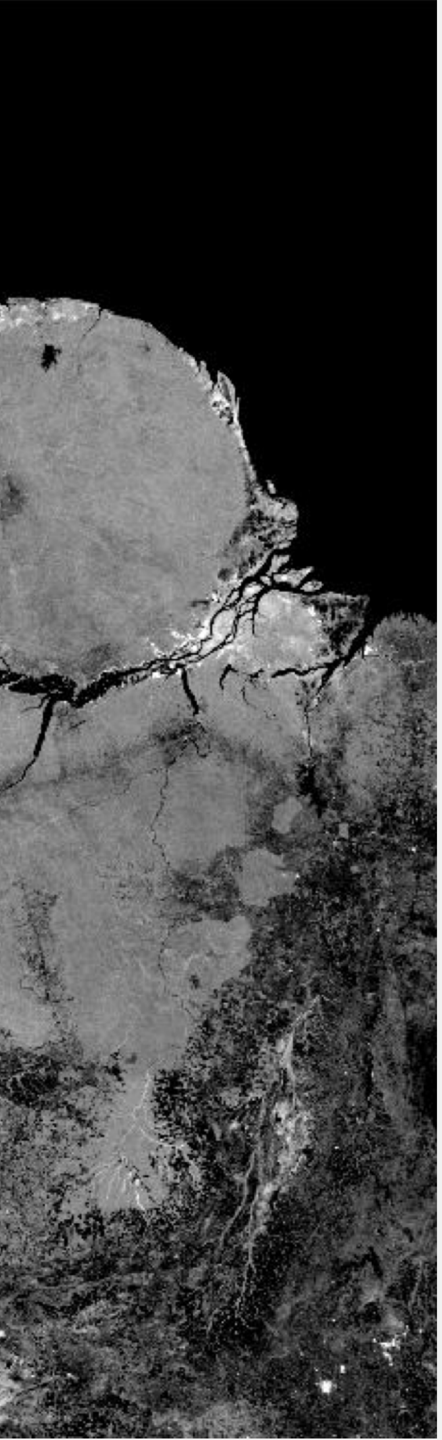

National Aeronautics and
Space Administration

ARSET

Applied Remote Sensing Training

http://arset.gsfc.nasa.gov

@NASAARSET

Introduction to Polarimetric SAR

Naiara Pinto – Caltech / Jet Propulsion Laboratory

Acknowledgements

From NASA:

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Yunling Lou

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UAVSAR team

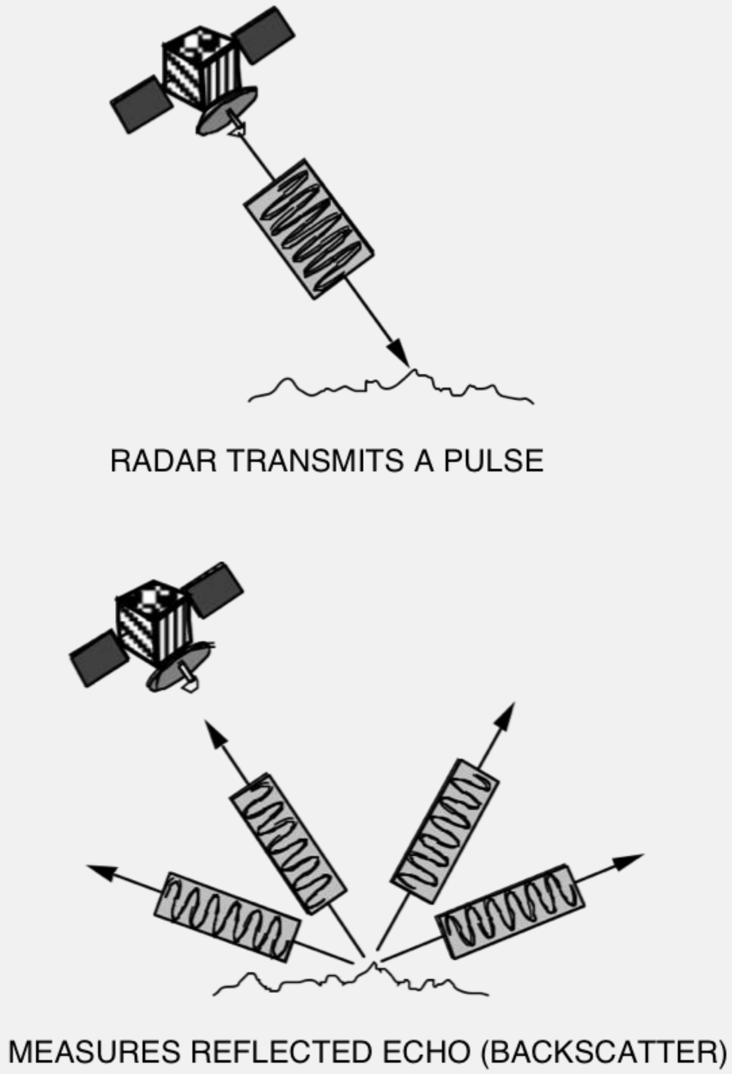
Armstrong Flight Research Center

From Alaska Satellite Facility:

Brian Huberty

Learning objectives

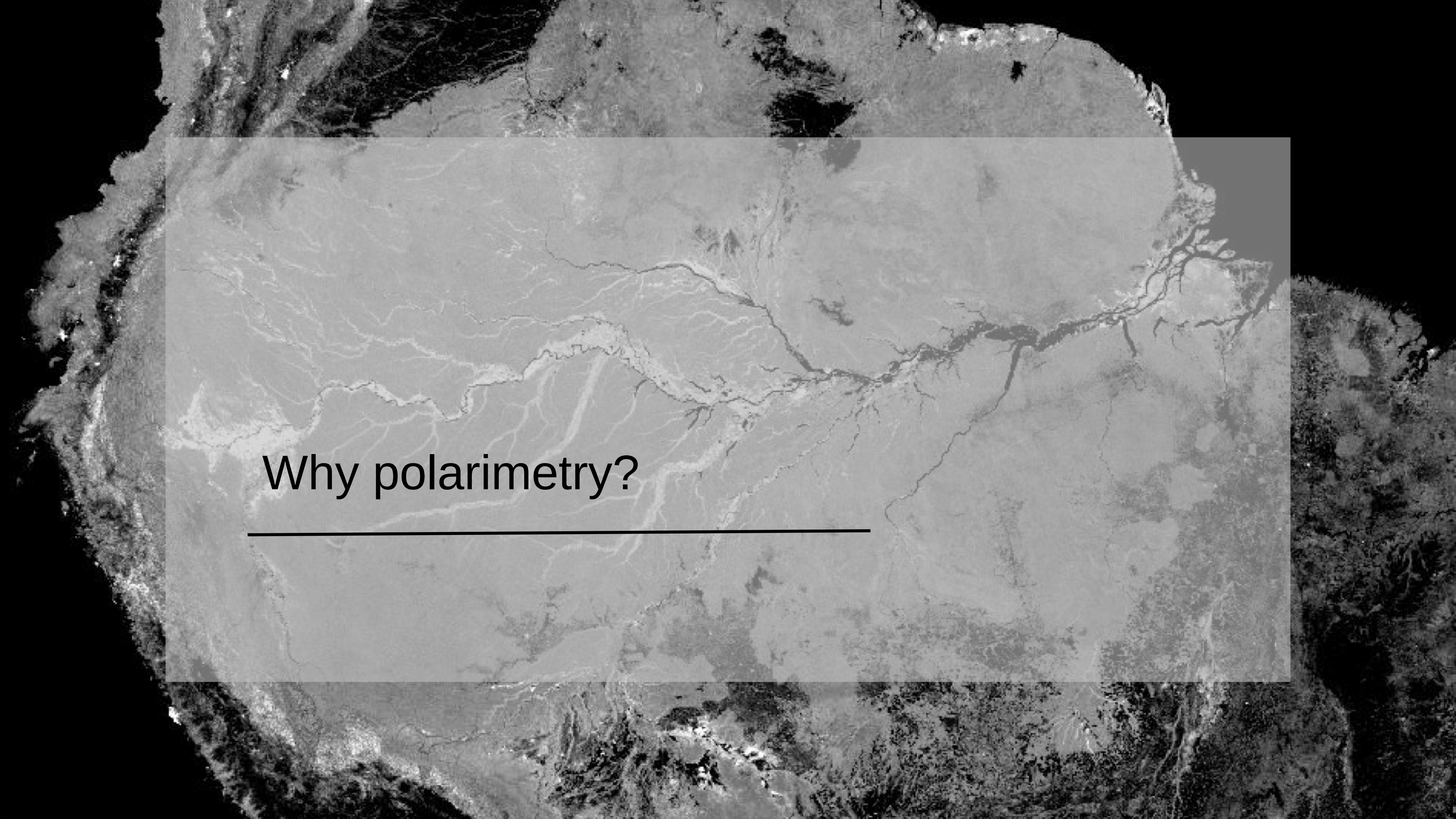
- In previous weeks, we learned that radar signals can interact with the earth’s surface
- The received signal provides information about properties of scatterers on the ground
- More information is gained by studying different polarizations
- Our objective is to provide a brief introduction to polarimetry and familiarize students with:
  - Mathematical representation
  - Data format
  - Data processing for land cover mapping



Source: ESA- ASAR Handbook

Outline

1. Why polarimetry?
2. Polarization
3. Scattering mechanisms
4. Data and software
5. Process Sentinel-1 dual-pol images
6. Process UAVSAR quad-pol images
7. Display results



Why polarimetry?

