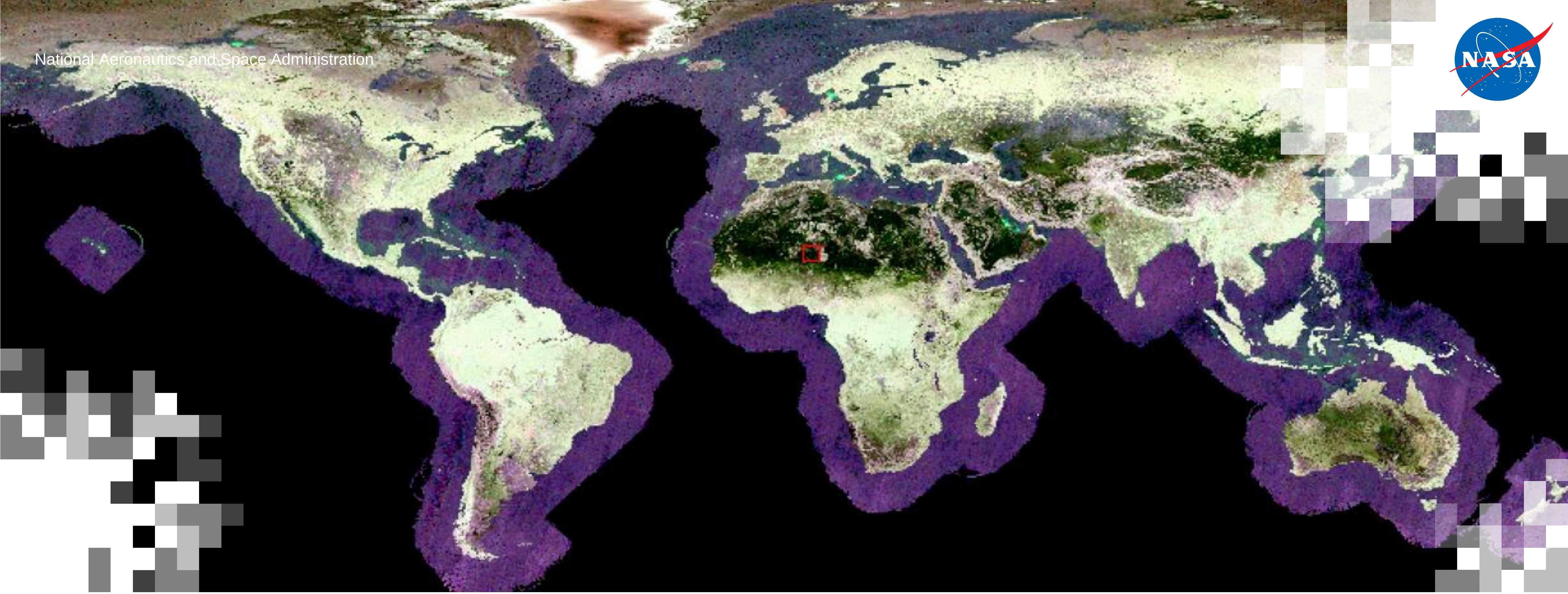
National Aeronautics and Space Administration



SAR for Flood Mapping using Google Earth Engine

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

Sean McCartney, NASA Goddard Space Flight Center

28 August 2019

Learning Objectives

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

- the information content in SAR images relevant to flooding
- how to generate a flood map using Google Earth Engine

Flooding Definition from a Radar Perspective:

The temporary or permanent occurrence of a water surface:

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

SAR Signal Scattering Over Inundated Regions

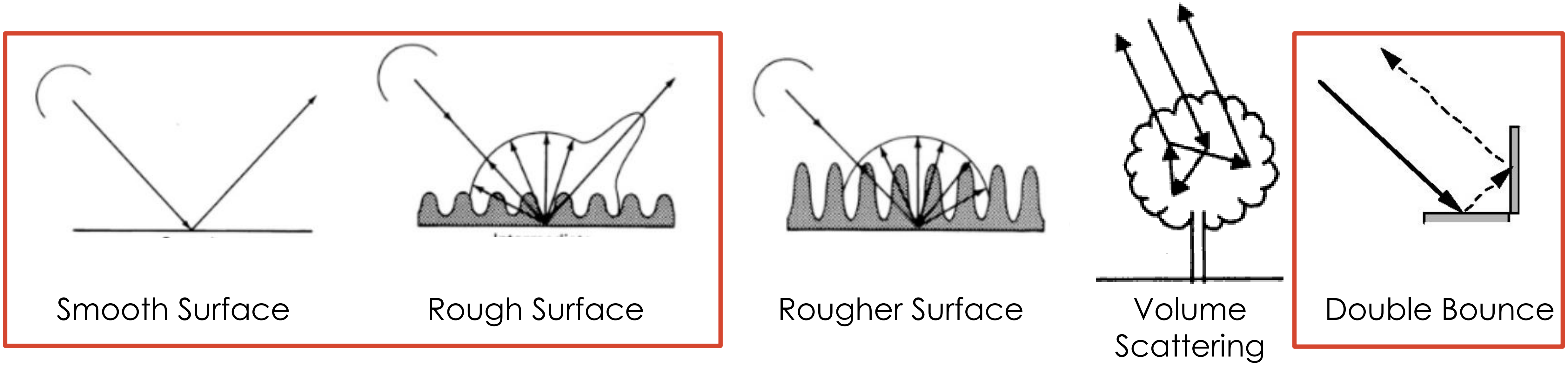
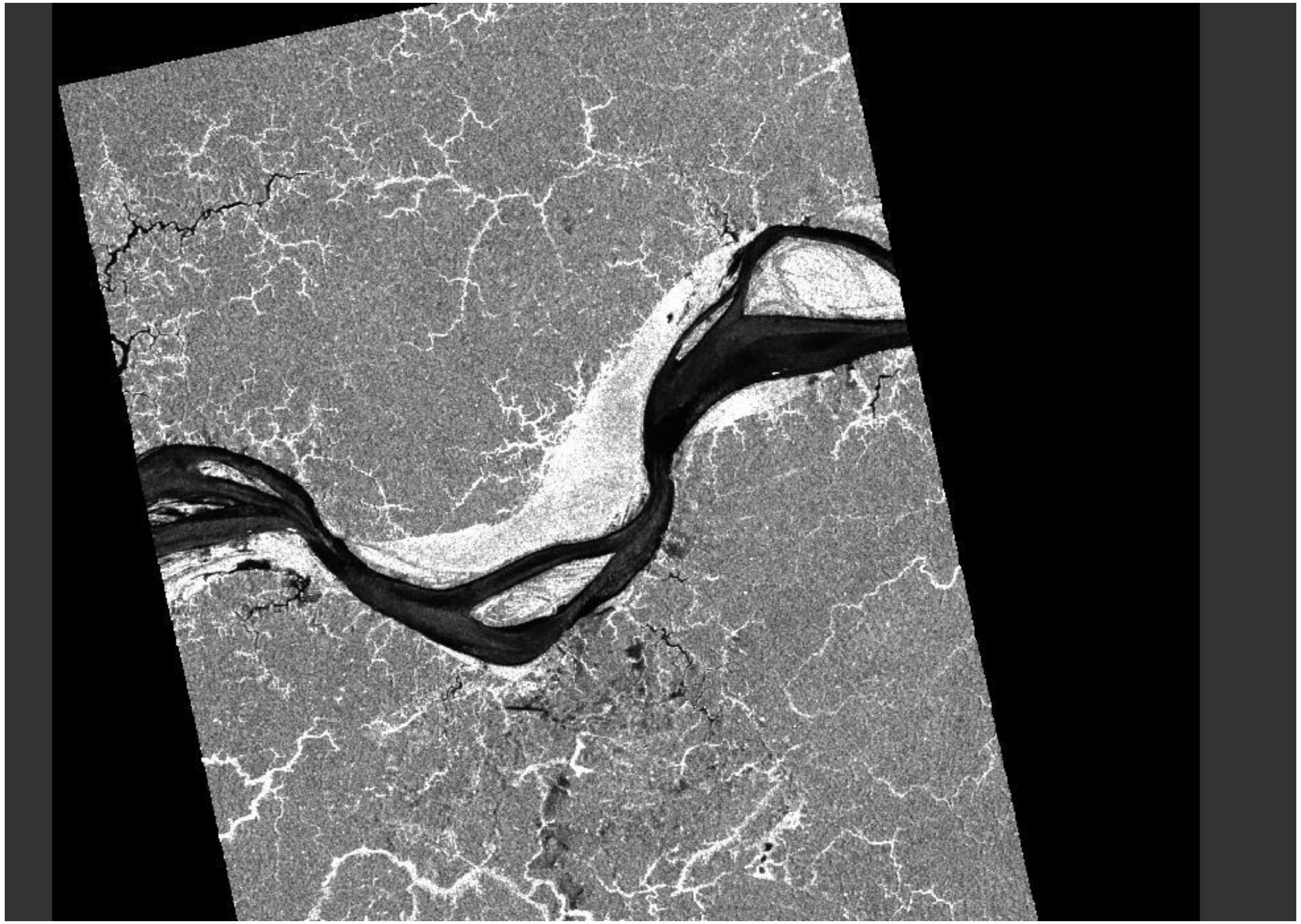


Image Credits: top: Ulaby et al. (1981a)

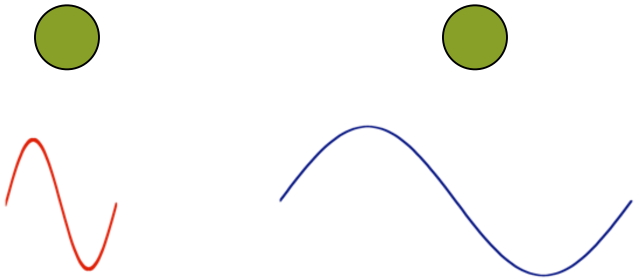
SAR Signal Scattering Over Inundated Regions

PALSAR Image (L-band) near Manaus, Brazil

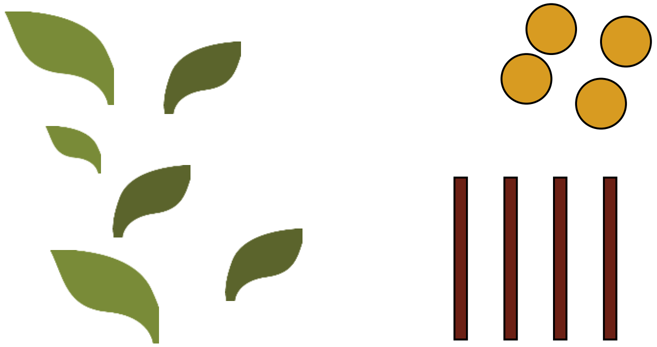


Surface Parameters Related to Structure

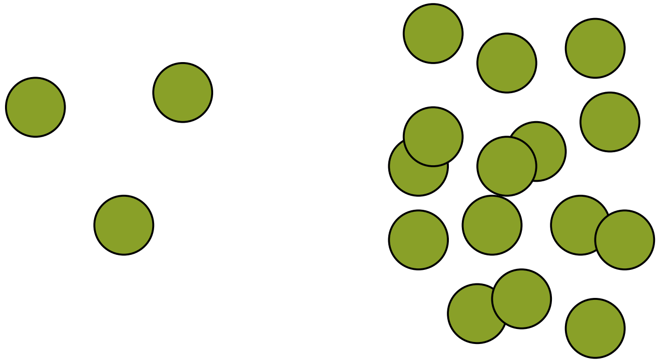
Size Relative to Wavelength



Orientation

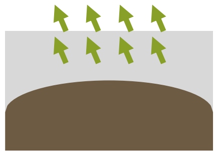
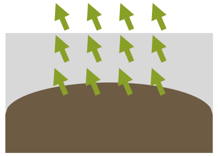
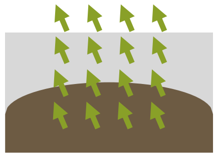


Density



Wavelength and SAR Signal Response Over Flooded Vegetation

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

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

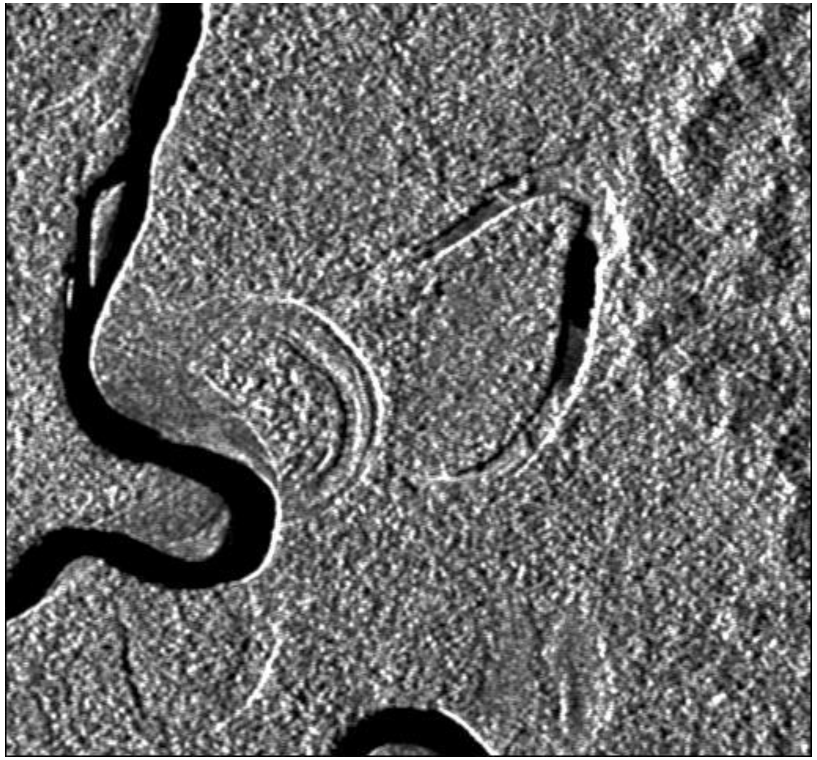
Band Designation*	Wavelength (λ), cm	Frequency (ν), GH_z (10^9 cycles·sec^{-1})
Ka (0.86 cm)	0.8 – 1.1	40.0 – 26.5
K	1.1 – 1.7	26.5 – 18.0
Ku	1.7 – 2.4	18.0 – 12.5
X (3.0 cm, 3.2 cm)	2.4 – 3.8	12.5 – 8.0
C (6.0)	3.8 – 7.5	8.0 – 4.0
S	7.5 – 15.0	4.0 – 2.0
L (23.5 cm, 25 cm)	15.0 – 30.0	2.0 – 1.0
P (68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

*wavelengths most frequently used in SAR are in parenthesis

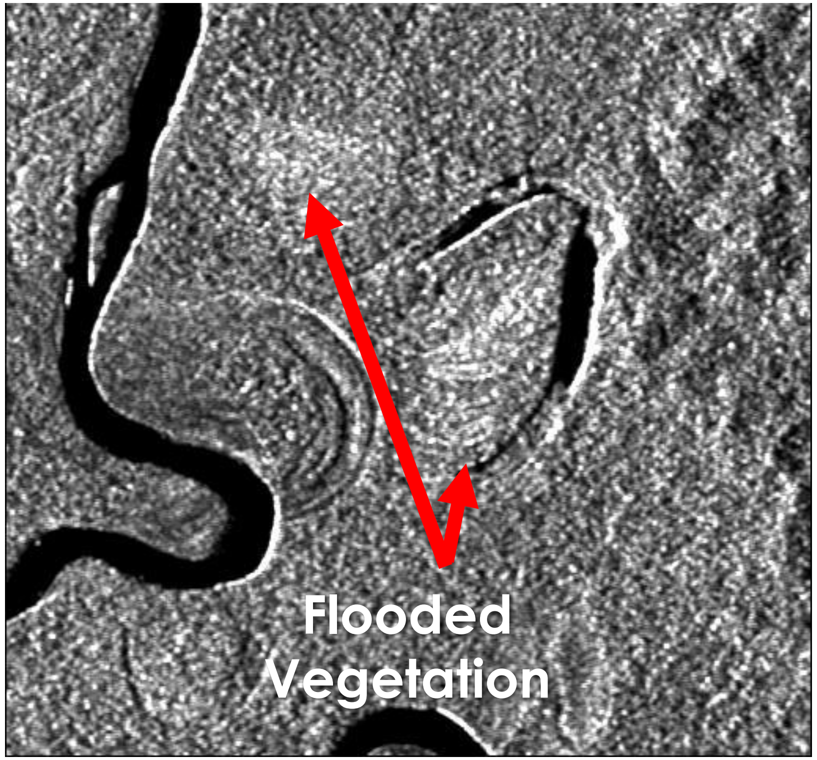
Signal Penetration Over Flooded Vegetation

