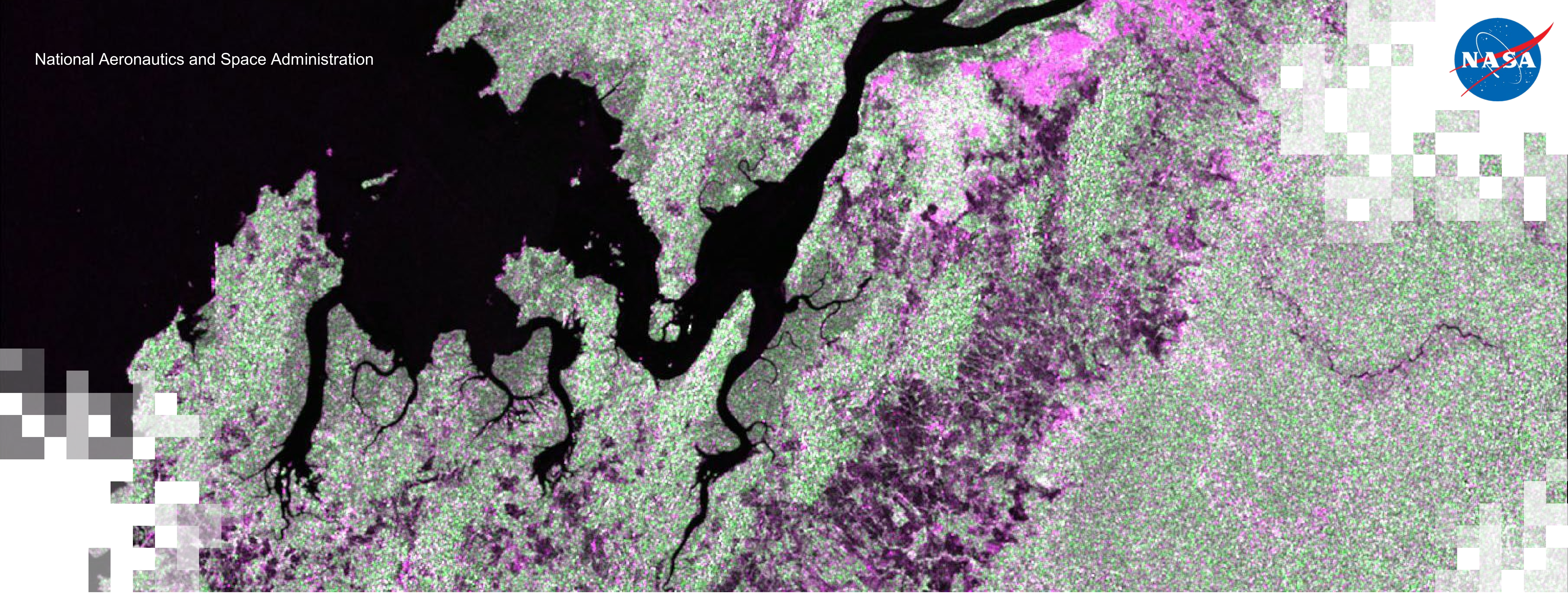
National Aeronautics and Space Administration



Forest Mapping and Monitoring with SAR Data: Time Series Analysis

Erika Podest, Amber McCullum, Juan Luis Torres Perez, Sean McCartney

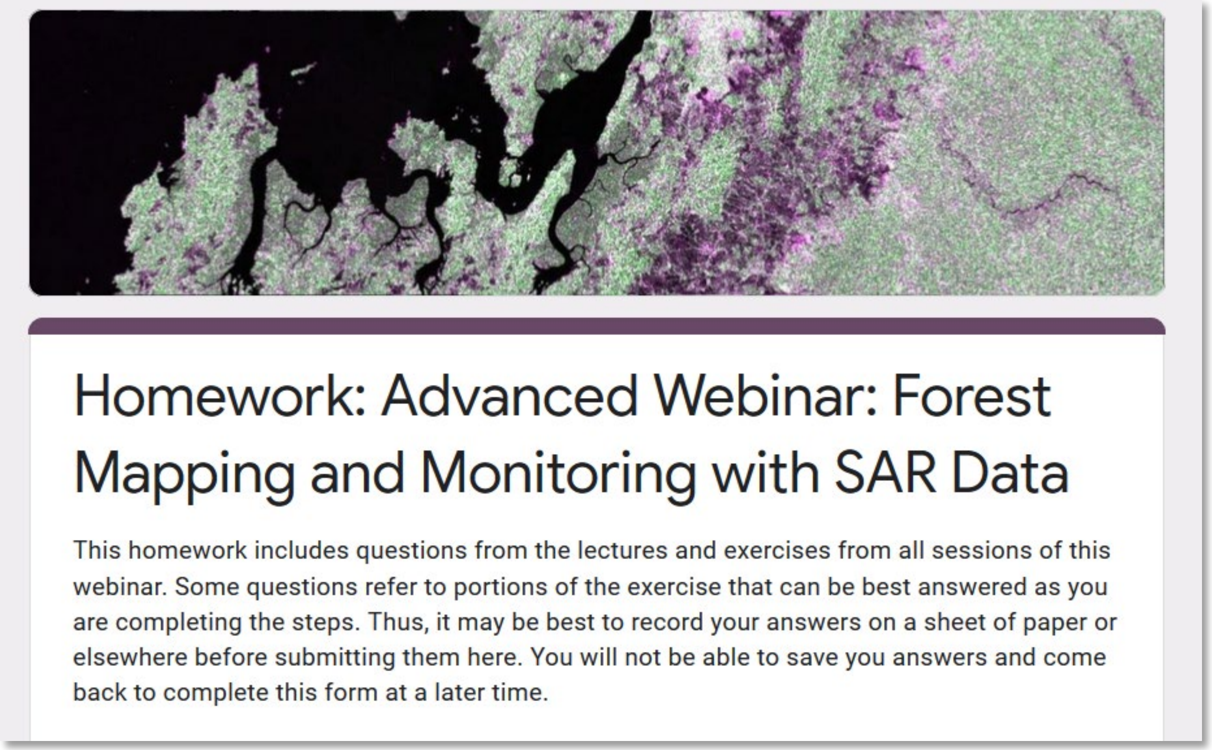
May 12, 2020

Course Structure

- Four, 2-hour sessions on **May 12, 14, 19,** and **21**
- There will be 2 sessions per day presenting the same material in
  - English (11:00-13:00 EST)
  - Spanish (14:00-16:00 EST)
  - **Please only sign up for and attend one session per day.**
- Webinar recordings, PowerPoint presentations, and the homework assignment can be found after each session at:
  - https://arset.gsfc.nasa.gov/land/webinars/forest-mapping-sar
  - Q&A: Following each lecture and/or by email:
    - erika.podest@jpl.nasa.gov
    - amberjean.mccullum@nasa.gov
    - juan.l.torresperez@nasa.gov

Homework and Certificates

- **Homework:**
  - One homework assignment
  - Answers must be submitted via Google Forms
- **Certificate of Completion:**
  - Attend all four live webinars
  - Complete the homework assignment by **Thursday, June 4th** (access from ARSET website)
  - You will receive certificates approximately two months after completion of the course from: marines.martins@ssaihq.com

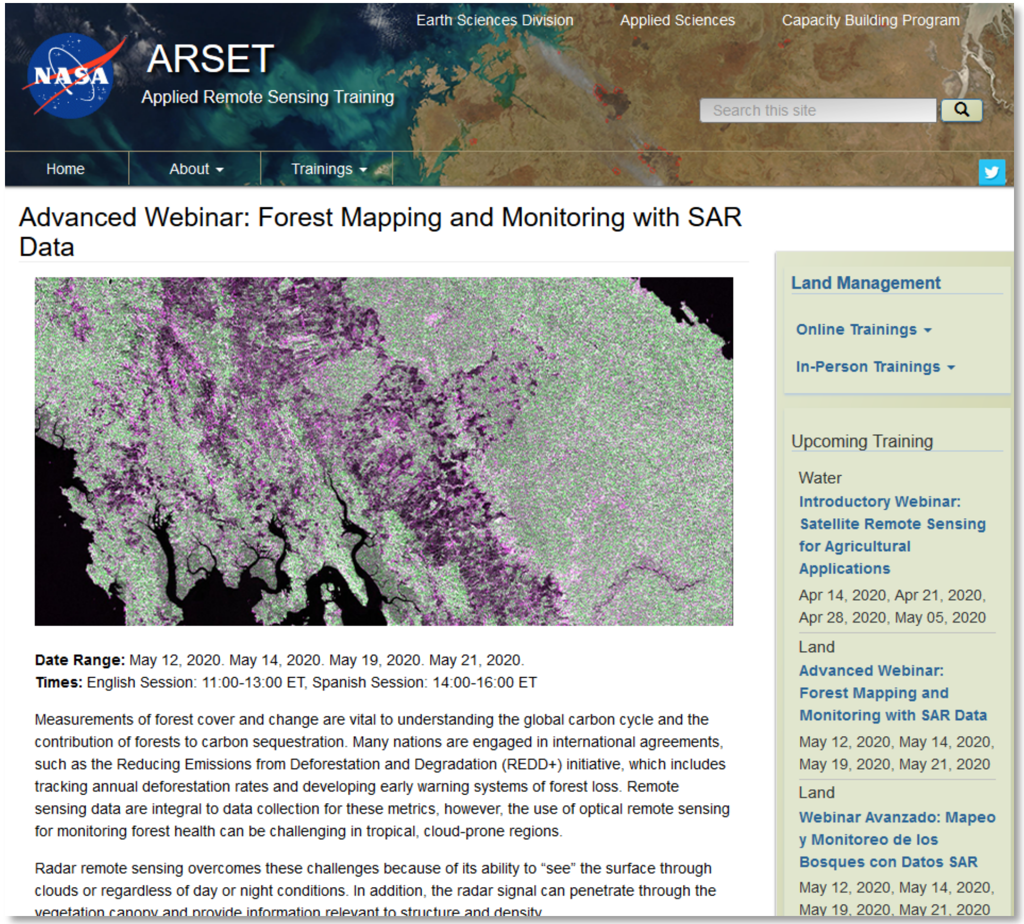


Homework: Advanced Webinar: Forest Mapping and Monitoring with SAR Data

This homework includes questions from the lectures and exercises from all sessions of this webinar. Some questions refer to portions of the exercise that can be best answered as you are completing the steps. Thus, it may be best to record your answers on a sheet of paper or elsewhere before submitting them here. You will not be able to save you answers and come back to complete this form at a later time.

Prerequisites and Course Materials

- **Prerequisites:**
  - Please complete the following courses or have equivalent experience:
    - Introduction to Synthetic Aperture Radar
    - Advanced Webinar: SAR for Landcover Applications
  - Set-up a Google Earth Engine account (free):
  - https://earthengine.google.com
- **Course Materials:**
  - https://arset.gsfc.nasa.gov/land/webinars/forest-mapping-sar



Course Outline

Part 1: Time Series Analysis of Forest Change

Part 2: Land Cover Classification with Radar and Optical Data

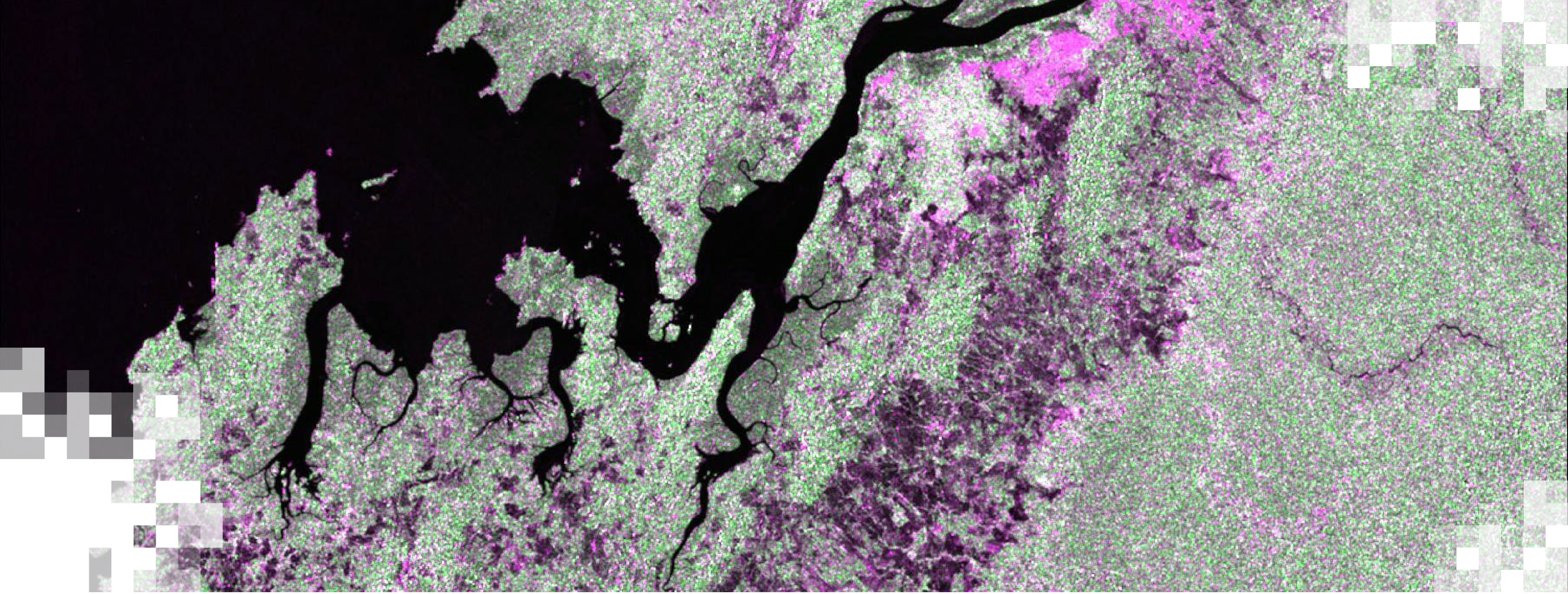
Part 3: Mangrove Mapping

Part 4: Forest Stand Height

Learning Objectives

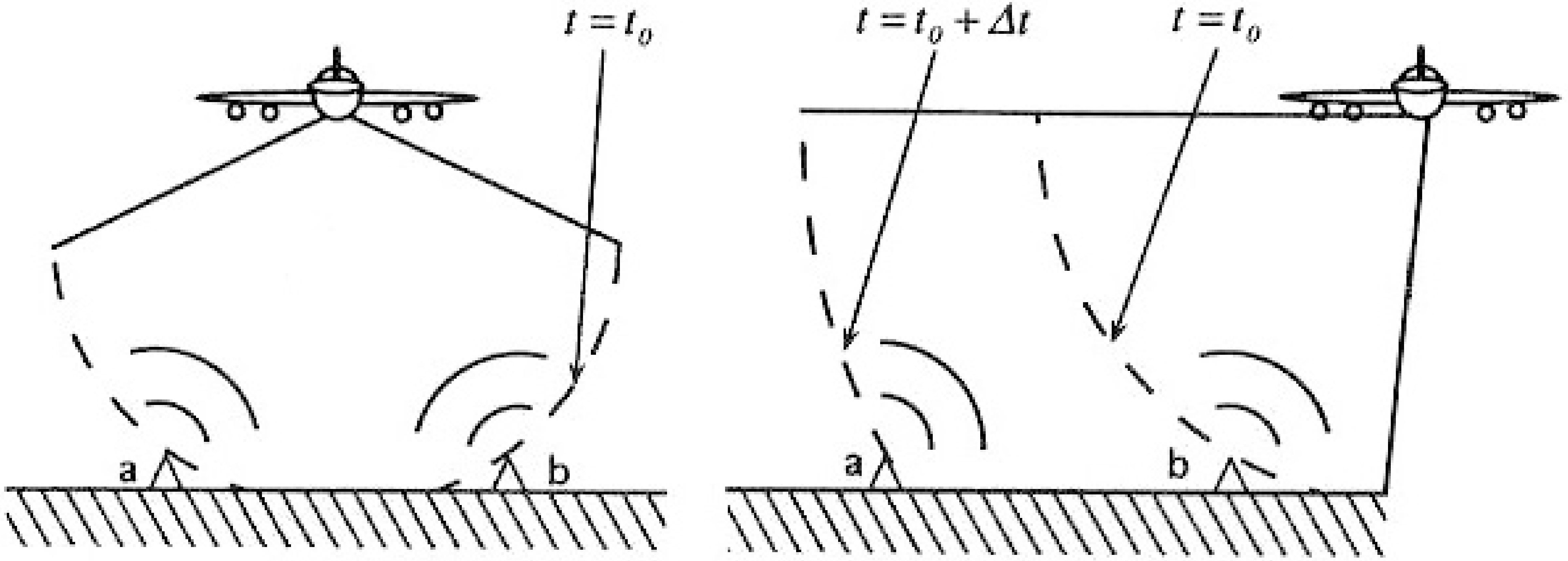
By the end of this presentation, you will be able to:

- Identify the unique attributes of radar data
- Understand how multiple radar images can be used to analyze change across time in forests
- Conduct a time series analysis of change in forest cover using radar data in Google Earth Engine



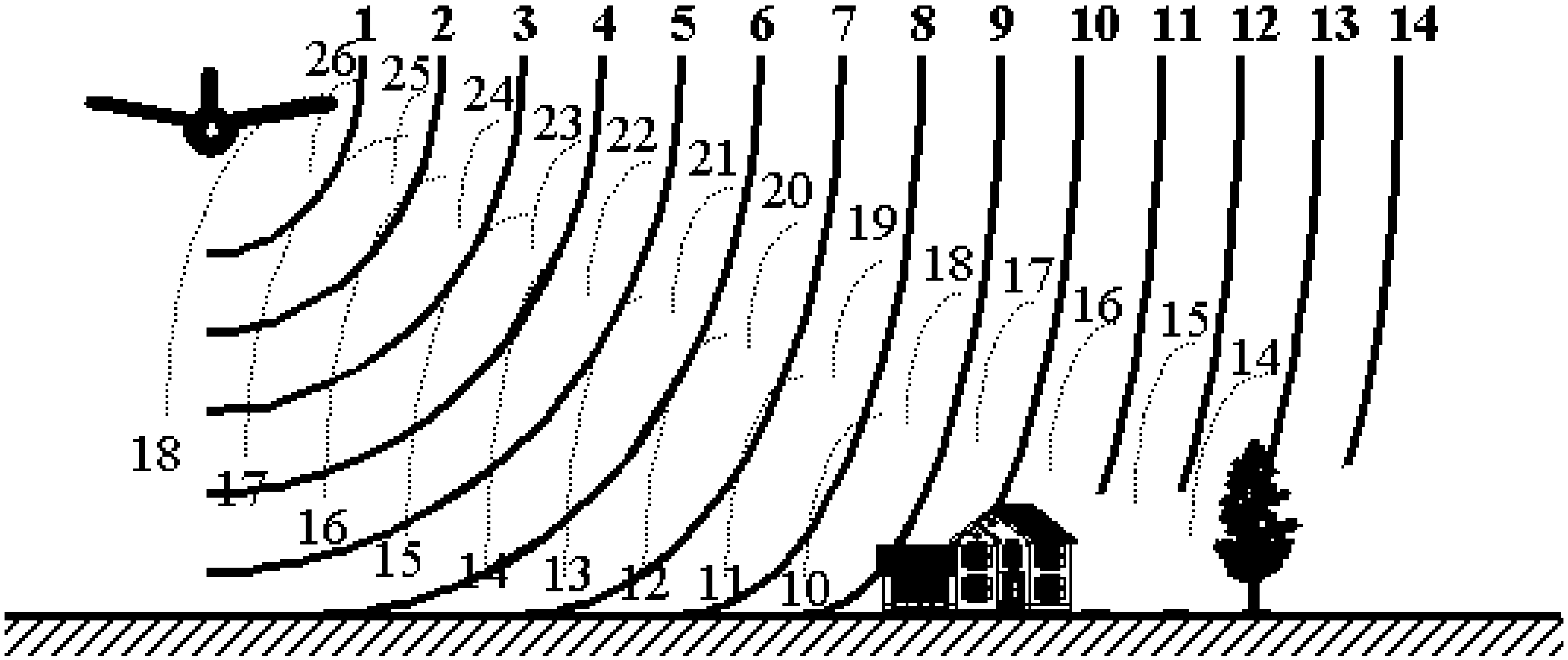
Radar Overview

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

Parameters to Consider for a Land Cover Mapping Study

Radar Parameters

- Wavelength
- Polarizations
- Incidence Angle

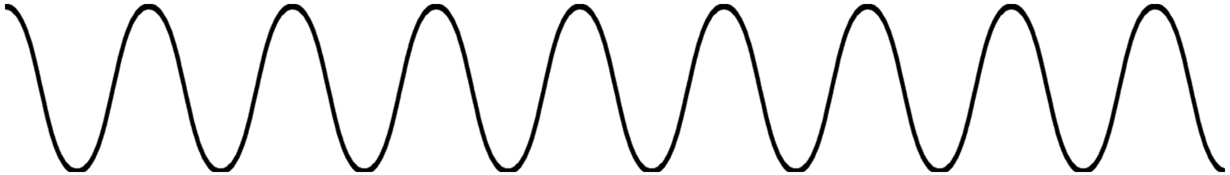
Surface Parameters

- Structure
- Dielectric

Radar Parameters: Wavelength

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

Higher Frequency



Shorter Wavelength

Lower Frequency

Longer Wavelength

Band Designation*	Wavelength (λ), cm	Frequency (ν), GH_z (10^9 cycles·sec^{-1})
Ka (**0.86 cm**)	0.8 – 1.1	40.0 – 26.5
K	1.1 – 1.7	26.5 – 18.0
Ku	1.7 – 2.4	18.0 – 12.5
X (**3.0 cm, 3.2 cm**)	2.4 – 3.8	12.5 – 8.0
C (**5.0**)	3.8 – 7.5	8.0 – 4.0
S	7.5 – 15.0	4.0 – 2.0
L (**23.5 cm, 25 cm**)	15.0 – 30.0	2.0 – 1.0
P (**68 cm**)	30.0 – 100.0	1.0 – 0.3

*Wavelengths most frequently used in SAR are in parentheses.

Penetration as a Function of Wavelength

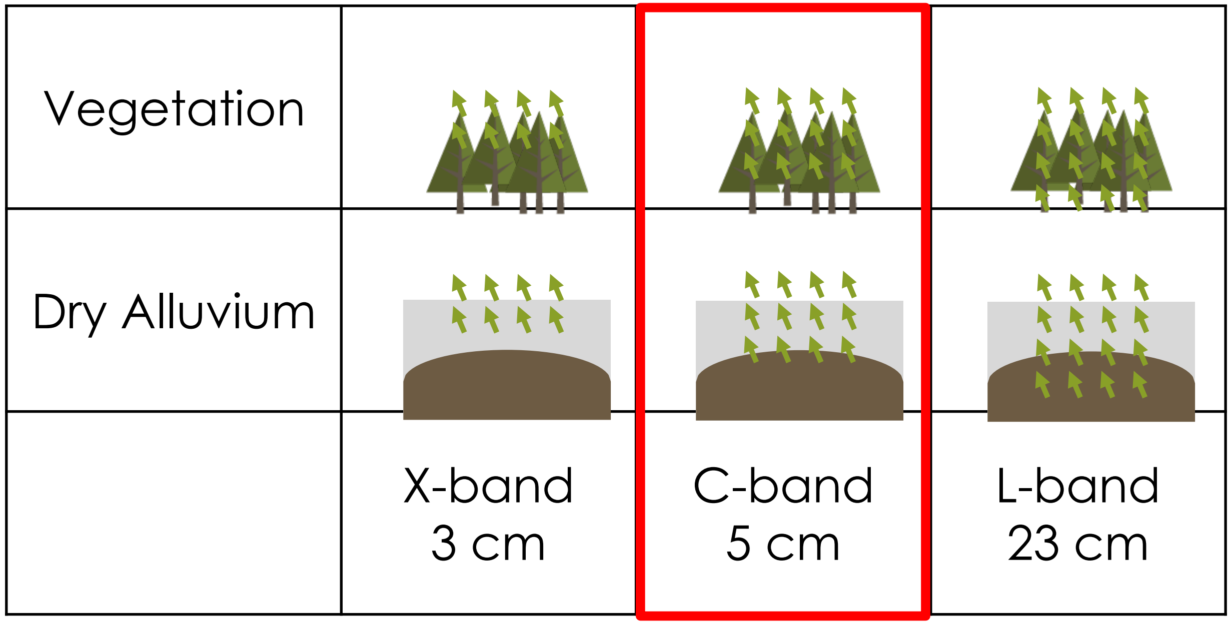


Image (left) based on ESA Radar Course 2; Table (right) Credit: DLR

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

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

Example: Radar Signal Penetration into Vegetation

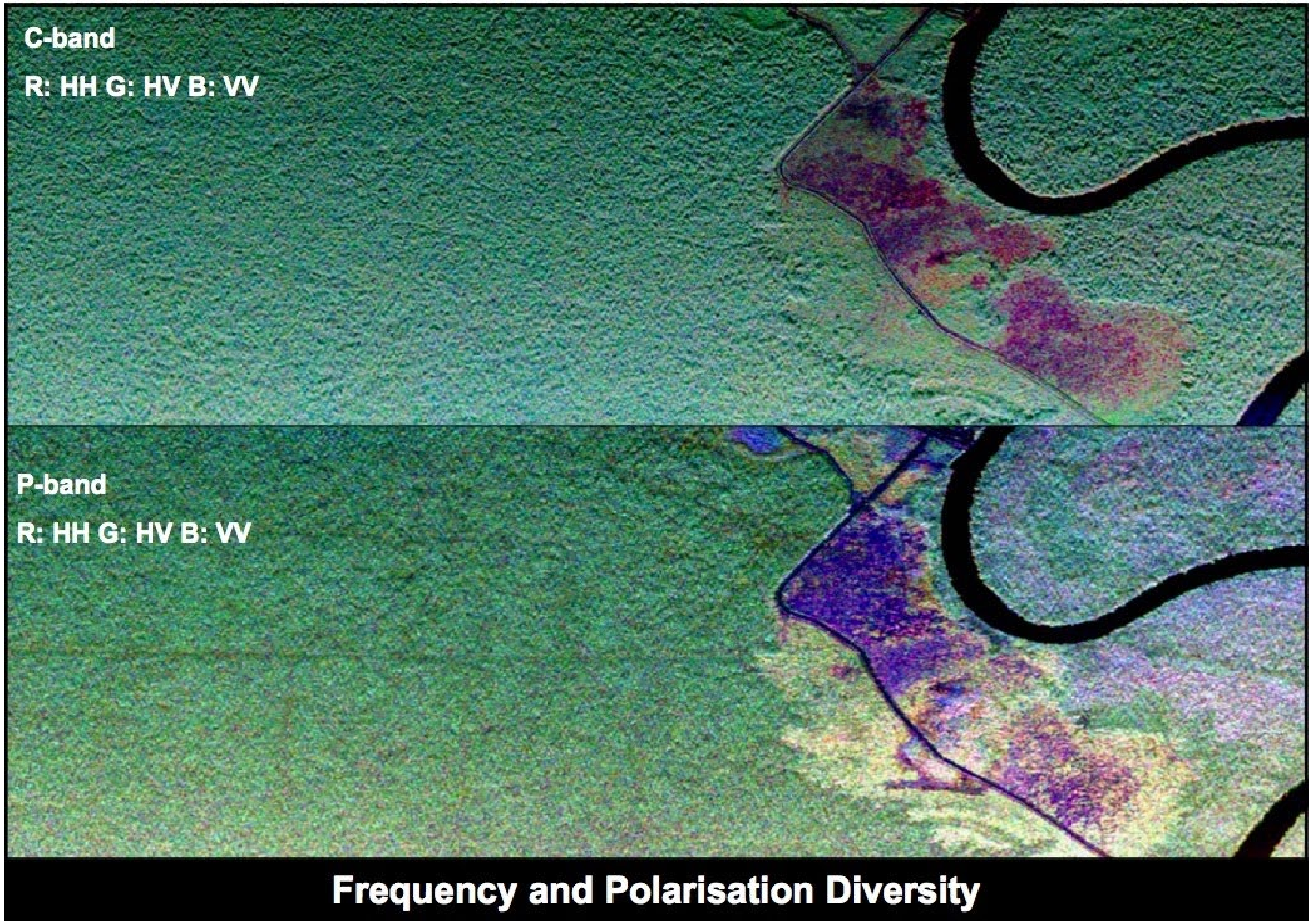


Image Credit: A. Moreira - ESA

Radar Parameters: Polarization

- The radar signal is polarized.
- The polarizations are usually controlled between H and V:
  - HH: Horizontal Transmit, Horizontal Receive
  - HV: Horizontal Transmit, Vertical Receive
  - VH: Vertical Transmit, Horizontal Receive
  - VV: Vertical Transmit, Vertical Receive
- Quad-Pol Mode: When all four polarizations are measured.
- Different polarizations can determine physical properties of the object observed.