Libreville, Gabon
As seen with optical imagery

forest

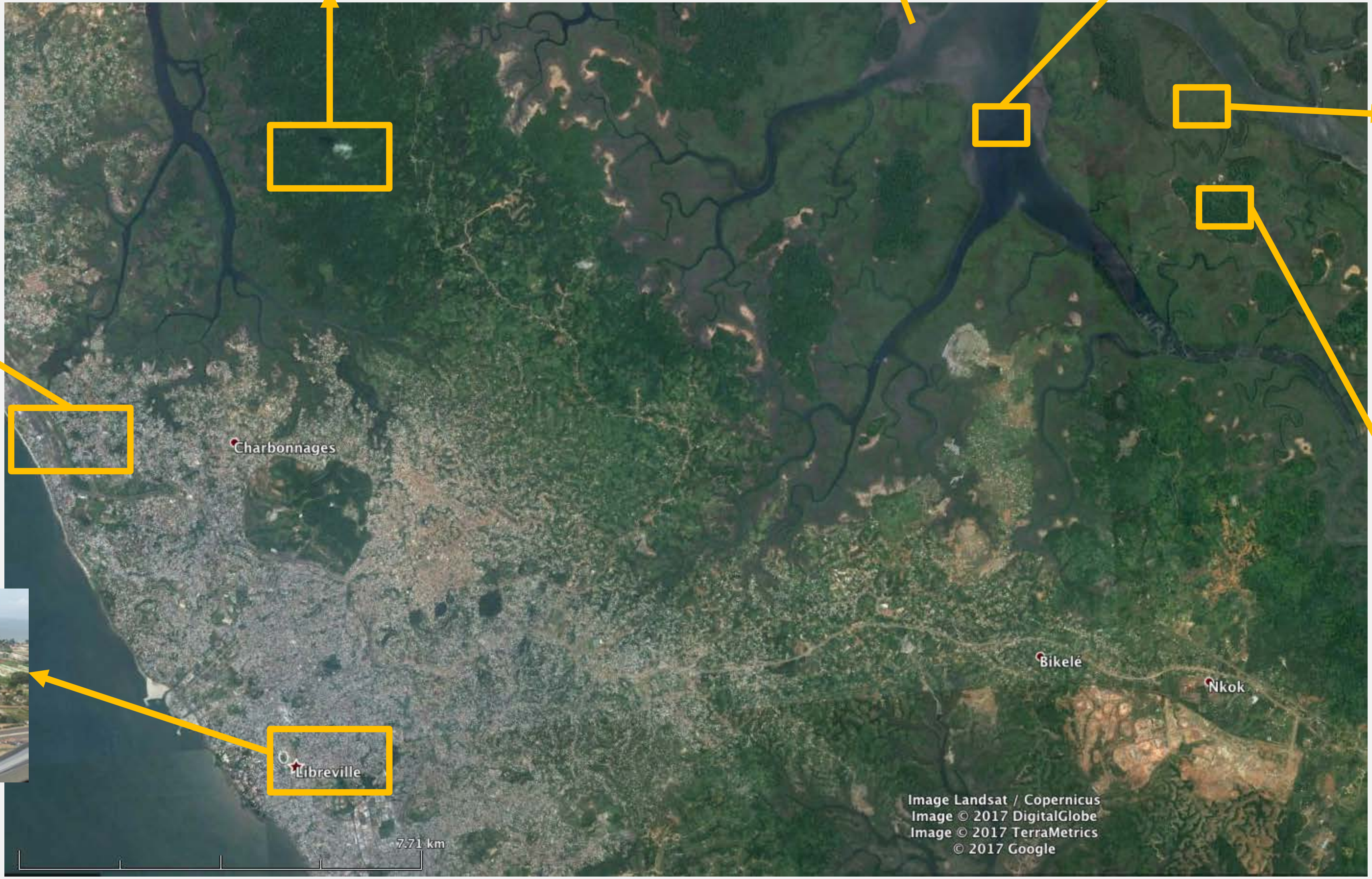
mud banks

open water

dense mangrove

runway

buildings



tall mangrove

Libreville, Gabon As seen with L-band SAR imagery

forest

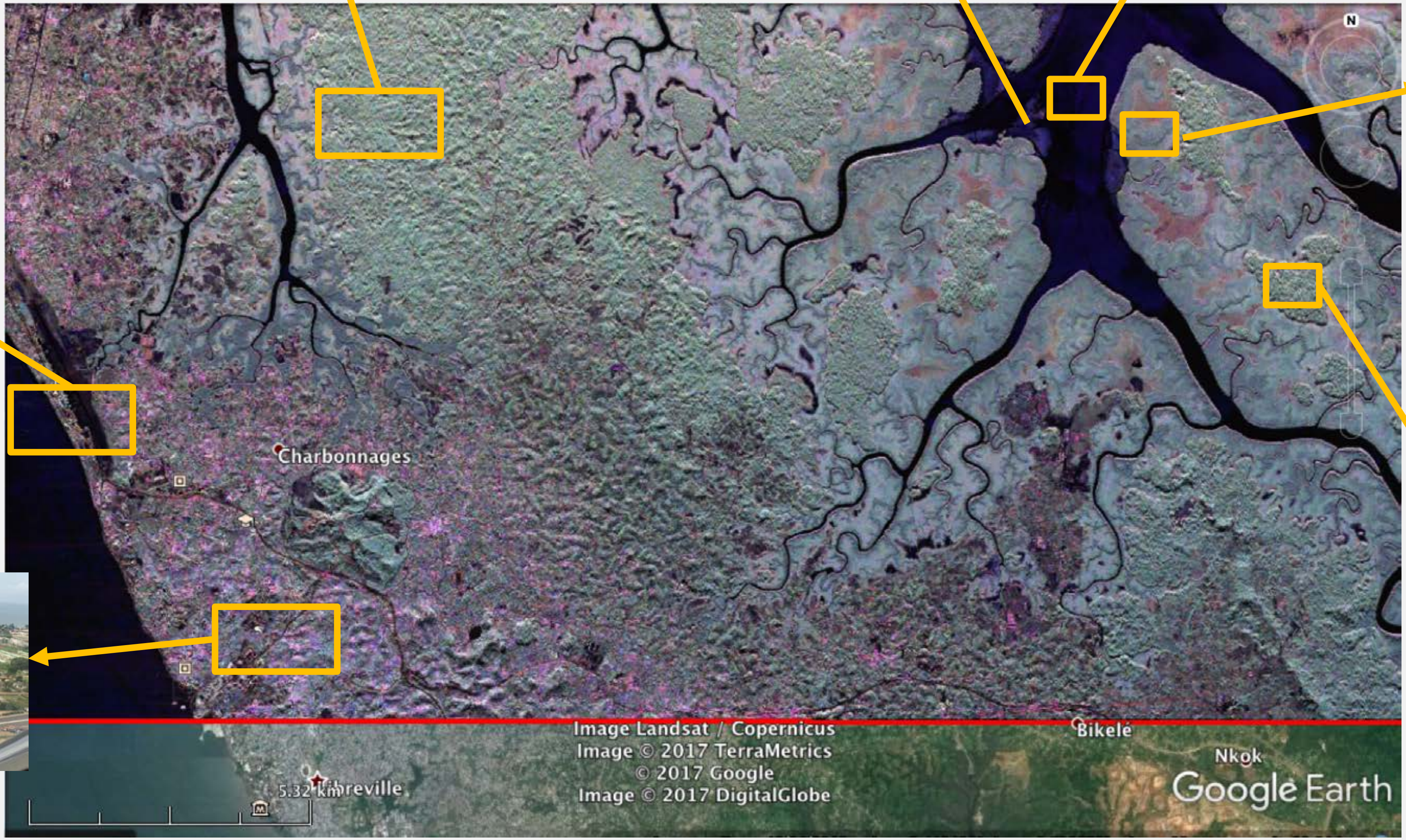
mud banks

open water

dense mangrove

runway

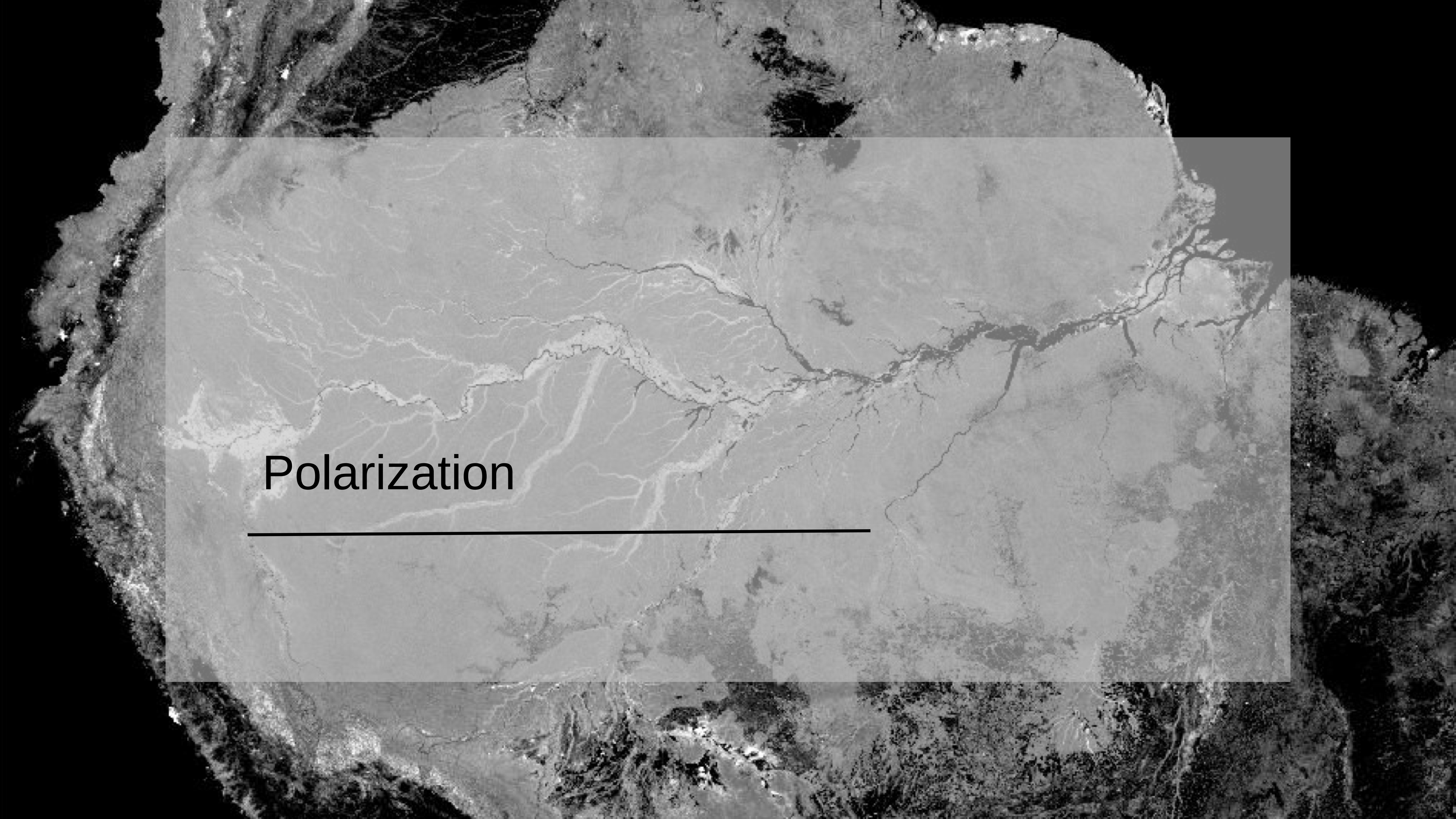
HH HV VV



buildings

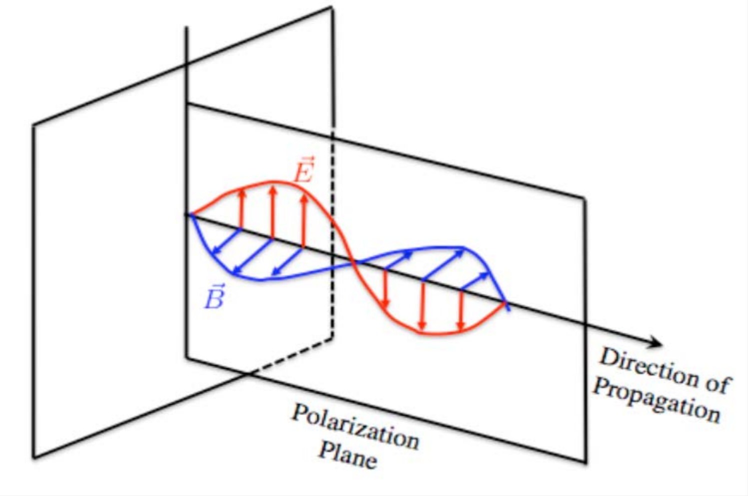
tall mangrove

Polarization



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

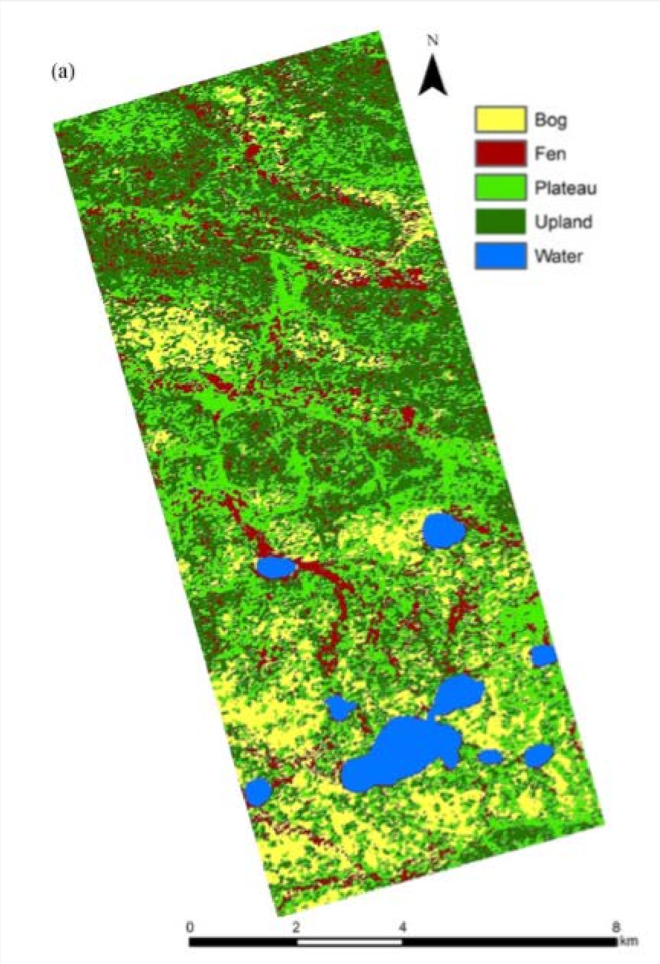
receive

	H	V
H	HH	VH
V	HV	VV

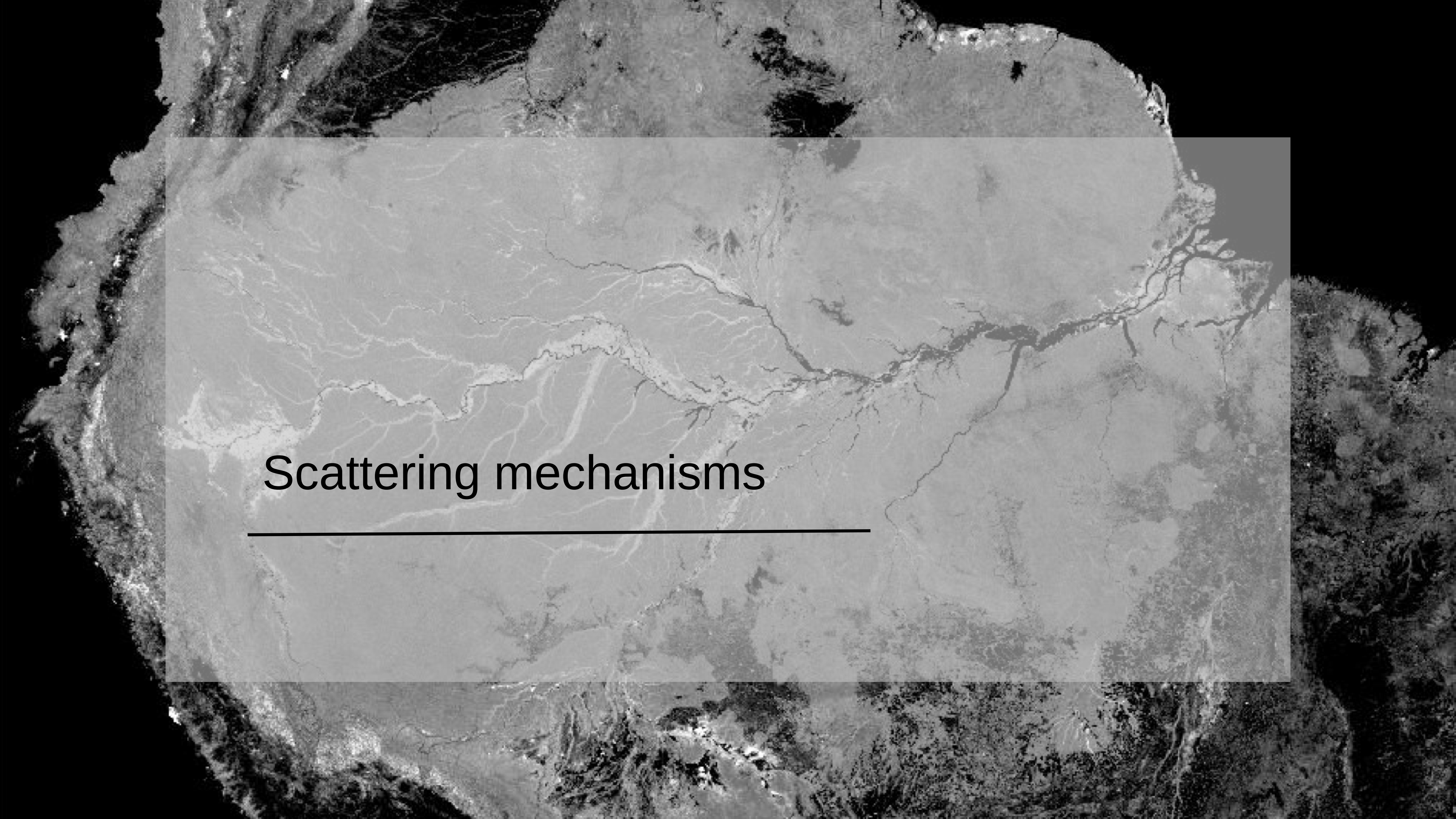
Polarimetry

Mapping Canadian peatlands: Merchant et al. 2017

- 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

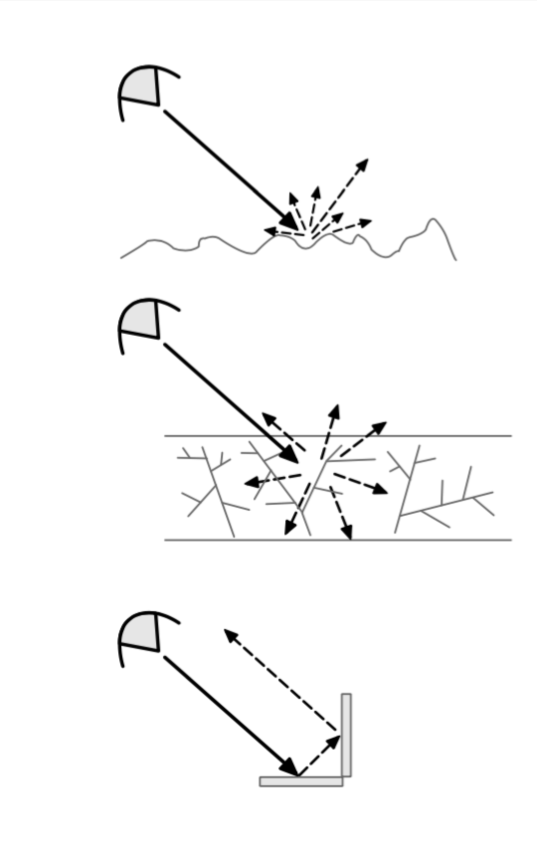


Scattering mechanisms



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.



