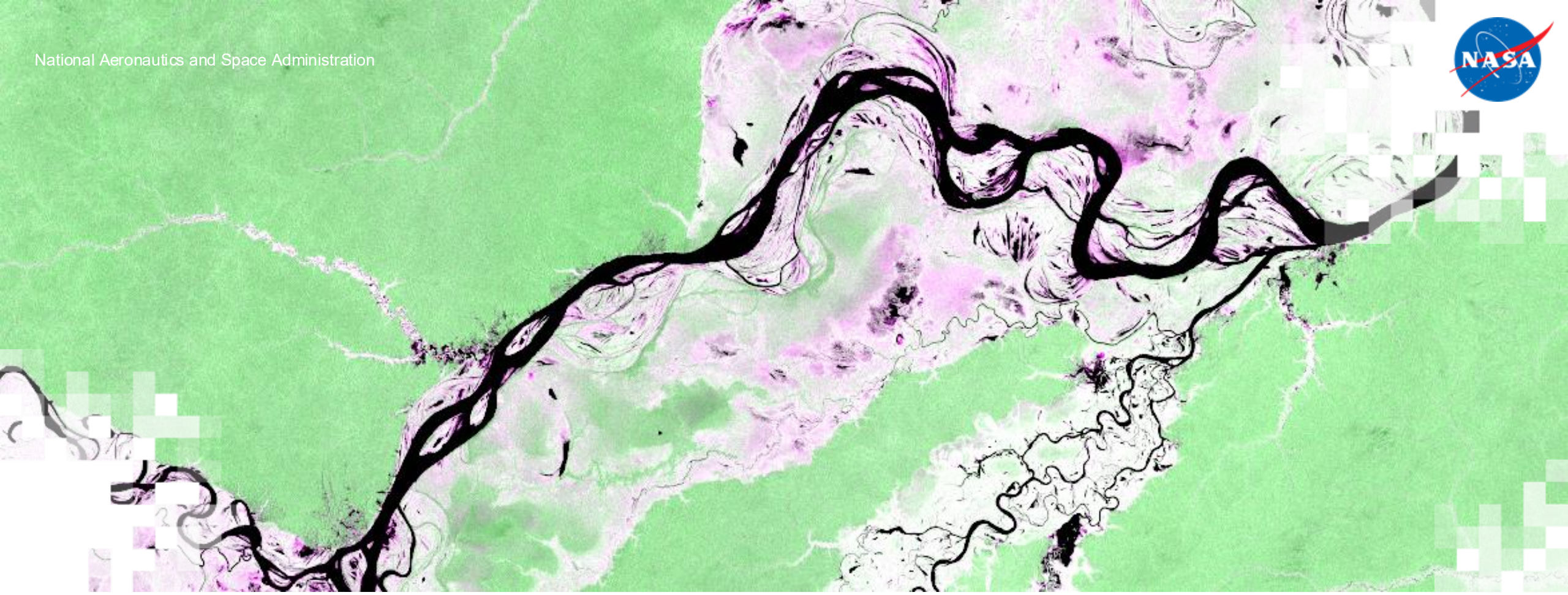
National Aeronautics and Space Administration

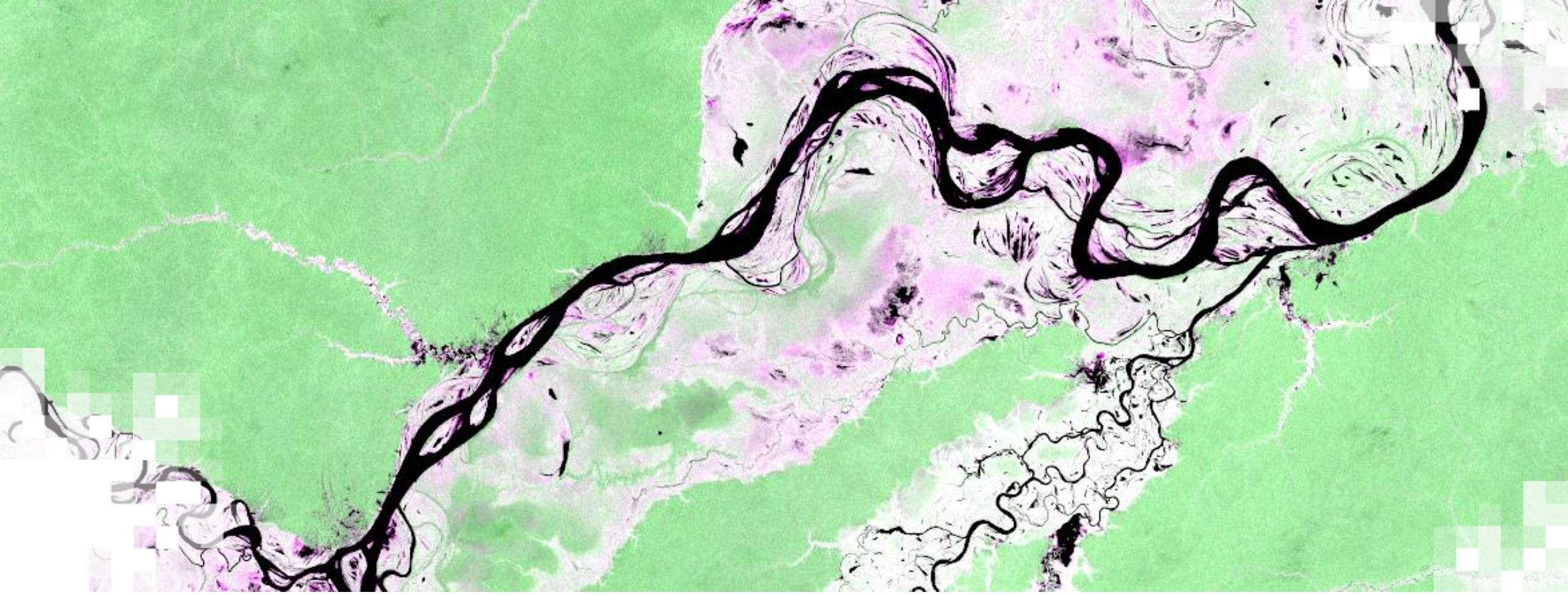


Monitoring Surface Water with SAR for Water Resource Management

Session 1: Mapping Inundation with NISAR

Erika Podest, Jet Propulsion Laboratory/California Institute of Technology

Oct. 20, 2026



The ARSET Program

About ARSET

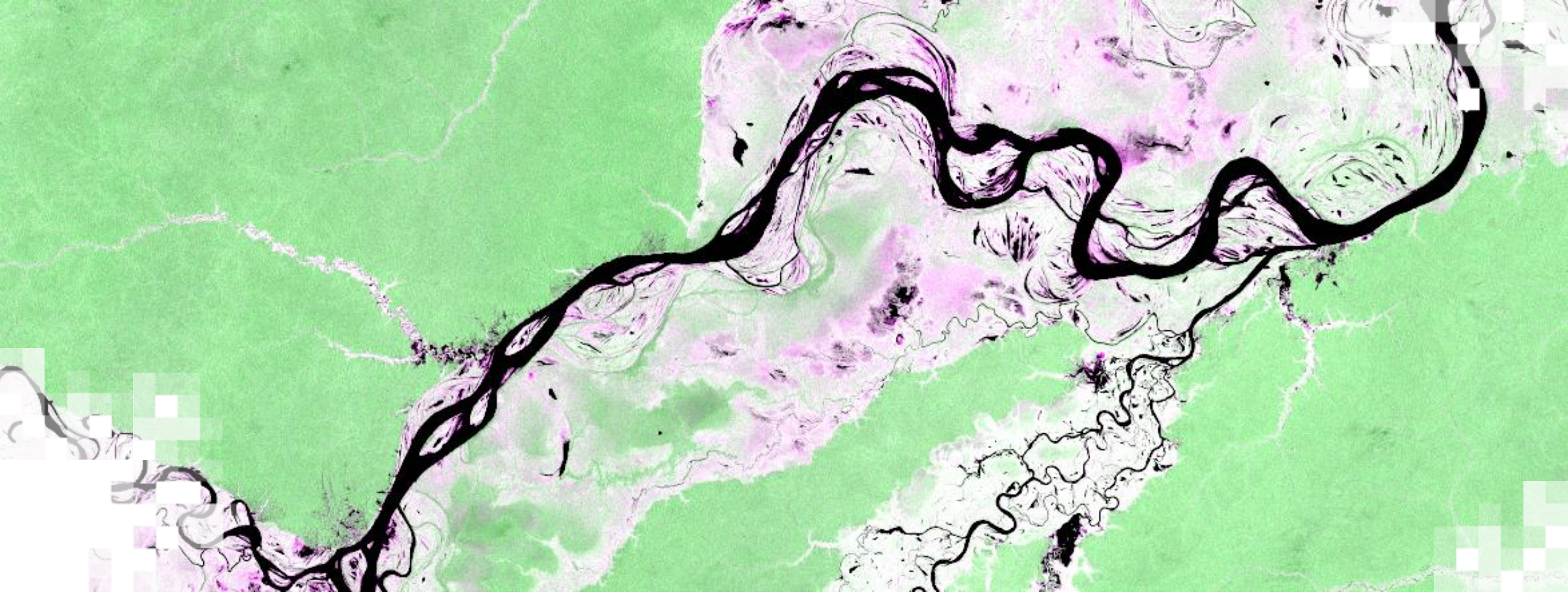
- **ARSET provides accessible, relevant, and cost-free training on remote sensing satellites, sensors, methods, and tools.**

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

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.



Monitoring Surface Water with SAR for Water Resource Management

Overview

How can we monitor surface water everywhere, even through clouds?

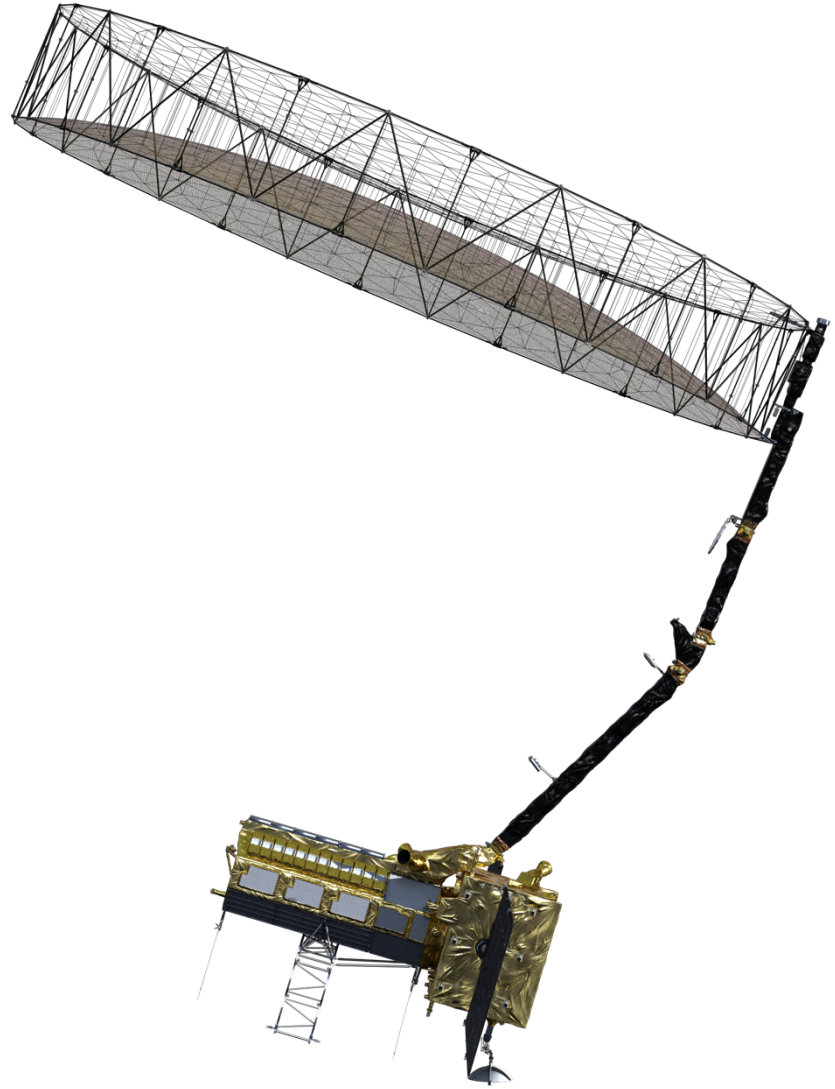
Surface water information is essential for:

- Water Resources
- Flood Response
- Agriculture
- Ecosystem Management

The challenge with optical data:

- Clouds hinder observations of the surface
- Nighttime limits visible observations
- Dense vegetation can obscure inundation

Synthetic Aperture Radar (SAR) provides the answer.



Training Learning Objectives

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

- Differentiate the radar backscatter characteristics in order to identify open water and inundated vegetation.
- Generate a flood map from NISAR amplitude data using open-source software.
- Recognize the capabilities and appropriate applications of the OPERA Surface Water Extent product for water resource monitoring.
- Evaluate when it is more appropriate to generate a flood map from NISAR observations versus using the OPERA Surface Water Extent product.
- Interpret OPERA Surface Water Extent products for flood and surface water monitoring applications.

Prerequisites

- Fundamentals of Remote Sensing
- An Introduction to Synthetic Aperture Radar (SAR) and its Applications
- Harnessing NISAR: Next-Generation Radar Observations for Earth Applications

Training Outline

Session 1

Mapping Inundation with NISAR

October 20, 2026

11:00 a.m. - 1:00 p.m. EDT(1500-1700 UTC)

Session 2

Water Surface Extent from OPERA

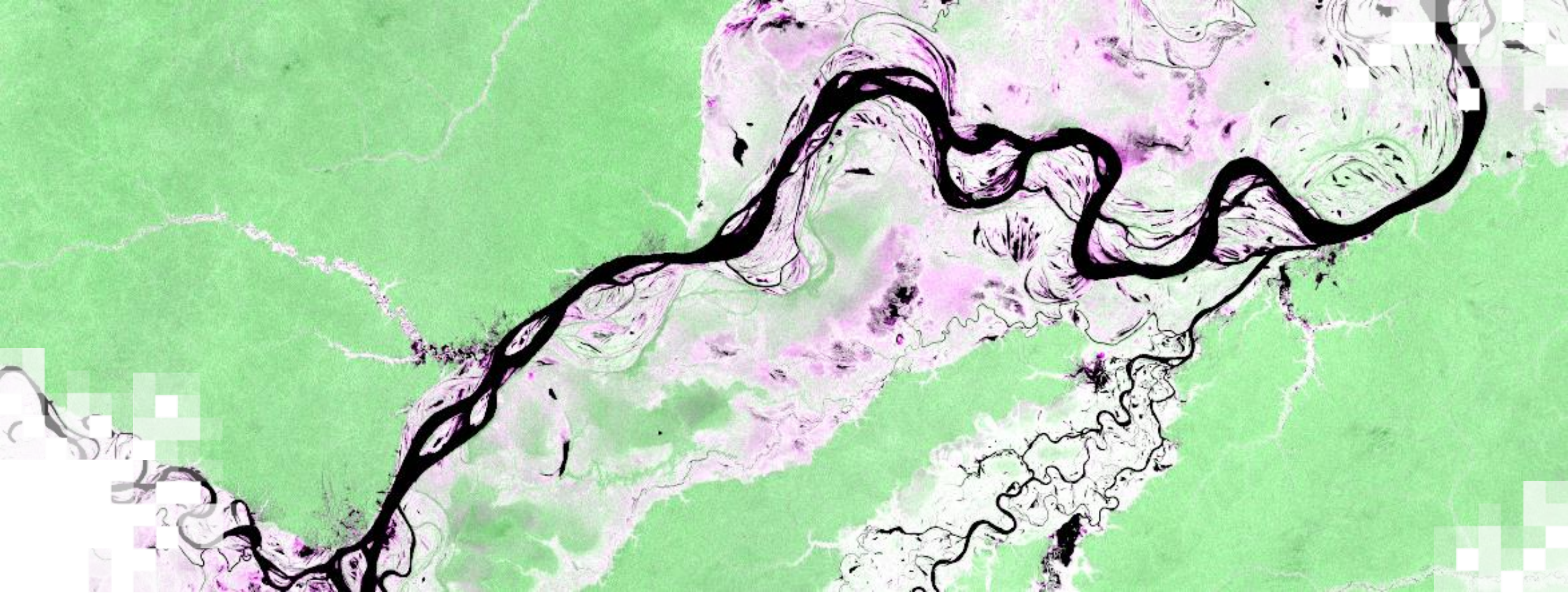
October 27, 2026

11:00 a.m. - 1:00 p.m. EDT(1500-1700 UTC)

Homework

Opens Oct. 27, 2026 – Due Nov. 17– Posted on 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.



Session 1: Flood Mapping with NISAR

Session 1 – Instructor

Erika Podest, Ph.D.

