EOS-04 Data Products

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EOS04 Highlights

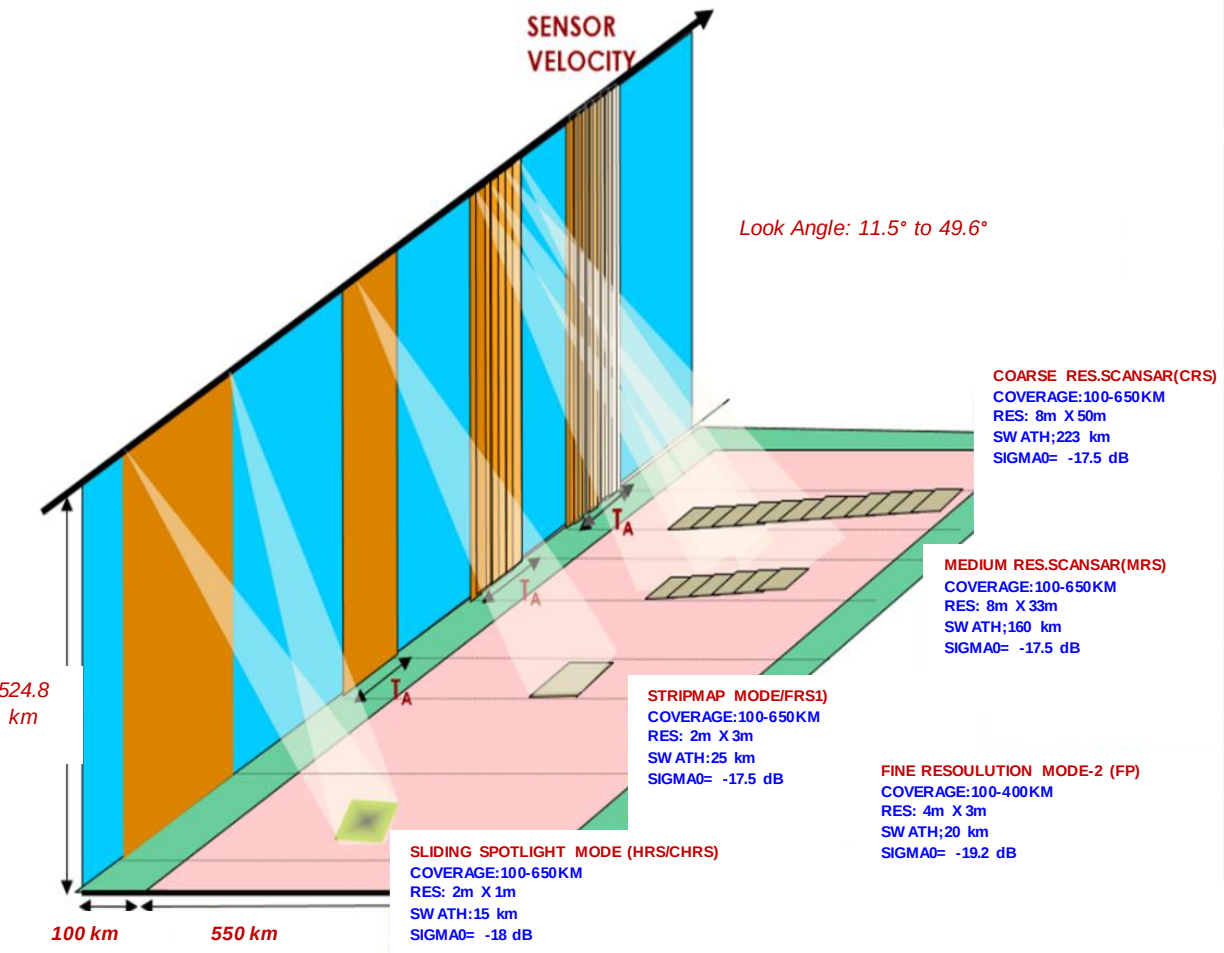
Mission & Payload :

- Centre frequency Changed to 5.4 GHz
- Orbit change to 524.8 km altitude
- Full polarisation in Stripmap and ScanSAR modes
- Flexible beam pointing – 0.1 deg incidence angle
- Special beams in far-range look angles identified for imaging polar regions.
- Improved internal calibration - Pre- & post-Cal (Replica & Noise)
- Pulse width changed w.r.t duty cycle
- Experimental Interferometric mode
- Left / Right Look definition is changed compared to RISAT1

Data Products

- ScanSAR SLC introduced to enable polarimetry/
- Calibration using system parameters and Amazon verification
- ARD Mosaic products introduced
- Higher level poalarimetric products (Level1C/3A)
- Improved geolocation accuracy

EOS-04 Imaging Geometry



MODES	FRS-1(FRS-1(FP))	FRS-2 (FRS-2 FP)	6-beam / 8-beam MRS / CRS	ScanSAR – FP(6/8/12 beam-Exp)	HRS
Chirp Bandwidth(MHz)	75	37.5	18.75	18.75	75
Worst Sigma Naught (dB)	- 17.5	-19.2	- 17.5	-16	-18
Swath (km)	25(20)	25(20)	115 / 160 / 223	87/115/168	15
Off-Nadir (km)	100 – 650 (100-400)	100-650 (100 – 400)	100 - 650	100 - 400	100 - 650
Incidence Angle	11-55 (11-36)	11-55 (11-36)	11-55 (11-36)	11-36	11-55
Slant range resolution(m)	2	4	8	8	2
Ground range resolution(m)	9.3 – 2.4	18.6 – 6.3	37.2-9.7	37.2-12.6	9.3 – 2.4
Azimuth Resolution(m)	3	9	23 / 33 / 50	23/33/50	1
Polarisation	S/D/C/F	S/D/C/F	S/D/C/F	S/D/C/F	S/D/C

(S-Single Pol: HH/VV, D-Dual Pol: HH+HV/VV+VH, C-Circular Pol: Circular Tx Linear Rx, F-Full Pol: HH+HV+VV+VH)

Levels of Products

SCENE WISE PRODUCTS	**Nominal Levels of Products**		
	Level 0	**RAW Signal Product** BAQ Decoded I/Q Samples and CEOS formatting	
	Level-1	**Geo-Tagged Product** Slant (Level-1A) / Ground (Level-1B) Range Product along with Grid File	
	Level-2A	**Geo-Referenced Product** UTM/Geographic Projection using Carto/SRTM/GTOPO DEM along with Grid File	
	Value Added Products		
	Level-1C	**Geo-Tagged Polarimetric Product** along with Grid File	
		DP/CP: 3 Layers (2 real Diagonal: 1 complex Off Diagonal Elements of COV Matrix) FP: 6 Layers (3 Real Diagonal : 3 Complex Off Diagonal Elements of COV Matrix)	
	Level-3A	**Geo-Referenced Polarimetric Product** in UTM/UPS projection along with Grid File	
		m-delta/m-chi decomposed (for circular polarisation mode)	Yamaguchi/Freeman decomposed (For Full polarization mode)
MOS AICS	**India Mosaic (for systematic coverage)**	**Large Area Mosaic**	**Full Strip Mosaic**

EOS-04 Data Product Formats

Img. Mode	RAW-L0 (CEOS)	L1-SLC (CEOS & GeoTIFF)	L1-Ground Range (CEOS & GeoTIFF)	L2- (GeoTIFF)
FRS-1	✓	✓	✓	✓
FRS-2	✓	✓	✓	✓
MRS	✓	✓ (GeoTIFF)	✓	✓
CRS	✓	✓ (GeoTIFF)	✓	✓
HRS	✓	✓ (GeoTIFF)	NA	✓

Table 1 Levels and Type of EOS-04 Data Products

✓ : *Available*

NA: *Not Available*

Other Processing Parameters

Earth Ellipsoid – WGS-84

Resampling Kernel – Cubic Convolution

Scene Orientation – North Oriented

Products Accuracy

Geometric: < 50 meters
Radiometric: ±1 dB

DEM: Carto / Copernicus 30m

L2 Products Projection Options: UTM/Geographic/UPS*

EOS-04 Data Products

Products Specifications

Mode	Level	Look Angle (deg)	Nominal Scene Size Azimuth * Range (Km)	Azimuth/ Range No of Looks	Azimuth/ Range Resolution(m) With Weighting	Azimuth/ Range Sampling (m)	Polarisation
HRS	L2	11-49	10*10	2/2	1/2.2	1.5*1.5	S/D/C
FRS1	L2	11-24	20*25	2/1	5.8/11 – 5.2	4.5/4.5	S/D/C
		24-49	20*25	2/1	5.8/5.2 – 2.8	2.25/2.25	S/D/C
FRS2	L2	11-49	20*25	2/2	6.6/8.6	5/5	S/D/C
MRS-8	L2	11-22	160*160	1/1	33/45-22	18/18	S/D/C
		23-49	160*160	1/2	33/43-22	18/18	S/D/C
MRS-6	L2	11-22	160*115	1/1	24/45-22	18/18	S/D/C
		23-49	160*115	1/2	24/43-22	18/18	S/D/C
CRS	L2	11-34	160*223	1/3	48/135-46	36/36	S/D/C
		34-49	160*223	1/4	48/60-45	36/36	S/D/C

Polarization Combinations

Transmit Polarization(Tx)	Receive Polarization(Rx)	Mnemonic
Vertical	Vertical	VV
Vertical	Horizontal	VH
Horizontal	Vertical	HV
Horizontal	Horizontal	HH
Right Circular	Vertical	RV
Right Circular	Horizontal	RH

Radiometric & Geometric Specifications

Parameters	Value
Geo-Location Accuracy (RMSE)	< 50 meters
Radiometric Resolution (SLC)	3.1 dB
PSLR	-17 dB
Relative Radiometric Accuracy	1 dB
Absolute Radiometric Accuracy	± 1dB

Volumes

Product Level	FRS-1	MRS	HRS	CRS	FRS-2
L0	1.04 GB	1.2 GB	3.6 GB	1.42 GB	720 MB
L1SLC	1.44 GB	2.0 GB	8.0 GB	1.78 GB	720 MB
L1GR	600 MB	275 MB	NA	178 MB	96 MB
L2	2.0 GB	680 MB	9.0 GB	412 MB	480 MB
L1C	800 MB	4.5GB	4 GB	4.1 GB	800 MB
L3A	320 MB	1.5 GB	9.0 GB	923 MB	320 MB

EOD-04 Radiometric Calibration

Calibration means characterizing the performance of end to end SAR system in terms of its ability to measure amplitude and phase of the backscattered signal.