surface

volume scatter

double bounce

H-α Decomposition

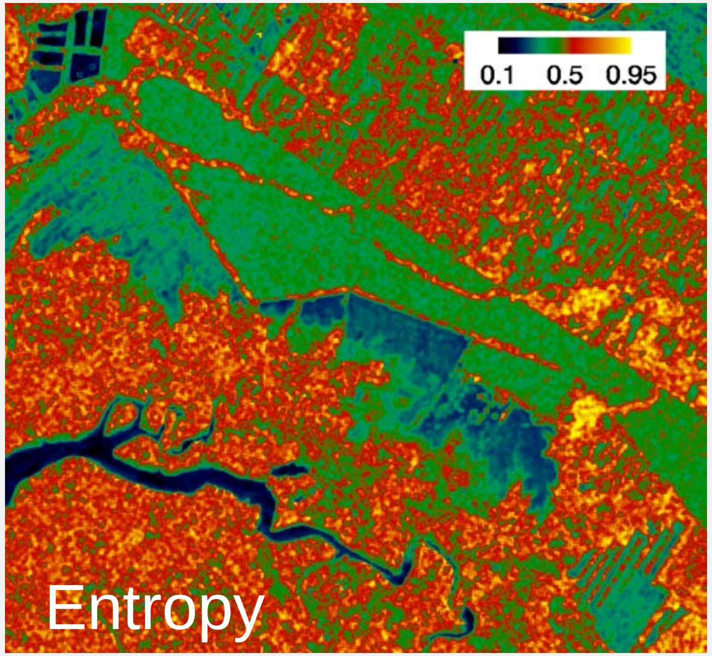
- Based on eigenvalue / eigenvector decomposition of the T3 matrix

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

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

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

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

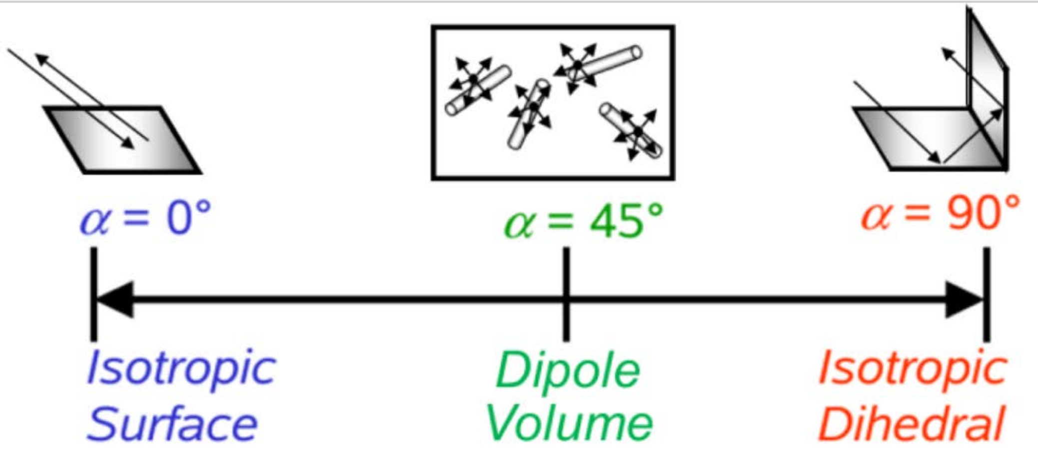


H-α Decomposition

- Based on eigenvalue / eigenvector decomposition of the T3 matrix

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

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

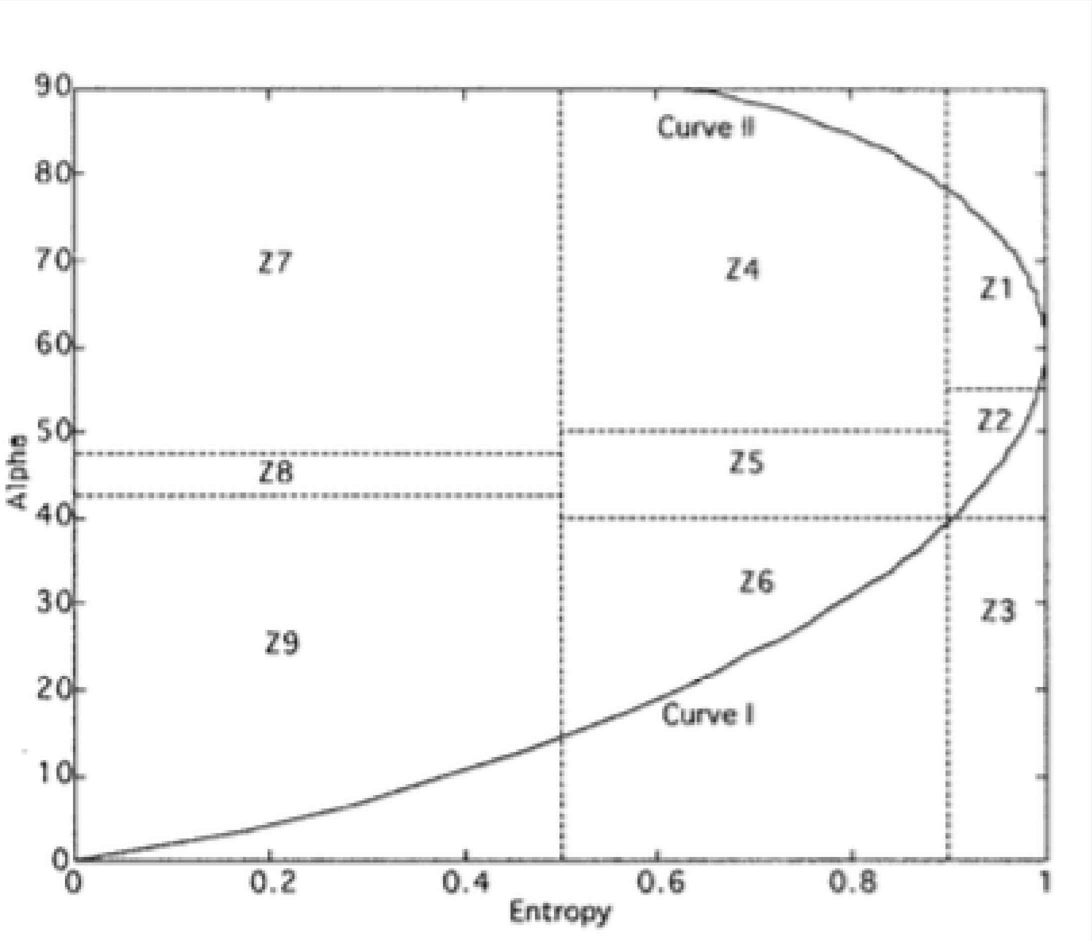


$$\text{alpha:} \quad \alpha = \sum_{i=1}^{3} p_i\alpha_i \quad 0 \le \alpha \le \frac{\pi}{2}$$

- 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.

