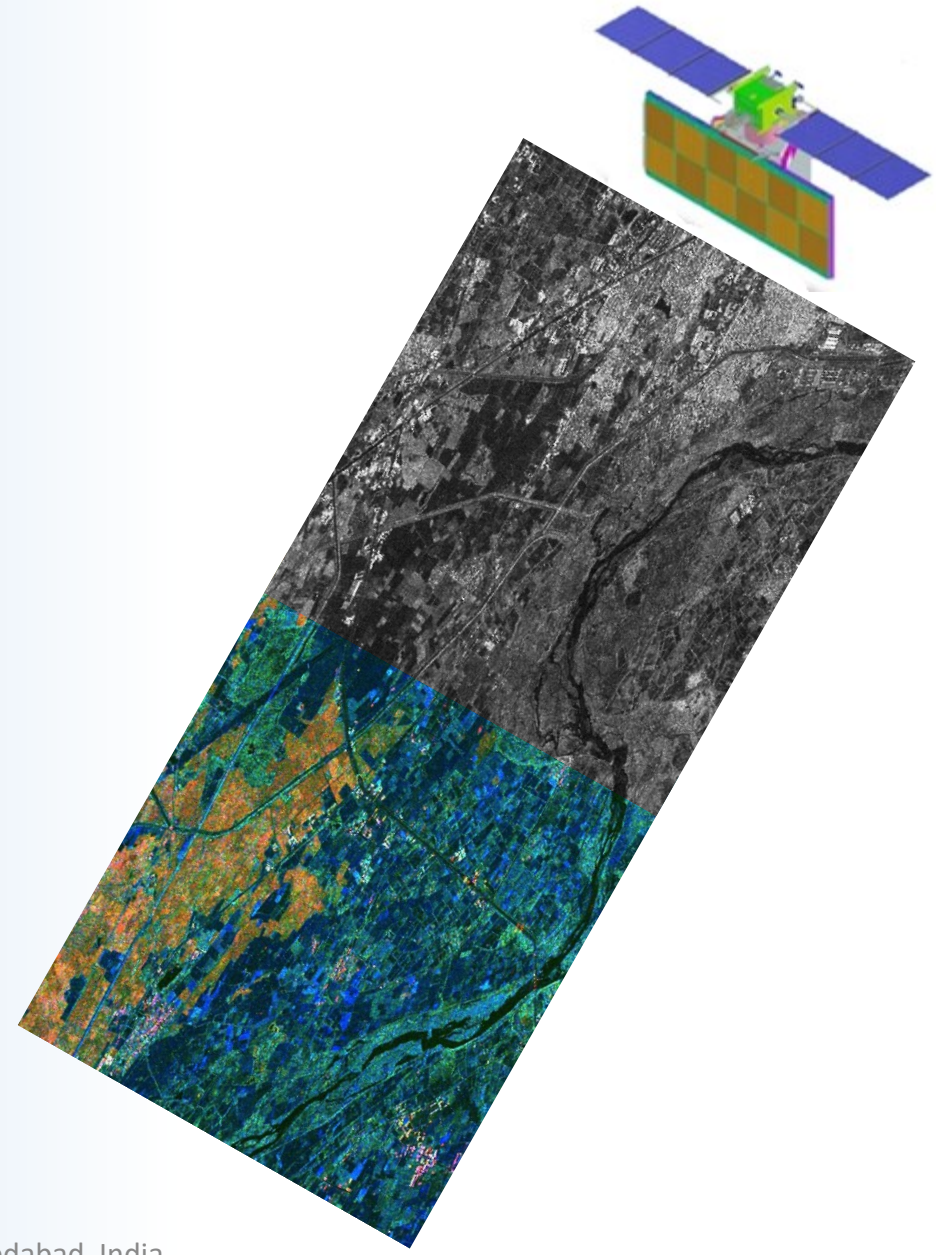
EOS-04 Data Products Calibration Updates



Presented By:

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Indian Space Research Organization (ISRO)

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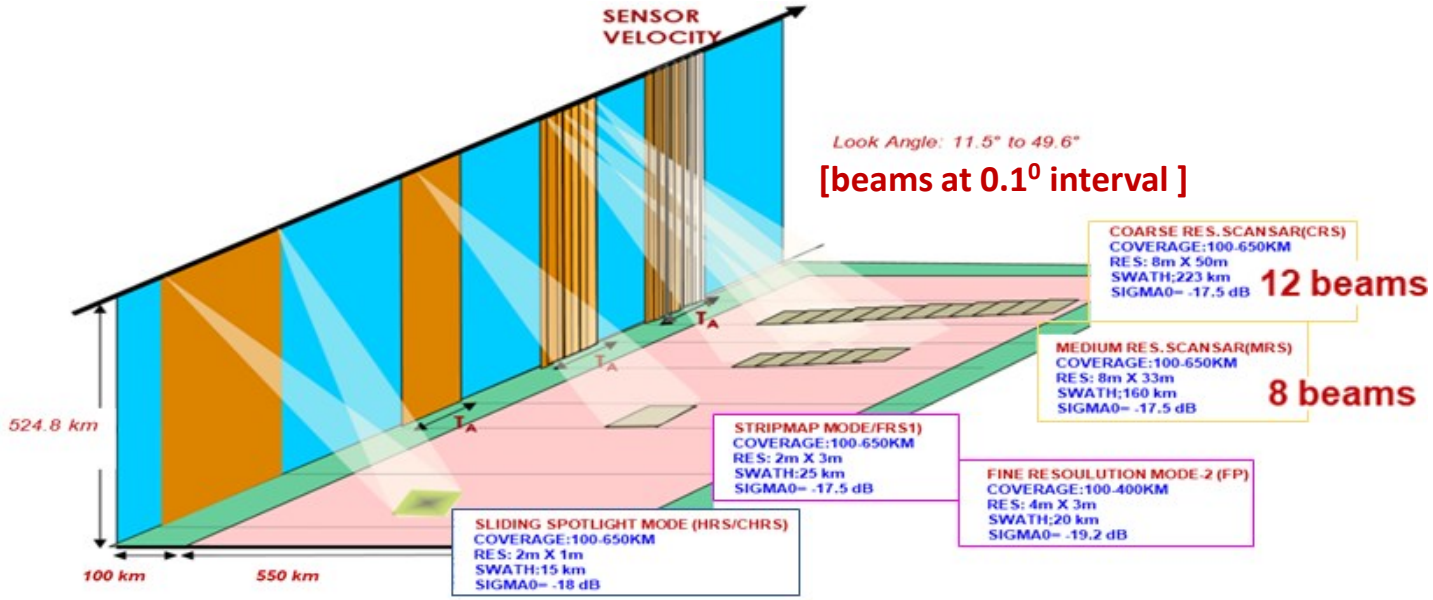
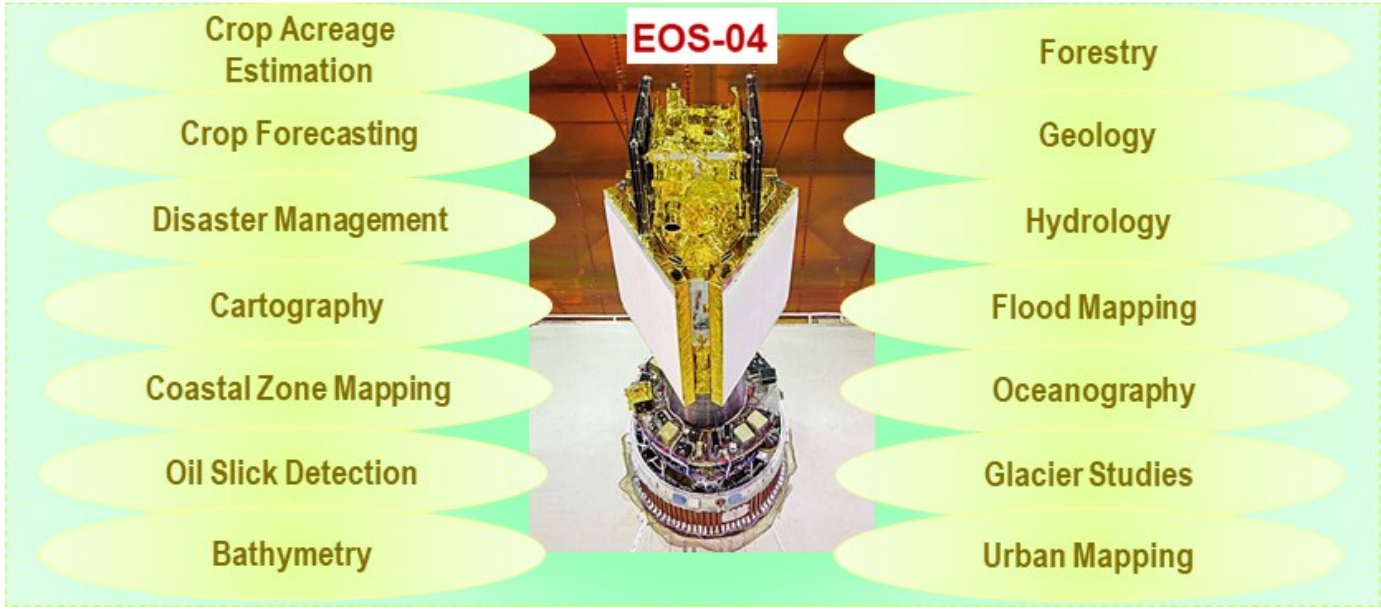
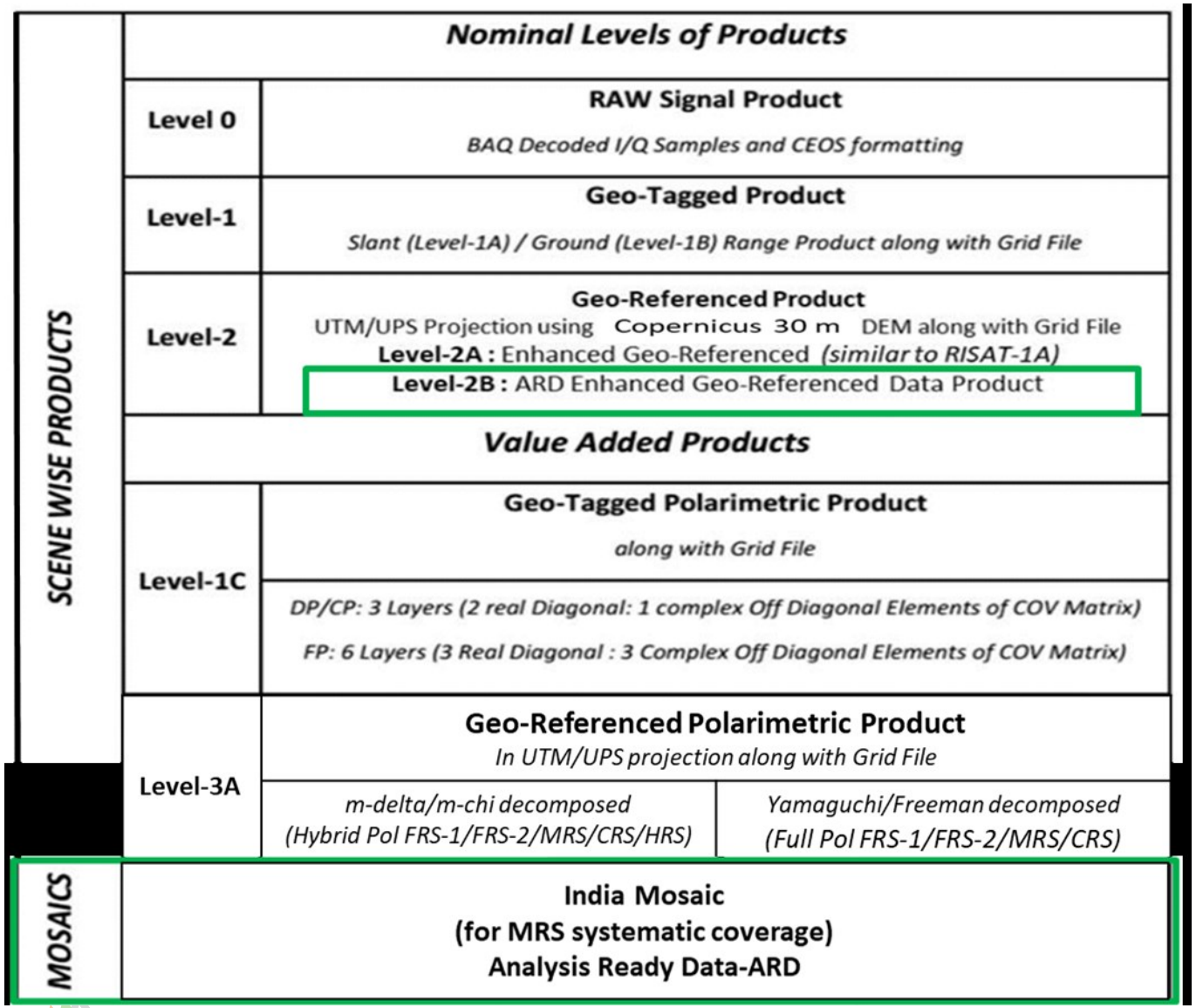
EOS-04 Synthetic Aperture Radar (SAR) Specifications