Multifrequency AIRSAR data in Manu National Park, Peru

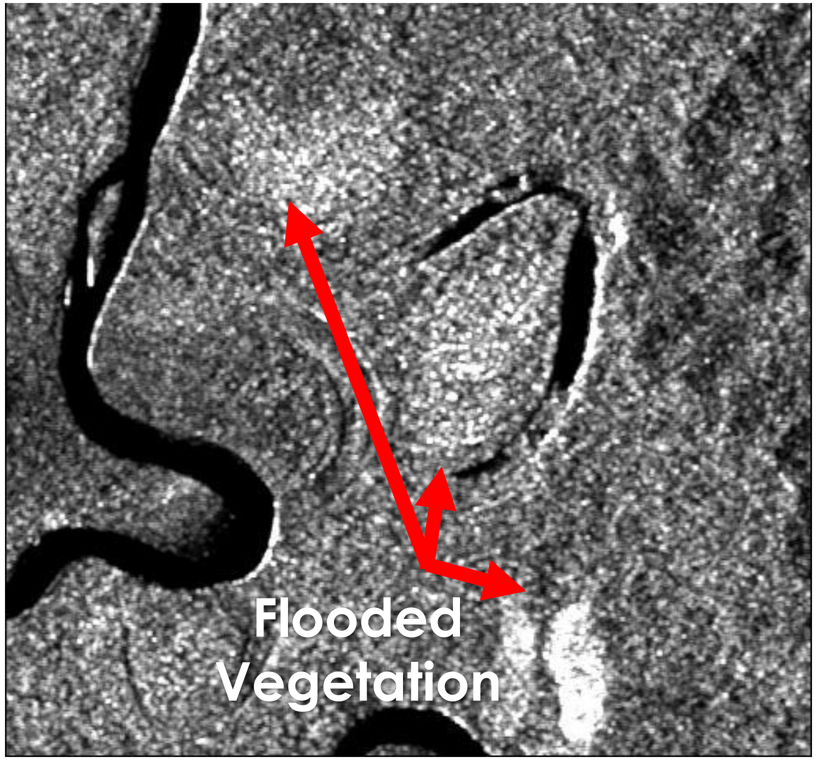
C-Band



L-Band



P-Band



Polarization

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

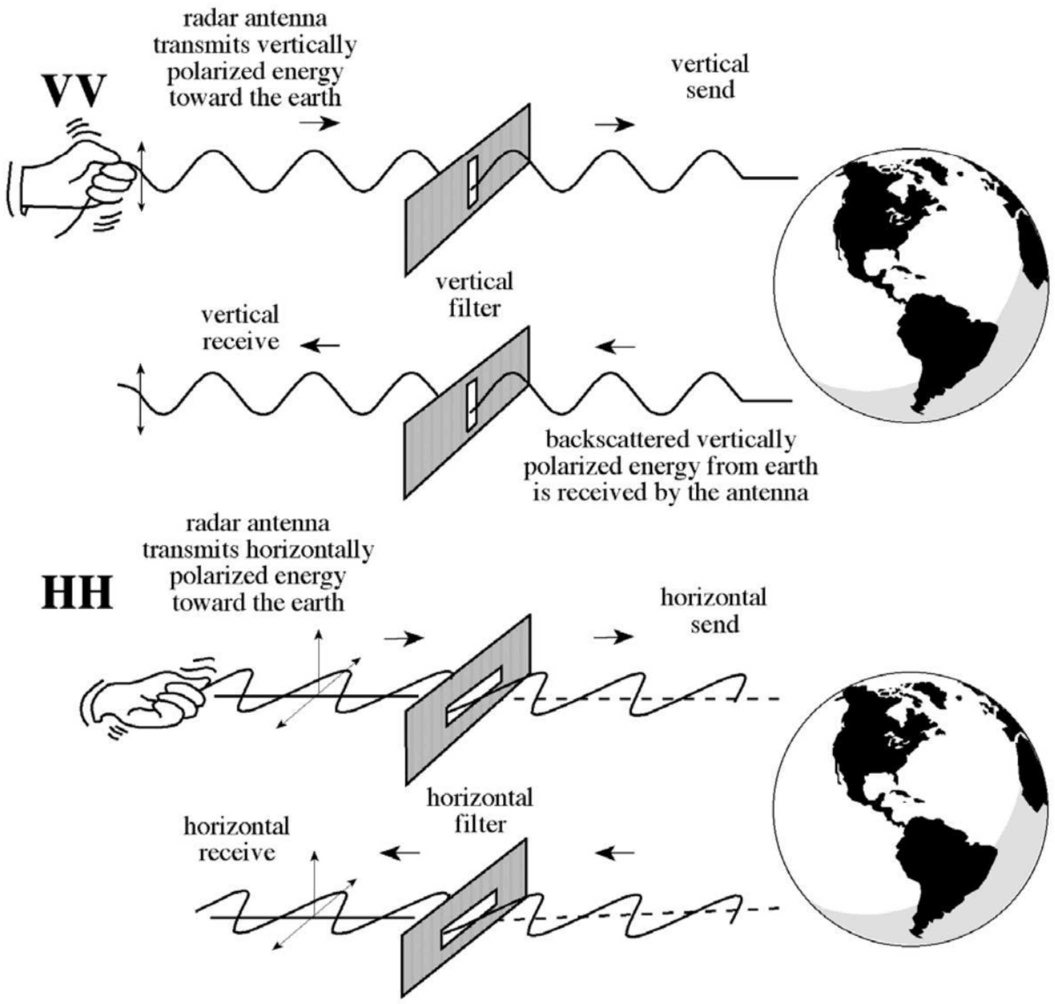
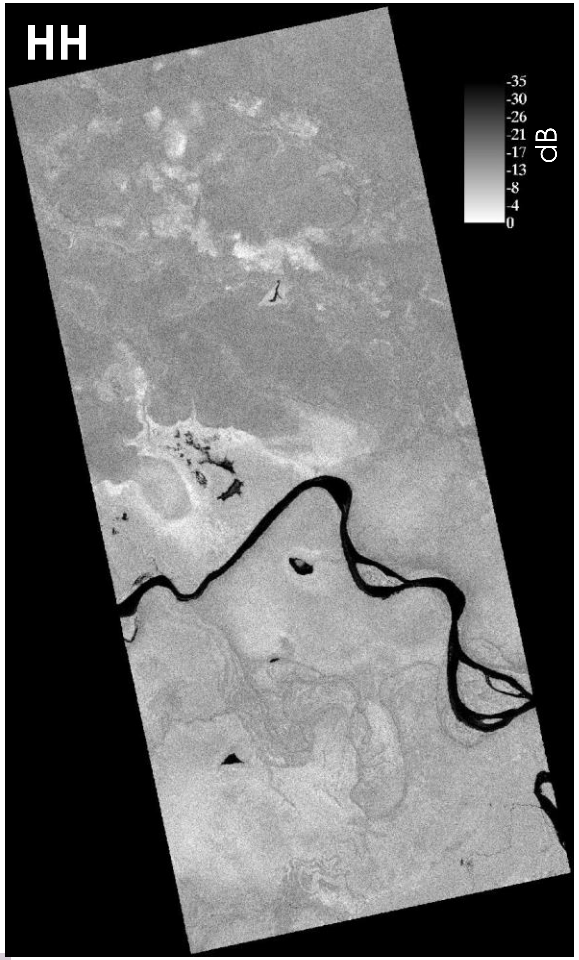
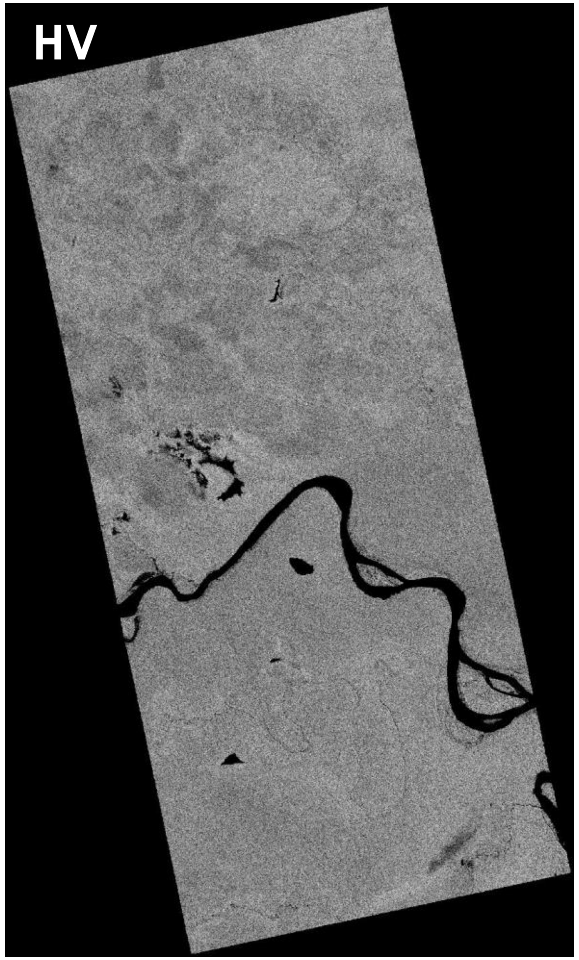


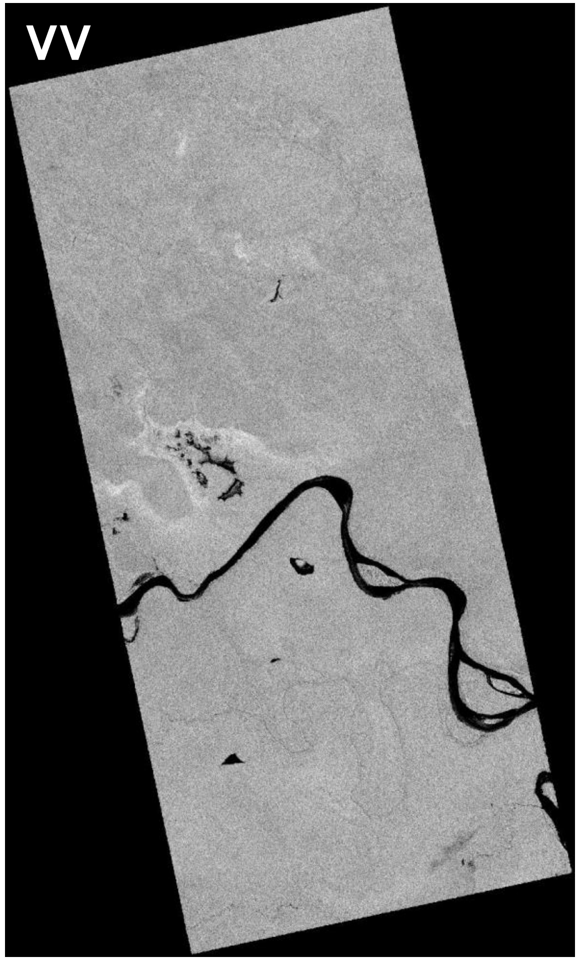
Image Credit: J.R. Jensen, 2000, Remote Sensing of the Environment

Multiple Polarizations for Detection of Inundated Vegetation

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

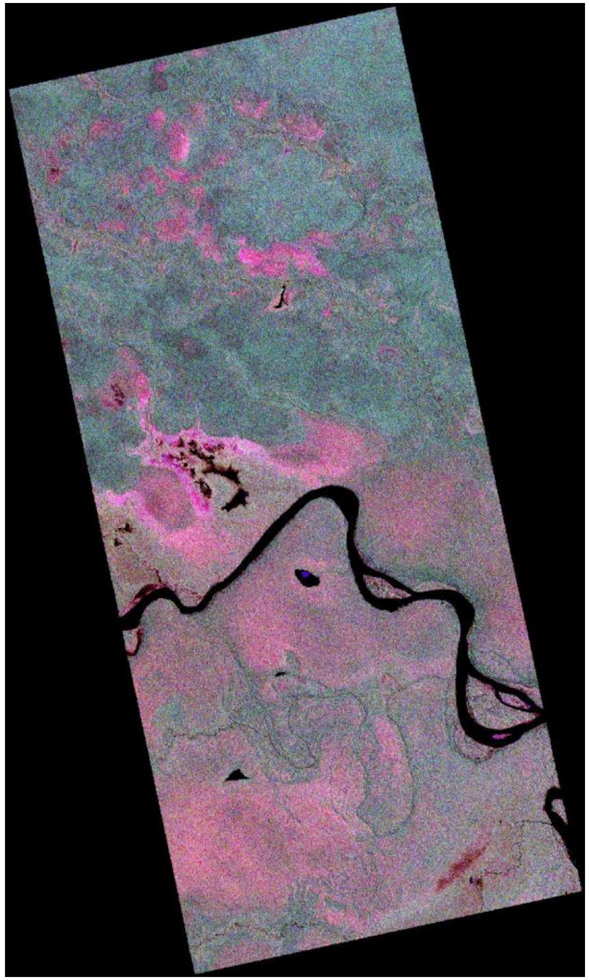






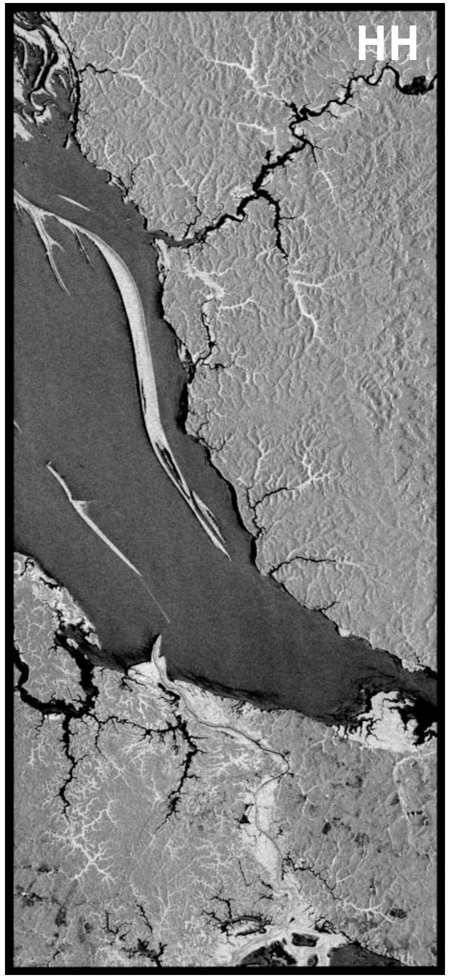
Multiple Polarizations for Detection of Inundated Vegetation

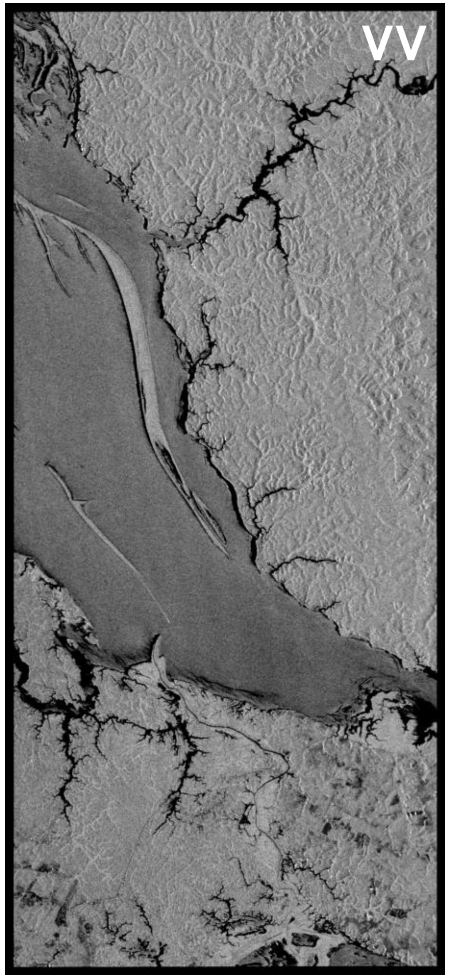
Images from PALSAR (L-band) over Pacaya-Samiria in Peru (HH-HV-VV)



Multiple Polarizations for Detection of Open Water

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

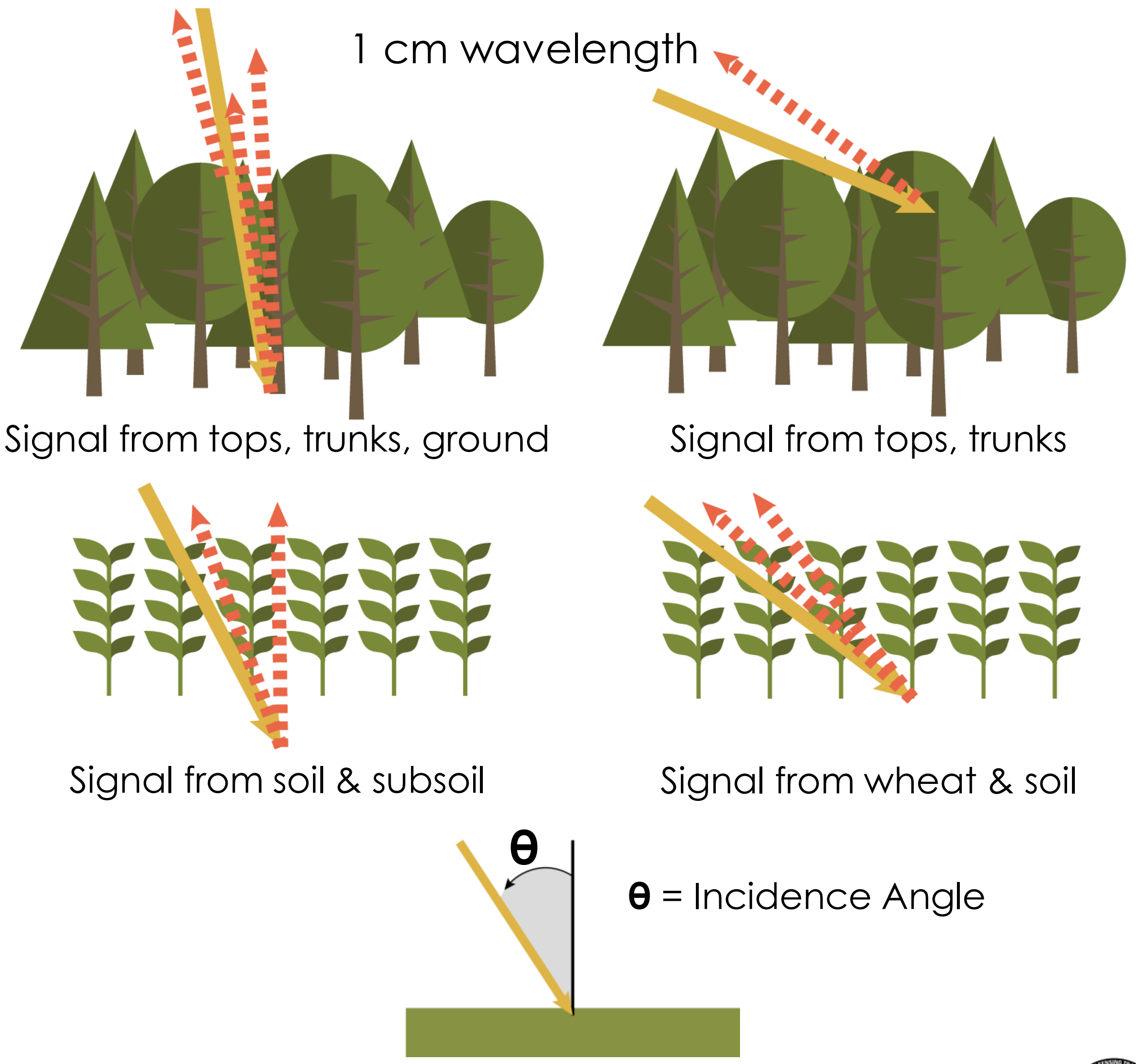




Incidence Angle

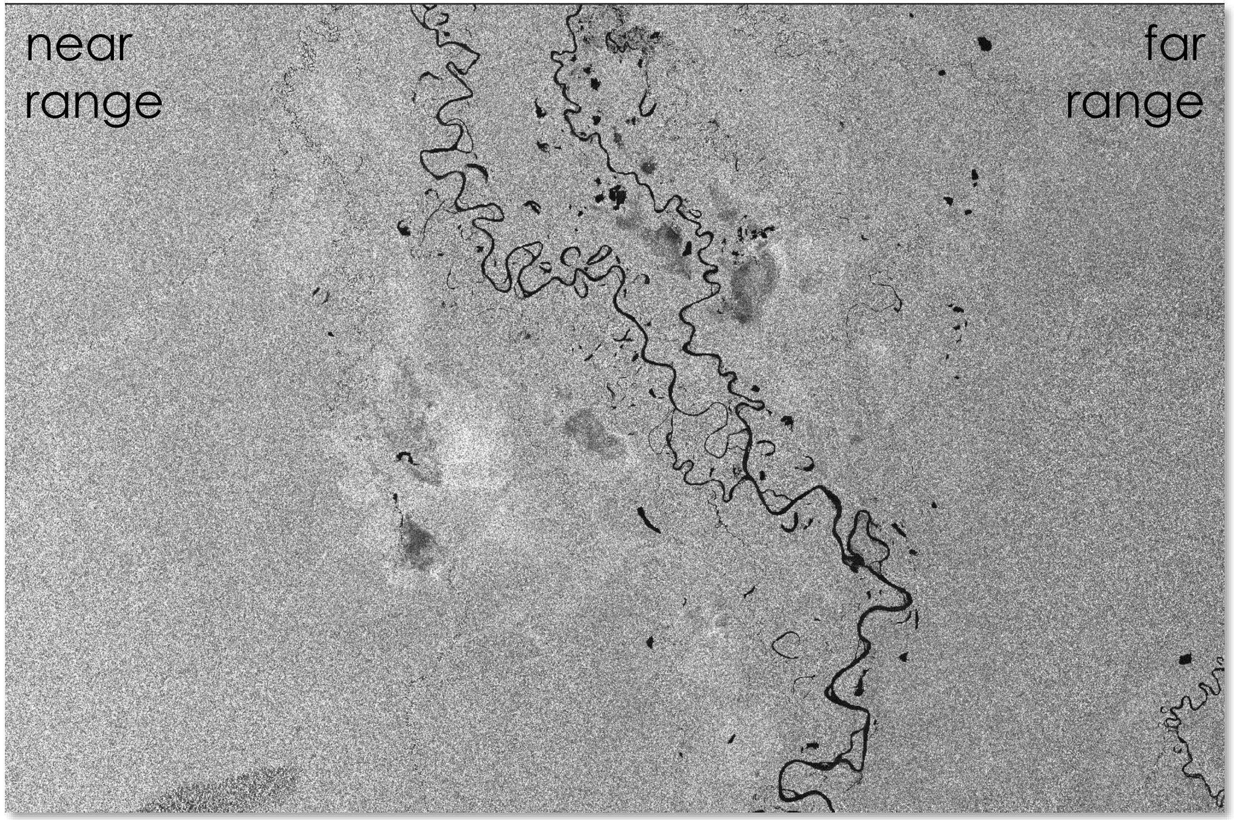
Local Incidence Angle:

- the angle between the direction of illumination of the radar and the Earth's surface plane
- accounts for local inclination of the surface
- influences image brightness
- 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

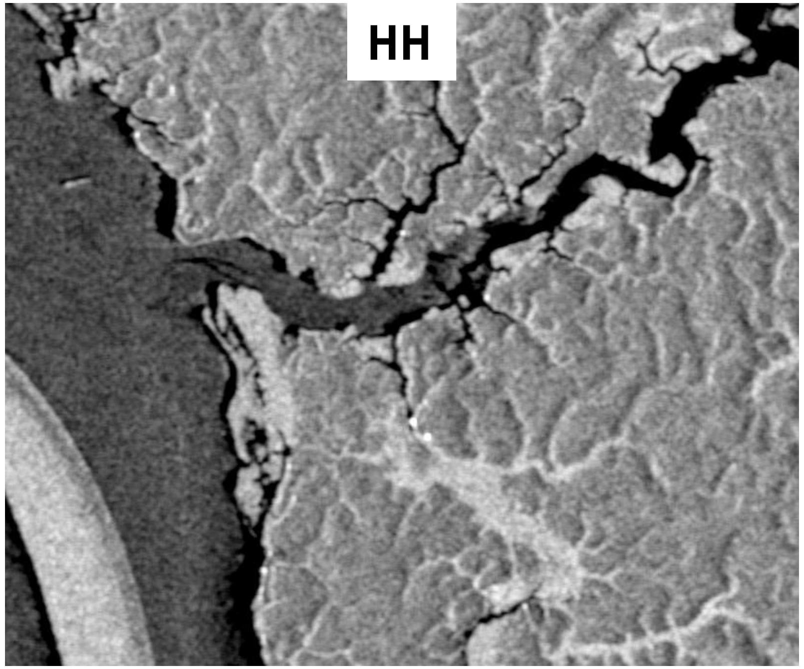
Effect of Incidence Angle Variation

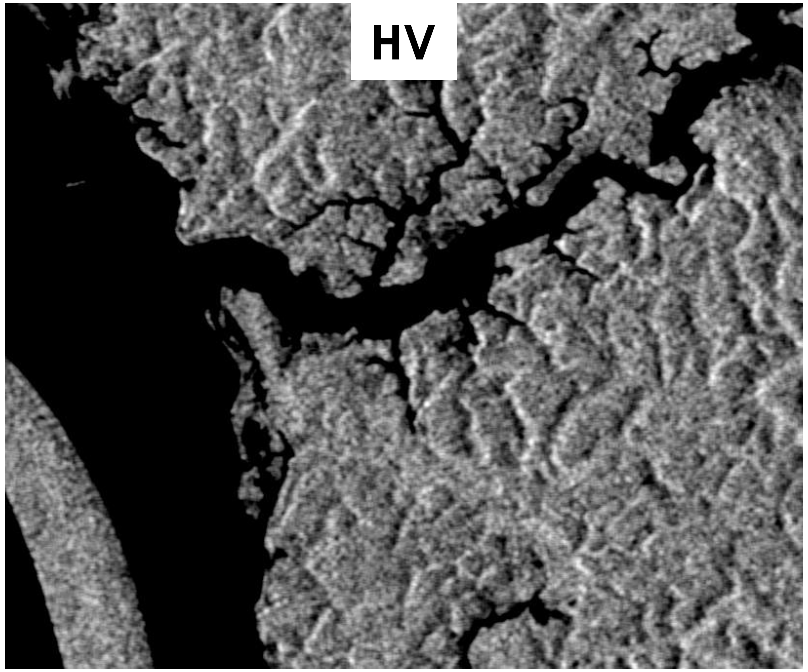


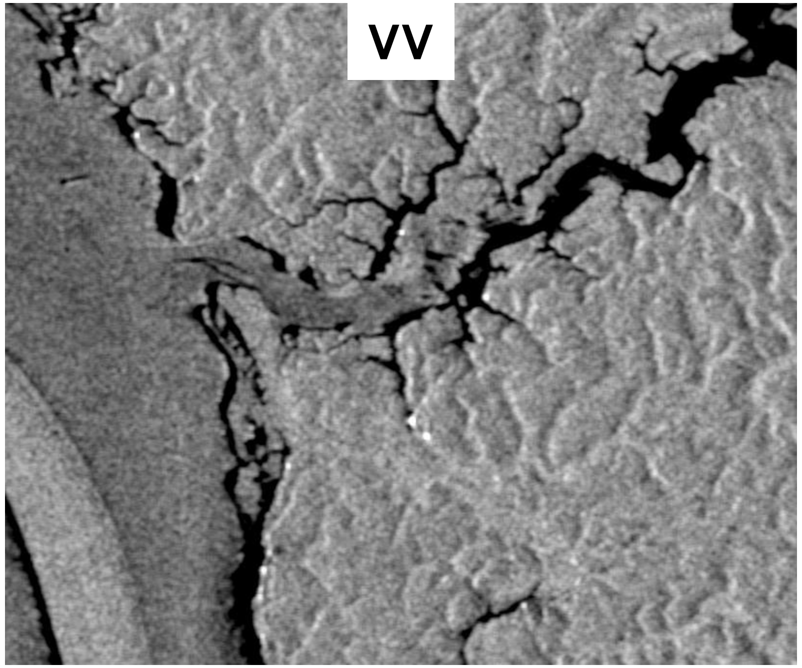
Sentinel-1

Source of Confusion: Wind

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

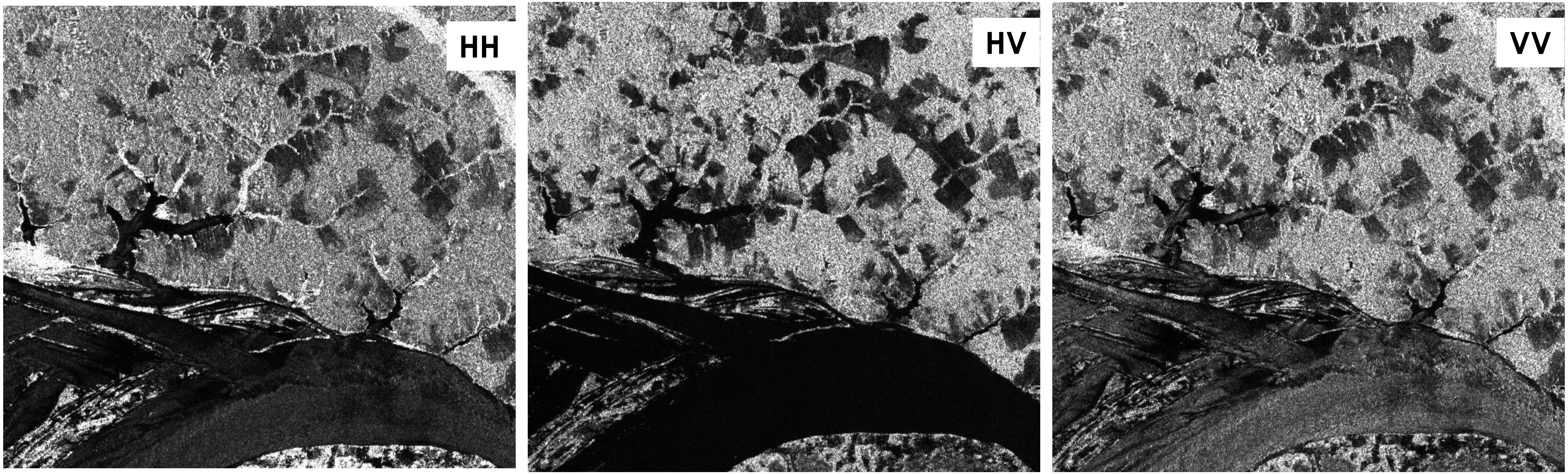






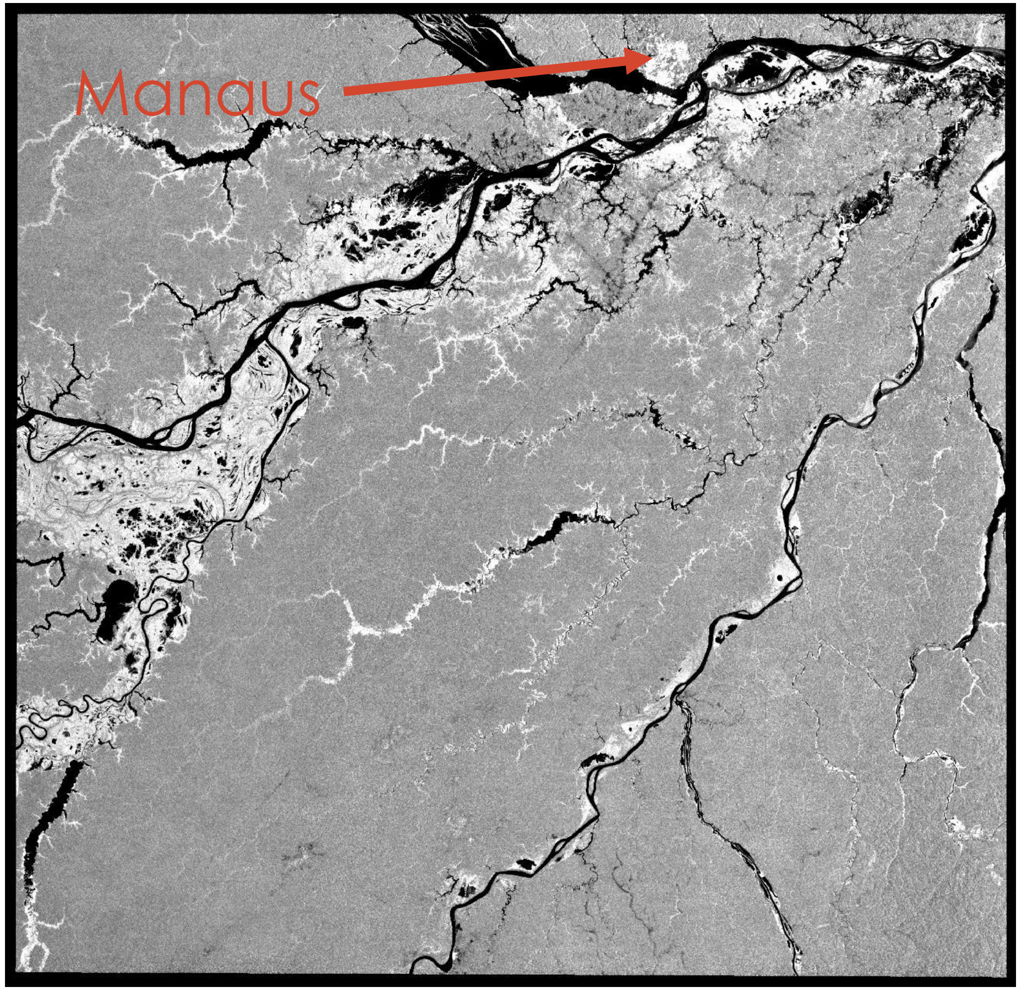
Source of Confusion: Open water and low vegetation

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

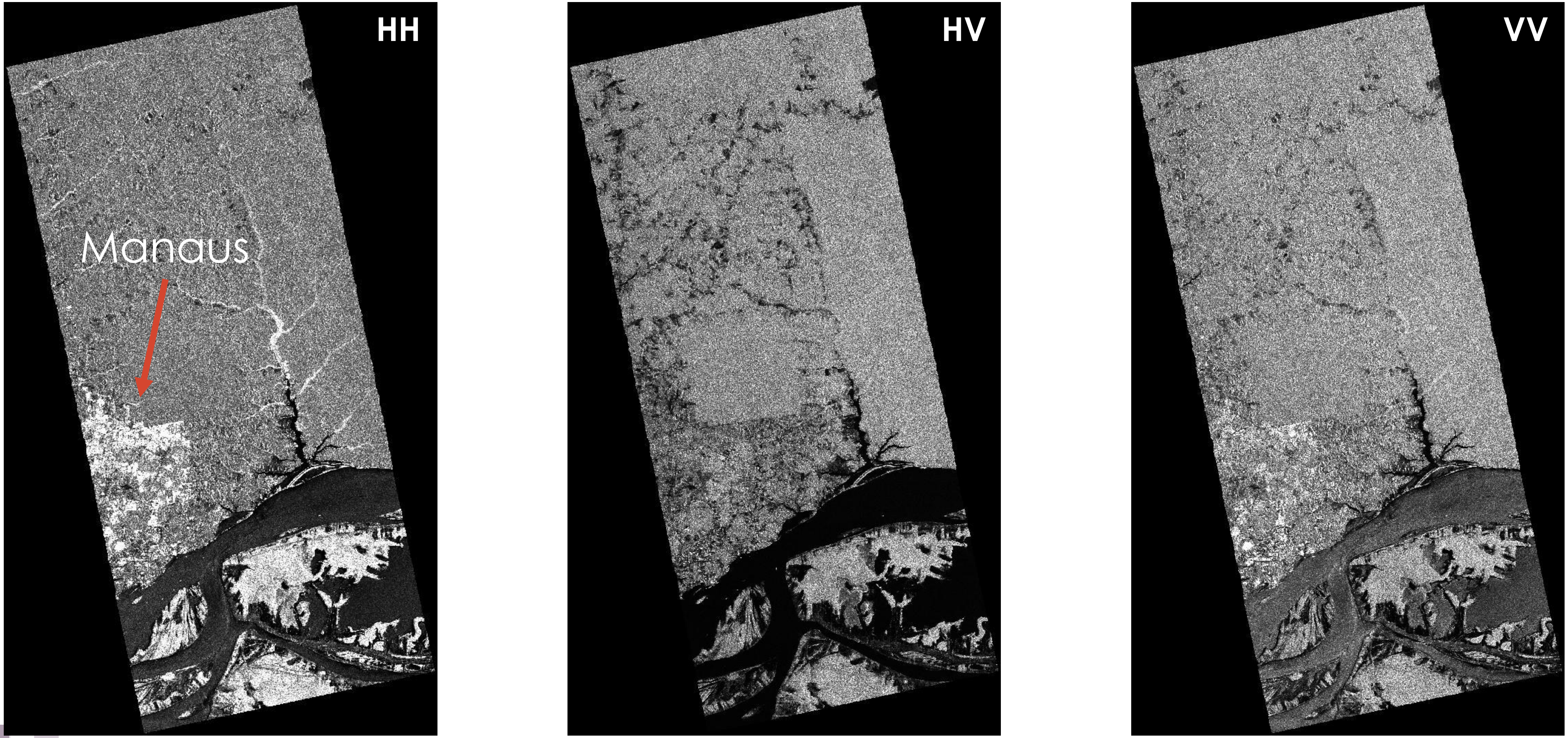


Source of Confusion: Urban Areas

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



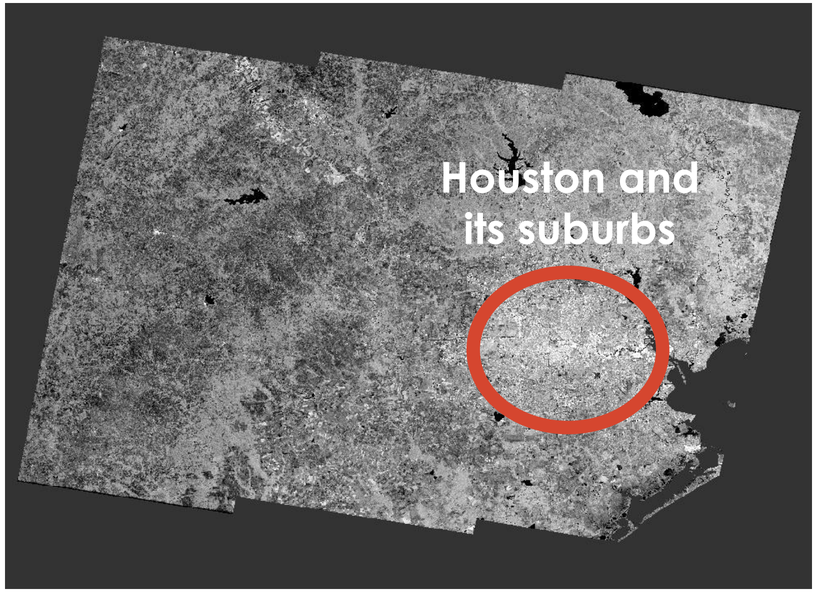
Source of Confusion: Urban Areas with Different Polarizations



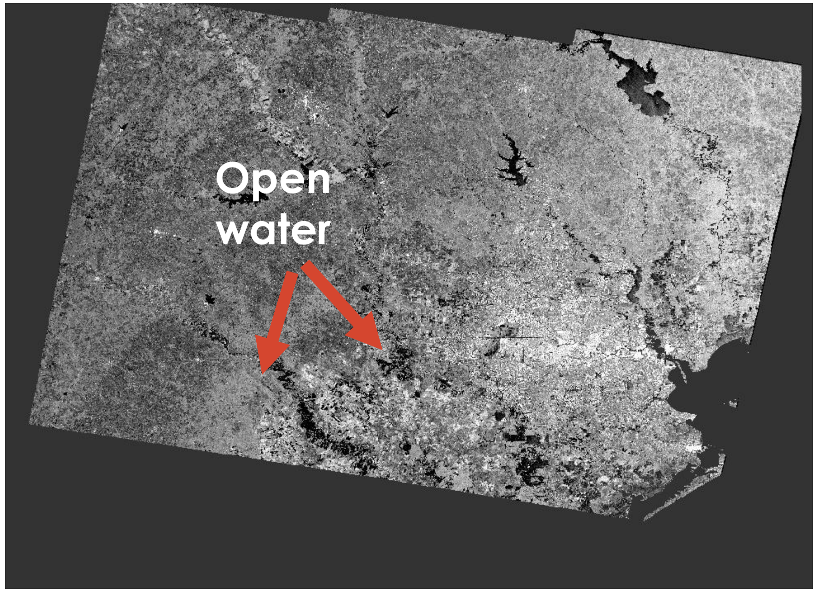
Hurricane Harvey in Houston Texas – August 2017

Sentinel-1 Images (VV)

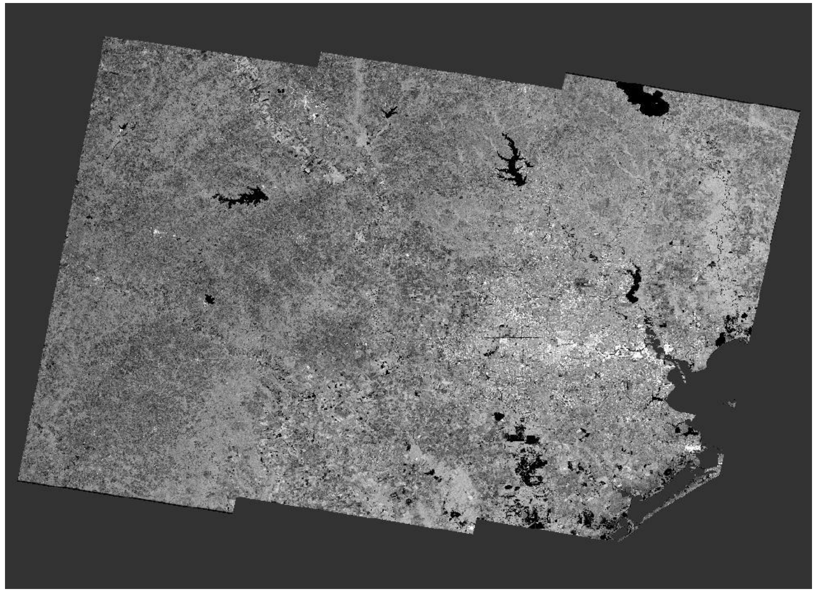
Aug 18, 2017
(Before the Event)



Aug 30, 2017
(During the Event)