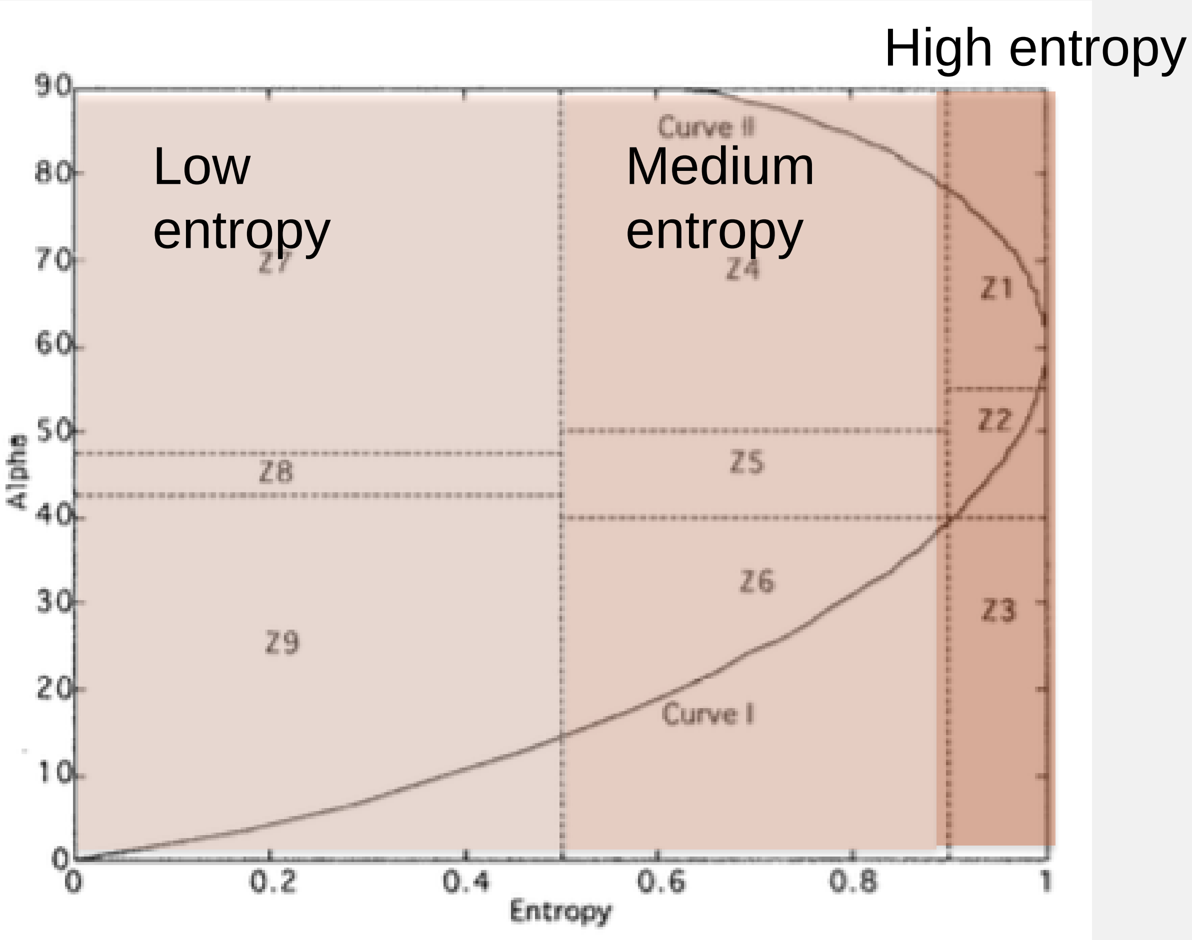
H-α Classification



- 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

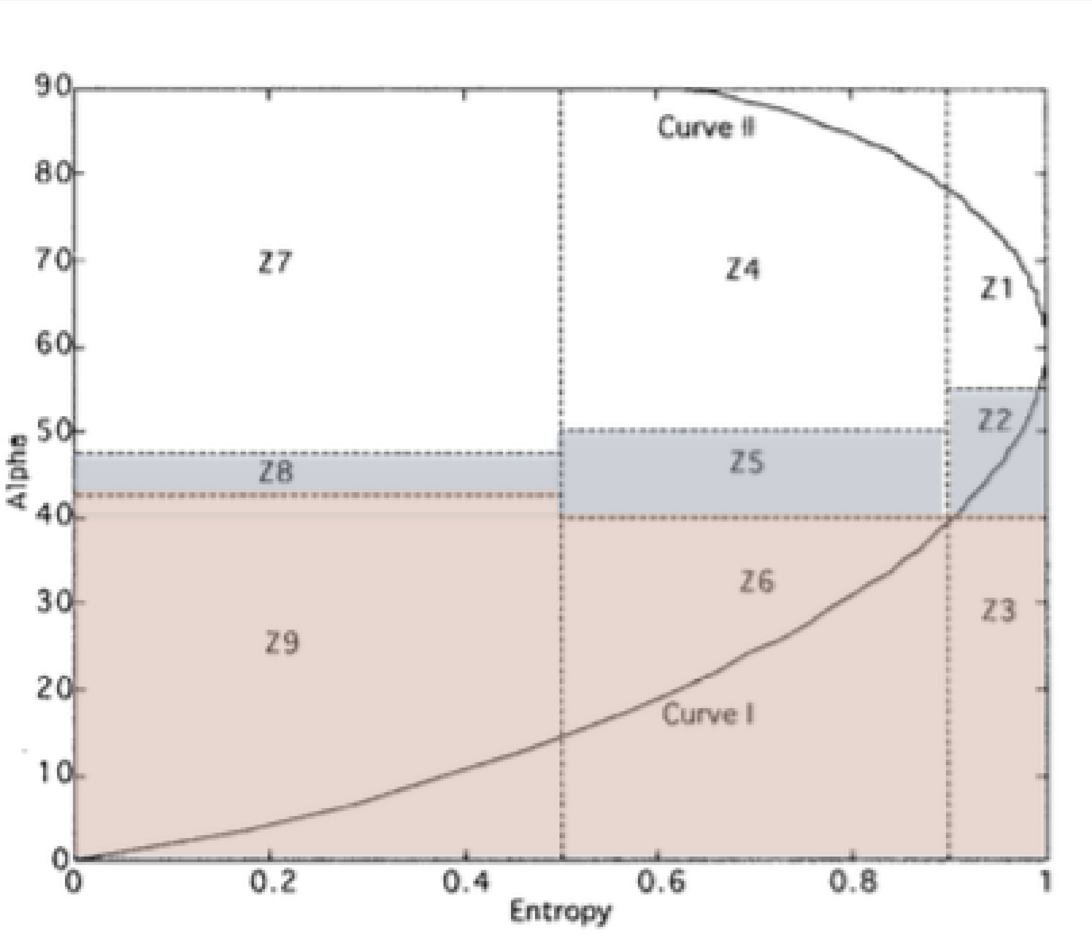


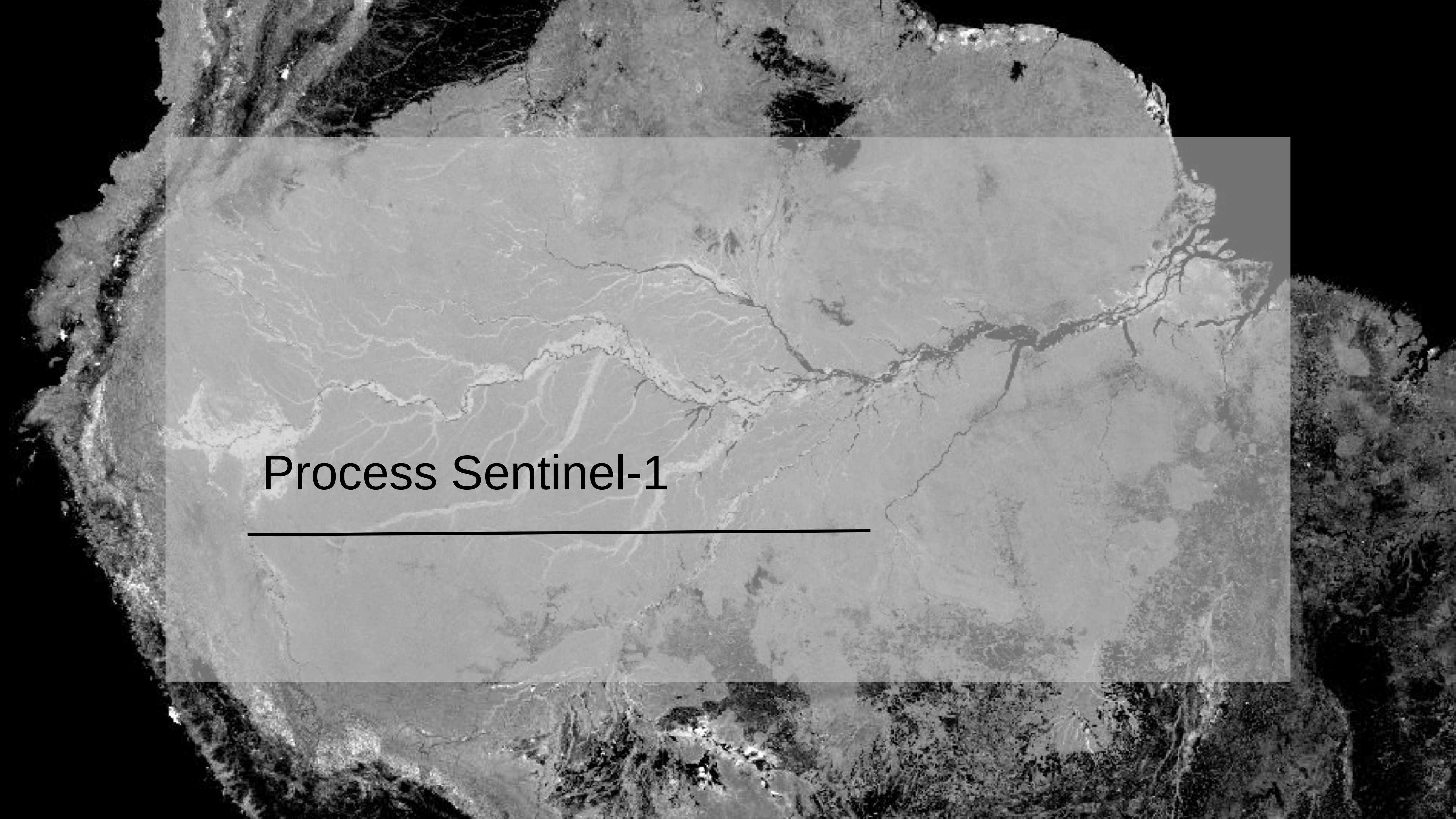
H-α Classification

Multiple

Dipole / vegetation

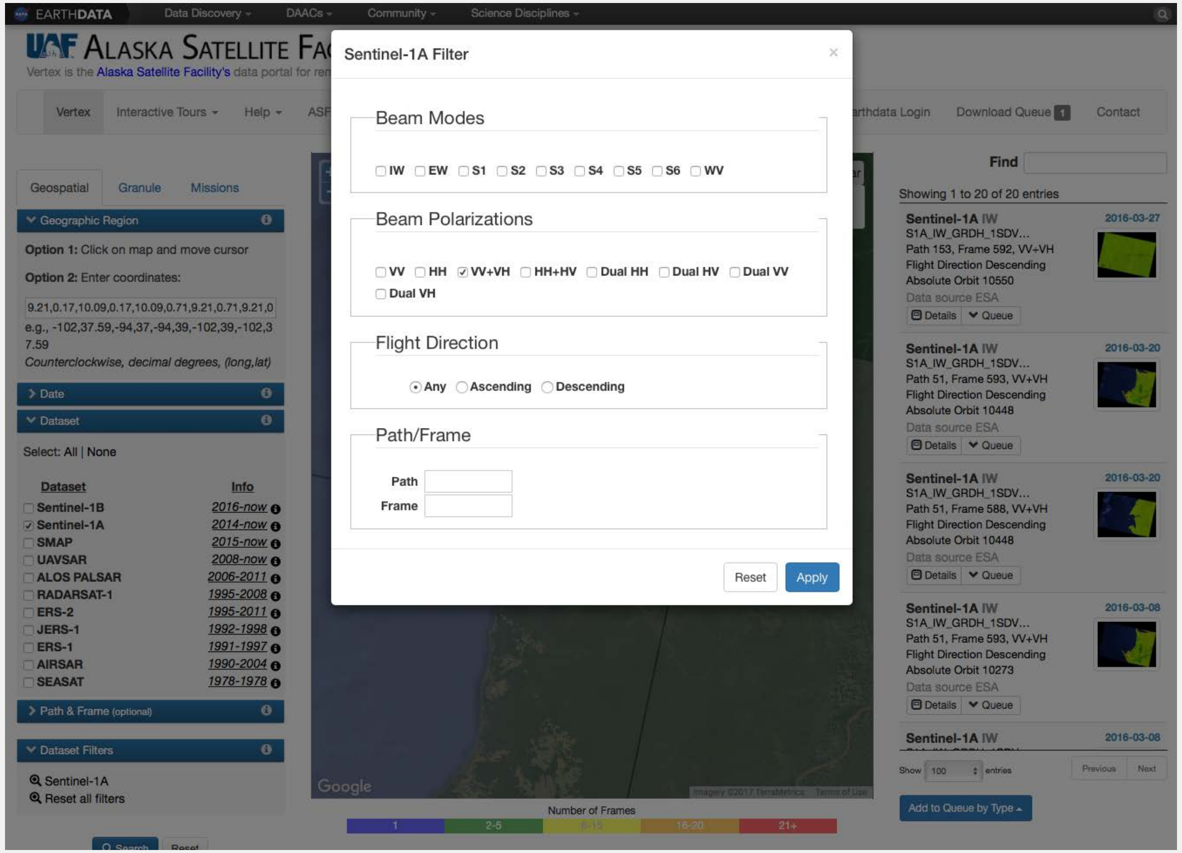
Surface





Process Sentinel-1

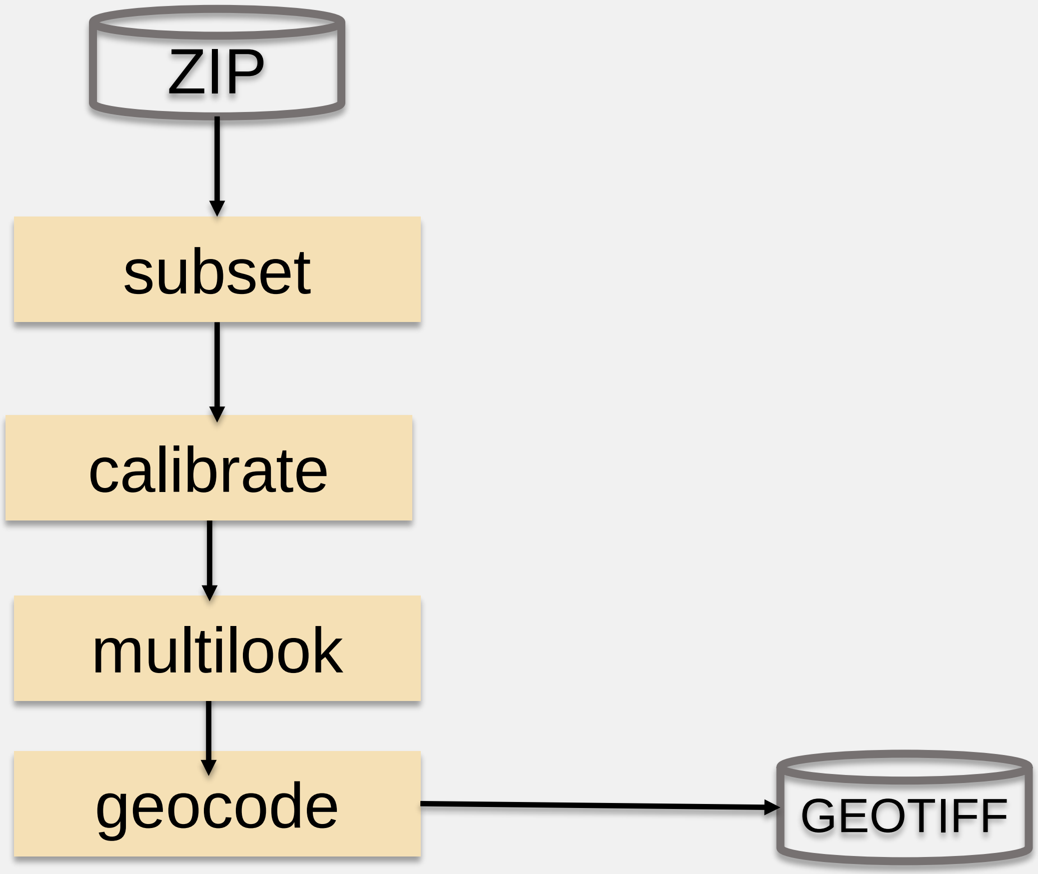
