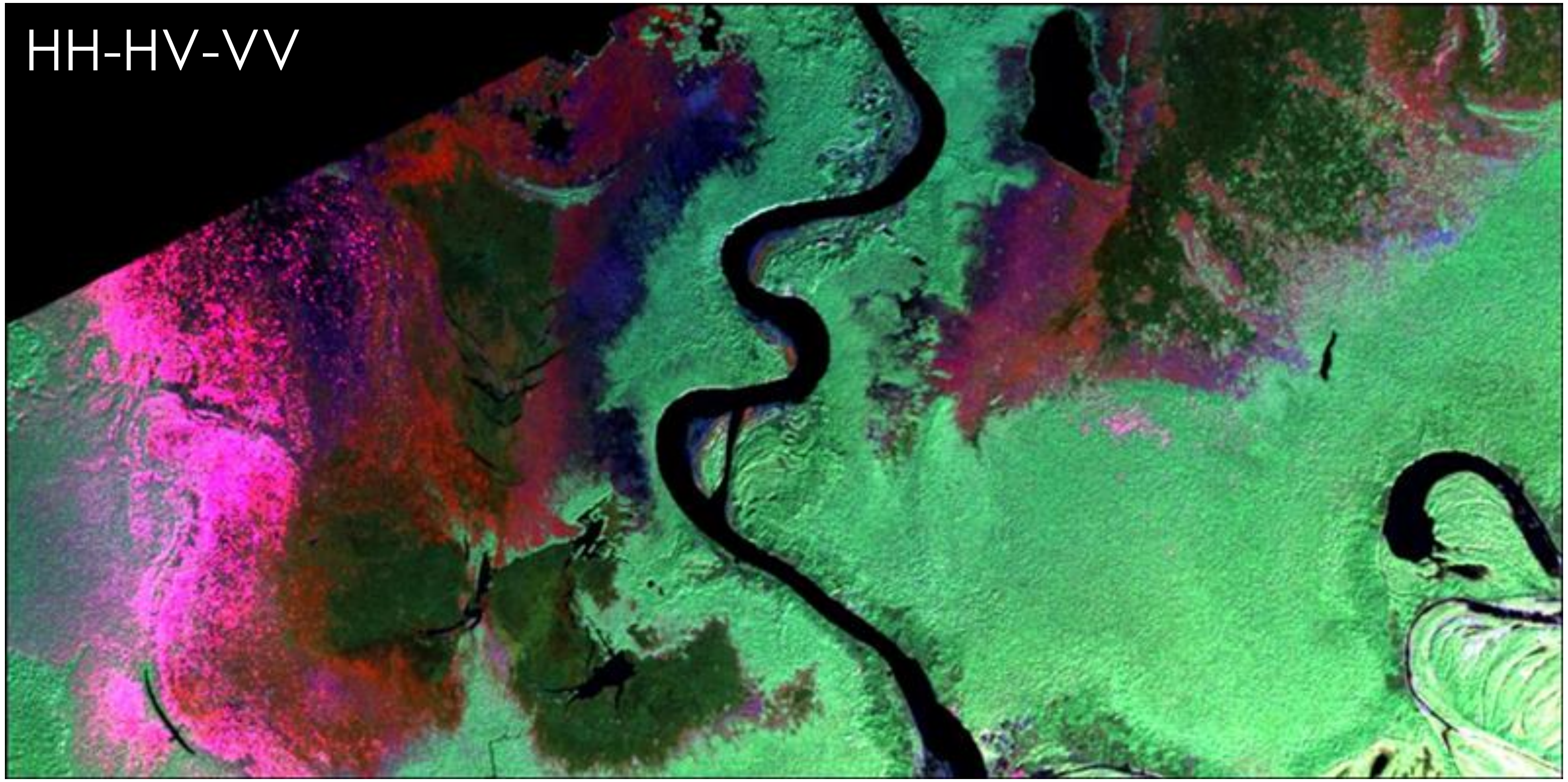


Visualization of Multiple Polarizations for Vegetation Studies

Pacaya-Samiria Forest Reserve in Peru

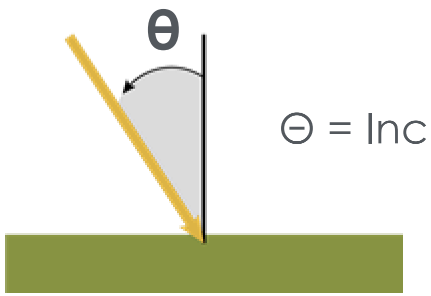
Images from UAVSAR (HH, HV, VV)





Radar Parameter: Incidence Angle

- The angle between the direction of illumination of the radar and the Earth's surface plane.
- Is dependent on the height of the sensor.
- Influences image brightness.
- This is why the geometry of an image is different from point to point in the range direction.



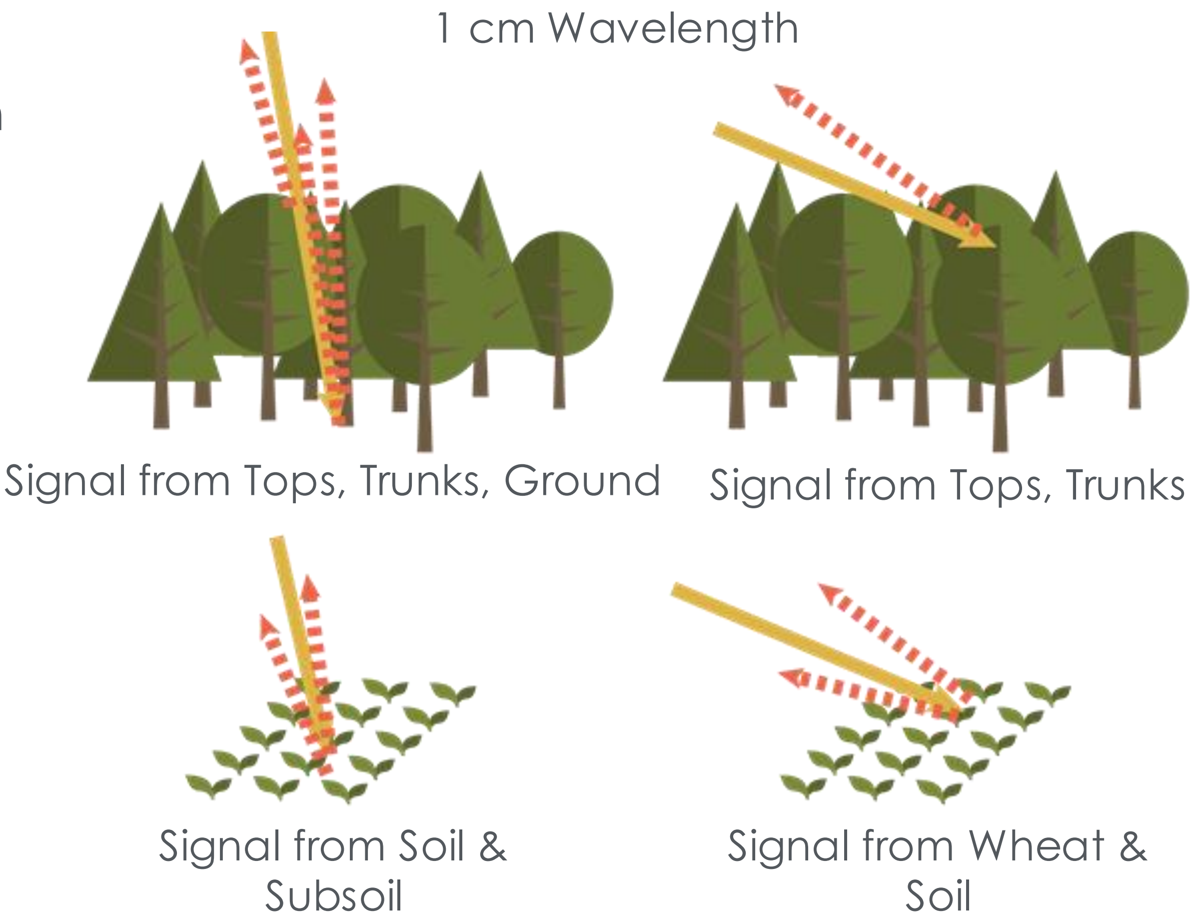
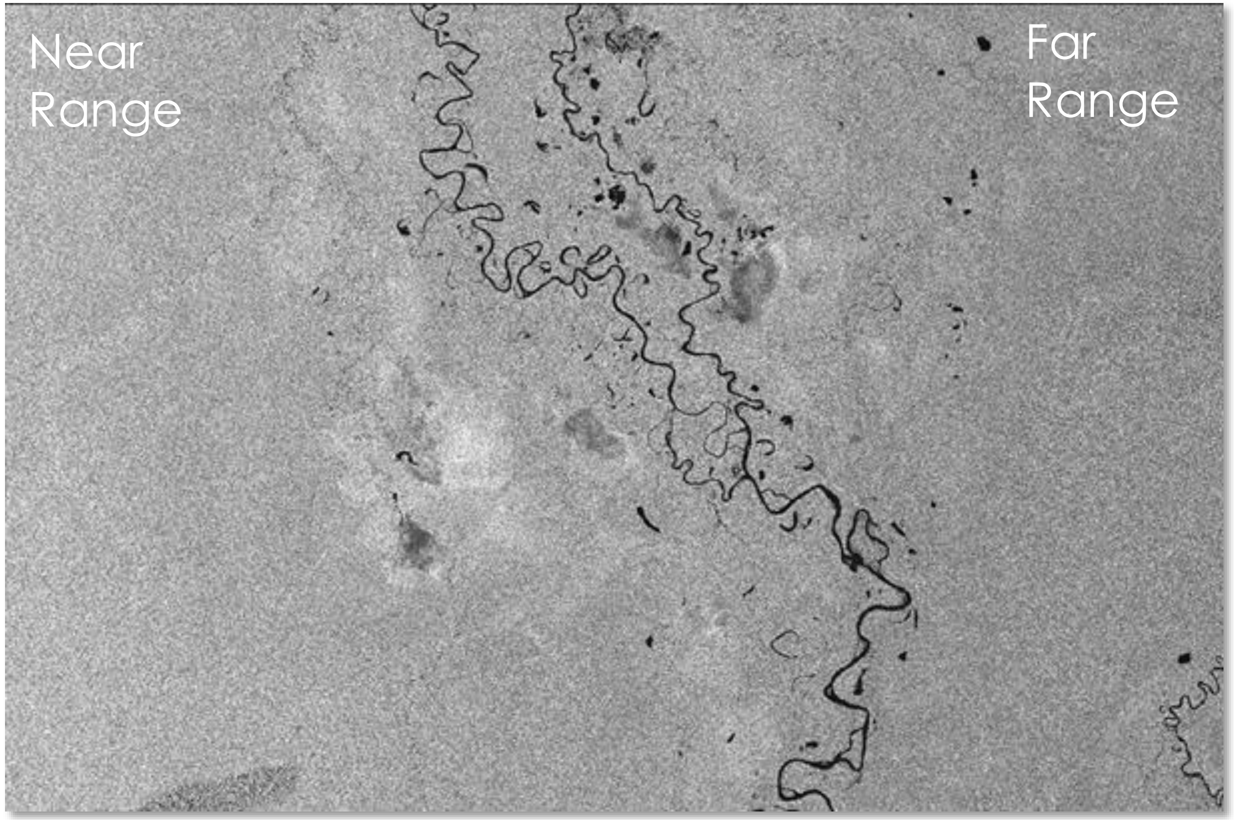
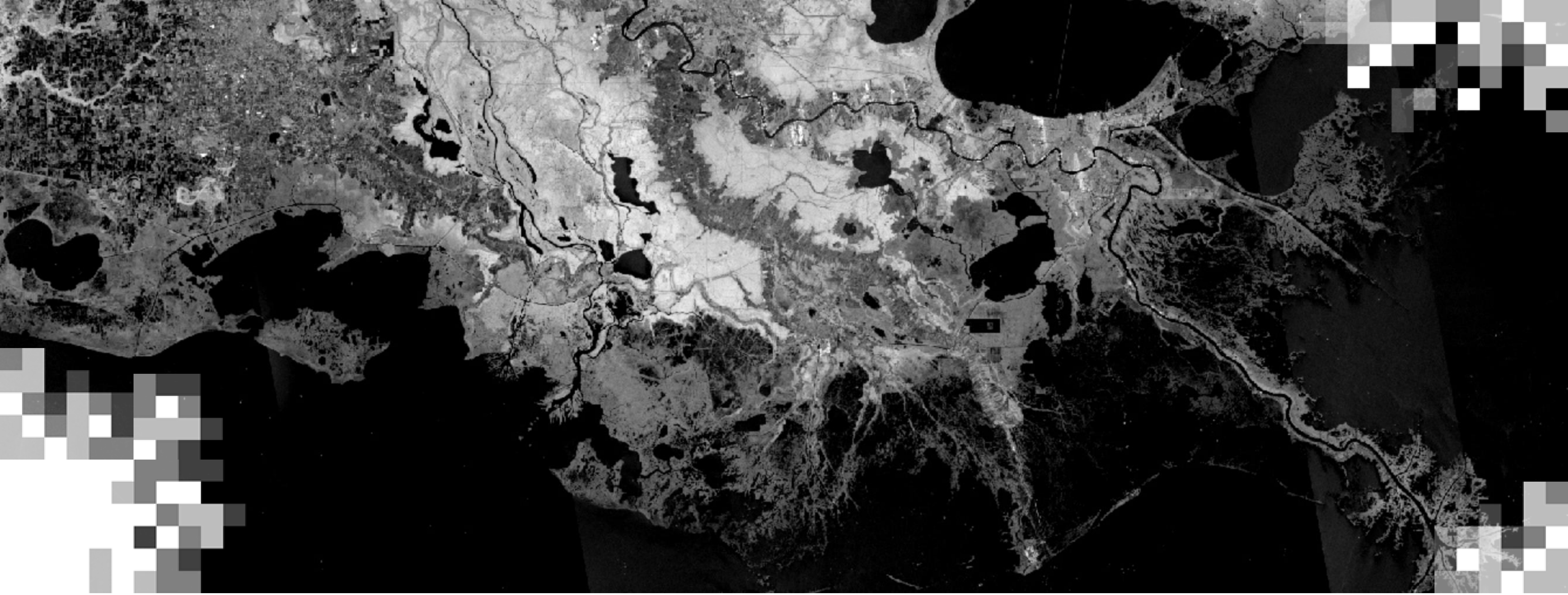


Image Credit: Ulaby et al. (1981a) and ESA

Effect of Incidence Angle Variation



Sentinel-1



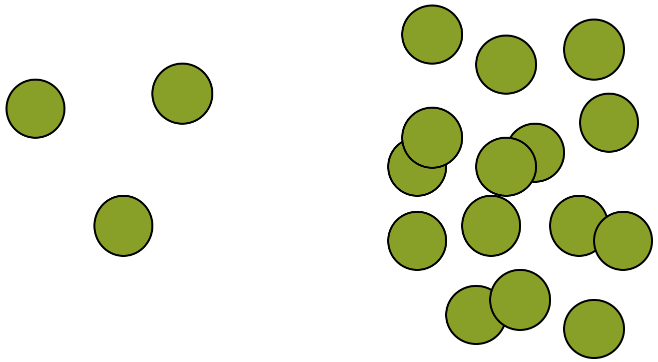
Surface Parameters that Influence the Signal

Radar Backscatter

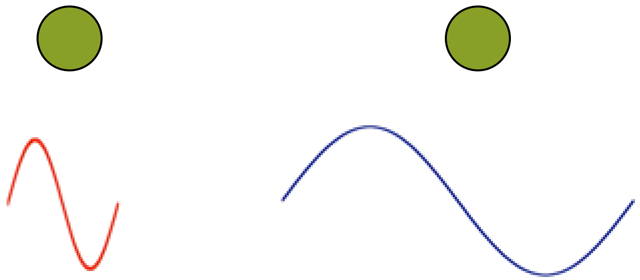
- The radar backscatter contains information about the Earth's surface, which drives the reflection of the radar signal.
- This reflection is driven by:
  - The Frequency or Wavelength: Radar Parameter
  - Polarization: Radar Parameter
  - Incidence Angle: Radar Parameter
  - **Structure (Surface Roughness Relative to the Wavelength):** Surface Parameter
  - **Moisture (Dielectric Constant):** Surface Parameter

