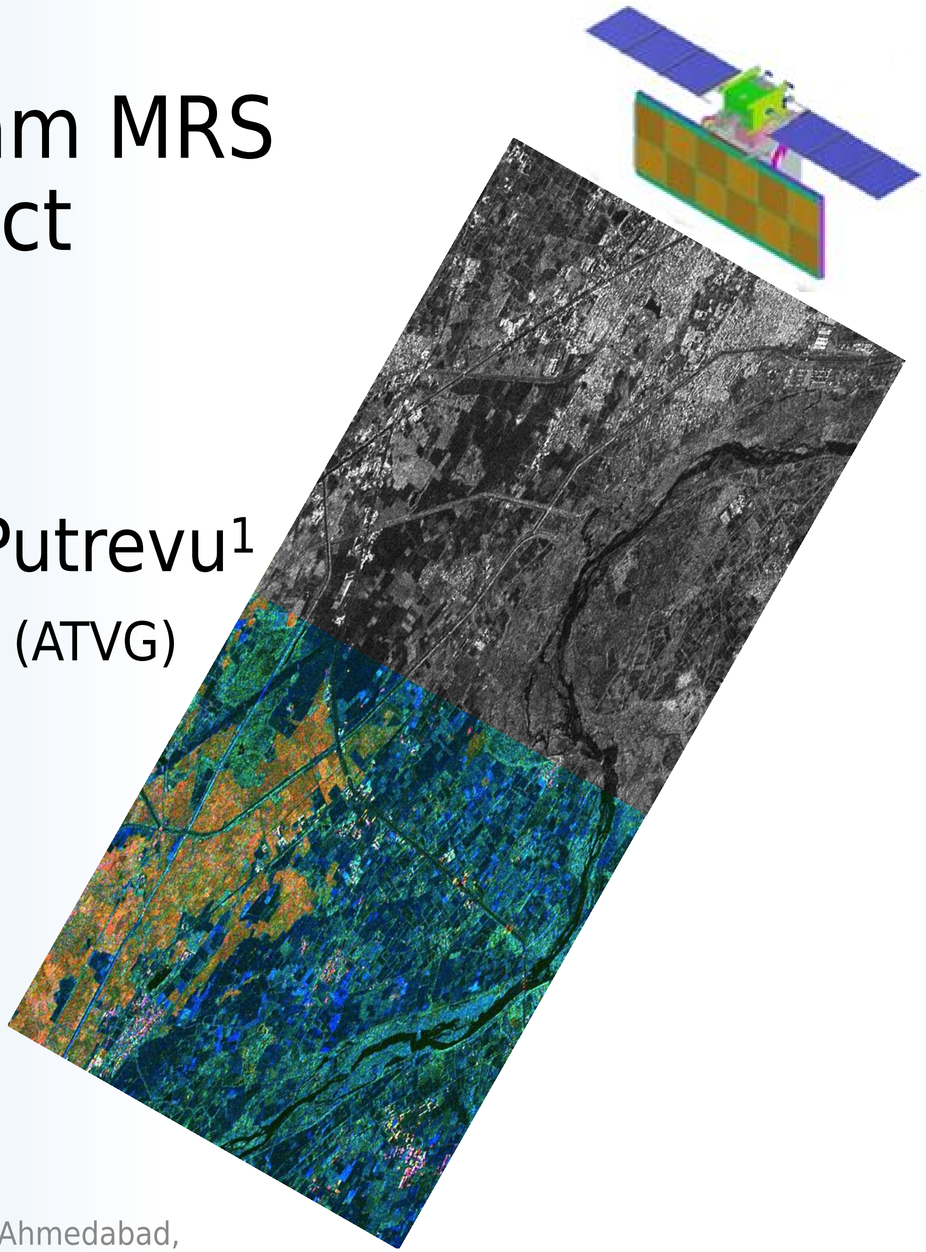
Performance evaluation of EOS-04 8 beam MRS mode dual polarimetric and compact polarimetric data



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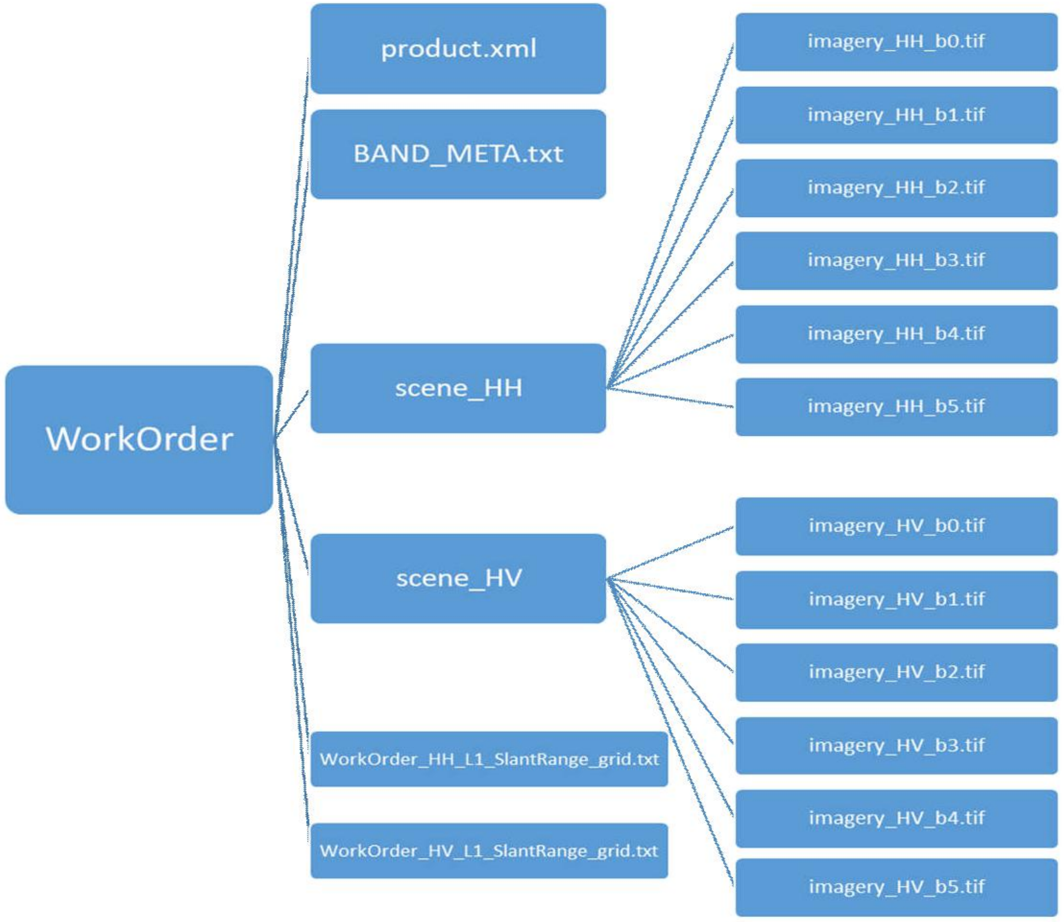
EOS-04 SCANSAR SLC Product Definition*

The Level-1 Slant Range Product for ScanSAR imaging mode in EOS-04 contains burstwise complex data on similar lines as Sentinel TOPS SLC data product.

For each polarization combination, one GeoTIFF for each beam is provided which would consist of concatenated bursts' data.

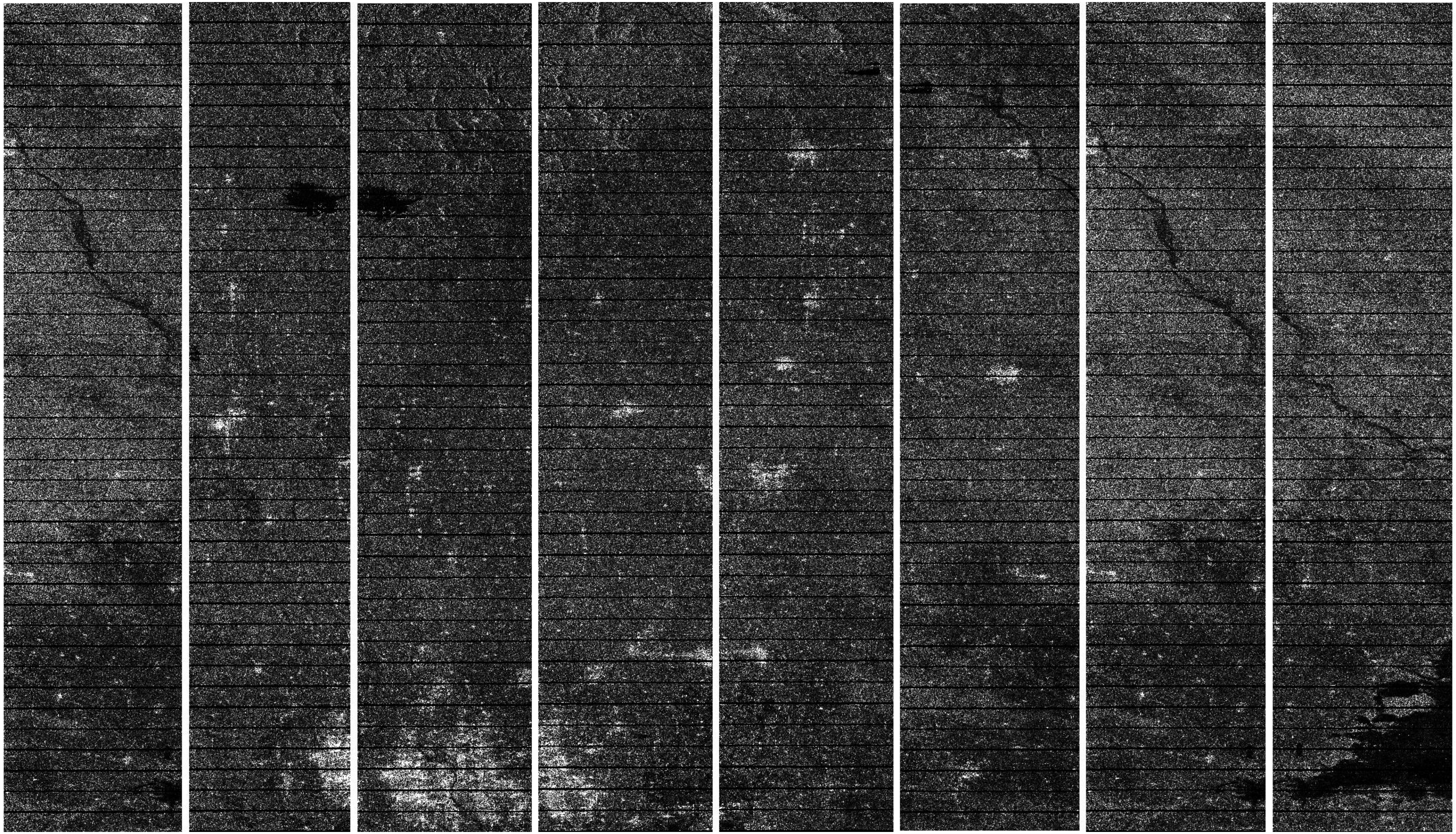
Relevant information to access and use the burst data is provided in an xml file (product.xml).



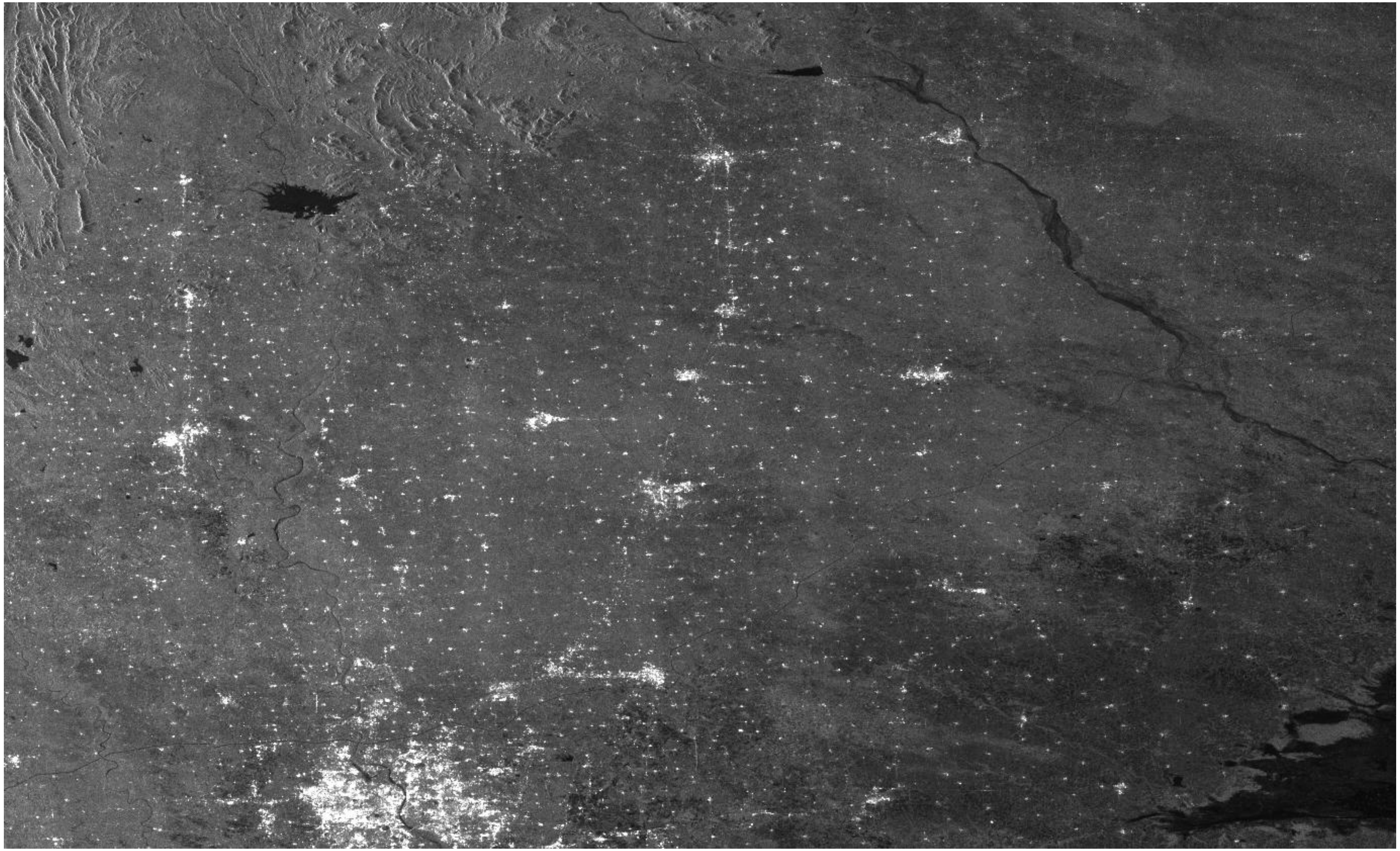
Product directory structure for an example MRS (6 Beam ScanSAR) product.
Product directory name: <WorkOrder>
Polarization: 2 (HH, HV); Number of beams: 6

