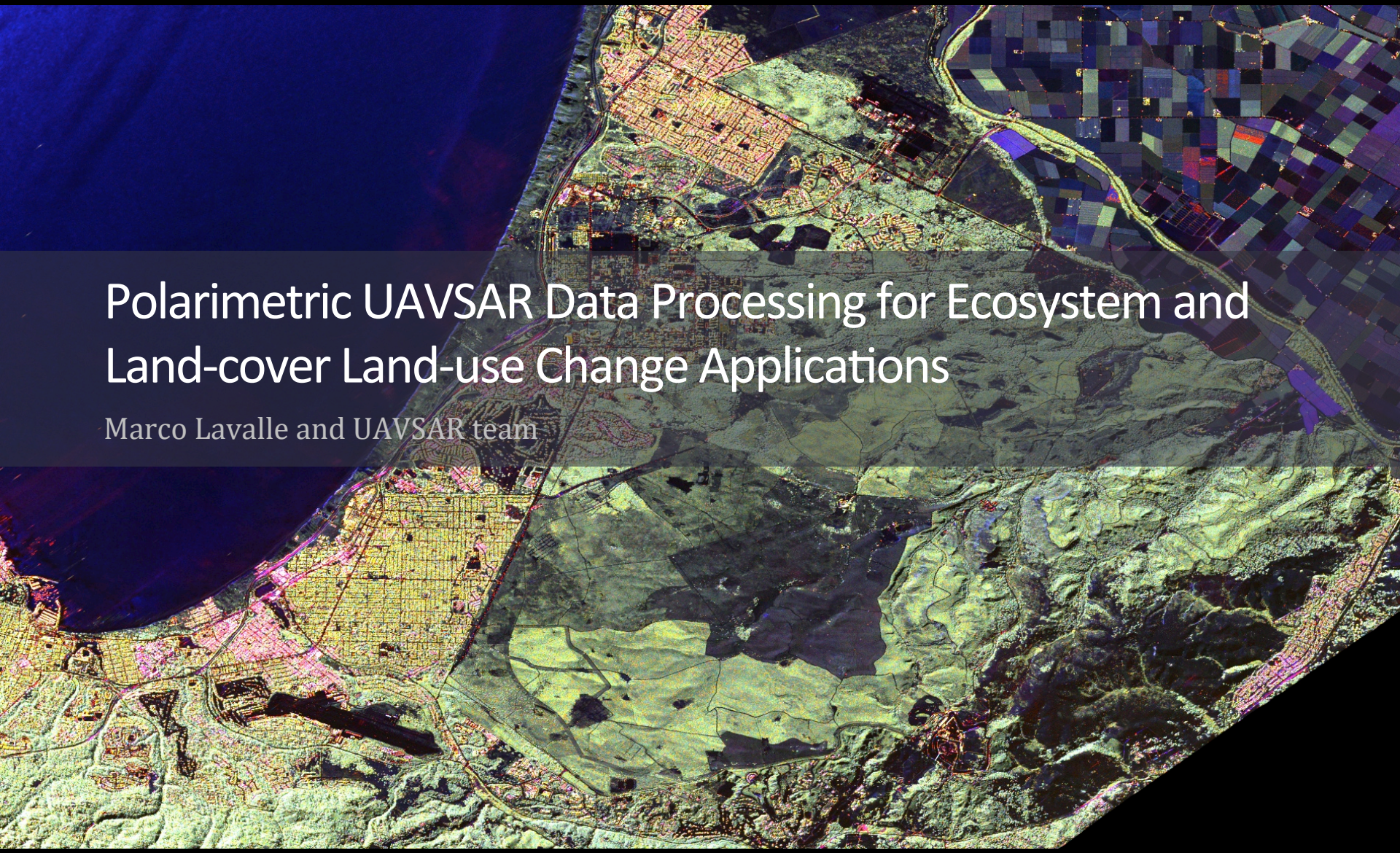


Polarimetric UAVSAR Data Processing for Ecosystem and Land-cover Land-use Change Applications

Marco Lavalle and UAVSAR team

October 16, 2015 • Jet Propulsion Laboratory, California Institute of Technology

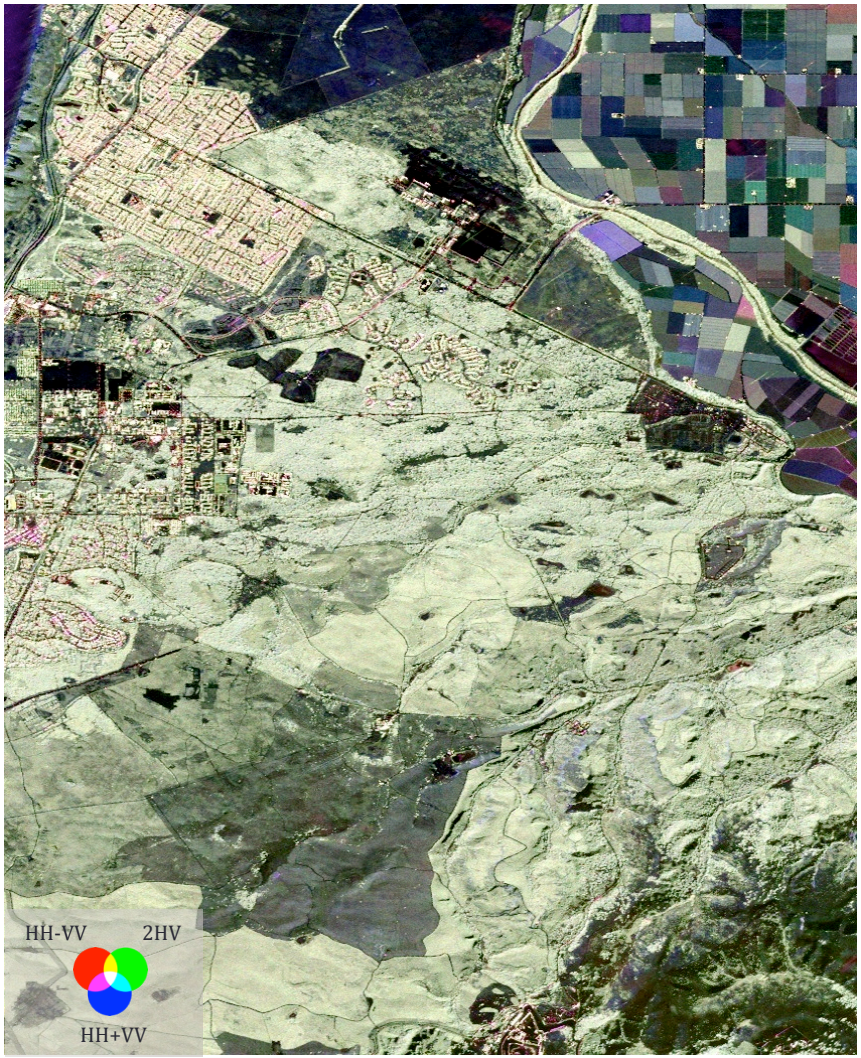
Outline

- Why polarimetry / Why UAVSAR
- Scattering matrix and covariance matrix
- Tools for polarimetric data processing and analysis
  - PolSARPro – European Space Agency
  - ISCE-PLAnT – Jet Propulsion Laboratory
- Exercise 1: Fire scar detection, Station Fire (CA), 2009
- Exercise 2: Segmentation, Monterey area (CA), 2012

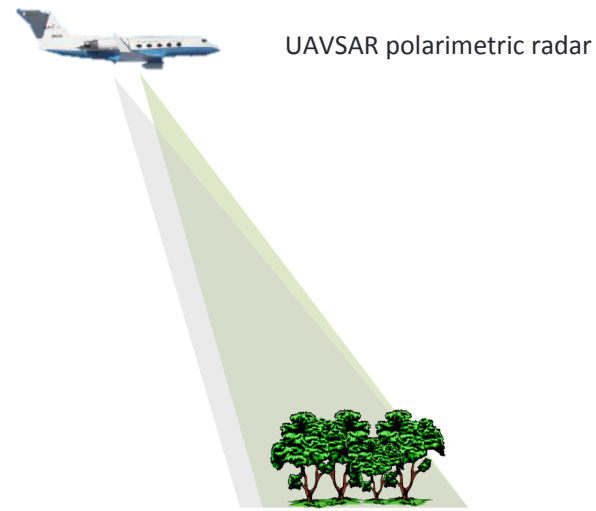
Why Polarimetry / Why UAVSAR

- Why Polarimetry
  - Sensitive to target structure
  - Useful for complex natural media
  - Full coherent information of electromagnetic waves
  - Extension of observation space
  - All recent spaceborne radars have polarimetry: ALOS-1/2, Sentinel-1, TerraSAR-X, BIOMASS, RISAT, NISAR, etc.

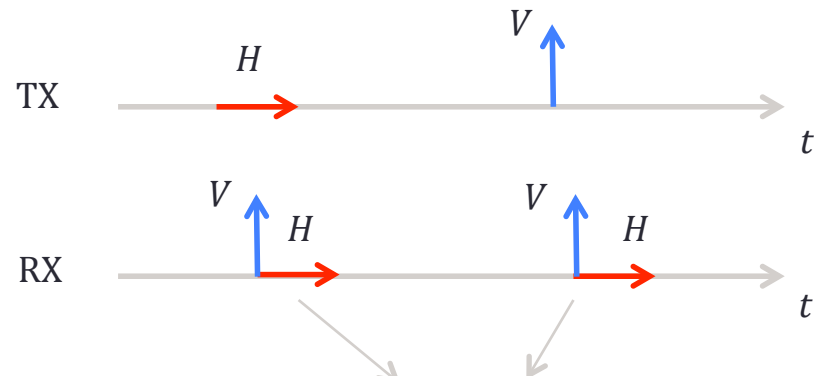
- Why UAVSAR
  - High resolution and large coverage
  - Well-calibrated polarimetric instrument
  - Ideal for algorithm testing
  - Easy to access data and plan acquisitions
  - 115 TB of polarimetric UAVSAR data over 15+ countries around the world



Polarimetric scattering matrix



- Radar transmits alternatively H and V polarized waves
- Radar receives simultaneously H and V
- Received signals are processed to form the scattering matrix → UAVSAR SLC data
- Scattering matrix is calibrated to remove distortions caused by cross-talk and channel imbalance
- Complex Gaussian distribution
- Scattering matrix contains information about the structure of the imaged target



$$\begin{pmatrix} E_H^s \\ E_V^s \end{pmatrix} = \frac{e^{-j\beta r}}{r} \underbrace{\begin{pmatrix} S_{HH} & S_{HV} \\ S_{VH} & S_{VV} \end{pmatrix}}_{\text{scattering matrix [S] → UAVSAR SLC data}} \begin{pmatrix} E_H^i \\ E_V^i \end{pmatrix}$$

Polarimetric covariance and coherency matrices

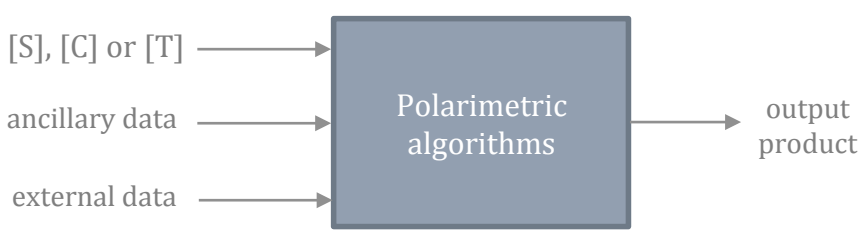
- Scattering vector formulation
- Complex correlation of scattering vectors (second-order statistics)
- 4 × 4 in the general case, 3 × 3 in monostatic and target reciprocity cases
- Depolarization effects
- Suitable to study distributed targets
- Statistical Wishart distribution
- Output of speckle filter or multi-look operation

$$\begin{pmatrix} S_{HH} & S_{HV} \\ S_{VH} & S_{VV} \end{pmatrix} \longrightarrow k = \begin{pmatrix} S_{HH} \\ \sqrt{2}S_{HV} \\ S_{VV} \end{pmatrix}$$

canonical scattering vector

$$[C] = \frac{1}{N}\sum_{i}^{N} k_i k_i^H = \begin{pmatrix} \langle |S_{HH}|^2 \rangle & \sqrt{2}\langle S_{HH}S_{HV}^* \rangle & \langle S_{HH}S_{VV}^* \rangle \\ \sqrt{2}\langle S_{HV}S_{HH}^* \rangle & 2\langle |S_{HV}|^2 \rangle & \sqrt{2}\langle S_{HV}S_{VV}^* \rangle \\ \langle S_{VV}S_{HH}^* \rangle & \sqrt{2}\langle S_{VV}S_{HV}^* \rangle & \langle |S_{VV}|^2 \rangle \end{pmatrix}$$

covariance matrix → UAVSAR MLC/GRD data



$$k_P = \frac{1}{\sqrt{2}} \begin{pmatrix} S_{HH} + S_{VV} \\ S_{HH} - S_{VV} \\ 2S_{HV} \end{pmatrix}$$