Structure: Density, Size, and Orientation

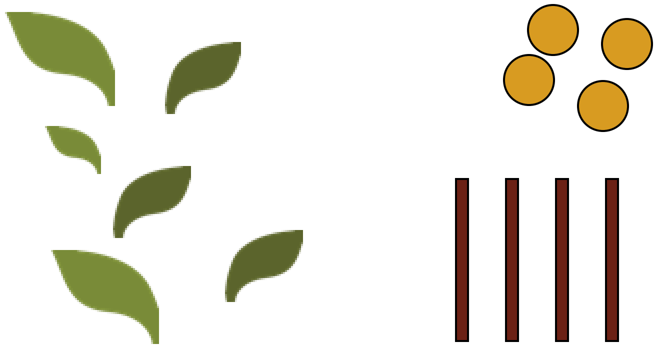
Density



Size Relative to Wavelength



Size & Orientation



Size Relative to Wavelength

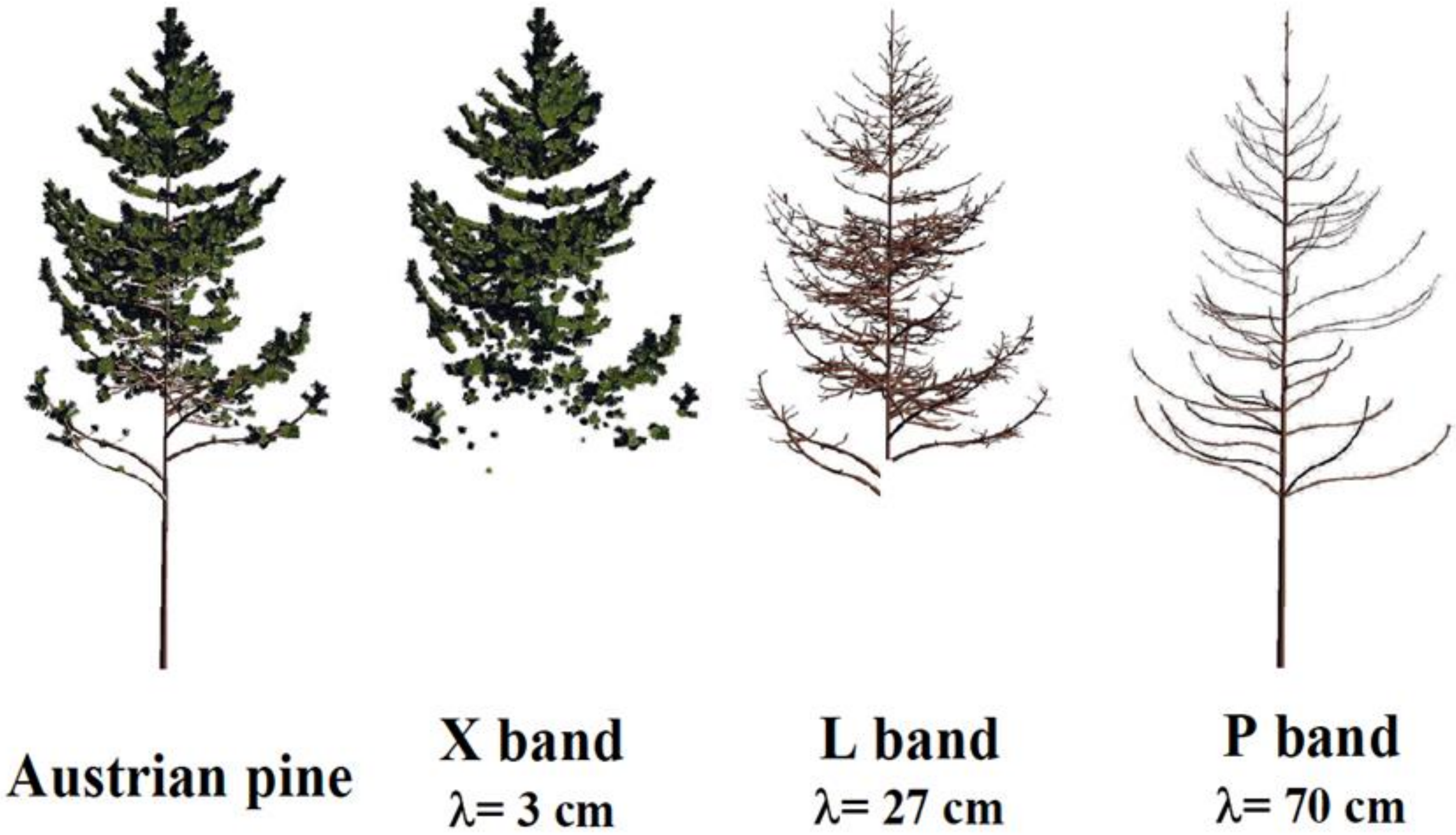


Image Credit: Thuy le Toan

Size and Orientation

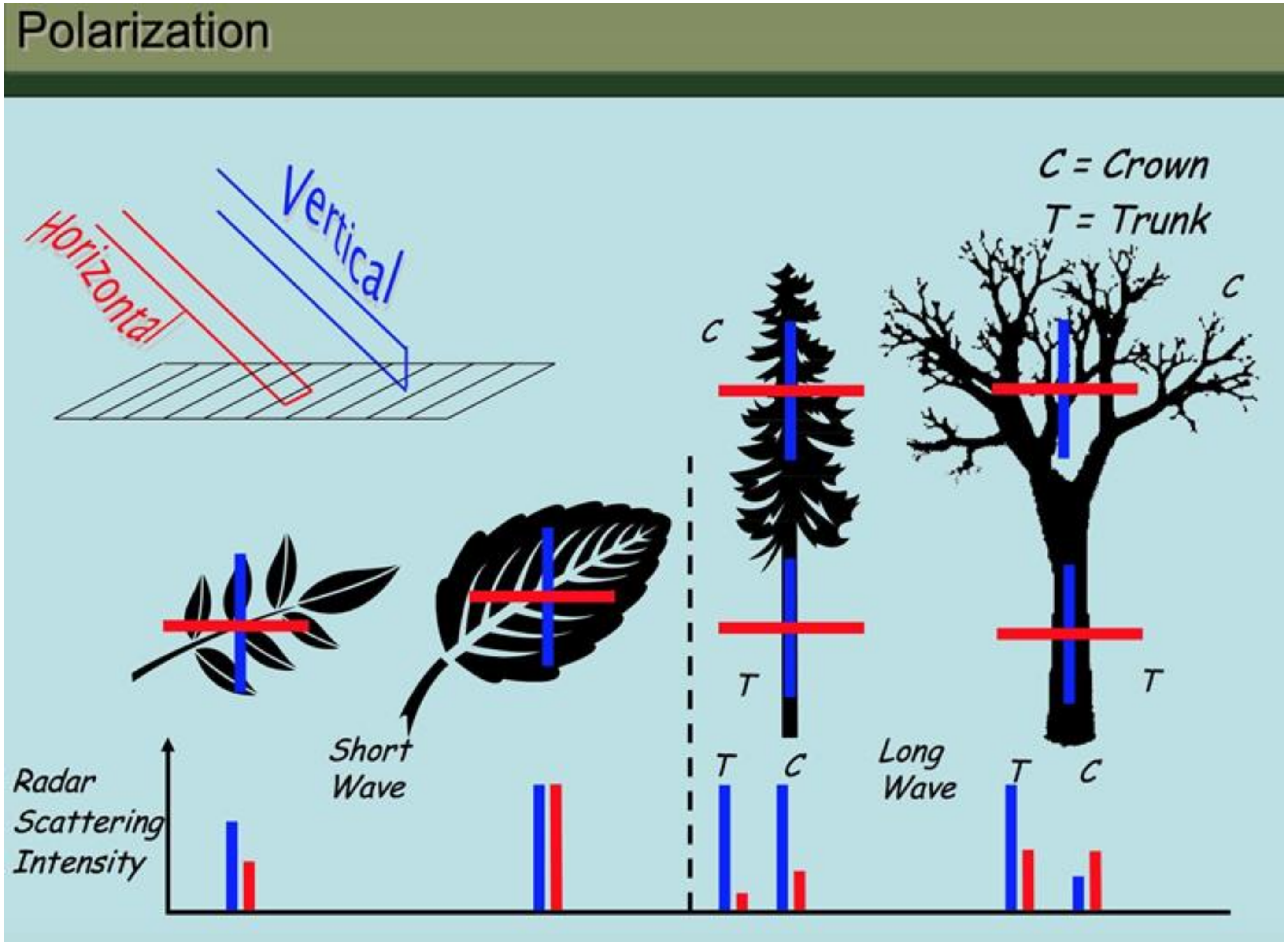
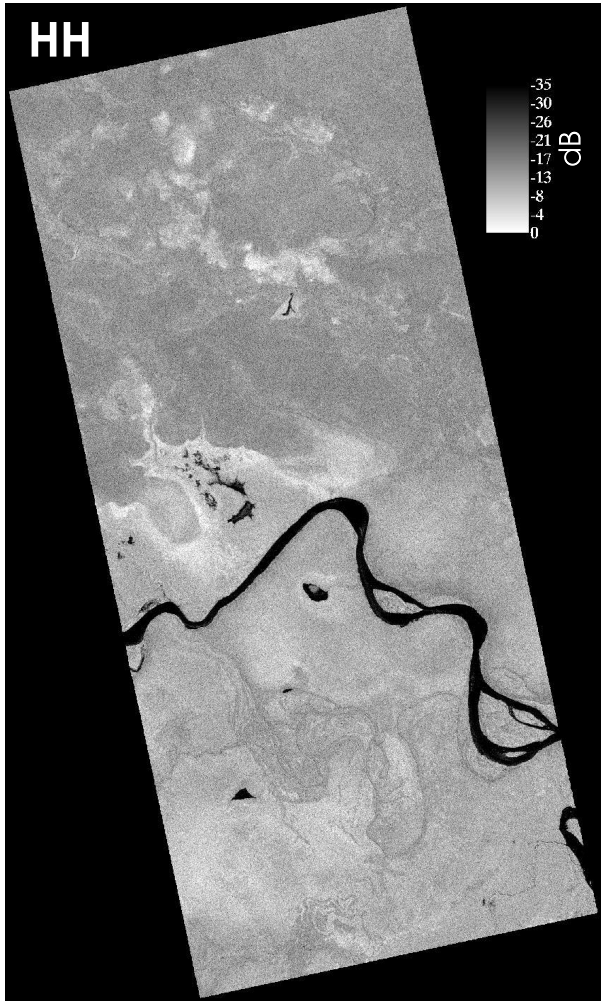
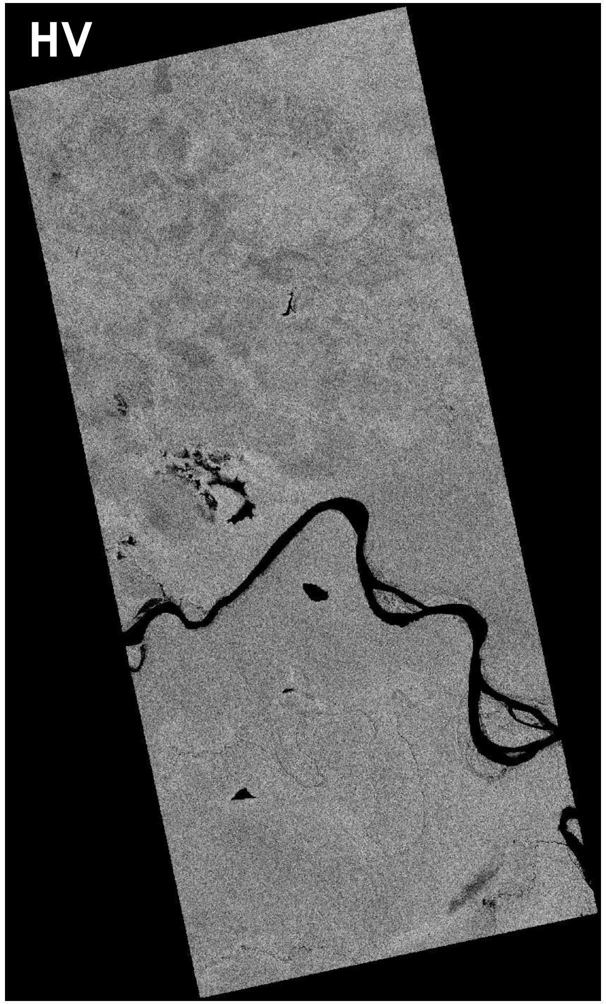


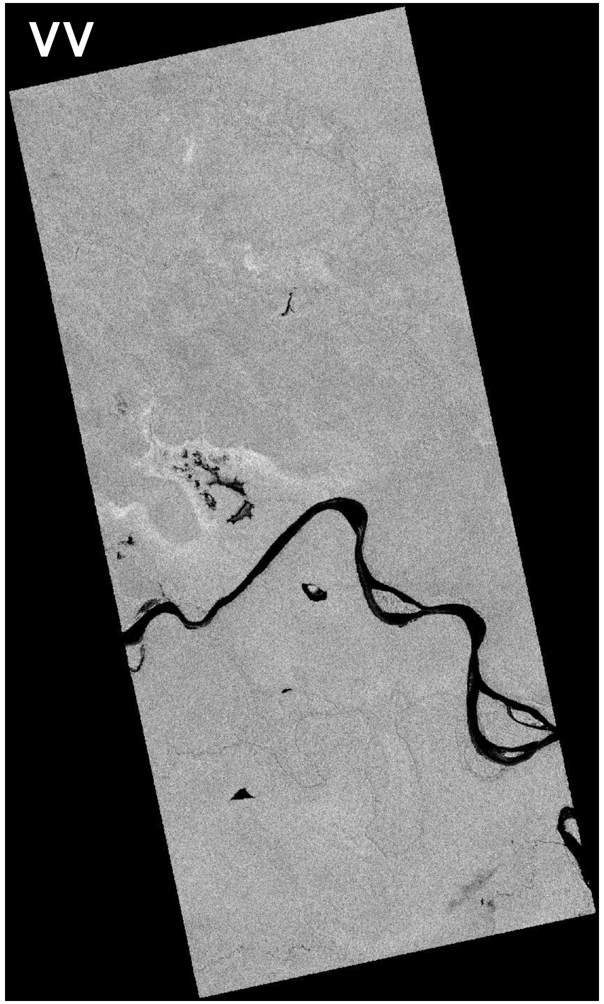
Image Credit: Walker, W. *Introduction to Radar Remote Sensing for Vegetation Mapping and Monitoring*

Orientation and Signal Penetration

Images from Palsar (L-band) over Pacaya-Samiria in Peru







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)