Parameter	Specification
Launch Date	14th February, 2022
Orbit	Circular Polar Sun Synchronous
Orbit altitude	524.8 km
Orbit inclination	97.552°
Orbit period	95.49 min
Operating Frequency	C-Band (5.4 GHz)
Operating Modes	FRS1, FRS2, MRS, CRS & HRS
No. of orbits per day	14
Equator crossing	6.00 a.m./6.00 p.m.
Polarizations	Single, Dual, Compact (CP), Full-Polarization (FP)
Pointing accuracy	0.05°
Swath Coverage	10 Km to 223 Km
Spatial Resolution	1 m to 50 m
Repeativity	17 days
Systematic Coverage of Indian Landmass	6 am pass in Medium Resolution ScanSAR (MRS) mode
Imaging Capability	Both Right and Left Look





EOS-04 Data Products and Performance Specifications



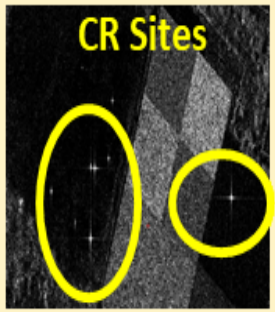
MODES	FRS-1(FP) SPECS	Measured	FRS-2 (FP)	Measured	8-beam MRS	Measured	8-Beam ScanSAR – FP	Measured
Worst Sigma Naught (dB)	- 17	-19	-18.5	-19	- 17	-19.1	-15	-18
Swath (km)	25(20)	25(20)	25(20)	25(20)	160	Complied	115	Complied
Off-Nadir (km)	100 – 650 (100-400)	Complied	100-650 (100 – 400)	Complied	100 - 650	Complied	100 - 400	Complied
Incidence Angle	11-55 (11-36)	Complied	11-55 (11-36)	Complied	11-55 (11-36)	Complied	11-36	Complied
Slant range resolution(m)*	2.1	2.1	4.2	4.0	8.6	8.5	8.6	8
Azimuth Resolution(m)*	3.24	3.24	3.24	3.24	33	32	33	33
Polarisation	S/D/C/F	Complied	S/D/C/F	Complied	S/D/C	Complied	F	Complied
PSLR (dB)	-17	Complied	-17	Complied	-17	Complied	-17	Complied
Absolute Radiometric Accuracy(dB)	±1dB					Complied		
Geometric Accuracy(m)	<50m					Complied <50m (For Level-2A) <30 m (For Level-2B)		

Analysis Ready Data Products

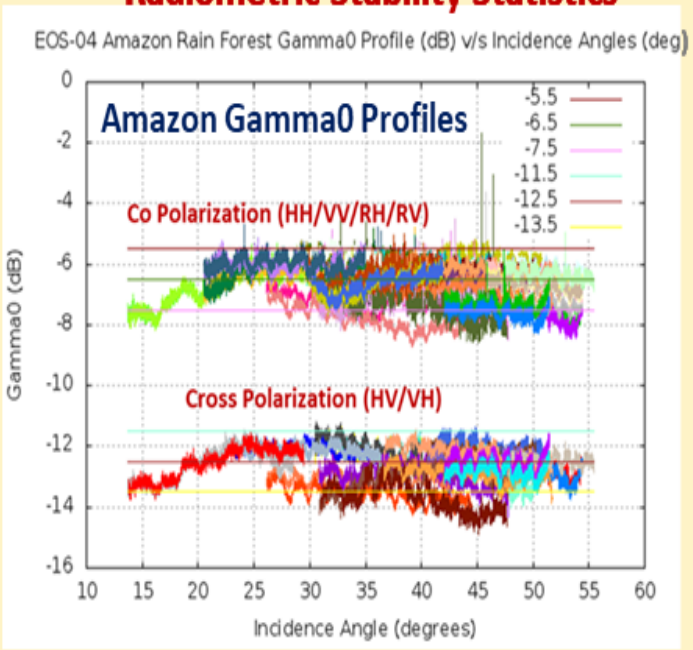
EOS-04 Data Products Calibration Summary

Radiometric Calibration

$$\sigma^0 = \frac{\overline{P_r} - \overline{P_n}}{K} \qquad K = \frac{P_t G_r G^2(\emptyset) \lambda^3 c \tau_p}{2(4\pi R)^3 L_a \sin\eta}$$



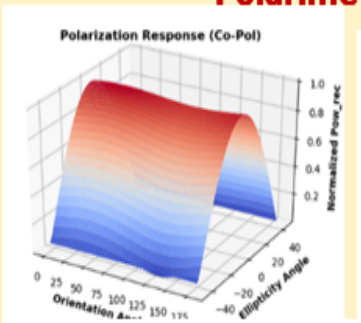
Radiometric Stability Statistics

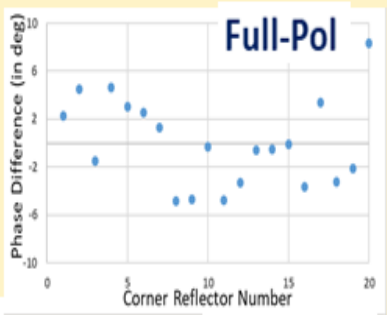


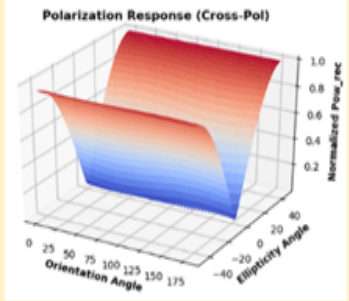
Polarimetric Calibration

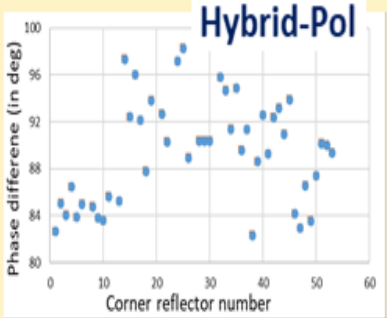
$$S' = A \begin{bmatrix} S_{vv} f^2 e^{i(\phi_t+\phi_r)} & S_{vh}\left(\frac{f}{g}\right) e^{i(\phi_r)} \\ S_{hv} f g\, e^{i(\phi_t)} & S_{hh} \end{bmatrix}$$

