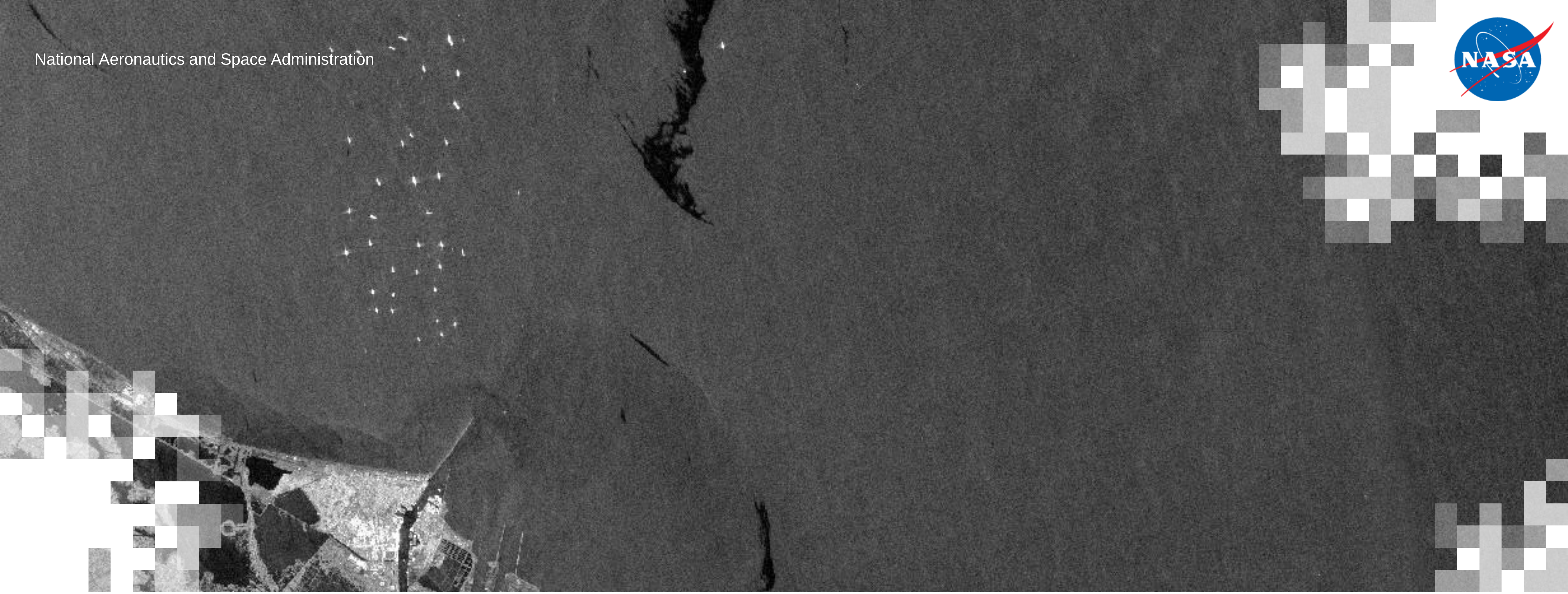
National Aeronautics and Space Administration



SAR for Flood Mapping

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

Oct. 19, 2022

Training Format

- Three 2-hour sessions including presentations and question and answer sessions
- The same content will be presented at two different times each day.
- Session A will be presented in **English.**
- Session B will be presented in **Spanish.**
  - Session A: 11:00-13:00 EST (UTC-4)
  - Session B: 14:00-16:00 EST (UTC-4)

- Training materials and recordings will be available from: https://appliedsciences.nasa.gov/join-mission/training/english/arset-disaster-assessment-using-synthetic-aperture-radar

Homework and Certificate

- Homework Assignment:
  - Answers must be submitted via Google Form
  - Due Date: **Nov. 17, 2022**
- A certificate of completion will be awarded to those who:
  - Attend all live webinars
  - Complete the homework assignment by the deadline (access from website)
  - You will receive a certificate approximately two months after the completion of the course from: marines.martins@ssaihq.com

Prerequisites

Fundamentals of Remote Sensing:

https://appliedsciences.nasa.gov/join-mission/training/english/fundamentals-remote-sensing

Radar Remote Sensing for Land, Water, & Disaster Applications (Session 2)

https://appliedsciences.nasa.gov/join-mission/training/english/arset-radar-remote-sensing-land-water-disaster-applications

Introduction to Synthetic Aperture Radar (Sessions 1, 2 and 4):

https://appliedsciences.nasa.gov/join-mission/training/english/arset-introduction-synthetic-aperture-radar

SAR for Disasters and Hydrological Applications (Session 3)

https://appliedsciences.nasa.gov/join-mission/training/english/arset-sar-disasters-and-hydrological-applications

Training Outline

Oct. 19, 2022

SAR for Flood Mapping

by Dr. Erika Podest (JPL)

Oct. 20, 2022

SAR for Mapping Landslide Motion
By Dr. Eric Fielding (JPL)

Oct. 27, 2022

SAR for Oil Spill Detection
by Dr. Malin Johansson (UiT The Arctic University of Norway)

Learning Objectives

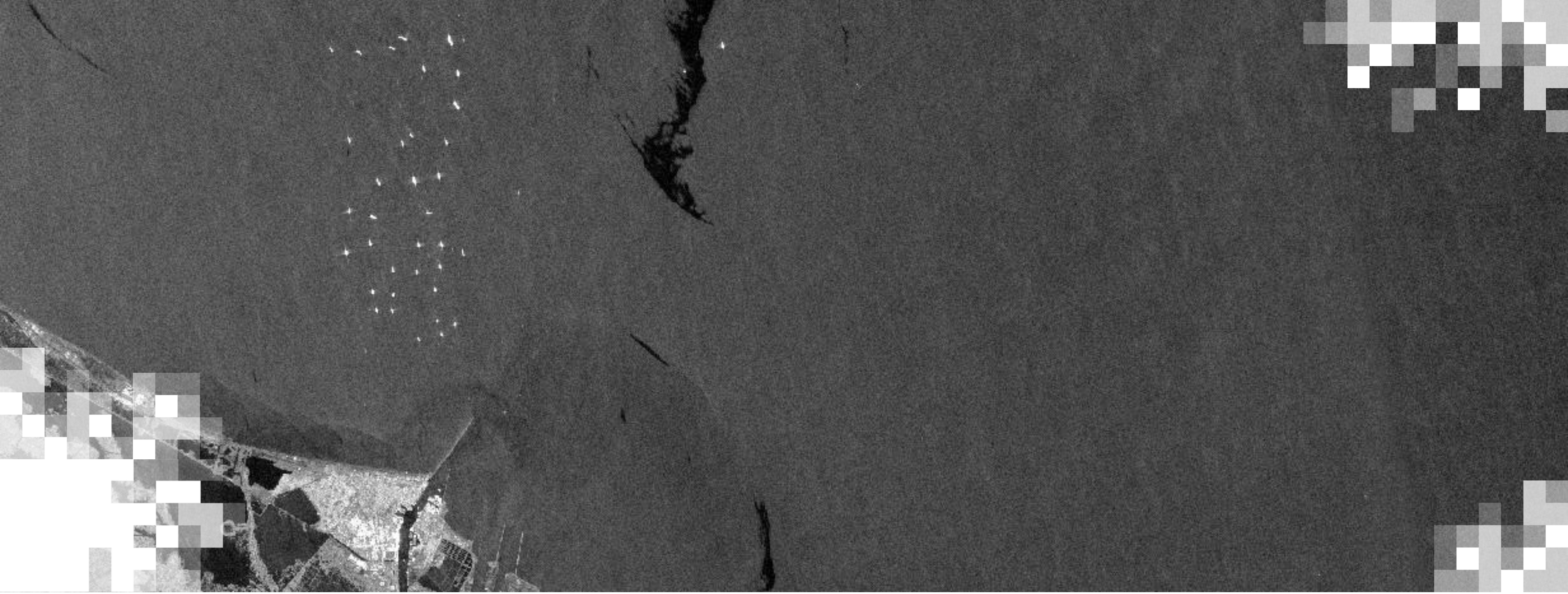
By the end of this session attendees will be able to:

- Understand the information content in SAR images relevant to flooding
- Understand the confounding factors in SAR relevant to flooding
- Access, process, and visually interpret SAR data
- Generate a time series flood map using Google Earth Engine

Outline

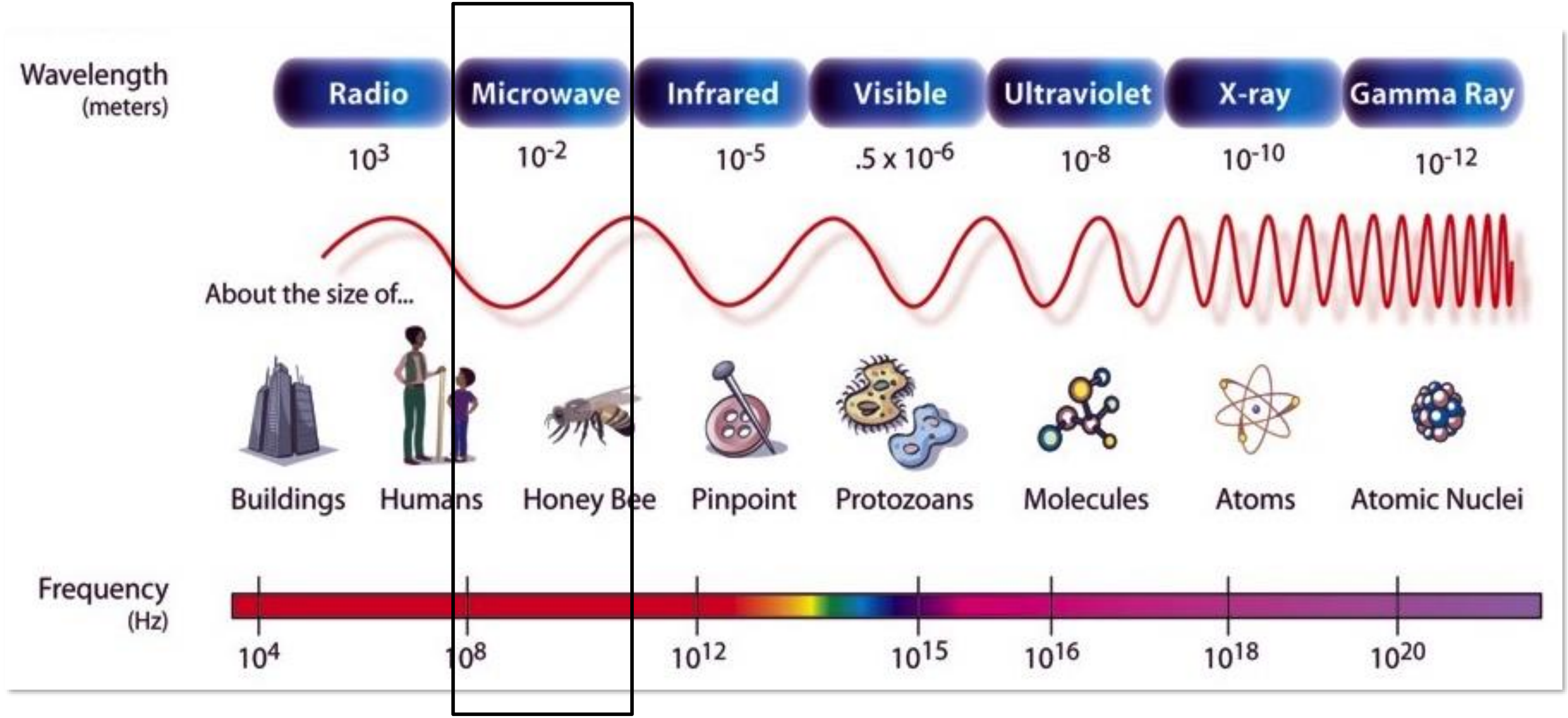
- Radar Overview
  - Radar Signal Interaction with the Land Surface
  - Radar and Surface Parameters
  - Distortions
  - Confounding Factors
  - Available SAR Data

- SAR Time Series Flood Demo
  - Define Area and Time of Interest
  - Visualize the SAR Data
  - Generate Time Series Flood Maps with SAR Data



Radar Overview

The Electromagnetic Spectrum



Advantages/Disadvantages of Microwave Remote Sensing over Optical

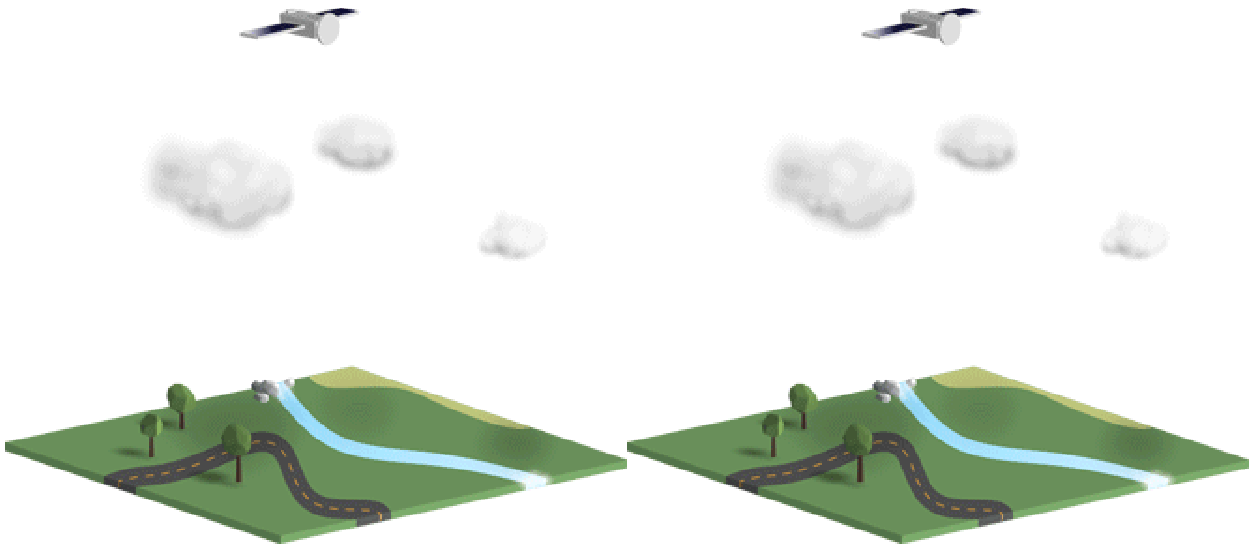
Advantages

- Nearly all weather capability
- Day or night capability
- Penetration through the vegetation canopy
- Penetration through the soil
- Minimal atmospheric effects
- Sensitivity to dielectric properties (surface wetness or 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

Active and Passive Remote Sensing



Passive | Sensors detect only what is emitted from the landscape, or 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.

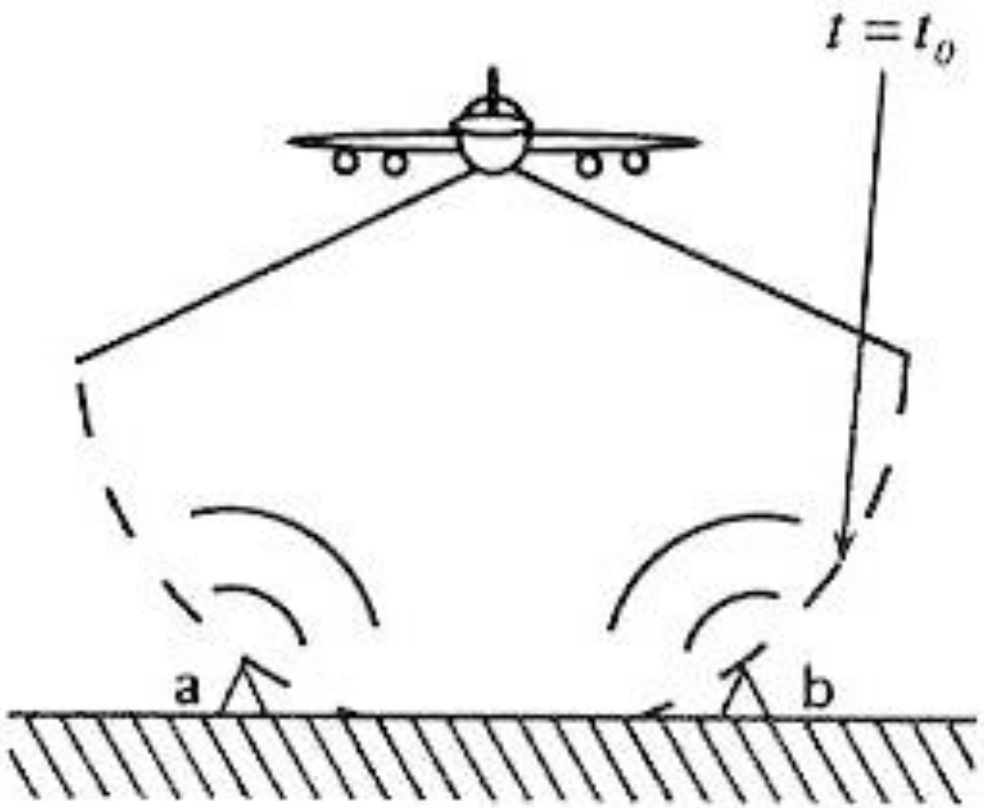
Passive Sensors:

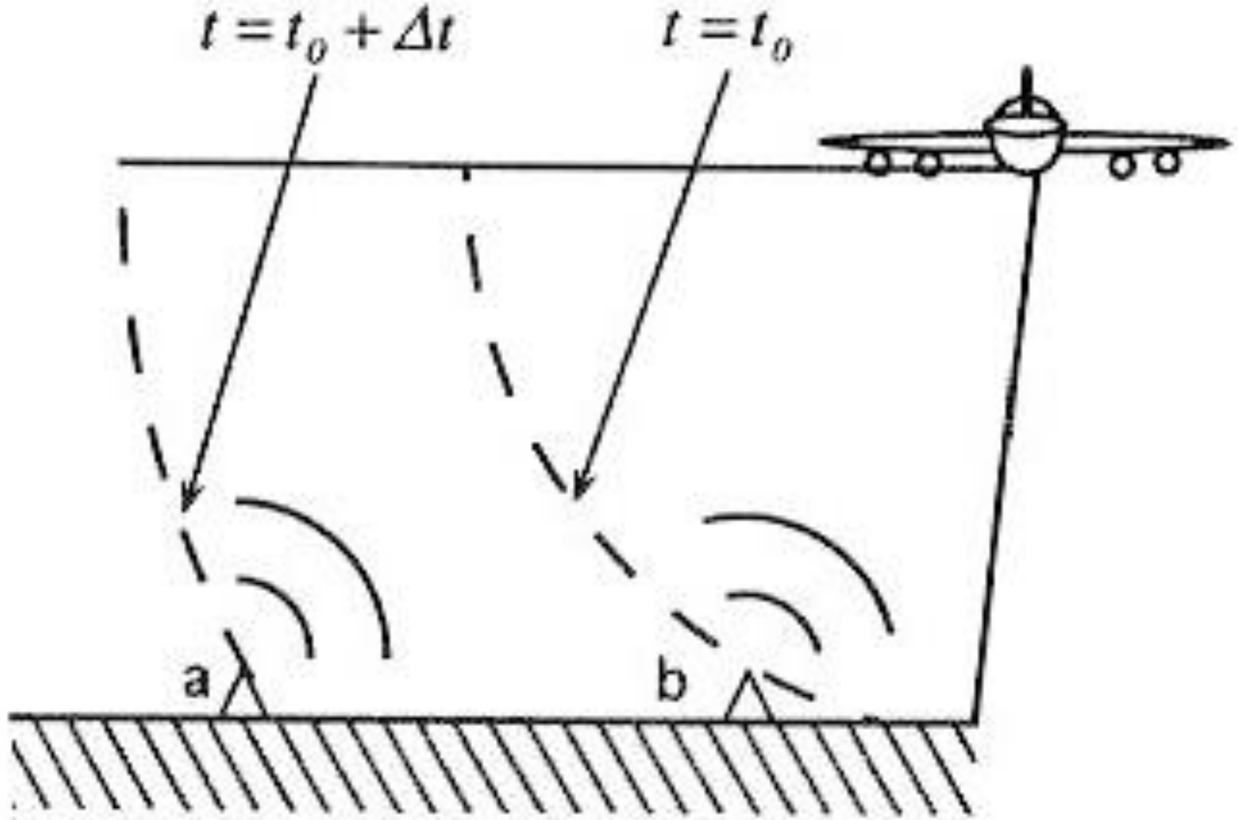
- The source of radiant energy arises from natural sources
- e.g., the sun, Earth, other "hot" bodies

Active Sensors

- Provide their own artificial radiant energy source for illumination
- e.g., radar, synthetic aperture radar (SAR), LiDAR