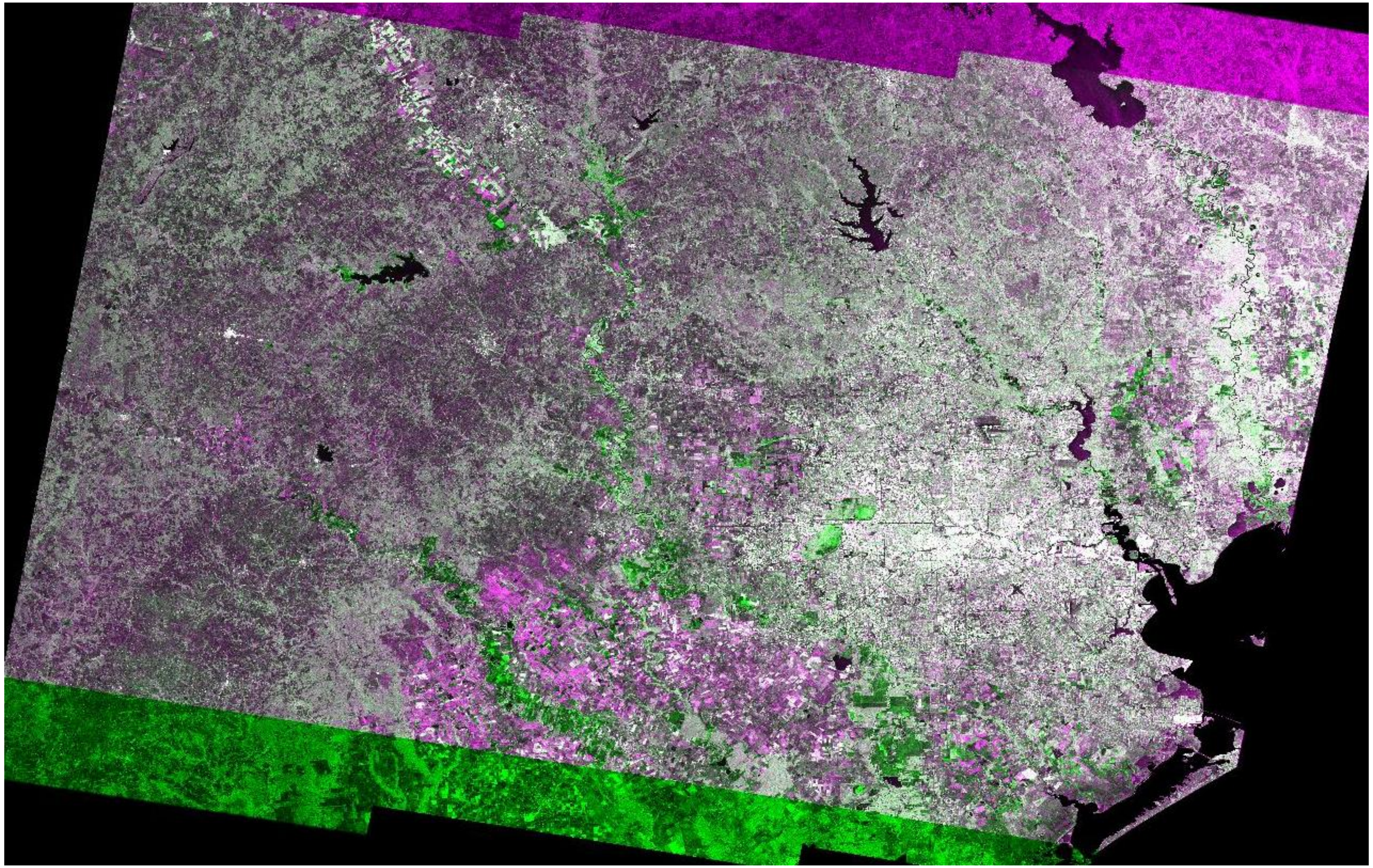


Sep 5, 2017
(After the Event)



Hurricane Harvey in Houston Texas - Before and During the Event

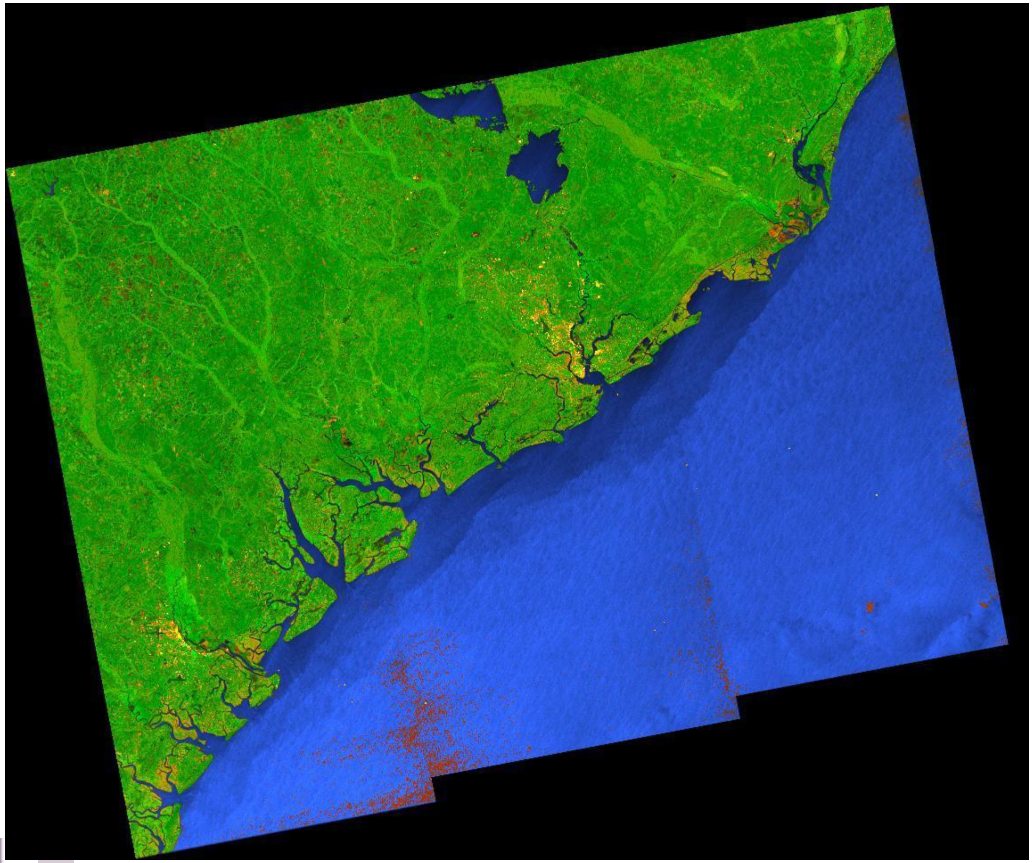
Sentinel-1 Radar Images, RGB: Aug 30 (R), Aug 18 (G), Aug 30 (B)



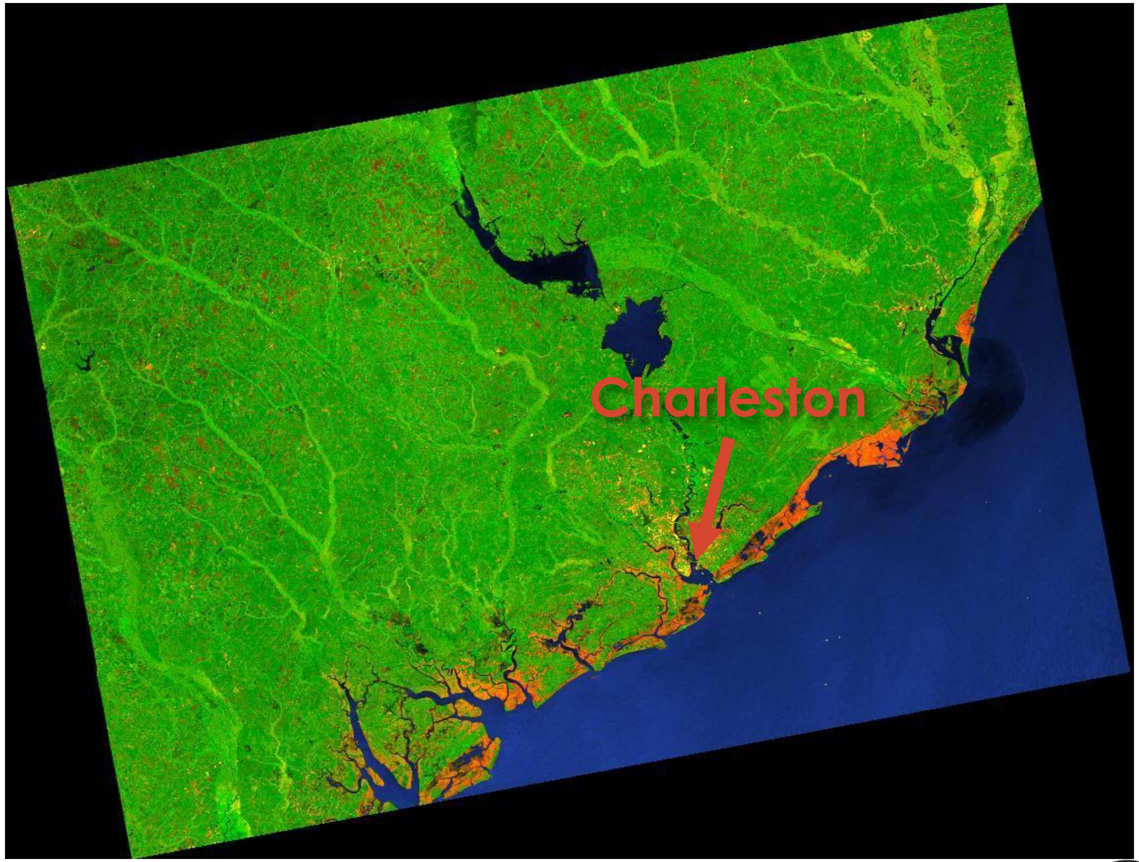
Hurricane Matthew on the East Coast of the U.S. – Coastal Flooding

Sentinel-1 Radar Images (R-VV; G-VH; B-VV/VH)

Oct 4, 2016
(Before the Event)



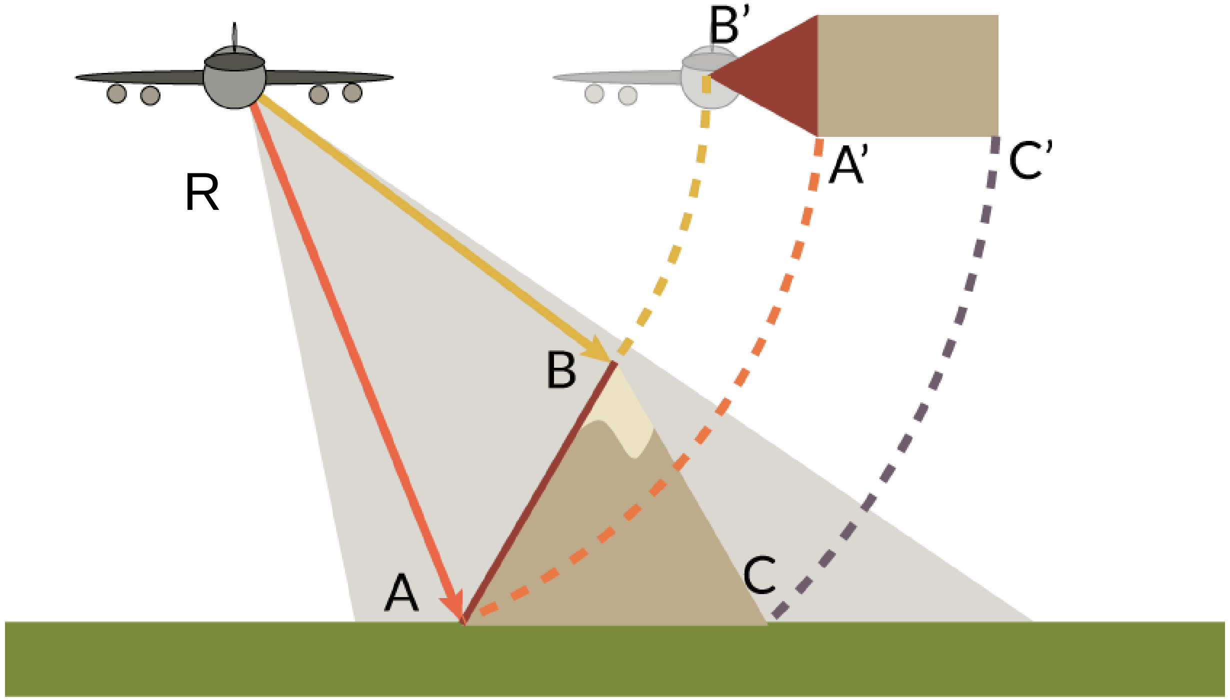
Oct 16, 2016
(After the Event)



Geometric Distortion

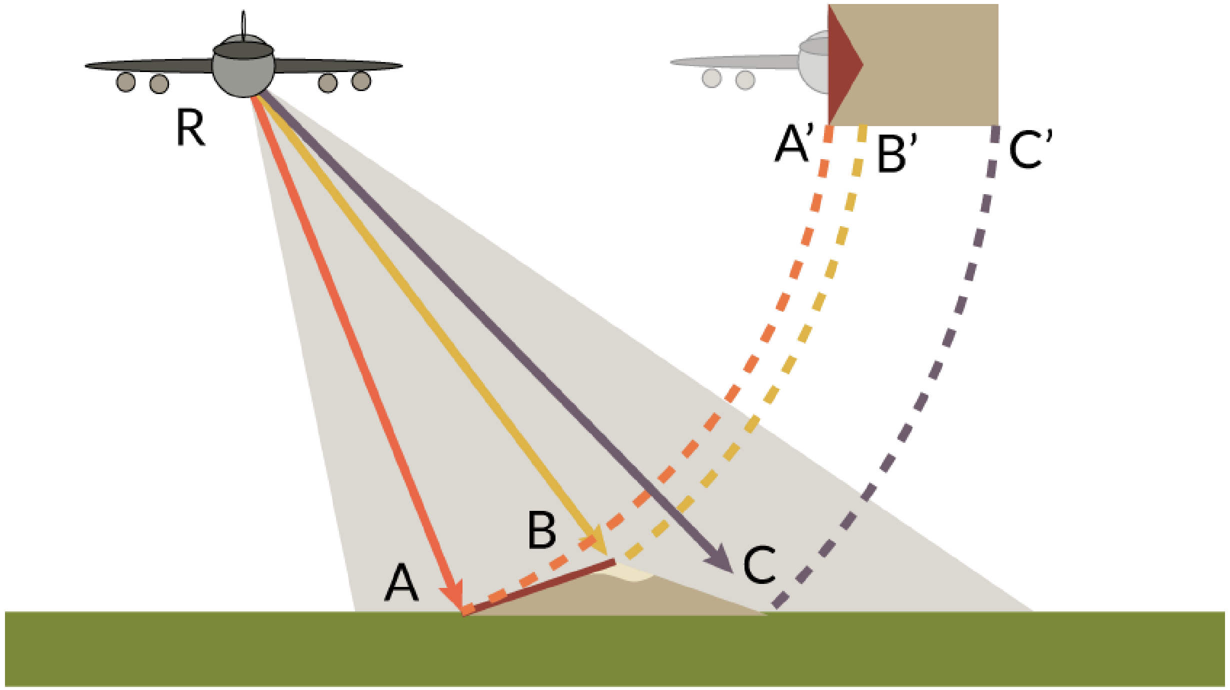
Layover

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

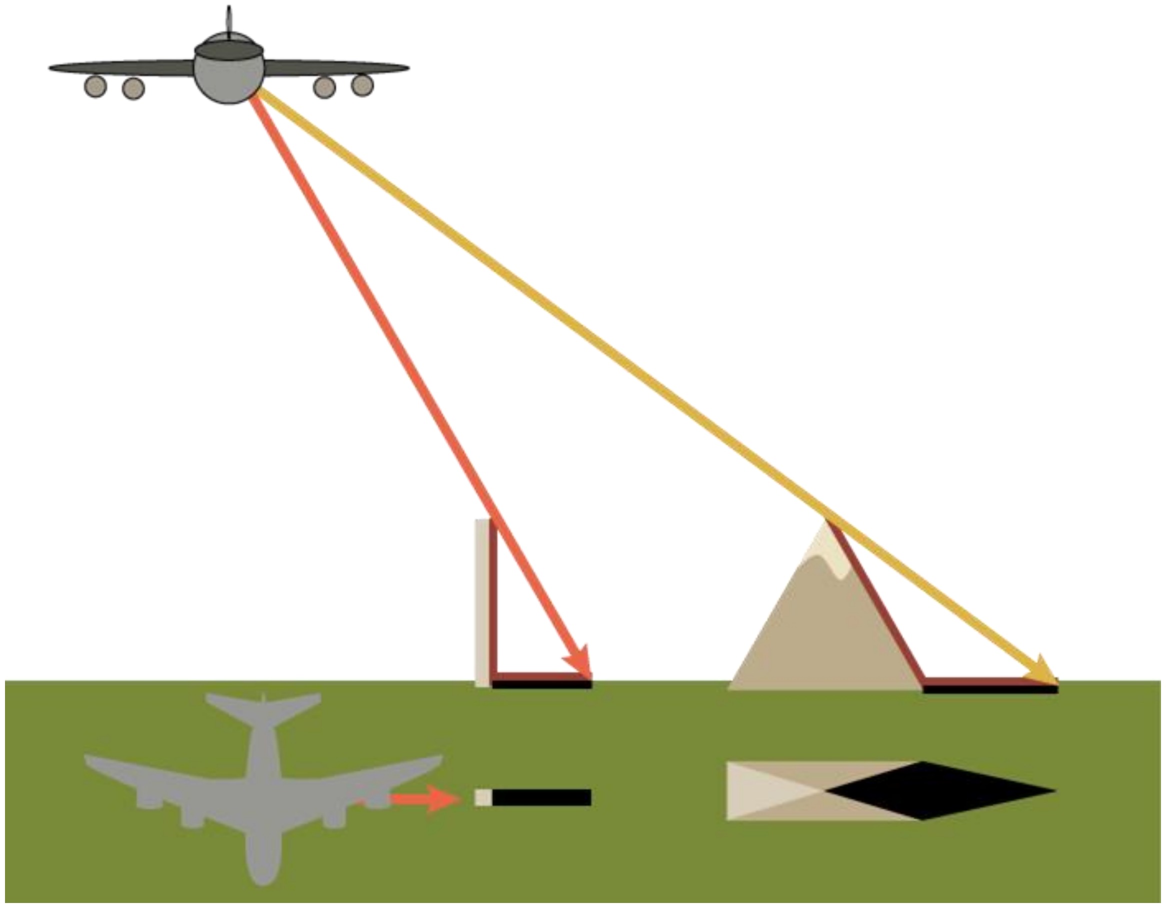
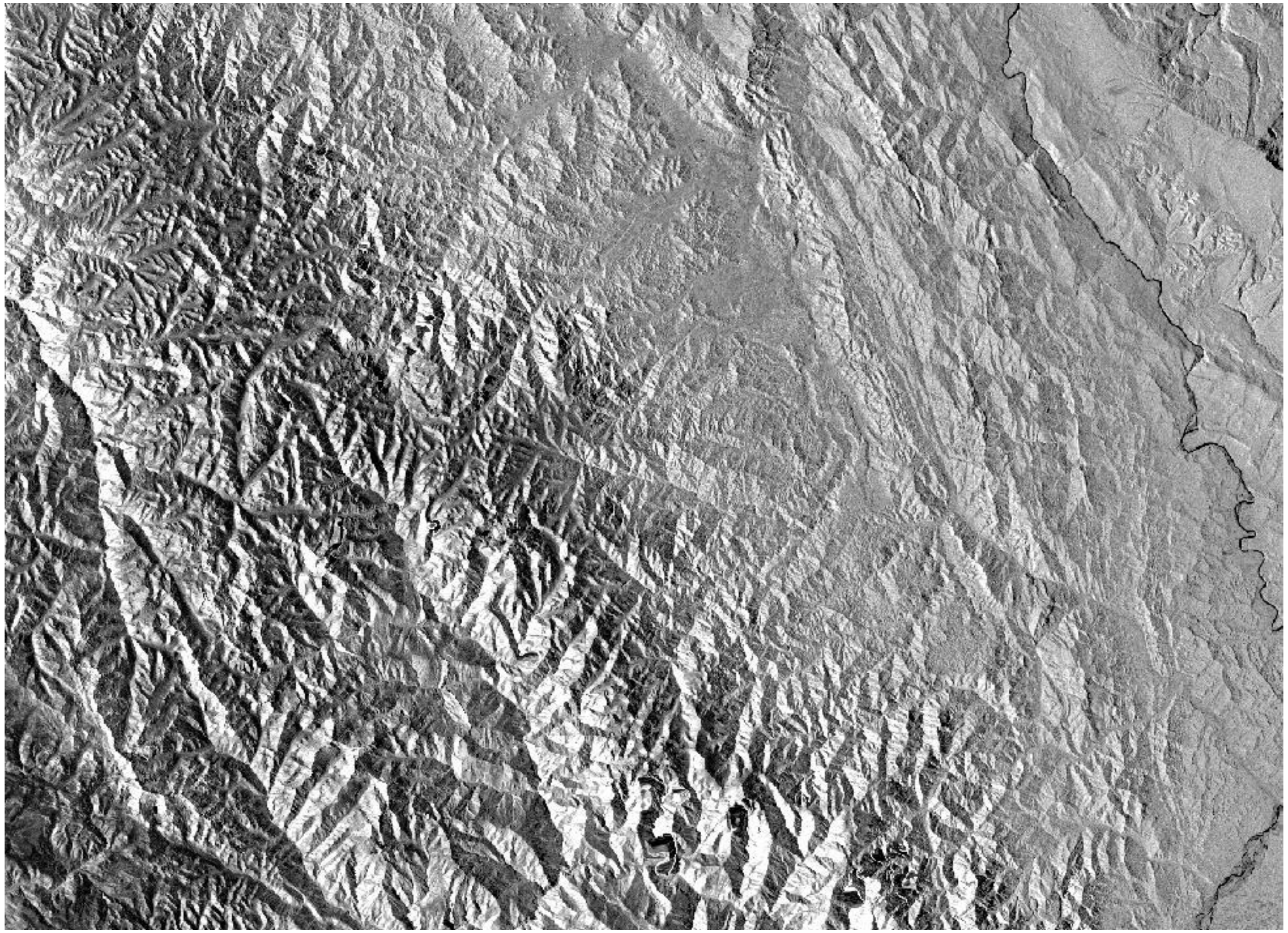