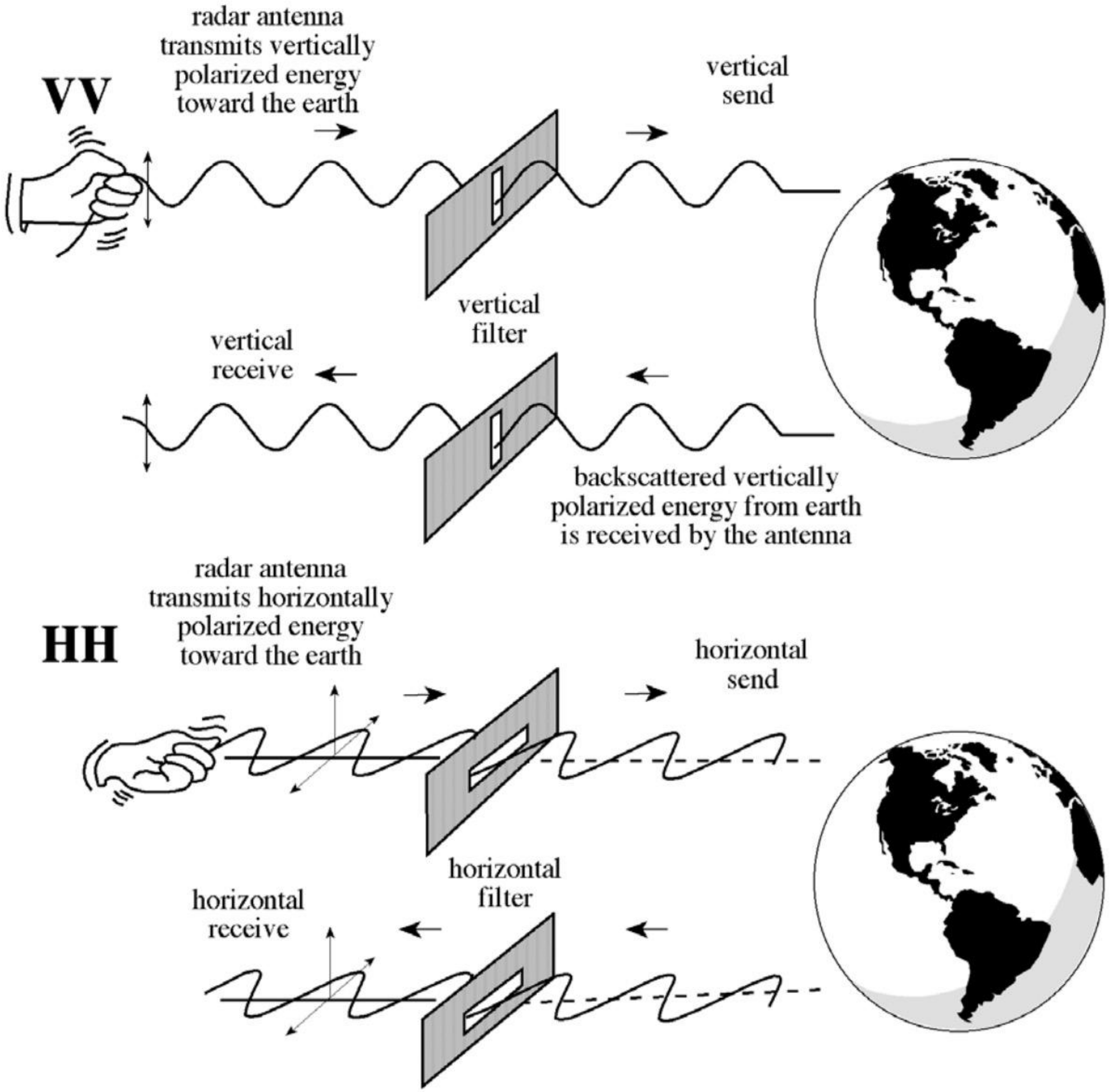


Image Credit: J.R. Jensen, 2000, Remote Sensing of the Environment

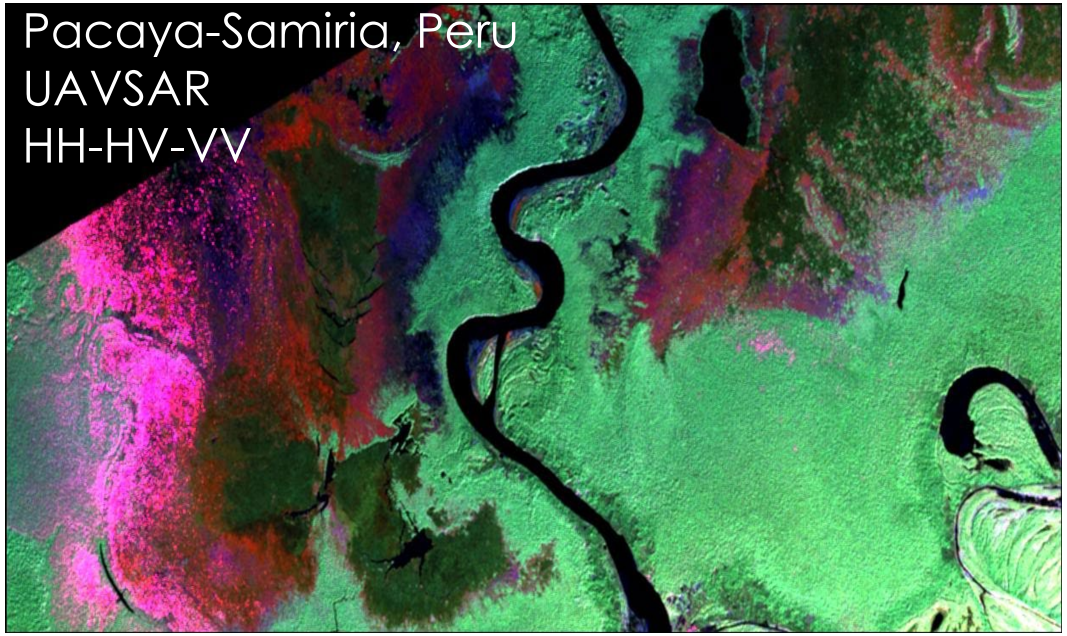
Example of Multiple Polarizations for Vegetation Studies

Pacaya-Samiria Forest Reserve in Peru

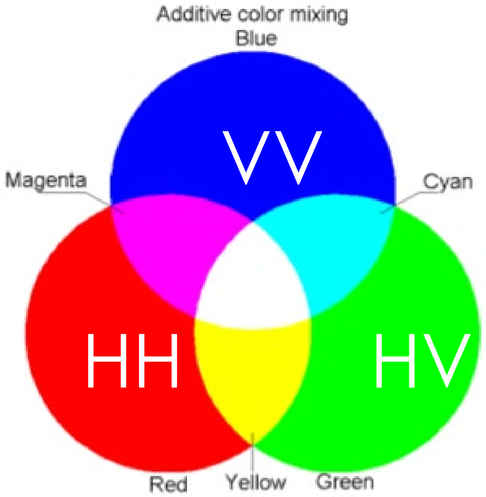
Images from UAVSAR (HH, HV, VV)

Example of Multiple Polarizations for Vegetation Studies

Pacaya-Samiria Forest Reserve in Peru



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

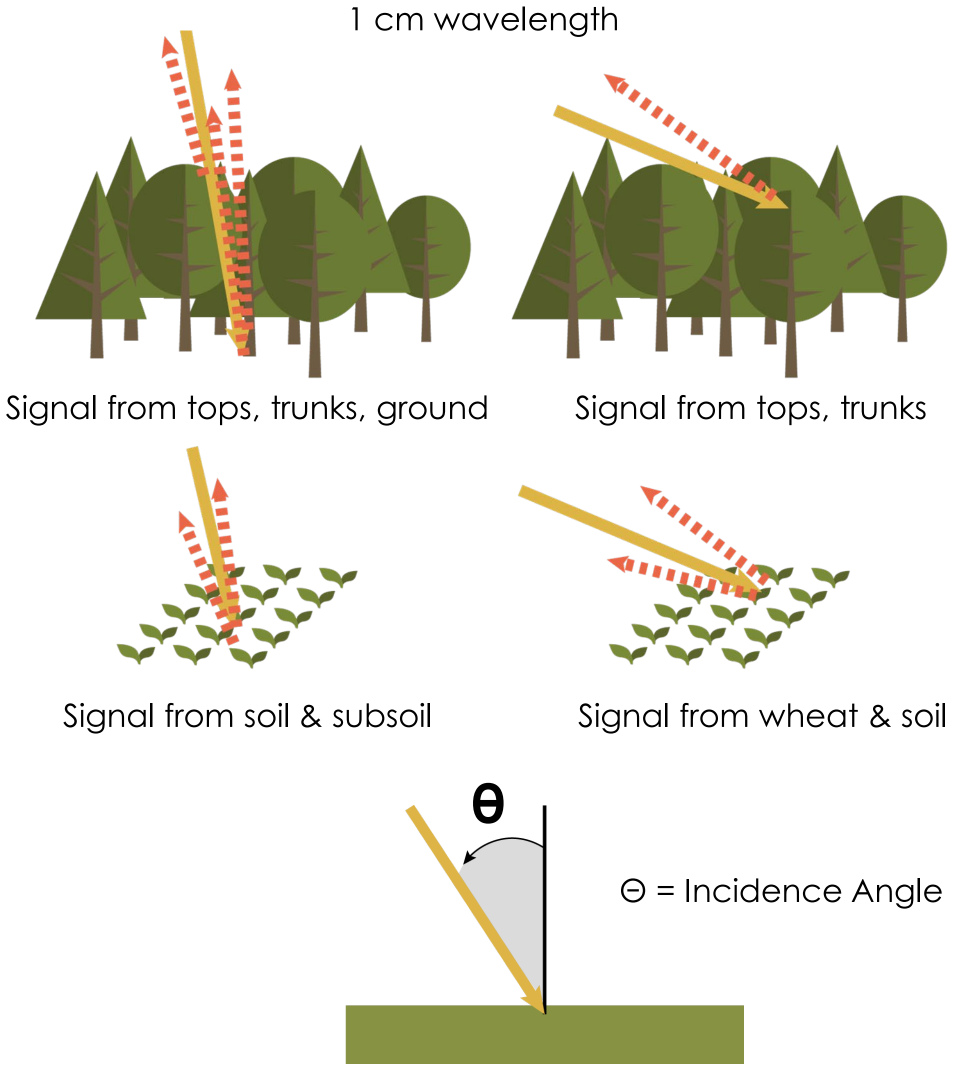


Source: SAR Handbook, Chapter 2 by J. Kellndorfer

Radar Parameters: Incidence Angle

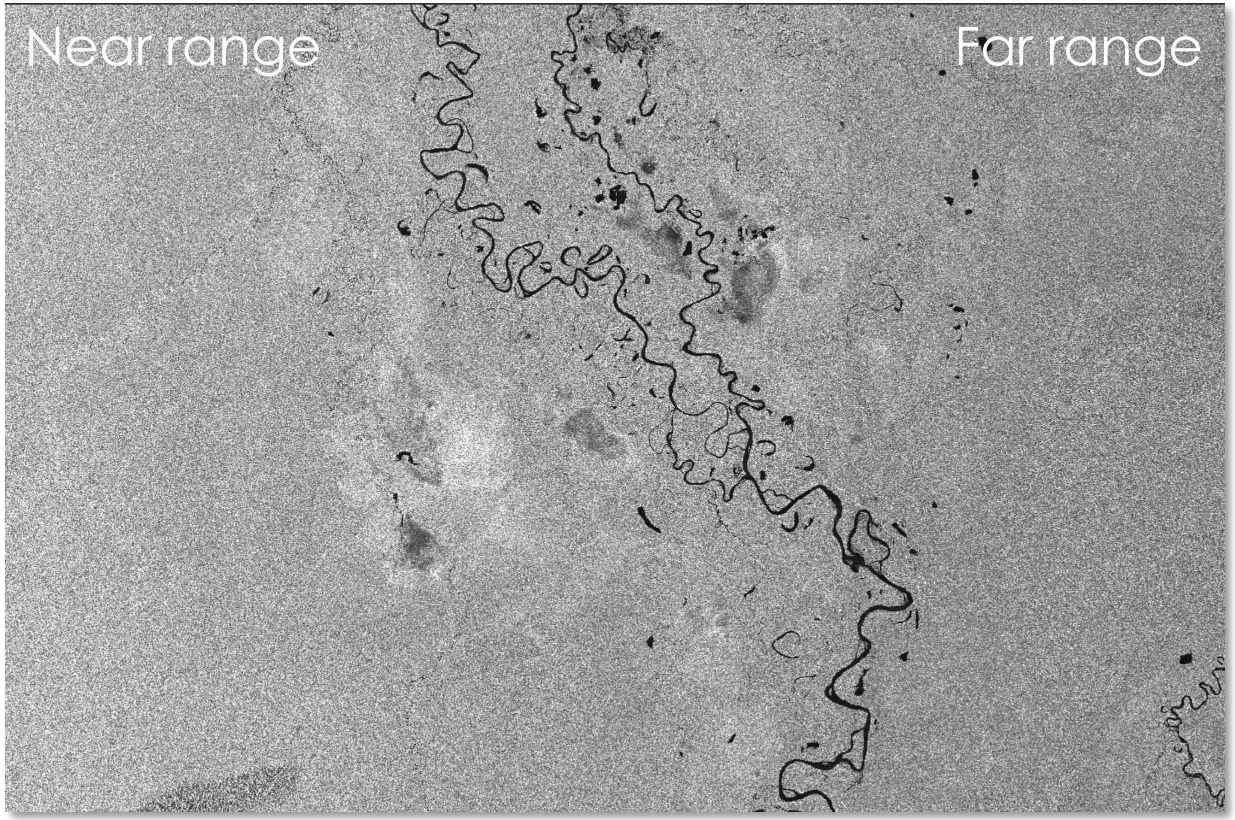
Local Incidence Angle:

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

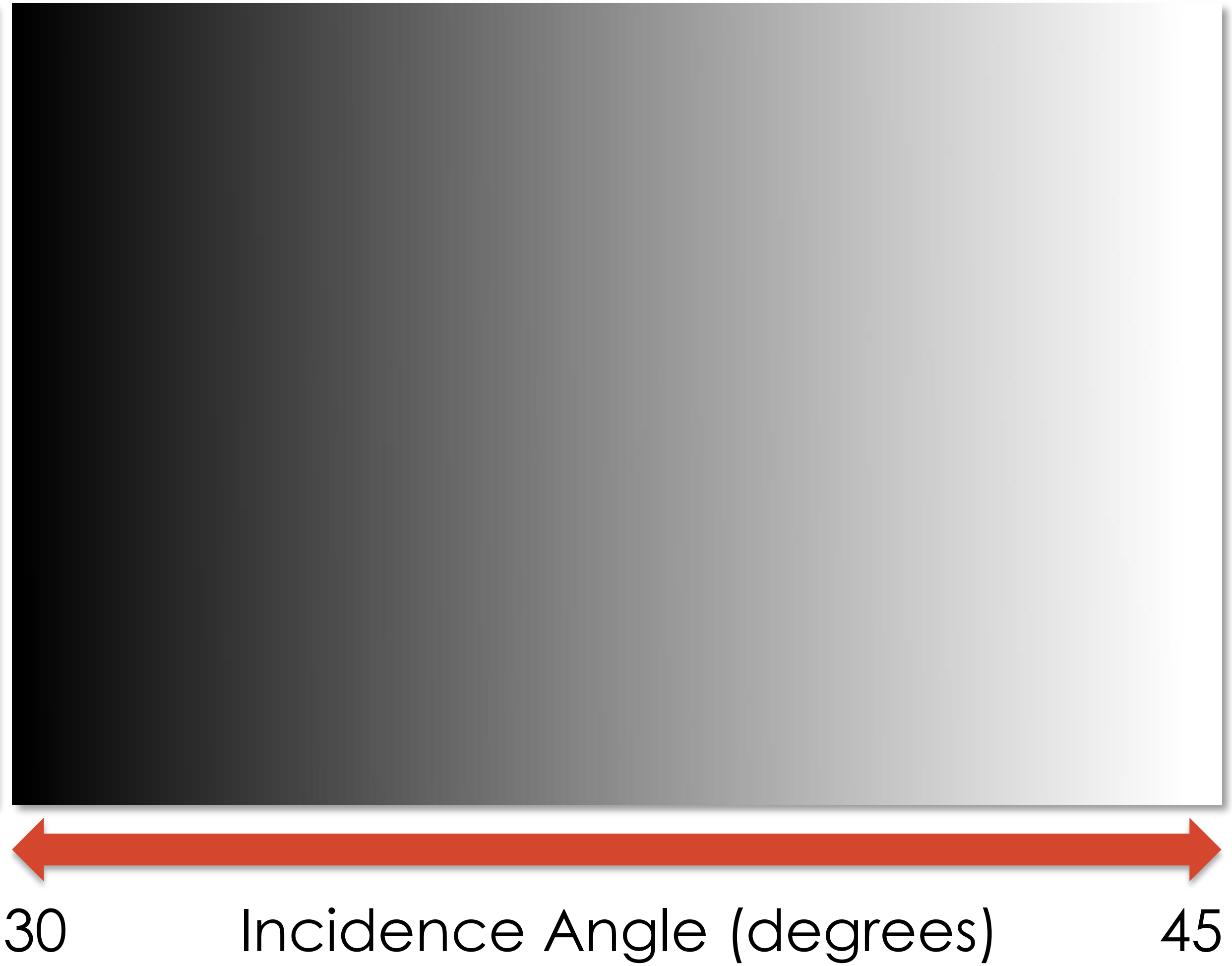


Images Based On: Top: Ulaby et al. (1981a), Bottom: ESA

Effect of Incidence Angle Variation

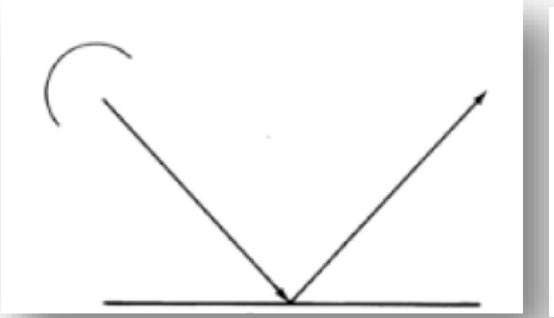


Sentinel-1

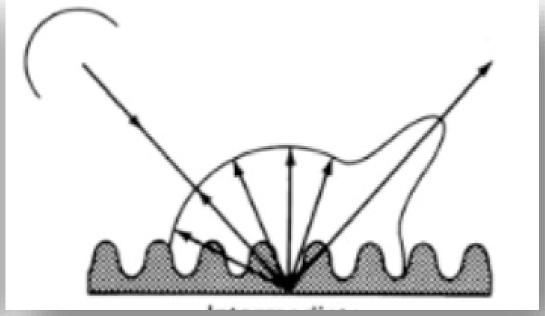


Radar Signal Interaction

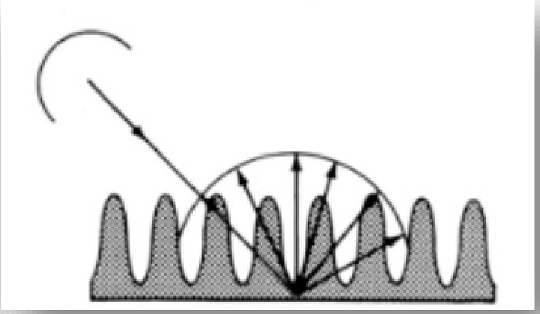
- The scale of the surface relative to the wavelength determines how rough or smooth it appears and how bright or dark they will appear on the image
- Backscattering Mechanisms:



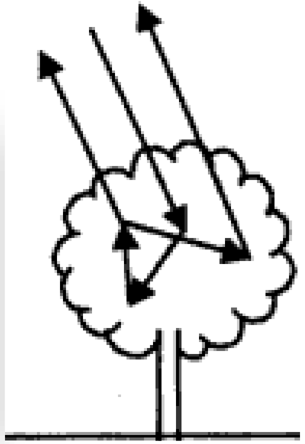
Smooth Surface



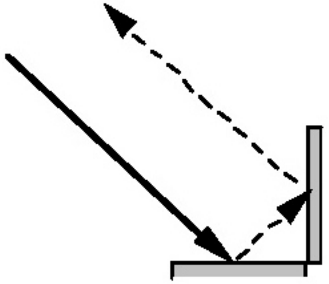
Rough Surface



Rougher Surface



Volume Scattering



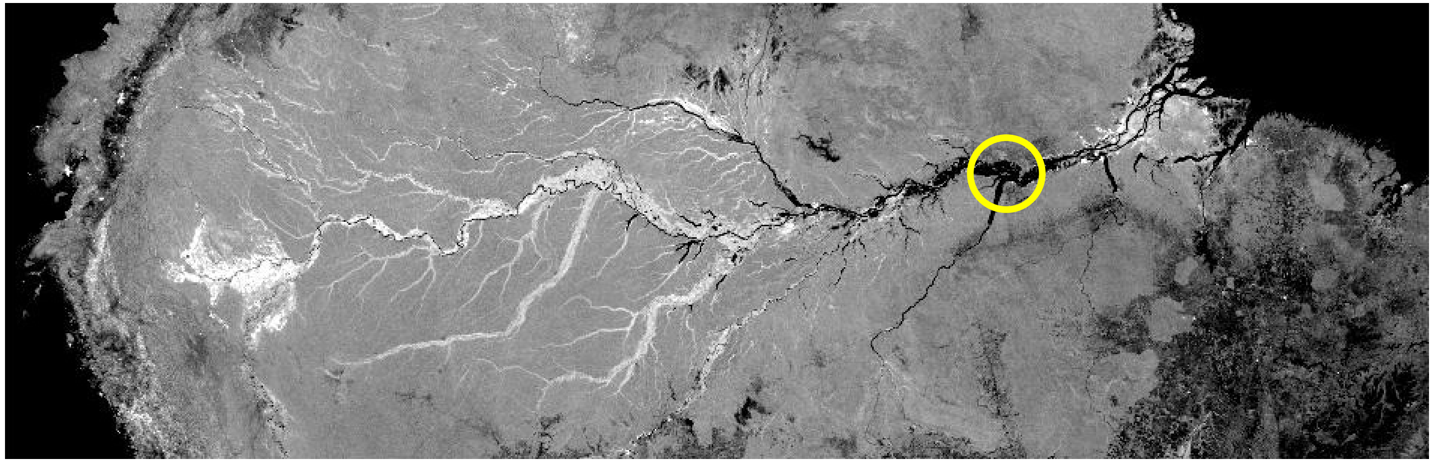
Double Bounce

Examples of Radar Interaction

Smooth Surface Reflection (Specular Reflection)

Smooth, level surface
(open water, road)

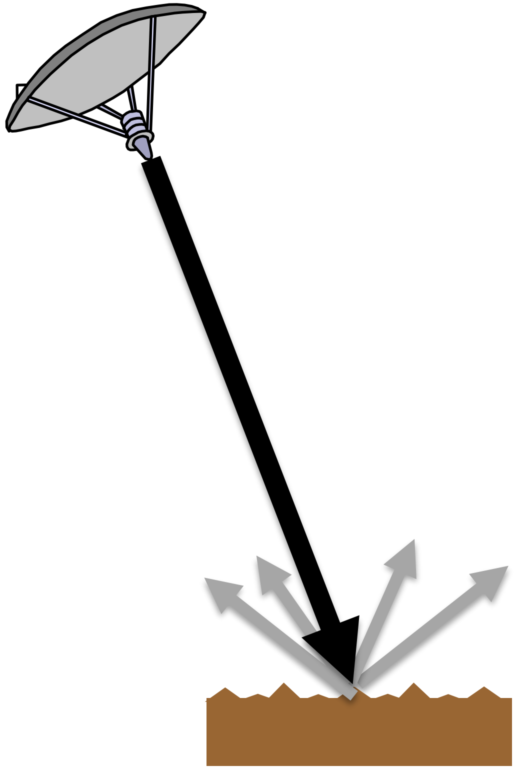
SMAP Radar Mosaic of the Amazon Basin
April 2015 (L-band, HH, 3 km)