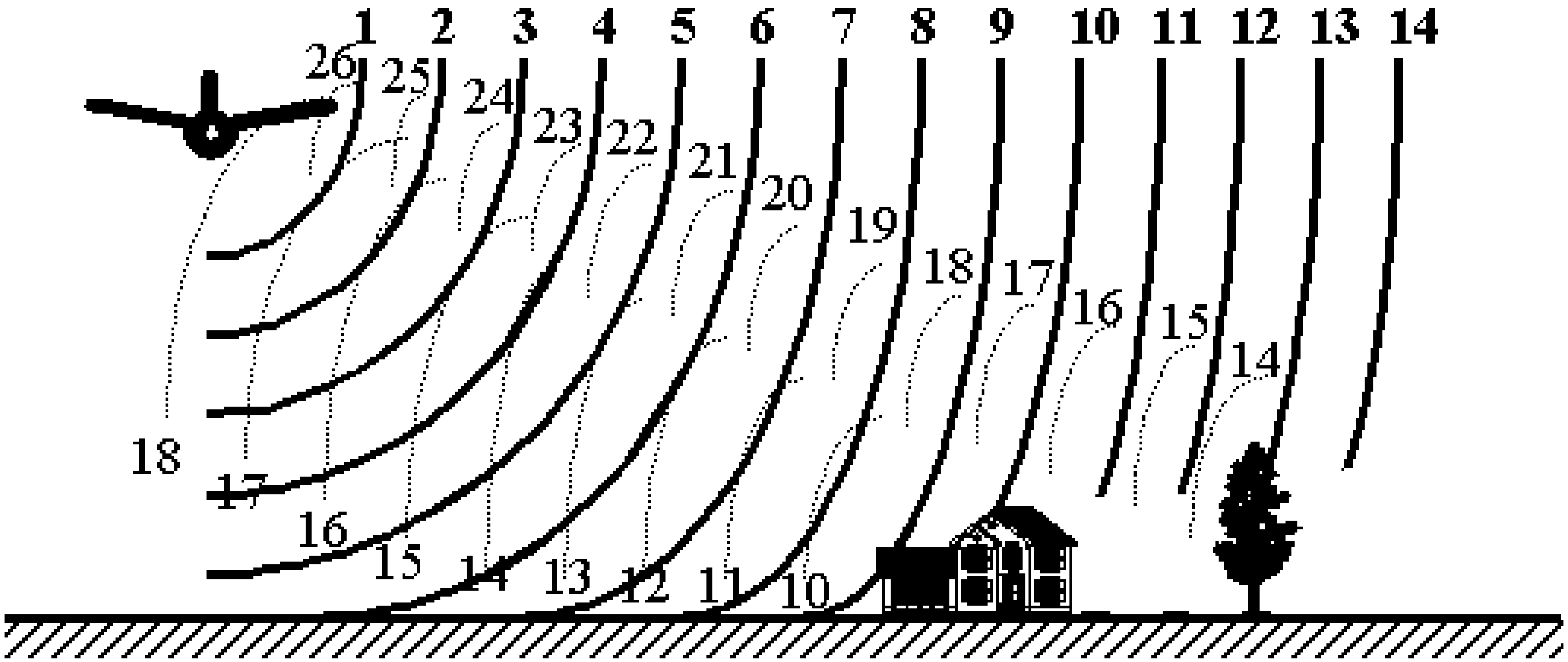
Basic Concepts: Down-Looking vs. Side-Looking Radar





Basic Concepts: Side-Looking Radar

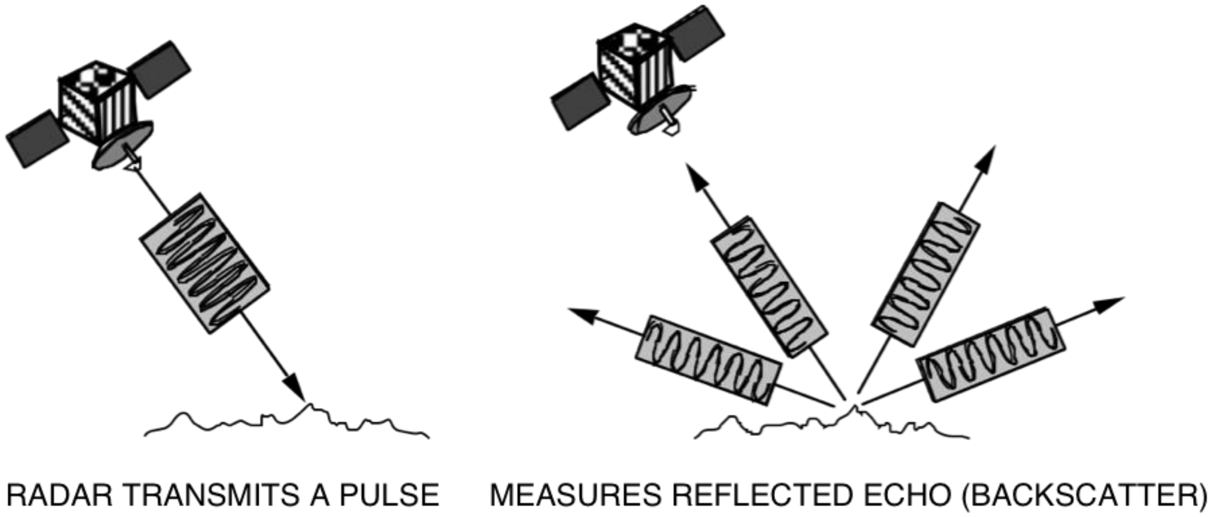
- Each pixel in the radar image represents complex quantity of the energy that was reflected back to the satellite.
- The magnitude of each pixel represents the intensity of the reflected echo.

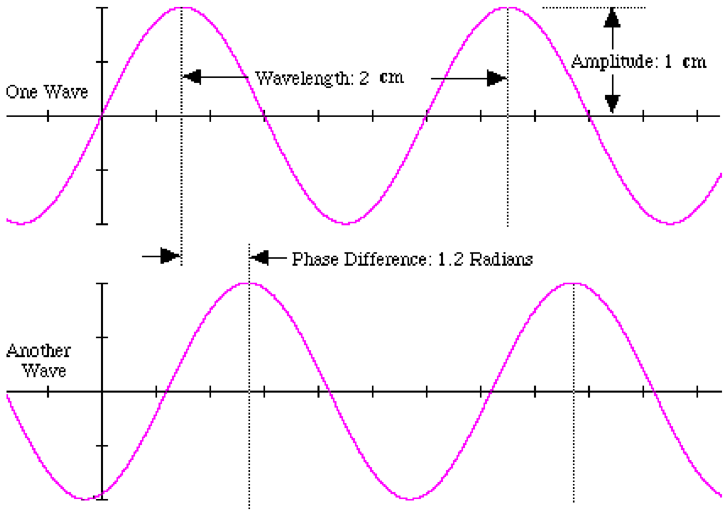


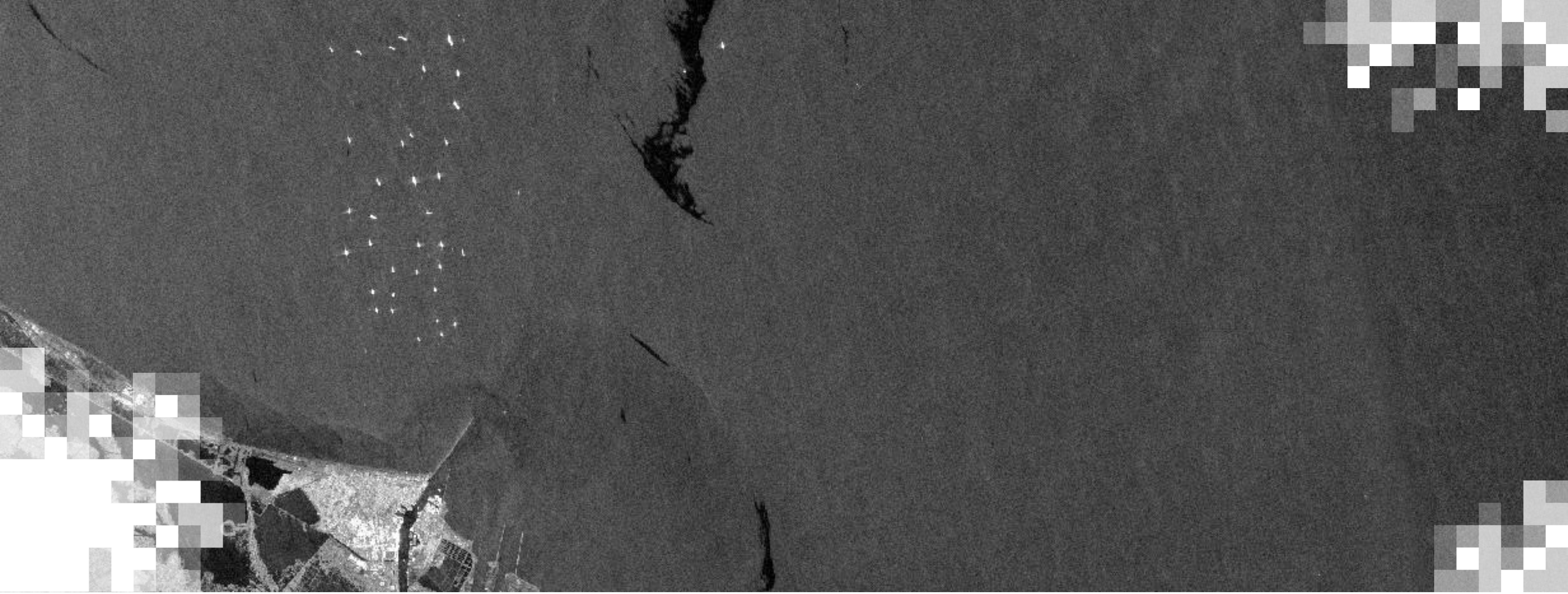
Credit: Paul Messina, CUNY NY, after Drury 1990, Lillesand and Kiefer, 1994

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. The strength of the reflected echo is the backscattering coefficient (sigma naught) and is expressed in decibels (dB).







Radar Signal Interaction with the Land Surface

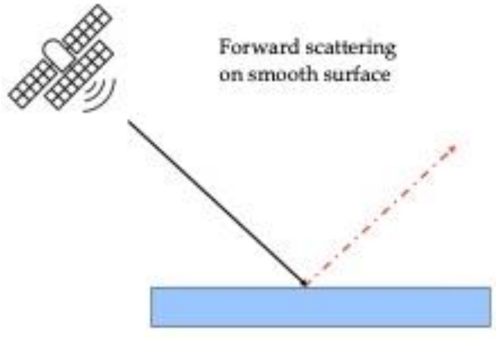
Flooding Definition from a Radar Perspective:

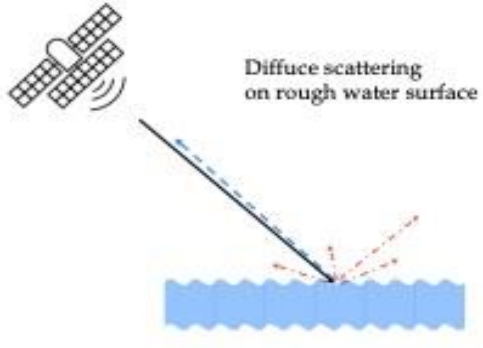
The temporary or permanent occurrence of a water surface:

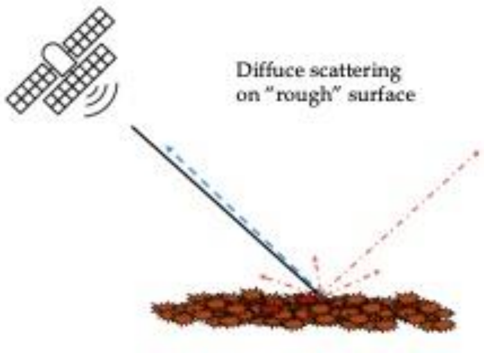
- Beneath a vegetation canopy (tall or short standing vegetation)
- Without any standing vegetation (referred to as open water)

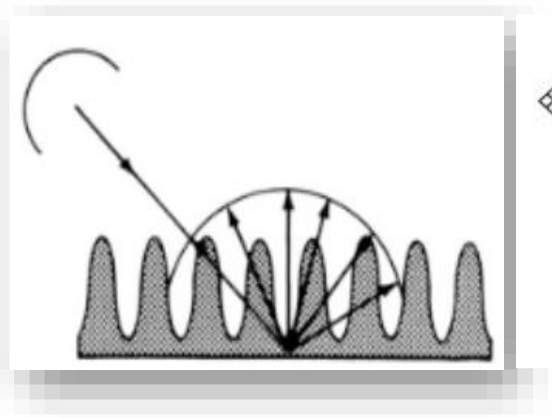
SAR Signal Backscattering Mechanisms

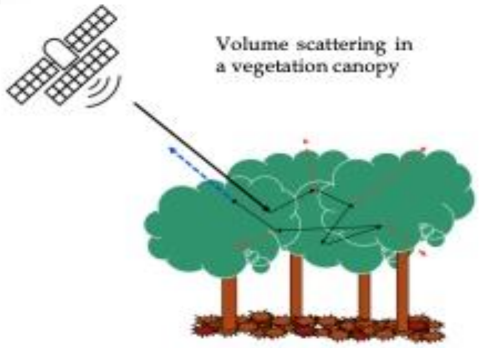
Smooth Surface | Rough Surface | Rougher Surface | Volume | Double Bounce

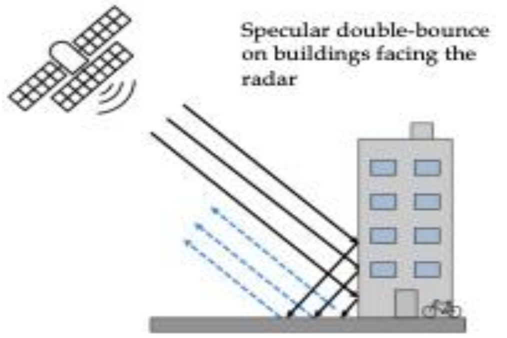


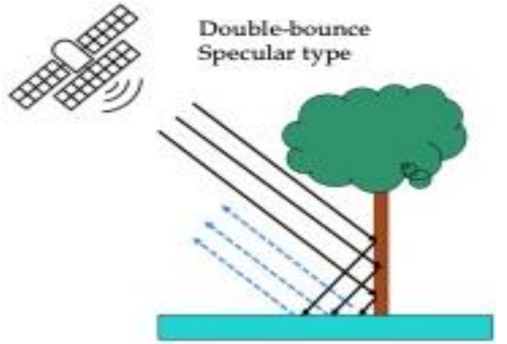








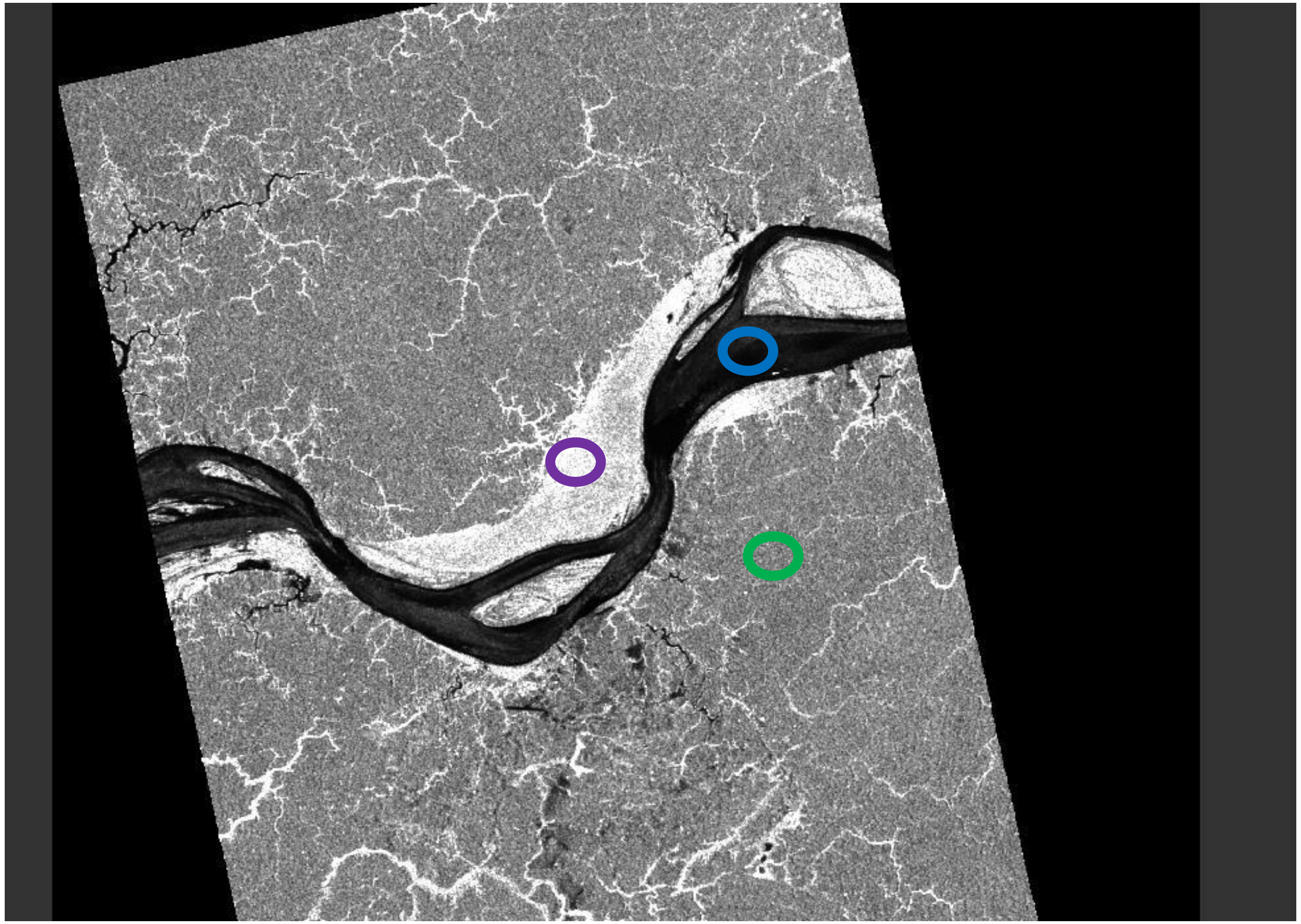


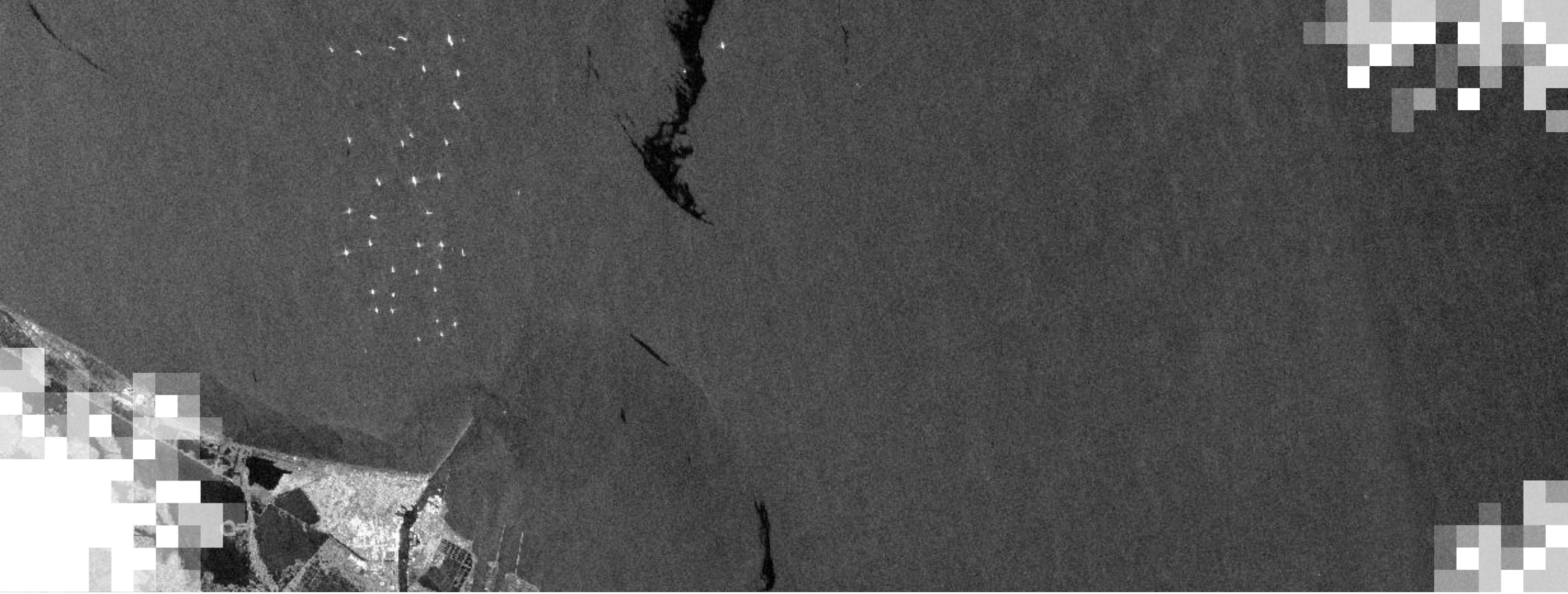


Source: CEOS Systems Engineering Office (SEO)

SAR Signal Scattering Over Inundated Regions

PALSAR Image (L-band) Near Manaus, Brazil





Radar and Surface Parameters

Parameters to Consider for a Land Cover Mapping Study

Radar Parameters

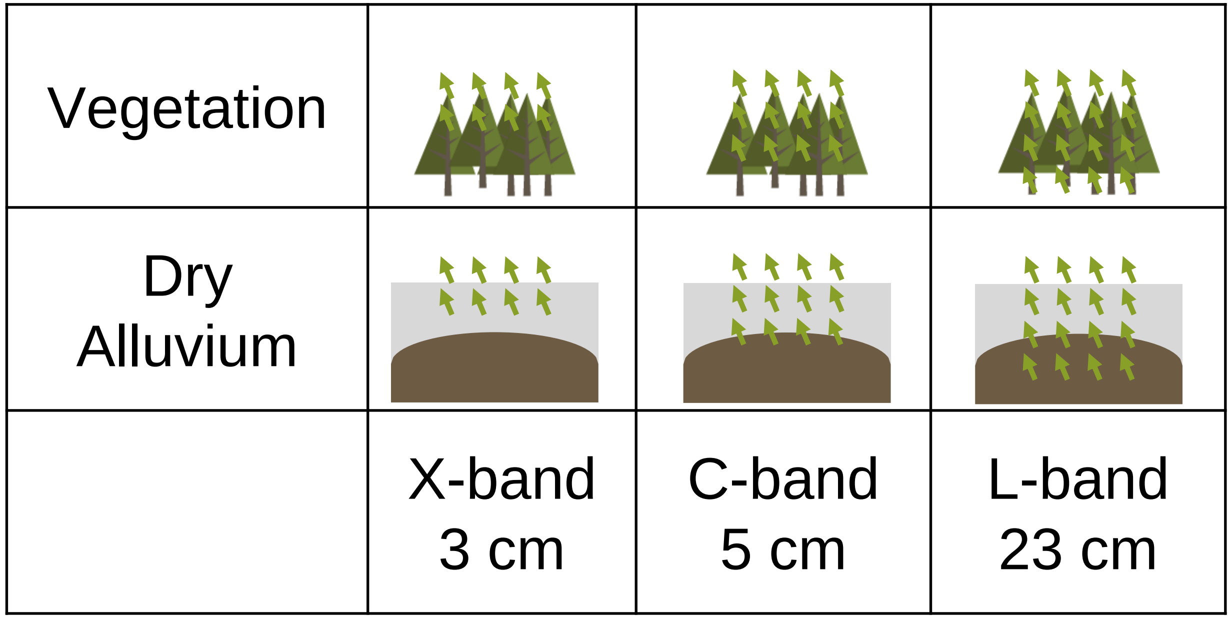
- Wavelength
- Polarization
- Incidence Angle

Surface Parameters

- Structure
- Dielectric

Wavelength and SAR Signal Response Over Flooded Vegetation

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



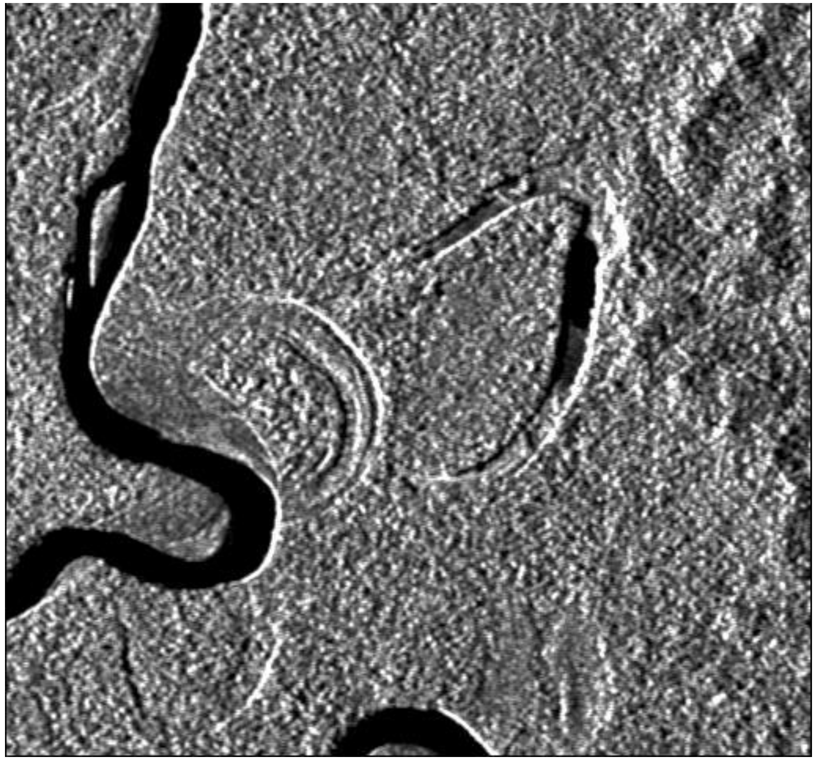
Band Designation*	Wavelength (λ), cm	Frequency (v), GH_z (10^9 cycles·sec^{-1})
Ka (0.86 cm)	0.8 – 1.1	40.0 – 26.5
K	1.1 – 1.7	26.5 – 18.0
Ku	1.7 – 2.4	18.0 – 12.5
X (3.0 cm, 3.2 cm)	2.4 – 3.8	12.5 – 8.0
C (6.0)	3.8 – 7.5	8.0 – 4.0
S	7.5 – 15.0	4.0 – 2.0
L (23.5 cm, 25 cm)	15.0 – 30.0	2.0 – 1.0
P (68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

*Wavelengths most frequently used in SAR are in parentheses.