Pauli scattering vector

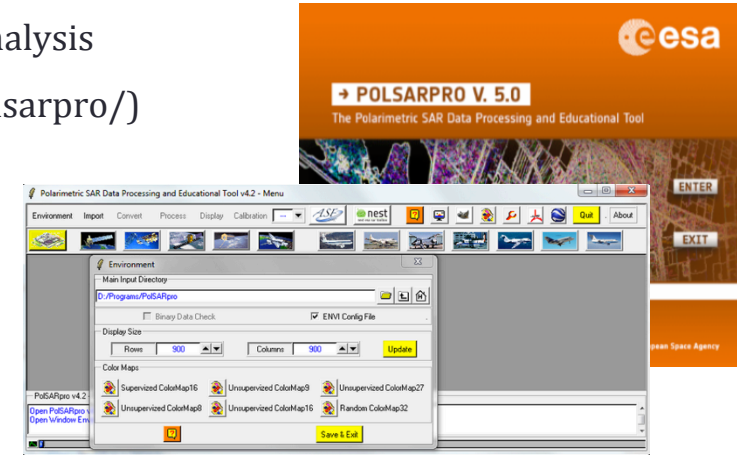
$$[T] = \frac{1}{N}\sum_{i}^{N} k_{P_i} k_{P_i}^H$$

number of looks

coherency matrix

The PolSARPro Tool

- Software package for polarimetric radar data processing and analysis
- Distributed by the European Space Agency (earth.eo.esa.int/polsarpro/)
- Airborne and spaceborne radar data
- Both GUI and command line interfaces
- Support for UAVSAR SLC, MLC and GRD data formats
- Content of the PolSARPro v4.2 folder Soft/:



Scattering simulators

```
PolSARproSIM
PolSARproSIMgr
PolSARproSIMsv
SVM
basis_change
bmp_process
calculator
calibration
data_convert
data_import
data_process_dual
data_process_mult
data_process_sngl
lib
speckle_filter
tools
```

Synthesis of polarimetric states

Polarimetric calibration

Conversions between matrix types

Import data into PolSARPro format

Polarimetric decompositions and various algorithms

Tools to reduce speckle noise

Image tools, conversion of data formats, etc.

PolSARPro v4 versus v5

- Additional algorithms and sensor support
- Change in the routine interface
- Some routines have been rewritten and merged in a single executable

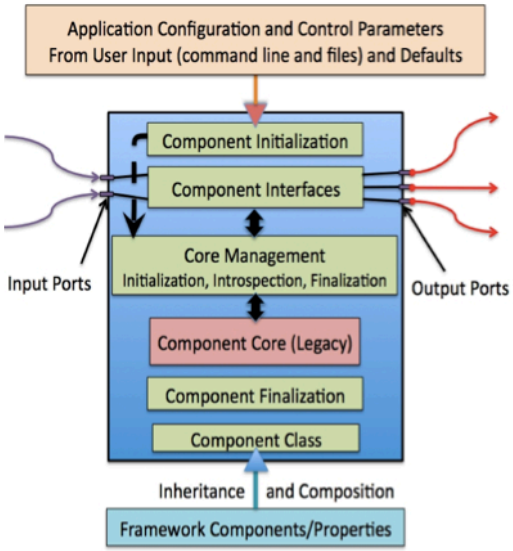
PolSARPro v4.2.0

```
h_a_alpha_decomposition_T3 in_dir out_dir Nwin offset_lig offset_col
sub_nlig sub_ncol alpbetdelgam lambda alpha entropy anisotropy CombHA
CombH1mA Comb1mHA Comb1mH1mA

h_a_alpha_decomposition_C3 in_dir out_dir Nwin offset_lig offset_col
sub_nlig sub_ncol alpbetdelgam lambda alpha entropy anisotropy CombHA
CombH1mA Comb1mHA Comb1mH1mA
```

PolSARPro v5.0.3

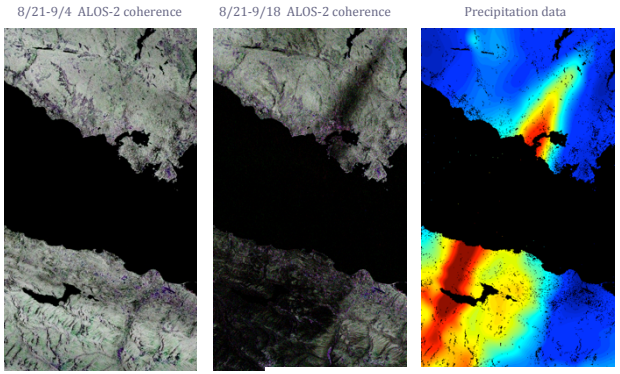
```
h_a_alpha_decomposition.exe

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
 (int)         -fl1    Flag Parameters (0/1)
 (int)         -fl2    Flag Lambda (0/1)
 (int)         -fl3    Flag Alpha (0/1)
 (int)         -fl4    Flag Entropy (0/1)
 (int)         -fl5    Flag Anisotropy (0/1)
 (int)         -fl6    Flag Comb HA (0/1)
 (int)         -fl7    Flag Comb H1mA (0/1)
 (int)         -fl8    Flag Comb 1mHA (0/1)
 (int)         -fl9    Flag Comb 1mH1mA (0/1)

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
```

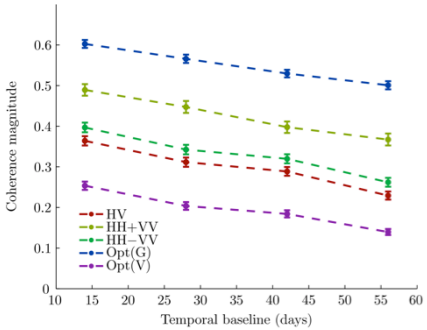
The PLAnT tool within ISCE

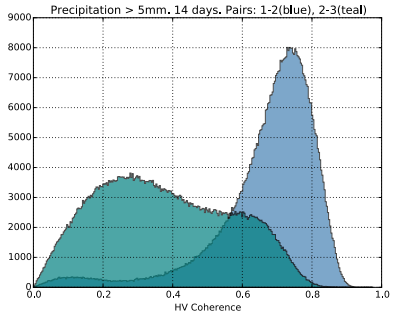


- ISCE: Interferometric Scientific Computing Environment
  - Python interface and data structures
  - C/Fortran core routines
  - RAW/SLC input data from spaceborne and airborne sensors
  - Flexible for building applications and custom workflows
  - XML-based user interface
  - Precise and efficient handling of platform geometry
  - winsar.unavco.org/isce.html

- PLAnT: Polarimetric-Interferometric Lab and Analysis Tool
  - Set of tools for polarimetric and PolInSAR data processing and analysis
  - Focus on ecosystem and land-cover/land-use change applications
  - Polarimetric time series analysis and visualization
  - ISCE framework and geometry support
  - Generation of image mosaic for regional/global applications
  - Seamless integration with other data such as lidar



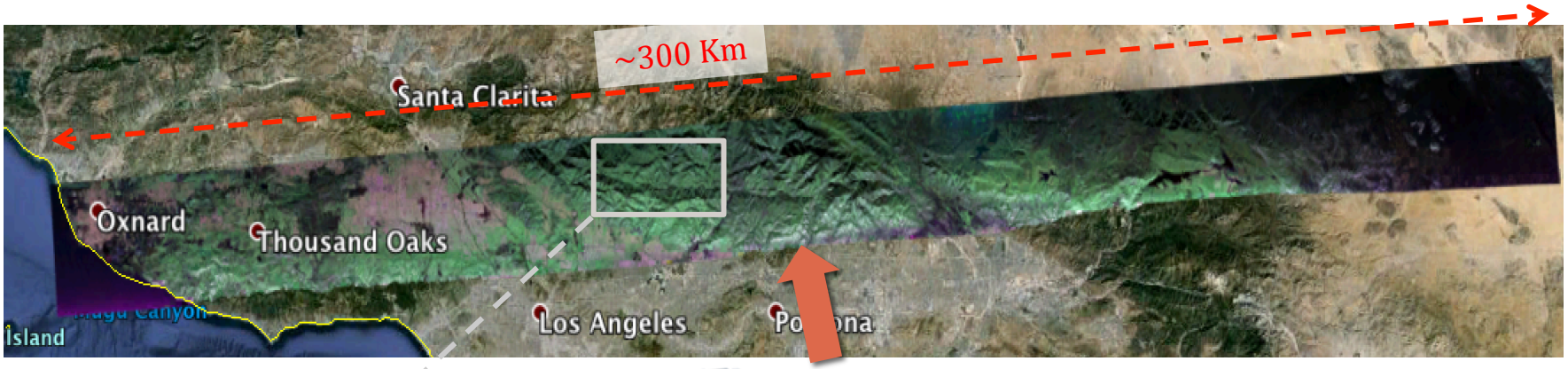




Exercise 1: Fire scar detection

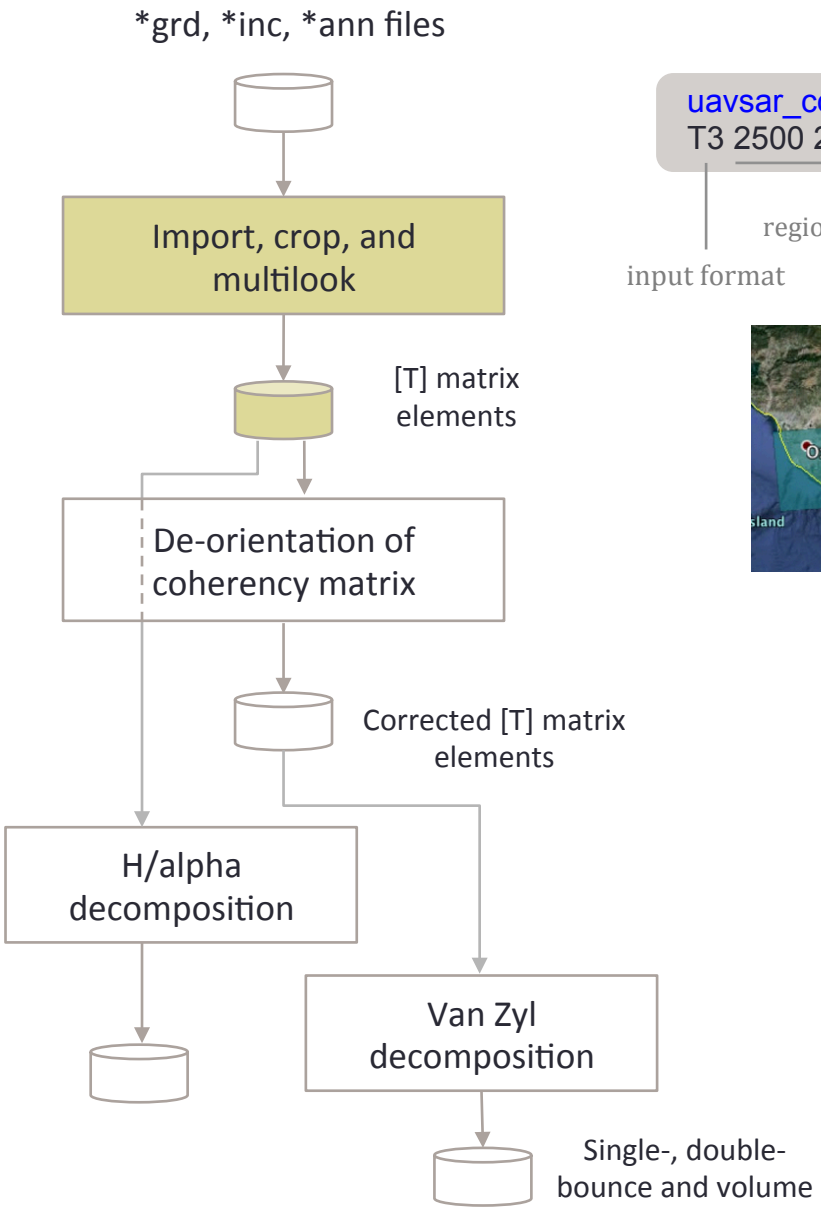
UAVSAR pre-fire GRD image (6m posting) : February 26, 2009
UAVSAR post-fire GRD image (6m posting) : September 18, 2009