*EOS-04 Data Products Formats (July 2023) Version 1.2.4

Example : Ahmedabad DP data (ProductID=244762211, Date Of Pass=22-JUL-2022)



Mosaicked HH



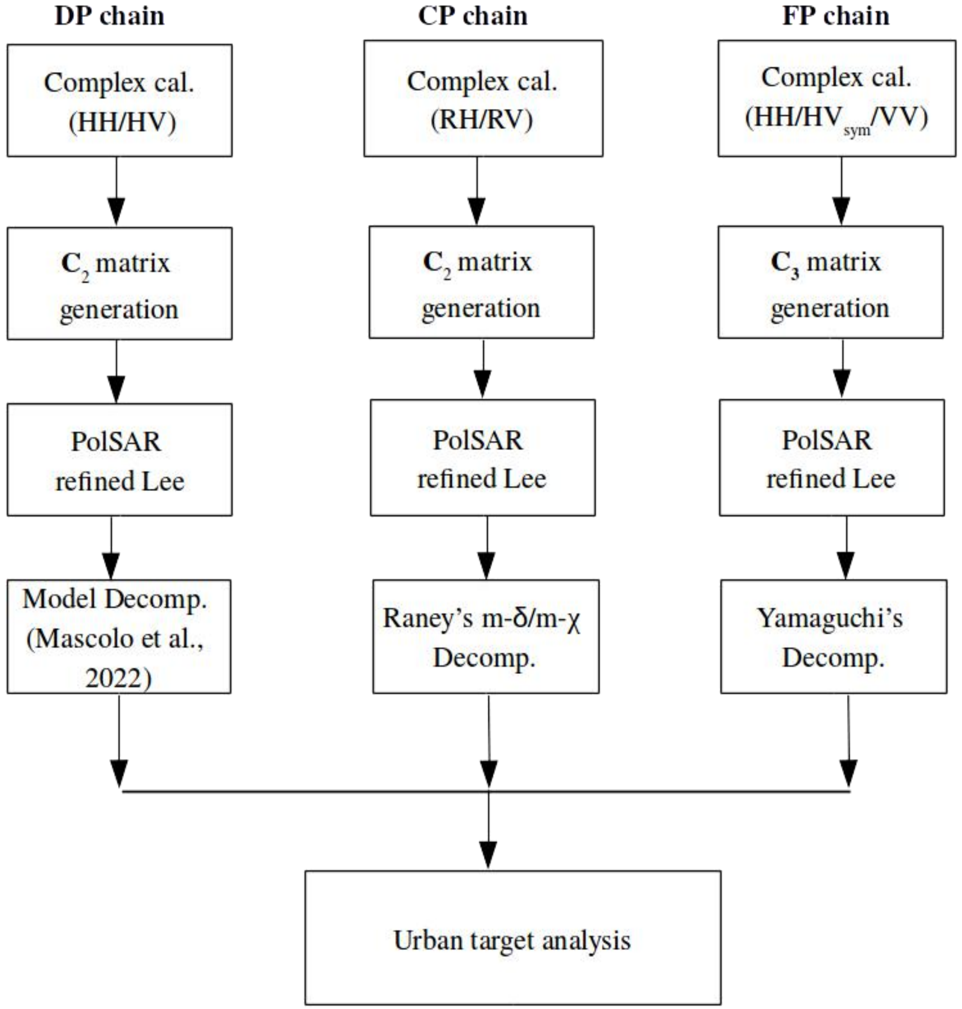
Problem definition:

Given the availability of the systematic EOS-04 SCANSAR MRS limited polarimetry modes - viz., Dual pol and compact pol modes - which of them provides better performance from an application point of view?

Caveats:

1. Well calibrated CP, DP and FP modes assumed.
2. Only urban targets are considered in this analysis.
3. Results are applicable to EOS-04 C-band data only.
4. Performance is evaluated w.r.t the full-pol mode data from the same sensor.

Flowchart



DP chain
CP chain
FP chain
Complex cal. (HH/HV)
Complex cal. (RH/RV)
Complex cal. (HH/HV$_{sym}$/VV)
C_2 matrix generation
C_2 matrix generation
C_3 matrix generation
PolSAR refined Lee
PolSAR refined Lee
PolSAR refined Lee
Model Decomp. (Mascolo et al., 2022)
Raney's m-δ/m-χ Decomp.
Yamaguchi's Decomp.
Urban target analysis

Model-Based Decomposition of Dual-Pol SAR Data*

Dual-pol systems employ a single transmitter polarization state with a dual channel coherent receiver, measuring both horizontal (H) and vertical (V) components of the scattered wave.

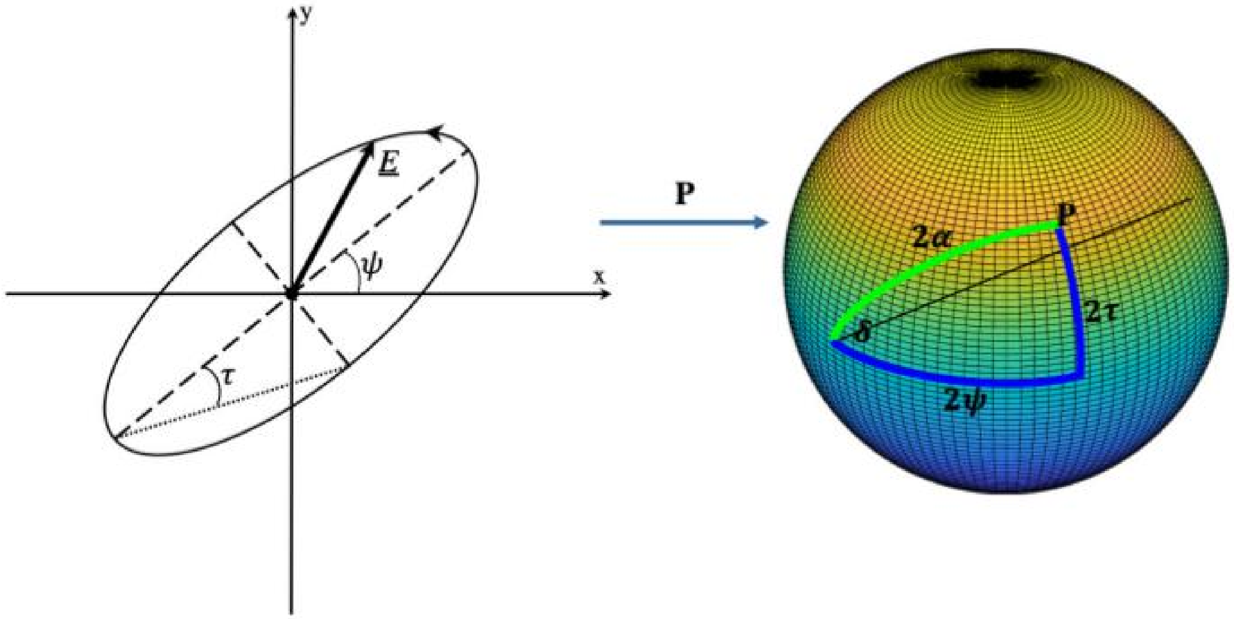
$$C2 = \left\langle \begin{bmatrix} E_{\mathrm{HT}} \\ E_{\mathrm{VT}} \end{bmatrix} \begin{bmatrix} E^*_{\mathrm{HT}} & E^*_{\mathrm{VT}} \end{bmatrix} \right\rangle = \begin{bmatrix} c_{11} & c_{12} \\ c^*_{12} & c_{22} \end{bmatrix}.$$

The Stokes vector ($\underline{S}$) of the scattered wave is fully determined from $\mathbf{C}_2$

$$\underline{s} = \begin{bmatrix} s_1 \\ s_2 \\ s_3 \\ s_4 \end{bmatrix} = \begin{bmatrix} c_{11} + c_{22} \\ c_{11} - c_{22} \\ 2\mathrm{Re}(c_{12}) \\ 2\mathrm{Im}(c_{12}) \end{bmatrix} \rightarrow \underline{s}_H = \begin{bmatrix} 1 \\ 1 \\ 0 \\ 0 \end{bmatrix}, \quad \underline{s}_V = \begin{bmatrix} 1 \\ -1 \\ 0 \\ 0 \end{bmatrix}.$$

*L. Mascolo, S. R. Cloude and J. M. Lopez-Sanchez, "Model-Based Decomposition of Dual-Pol SAR Data: Application to Sentinel-1," in IEEE Transactions on Geoscience and Remote Sensing, vol. 60, pp. 1-19, 2022

The Poincarè sphere and various angles in limited polarimetry -



$$\underline{s}_p = A^2 \begin{bmatrix} 1 \\ \cos 2\psi \cos 2\tau \\ \sin 2\psi \cos 2\tau \\ \sin \tau \end{bmatrix} \leftrightarrow A^2 \begin{bmatrix} 1 \\ \cos 2\alpha \\ \sin 2\alpha \cos \delta \\ \sin 2\alpha \sin \delta \end{bmatrix}.$$

- Poincaré sphere and spherical triangle construction relating ellipse geometry (ψ, τ) and wave ratio (α, δ) parameters for general elliptical polarization state P.

- Any polarized Stokes vector can then be written in terms of either set of these angles, where A is the ellipse amplitude

Generalized Stokes Vector Decomposition

$$\underline{s} = m_v \underline{s}_v + m_s \underline{s}_p + n \underline{s}_n.$$

Decompose an arbitrary Stokes vector into partially polarized ($\underline{S}_v$), polarized ($\underline{S}_p$) and randomly polarized ($\underline{S}_n$) wave components. Dual-pol volume scattering models are NOT randomly polarized. (noise term can be mitigated using noise subtraction techniques).

Problem reduces to a two component decomp.

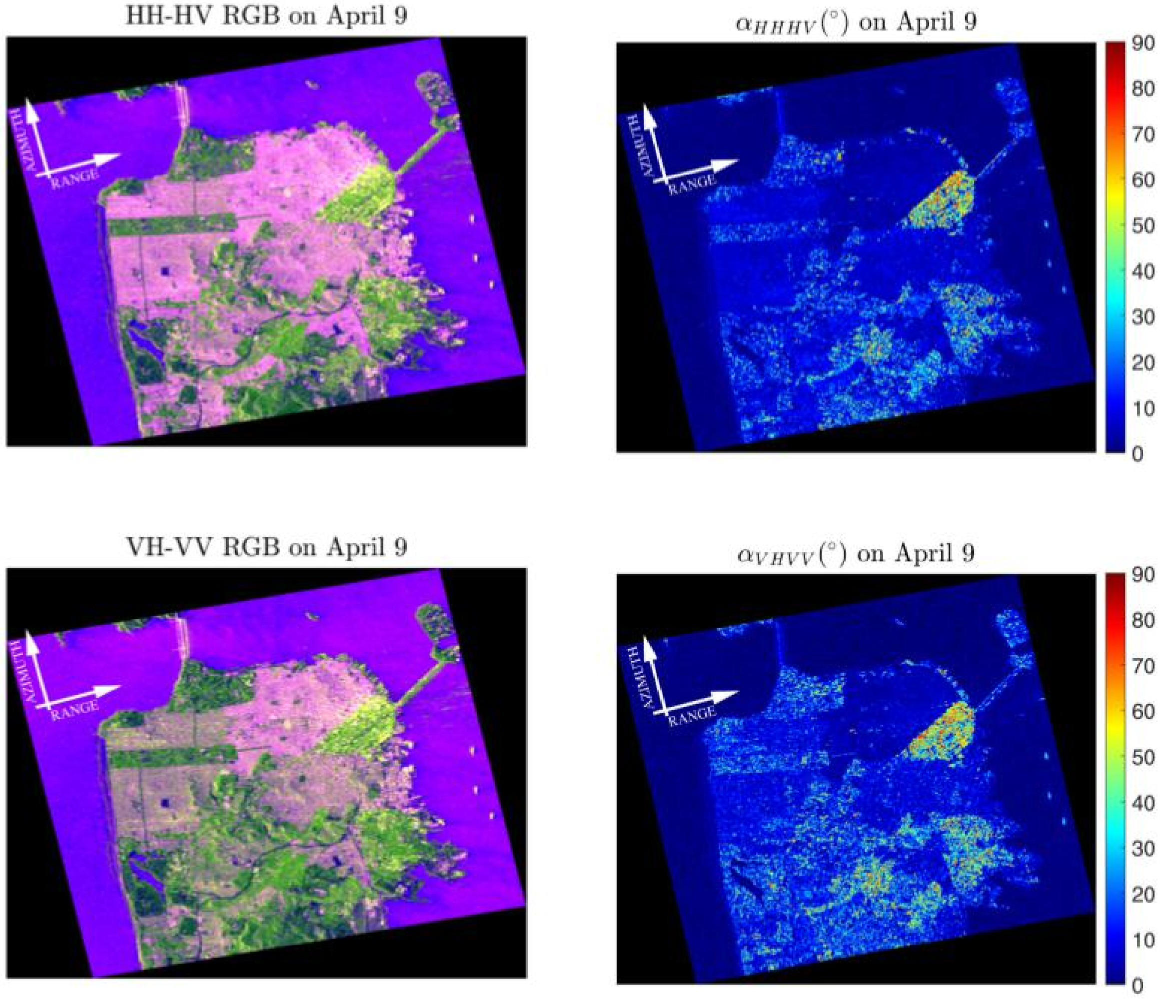
For a random dipole cloud as volume model, the decomposition takes the following explicit form -

$$\underline{s} = m_v \begin{bmatrix} 1 \\ \pm 0.5 \\ 0 \\ 0 \end{bmatrix} + m_s \begin{bmatrix} 1 \\ \cos 2\alpha \\ \sin 2\alpha \cos \delta \\ \sin 2\alpha \sin \delta \end{bmatrix}.$$

$$\left.\begin{aligned} \alpha &= \frac{1}{2} \cos^{-1}\left(\frac{s_2}{s_1}\right) \\ \delta &= \arg\left(s_3 + i s_4\right) \end{aligned}\right\}$$