Pixel Color

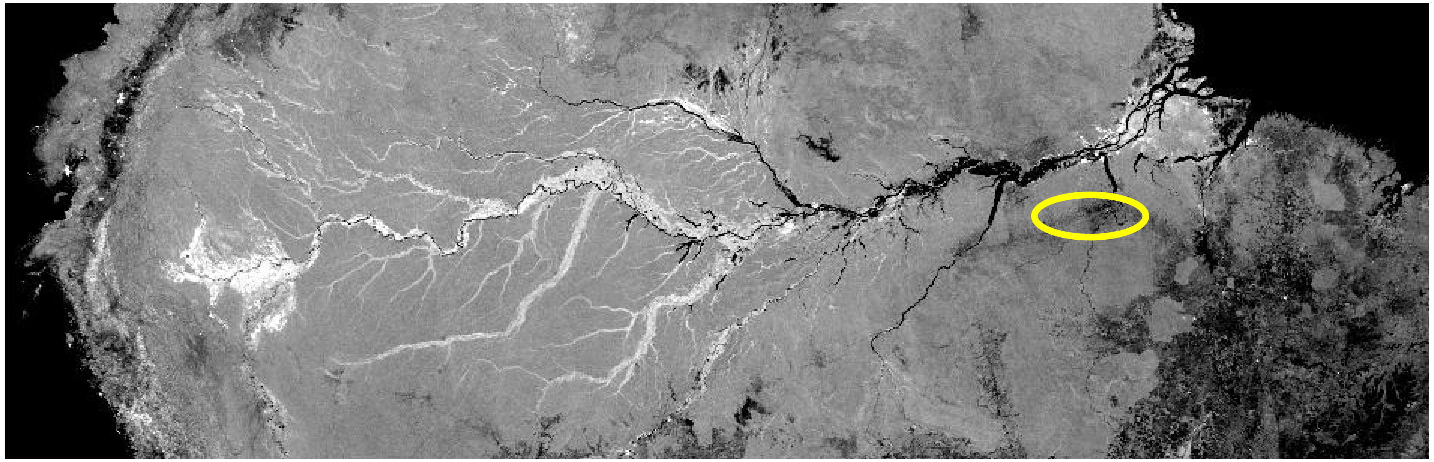
Examples of Radar Interaction

Rough Surface Reflection



Rough, bare surface (deforested areas, tilled agricultural fields)

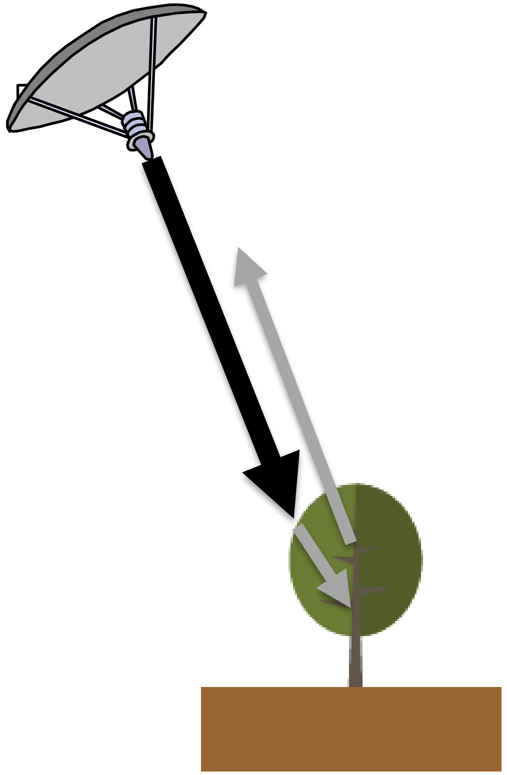
SMAP Radar Mosaic of the Amazon Basin April 2015 (L-band, HH, 3 km)



Pixel Color

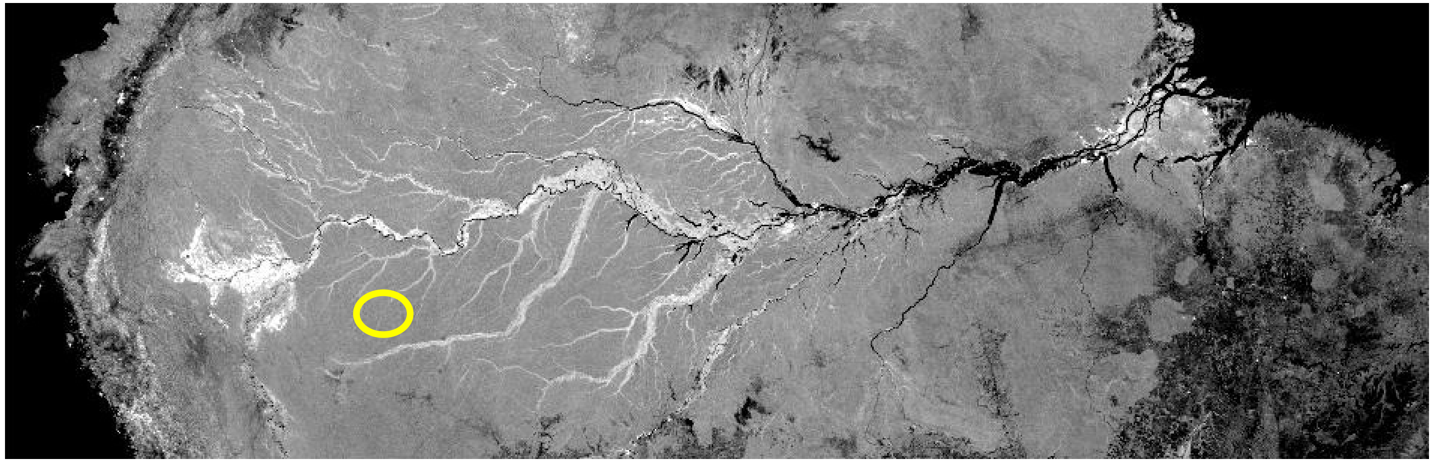
Examples of Radar Interaction

Volume Scattering by Vegetation



Vegetation

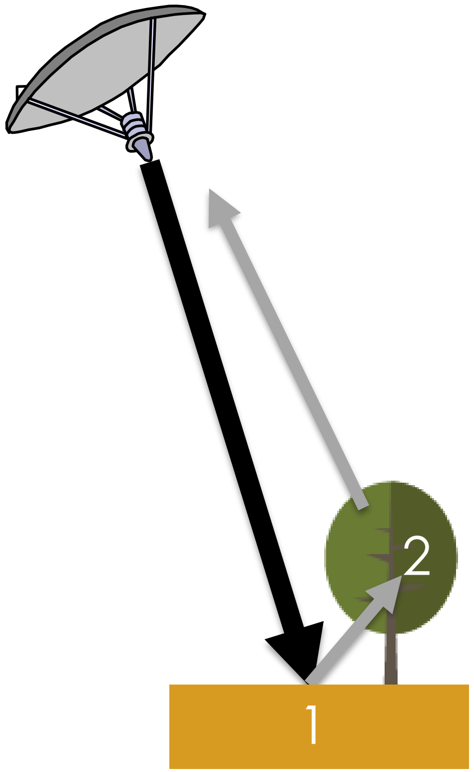
SMAP Radar Mosaic of the Amazon Basin April 2015 (L-band, HH, 3 km)



Pixel Color

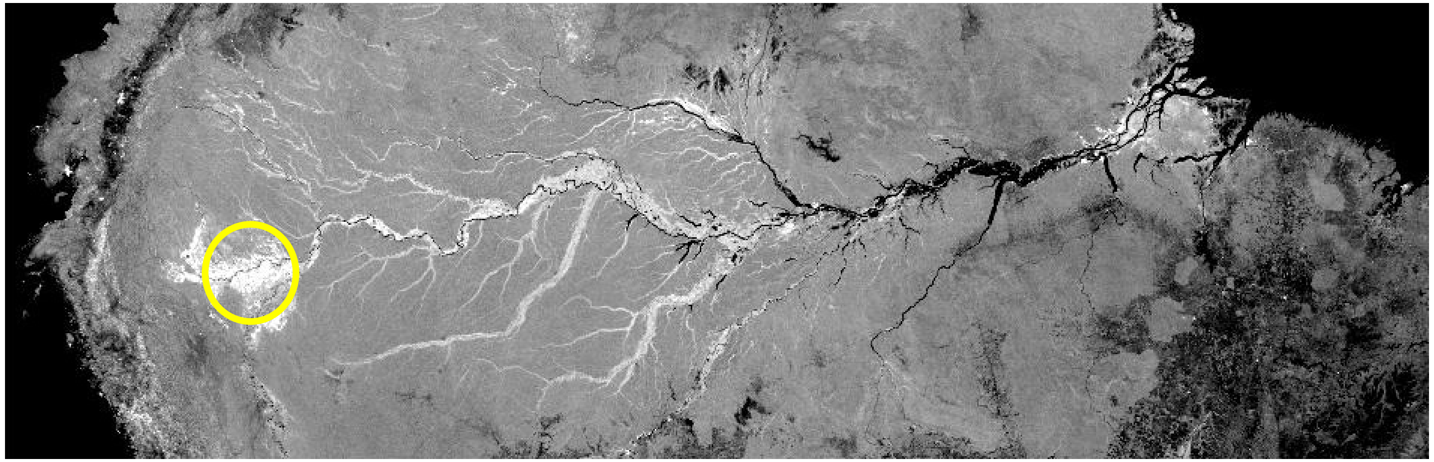
Examples of Radar Interaction

Double Bounce



Inundated Vegetation

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



Pixel Color

Parameters to Consider for a Land Cover Mapping Study

Radar Parameters

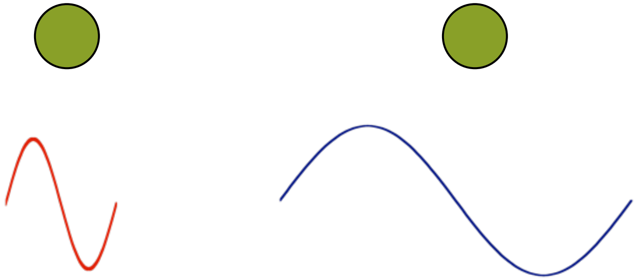
- Wavelength
- Polarizations
- Incidence Angle

Surface Parameters

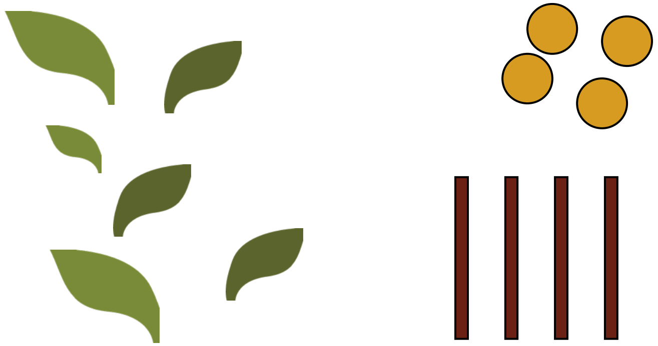
- Structure
- Dielectric

Surface Parameters Related to Structure

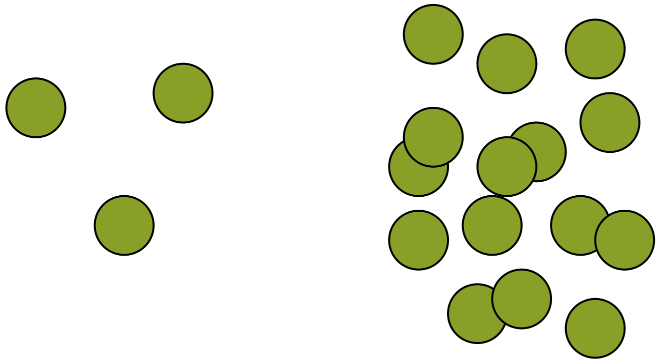
Size Relative to Wavelength



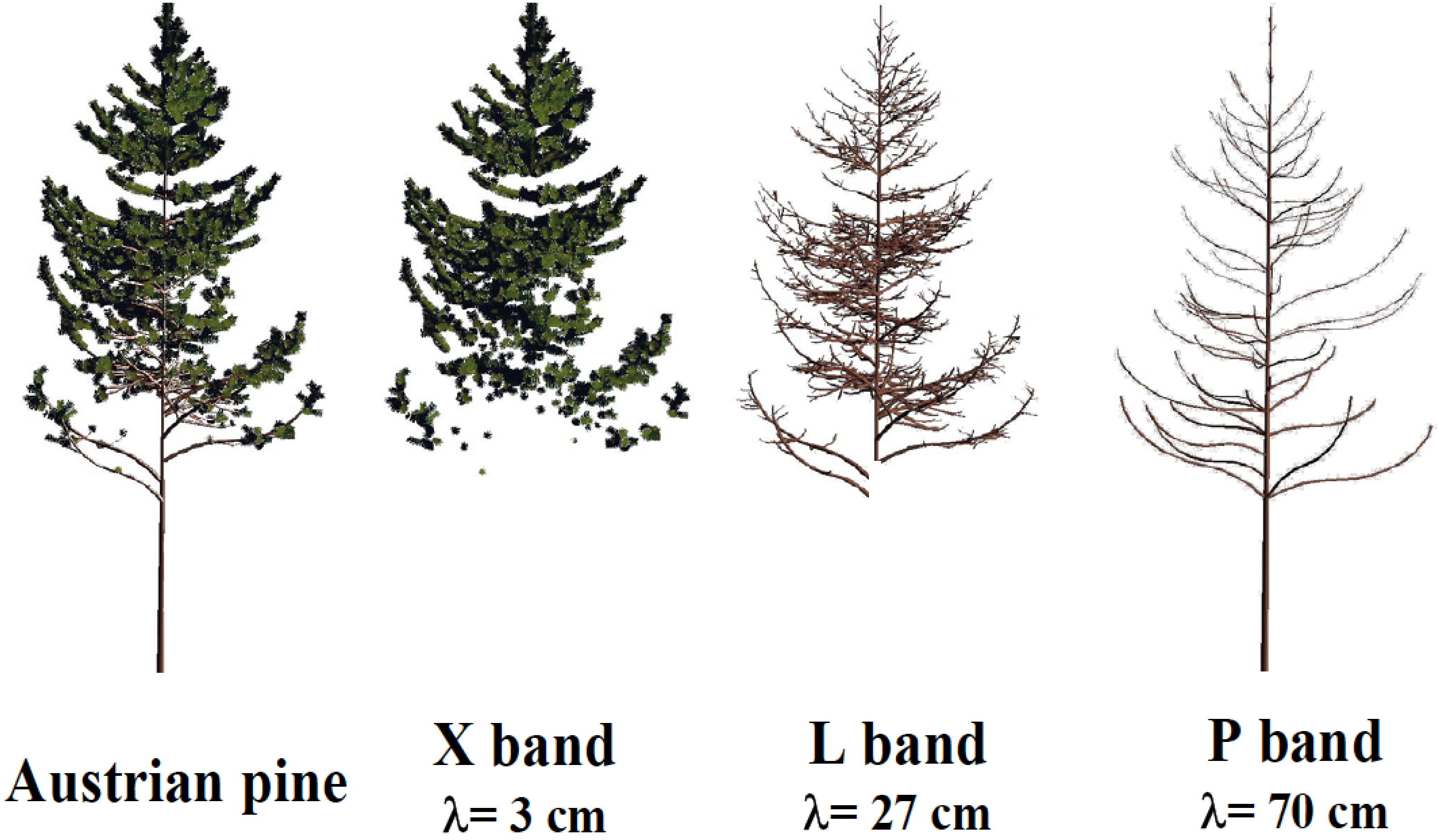
Size & Orientation



Density

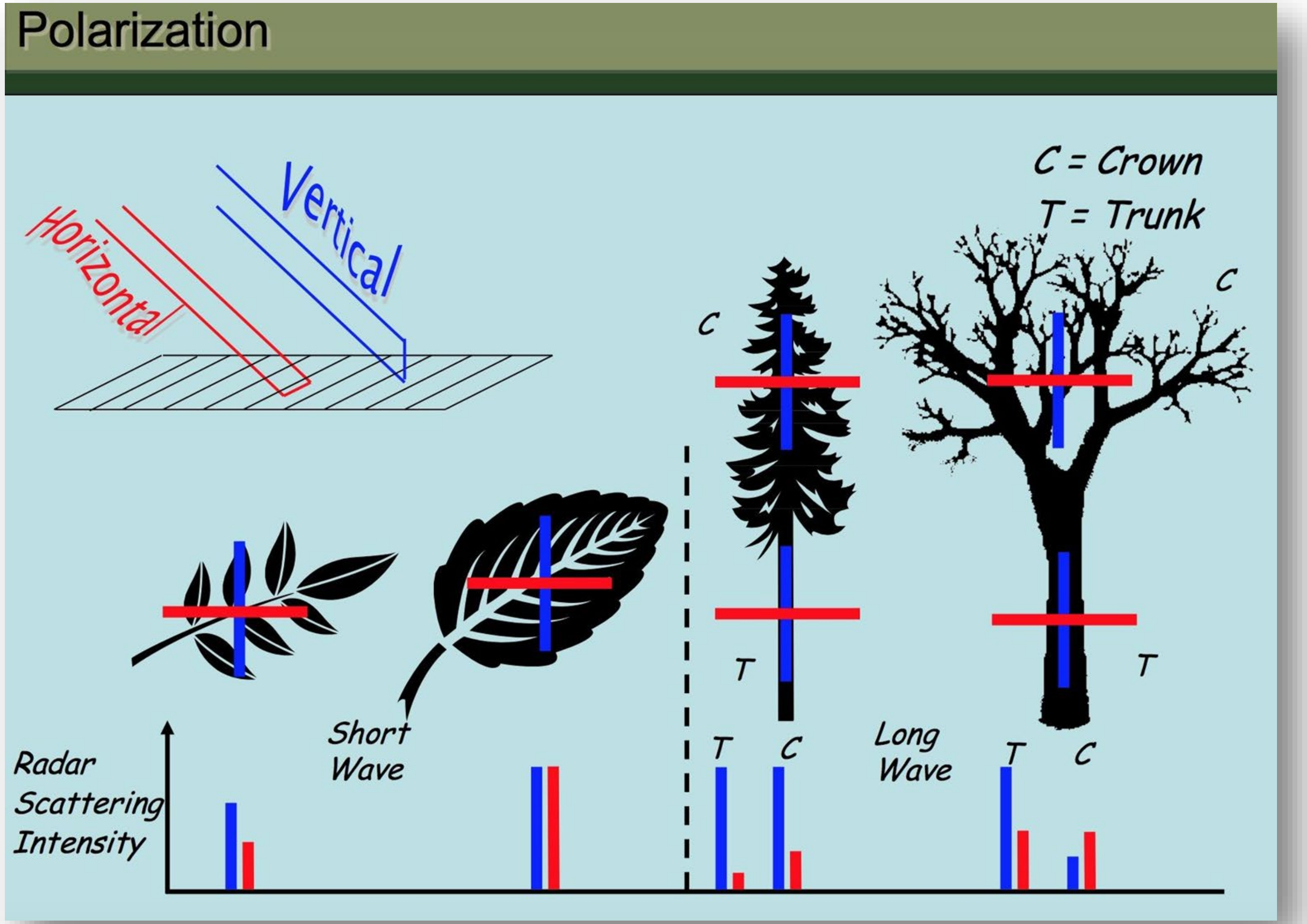


Size Relative to Wavelength



Source: Thuy le Toan

Size and Orientation



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

RELATIVE SCATTERING STRENGTH BY POLARIZATION:

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

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)

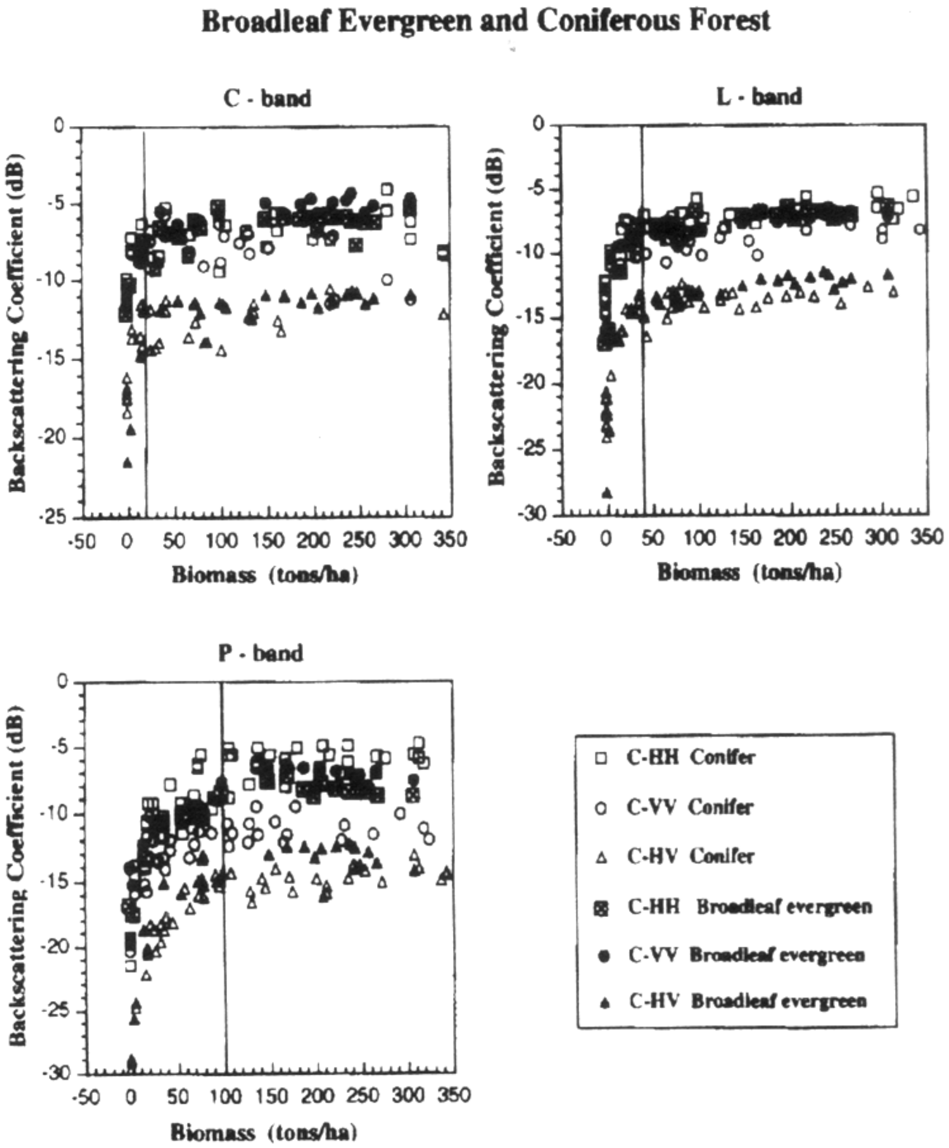
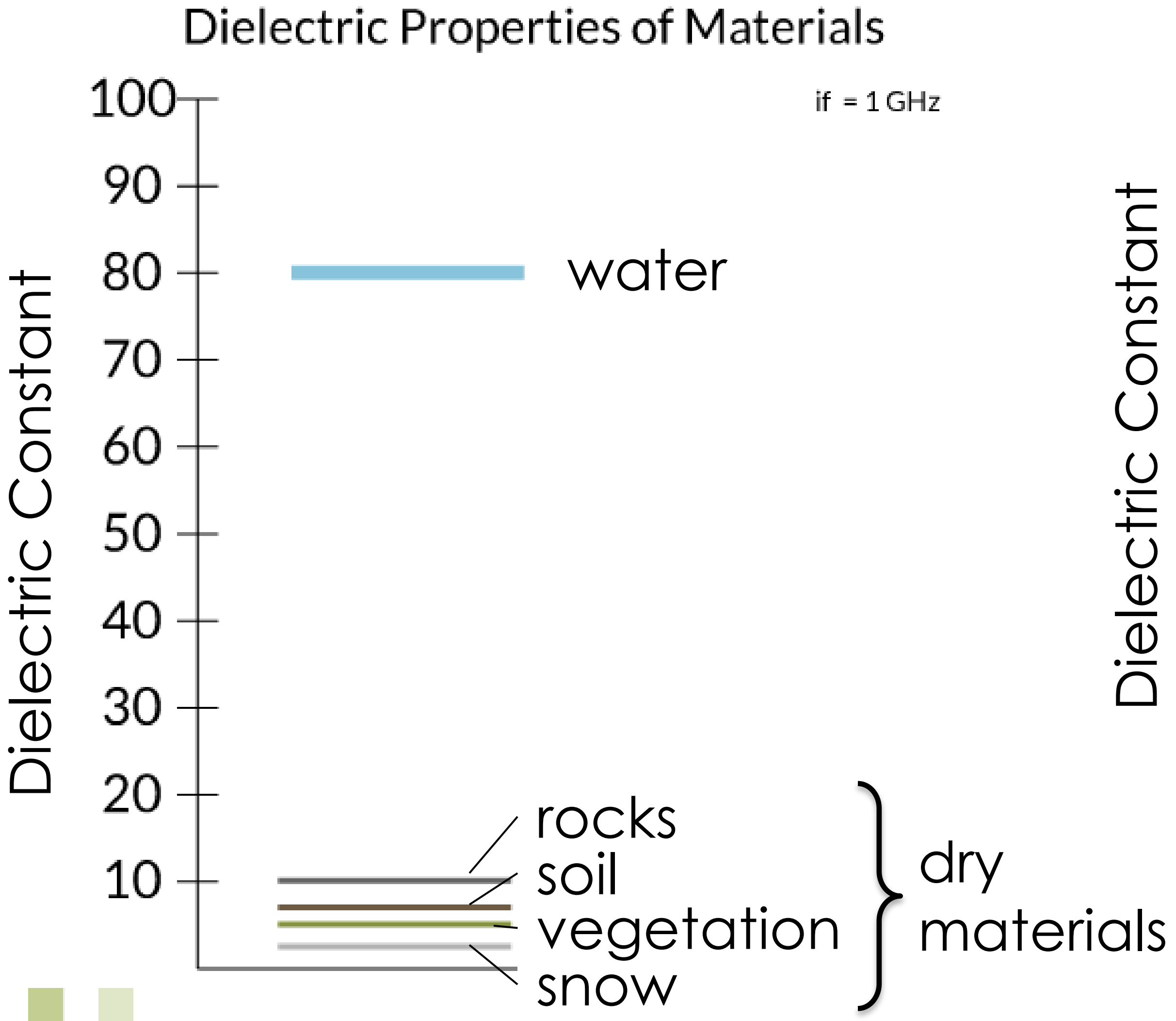
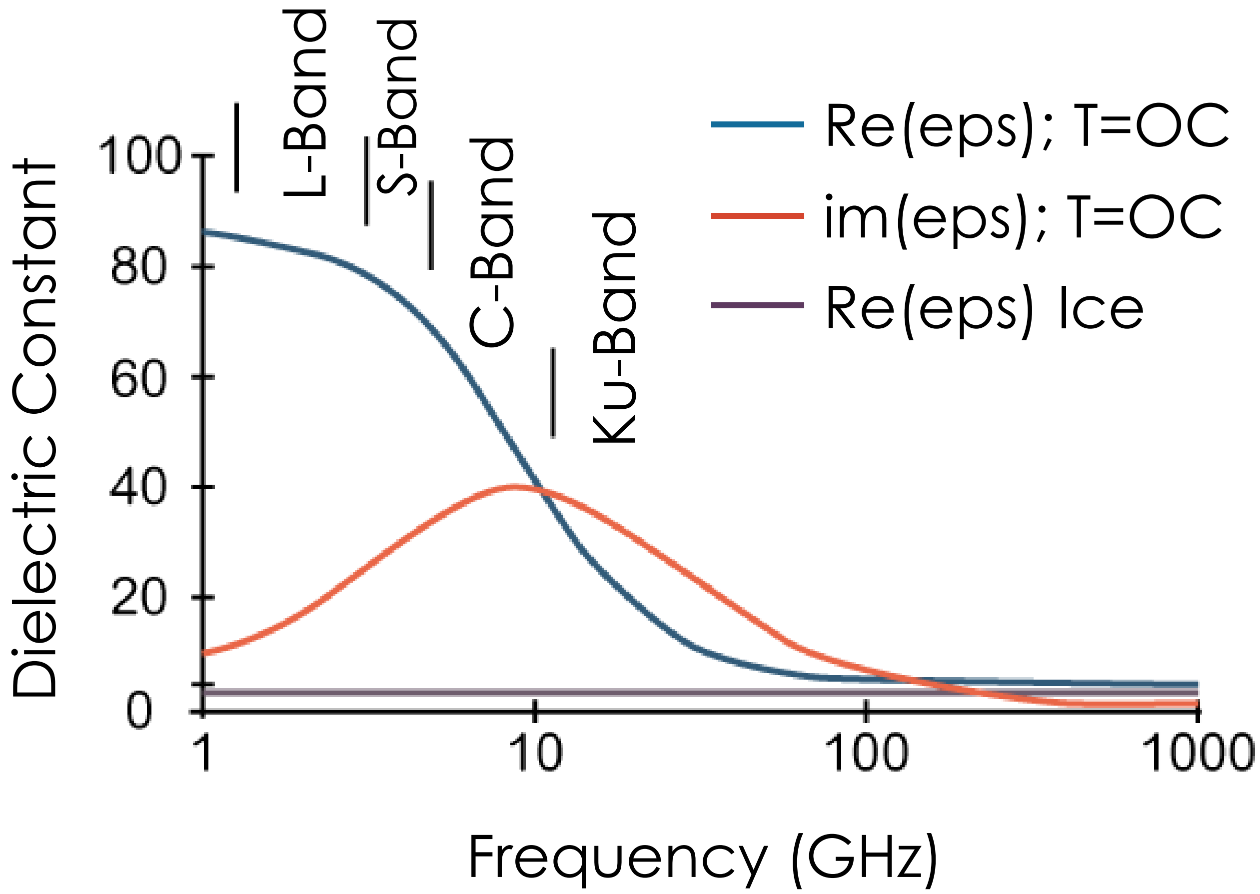