Max extension of Station Fire



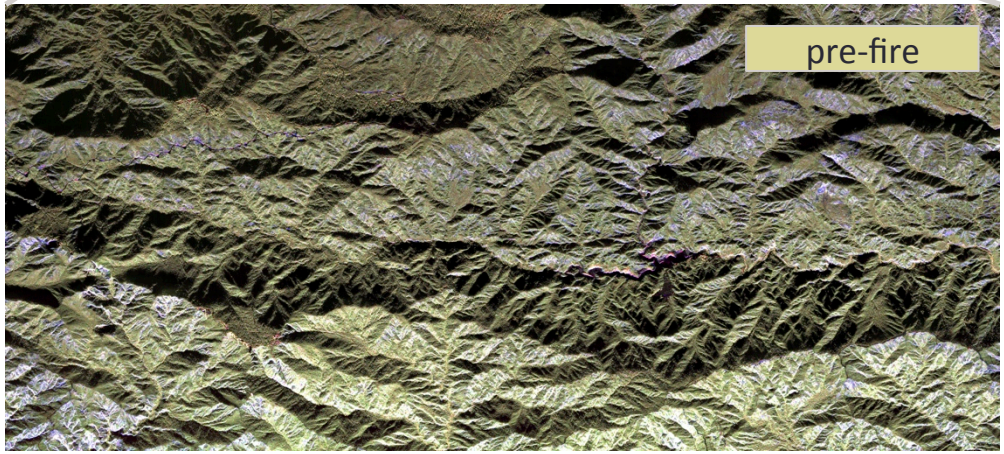
Region of interest

Exercise 1: Fire scar detection

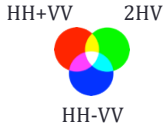



```
uavsar_convert_grd_MLK_T3.exe flight_09010/*annflight_09010 output_09010/
T3 2500 21000 1800 4000 2 2
```

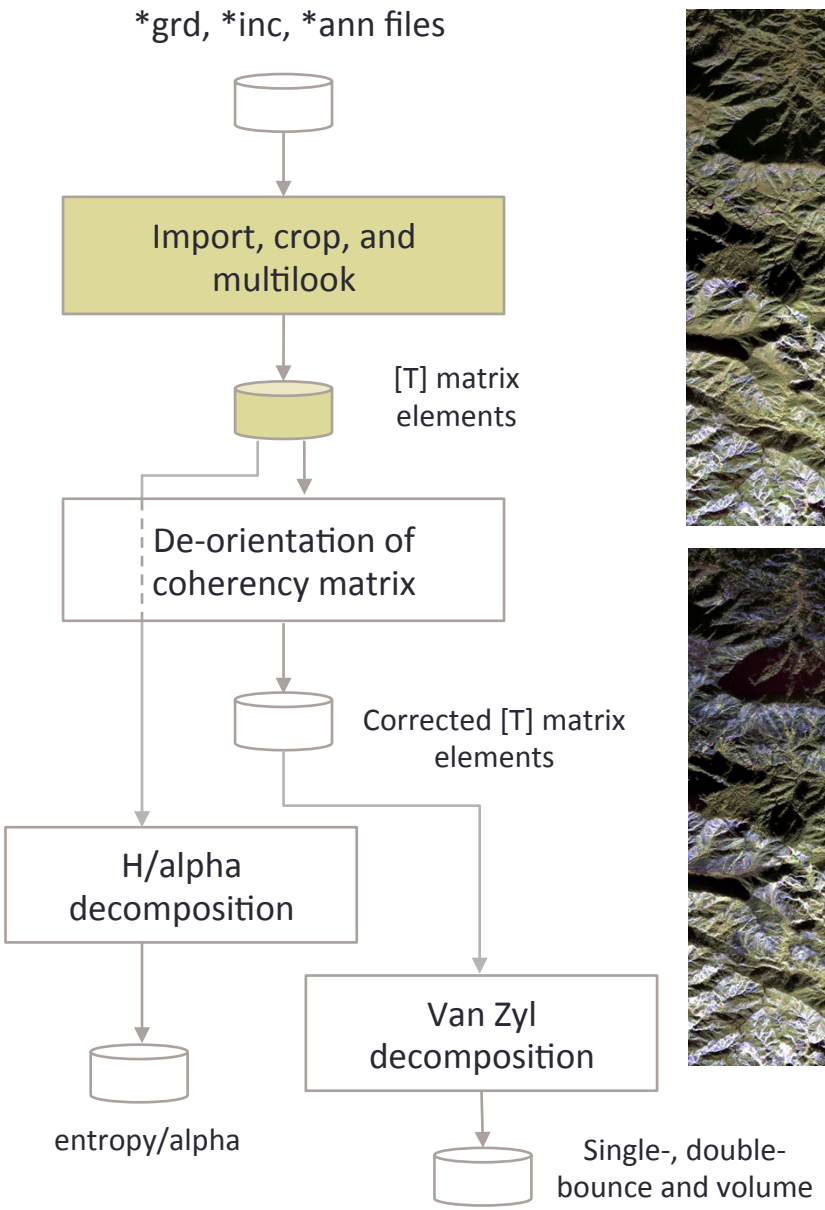
input format | region to be cropped | multilook factors | I/O folders

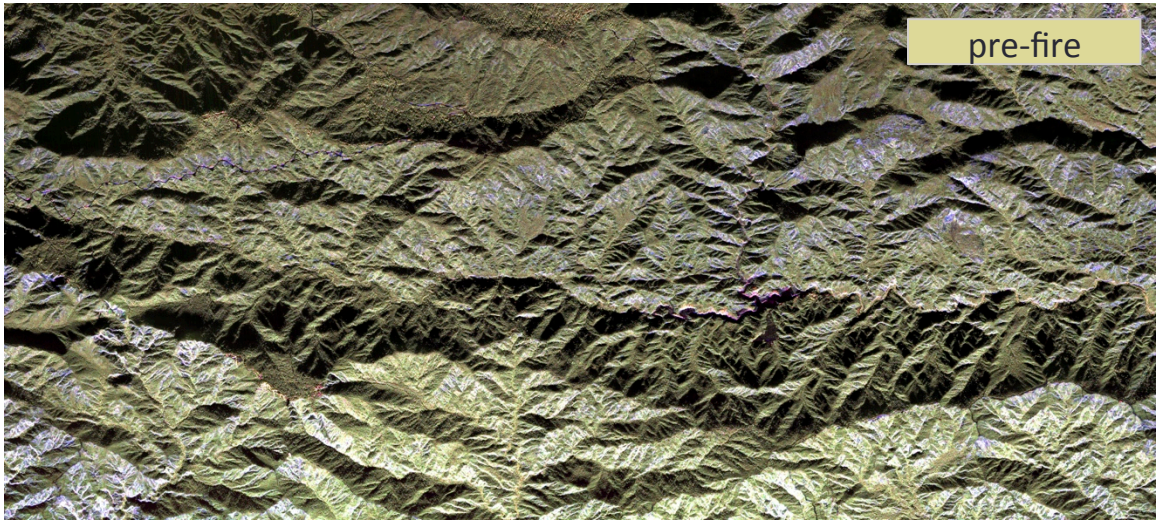


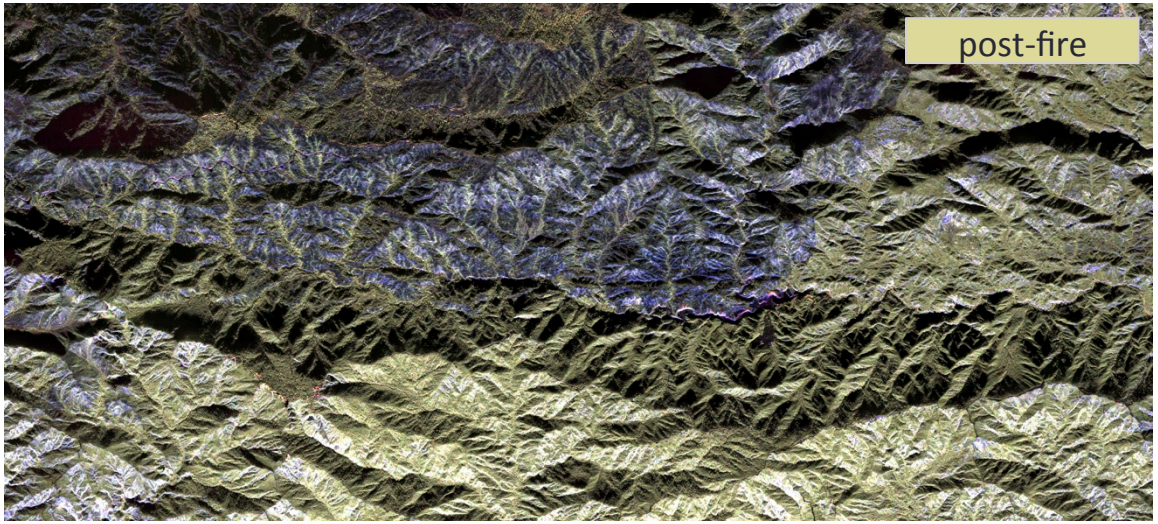
What does the post-fire look like?



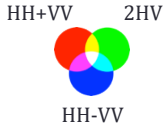
Exercise 1: Fire scar detection





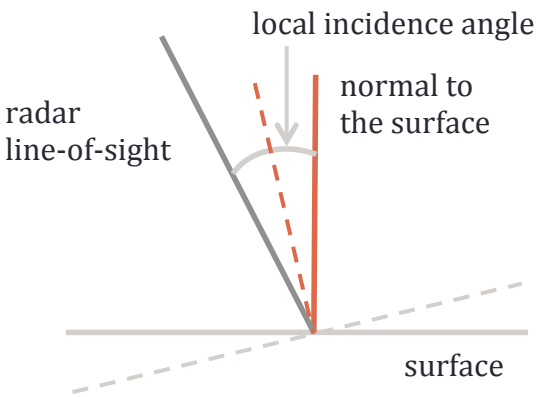


What is the posting of the imported images?

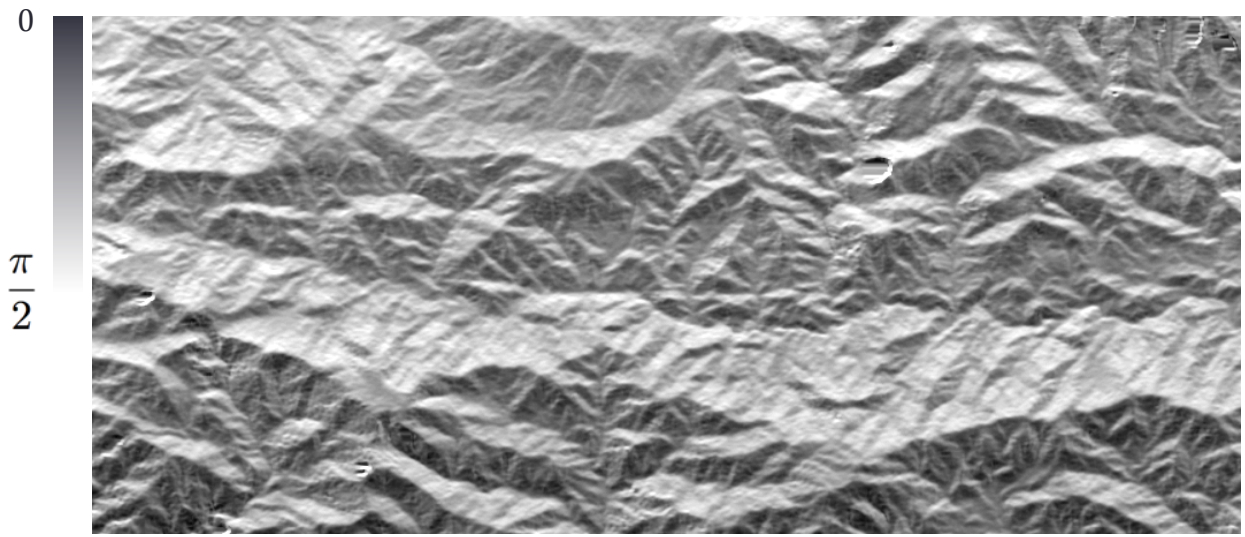


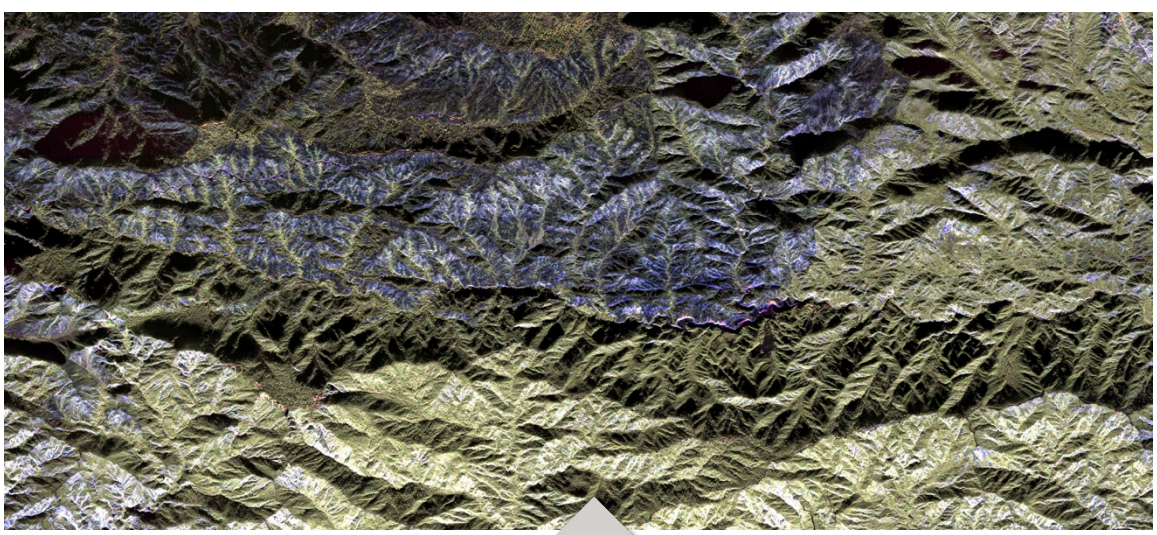
Exercise 1: Fire scar detection

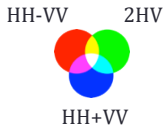
Maps of local incidence and DEM are also provided with GRD data:



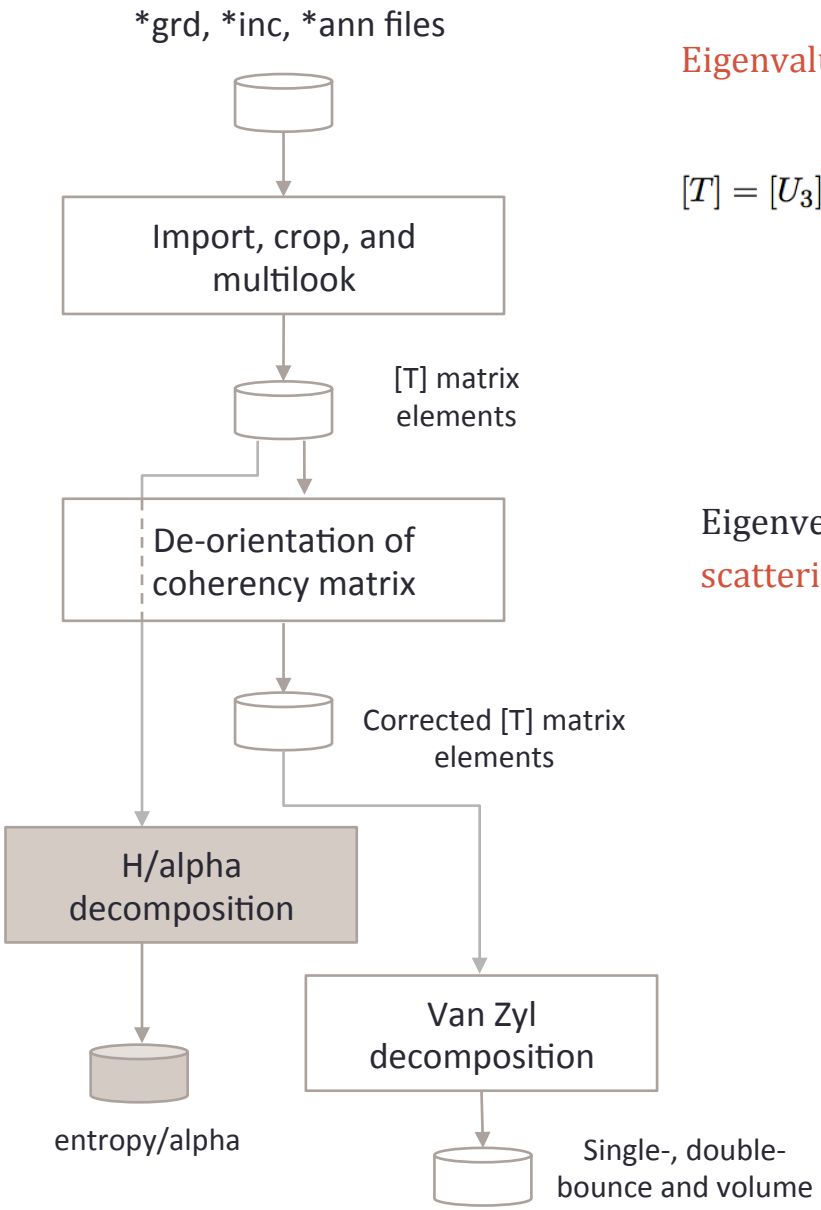
Display example using MDX:
> mdx –s 2000 inc.bin







Exercise 1: Fire scar detection



Eigenvalues/eigenvector or H/A/alpha decomposition

$$[T] = [U_3][\Sigma][U_3]^{-1} = \begin{pmatrix} u_1 & u_2 & u_3 \end{pmatrix} \begin{pmatrix} \lambda_1 & 0 & 0 \\ 0 & \lambda_2 & 0 \\ 0 & 0 & \lambda_3 \end{pmatrix} \begin{pmatrix} u_1 & u_2 & u_3 \end{pmatrix}^H$$

eigenvectors

eigenvalues $\lambda_1 > \lambda_2 > \lambda_3$

Eigenvectors represents independent scattering mechanisms

$$u_i = \begin{pmatrix} \cos\alpha_i \\ \sin\alpha_i \cos\beta_i e^{j\delta_i} \\ \sin\alpha_i \sin\beta_i e^{j\gamma_i} \end{pmatrix}$$

parameterized eigenvector

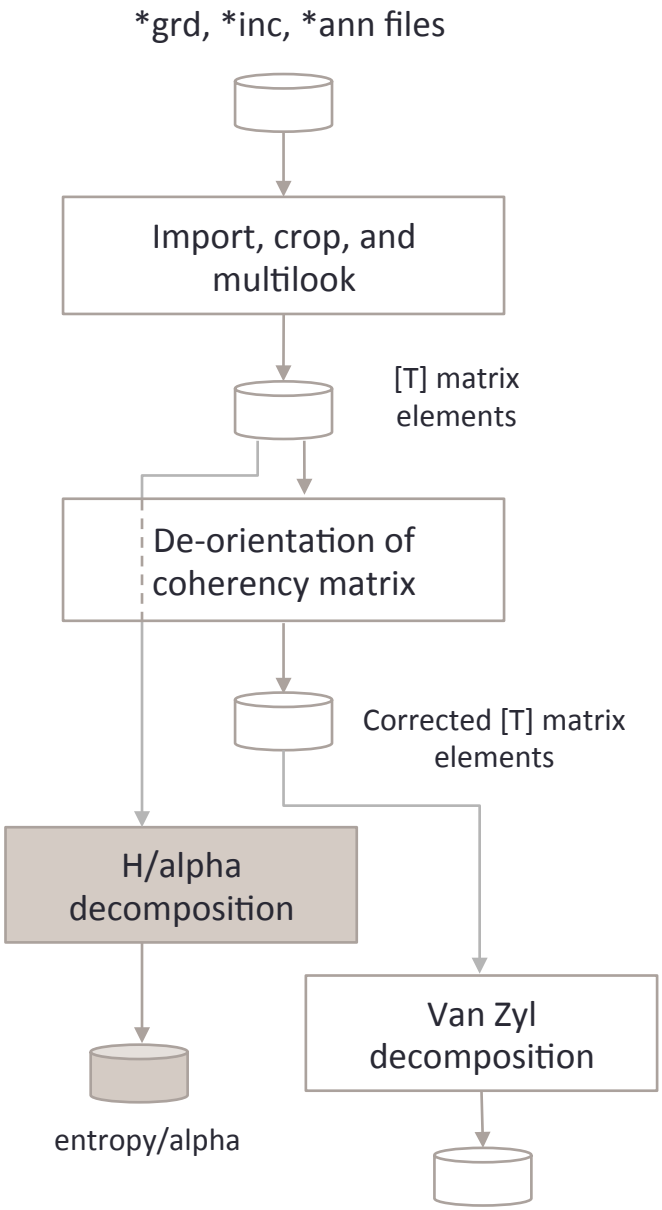
alpha: $\alpha = \sum_{i=1}^{3} p_i \alpha_i \quad 0 \le \alpha \le \frac{\pi}{2}$

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

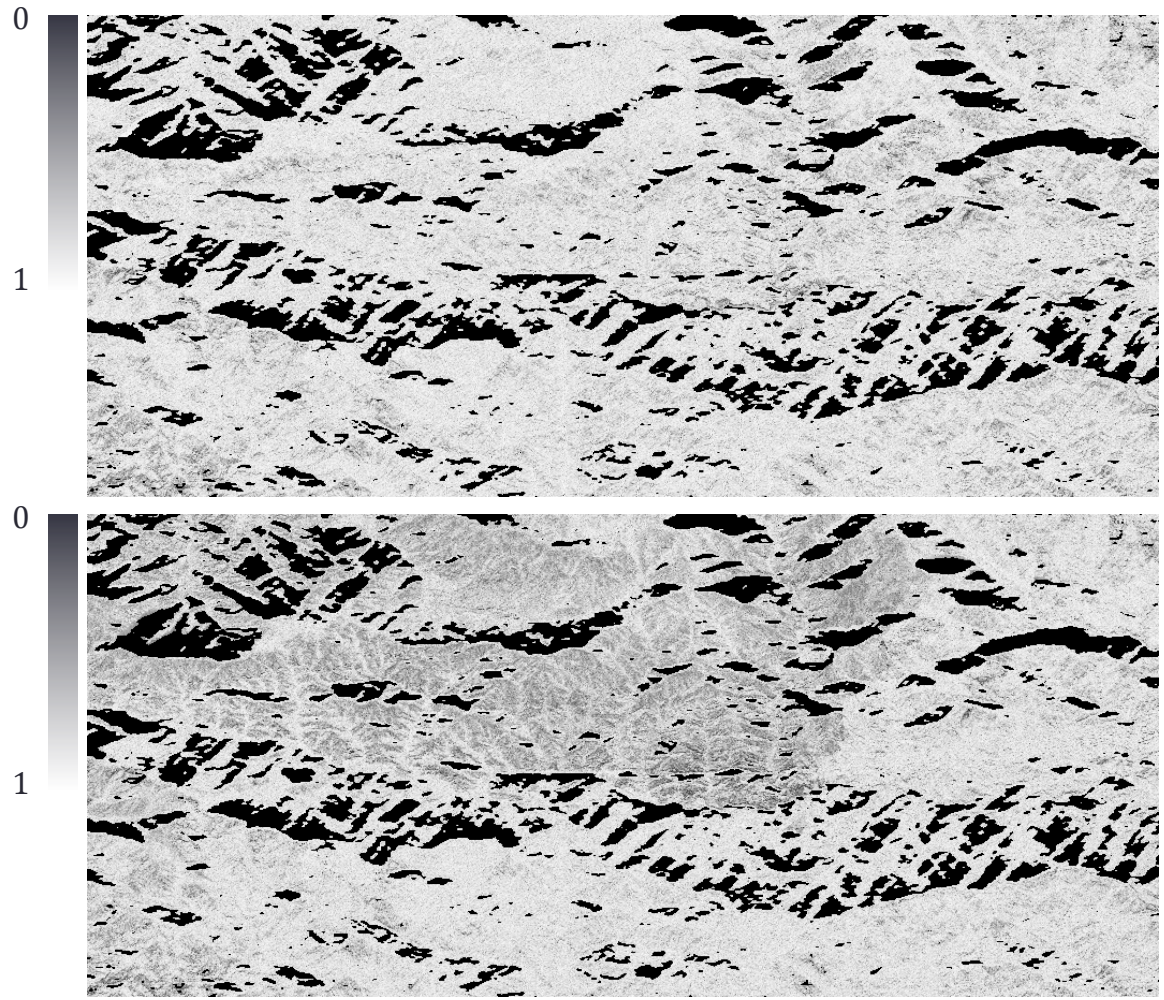
```
h_a_alpha_decomposition_T3.exeoutput_09010/T3_poa
output_09010/T3_poa 1 0 0 900 2000 0 0 1 1 1 0 0 0 0
```

S. R. Cloude and E. Pottier, "A review of target decomposition theorems in radar polarimetry," *IEEE Trans. Geosci. Remote Sensing*, vol. 34, pp. 498–518, Mar. 1996.