Polarimetric Phase Statistics







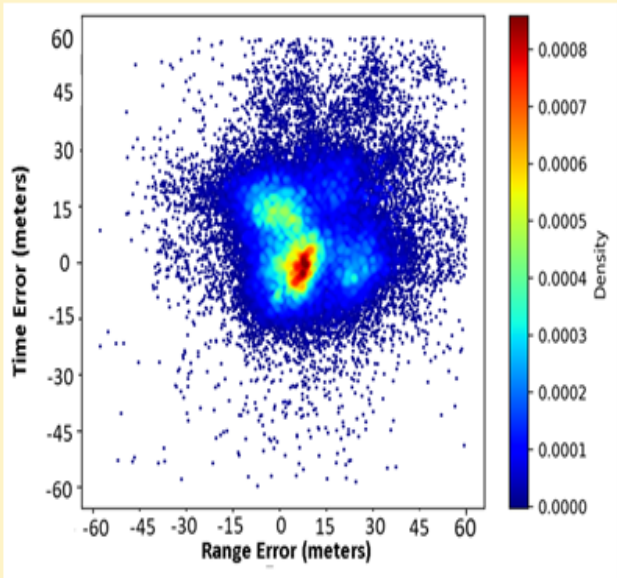


Geometric Calibration

$$F_1(i,j) = f_{dc}(i,j) - \frac{2(\vec{p} - \vec{s}(i))\left(\dot{\vec{p}} - \dot{\vec{s}}(i)\right)}{\lambda|\vec{p} - \vec{s}(i)|}$$

$$F_2(i,j) = R_0 + \Delta r.j - |\vec{p} - \vec{s}(i)|$$

Geo-Location Error Statistics



EOS-04 Radiometric Calibration Model

$$\sigma^0 = \frac{\overline{P_r} - \overline{P_n}}{K} \qquad K = \frac{P_t G_r G^2(\emptyset) \lambda^3 c \tau_p}{2(4\pi R)^3 \, L_a \sin\eta}$$

$\overline{P_r}$	:	Received Power
P_t	:	Transmit Power
$\overline{P_n}$	:	Noise Power
$G^2(\emptyset)$	:	Transmit x Receive Gain
R	:	Range
λ	:	Wavelength
c	:	Velocity of light
G_r	:	Receiver Gain
L_a	:	Azimuth Antenna Length
τ_p	:	Pulse Width
η	:	Incidence Angle
K	:	Calibration Constant

Other System Parameters Considered

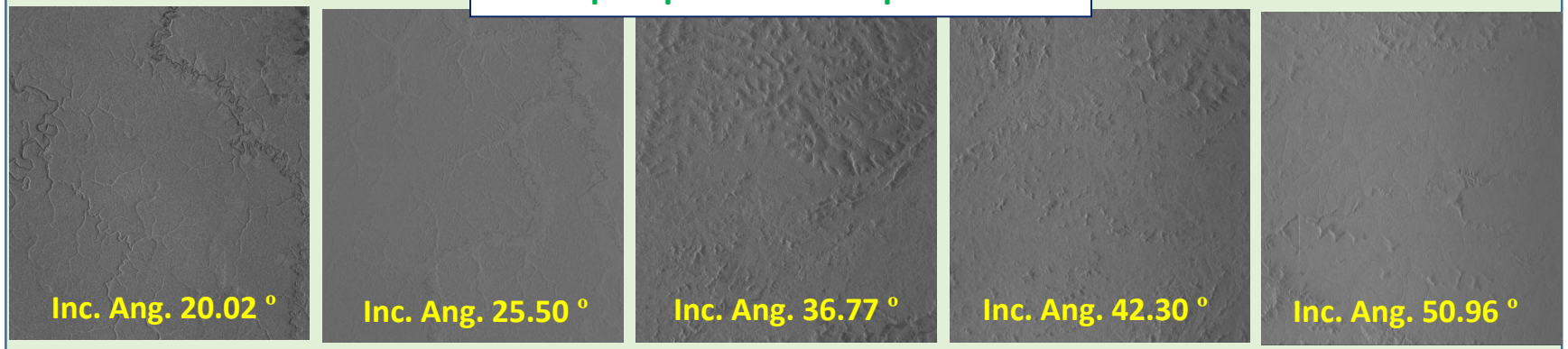
MGC

Number of TR Modules for a Beam

Count To Power Conversion Factor

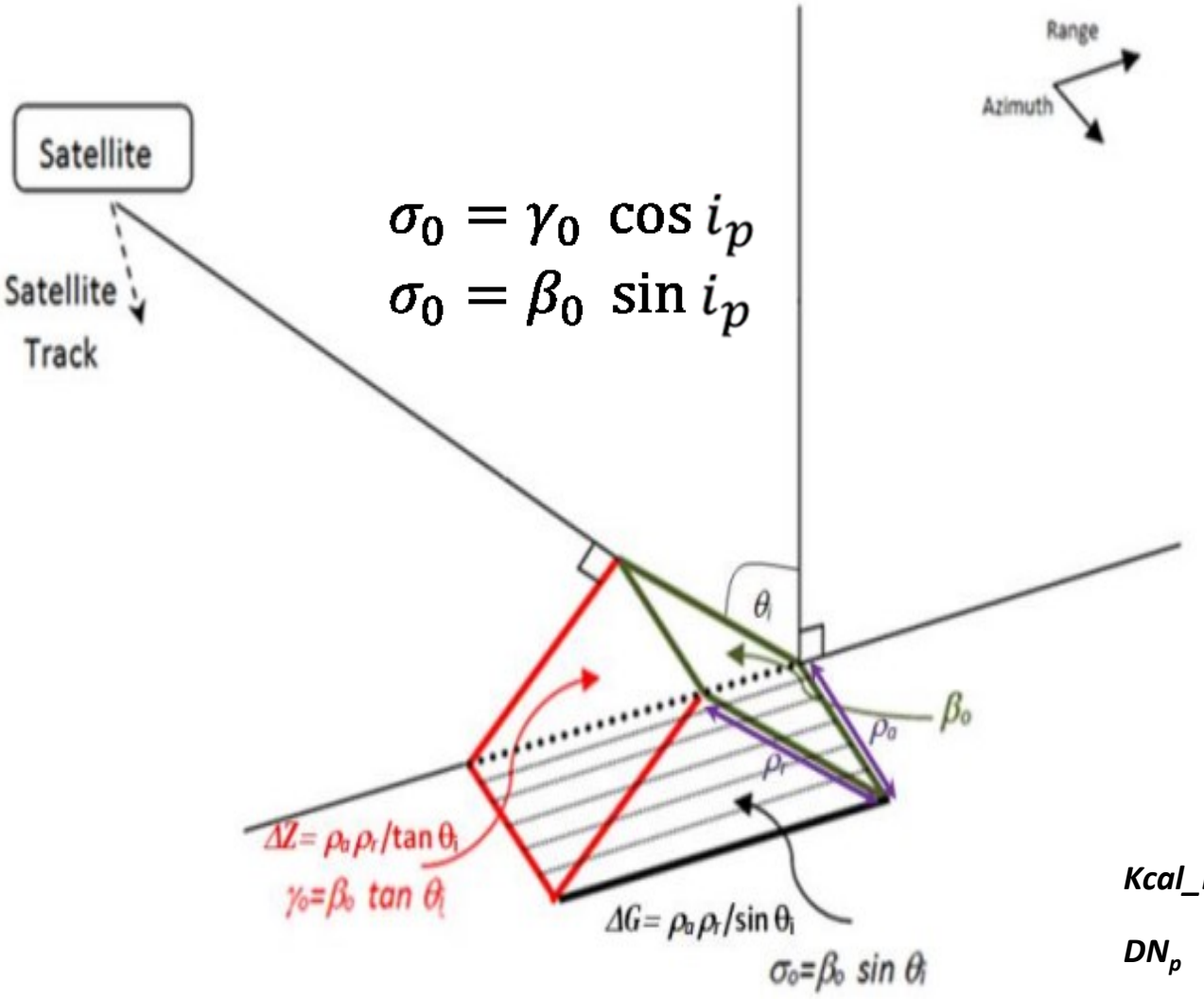
- Extensive Lab Characterization of EOS-04 SAR Sensor
- Sensor Periodic Stability monitored through dedicated Calibration modes
- Based on the observed uniformity of Gamma0 for Amazon Rain Forests at different Incidence Angles