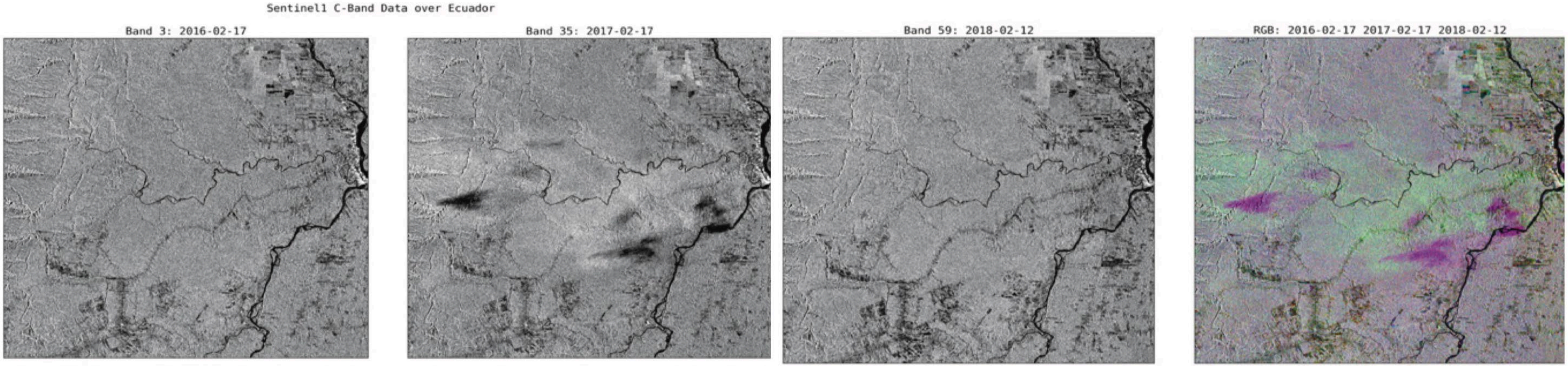
Image Source: Imhoff, 1995:514)

Surface Parameters: Dielectric Constant





Rain Event and an Increase in Surface Moisture

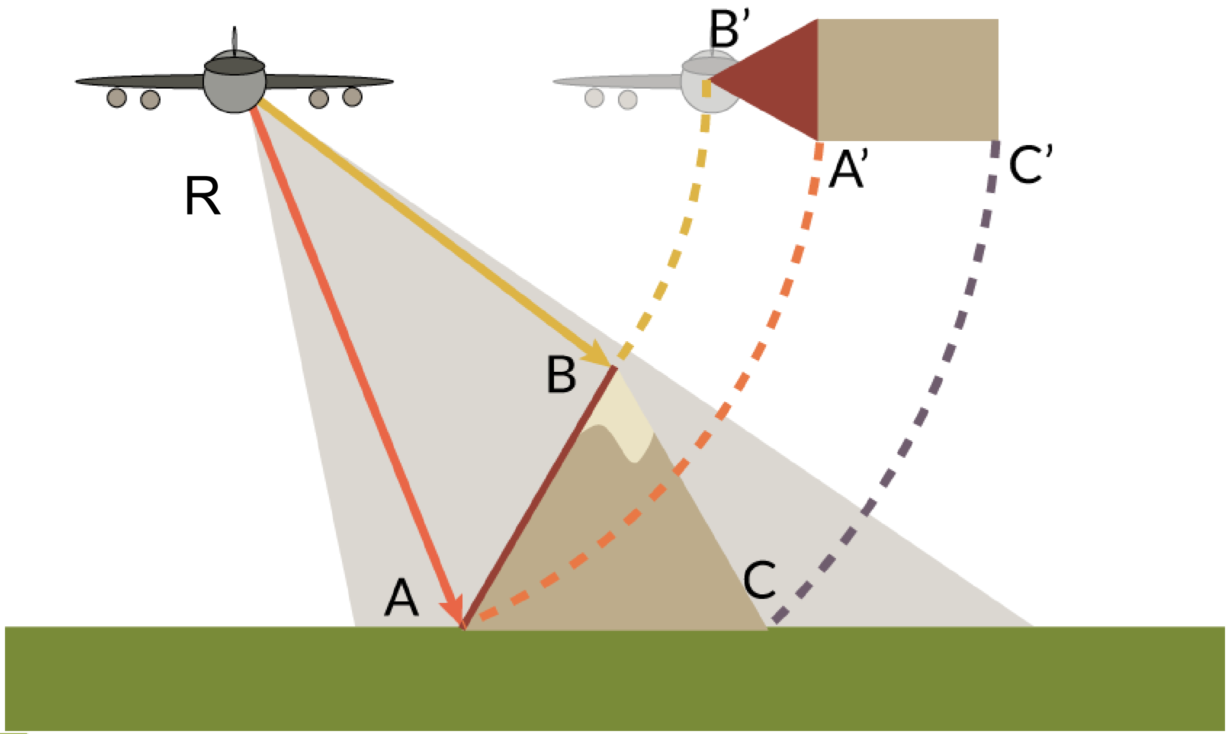


Source: SAR Handbook, Chapter 2 by Josef Kellndorfer

Geometric Distortion

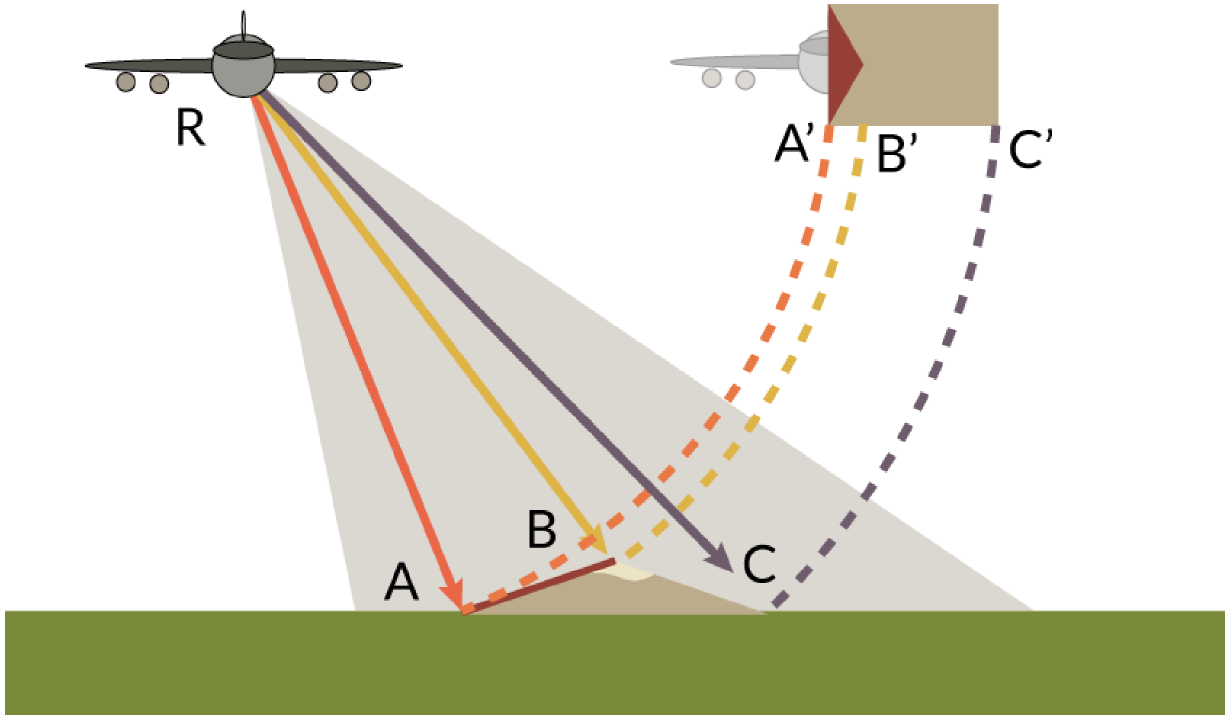
Layover

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

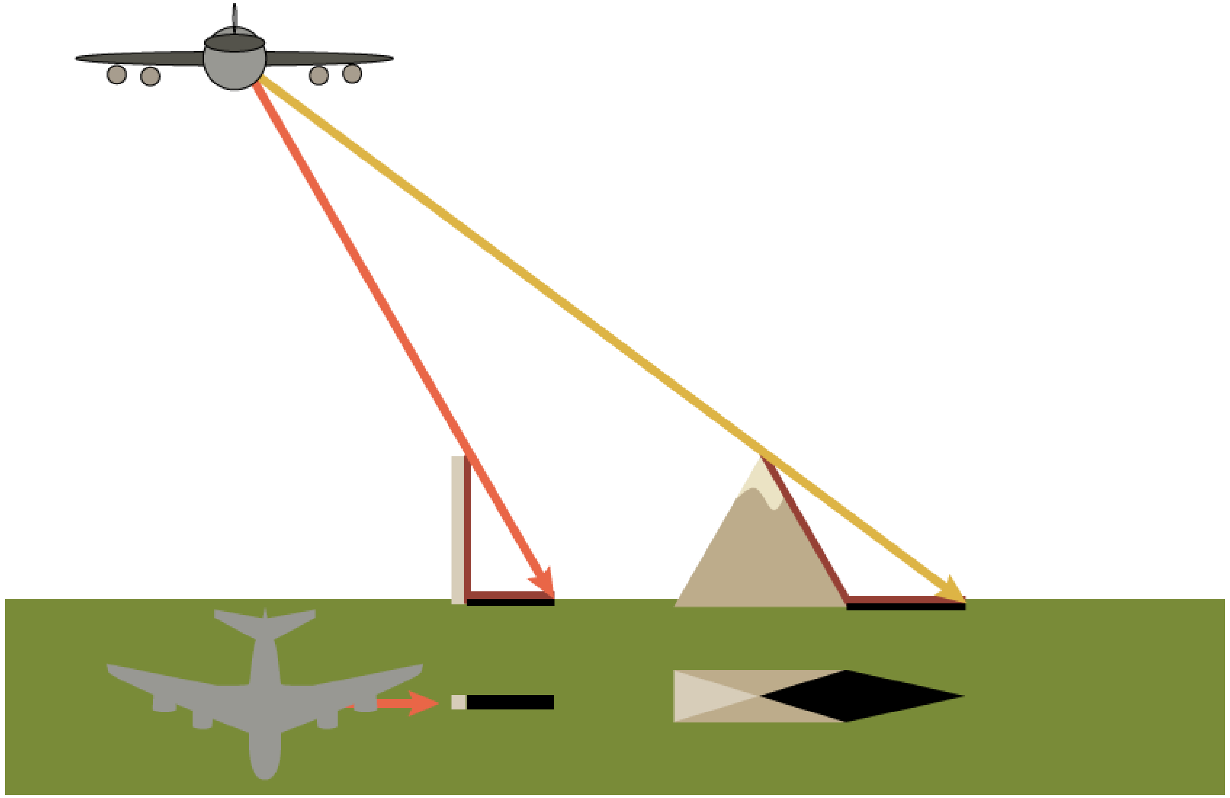


Image (left) based on NRC

Speckle

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

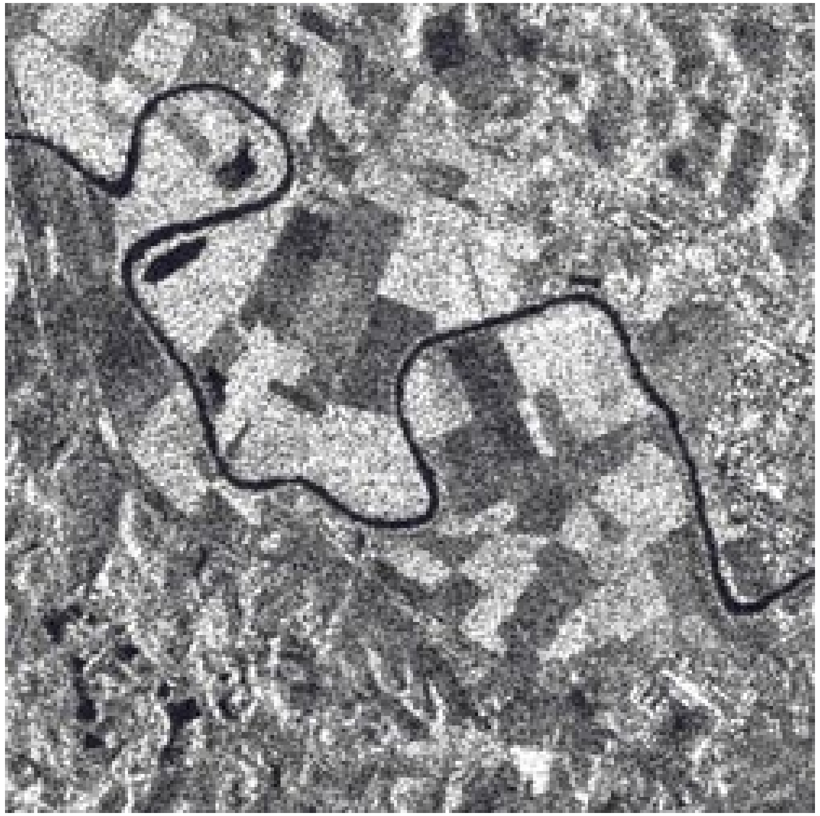


Image Credit: ESA

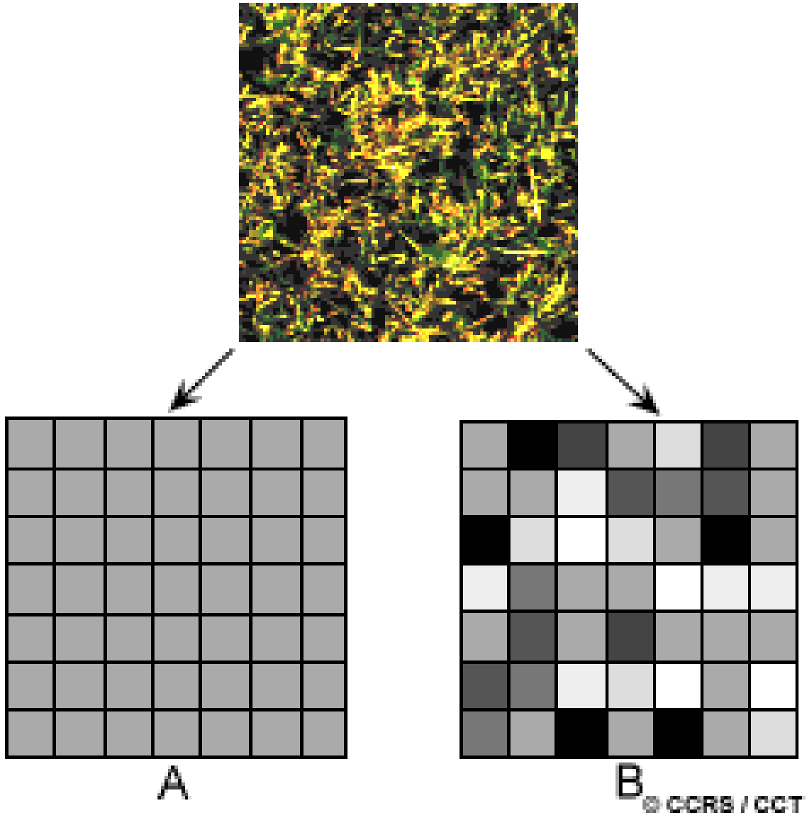
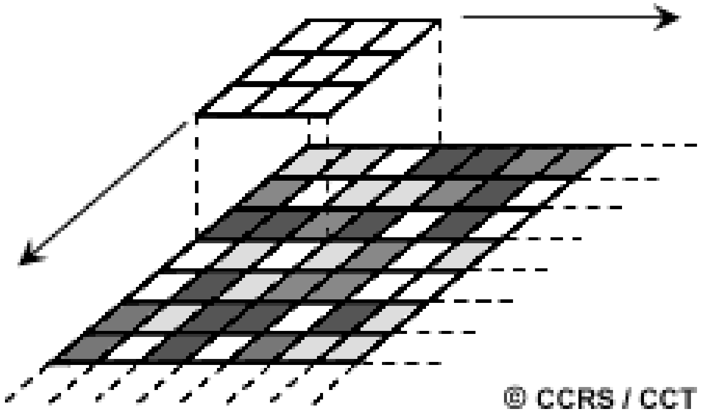
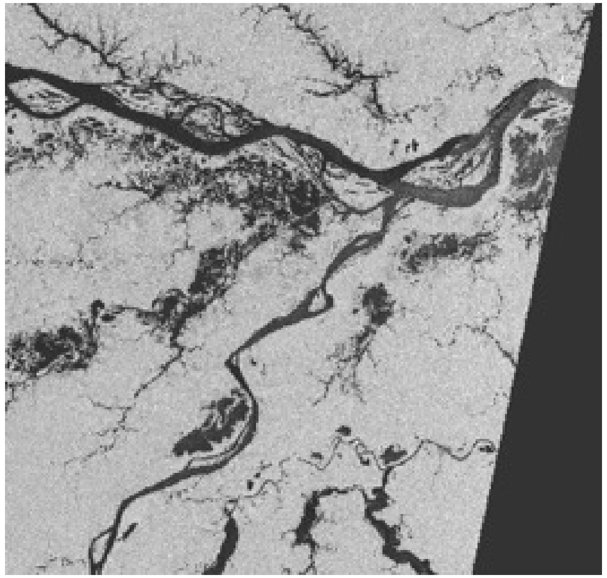


Image Credit: Natural Resources Canada

Speckle Reduction: Spatial Filtering

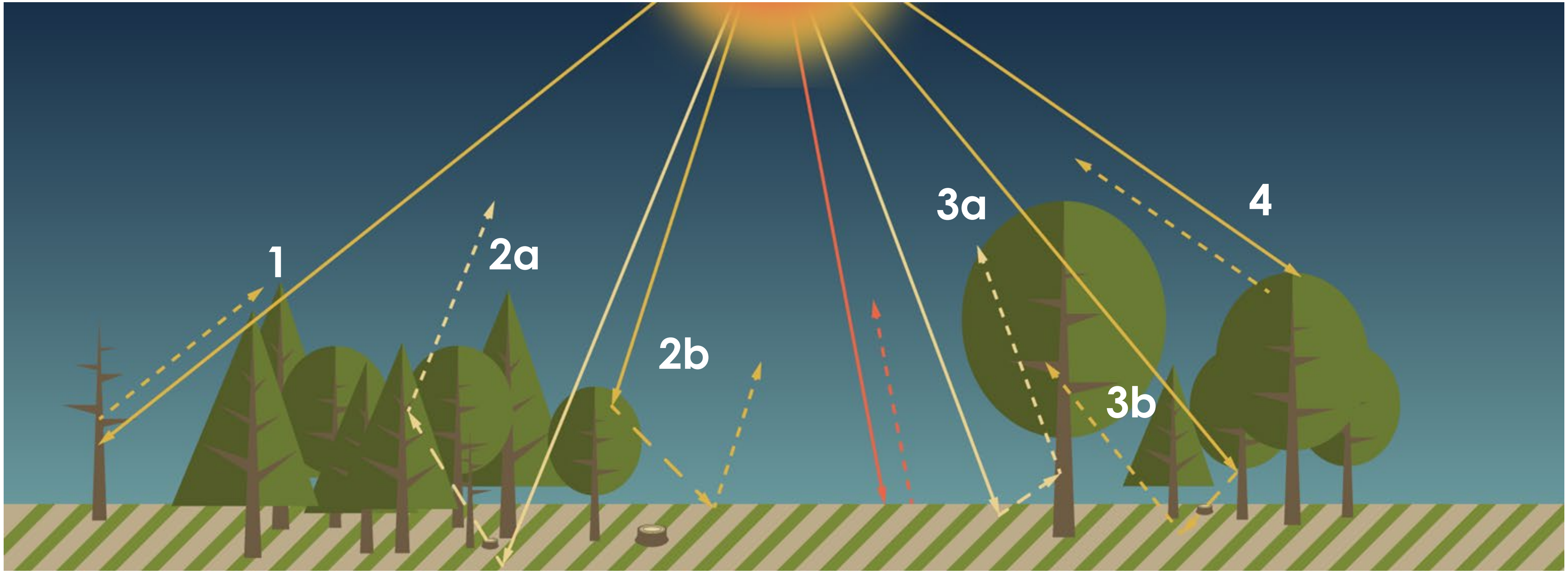
- Moving window over each pixel in the image
- Applies a mathematical calculation on the pixel values within the window
- The central pixel is replaced with the new value
- The window is moved along the x and y dimensions one pixel at a time
- Reduces visual appearance of speckle and applies a smoothing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