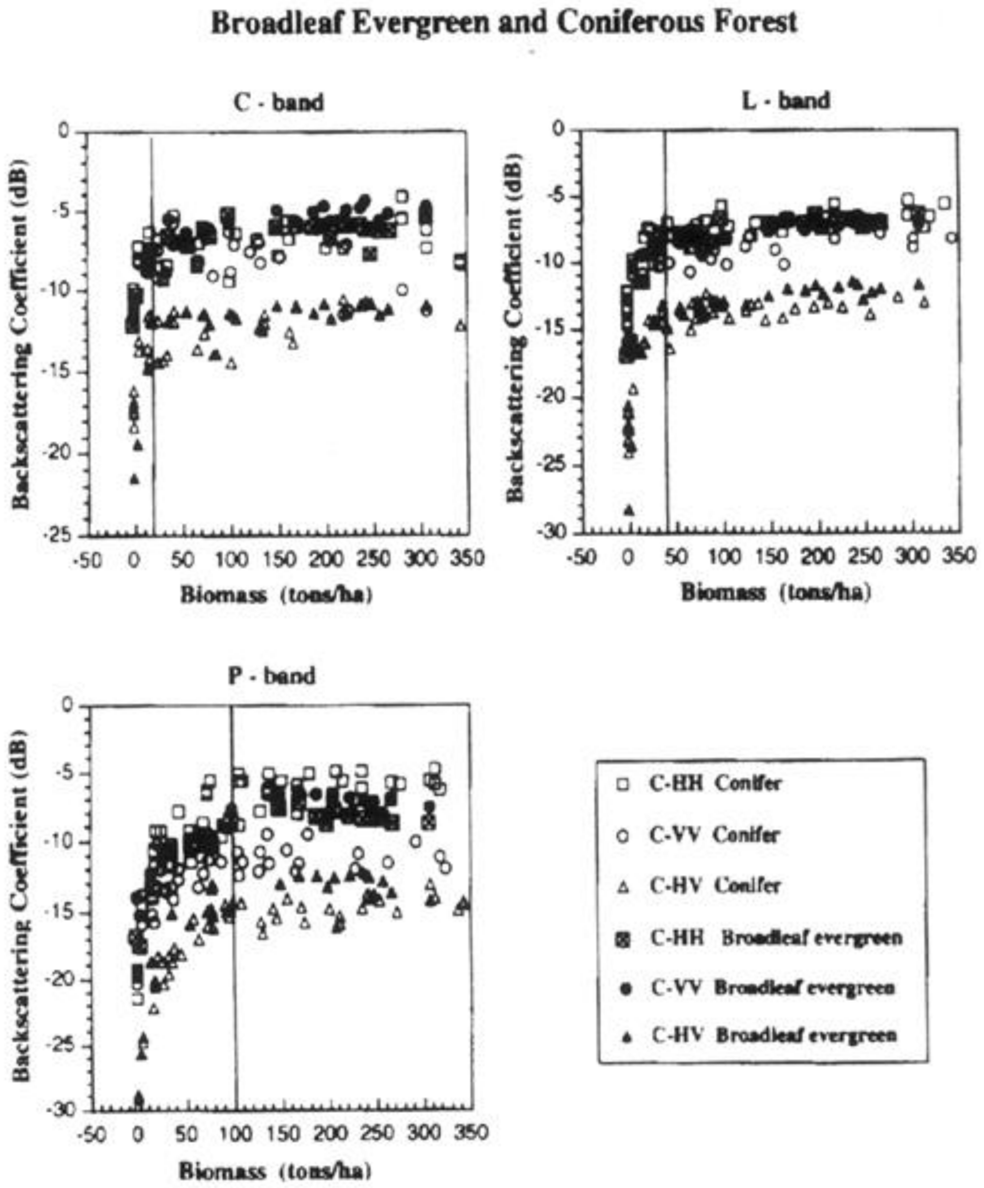
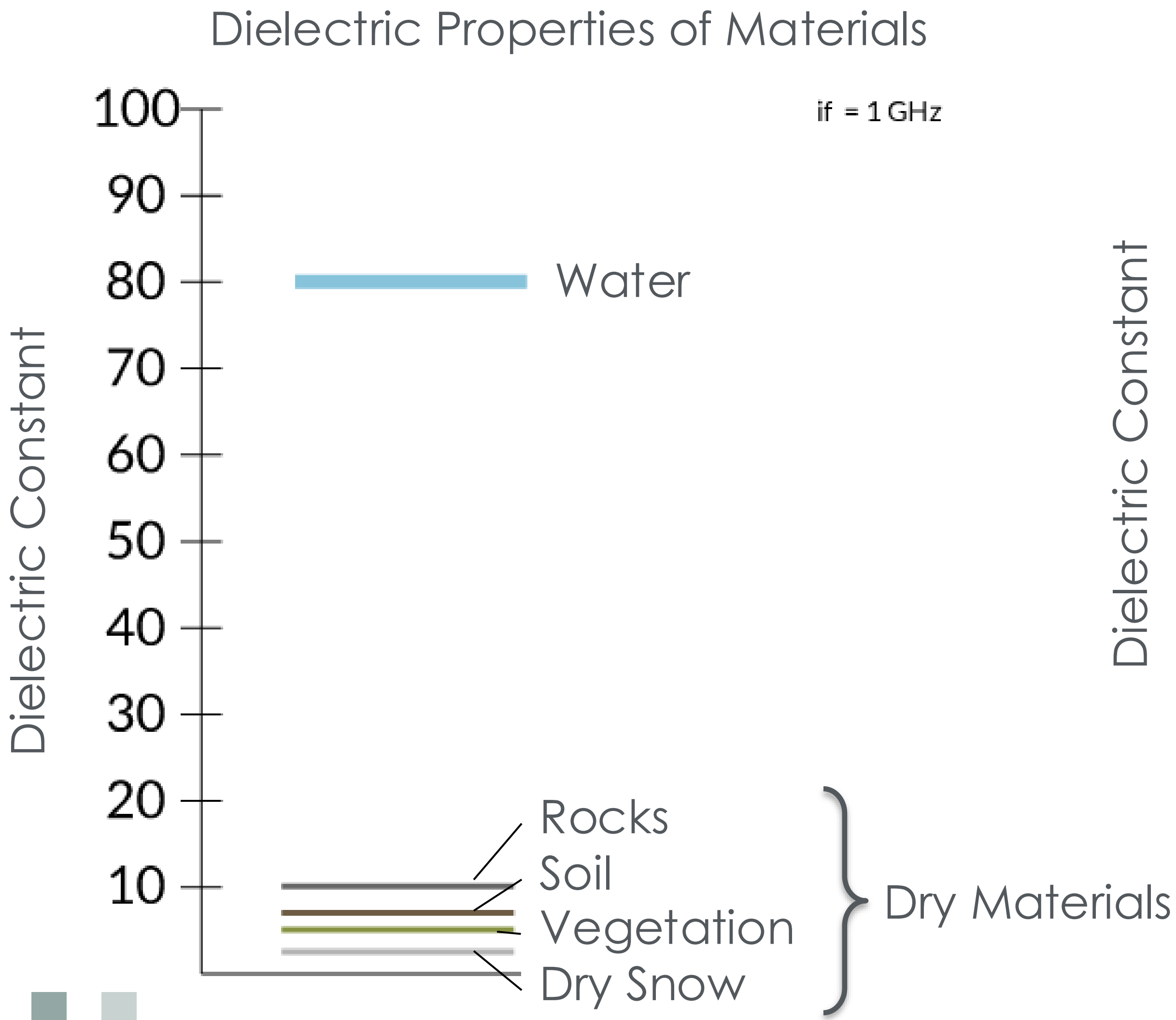
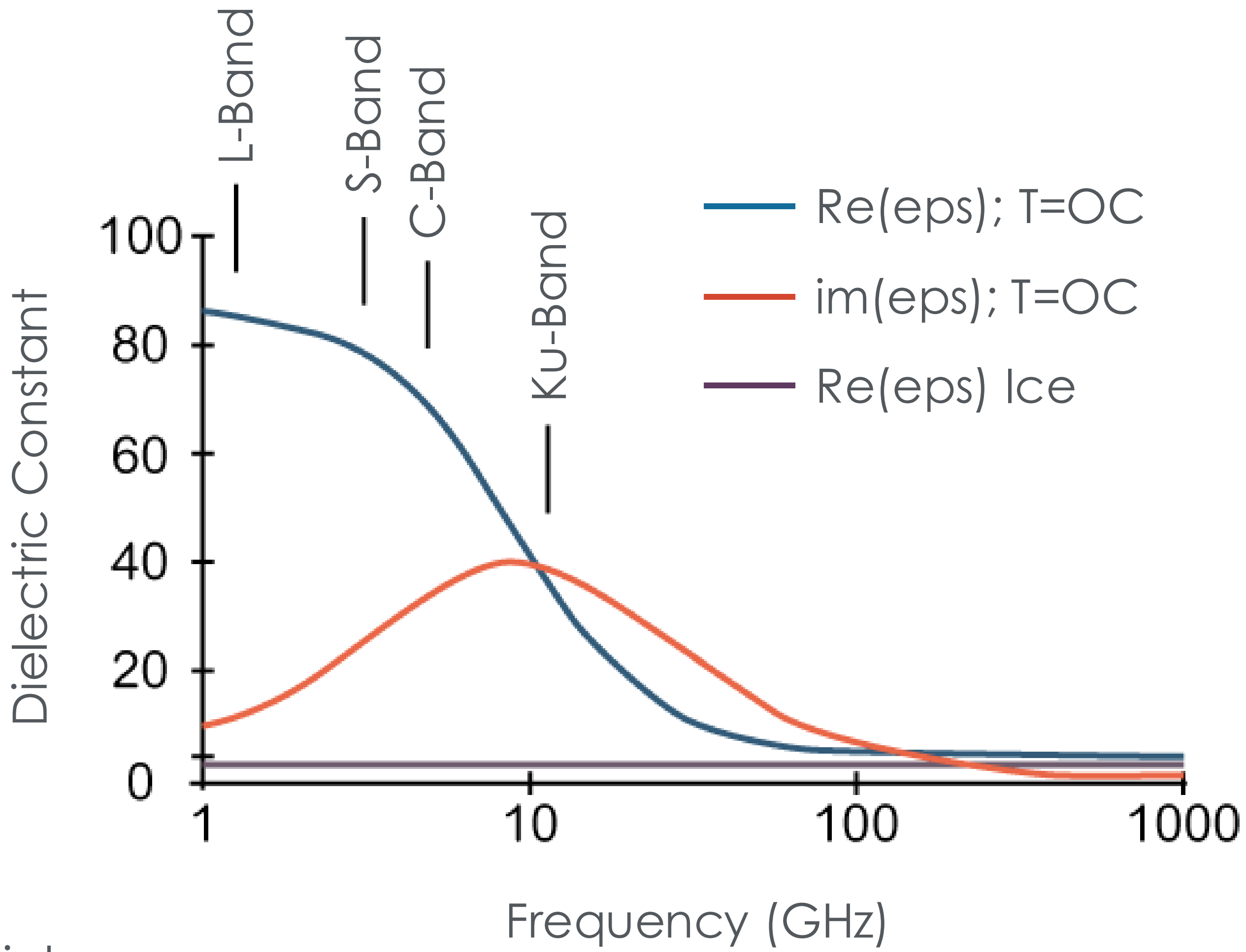