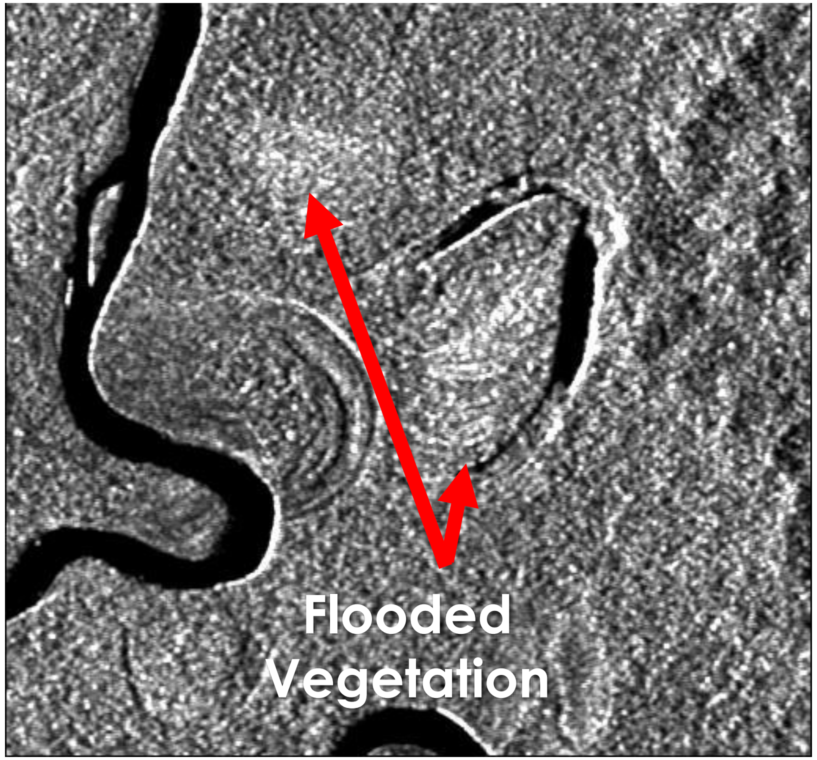
Signal Penetration Over Flooded Vegetation

Multifrequency AIRSAR data in Manu National Park, Peru

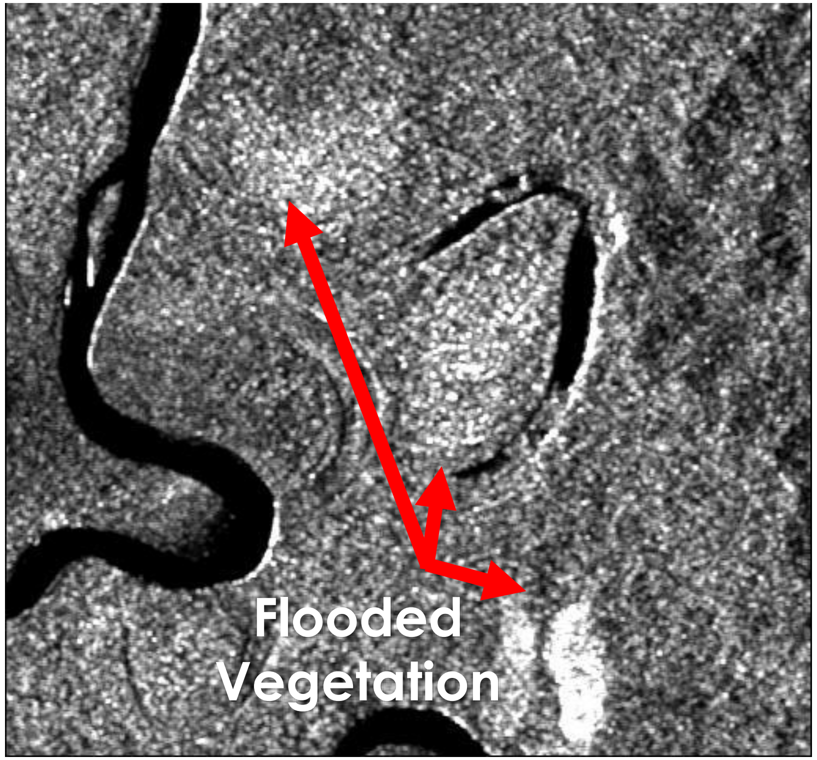
C-Band



L-Band



P-Band



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.

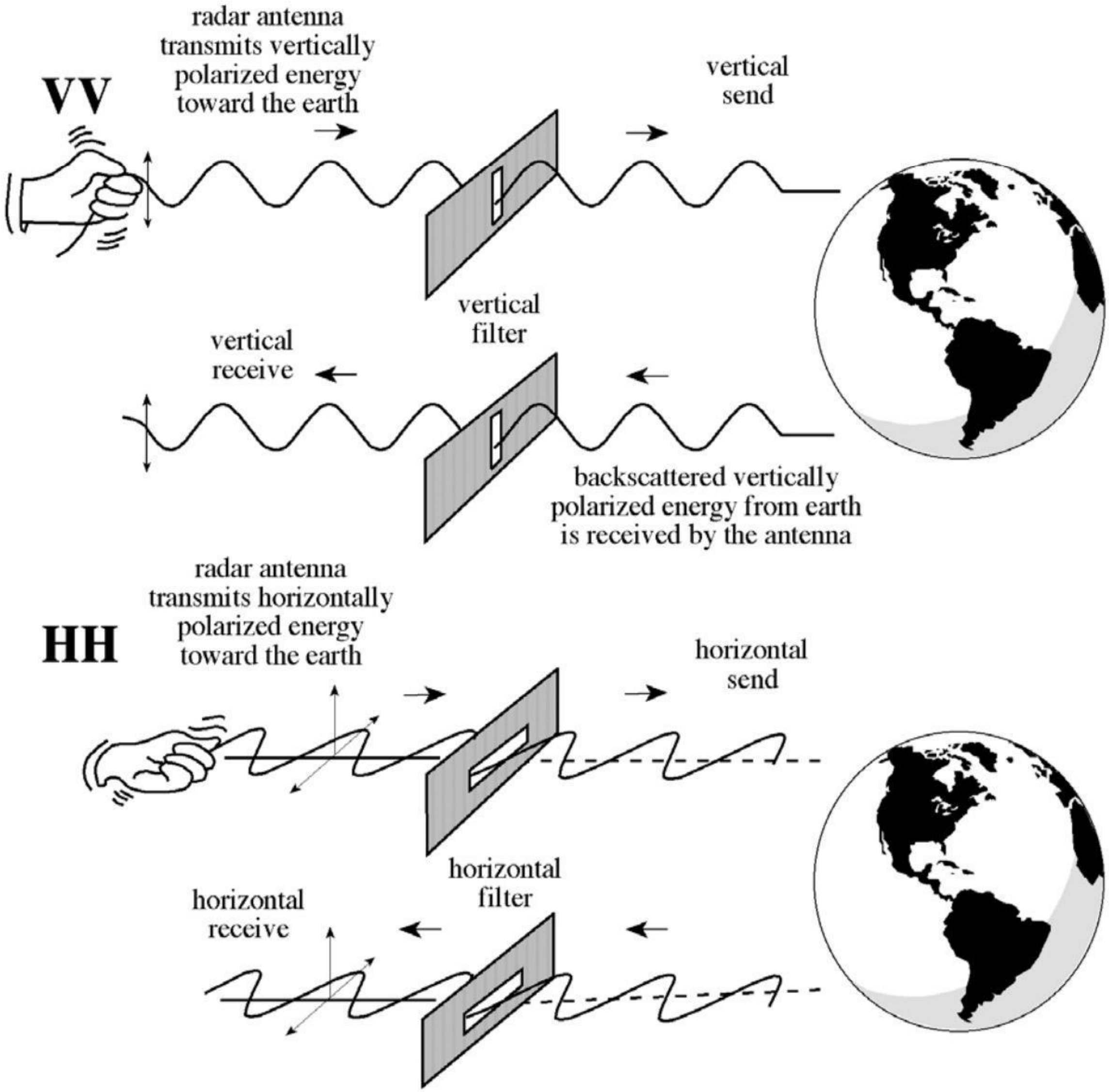
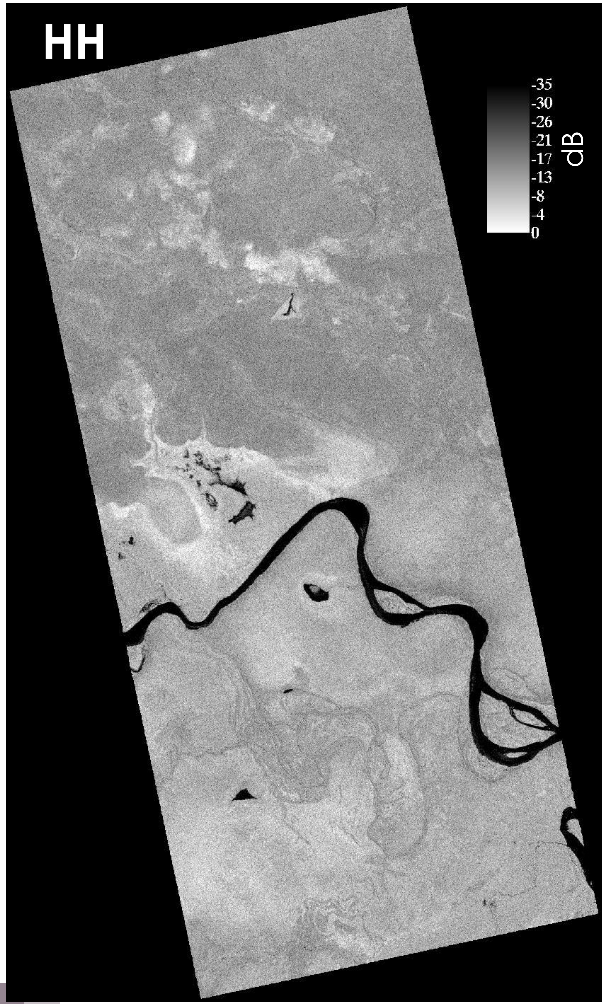
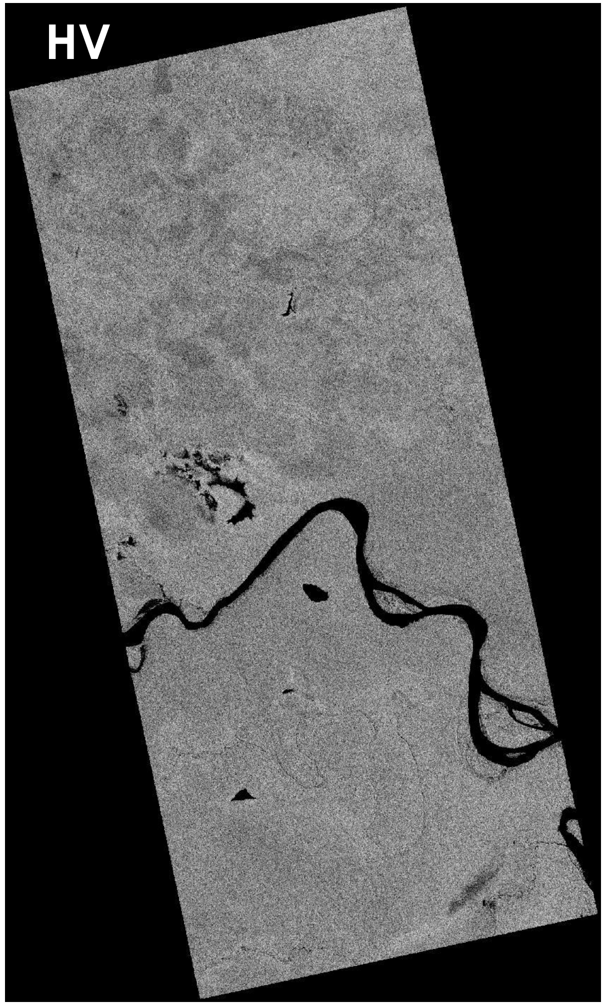


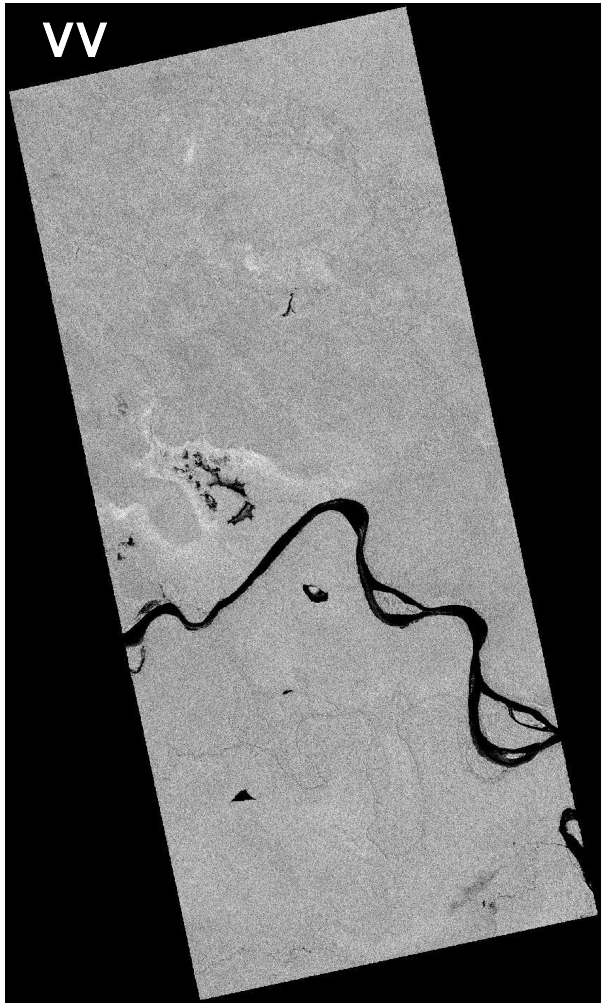
Image Credit: J.R. Jensen, 2000, Remote Sensing of the Environment

Multiple Polarizations for Detecting Inundated Vegetation

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

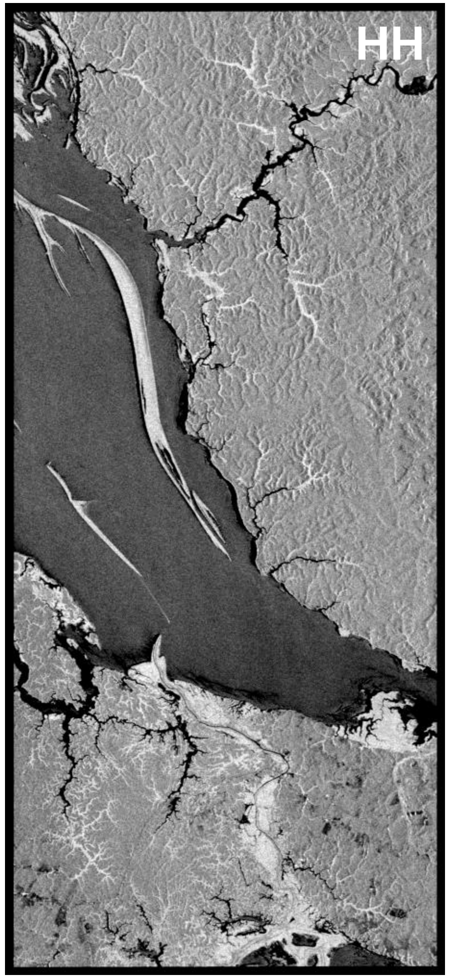


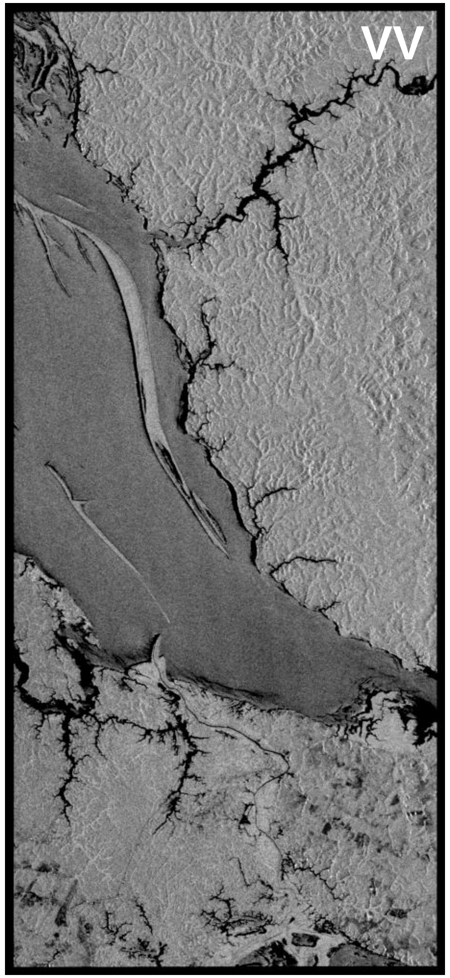




Multiple Polarizations for Detection of Open Water

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

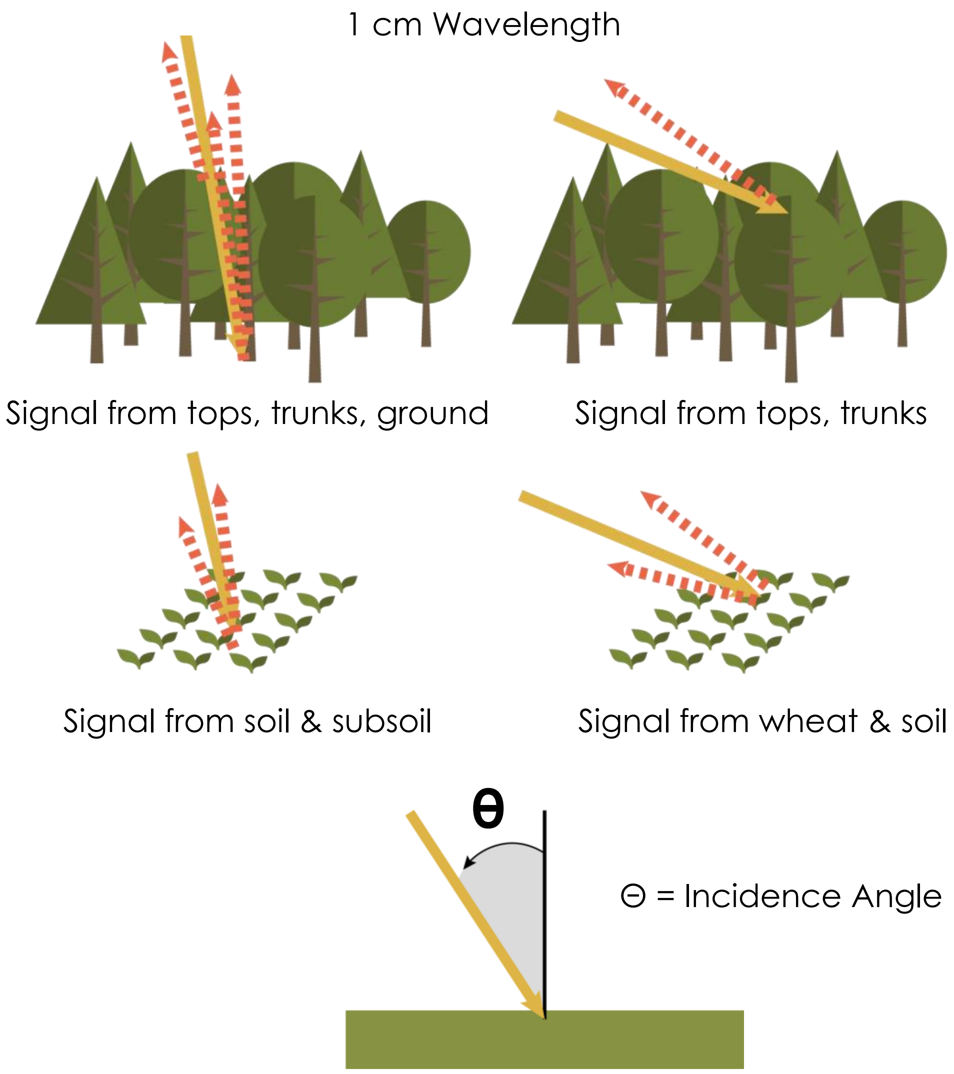




Radar Parameters: Incidence Angle

Local Incidence Angle:

- The angle between the direction of the incident wave 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

Parameters to Consider for a Land Cover Mapping Study

Radar Parameters

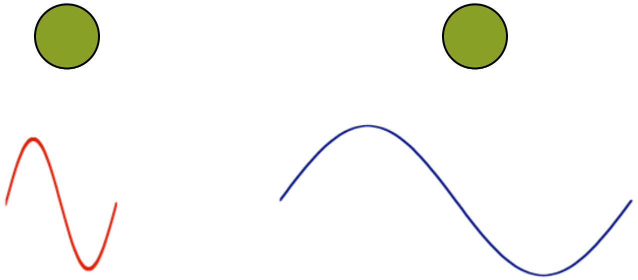
- Wavelength
- Polarizations
- Incidence Angle

Surface Parameters

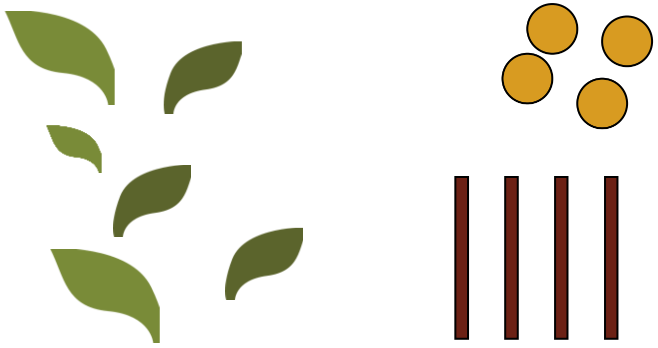
- Structure
- Dielectric

Surface Parameters Related to Structure

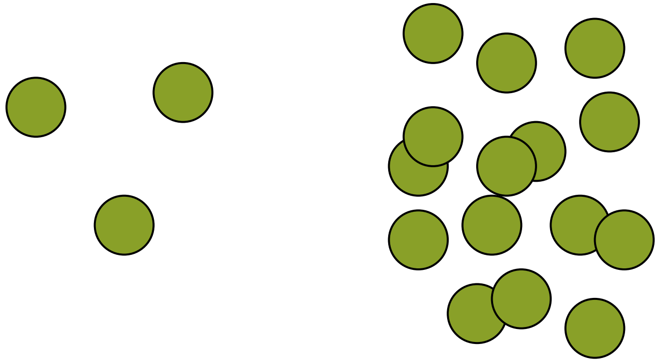
Size Relative to Wavelength



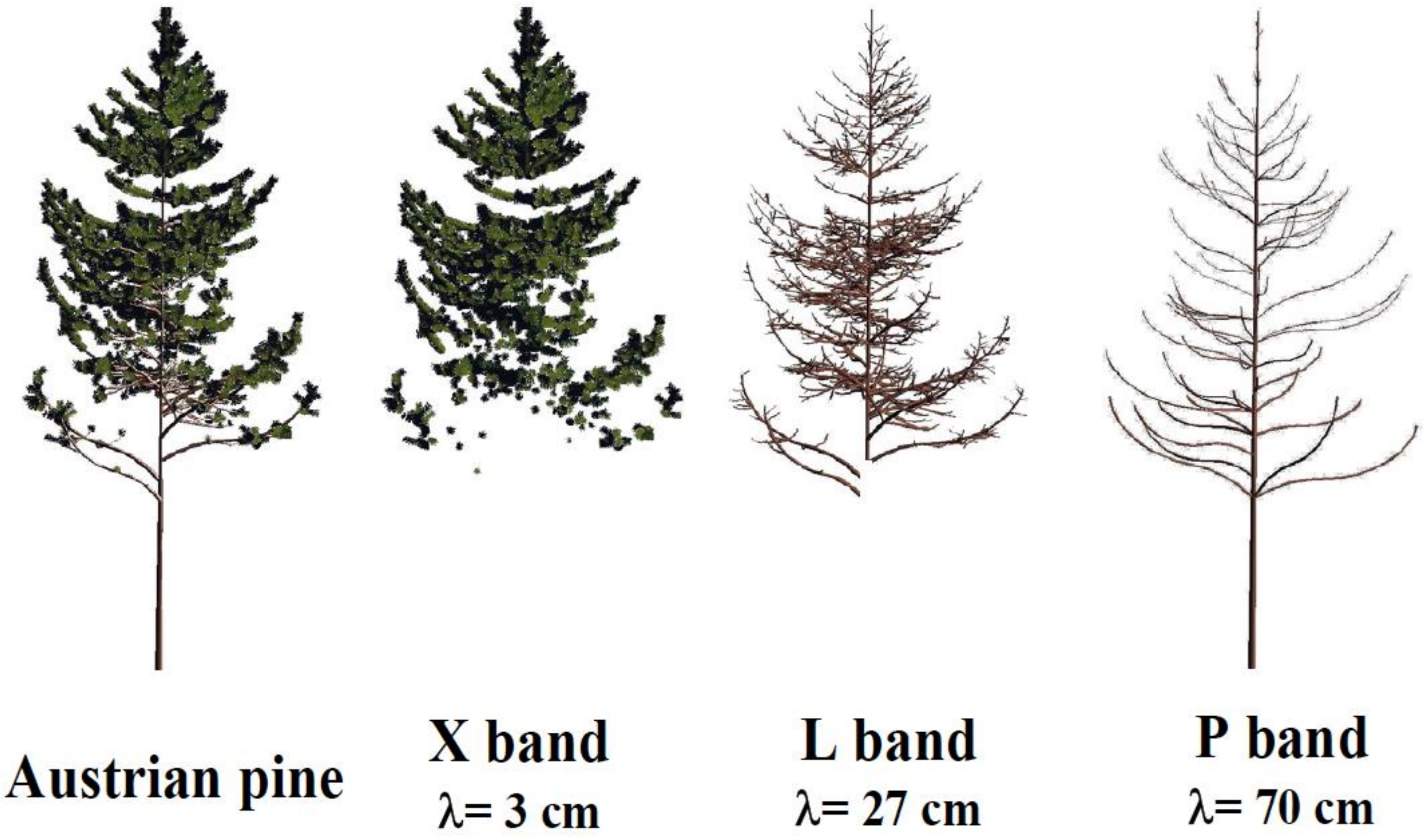
Orientation



Density

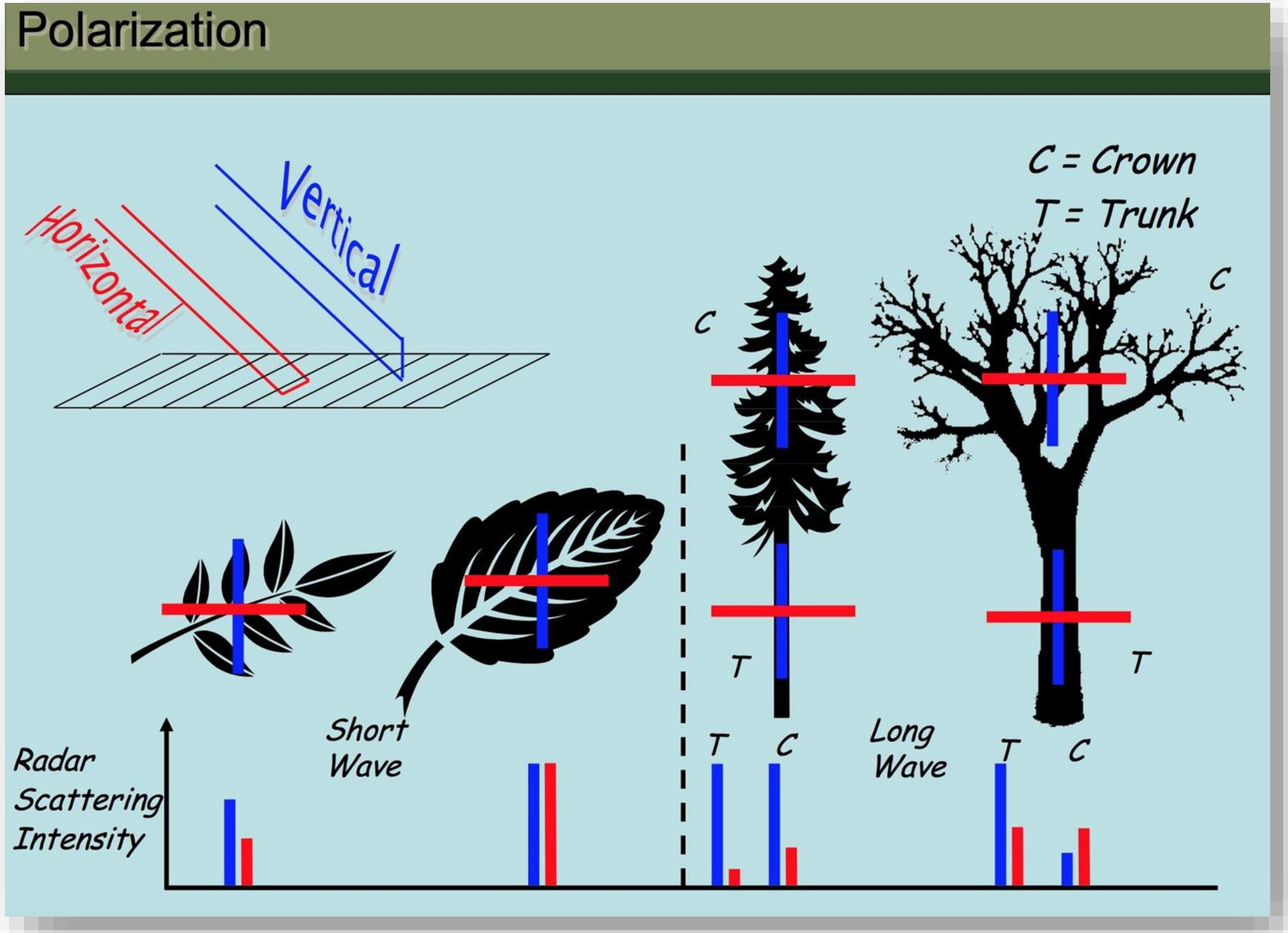


Size Relative to Wavelength



Source: Thuy le Toan

Size and Orientation



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

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

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)

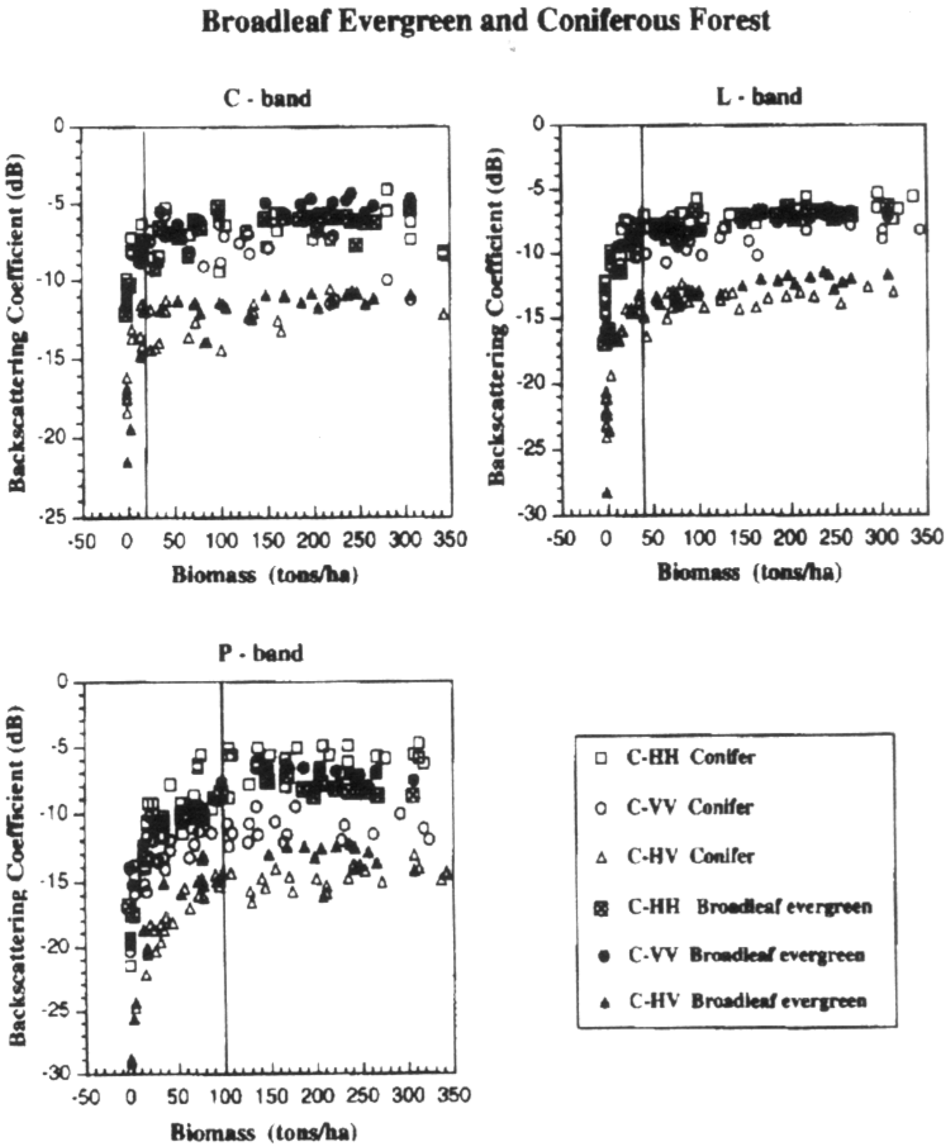
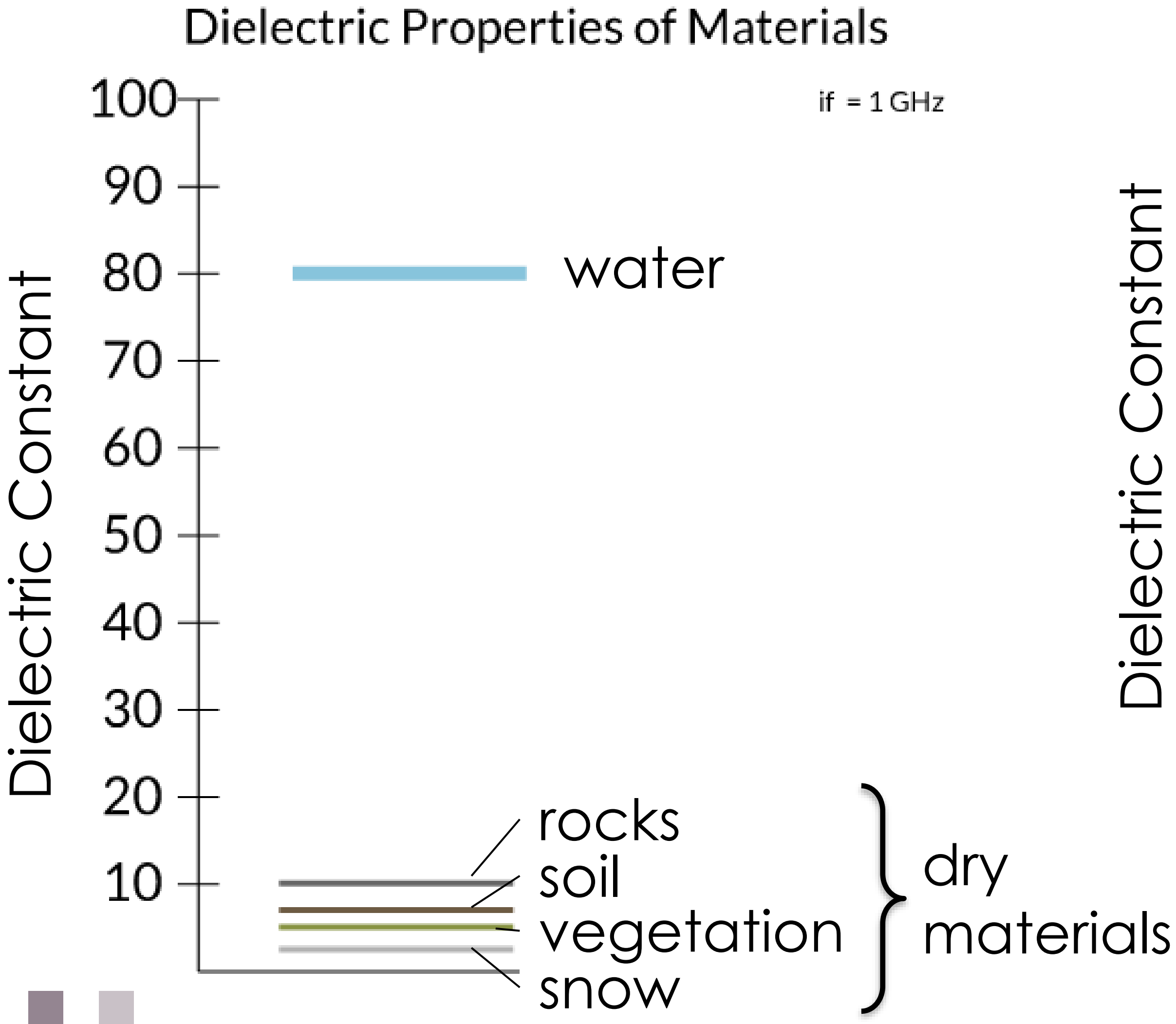
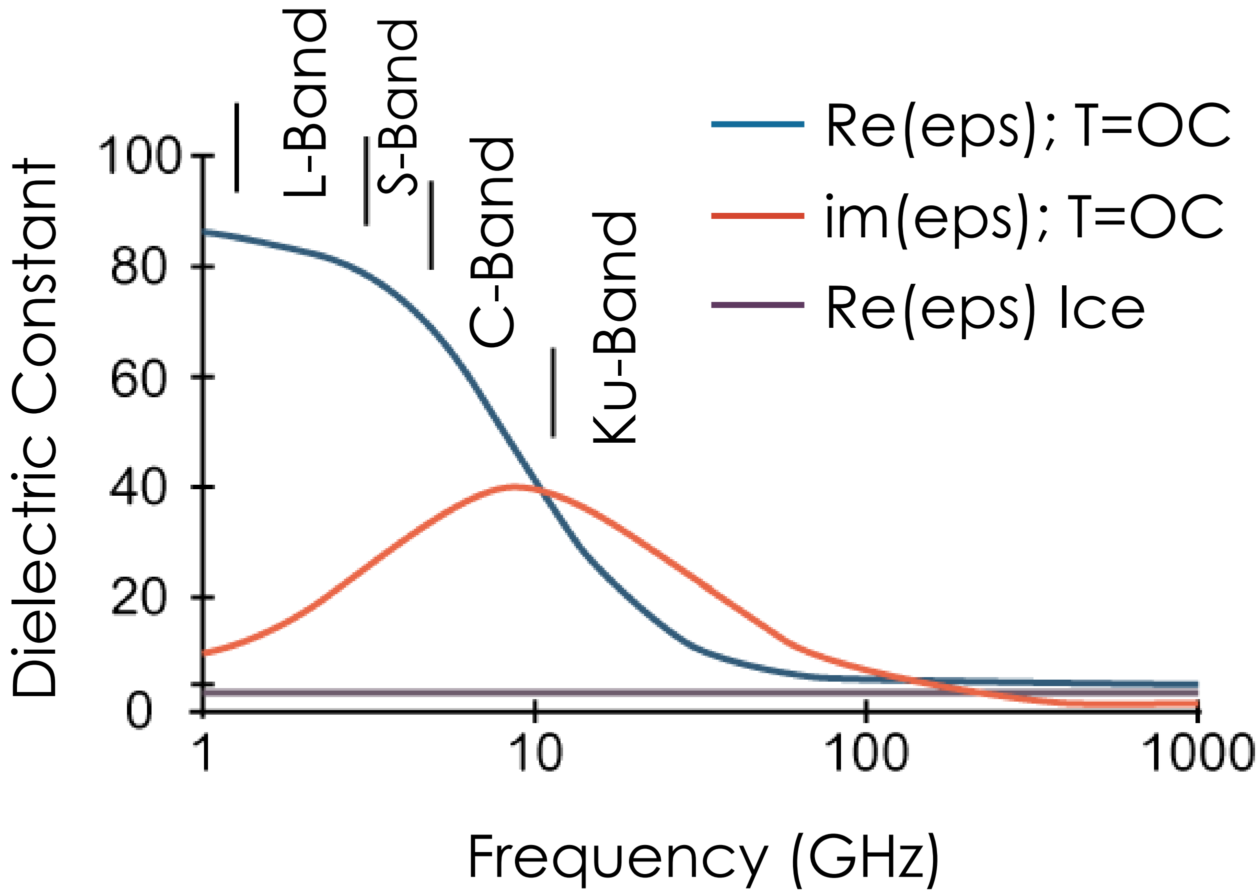
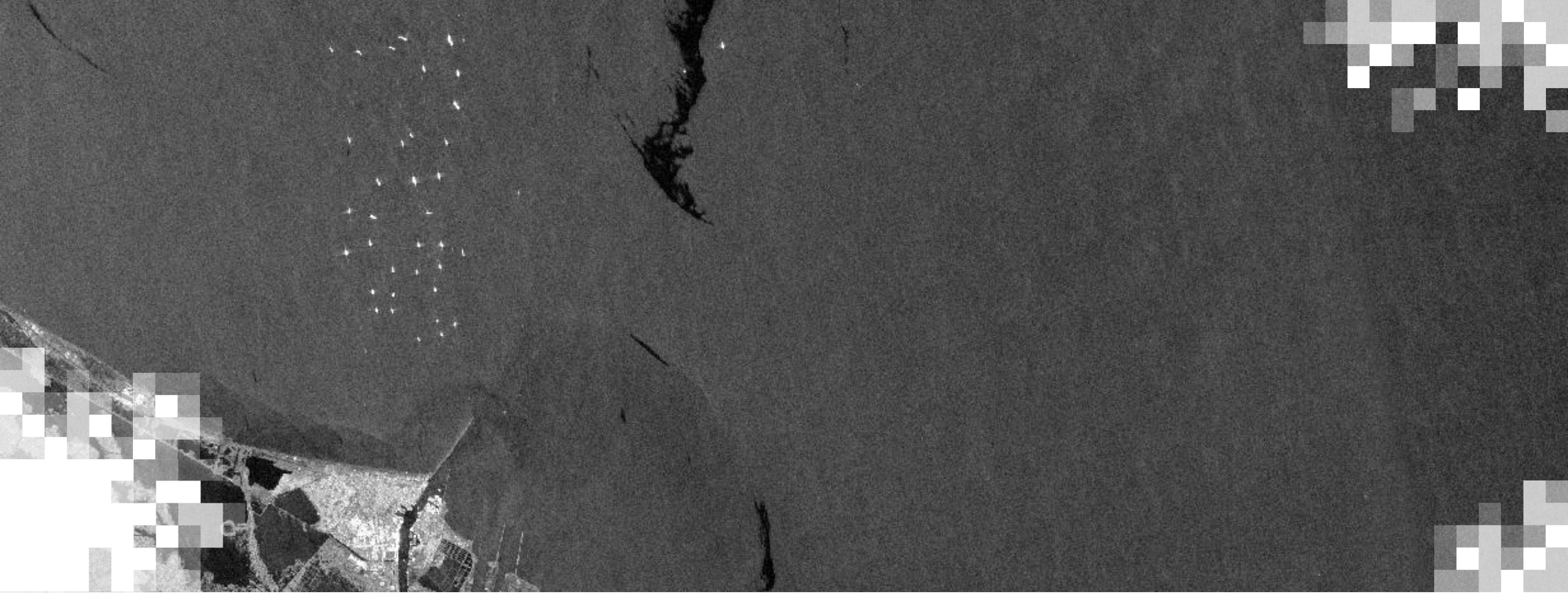