Source: Natural Resources Canada

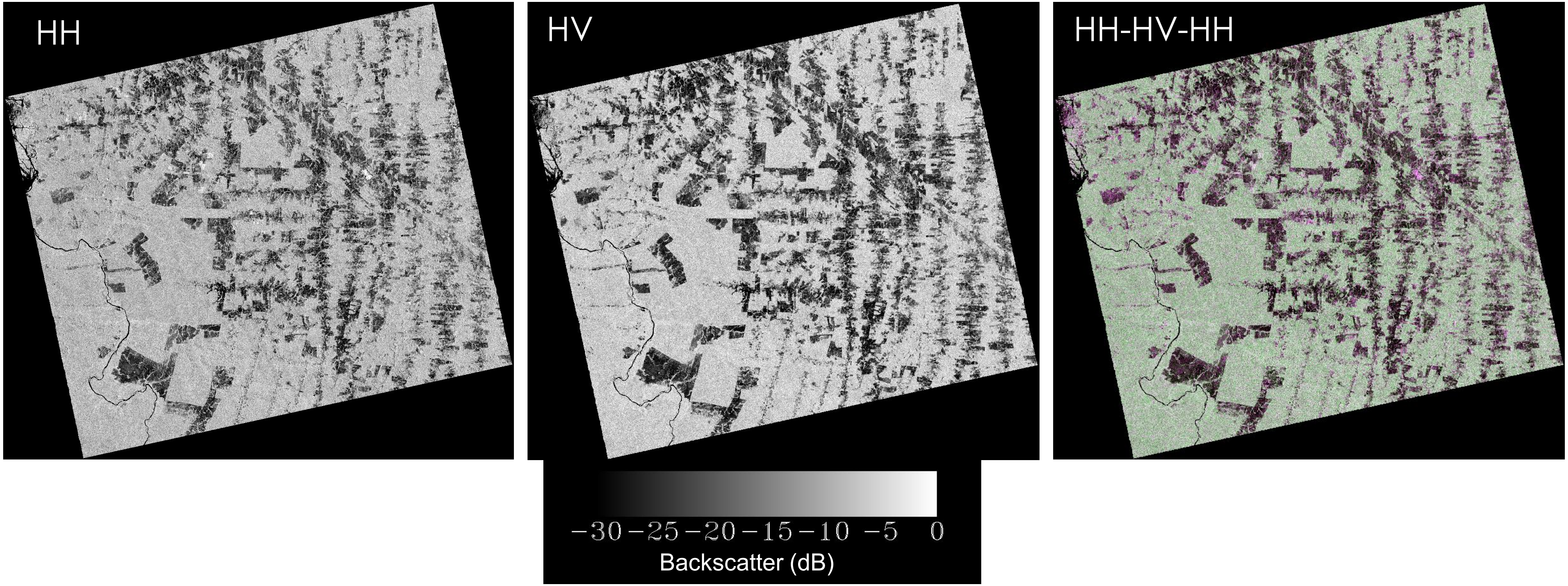
Radar Backscattering in Forests



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

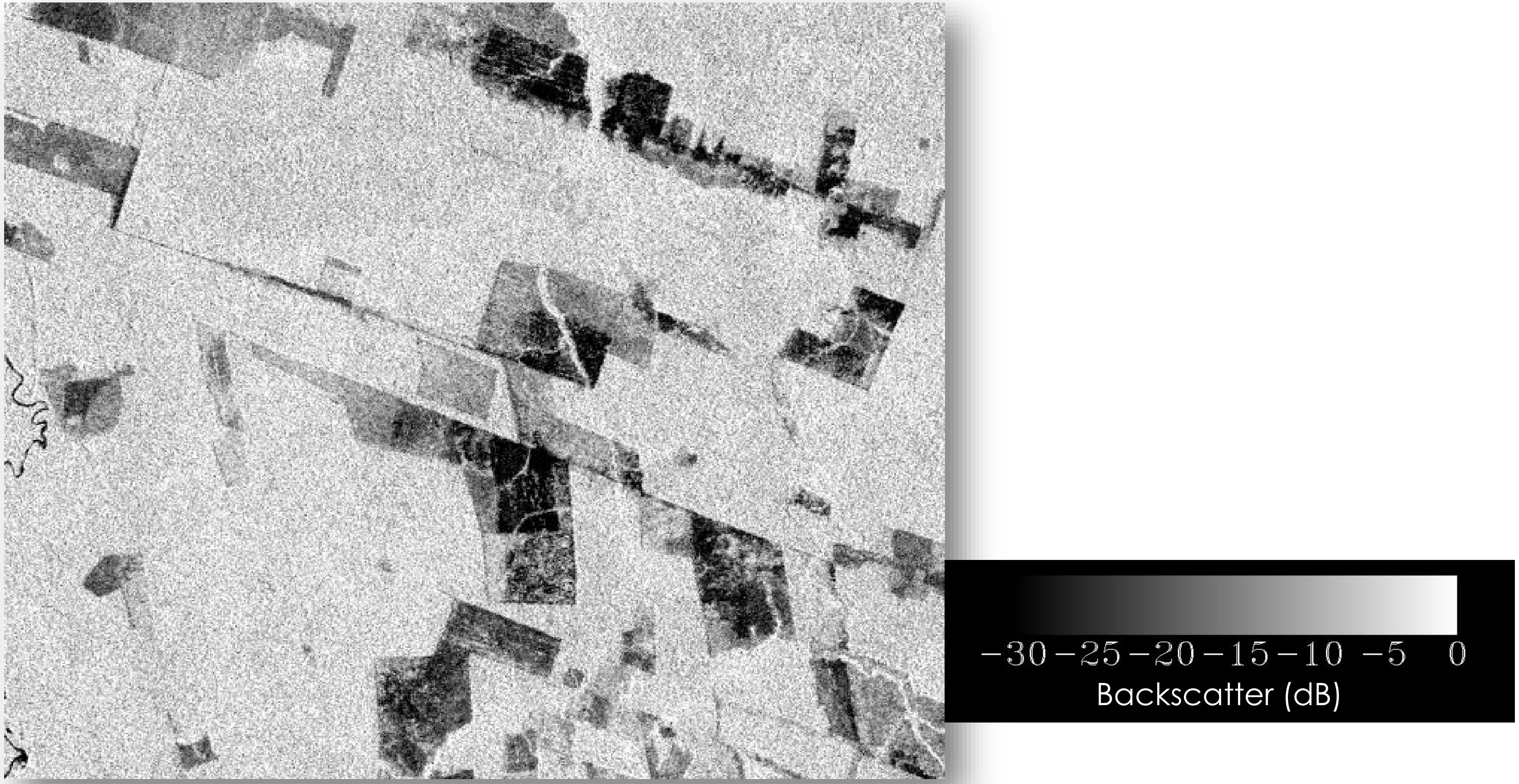
SAR Characteristics to Forested and Deforested Areas

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



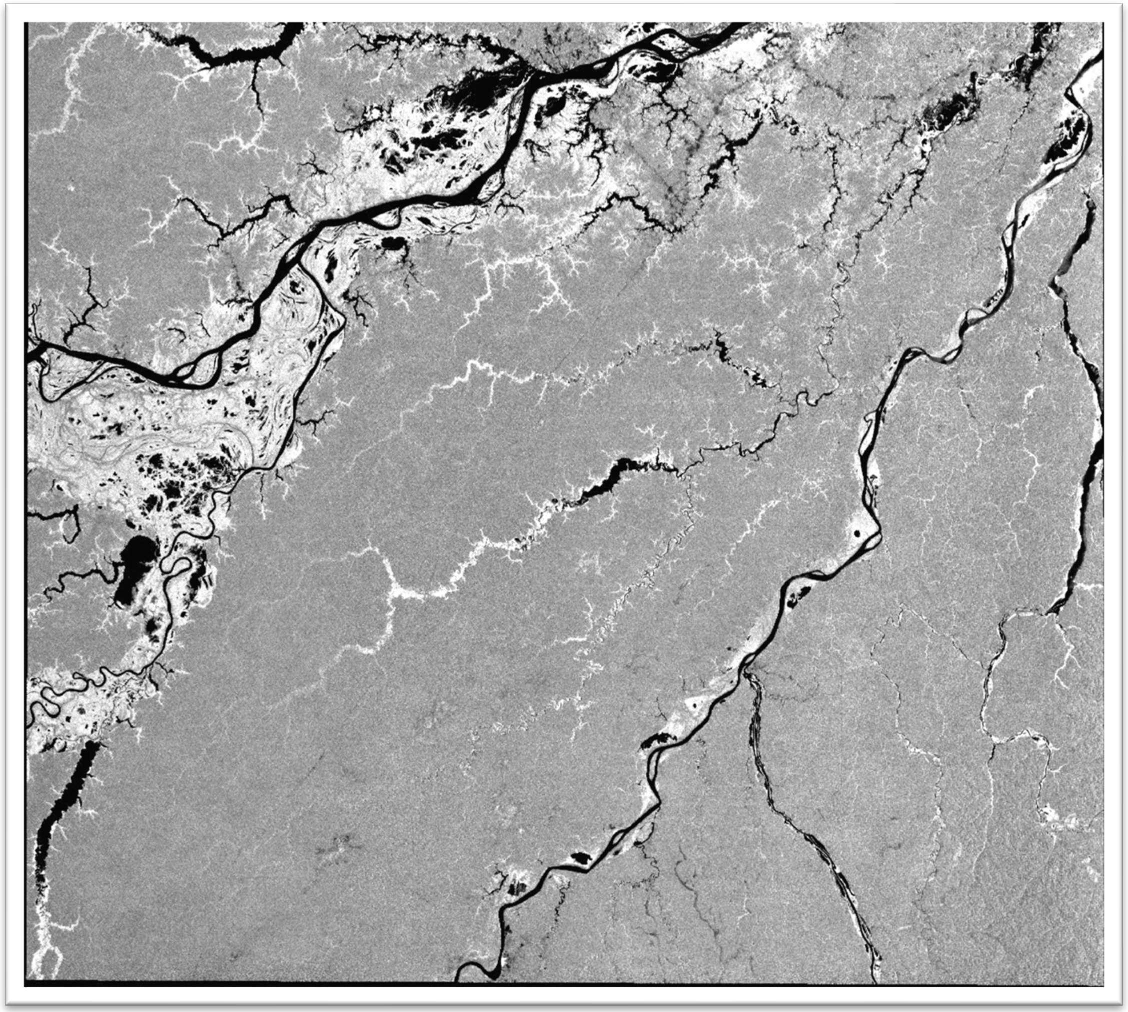
SAR Characteristics to Forested and Deforested Areas

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



SAR Characteristics to Inundated Vegetation

PALSAR HV for Rondonia, Brazil



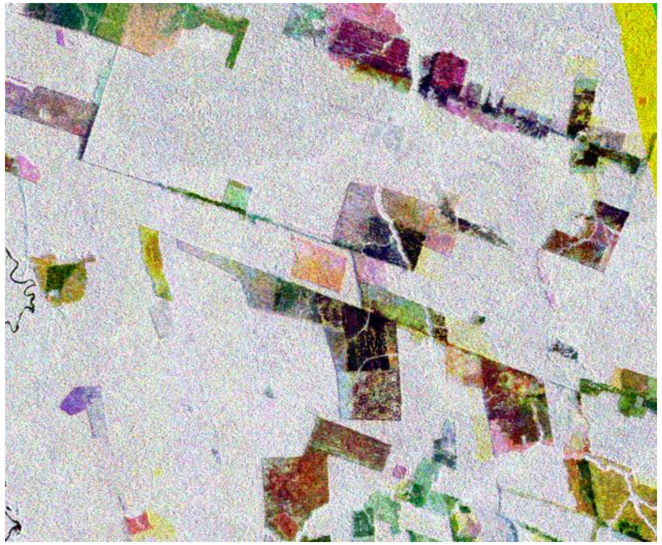
Expected Backscatter for Different Vegetation Scenarios

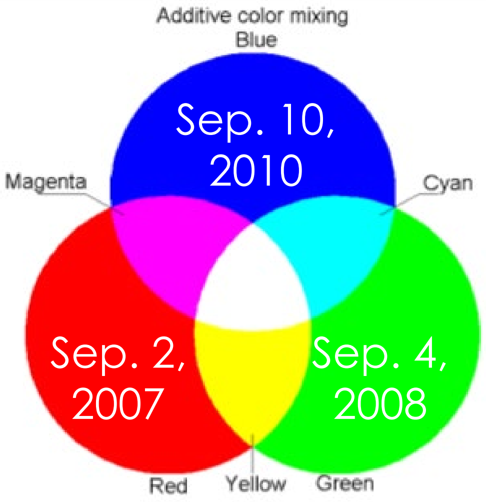
WAVELENGTH	POLARIZATION	RESPONSE BY FOREST TYPE					
		Sparse Forest (dry)	Sparse Forest (flooded)	Degraded Forest (dry)	Degraded Forest (flooded)	Dense Forest (dry)	Dense Forest (flooded)
C-band backscatter (g0)	VV	Medium to high; Depending on the roughness of the forest floor and moisture, there is lots of variation in this category	Low to medium; Depending on forest density, lots of forward scattering	Medium to high; most scattering from crown	Medium to high; most scattering from crown	Medium to high; most scattering from crown (Can be low in scenarios where absorption dominates and diminishes backscatter)	Medium to high; most scattering from crown (Can be low in scenarios where absorption dominates and diminishes backscatter)
	VH	Medium to high; Depending on the roughness of the forest floor and moisture, there is lots of variation in this category	Low to medium; Depending on forest density, lots of forward scattering	Medium to high; most scattering from crown	Medium to high; most scattering from crown	Medium to high; most scattering from crown (Can be low in scenarios where absorption dominates and diminishes backscatter)	Medium to high; most scattering from crown (Can be low in scenarios where absorption dominates and diminishes backscatter)
	VV/VH Ratio	Medium to high	Medium to high	Medium	Medium	Medium	Medium
L-band backscatter (g0)	HH	Low to medium; lower than dense forest and flooded sparse forest. At steep incidence angles, backscatter can be medium to high	Medium to high, depending on how much double bounce is contributing to the signal	Medium to high	High to very high, double bounce contributes to high backscatter	High to very high; higher than degraded forest, however at very high biomass levels we see saturation and no distinction with degraded forests	High to very high, double bounce contributes to high backscatter
	HV	Low to very low, depending on how dry the soils are	Low to very low. Most scattering is in the forward direction due to specular reflection	Medium to high	Medium to high, no seasonal variation with flooded forest floor	High to very high; volume scattering is dominant – best sensitivity to biomass	Medium to high, no seasonal variation with flooded forest floor
	HH/HV Ratio	Medium	High	Medium	High	Medium	High

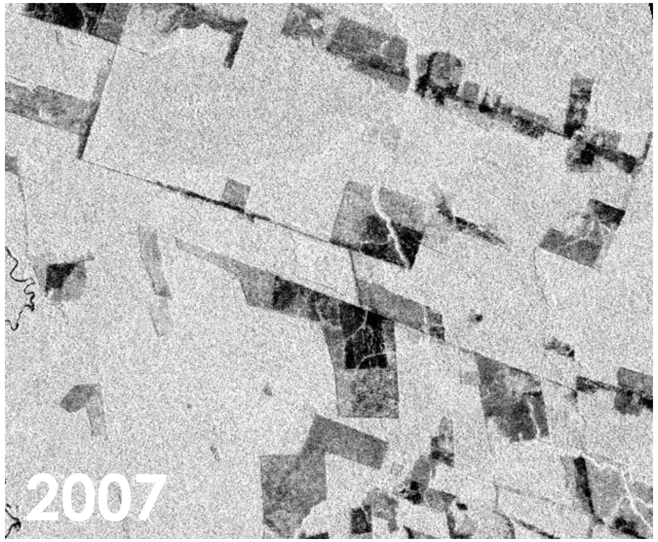
Source: SAR Handbook, Chapter 2 by Josef Kellndorfer

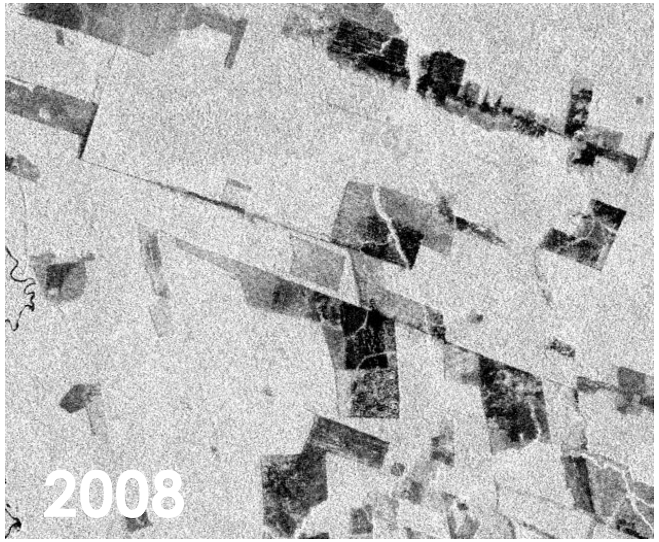
Example of Multiple Dates for Vegetation Studies

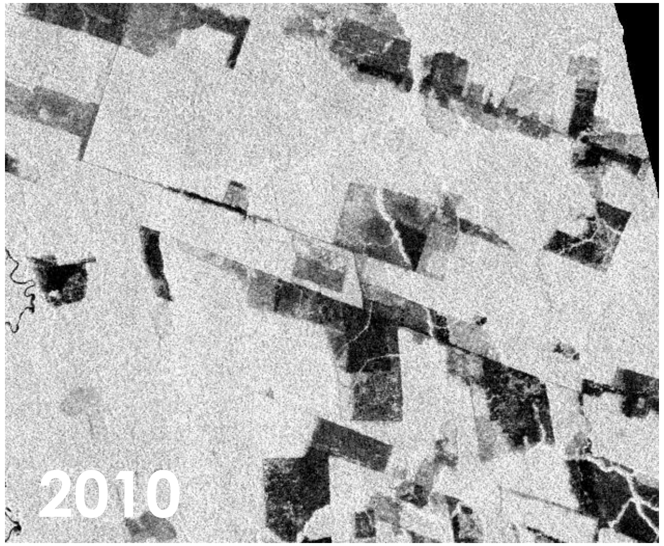
PALSAR HV Multi-Temporal RGB for Rondonia, Brazil





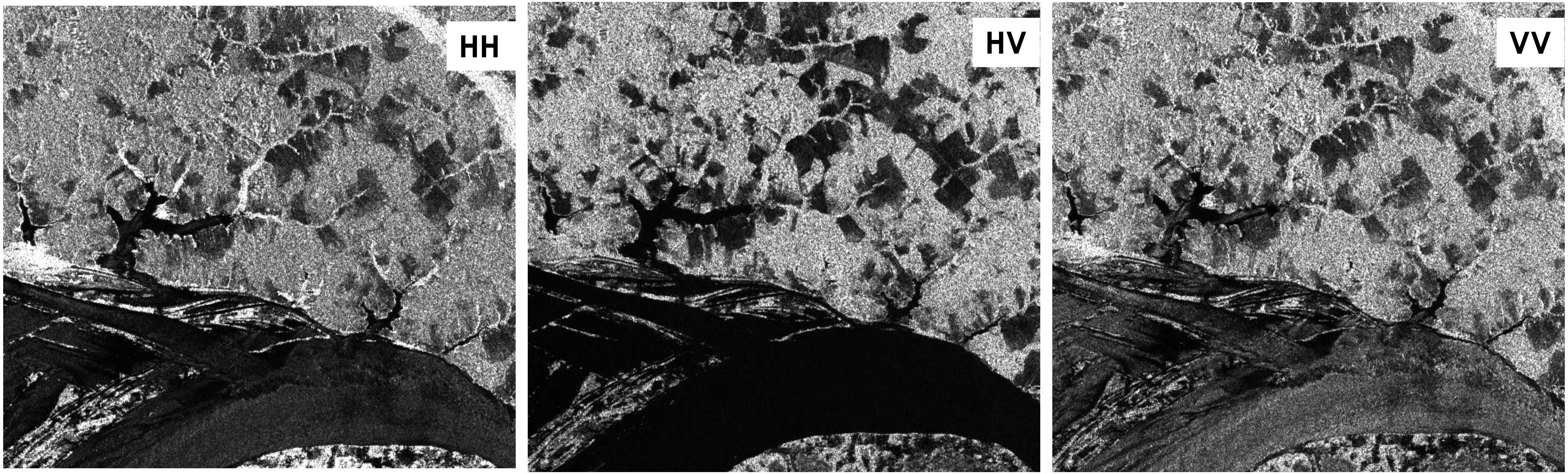






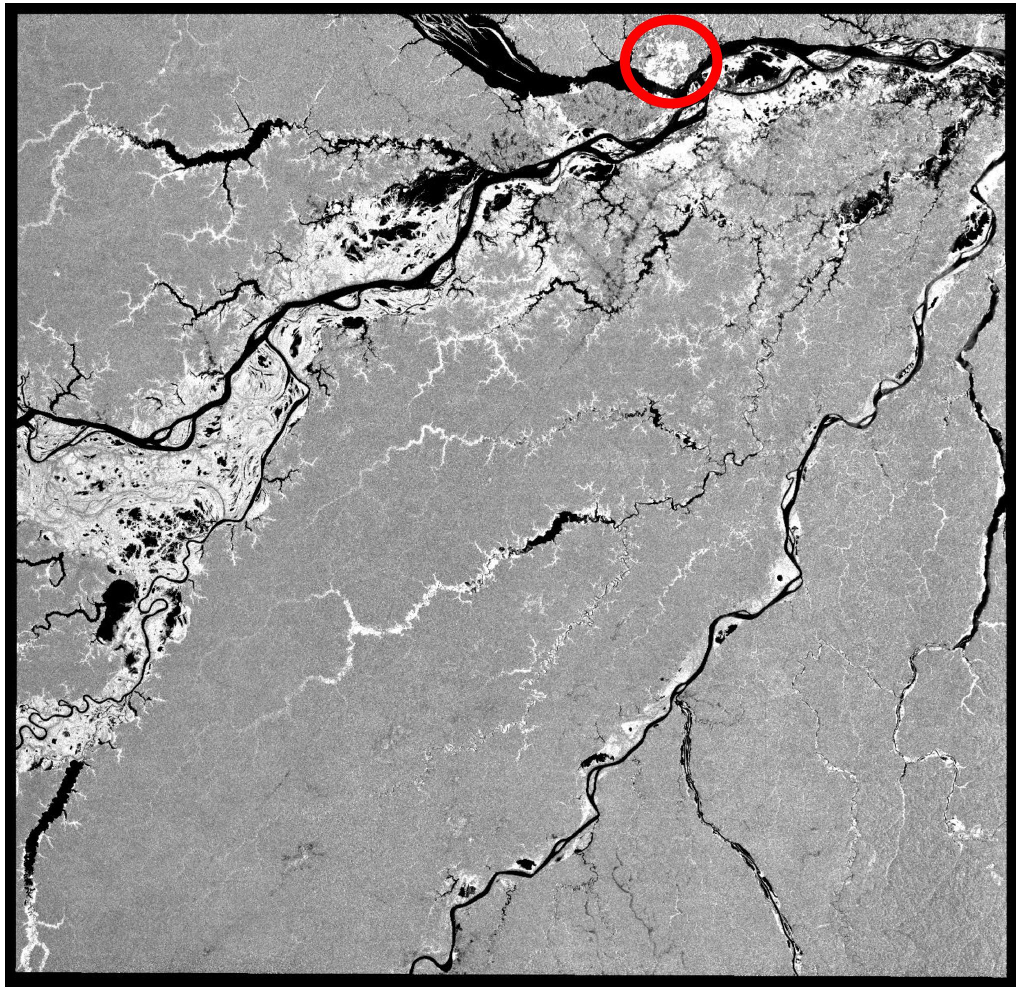
Source of Confusion: Open Water and Low Vegetation

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

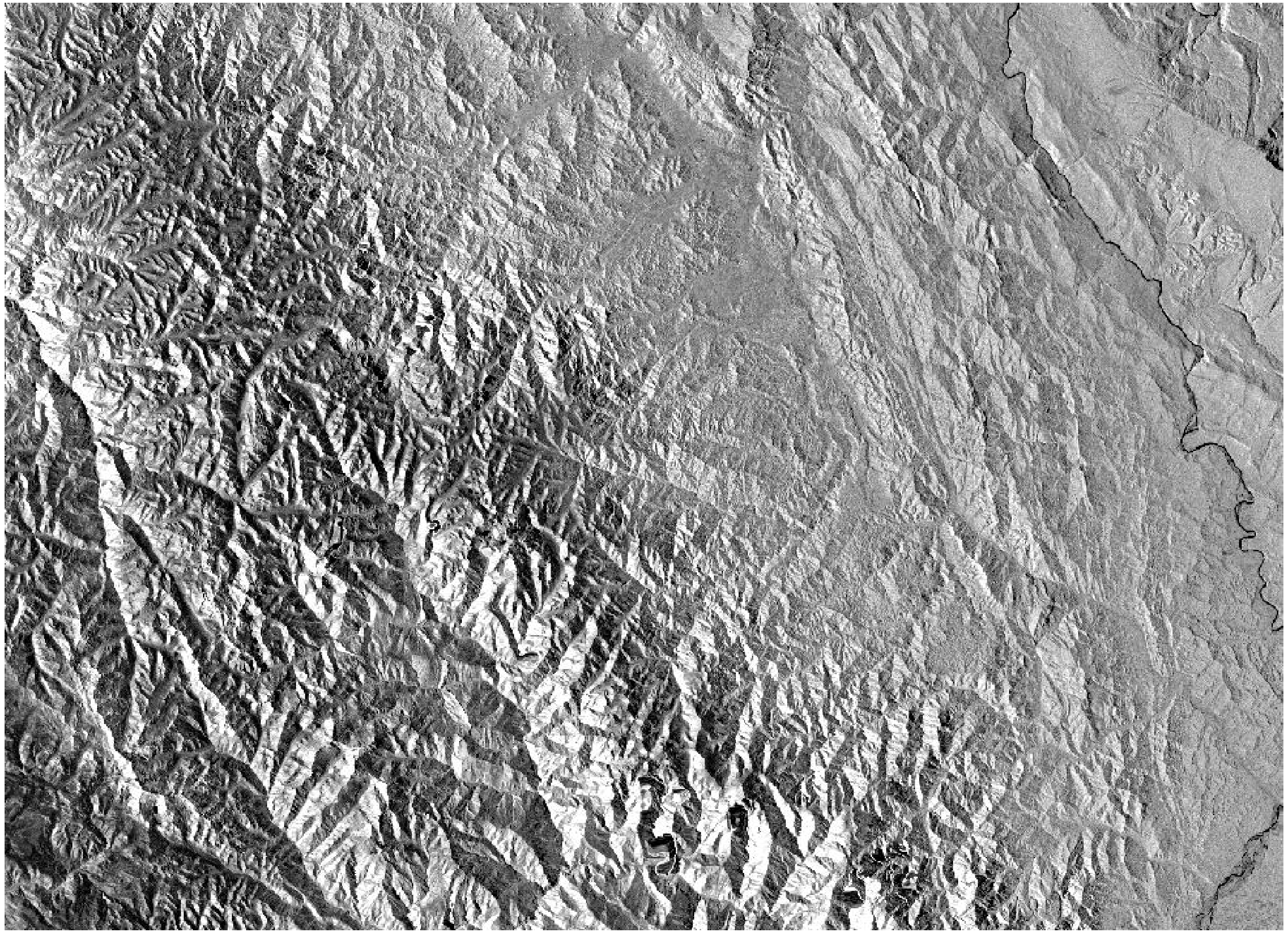


Source of Confusion: Urban Areas and Flooded Areas

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



Source of Confusion: Topography and Inundated Vegetation



Radar Data Available

Legacy:

SeaSAT
1978

JERS-1
1992-1998

ERS 1/2
1991-2011

ENVISAT
2002-2012

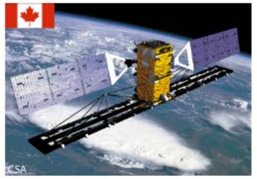
ALOS-1
2002-2012

Radarsat-1
1995-2013

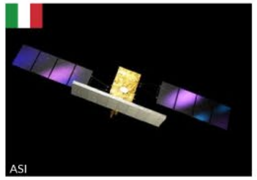
Current:

TanDEM-X
2007

Radarsat-2
2007



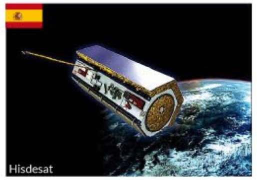
COSMO-SkyMed
2007



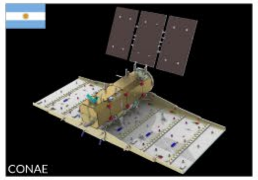
ALOS-2
2014

Sentinel-1
2014

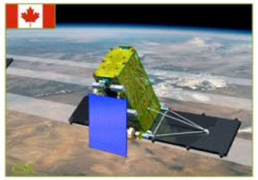
PAZ SAR
2018



SAOCOM
2018



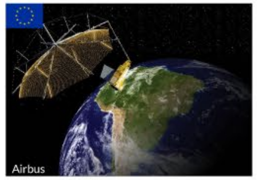
RCM
2018



Future:

NISAR
2022

Biomass
2022



Freely Accessible

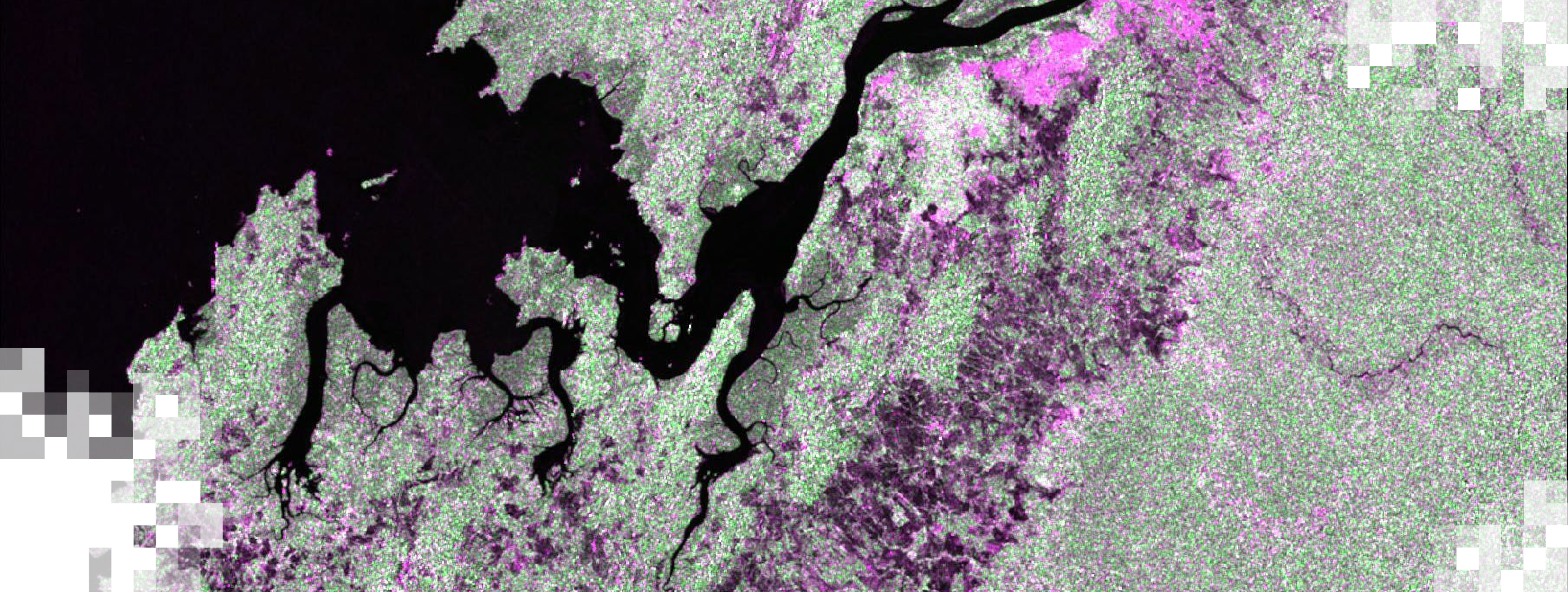
Image Credit: Franz Meyer, University of Alaska, Fairbanks

NASA-ISRO SAR Mission (NISAR)

- High spatial resolution with frequent revisit time
- Earliest Baseline Launch Date: 2022
- Dual frequency L- and S-band SAR
  - L-band SAR from NASA and S-band SAR from ISRO
- 3 years of science operations (5+ years of consumables)
- All science data will be made freely and openly available.