Image Credit: Imhoff et al., 1995

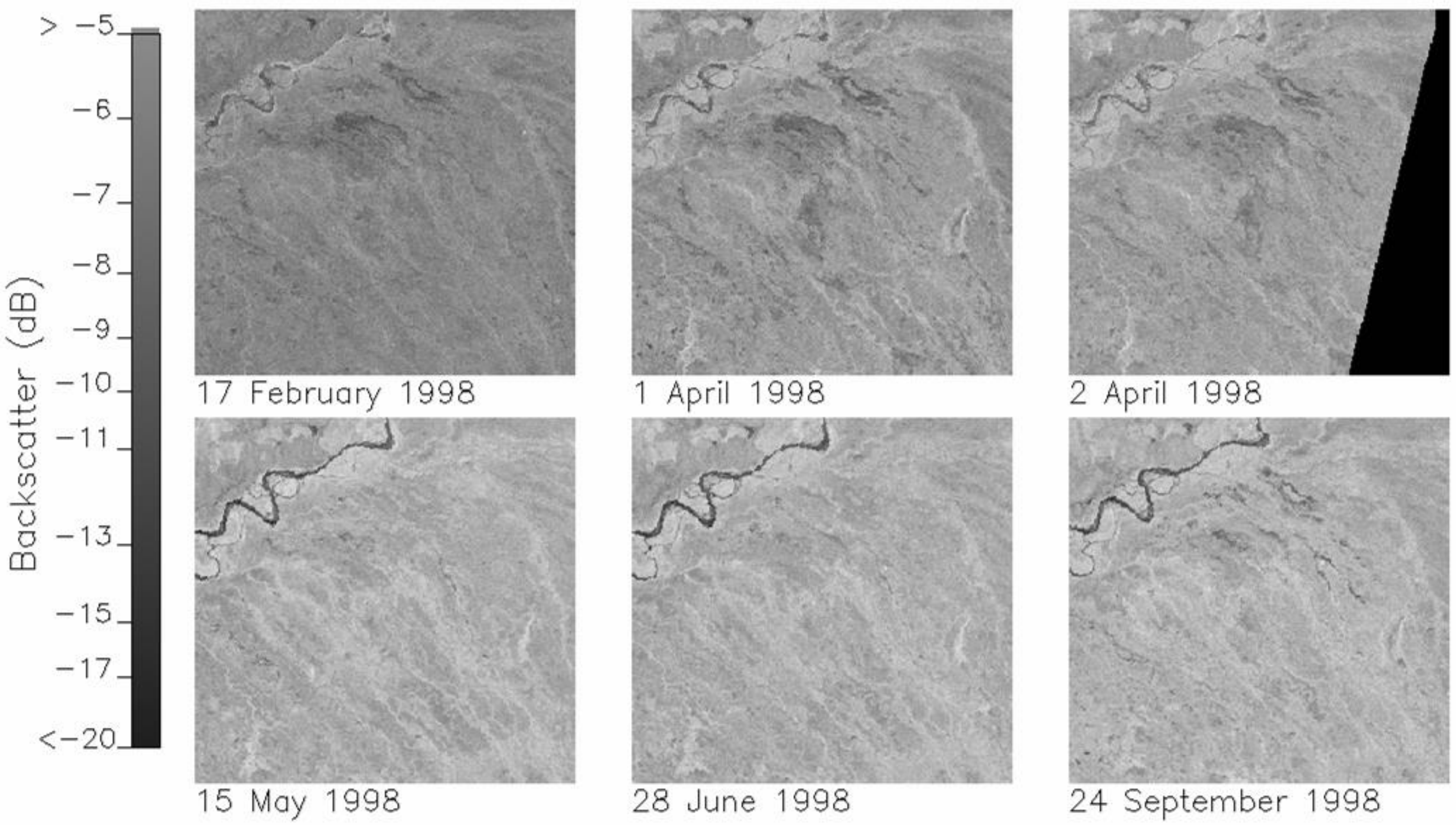
Surface Parameter: Dielectric Constant

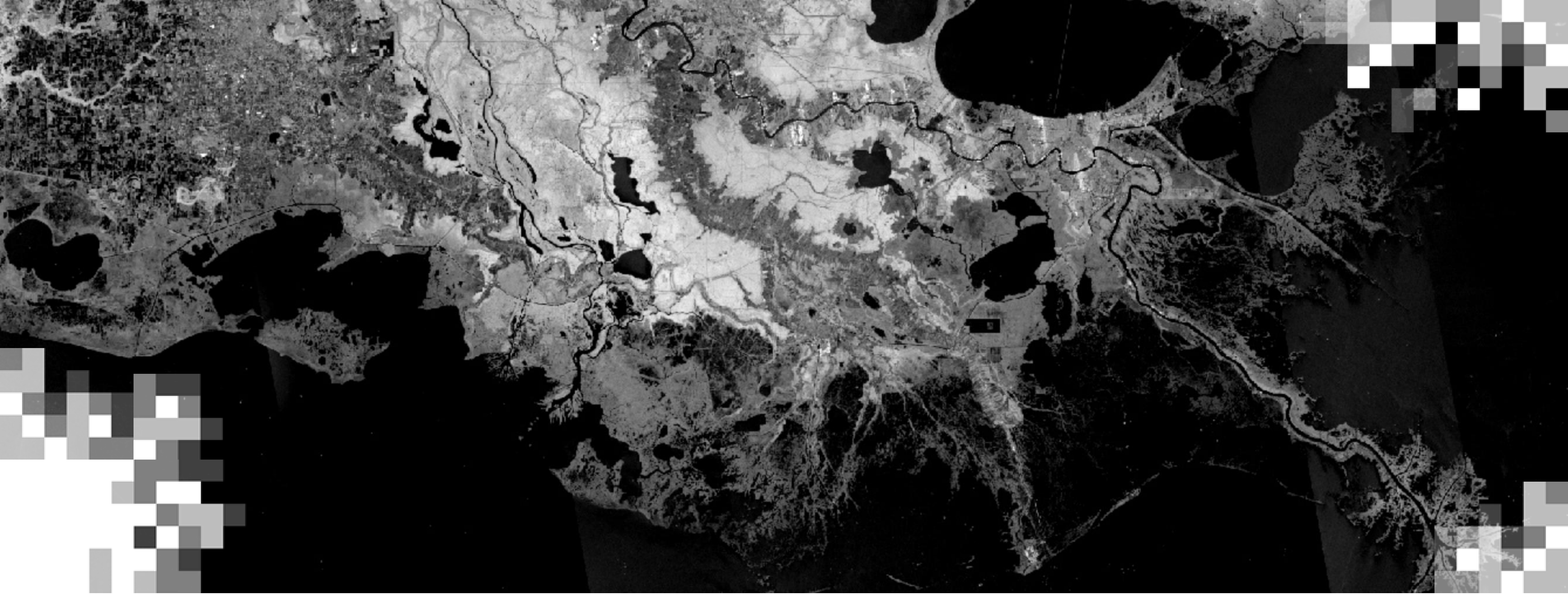




Dielectric Properties of the Surface and its Frozen or Thawed State

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

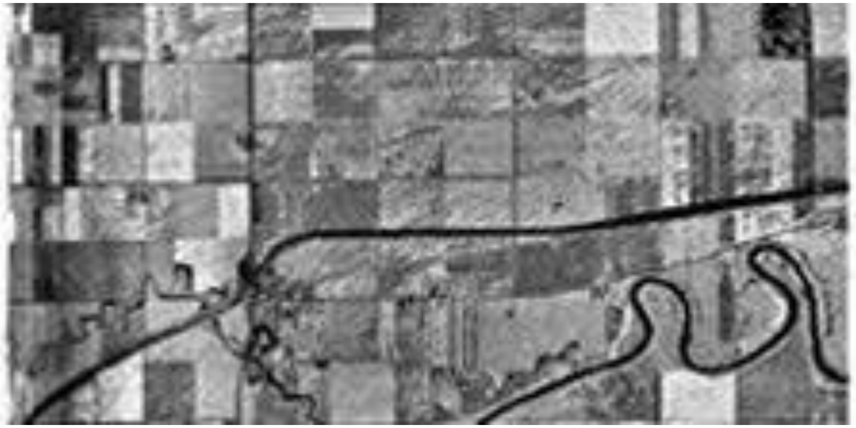




Radiometric and Geometric Distortions

Slant Range Distortion

Slant Range



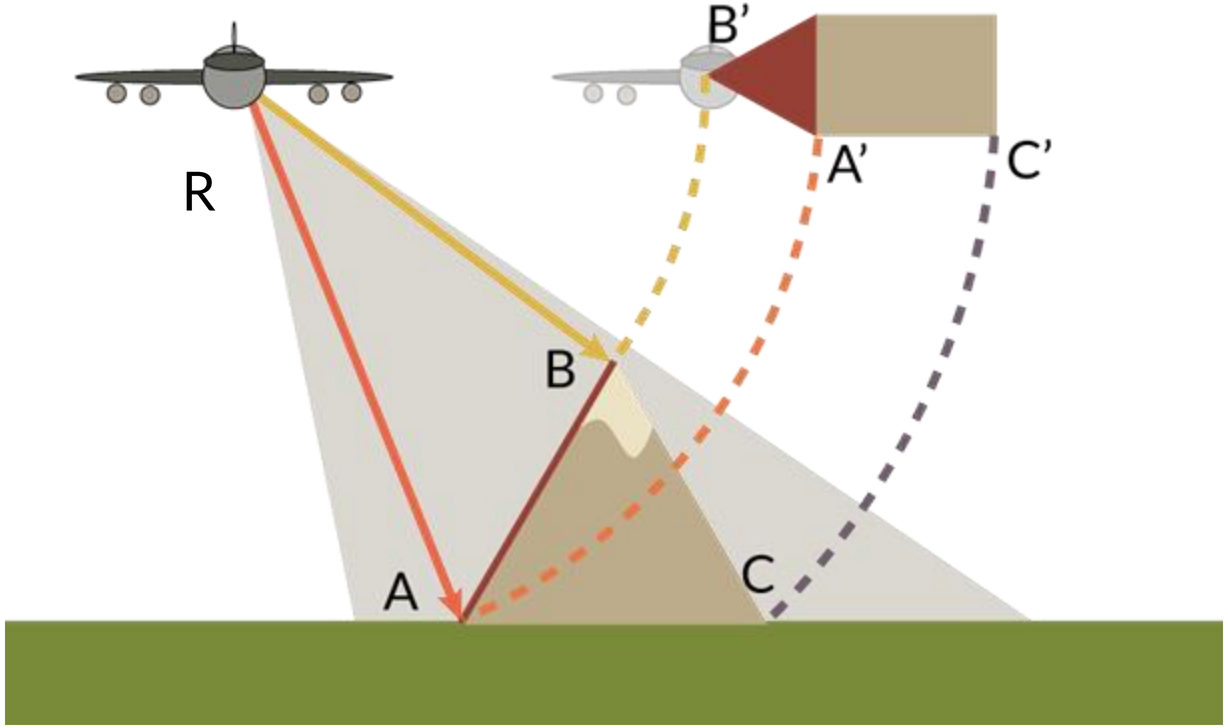
Ground Range

Source: Natural Resources Canada

Geometric Distortion: Layover and Foreshortening

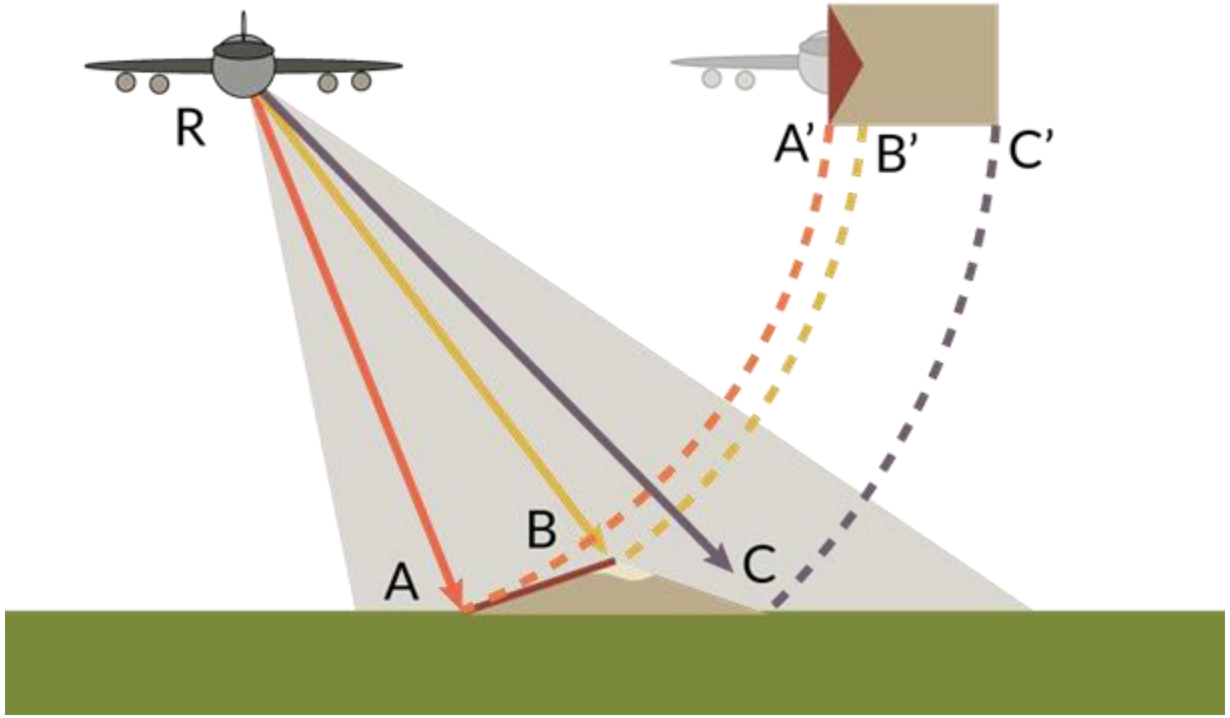
Layover

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



Foreshortening

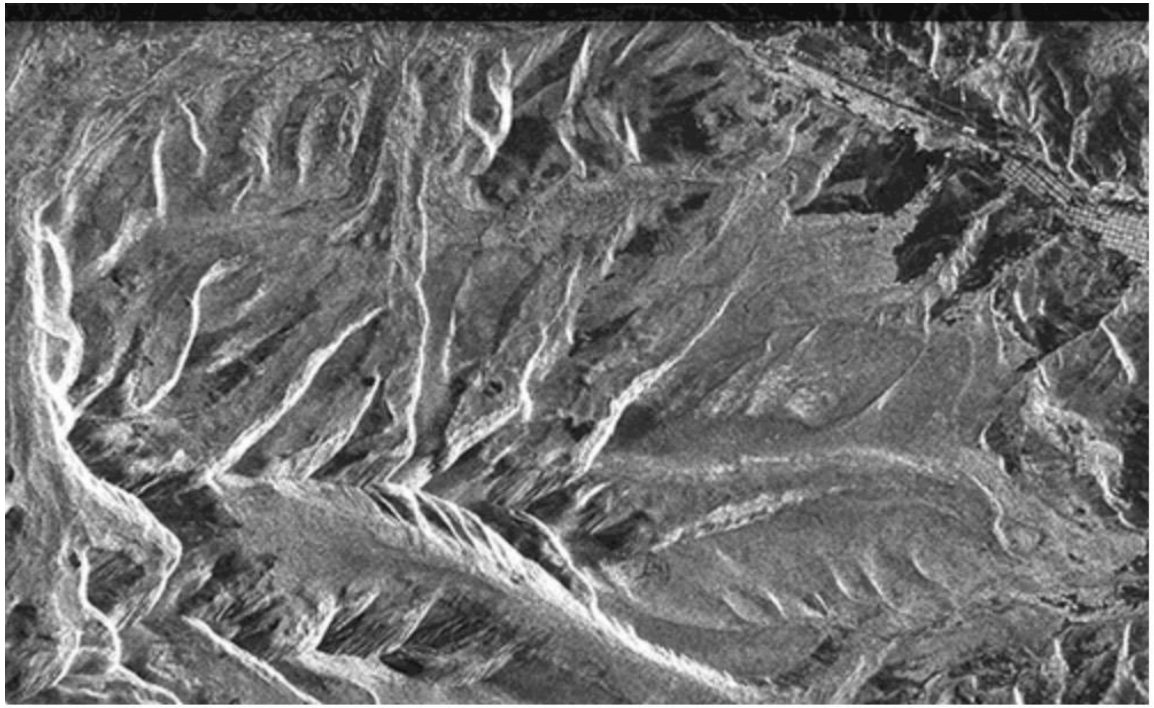
RA < RB < RC
AB = BC
A'B' < B'C'



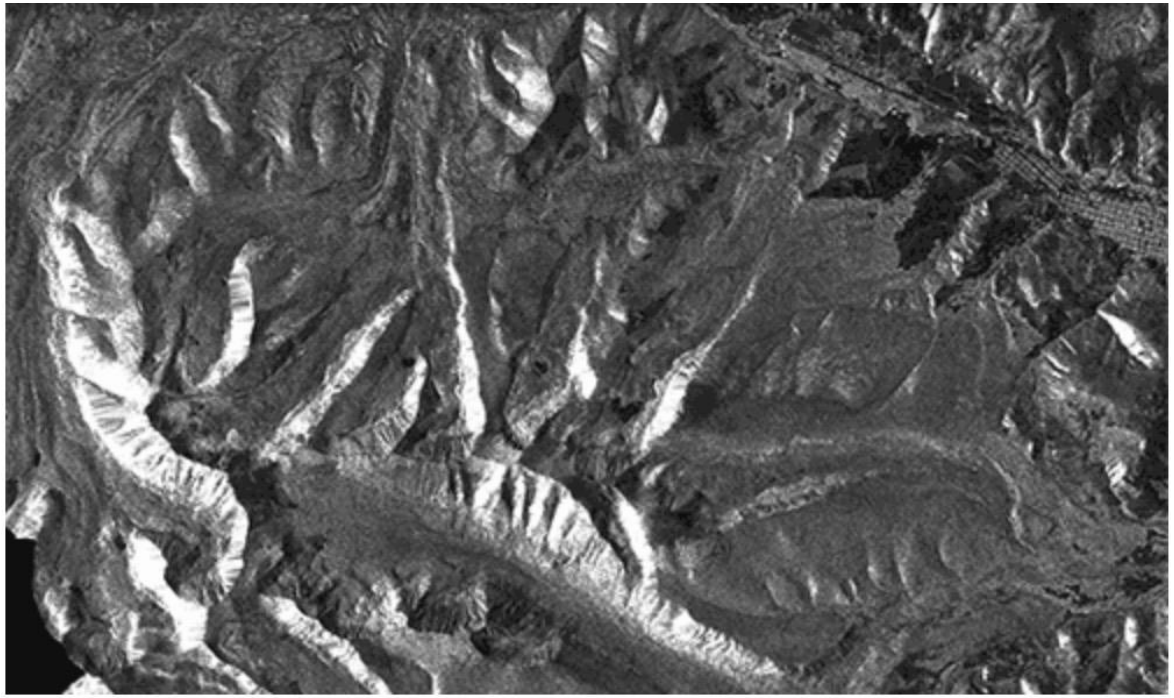
Source: Natural Resources Canada

Foreshortening

Before Correction

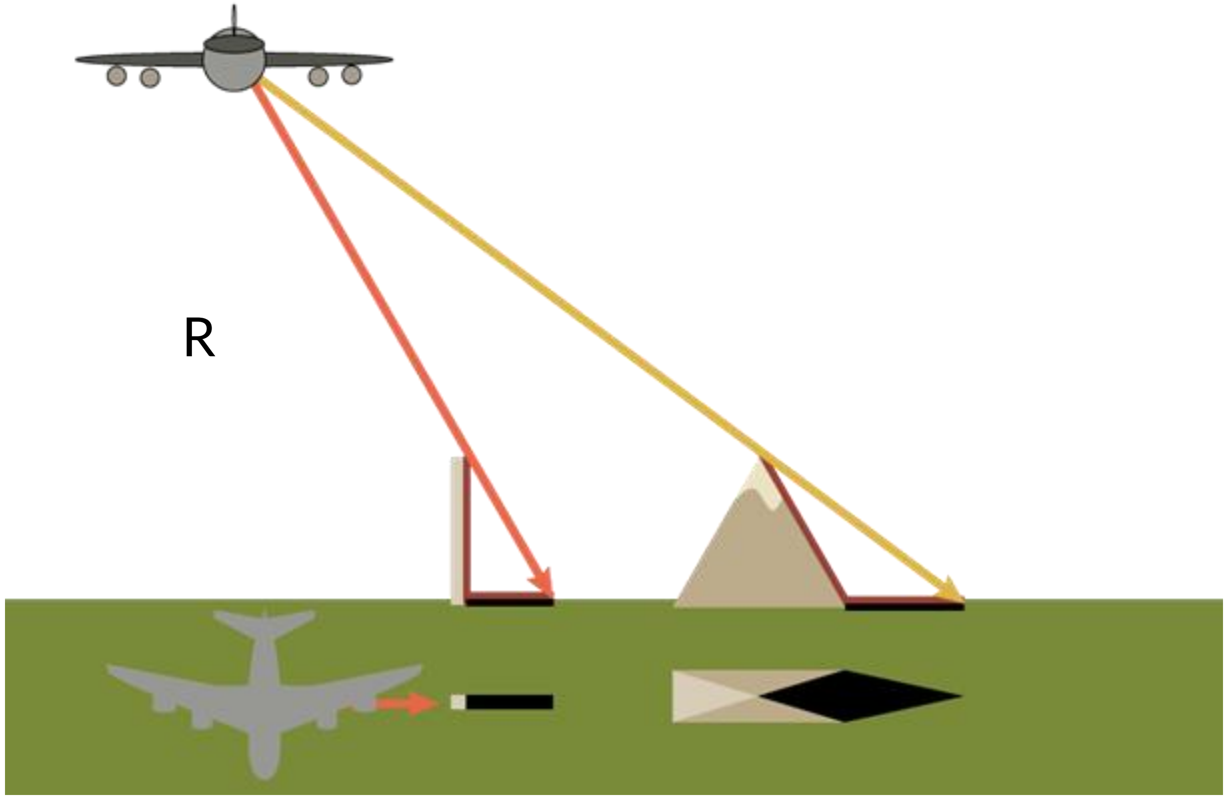


After Correction



Source: ASF

Shadow

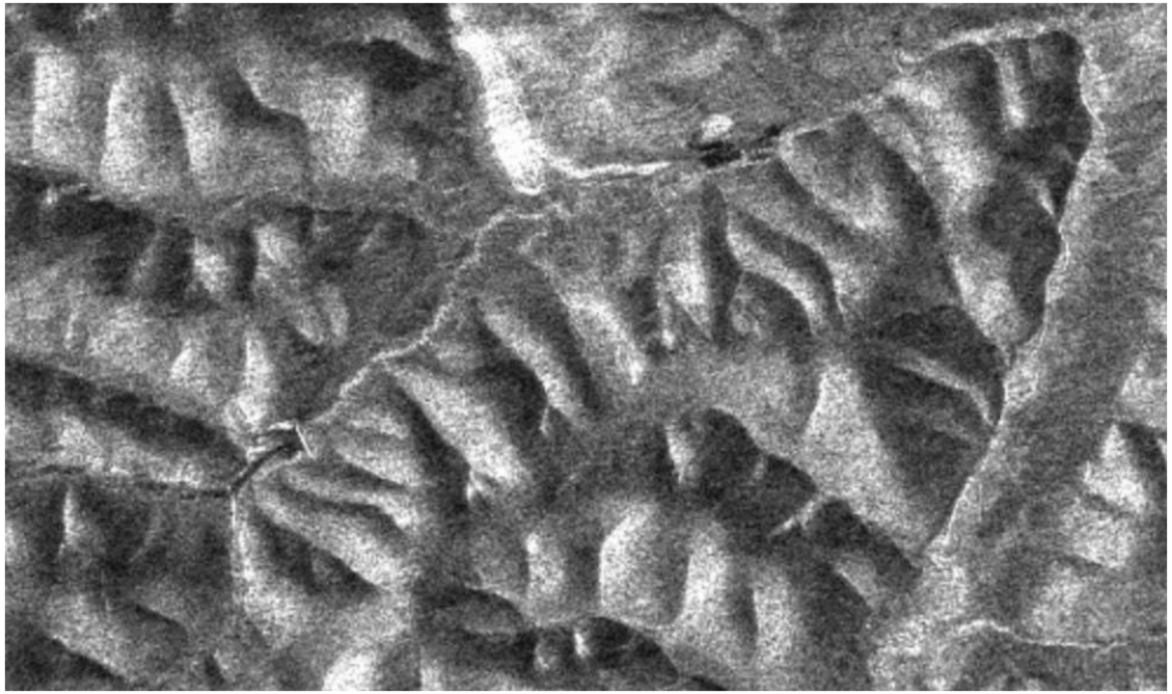


Source: Natural Resources Canada

Radiometric Distortions

- The influence of topography on backscatter should be corrected.
- This correction eliminates high values in areas of complex topography.

Before Correction



After Correction

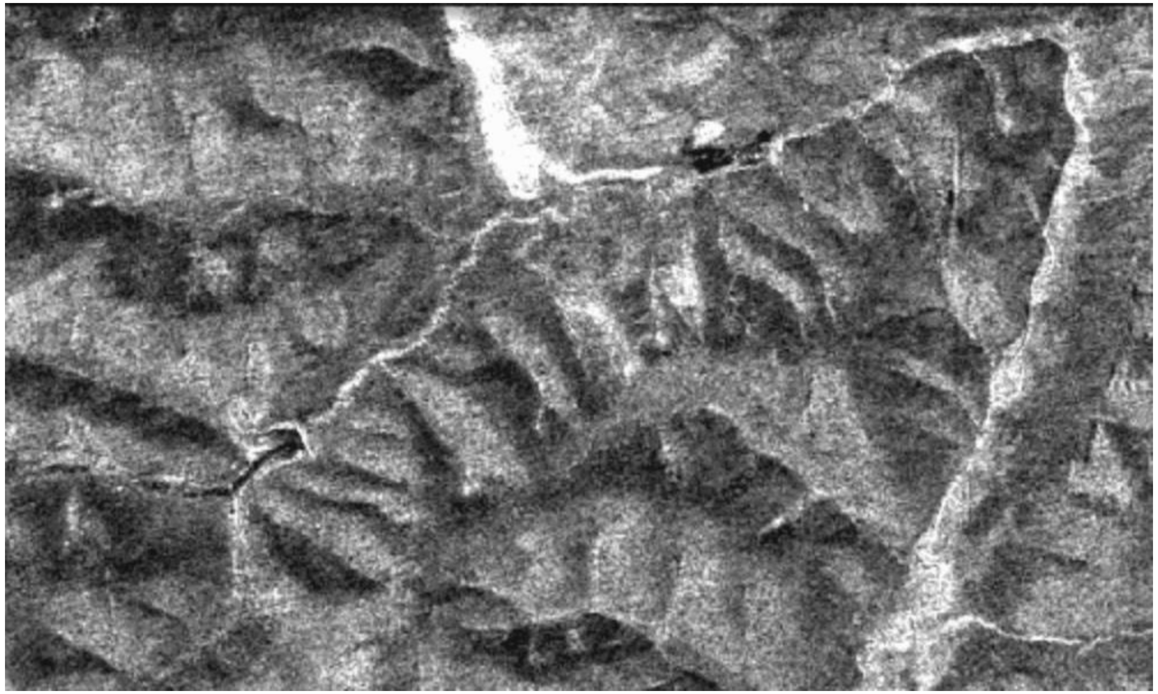
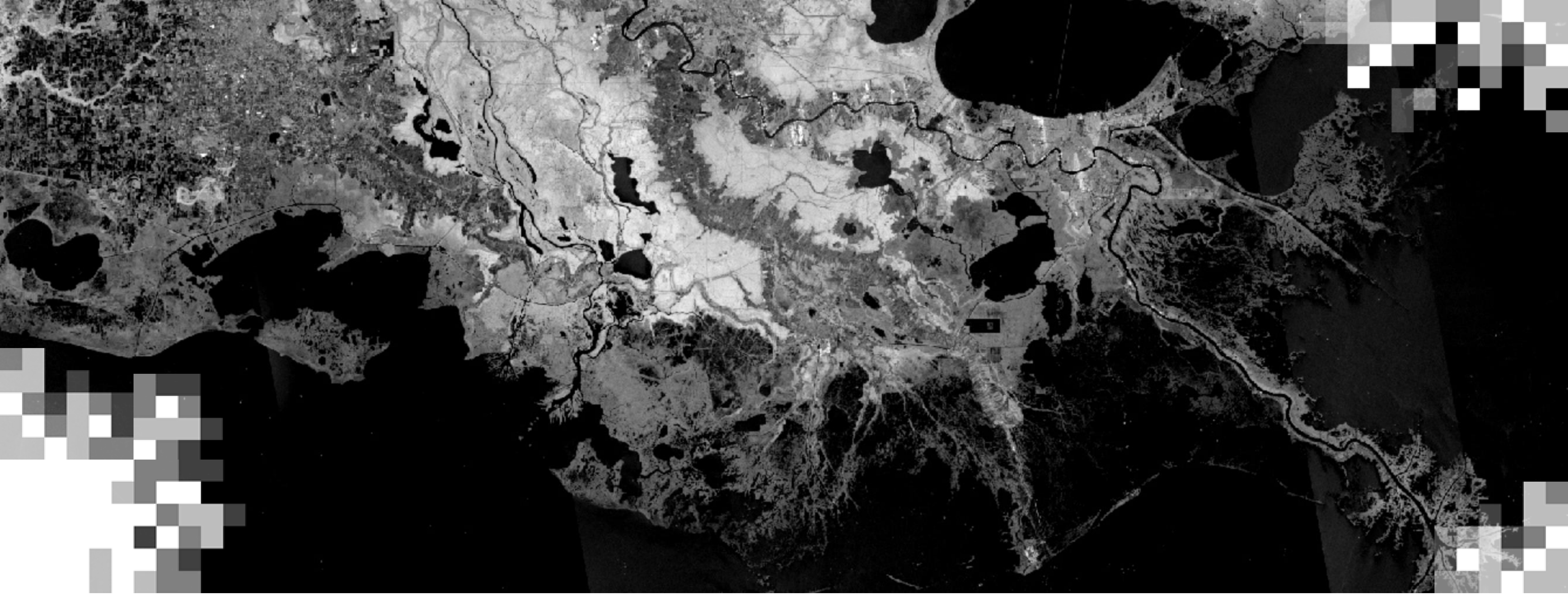


Image Credit: ASF



Speckle

Speckle

- **Speckle** is a granular 'noise' that inherently exists in and degrades the quality of SAR images.