Image (left) based on NRC images

Radiometric Distortion

Sentinel-1 Radar Image Over the Andes



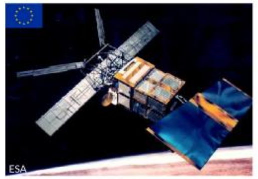
Radar Data Available

Legacy:

SeaSAT
1978

JERS-1
1992-1998

ERS 1/2
1991-2011



ENVISAT
2002-2012

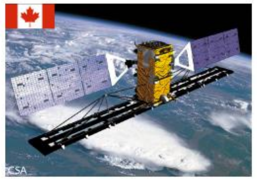
ALOS-1
2002-2012

Radarsat-1
1995-2013

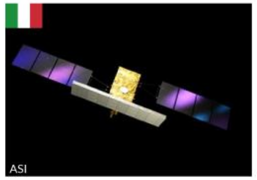
Current:

TanDEM-X
2007

Radarsat-2
2007



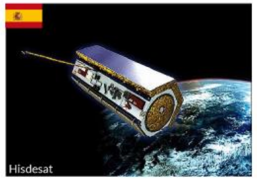
COSMO-SkyMed
2007



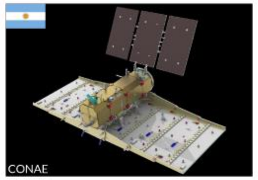
ALOS-2
2014

Sentinel-1
2014

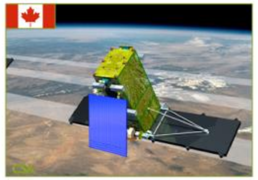
PAZ SAR
2018



SAOCOM
2018



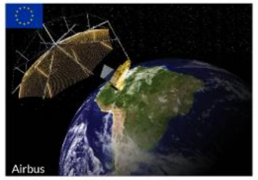
RCM
2018



Future:

NISAR
2021

Biomass
2021



■ freely accessible

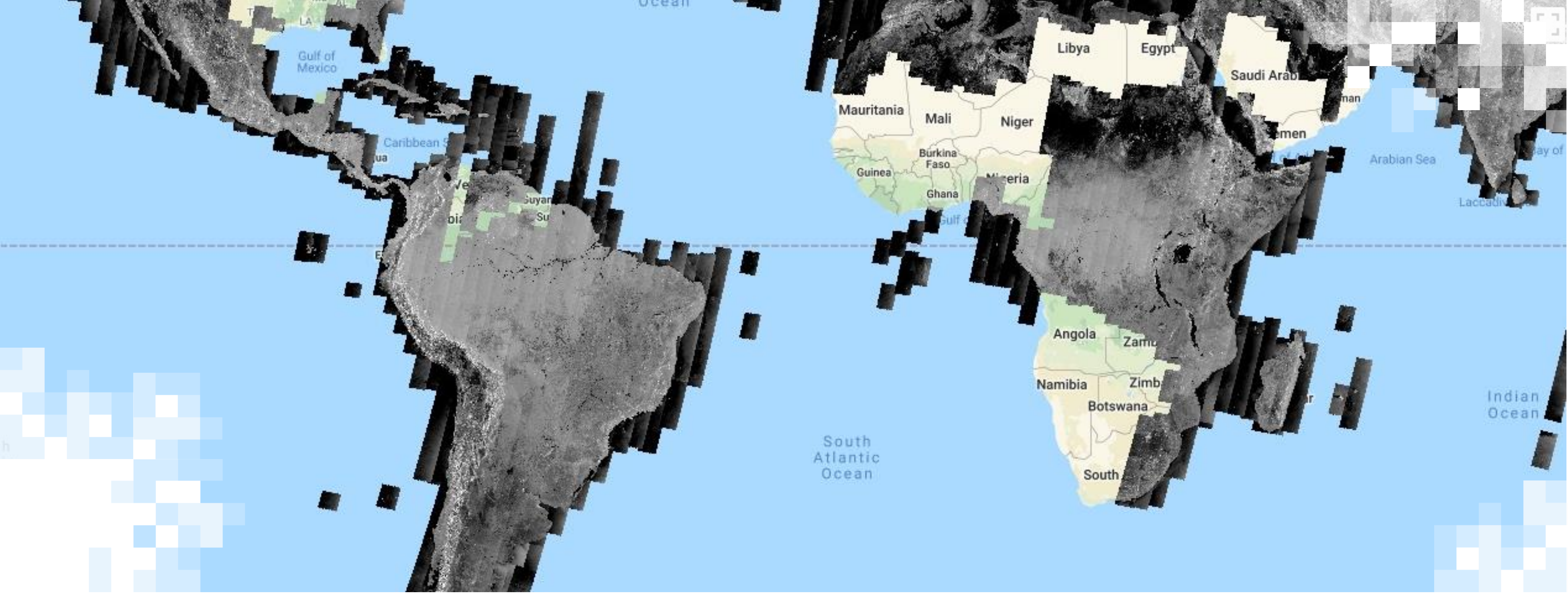
Image Credit: Franz Meyer, University of Alaska, Fairbanks

NASA-ISRO SAR Mission (NISAR)

- High spatial resolution with frequent revisit time
- Expected launch date: beginning of 2022
- Dual frequency L- and S-band SAR
  - L-band SAR from NASA and S-band SAR from ISRO
- 3 years science operations (5+ years consumables)
- All science data will be made available free and open

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

Slide Courtesy of Paul Rosen (JPL)

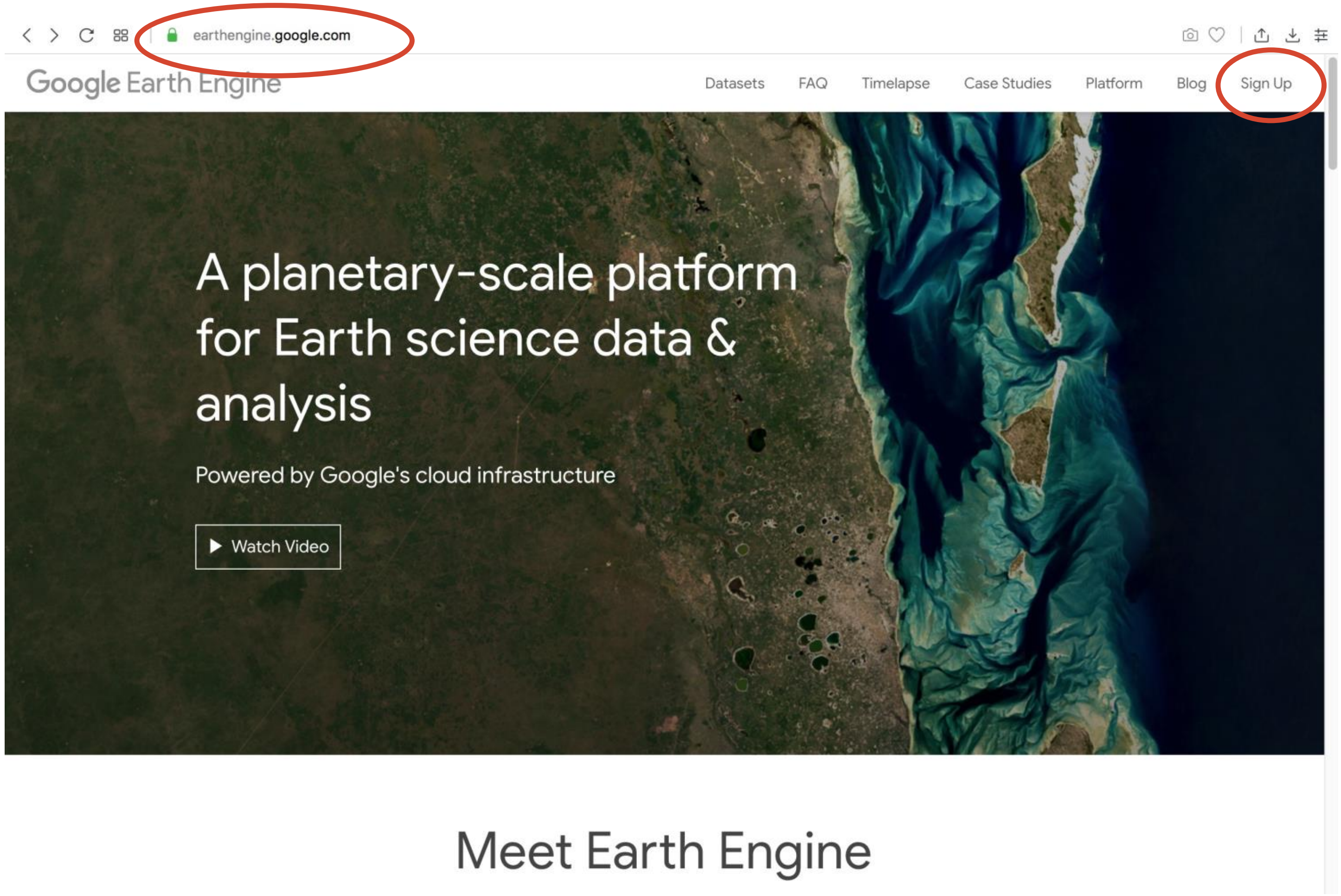


Hands-on Exercise Using Google Earth Engine

Google Earth Engine

https://earthengine.google.com

- Cloud based geospatial processing platform
- Available to scientists, researchers, and developers for analysis of the Earth's surface
- Contains a catalog of satellite imagery and geospatial datasets (including Sentinel-1):
- https://developers.google.com/earth-engine/datasets/catalog/
- Uses Javascript code editor
- Sign up for a (free) account