Various System Parameters Taken care during calibration

- MGC
- Pulse-width
- Number of TRMs
- Count to Power Conversion Factor
- Transmit Power
- Receive Power
- Transmit & Receive Antenna Gain

Calibration

Radiometric Calibration
Amplitude and Phase

Geometric Calibration

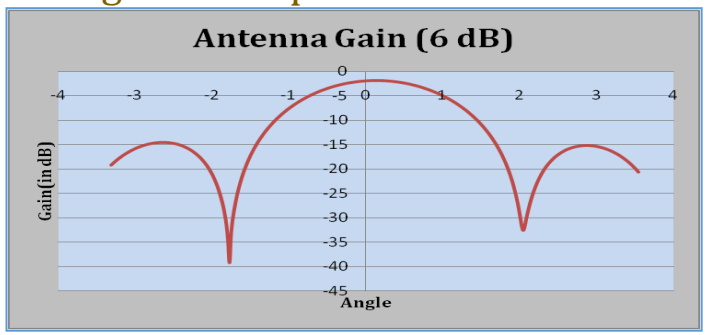
Natural Calibration Targets- Amazon Rain Forests

Corner Reflectors

- ✓ **RISAT-1**
- ✓ **EOS-04**
- ✓ **Sentinel-1A/1B**

Inter Sensor Calibration

Following Radar Equation has been used to derive the Calibration Constant for EOS-04 Data Products. Principle of Amazon Rain Forests Gamma0 uniformity over different incidence angles and hence Amazon C-Band Gamma0 values for different polarizations have been used for calibration. Model has been validated with several Amazon , Corner Reflectors acquisitions and Inter-Sensor C-Band Sigma0 comparison for RISAT-1.



Antenna Pattern for a beam from Payload Team

Radar Equation (SAR)

$$P_d = \frac{\lambda^2}{(4\pi)^3} \frac{P_T . G_A^2 . G_e^{\ E} . G_P}{R_{sl} \ . L_S . L_a} \sigma_0 . A_S + P_n$$

P_d = Received Power for Distributed Targets

P_t = Transmitted Power

G_A = Transmitted & Received Antenna Gain

G^E= Electronic Gain in Radar Receiver

G_P = Processor Constant

R_{sl} = Range Spread Loss

L_s = System Loss term

L_a = Atmospheric Attenuation

A_s = Scattering Area

P_n = Additive Noise

where

$$R_{sl} = R^3$$

$$G_A^{\ 2} = G_t^{\ A}(\theta_{el}, \theta_{az}) . G_r^{\ A}(\theta_{el}, \theta_{az})$$

$$G(\theta_{el}, \theta_{az}) = G_{el}^{\ A}(\theta_{el}) . \hat{G}_{az}^{\ A}(\theta_{az})$$

$$\hat{G}_A(\theta_{az}) = \int_{\theta_{az}-\Delta\theta}^{\theta_{az}+\Delta\theta} G_{az}(\theta) d\theta$$

R = Range

G_t = Transmit Gain

G_r = Receiver Gain

p_r = Image Pixel Dimension in Range

p_a = Image Pixel Dimension in Azimuth

$$A_s = \frac{p_r . p_a}{\sin\theta_{ir} . \cos\theta_{ia}}$$

$$P_n = F.k.B.T$$

Source : University of Zurick

Finally, $P_d = K . \frac{P_T . G_t(\theta_{el}) G_r(\theta_{el})}{R^3 . \sin(\theta_{ir})} \sigma_0$ where $\theta_{el}(each \quad pixel) = f(R, H)$ & $\sigma_0 = C . \frac{R^3 \sin(\theta_{ir})}{G^2(\theta_{el}) . n_{TR}} . DN^2$

Application of DEM ensures appropriate swath selection and correct radiometric correction

Calibration:EOS-04 Data Products

EOS-04 images for different polarizations are available as **Beta-Naught (Beta0) images** (RISAT-1) were Sigma0 images). Following is the Calibration Equation for generating Sigma-Naught (Sigma0) for EOS-04 Data Products.

$$\sigma_0\,(dB) = 10log10(DN^2 - N) + 10log10\left(\sin i_p\right) - K_{dB}$$

where,

σ0 (dB) is the backscattering coefficient Sigma0 in dB

DN is the Digital Number available in the product for different polarizations

N is the IMAGE_NOISE_BIAS available for all polarizations in BAND_META.txt. As noise correction has been applied in EOS-04 images, an image noise bias "N" has been added on EOS-04 images to avoid negative numbers/nulls in images. Thus, (DN ^{2}- N) may result in negative values and hence should be avoided in any computations.

*i_p is the per pixel incidence angle and can be obtained fron*grid.txt file available with product*

K_{dB} is the Beta0 Calibration Constant for different polarizations available in BAND_META.txt and in product.xml also

EOS-04 : Polarimetric Calibration Model [1][2]

$$S' = A \begin{bmatrix} s_{vv} f^2 e^{i(\phi_t + \phi_r)} & s_{vh}\left(\frac{f}{g}\right) e^{i(\phi_r)} \\ s_{hv} f g e^{i(\phi_t)} & s_{hh} \end{bmatrix}$$

Polarimetric Parameter	Description
A	Absolute Calibration Constant
f	Co-Polarization Channel Imbalance
G	Cross-Polarization Channel Imbalance
$\varphi_t = \varphi_{t,v} - \varphi_{t,h}$	$\varphi_{t,j}$ is the phase error incurrent when transmitting polarization j
$\varphi_r = \varphi_{r,v} - \varphi_{r,h}$	$\varphi_{r,j}$ is the phase error incurrent for receiving polarization j
S'	Measured Scattering Matrix

$$S_{cr} = \sqrt{\sigma_{cr}} \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$$

S_{cr} = Scattering matrix for a trihedral CR

Parameters (A , f , $\phi_t + \phi_r$) estimated from interpolated corner reflector response peaks

Parameters (g , $\phi_t - \phi_r$) estimated by coherent average of distributed targets

Cross-Talk parameters derived from distributed targets by applying the model described in [1]

1. Alexander G. Fore, Bruce D. Chapman, Brian P. Hawkins, Scott Hensley, Cathleen E. Jones, Thierry R. Michel and Ronal J. Muellerschoen, "UAVSAR Polarimetric Calibration", IEEE Trans. Geosci. Remote Sens. vol. 53 no. 6, June 2015

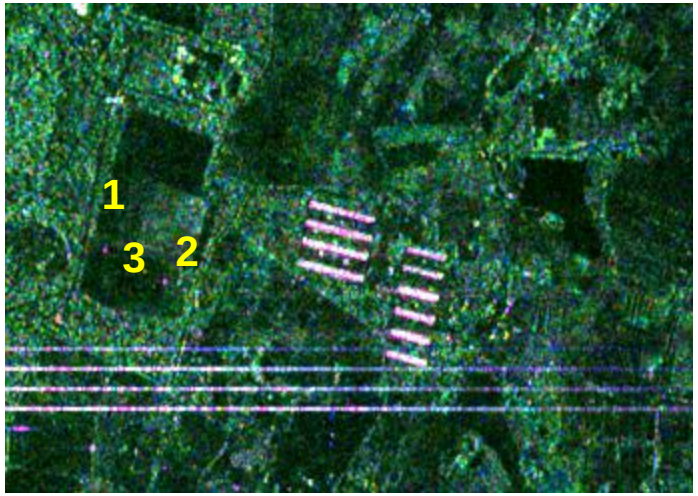
2. A Quad Polarimetric SAR calibration Algorithm using Rotation Symmetry, Guangde Sun, Zhen Li & Lei Huang, International Journal of Remore Sensing, Taylor and Francis, https://doi.org/10.1080/01431161.2018.1552817

FRS-1 Hybrid Polarimetric Phase Calibration : RH-RV

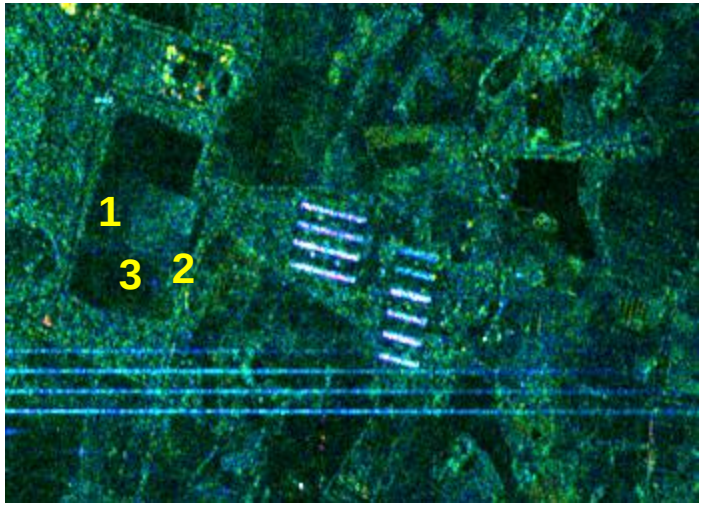
Site: Shadnagar DOP: 05 March 2022 Strip-Id : 73

S.No.	Corner Reflector
1	Sqr. Trihedral
2	Sqr. Trihedral
3	Sqr. Dihedral

Un-Calibrated Data



Calibrated Data



Channel Imb.	0.988766
Phase Imb.	-15.68 deg.