StripMap Amazon Acquisitions



ScanSAR Amazon Acquisitions

EOS-04 Radiometric Calibration Product Meta Information



$$Beta0_p = \frac{DN_p^2}{K_{cal\_Beta0\_linear}}$$

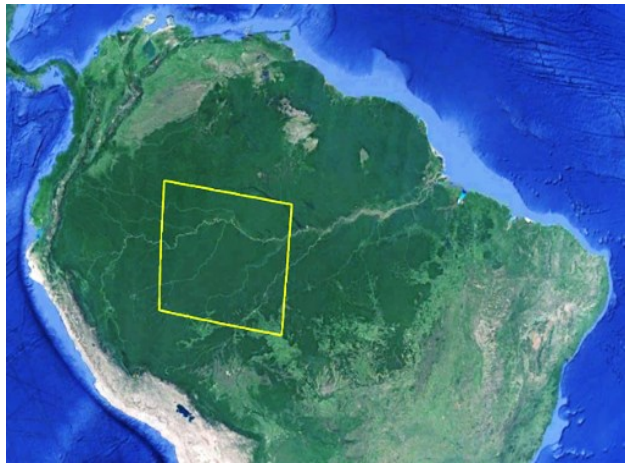
$$Sigma0_p = \frac{DN_p^2 \; X \sin i_p}{K_{cal\_Beta0\_linear}}$$

$$Gamma0_p = \frac{DN_p^2 \; X \tan i_p}{K_{cal\_Beta0\_linear}}$$

$$K_{cal\_Beta0\_linear} = 10^{\left(\frac{Kcal\_Beta0\_dB}{10}\right)}$$

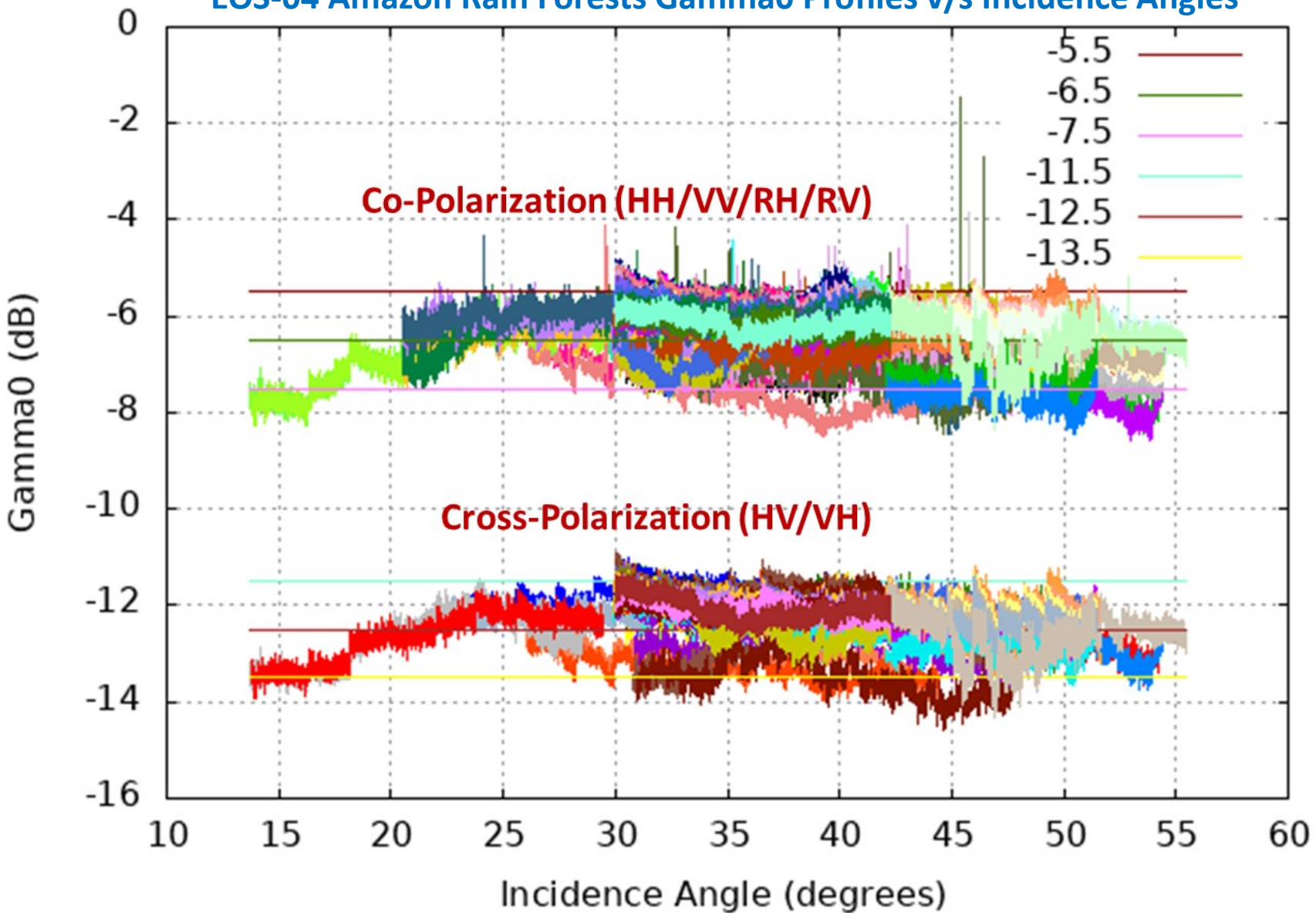
Kcal_Beta0_dB	**:**	Calibration Constant provided in Product Meta
DN_p	**:**	Per Pixel Product Digital Number
I_p	**:**	Per Pixel Incidence Angle ; Available as Map for Level-2 products and in ASCII Grid File for Level-1 data products

EOS-04 Radiometric Calibration Validation over Homogeneous Cal Sites

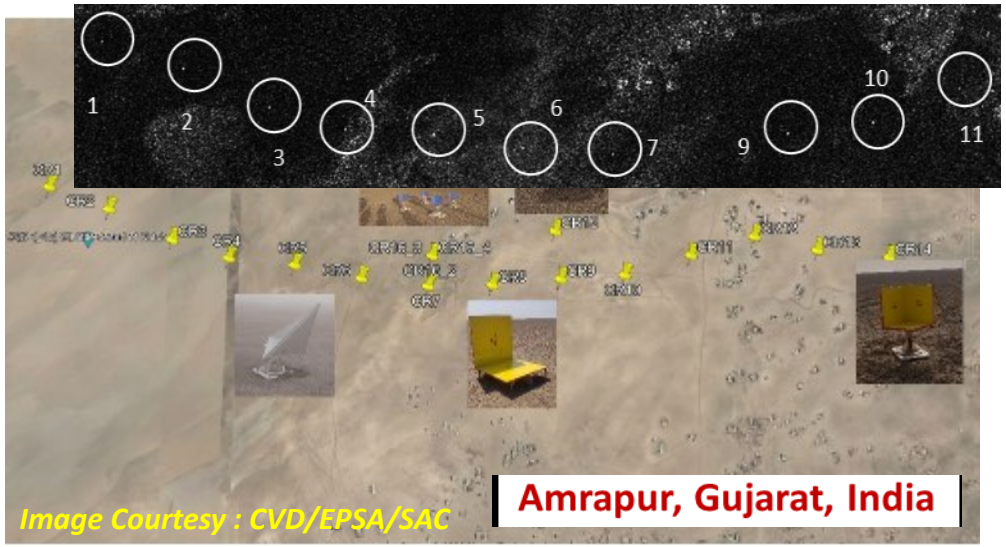


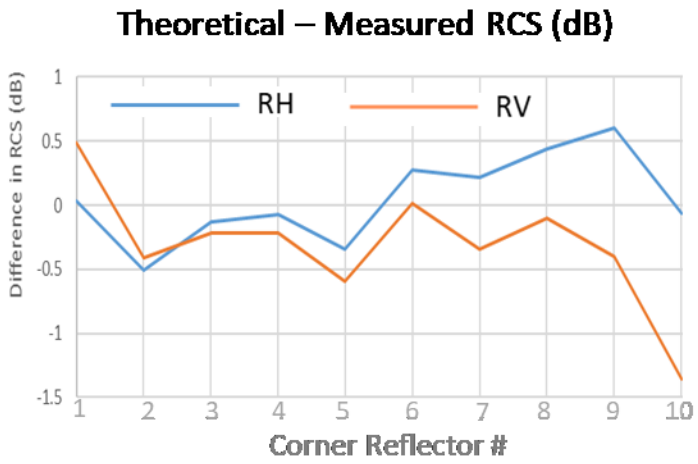
EOS-04 Amazon Cal Site

- EOS-04 acquisitions over Amazon Cal Site are being periodically evaluated to monitor stability of Radiometric Calibration within ± 1 dB over full span of incidence angles
- Plot shows Gamma0 profiles for sample Amazon acquisitions from initial Phase (March-June 2022) and recent (April-October 2024) to depict the stability of EOS-04 Radiometric Calibration Model for linear Co, Cross and Circular polarizations

