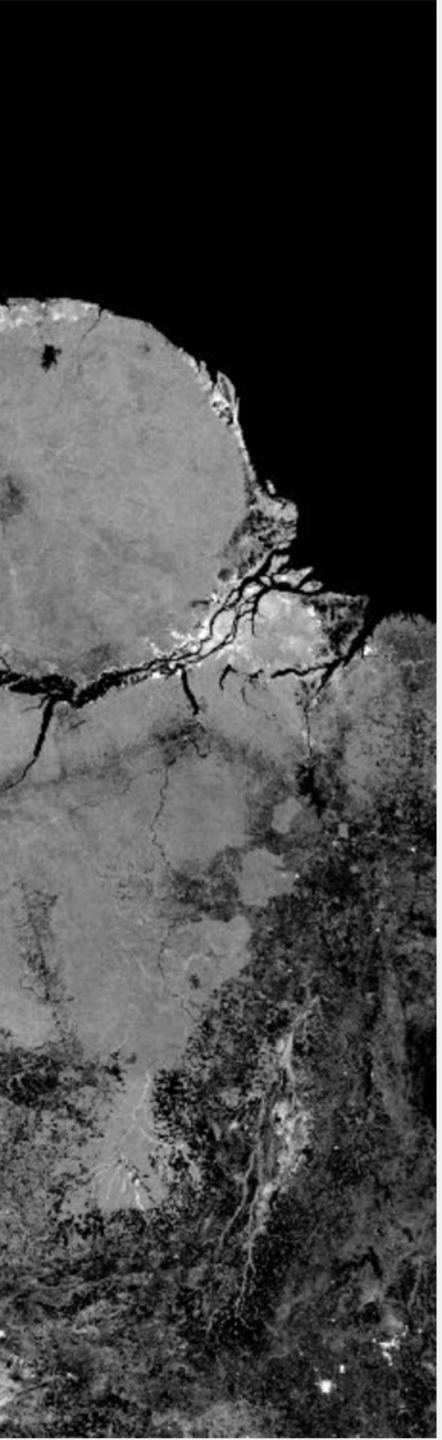

SAR Tutorial

USGEO Satellite Needs Working Group Radar Workshop
Mar. 17, 2020

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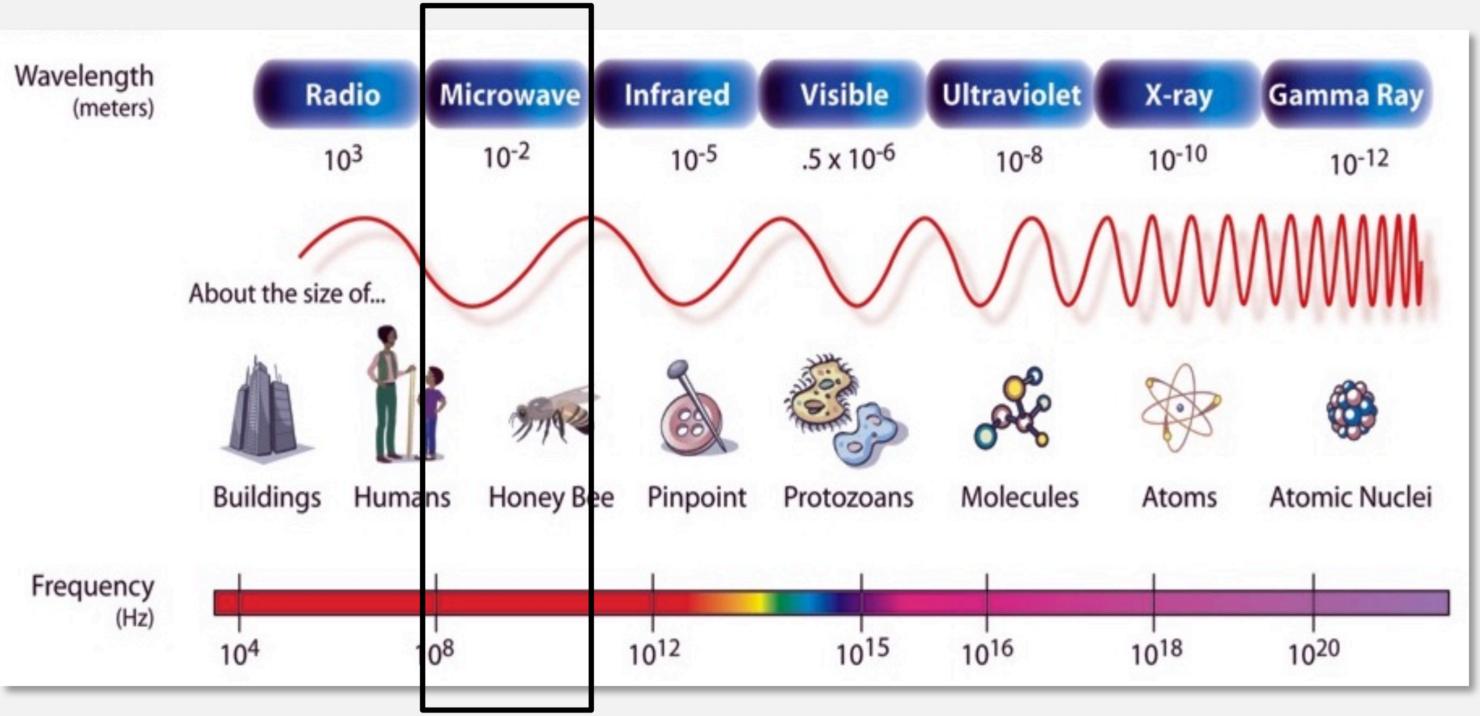
Carbon Cycle and Ecosystems Group
Jet Propulsion Laboratory

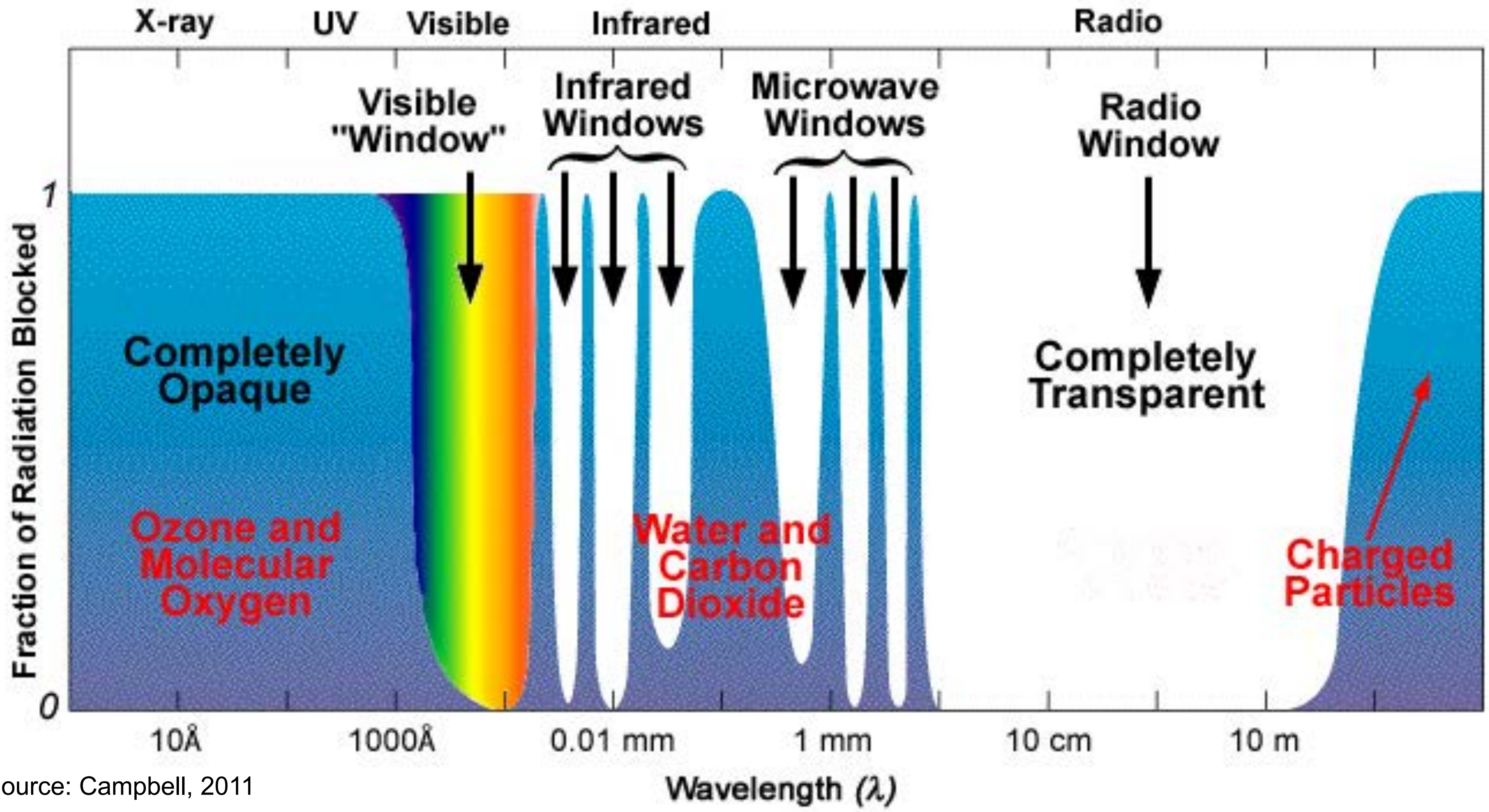
Fundamentals of Microwave Remote Sensing

The Electromagnetic Spectrum

- 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



Atmospheric Windows



Source: Campbell, 2011

Advantages and Disadvantages of Microwave Remote Sensing over Optical

Advantages:

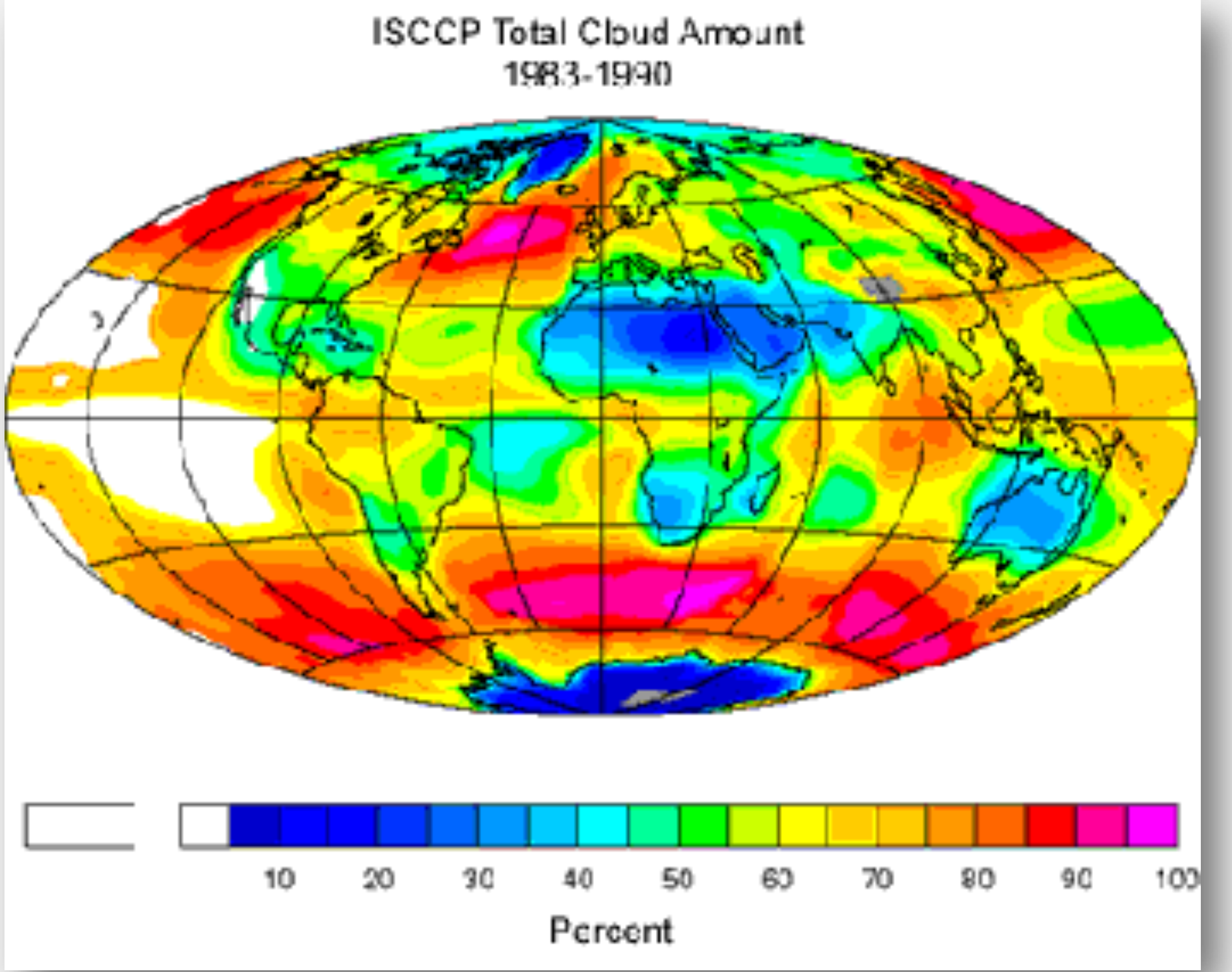
- Nearly all weather capability
- Day or night capability
- Penetration through the vegetation canopy
- Penetration through the soil
- Minimal atmospheric effects
- Sensitivity to dielectric properties (liquid vs frozen water)
- Sensitivity to structure

Disadvantages:

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

Global Cloud Coverage

Total fractional annual cloud cover averaged from 1983-1990, compiled using data from the International Satellite Cloud Climatology Project (ISCCP).



Source: ISCCP, NASA Earth Observatory

Optical vs. Radar

Volcano in Kamchatka, Russia, Oct 5, 1994

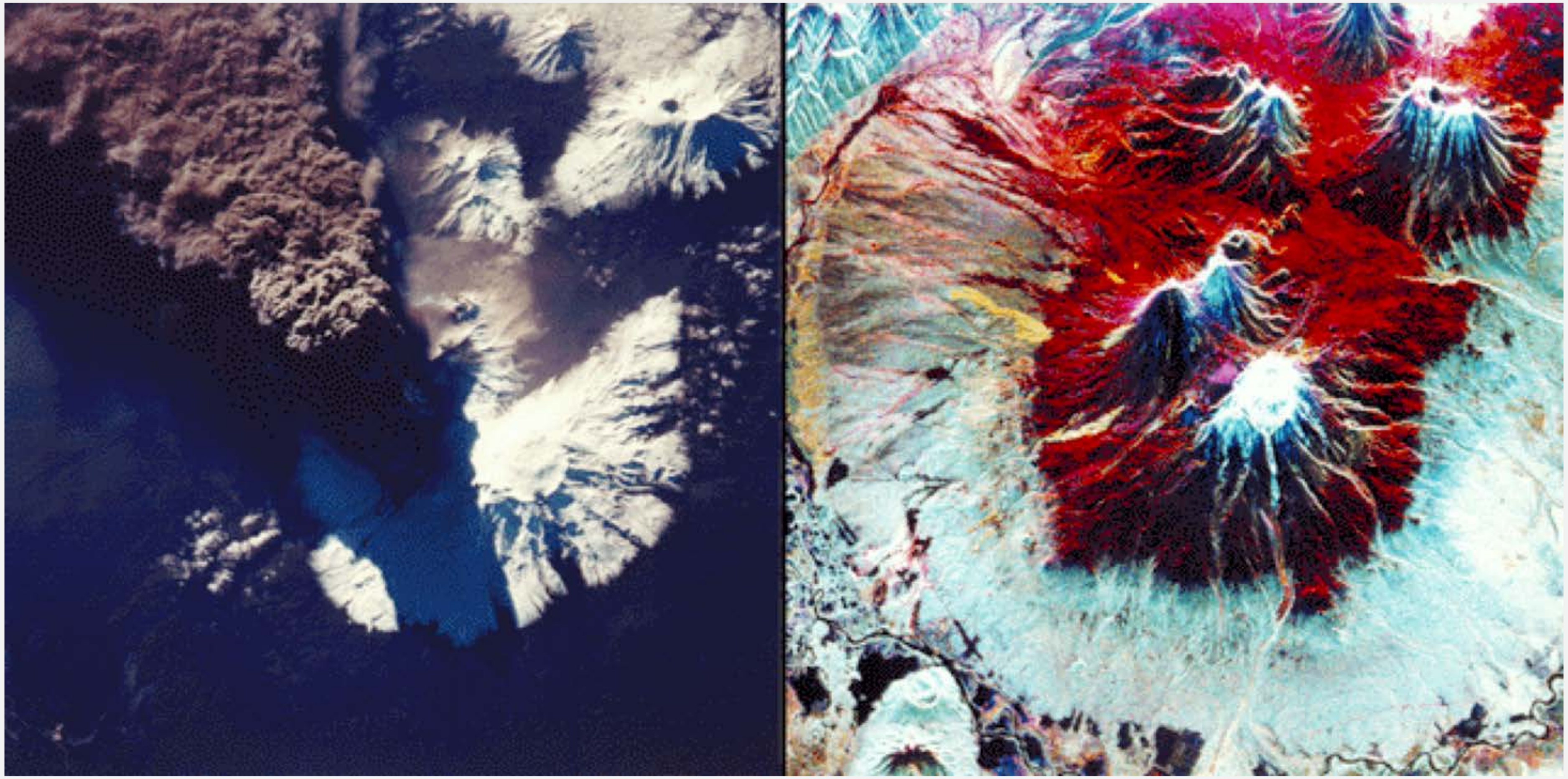
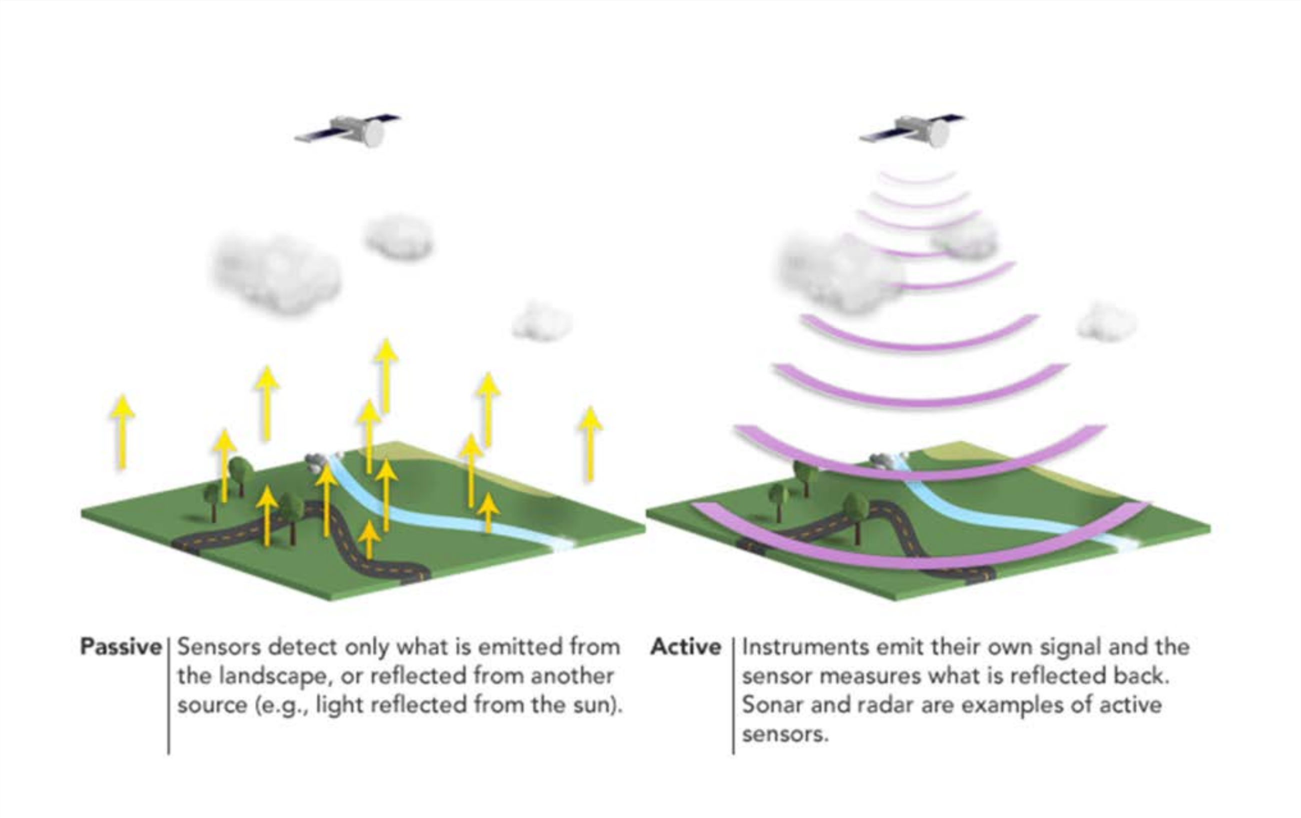


Image Credit: Michigan Tech Volcanology

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.

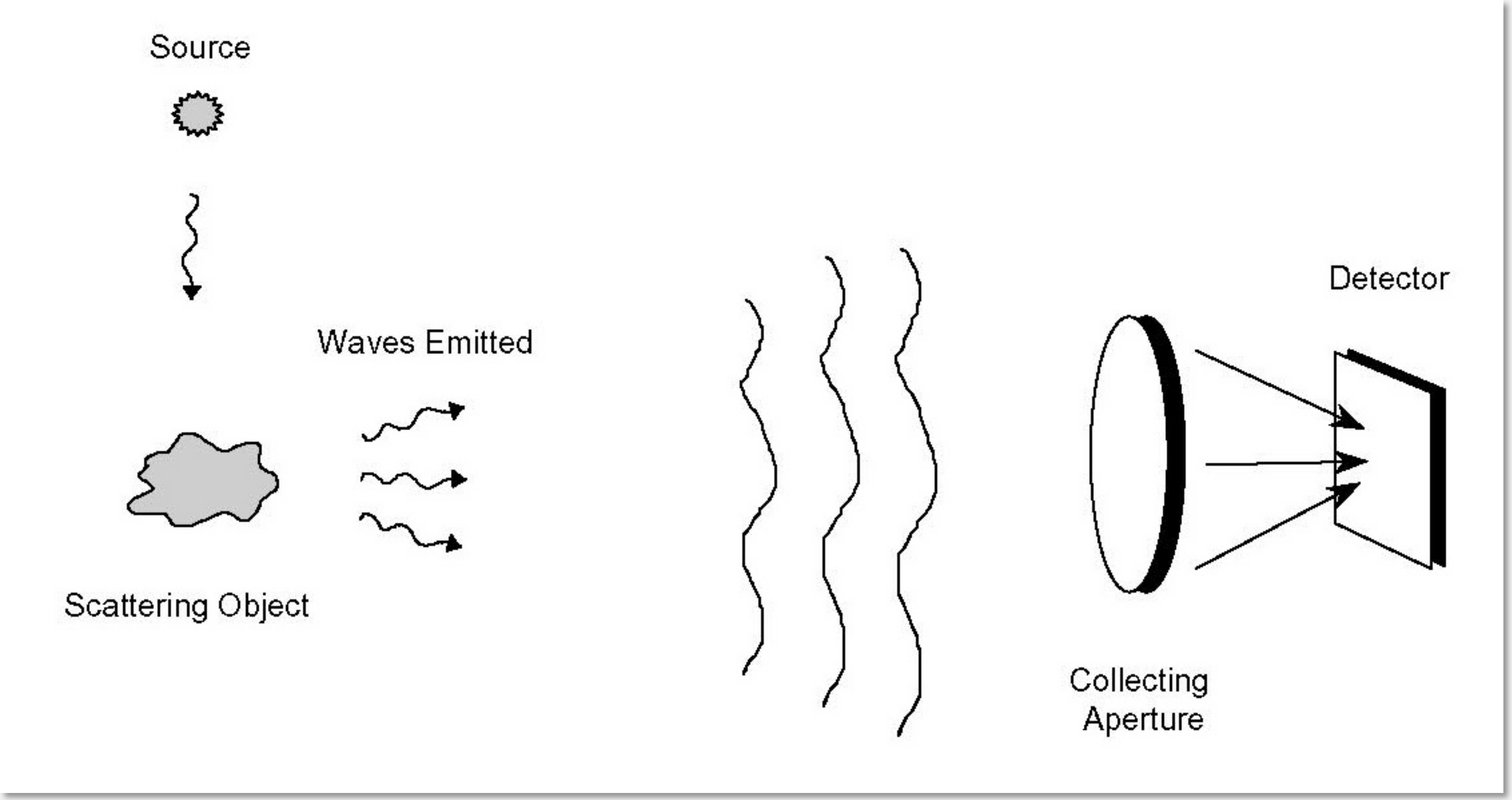
Passive Sensors:

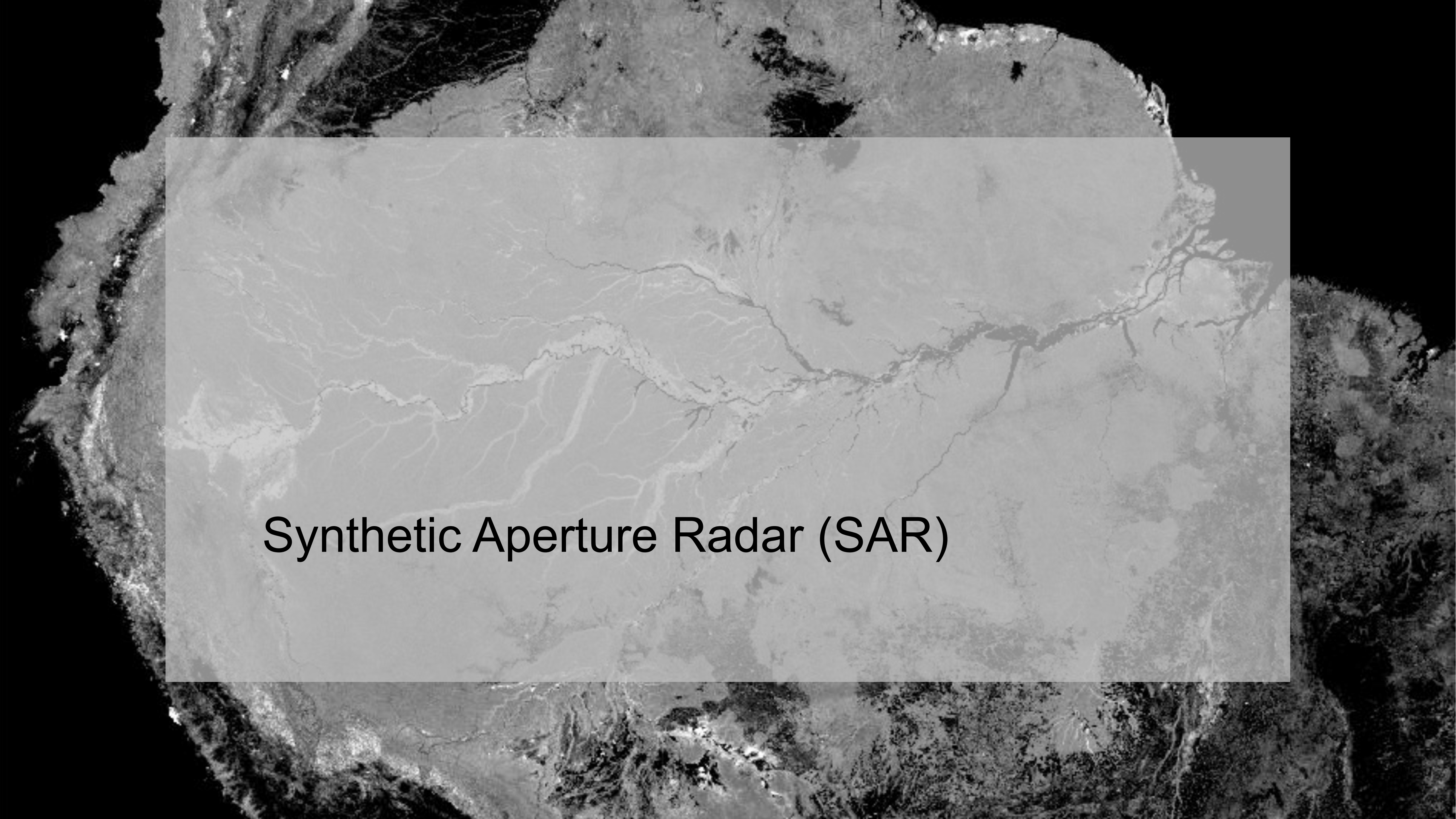
- The source of radiant energy arises from natural sources
- e.g. the sun, Earth, other “hot” bodies

Active Sensors

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

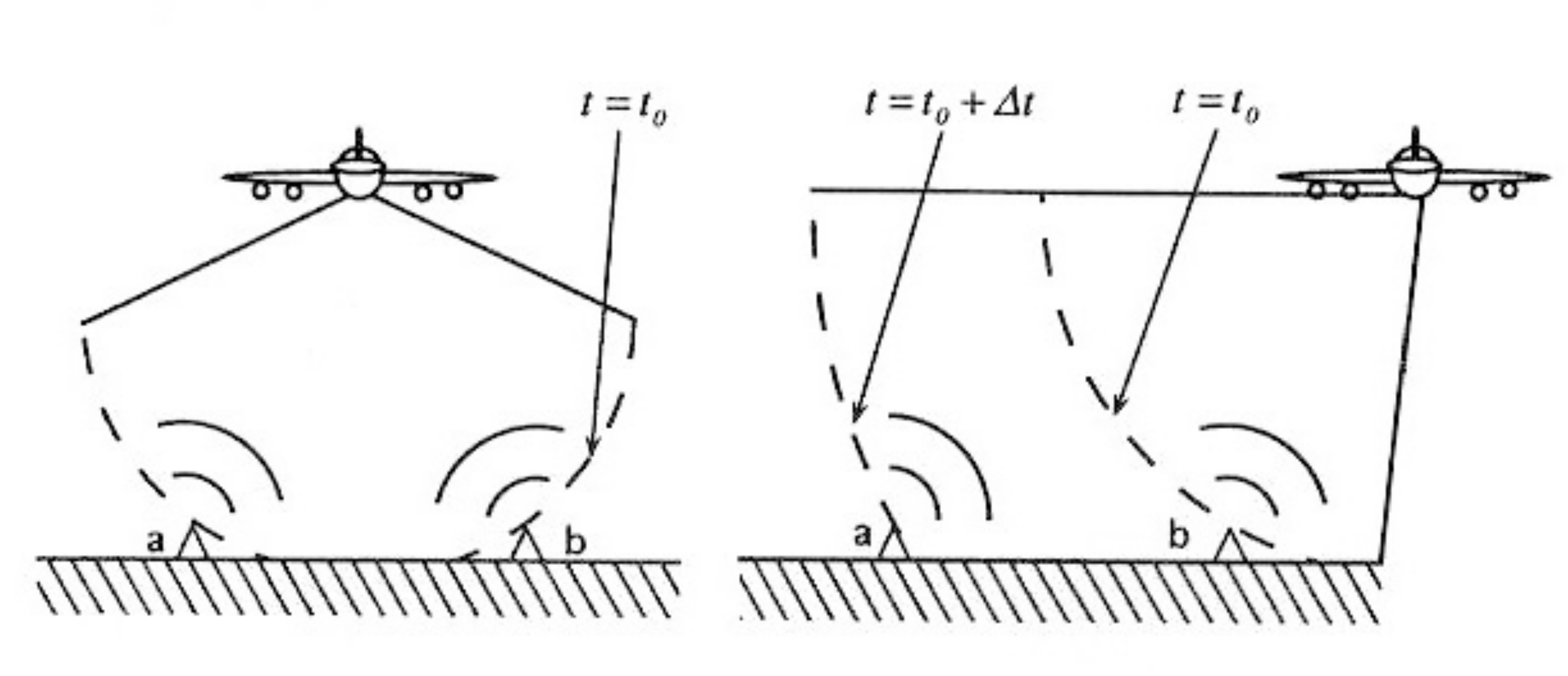
Basic Remote Sensing System





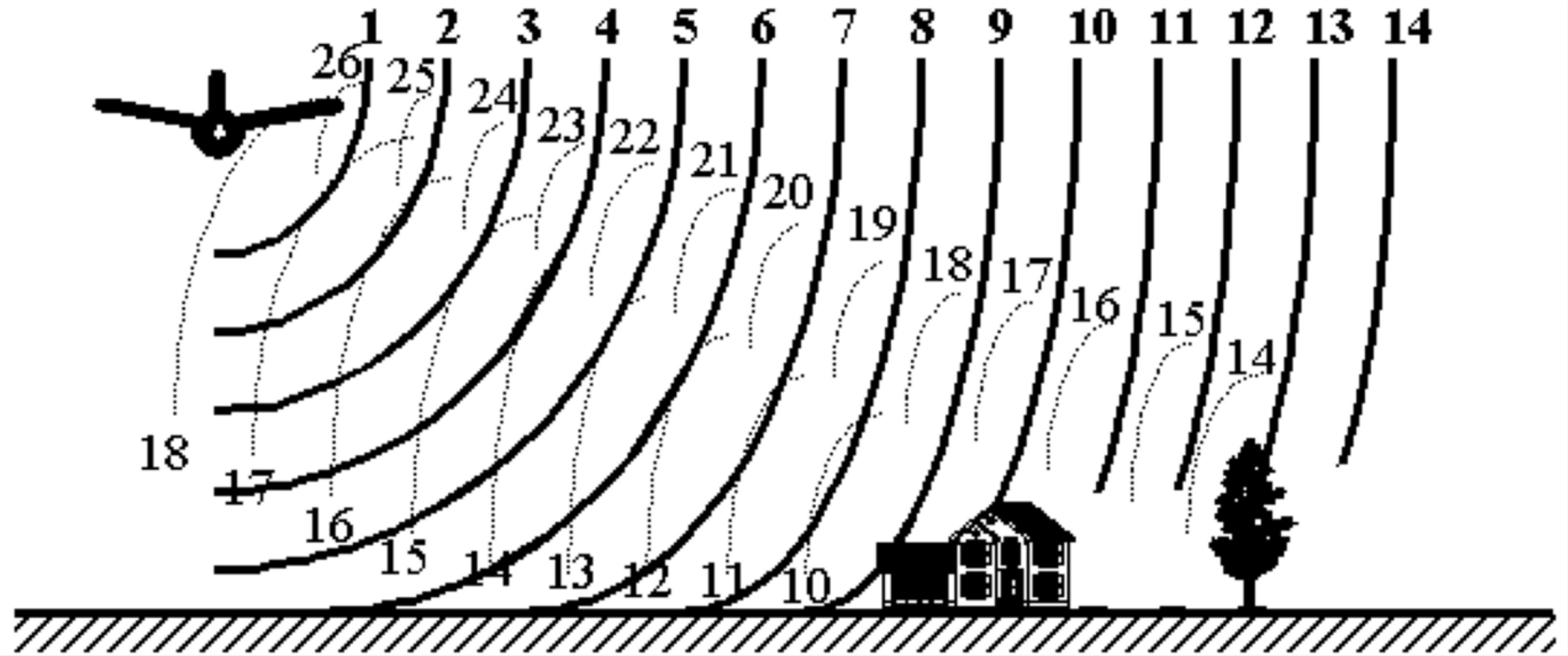
Synthetic Aperture Radar (SAR)