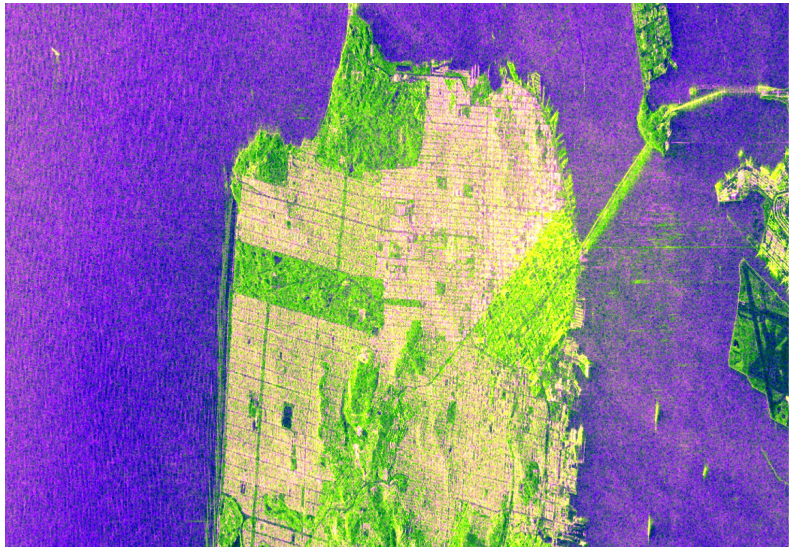
4 unknown in the model and 4 observables !

Illustration - The San Francisco Bay data (RADARSAT-2, Full-Pol)

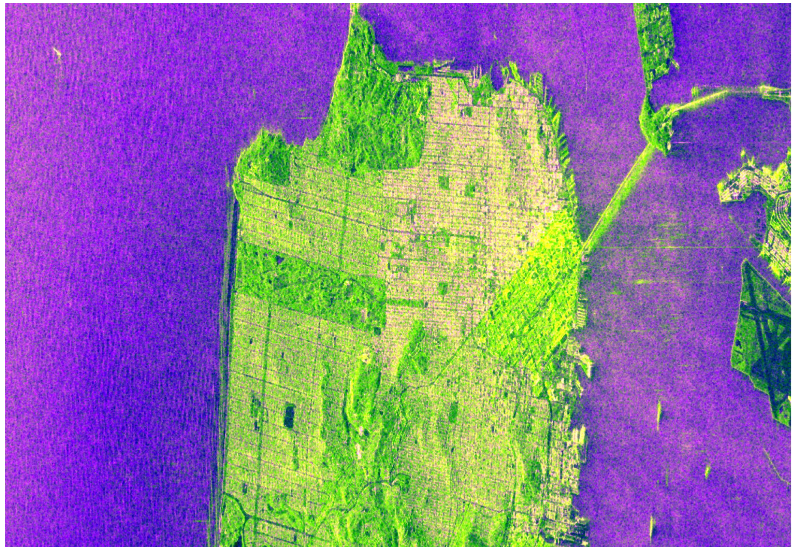


*L. Mascolo, S. R. Cloude and J. M. Lopez-Sanchez, "Model-Based Decomposition of Dual-Pol SAR Data: Application to Sentinel-1," in IEEE Transactions on Geoscience and Remote Sensing, vol. 60, pp. 1-19, 2022

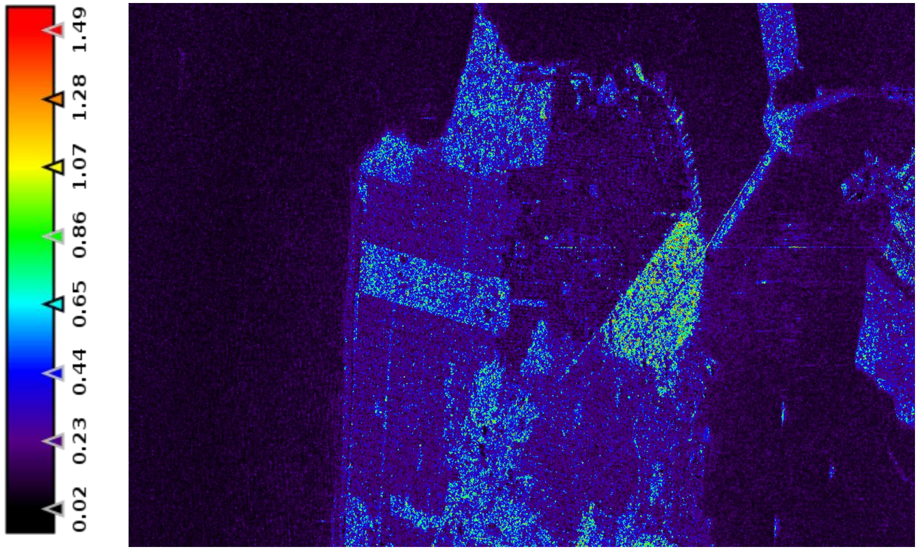
Implementation of the DP decomposition (RS2, FQ9, April, 2008)



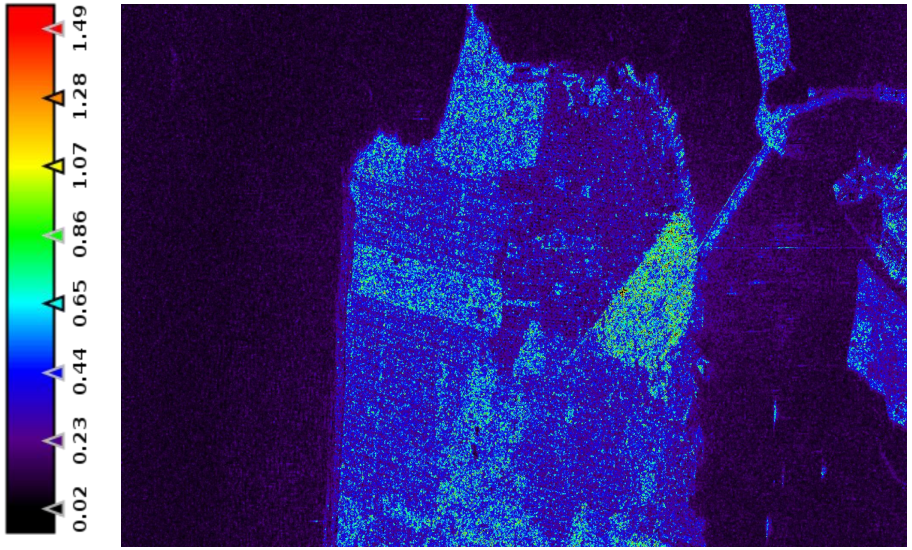
HH-HV based decomposition RGB



VH-VV based decomposition RGB



α_{HHHV}

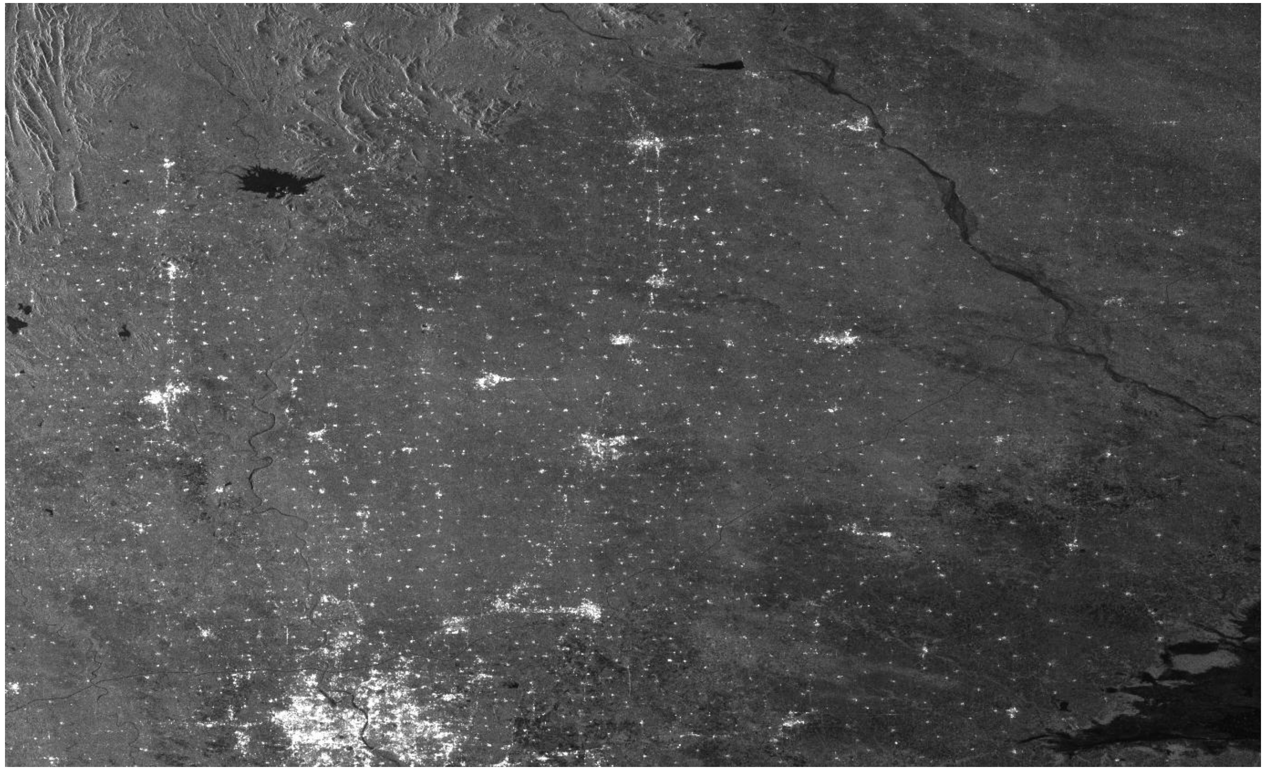


α_{VHVV}

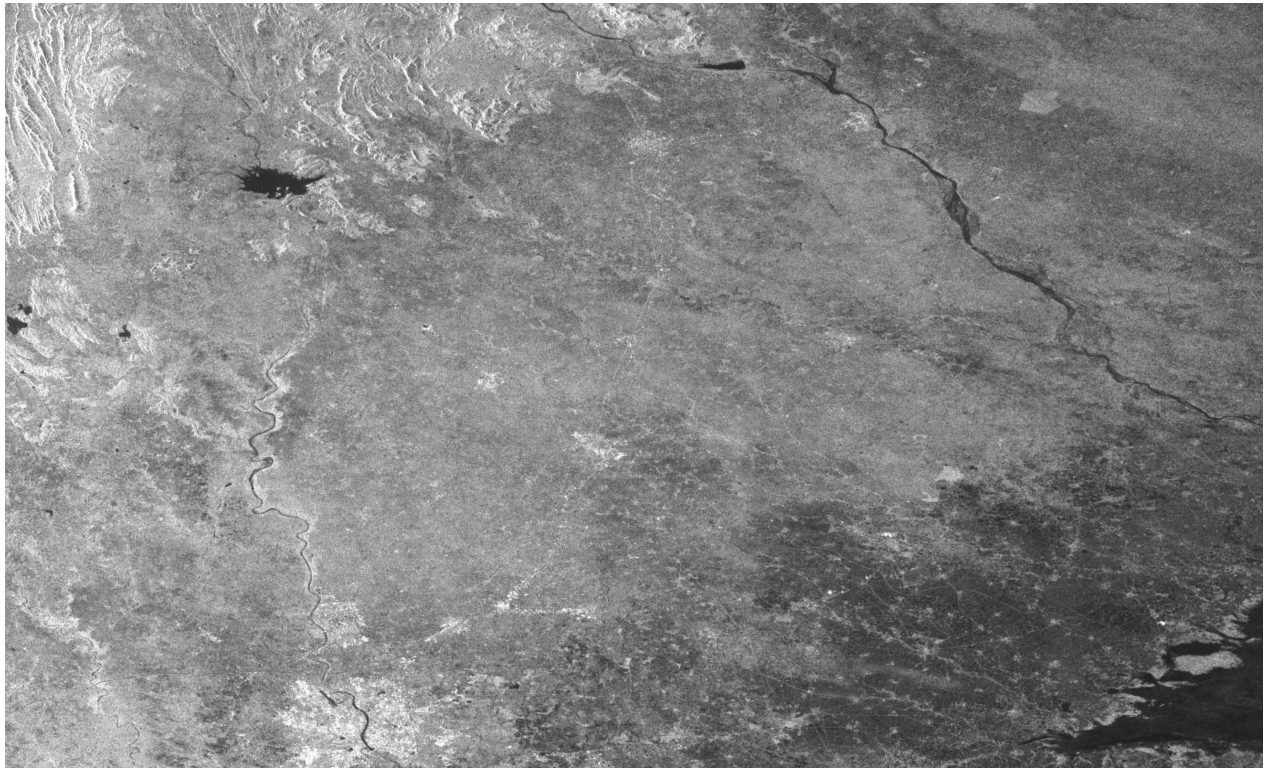
EOS-04 DP SCANSAR MRS dataset

Attribute	Value
PrdouctID	244762211
Date of Pass	22-JUL-2022
Product Type	L1 - SLANT RANGE
Azimuth Pixel Spacing (m)	19.1
Range Pixel Spacing (m)	7.2
Azimuth Resolution (m)	30.36
Range Resolution (m)	9.59
Scene Center Lat (deg)	23.721951
Scene Center Lon (deg)	72.359960
Incidence Angle (deg)	38.30458
Satellite Altitude (km)	527.956