Sentinel-1 download from Alaska Satellite Facility



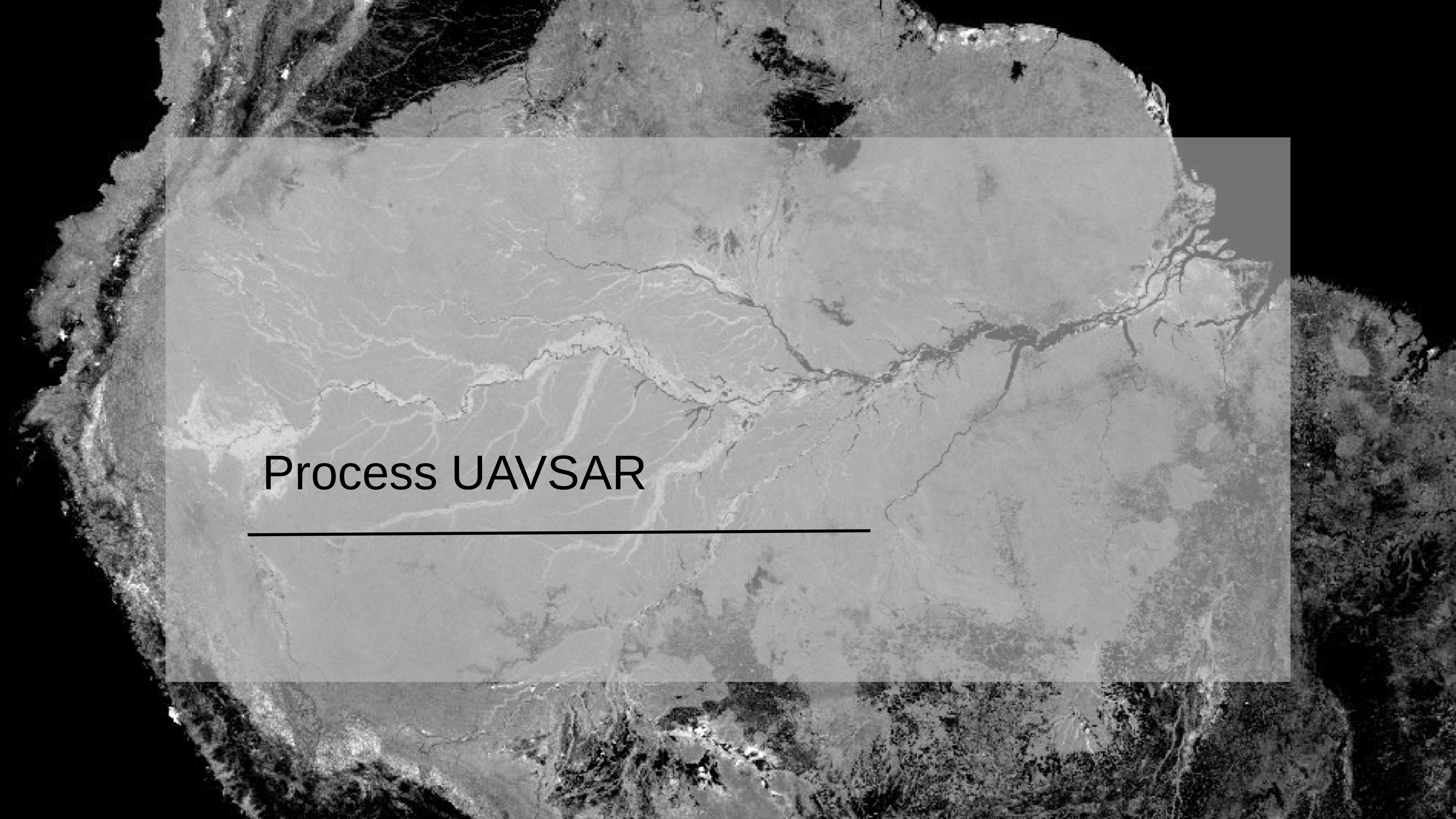
- Spaceborne instrument operated by ESA
- C band (5-cm wavelength)
- Two polarizations:
  - VH
  - VV
- GRD (Ground Range Detected) product
- 10 meters spatial posting
- Product ID: S1A_IW_GRDH_1SDV_20160320T050613_20160320T050638_010448_00F805_14D5
- Acquired on March 20, 2016
- Download the zip file