Image Source: Imhoff, 1995:514)

Surface Parameters: Dielectric Constant







Effects of Topography and Speckle

Geometric Distortion

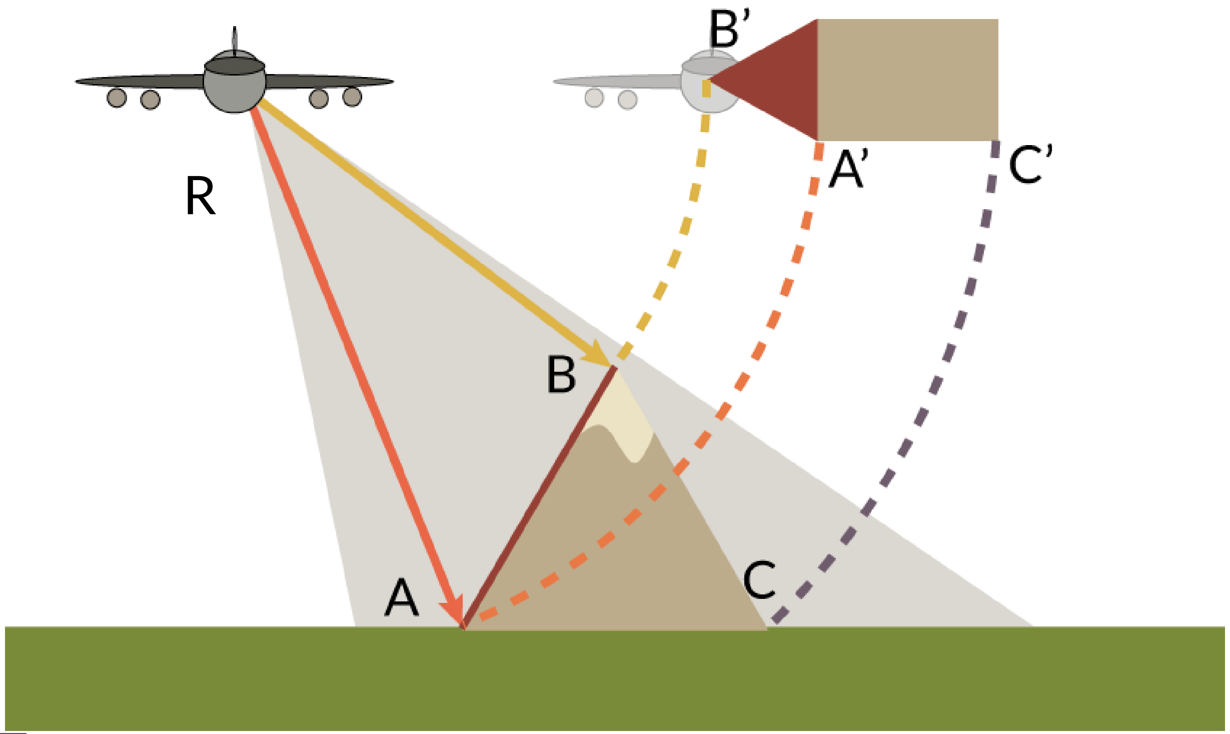
Layover

$AB = BC$

$A'B' < B'C'$

$RA > RB$

$RA' > RB'$

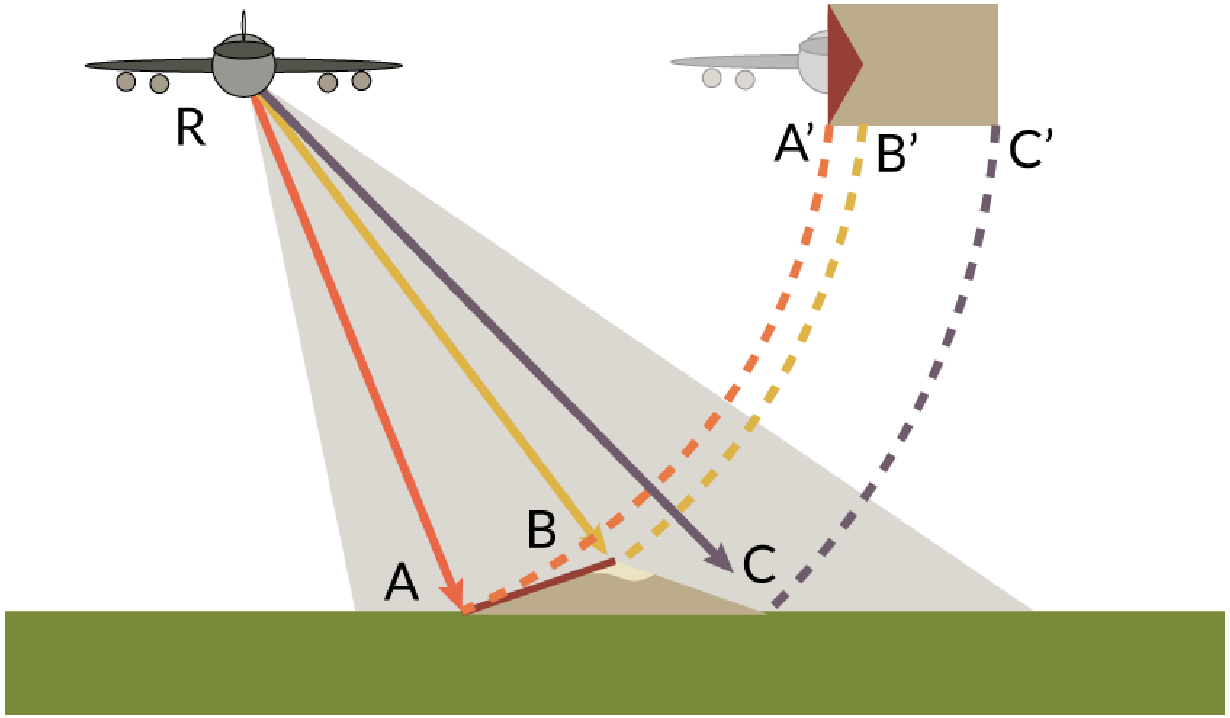


Foreshortening

$RA < RB < RC$

$AB = BC$

$A'B' < B'C'$



Images based on NRC images.

Shadow

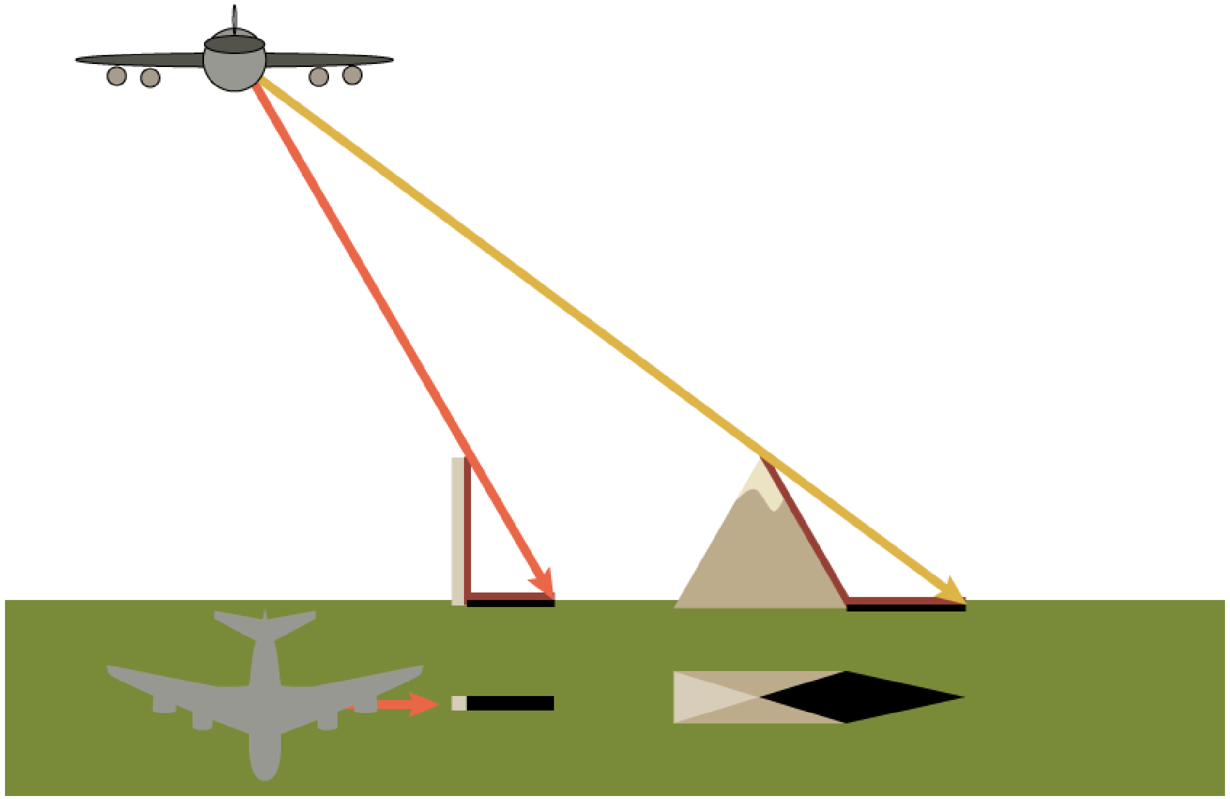


Image (left) Based on NRC

Speckle

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

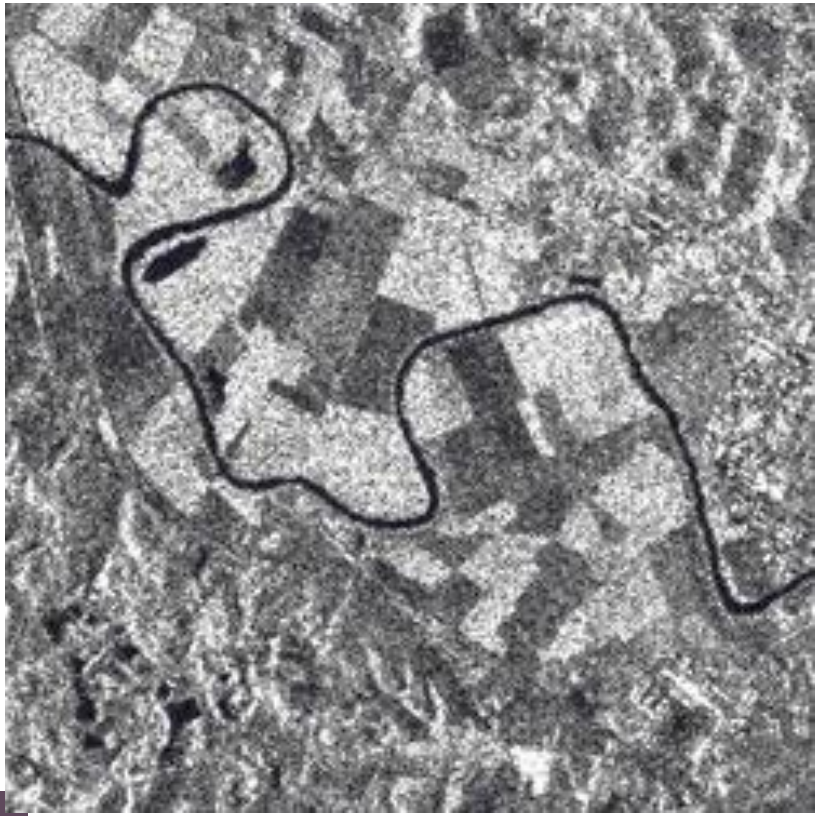
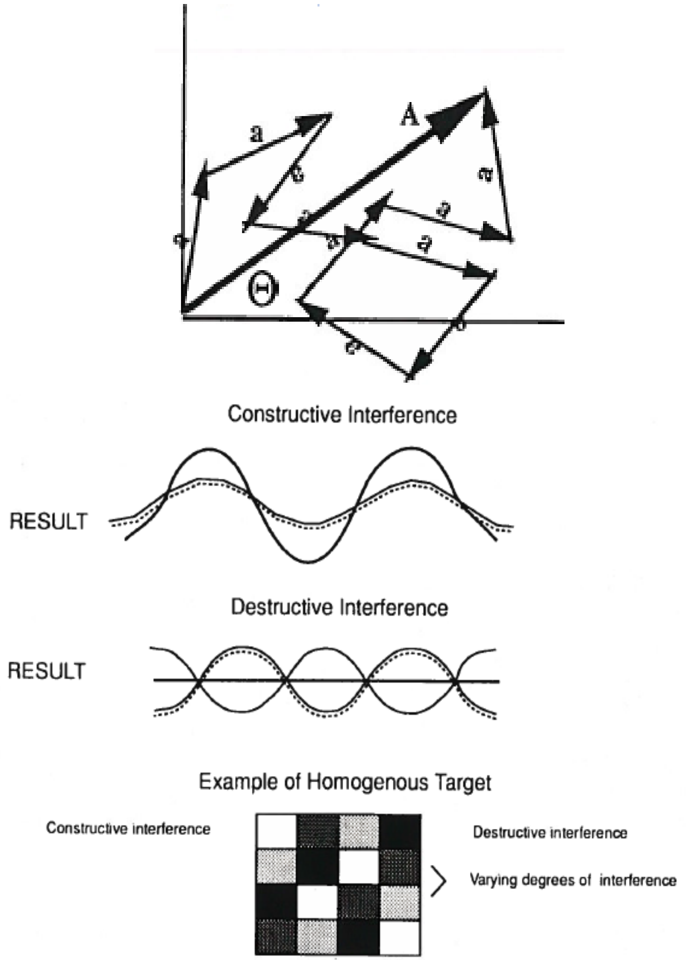


Image Credit: ESA



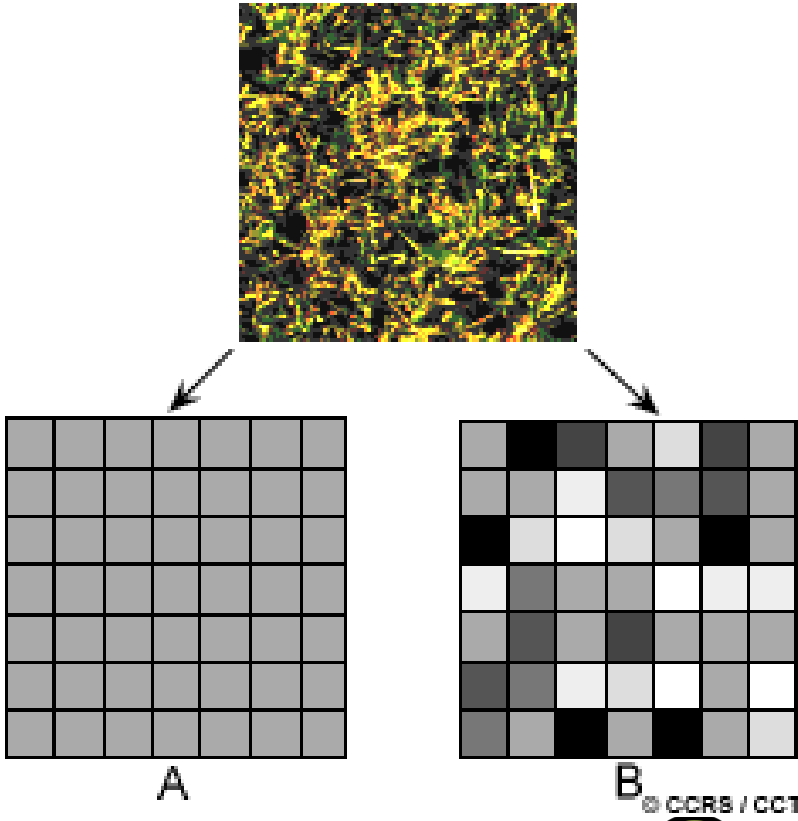
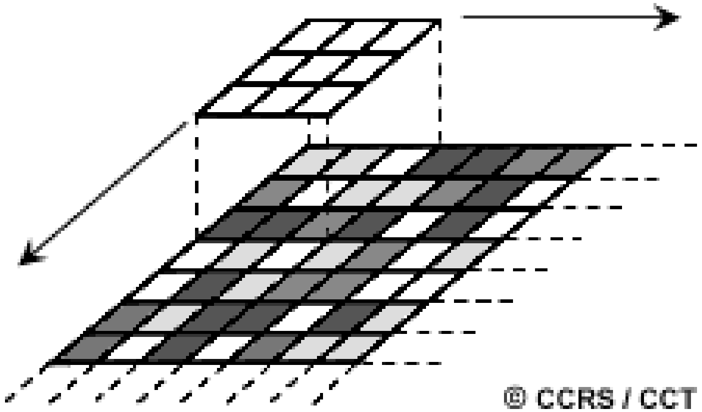
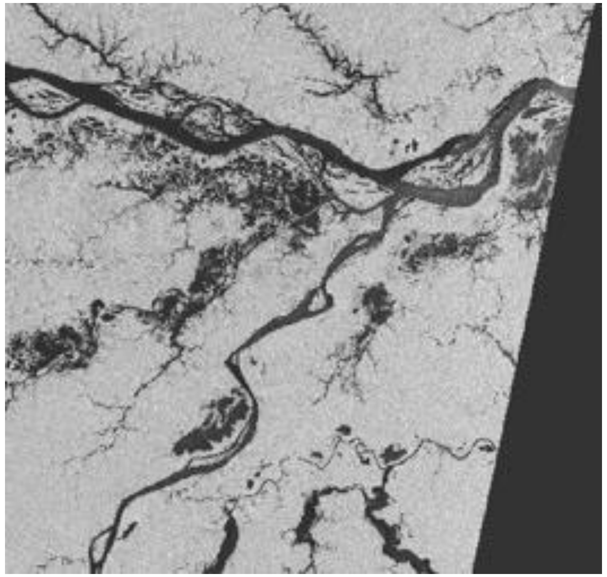