.	Reflector
1	Sqr. Trihedral
2	Sqr. Trihedral
3	Sqr. Dihedral

CP Parameters	CR# 1	CR #2	CR #3
Deg. Of Polarization (m)	0.9965	0.9997	0.9604
Deg. Of Circular Pol.	-0.3008	-0.2367	0.7904
Circular Pol. Ratio	1.8607	1.6203	0.1170
Axial Ratio	-0.1545	-0.1201	0.5249
Relative Phase (δ)	-17.6441	-13.735	117.874
Ellipticity Angle (χ)	-8.7555	-6.8469	26.1151

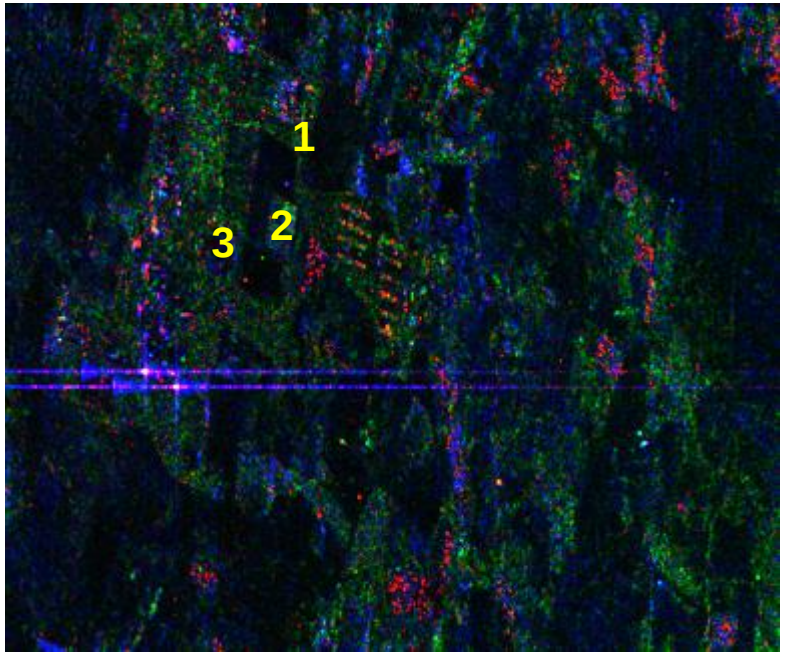
CP Parameters	CR# 1*	CR #2*	CR #3*
Deg. Of Polarization (m)	0.9967	0.9996	0.9601
Deg. Of Circular Pol.	0.9928	0.9968	-0.6171
Circular Pol. Ratio	0.0036	0.0015	4.2233
Axial Ratio	0.9148	0.9277	-0.3639
Relative Phase (δ)	92.515	87.616	-43.430
Ellipticity Angle (χ)	41.563	42.727	-19.052

*To be verified on multiple Corner Reflector Acquisitions

FRS-1 Full Polarimetric Phase Calibration : HH-HV-VH-VV

Site: Shadnagar DOP: 12 March 2022 Strip-Id : 159

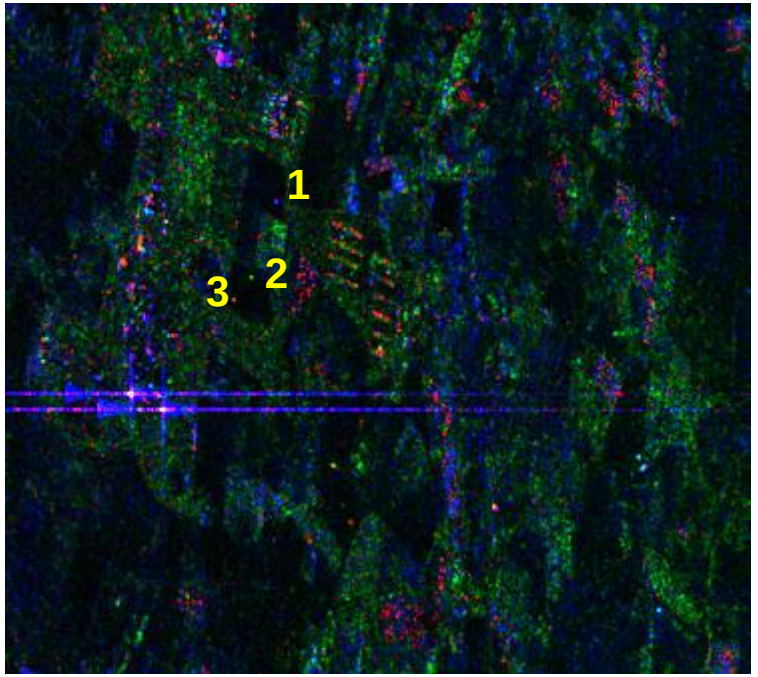
Un-Calibrated Data



S.No.	Corner Reflector
1	Sqr. Trihedral
2	Sqr. Trihedral (45^0)
3	Sqr. Dihedral (22.5^0)

FP Cal Parameters	Value
Co-Pol Channel Imbalance	1.0493
Co-Pol Phase Imbalance	-19.4806
Cross-Pol Channel Imbalance	0.99119
Cross-Pol Phase Imbalance	30.6788

Calibrated Data

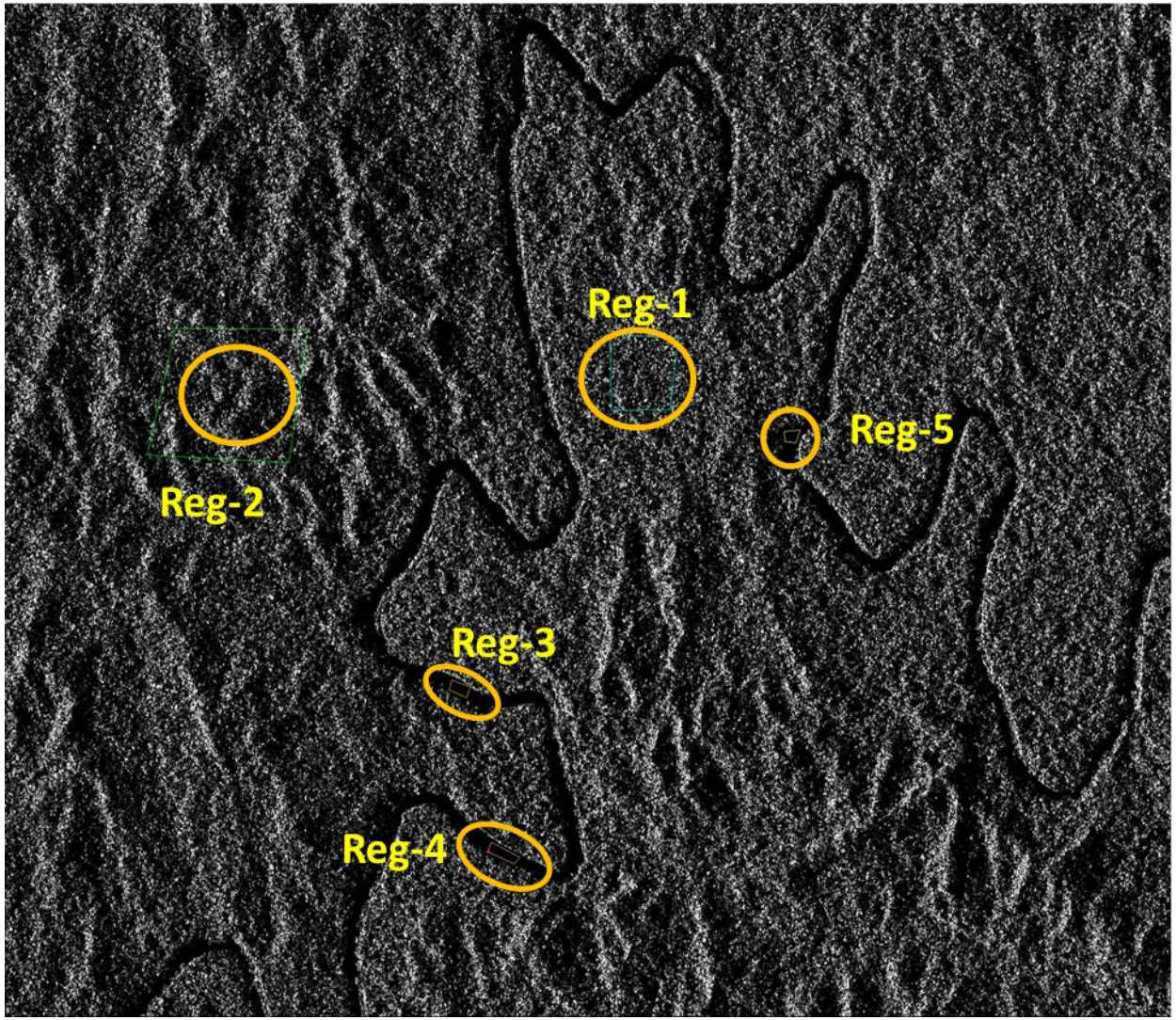


S.No.	Corner Reflector
1	Sqr. Trihedral
2	Sqr. Trihedral (45^0)
3	Sqr. Dihedral (22.5^0)

FP Cal Parameters	Value*
Co-Pol Channel Imbalance	~1.0
Co-Pol Phase Imbalance	~0.0
Cross-Pol Channel Imbalance	~1
Cross-Pol Phase Imbalance	~0.0