Scientist

NASA Jet Propulsion Laboratory

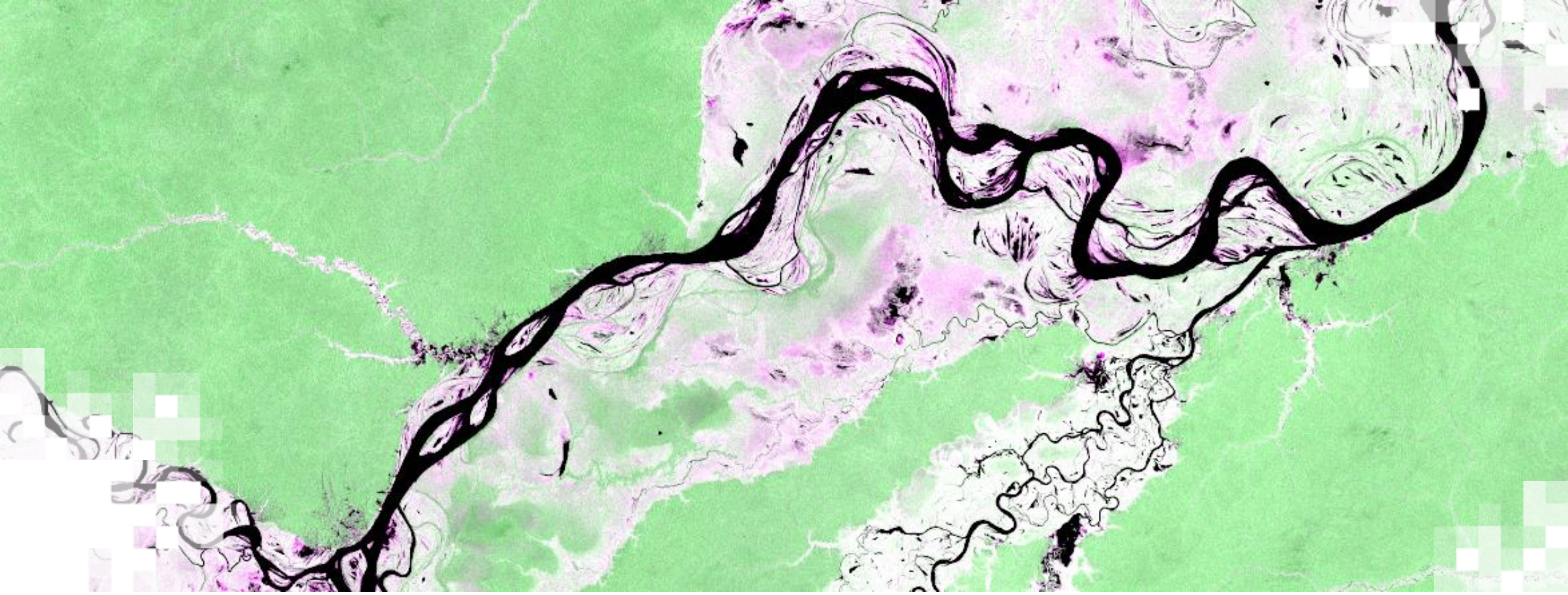
Session 1 Objectives

By the end of today's session, participants will be able to:

- Differentiate the radar backscatter characteristics in order to identify open water and inundated vegetation.
- Generate a flood map from NISAR amplitude data using open-source software.

How to Ask Questions

- To ensure we see your question, please locate the three dots or boxes to the bottom right of your training window.
- You will see a Slido/Q&A option. You may also see a standalone Slido tab or app.
- Please write all questions there and we will answer them during the Q&A session.
- We will try to respond all of the questions during the Q&A session at the end of today's presentation. The remaining questions will be answered in the Q&A document, which will be posted to the training website about a week after the training.



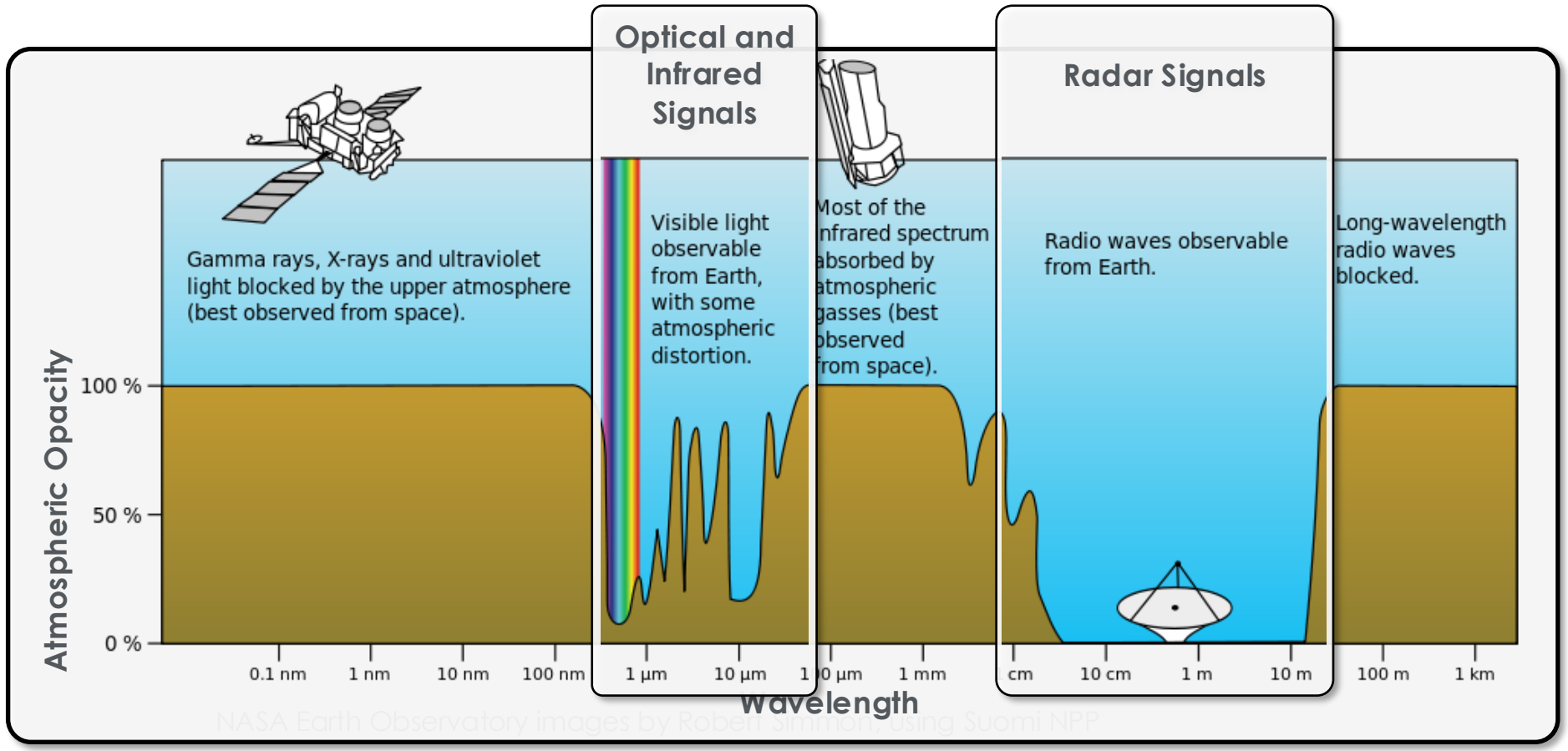
Session 1:
Fundamentals of SAR

Flood Mapping

- The temporary or permanent occurrence of a water surface beneath a vegetation canopy.
- Water without any standing vegetation.

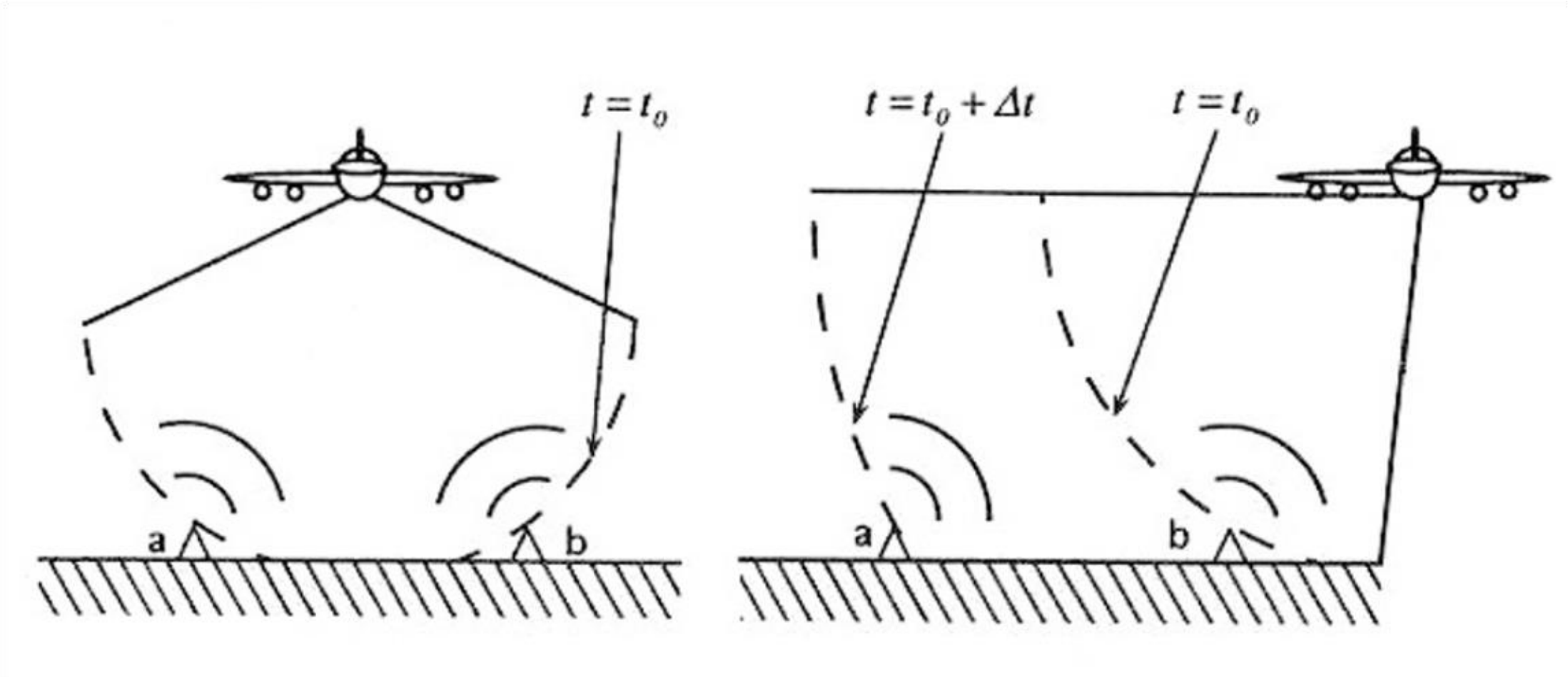
Flood Mapping: Radar Capabilities Over Optical Data

- 24/7 imaging capabilities
- Advanced change detection performance
- Detects inundation underneath the vegetation
- Complementary to optical sensors



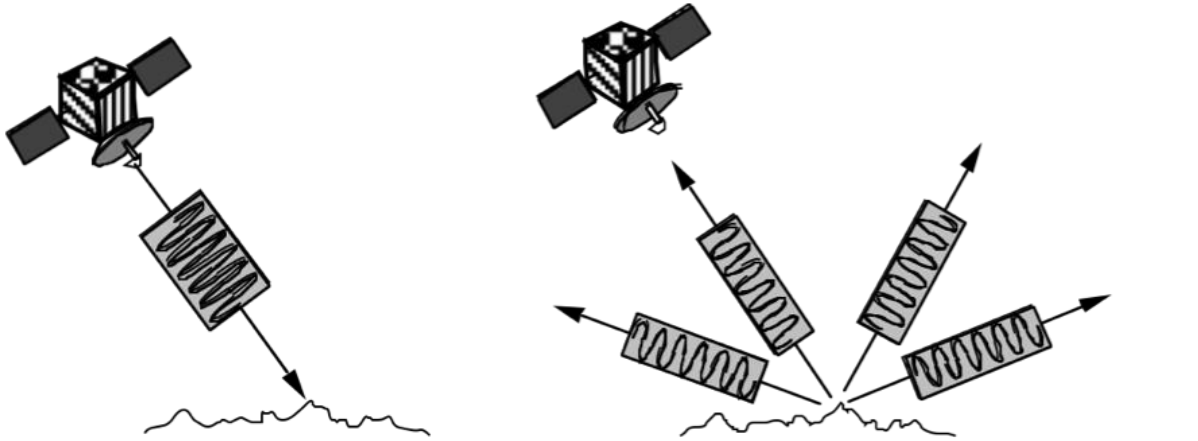
NASA Earth Observatory images by Robert Simmon, using Suomi NPP

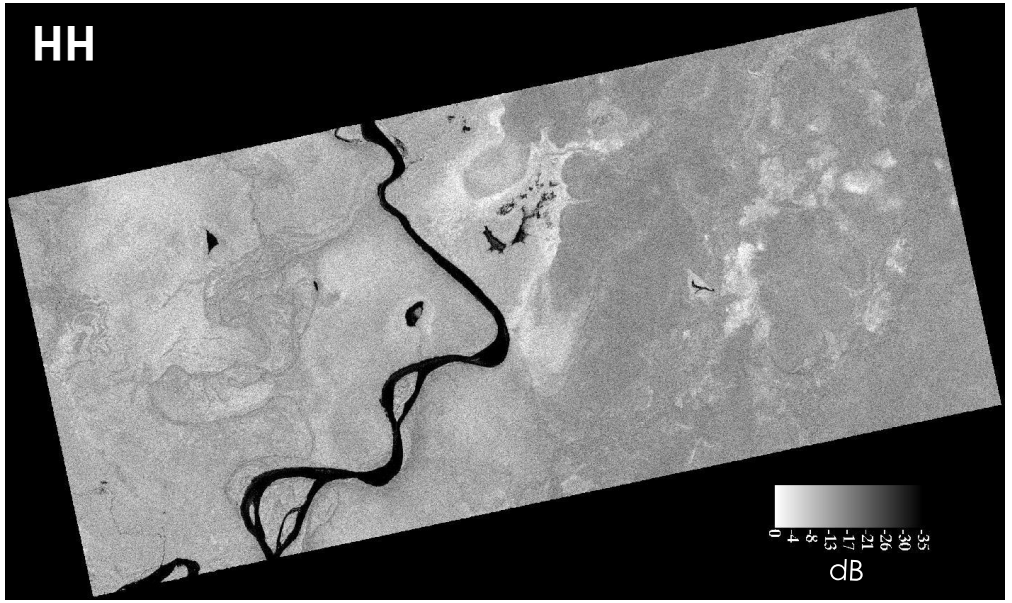
Down-Looking vs. Side-Looking Radar



Review of Radar Image Formation: Amplitude

1. Radar pulses travel at the speed of light.
2. Radar can measure amplitude (the strength of the reflected echo) and phase (the position of a point in time on a waveform cycle).
3. Radar can only measure the part of the signal reflected back towards the antenna (backscatter).
4. The received radar signal is calibrated and normalized to produce the radar backscattering coefficient (σ^0, or sigma naught), a measure of the backscattered power that is typically expressed in decibels (dB).

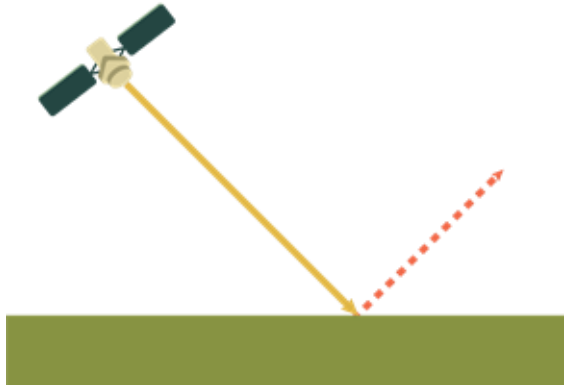




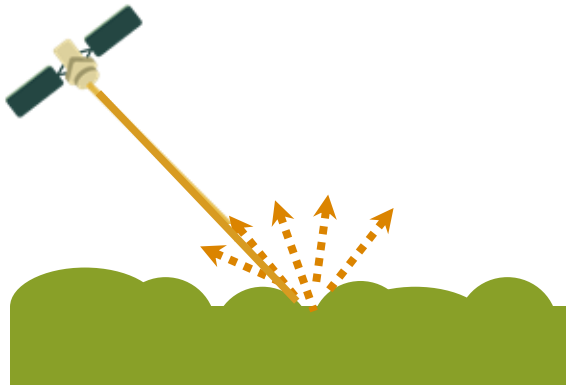
Source: ESA-ASAR Handbook

Radar Signal Interaction in Inundated Areas

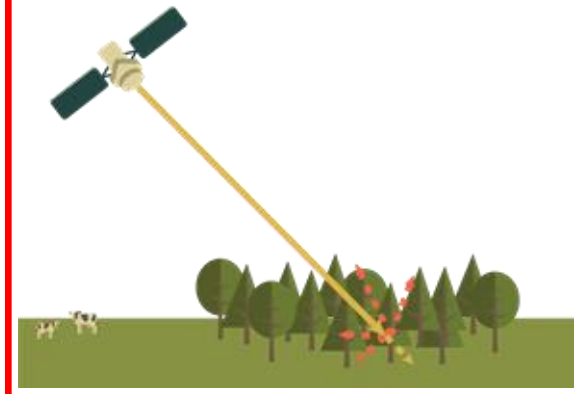
Radar Backscattering Mechanisms:



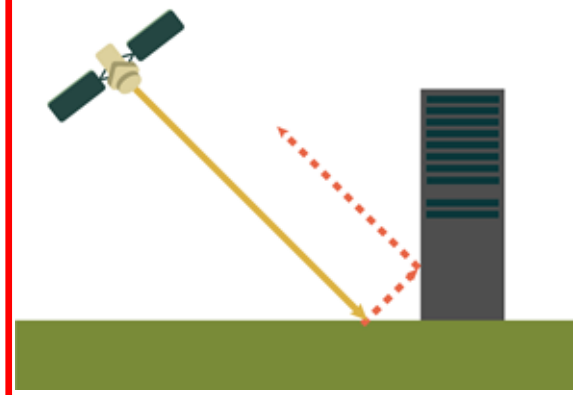
Smooth Surface
(specular reflector)