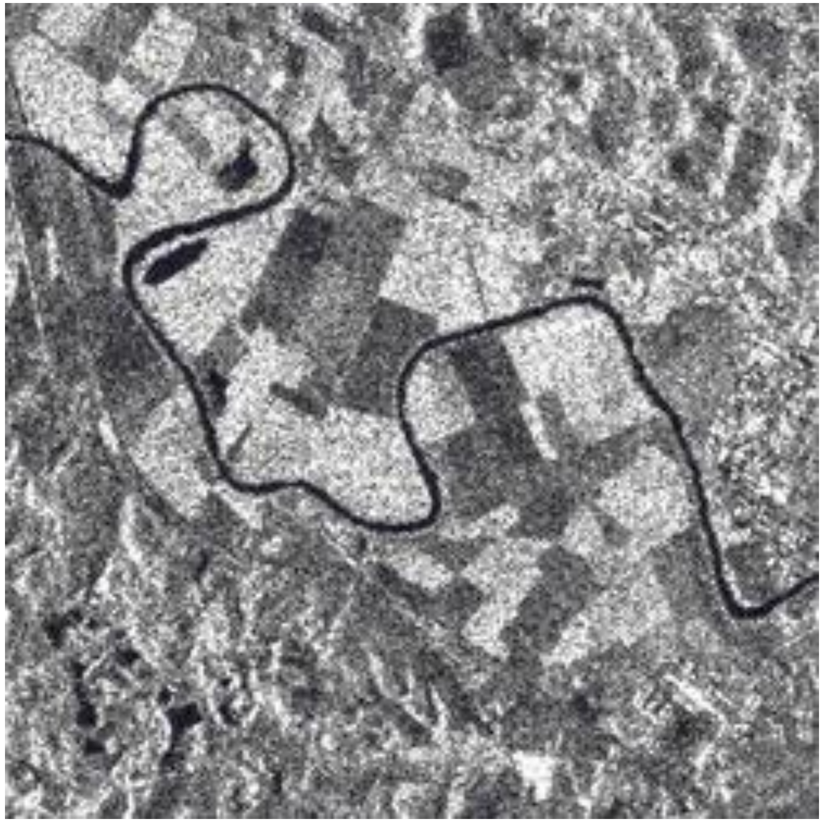


Image Credit: ESA

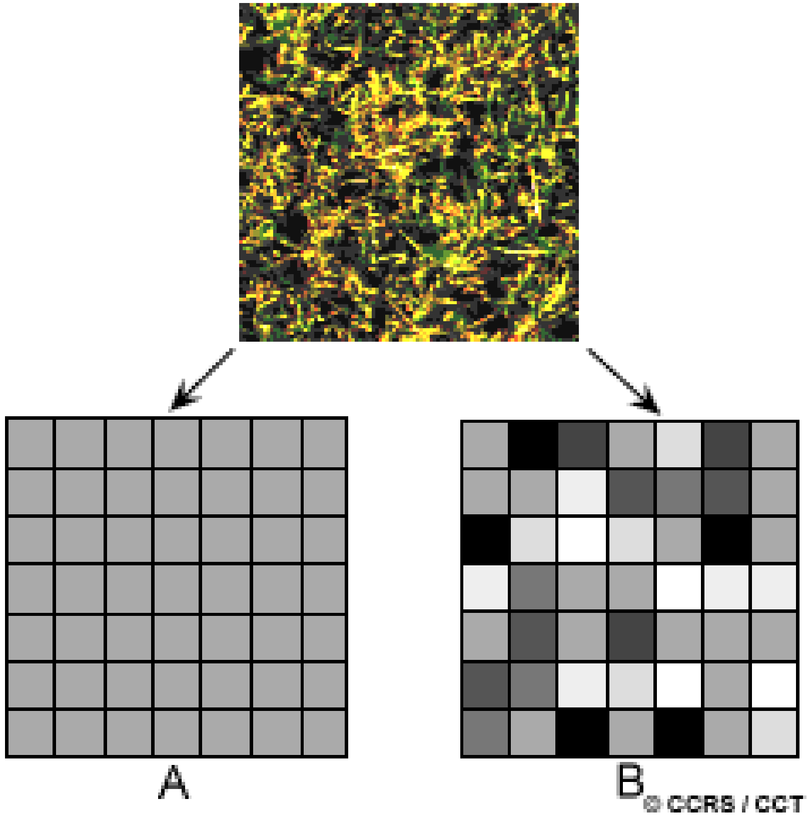
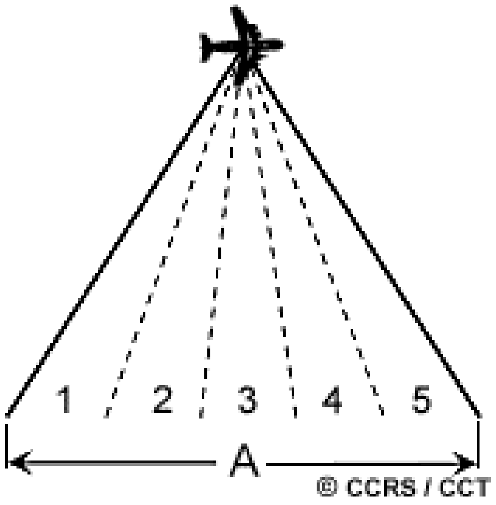
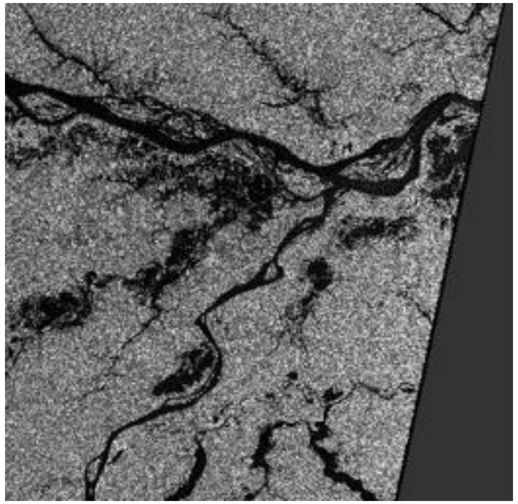


Image Credit: Natural Resources Canada

Speckle Reduction: Multi-Look Processing

- Divides radar beam into several, narrower sub-beams
  - E.g., 5 beams on the right
- Each sub-beam is a "look" at the scene.
- These "looks" are subject to speckle.
- By averaging the different "looks" together, the amount of speckle will be reduced in the final output image.
- Spatial resolution is also reduced.

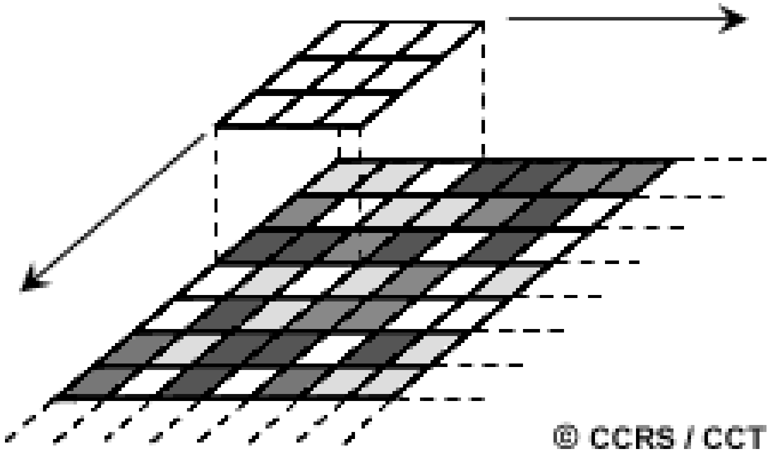




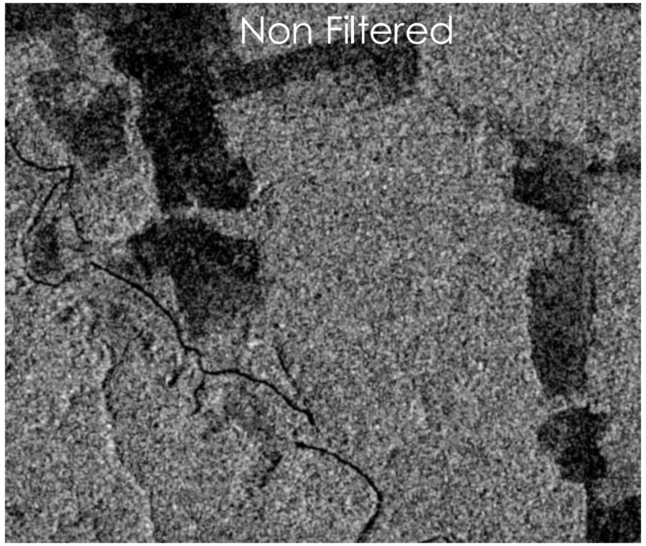
Source: Natural Resources Canada

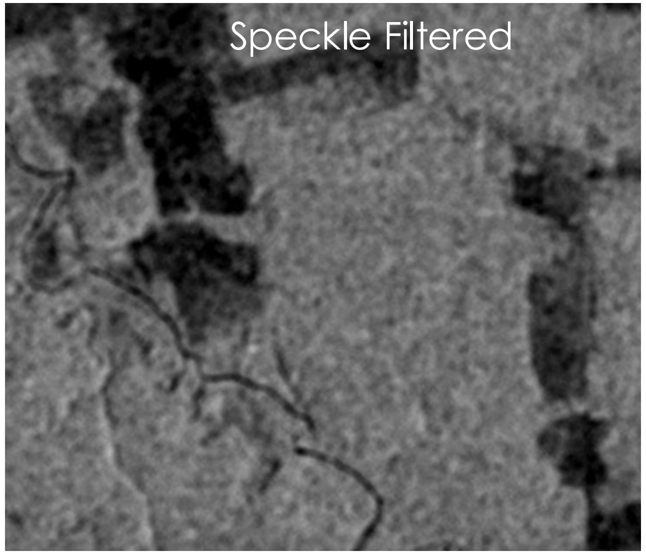
Speckle Reduction: Spatial Filtering

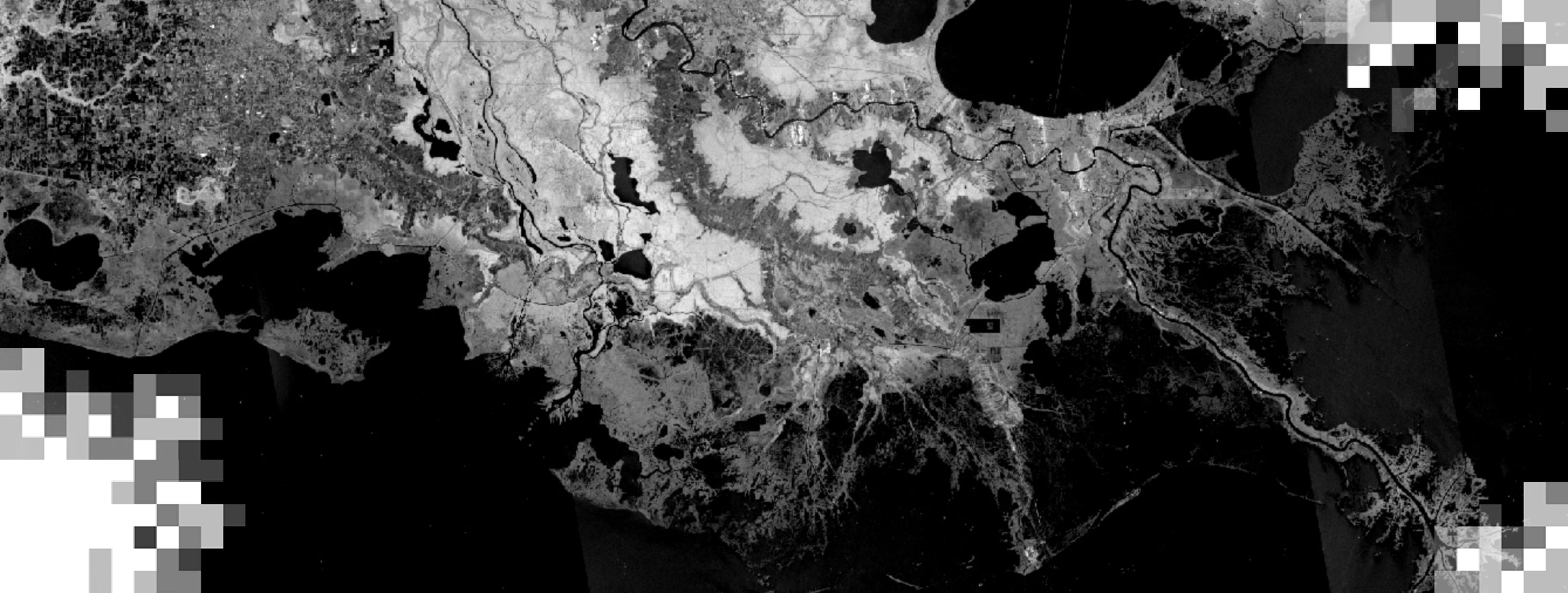
- Moving window over each pixel in the image
- Applies a mathematical calculation on the pixel values within the window
- The central pixel is replaced with the new value
- The window is moved along the x and y dimensions one pixel at a time
- Reduces visual appearance of speckle and applies a smoothing effect



Source: Natural Resources Canada



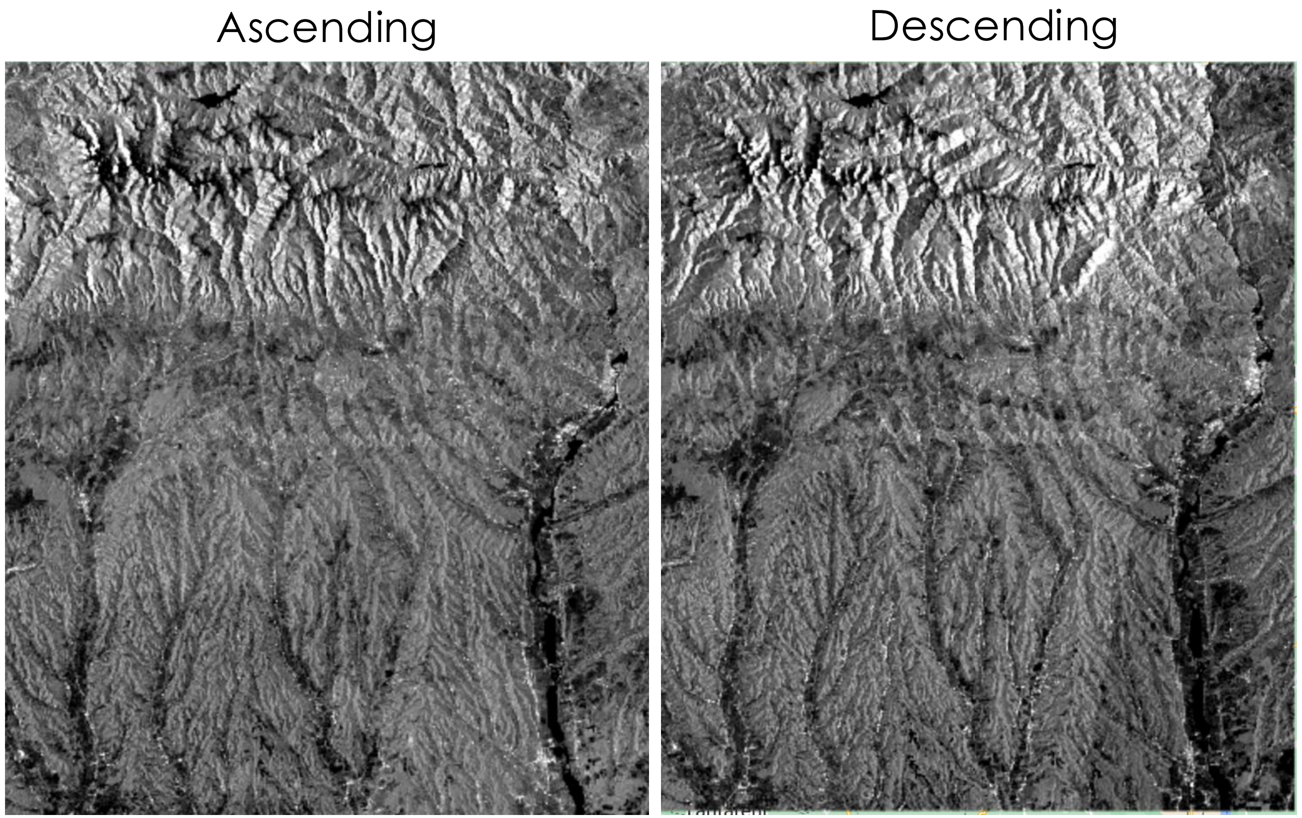




Additional Considerations

Look Direction

- The look direction of a SAR refers to the direction the radar antenna is pointed when emitting and receiving the radar beam.
- The illumination of an area by a radar beam changes with image acquisitions during ascending and descending overpasses.
- The viewing geometry is different between ascending and descending passes.
- For time series analysis it is advisable to not combine data from ascending and descending passes.