Image Credit: Natural Resources Canada

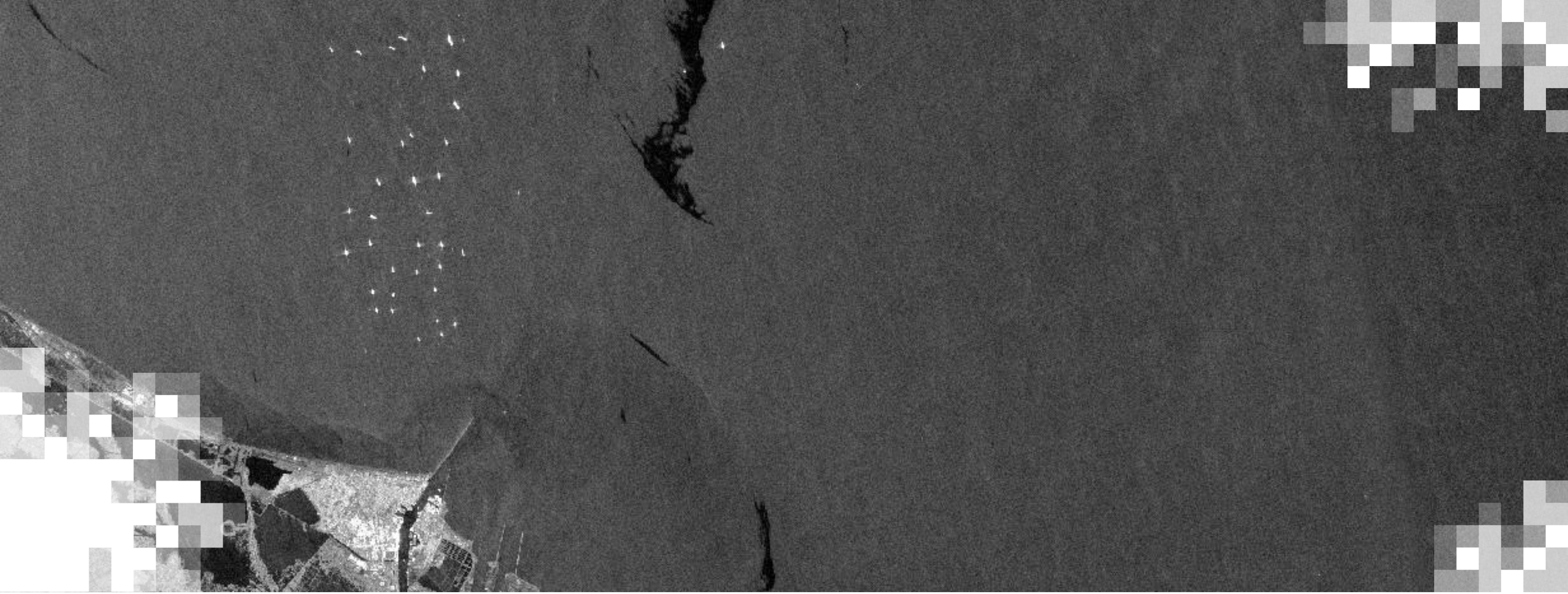
Speckle Reduction: Spatial Filtering

- 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





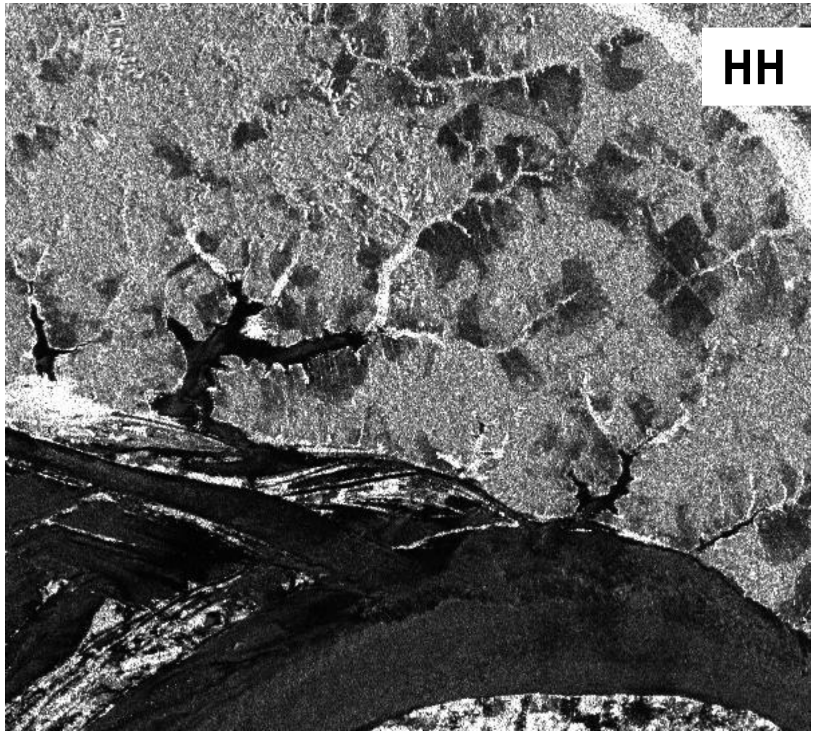
Source: Natural Resources Canada

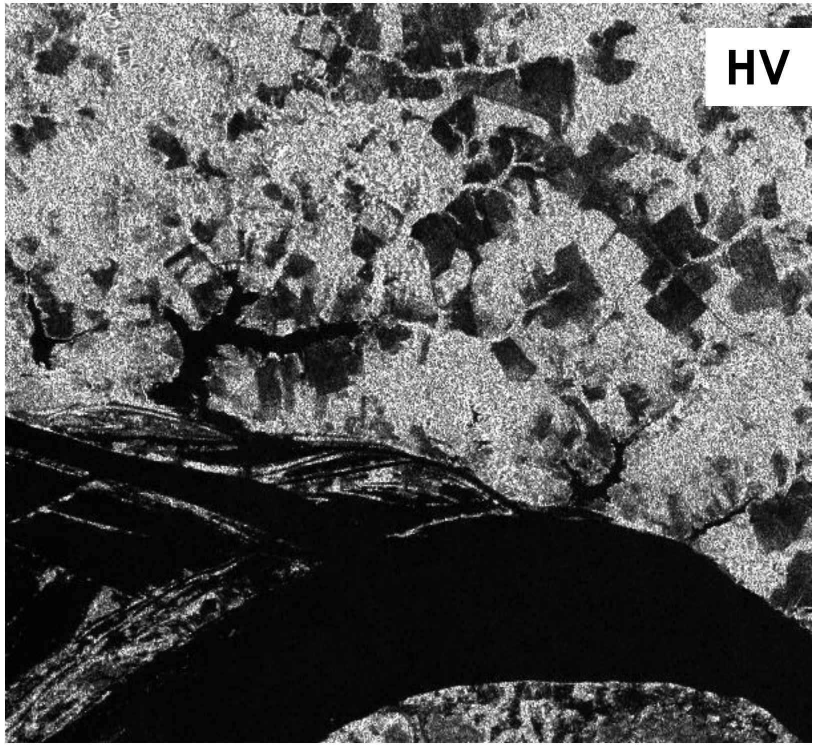


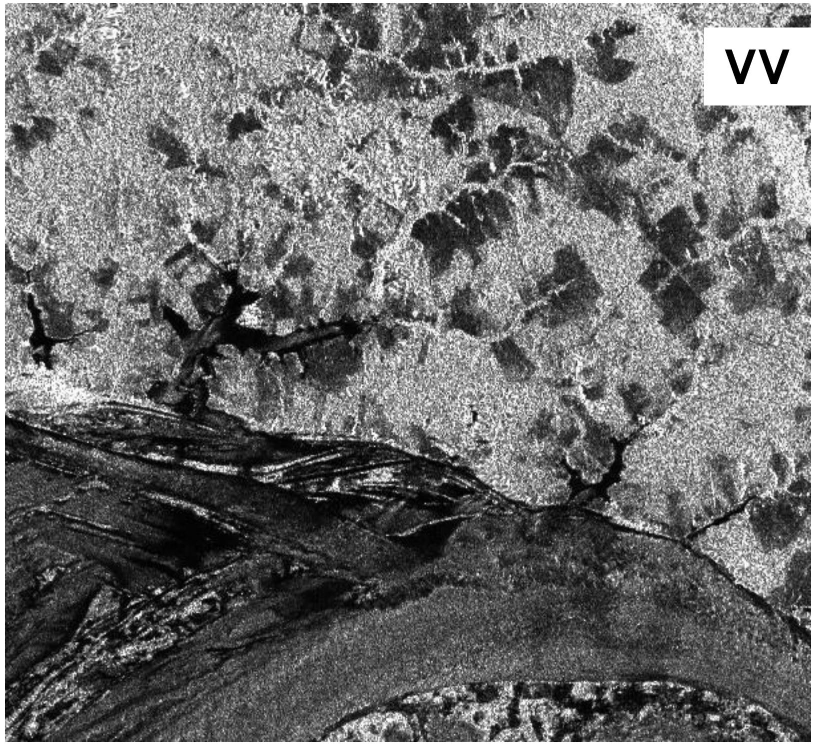
Confounding Factors

Source of Confusion: Open Water and Low Vegetation

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

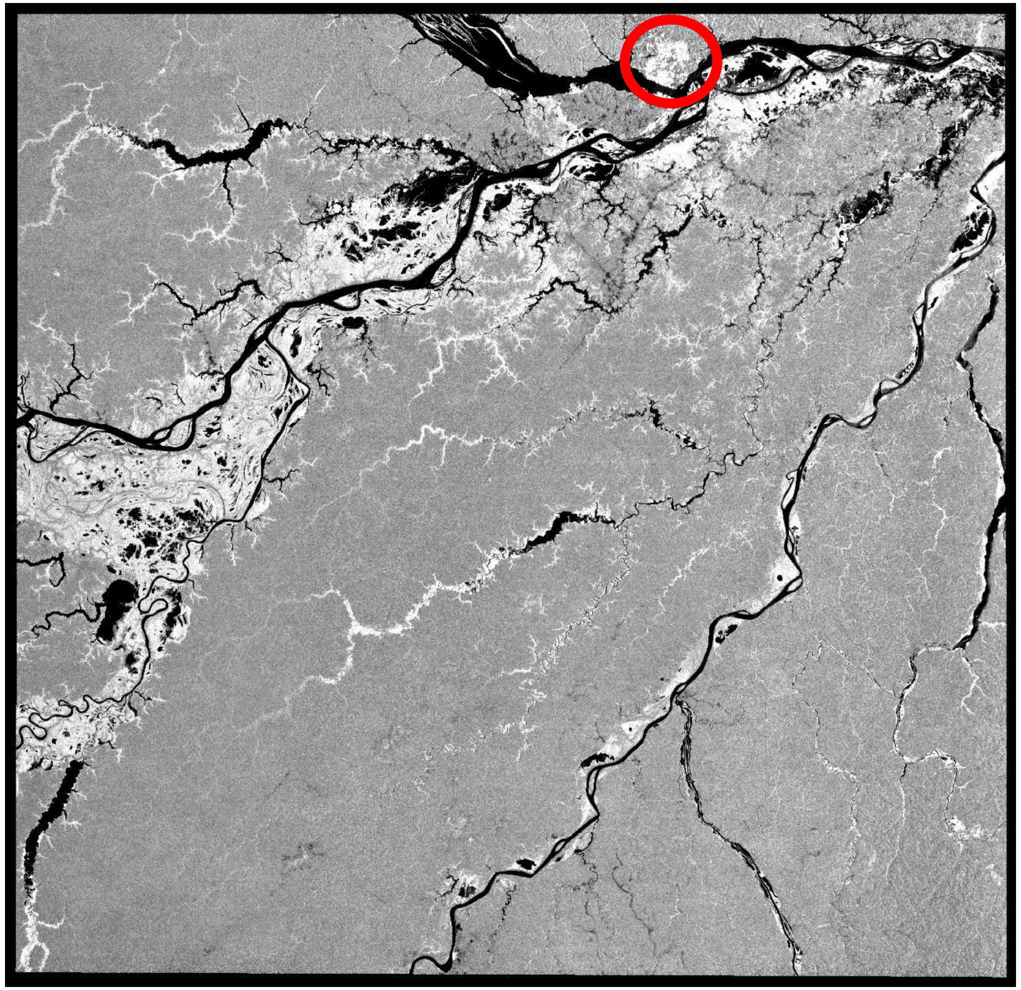




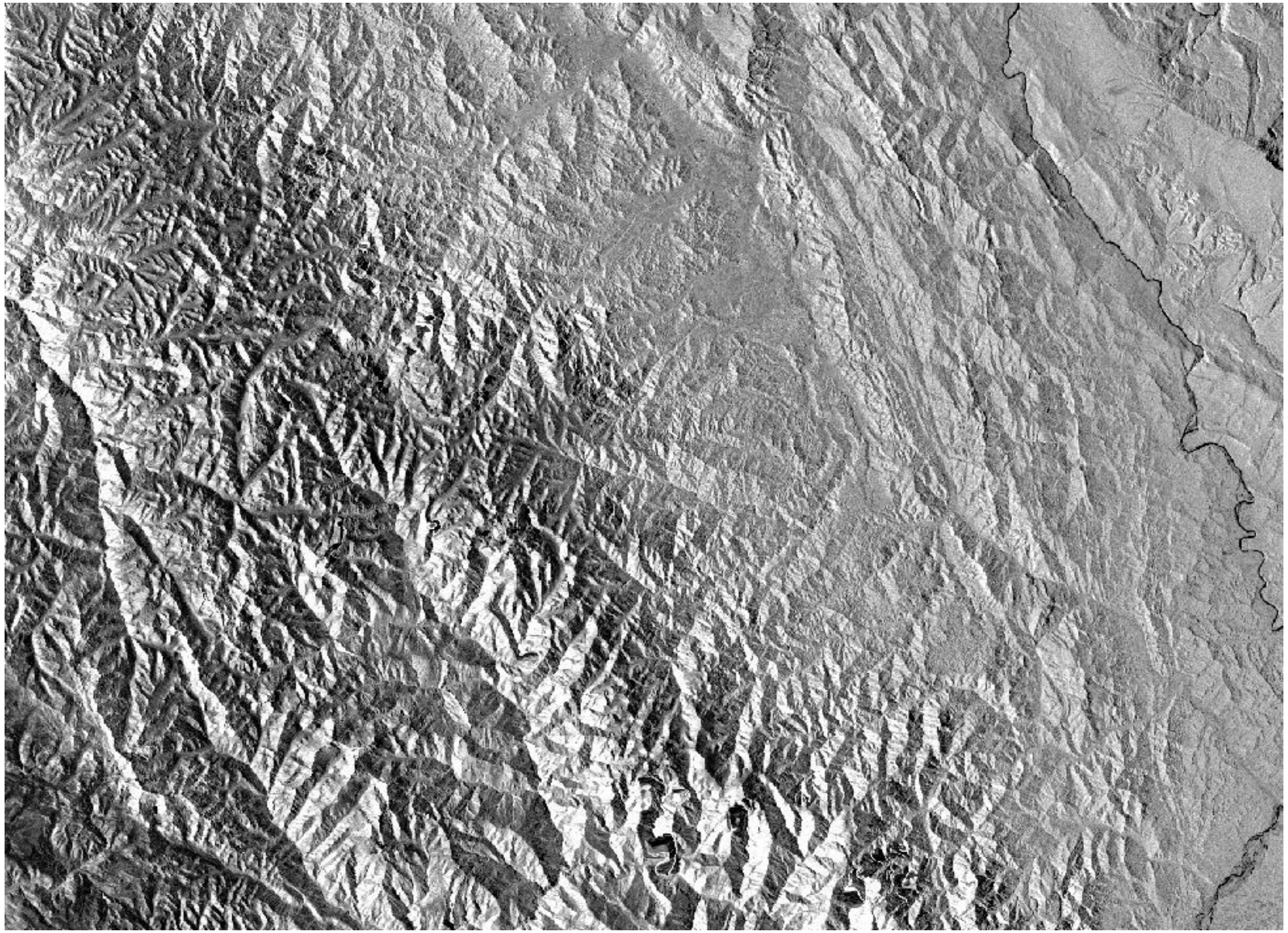


Source of Confusion: Urban Areas and Flooded Areas

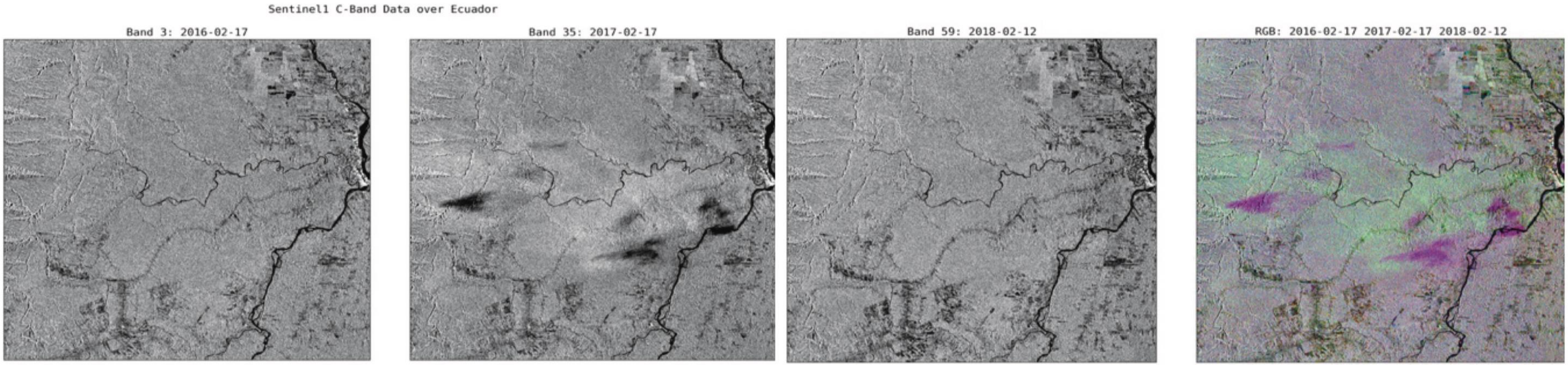
Images from PALSAR (L-band) Near Manaus, Brazil



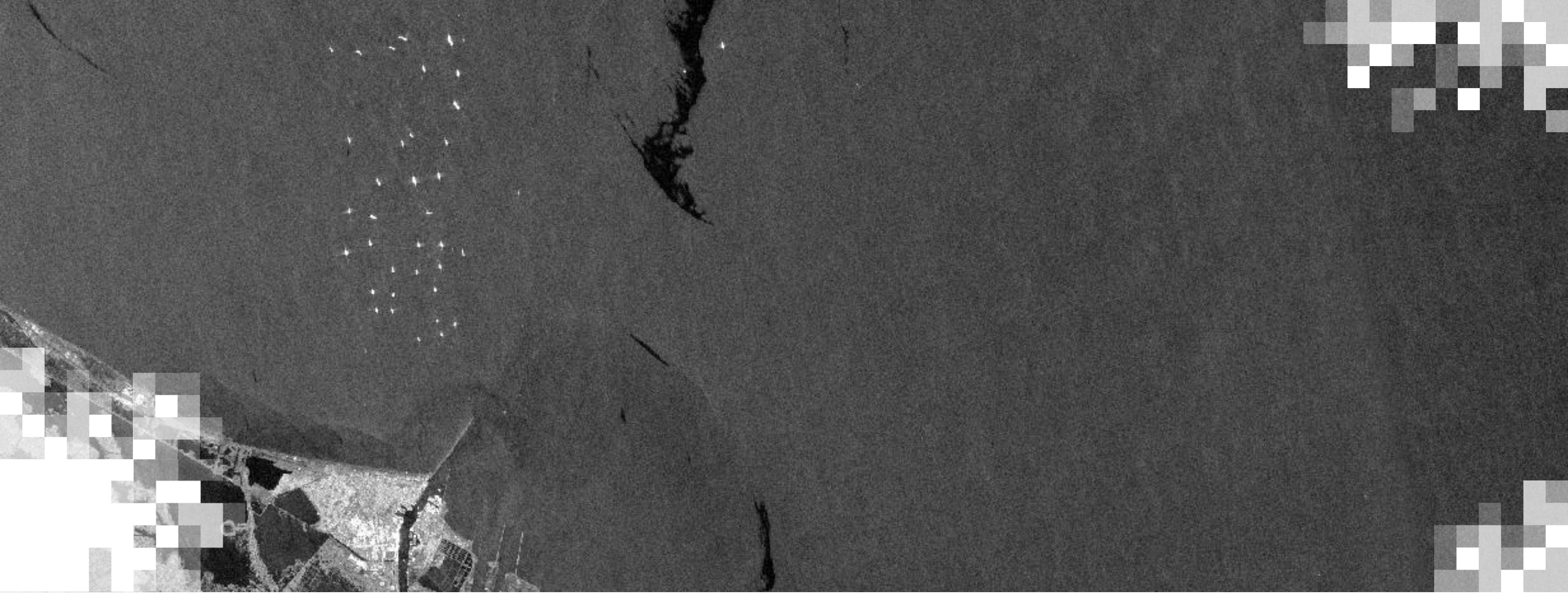
Source of Confusion: Topography and Inundated Vegetation



Rain Event and an Increase in Surface Moisture



Source: SAR Handbook, Chapter 2 by Josef Kellndorfer



Available Radar Data

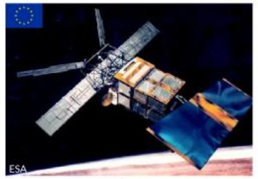
Radar Data Available

Legacy:

SeaSAT
1978

JERS-1
1992-1998

ERS 1/2
1991-2011



ENVISAT
2002-2012

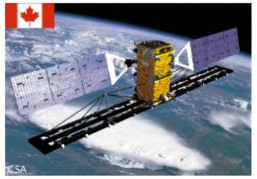
ALOS-1
2006-2011

Radarsat-1
1995-2013

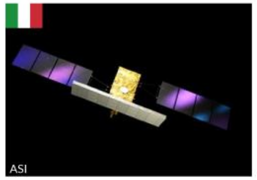
Current:

TanDEM-X
2007

Radarsat-2
2007



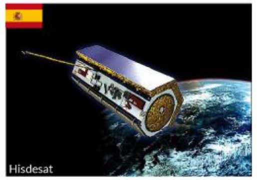
COSMO-SkyMed
2007



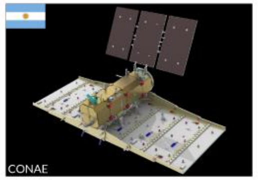
ALOS-2
2014

Sentinel-1
2014

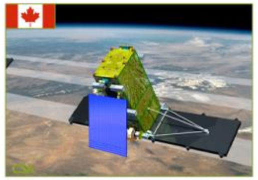
PAZ SAR
2018



SAOCOM
2018



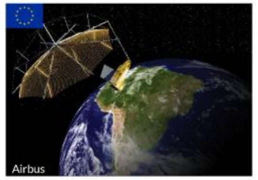
RCM
2018



Future:

NISAR
2024

Biomass
2023

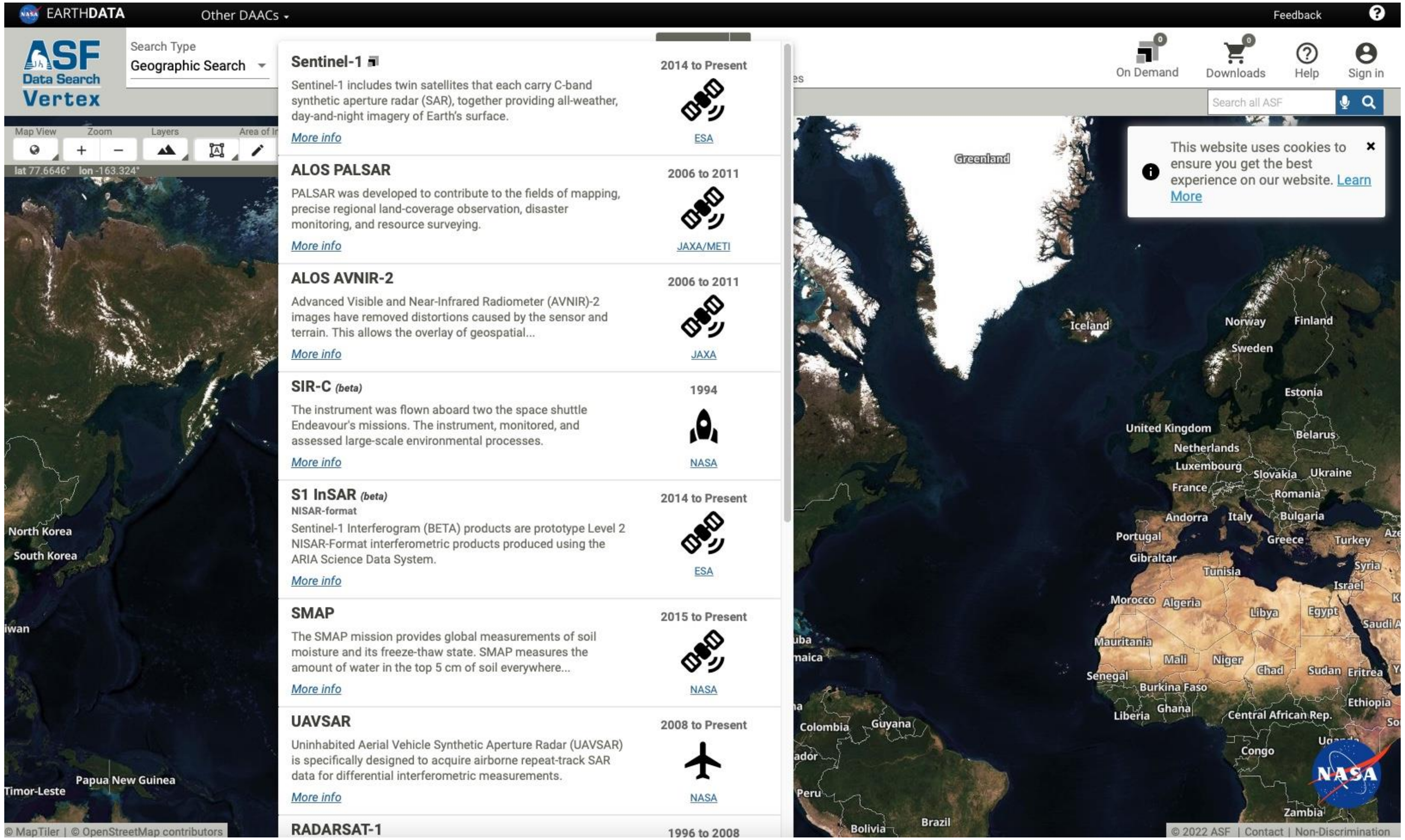


Freely Accessible

Image Credit: Franz Meyer, University of Alaska, Fairbanks

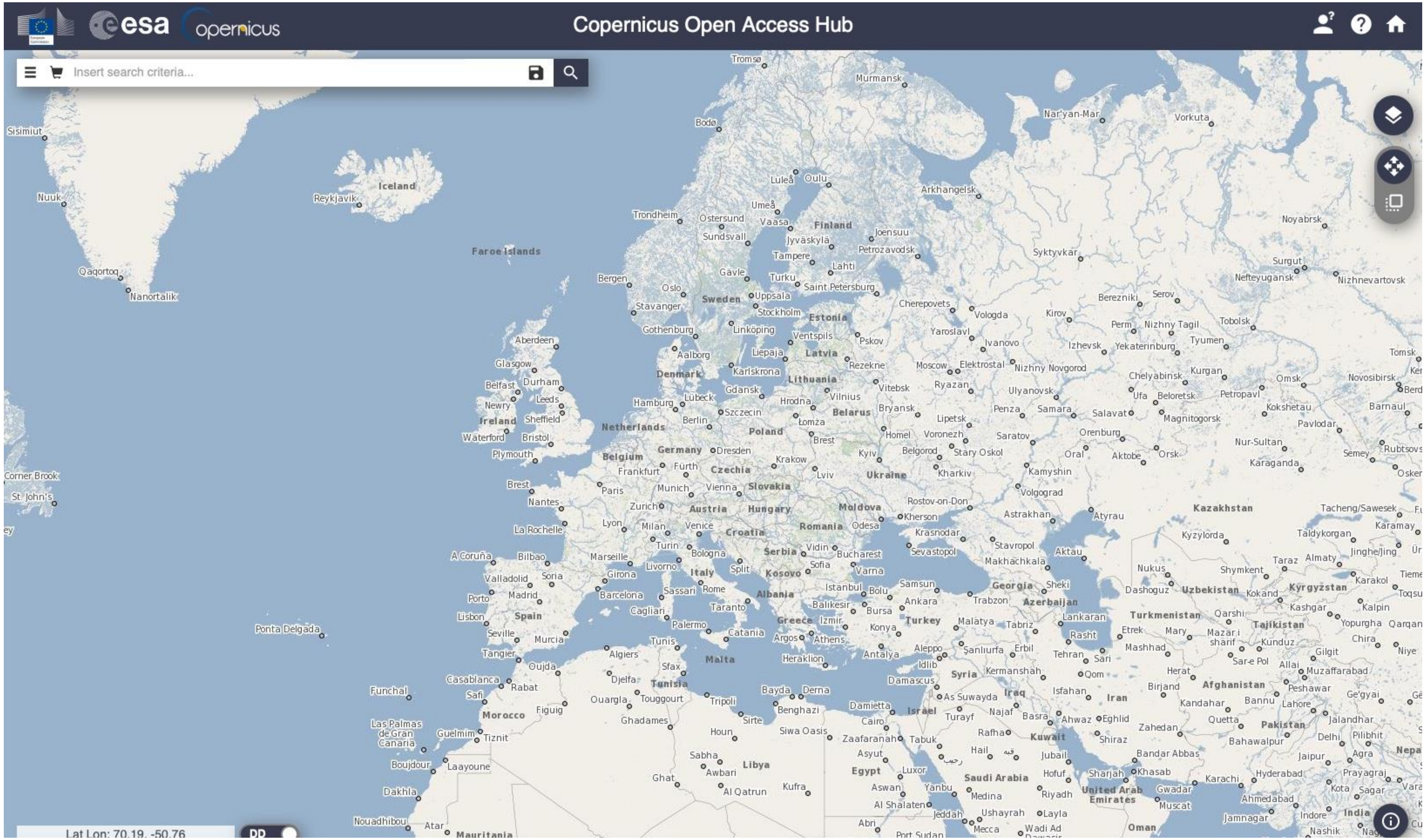
Open Radar Data Access: Alaska Satellite Facility

https://search.asf.alaska.edu/#/



Open Radar Data Access: ESA's Copernicus Hub

https://scihub.copernicus.eu/dhus/#/home



Open Radar Data Access: Google Earth Engine

https://developers.google.com/earth-engine/datasets/catalog

Earth Engine Data Catalog

Search

Home | View all datasets | Browse by tags | Landsat | MODIS | Sentinel | API Docs

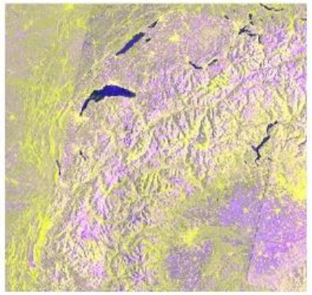
Earth Engine Data Catalog

Earth Engine's public data catalog includes a variety of standard Earth science raster datasets. You can import these datasets into your script environment with a single click. You can also upload your own raster data or vector data for private use or sharing in your scripts.

Looking for another dataset not in Earth Engine yet? Let us know by suggesting a dataset.

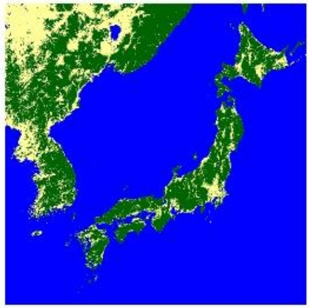
sar

Sentinel-1 SAR GRD: C-band Synthetic Aperture Radar Ground Range Detected, log scaling



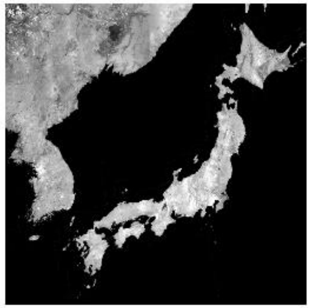
The Sentinel-1 mission provides data from a dual-polarization C-band Synthetic Aperture Radar (SAR) instrument at 5.405GHz (C band). This collection includes the S1 Ground Range Detected (GRD) scenes, processed using the Sentinel-1 Toolbox to generate a calibrated, ortho-corrected product. The collection is updated daily. New ...

Global PALSAR-2/PALSAR Forest/Non-Forest Map



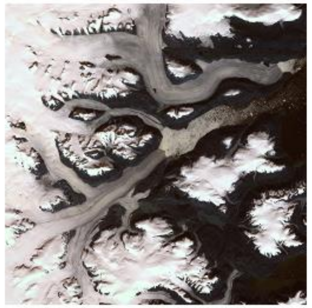
The global forest/non-forest map (FNF) is generated by classifying the SAR image (backscattering coefficient) in the global 25m resolution PALSAR-2/PALSAR SAR mosaic so that strong and low backscatter pixels are assigned as "forest" and "non-forest", respectively. Here, "forest" is defined as the natural forest with ...

Global PALSAR-2/PALSAR Yearly Mosaic



The global 25m PALSAR/PALSAR-2 mosaic is a seamless global SAR image created by mosaicking strips of SAR imagery from PALSAR/PALSAR-2. For each year and location, the strip data were selected through visual inspection of the browse mosaics available over the period, with those showing minimum ...

2000 Greenland Mosaic - Greenland Ice Mapping Project (GIMP)



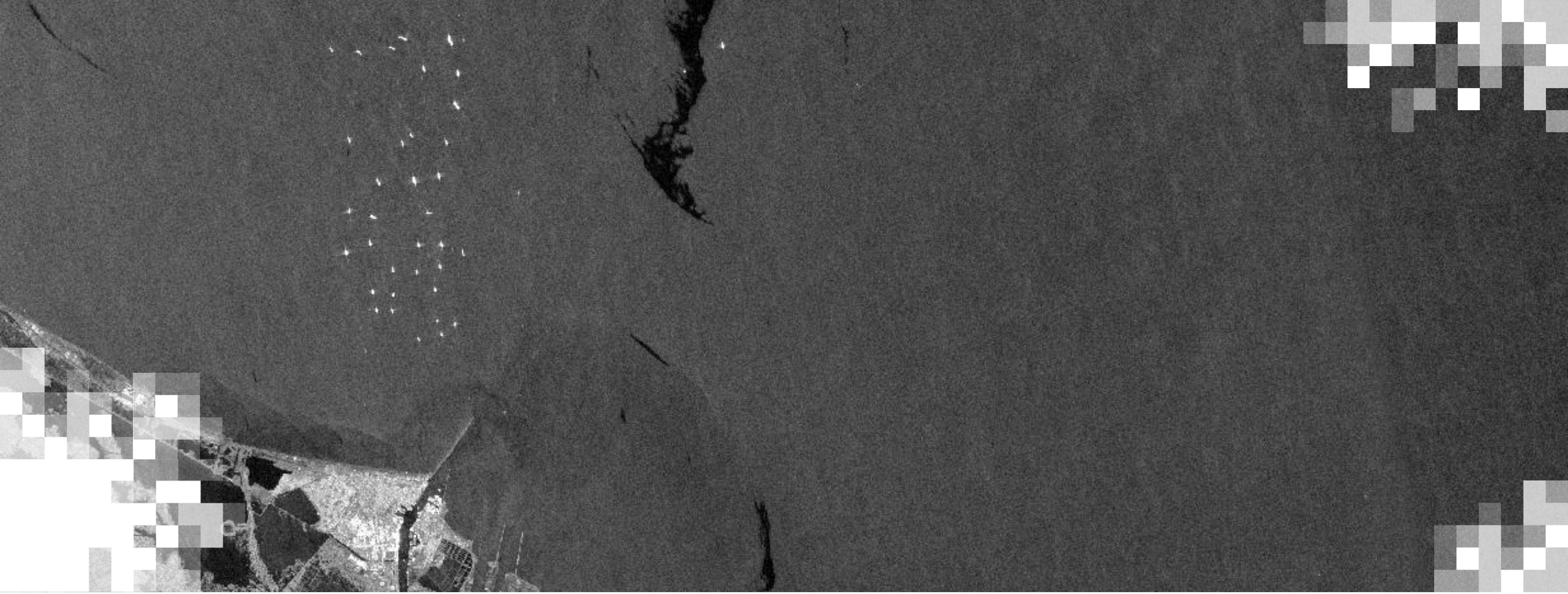
This dataset provides a complete 15 m resolution image mosaic of the Greenland ice sheet derived from Landsat 7 ETM+ and RADARSAT-1 SAR imagery from the years 1999 to 2002. The methods include a combination of image cloud masking, pan sharpening, image sampling and resizing, ...

Processing Steps for Analysis Ready SAR Data

1. Radiometric Calibration

2. Terrain correction using SRTM 30 or ASTER DEM for areas greater than 60 degrees latitude, where SRTM is not available.

3. Speckle Filtering



Flood Mapping Demonstration

Google Earth Engine Overview

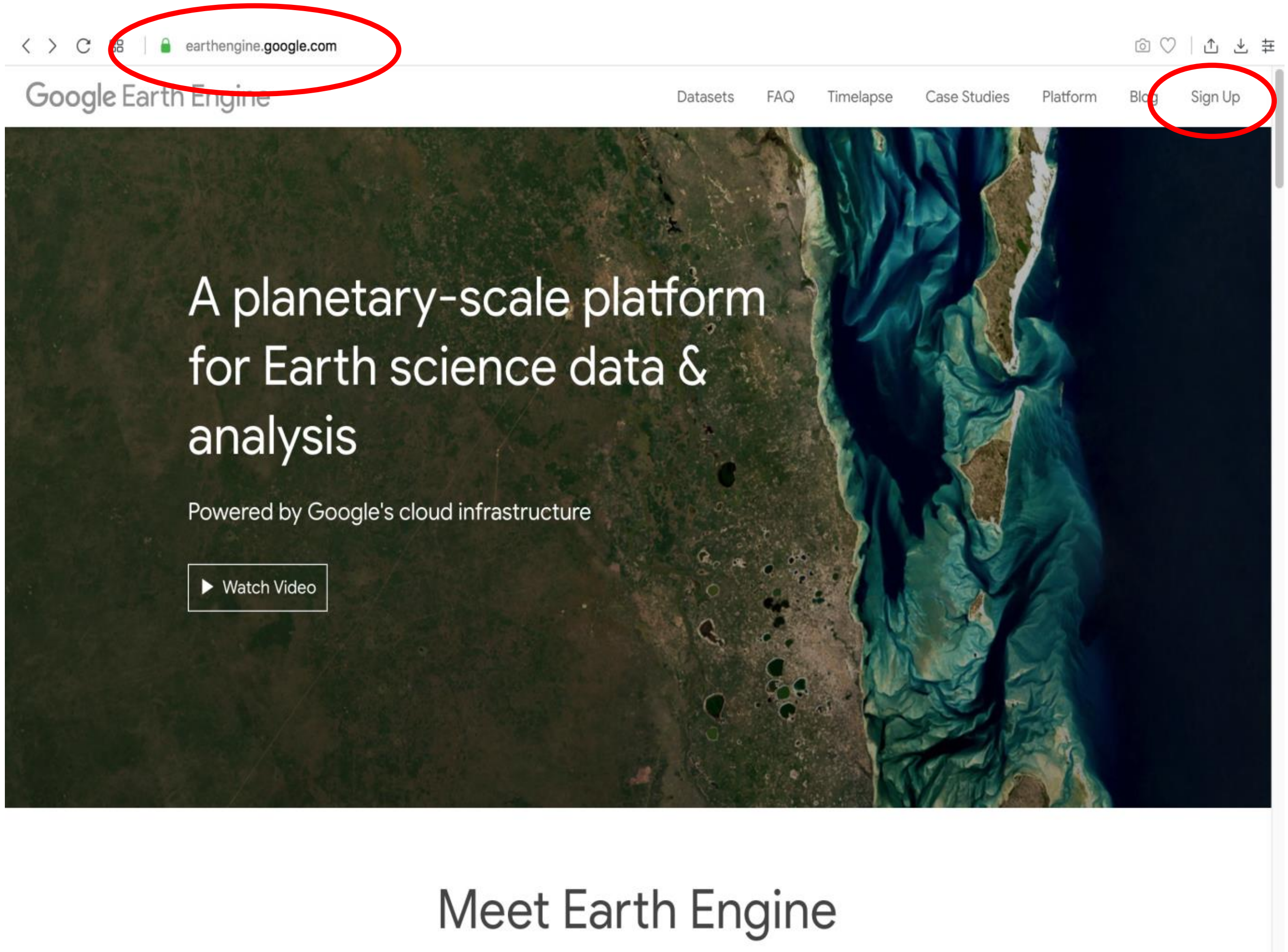
- A cloud-based geospatial processing platform
- Available to scientists, researchers, and developers for analysis of the Earth's surface
- Catalog of satellite imagery and geospatial datasets (including Sentinel-1):

https://developers.google.com/earth-engine/datasets/catalog/

- JavaScript code editor
- Go to Google Earth Engine:

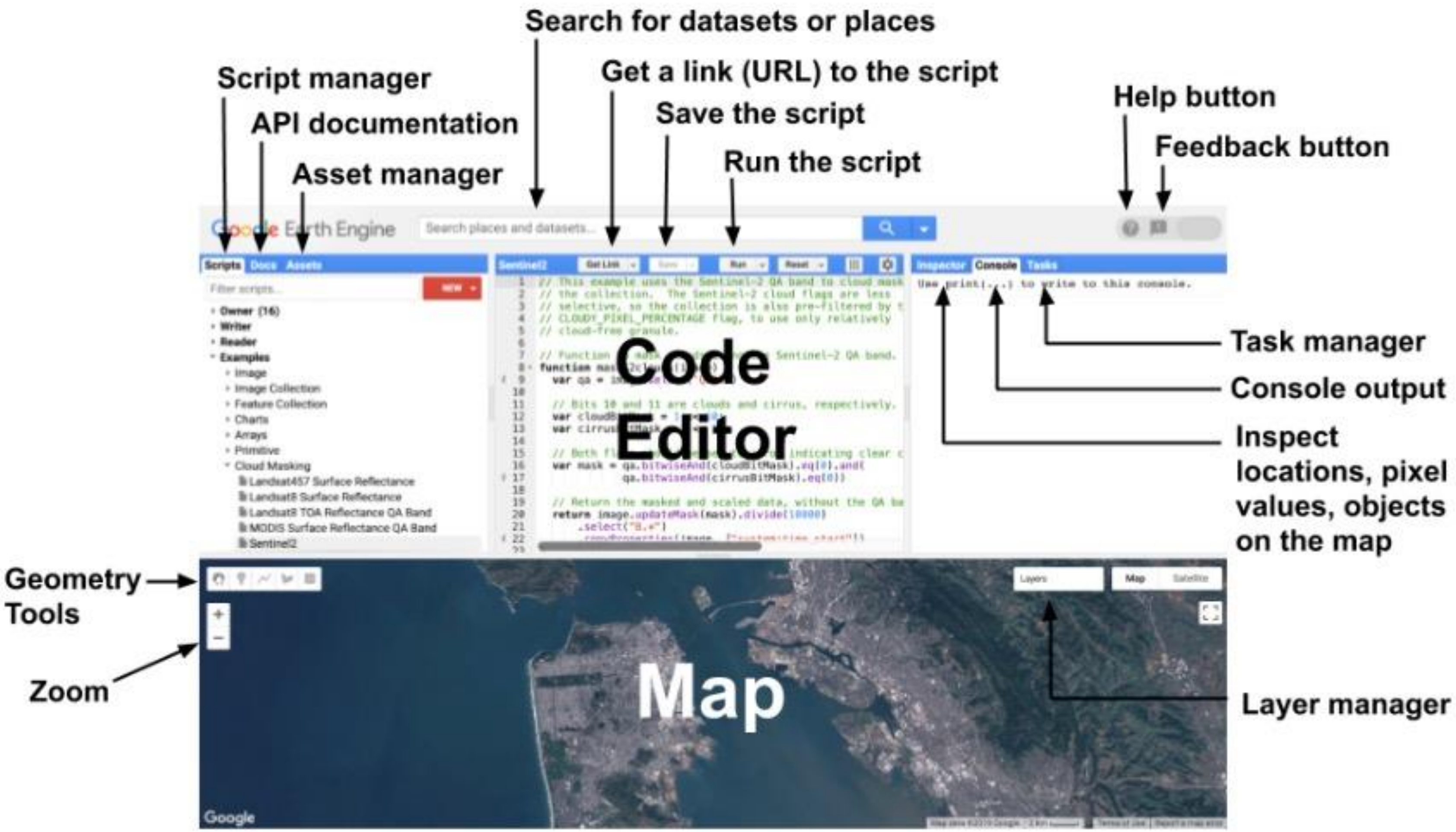
https://earthengine.google.com

- Sign up for an account (it's free)



Google Earth Engine Code Editor

https://code.earthengine.google.com



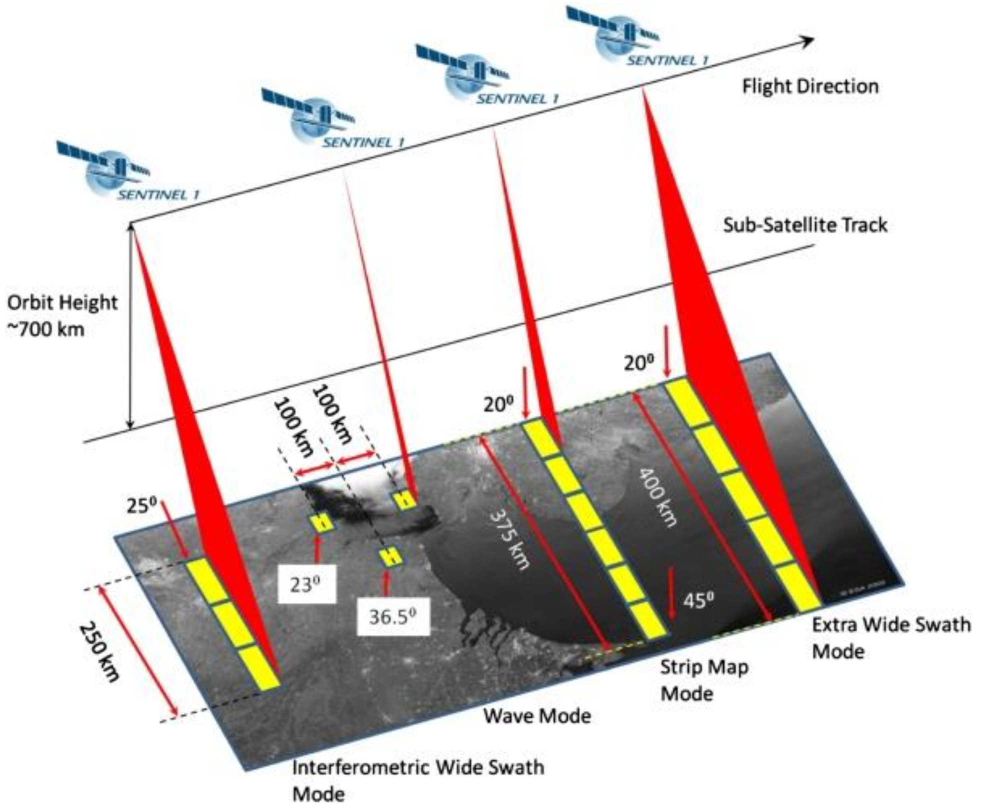
Sentinel-1 Data Review

Two Satellites: A & B

- C-band data
- Each satellite has global coverage every 12 days
- Global coverage of 6 days over the equator when using data from both satellites