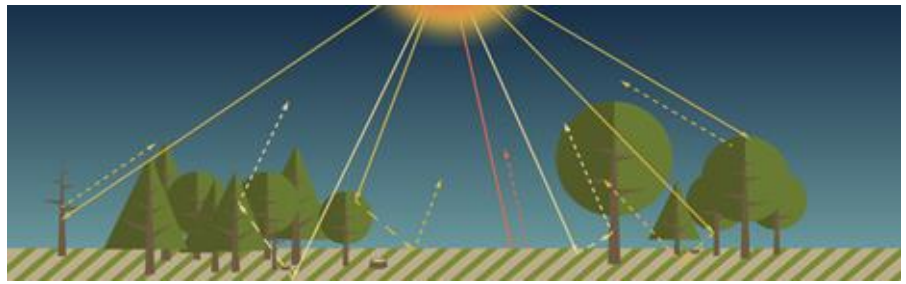
Rough Surface



Volumetric

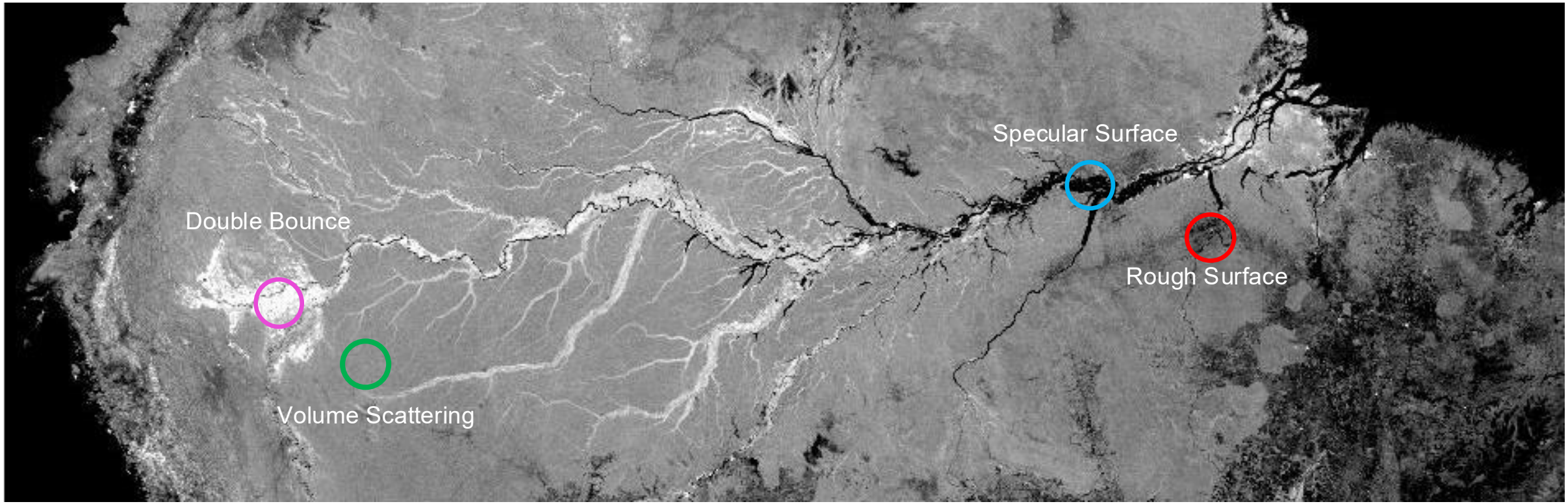


Double Bounce



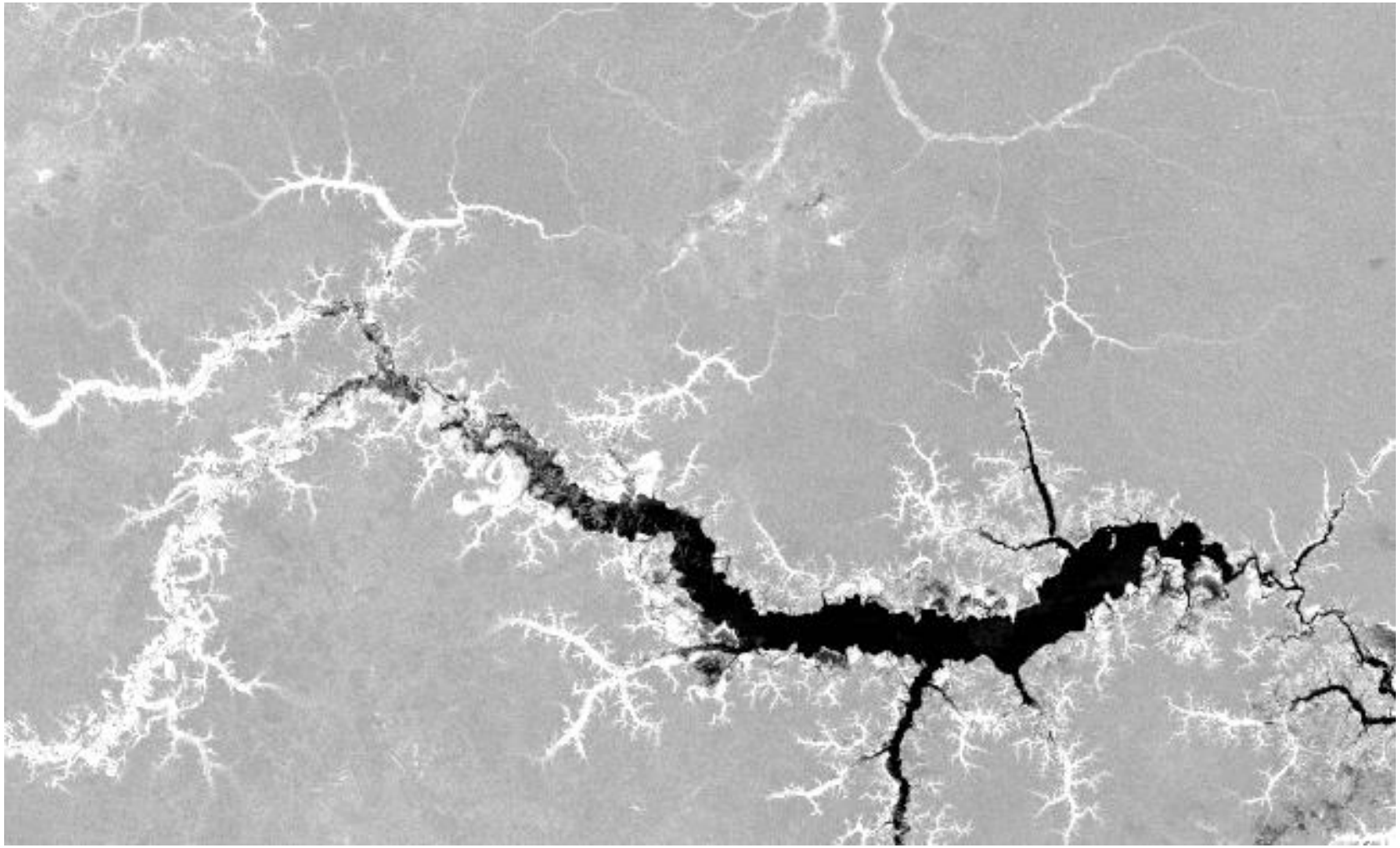
Backscattering Mechanisms

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



SAR Signal Scattering Over Inundated Regions

NISAR Image (L-band) near Manaus, Brazil



Radar Bands

(Approximate)

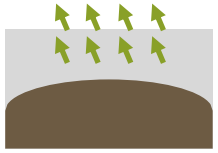
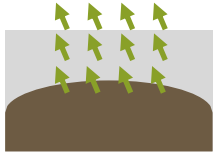
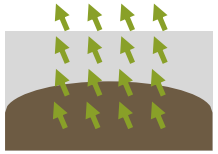
Band	Frequency f_0	Wavelength $\lambda = c/f_0$	Typical Application
Ka	27 – 40 GHz	1.1 – 0.8 cm	
K	18 – 27 GHz	1.7 – 1.1 cm	Rarely used for SAR
Ku	12 – 18 GHz	2.4 – 1.7 cm	
X	8 – 12 GHz	3.8 – 2.4 cm	High Spatial Resolution (urban monitoring; little penetration into vegetation cover → can't see water under vegetation)
C	4 – 8 GHz	7.5 – 3.8 cm	Sentinel-1; global mapping; improved vegetation penetration)
S	2 – 4 GHz	15 – 7.5 cm	Increasingly Used for SAR-Based Earth Observation; NISAR has S-band
L	1 – 2 GHz	30 – 15 cm	NISAR; Geophysical monitoring; biomass and vegetation mapping; high penetration → can see standing water under dense vegetation
P	0.3 – 1 GHz	100 – 30 cm	Biomass Estimation. ESA Biomass is the first P-band spaceborne SAR

Source: Franz Meyer

Wavelength and SAR Signal Response Over Flooded Vegetation

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

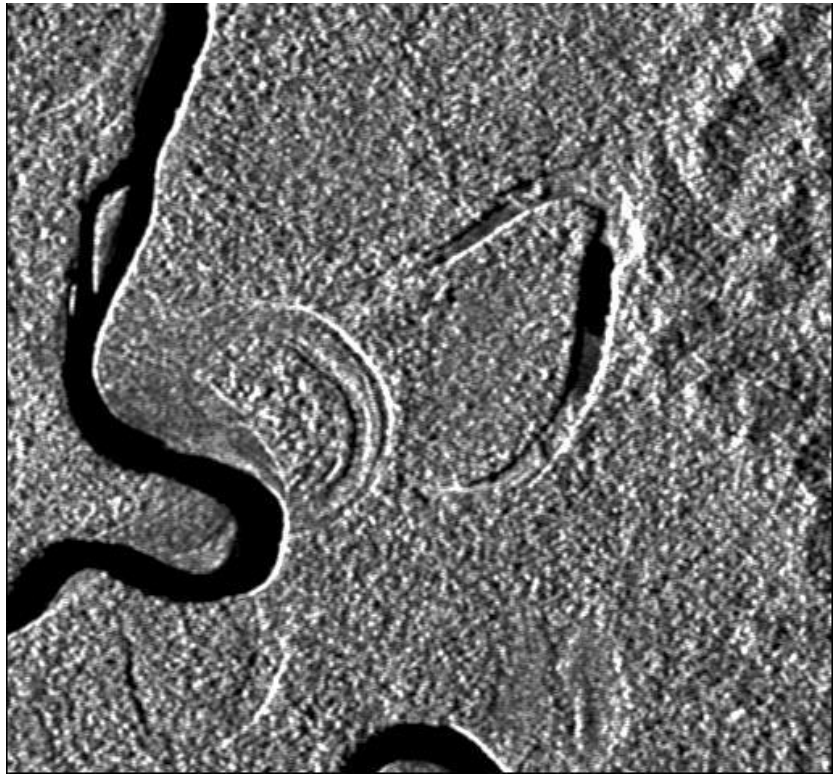
L-Band Penetration **>** C-band **>** X-band

Vegetation			
Dry Alluvium			
	X-band 3 cm	C-band 5 cm	L-band 24 cm

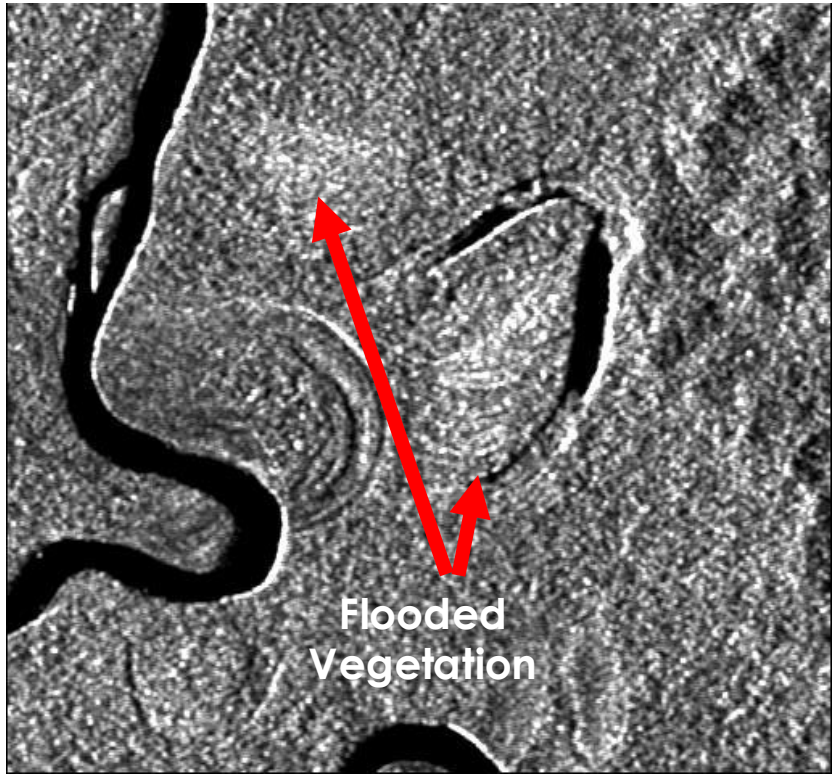
Signal Penetration Over Flooded Vegetation

Multi-Frequency AIRSAR data in Manu National Park, Peru

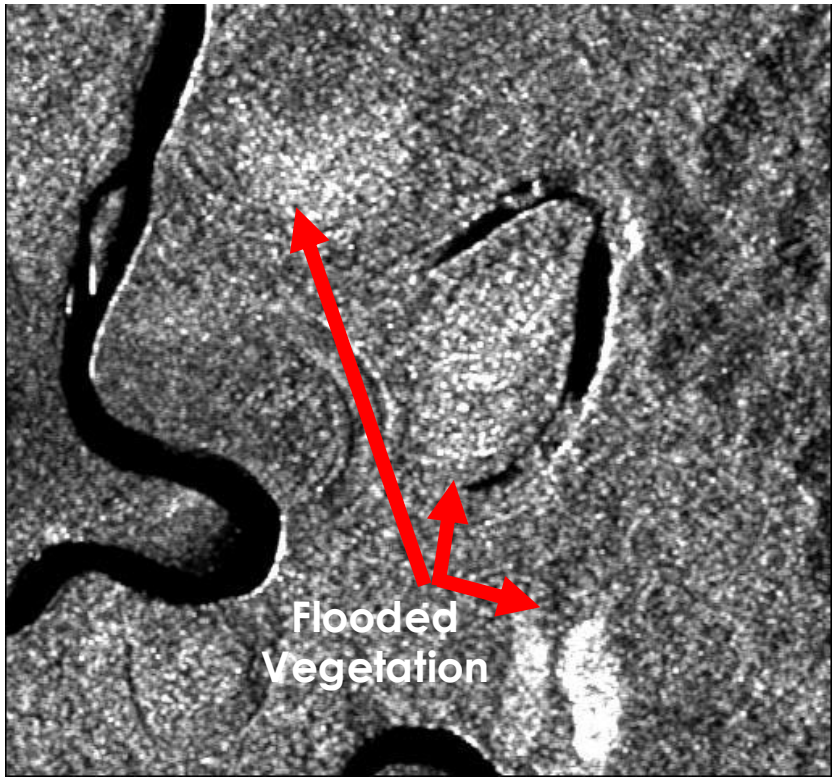
C-Band



L-Band



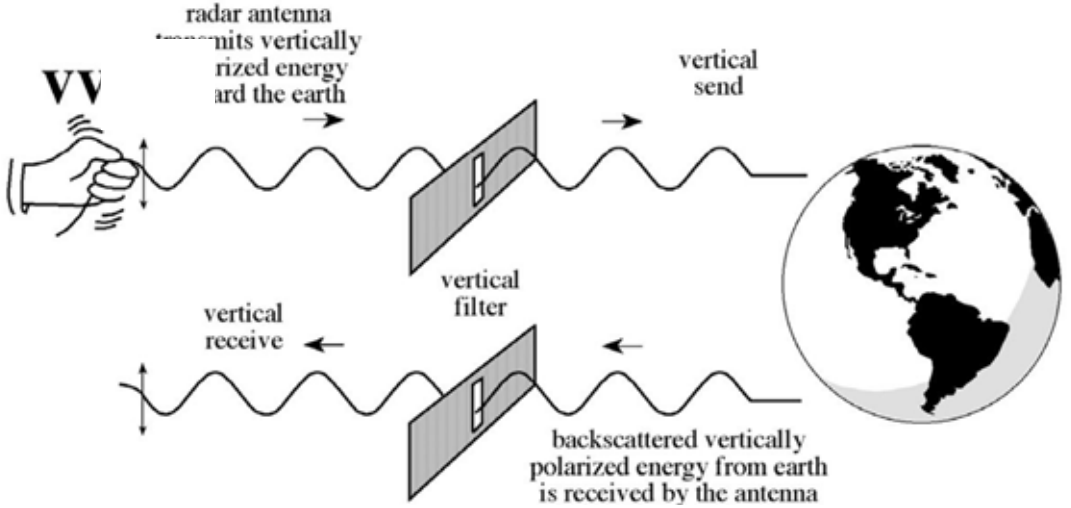
P-Band



Polarization

- The polarizations are usually controlled between Horizontal (H) and Vertical (V):
  - VV: Vertical Transmit, Vertical Receive
  - HH: Horizontal Transmit, Horizontal Receive
  - HV: Horizontal Transmit, Vertical Receive
  - VH: Vertical Transmit, Horizontal Receive
- Quad-Pol Mode: When all four polarizations are measured
- Different polarizations provide complementary information about surface properties.