Google Earth Engine Code Editor

https://code.earthengine.google.com

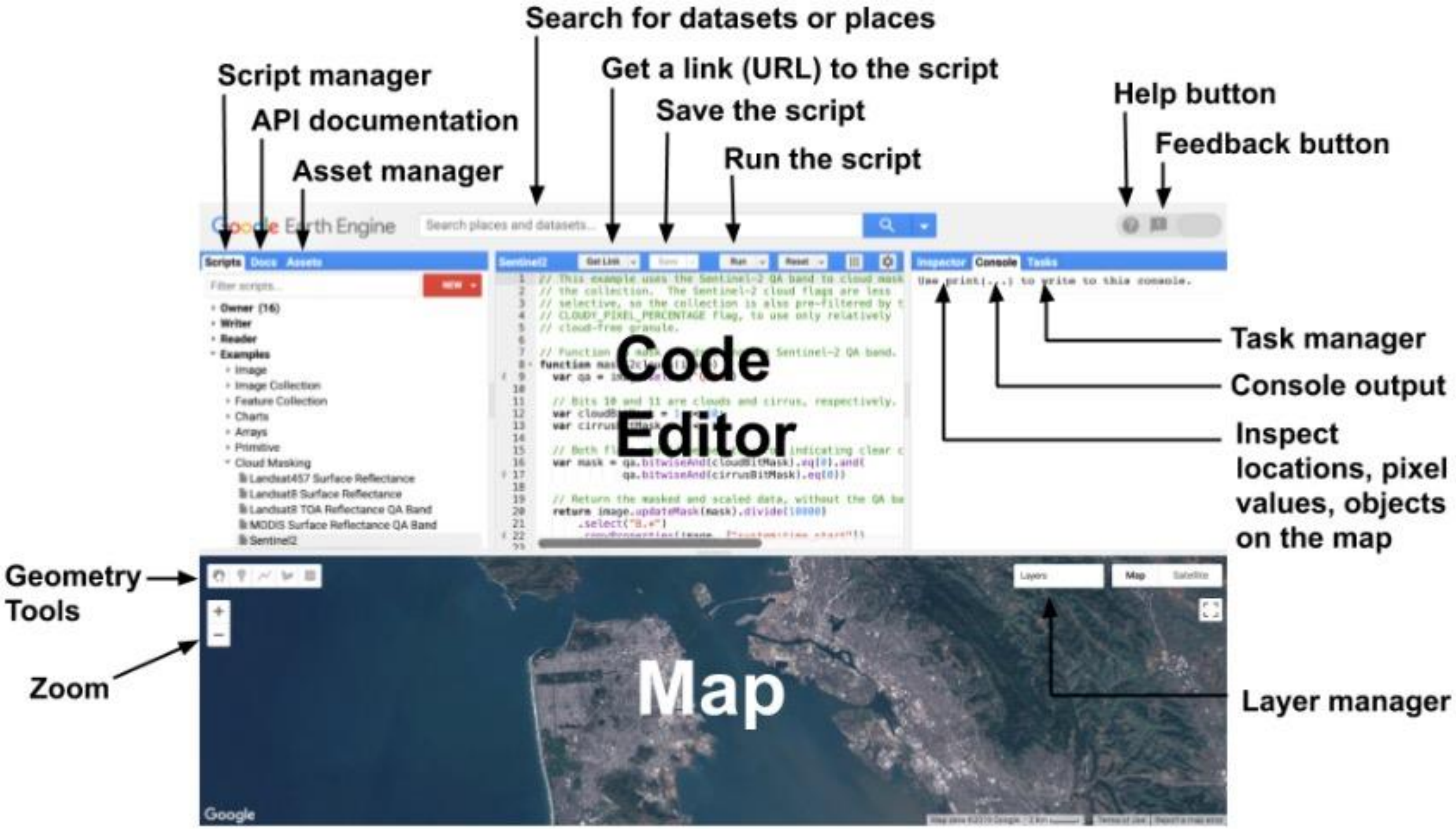


Image Credit: Google

Sentinel-1 Data

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

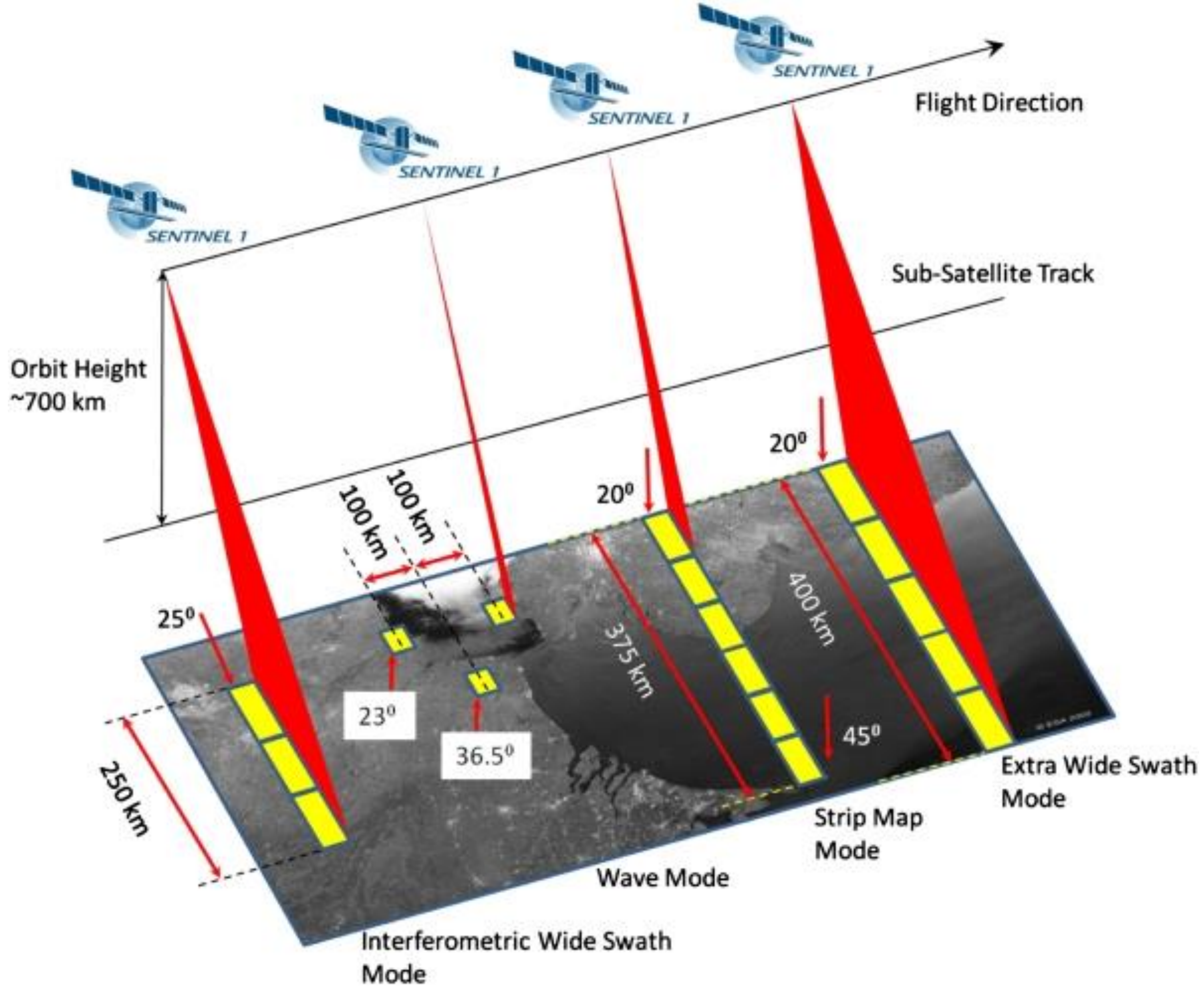


Image Credit: ESA

Sentinel-1 Data

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 for flood mapping)**

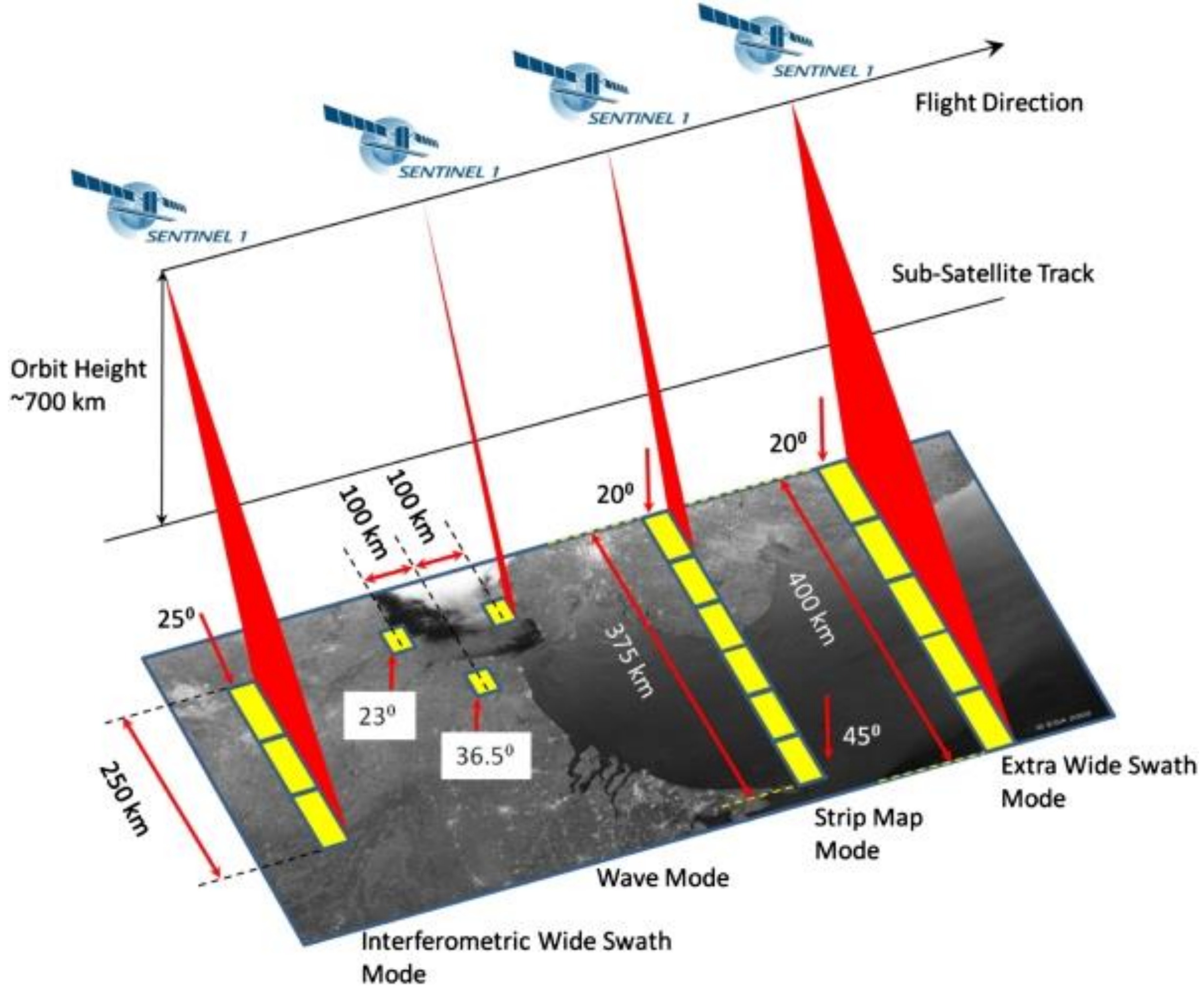


Image Credit: ESA

Sentinel-1 Catalog

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

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

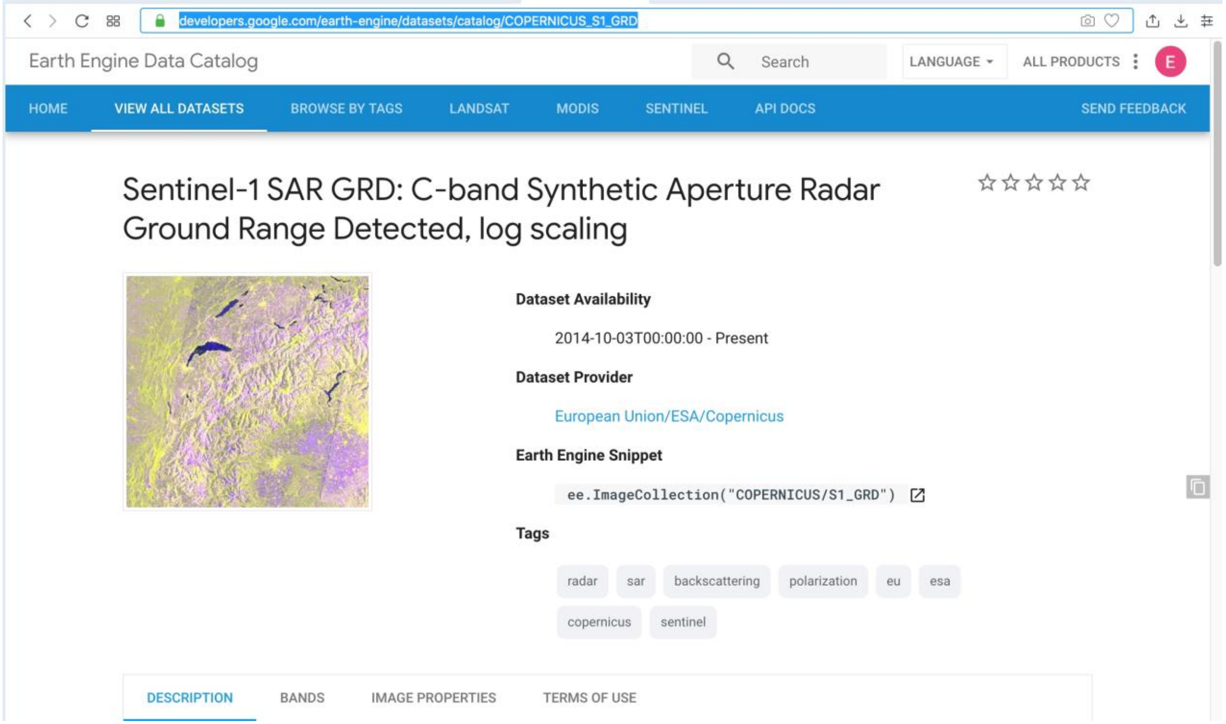
Each scene also includes an additional 'angle' band that contains the approximate viewing incidence angle in degrees at every point. This band is generated by interpolating the 'incidenceAngle' property of the 'geolocationGridPoint' gridded field provided with each asset.

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.



Focus Area

Our demo is focused on floods that occurred in March of 2019 in Mozambique due to Cyclone Idai

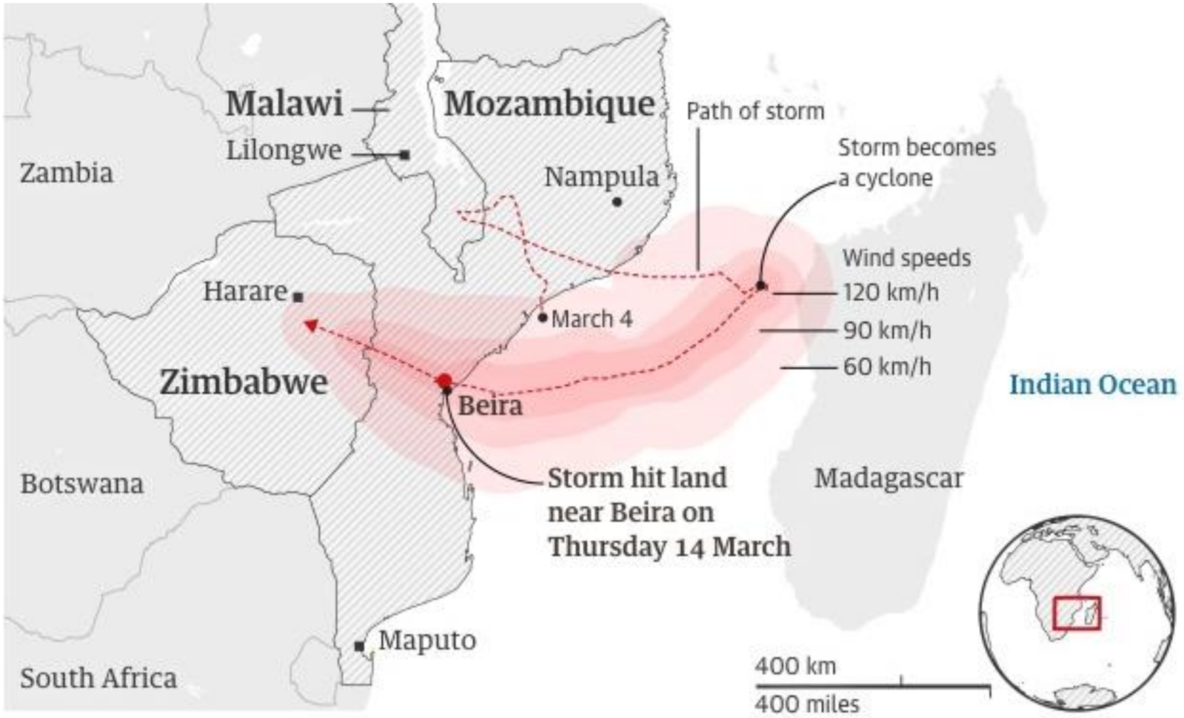
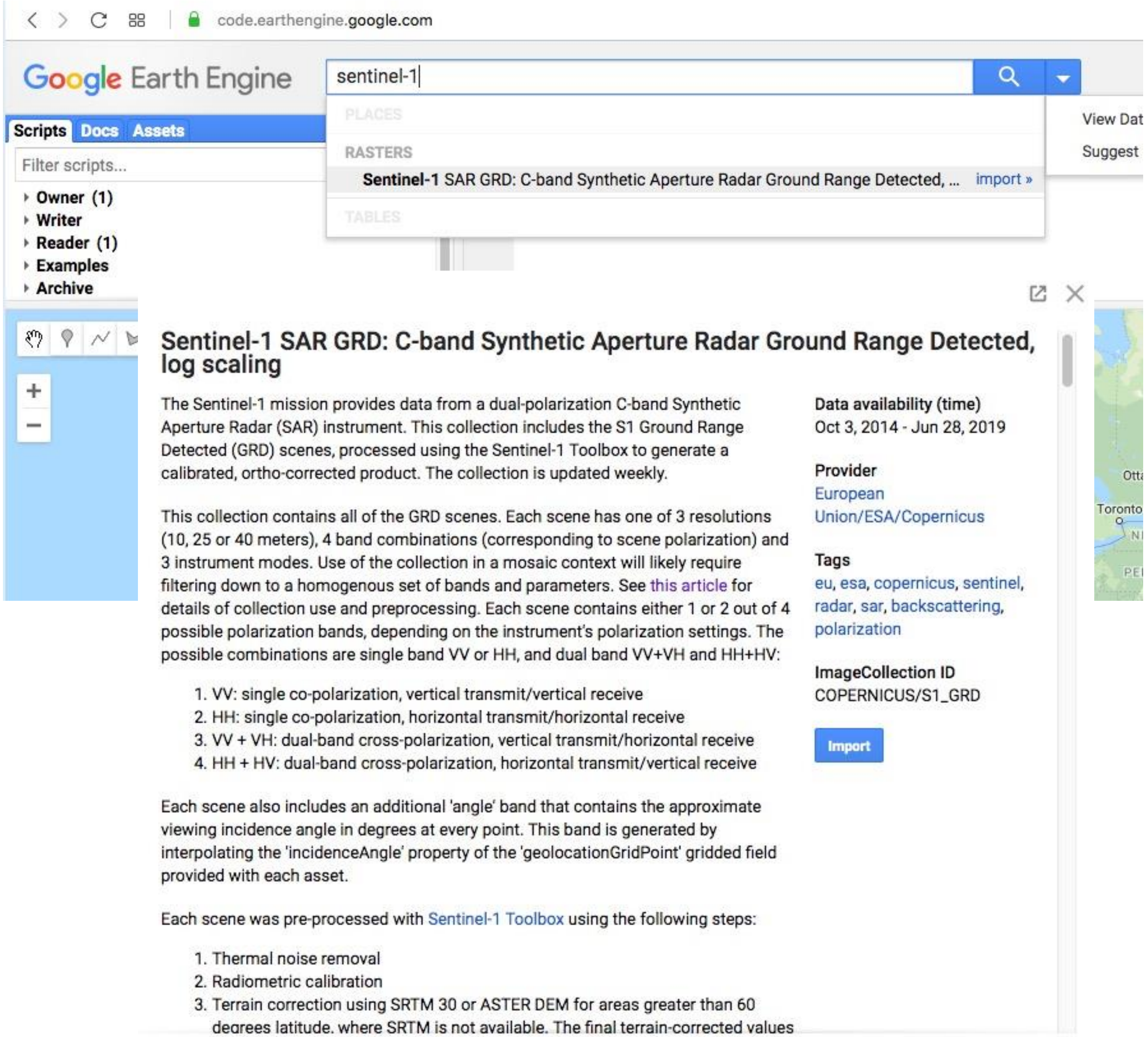


Image Credits: (left) Global Disaster Alert and Coordination System; (right) Flooded homes in the Buzi district outside Beira, Mozambique. Credit: Reuters/Siphiwe Sibeko/File Photo

Visualize Sentinel-1 Data

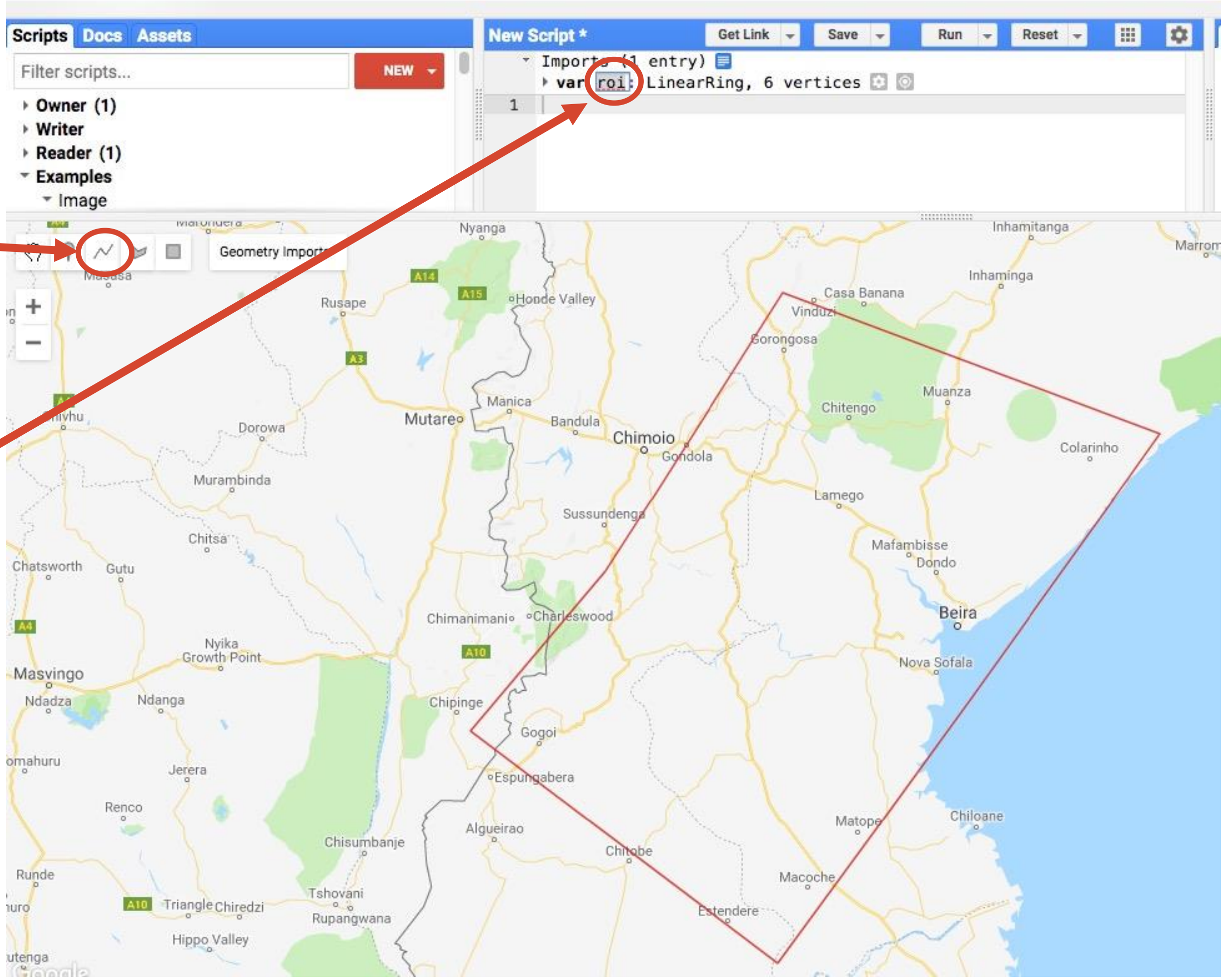
1. Start by opening Google Earth Engine: https://code.earthengine.google.com
2. Search for Sentinel-1 data
3. A window with a description of the data will open showing:
   – the steps taken to process the data (thermal noise removal, radiometric calibration, terrain correction)
   – bands and resolution
   – metadata (important parameters are mode and orbit properties - descending or ascending)



Select Area of Interest

Define your area of interest

4. Zoom into Beira in Mozambique
5. Select the “draw a line” icon
6. Draw a rectangle similar to the one here over our area of interest
7. Rename “geometry” to “roi” (region of interest) - as indicated here

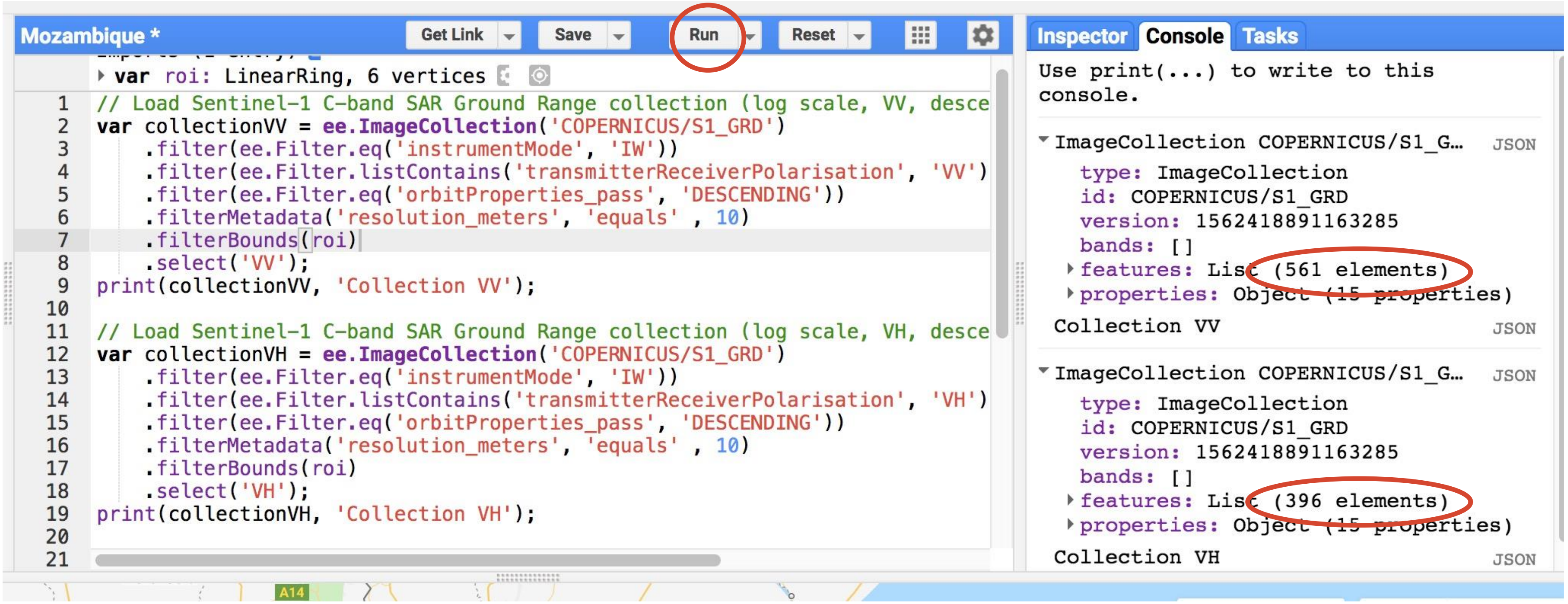


Filter the Sentinel-1 Data

```
// 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');

// 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');
```