https://vertex.daac.asf.alaska.edu

Sentinel-1 process in SNAP

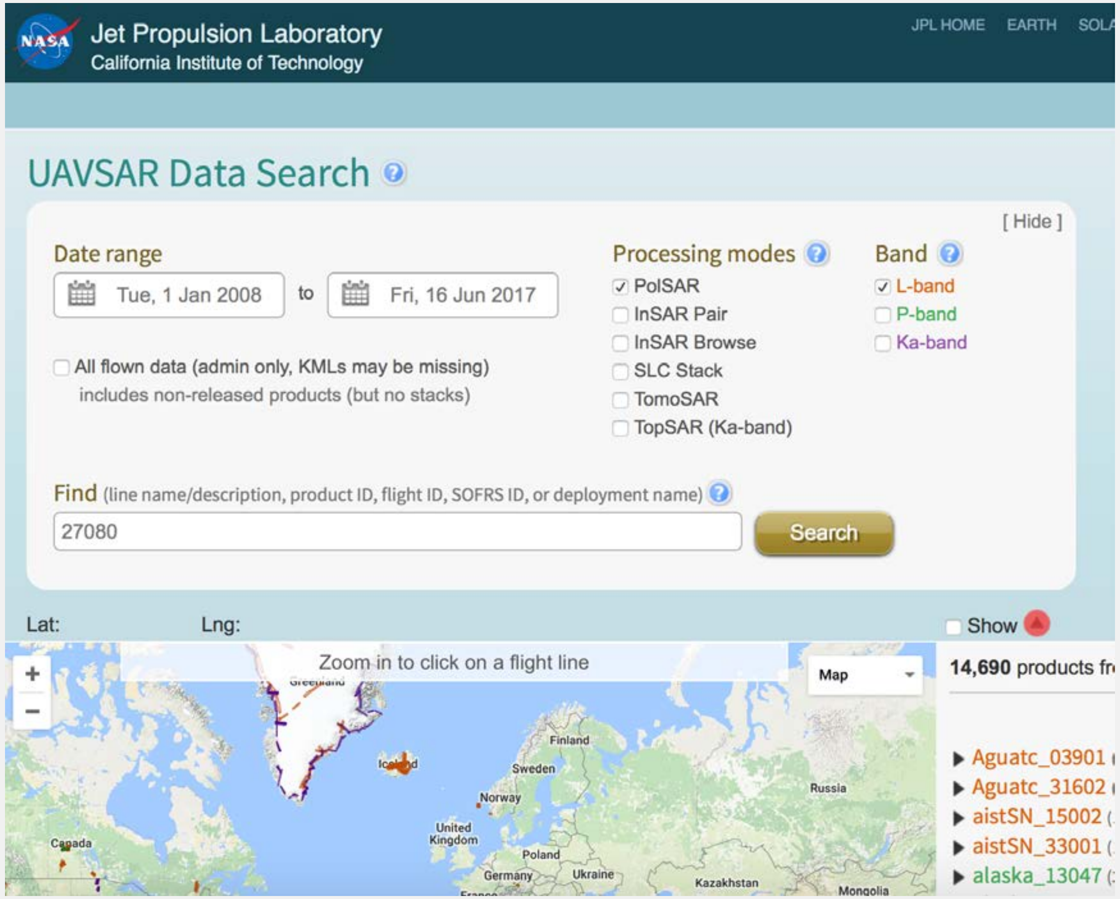


- Process following the steps in ARSET tutorial "SAR Processing and Data Analysis"
- Outputs two files:
  - VV
  - VH



Process UAVSAR

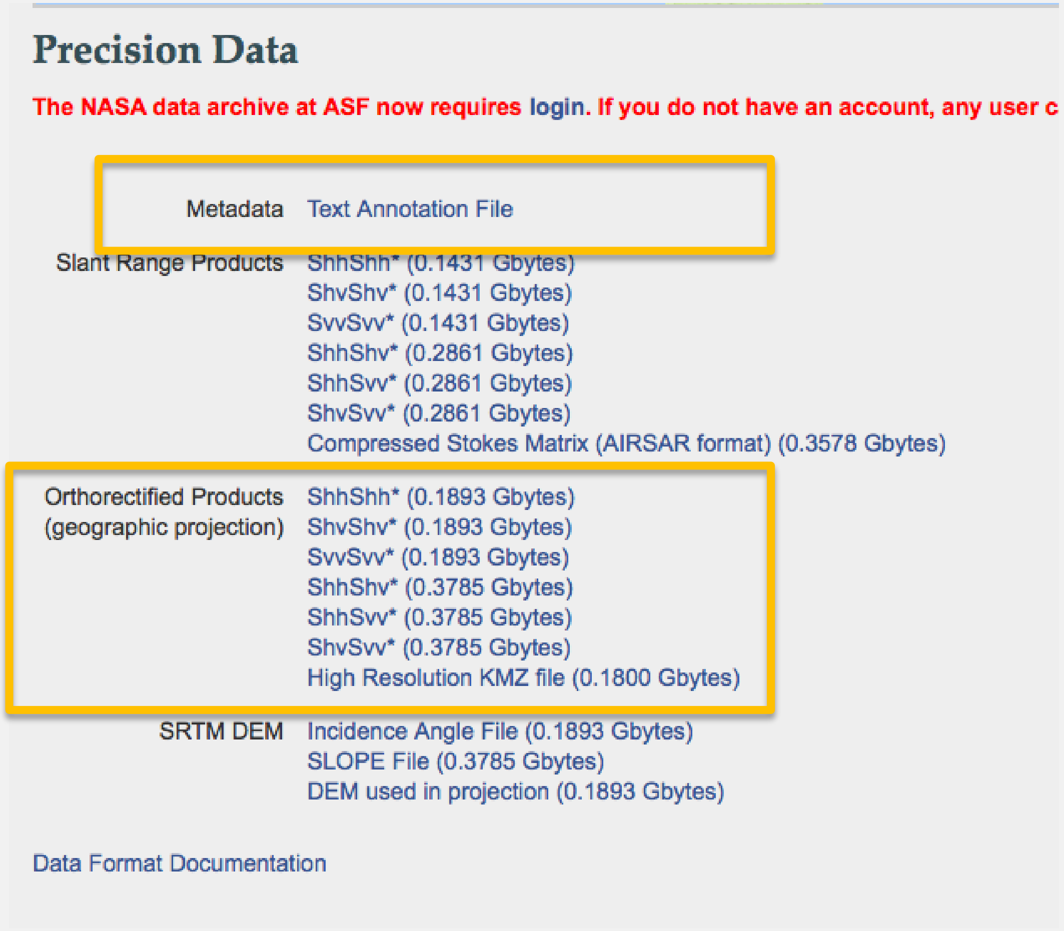
Uninhabited Aerial Synthetic Aperture Radar (UAVSAR)



https://uavsar.jpl.nasa.gov

- Airborne instrument operated by NASA
- L band (24-cm wavelength)
- Fully polarimetric
- GRD (Ground Range Detected) product
- 6 meters posting

Uninhabited Aerial Synthetic Aperture Radar (UAVSAR)



Precision Data

The NASA data archive at ASF now requires login. If you do not have an account, any user c

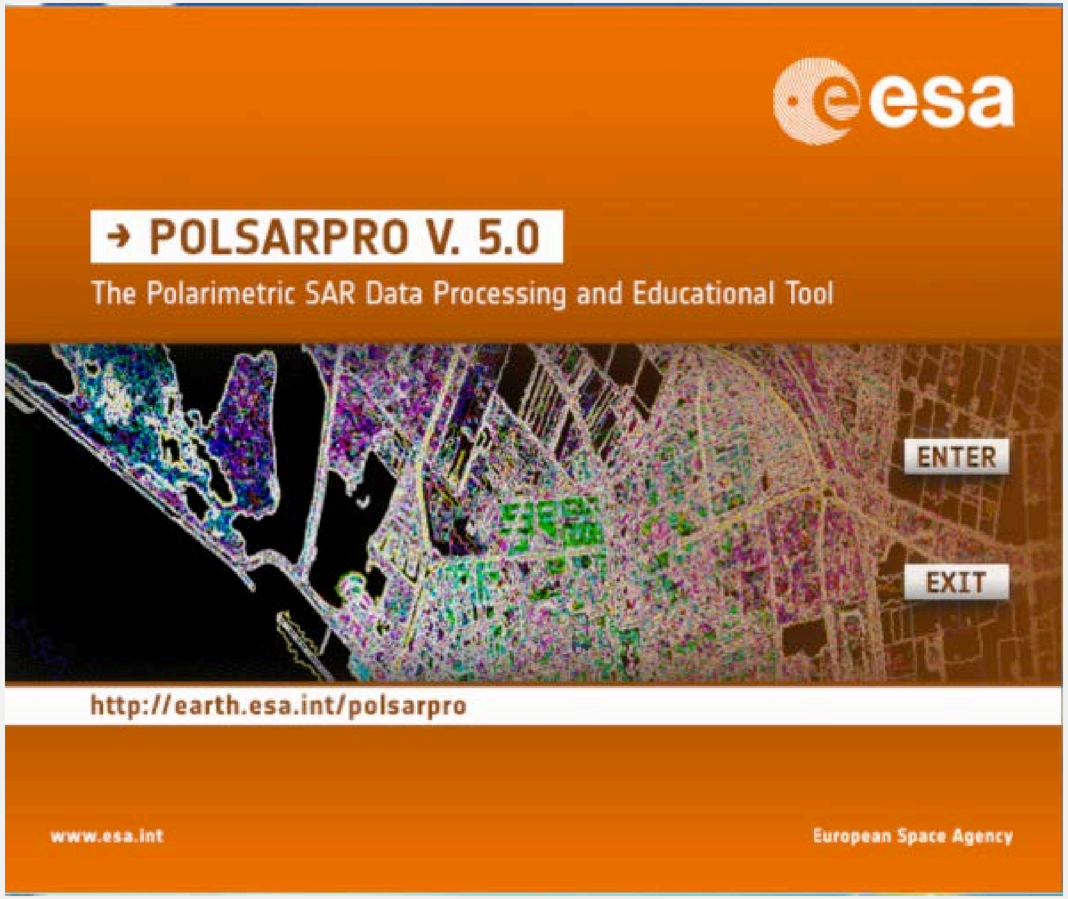
Metadata	Text Annotation File
Slant Range Products	ShhShh* (0.1431 Gbytes) ShvShv* (0.1431 Gbytes) SvvSvv* (0.1431 Gbytes) ShhShv* (0.2861 Gbytes) ShhSvv* (0.2861 Gbytes) ShvSvv* (0.2861 Gbytes) Compressed Stokes Matrix (AIRSAR format) (0.3578 Gbytes)
Orthorectified Products (geographic projection)	ShhShh* (0.1893 Gbytes) ShvShv* (0.1893 Gbytes) SvvSvv* (0.1893 Gbytes) ShhShv* (0.3785 Gbytes) ShhSvv* (0.3785 Gbytes) ShvSvv* (0.3785 Gbytes) High Resolution KMZ file (0.1800 Gbytes)
SRTM DEM	Incidence Angle File (0.1893 Gbytes) SLOPE File (0.3785 Gbytes) DEM used in projection (0.1893 Gbytes)

Data Format Documentation

https://uavsar.jpl.nasa.gov

- Product ID: Mondah_27080_16015_000_160308_L090_CX_02
- Acquired on March 03, 2016
- Download all 6 *GRD files as well as annotation file *ANN