The mosaicked HH and HV bands

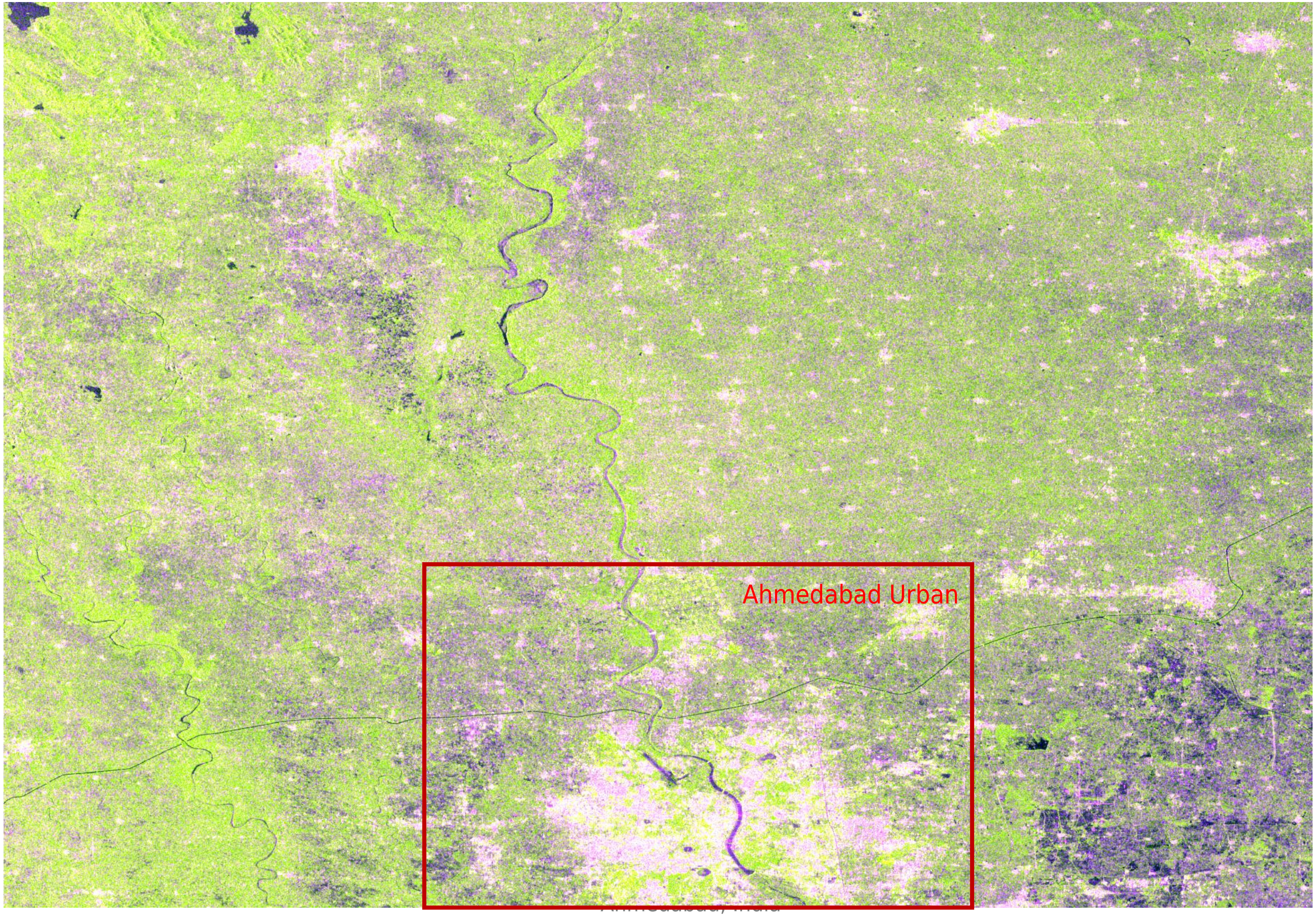


HH intensity imagery - quicklook file



HV intensity imagery - quicklook file

The RGB composite of the dual-pol decomposition imagery



Raney decomposition of the compact-pol (RHCP transmit) data*

The Stokes and various child parameters of interest -

$$S_1 = \langle |E_{\mathrm{RH}}|^2 + |E_{\mathrm{RV}}|^2 \rangle$$

$$S_2 = \langle |E_{\mathrm{RH}}|^2 - |E_{\mathrm{RV}}|^2 \rangle$$

$$S_3 = 2\,\mathrm{Re}\,\langle E_{\mathrm{RH}} E_{\mathrm{RV}}^* \rangle$$

$$S_4 = -2\,\mathrm{Im}\,\langle E_{\mathrm{RH}} E_{\mathrm{RV}}^* \rangle$$

$$m = \left(S_2^2 + S_3^2 + S_4^2\right)^{1/2} / S_1.$$

$$\delta = \mathrm{atan}(S_4/S_3) \qquad -180^\circ < \delta \le 180^\circ$$

$$\sin 2\chi = -\mathrm{S}_4/m\mathrm{S}_1$$

The decomposition can be expressed as -

$$\mathrm{B} = [\mathrm{mS}_1(1 - \sin 2\chi)/2]^{1/2}$$
$$\mathrm{R} = [\mathrm{mS}_1(1 + \sin 2\chi)/2]^{1/2}$$
$$\mathrm{G} = [\mathrm{S}_1(1 - \mathrm{m})]^{1/2}$$

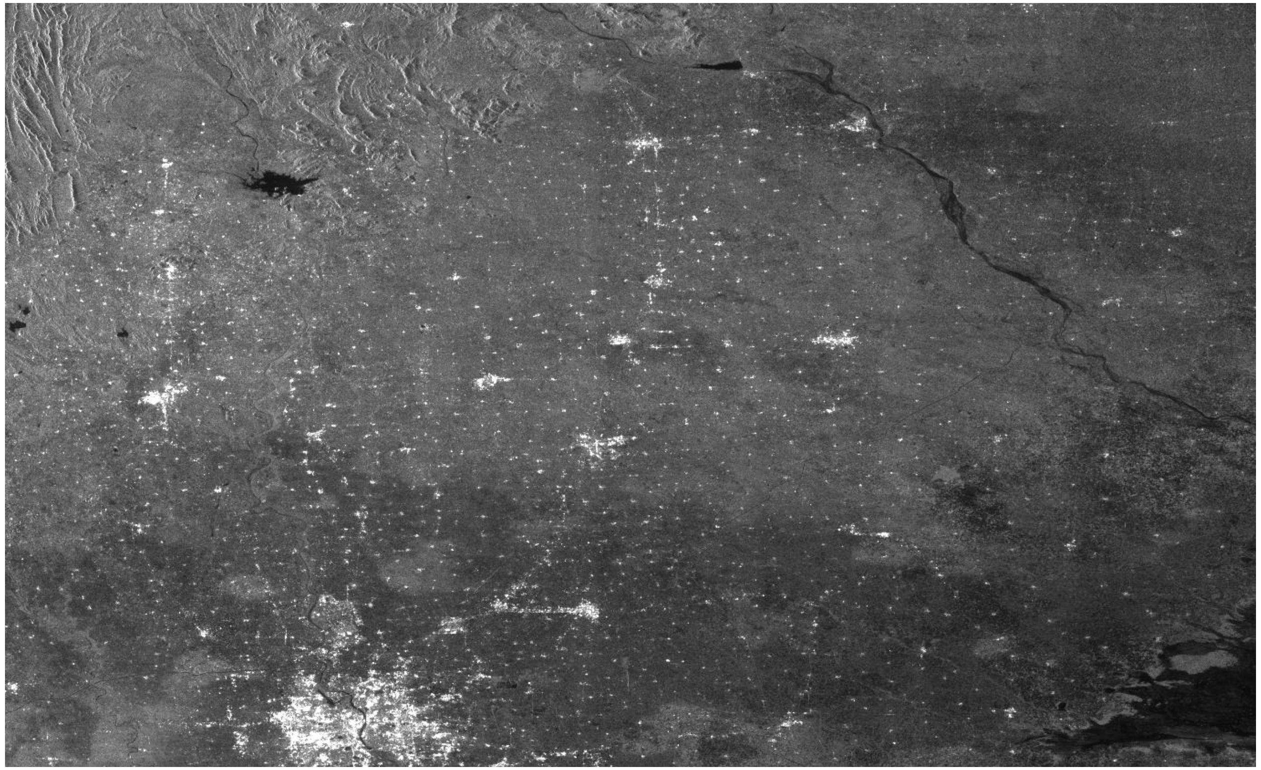
*Raney, R. K., J. T. S. Cahill, G. W. Patterson, and D. B. J. Bussey (2012), The m-chi decomposition of hybrid dual-polarimetric radar data with application to lunar craters, J. Geophys. Res., 117, E00H21

R. K. Raney, "Hybrid-Polarity SAR Architecture," in IEEE Transactions on Geoscience and Remote Sensing, vol. 45, no. 11, pp. 3397-3404, Nov. 2007

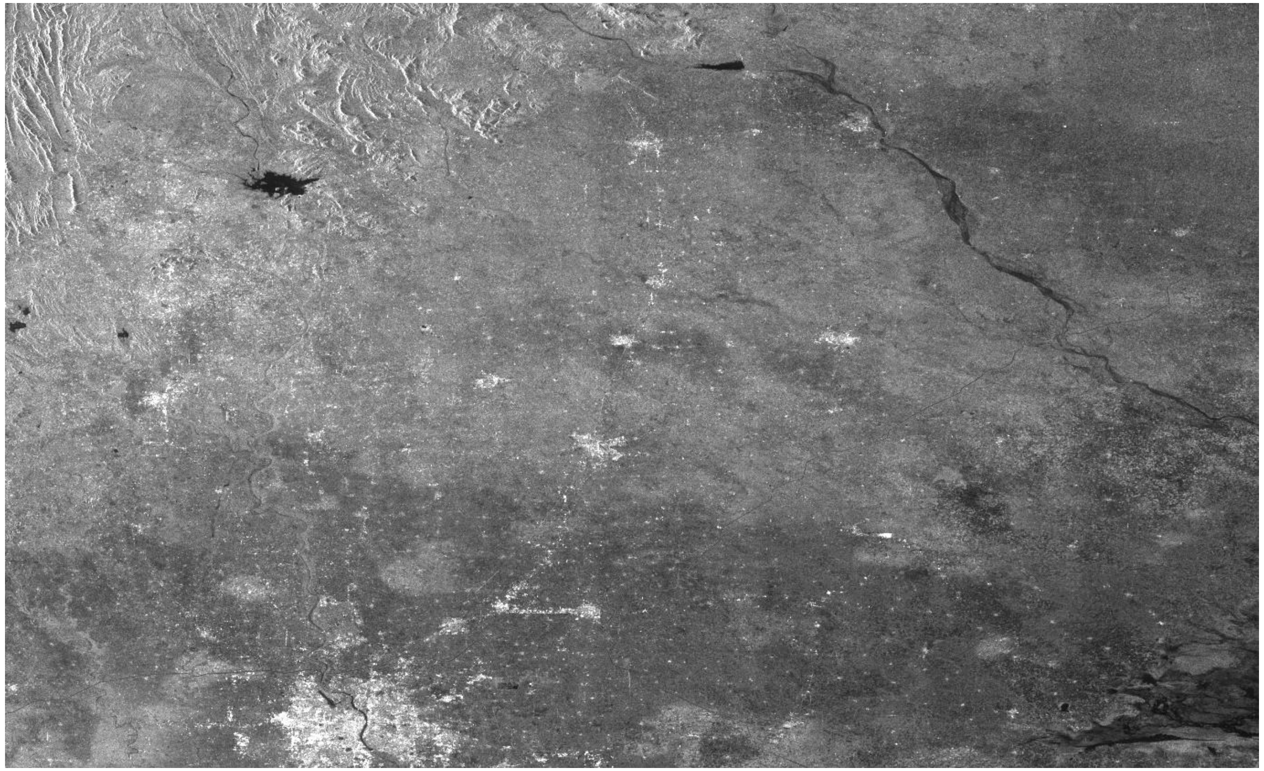
EOS-04 CP SCANSAR MRS dataset

Attribute	Value
PrdouctID	244640211
Date of Pass	05-JUL-2022
Product Type	L1 - SLANT RANGE
Azimuth Pixel Spacing (m)	19.1
Range Pixel Spacing (m)	7.2
Azimuth Resolution (m)	30.36
Range Resolution (m)	9.59
Scene Center Lat (deg)	23.722304
Scene Center Lon (deg)	72.360888
Incidence Angle (deg)	38.29270
Satellite Altitude (km)	527.794