NISAR Characteristic:	Would Enable:
L-band (24 cm wavelength)	Low temporal decorrelation and foliage penetration
S-band (12 cm wavelength)	Sensitivity to light vegetation
SweepSAR technique with Imaging Swath >240 km	Global data collection
Polarimetry (Single/Dual/Quad)	Surface characterization and biomass estimation
12-day exact repeat	Rapid Sampling
3-10 meters mode-dependent SAR resolution	Small-scale observations
3 years since operations (5 years consumables)	Time-series analysis
Pointing control < 273 arcseconds	Deformation interferometry
Orbit control < 500 meters	Deformation interferometry
>30% observation duty cycle	Complete land/ice coverage
Left/Right pointing capability	Polar coverage, North and South
Noise Equivalent Sigma Zero ≤ -23 db	Surface characterization of smooth surfaces

Courtesy: Paul Rosen (JPL)



Hands-on Exercise: Time Series Analysis

Exercise Overview

- Visualize Sentinel-1 Data
- Select an area of interest to run the analysis
- Load images from multiple dates (2016, 2018, and 2019)
- Apply a filter to reduce noise in the images
- Calculate differences in forest cover from 2016 to 2018, and from 2018 to 2019
- Apply a threshold
- Compare the changes in forest cover throughout time

Google Earth Engine Overview

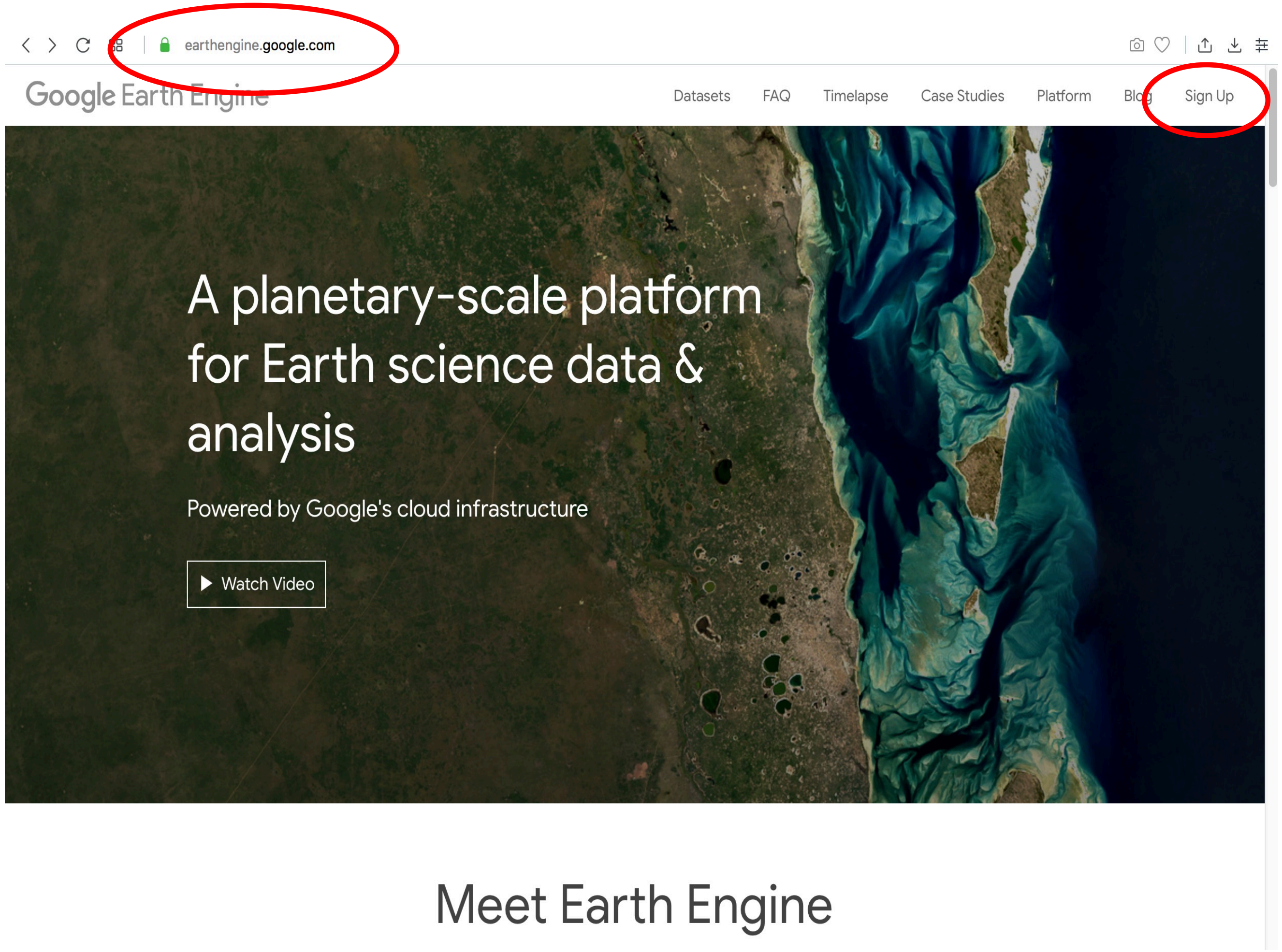
- A cloud-based geospatial processing platform
- Available to scientists, researchers, and developers for analysis of the Earth's surface
- Catalog of satellite imagery and geospatial datasets (including Sentinel-1):

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

- JavaScript code editor
- Go to Google Earth Engine:

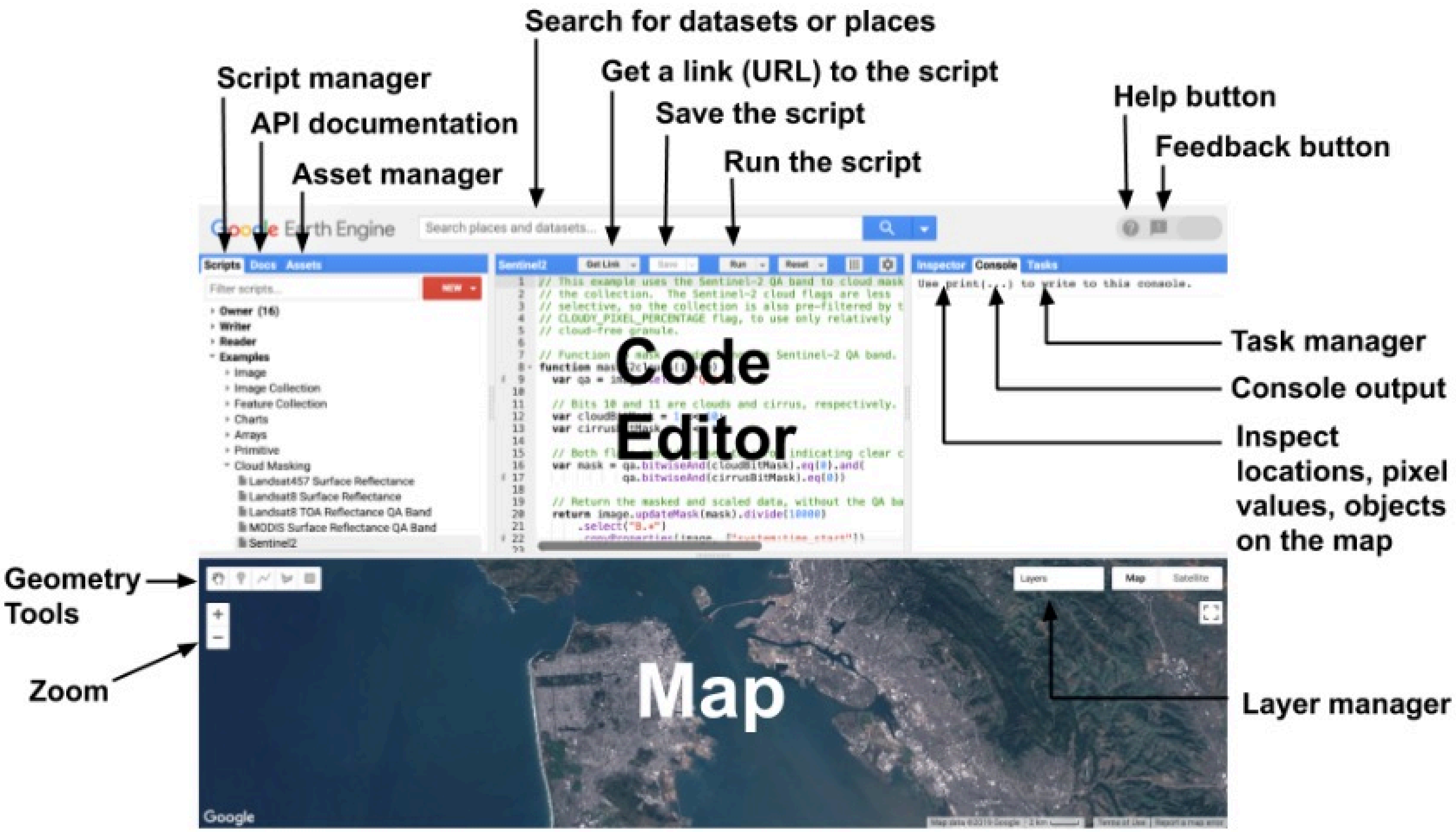
https://earthengine.google.com

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



Google Earth Engine Code Editor

https://code.earthengine.google.com



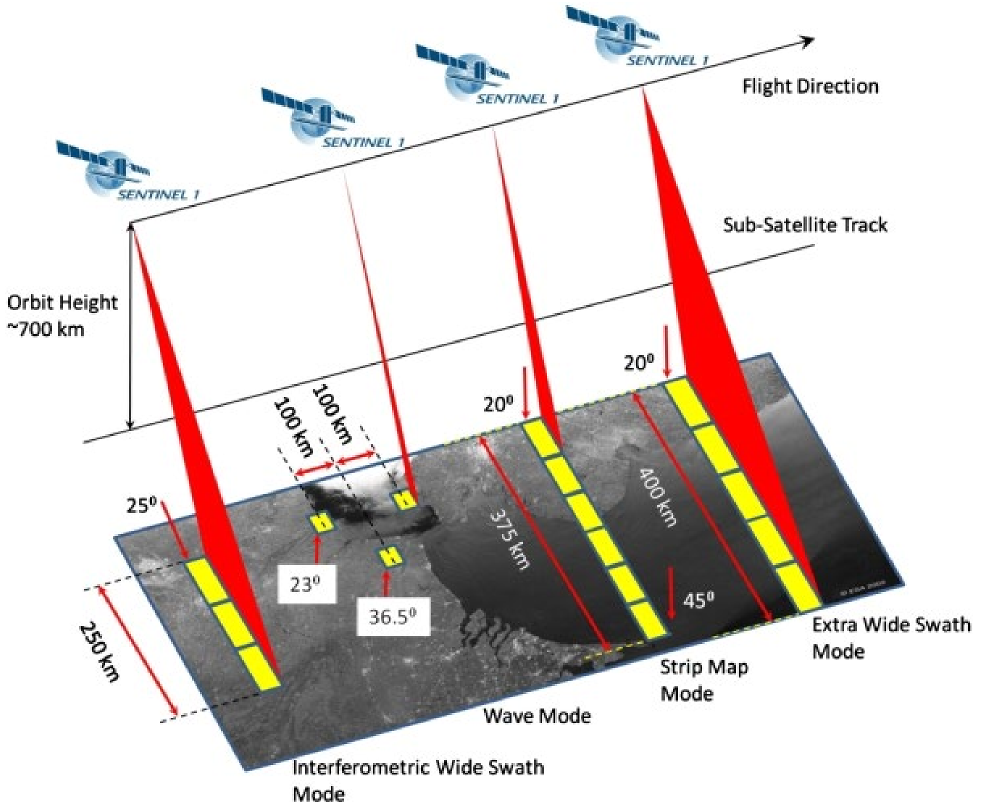
Sentinel-1 Data Review

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

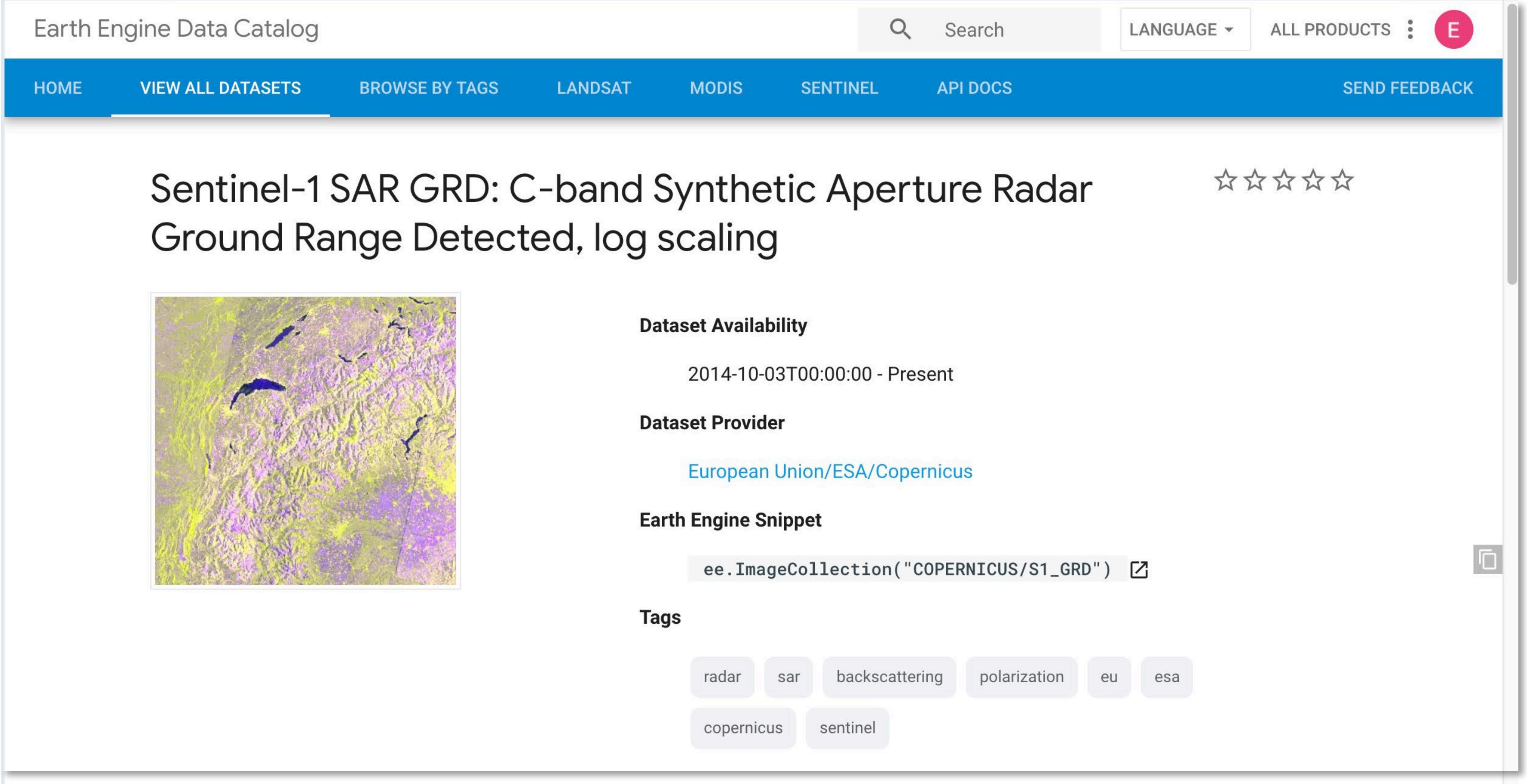
Different Modes:

- 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



Focus Area

Rondonia, Brazil

Google Earth Engine Time Series Demo Code

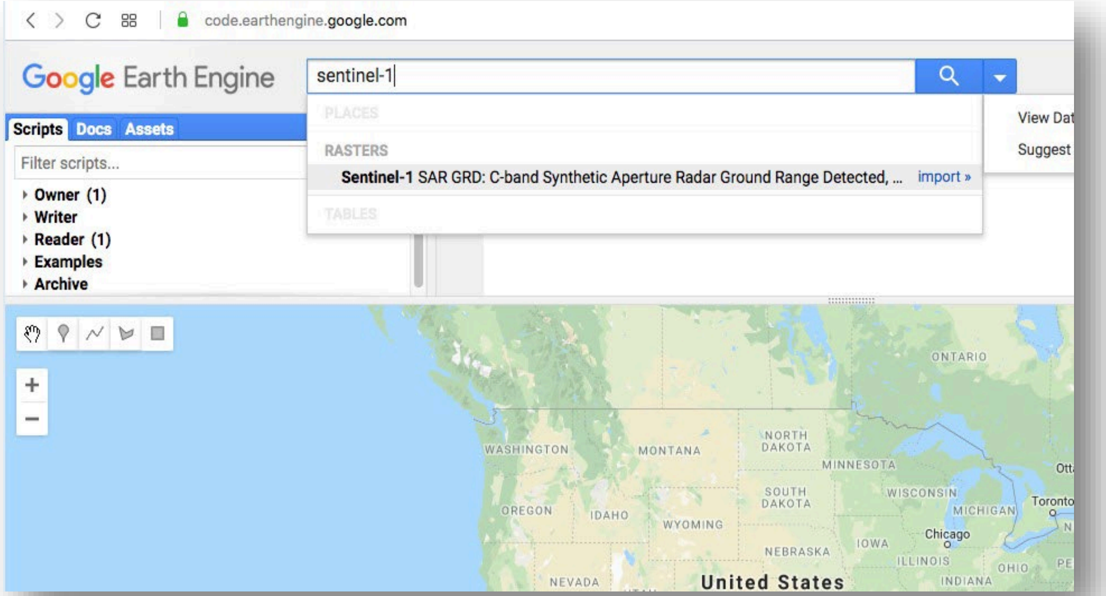
https://code.earthengine.google.com/cfa42183bac06bdac5a16ed8a05233a5?accept_repo=users%2Fwolterpt%2FSAR_TimeSeries_PTW

Visualize Sentinel-1 Data

1. Start by opening Google Earth Engine: https://code.earthengine.google.com

2. Search for **Sentinel-1** data.

- A window with a description of the data will open showing:
  - The steps taken to process the data (thermal noise removal, radiometric calibration, terrain correction)
  - Bands and resolution
  - Metadata (important parameters are mode and orbit properties - descending or ascending)



3. Click back on the map portion of the webpage to exit out of the Sentinel-1 data information tab.

Select Area of Interest

<u>**Define your area of interest**</u>

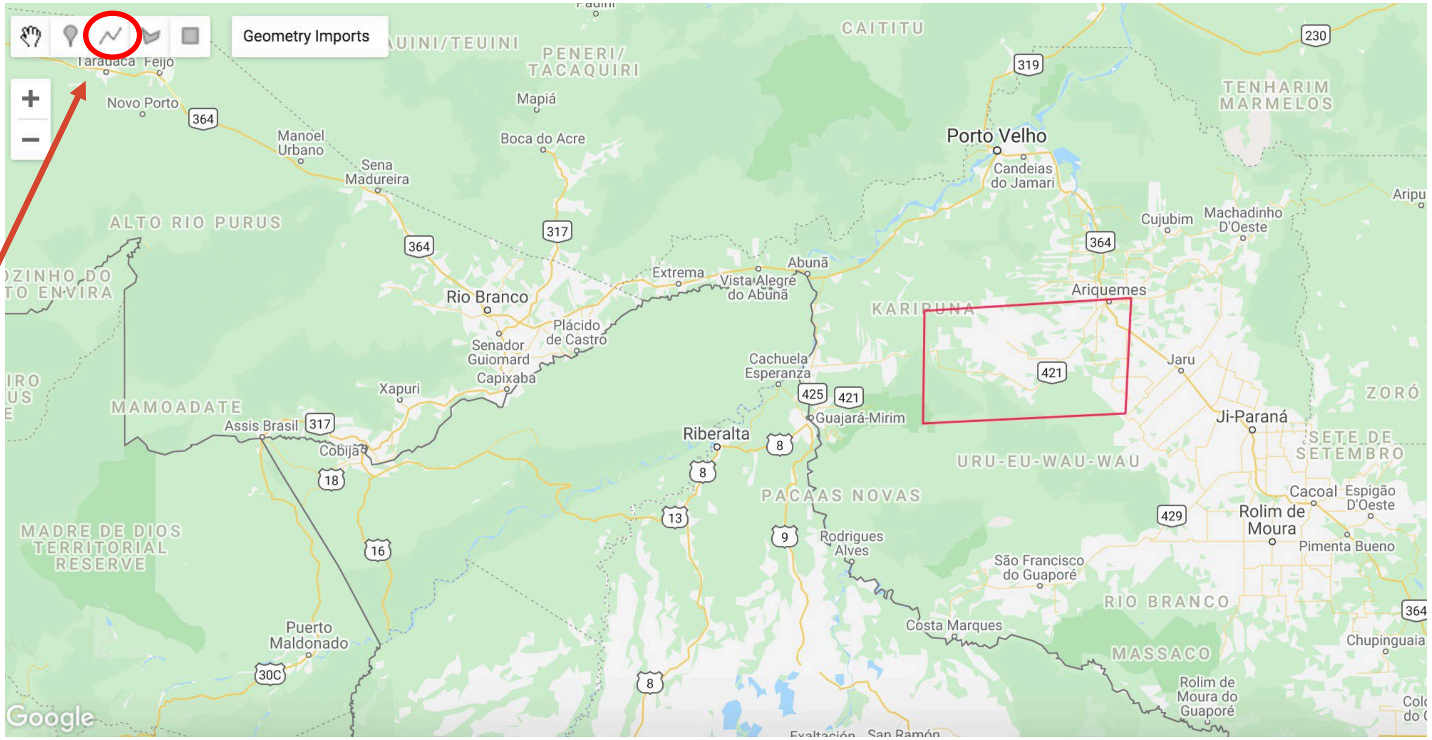
4. Zoom into **Rondonia, Brazil**.

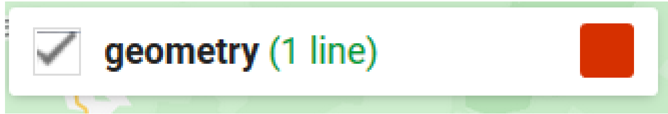
- You can do this by typing Rondonia, Brazil into the search bar along the top, and then zooming into the region until you see the town of Porto Velho.

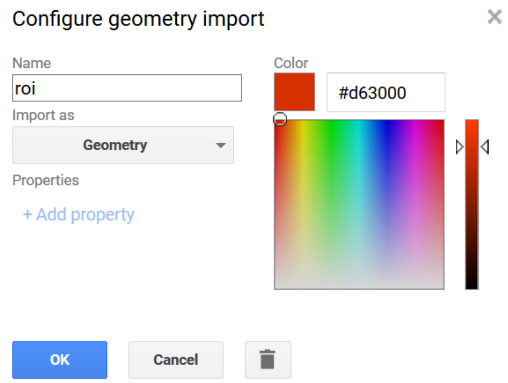
5. Select the **draw a line** icon.