Exercise 1: Fire scar detection

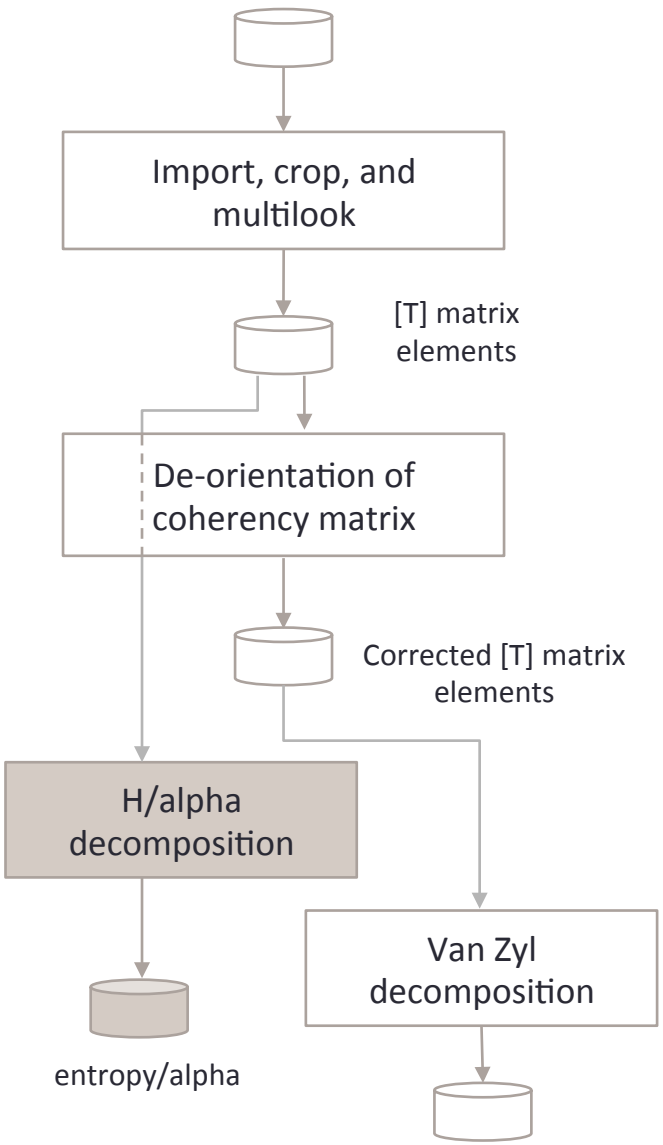


Entropy → depolarization (~ randomness of scattering mechanisms)



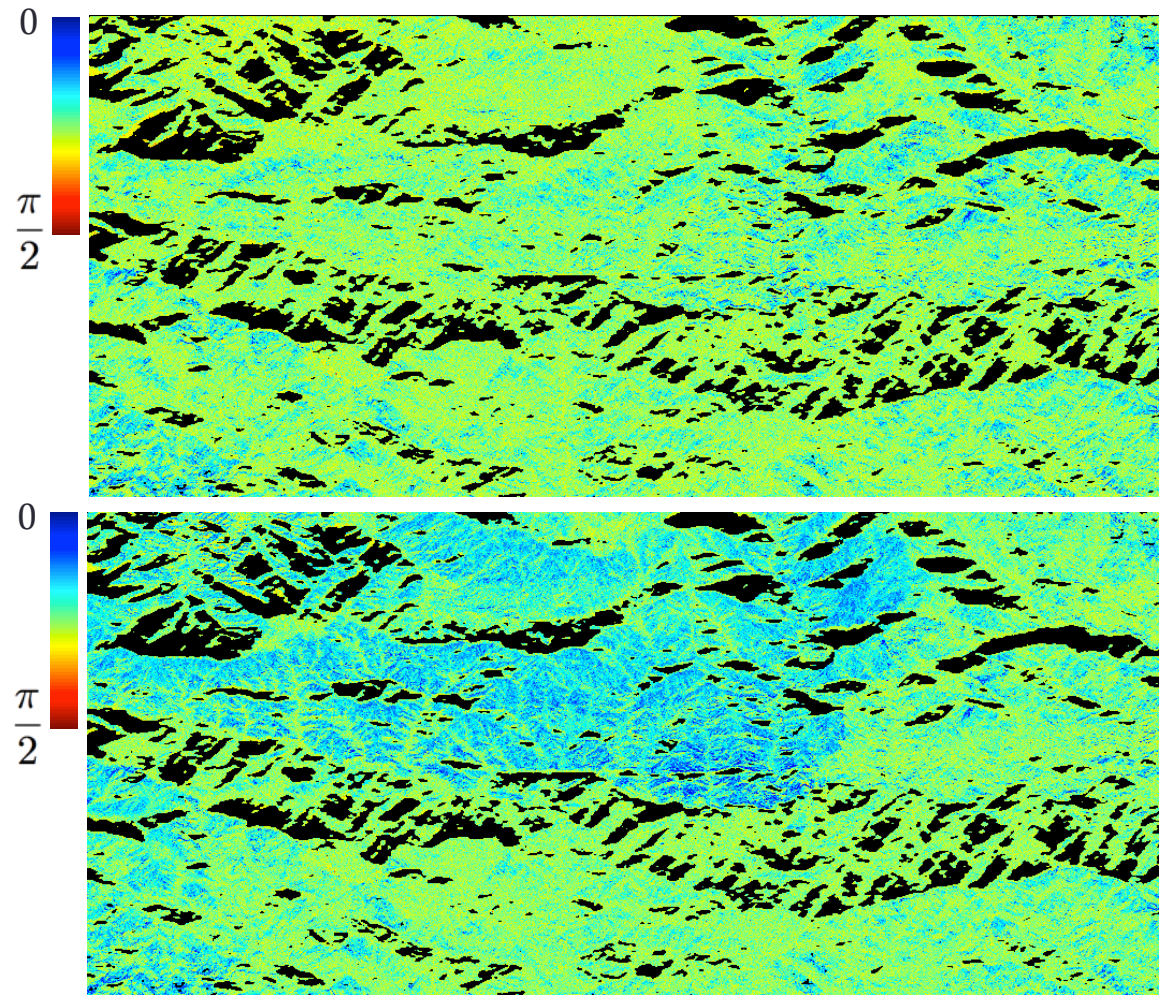
Exercise 1: Fire scar detection

*grd, *inc, *ann files



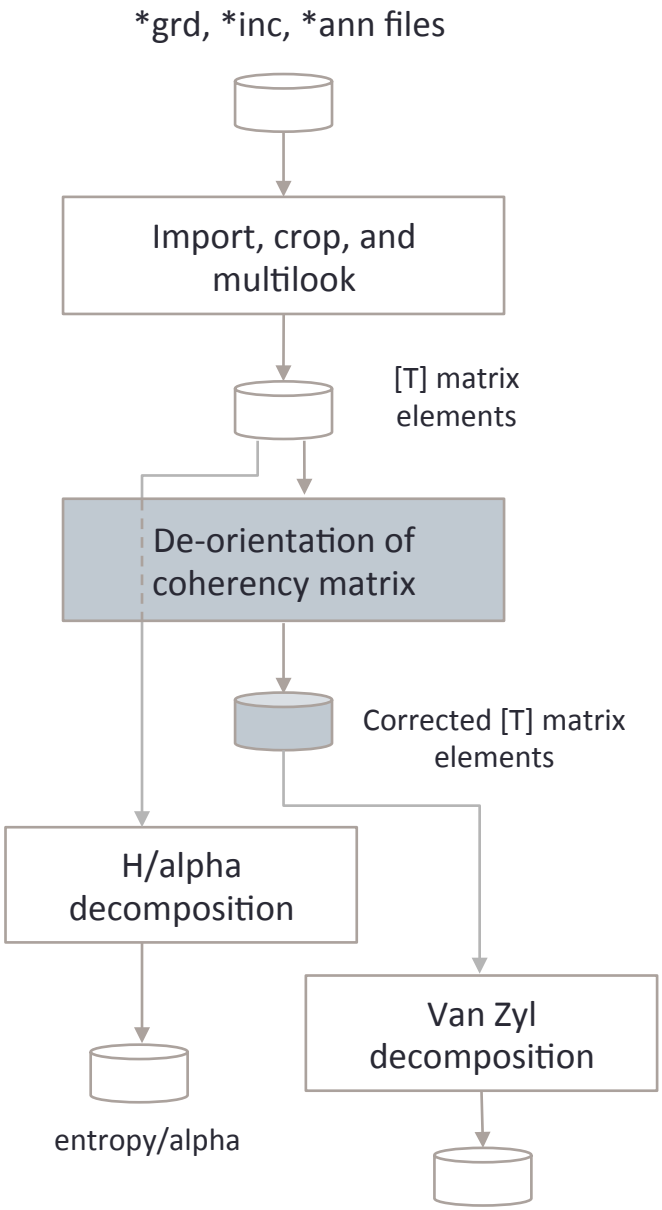
Alpha → scattering mechanism

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

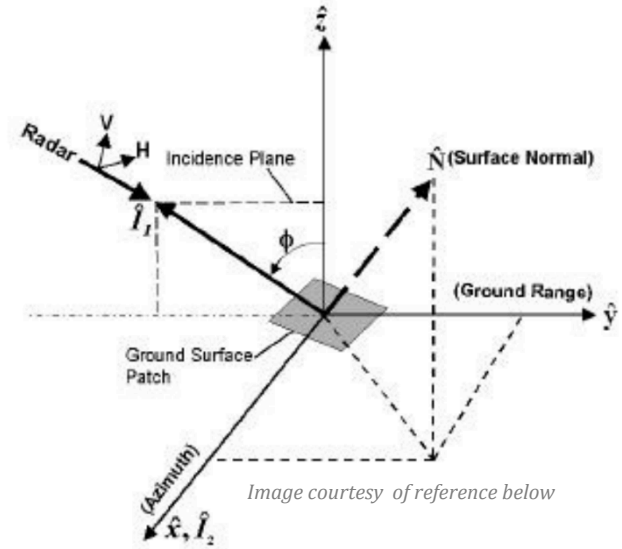


sphere	dipole	dihedral
$\alpha = 0$	$\alpha = \frac{\pi}{4}$	$\alpha = \frac{\pi}{2}$