The mosaicked RH and RV bands

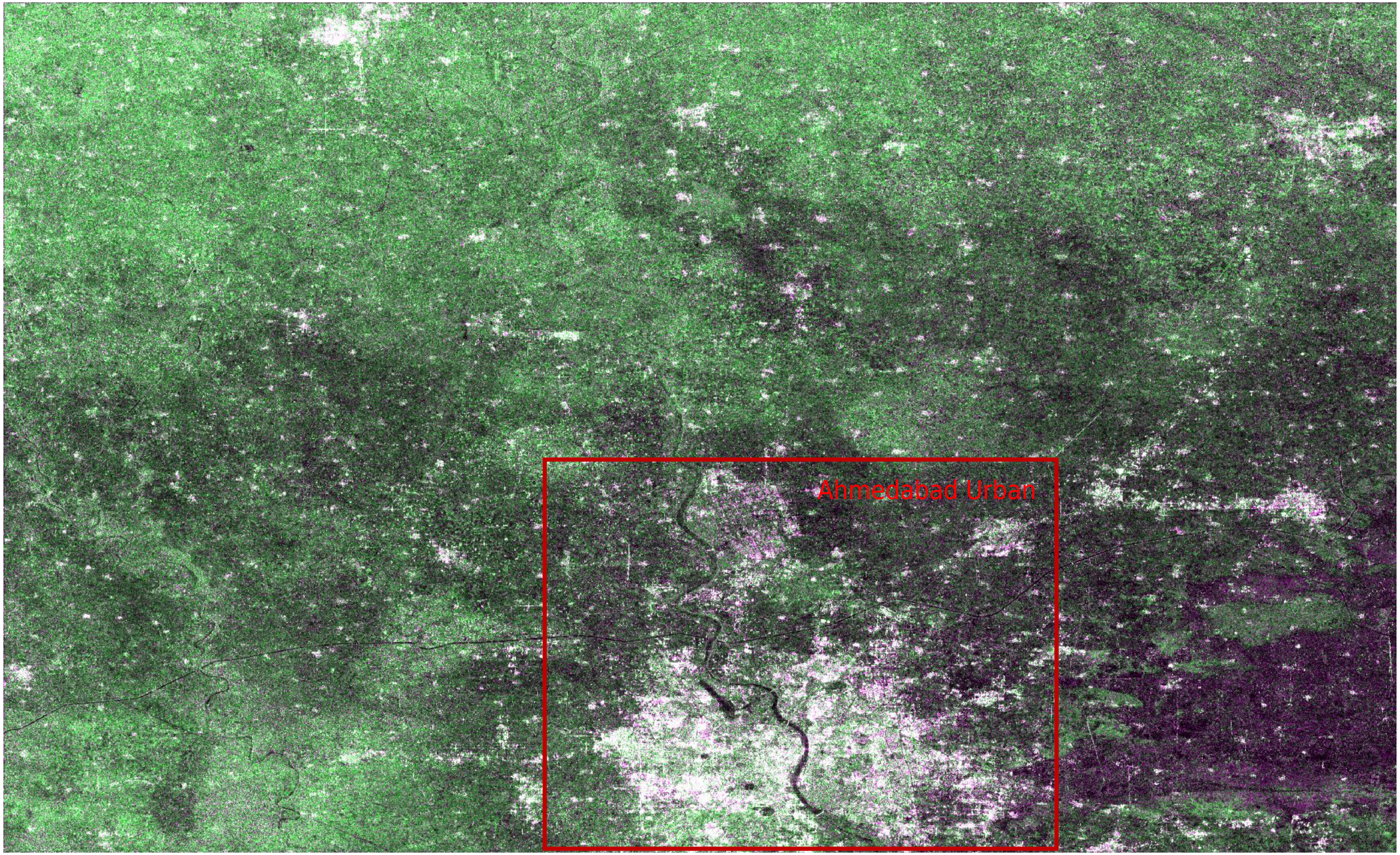


RH intensity imagery - quicklook file



RV intensity imagery - quicklook file

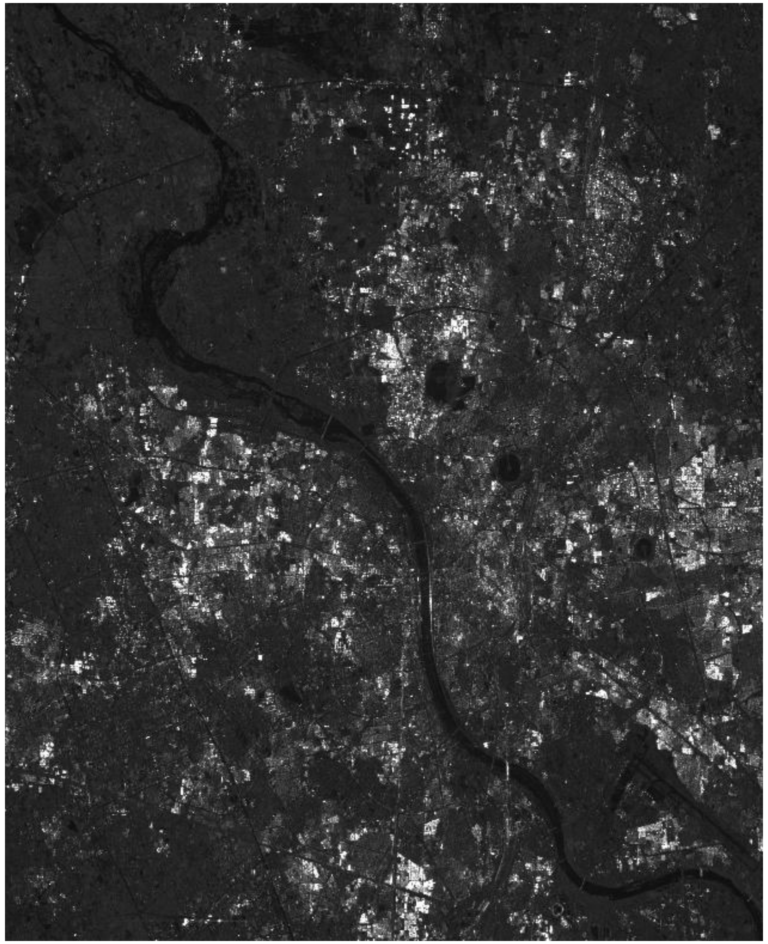
The RGB composite of the m-chi decomposition imagery



EOS-04 FP FRS1 dataset

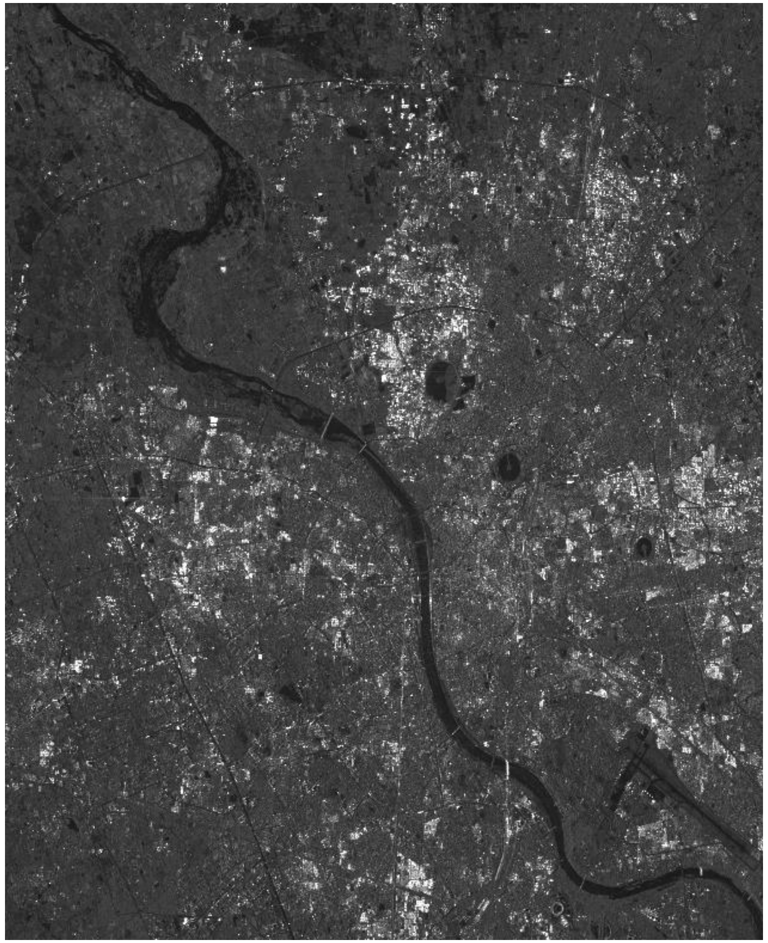
Attribute	Value
PrdouctID	249949311
Date of Pass	17-AUG-2022
Product Type	L1 - SLANT RANGE
Azimuth Pixel Spacing (m)	2.5
Range Pixel Spacing (m)	1.8
Azimuth Resolution (m)	3.0
Range Resolution (m)	2.4
Scene Center Lat (deg)	23.001523
Scene Center Lon (deg)	72.569129
Incidence Angle (deg)	34.15460
Satellite Altitude (km)	528.375