Weather Events

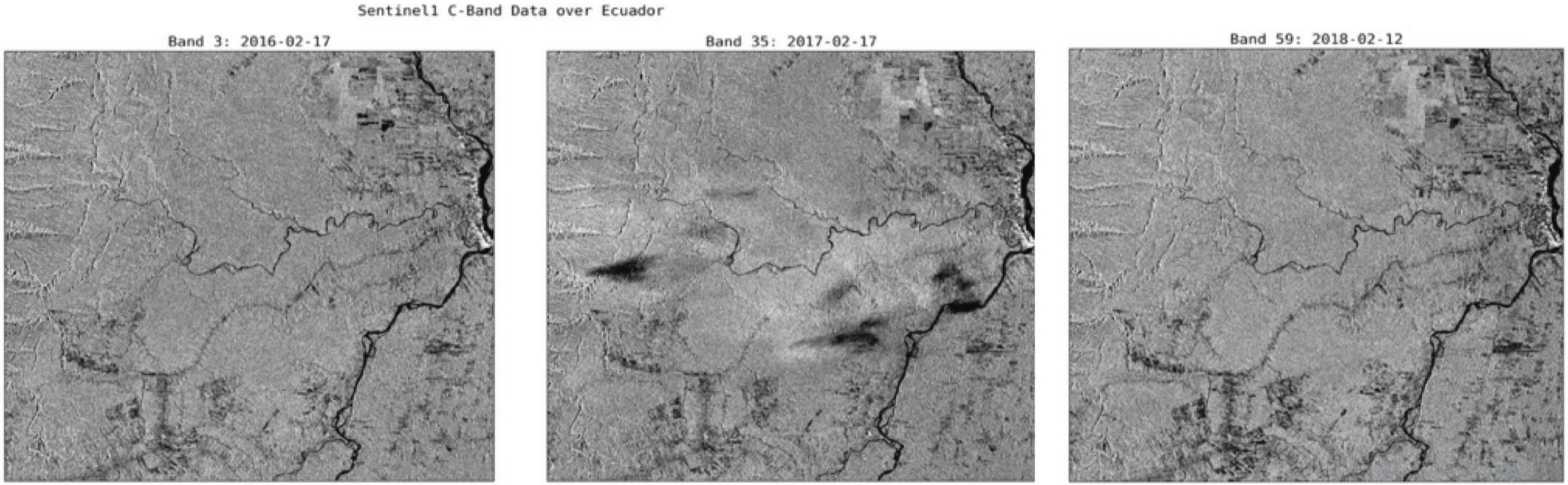
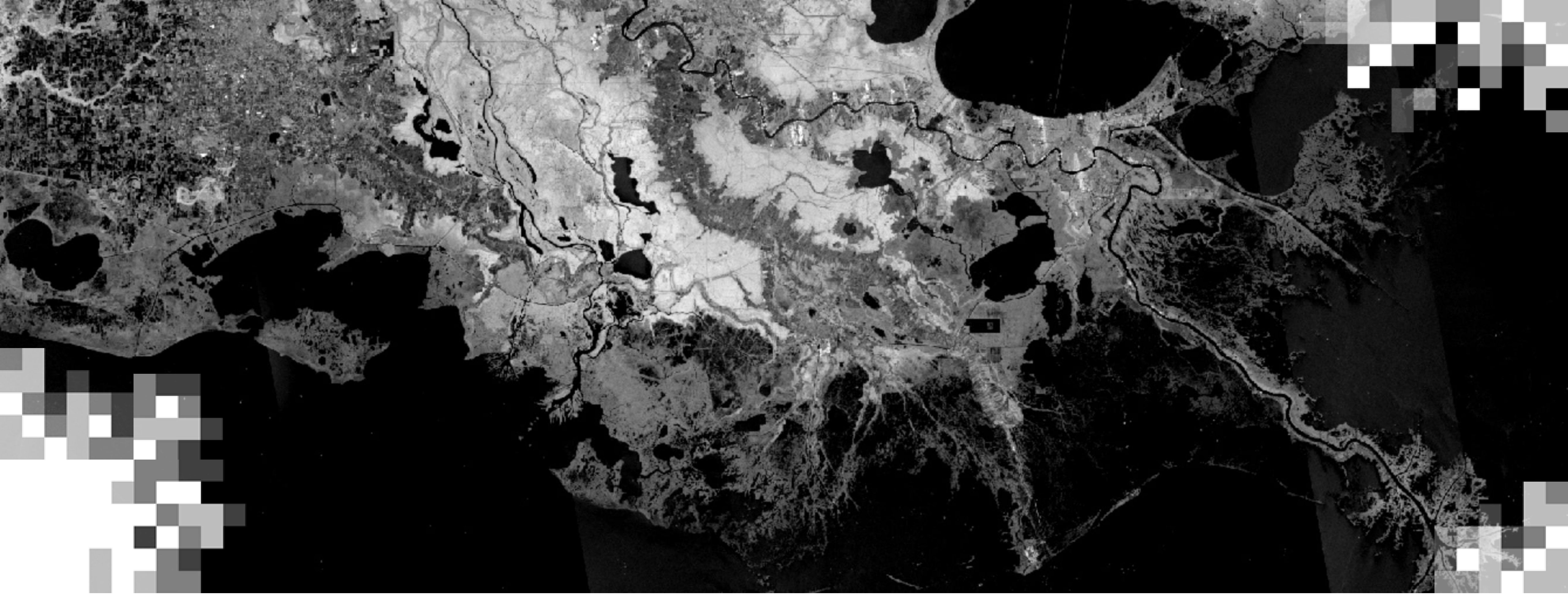


Image Credit: SAR Handbook, Chapter 2 by Josef Kellndorfer



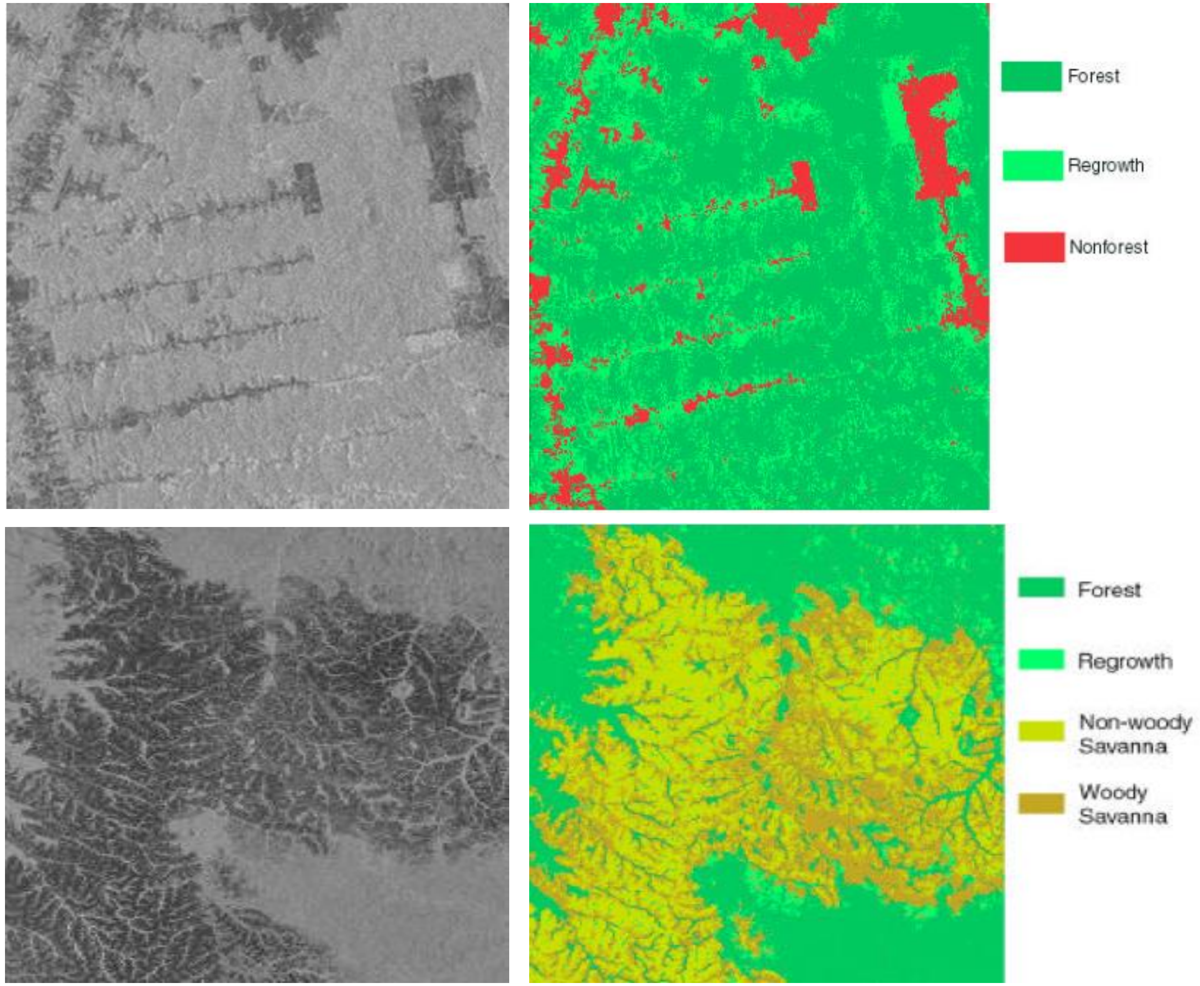
Applications of SAR Data

Detection of Oil Spills on Water

UAVSAR (2 meters):

HH, HV, VV

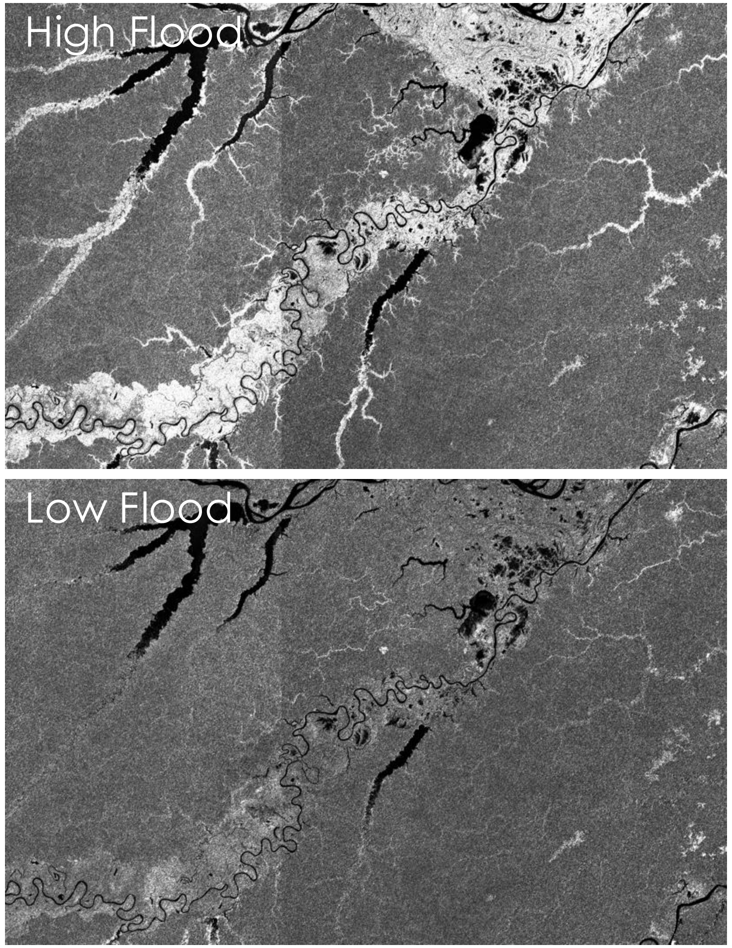
Landcover Classification

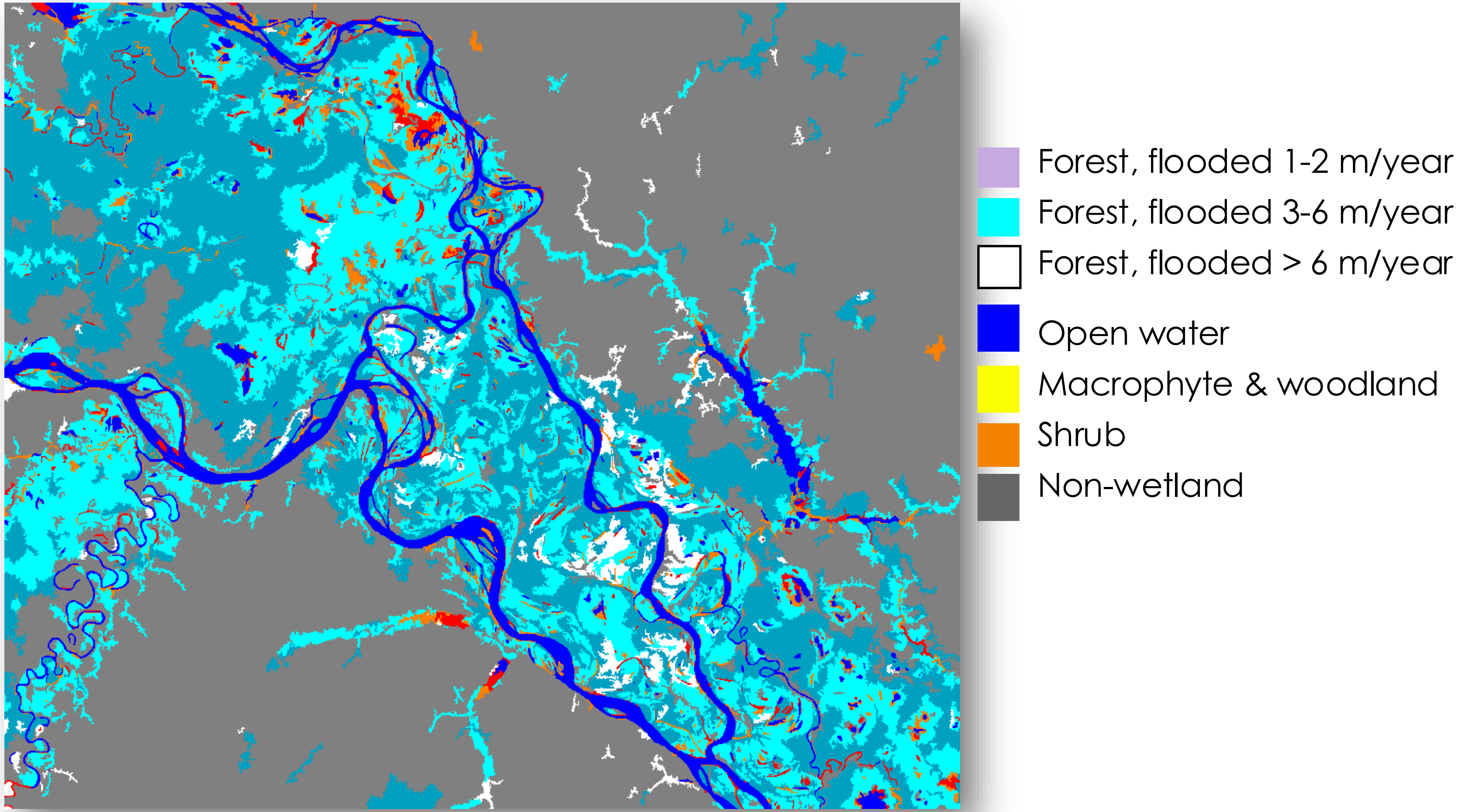


Brazil
JERS-1 L-band
100 meter resolution

Image Credit: E. Podest

Wetland Inundation



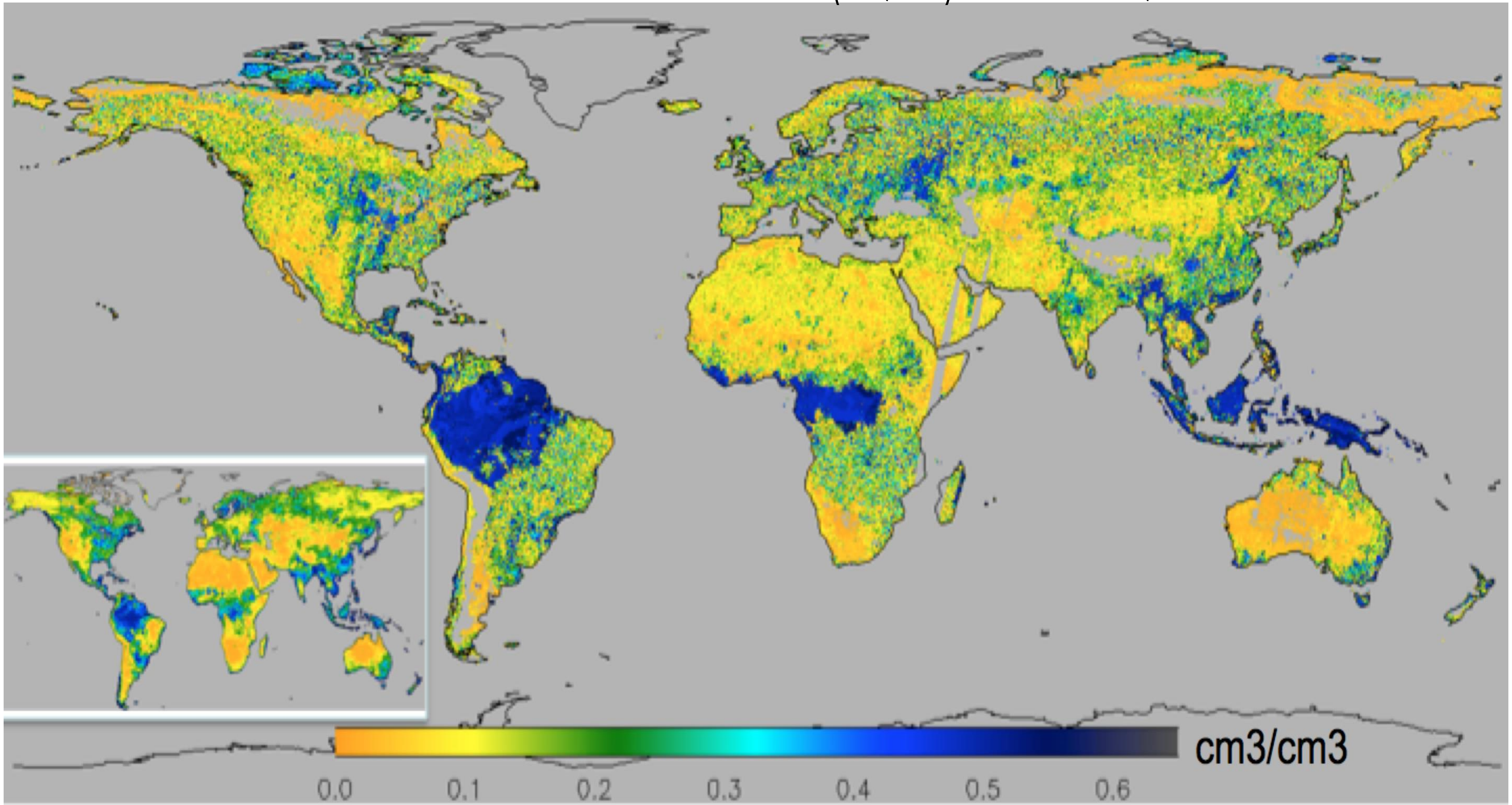


Wetland vegetation and inundation period product derived from changes in flooding state using multi-date PALSAR ScanSAR