6. Draw a rectangle like the one here over our area of interest.

7. Hover over **geometry** and then click on the wheel icon to change the name to **roi** (region of interest), then click **OK**.







Filter the Sentinel-1 Data

8. Load the Sentinel-1 database and filter for images that are in Interferometric Wide Swath Mode (IW), Descending Pass, 10-meter resolution, and VV polarization.
In the script editor, add the following code:

```
// Load Sentinel-1 C-band SAR Ground Range collection (log scale, VV, descending)
var collectionVV = ee.ImageCollection('COPERNICUS/S1_GRD')
.filter(ee.Filter.eq('instrumentMode', 'IW'))
.filter(ee.Filter.listContains('transmitterReceiverPolarisation', 'VV'))
.filter(ee.Filter.eq('orbitProperties_pass', 'DESCENDING'))  .filterMetadata('resolution_meters',
'equals' , 10)
.filterBounds(roi)
.select('VV');
print(collectionVV, 'Collection VV');
```

** Note that all Sentinel-1 images in Google Earth Engine are in dB*

Filter the Sentinel-1 Data

9. Click enter or return, so that you are now on line 11 in the code editor. Repeat step 8, but this time filter the data for VH polarization by adding the following code:

```
// Load Sentinel-1 C-band SAR Ground Range collection (log scale, VH, descending)
var collectionVH = ee.ImageCollection('COPERNICUS/S1_GRD')
.filter(ee.Filter.eq('instrumentMode', 'IW'))
.filter(ee.Filter.listContains('transmitterReceiverPolarisation', 'VH'))
.filter(ee.Filter.eq('orbitProperties_pass', 'DESCENDING'))
.filterMetadata('resolution_meters', 'equals' , 10)
.filterBounds(roi)
.select('VH');
print(collectionVH, 'Collection VH');
```

** Note that all Sentinel-1 images in Google Earth Engine are in dB*

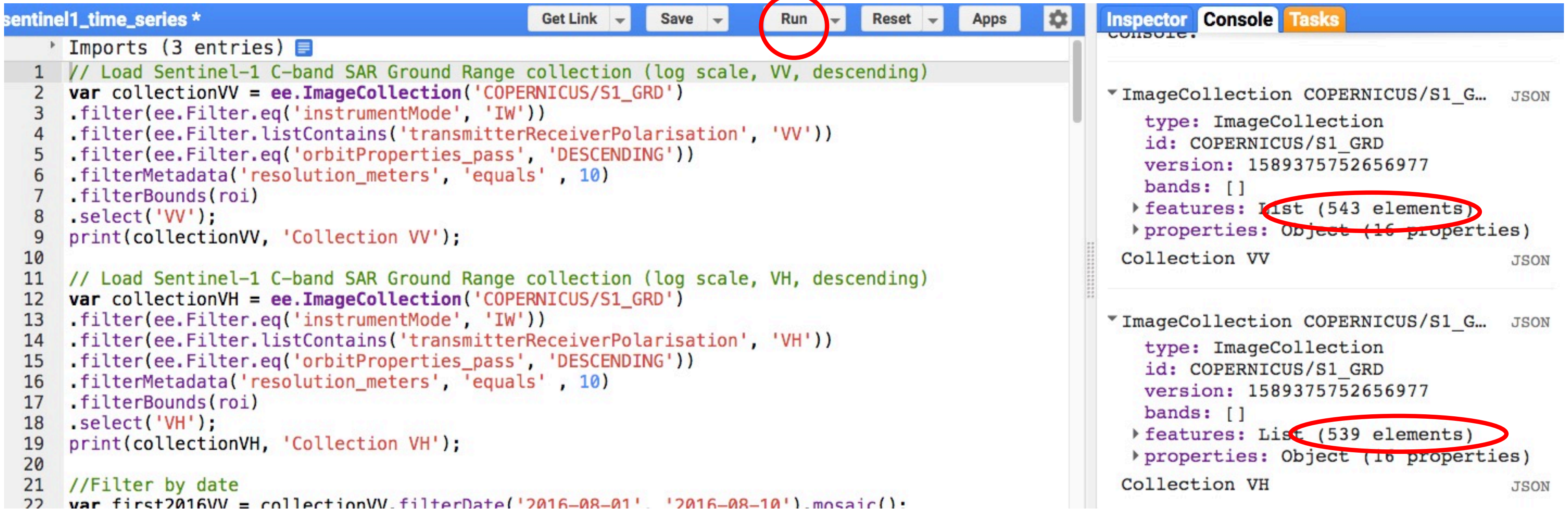
Filter the Sentinel-1 Data

10. Ensure that your script is the same as the image below.

- Note, you may need to enter each piece of the code on a separate line so that they are indicated as actions.

11. Click on **Run** in the top menu.

- The **Console** window on the right shows the results for VV (543 images) and VH (539 images)*.
- *Number of elements may be different due to the size of the roi you created in step 6.



Filter the Sentinel-1 Data

Filter the Sentinel-1 by date

12. Filter by three different date ranges.
Click enter or return, so that you are now on line 21 in the code editor and add the code below:

```
//Filter by date
var first2016VV = collectionVV.filterDate('2016-08-01', '2016-08-10').mosaic();
var second2018VV = collectionVV.filterDate('2018-08-05', '2018-08-10').mosaic();
var third2019VV = collectionVV.filterDate('2019-08-01', '2019-08-15').mosaic();
var first2016VH = collectionVH.filterDate('2016-08-01', '2016-08-10').mosaic();
var second2018VH = collectionVH.filterDate('2018-08-05', '2018-08-10').mosaic();
var third2019VH = collectionVH.filterDate('2019-08-01', '2019-08-15').mosaic();
```

13. Click on **Run** in the top menu.

Display the Images

Display the Images

14. Add the VV and VH images that were identified in the previous step onto the ”layers” bar in order to visualize the images.

Click enter or return, so that you are now on line 29 in the code editor and add the code below:

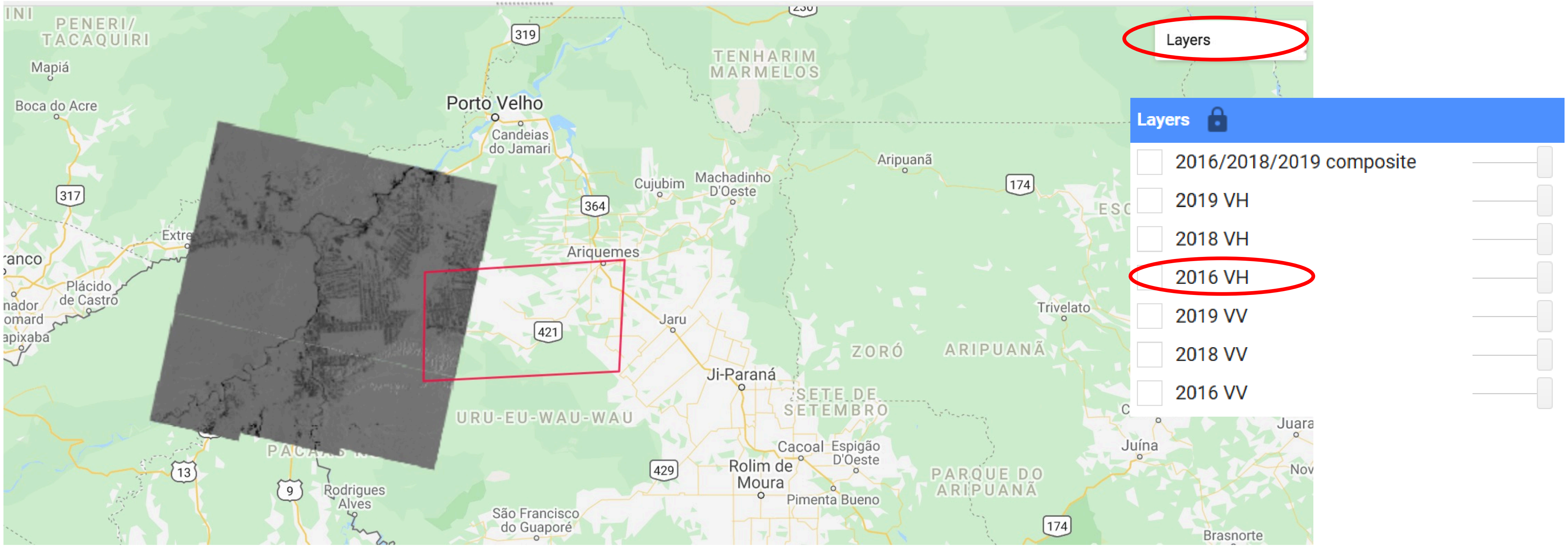
```
// Display map
Map.centerObject(roi, 7);
Map.addLayer(first2016VV, {min:-15,max:0}, '2016 VV', 0);
Map.addLayer(second2018VV, {min:-15,max:0}, '2018 VV', 0);
Map.addLayer(third2019VV, {min:-15,max:0}, '2019 VV', 0);
Map.addLayer(first2016VH, {min:-25,max:0}, '2016 VH', 0);
Map.addLayer(second2018VH, {min:-25,max:0}, '2018 VH', 0);
Map.addLayer(third2019VH, {min:-25,max:0}, '2019 VH', 0);
Map.addLayer(first2016VH.addBands(second2018VH).addBands(third2019VH), {min: -25,
max: -8}, '2016/2018/2019 composite', 0);
```

15. Click on **Run** in the top menu.

Display the Individual Images

16. Hover over the **Layers** box to see all the layers you have generated with your code.

17. Select the 2016 VH image to display it on the map.



Display the RGB Image

18. Hover again over the **Layers** box and deselect 2016 VH image

19. Select 2016/2018/2019 composite

Apply a Speckle Filter

20. Apply a speckle filter
Click enter or return, so that you are now on line 39 in the code editor and add the code below:

```
//Apply filter to reduce speckle
var SMOOTHING_RADIUS = 50;
var first2016VV_filtered = first2016VV.focal_mean(SMOOTHING_RADIUS, 'circle', 'meters');
var first2016VH_filtered = first2016VH.focal_mean(SMOOTHING_RADIUS, 'circle', 'meters');
var second2018VV_filtered = second2018VV.focal_mean(SMOOTHING_RADIUS, 'circle', 'meters');
var second2018VH_filtered = second2018VH.focal_mean(SMOOTHING_RADIUS, 'circle', 'meters');
var third2019VV_filtered = third2019VV.focal_mean(SMOOTHING_RADIUS, 'circle', 'meters');
var third2019VH_filtered = third2019VH.focal_mean(SMOOTHING_RADIUS, 'circle', 'meters');
```

21. Click on **Run** in the top menu

Add the Filtered Images to Layers

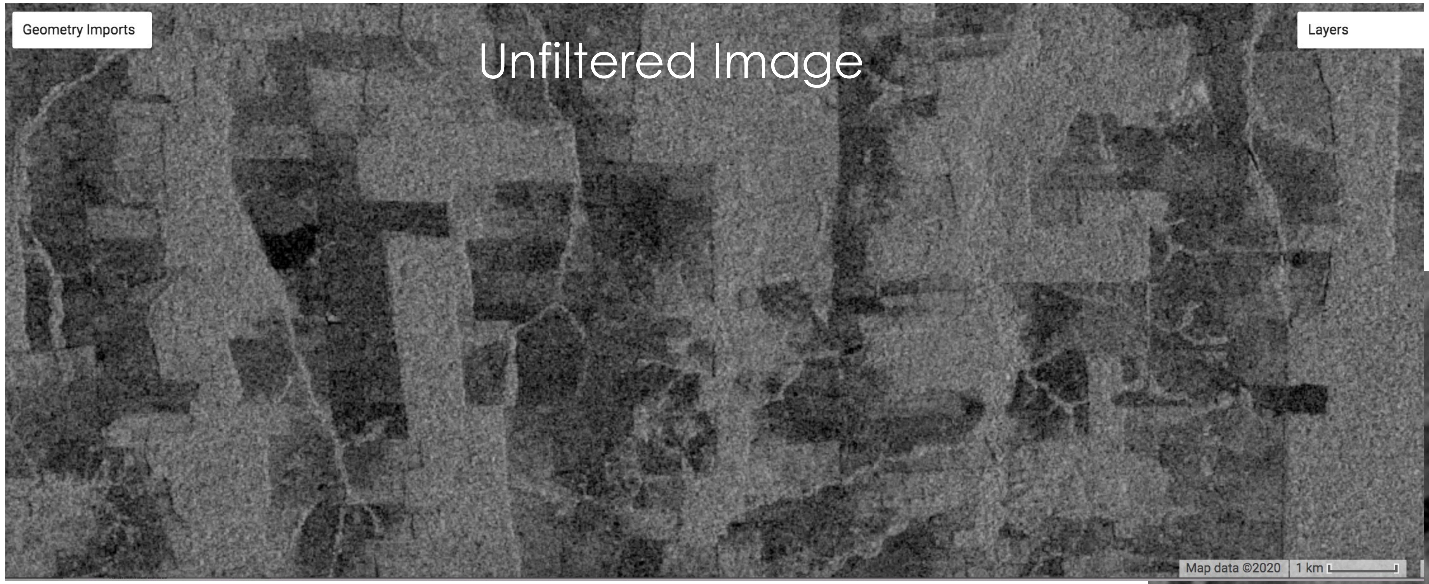
22. Add the filtered images to “layers” in order to display them
Click enter or return, so that you are now on line 48 in the code editor and add the code below:

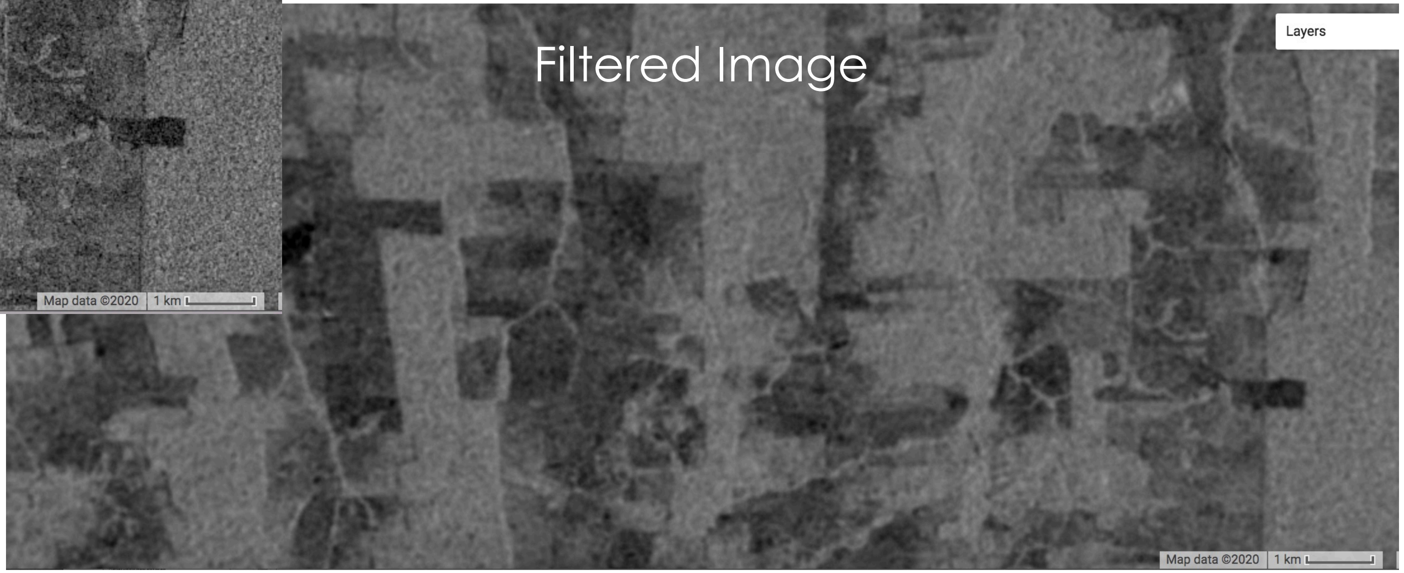
```
//Display filtered images
Map.addLayer(first2016VV_filtered, {min:-15,max:0}, '2016 VV Filtered',0);
Map.addLayer(first2016VH_filtered, {min:-27,max:0}, '2016 VH Filtered',0);
Map.addLayer(second2018VV_filtered, {min:-15,max:0}, '2018 VV Filtered',0);
Map.addLayer(second2018VH_filtered, {min:-27,max:0}, '2018 VH Filtered',0);
Map.addLayer(third2019VV_filtered, {min:-15,max:0}, '2019 VV Filtered',0);
Map.addLayer(third2019VH_filtered, {min:-27,max:0}, '2019 VH Filtered',0);
Map.addLayer(first2016VH_filtered.addBands(second2018VH_filtered).addBands(third2019VH_filtered), {min: -25, max: -8}, '2016/2018/2019 HV filtered RGB', 0);
```

23. Click on **Run** in the top menu

Display the Filtered vs. Unfiltered

24. In the "layers" menu, toggle between the same filtered and unfiltered image to see the difference (e.g. 2019 VH Filtered and 2019 VH).





Calculate the Ratio Between Before and After Images

25. Calculate the ratio between before and after images for 2016 and 2018 and for 2018 and 2019. Click enter or return, so that you are now on line 57 in the code editor and add the code below:

```
// Calculate the ratio between before and after
var ratio1618VH= first2016VH_filtered.subtract(second2018VH_filtered);
var ratio1618VV= first2016VV_filtered.subtract(second2018VV_filtered);
var ratio1819VH= second2018VH_filtered.subtract(third2019VH_filtered);
var ratio1819VV= second2018VV_filtered.subtract(third2019VV_filtered);
```

26. Click on **Run** in the top menu

* Note: The code is performing a subtraction because the images are in log scale (dB) and the rule when dividing two log numbers is to subtract the values.

Add the Ratio Images to Layers

27. Add the ratio images to ”layers”: in order to display them.
Click enter or return, so that you are now on line 63 in the code editor and add the code below:

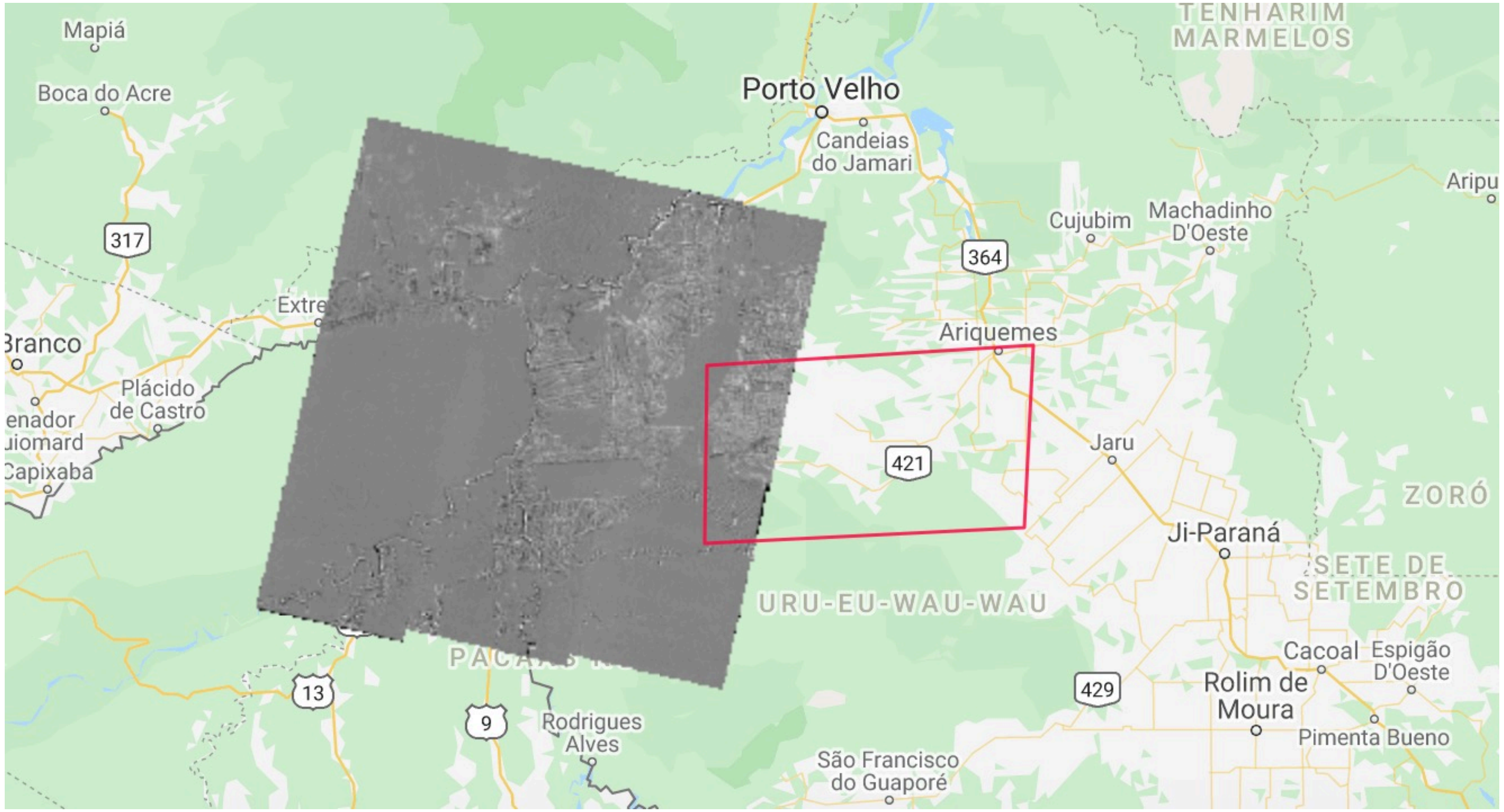
```
// Display the ratio images
Map.addLayer(ratio1618VH, {min: -9,max:9}, ‘Ratio VH 2016/2018', 0);
Map.addLayer(ratio1618VV, {min: -9,max:9}, 'Ratio VV 2016/2018', 0);
Map.addLayer(ratio1819VH, {min: -9,max:9}, ‘Ratio VH 2018/2019', 0);
Map.addLayer(ratio1819VV, {min: -9,max:9}, ‘Ratio VV 2018/2019', 0);
```

28. Click on **Run** in the top menu

Display the Ratio Images

29. Hover again over the **Layers** box and deselect everything.

30. Select any of the ratio images that you want to view.

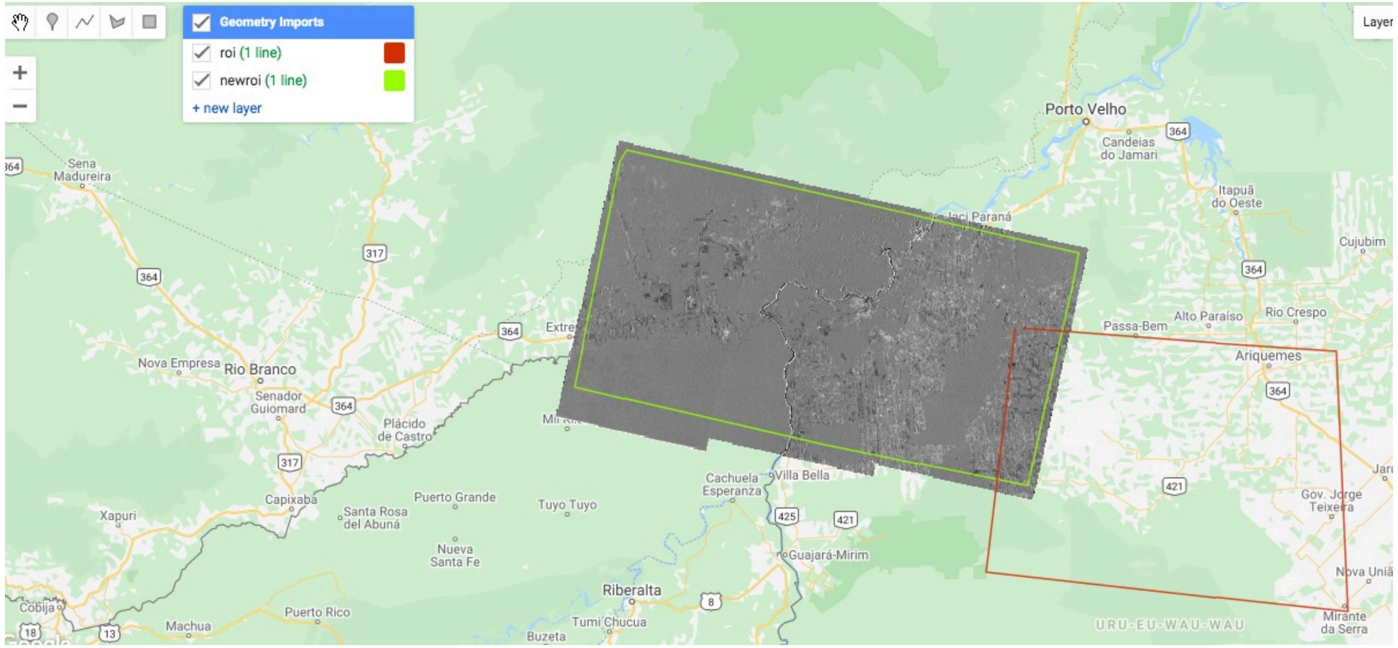


Select a New Region of Interest

Select a new region of interest that delineates the area covered by the ratio images
31. Select the **draw a line** icon.

32. Draw a rectangle similar to the one here over our area of interest.

33. Hover over **geometry** and then click on the wheel icon to change the name to **newroi** (region of interest), then click **OK**.