*To be verified on multiple Corner Reflector Acquisitions

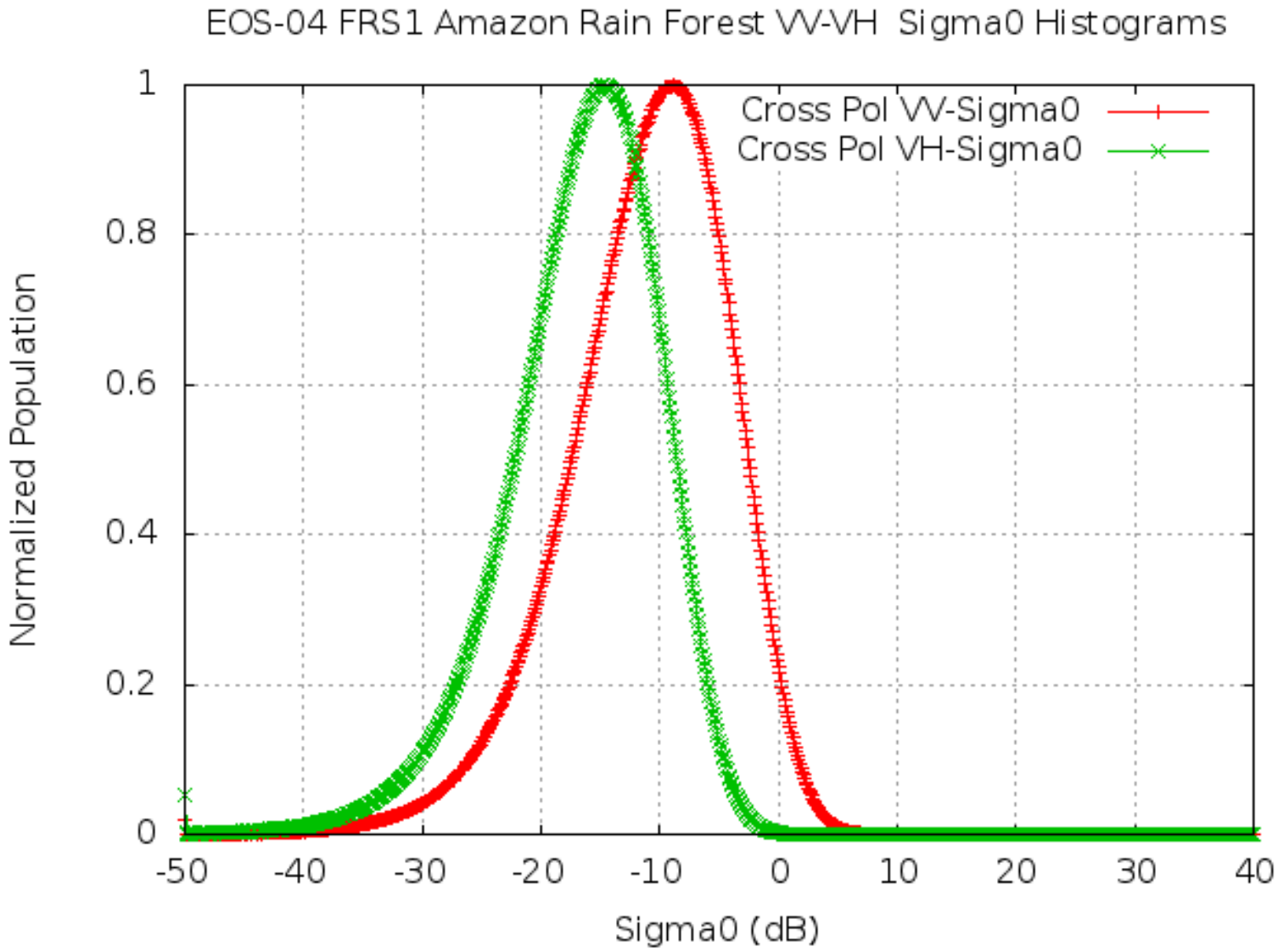
DOP: 10 March 2022 Strip Id: 131 Pol. VV-VH



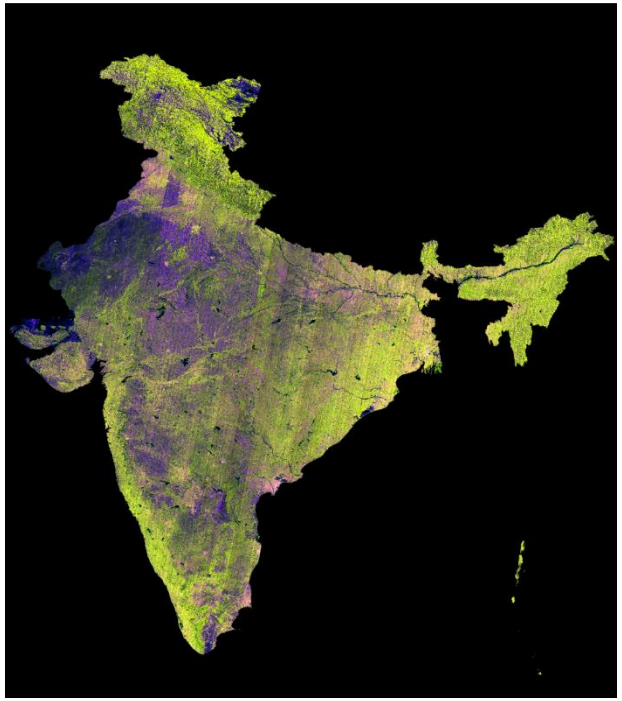
Reg-#	Reg. Type	VV Polrzn.		VH Polrzn.	
		γ0 (dB)	σ0 (dB)	γ0 (dB)	σ0 (dB)
Reg-1	Forest	-6.14	-7.06	-12.14	-13.06
Reg-2	Forest	-6.38	-7.30	-12.21	-13.13
Reg-3	River	-18.15	-19.07	-21.25	-22.17
Reg-4	River	-18.42	-19.34	-21.14	-22.06
Reg-5	River	-18.22	-19.14	-21.30	-22.22

NEσ0

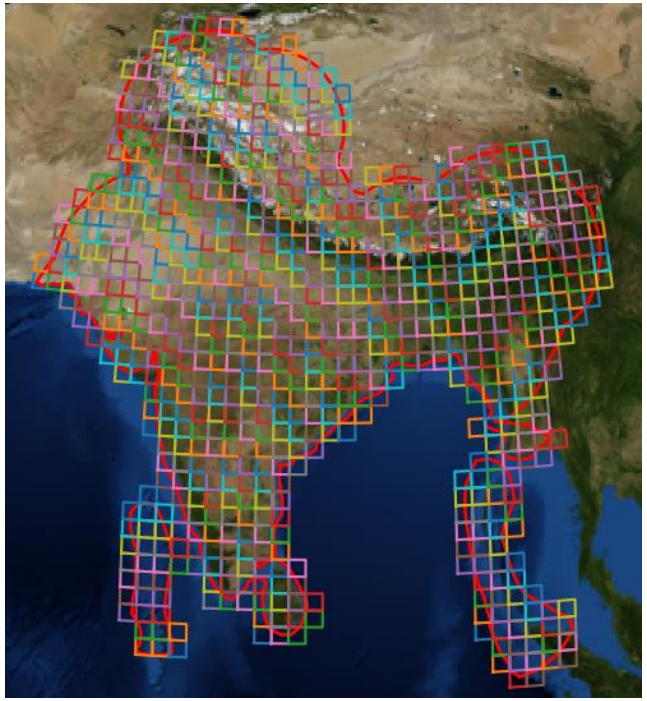
DOP: 10 March 2022 Strip Id: 131 Pol. VV-VH