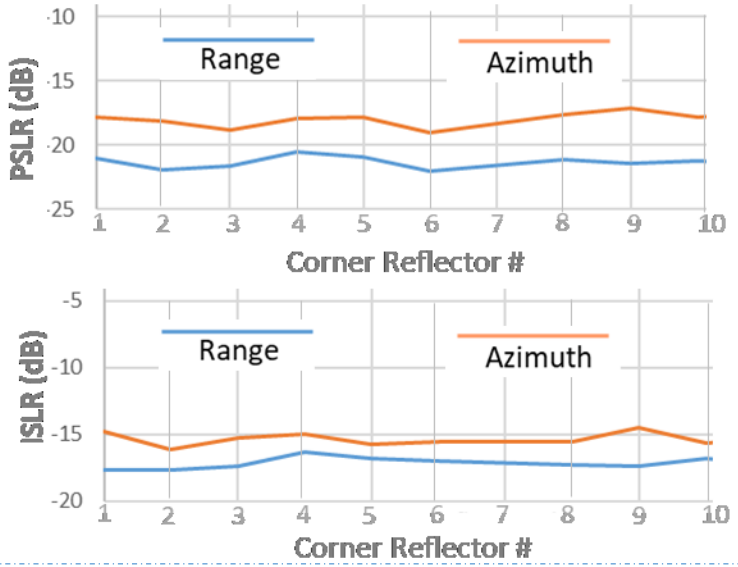


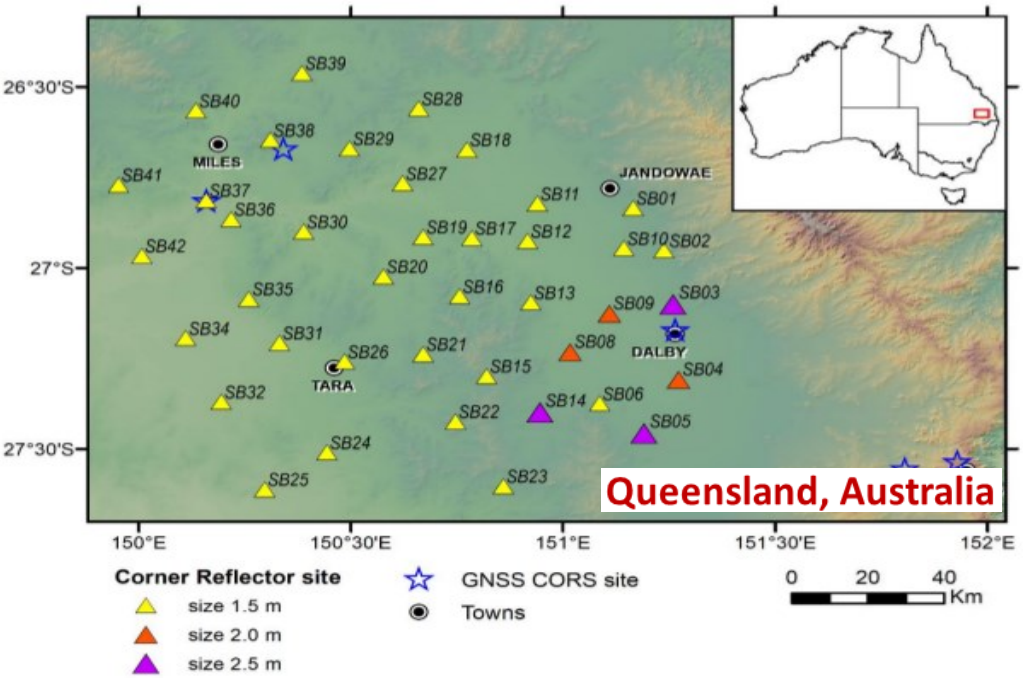
EOS-04 Radiometric Calibration Validation over Corner Reflectors

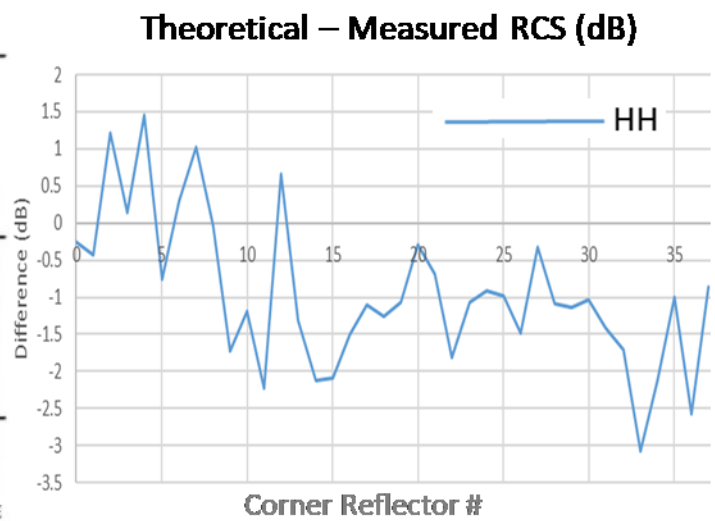




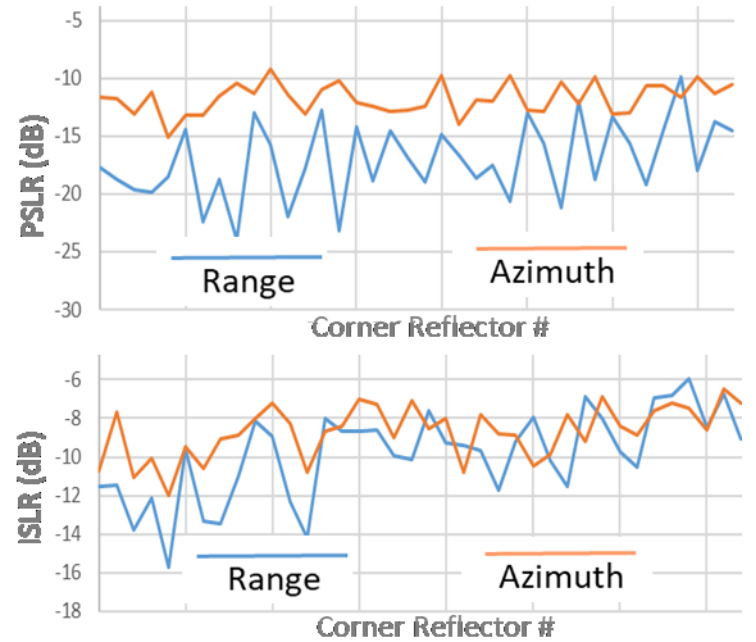
60 cm Sq. Trihedral; 60,90,100 cm Tri. Trihedral



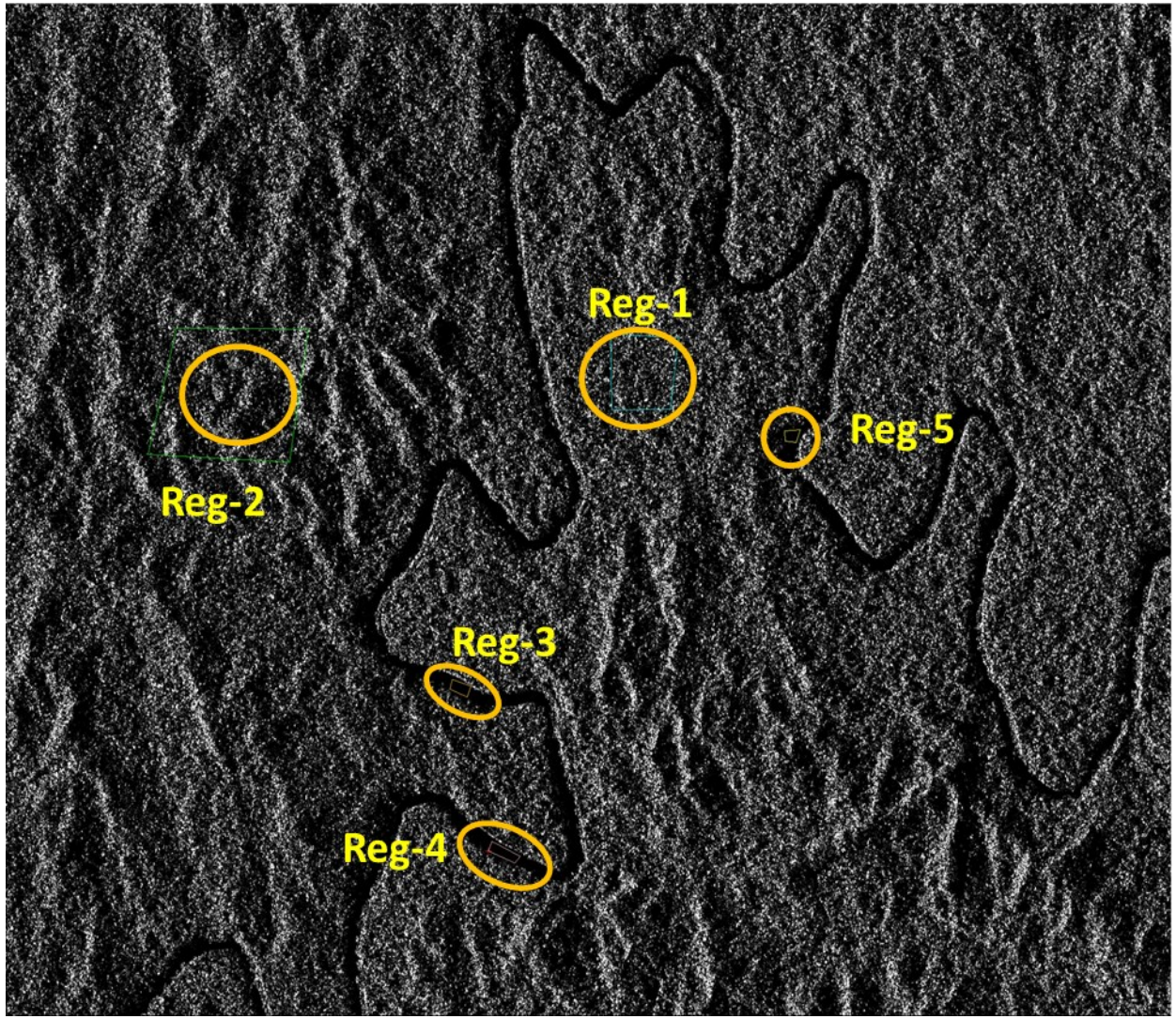




150,200,250 cm Triangular Trihedral



EOS-04 Radiometric Calibration : Noise Equivalent Sigma0



EOS-04 Amazon Acquisitions Results
Date Of Pass : 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