Filter the Sentinel-1 Data

8. Copy the code from the previous slide to the Code Editor
9. Select **Run** in the top menu
   – The right window will show the results for VV (561 images) and VH (396 images)
   – The image number will vary depending on the size of your area of interest

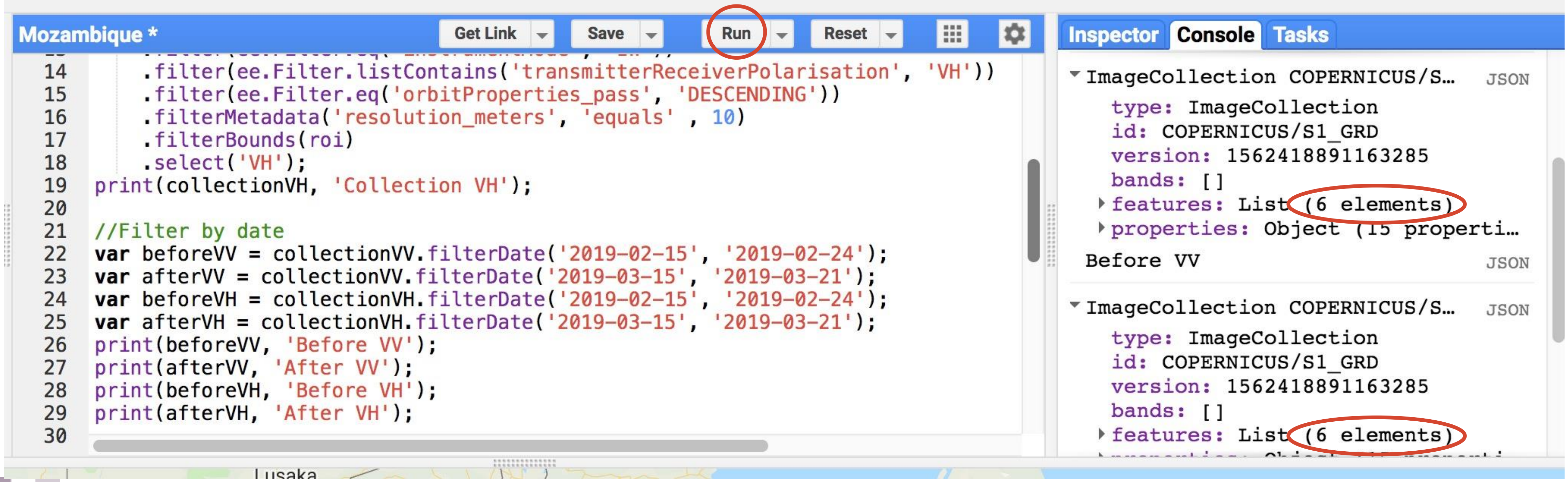


Filter the Sentinel-1 Data by Date

```
//Filter by date
var beforeVV = collectionVV.filterDate('2019-02-15', '2019-02-24');
var afterVV = collectionVV.filterDate('2019-03-15', '2019-03-21');
var beforeVH = collectionVH.filterDate('2019-02-15', '2019-02-24');
var afterVH = collectionVH.filterDate('2019-03-15', '2019-03-21');
print(beforeVV, 'Before VV');
print(afterVV, 'After VV');
print(beforeVH, 'Before VH');
print(afterVH, 'After VH');
```

Filter the Sentinel-1 Data by Date

10. Copy the code from the previous slide into the Code Editor
11. Select **Run** in the top menu
    - The right window will show the results for: before (VV and VH) 6 images after (VV and VH) 6 images

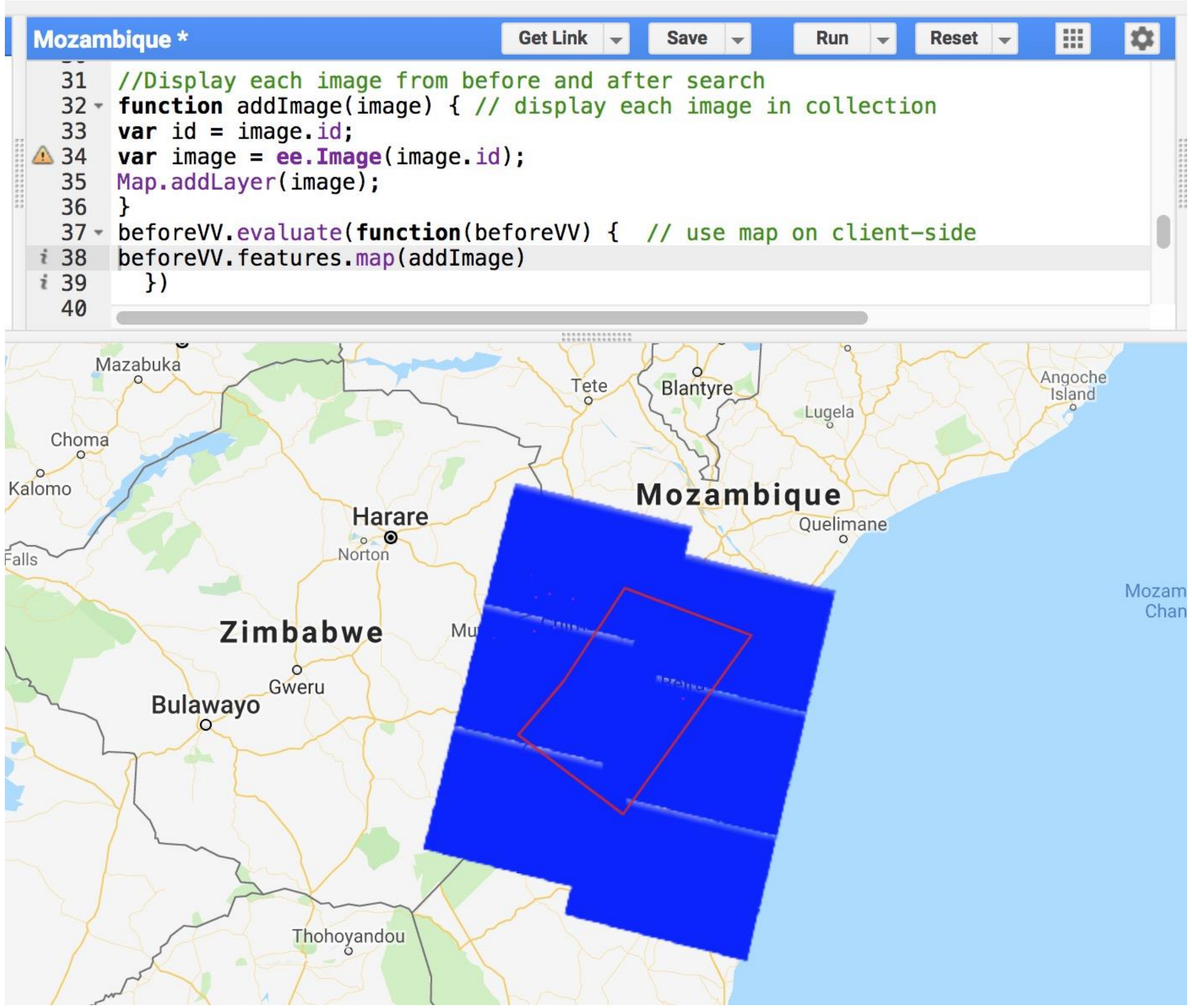


Display the Sentinel-1 Data by Date

```
//Display each image from before and after search
function addImage(image) { // display each image in collection
var id = image.id;
var image = ee.Image(image.id);
Map.addLayer(image);
}
beforeVV.evaluate(function(beforeVV) {  // use map on client-side
beforeVV.features.map(addImage)
})
```

Display the Individual Images

12. Copy the previous code to the Code Editor
13. Select **Run** in the top menu
    – 6 images from before VV will be displayed



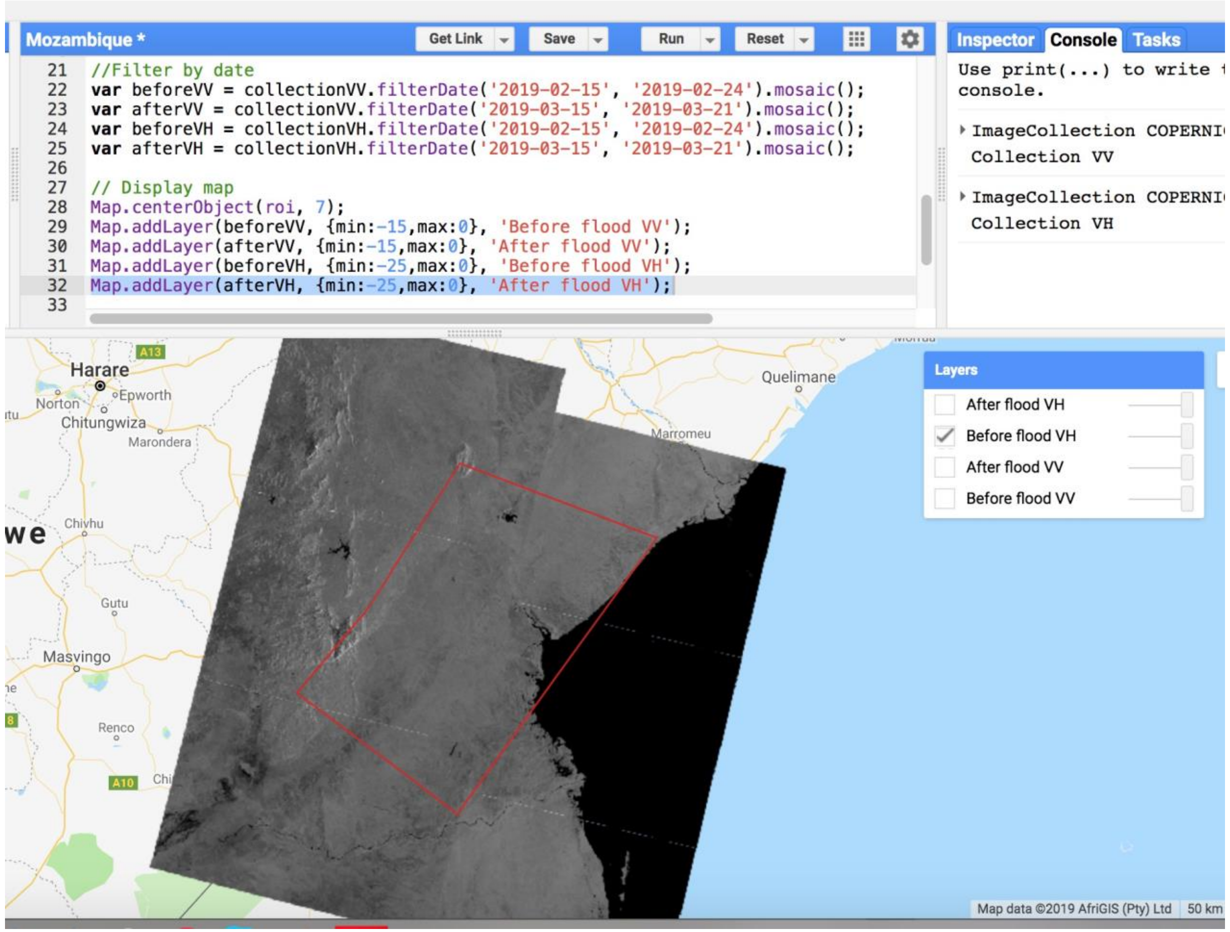
Display Mosaic

Filter the Sentinel-1 Data by Date and Create a Mosaic for Before & After

```
//Filter by date
var beforeVV = collectionVV.filterDate('2019-02-15', '2019-02-24').mosaic();
var afterVV = collectionVV.filterDate('2019-03-15', '2019-03-21').mosaic();
var beforeVH = collectionVH.filterDate('2019-02-15', '2019-02-24').mosaic();
var afterVH = collectionVH.filterDate('2019-03-15', '2019-03-21').mosaic();

// Display map
Map.centerObject(roi, 7);
Map.addLayer(beforeVV, {min:-15,max:0}, 'Before flood VV', 0);
Map.addLayer(afterVV, {min:-15,max:0}, 'After flood VV', 0);
Map.addLayer(beforeVH, {min:-25,max:0}, 'Before flood VH', 0);
Map.addLayer(afterVH, {min:-25,max:0}, 'After flood VH', 0);
```

Display Mosaic

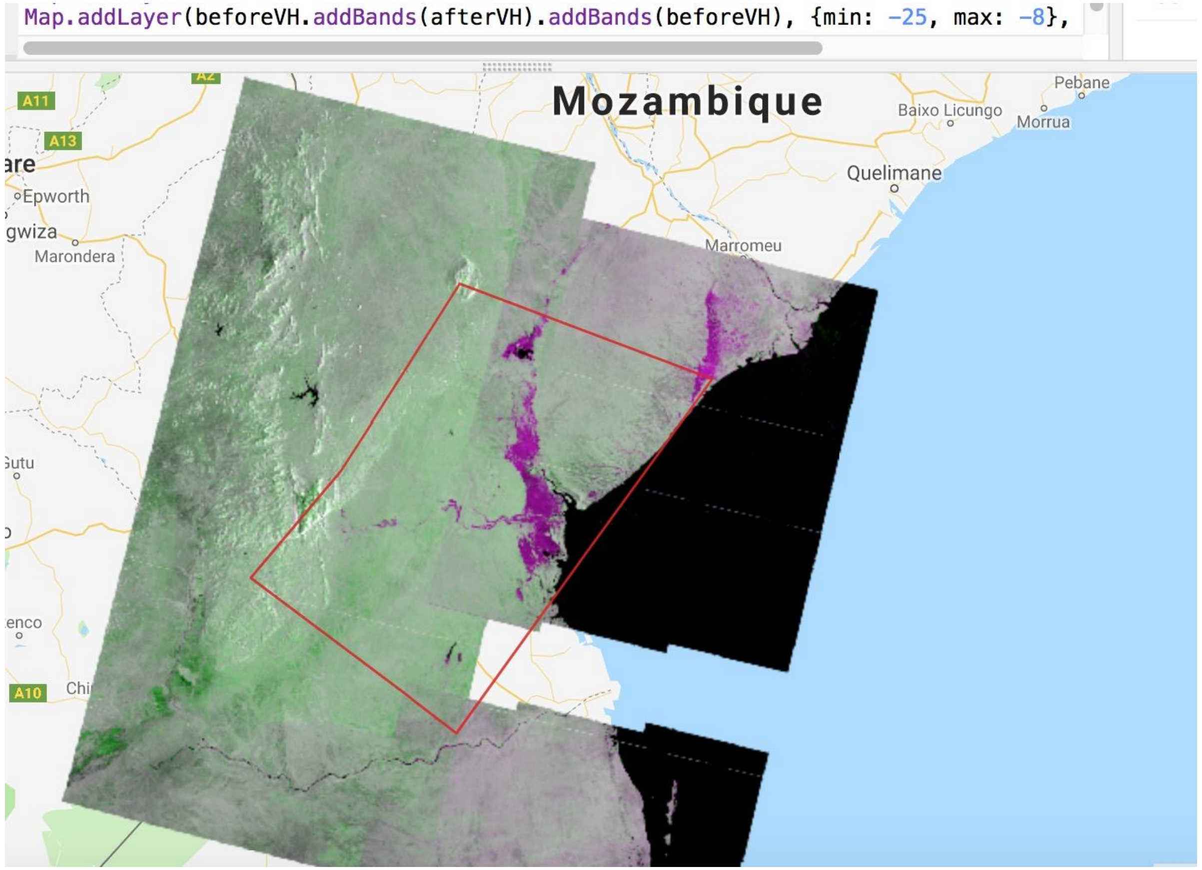
14. Copy the previous code to the Code Editor
15. Select **Run** in the top menu
16. Go to the Layers manager on the top right of the map pane
17. De-select all layers
18. Select **Before flood VH**



Display RGB

```
Map.addLayer(beforeVH.addBands(afterVH).addBands(beforeVH), {min: -25, max: -8},
'BVH/AVV/AVH composite', 0);
```

19. Copy the above code to the Code Editor
20. Select **Run** in the top menu
21. Go to the Layers manager on the top right of the map pane
22. De-select all numbered layers (Layer 6, Layer 7, Layer 8, etc.)
23. Select **BVH/AVV/AVH composite**