The quicklook imageries



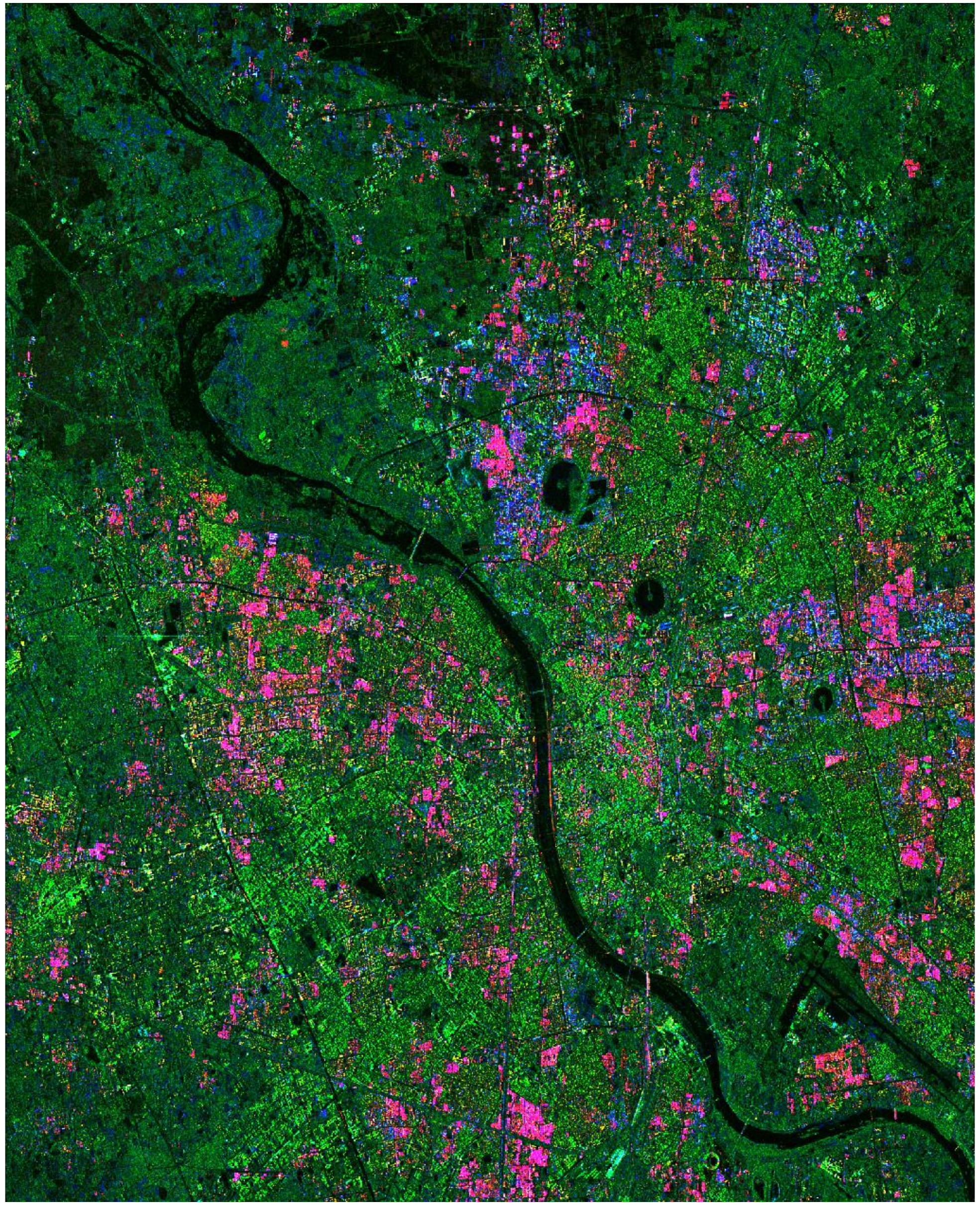
HH intensity

HV intensity

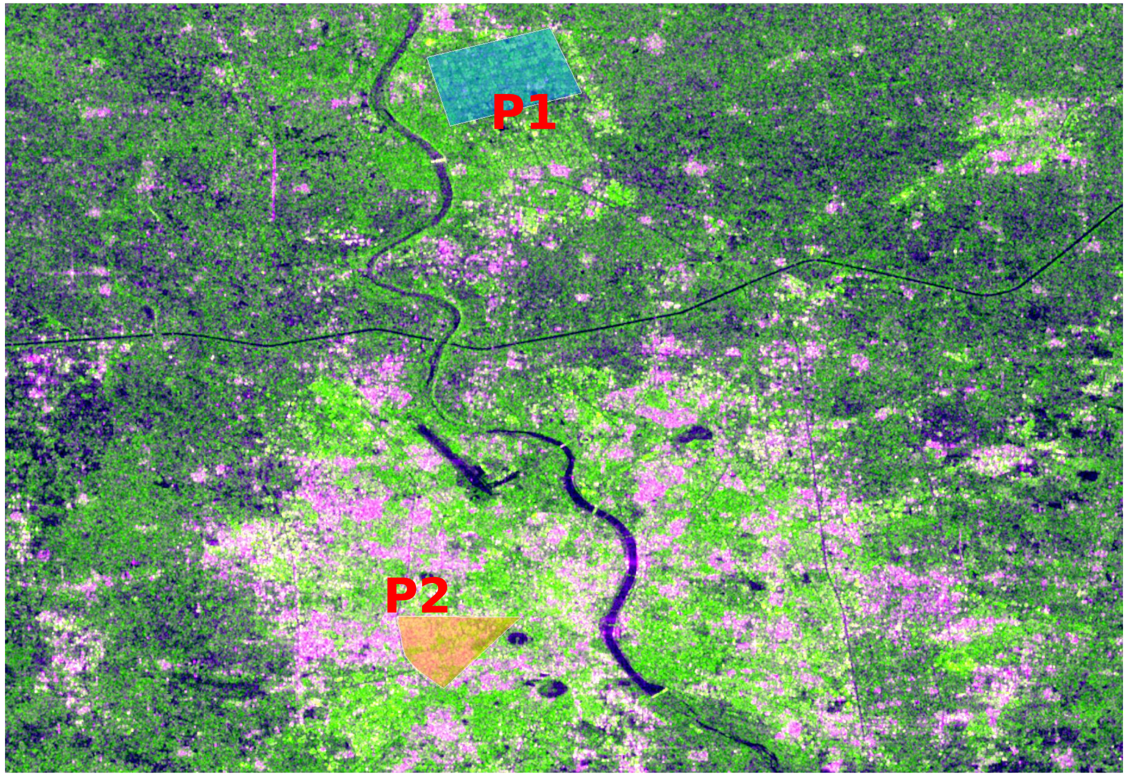


VV intensity

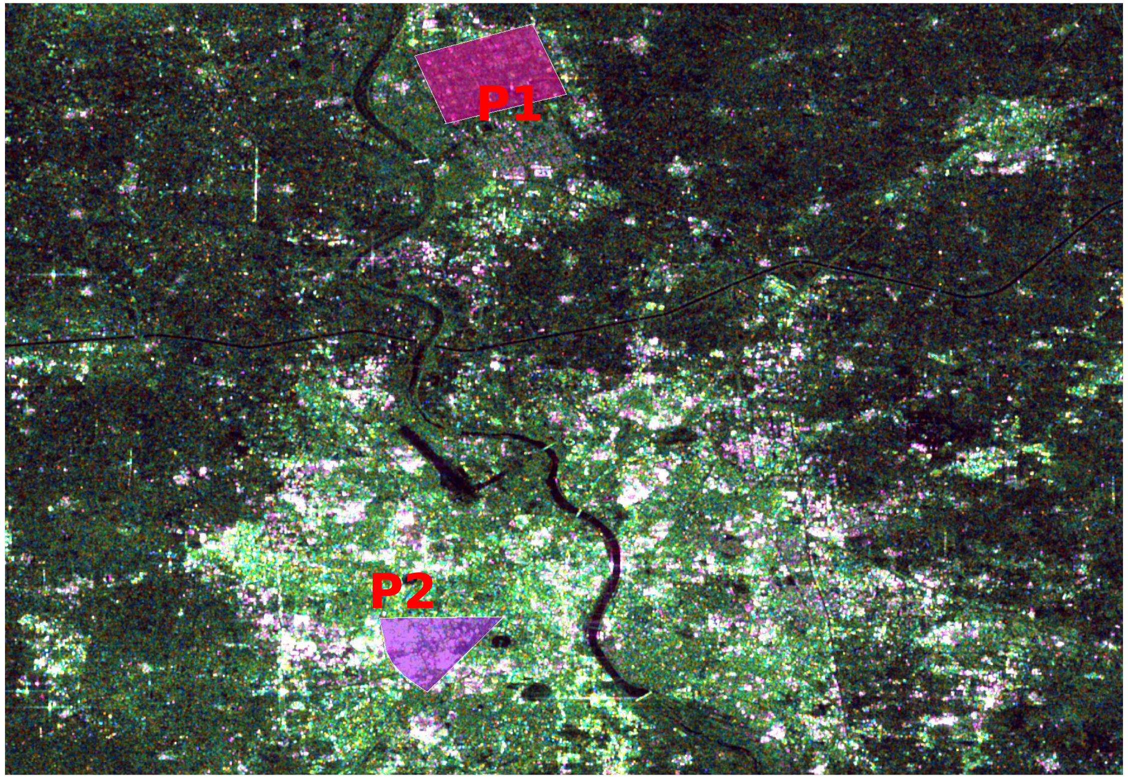
The Yamaguchi decomposed imagery



The urban patches



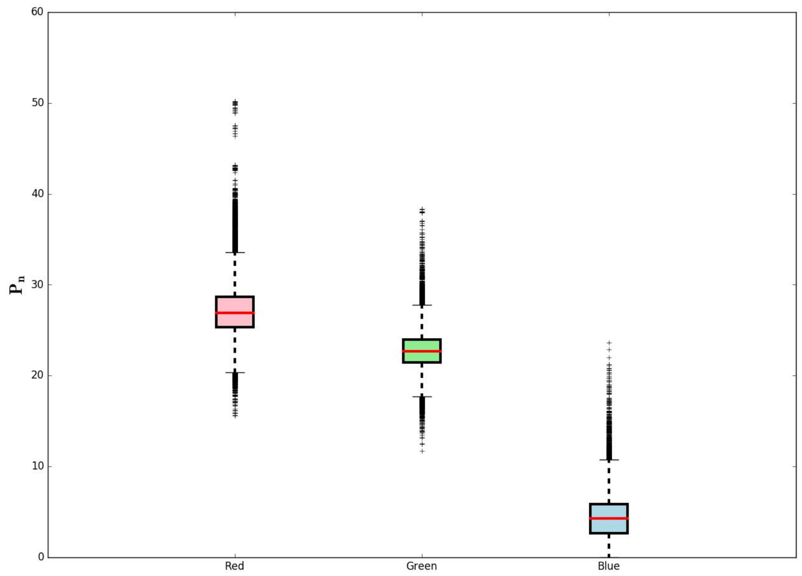
DP model-based decomposition

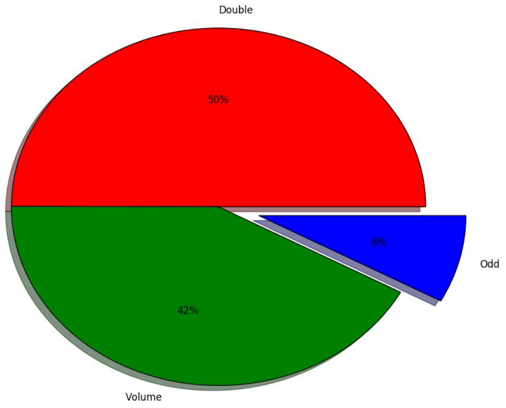


CP m-chi decomposition

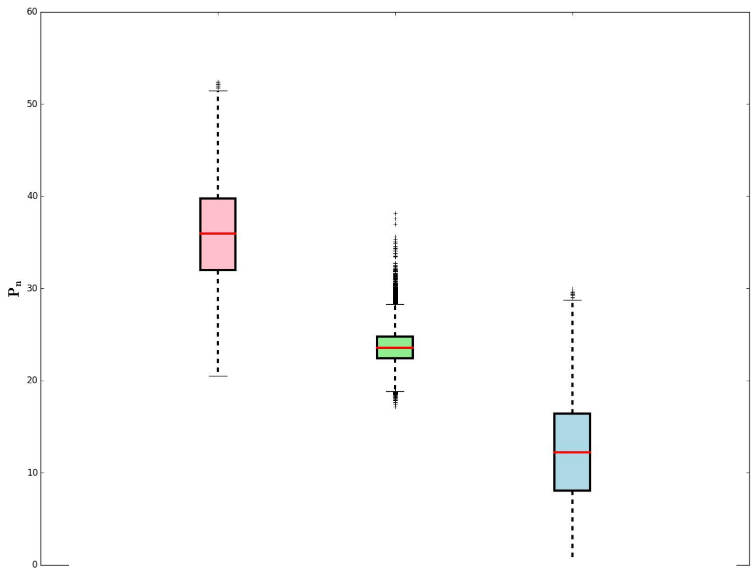
DP decomposition stats

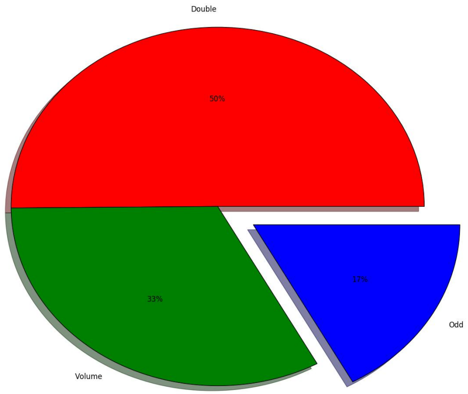
Urban Patch 1 (P1)





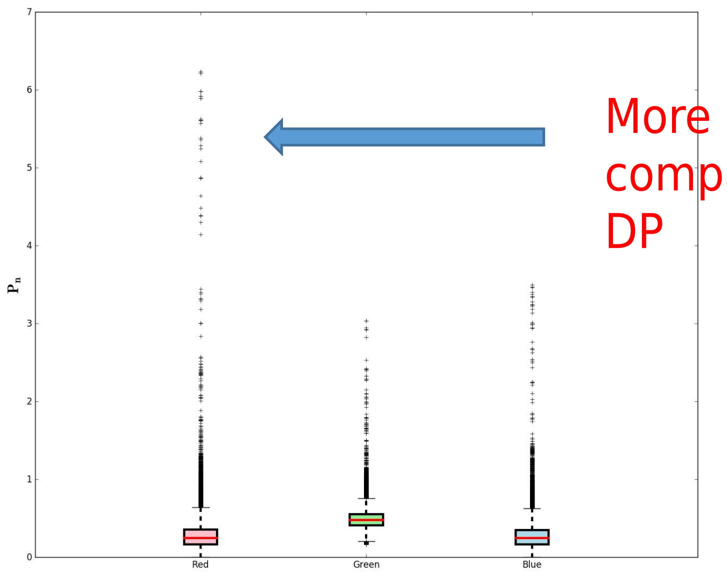
Urban Patch 2 (P2)



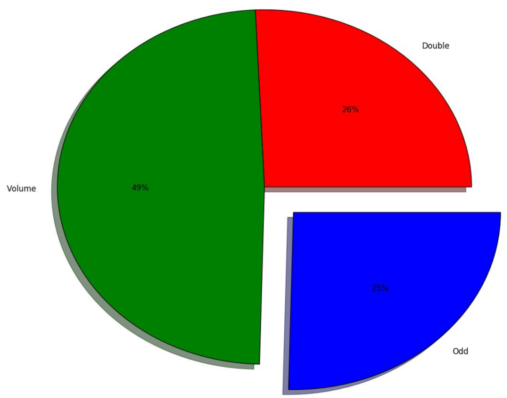


CP decomposition stats

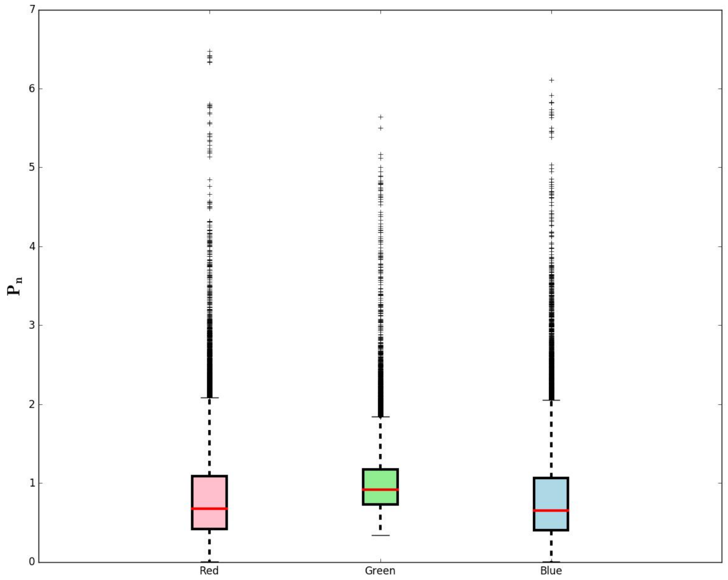
Urban Patch 1 (P1)