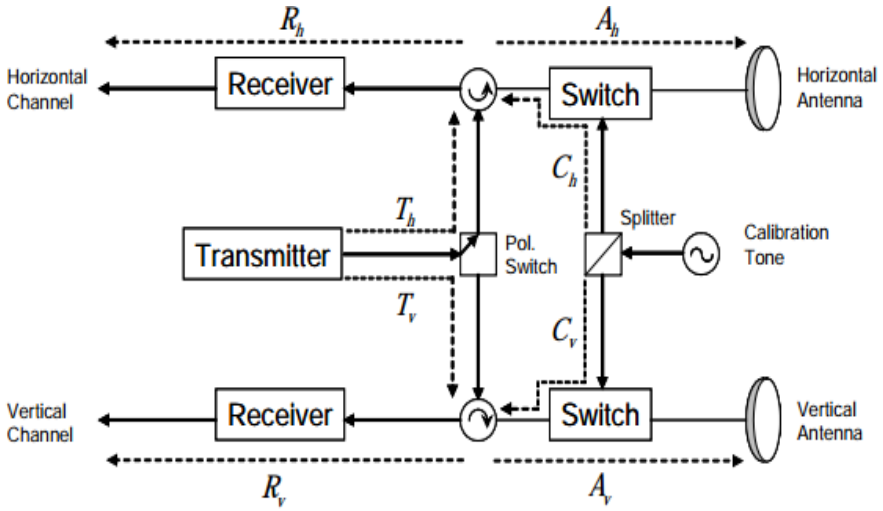
EOS-04 Polarimetric Calibration Model

Scattering Matrix [S] is as follows :

$$[S] = \begin{bmatrix} S_{hh} & S_{hv} \\ S_{vh} & S_{vv} \end{bmatrix}$$

$S_{(tr)}$ t-Transmit Polarization
r – Receive Polarization

$$[M] = \begin{bmatrix} R_{hh} & R_{hv} \\ R_{vh} & R_{vv} \end{bmatrix} \begin{bmatrix} S_{hh} & S_{hv} \\ S_{vh} & S_{vv} \end{bmatrix} \begin{bmatrix} T_{hh} & T_{hv} \\ T_{vh} & T_{vv} \end{bmatrix}$$



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

$$S' = K \begin{bmatrix} s_{vv} f^2 e^{i(\emptyset_t + \emptyset_r)} & s_{vh}\left(\frac{f}{g}\right) e^{i(\emptyset_r)} \\ s_{hv} f g e^{i(\emptyset_t)} & s_{hh} \end{bmatrix} \quad [1][2]$$

Polarimetric Parameter	Description
K	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

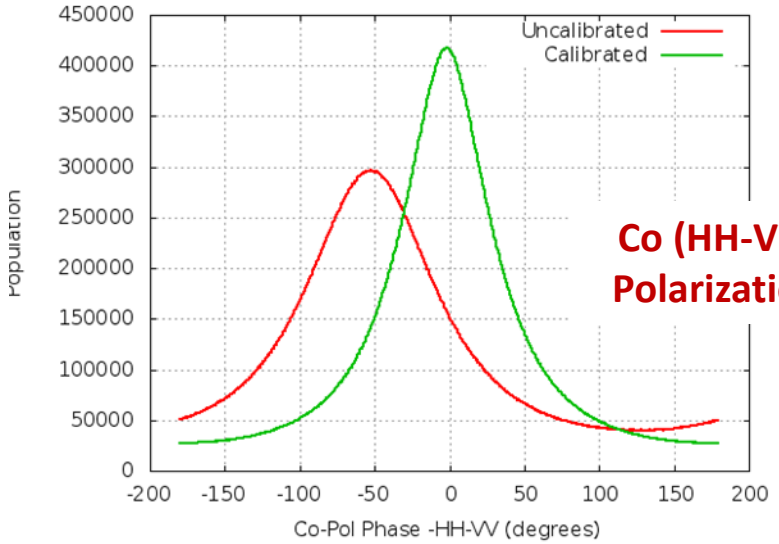
- ✓ *Absolute Calibration Constant 'K' estimated from Amazon and Corner Reflector's RCS*
- ✓ *Parameters (f , $\phi_t + \phi_r$) estimated from interpolated corner reflector response peaks*
- ✓ *Parameters (g , $\phi_t - \phi_r$) estimated by coherent average of distributed targets*

[1] Alexander G. Fore et al. "UAVSAR Polarimetric Calibration," IEEE Transactions on Geoscience and Remote Sensing, vol. 53, no. 6, June 2015

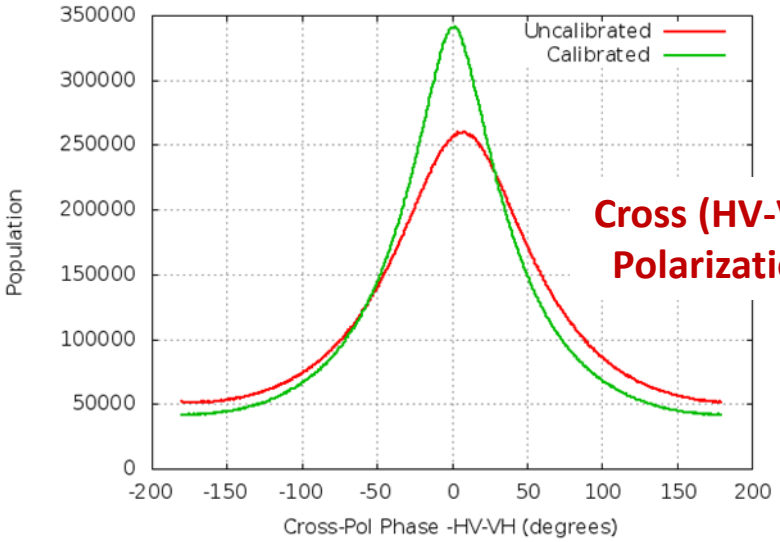
[2] Guangde Sun,Zhen Li, Lei Huang, "A Quad Polarimetric SAR Calibration Algorithm using Rotation Symmetry," International Journal of Remote Sensing, 2019, vol.40,no. 10,3787-3807

EOS-04 Polarimetric Calibration Model (Full-Polarization)