Different Modes:

- Extra Wide Swath – For monitoring oceans and coasts
- Strip Mode – By special order only and intended for special needs
- Wave Mode – Routine collection for the ocean
- *Interferometric Wide Swath – Routine collection for land (**this is the one you want to use**)*

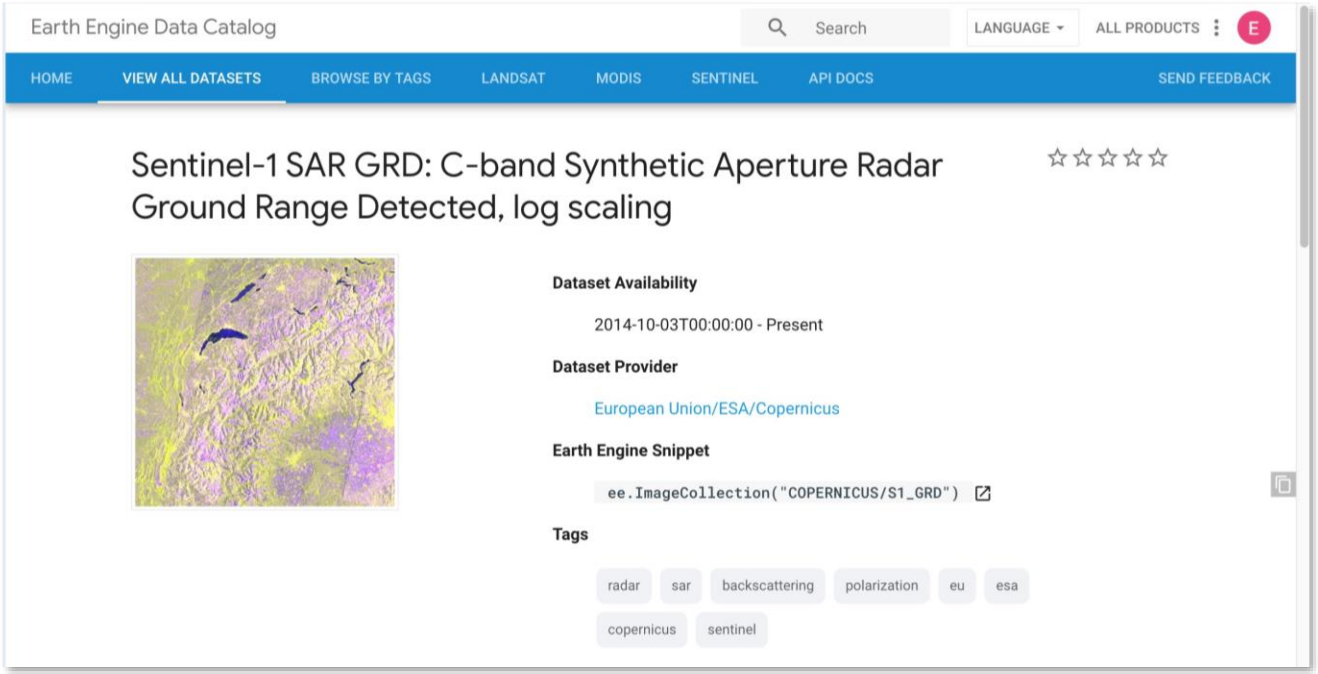


Sentinel-1 Catalog

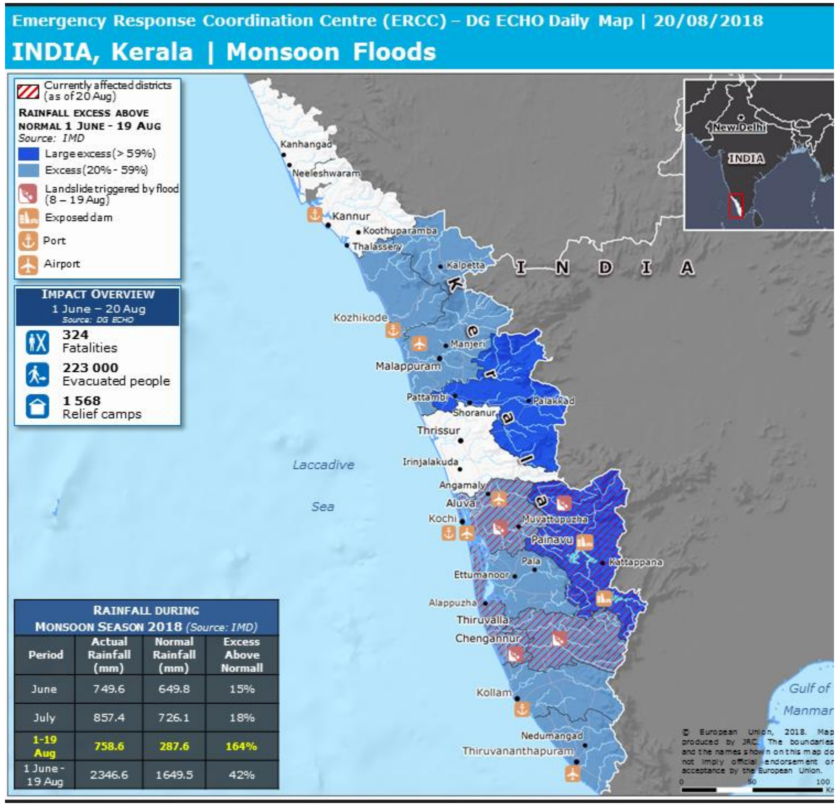
https://developers.google.com/earth-engine/datasets/catalog/COPERNICUS_S1_GRD

Each scene was pre-processed with [Sentinel-1 Toolbox]() using the following steps:

1. Thermal noise removal
2. Radiometric calibration
3. Terrain correction using SRTM 30 or ASTER DEM for areas greater than 60 degrees latitude, where SRTM is not available. The final terrain-corrected values are converted to decibels via log scaling (10*log10(x)).



Flood Case: Kerala Floods, August 2018



Period	Actual Rainfall (mm)	Normal Rainfall (mm)	Excess Above Normall
June	749.6	649.8	15%
July	857.4	726.1	18%
1-19 Aug	758.6	287.6	164%
1 June - 19 Aug	2346.6	1649.5	42%

http://www.gdacs.org/contentdata/maps/daily/FL/1000212/ECDM_20180820_Kerala_Floods.png

Kerala floods: death toll rises to at least 324 as rescue effort continues

220,000 people left homeless and thousands still trapped in southern Indian state after unusually heavy rain

▲ 'Please pray for us': Kerala experiences worst monsoon in nearly a century – video report

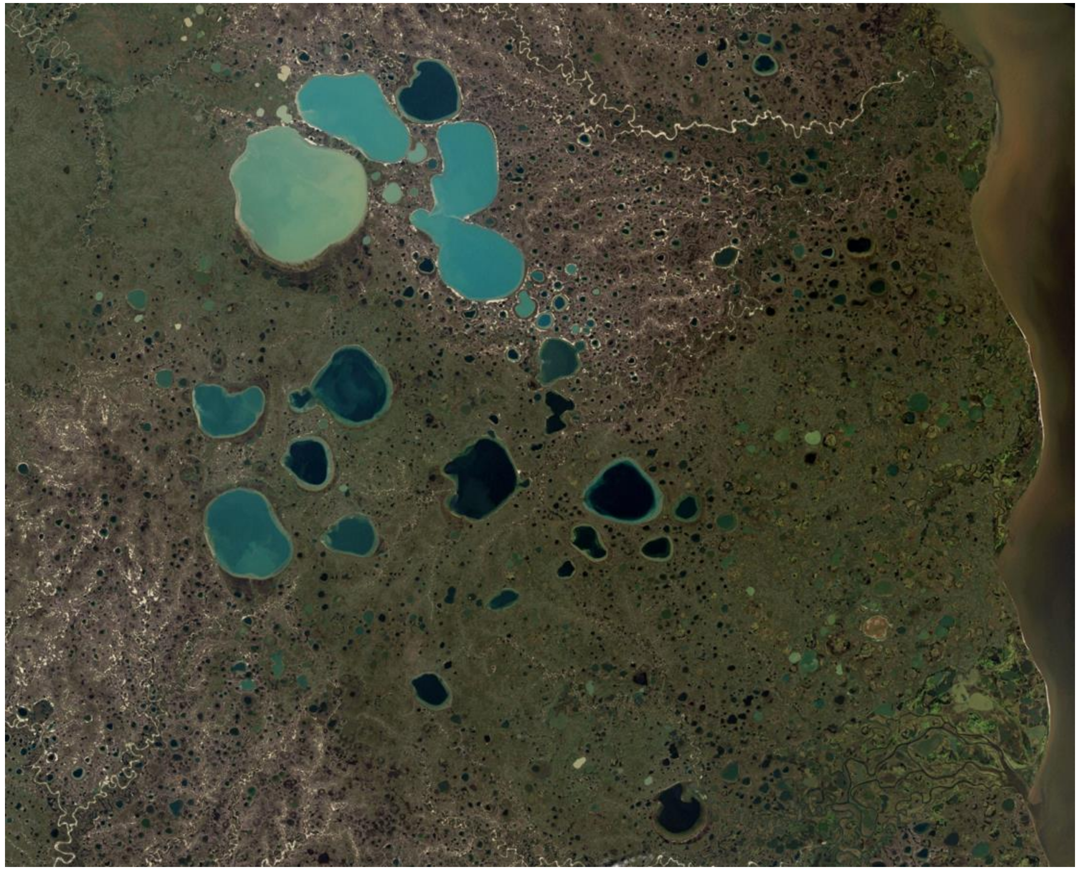
https://www.theguardian.com/world/2018/aug/17/kerala-floods-death-toll-rescue-effort-india

GEE Code

Time Series Flood Mapping:
https://code.earthengine.google.com/34ef34c863d26bceee24e194d71236e5

Questions?

- Please enter your questions in the Q&A box. We will answer them in the order they were received.
- We will post the Q&A to the training website following the conclusion of this session.

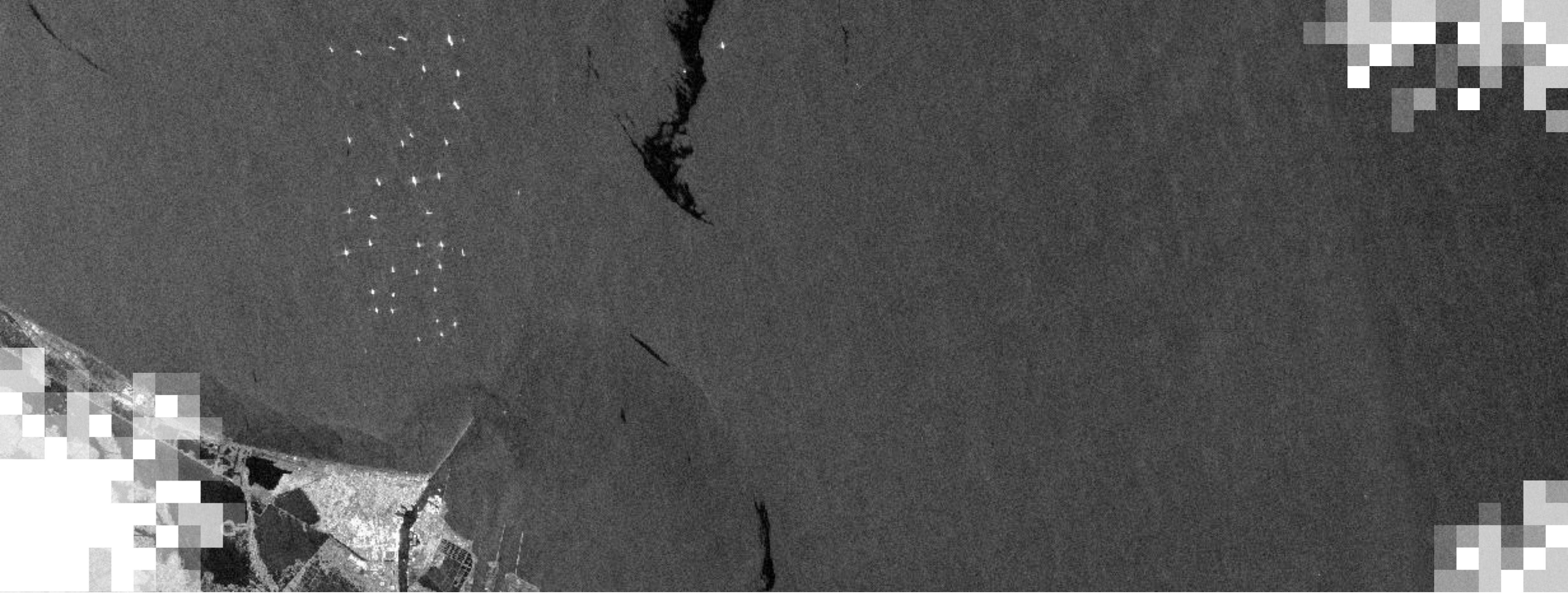


https://earthobservatory.nasa.gov/images/6034/pothole-lakes-in-siberia

Contacts

- Trainer:
  - Erika Podest: erika.podest@jpl.nasa.gov
- Training Webpage:
  - https://appliedsciences.nasa.gov/join-mission/training/english/arset-disaster-assessment-using-synthetic-aperture-radar
- ARSET Website:
  - https://appliedsciences.nasa.gov/arset
- Twitter: @NASAARSET

Thank You!



Appendix: SAR Tutorial References and Resources

ARSET SAR Tutorials

Introduction to SAR Webinar Series:

Session 1: Basics of SAR
https://www.youtube.com/watch?v=Xemo2ZpduHA

Session 2: SAR Processing and Data Analysis
https://www.youtube.com/watch?v=OwrLh7pjHRQ

Session 3: Introduction to Polarimetric SAR
https://www.youtube.com/watch?v=-xU4oE66pgY

Session 4: Introduction to SAR Interferometry
https://www.youtube.com/watch?v=P8lQ7pjkRlw

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

Alaska Satellite Facility Resources

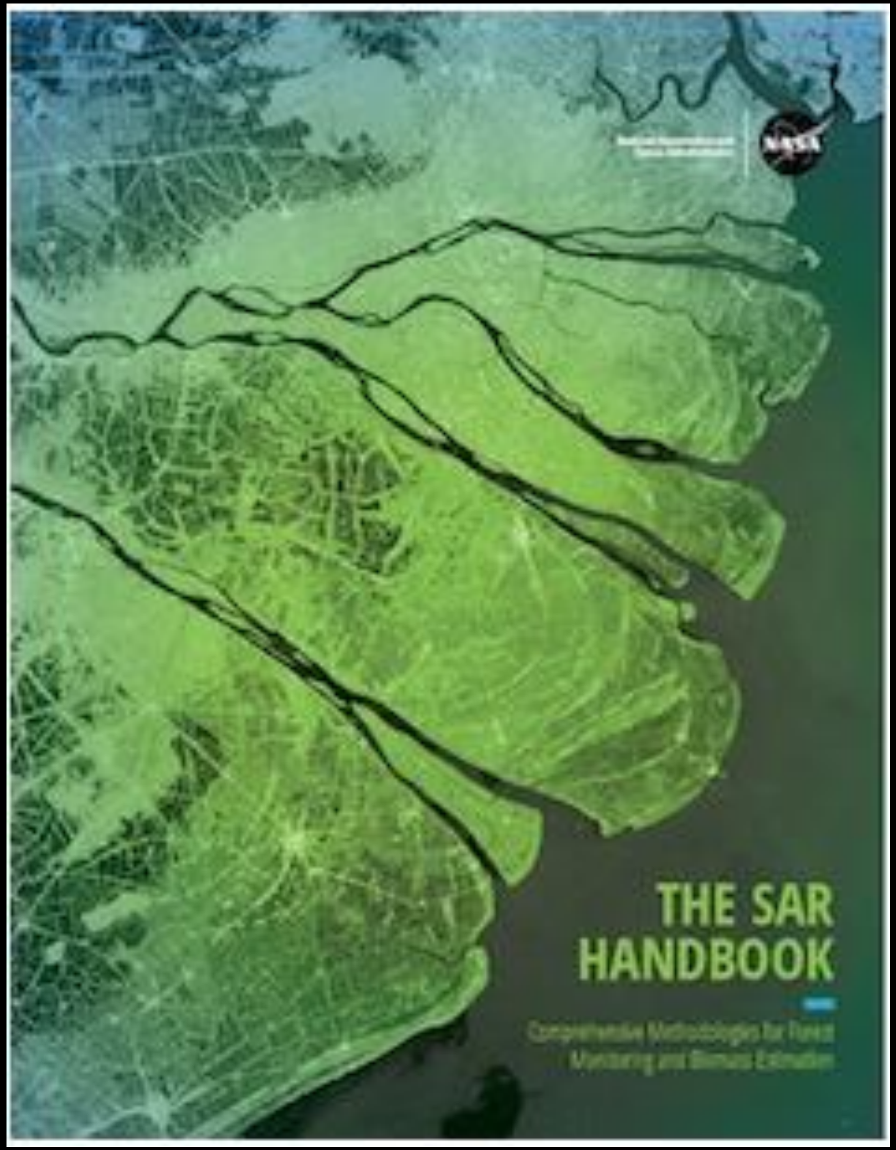
Fundamentals of SAR

Data Tools

Data Recipes

SAR Handbook

Comprehensive Methodologies for Forest Monitoring and Biomass Estimation



SAR Tutorial References

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

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

SAR Tutorial References

-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_ptA.pdf

SAR Tutorial References

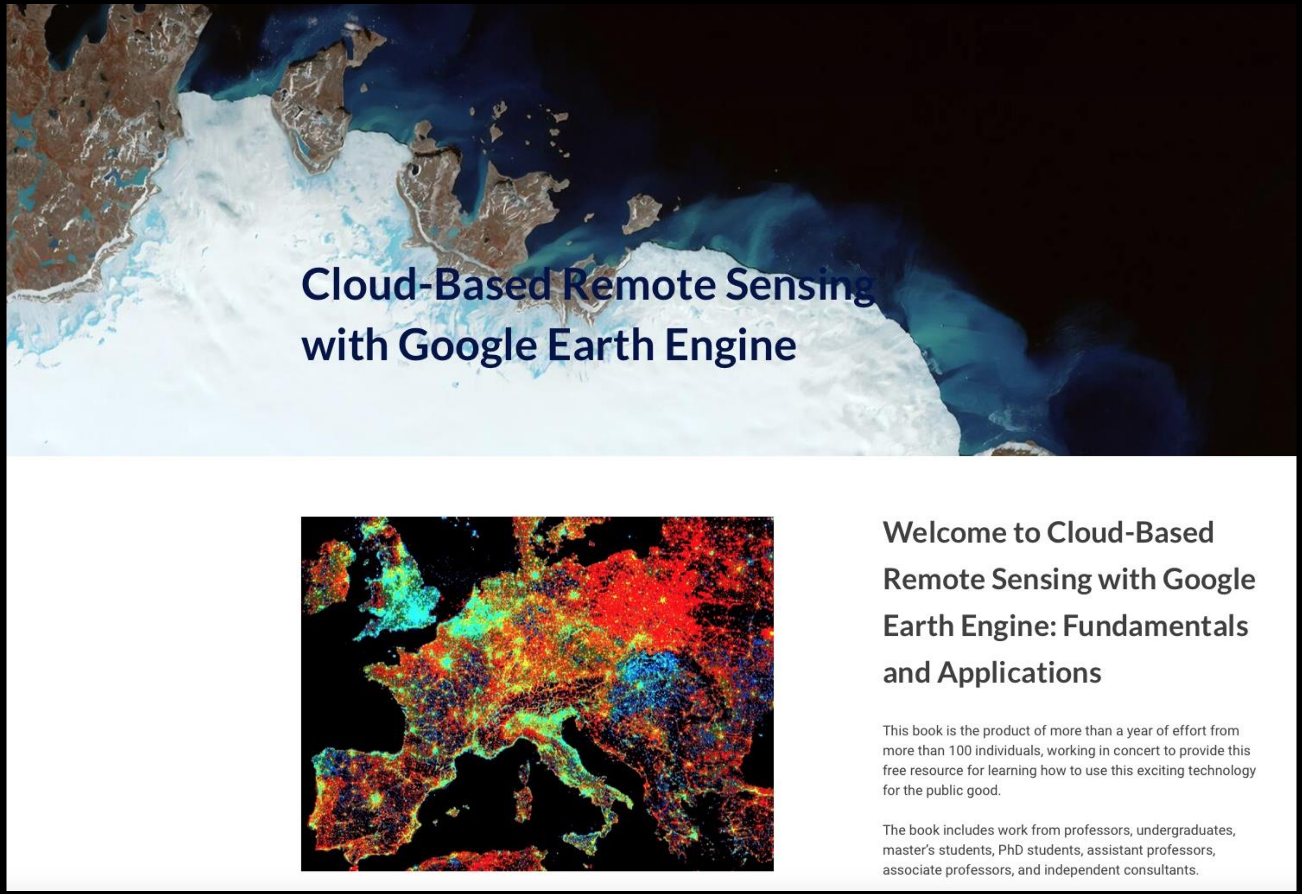
Fundamentals of Remote Sensing by Natural Resources Canada:
http://www.nrcan.gc.ca/earth-sciences/geomatics/satellite-imagery-air-photos/satellite-imagery-products/educational-resources/9371

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/

Google Earth Engine

Cloud Based Remote Sensing with Google Earth Engine
https://www.eefabook.org



Sisters of SAR

Sisters of SAR

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Twitter: @SistersofSAR
LinkedIn: Sisters of SAR