Basic Concepts: Down Looking vs. Side Looking Radar



Basic Concepts: Side Looking Radar

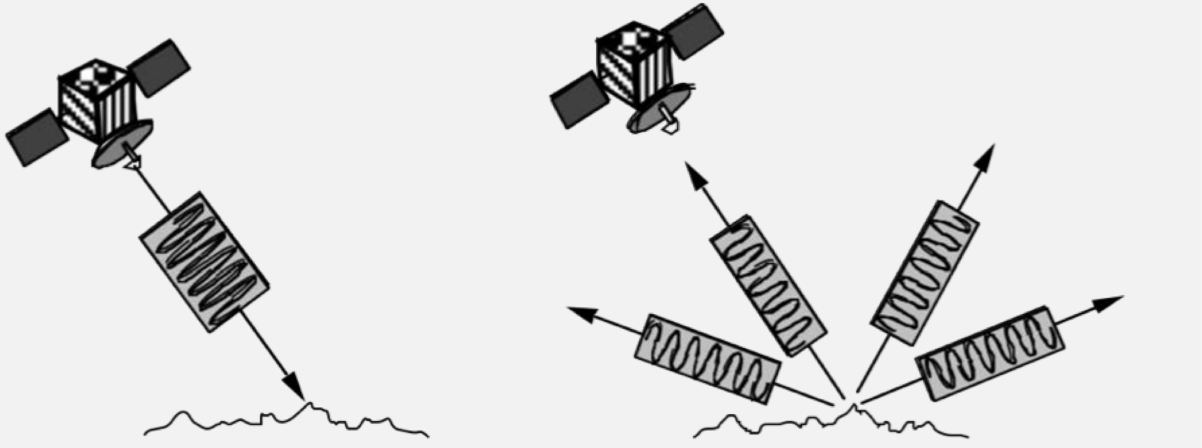
- Each pixel in the radar image represents a complex quantity of the energy that was reflected back to the satellite
- The magnitude of each pixel represents the intensity of the reflected echo



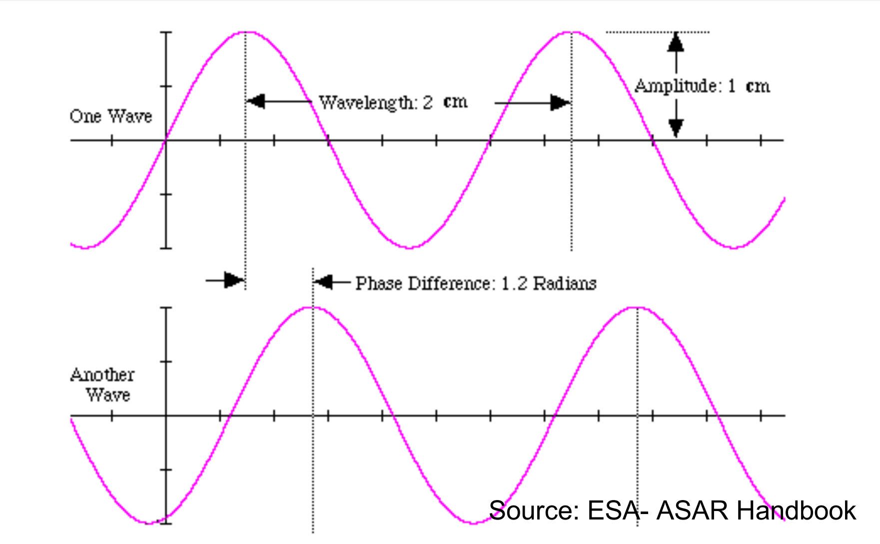
Credit: Paul Messina, CUNY NY, after Drury 1990, Lillesand and Kiefer, 1994

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. 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)



RADAR TRANSMITS A PULSE MEASURES REFLECTED ECHO (BACKSCATTER



Source: ESA- ASAR Handbook

Source: ESA- ASAR Handbook

Radar Parameters to Consider for a Study

1. Wavelength
2. Polarization
3. Incidence Angle

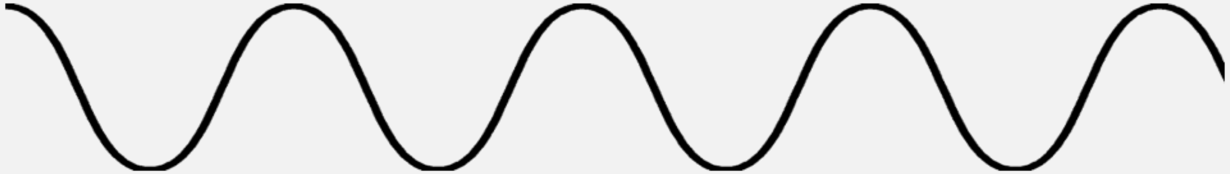
Radar Parameters: Wavelength

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

Higher Frequency

Shorter Wavelength

Lower Frequency

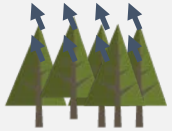
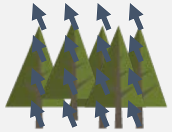
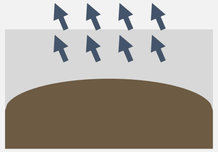
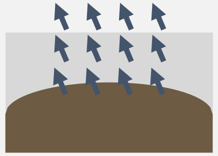
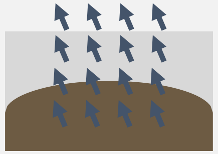


Longer Wavelength

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

*wavelengths most frequently used in SAR are in parenthesis

Penetration as a Function of Wavelength

Vegetation			
Dry Alluvium			
	X-band 3 cm	C-band 5 cm	L-band 23 cm

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

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

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

Example: Radar Signal Penetration into Dry Soils

- Different satellite images over southwest Libya
- The arrows indicate possible fluvial systems

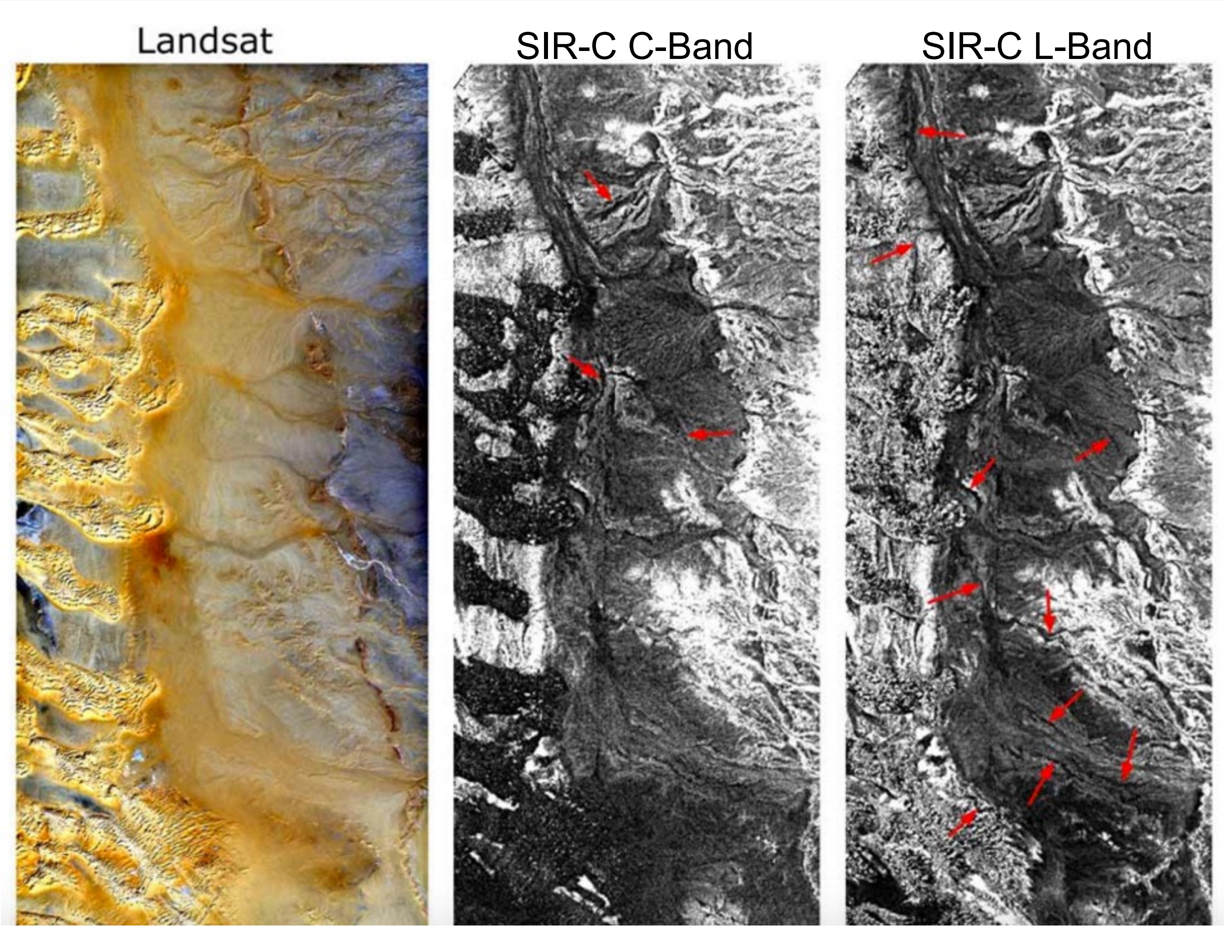
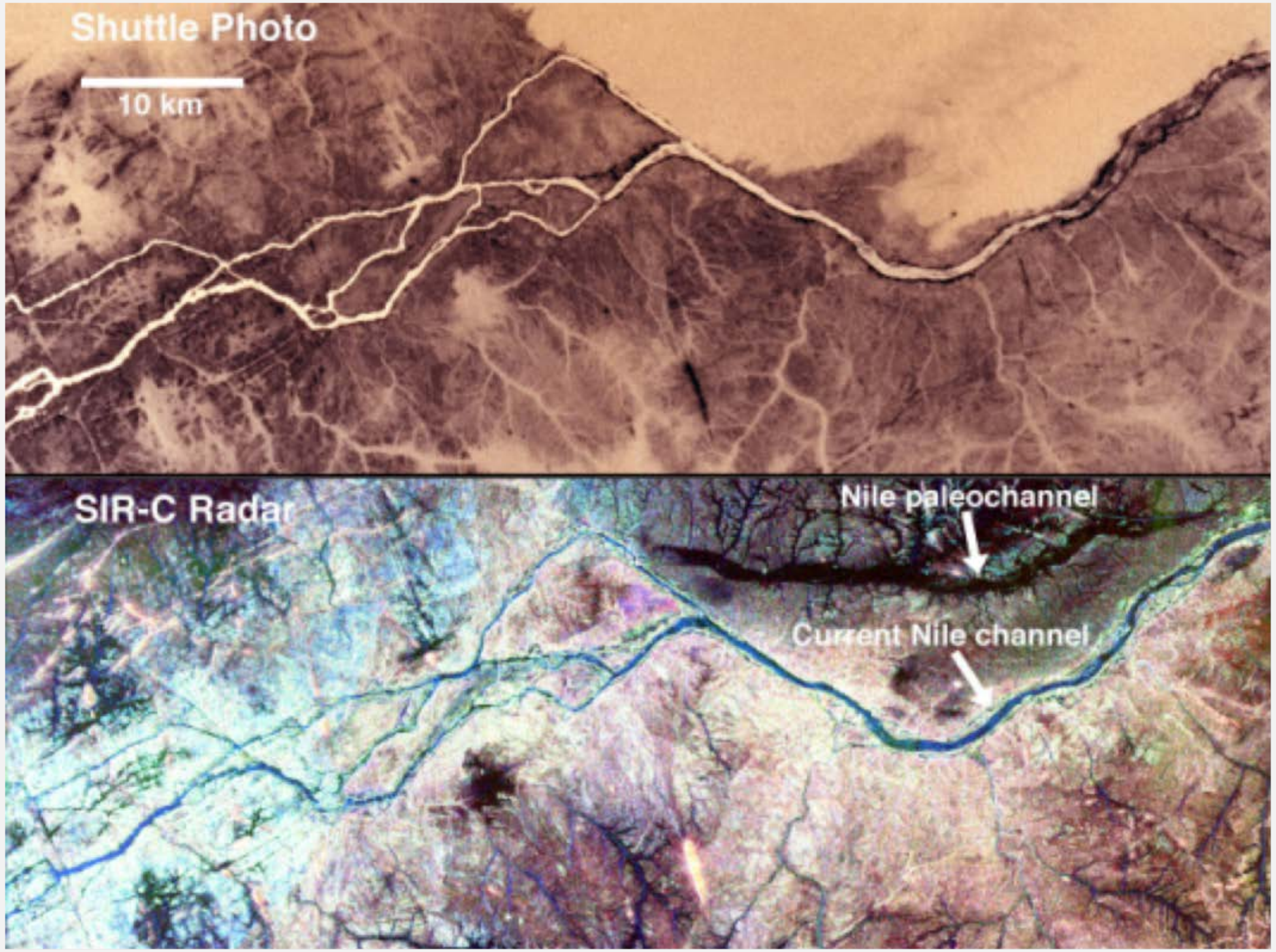


Image Credit: A Perego

Example: Radar Signal Penetration into Dry Soils



Example: Radar Signal Penetration into Vegetation

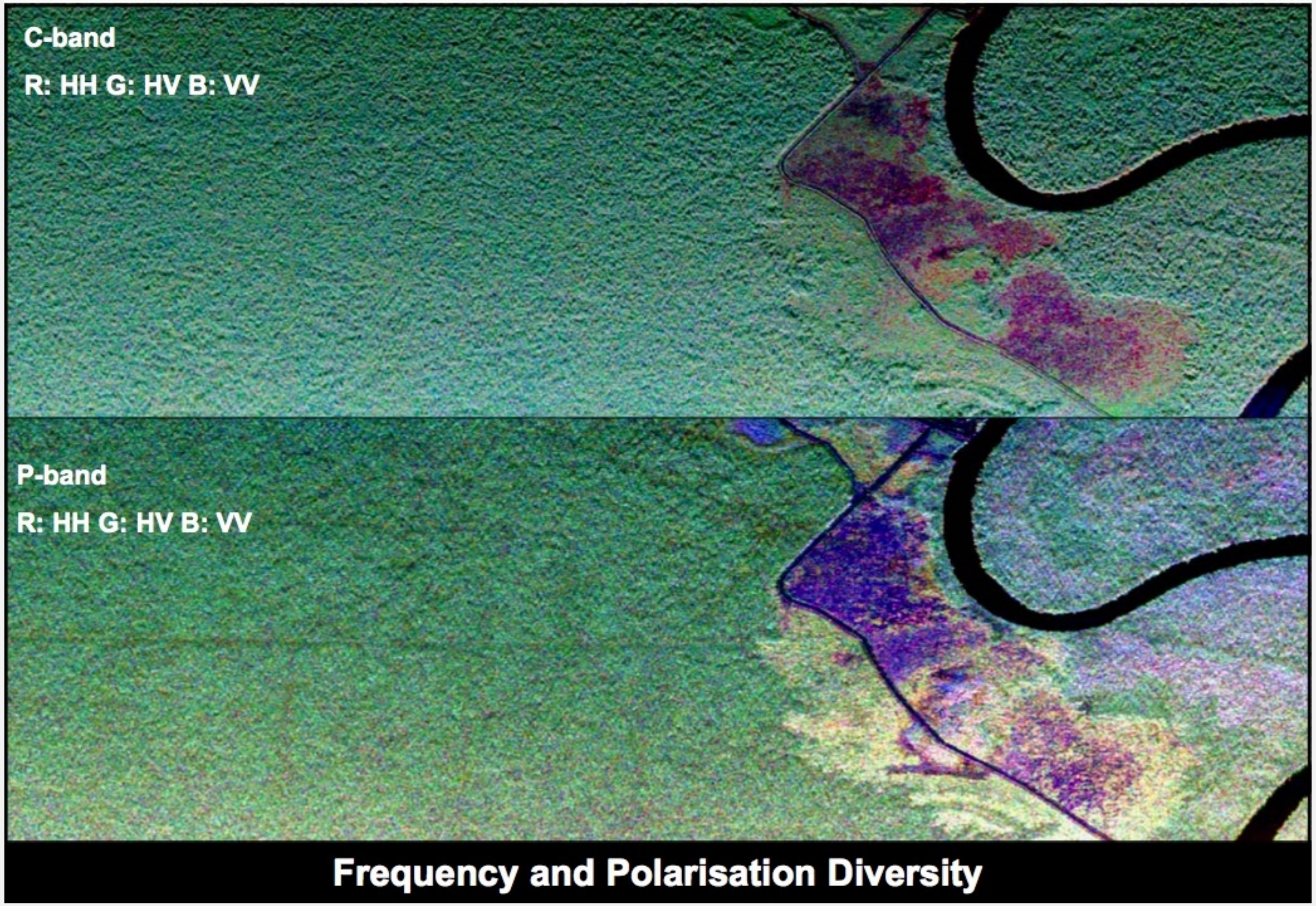
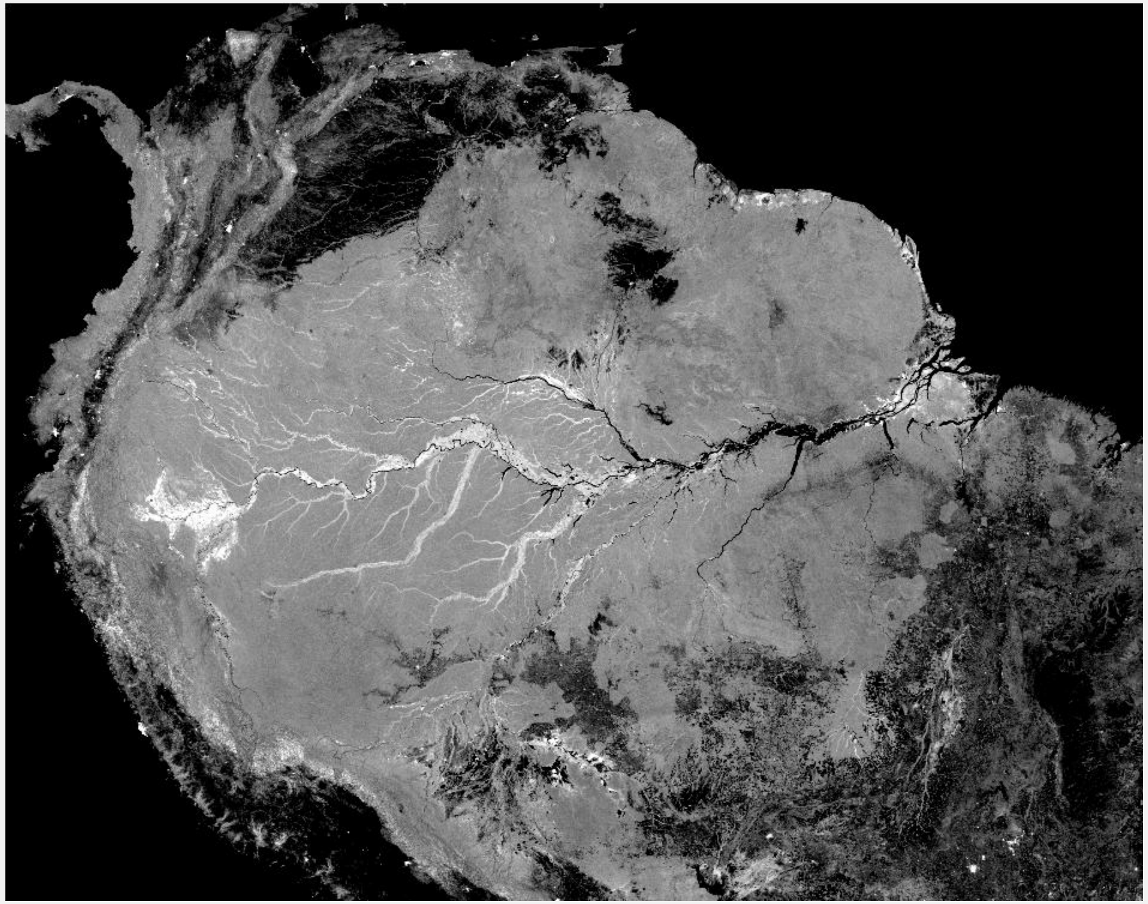


Image Credit: A. Moreira - ESA

Example: Radar Signal Penetration into Wetlands

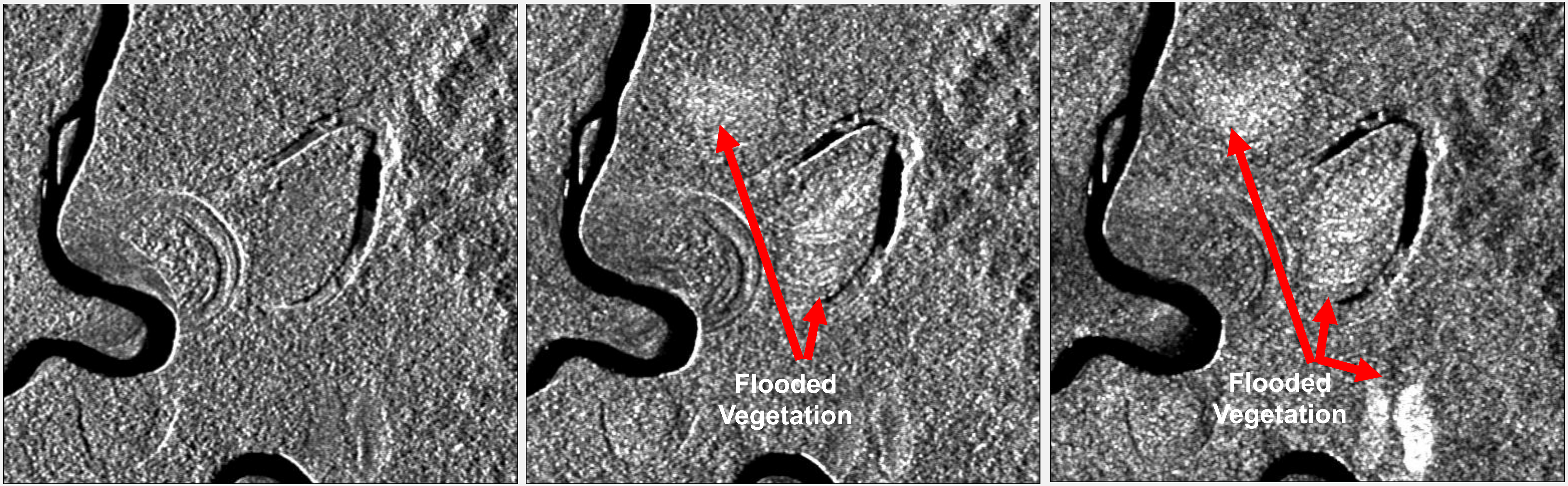
- L-band is ideal for the study of wetlands because the signal penetrates through the canopy and can sense if there is standing water underneath
- Inundated areas appear white in the image to the right

SMAP Radar Mosaic of the Amazon



Signal Penetration Over Flooded Vegetation

Multi-frequency 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

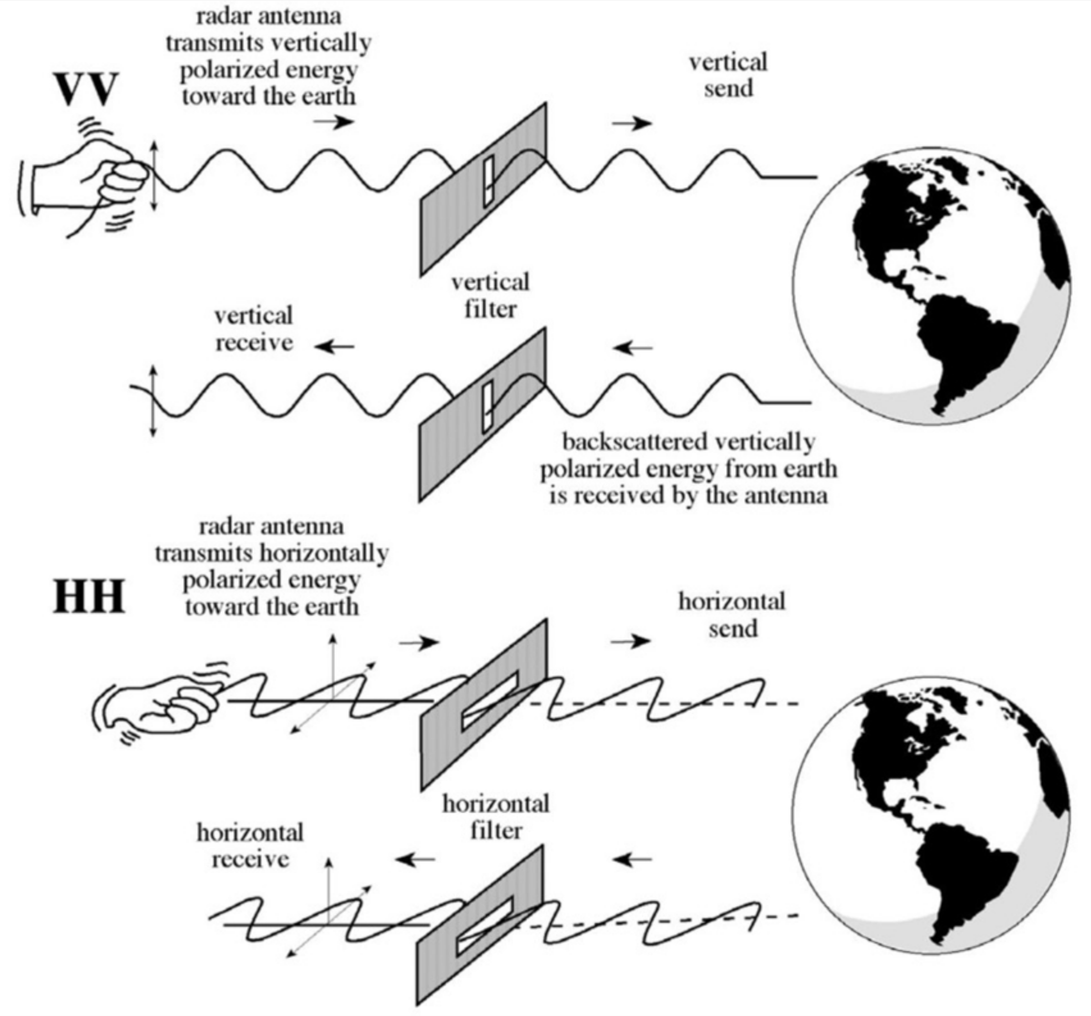
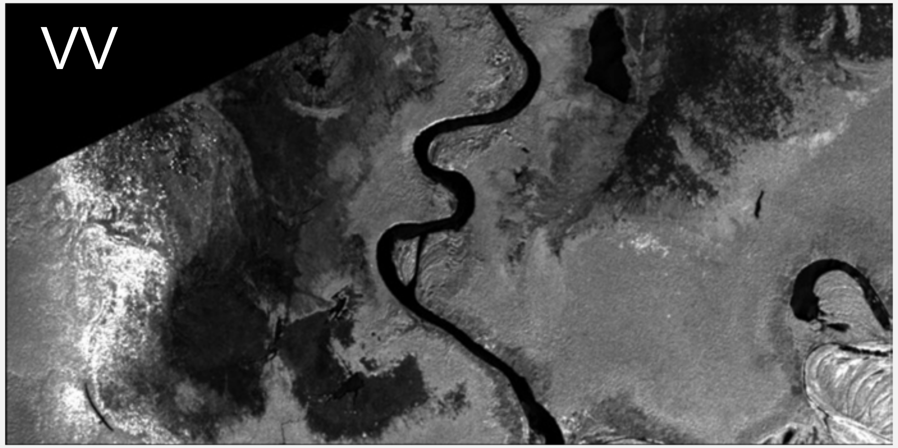


Image Credit: J.R. Jensen, 2000, Remote Sensing of the Environment

Example of Multiple Polarizations for Vegetation Studies

Pacaya-Samiria Forest Reserve in Peru

Images from UAVSAR (HH, HV, VV)



Example of Multiple Polarization for Vegetation Studies

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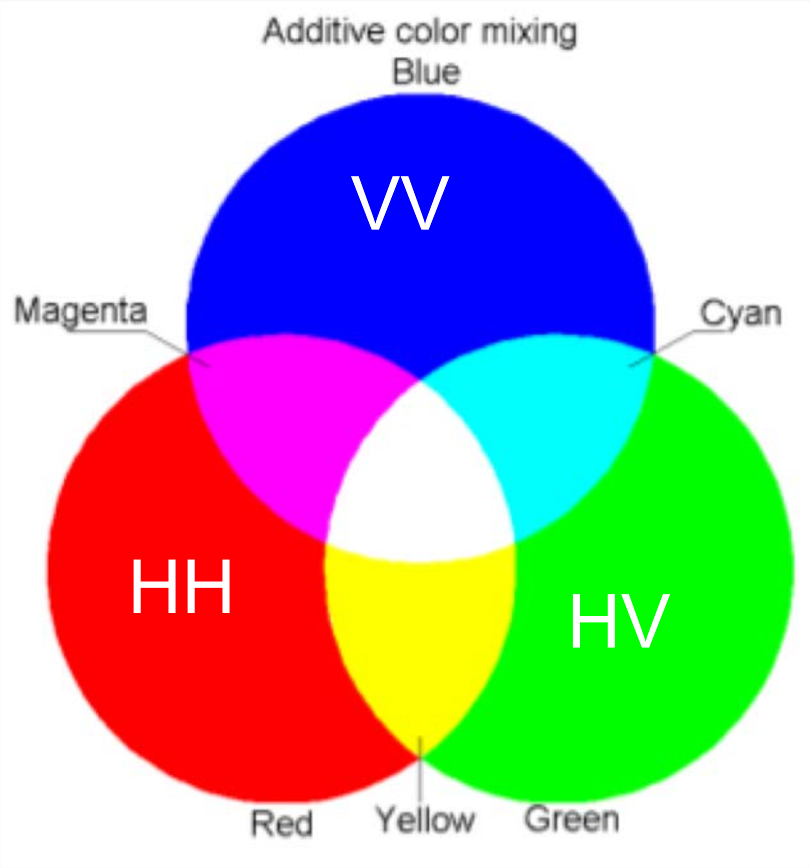
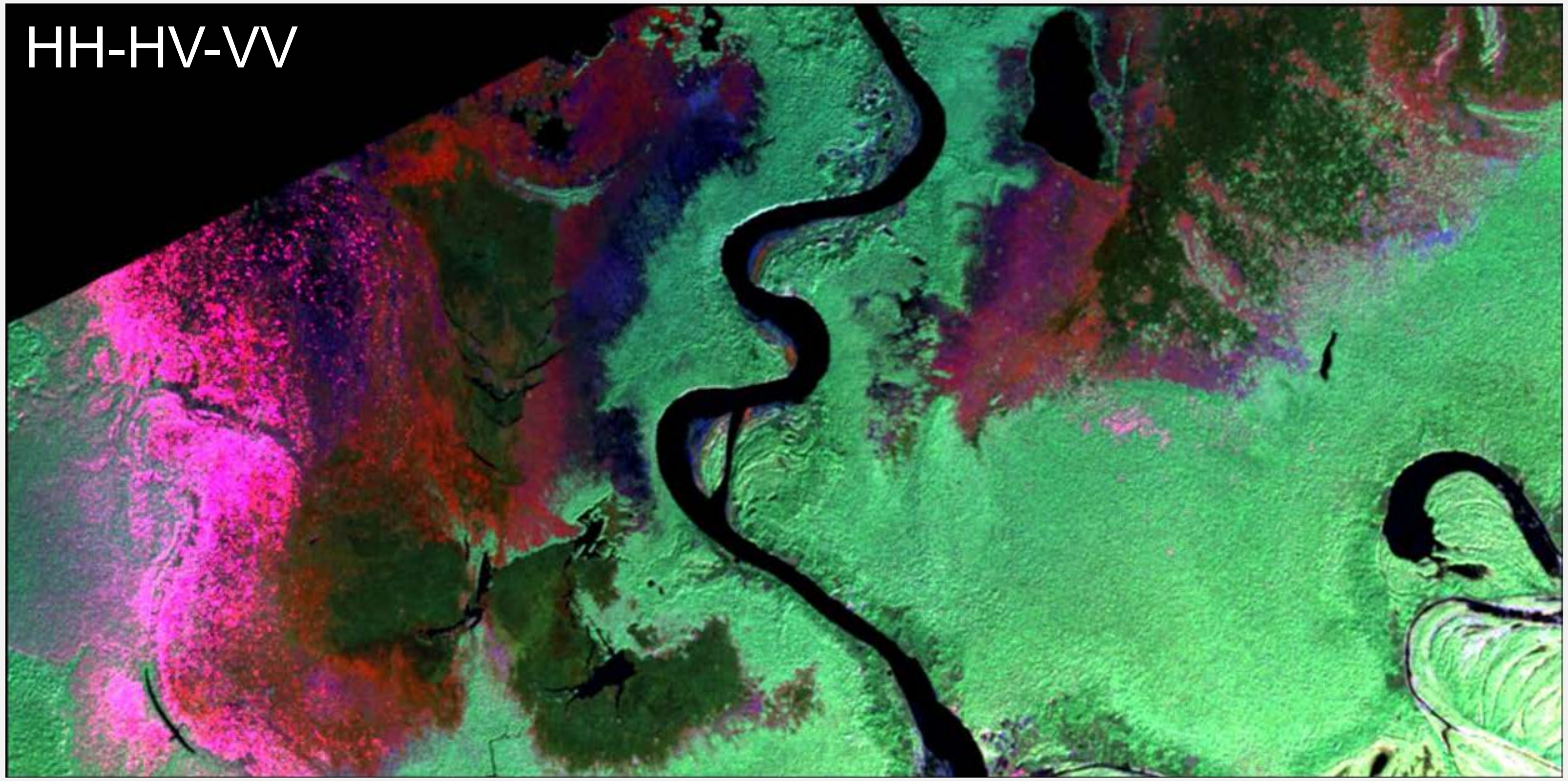
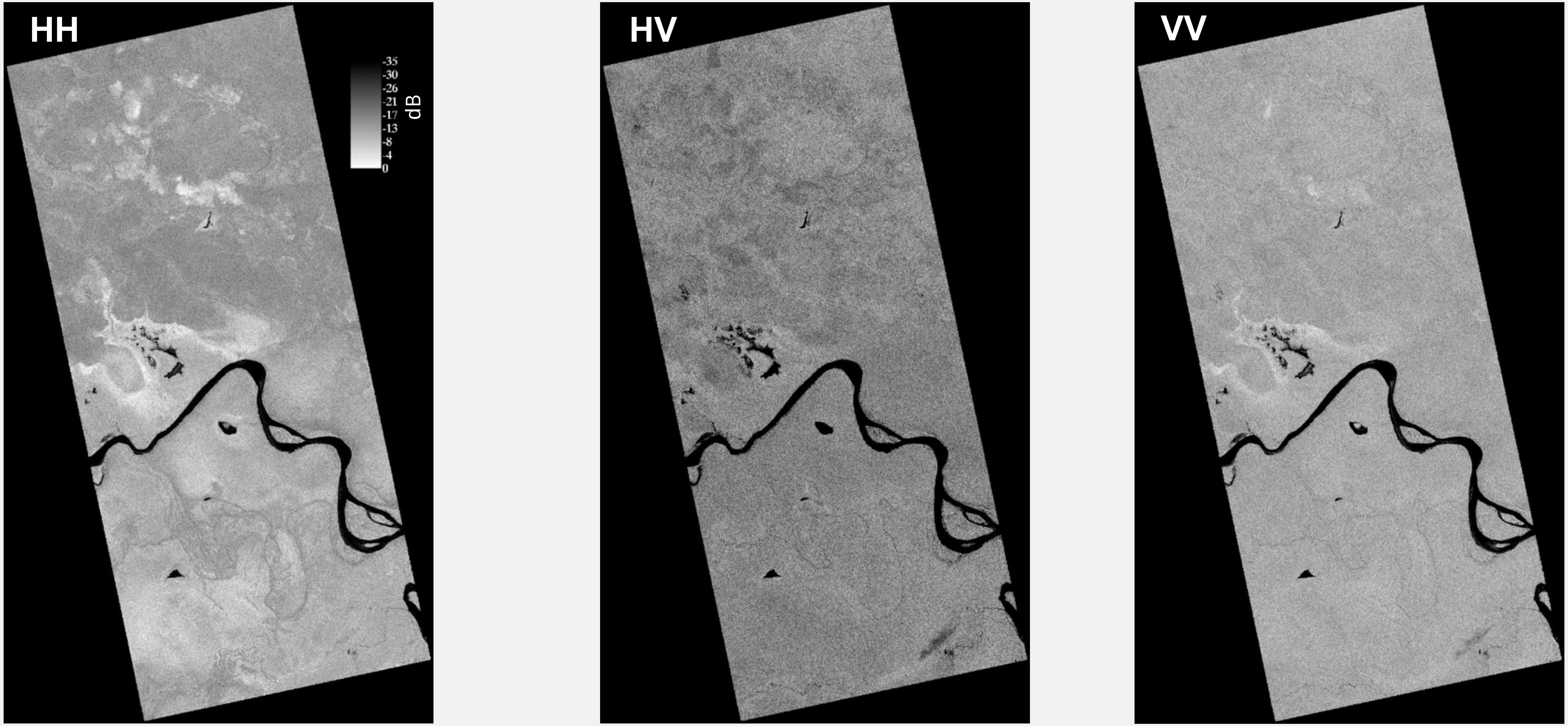