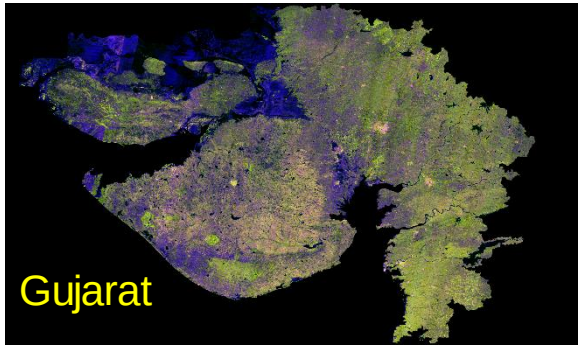
EOS-04 MOSAIC Products

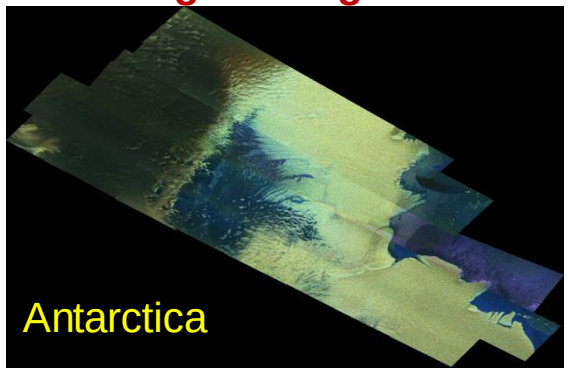


RISAT-1 India Gamma0 Mosaic



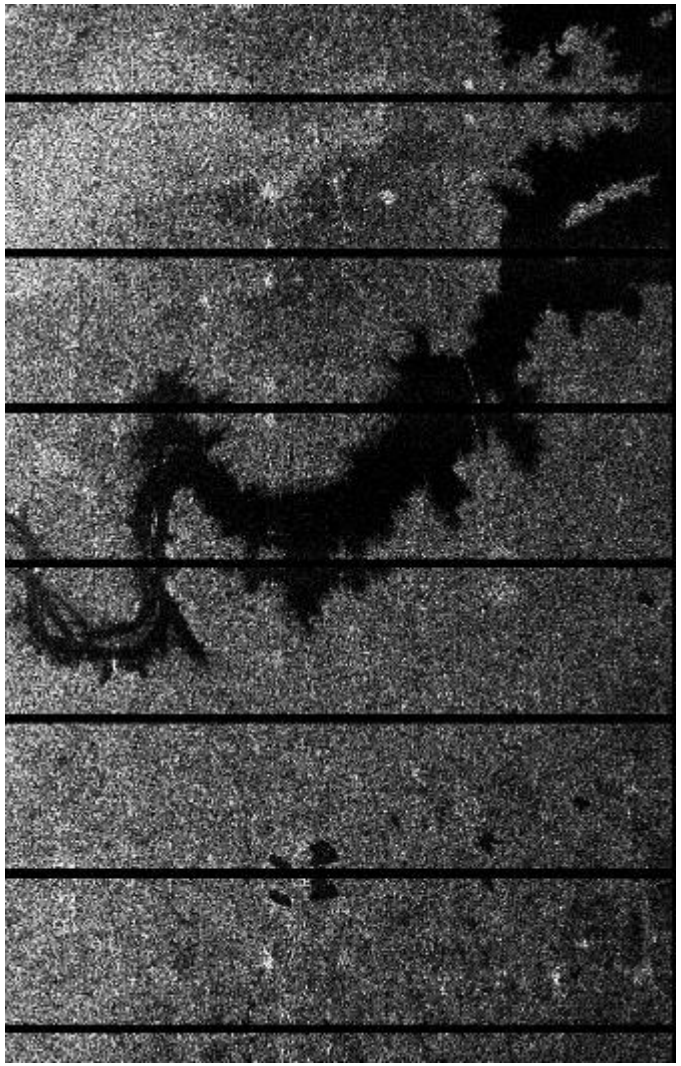
EOS-04 India Mosaic
1deg. X 1deg. Tiles



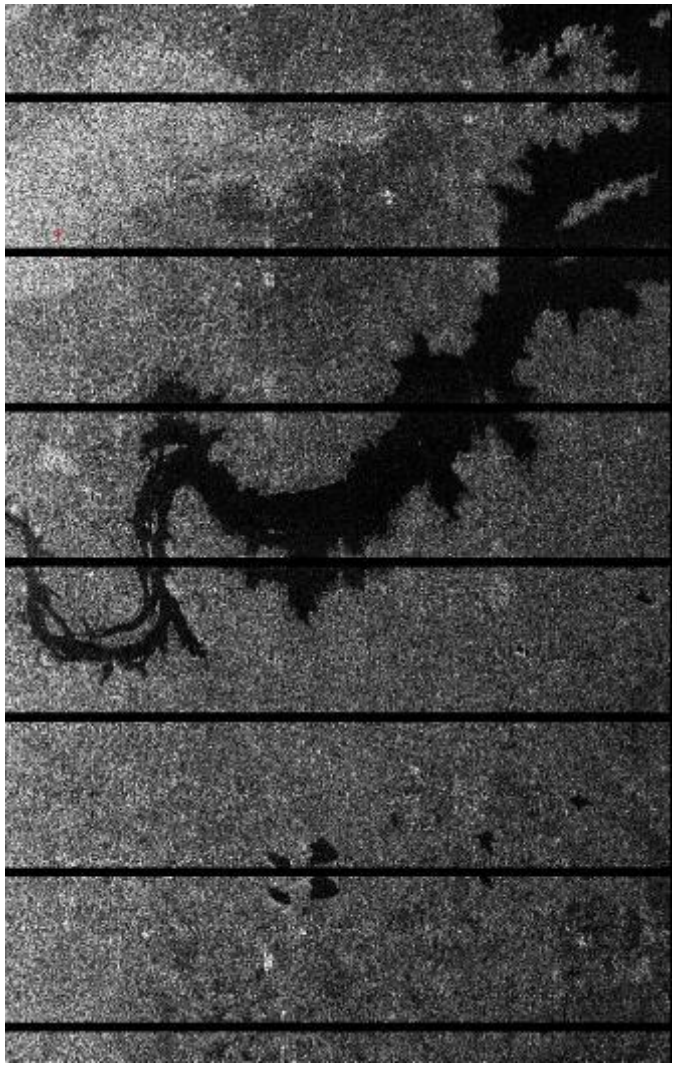


Specification	
1	RISAT-1A India Mosaic will be generated as a default mosaicked product for every Systematic coverage Cycle.
2	Every MRS scene for a Mosaicked product will be Registered to Reference Image enabling **time series analysis**.
3	Mosaicked output will be Application Ready Data (ARD) available as Gamma0 Image for each polarization (HH/HV) in Geographic Projection
4	MRS products have scan-pixel spacing of 18 meters.
5	Mosaicked output to be made available in 1deg. X 1 deg
6	Output Format : GeoTIFF ; Unsigned short Int
7	Date of acquisition of pixel is given as additional layer
8	Each tile can be ordered separately