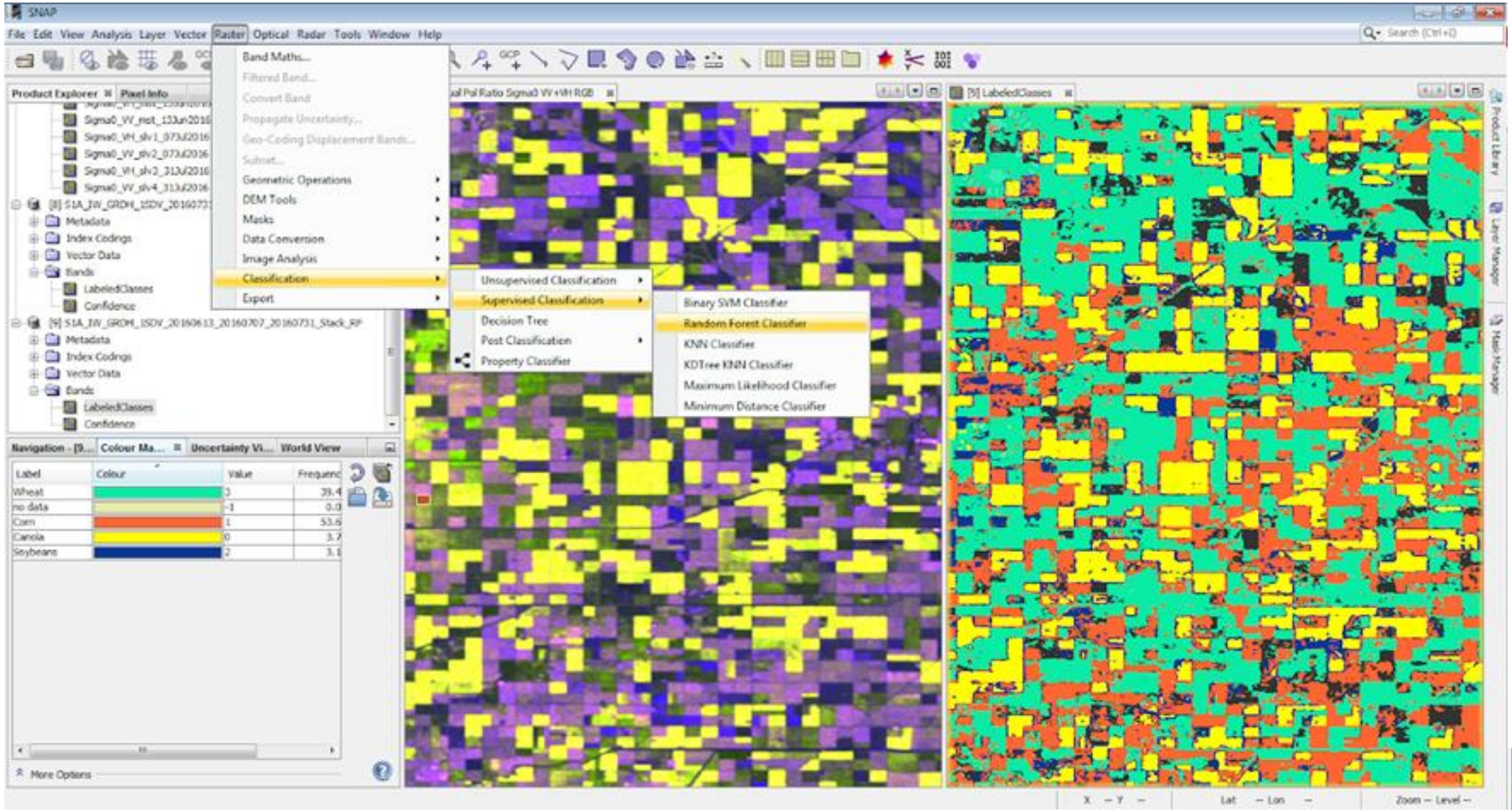
Image Credit: L. Hess, B. Chapman, and K. McDonald

Soil Moisture Monitoring

Soil Moisture from the SMAP Radar (HH, HV) - June 19-26, 2015



Crop Classification



crop type classification map

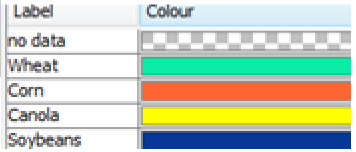
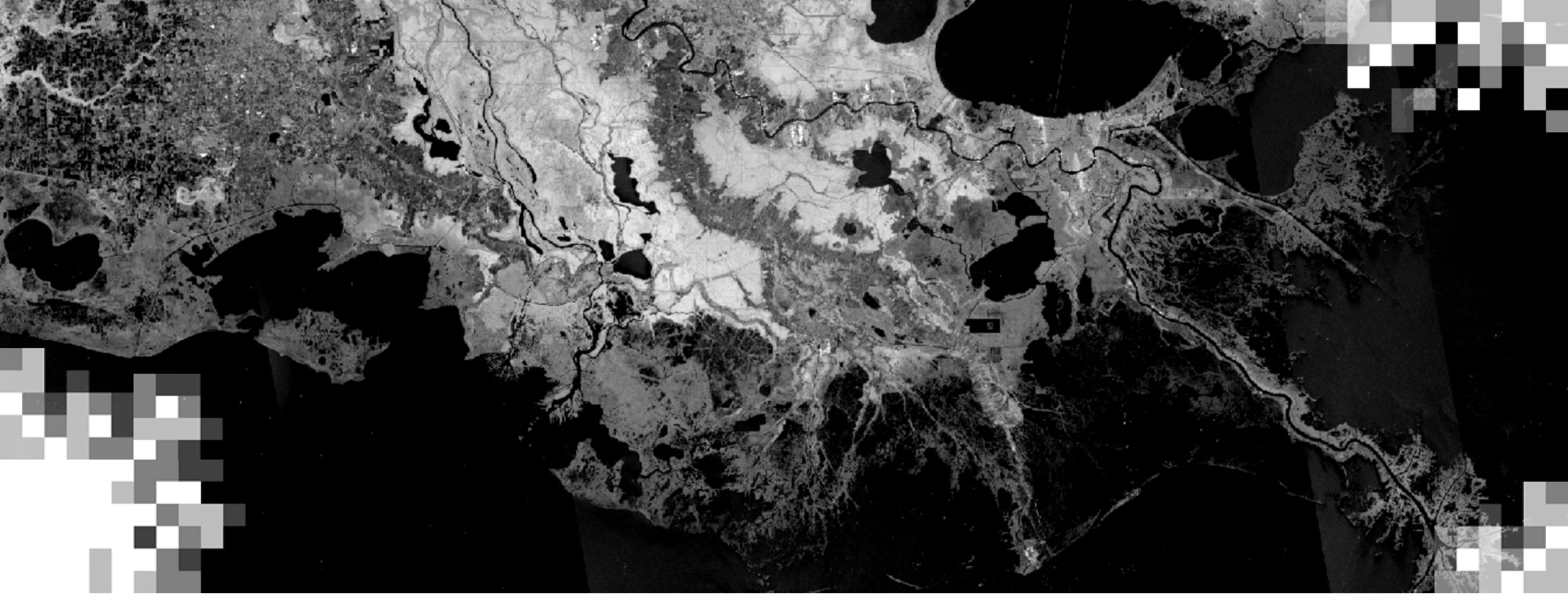


Image Credit: H. McNairn, Agriculture and Agri-Food Canada



SAR Data

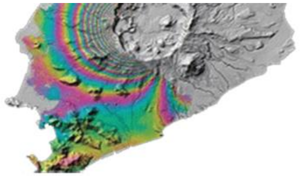
Alaska Satellite Facility (ASF)

https://asf.alaska.edu

Synthetic Aperture Radar Data

OPEN SAR DATA

These SAR datasets are Open Data and available to download at **no cost**.



ALOS PALSAR

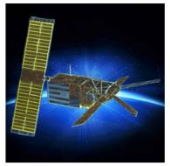
A JAXA (Japan Aerospace Exploration Agency) L-band satellite sensor active 2006-2011. Data coverage includes all of the Americas and many areas worldwide, with a 46-day repeat cycle.

Sentinel-1

An ESA (European Space Agency) C-band satellite constellation active in 2014-present. Data coverage is worldwide, with a 6-12 day repeat cycle.

ERS-2

An ESA C-band satellite active 1995-2011. Data coverage is primarily within the ASF and McMurdo ground station masks, with a 35-day repeat cycle.



ERS-1

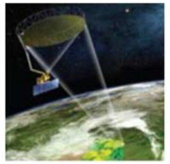
An ESA C-band satellite active 1991-2000. Data coverage is primarily within the ASF and McMurdo ground station masks, with a 35-day repeat cycle.

UAVSAR

A NASA L-band airborne sensor active 2008-present. Data coverage over North, Central, and South America, Greenland, and Iceland.

AIRSAR

A NASA C-band, L-band, and P-band airborne sensor active 1988-2004. Data coverage is primarily over the United States.



SMAP

A NASA L-band satellite sensor active April-August 2015. Data coverage is worldwide, with a 3-day repeat cycle.

Seasat

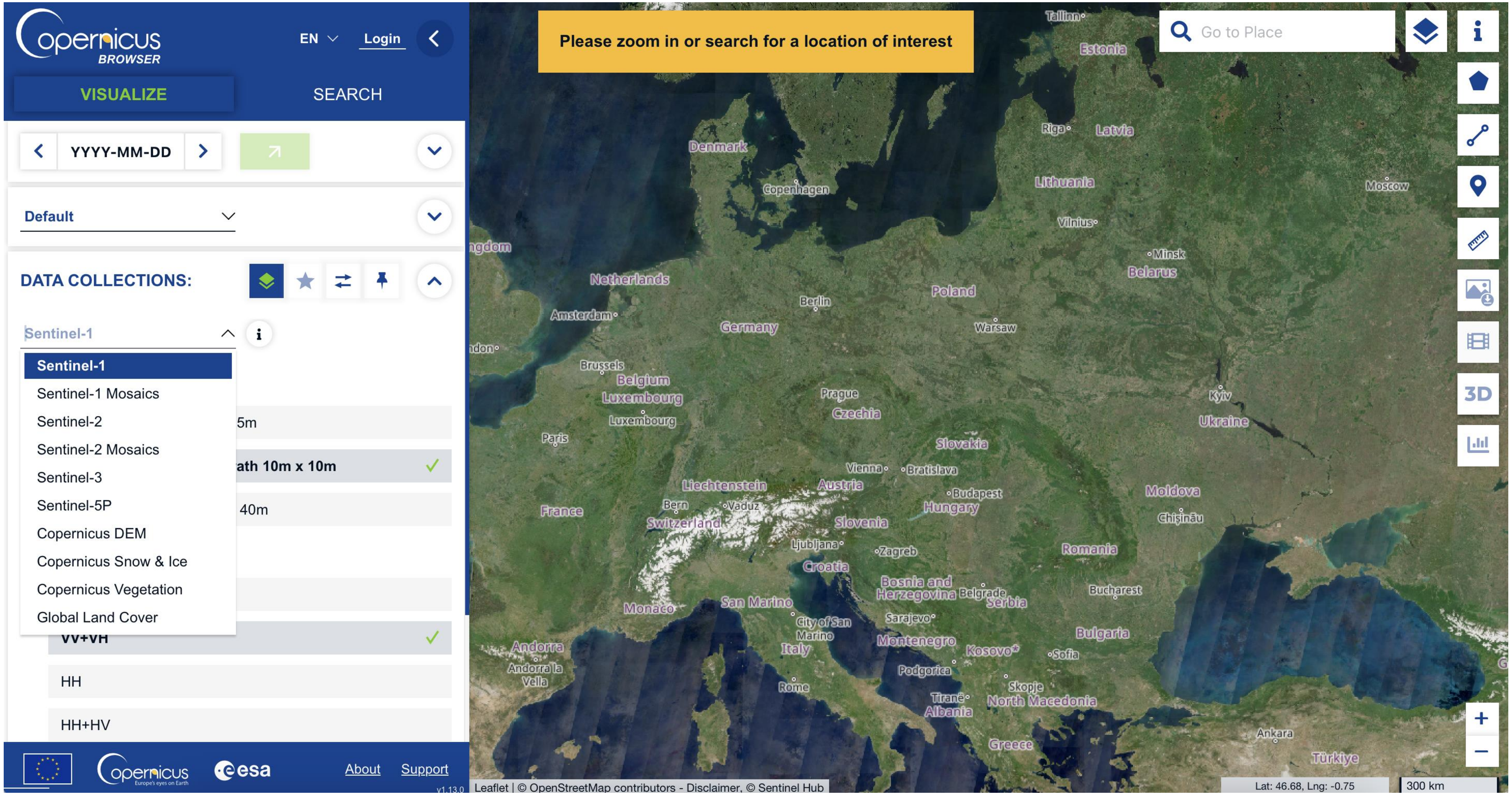
A NASA L-band satellite was active in 1978. Seasat was one of the first earth-observing orbital sensors. Coverage is primarily over northern oceans, with a 17-day repeat cycle.

RADARSAT-1

A CSA (Canadian Space Agency) C-band satellite active 1995-2013. Data from ASF are available through 2008. Data coverage is worldwide, with a