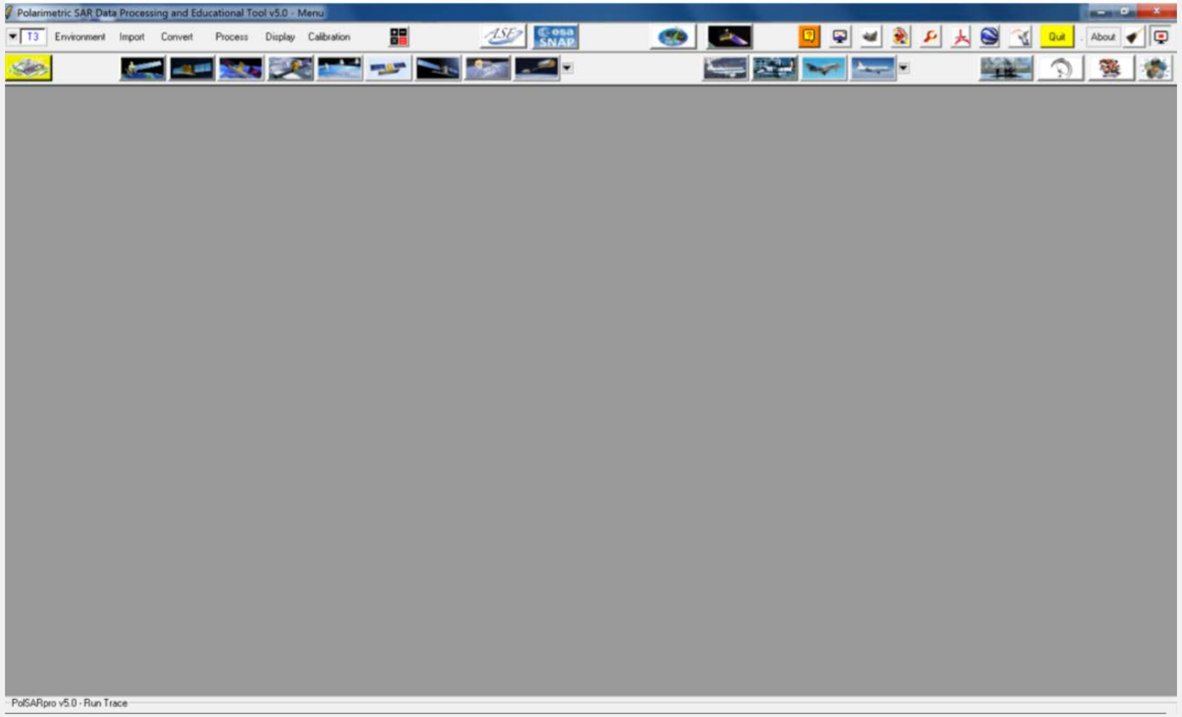
PolSARpro



https://earth.esa.int/web/polsarpro/download/version-5.0

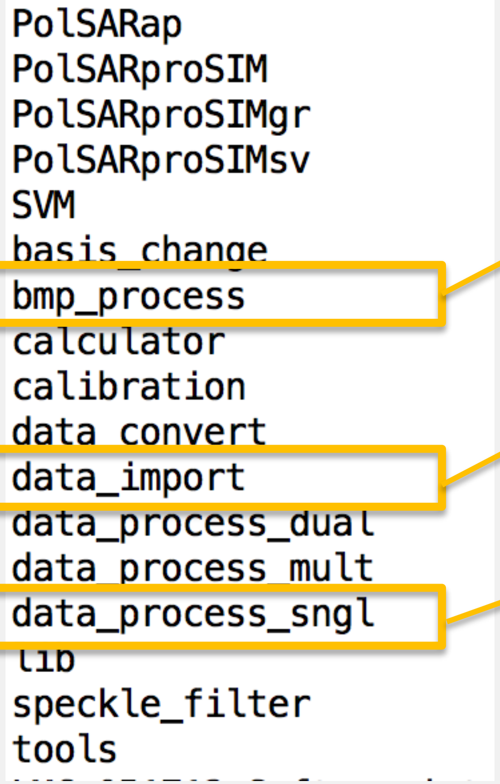
- PolSARpro is developed under contract with ESA since 2003. The IETR (Institute of Electronics and Telecommunications of Rennes - UMR CNRS 6164) of the University of Rennes 1, France is in charge of the development of the PolSARpro software.
- Windows and Linux; it is possible to compile on MacOSX from Linux source files
- GUI or command line
- Open source
- We will show command line routines but an example practice with GUI is here: https://uavsar.jpl.nasa.gov/science/workshops/presentations2015/UAVSAR_Workshop2015_Polarimetry_Tutorial_(Chapman).pdf

PolSARpro



GUI

Command Line



make quicklooks

import files from UAVSAR, ALOS, etc.

polarimetric decomposition, classification

PolSARpro

You can call any function with no arguments to see the expected inputs

#cd to directory Soft/data_process_sngl
./wishart_h_a_alpha_classifier.exe

PolSARPro will warn you about the lack of arguments, then provide the usage

```
 A processing error occured !
 Not enough input arguments
 Usage:

wishart_h_a_alpha_classifier.exe

Parameters:
 (string)       -id     input directory
 (string)       -od     output directory
 (string)       -iodf   input-output data format
 (int)          -nwr    Nwin Row
 (int)          -nwc    Nwin Col
 (int)          -ofr    Offset Row
 (int)          -ofc    Offset Col
 (int)          -fnr    Final Number of Row
 (int)          -fnc    Final Number of Col
 (string)       -hf     input entropy file
 (string)       -af     input anisotropy file
 (string)       -alf    input alpha file
 (int)          -nit    maximum interation number
 (float)        -pct    maximum of pixel switching classes
 (int)          -bmp    BMP flag (0/1)
 (string)       -co8    input colormap8 file (valid if BMP flag = 1)
 (string)       -co16   input colormap16 file (valid if BMP flag = 1)

Optional Parameters:
 (string)       -mask   mask file (valid pixels)
 (int)          -mem    Allocated memory for blocksize determination (in Mb)
 (string)       -errf   memory error file
 (noarg)        -help   displays this message
 (noarg)        -data   displays the help concerning Data Format parameter
```

Ingest UAVSAR files and make a T3 matrix

```
uavsar_convert_MLC.exe –hf Mondah_27080_16015_000_160308_L090_CX_02.ann\
-if1 Mondah_27080_16015_000_160308_L090HHHH_CX_02.grd \
-if2 Mondah_27080_16015_000_160308_L090HHHV_CX_02.grd \
-if3 Mondah_27080_16015_000_160308_L090HHVV_CX_02.grd \
-if4 Mondah_27080_16015_000_160308_L090HVHV_CX_02.grd \
-if5 Mondah_27080_16015_000_160308_L090HVVV_CX_02.grd \
-if6 Mondah_27080_16015_000_160308_L090VVVV_CX_02.grd \
-od T3 -odf T3 -inr 3750 -inc 12618 -ofr 0 -ofc 0 -fnr 3750 -fnc 12618 -nlr 2 -nlc 2 -ssr 1 -ssc 1
```

input rows and cols

I called the output directory 'T3'

taking looks

H-α decomposition and classification

```
h_a_alpha_decomposition.exe -id T3 -od decomposition -iodf T3 \
-nwr 7 -nwc 7 -ofr 0 -ofc 0 -fnr 1875 -fnc 6309 \
-fl1 0 -fl2 1 -fl3 1 -fl4 1 -fl5 0 -fl6 0 -fl7 0 -fl8 0 -fl9 0
```

-od is the output directory, I'm calling it 'decomposition'

-id is the input directory with T3 elements, I'm calling it 'T3'

-nwr and nwc is the window size used to calculate coherence (7x7)

-fnr and fnc refer to number of rows and cols from config.txt file

-lf are flags to indicate the desired output files (alpha, entropy, lambda)

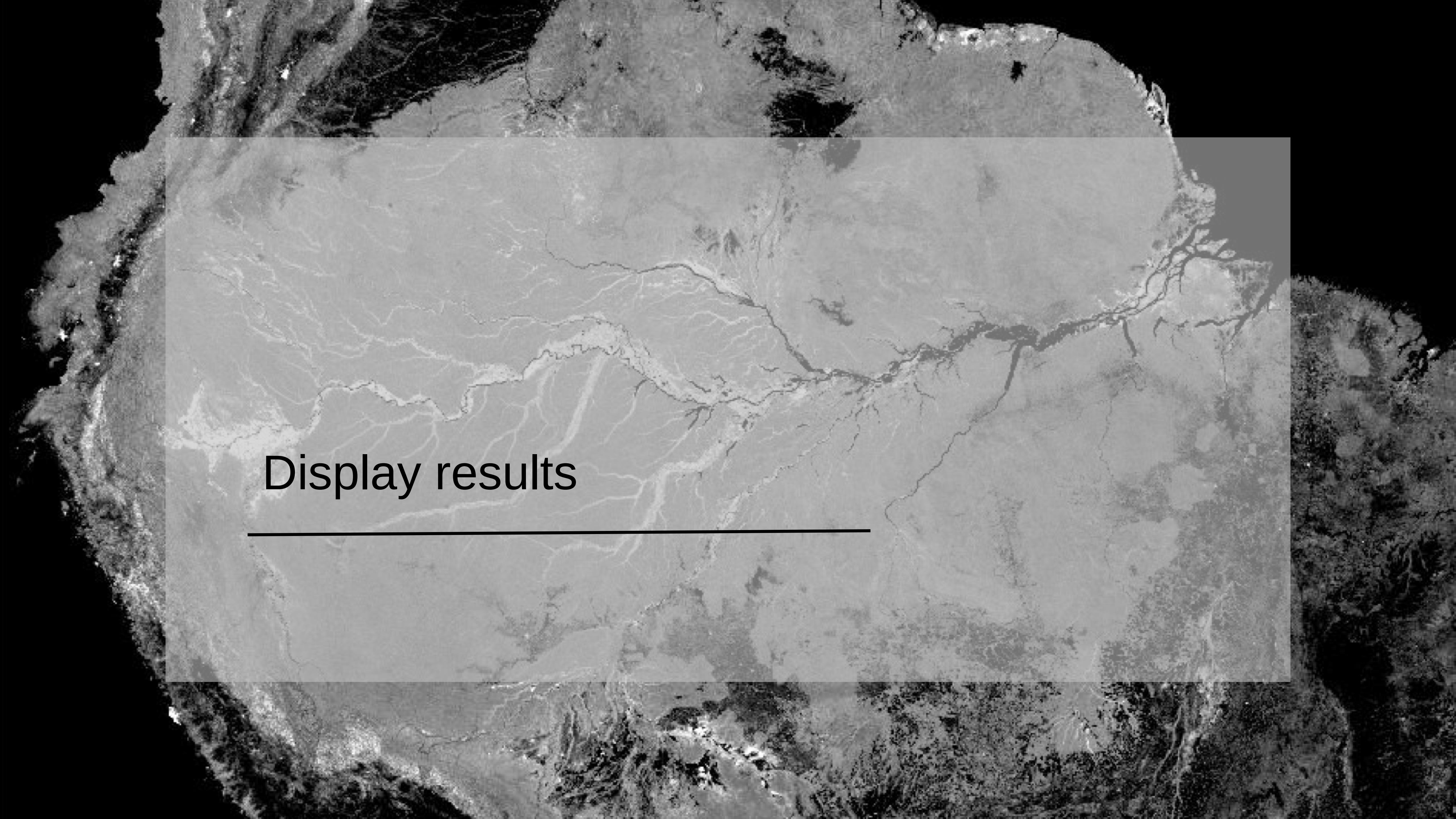
```
h_a_alpha_planes_classifier.exe -id decomposition -od classification -ofr 0 -ofc 0 -fnr 1875 -fnc 6309 -hal 1 -han 0
-anal 0 -clm Planes_H_A_Alpha_ColorMap9.pal
```

-od is the output directory, I'm calling it 'classification'

Make an ENVI header

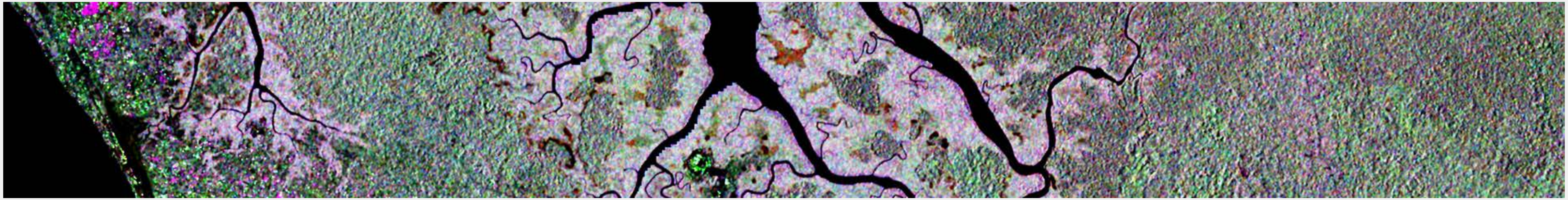
ENVIdescription = { File Imported into ENVI.}
samples = 6309
lines   = 1875
bands   = 1
header offset = 0
file type = ENVI Standard
data type = 4
interleave = bsq
sensor type = Unknown
byte order = 0
map info = {Geographic Lat/Lon, 1.5000, 1.5000, **9.17956764, 0.60482616**, **1.1112000000e-04, 1.1112000000e-04**, WGS-84, units=Degrees}coordinate system string = {GEOGCS["GCS_WGS_1984",DATUM["D_WGS_1984",SPHEROID["WGS_1984",6378137.0,298.257223563]],PRIMEM["Greenwich",0.0],UNIT["Degree",0.0174532925199433]]}
wavelength units = Unknown