Single Look Complex – 8 Beam ScanSAR Data- Hybrid Polarisation



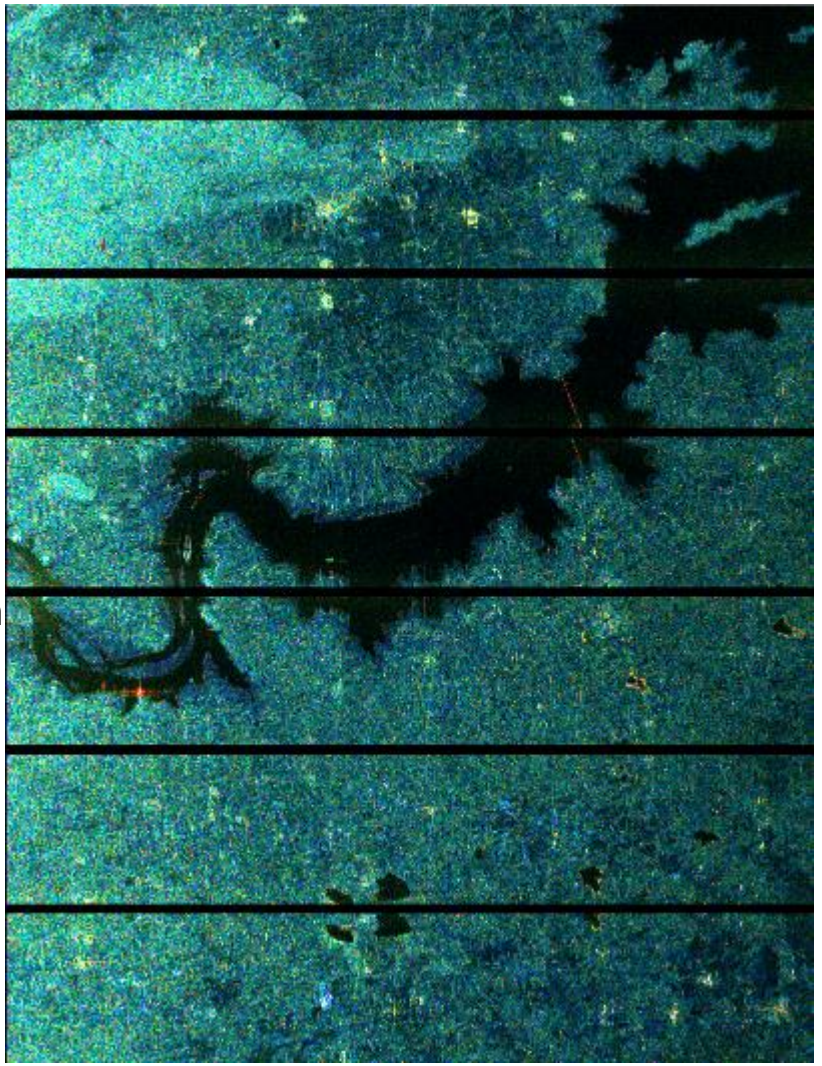
RH – Beam-3



RV – Beam- 3

Strip Id: 40
Scene No: 7

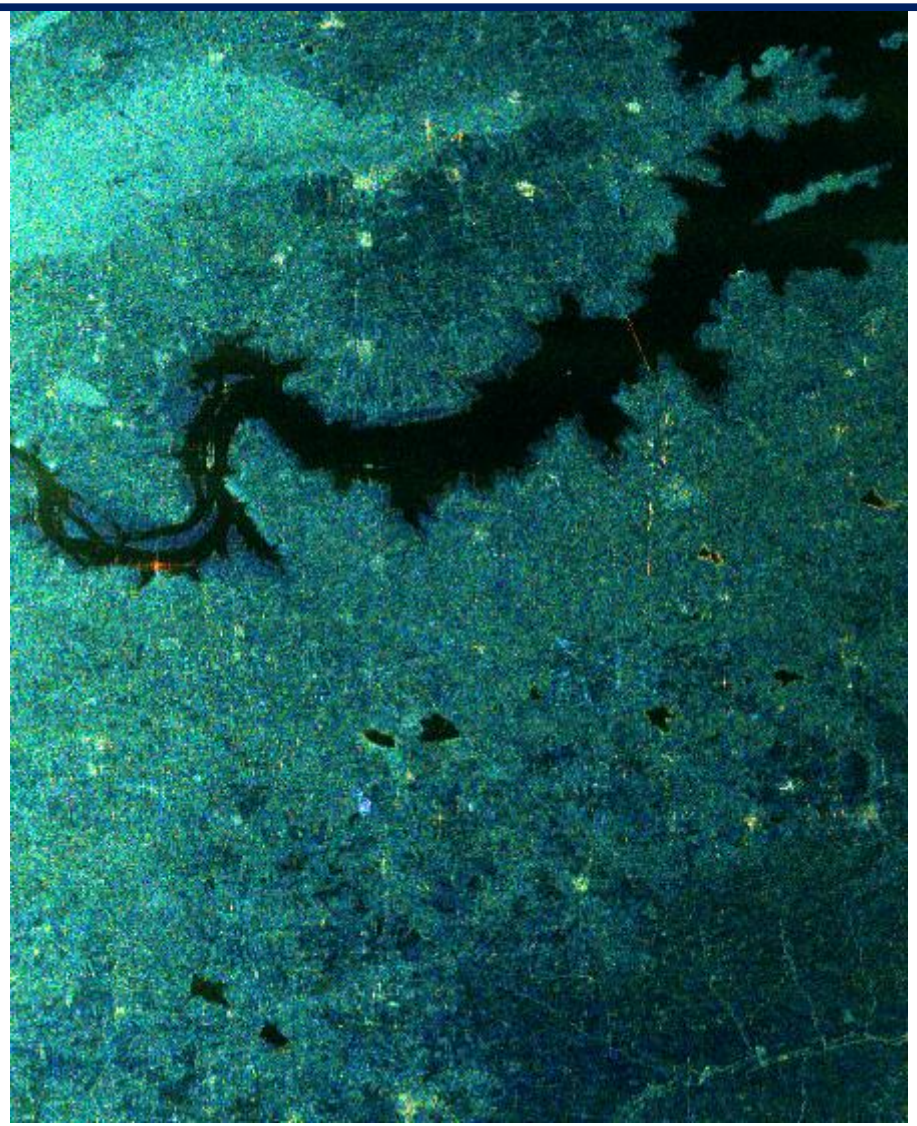
After Decomposition



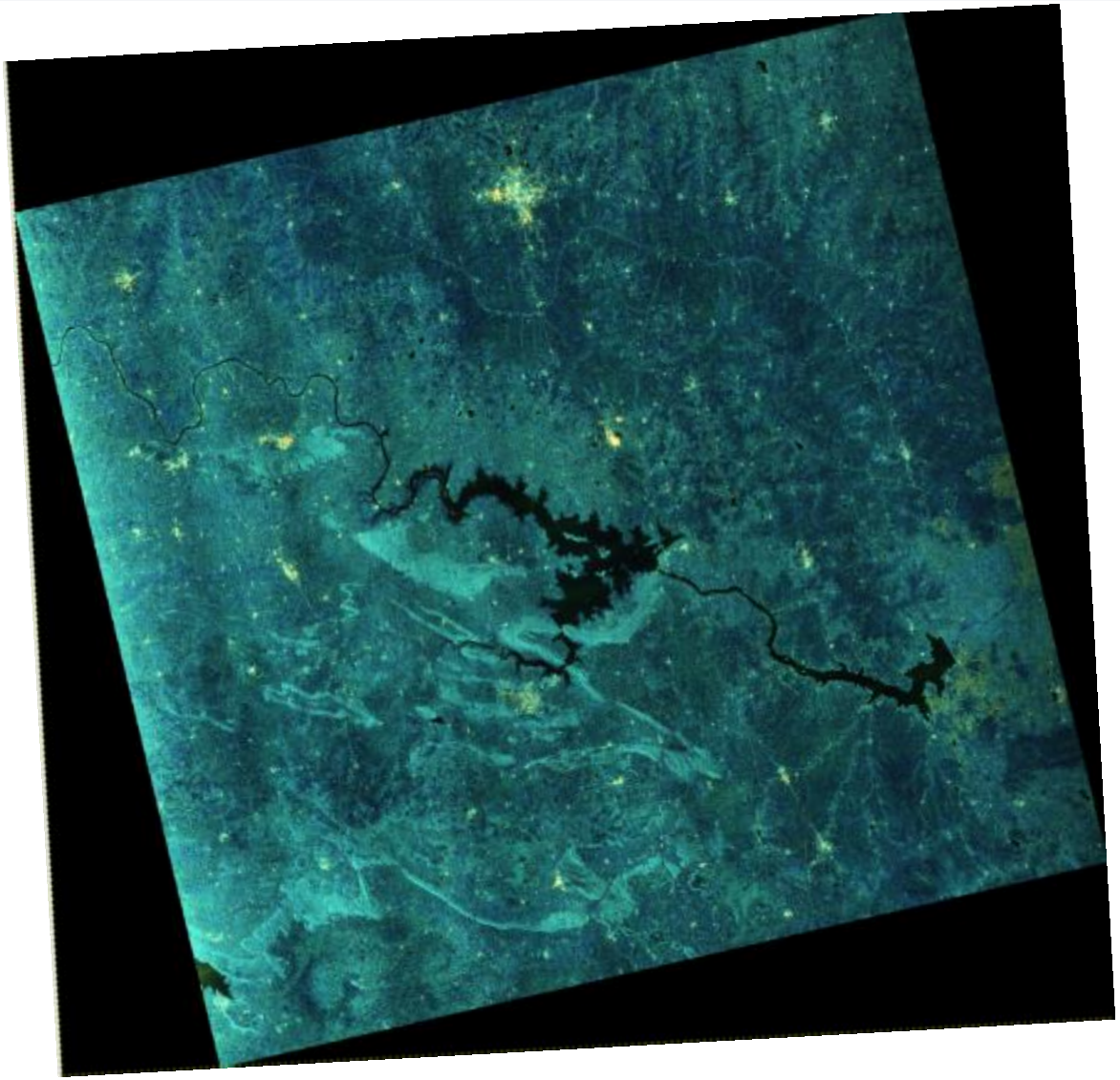
M-DELTA Burst Wise Decomposed Image o
Beam-3

R = Double G= Volume B = Surface

Single Look Complex – 8 Beam ScanSAR Data- Hybrid Polarisation



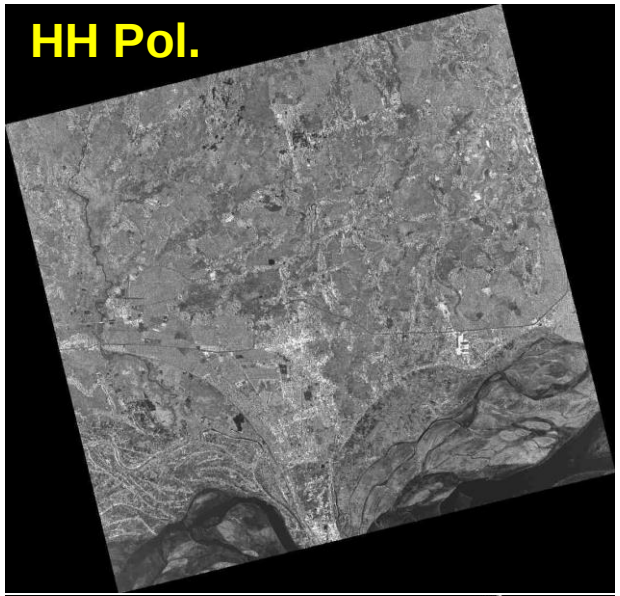
M-DELTA Decomposed
Burst Mosaicked Image of Beam-3

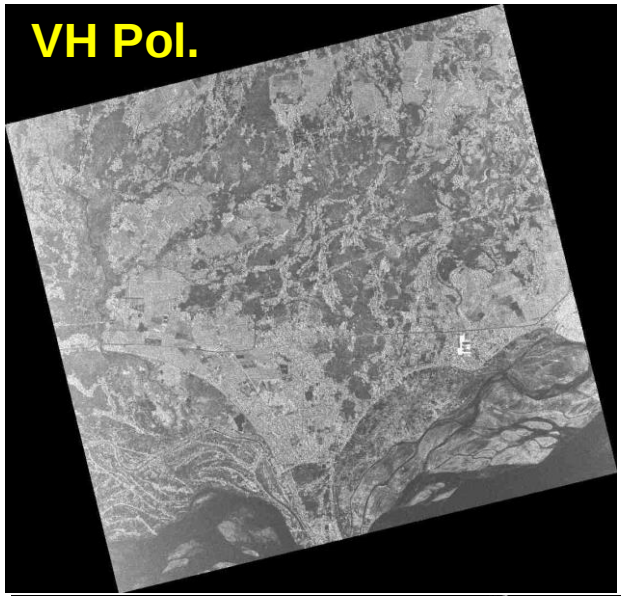


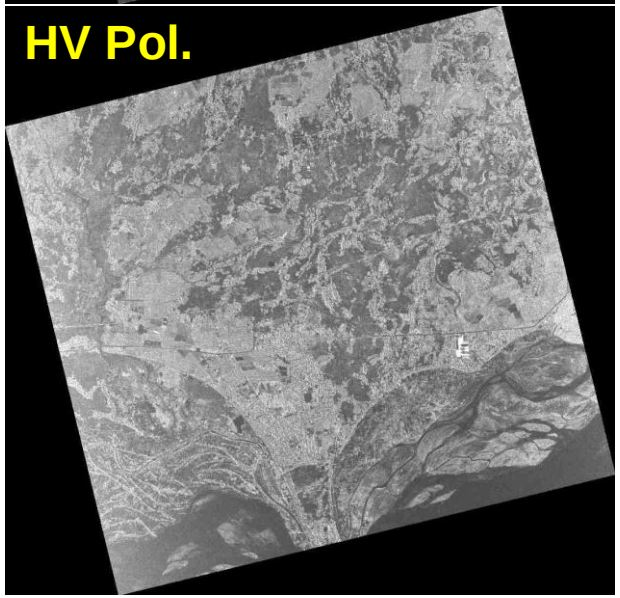
M-DELTA Decomposed – Geocoded - 8 Beam Mosaicked Image