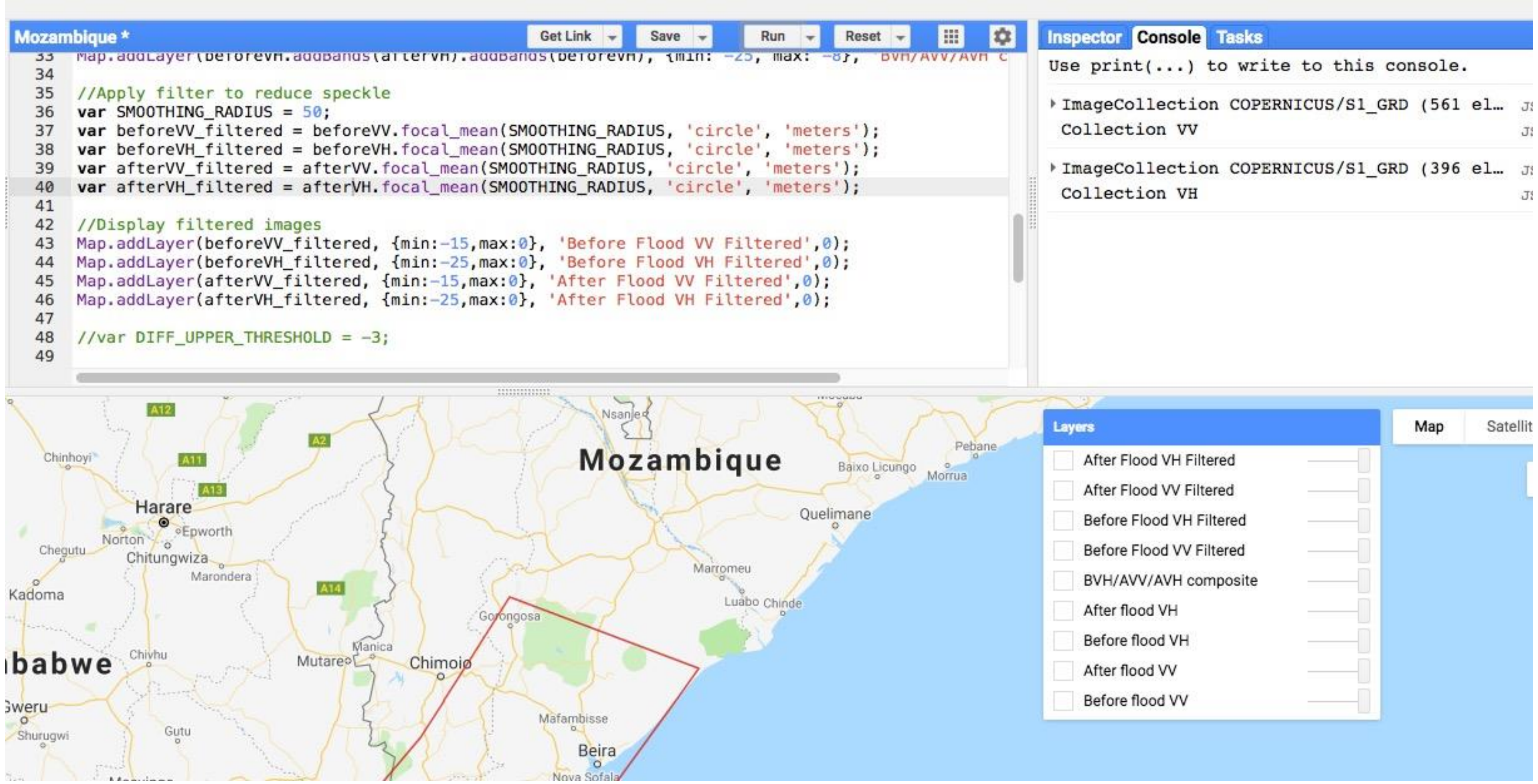


Apply Speckle Filter

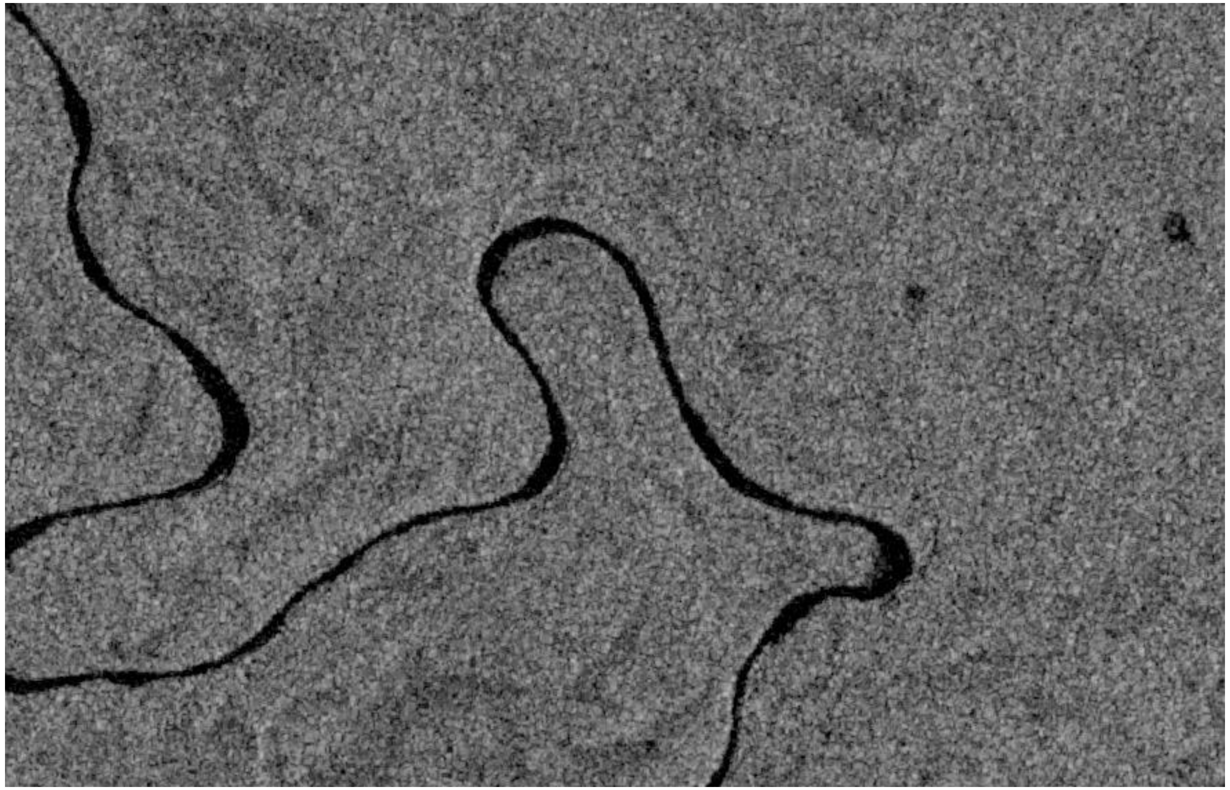
```
//Apply filter to reduce speckle
var SMOOTHING_RADIUS = 50;
var beforeVV_filtered = beforeVV.focal_mean(SMOOTHING_RADIUS, 'circle', 'meters');
var beforeVH_filtered = beforeVH.focal_mean(SMOOTHING_RADIUS, 'circle', 'meters');
var afterVV_filtered = afterVV.focal_mean(SMOOTHING_RADIUS, 'circle', 'meters');
var afterVH_filtered = afterVH.focal_mean(SMOOTHING_RADIUS, 'circle', 'meters');

//Display filtered images
Map.addLayer(beforeVV_filtered, {min:-15,max:0}, 'Before Flood VV Filtered',0);
Map.addLayer(beforeVH_filtered, {min:-25,max:0}, 'Before Flood VH Filtered',0);
Map.addLayer(afterVV_filtered, {min:-15,max:0}, 'After Flood VV Filtered',0);
Map.addLayer(afterVH_filtered, {min:-25,max:0}, 'After Flood VH Filtered',0);
```

Apply Speckle Filter

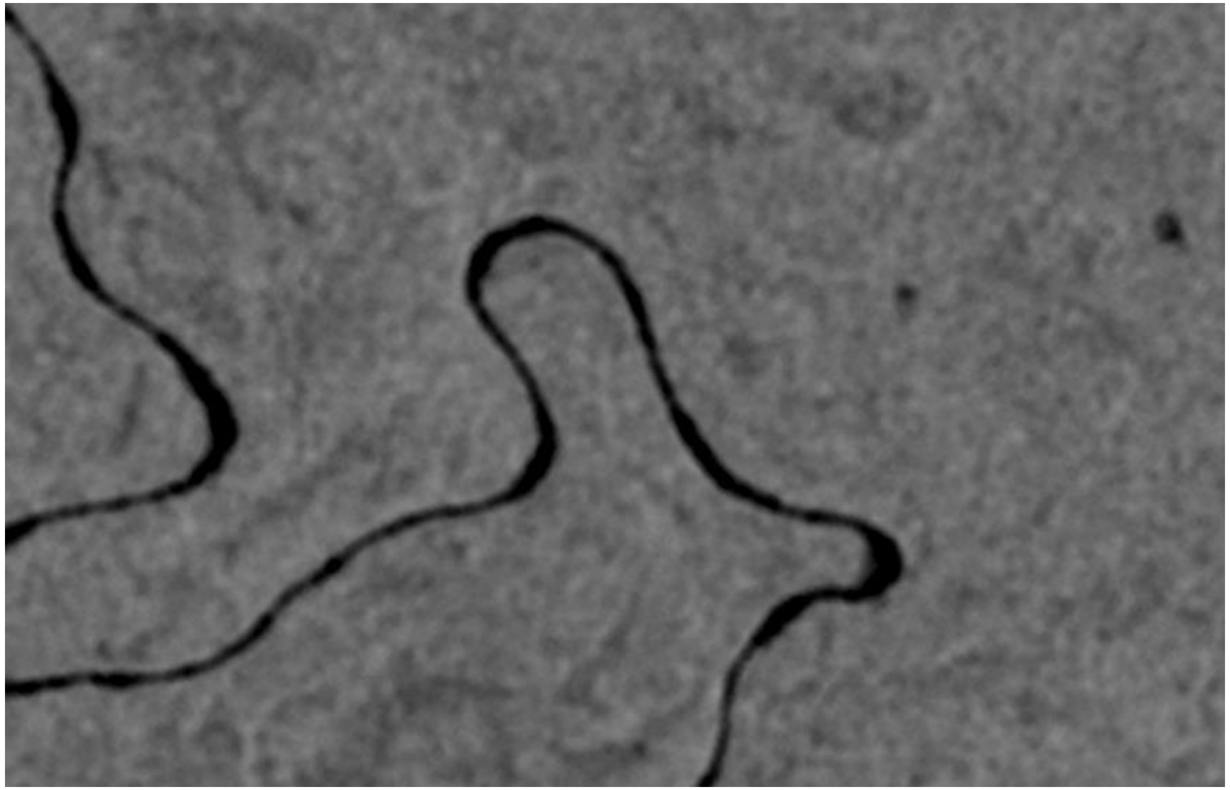
24. Copy the previous code to the Code Editor
25. Select **Run** in the top menu
26. Go to the Layers manager
27. De-select all layers
28. Select **Before flood VH** and **Before flood VH Filtered**
29. Zoom into an area and turn the layers on and off one at a time



Apply Speckle Filter



Original

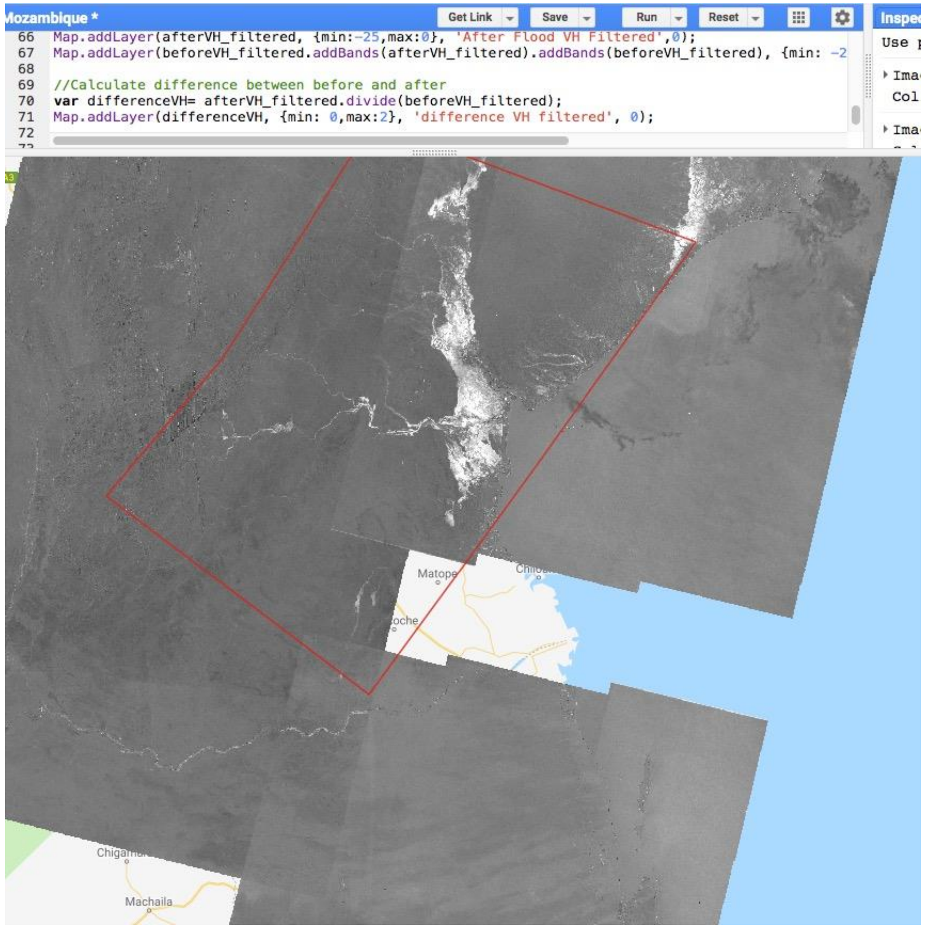


Filtered

Calculate Difference Between Before and After

```
// Calculate difference between before and after
var differenceVH=
afterVH_filtered.divide(beforeVH_filtered);
Map.addLayer(differenceVH, {min: 0,max:2},
'difference VH filtered', 0);
```

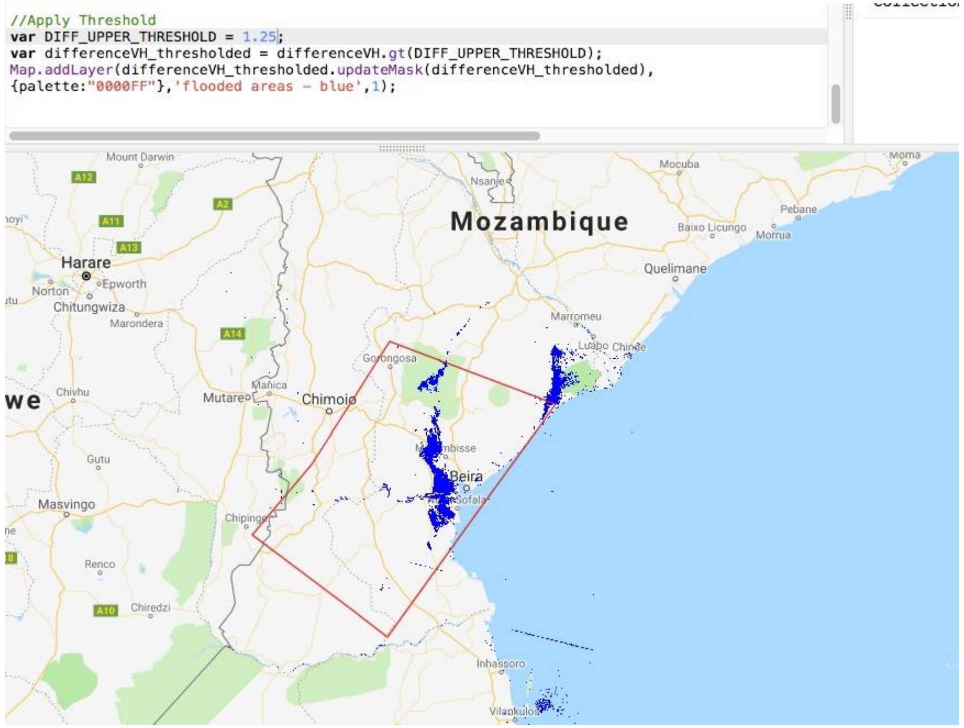
30. Copy the above code to the Code Editor
31. Select **Run** in the top menu
32. Go to the Layers manager
33. De-select all layers
34. Select **difference VH filtered**



Apply a Threshold

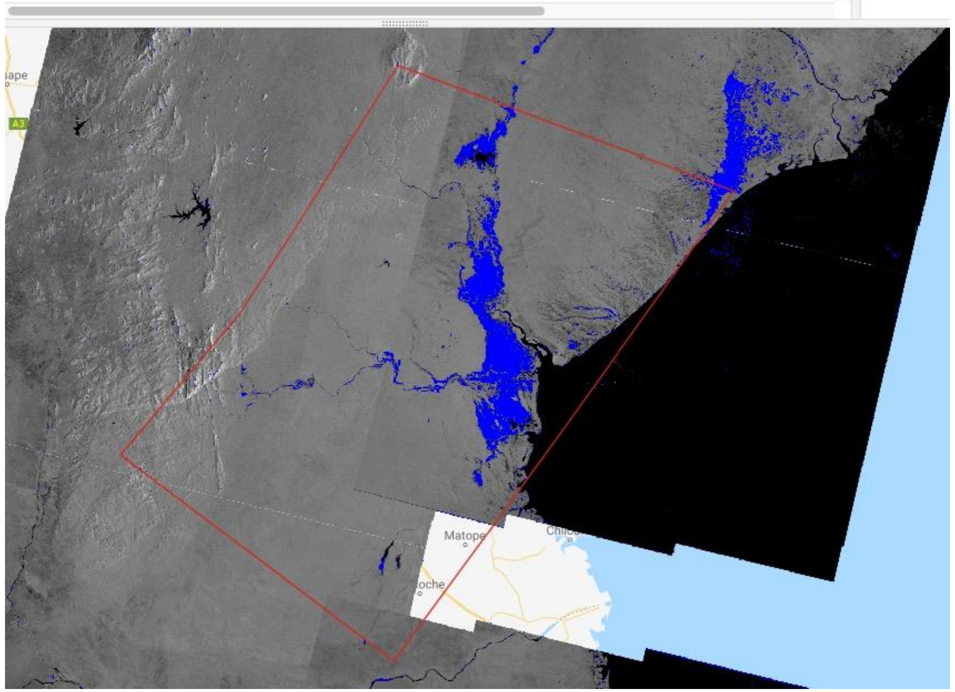
```
//Apply Threshold
var DIFF_UPPER_THRESHOLD = 1.25;
var differenceVH_thresholded = differenceVH.gt(DIFF_UPPER_THRESHOLD);
Map.addLayer(differenceVH_thresholded.updateMask(differenceVH_thresholded),{palett
e:"0000FF"},'flooded areas - blue',1);
```

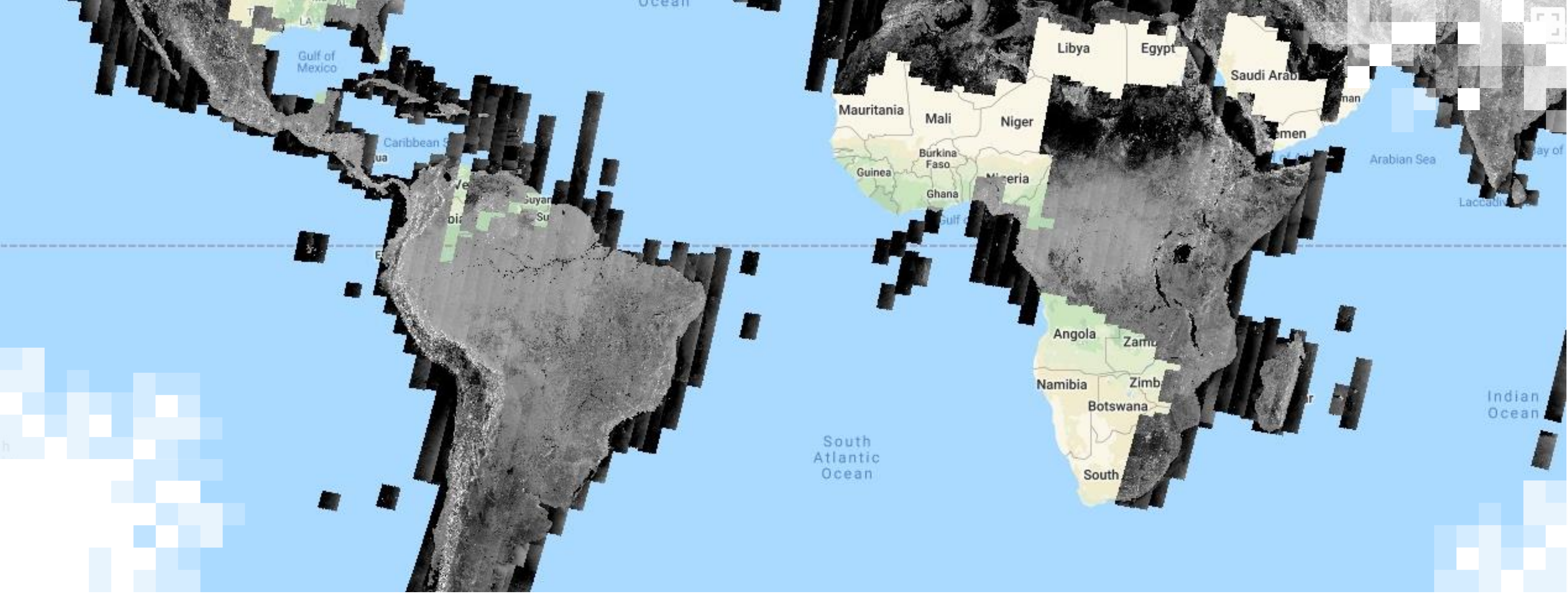
35. Copy the above code to the Code Editor
36. Select **Run** in the top menu
37. Go to the Layers manager
38. De-select all layers
39. Select **flooded areas - blue**



Overlay the SAR Image

40. Go to the Layers manager
41. De-select all layers
42. Select **flooded areas – blue** and **After Flood VH Filtered**




Gulf of Mexico
Libya
Egypt
Mauritania
Mali
Niger
Burkina Faso
Guinea
Ghana
Arabian Sea
Angola
Namibia
Botswana
South Atlantic Ocean
Indian Ocean

THANK YOU

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