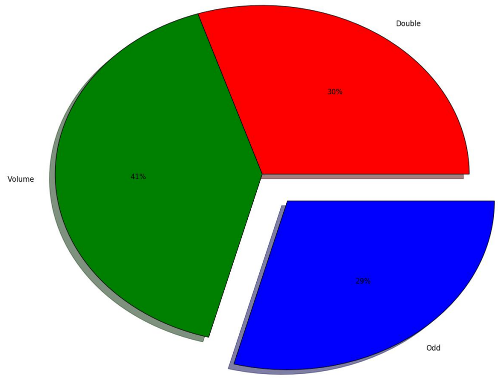


More outliers compared to DP

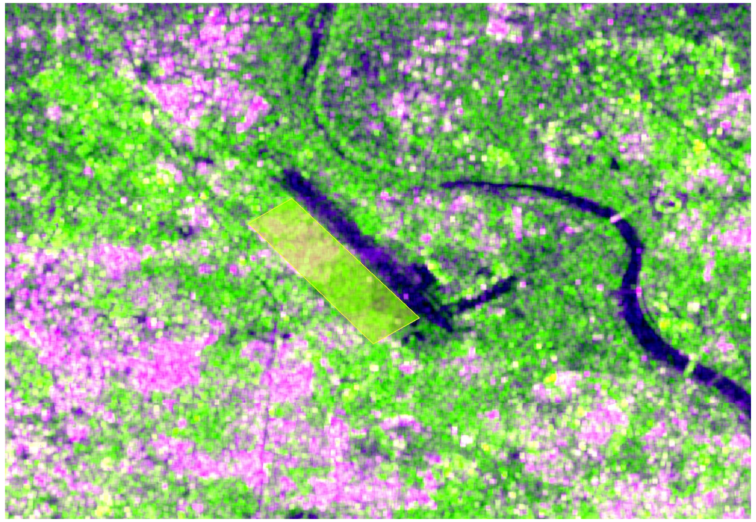


Urban Patch 2 (P2)

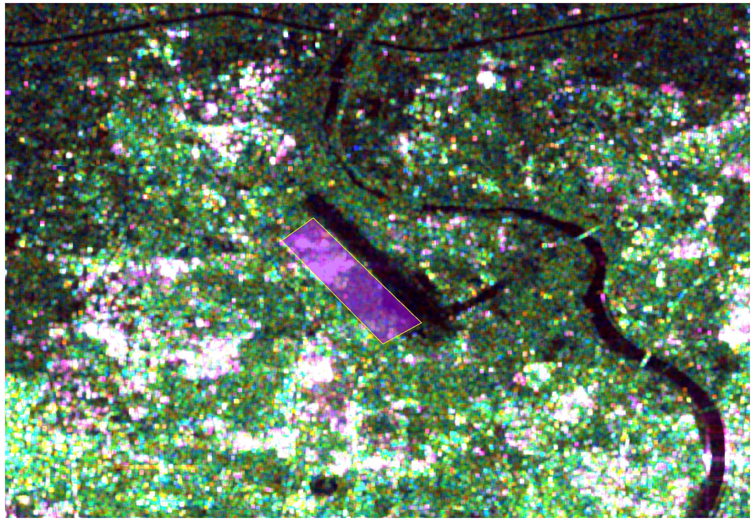




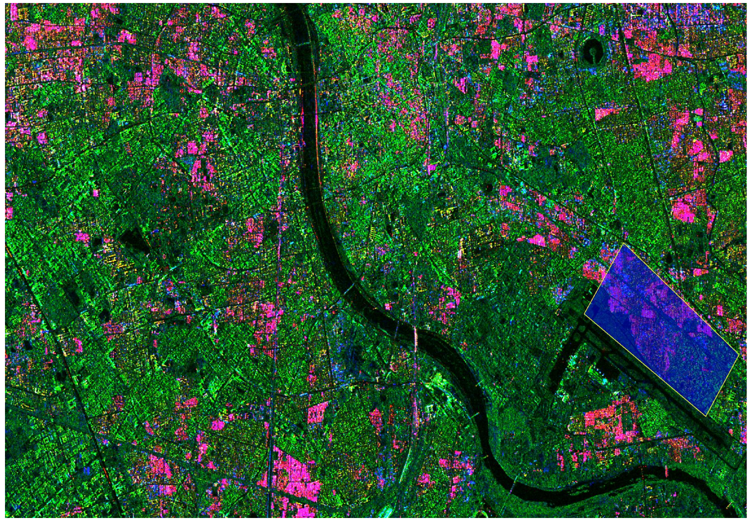
Comparing with FP decomposition stats



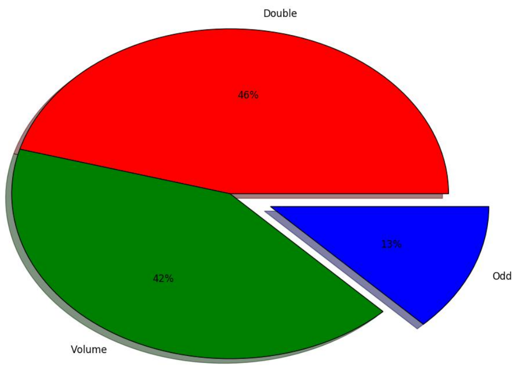
DP model-based decomposition



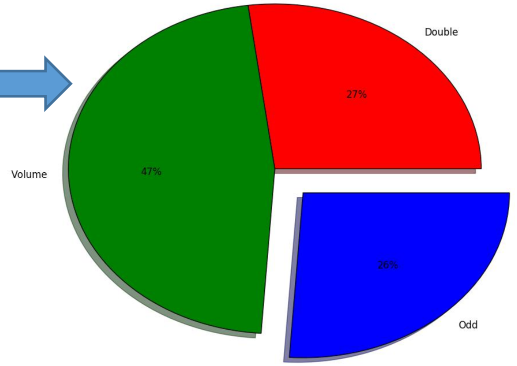
CP m-chi decomposition

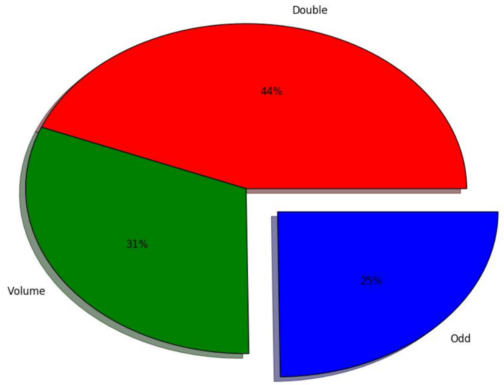


FP Yamaguchi decomposition

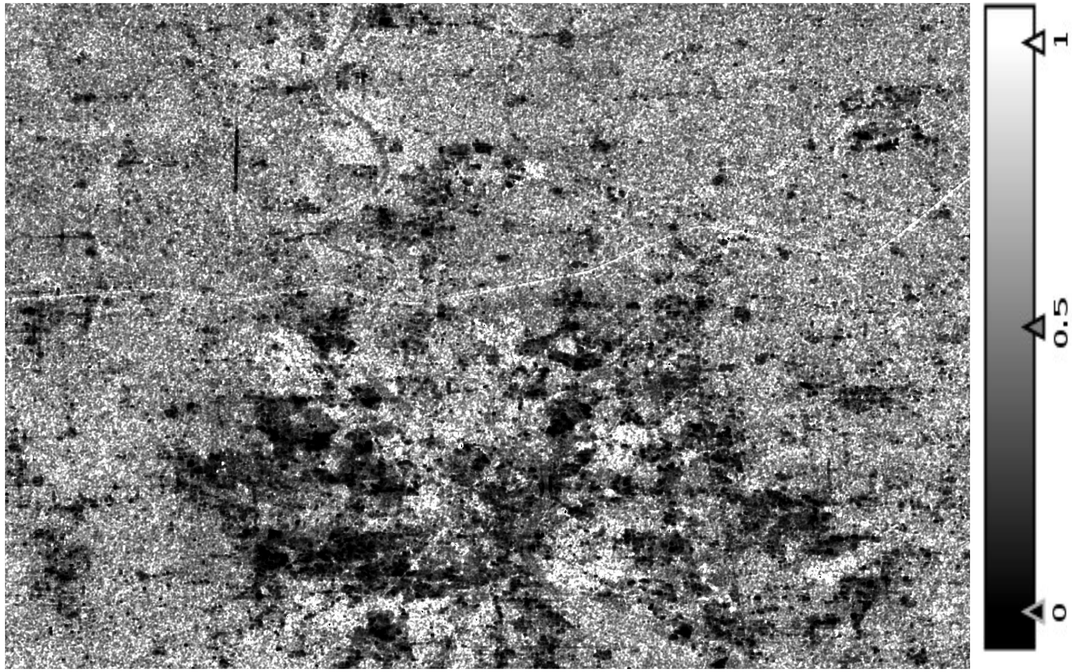


Over estimating volume scattering

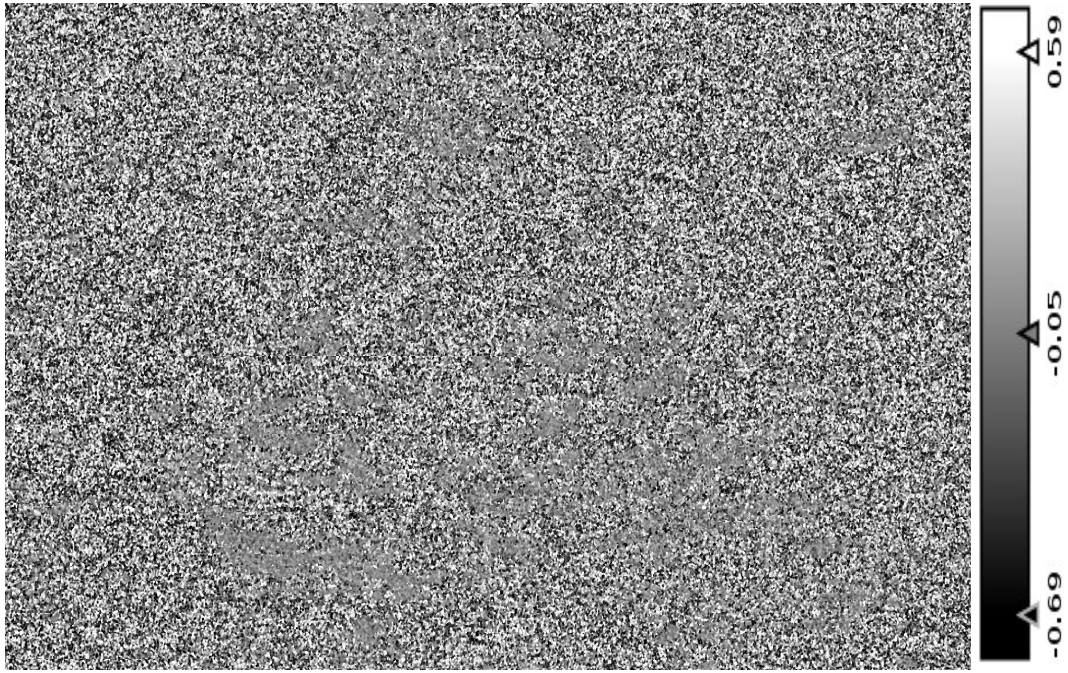




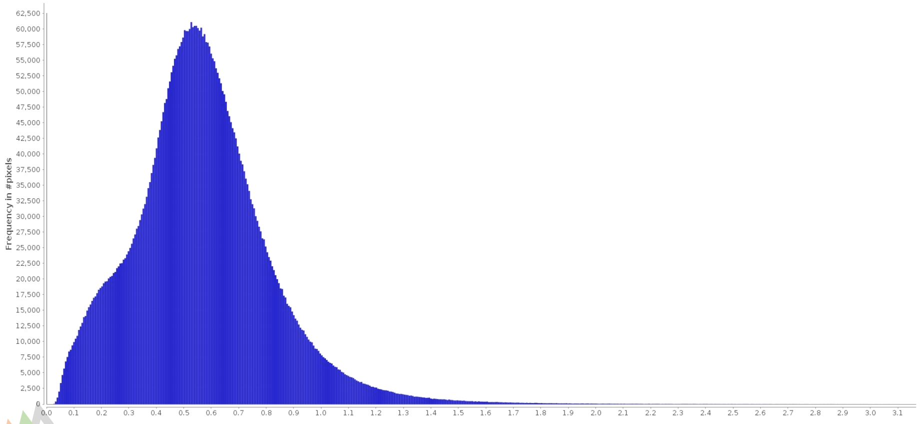
Digging deeper - The α & χ angles

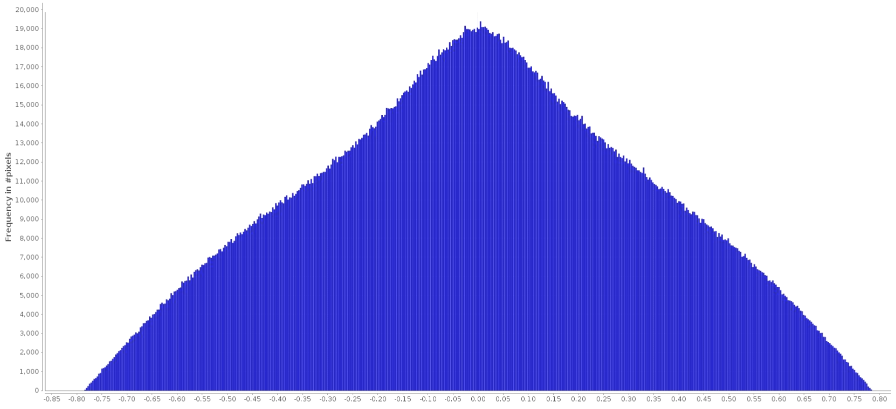


The α angle from the dual-pol decomp.