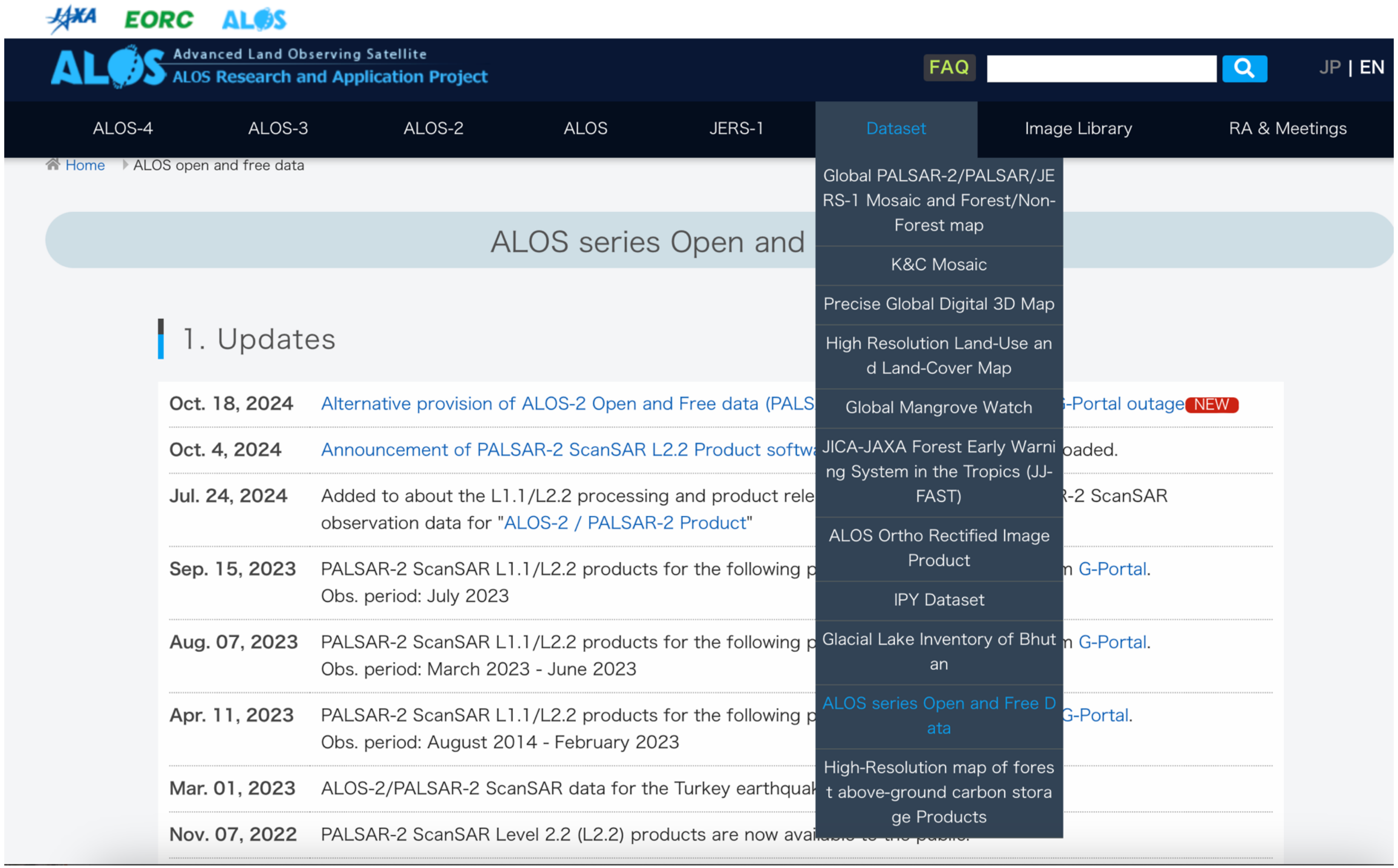
ASF

Copernicus Hub



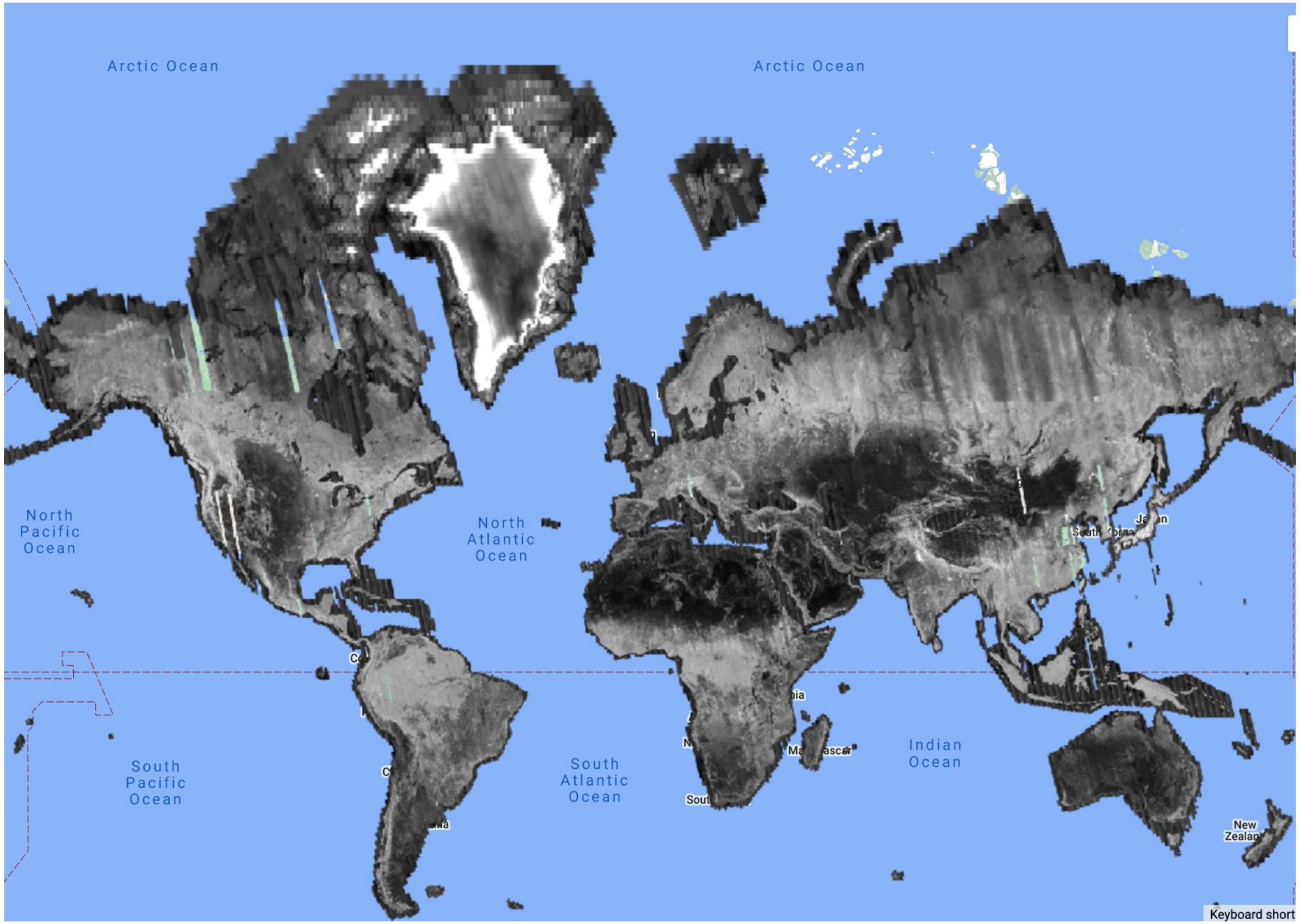
https://browser.dataspace.copernicus.eu

JAXA



https://www.eorc.jaxa.jp/ALOS/en/index_e.htm

Google Earth Engine



https://code.earthengine.google.com/

Radar Data Available

Legacy:

SeaSAT
1978

JERS-1
1992-1998

ERS 1/2
1991-2011

ENVISAT
2002-2012

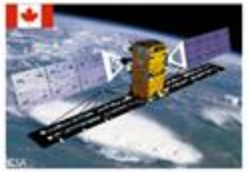
ALOS-1
2006-2012

Radarsat-1
1995-2013

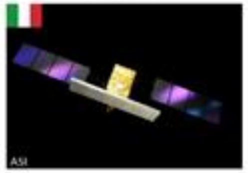
Current:

TanDEM-X
2007

Radarsat-2
2007



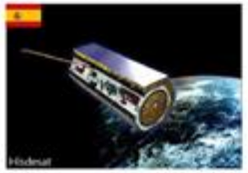
COSMO-SkyMed
2007



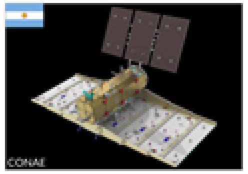
ALOS-2
2014

Sentinel-1
2014

PAZ SAR
2018



SAOCOM
2018

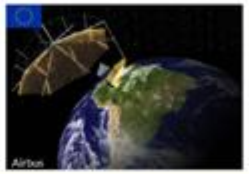


RCM
2018

Future:

NISAR
2025

Biomass
2025



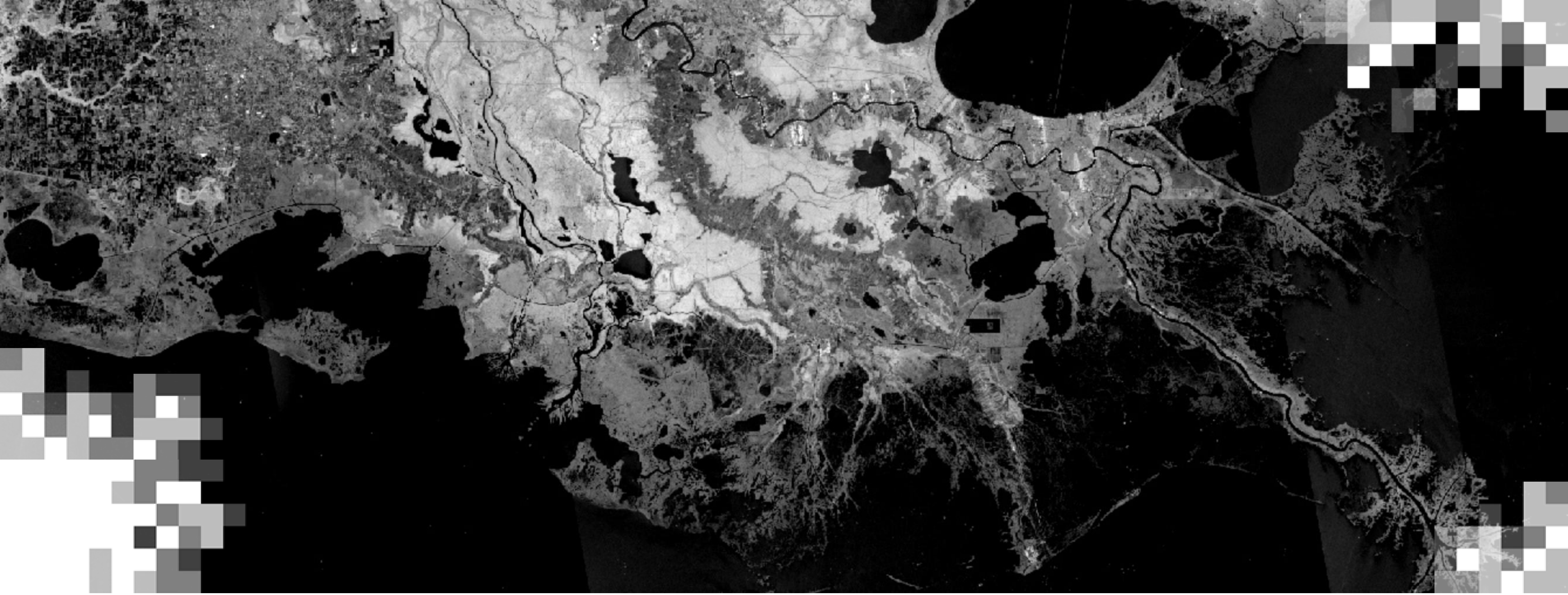
freely accessible

Image Credit: Franz Meyer, University of Alaska, Fairbanks

NISAR

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

- Major partnership between US National Aeronautics and Space Administration (NASA) and Indian Space Research Organization (ISRO)
- Launch date: 2025
- Dual frequency L- and S-band Synthetic Aperture Radar (SAR)
  - L-band SAR from NASA and S-band SAR from ISRO
- 3 years science operations (5+ years consumables)
- All science data (L- and S-band) will be made available free and open



Part 1:
Summary

Summary

- In SAR the azimuth (along track) resolution is different from the range (across track) resolution
- The three radar parameters are wavelength, polarization and incidence angle
- The longer the wavelength the greater the penetration depth
- The length of the wave will determine the interaction with the surface objects
- Polarization provides information related to the structural characteristics of the objects on the surface
- Incidence angle will influence the signal penetration into the target
- The two surface parameters that influence the radar signal are structure and moisture
- The main backscatter mechanisms are specular scattering, rough surface scattering, volume scattering and double bounce
- Radar images have geometric distortions in areas of complex topography
- Speckle is the graininess inherent in SAR images. It can be reduced through multi-looking or with a spatial or temporal filter
- Radar can be used for different ecosystem studies such as mapping landcover, crops, wetland inundation, and soil moisture

Session 2

Session 2 will cover:

1. Identify the basics concepts of Interferometric SAR
2. Identify the steps to generate a SAR interferogram
3. Interpret an interferogram to measure surface deformation
4. Identify the applications that InSAR can address

Homework and Certificates

- **Homework:**
  - One homework assignment
  - Opens on 11/20/2024
  - Access from the training webpage
  - Answers must be submitted via Google Forms
  - **Due by 12/04/2024**

- **Certificate of Completion:**
  - Attend all three live webinars (attendance is recorded automatically)
  - Complete the homework assignment by the deadline
  - You will receive a certificate via email approximately two months after completion of the course.

Contact Information

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- ARSET Website
- Follow us on Twitter!
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- ARSET YouTube

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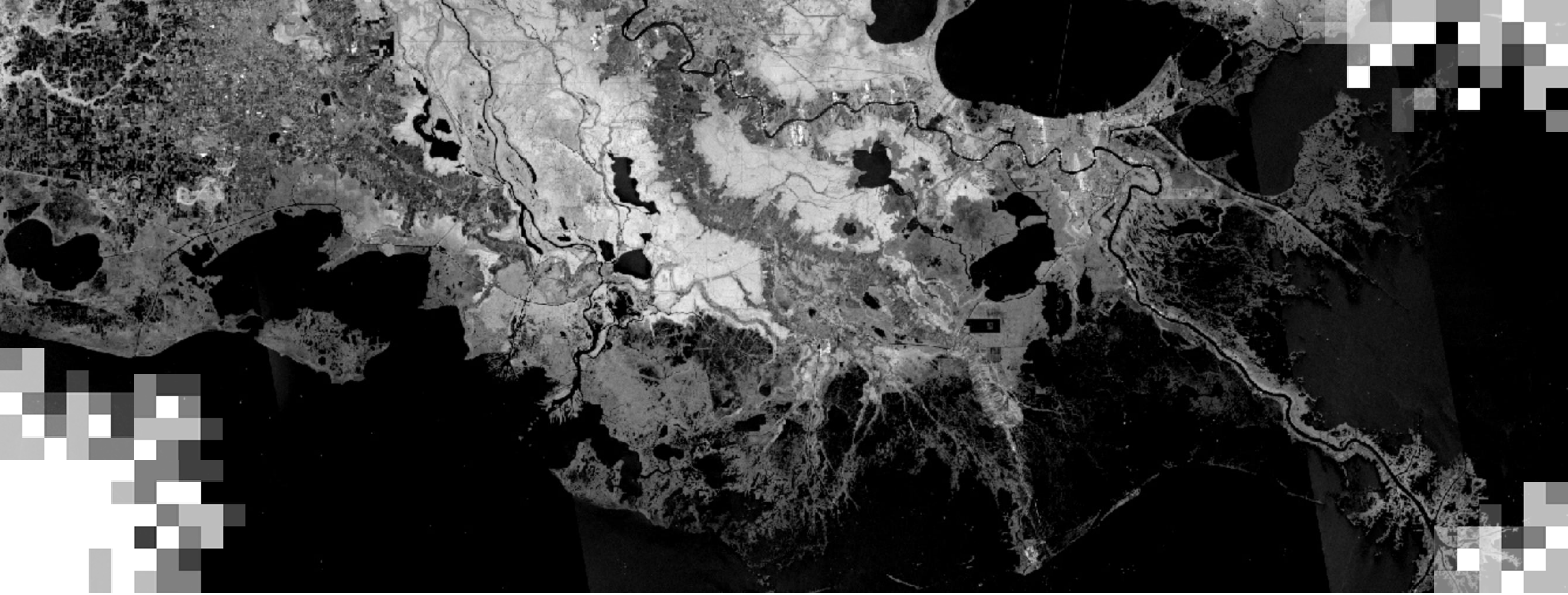
Thank You!



Appendix: SAR Tutorial References

ARSET SAR Tutorials

Radar Remote Sensing for Land, Water, & Disaster Applications Webinar Series:

Session 1: SAR for Mapping Land Cover
https://www.youtube.com/watch?v=lDxBgK1VY_4

Session 2: SAR for Flood Mapping
https://www.youtube.com/watch?v=QKrG5jYZe10

Session 3: SAR for Mapping Soils and Crops
https://www.youtube.com/watch?v=yoEu2P1i5xE

Session 4: InSAR for Earthquake Studies
https://www.youtube.com/watch?v=P8lQ7pjkRlw

ARSET SAR Tutorials

SAR for Landcover Applications:
Session 1: SAR for Flood Mapping Using Google Earth Engine
https://www.youtube.com/watch?v=J5RPibJ8my4

Session 2: Exploiting SAR to Monitor Agriculture
https://www.youtube.com/watch?v=vS7r50EbFQY

SAR for Disasters and Hydrological Applications:
Session 1: SAR for Flood Mapping Using Google Earth Engine
https://www.youtube.com/watch?v=4Y2giuRPCuc

Session 2: In SAR for Landslide Observations
https://www.youtube.com/watch?v=biqoDH9VsiA

Session 3: Generating a DEM
https://www.youtube.com/watch?v=9PbFbHqRufQ

ARSET SAR Tutorials

Forest Mapping and Monitoring with SAR Data:

Session 1: Time Series Analysis of Forest Change

https://www.youtube.com/watch?v=KitbOq7ARNQ

Session 2: Land Cover Classification with Radar and Optical Data
https://www.youtube.com/watch?v=raXA3gnb94Q

Session 3: Mangrove Mapping

https://www.youtube.com/watch?v=vaBEHALn-js

Session 4: Forest Stand Height

https://www.youtube.com/watch?v=RROJ_4Ud78g

SAR Tutorial References

The SERVIR SAR Handbook: https://servirglobal.net/resources/sar-handbook

A Laymans Guide to Interpreting L and C-band SAR:
http://ceos.org/document_management/SEO/DataCube/Laymans_SAR_Interpretation_Guide_2.0.pdf

SAR Tutorials (written):
-A tutorial on SAR by ESA
http://ieeexplore.ieee.org/document/6504845/?reload=true
http://www2.geog.ucl.ac.uk/~mdisney/teaching/PPRS/PPRS_7/esa_sar_tutorial.pdf
https://earth.esa.int/documents/10174/2700124/sar_land_apps_1_theory.pdf
https://earth.esa.int/handbooks/asar/toc.html

by the EU:
http://www.radartutorial.eu/20.airborne/ab07.en.html

SAR Tutorial References

Microwave Remote Sensing tutorials and data recipes by ASF:
https://radar.community.uaf.edu/module-1/
https://asf.alaska.edu/how-to/data-recipes/data-recipe-tutorials/

CRISP Center:
https://crisp.nus.edu.sg/~research/tutorial/mw.htm

Lincoln Lab:
http://www.egr.msu.edu/classes/ece480/capstone/spring12/group05/docs/presentations/TechLecture_Team5.pdf

INSAR by ESA:
http://www.esa.int/esapub/tm/tm19/TM-19

SAR Tutorial References

Fundamentals of Remote Sensing by Natural Resources Canada:
http://www.nrcan.gc.ca/earth-sciences/geomatics/satellite-imagery-air-photos/satellite-imagery-products/educational-resources/9371

SAR Tutorial (video)
-Echoes in Space – Radar Remote Sensing by ESA
https://eo-college.org/courses/echoes-in-space/

Sentinel-1 Tutorials:
http://step.esa.int/main/doc/tutorials/sentinel-1-toolbox-tutorials/

Sisters of SAR Resources
https://sistersofsar.wixsite.com/sistersofsar/sar-resources