Multiple Polarizations for Detection of Inundated Vegetation

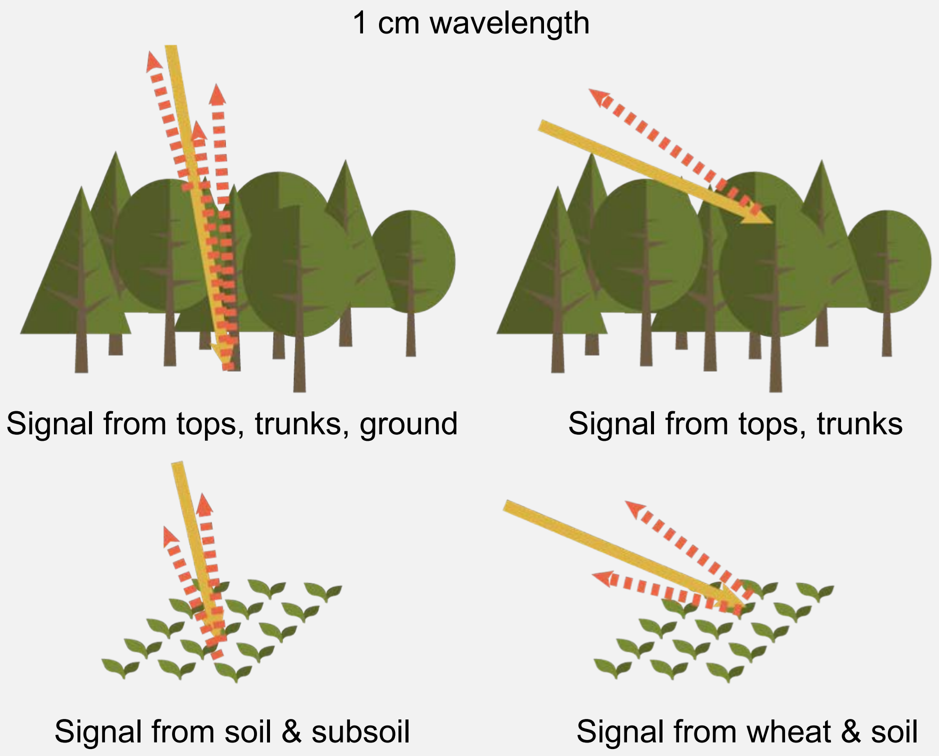
Images from Palsar (L-band) over Pacaya-Samiria in Peru

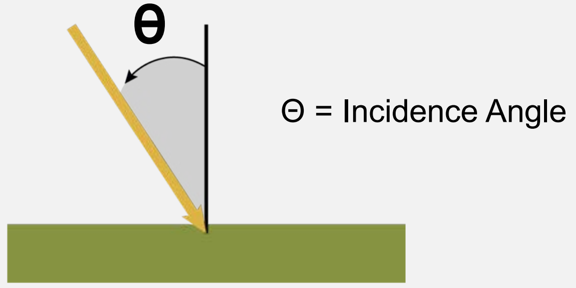


Radar Parameters: Incidence Angle

Local Incidence Angle:

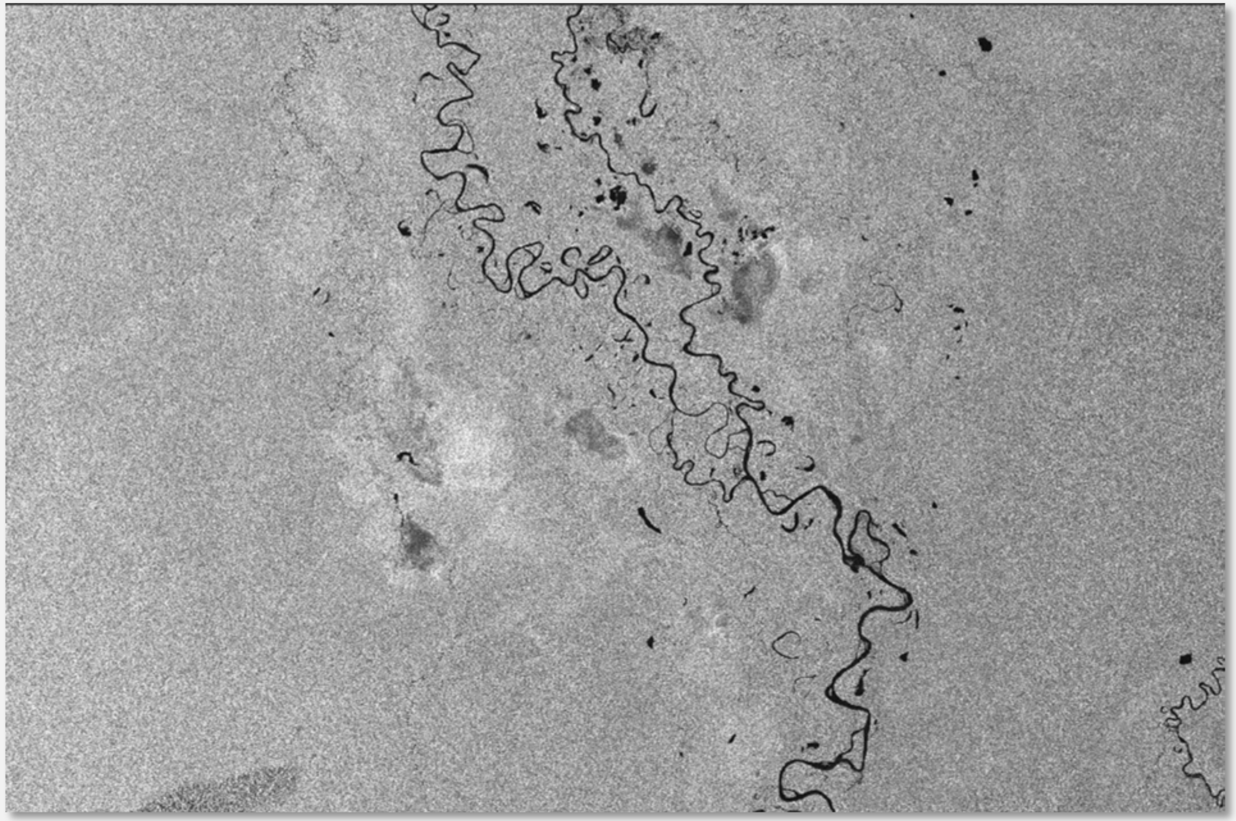
- The angle between the direction of illumination of the radar and the Earth’s surface plane
- accounts for local inclination of the surface
- influences image brightness
- is dependent on the height of the sensor
- the geometry of an image is different from point to point in the range direction



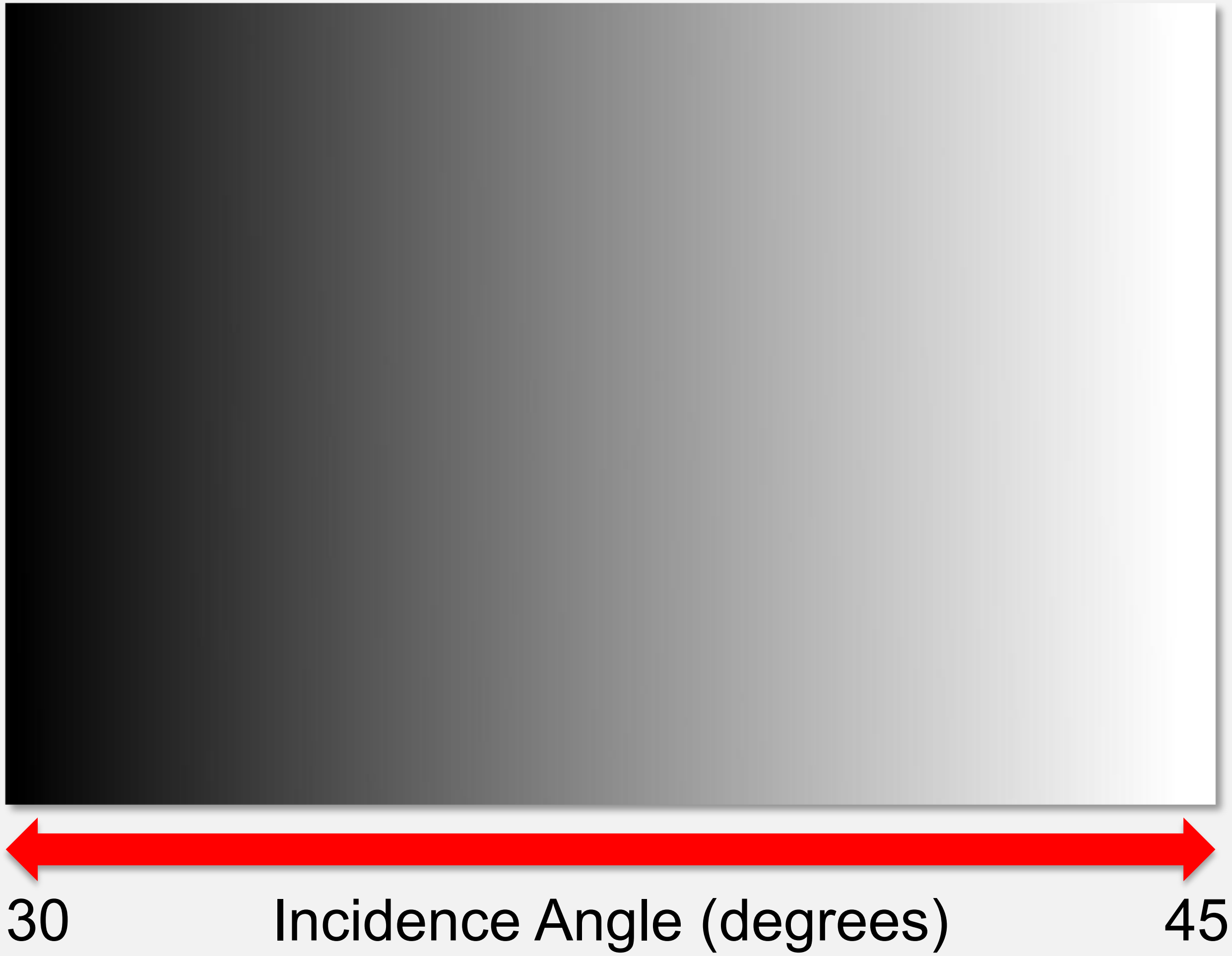


Images based on: top: Ulaby et al. (1981a), bottom: ESA

Effect of Incidence Angle Variation



Sentinel-1



Questions

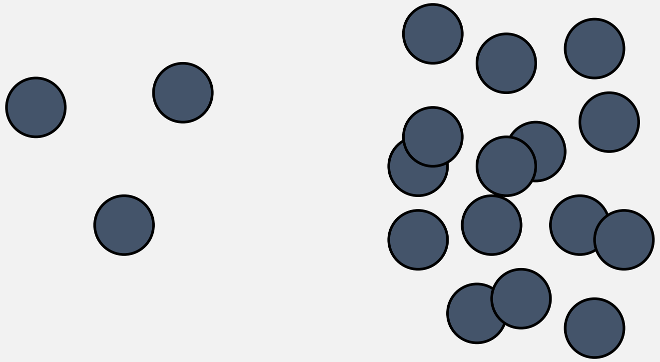
1. What are three main radar parameters that need to be considered for a specific study?
2. What is the relationship between wavelength and penetration?
3. What’s the usefulness of having different polarizations?
4. What’s the effect of varying incidence angles?

Surface Parameters that Influence the Radar Signal

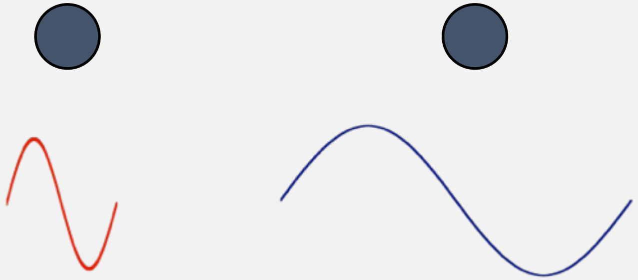
1. Structure
2. Dielectric

Surface Parameters Related to Structure

Density



Size Relative to Wavelength



Size & Orientation

Size in Relation to Wavelength

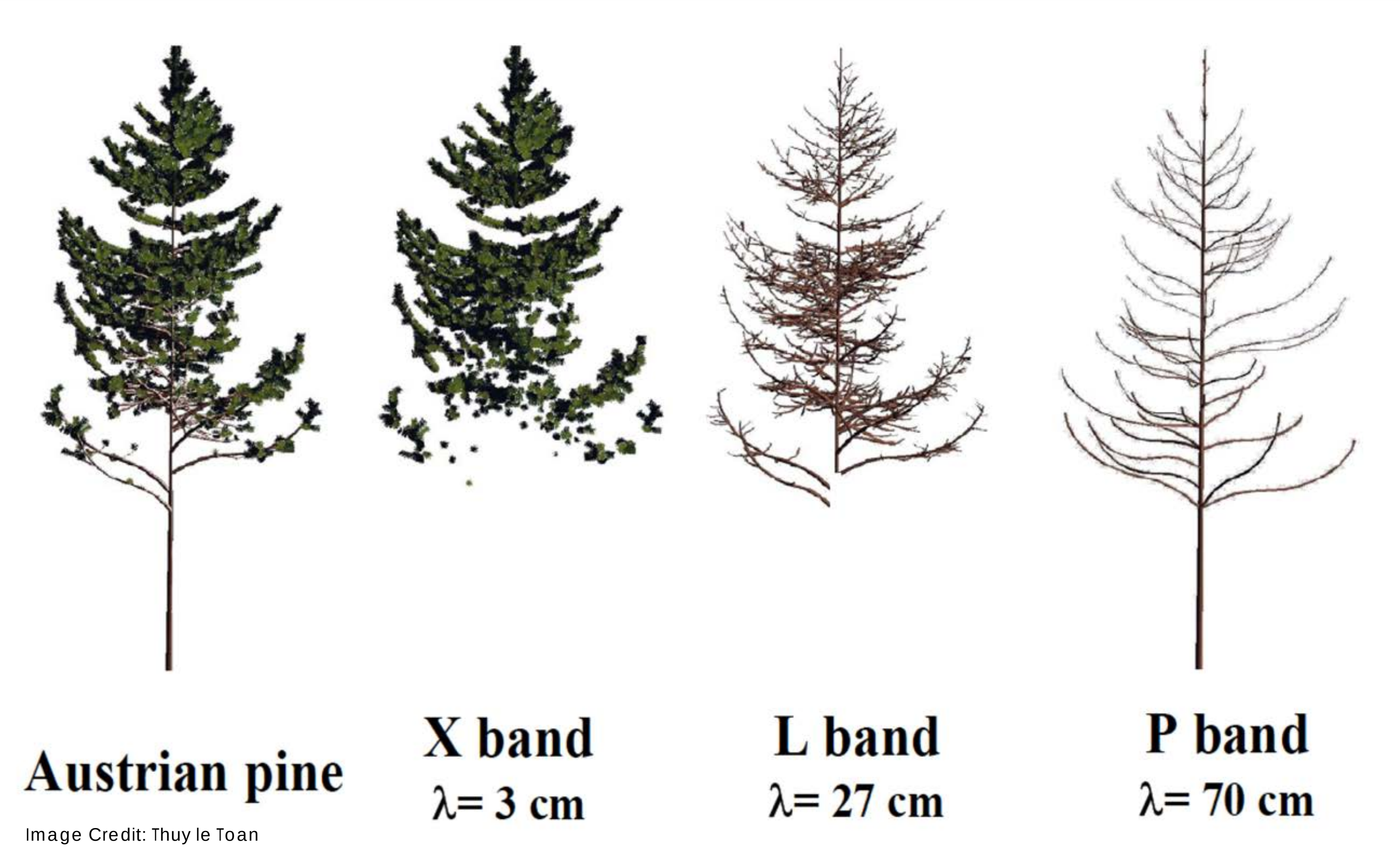
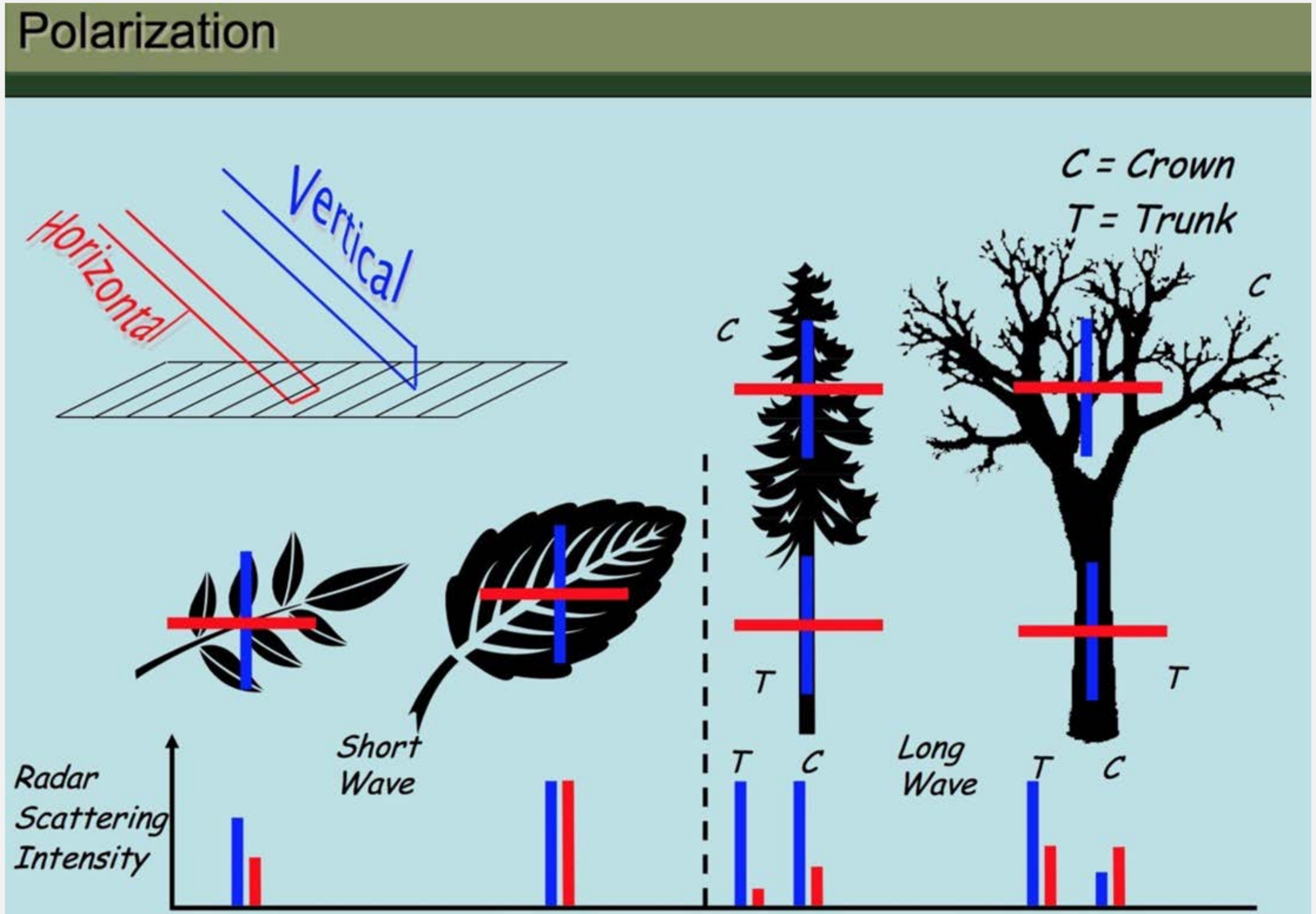


Image Credit: Thuy le Toan

Size and Orientation



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

Density

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

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

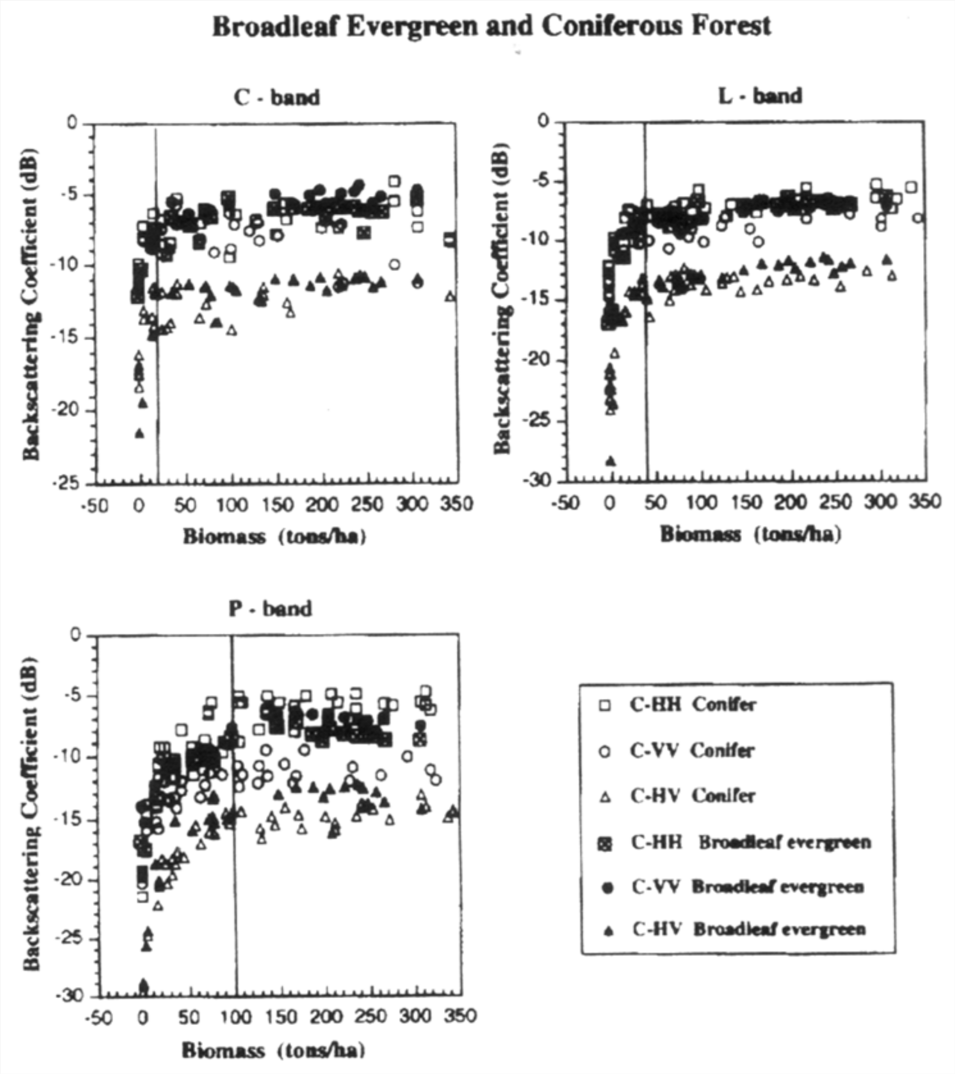
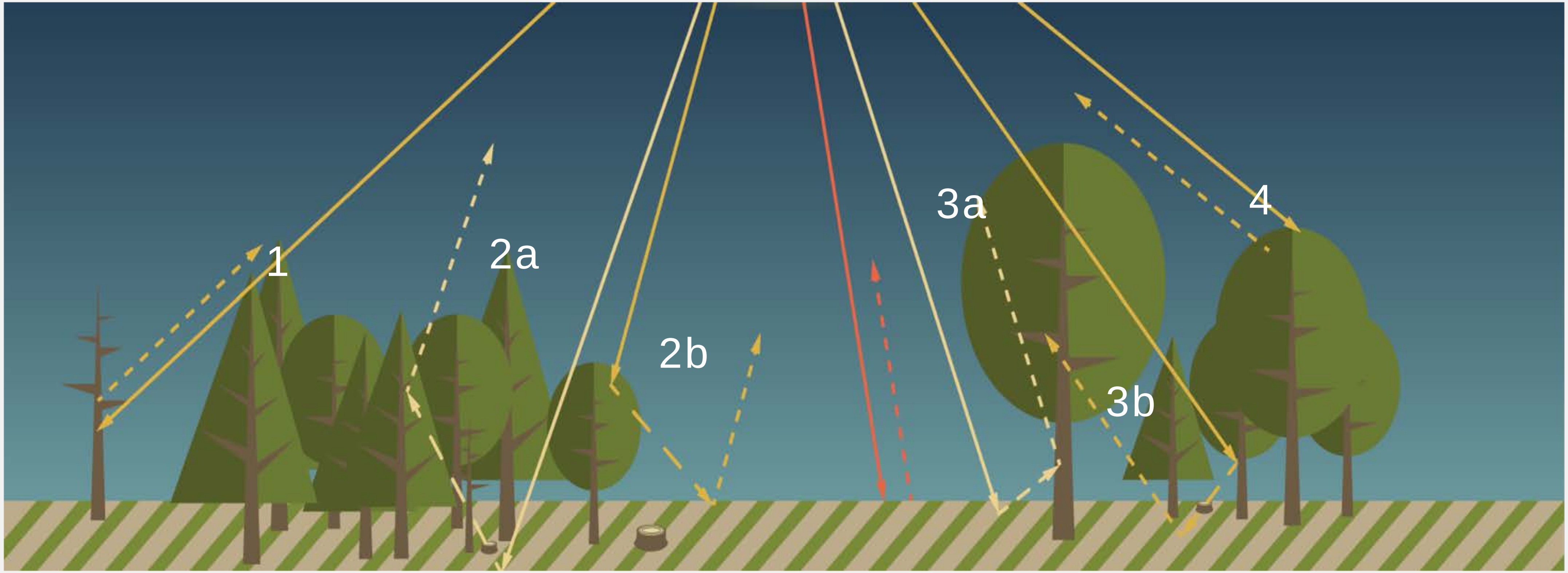


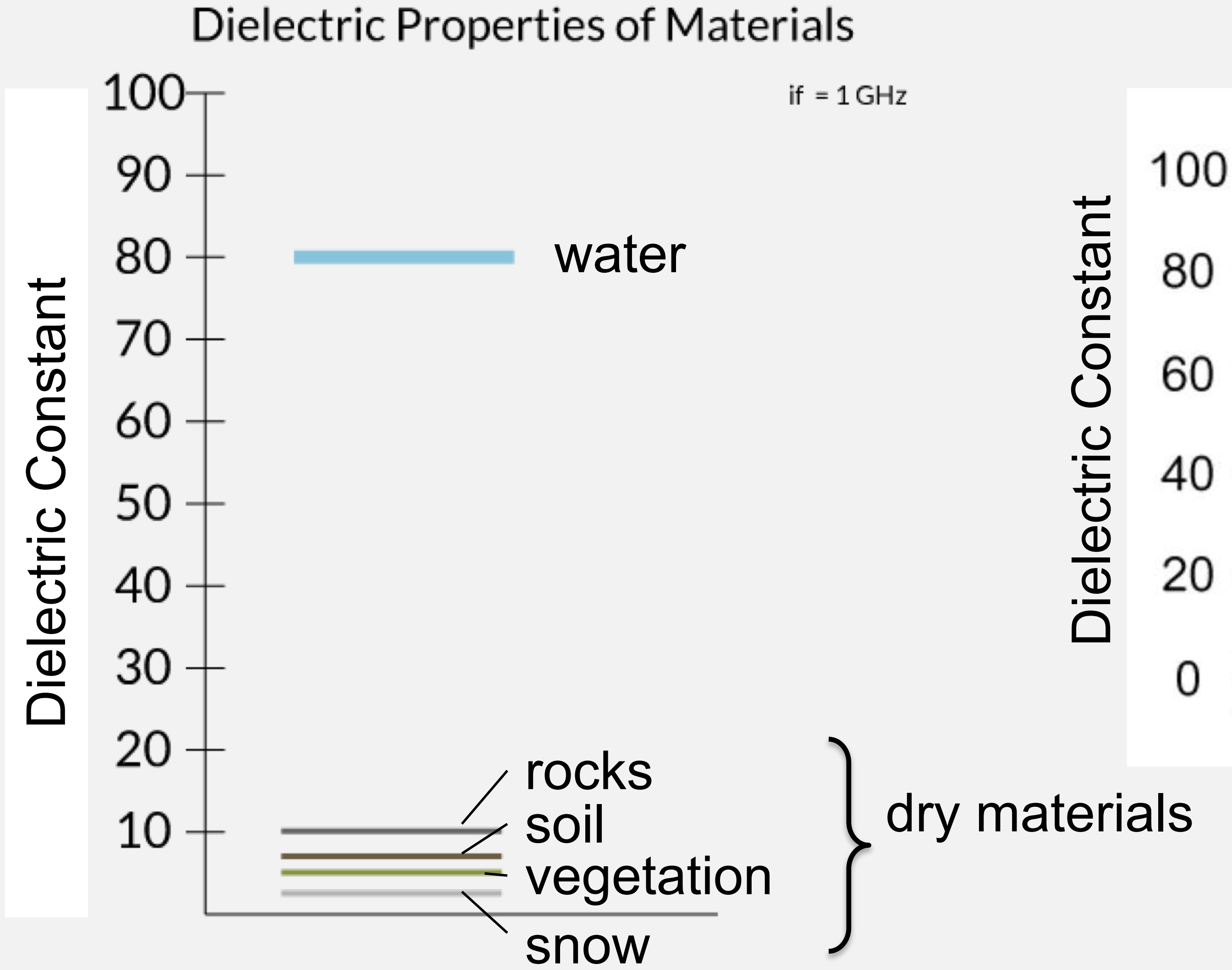
Image Source: Imhoff, 1995:514)

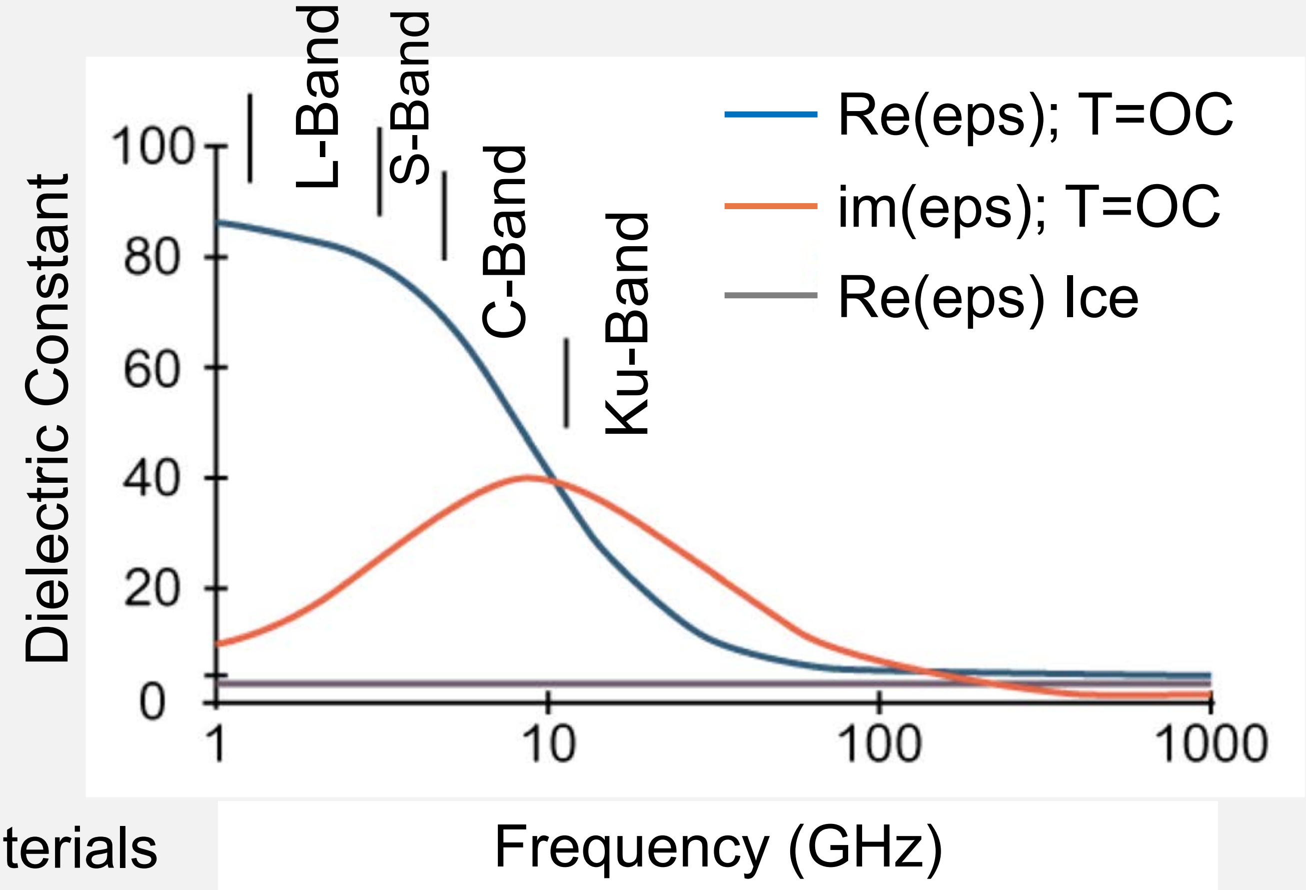
Radar Backscattering in Forests



Dominant backscattering sources in forests: (1) direct scattering from tree trunks, (2a) ground-crown scattering, (2b) crown-ground scattering, (3a) ground-trunk scattering, (3b) trunk-ground scattering, (4) crown volume scattering