Relative Phase Histograms

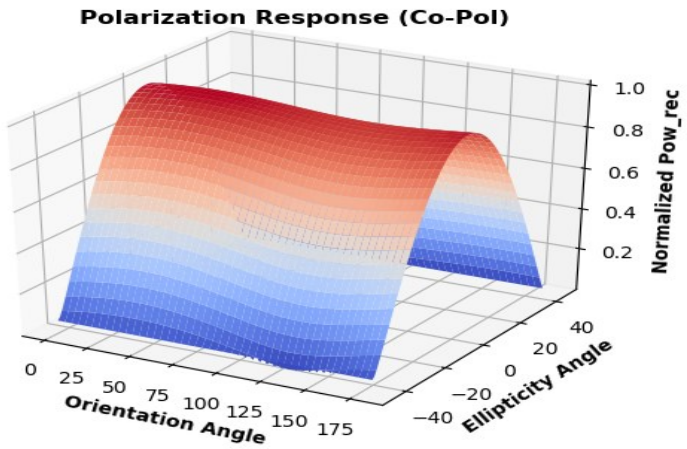


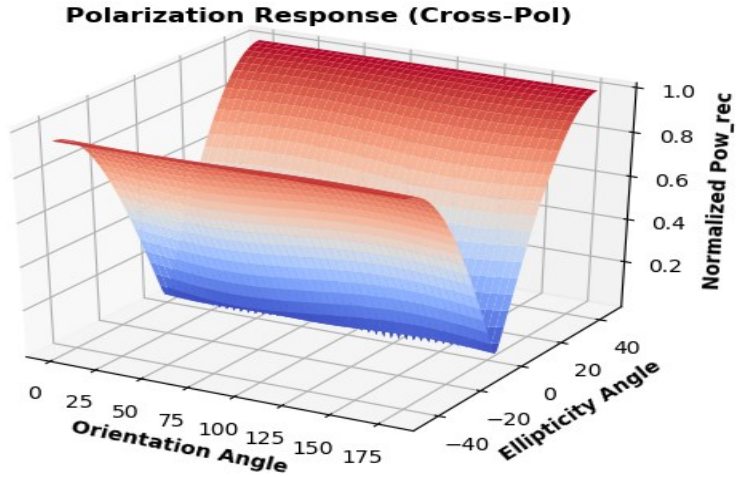
Co (HH-VV) Polarization

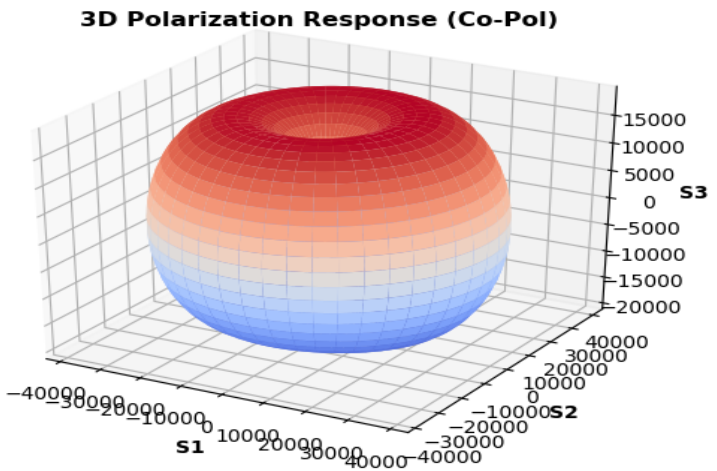


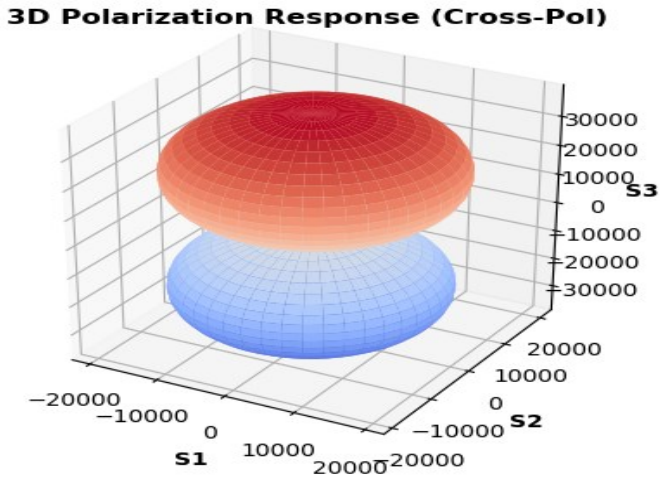
Cross (HV-VH) Polarization

Van Zyl Signatures for a Triangular Trihedral CR acquired by EOS-04



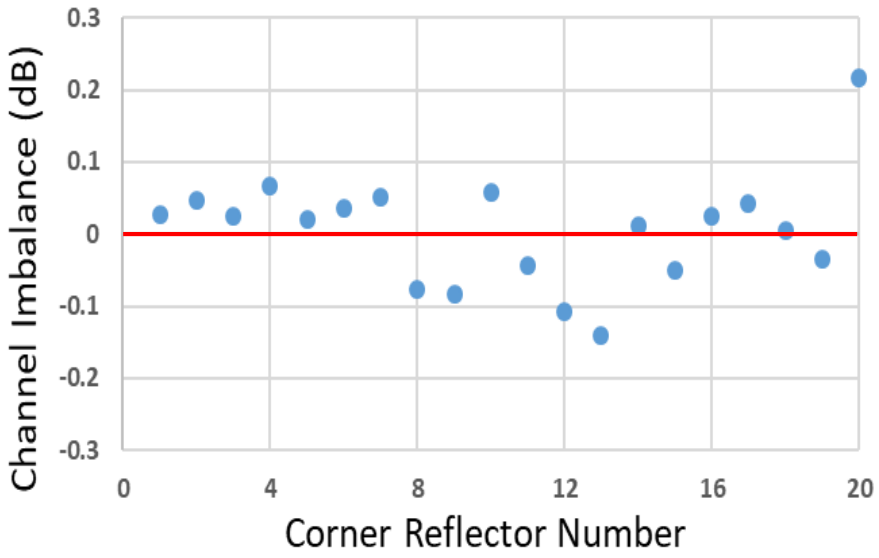


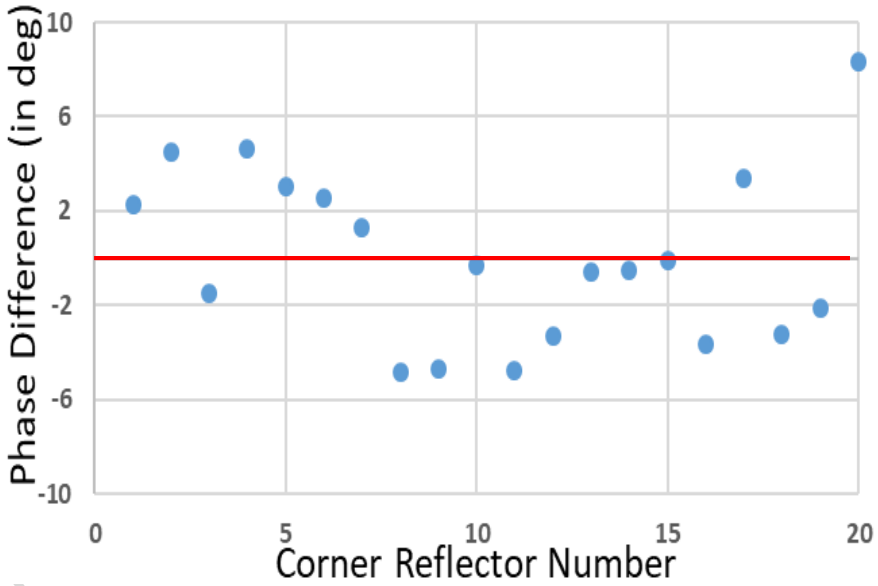




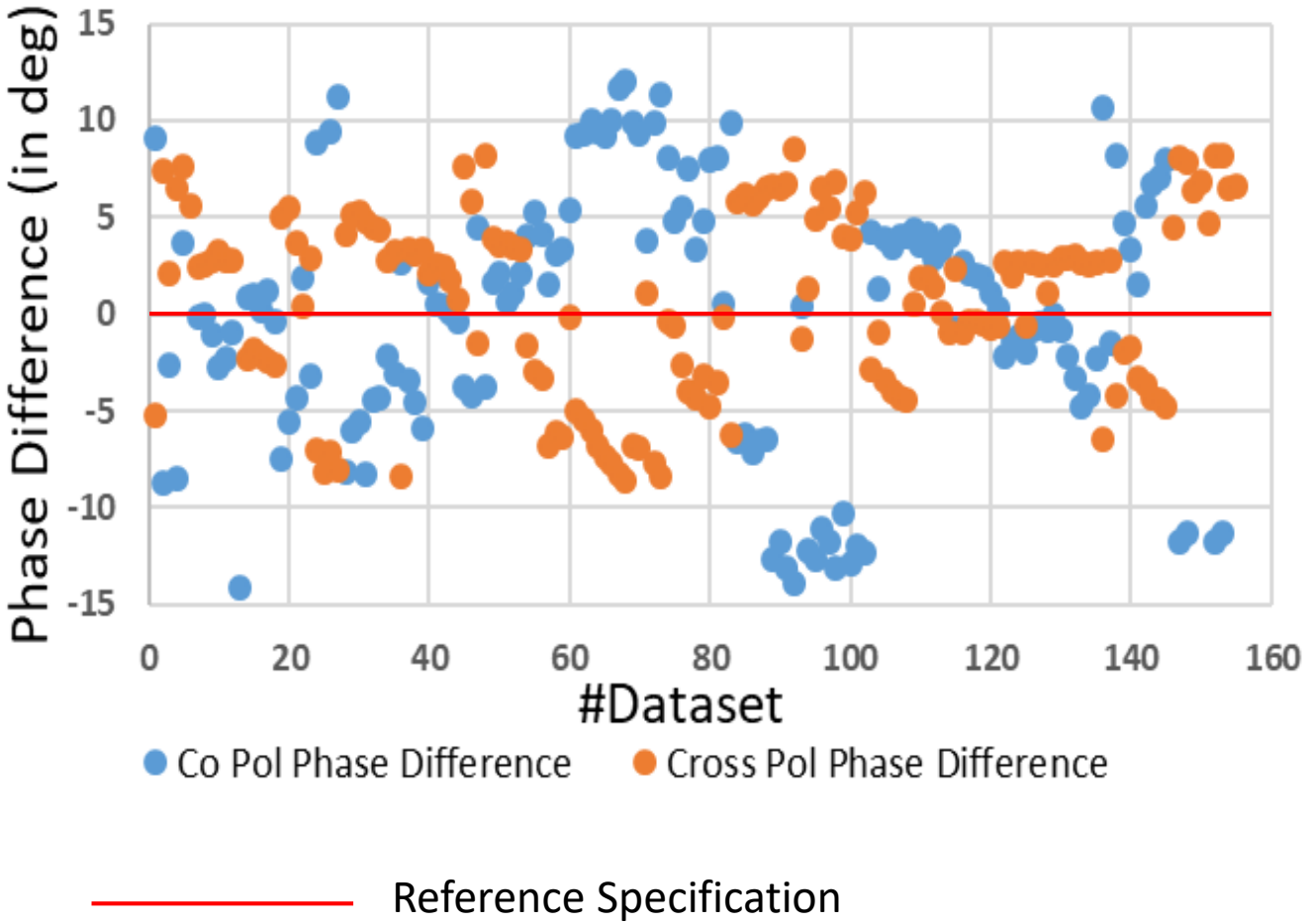
EOS-04 Polarimetric Calibration Model (Full-Polarization) Validation