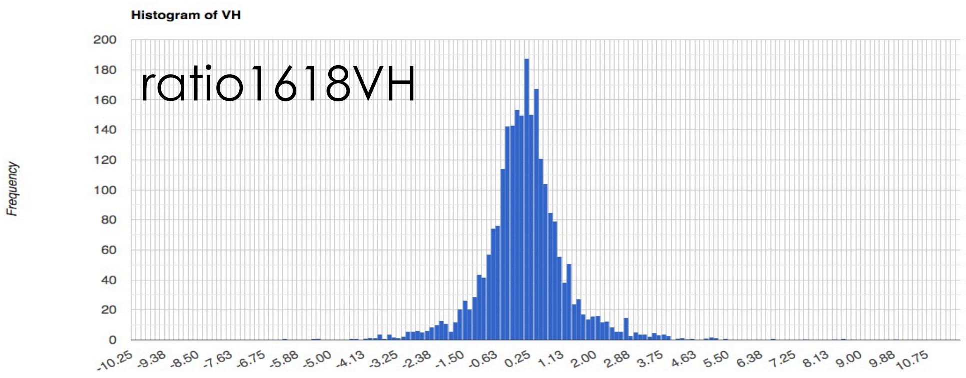
Create a Histogram

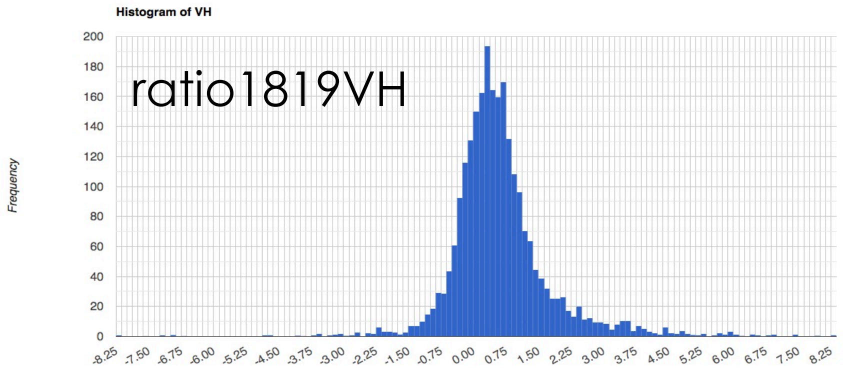
34. Create a histogram for the values in each of the ratio images.
Click enter or return, so that you are now on line 69 in the code editor and add the code below:

```
//Calculate histograms for each image
print(ui.Chart.image.histogram({image:ratio1618VH, region:newroi, scale:300}));
print(ui.Chart.image.histogram({image:ratio1819VH, region:newroi, scale:300}));
```

35. Click on **Run** in the top menu.

36. Display the histograms in a separate screen by going into the console window and clicking on the arrow next to the top right of each histogram.





Calculate the Mean and Standard Deviation

37. Calculate the mean and standard deviation for each of the ratio images.
First combine the mean and standard deviations.
Click enter, so that you are now on line 73 in the code editor and add the code below:

```
// Combine the mean and standard deviation reducers.
var reducers = ee.Reducer.mean().combine({
 reducer2: ee.Reducer.stdDev(),
 sharedInputs: true
});
```

Calculate the Mean and Standard Deviation

38. Calculate the mean and standard deviation for each of the ratio images.
Click enter, so that you are now on line 79 in the code editor and add the code below:

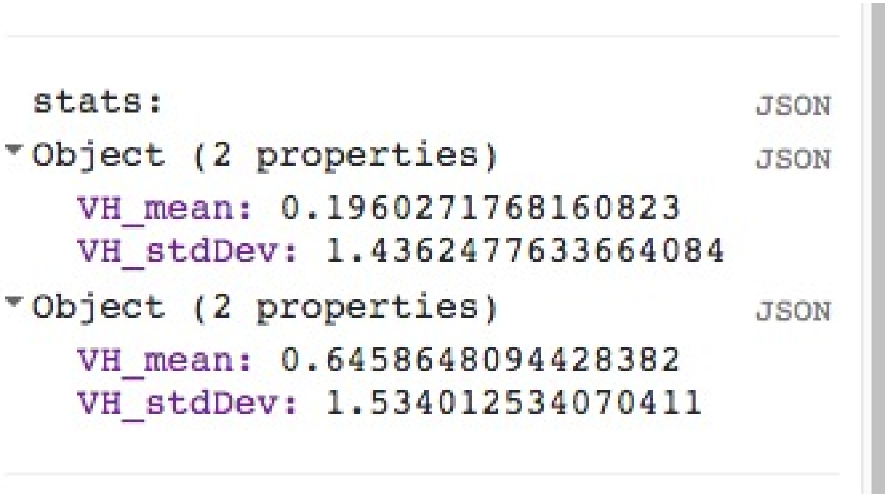
```
//Calculate the mean and standard deviation for each ratio image
var stats1618 = ratio1618VH.reduceRegion({
 reducer: reducers,
 geometry: newroi,
 scale: 10,
});

var stats1819 = ratio1819VH.reduceRegion({
 reducer: reducers,
 geometry: newroi,
 scale: 10,
});
```

Print the Mean and Standard Deviation

39. Print the mean and standard deviation.
Click enter, so that you are now on line 92 in the code editor and add the code below:

```
//Print the mean and stdv for each difference image
print('stats:', stats1618, stats1819)
```

40. Click on **Run** in the top menu.



Apply a Threshold to Create a Vegetation Loss Mask

41. Apply thresholds based on values greater than the standard deviation x 1.5.
Click enter, so that you are now on line 95 in the code editor and add the code below:

```
//Apply Thresholds based on < stdvx1.5 to create a vegetation regrowth mask
var RATIO_UPPER_THRESHOLD1618 = 2.35;
var RATIO_UPPER_THRESHOLD1819 = 2.95;
var ratio1618VH_thresholded = ratio1618VH.gt(RATIO_UPPER_THRESHOLD1618);
var ratio1819VH_thresholded = ratio1819VH.gt(RATIO_UPPER_THRESHOLD1819);
```

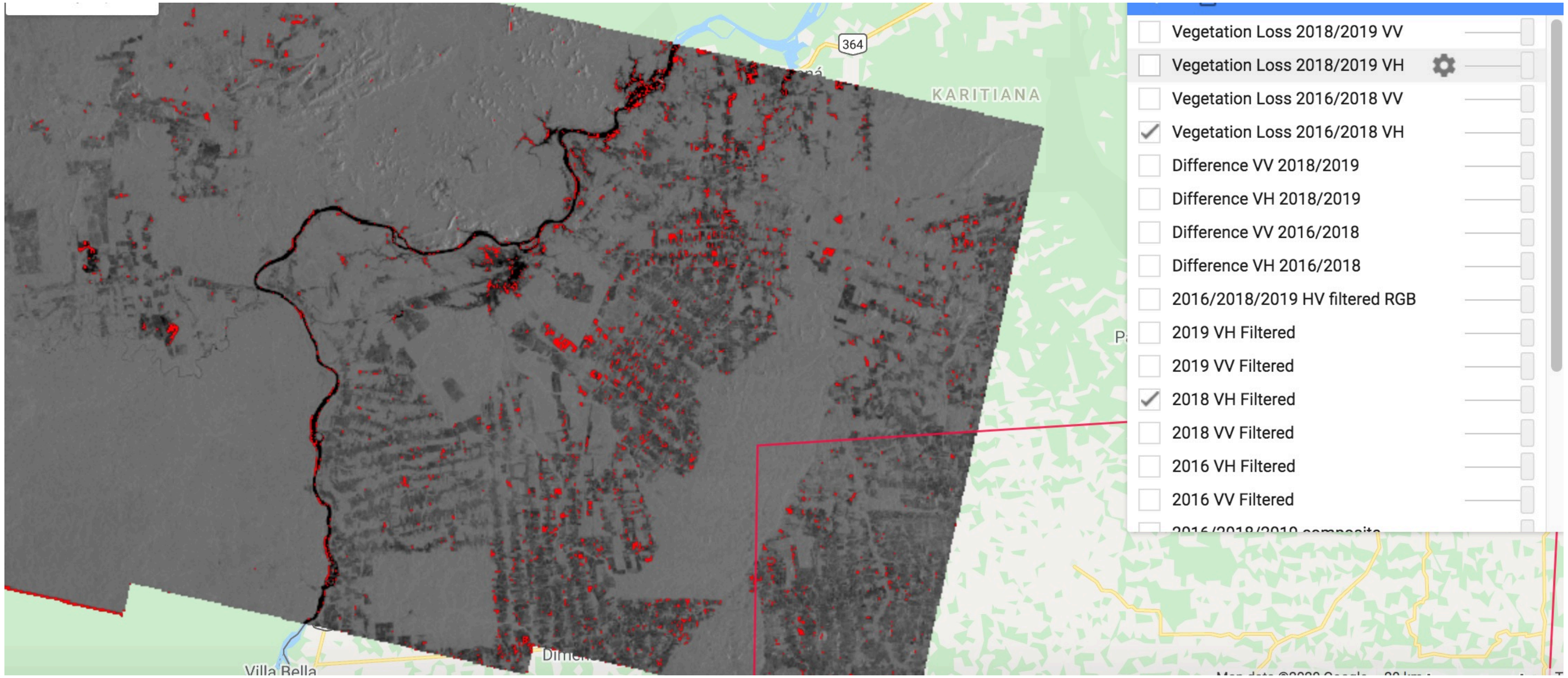
42. Add the masks to “Layers”.
Click enter, so that you are now on line 101 in the code editor and add the code below:

```
//Display Masks
Map.addLayer(ratio1618VH_thresholded.updateMask(ratio1618VH_thresholded),{palette:
"FF0000"},'Vegetation Loss 16/18',1);
Map.addLayer(ratio1819VH_thresholded.updateMask(ratio1819VH_thresholded),{palette:
"FF0000"},'Vegetation Loss 18/19',1);
```

43. Click on **Run** in the top menu

Overlay the Vegetation Loss Mask

44. In your **Layers** panel turn on the
- Vegetation Loss 16/18 VH
- 2018 VH Filtered
- Toggle back and forth between the two



Compare Vegetation Loss Between the Two Time Periods

45. Identify a new region of interest using the "draw a shape" icon in the top left (make sure the area is within the extent of the difference images already created) where you want to perform your statistics of change, and label it as **stats_area**.

46. Calculate the number of pixels masked as vegetation loss in each of the mask images. Click enter, so that you are now on line 105 in the code editor and add the code below:

```
//Compare differences in vegetation loss between 16/18 and 18/19
var area_loss1618 = ratio1618VH_thresholded.reduceRegion({
 reducer: ee.Reducer.sum(),
 geometry: stats_area,
 scale: 10,
});

var area_loss1819 = ratio1819VH_thresholded.reduceRegion({
 reducer: ee.Reducer.sum(),
 geometry: stats_area,
 scale: 10,
});
```

Calculate Vegetation Loss Between the Two Time Periods

47. Print the count for each mask.
Click enter, so that you are now on line 118 in the code editor and add the code below:

```
//Print the mean and stdv for each ratio image
print('stats:', area_loss1618, area_loss1819);
```

```
stats:
▾Object (1 property)
   VH: 704417.0039215685
▾Object (1 property)
   VH: 581006.9411764706
```

48. Click on **Run** in the top menu.

49. The area of a pixel is 10 meters (which is 10 m × 10 m = 100 sq meters or 0.01 ha)

704417 pixels x 0.01 = 7044 ha in 2016/2018
581006 pixels x 0.01 = 5810 ha in 2018/2019

Export the Result as GeoTIFF

50. Export your vegetation loss mask as a GeoTIFF to your Google Drive
Click enter, so that you are now on line 120 in the code editor and add the code below:

```
// Export the image, specifying scale and region.
Export.image.toDrive({
  image: ratio1819VH_thresholded,
  description: '2018_2019_mask',
  scale: 10,
  region: newroi,
  fileFormat: 'GeoTIFF',
});
```

51. Click on **Run** in the top menu.

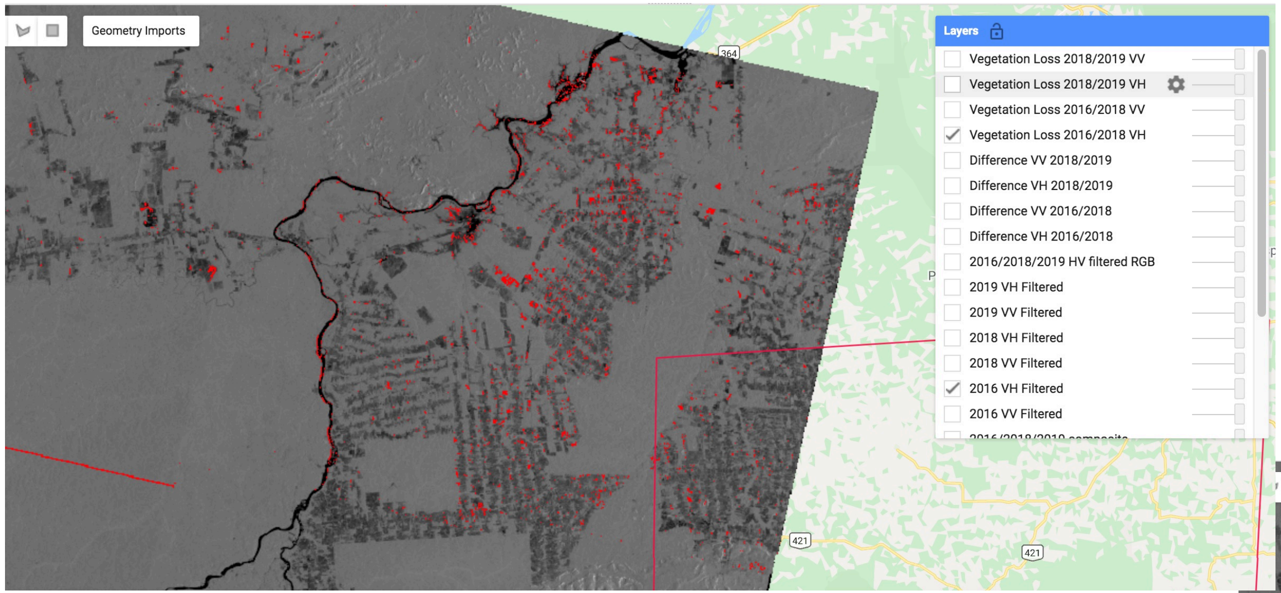
Save your Forest Change Code

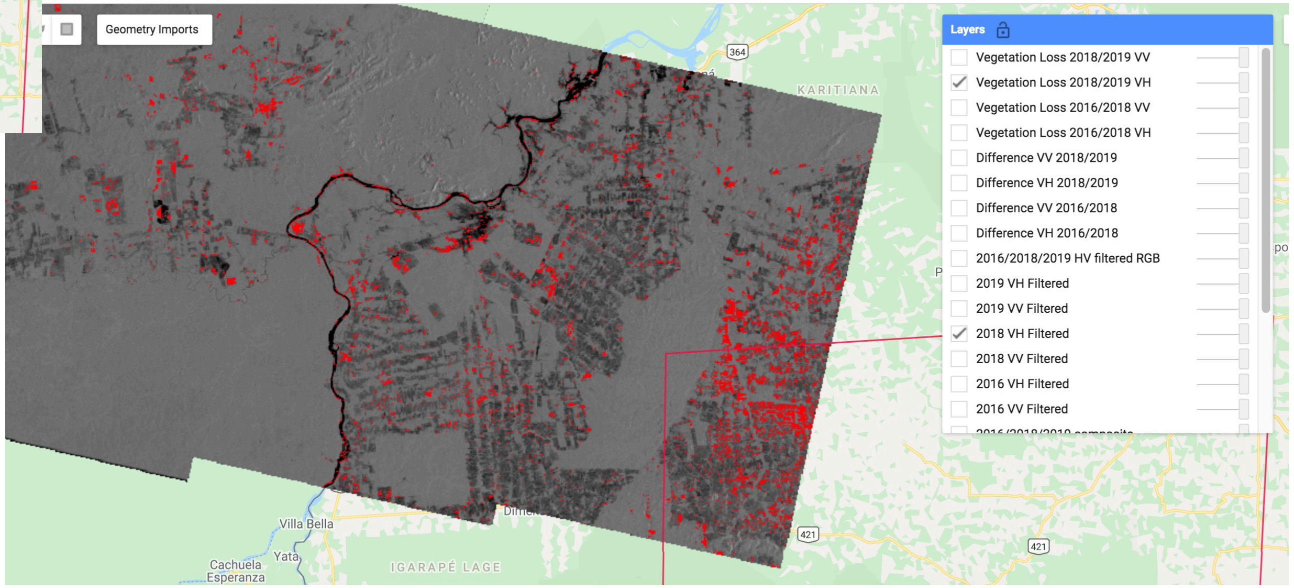
52. Along the top panel, click on Save and save your code as: **SAR_Landcover_Part1** to your directory.

Google Earth Engine Time Series Demo Code

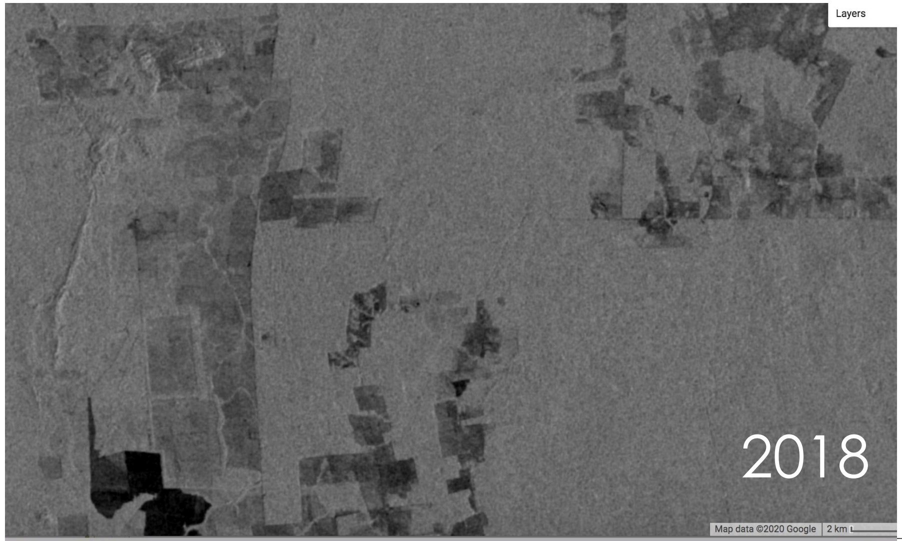
https://code.earthengine.google.com/cfa42183bac06bdac5a16ed8a05233a5?accept_repo=users%2Fwolterpt%2FSAR_TimeSeries_PTW

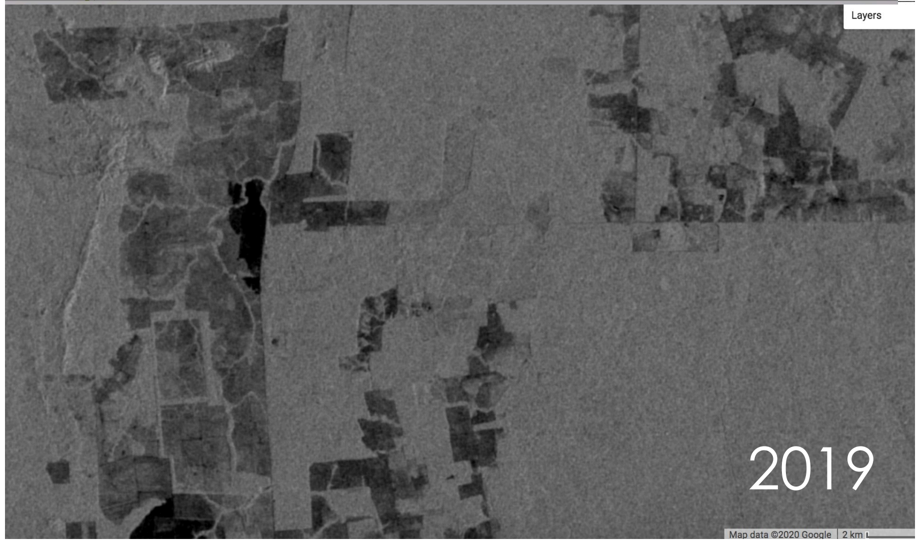
Vegetation Loss 2016/2018 and 2018/2019

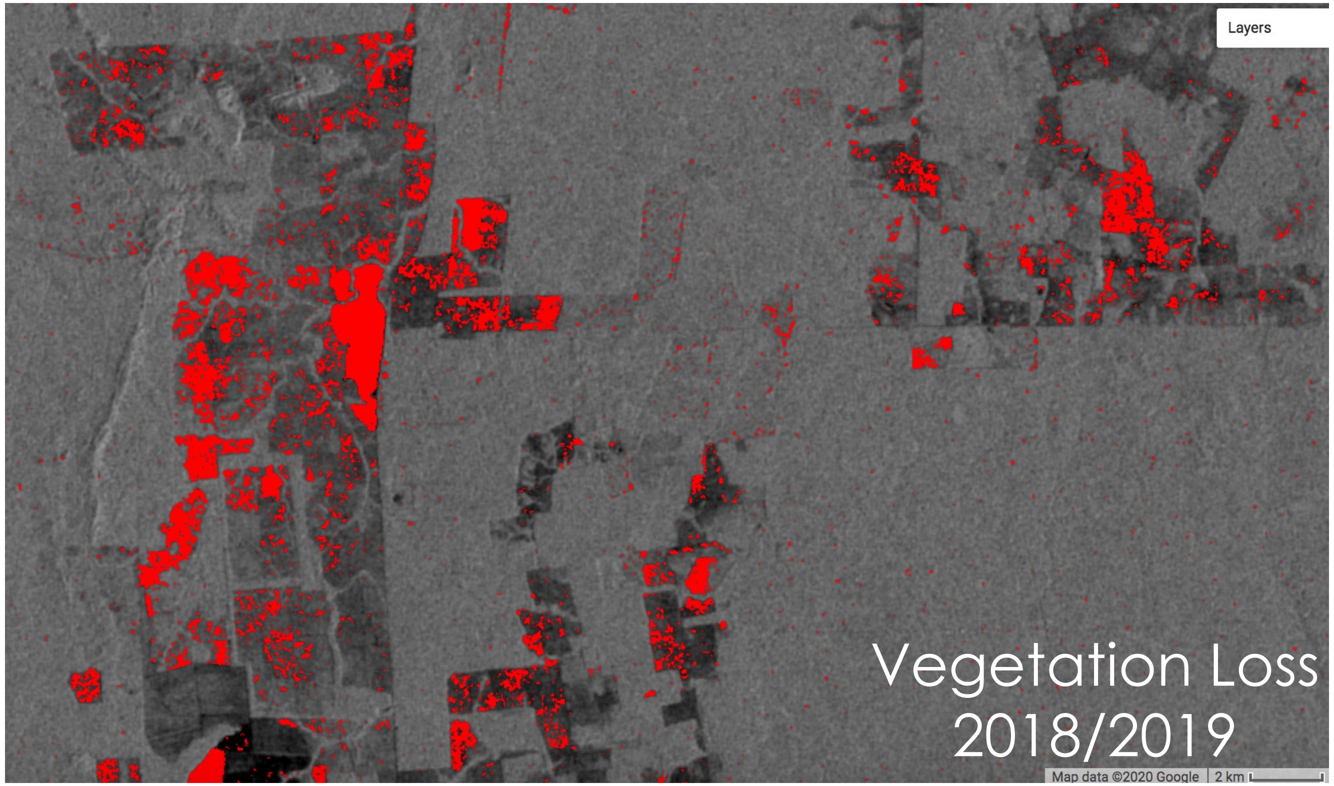




Vegetation Loss 2018/2019







Exercise Summary

- In this demo we identified Sentinel-1 images for three different years and created ratio images for 2016/2018 and 2018/2019. A threshold was then applied to create a mask of the areas where vegetation loss occurred.
- The ratio images indicate that the areas where the ratio is high is where vegetation loss occurred. A threshold was selected for pixels exceeding the standard deviation x 1.5.
- A statistical comparison of vegetation loss was performed between 2016/2018 and 2018/2019.

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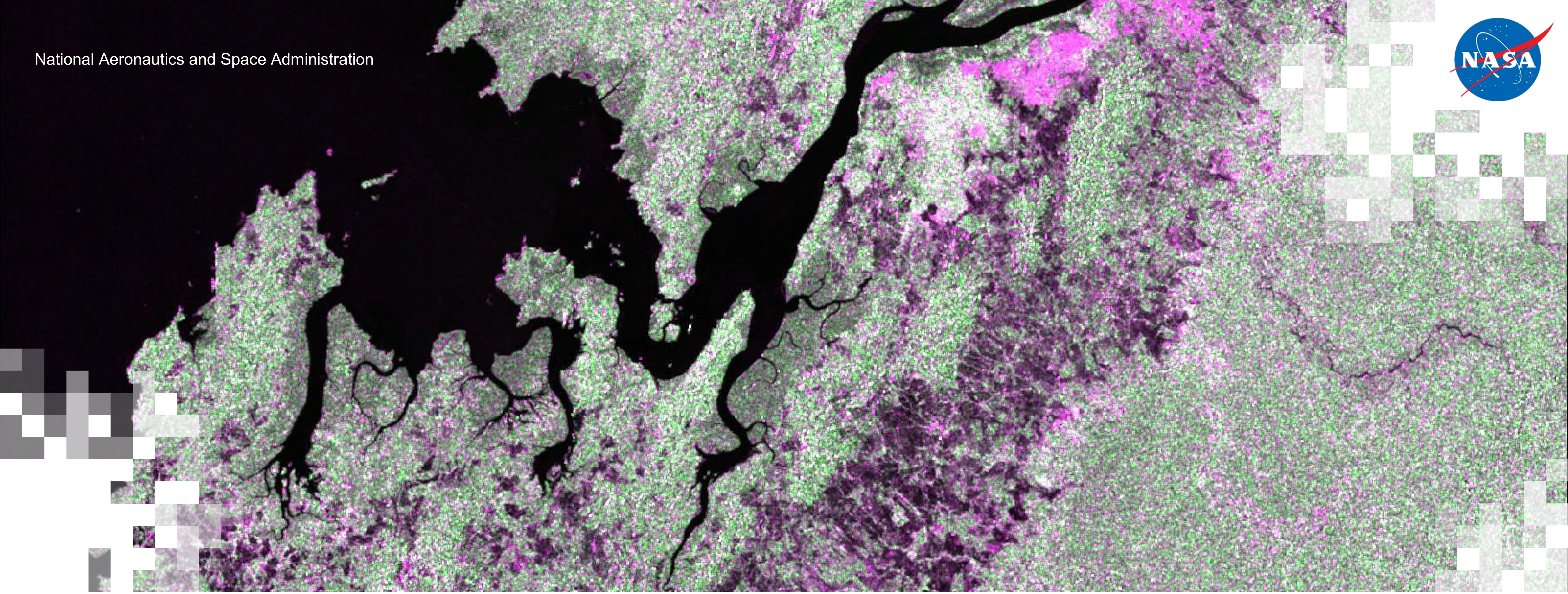
National Aeronautics and Space Administration



Next Session: Land Cover Classification

May 14, 2020

Questions

- Please enter your questions into the Q&A box
- We will post the questions and answers to the training website following the conclusion of the course

Thank You!