Surface Parameters: Dielectric Constant

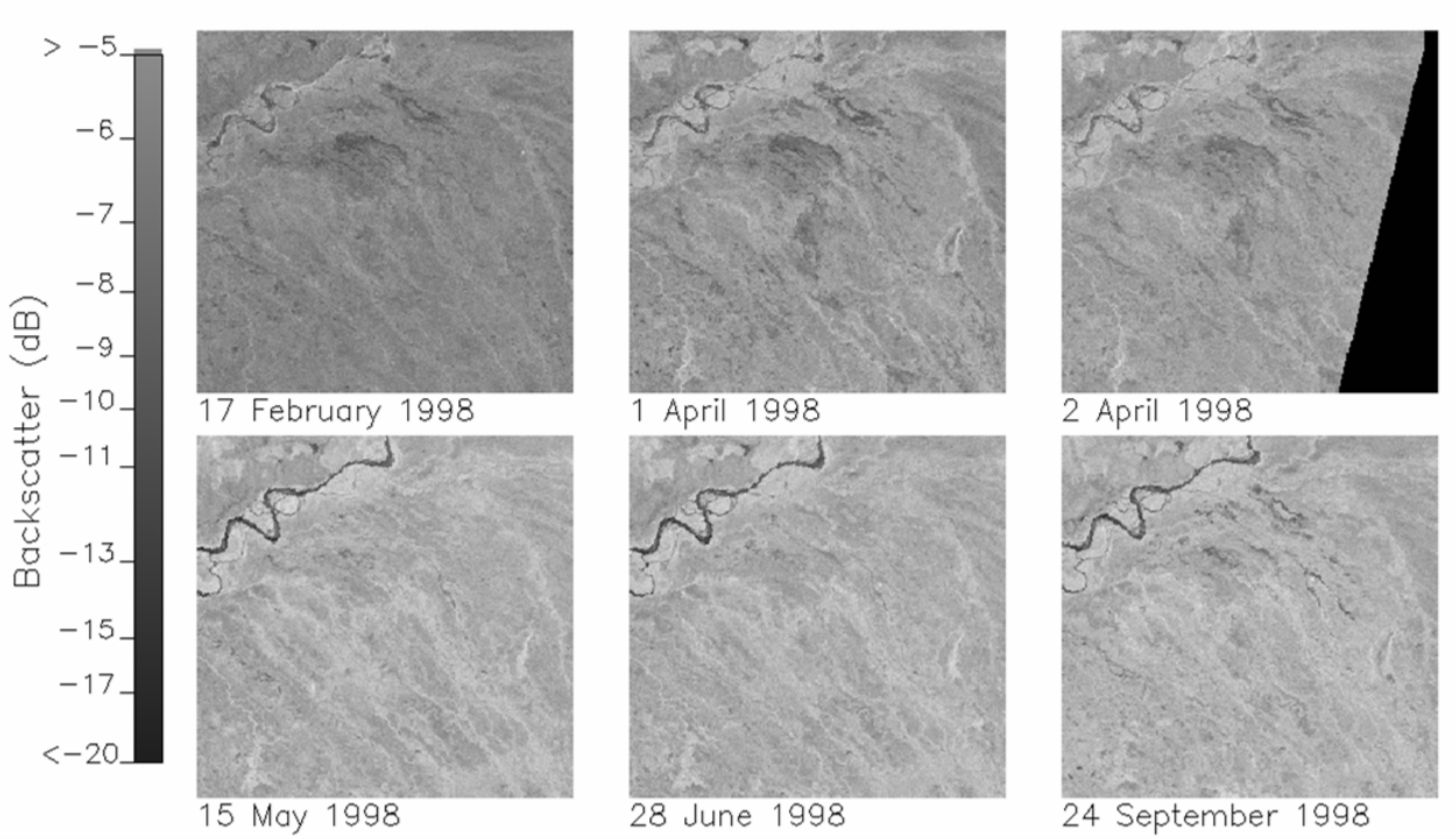


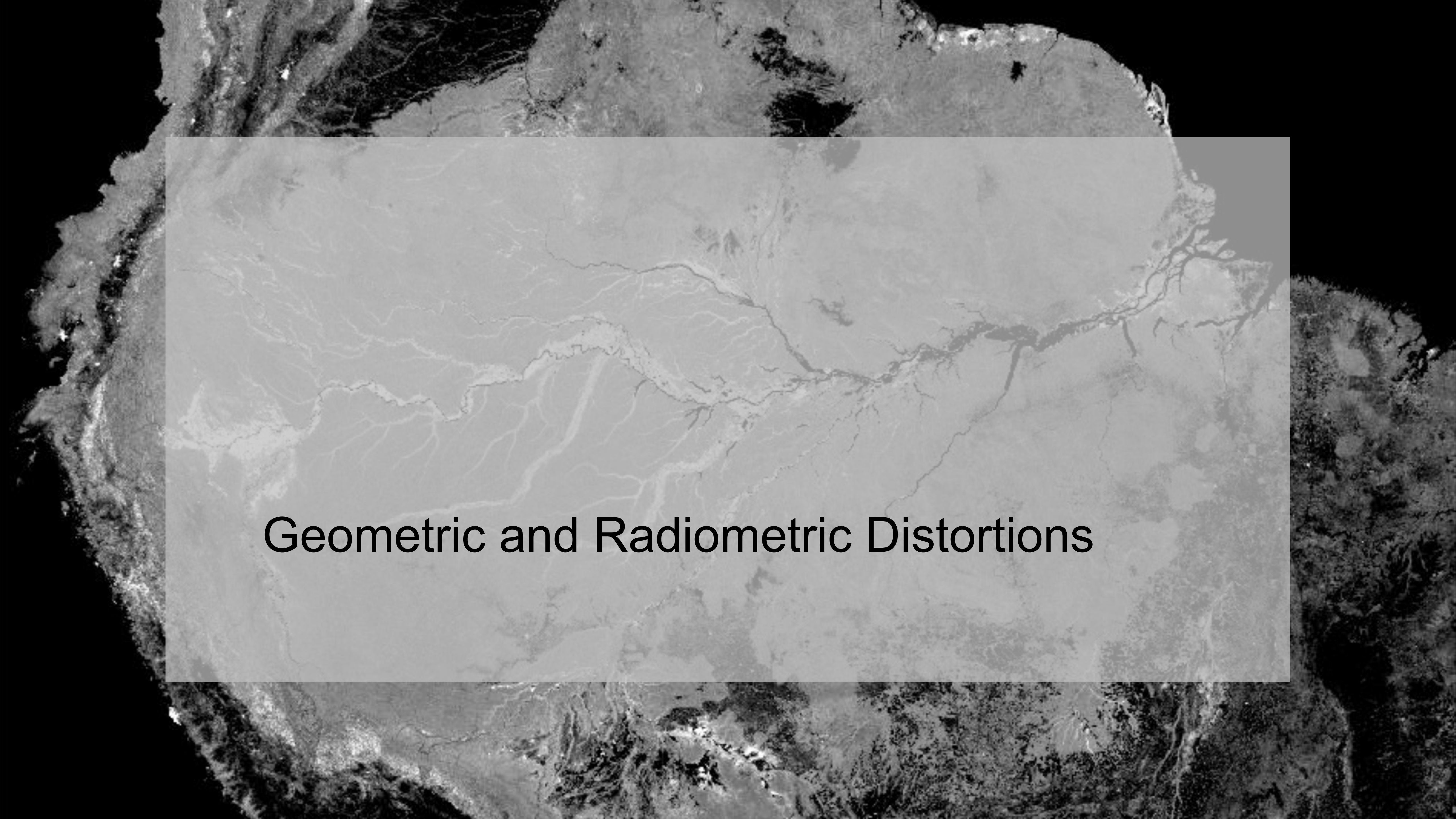


Dielectric Properties of the Surface

Bonanza Creek, near Fairbanks, Alaska - JERS-1 L-band, 100m, HH

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





Geometric and Radiometric Distortions

Slant Range Distortion

Slant Range

Ground Range

Source: Natural Resources Canada

Geometric Distortion

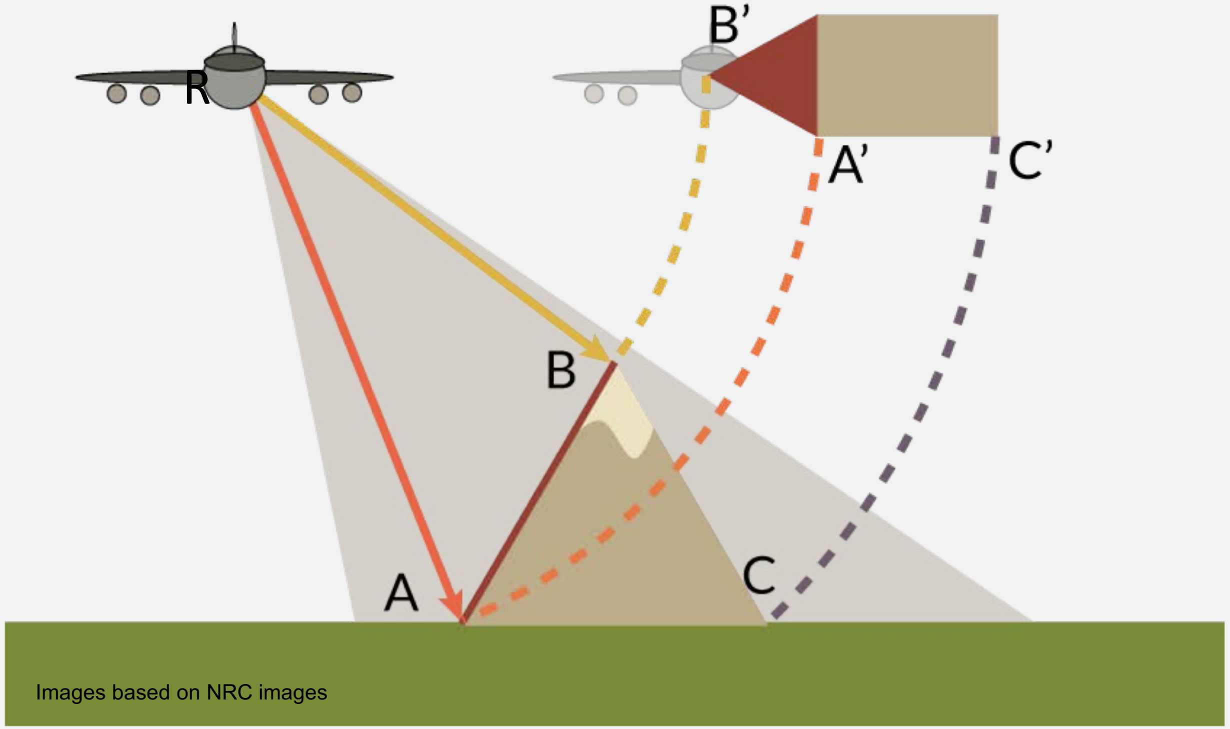
Layover

$AB = BC$

$A'B' < B'C'$

$RA > RB$

$RA' > RB'$



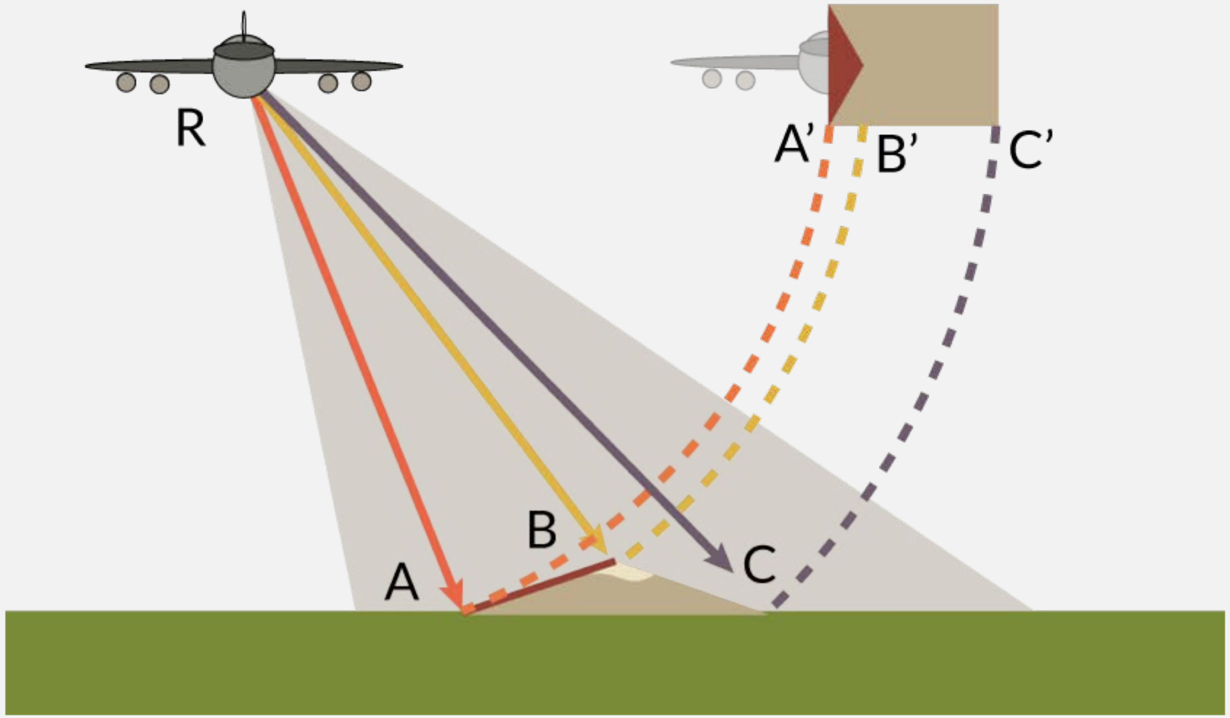
Images based on NRC images

Foreshortening

$RA < RB < RC$

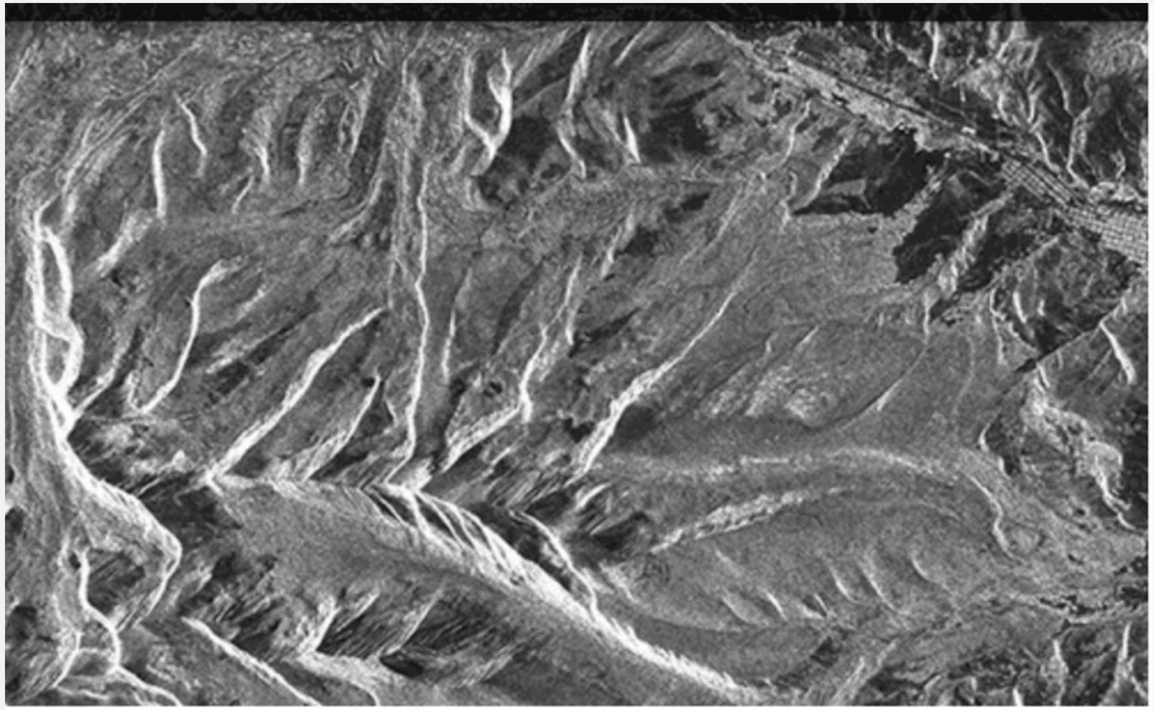
$AB = BC$

$A'B' < B'C'$

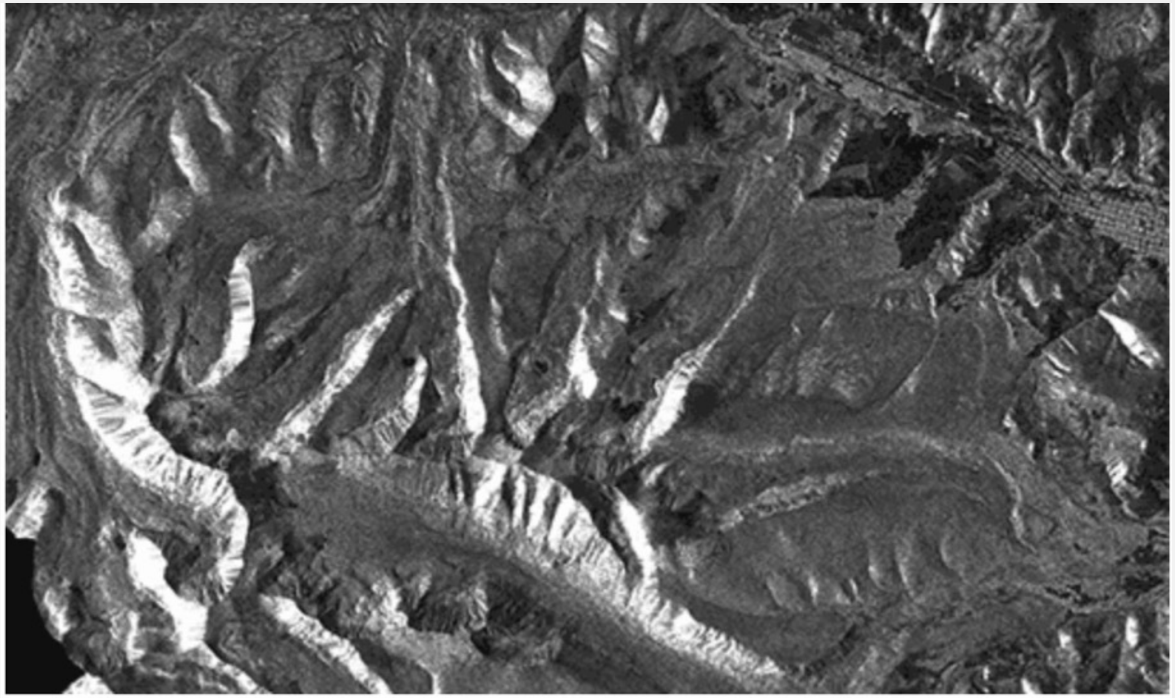


Foreshortening

Before Correction



After Correction



Source: ASF

Shadow

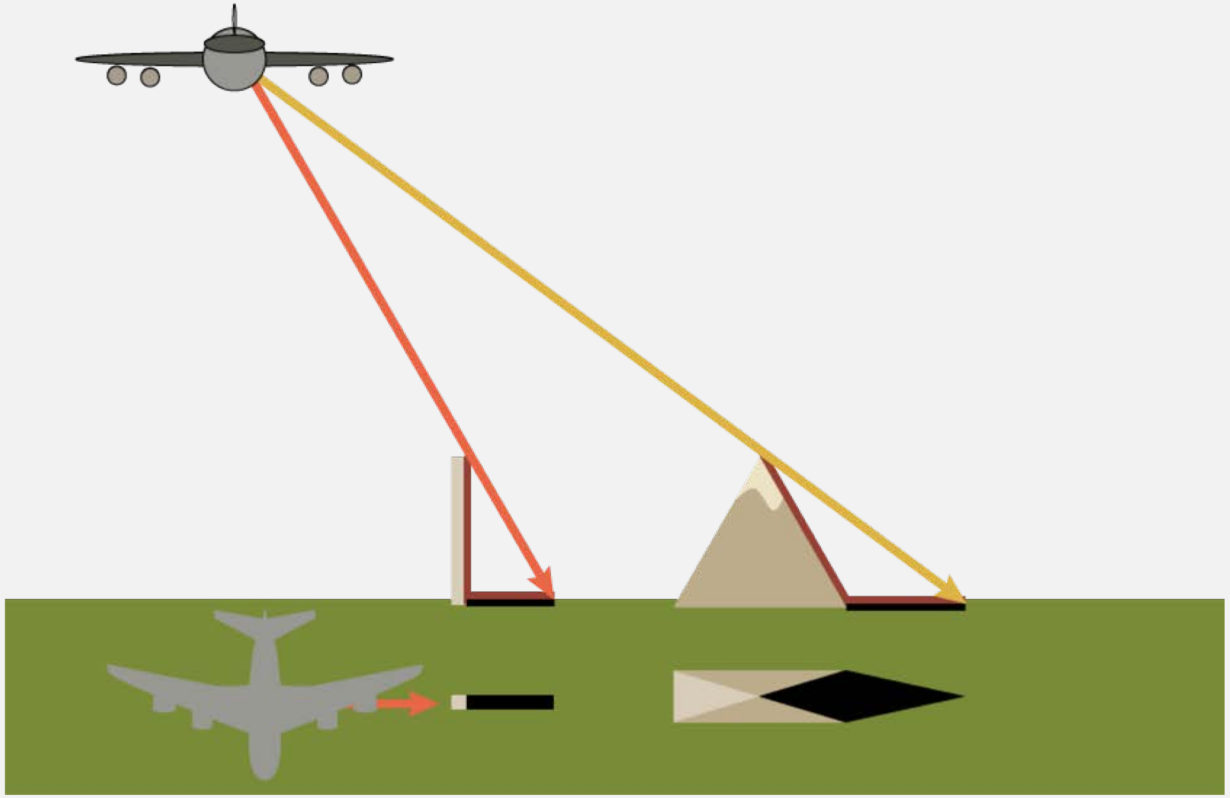
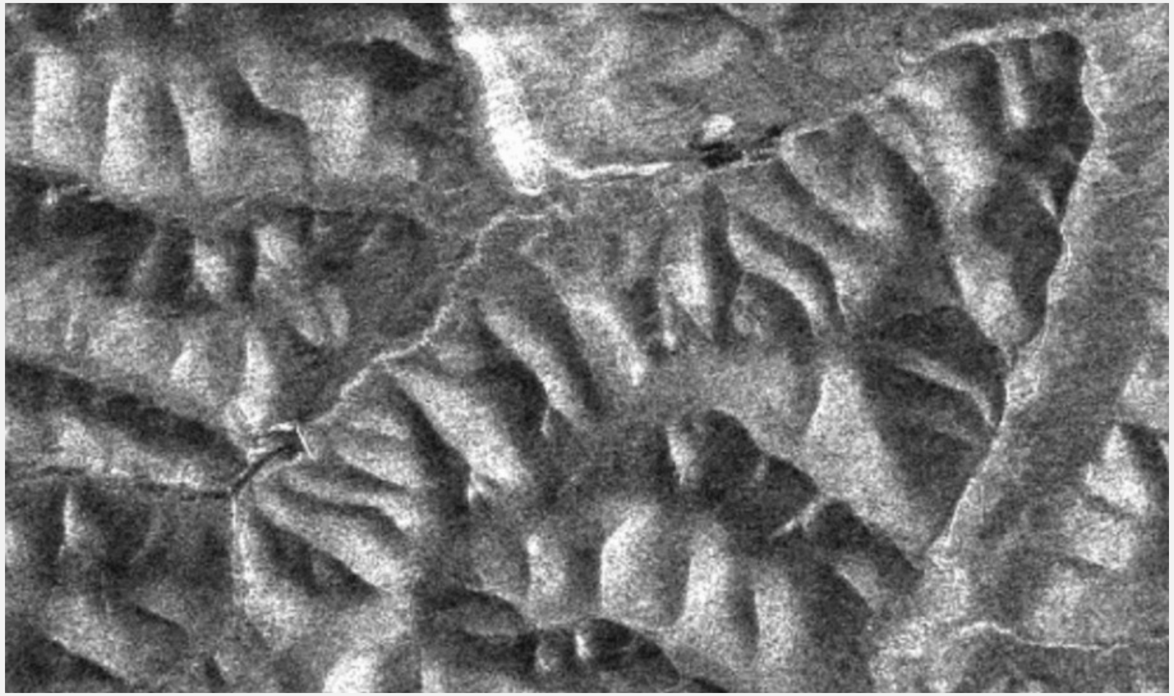


Image (left) based on NRC

Radiometric Distortion

- The user must correct for the influence of topography on backscatter
- This correction eliminates high values in areas of complex topography

Before Correction



After Correction

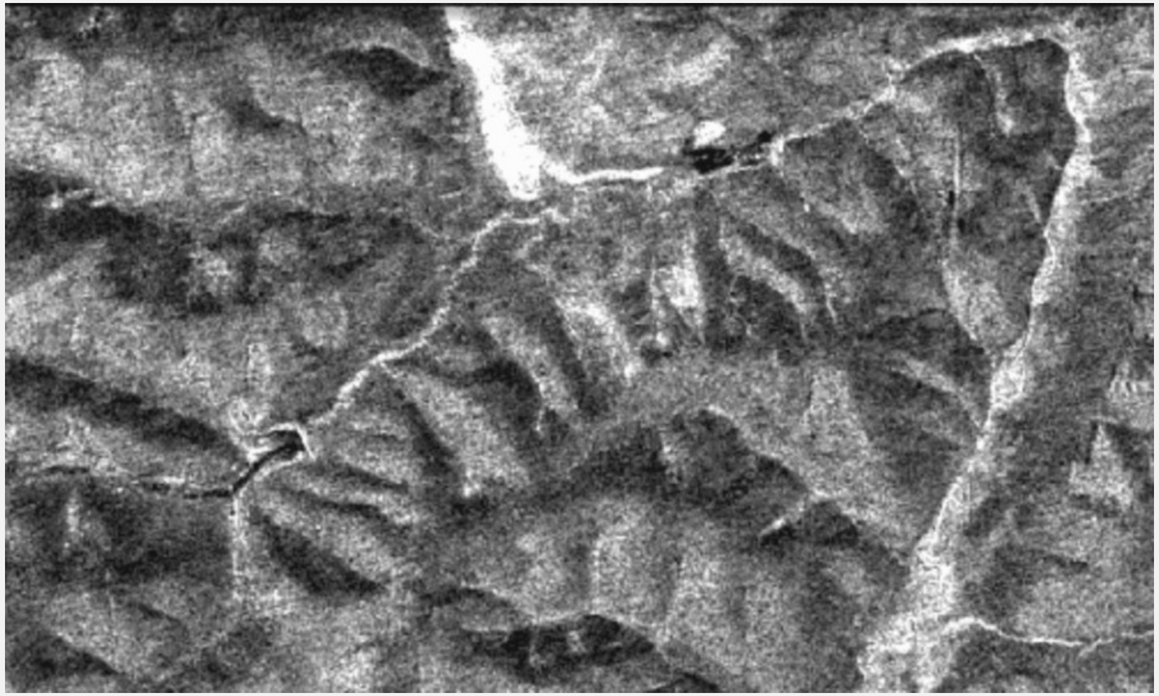
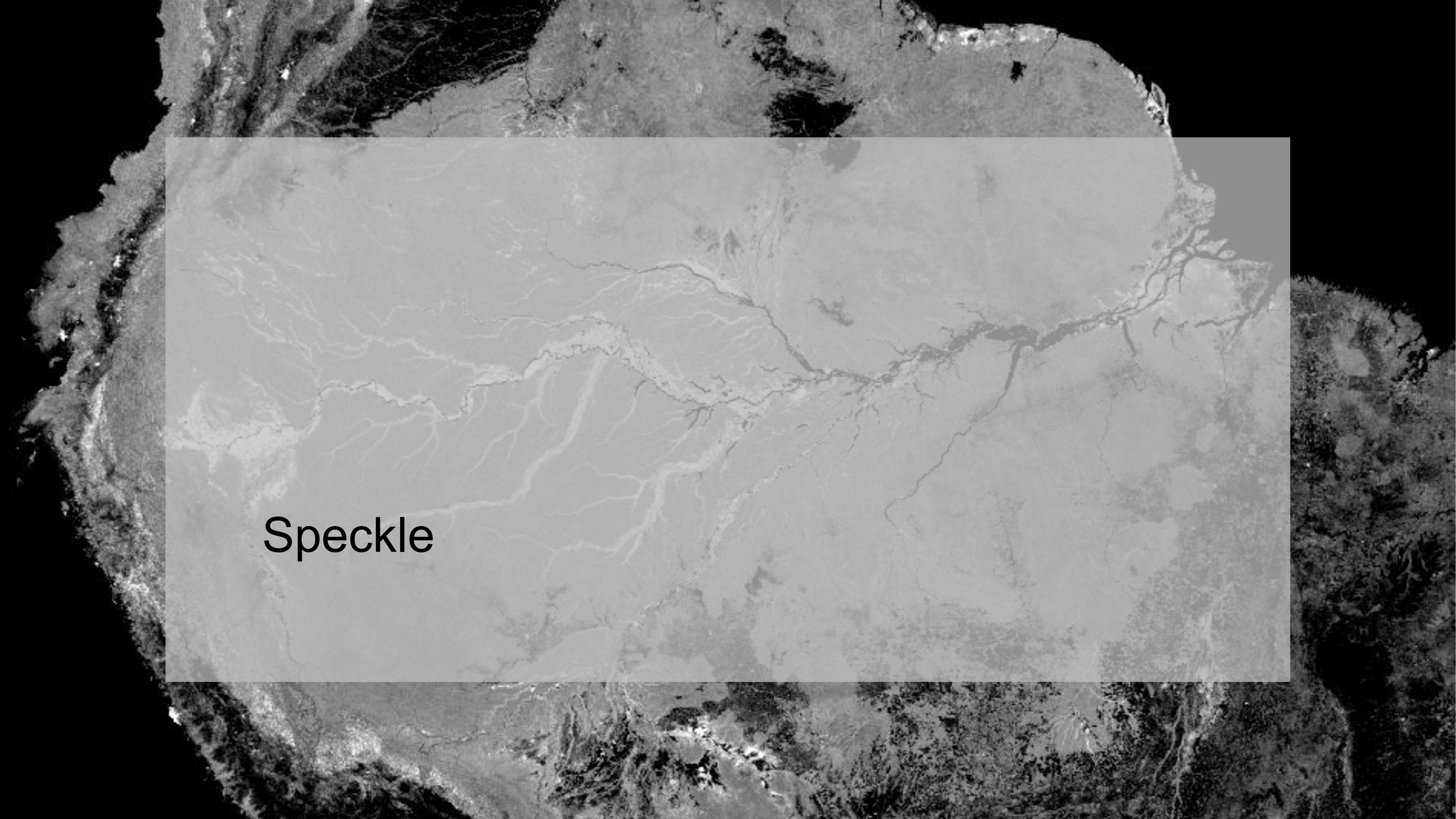


Image Credits: ASF



Speckle

Speckle

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

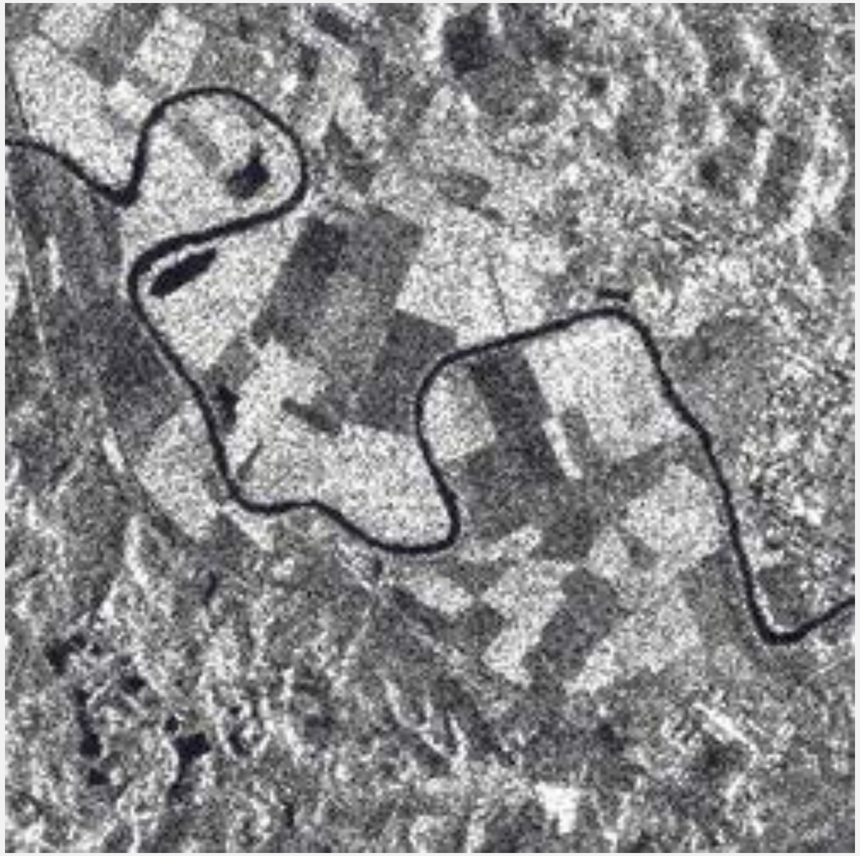
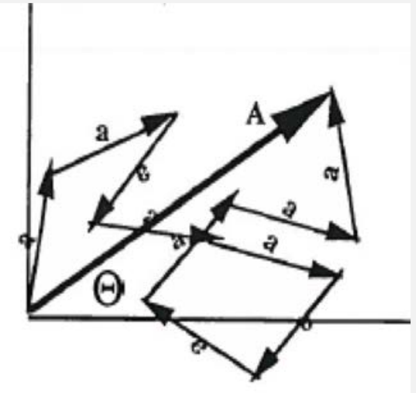
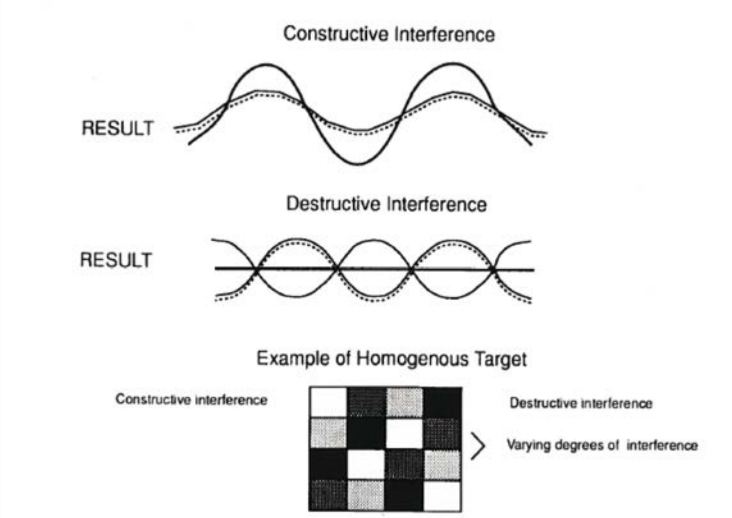


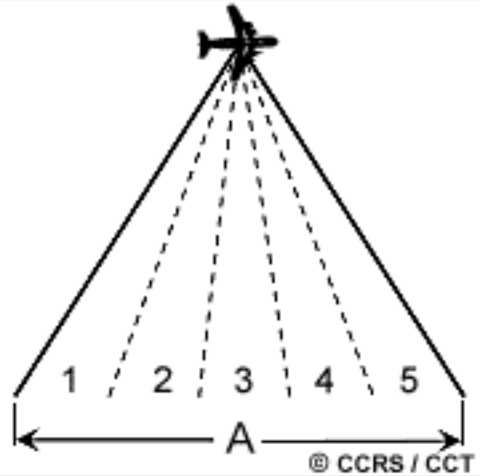
Image Credit: ESA

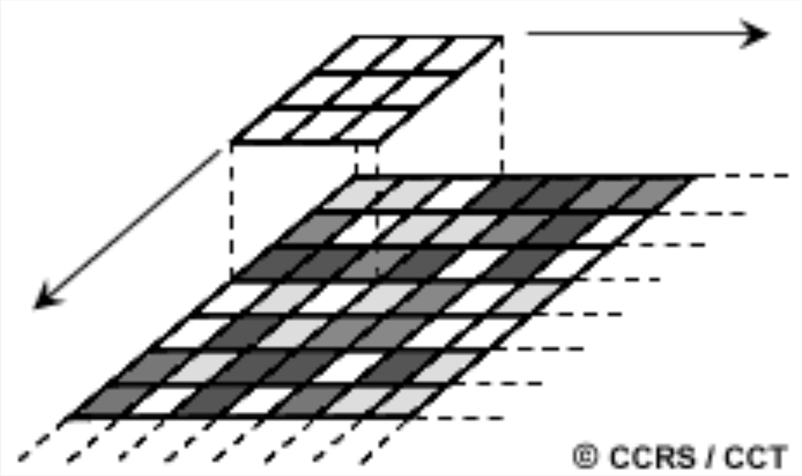




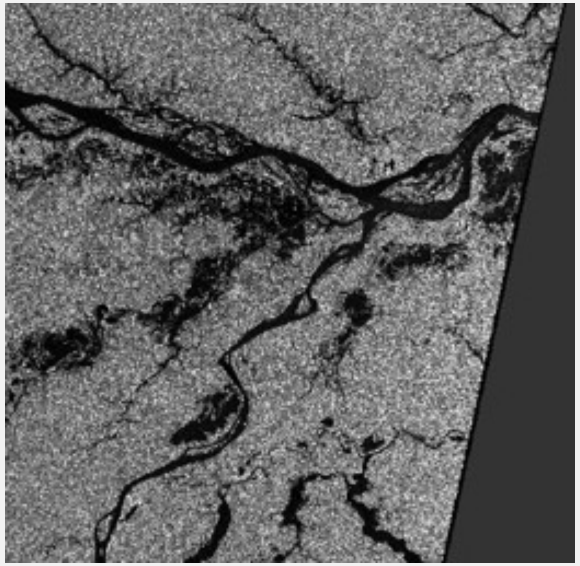
Speckle Reduction

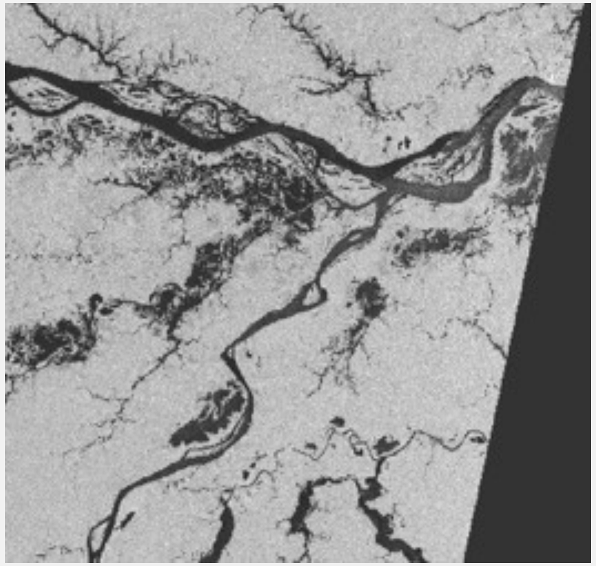
1. Multi-look processing: the division of the radar beam (A) into several (in this example, five) narrower sub-beams (1 to 5). Each sub-beam provides an independent "look" at the illuminated scene. Each look will also be subject to speckle, but by summing and averaging them together to form the final output image, the amount of speckle will be reduced.