Exercise 1: Fire scar detection



Correction of distortions cause by azimuth and range slopes



rotation of polarization plane

azimuth slope

$$\tan\theta = \frac{\tan\omega}{-\tan\gamma\cos\phi + \sin\phi}$$

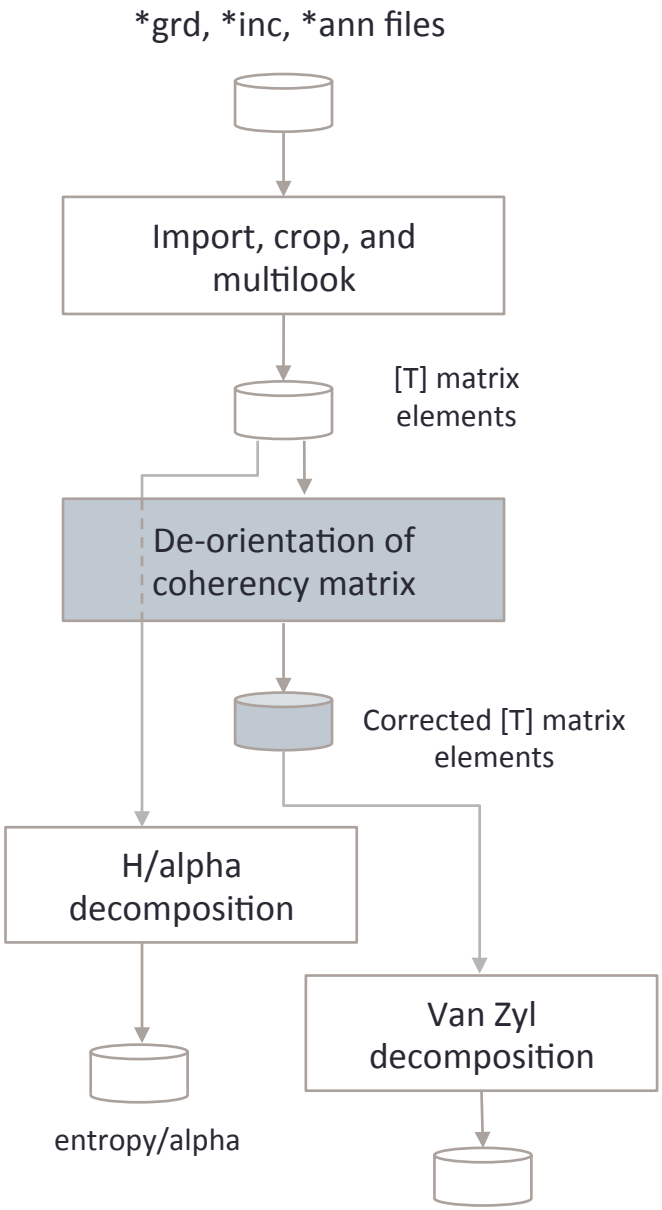
range slope

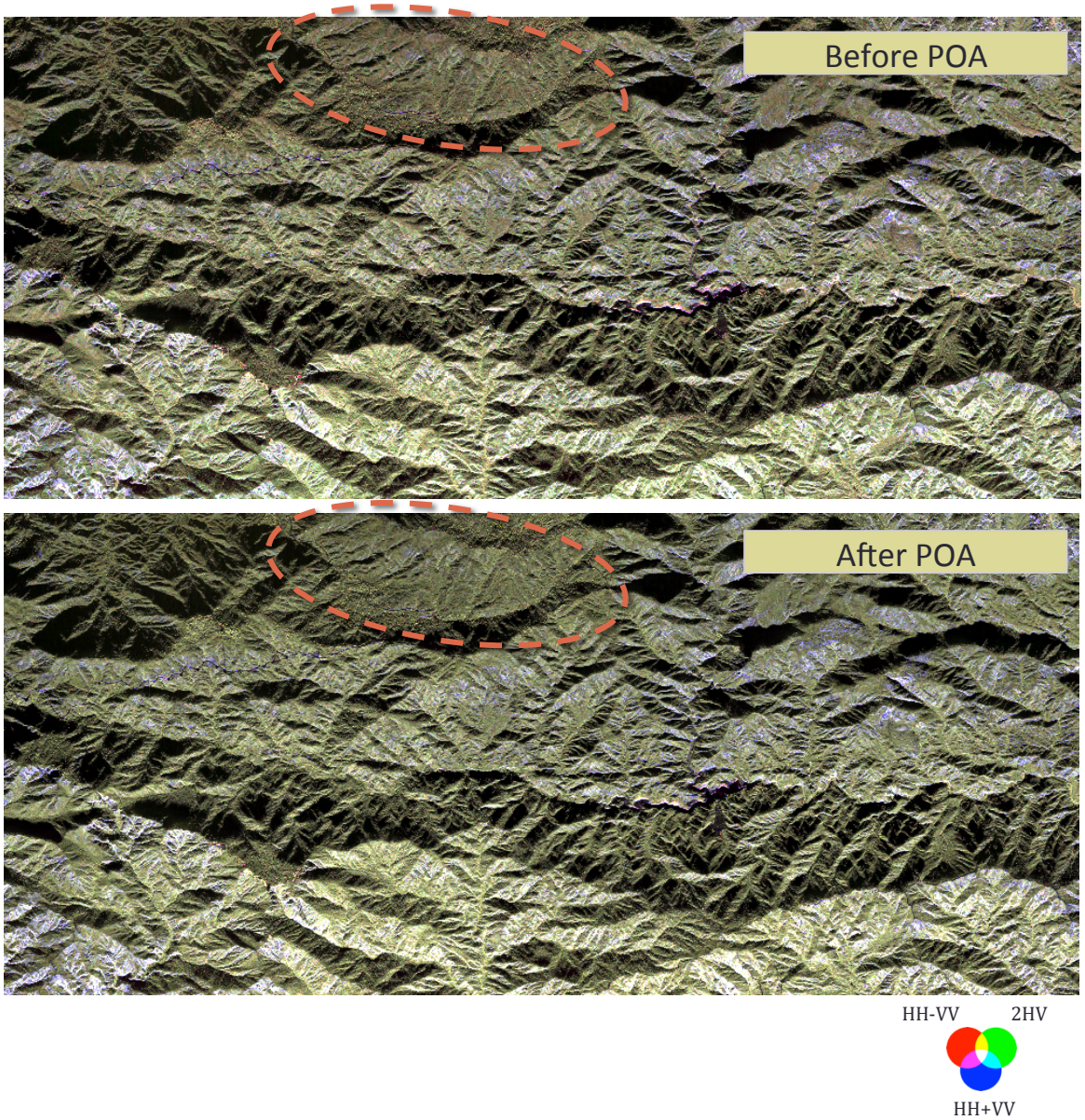
incidence angle

```
orientation_estimation_T3.exe output_09010/
T3output_09010/T3_poa 0 0 900 2000
```

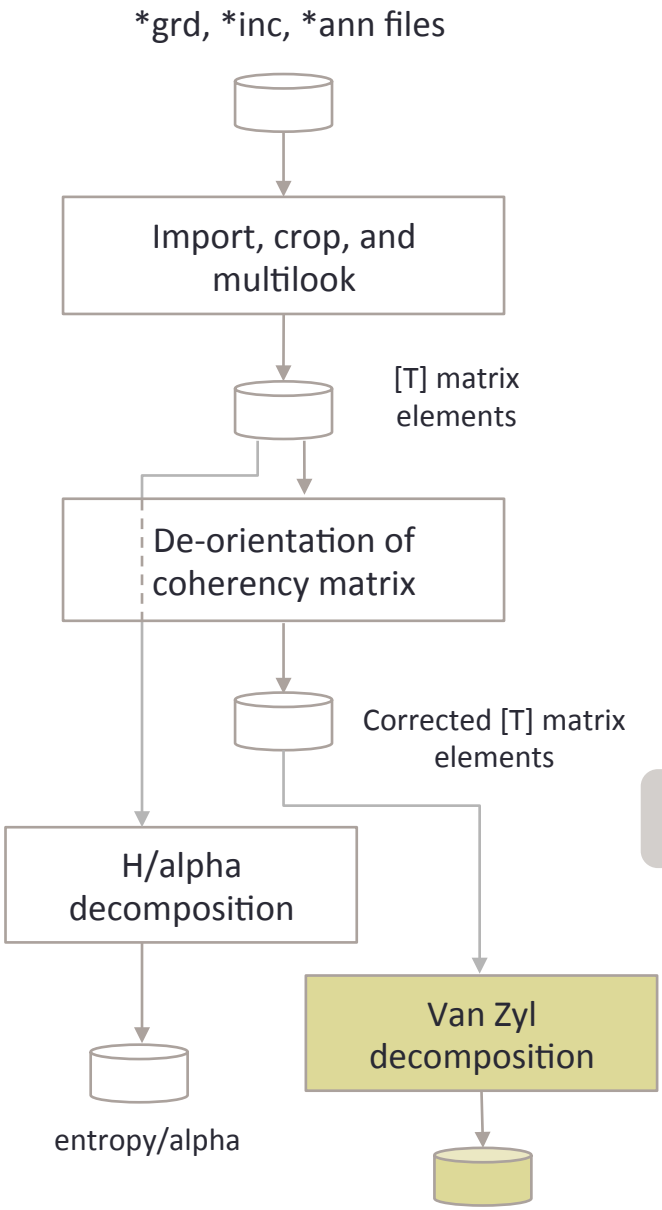
J. S. Lee, D. L. Schuler, and T. L. Ainsworth, "Polarimetric SAR data compensation for terrain azimuth slope variation," *IEEE Trans. Geosci. Remote Sens.*, vol. 38, no. 5, pp. 2153–2163, Sep. 2000.

Exercise 1: Fire scar detection





Exercise 1: Fire scar detection



Model-based decomposition of the coherency matrix (e.g., Freeman-Durden, Van Zyl, Yamaguchi):

$$[T] = [T_s] + [T_d] + [T_v]$$

surface

double bounce

volume

```
vanzyl_3components_decomposition_T3.exe
T3_poa/ T3_poa/ 1 0 0 900 2000
```

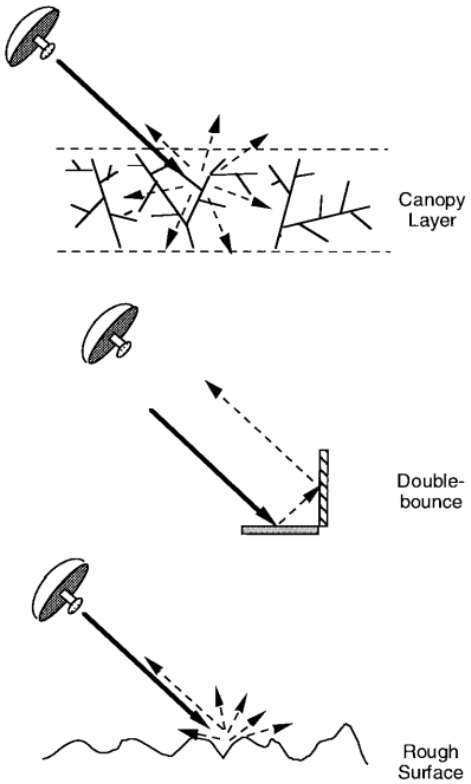
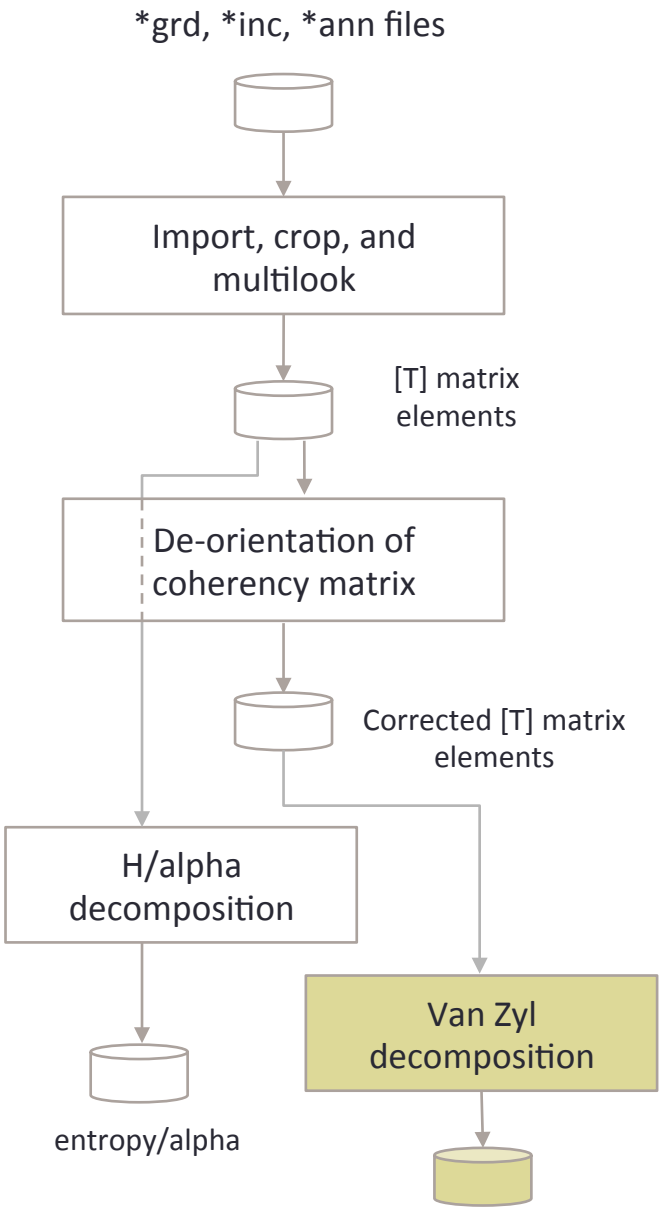


Image courtesy of reference below

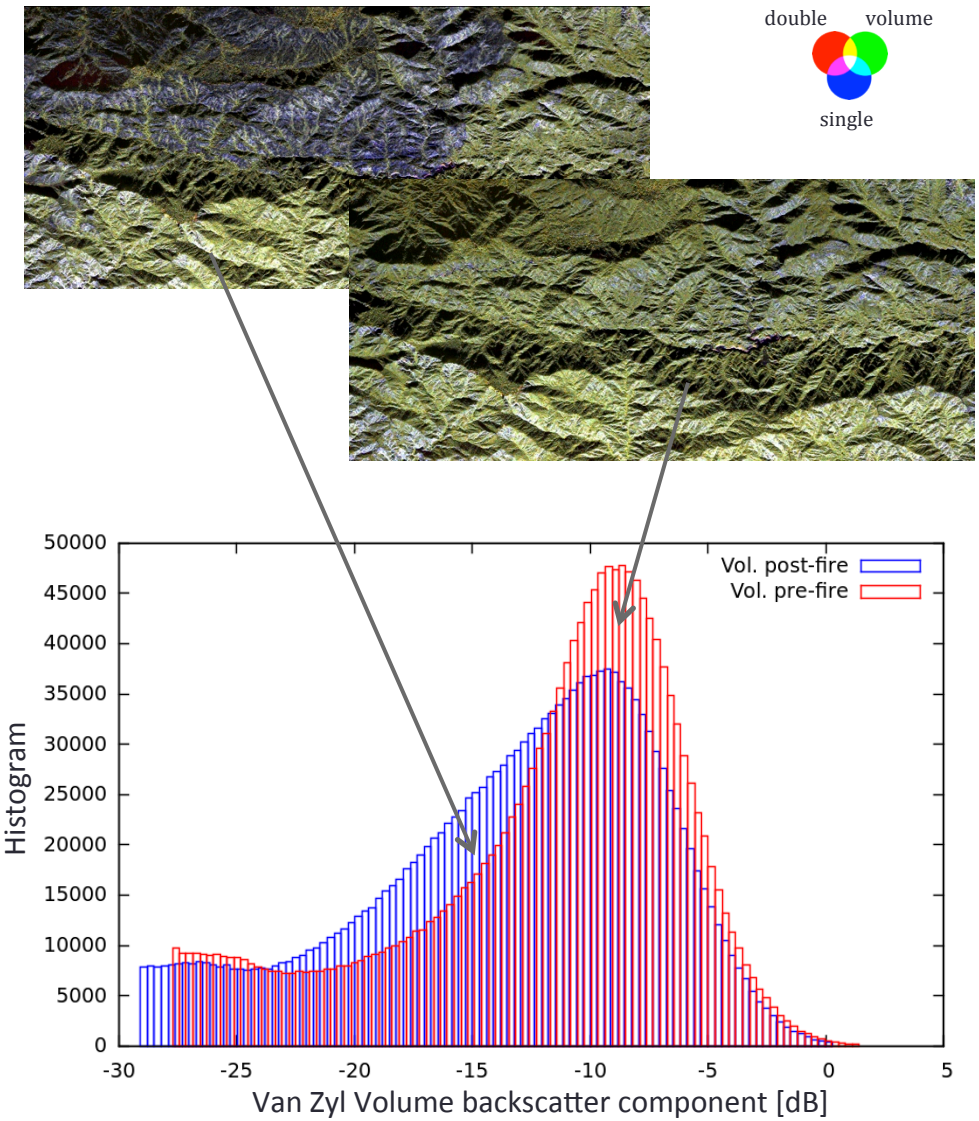
A. Freeman and S. L. Durden, "A three-component scattering model for polarimetric SAR data," *IEEE Trans. Geosci. Remote Sens.*, vol. 36, no. 3, pp. 963–973, May 1998.