- From PolSARPro config.txt file:
  - Nrow
  - Ncol
- From UAVSAR annotation file:
  - Center Latitude of Upper Left Pixel of Image
  - Center Longitude of Upper Left Pixel of Image
  - Multiply GRD Latitude Pixel Spacing by 2 since we took 2 looks: 0.00005556 *2 = 0.0011112

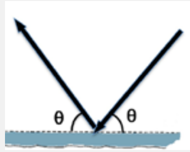


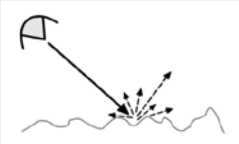
Display results

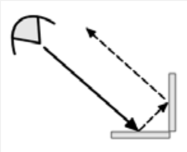
Sentinel

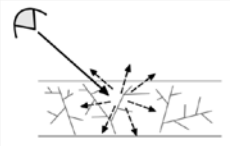


VV VH VV

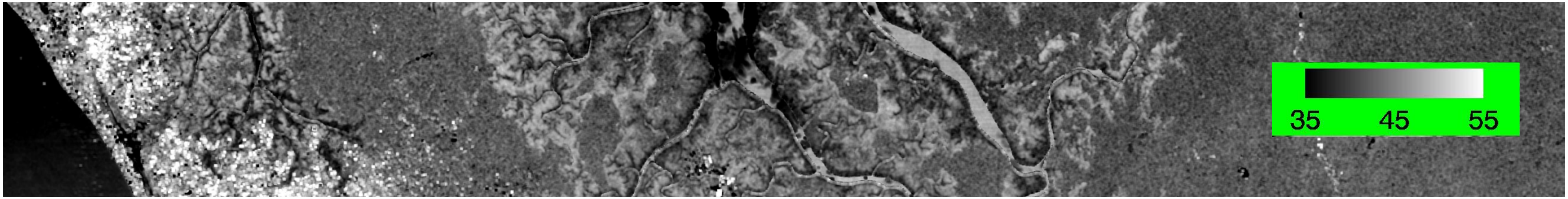


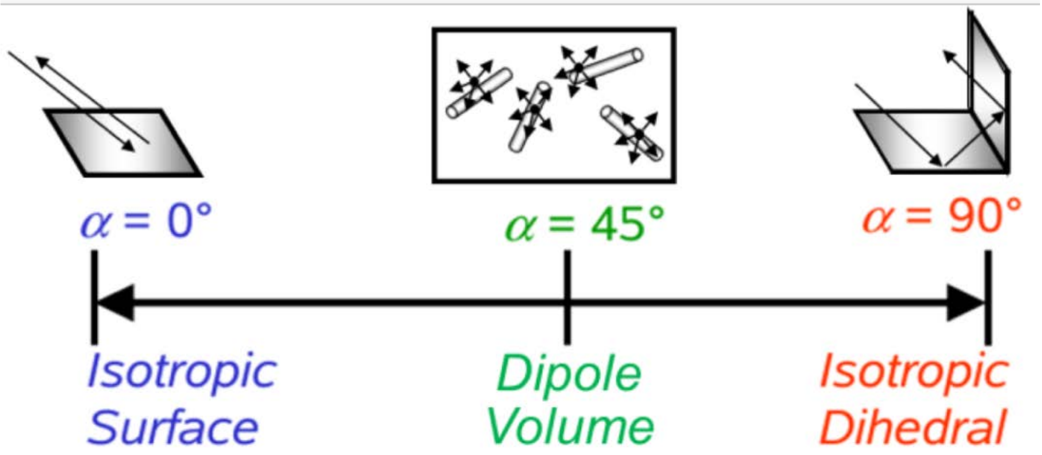




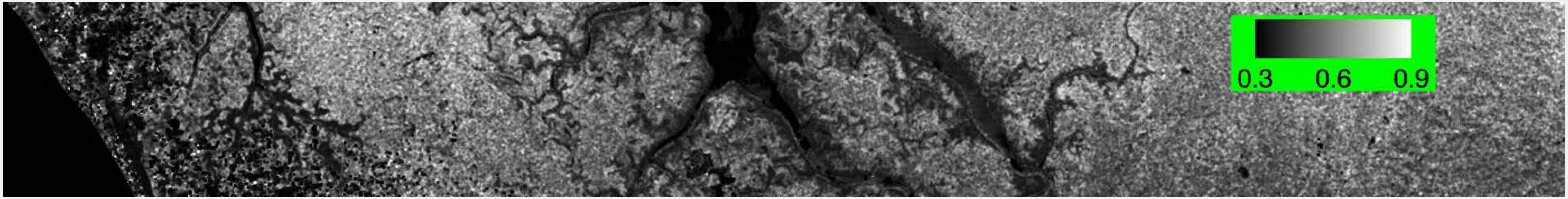


	specular	surface	double bounce	volume	
dB	Open Water	Runway	Buildings	Forest	Tall mangrove
VV Mar 20	-16.0	-11.7	-0.5	-4.5	-4.2
VH Mean (Mar 20, 08)	-19.5	-16.5	-13	-10.9	-11.9
VV Mar 08	-17.0	-12.6	-0.5	-5.6	-4.3



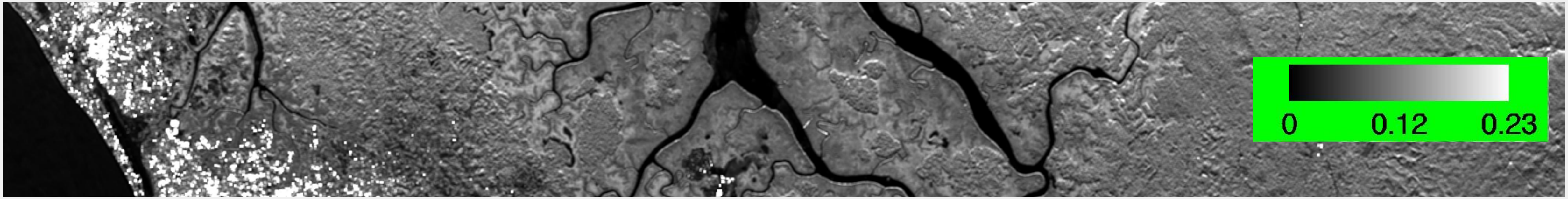


	Open Water	Runway	Buildings	Forest	Tall mangrove
Alpha (α)	36	29	55	42	46
Entropy (H)					
Lambda					



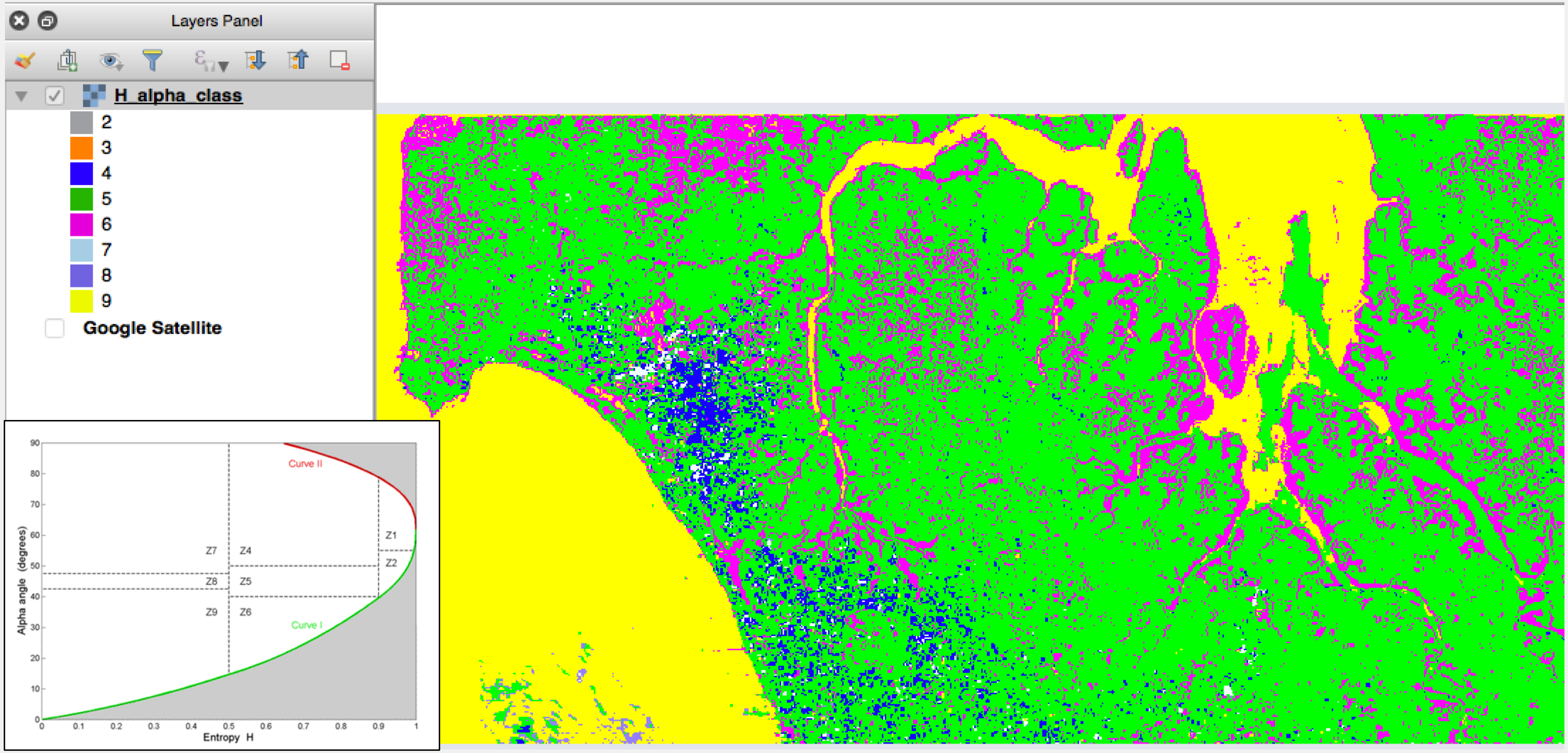
Low entropy $0 < H < 1$ High entropy

	Open Water	Runway	Buildings	Forest	Tall mangrove
Alpha (α)	36	29	55	42	46
Entropy (H)	0.15	0.67	0.45	0.89	0.79
Lambda					



	Open Water	Runway	Buildings	Forest	Tall mangrove
Alpha (α)	36	29	55	42	46
Entropy (H)	0.15	0.67	0.45	0.89	0.79
Lambda	0.009	0.007	0.55	0.085	0.067

Entropy + Alpha



Additional Resources

- Land Remote Sensing course from the European Space Agency.

http://seom.esa.int/landtraining2014/files/LTC2014_Programme_Materials.pdf

- Polarimetry tutorials accompanying PolSARPro:

https://earth.esa.int/web/polsarpro/polarimetry-tutorial

- Natural Resources Canada tutorial:

http://www.nrcan.gc.ca/node/9579


Thank you!