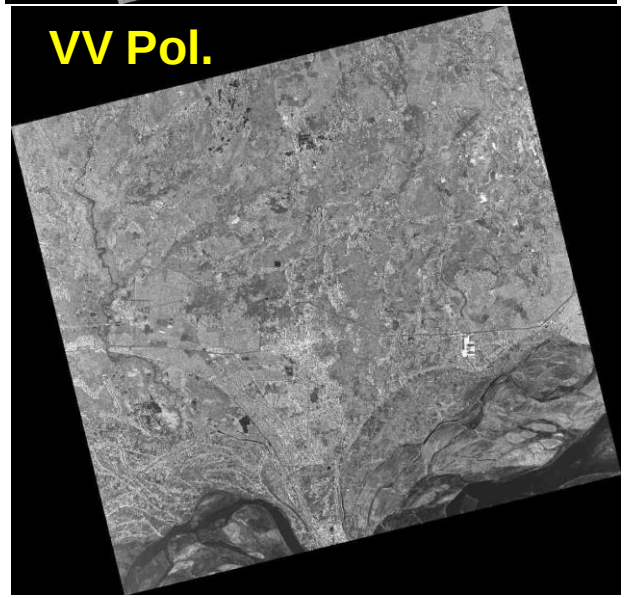
R = Double G= Volume B = Surface

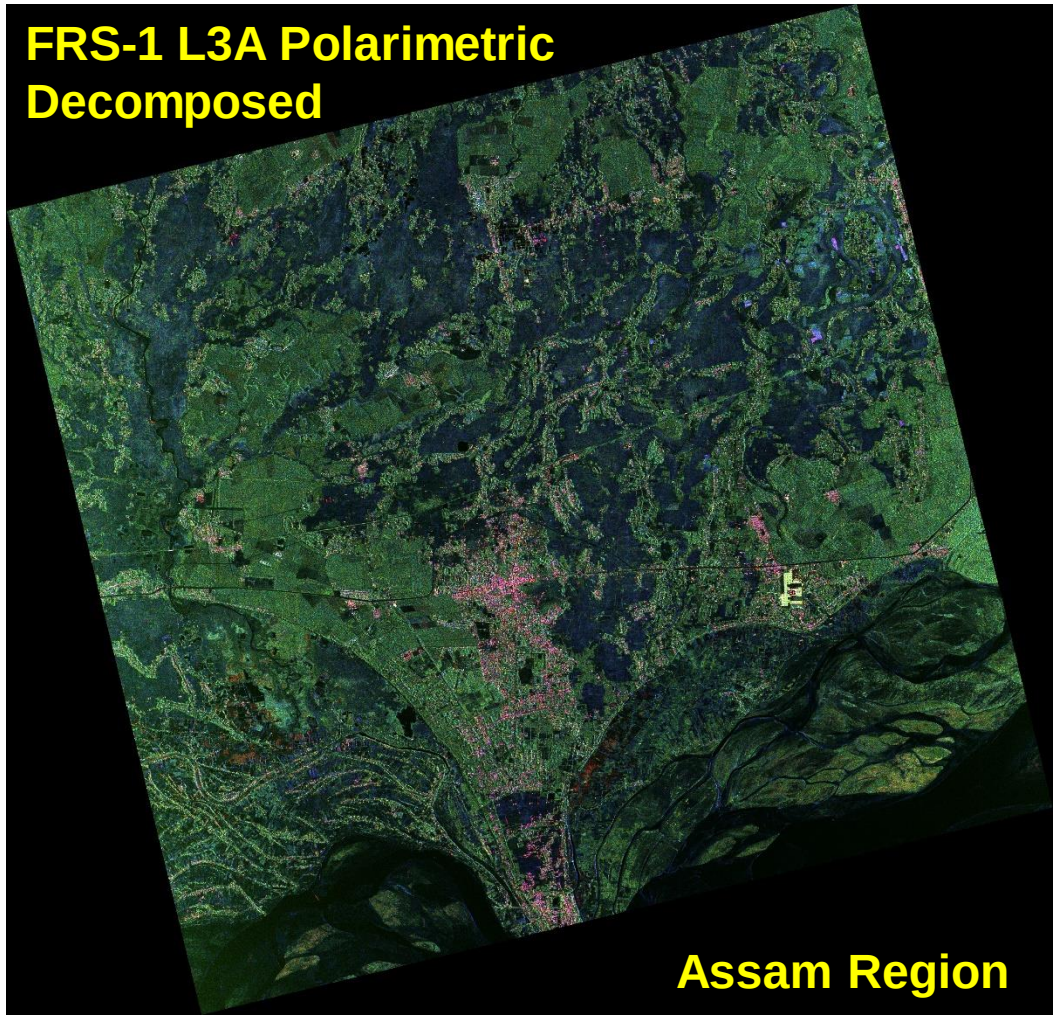
EOS-04 –FRS-1 Full Polarimetric Images











Yamaguchi Decomposition

Even	Volume	Odd

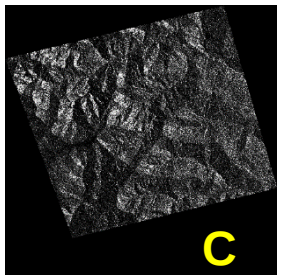
Product Contents :EOS-04 Data Products

Content	Description	Remarks
BAND_META.txt	Product Meta Parameters File	-
Grid Files	Polarization Wise Grid Files	Not available for Level-0 Product
Polarization Wise Image Files	Raw/Complex/Amplitude Image Files	1. Available in CEOS/GeoTIFF Format 2. Beam Wise Files for ScanSAR SLC
Product XML Files	XML File for Product Processing parameters	Available only for GeoTIFF Format
Polarization Wise Thumbnail Jpg Files	Browse Jpegs for Product quick view	Not available for Level-0 Product
Mask and LIA Files	Layover Masks and Local Incidence Angle Files	Available only for Level-2 data product
Covariance Matrix Elements	COV elements of Scattering Matrix	Available only for Level-1C data product
Even Odd Volume Scattering elements	Polarimetric Decomposition Layers	Available only for Level-3A data product

EOS-04 Data Products :: Level-2

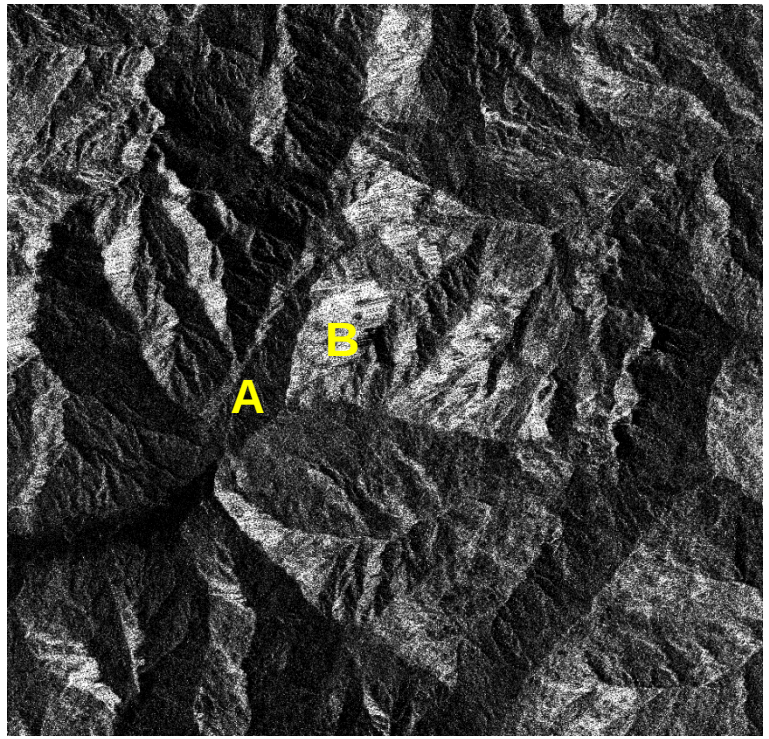
Local Incidence Angle Definition

Value	Significance	Region
0.0 to 90.0	Valid Incidence Angle Range	(A)
-1.0	Invalid Value (Masked region from Layover mask file)	(B)
-2.0	Region Outside Geo-Referenced Image	(C)