Vertical Transmit, Vertical Receive **VV**



Horizontal Transmit, Horizontal Receive **HH**

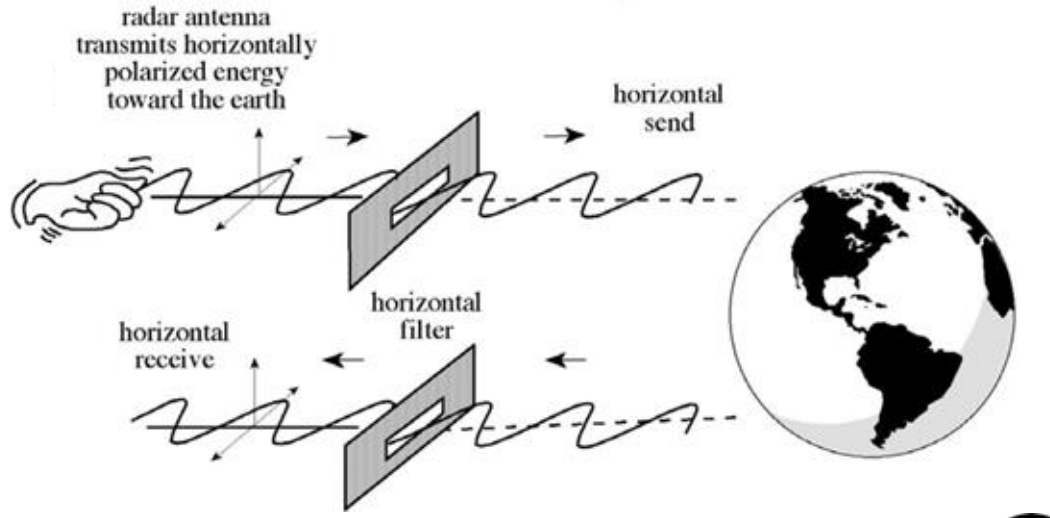
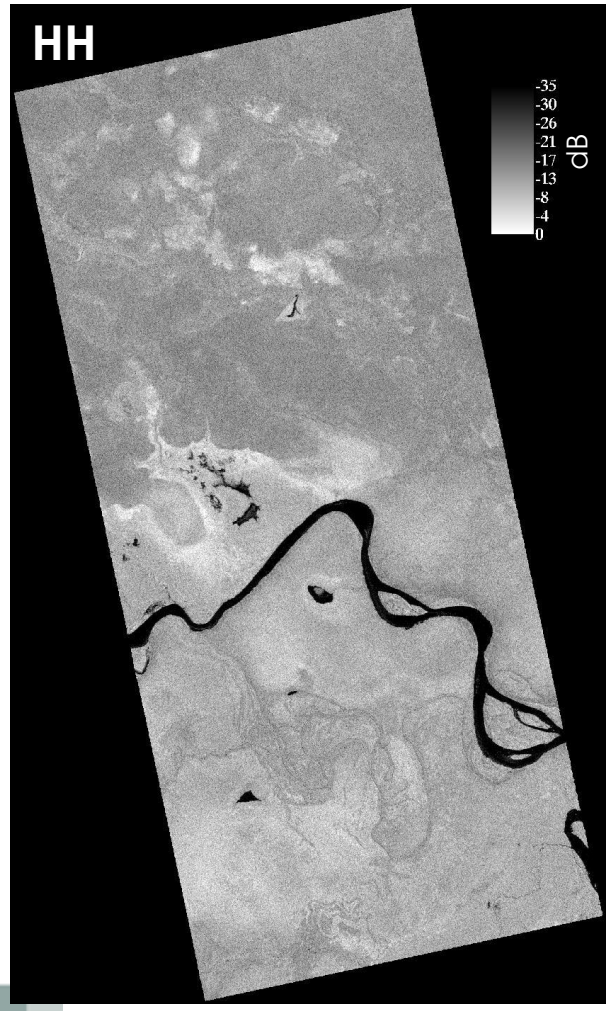
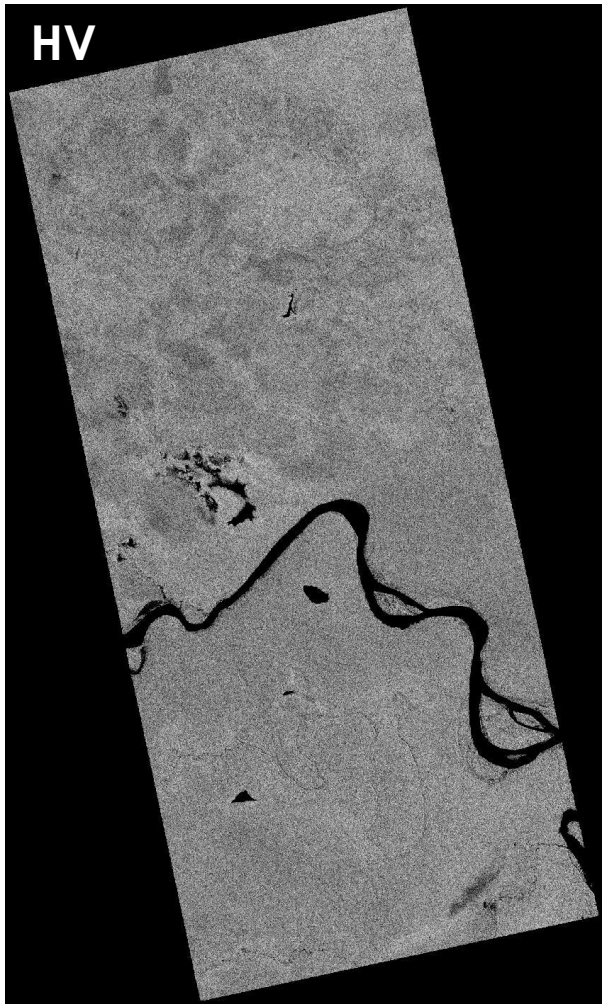


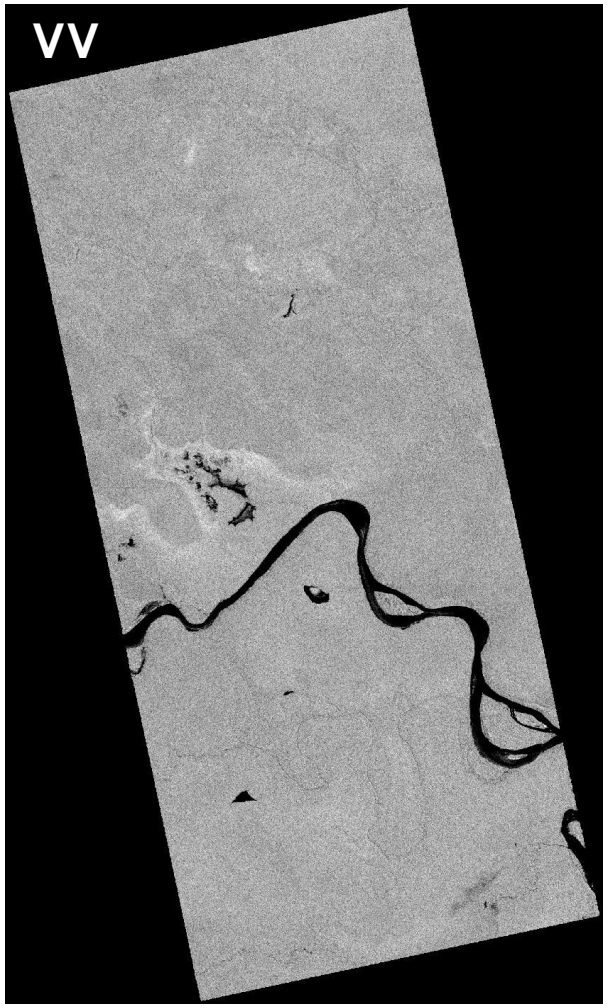
Image Credit: J.R. Jensen, 2000, Remote Sensing of the Environment

Multiple Polarizations for Detection of Inundated Vegetation

PALSAR (L-band) over Pacaya-Samiria in Peru

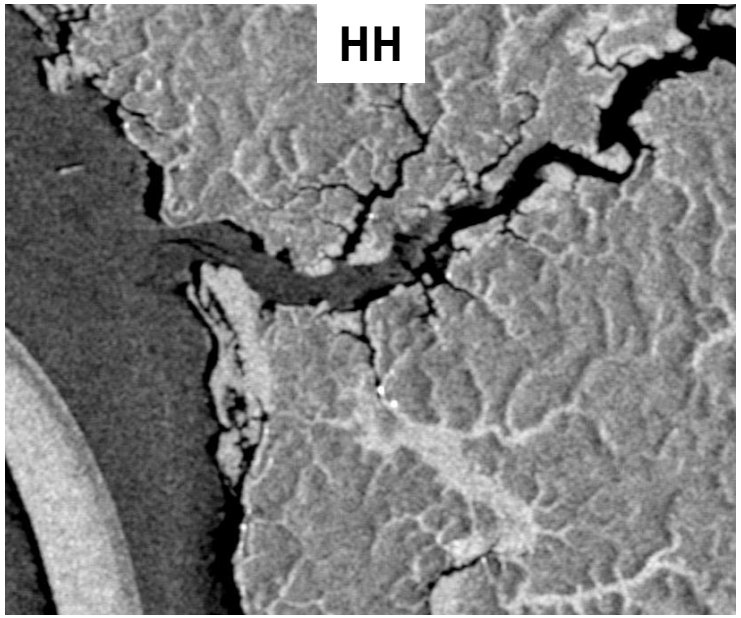


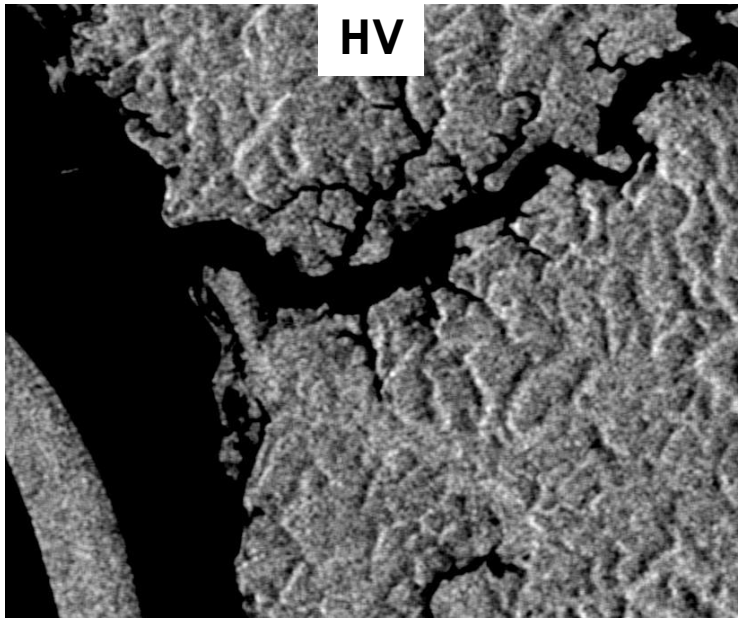


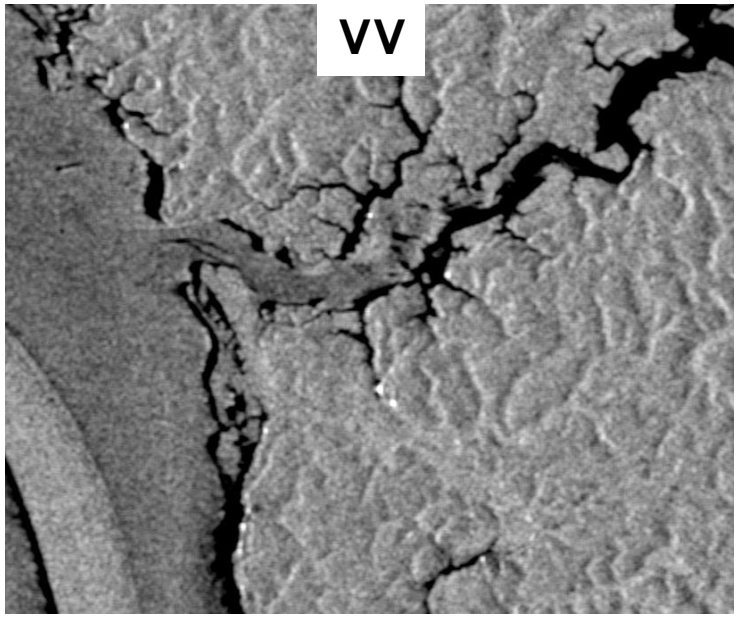


Multiple Polarizations for Detection of Open Water

Images from Palsar (L-band) near Manaus, Brazil



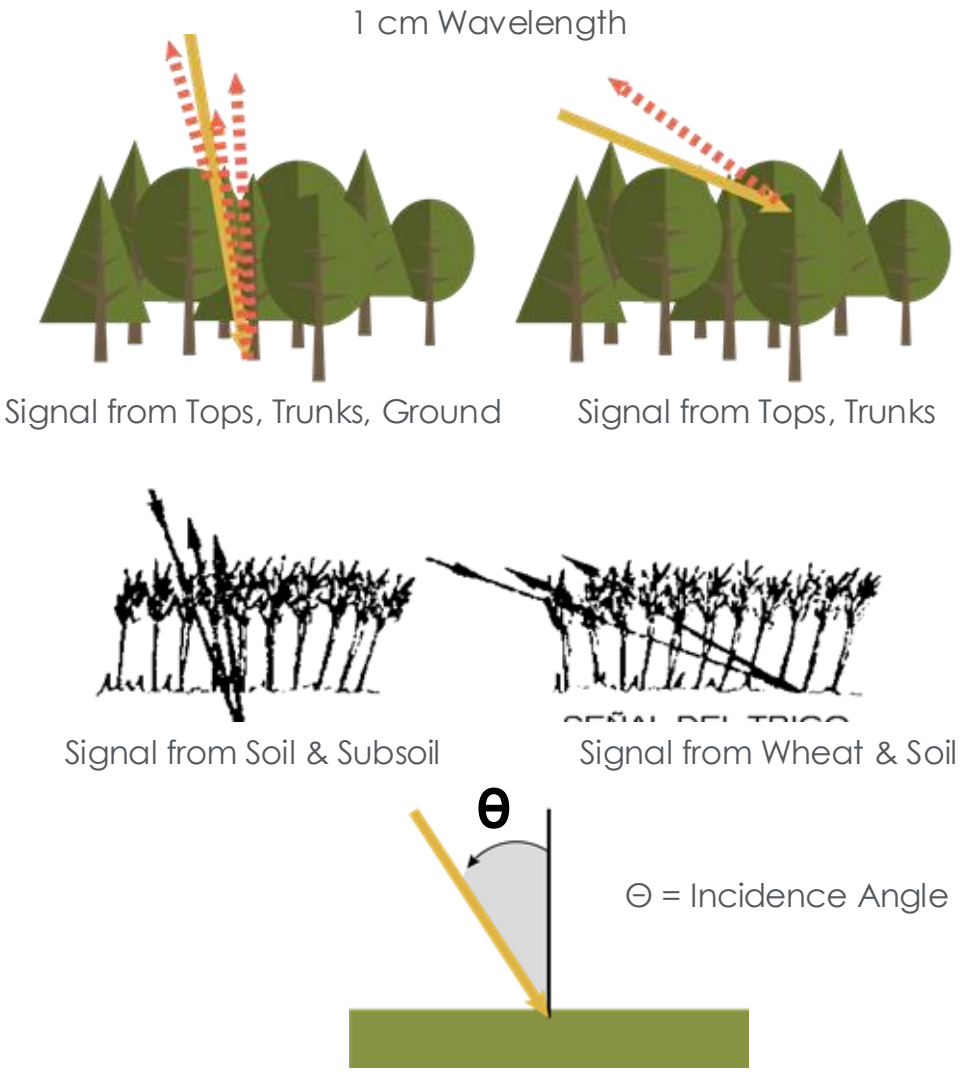




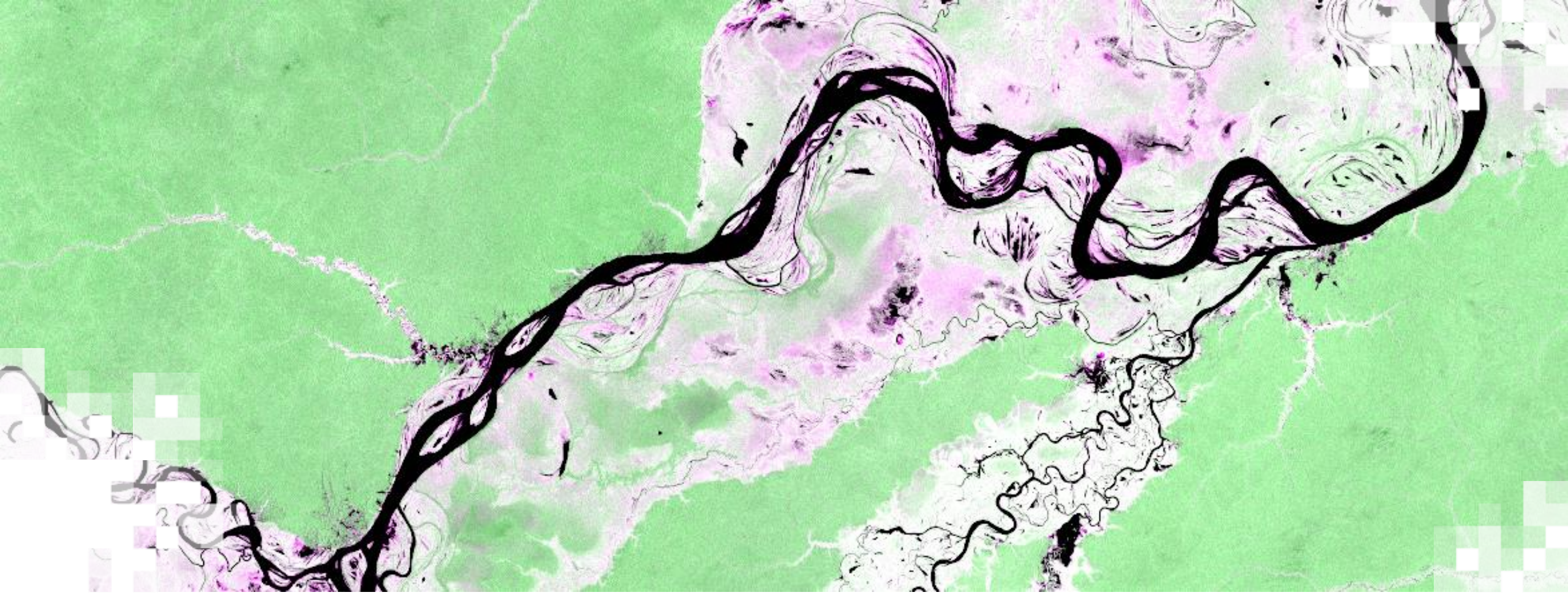
Incidence Angle

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
- The geometry of an image is different from point to point in the range direction