J. J. van Zyl, M. Arii, and K. Yunjin, "Model-based decomposition of polarimetric SAR covariance matrices constrained for nonnegative eigenvalues," *IEEE Trans. Geosci. Remote Sens.*, vol. 49, no. 9, pp. 3452–3459, Sep. 2011.

Exercise 1: Fire scar detection

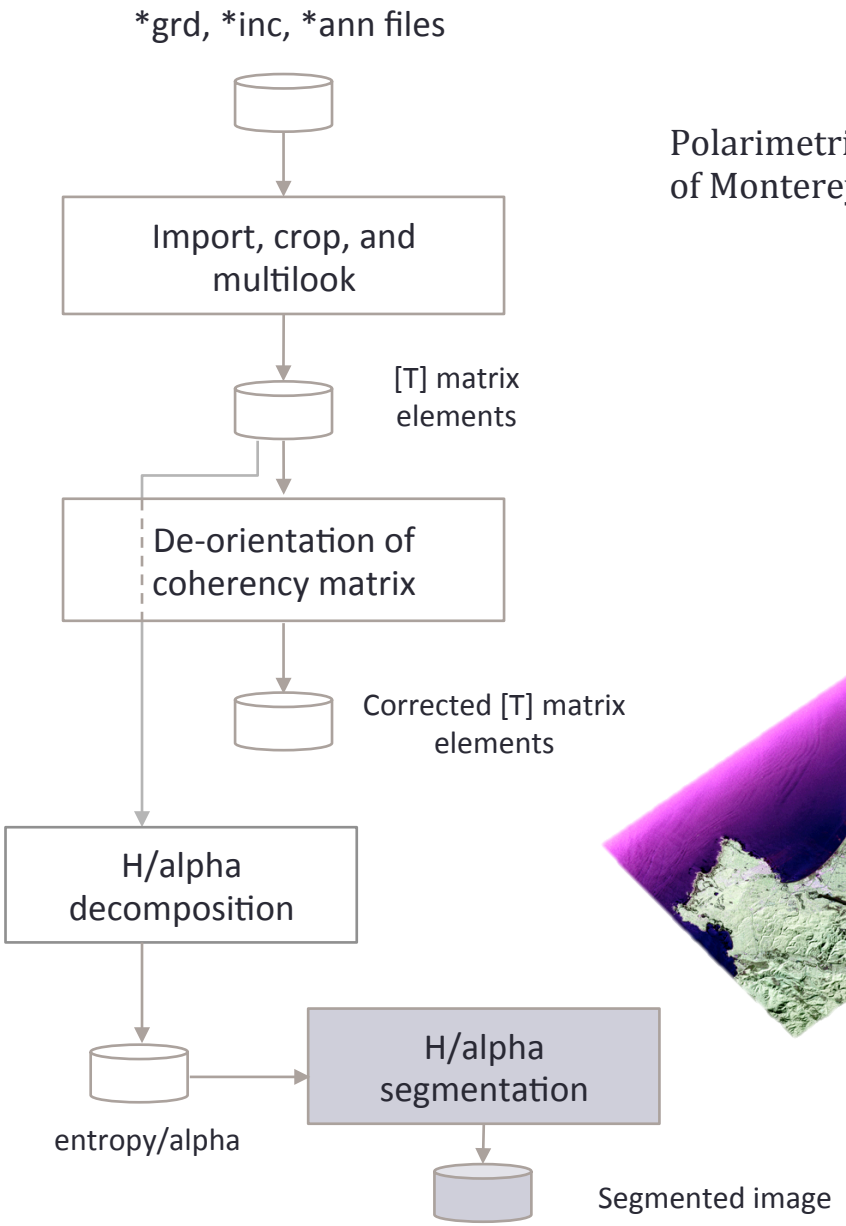


Van Zyl decomposition

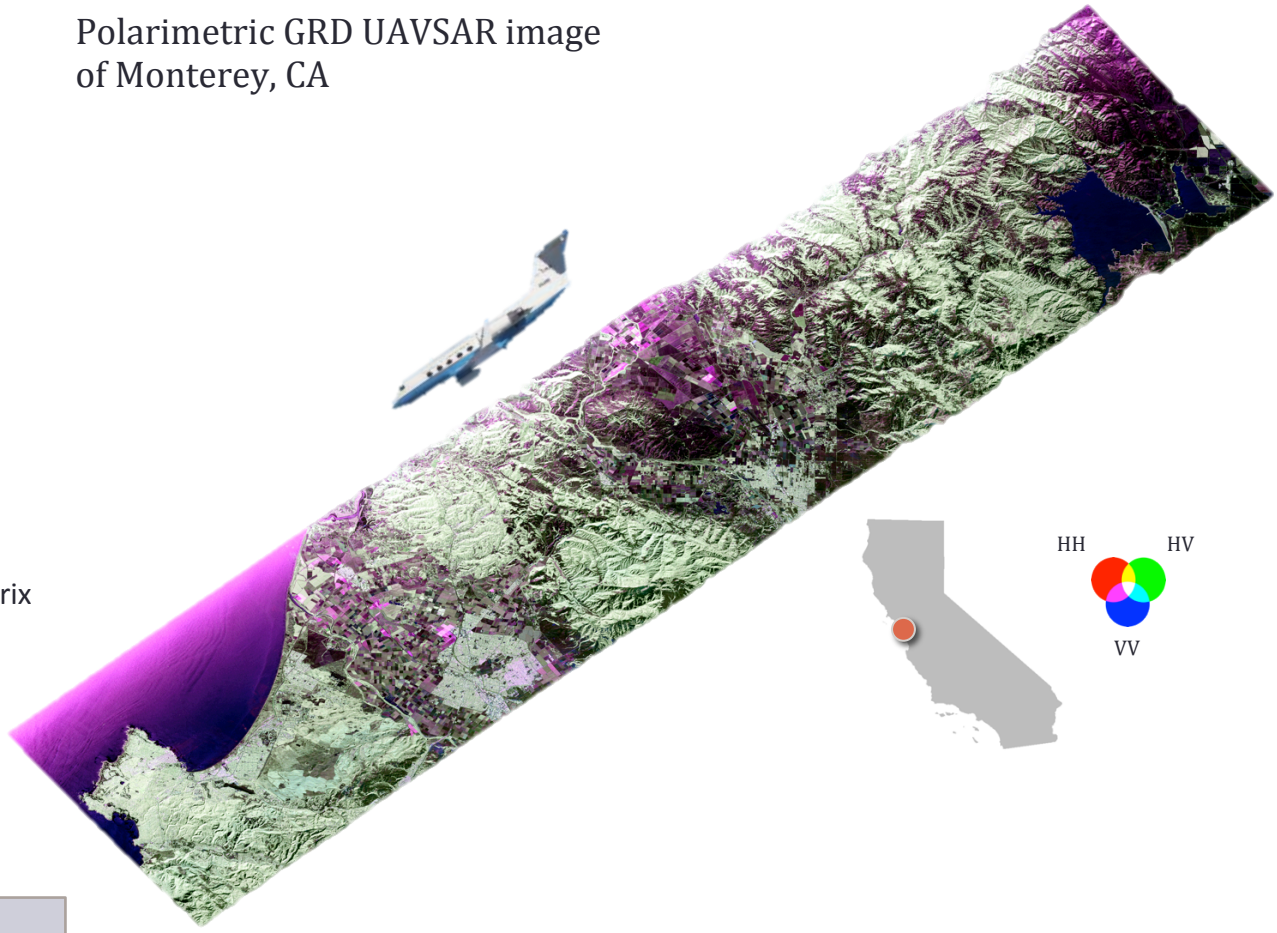


Exercise 2: Segmentation

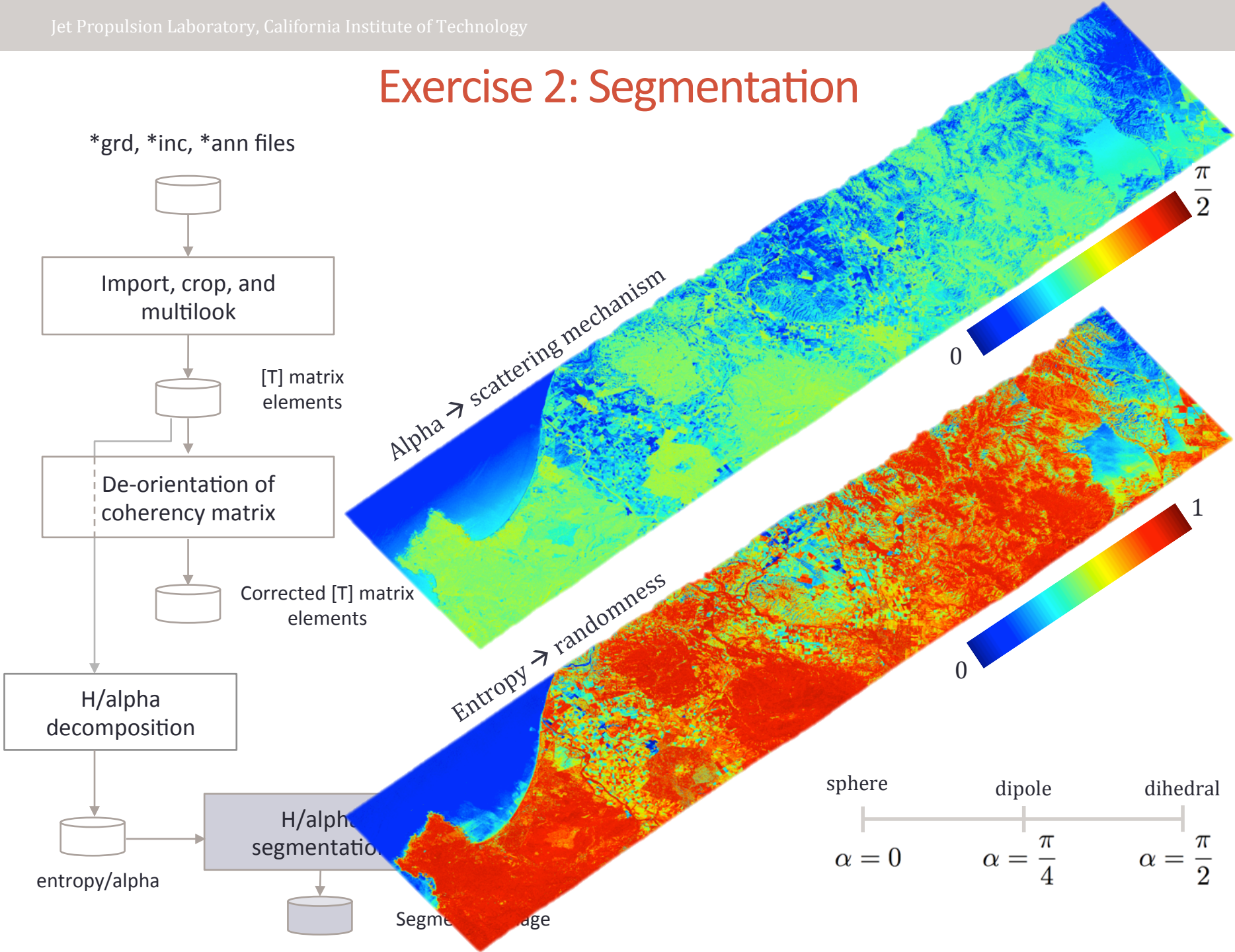