2. Spatial Filtering: a moving window (e.g. 5x5) over each pixel in the image, applying a mathematical calculation on the pixel values within the window (e.g. the average), and replacing the central pixel with the new value. The window is moved in the x and y dimensions one pixel at a time, until the entire image is covered. A smoothing effect is achieved and the visual appearance of the speckle is reduced.

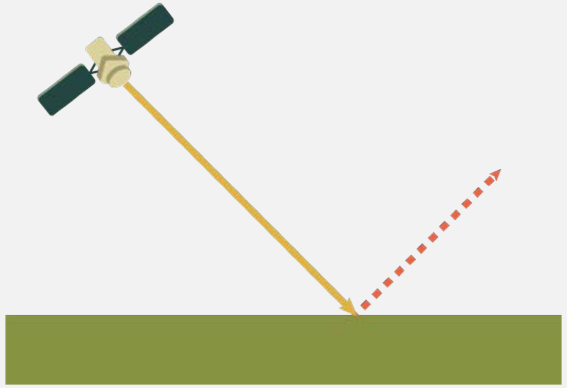




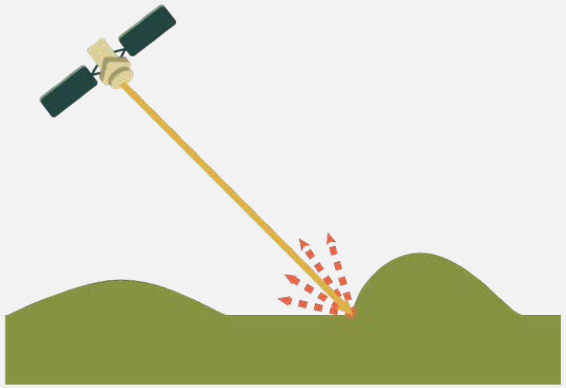
Radar Backscatter

Radar Signal Interaction

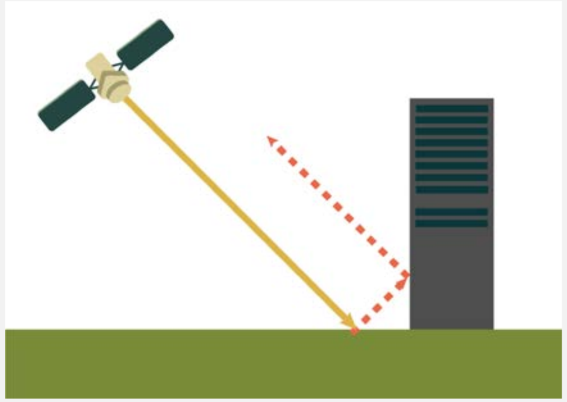
- The scale of the surface relative to the wavelength determine how rough or smooth they appear and how bright or dark they will appear on the image
- Backscattering Mechanisms:



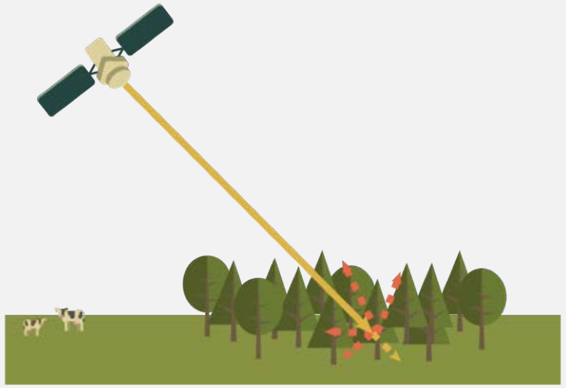
Smooth Surface



Rough Surface



Double Bounce

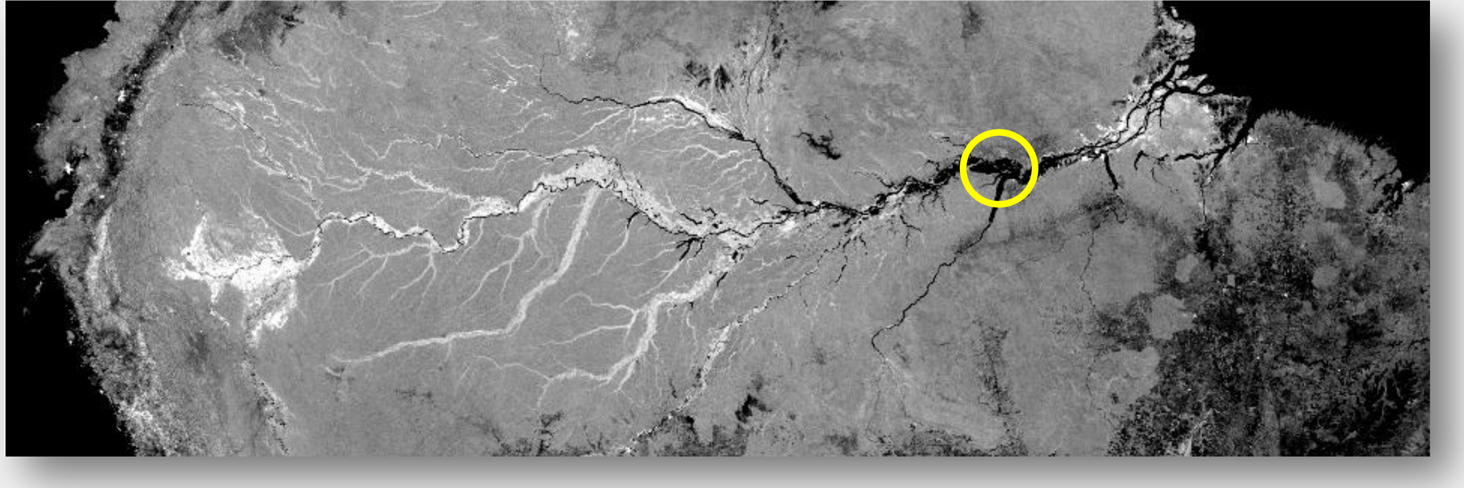


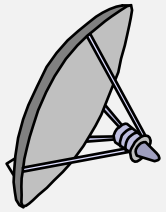
Volume Scattering

Radar Signal Interaction: Specular Reflection

Smooth surface reflection (specular reflection)

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





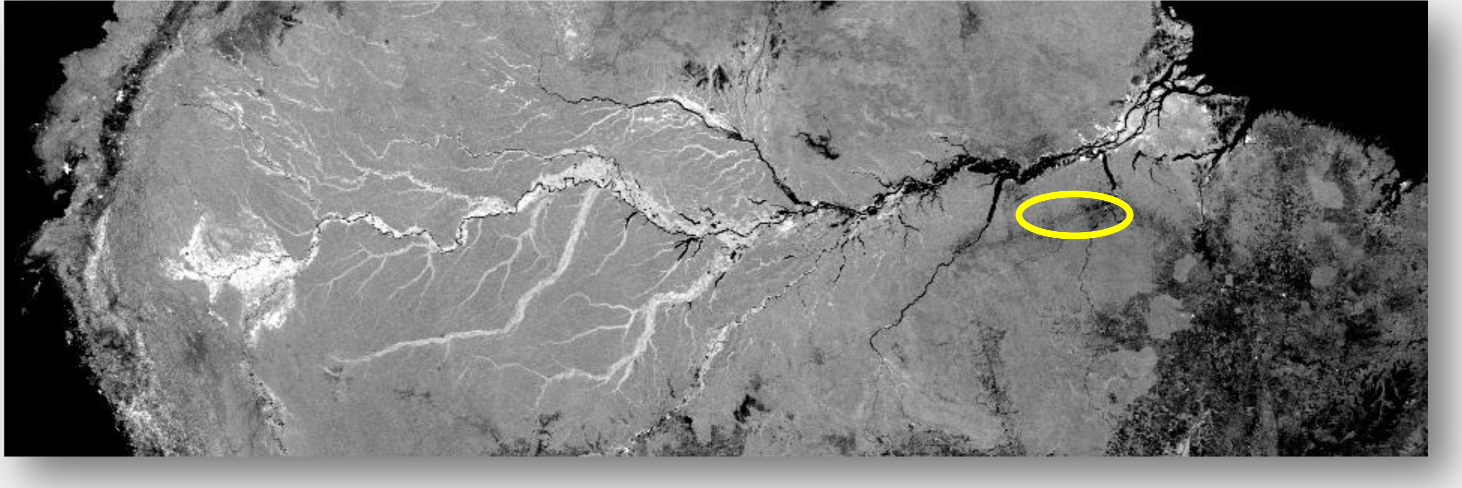
Pixel Color

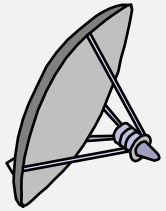
Smooth, level surface
(open water, road)

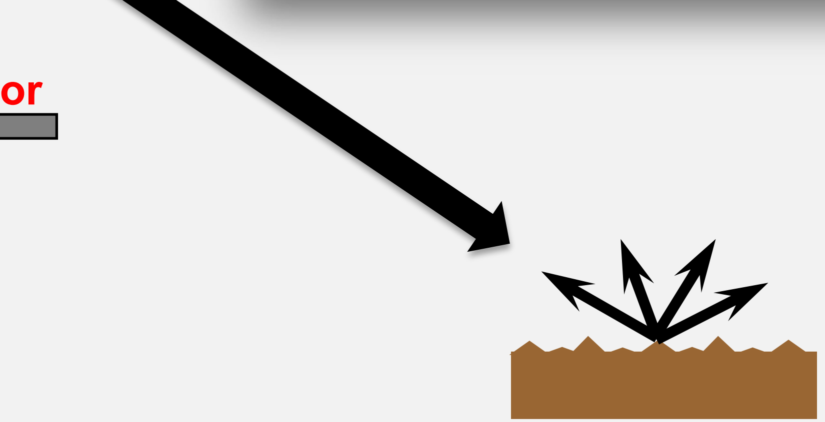
Radar Signal Interaction: Rough Surface Reflection

Rough surface reflection

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







Pixel Color

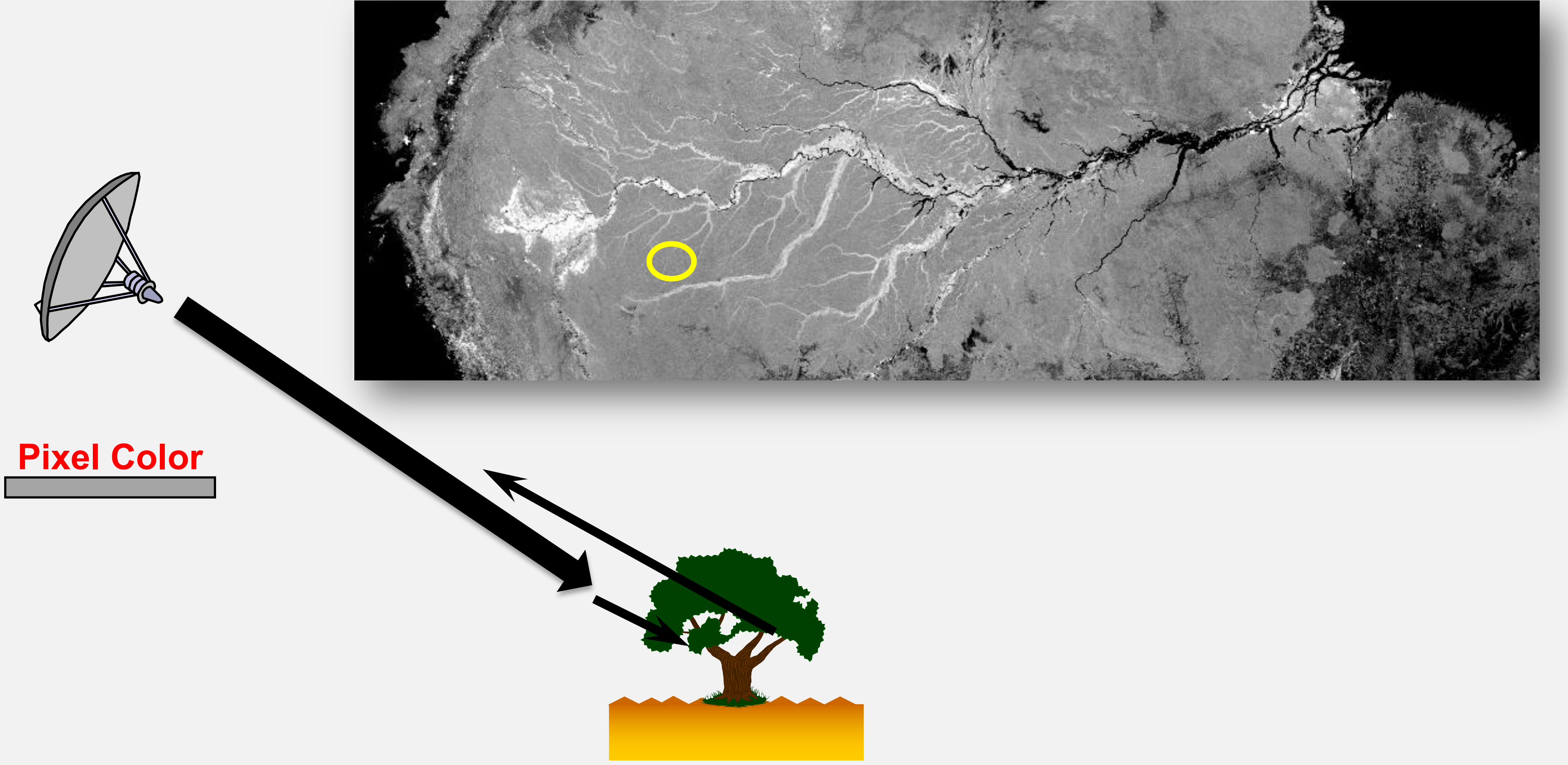
▬

Rough bare surface
(deforested areas, tilled agricultural fields)

Radar Signal Interaction: Volume Scattering

Volume Scattering by Vegetation

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

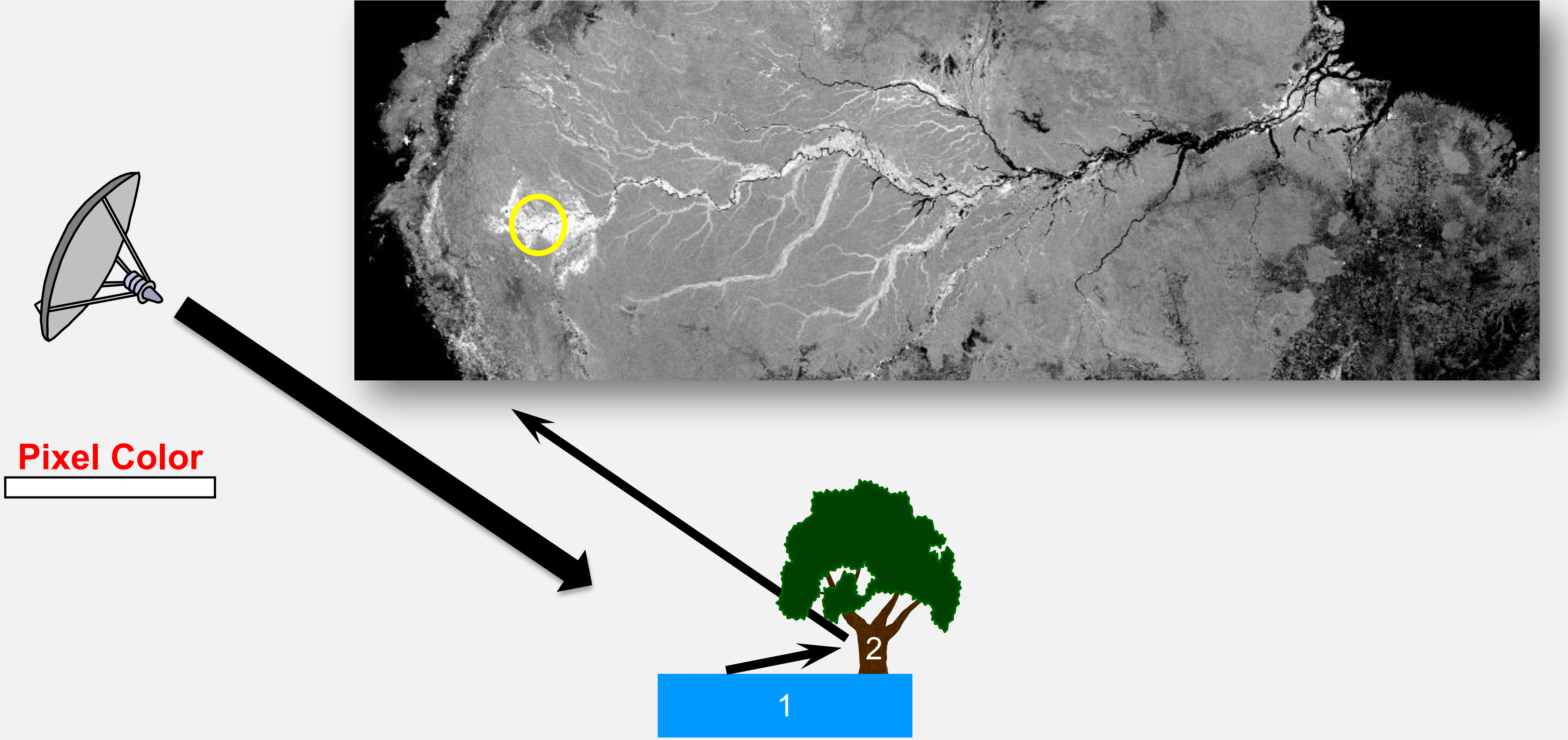


Vegetation

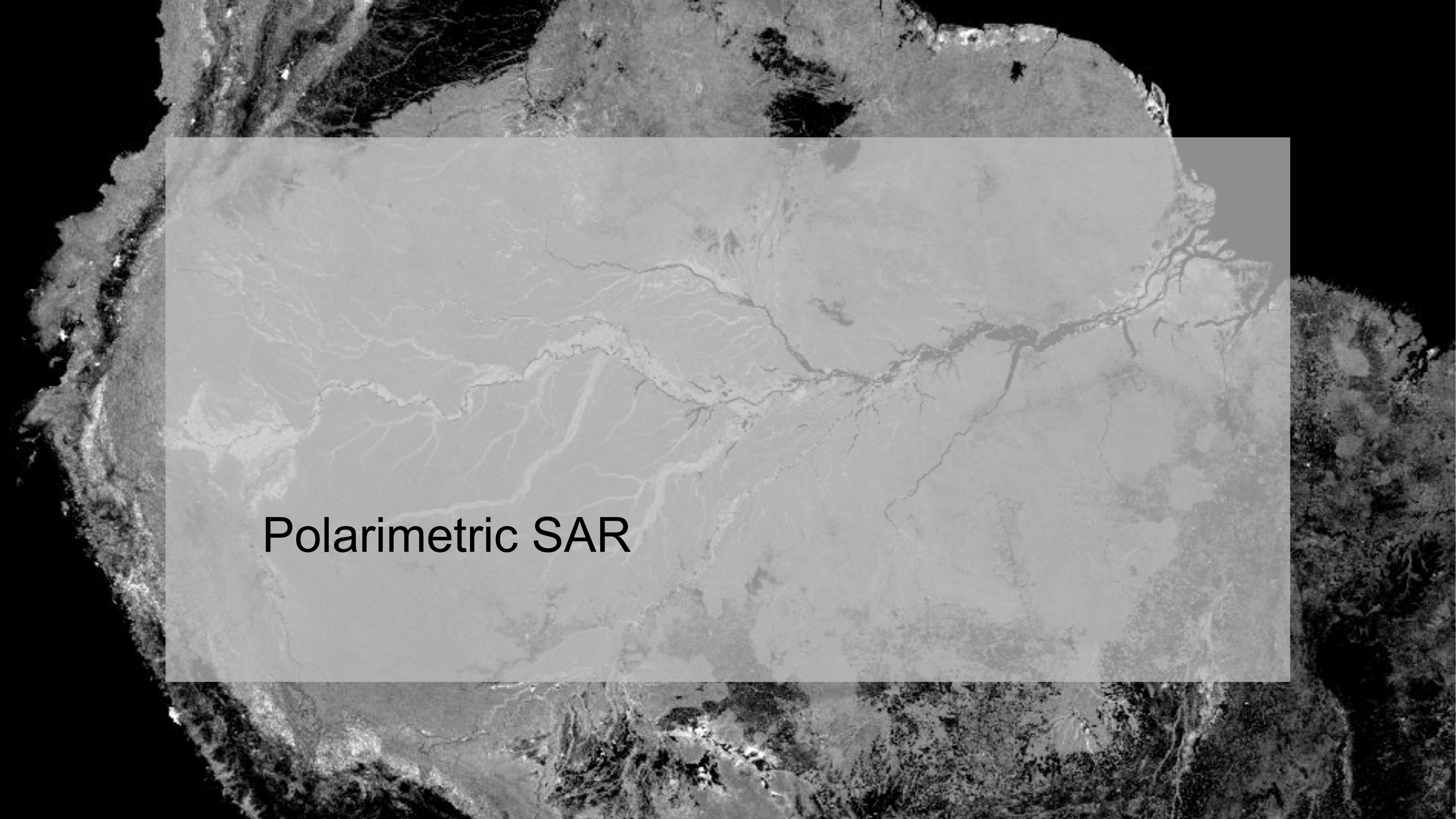
Radar Signal Interaction: Double Bounce

Double- Bounce

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

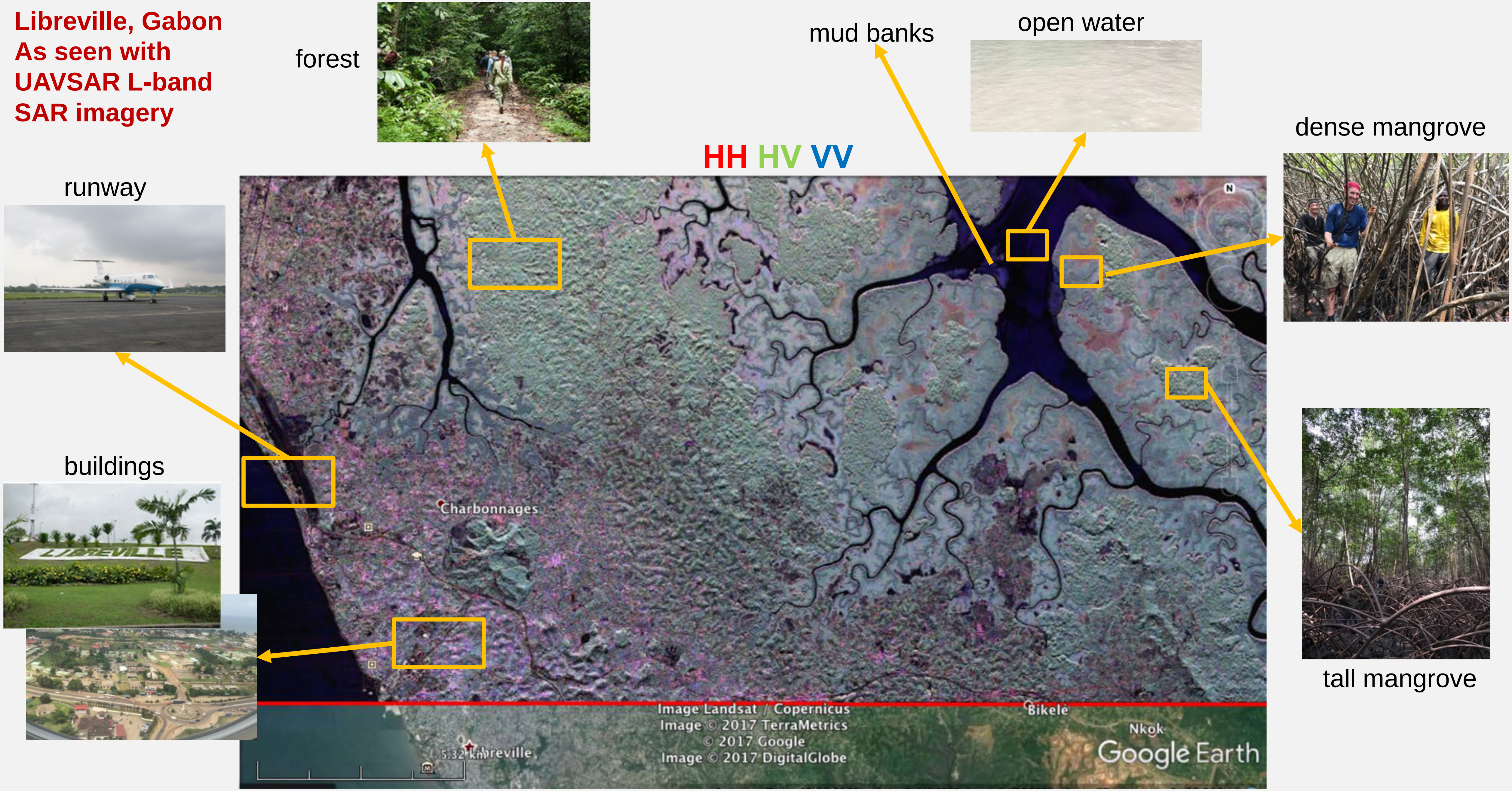


Inundated Vegetation



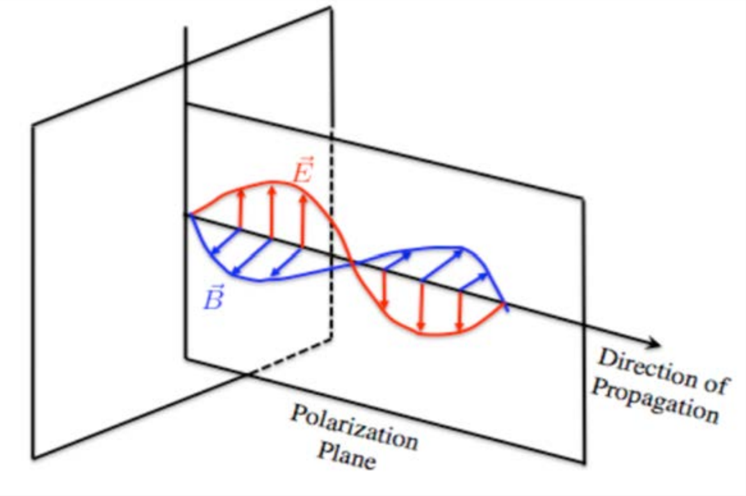
Polarimetric SAR

Libreville, Gabon As seen with UAVSAR L-band SAR imagery



Polarization

- Radars produce electromagnetic waves. The direction of the electric field lies in the plane perpendicular to the direction of propagation and defines the polarization of the wave.
- Dual-pol instruments:
  - Transmit H or V, receive H and V simultaneously
- Quad-pol instruments:
  - Transmit H and V on alternate pulses, receive H and V simultaneously
- The amount of returned signal for different polarizations depends on the physics of the interaction of microwaves with the surface.



transmit

receive

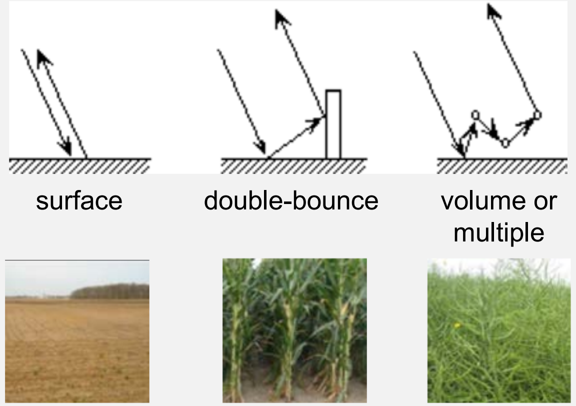
	H	V
H	HH	VH
V	HV	VV

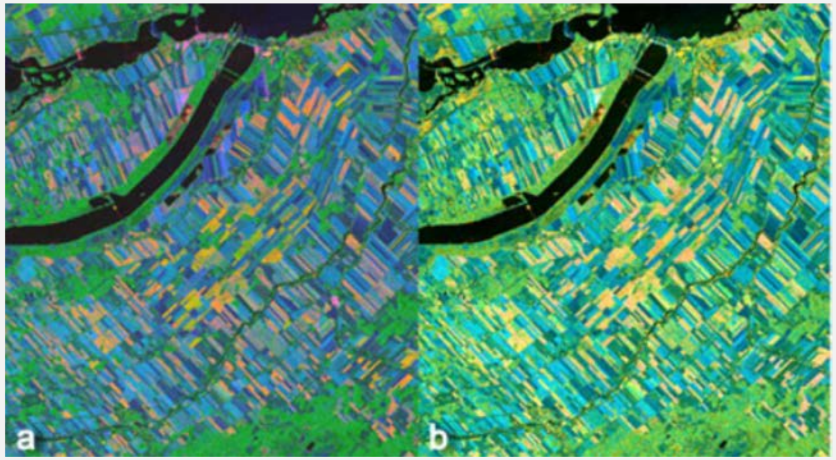
Fully Polarimetric SAR

- transmits and receives two orthogonal polarizations (usually H and V) and retains the phase between these two polarizations
- permits the complete characterization of the scattering field

Why is this important?

- With these coherent systems one can:
  - synthesize any polarization (linear, circular or elliptical)
  - determine degree of polarization
  - decompose the signal to determine the dominant and secondary or tertiary types of scattering



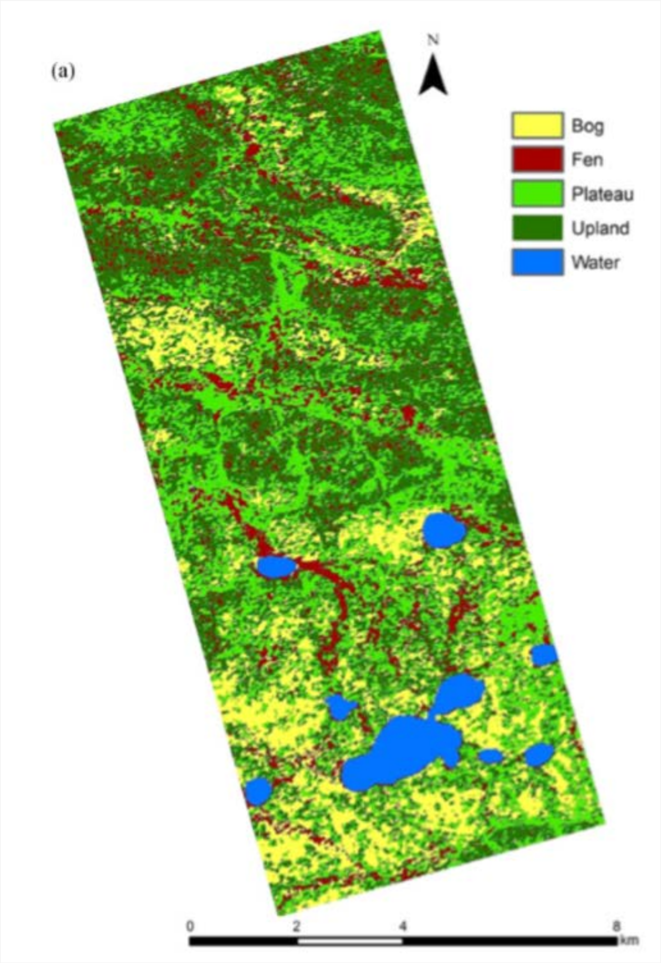


(a) Freeman-Durden decomposition applied to RADARSAT-2 fully polarimetric data and (b) m-δ decomposition applied to simulated compact polarimetric data. Red (double bounce) Green (multiple/volume) Blue (single bounce)

Image Source: Source: Dr. Francois Charbonneau

Polarimetry

- Radar polarimetry is the study of using multiple polarimetric returns to infer information about a surface.
- Applications include:
  - Cryosphere
  - Vegetation
  - Hydrology
- Two complementary approaches to studying polarimetry:
  - Theoretical models predict how polarized signal interacts with different media
  - Observations made with remote sensing instruments reveal polarization signatures for a range of land cover types



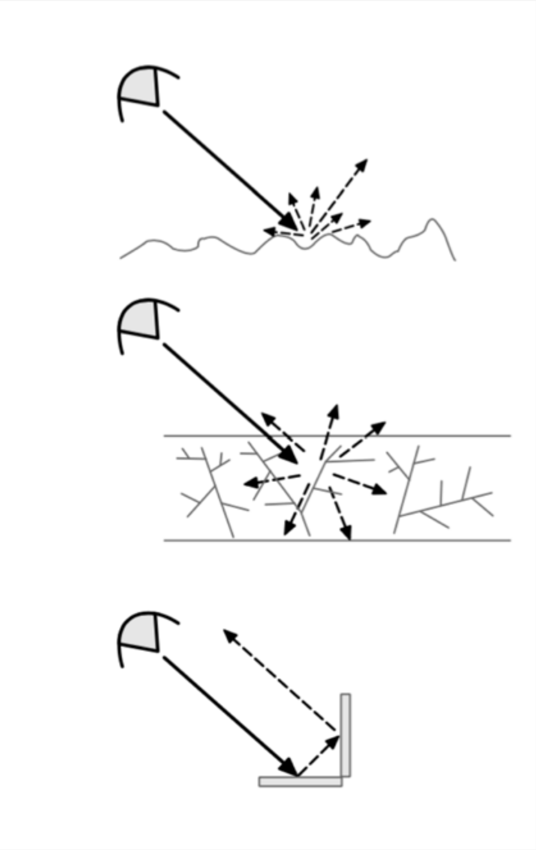
Mapping Canadian peatlands: Merchant et al. 2017

Scattering mechanisms

- Quantifying scattering mechanisms starts by encoding the received radar signal in a scattering matrix.
- In the quad pol scenario, we can represent the received signal with a 3x3 T3 coherency matrix:
- [T] =

$$\frac{1}{2}\begin{bmatrix} \langle | S_{HH}+S_{VV} |^2 \rangle & \langle (S_{HH}+S_{VV})(S_{HH}-S_{VV})^* \rangle & 2\langle (S_{HH}+S_{VV})S_{HV}^* \rangle \\ \langle (S_{HH}-S_{VV})(S_{HH}+S_{VV})^* \rangle & \langle | S_{HH}-S_{VV} |^2 \rangle & 2\langle (S_{HH}-S_{VV})S_{HV}^* \rangle \\ 2\langle S_{HV}(S_{HH}+S_{VV})^* \rangle & 2\langle S_{HV}(S_{HH}-S_{VV})^* \rangle & 4\langle | S_{HV} |^2 \rangle \end{bmatrix}$$

- * denotes conjugation and < > denotes averaging
- All 9 elements in the T matrix are calculated for each pixel in your image.
- We employ polarimetric decompositions to obtain a small set of parameters to classify scattering mechanisms.