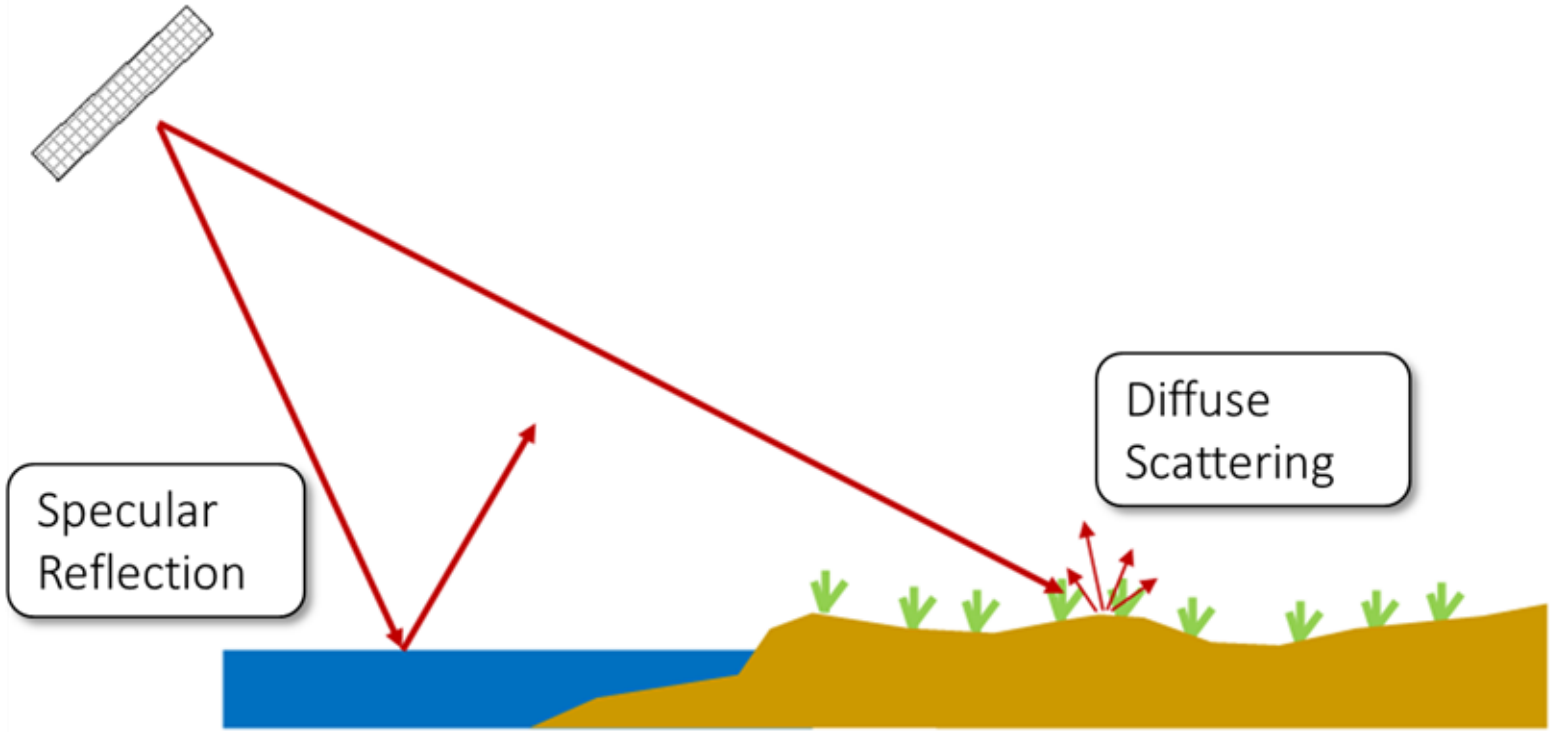
Images Based On: (Top) Ulaby et al. [1981a], (Bottom) ESA



Surface Water Signatures in SAR Images

Surface Water Signature: Open Water vs. Land

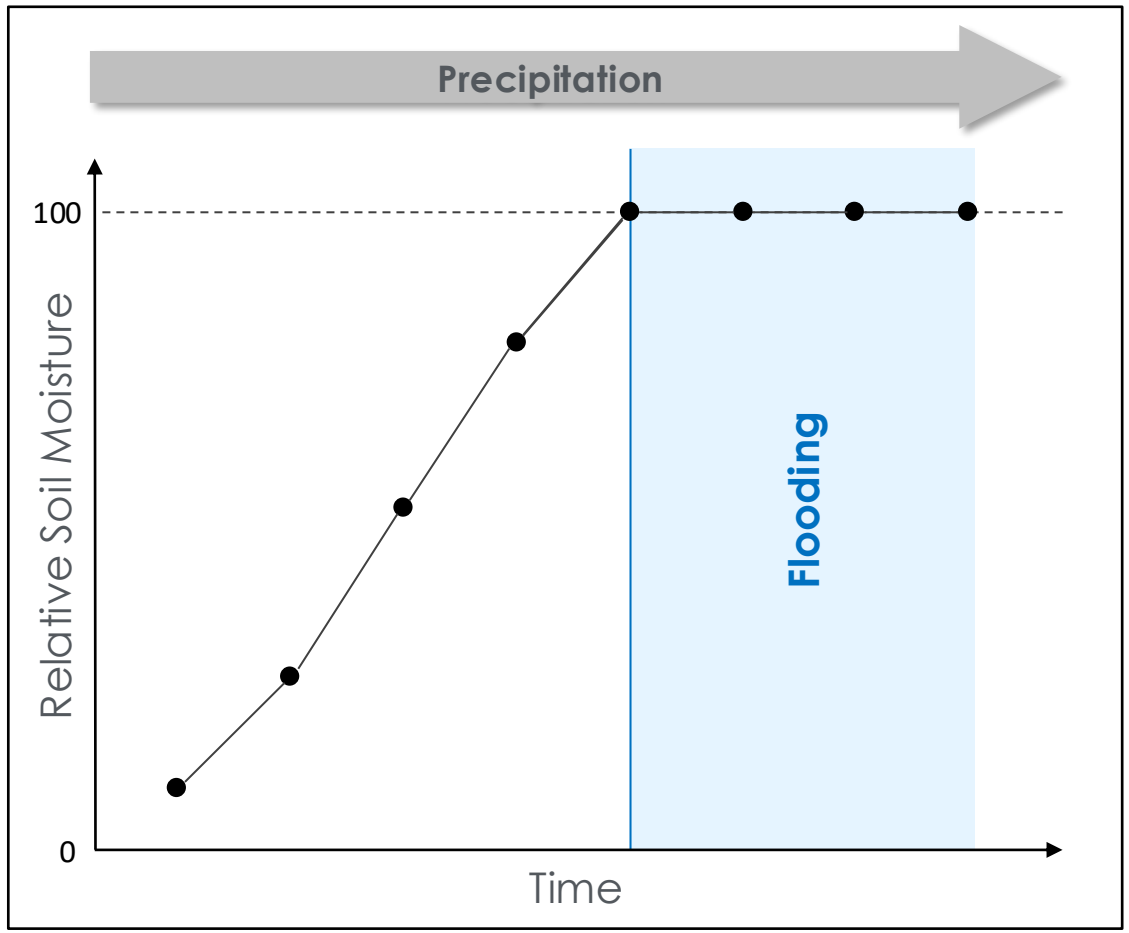
- **Mapping water surfaces based on different radar signatures of water and land**
  - Calm water surfaces appear smooth and cause specular reflection leading to low backscatter.
  - Surrounding land surfaces have greater surface roughness, causing higher backscatter.

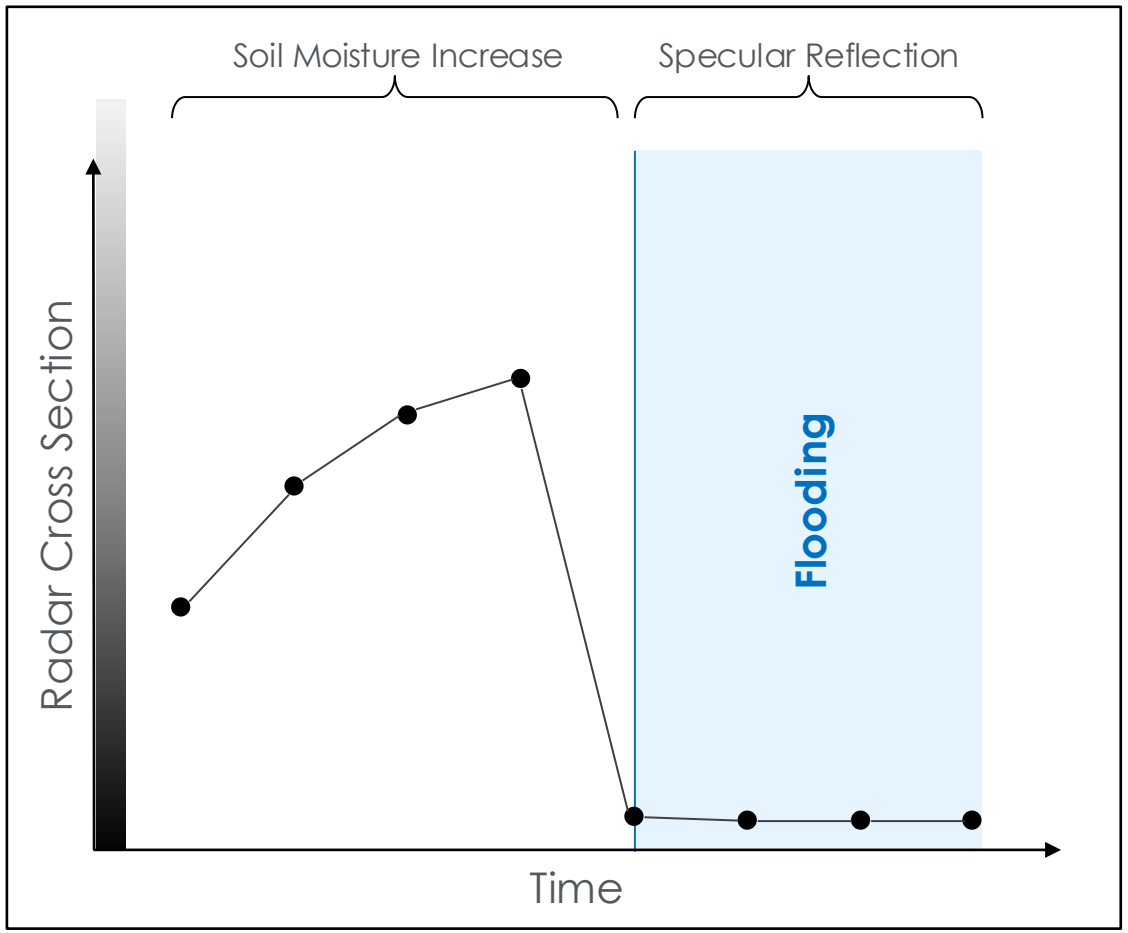


Source: Franz Meyer, Univ. of Alaska, Fairbanks/ASF

Flooding Signature in Land with Little or No Vegetation Cover

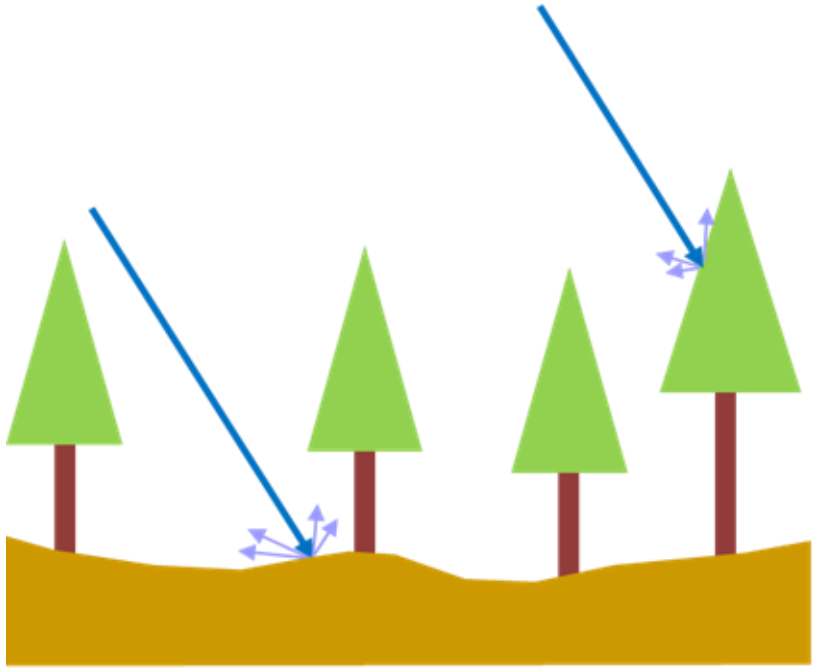
Relative SAR Response Over Land as Precipitation Increases:

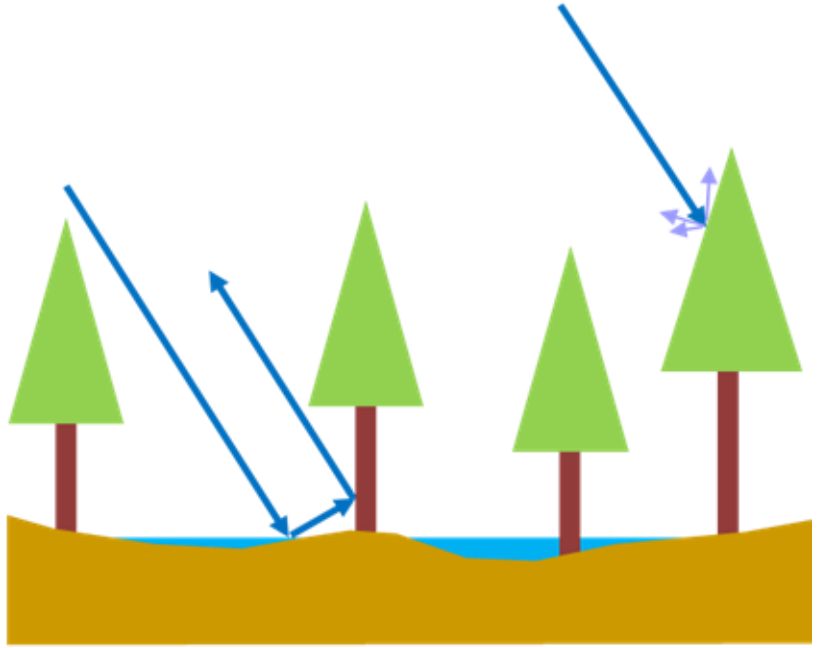




Source: Franz Meyer, Univ. of Alaska, Fairbanks/ASF

Surface Water Signature Under Vegetation Canopies



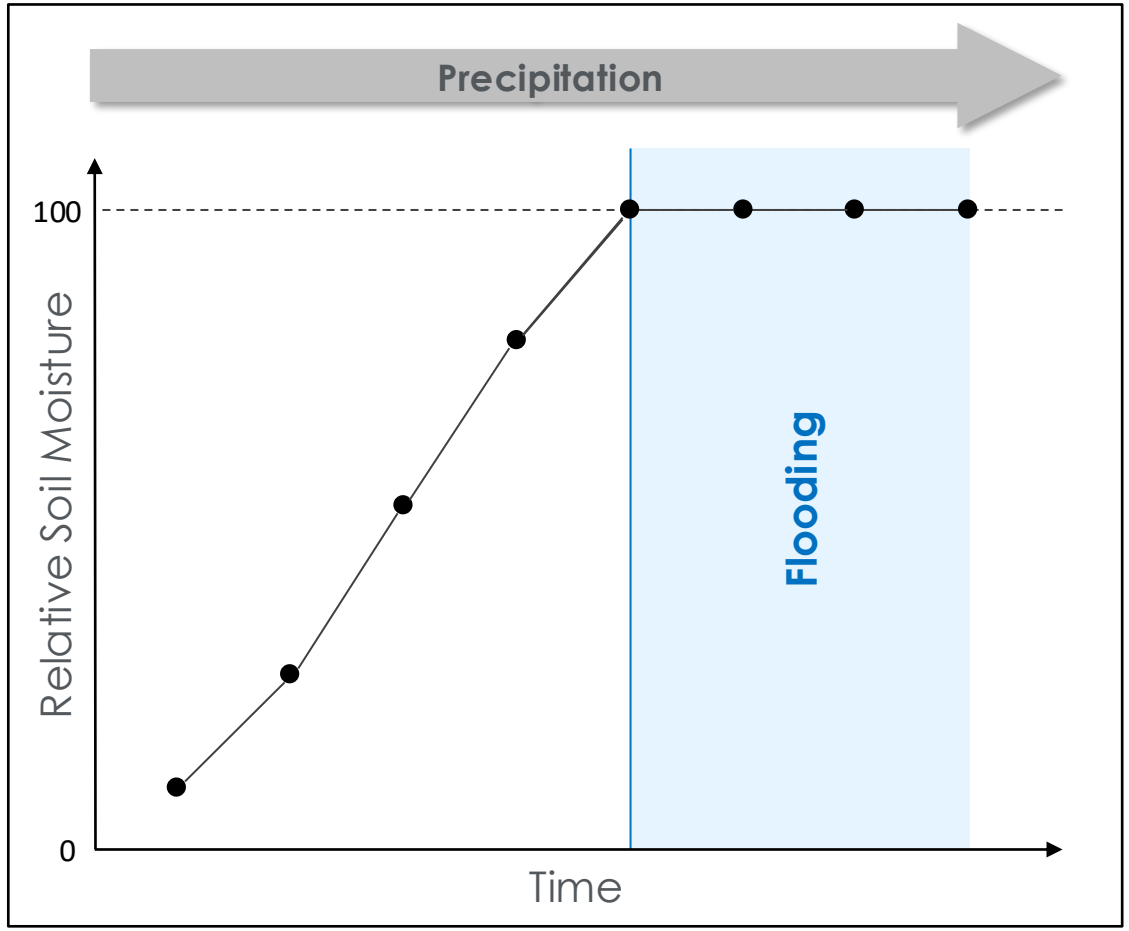


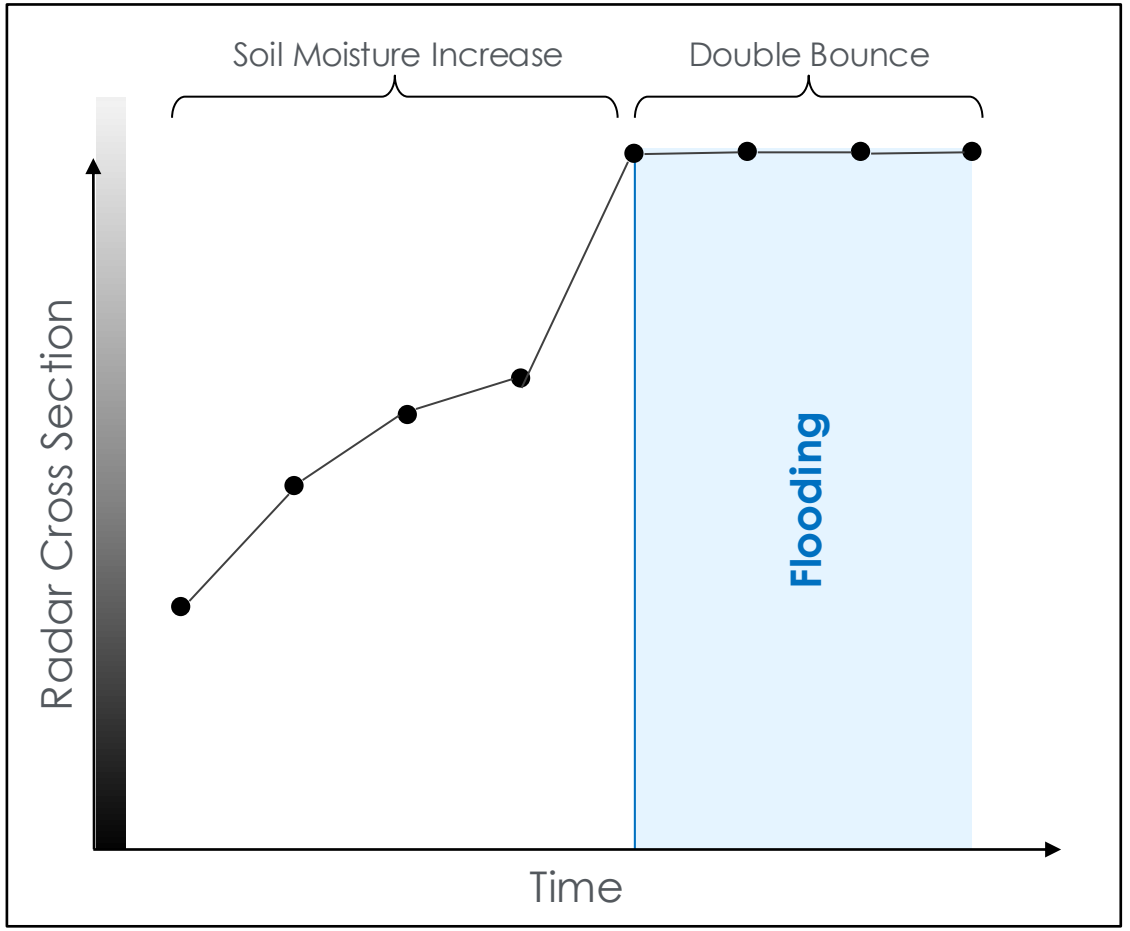
Enhanced backscatter from inundated vegetation due to double-bounce scattering between the smooth water surface and vertical tree trunks.

Source: Franz Meyer, Univ. of Alaska, Fairbanks/ASF

Flooding Signature under Vegetation Canopies

Relative SAR Response in Vegetated Canopies as Precipitation Increases:



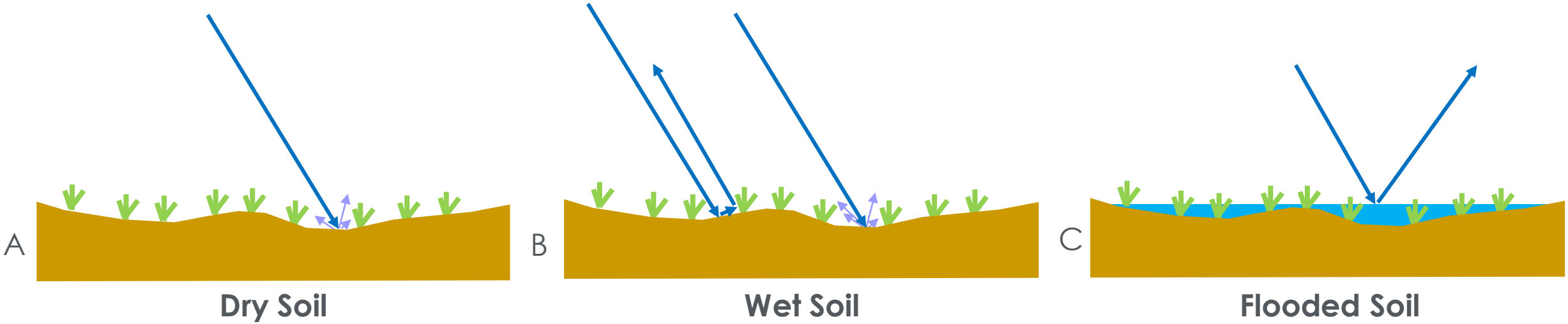


Mostly observable at L-band (NISAR) and much less observable at C-band (Sentinel-1)

Source: Franz Meyer, Univ. of Alaska, Fairbanks/ASF

Surface Water Signature in Crop Lands

Mapping Inundation in Crop Lands and Wet Meadows:



A to B: Backscatter increases with soil moisture.

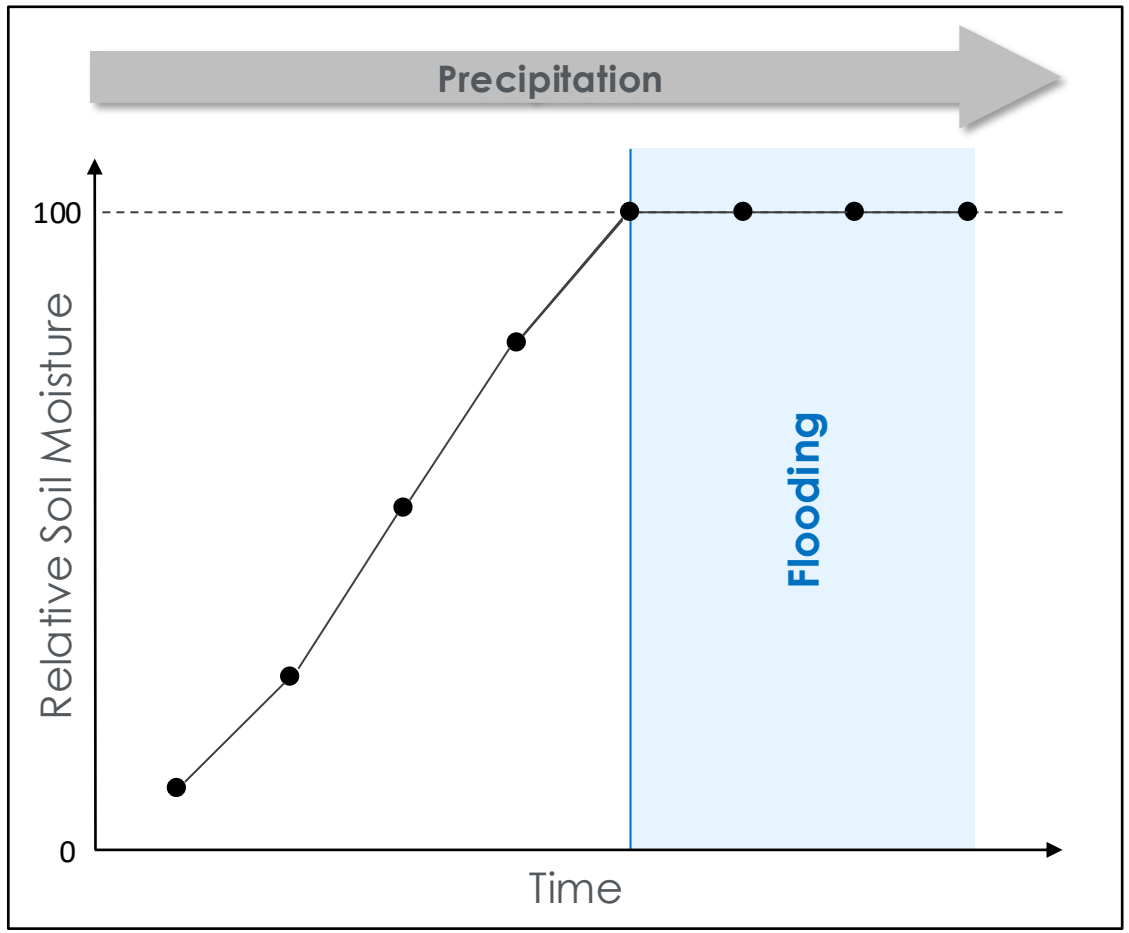
C: As water levels rise, backscatter decreases as specular reflection directs more of the radar signal away from the sensor.

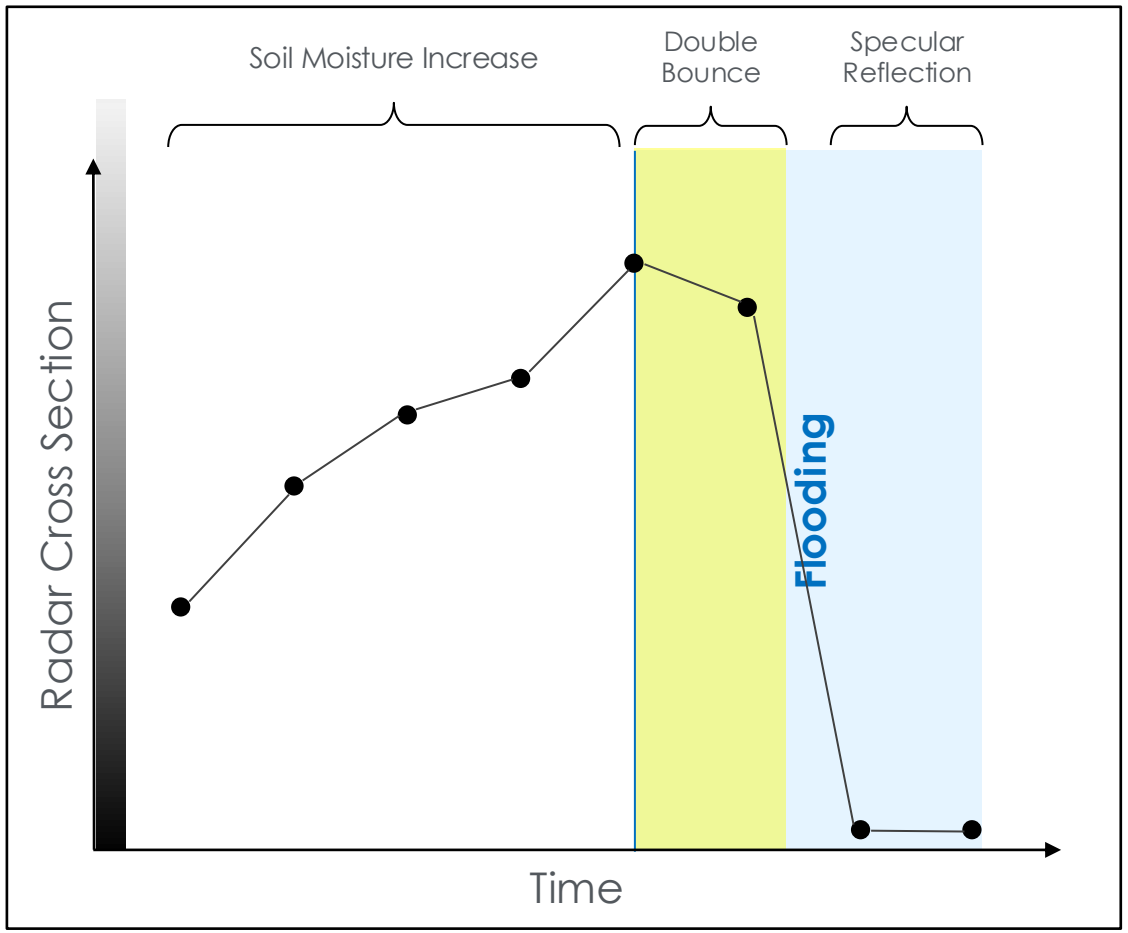
Fig.: Inundation effects on radar backscatter for wet meadows (after Bourgeau-Chavez et al., 2009)

Source: Franz Meyer, Univ. of Alaska, Fairbanks/ASF

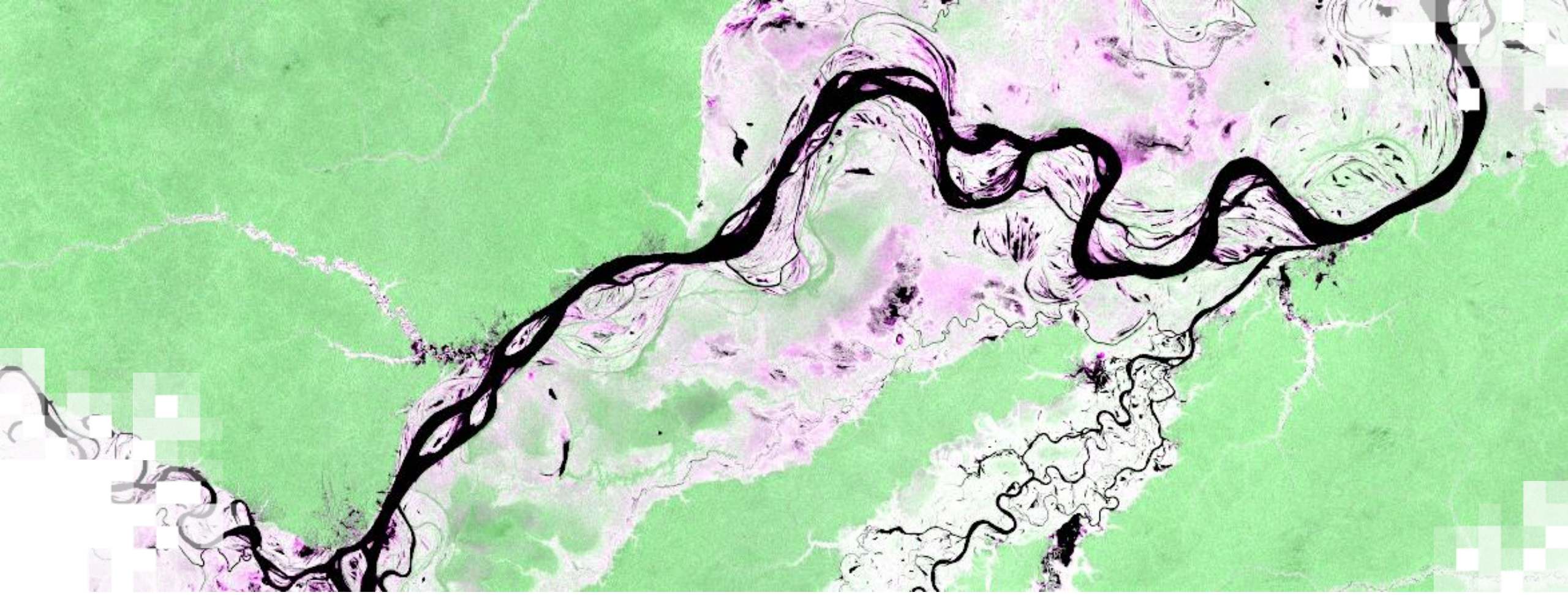
Flooding Signature in Crop Lands

Relative SAR Response in Crop Lands as Precipitation Increases:





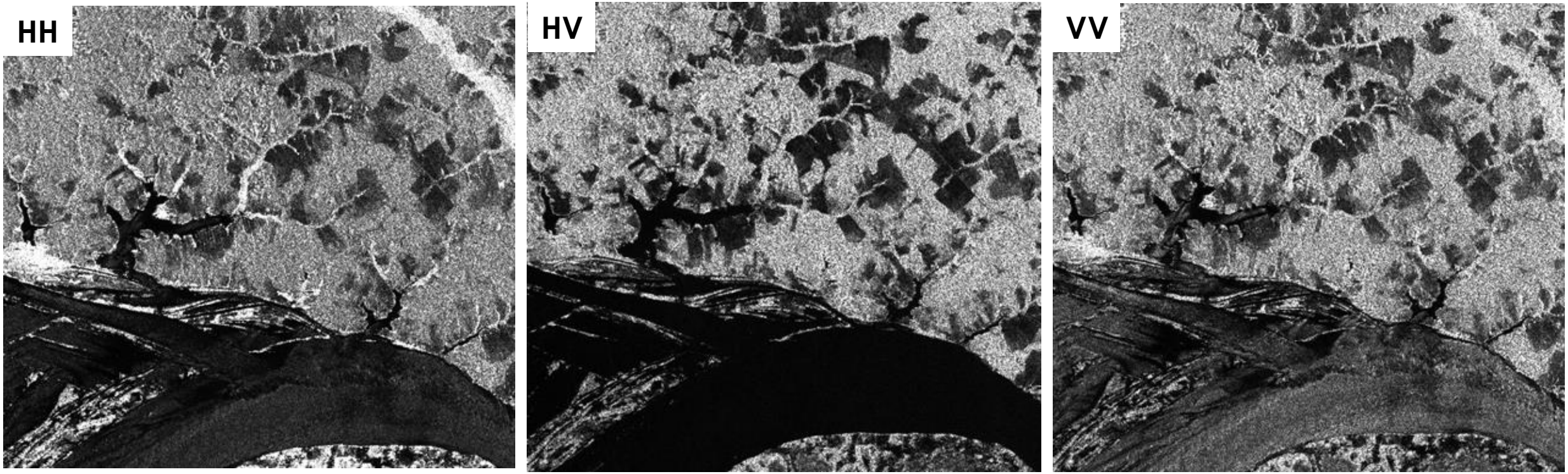
Source: Franz Meyer, Univ. of Alaska, Fairbanks/ASF



Sources of Confusion

Source of Confusion with Open Water: Wind and Agricultural Areas

PALSAR (L-band) near Manaus, Brazil



Source of Confusion with Open Water: Radar Shadow

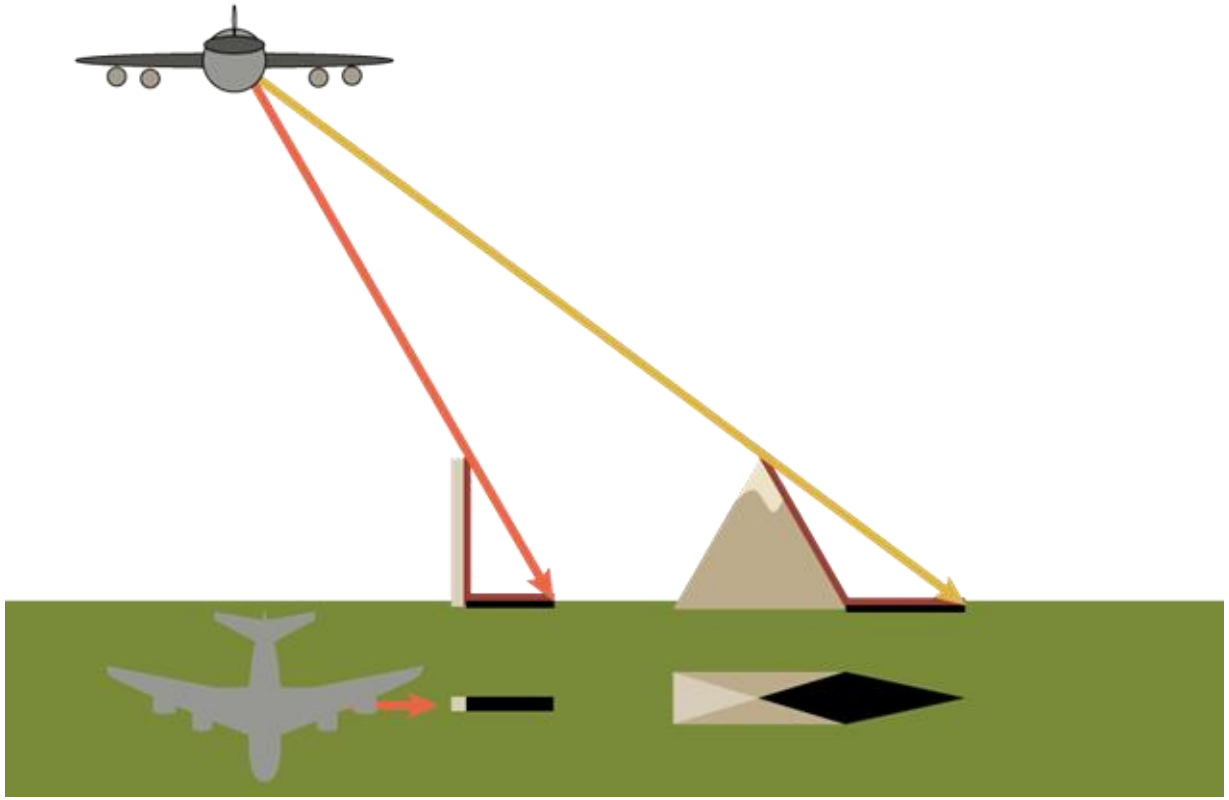
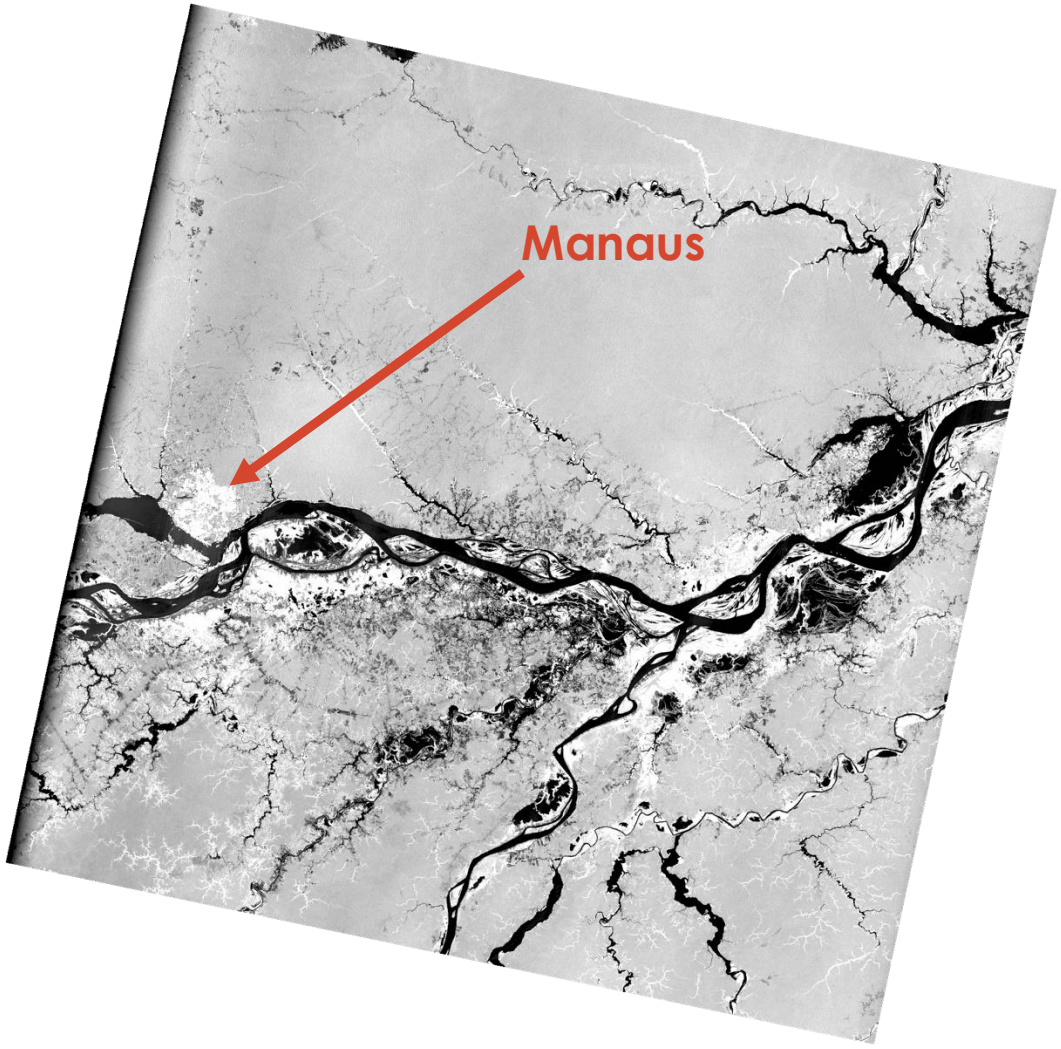


Image (left) based on NRC

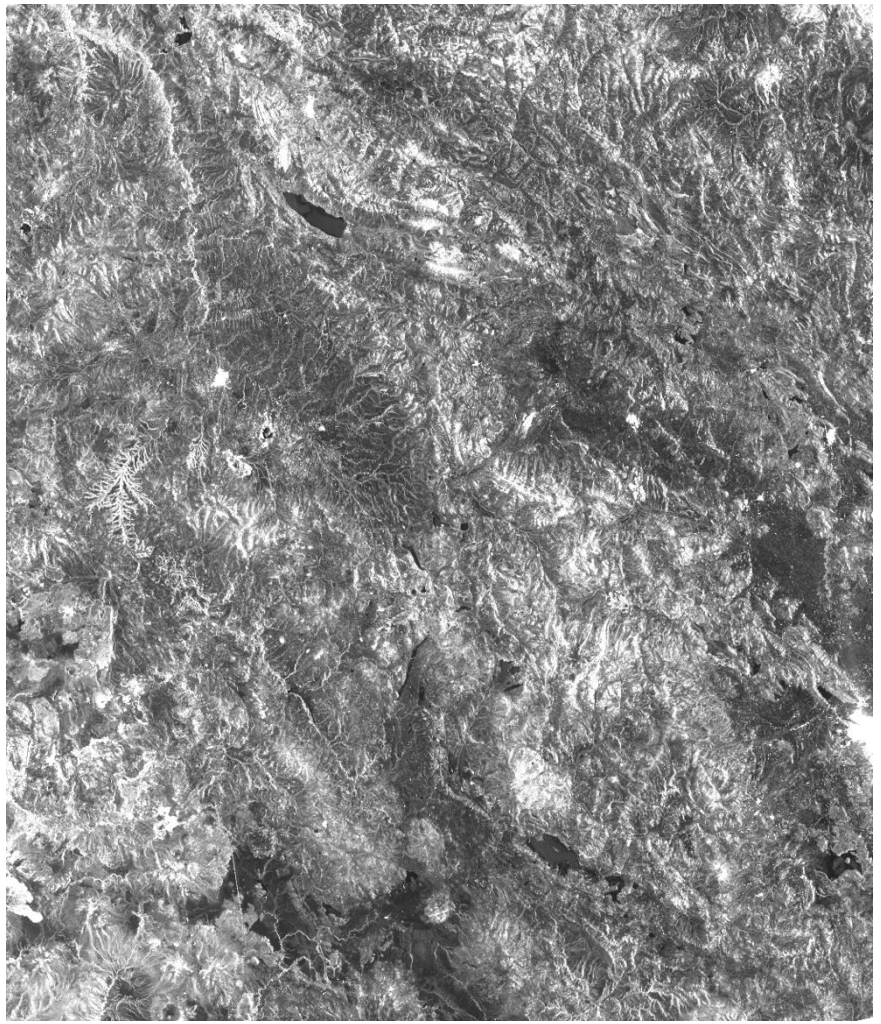
Source of Confusion with Inundated Vegetation: Urban Areas