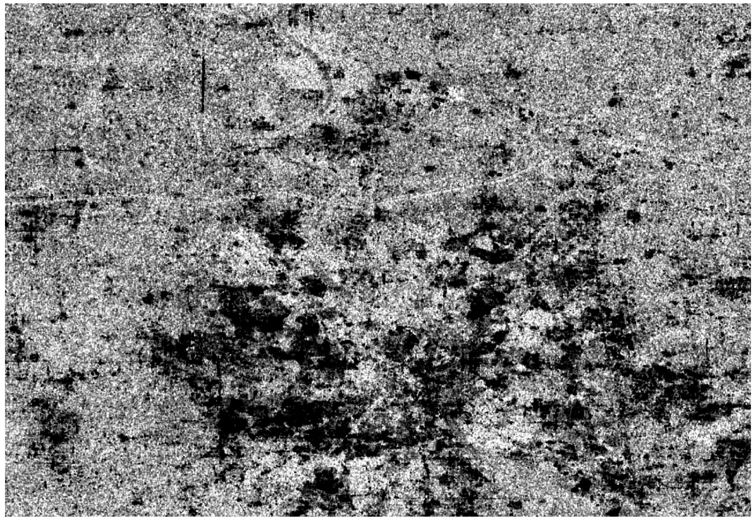


The χ angle from the compact-pol decomp.

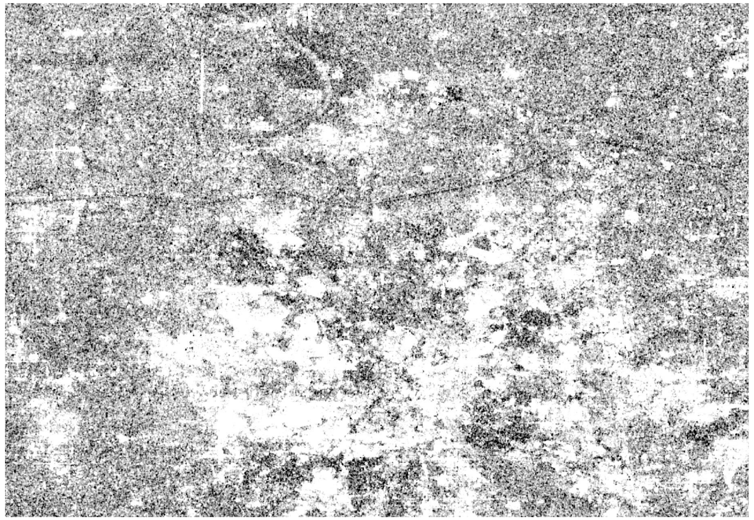




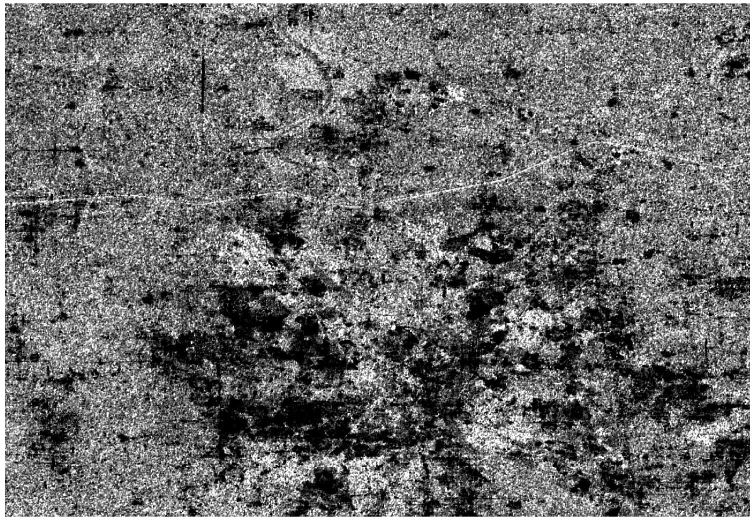
The H-A-ALPHA decomposition of the dual-pol dataset



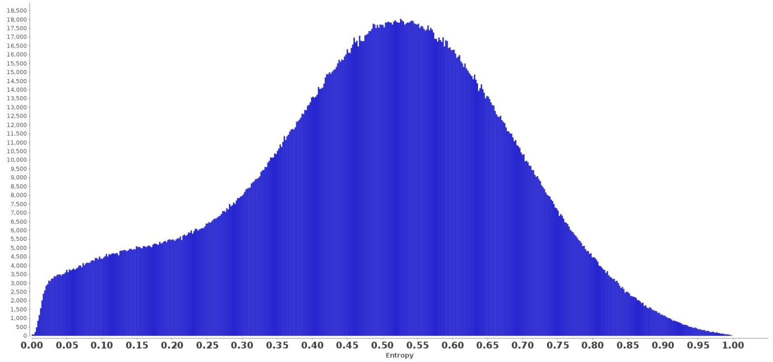
Entropy (H) parameter

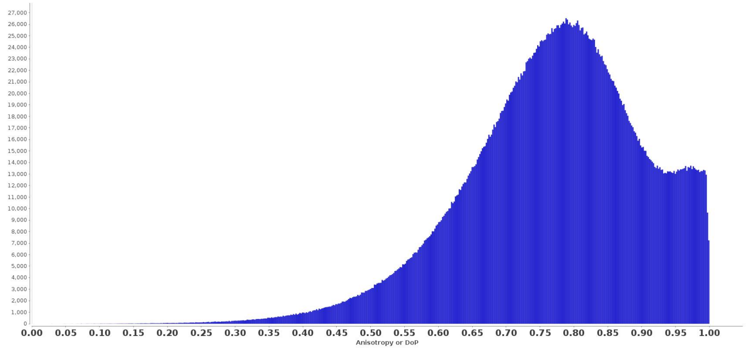


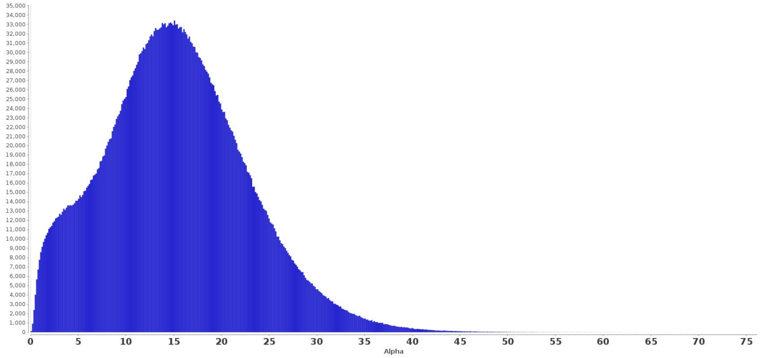
Anisotropy (~DoP) parameter



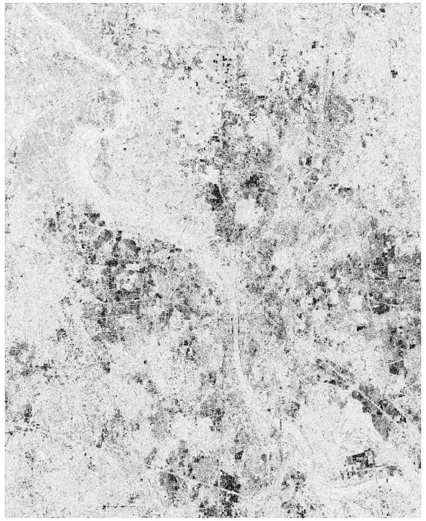
Alpha angle parameter



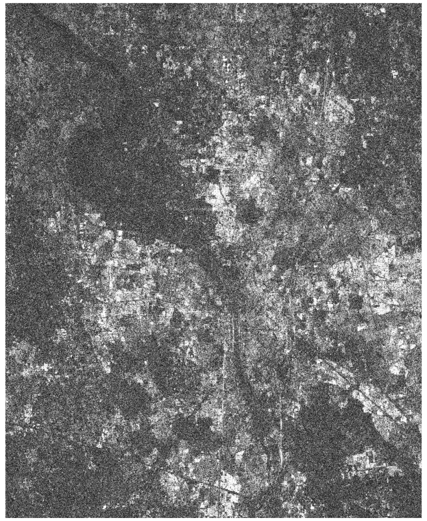




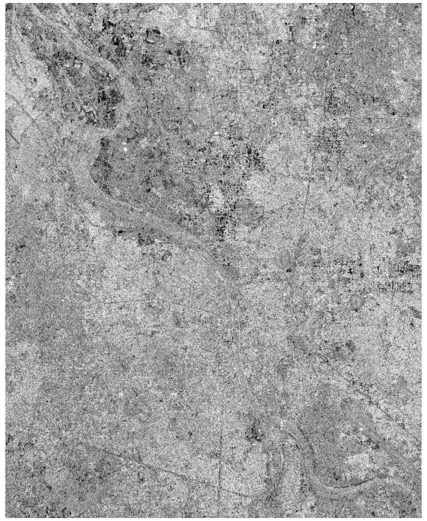
The H-A-ALPHA decomposition of the full-pol dataset



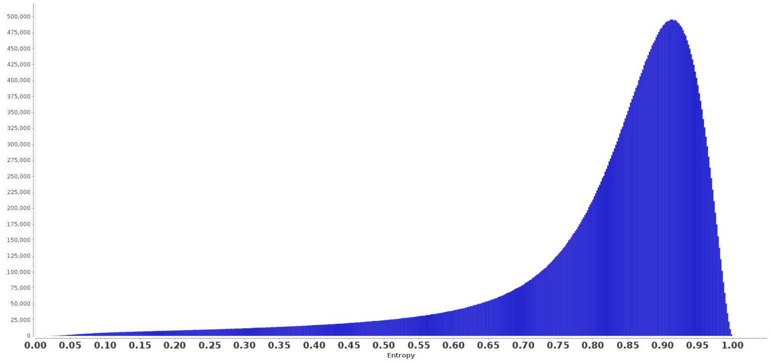
Entropy (H) parameter

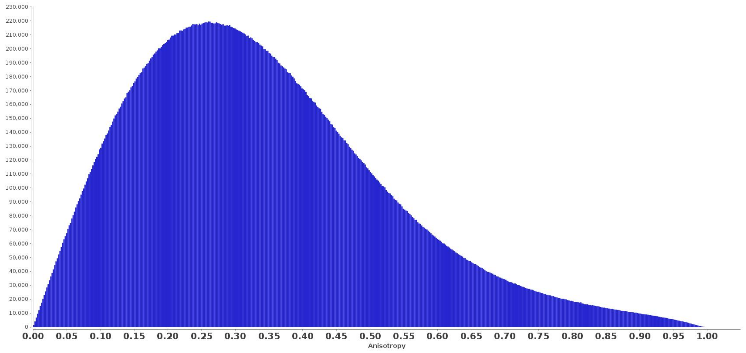


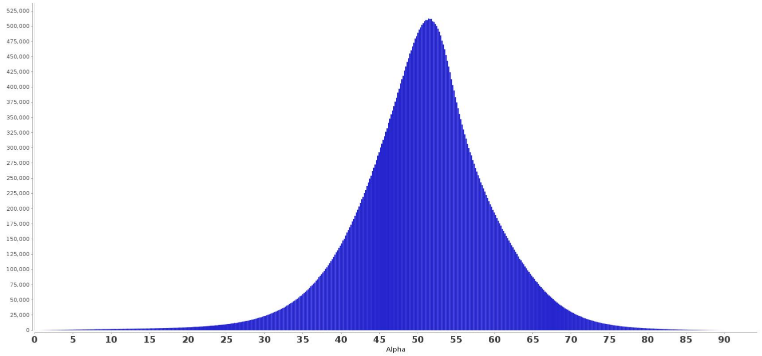
Anisotropy (A) parameter



Alpha angle parameter







The takeaways

- The model based dual-pol decomposition appear to be closer to the result produced by the full-pol decomposition over Ahmedabad city urban targets, consistently producing more double bounce power as expected. The compact-pol decomposition methodology largely over emphasized volume scattering power relative to the DP case.

- Both dual-pol and compact-pol decompositions introduced significant deviations from the full-pol result.

- The **α** angle (either derived through an H-Alpha decomposition paradigm or through the model-based decomp.) is found to be more sensitive to the urban features as compared to the **χ** angle of the compact-pol decomposition.

- The H-Alpha decomposition on the dual-pol data is found to be sensitive to urban features, with alpha having a much compressed dynamic range as compared to the full-pol alpha parameter.

- While the fully polarimetric anisotropy parameter is found to be rich in information, the dual-pol anisotropy just reproduced the DoP parameter.

- Overall, the MRS SCANSAR mode limited polarimetry offers great opportunity to do polarimetric analysis of various features over a much larger area with unprecedented repetitiveness. Exciting news for RS application scientists!

Thank you for your attention