H-α Decomposition

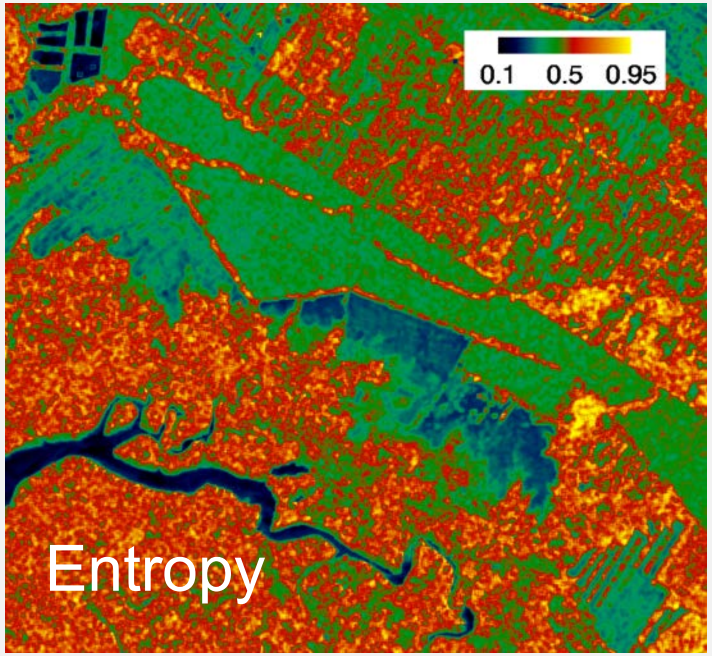
- Based on eigenvalue / eigenvector decomposition of the T3 matrix

$$[T] = [U_3]\begin{bmatrix}\lambda_1 & 0 & 0\\ 0 & \lambda_2 & 0\\ 0 & 0 & \lambda_3\end{bmatrix}[U_3]^{*T}$$

$$[U_3] = \begin{bmatrix}\cos\alpha_1 & \cos\alpha_2 & \cos\alpha_3\\ \sin\alpha_1\cos\beta_1 e^{i\delta_1} & \sin\alpha_2\cos\beta_2 e^{i\delta_2} & \sin\alpha_3\cos\beta_3 e^{i\delta_3}\\ \sin\alpha_1\sin\beta_1 e^{i\gamma_1} & \sin\alpha_2\sin\beta_2 e^{i\gamma_2} & \sin\alpha_3\sin\beta_3 e^{i\gamma_3}\end{bmatrix}$$

- Eigenvalues λ are used to calculate entropy, (H) which is a function of noise owing to depolarization.

$$\text{entropy:}\quad H = \sum_{i=1}^{3} p_i \log_3 p_i \quad 0 \leq H \leq 1 \qquad p_i = \frac{\lambda_i}{\sum_{q=1}^{3}\lambda_q}$$



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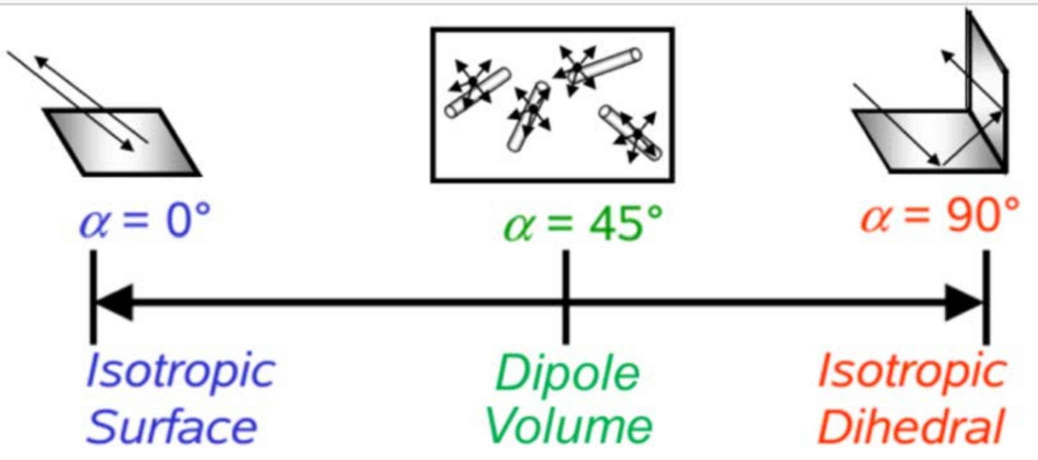
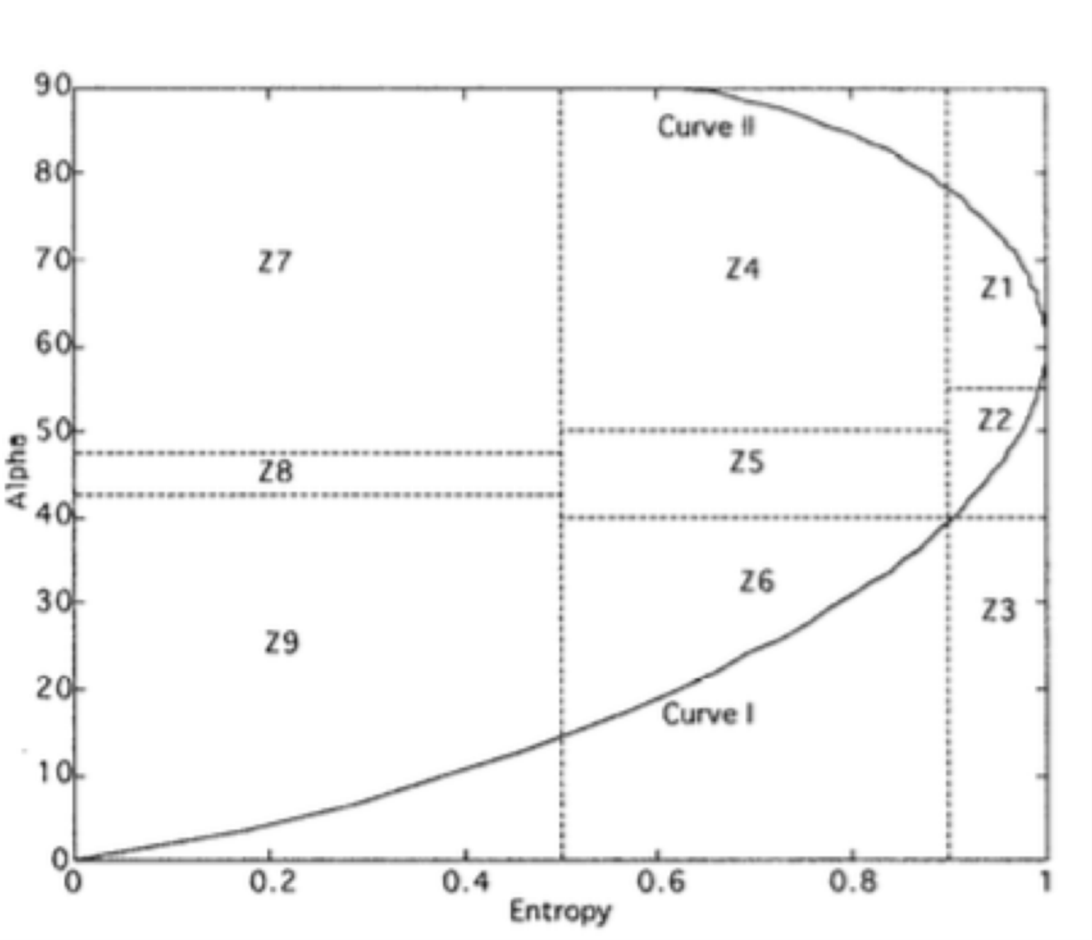


$$\text{alpha:}\quad \alpha = \sum_{i=1}^{3} p_i\alpha_i \quad 0 \le \alpha \le \frac{\pi}{2}$$

- Eingenvectors contain the parameter α which represents the dominant scattering mechanism.

Figure from Jagdhuber, Thomas, et al. "Identification of soil freezing and thawing states using SAR polarimetry at C-Band." *Remote Sensing* 6.3 (2014): 2008-2023.

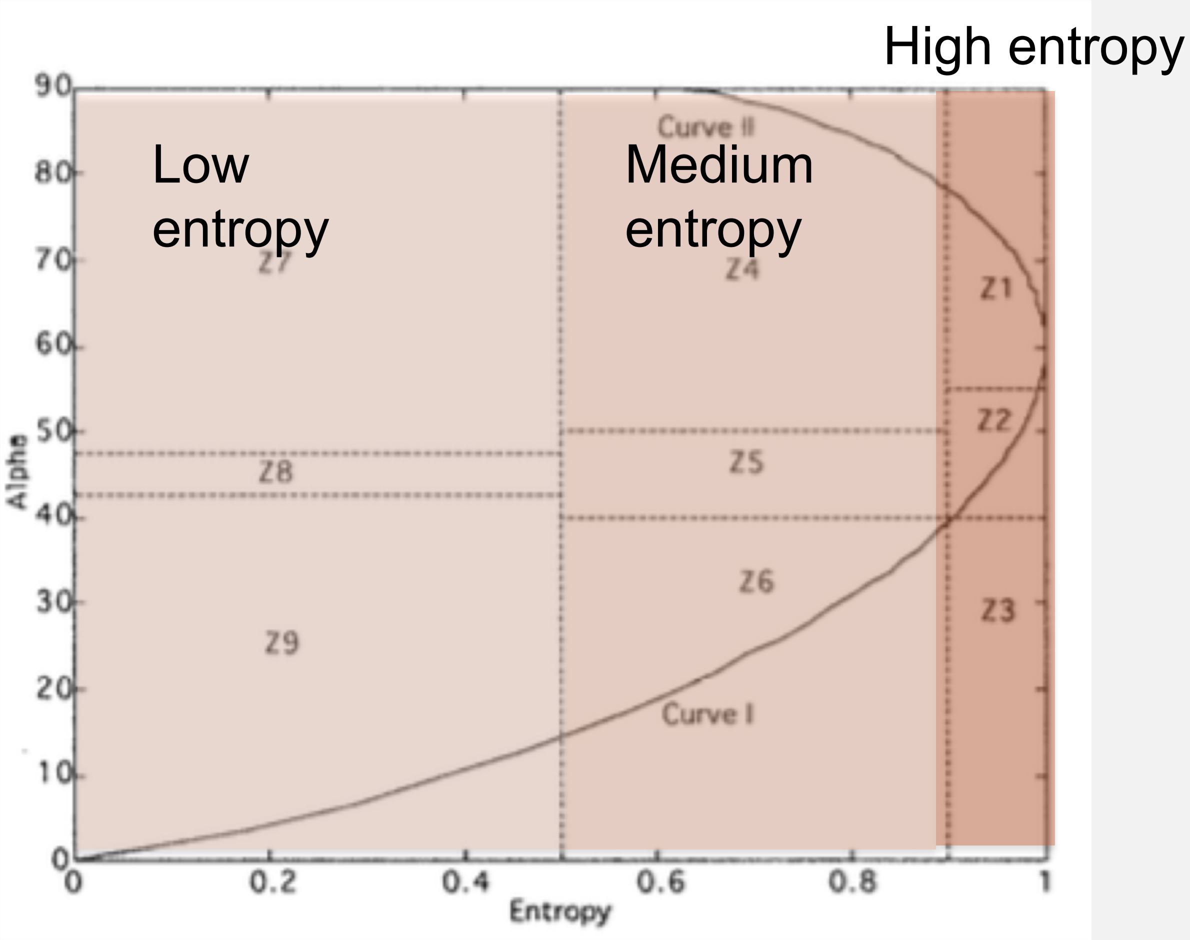
H-α Classification



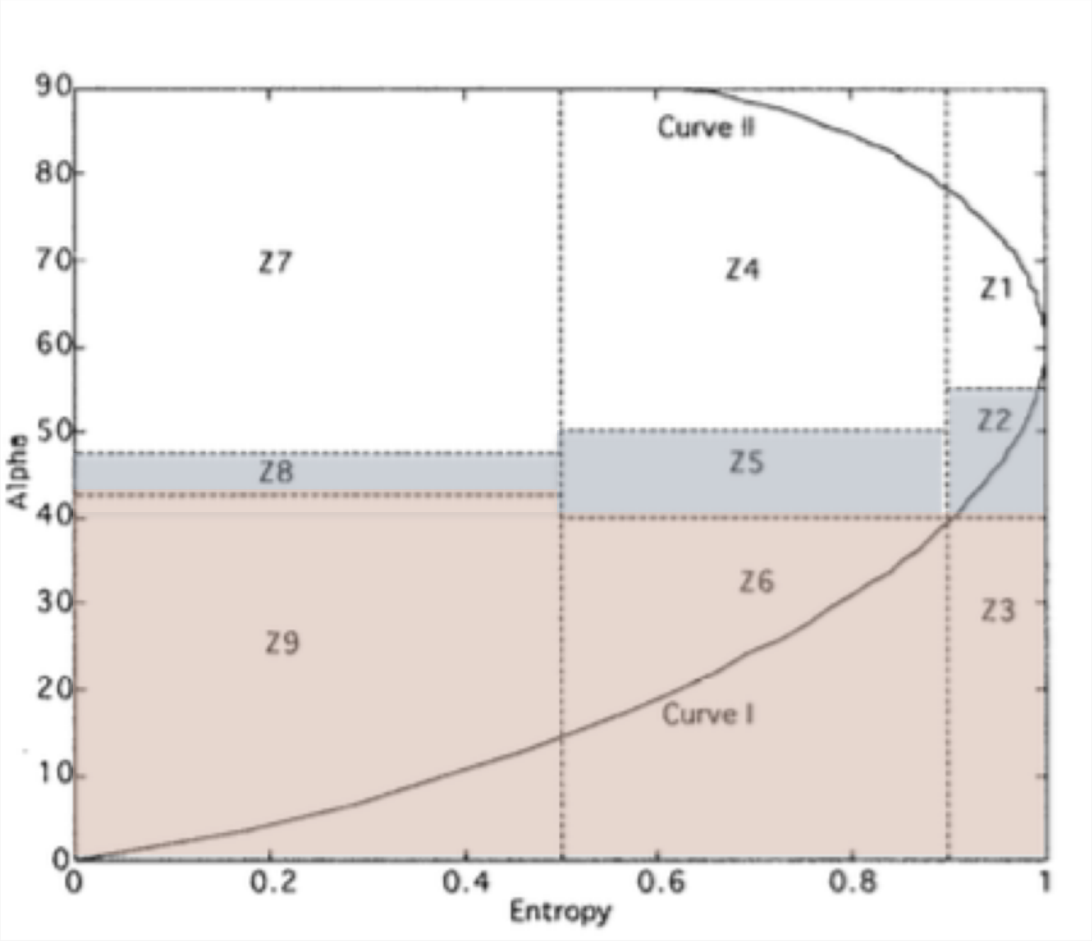
- Two-parameter system used to classify different types of scattering behavior
- 9 Zones
- Results from this unsupervised classification can be combined with other layers and used as inputs for a supervised classifier.
- For example: Qi, Zhixin, et al. "A novel algorithm for land use and land cover classification using RADARSAT-2 polarimetric SAR data." *Remote Sensing of Environment*118 (2012): 21-39.

Cloude, Shane R., and Eric Pottier. "An entropy based classification scheme for land applications of polarimetric SAR." *IEEE Transactions on Geoscience and Remote Sensing* 35.1 (1997): 68-78.

H-α Classification



H-α Classification

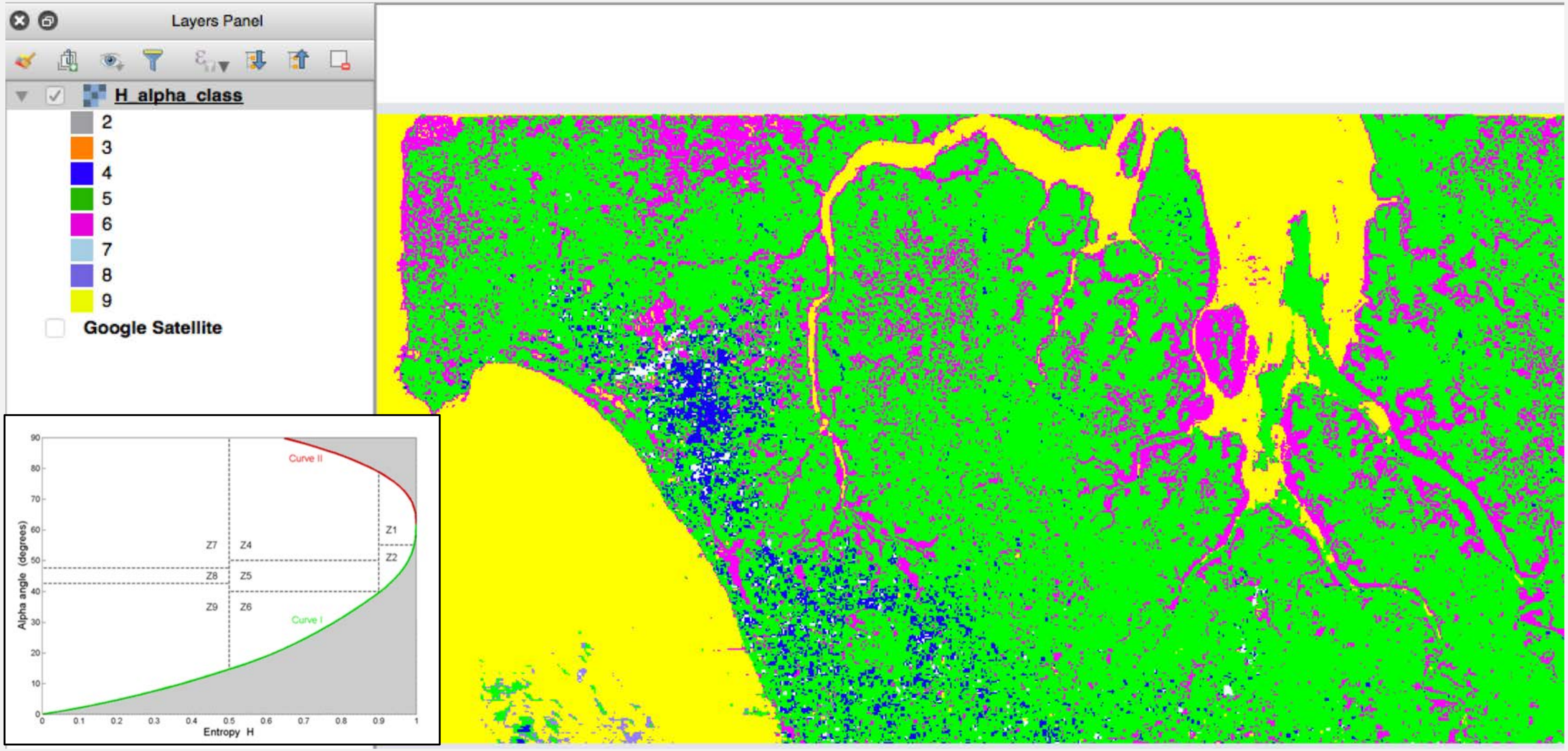


Multiple

Dipole / vegetation

Surface

Entropy+ Alpha



Layers Panel

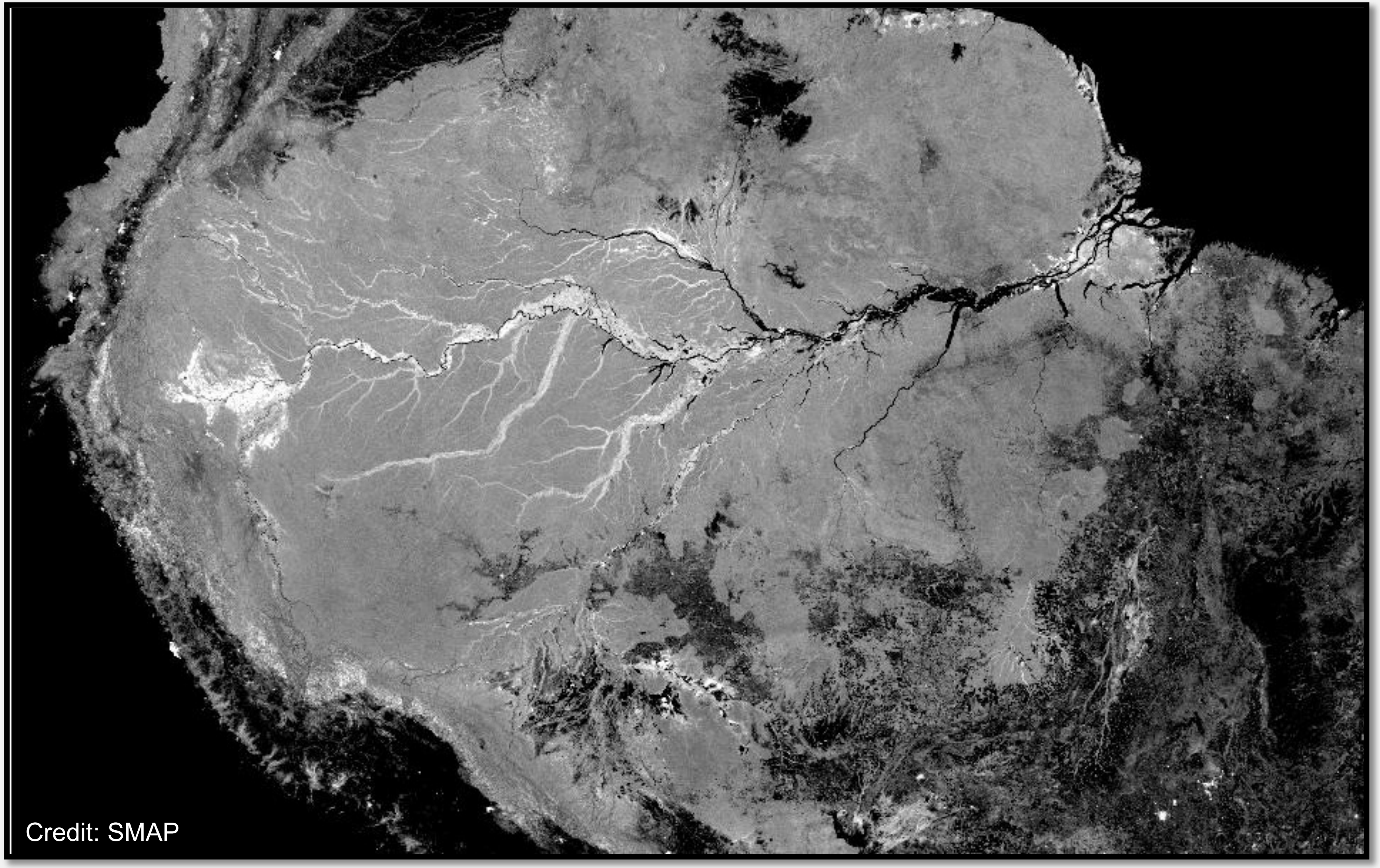
☑ **H_alpha_class**

- ⬜ 2
- 🟧 3
- 🟦 4
- 🟩 5
- 🟪 6
- 🟦 7
- 🟪 8
- 🟨 9

☐ **Google Satellite**

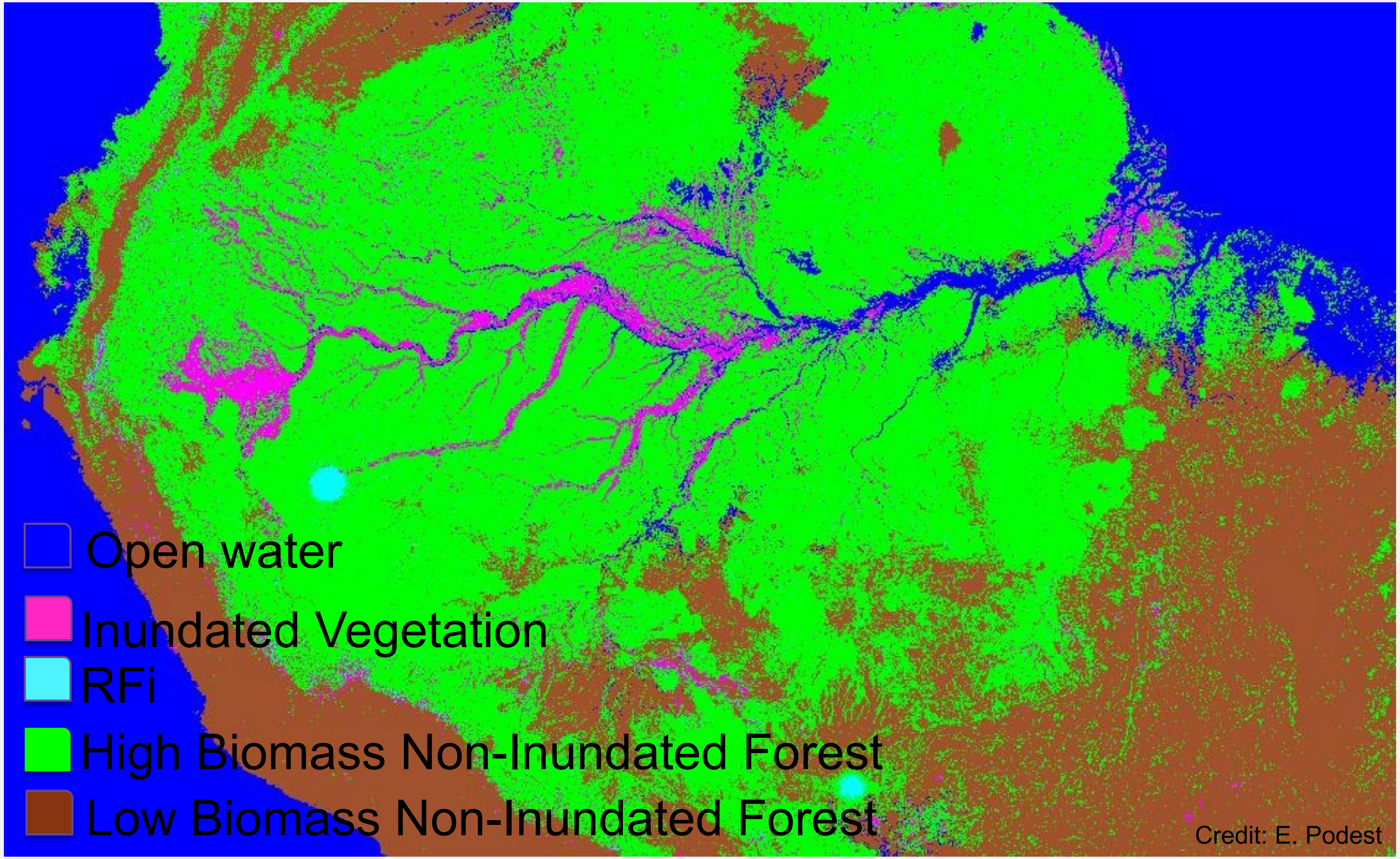
SAR Applications

SMAP Radar Mosaic- Amazon (L-band, HH, 3km res., - Apr. 2015)



Credit: SMAP

SMAP Radar Mosaic- Wetland Classification

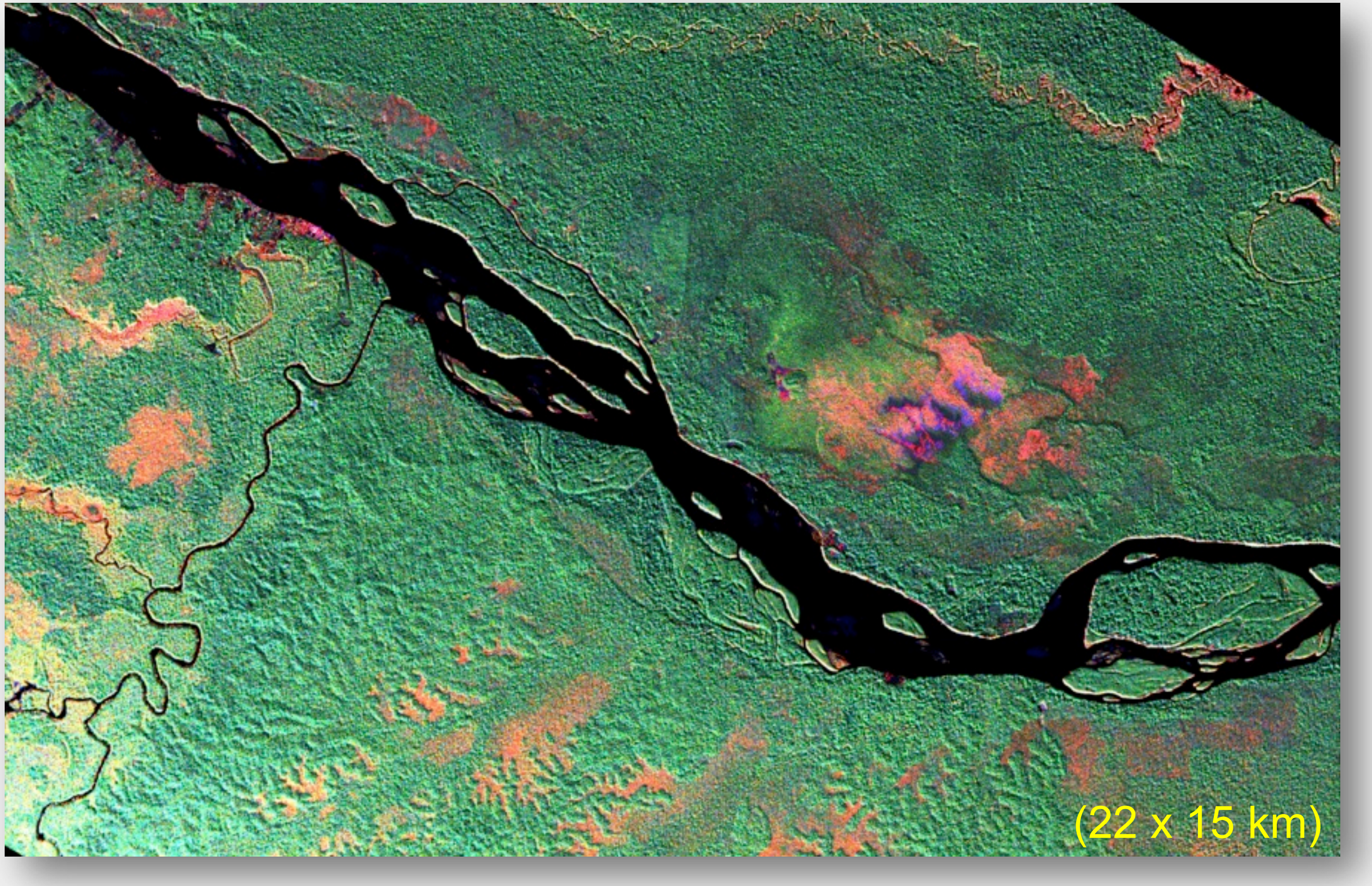


Credit: E. Podest

Mapping Inundation Extent with UAVSAR - Fully Polarimetric

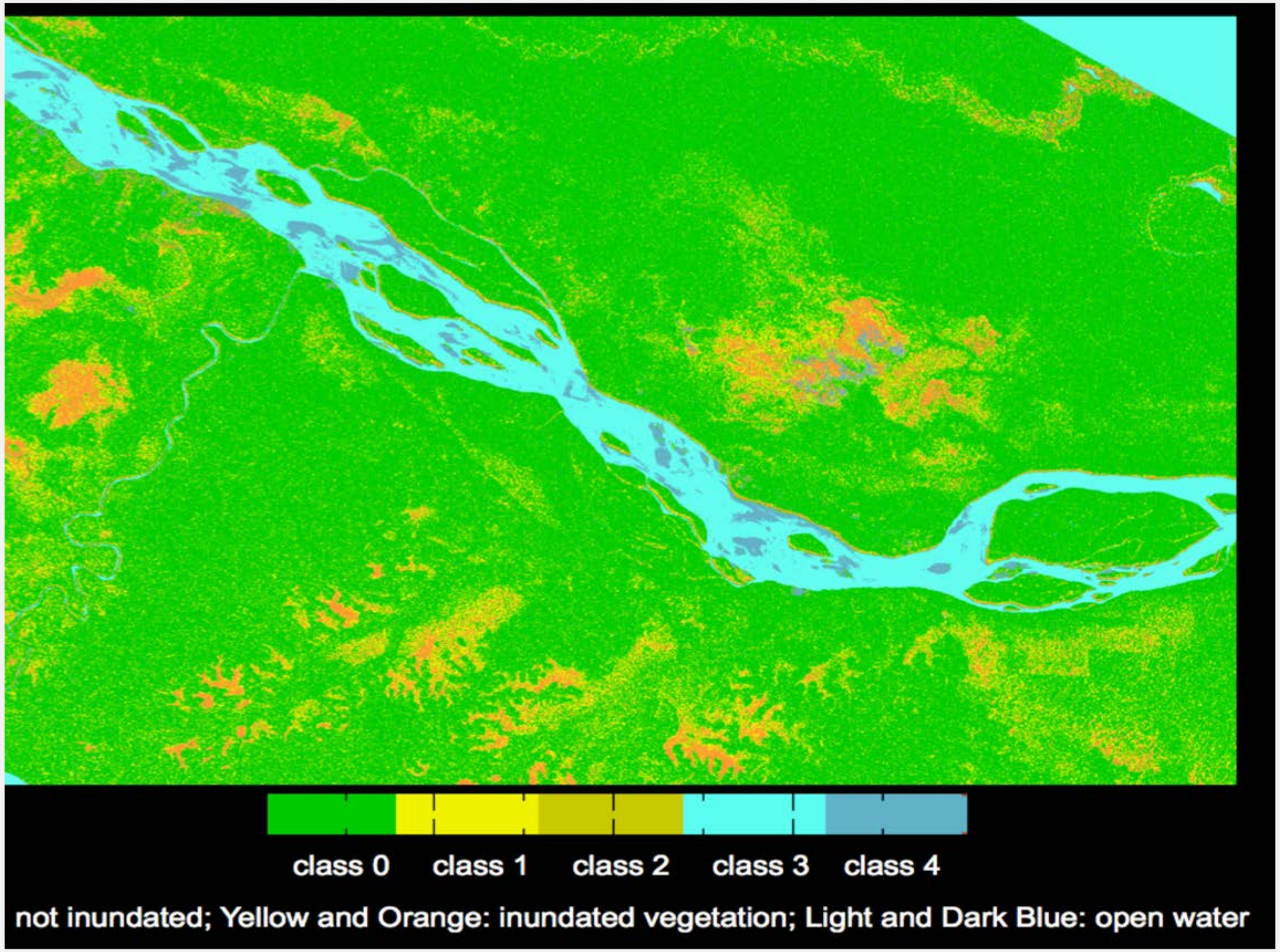
UAVSAR quad-pol
Napo River, Ecuador
March 31, 2013