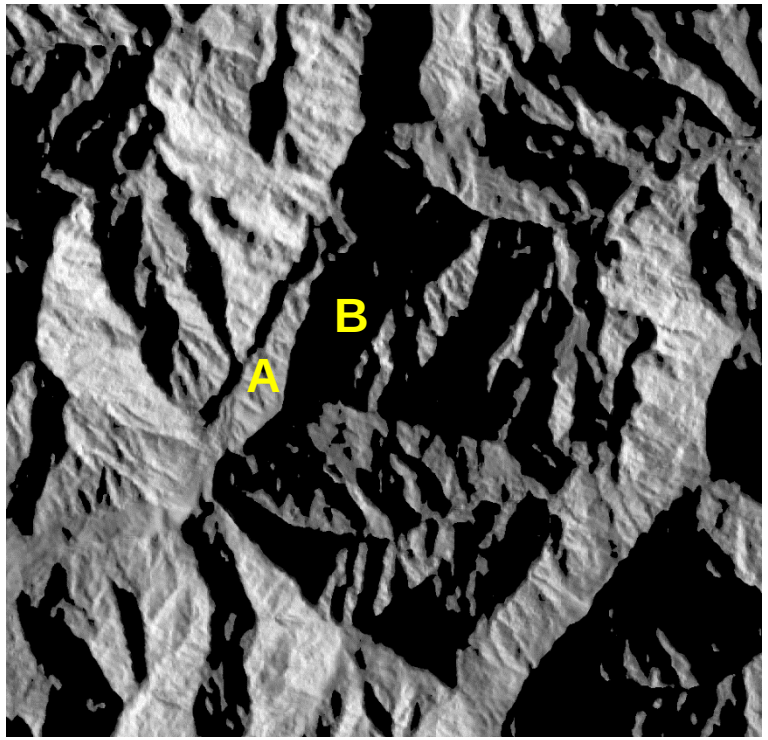


Layover Mask Definition

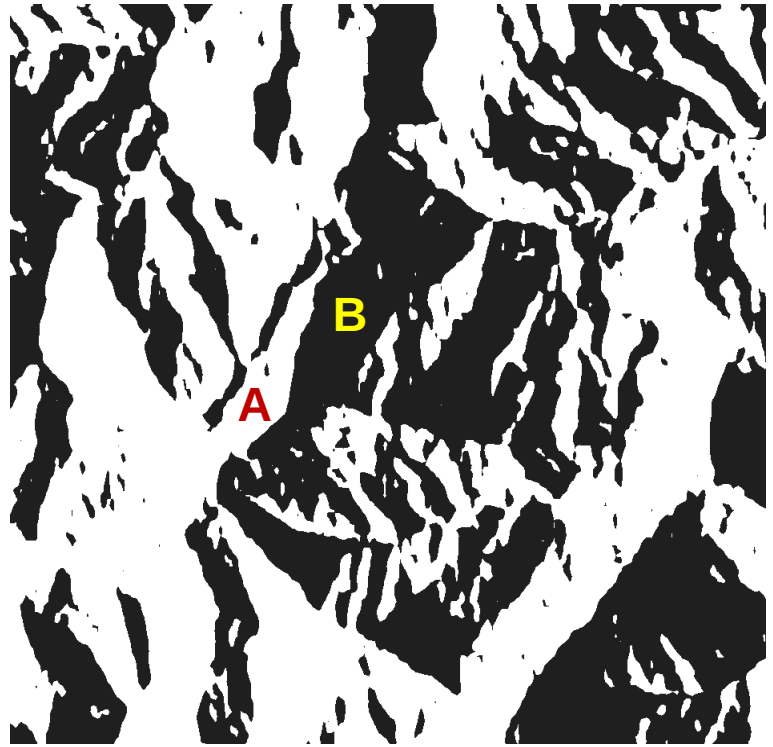
Value	Significance	Correspondence with Local Incidence Angle Map
128	Undistorted valid Region in Image	Region (A)
16	Distorted Layover Region in Image (Not to be used for further analysis)	Region (B)
0	Region Outside Geo-Referenced Image	Region (C)



Image

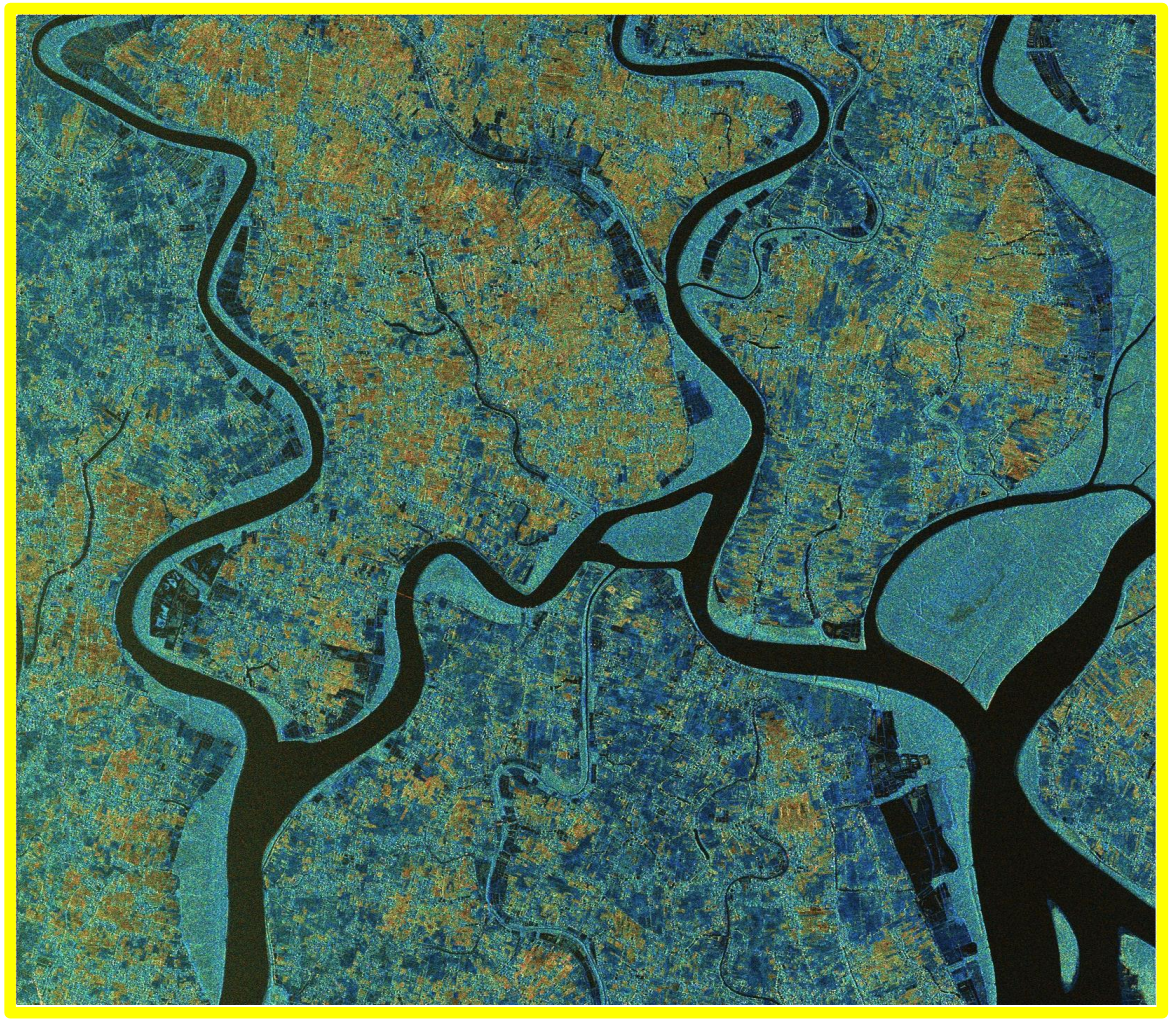


Local Incidence Angle



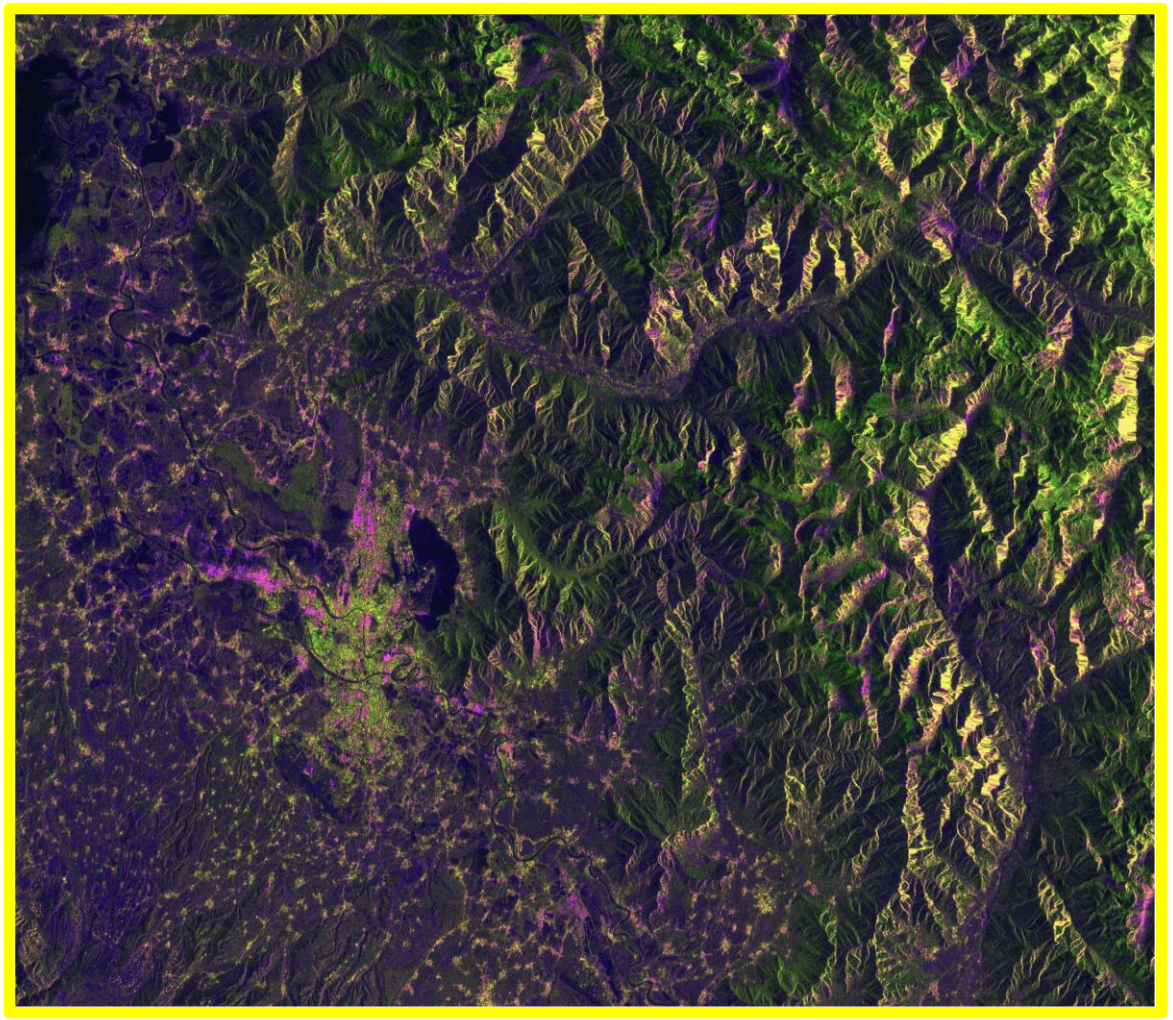
Layover Mask

Thank You



FRS-1 Hybrid Polarimetry Data (Sundarbans)

Even | Volume | Odd



MRS ScanSAR Dual Pol. Data (Kashmir Valley)

HH | HV | HH/HV