Exercise 2: Segmentation



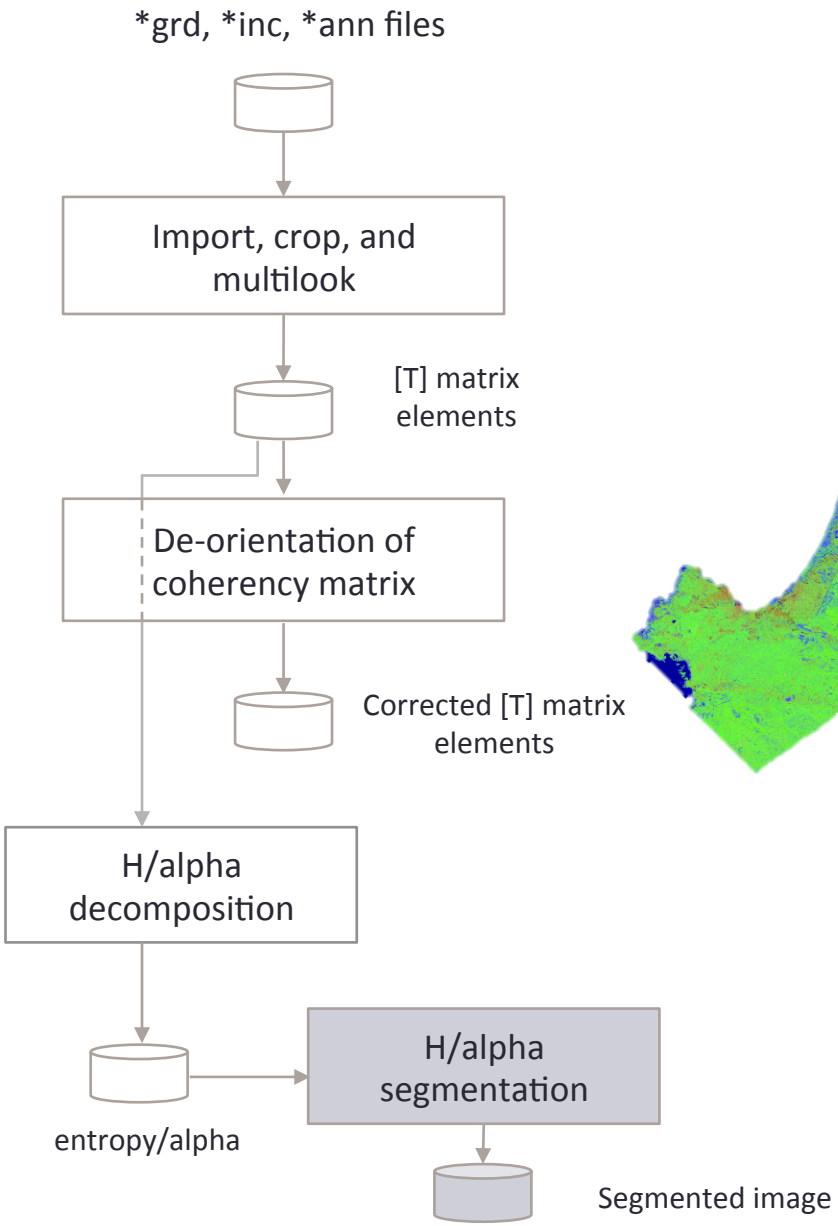
Polarimetric GRD UAVSAR image of Monterey, CA

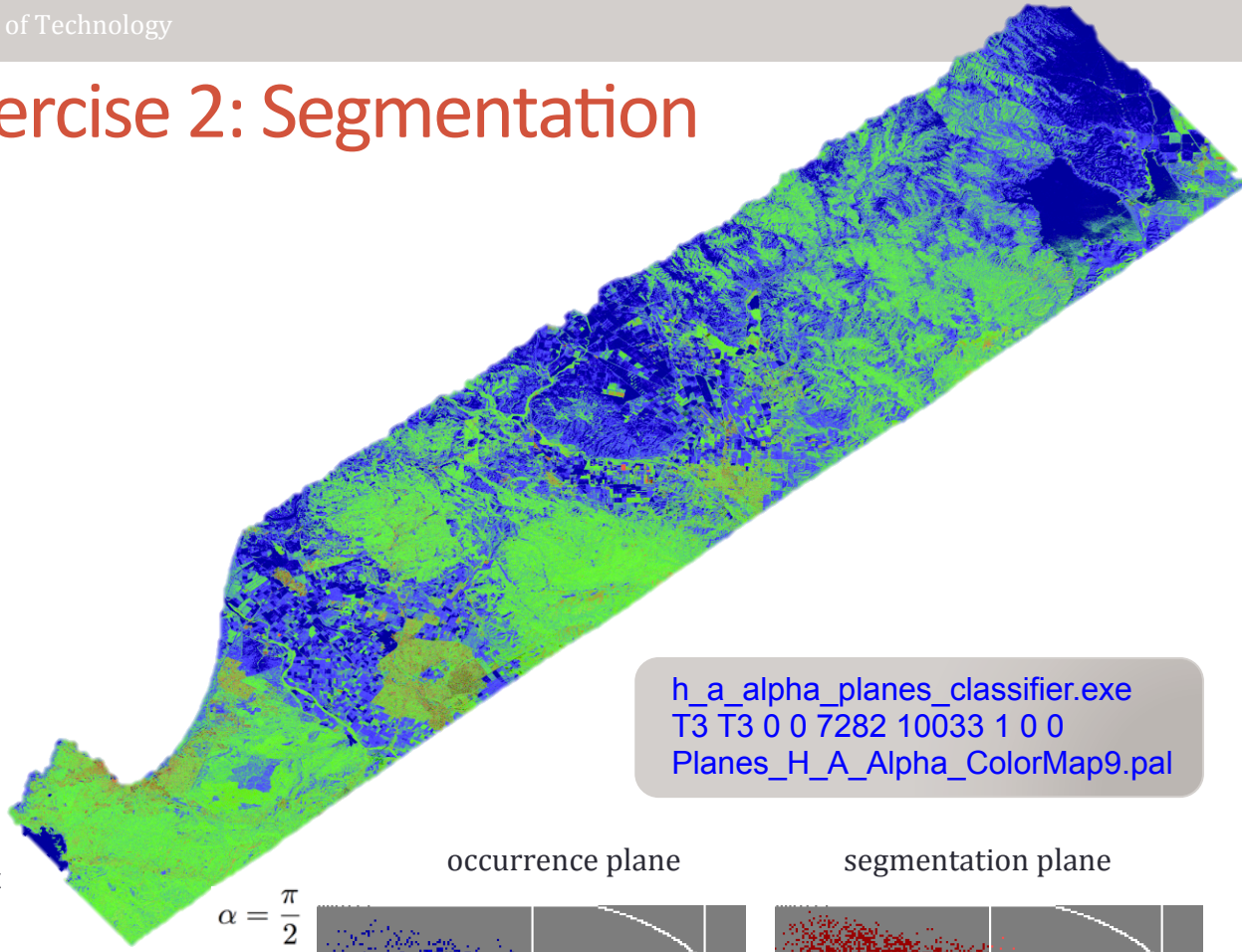


Exercise 2: Segmentation

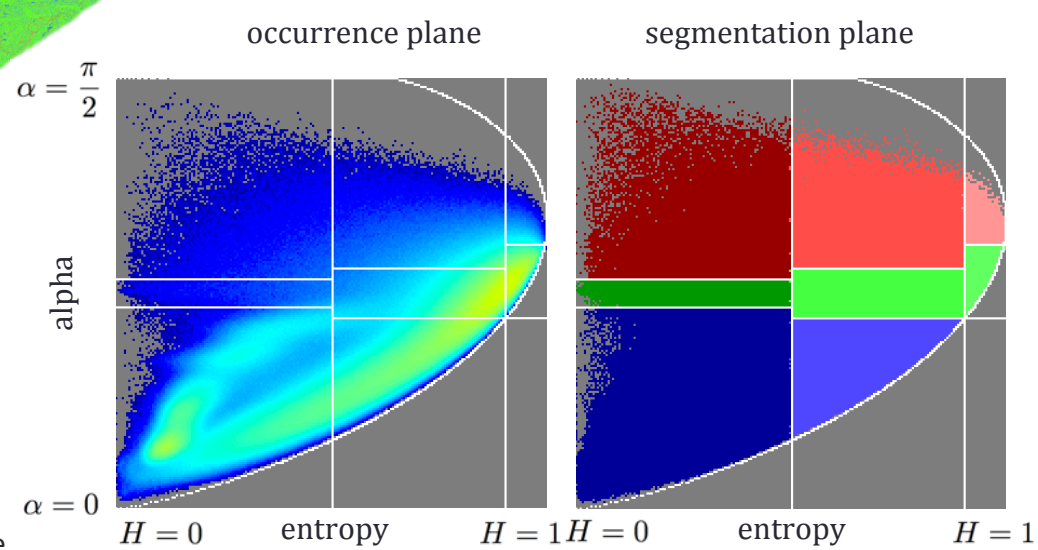


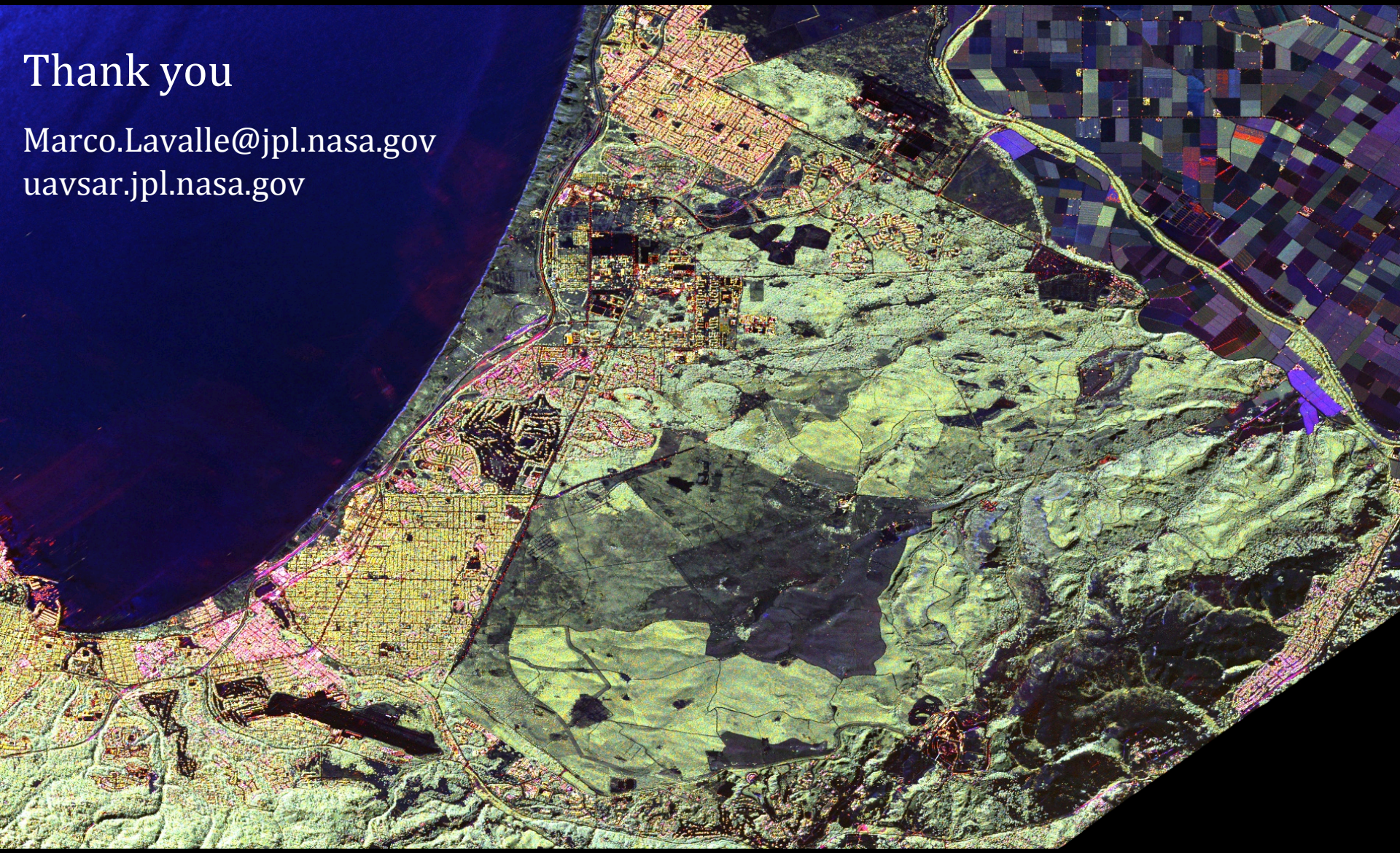
Exercise 2: Segmentation





```
h_a_alpha_planes_classifier.exe
T3 T3 0 0 7282 10033 1 0 0
Planes_H_A_Alpha_ColorMap9.pal
```



Thank you

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