VanZyl decomposition of a subset of the UAVSAR image swath



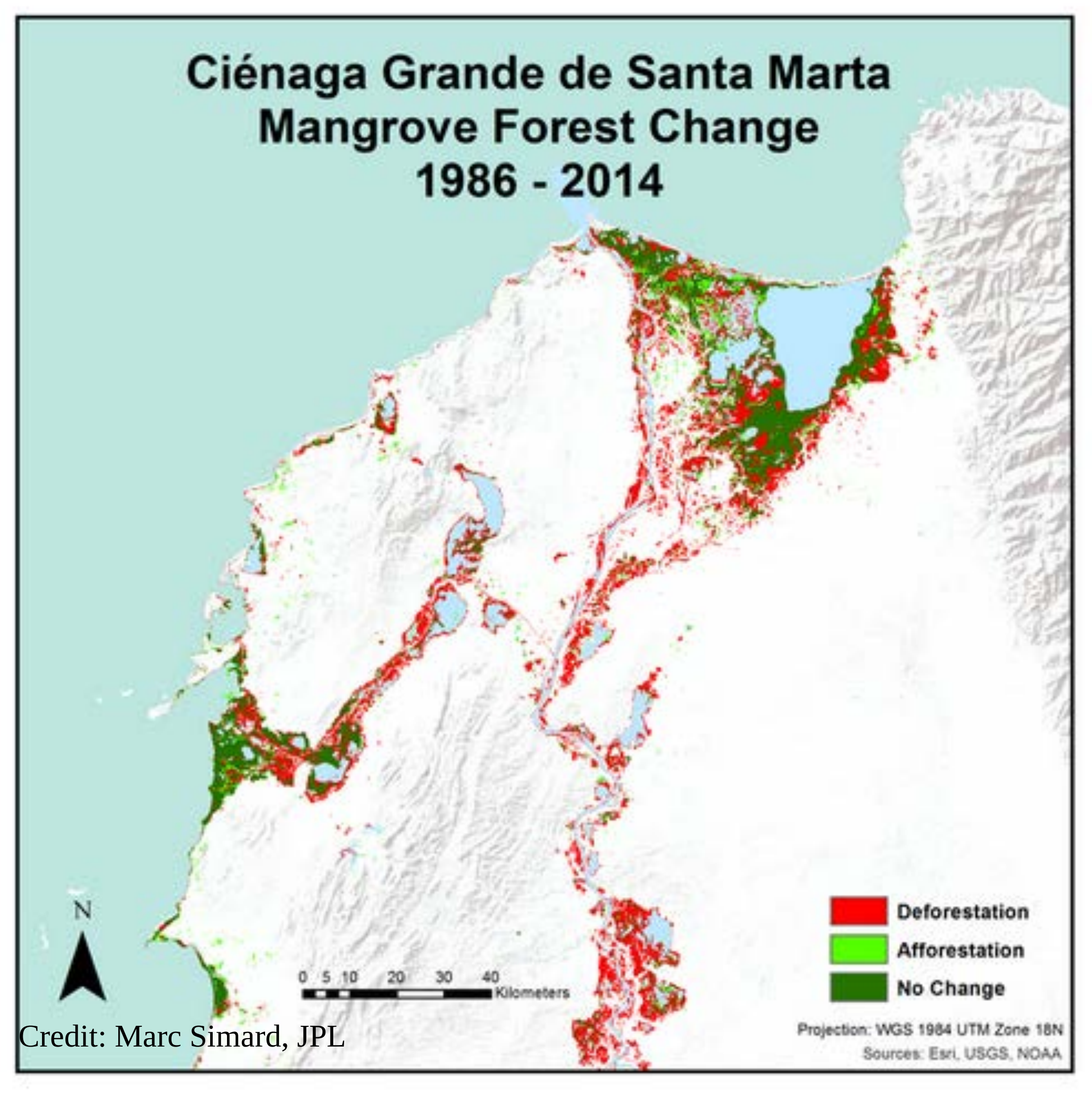
Red : double bounce scatter; Green : Volume scatter; Blue: odd scatter

Wetland Classification Using the van Zyl Decomposition Results



not inundated; Yellow and Orange: inundated vegetation; Light and Dark Blue: open water

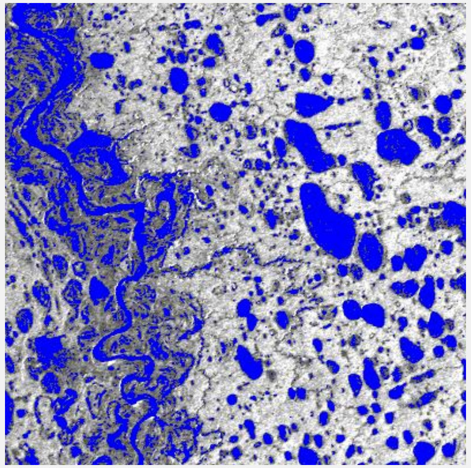
Mangrove Monitoring



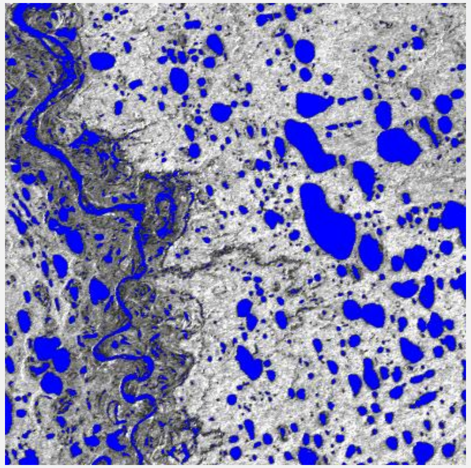
Credit: Marc Simard, JPL

Open Water Change - North Slope, Alaska

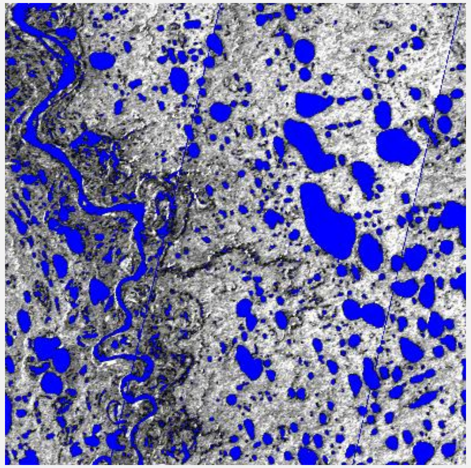
The top shows open water overlayed on JERS (L-band, HH, 100m) images and the bottom shows open water change relative to June.



June 1998



July 1998



August 1998

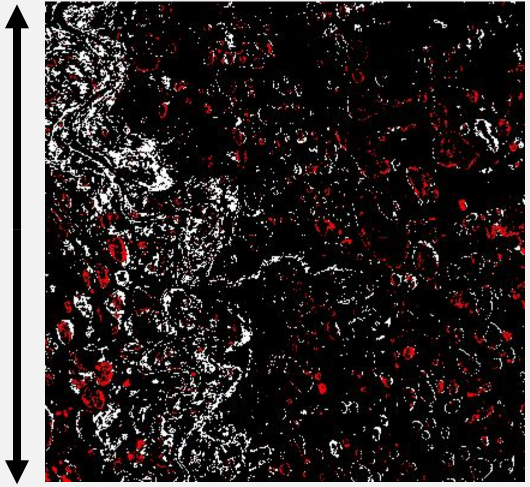
Open Water Change Relative to June

	Dryer	Wetter
Jul.	7.7%	2.7%
Aug.	6.9%	3.2%

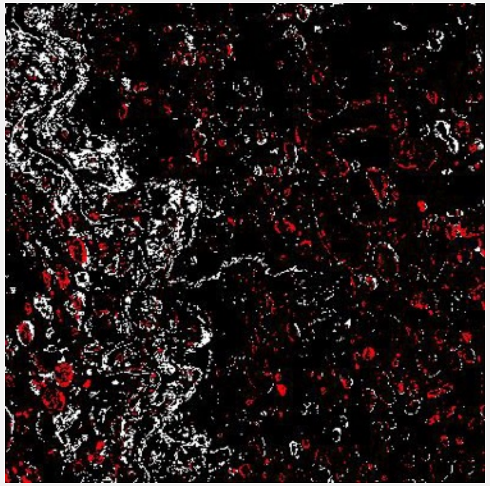
🟥 More open water

⬜ Less open water

⬛ No change



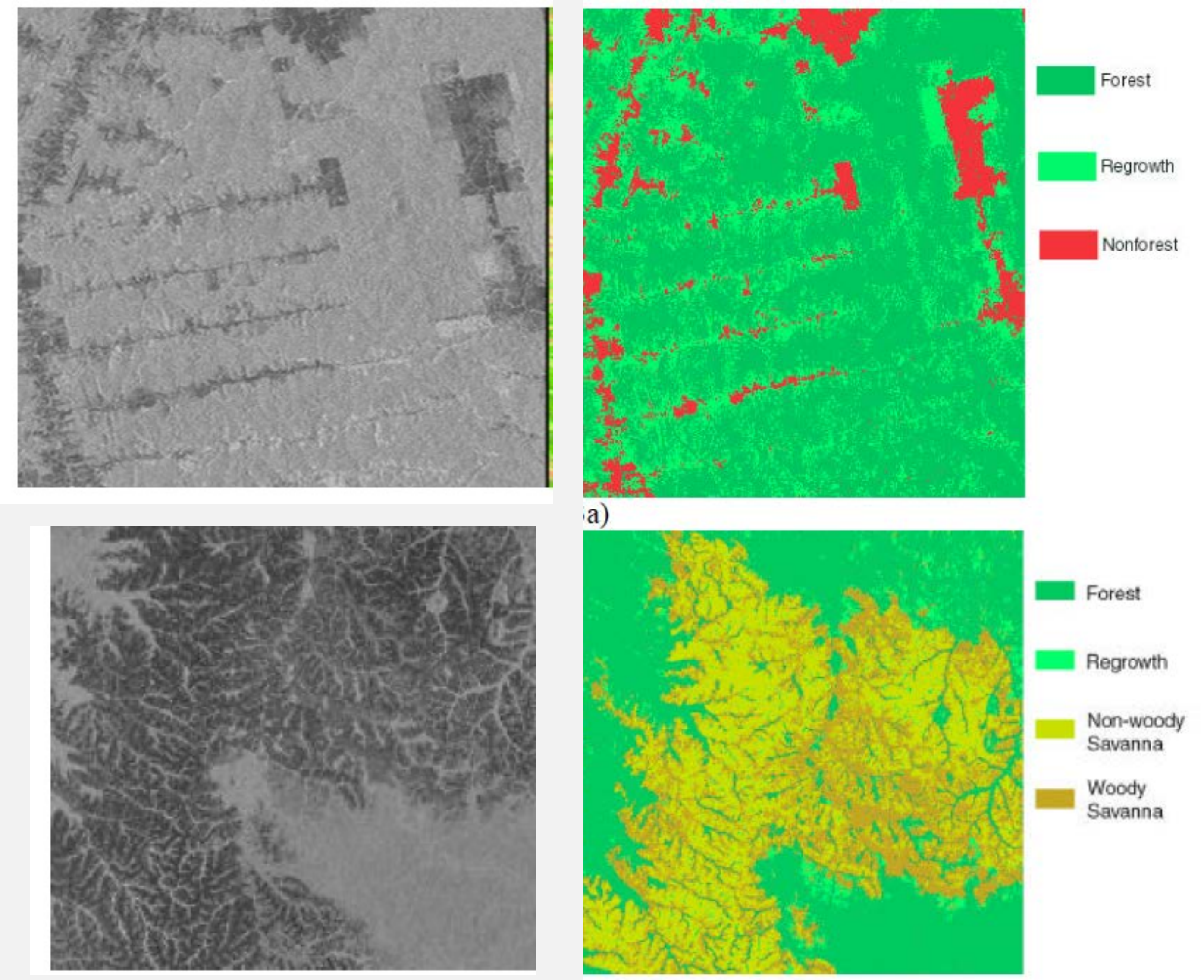
Open water change June/July



Open water change June/August

Credit: E. Podest

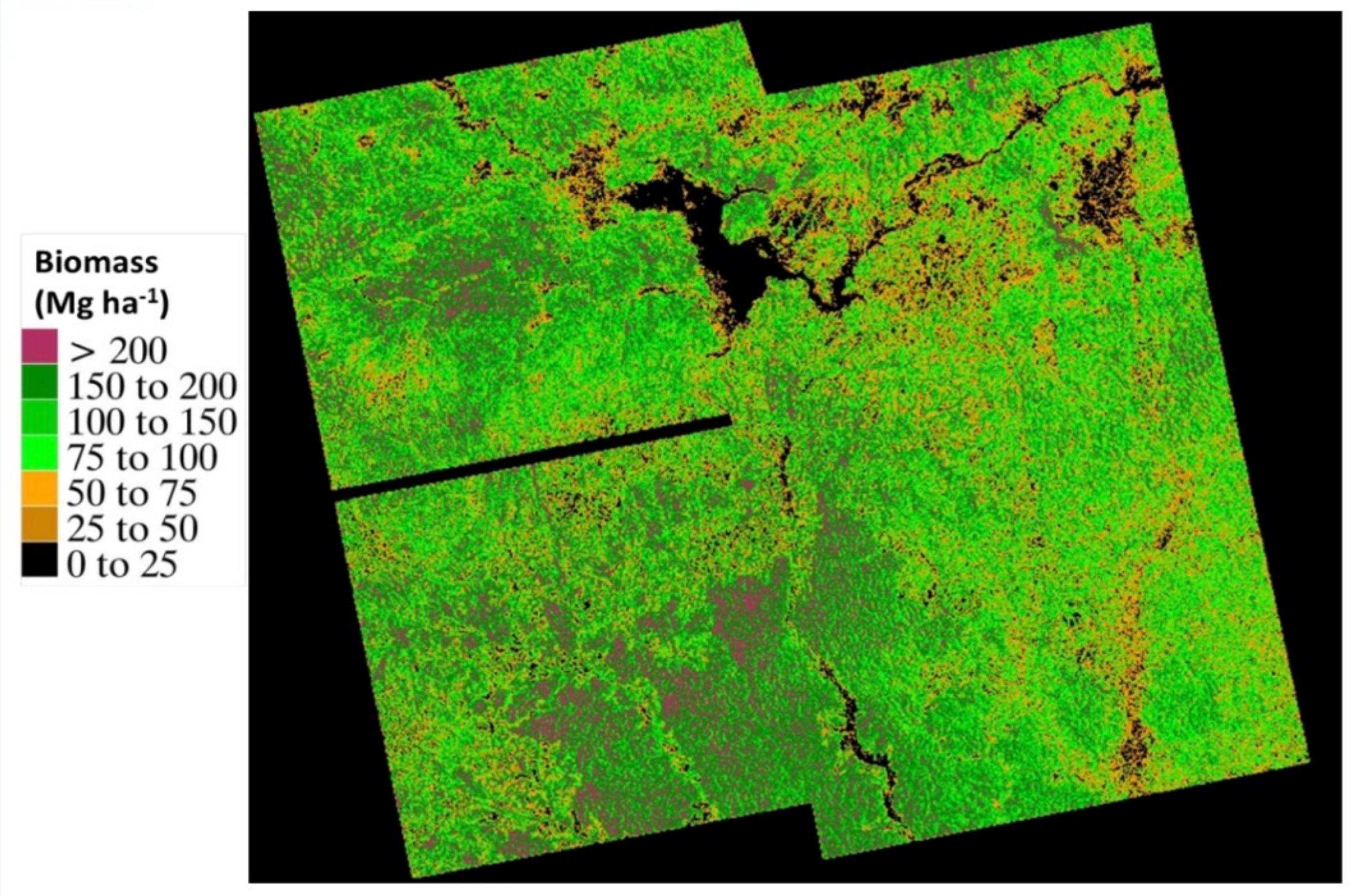
Land Cover in Brazil - Single Polarization



Brazil
JERS-1 L-band, HH, data
100 meter resolution

Credit: E. Podest, JPL

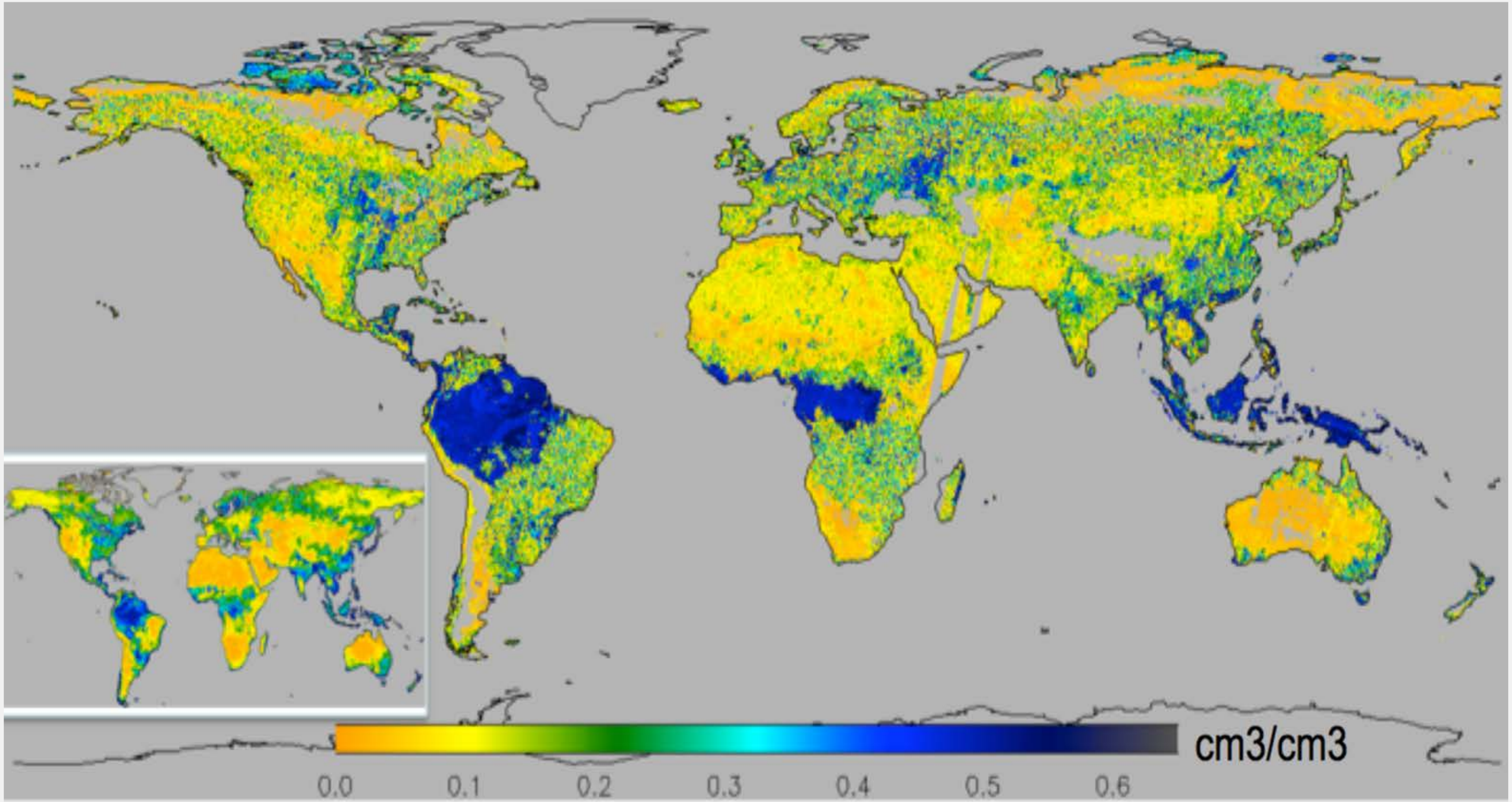
Mapping Above Ground Biomass



Biomass map over Mbam Djerem National Park in Cameroon. Derived from ALOS PALSAR data from 2007 and local field plot calibration.

Measuring biomass changes due to woody encroachment and deforestation/degradation in a forest-savanna boundary region of central Africa using multi-temporal L-band radar backscatter. / Mitchard, E. T. A.; Saatchi, S. S.; Lewis, S. L.; Feldpausch, T. R.; Woodhouse, I. H.; Sonke, B.; Rowland, C.; Meir, P. In: Remote Sensing of Environment, Vol. 115, No. 11, 15.11.2011, p. 2861-2873.

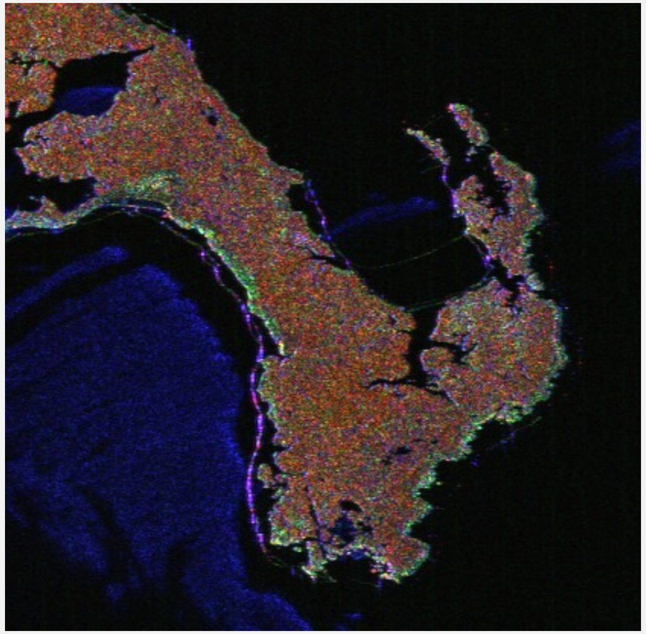
Soil Moisture from the SMAP Radar (HH, HV) - June 19-26, 2015



UAVSAR Deepwater Horizon Oil Spill Campaign

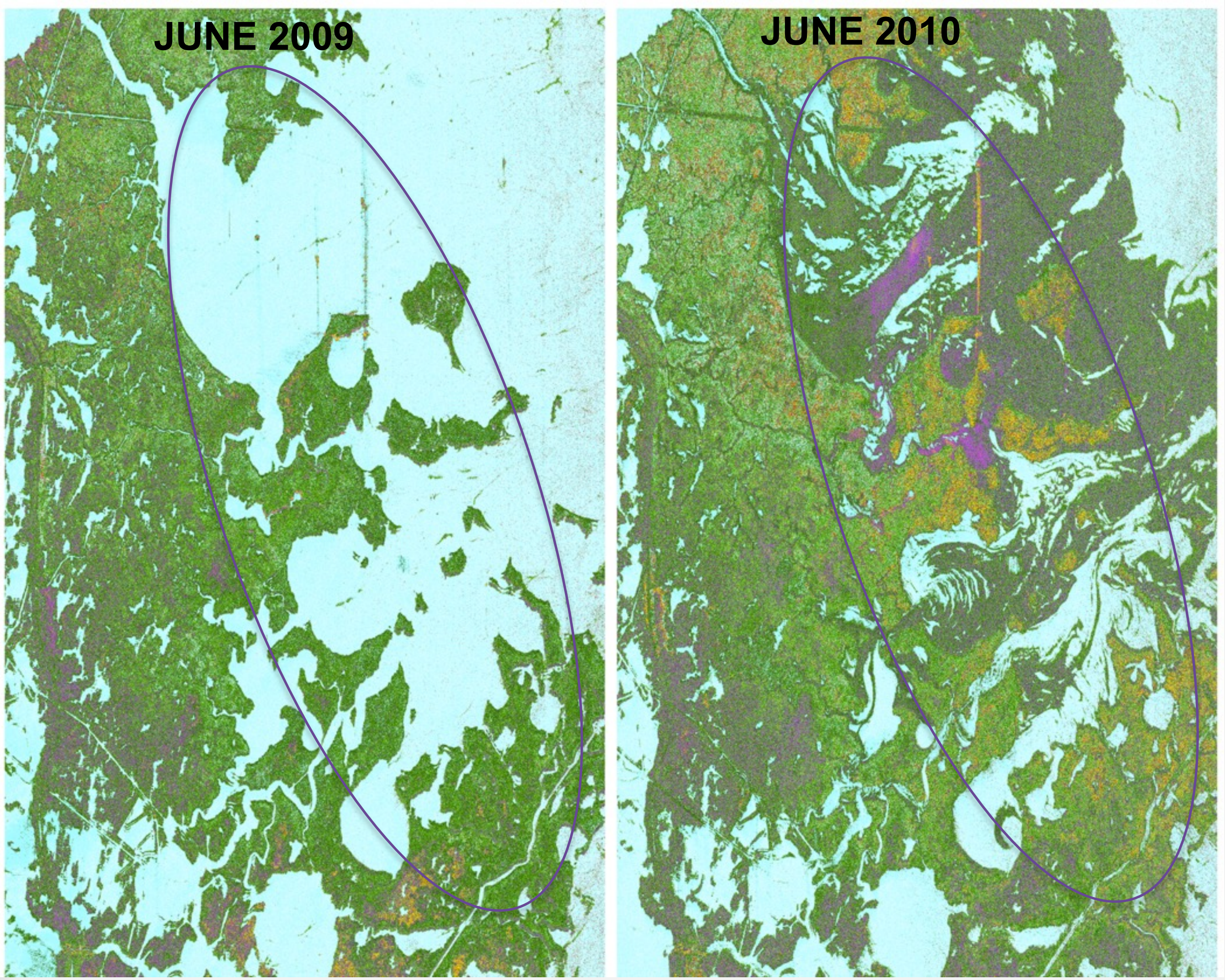
Oil Intrusion into Wetlands - UAVSAR

Ground truth from boats and helicopters were used to validate POLSAR-based algorithms for oil detection on vegetation and inland waterways.



Impact on Wetlands

Cloude-Pottier Decomposition (H,α,A) on UAVSAR data



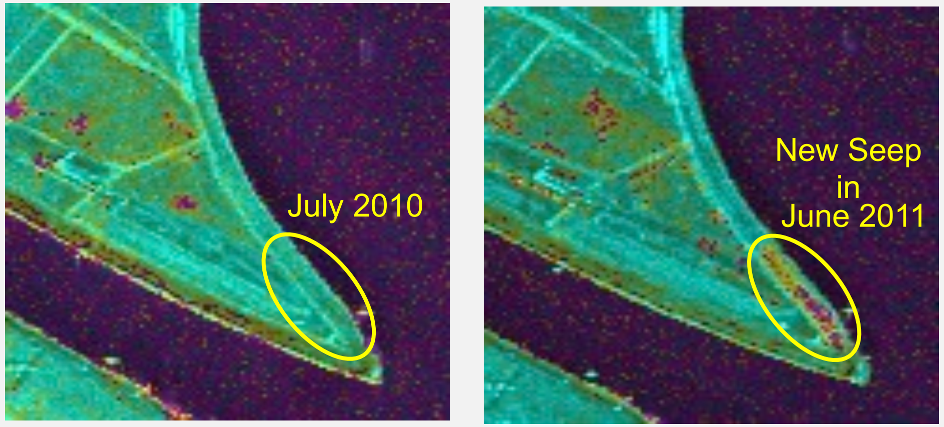
Levee Monitoring in the Sacramento San Joaquin Delta

Cracks in levees identified with DInSAR.

1. Post-repair settlement along levees detected and monitored.
2. Seeps identified with coherence change detection; detection methodology developed.
3. Subsidence rates within the islands can be measured despite temporal decorrelation & show general subsidence on sub-island scale.

Reference: Cathleen E. Jones, G. Bawden, S. Deverel, J. Dudas, S. Hensley (2012). Study of movement and seepage along levees using DINSAR and the airborne UAVSAR instrument, *Proc. SPIE* 8536, SAR Image Analysis, Modeling, and Techniques XII, 85360E (November 21, 2012); doi:10.1117/12.976885.

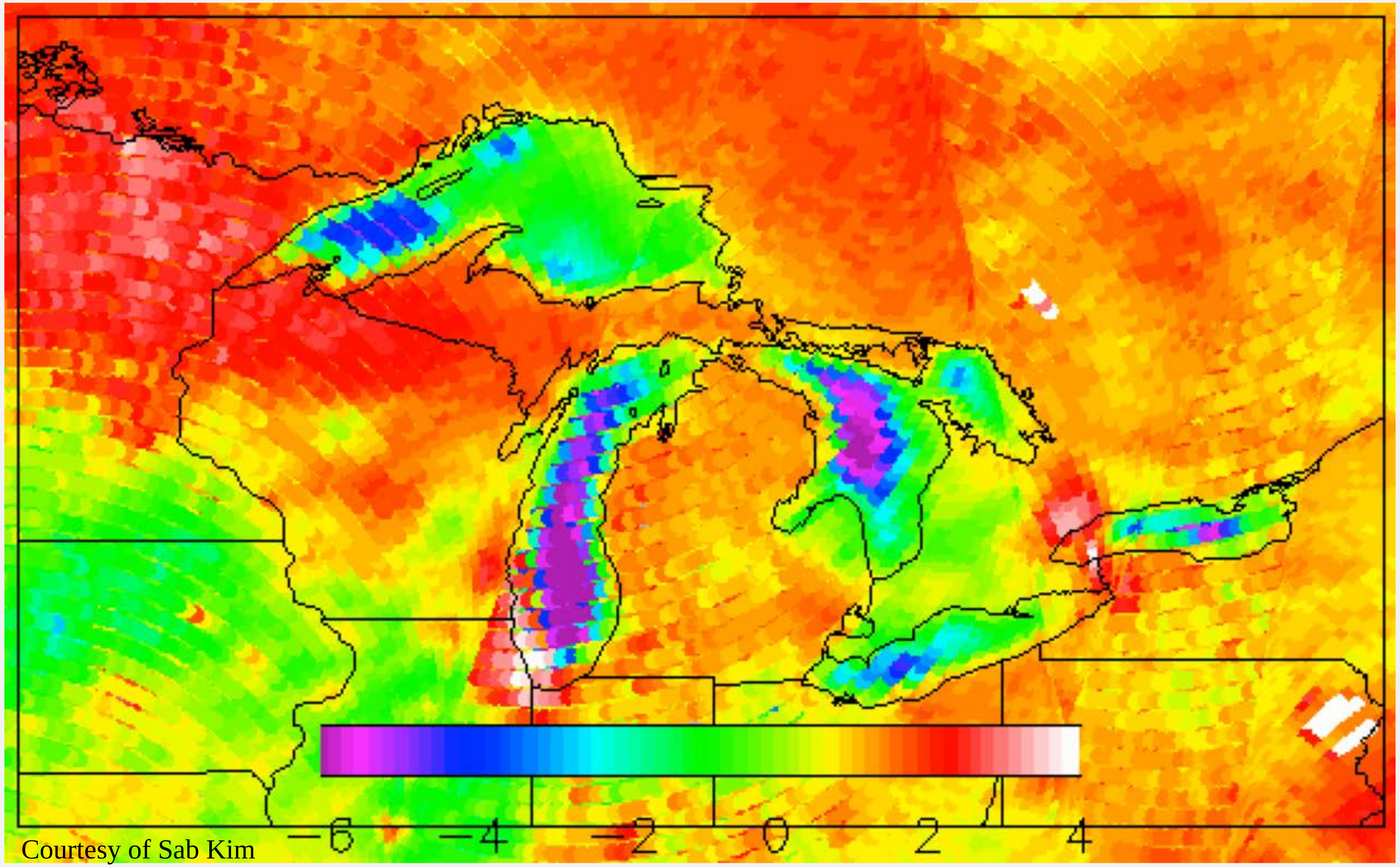
Levee Crown, Slope, and Toe Movement



Seep Detection

Lake Ice Melt - SMAP Radar

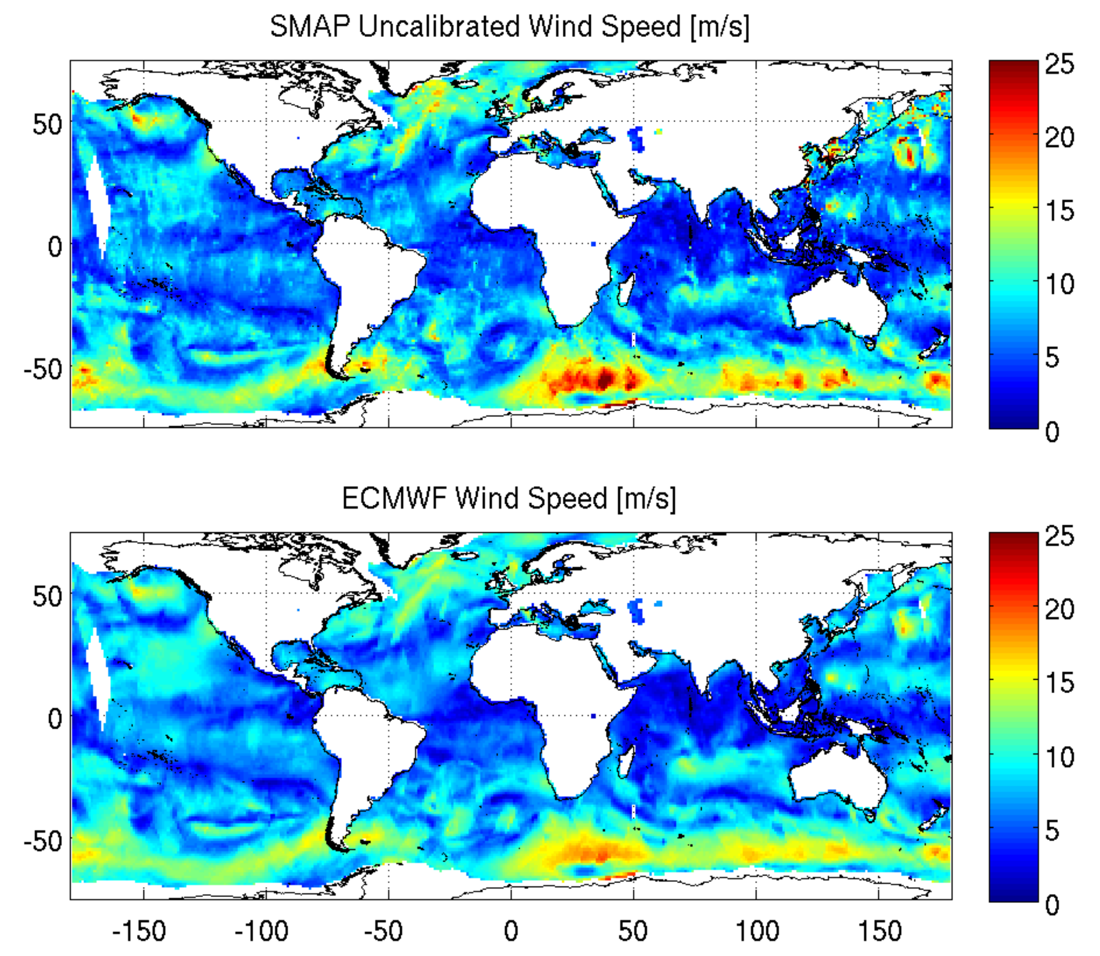
SMAP Radar HH/VV Ratio Indicates Melting of Lake Ice in the Great Lakes