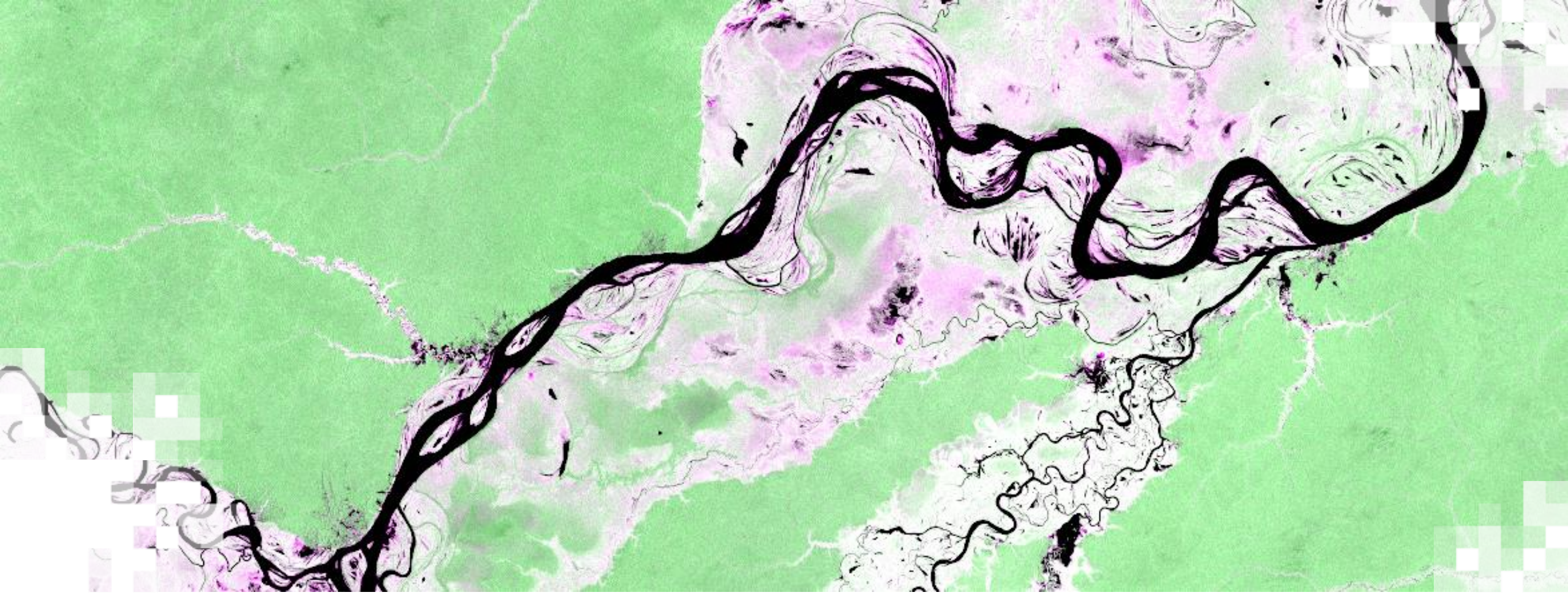
NISAR (L-band, HH) near Manaus, Brazil



Source of Confusion with Inundated Vegetation: Topographic Areas

NISAR GCOV Image (HH) Over the Andes



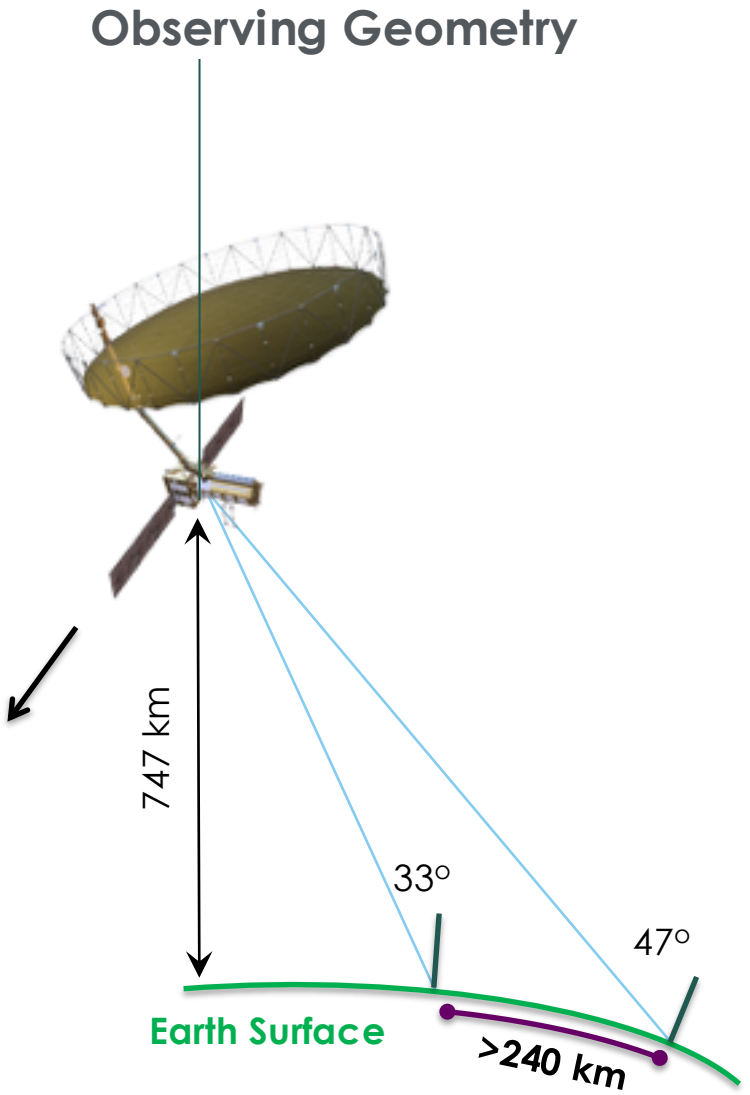


NISAR for Surface Water Mapping

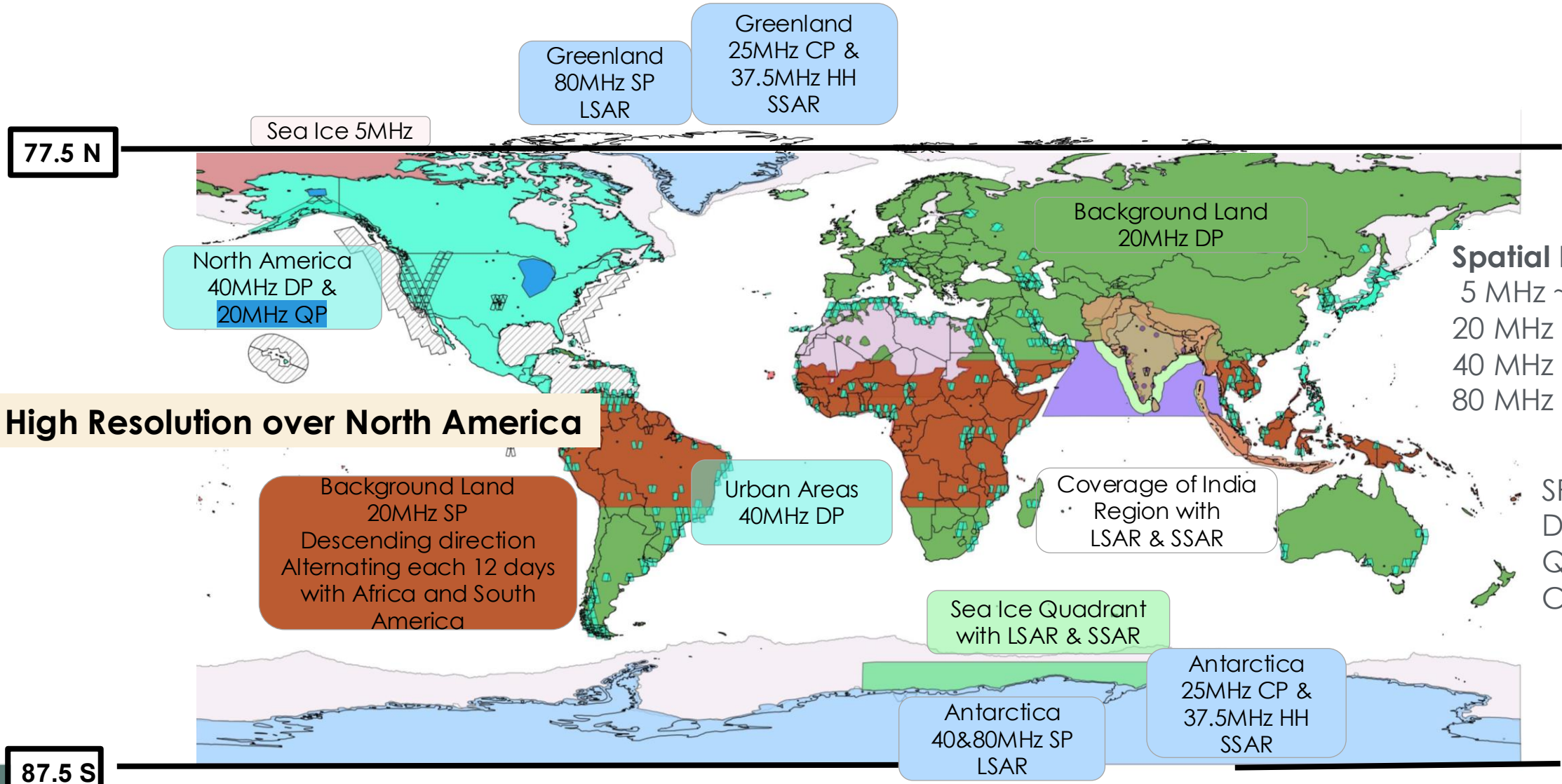
NISAR Characteristics

NISAR Launched on July 30, 2025

NISAR Characteristic:	Enables:
L-band (24 cm wavelength)	Low temporal decorrelation and foliage penetration
S-band (9.4 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
10 -50 meters mode-dependent SAR resolution	Small-scale observations
3 yrs (NASA)/5 yrs (ISRO) science operations	Time-series analysis
Pointing control < 273 arcseconds	Deformation interferometry
Orbit control < 500 meters	Deformation interferometry
> 10% (S)/50% (L) observation duty cycle	Complete land/ice coverage
Left-only pointing (Left/Right capability)	Uninterrupted time-series Rely on Sentinel-1 for Arctic



Current Observation Plan



High Resolution over North America

Spatial Resolution

5 MHz ~ 30 x 6 m
20 MHz ~ 7.5 x 6 m
40 MHz ~ 3.75 x 6 m
80 MHz ~ 1.95 x 6 m

SP – Single Pol
DP – Dual Pol
QP – Quad Pol
CP – Cross Pol

Accessed Via: https://experience.arcgis.com/experience/6052a864cd01459393884a7f751558e3

NISAR Data Levels

Data Product	Description
Level 0	Raw telemetry and signal data.
Level 1	Data are provided in radar coordinates (range-Doppler) rather than geographic coordinates.
Level 2	Data are geocoded onto a map grid (UTM or polar stereographic projection) and can be directly overlaid on a map or combined with other geocoded data.
Level 3	Data are geocoded, derived science products expressed in physical units. The only global Level 3 product generated by NISAR is soil moisture. There are algorithms (ATBD's) to generate discipline-specific Level 3 products, and these have been validated over calibration/validation sites. These are biomass, vegetation disturbance, wetlands inundation, crop area, surface deformation, damage proxy, ice sheet/glacier velocity, sea ice velocity.

NISAR L-Band Data

Products	Product Level	Extent
RSLC (Range Doppler Single Look Complex)	L1	Global
GSLC (Geocoded SLC)	L2	Global
GCOV (Geocoded Covariance)	L2	Global
GUNW (Geocoded Unwrapped and Wrapped Interferogram)	L2	Global
GOFF (Geocoded Pixel Offsets)	L2	Cryosphere Regions
RIFG (Range-Doppler Wrapped Interferogram)	L1	Cryosphere Regions
RUNW (Range-Doppler Unwrapped Interferogram)	L1	Cryosphere Regions
ROFF (Range-Doppler Pixel Offsets)	L1	Cryosphere Regions
Soil Moisture	L3	Near Global

NISAR Data Status

Feb 2026: Beta products

- Over 100,000 Level 1-3 pre-calibrated global data products were released on February 27, 2026.

Jul 20, 2026: Provisional Data Released

- This release includes acquisitions starting June 17, 2026.
- Data is fully calibrated and have undergone validation at a limited set of sites around the world
- Significant improvement over beta products.
- More complete validation over larger areas around the globe is still needed.

Late 2026: Validated Reprocessing

- Fully validated Level 0-3 products from the global backlog of all data collected during the science phase of the mission. This processing is expected to be completed before the end of the calendar year.

NISAR Data Access

Map-Based Search and Discovery:

- Earthdata Search
- ASF Vertex
- Bhoonidhi (for access to ISRO L- and S-Band data)

Programmatic Search and Discovery:

- earthaccess
- asf-search

AWS S3 Direct Bucket Access

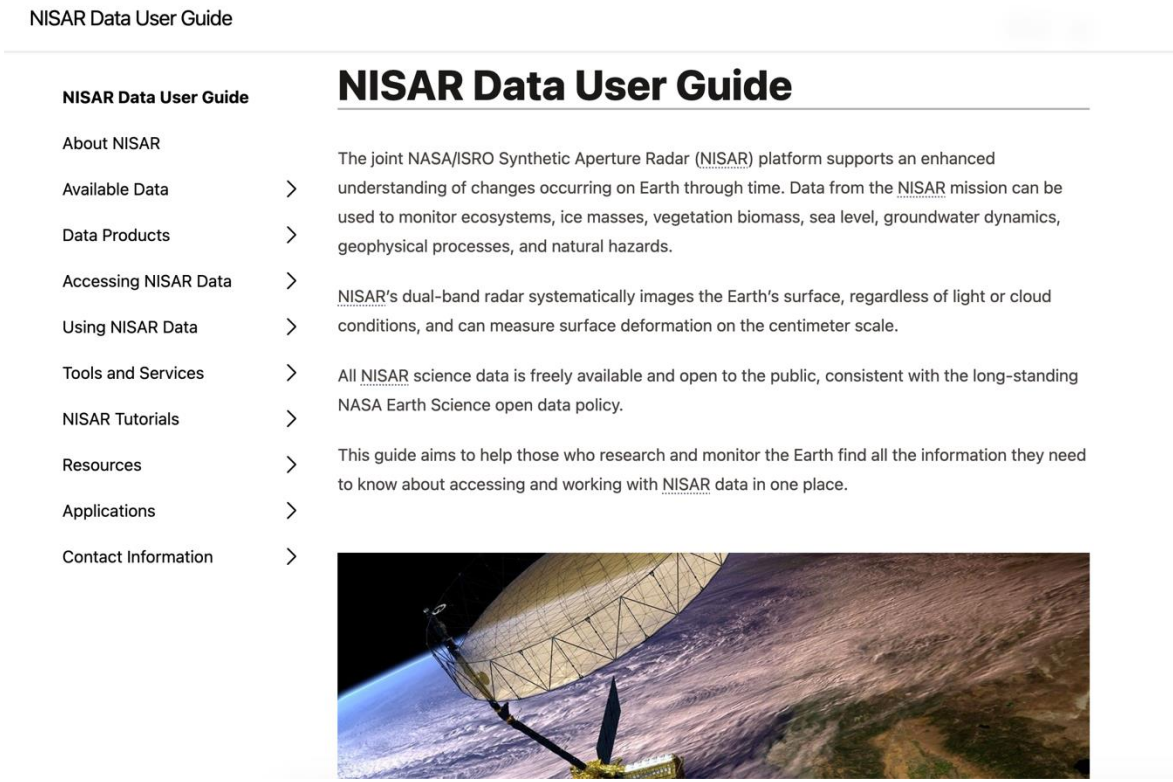
nisar-docs.asf.alaska.edu/access-overview/

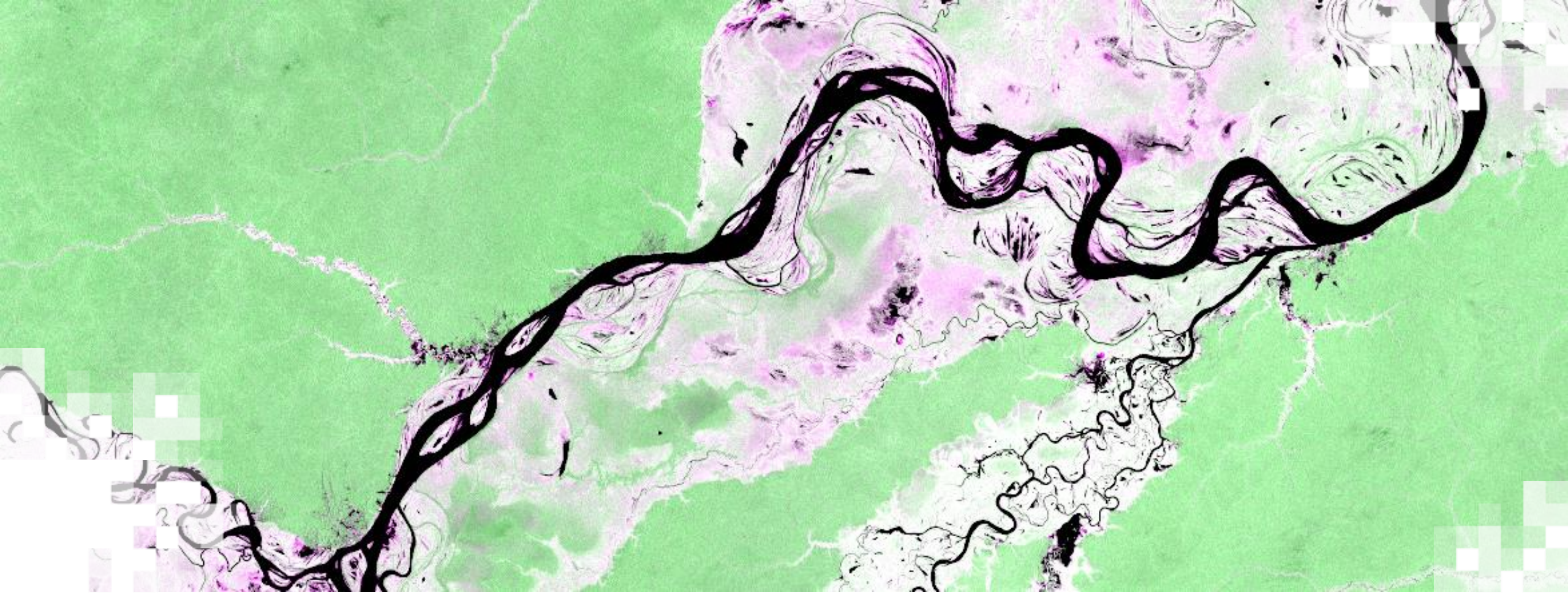
NISAR Resources

NISAR Handbook

NISAR Data User Guide

https://nisar-docs.asf.alaska.edu/





Demonstration

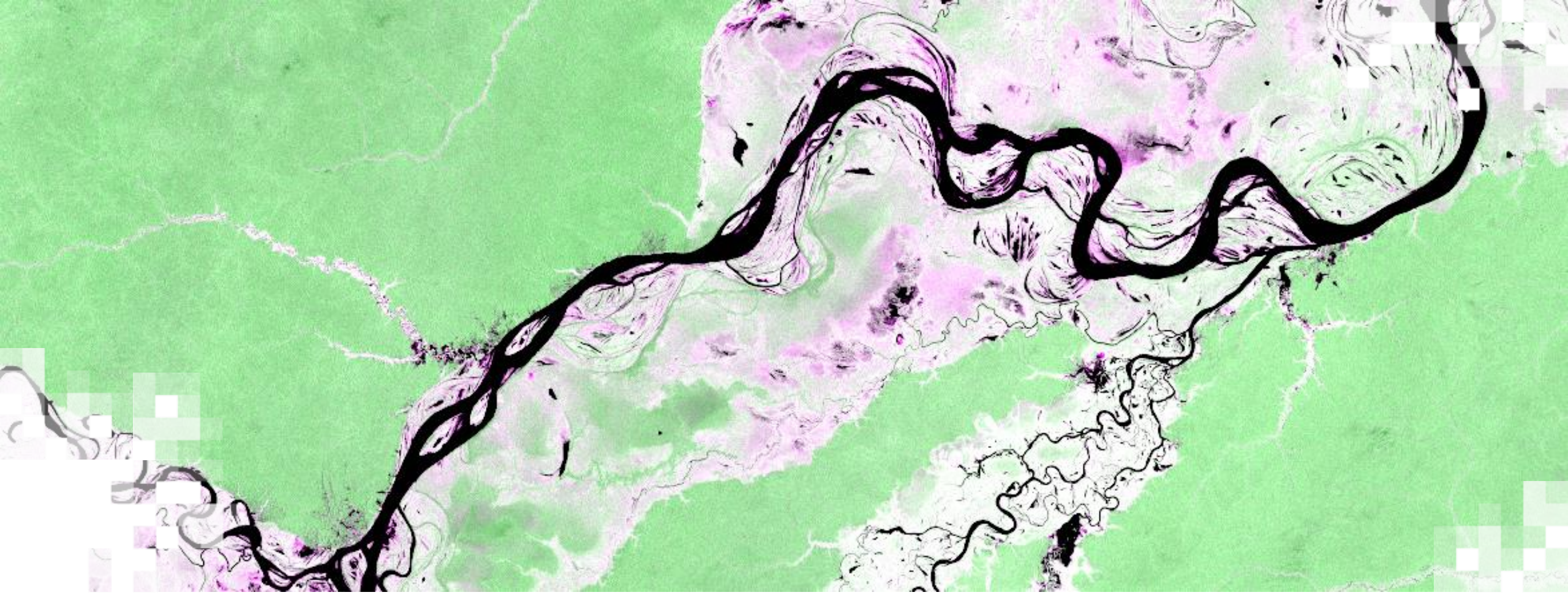
Demonstration Overview

Objective:

- Generate a flood map using a before and after NISAR GCOV image where flooding occurred
- Apply a threshold to identify open water and inundated vegetation

Outline:

- Download the GCOV NISAR image of the area of interest
- Visualize both polarizations
- Determine average values for open water and inundated vegetation
- Define a threshold based on those average values
- Generate a flood map



Session 1:
Summary

Summary

- SAR is an active microwave remote sensing technology that provides day/night, cloud-penetrating observations for monitoring Earth's surface.
- SAR is particularly valuable for flood monitoring because it can detect inundation during and immediately after storms, when optical imagery is often unavailable due to cloud cover.
- SAR is particularly sensitive to open water bodies (low backscatter) and to inundate vegetation (very high backscatter).
- NISAR has an L-band (24 cm) and an S-band (9.4 cm) SAR.
- Longer wavelengths are better suited for monitoring inundation in dense forests while the shorter wavelengths are better for low inundated vegetation such as agricultural areas.
- The NISAR GCOV product is the best suited to detect and monitor surface water.

Looking Ahead to Session 2

Participants will learn how to:

- Recognize the capabilities and appropriate applications of the OPERA Surface Water Extent product for water resource monitoring.
- Evaluate when it is more appropriate to generate a flood map from NISAR data versus using the OPERA Surface Water Extent product.
- Access OPERA surface water extent products to interpret flood monitoring applications with GIS.

Homework and Certificates

- **Homework:**
  - One homework assignment
  - Opens on 10/27/2026
  - Access from the training webpage
  - Answers must be submitted via Google Forms
  - **Due by Nov. 17, 2026**

- **Certificate of Completion:**
  - Attend both live sessions (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

Instructor:

- Erika Podest
  - erika.podest@jpl.nasa.gov

- ARSET Website
- ARSET YouTube

For questions, comments, or to share how you have applied our trainings to your work or studies, email nasa.arset@gmail.com.

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Thank You!