Courtesy of Sab Kim

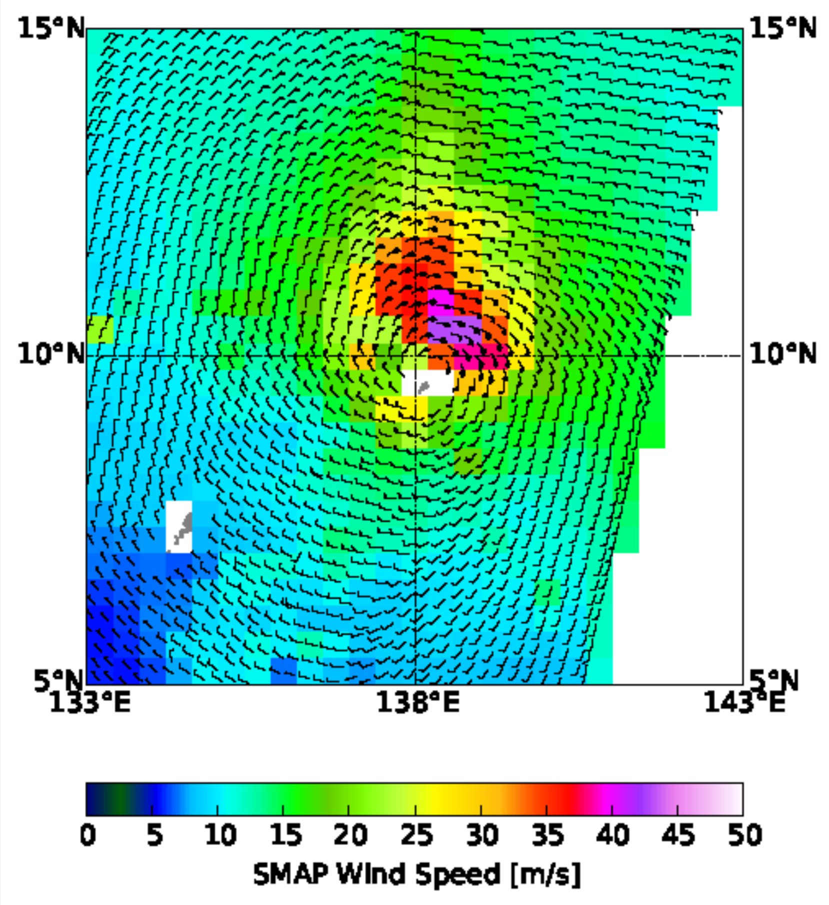
Ocean Surface Winds- SMAP Radar

SMAP two look radar data was used to produce ocean surface winds – good agreement with the ECMWF analysis

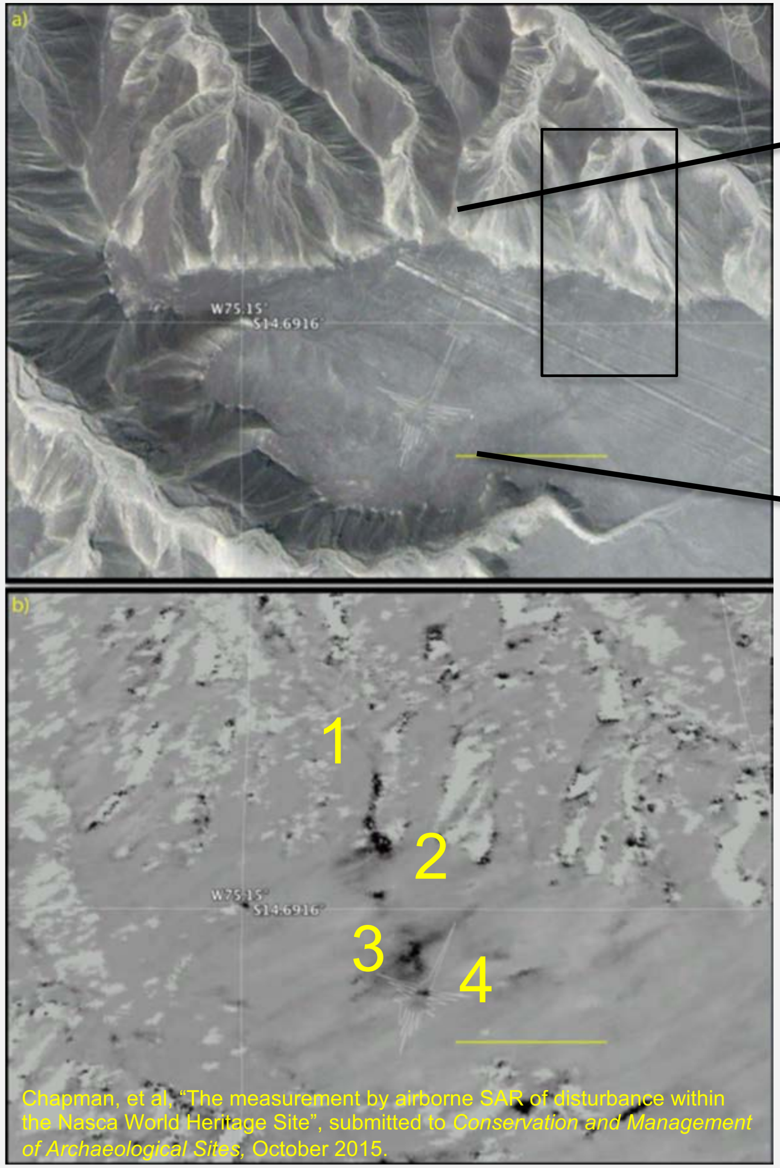


Courtesy of Lindstrom's Oceanography Program

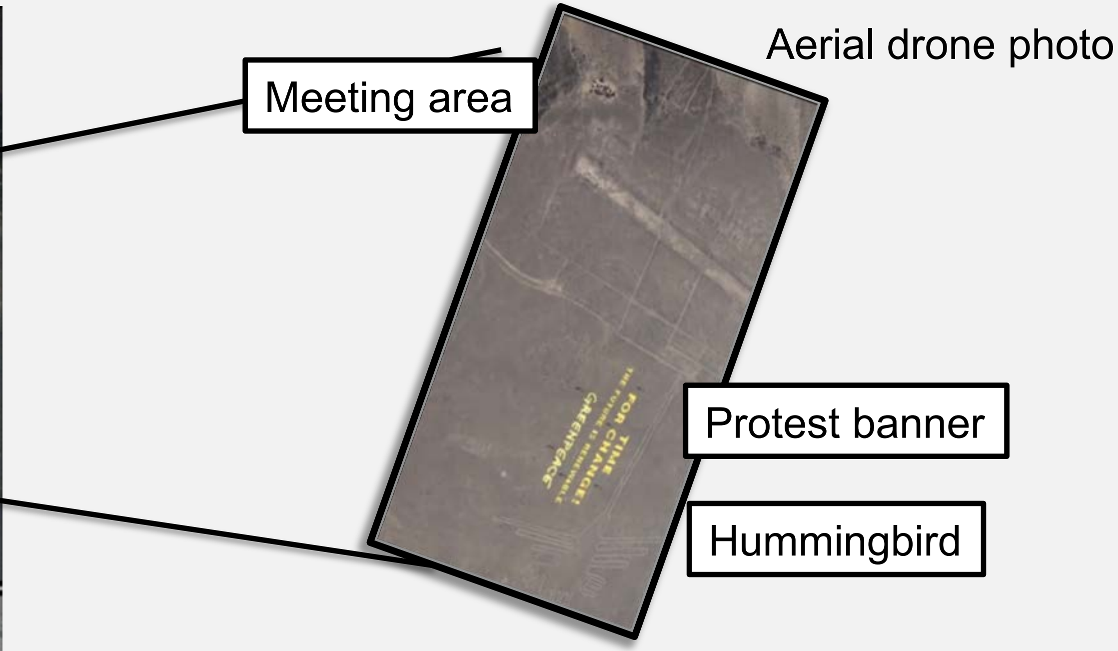
SMAP Radar Wind for Super Typhoon Maysak



Mapping Surface Disruption: Nazca Lines - Peru



Chapman, et al. "The measurement by airborne SAR of disturbance within the Nasca World Heritage Site", submitted to *Conservation and Management of Archaeological Sites*, October 2015.



Black corresponds to decorrelation between the two UAVSAR observations (March 2013 – March 2015), while grey and light grey correspond to areas with minimal decorrelation.

Five indications of disturbance are observed:

1) A path from the unpaved road to the North;
2) An area as one enters the pampa from below, where the protestors congregated and kept equipment;
3) The area near the hummingbird geoglyph, in close approximation to where the Greenpeace banners where placed;
4) Decorrelation within the head of the hummingbird itself;
5) Ridgeline areas of decorrelation where the slope is large and natural erosion may be occurring.

The yellow line indicates 100 m. North is up.

Radar Data Available

Legacy:

Current:

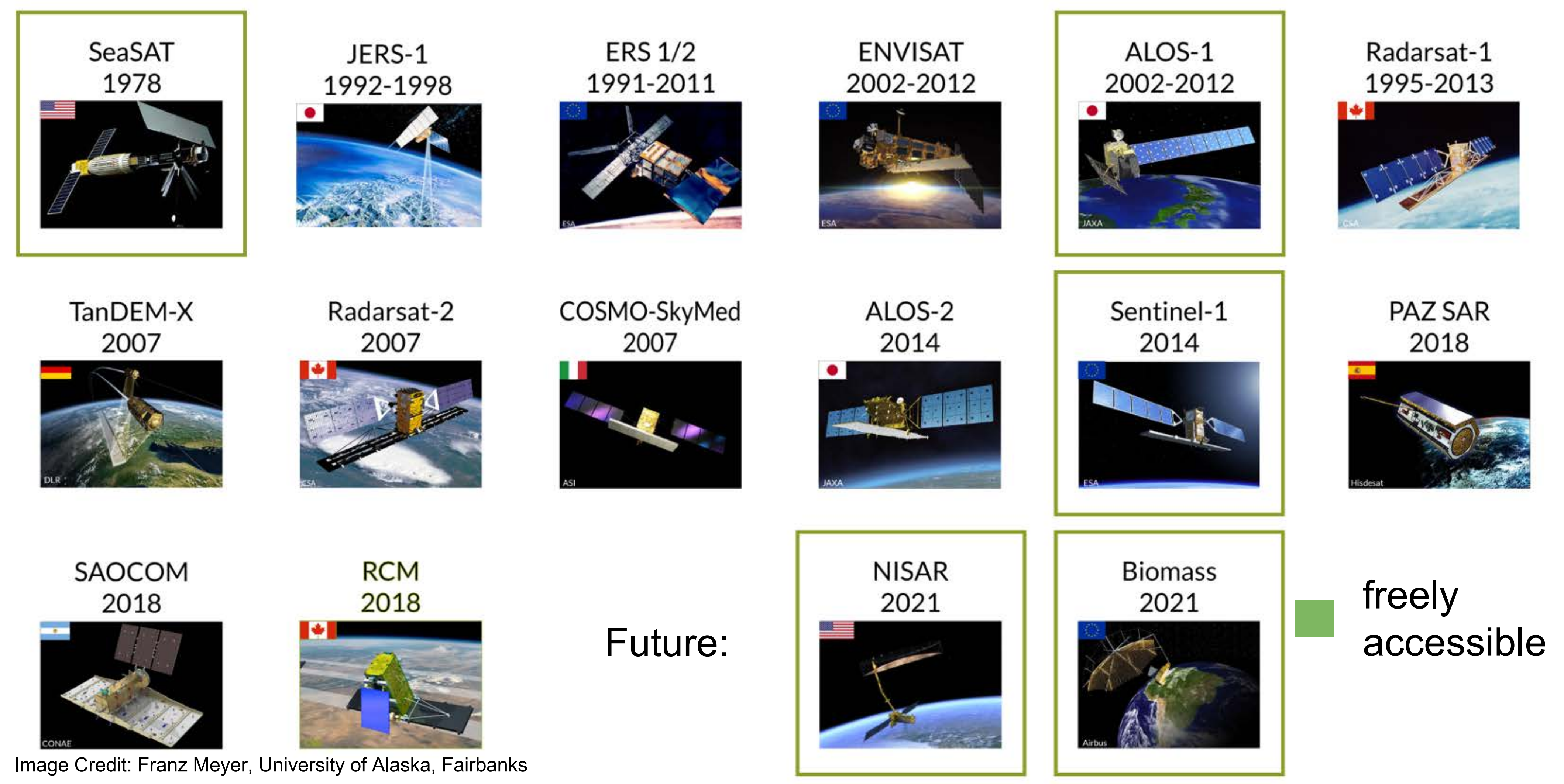
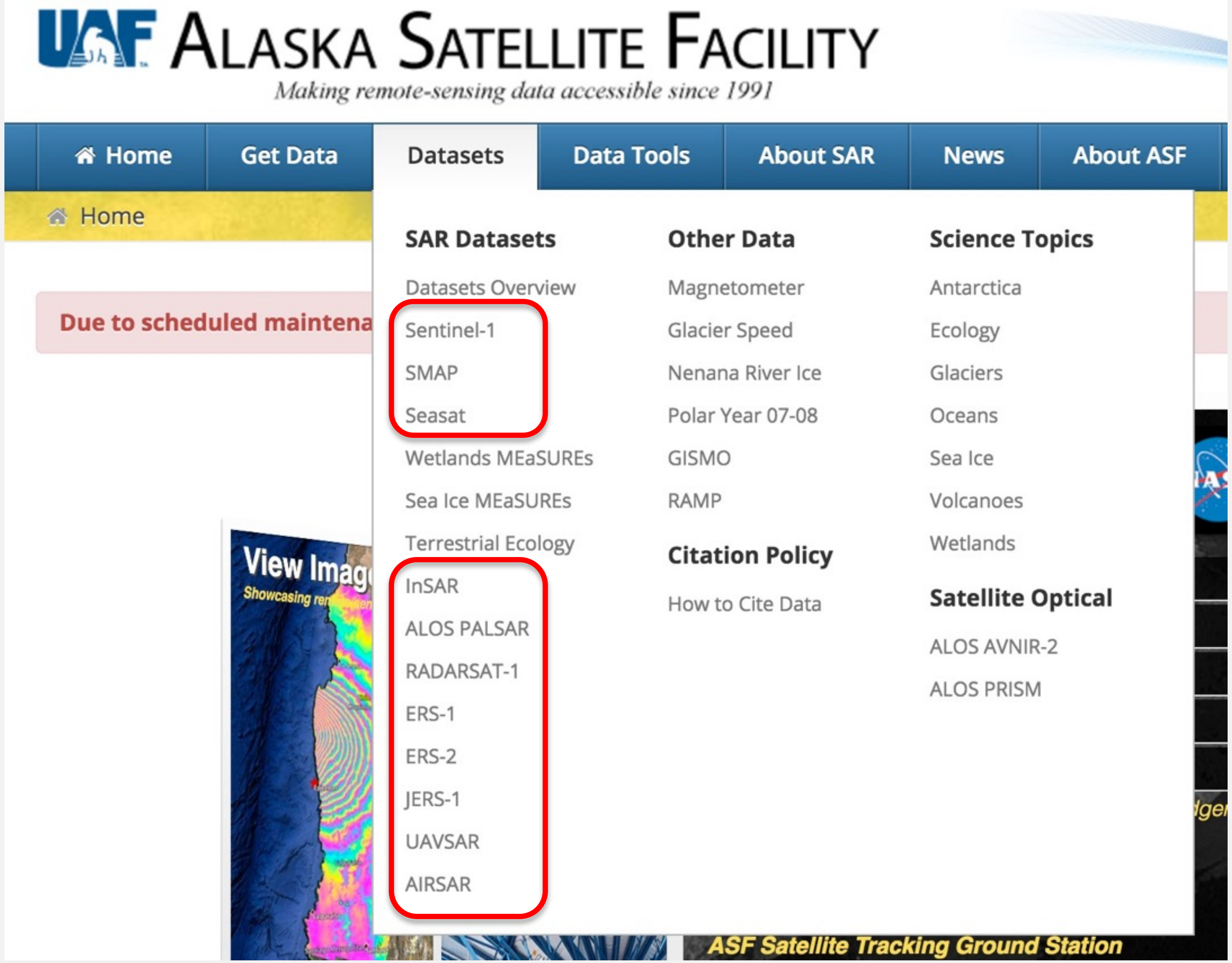


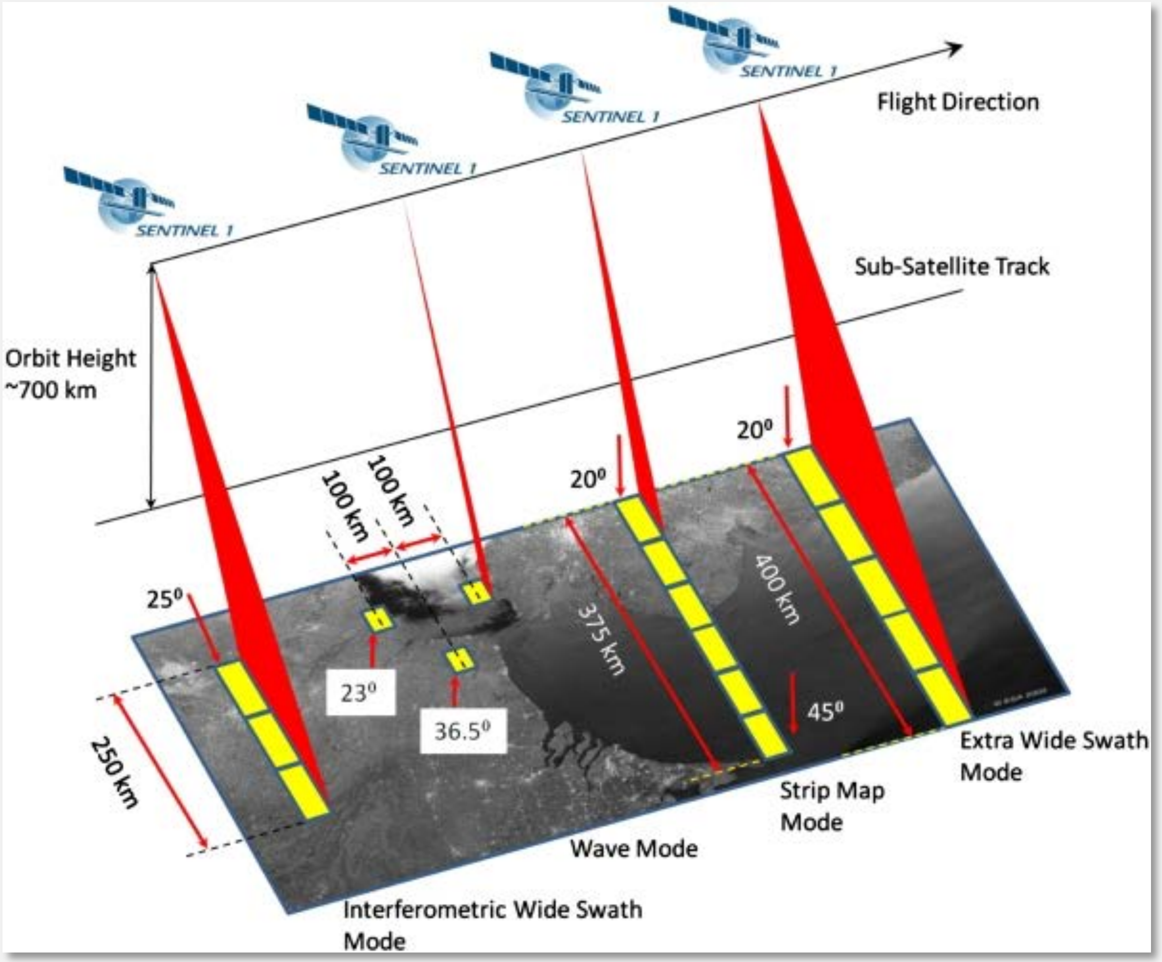
Image Credit: Franz Meyer, University of Alaska, Fairbanks

SAR Data at the Alaska Satellite Facility



Sentinel-1: Modes of Acquisition

1. Extra Wide Swath – for monitoring oceans and coasts (400 km swath, 25 x 100 m spatial resolution)
2. Strip Mode – by special order only and intended for special needs (80 km swath, 5 x 5 m spatial resolution)
3. Wave Mode – routine collection for the ocean (20 km x 20 km swath, 5 x 20 m spatial resolution)
4. Interferometric Wide Swath – routine collection for land (250 km swath, 5x20 m spatial resolution)



How to Access Sentinel-1 Images

- Alaska Satellite Facility (ASF)
  - http://www.asf.alaska.edu/sentinel/

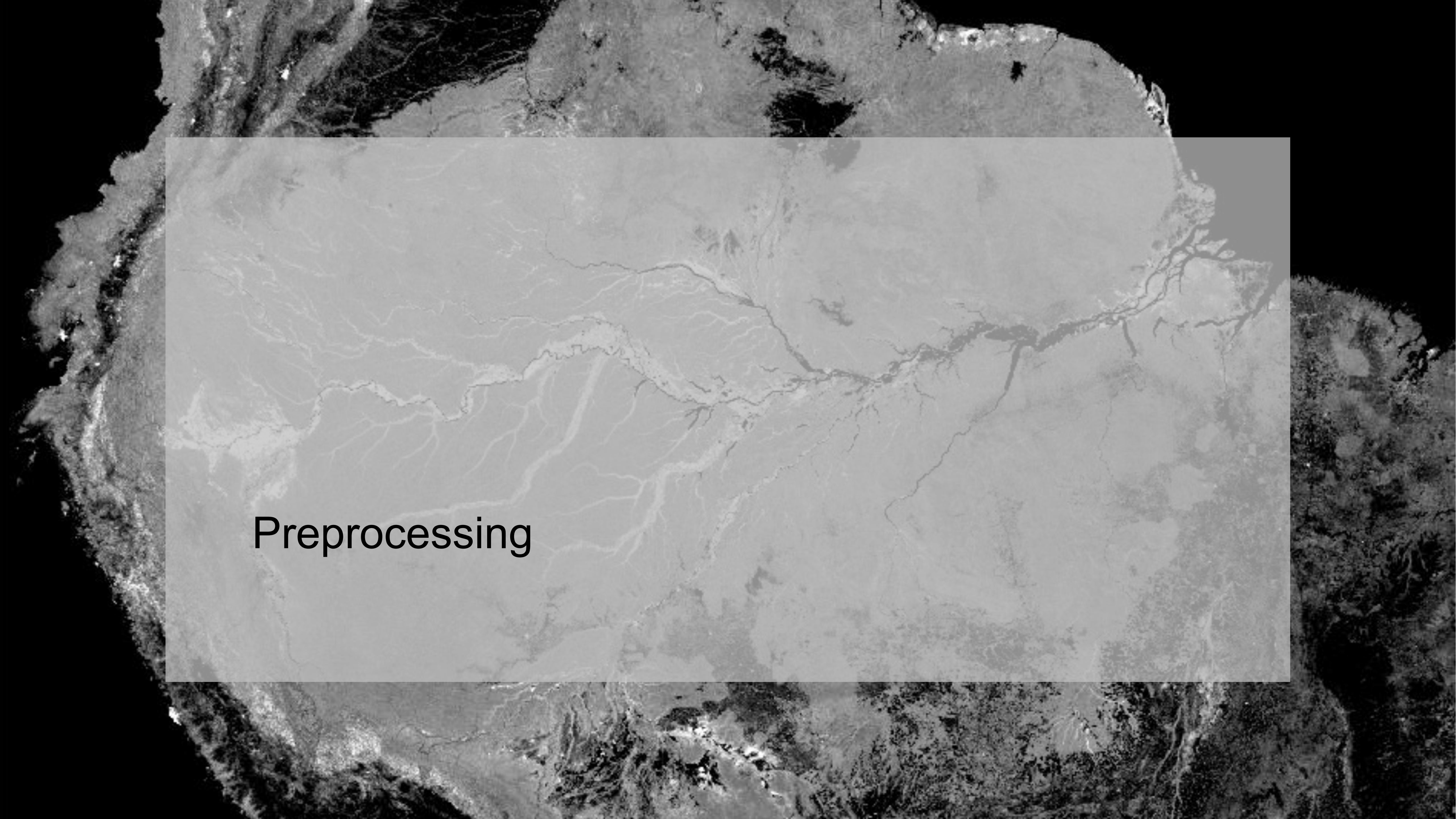
- European Space Agency Portal
  - https://scihub.copernicus.eu/dhus/#/home

Sentinel-1 Toolbox

- A free and open source software developed by ESA for processing and analyzing radar images from Sentinel-1 and other satellites.
- It can be accessed through the following site:

http://step.esa.int/main/download/snap-download/

- It includes the following tools
  - Calibration
  - Speckle noise
  - Terrain correction
  - Mosaic production
  - Polarimetry
  - Interferometry
  - Classification



Preprocessing

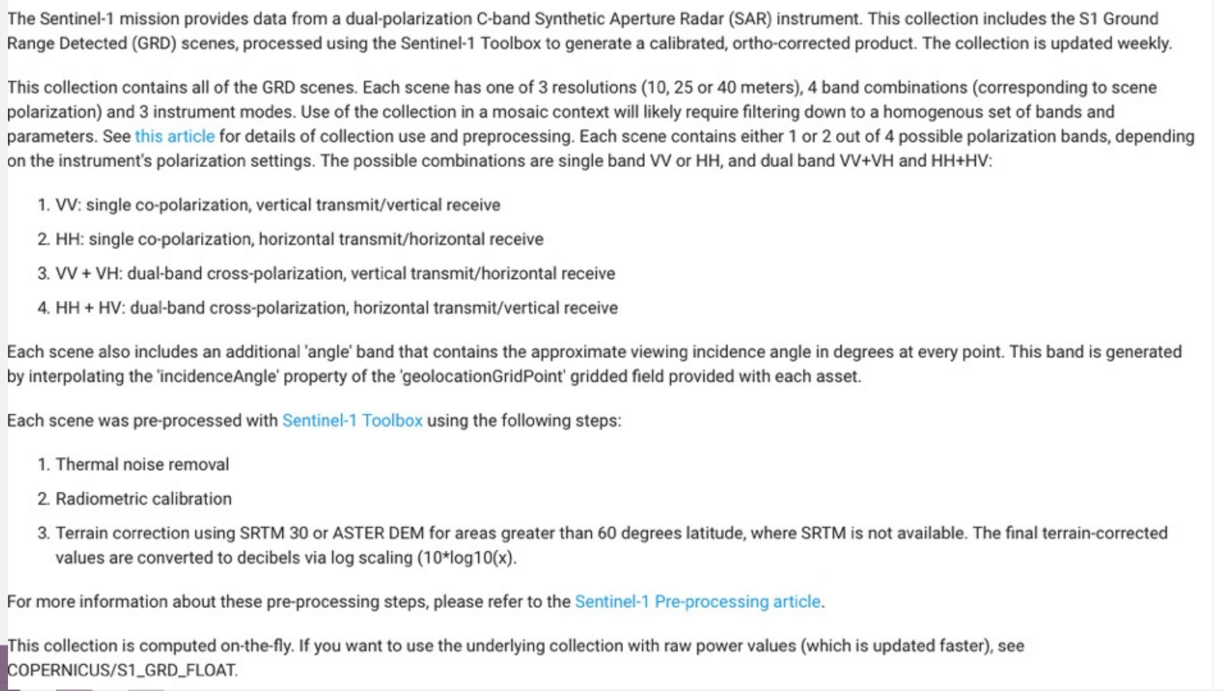
Preprocessing Steps

1. Apply Orbit File
2. Radiometric Calibration
3. Speckle Reduction
4. Geometric Calibration

Google Earth Engine - Sentinel-1 Catalog

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

-Analysis ready data.
-Only the amplitude images are available (no phase).
-All images are in dB



The Sentinel-1 mission provides data from a dual-polarization C-band Synthetic Aperture Radar (SAR) instrument. 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 weekly.

This collection contains all of the GRD scenes. Each scene has one of 3 resolutions (10, 25 or 40 meters), 4 band combinations (corresponding to scene polarization) and 3 instrument modes. Use of the collection in a mosaic context will likely require filtering down to a homogenous set of bands and parameters. See this article for details of collection use and preprocessing. Each scene contains either 1 or 2 out of 4 possible polarization bands, depending on the instrument's polarization settings. The possible combinations are single band VV or HH, and dual band VV+VH and HH+HV:

1. VV: single co-polarization, vertical transmit/vertical receive
2. HH: single co-polarization, horizontal transmit/horizontal receive
3. VV + VH: dual-band cross-polarization, vertical transmit/horizontal receive
4. HH + HV: dual-band cross-polarization, horizontal transmit/vertical receive

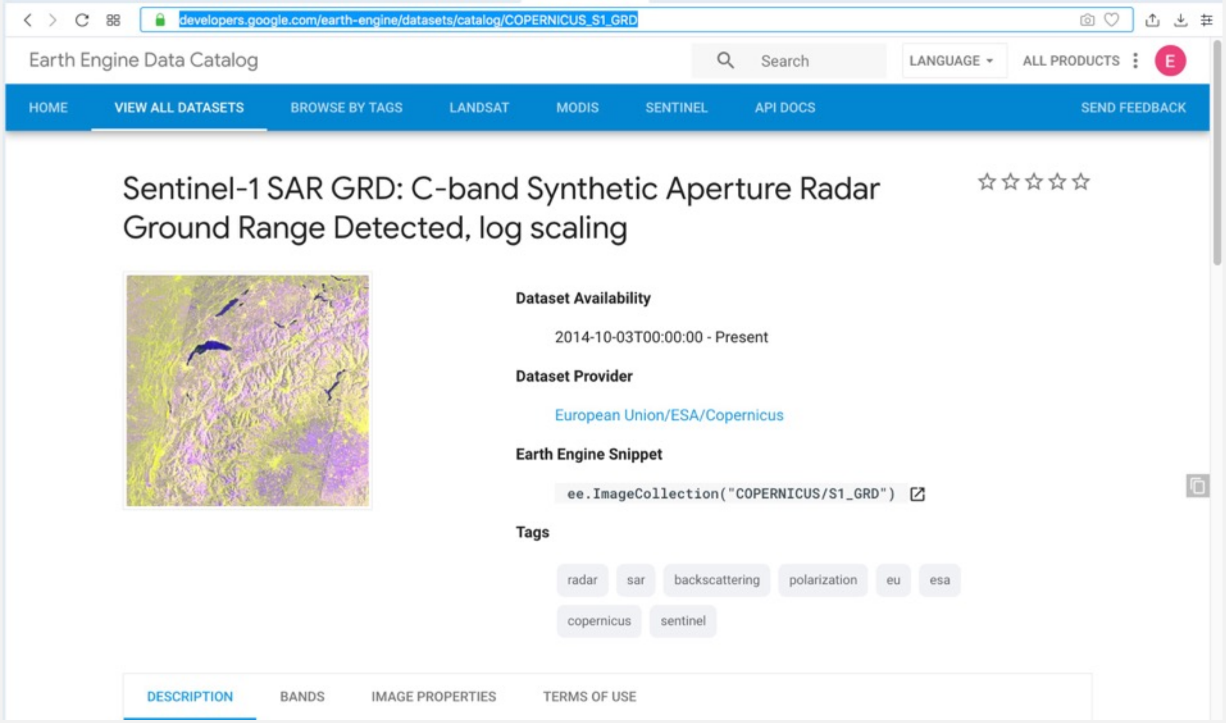
Each scene also includes an additional 'angle' band that contains the approximate viewing incidence angle in degrees at every point. This band is generated by interpolating the 'incidenceAngle' property of the 'geolocationGridPoint' gridded field provided with each asset.

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).

For more information about these pre-processing steps, please refer to the Sentinel-1 Pre-processing article.

This collection is computed on-the-fly. If you want to use the underlying collection with raw power values (which is updated faster), see COPERNICUS/S1_GRD_FLOAT.



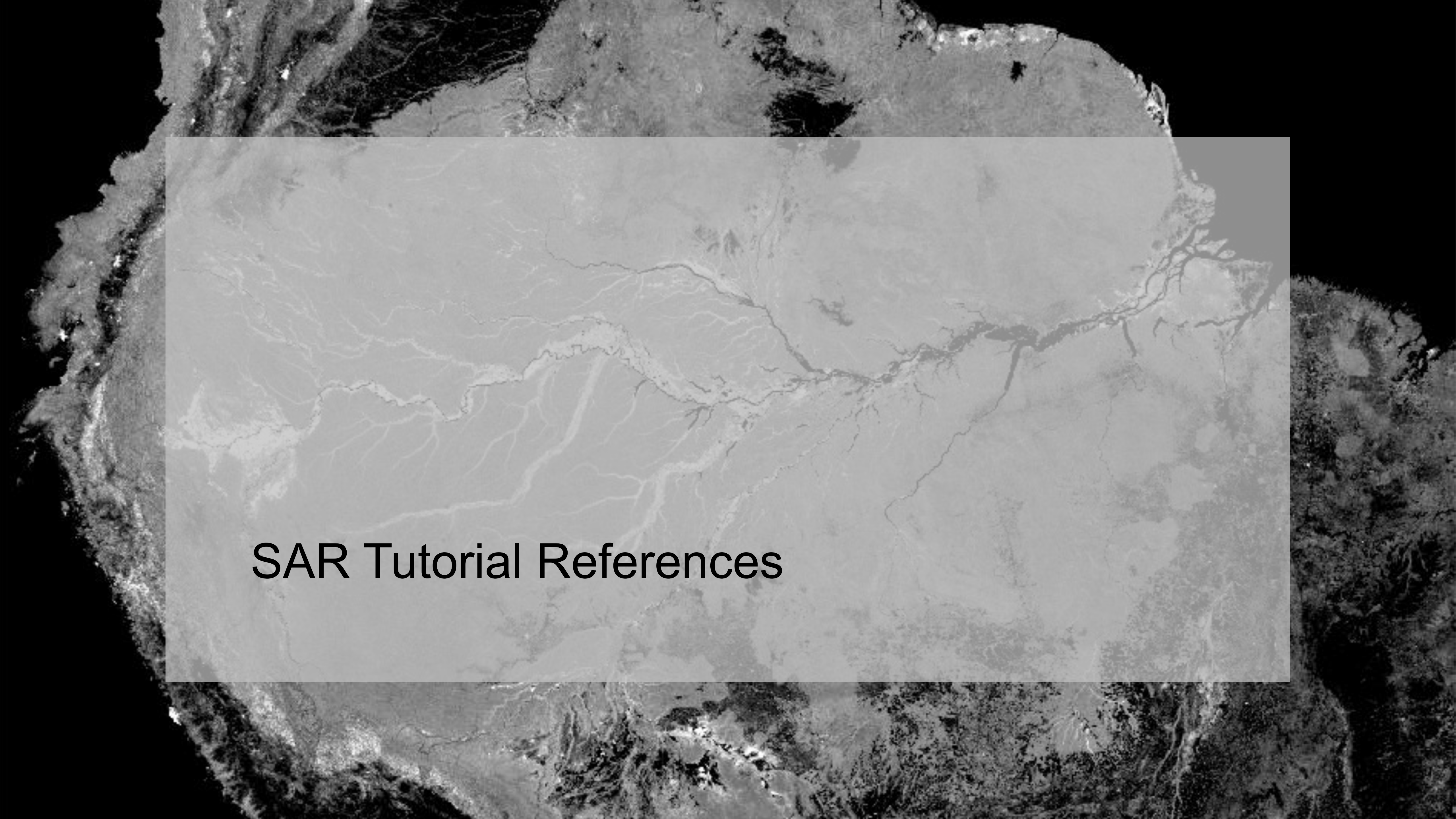
Sentinel-1 SAR GRD: C-band Synthetic Aperture Radar Ground Range Detected, log scaling

Dataset Availability
2014-10-03T00:00:00 - Present

Dataset Provider
European Union/ESA/Copernicus

Earth Engine Snippet
`ee.ImageCollection("COPERNICUS/S1_GRD")`

Tags
radar sar backscattering polarization eu esa copernicus sentinel



SAR Tutorial References

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=IDxBgK1VY_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

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
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_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/sentinel-1-toolbox-tutorials/

Questions?

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