Pol Cal Validation for Corner Reflectors



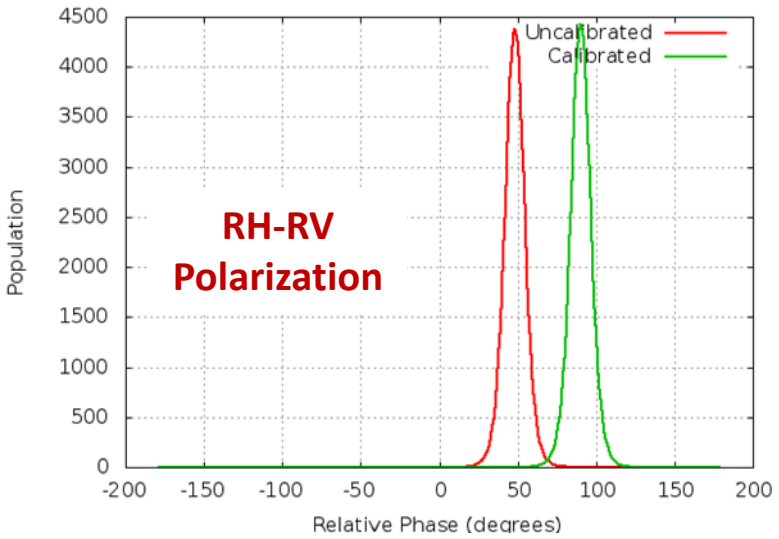


Pol Cal Validation for Homogeneous Targets

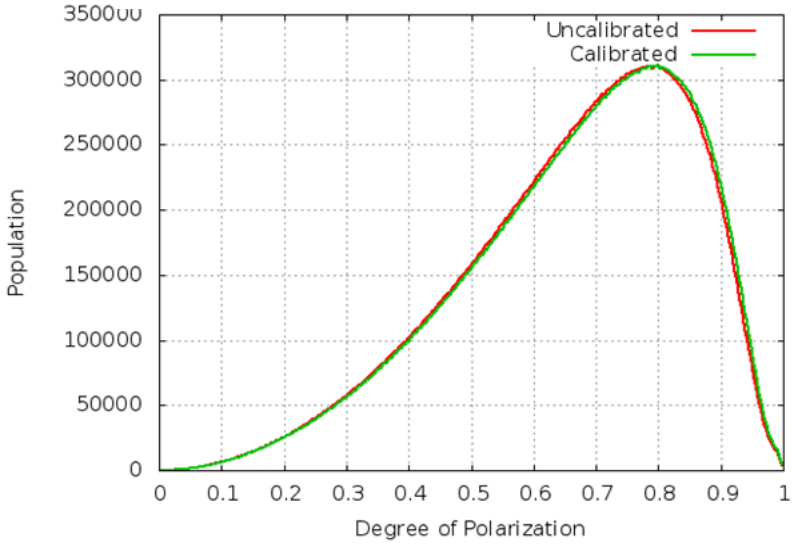


EOS-04 Polarimetric Calibration Model (Circular Polarization)

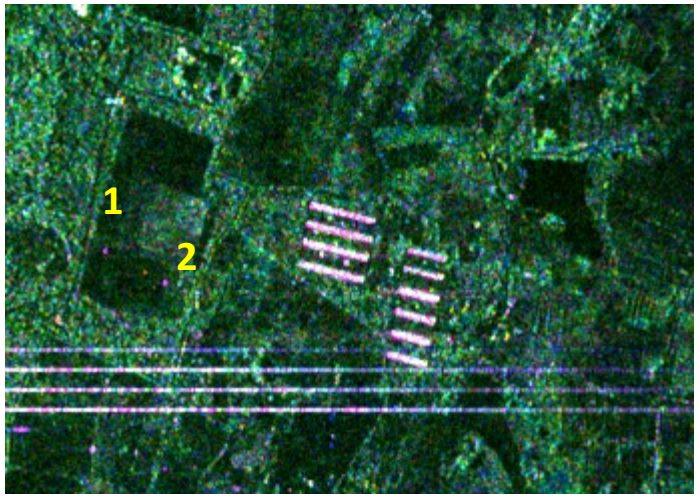
Relative Phase Histogram



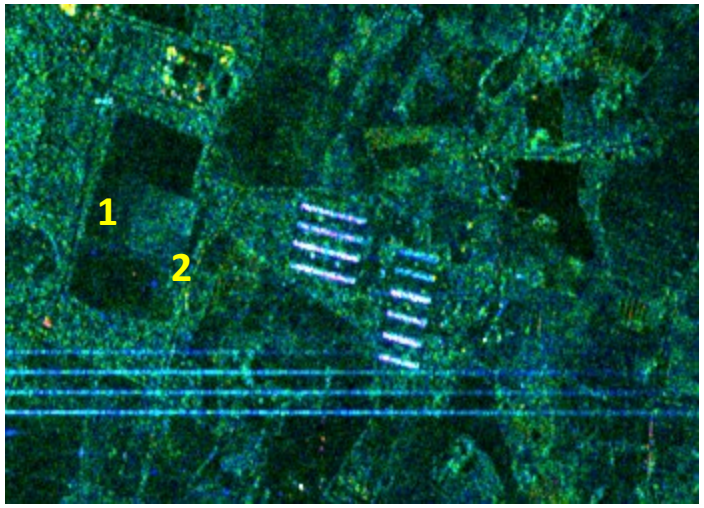
Degree of Polarization



Un-Calibrated Data



Calibrated Data

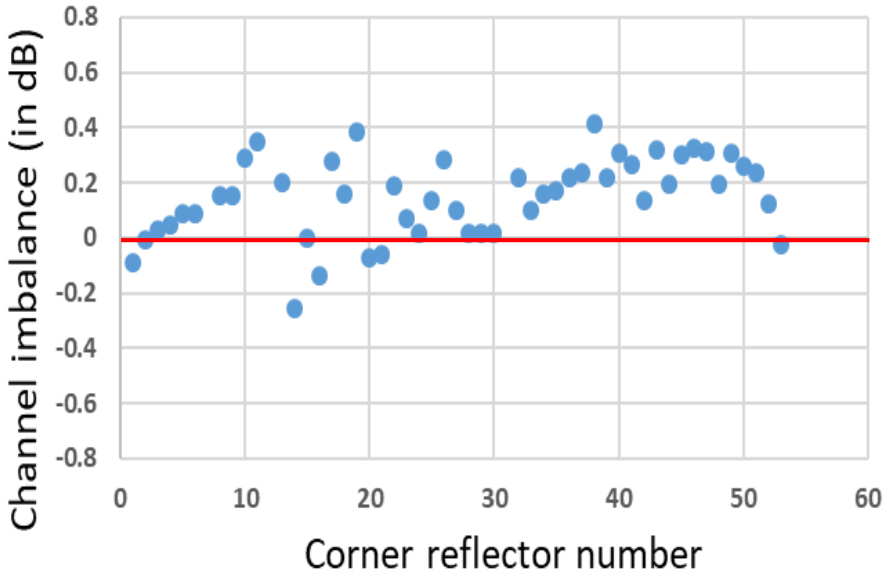


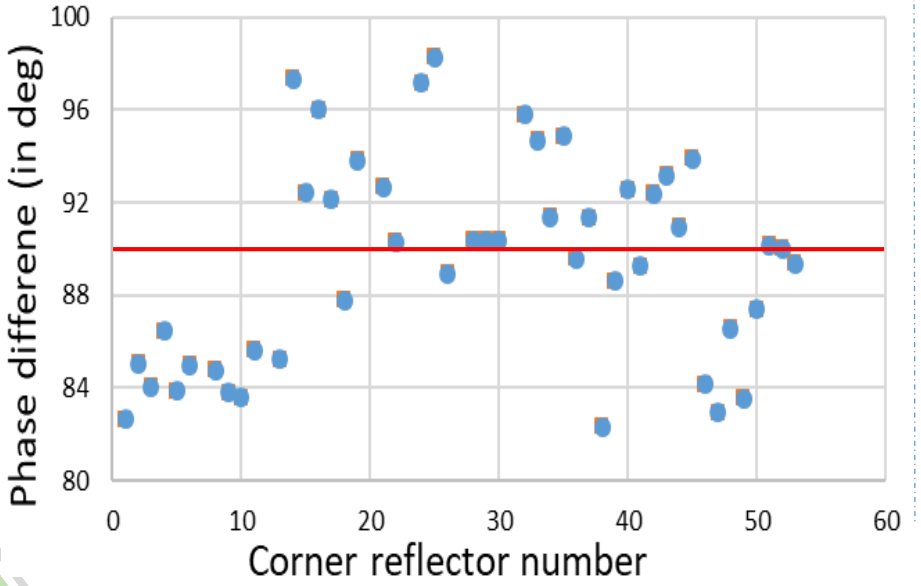
Circular Polarimetry Child Parameters	Un-Calibrated Data		Calibrated Data	
	CR# 1	CR #2	CR# 1	CR #2
Deg. Of Polarization (m)	0.9965	0.9997	0.9967	0.9996
Deg. Of Circular Pol.	-0.3008	-0.2367	0.9928	0.9968
Circular Pol. Ratio	1.8607	1.6203	0.0036	0.0015
Axial Ratio	-0.1545	-0.1201	0.9148	0.9277
Relative Phase (δ)	-17.6441	-13.735	92.515	87.616
Ellipticity Angle (χ)	-8.7555	-6.8469	41.563	42.727

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

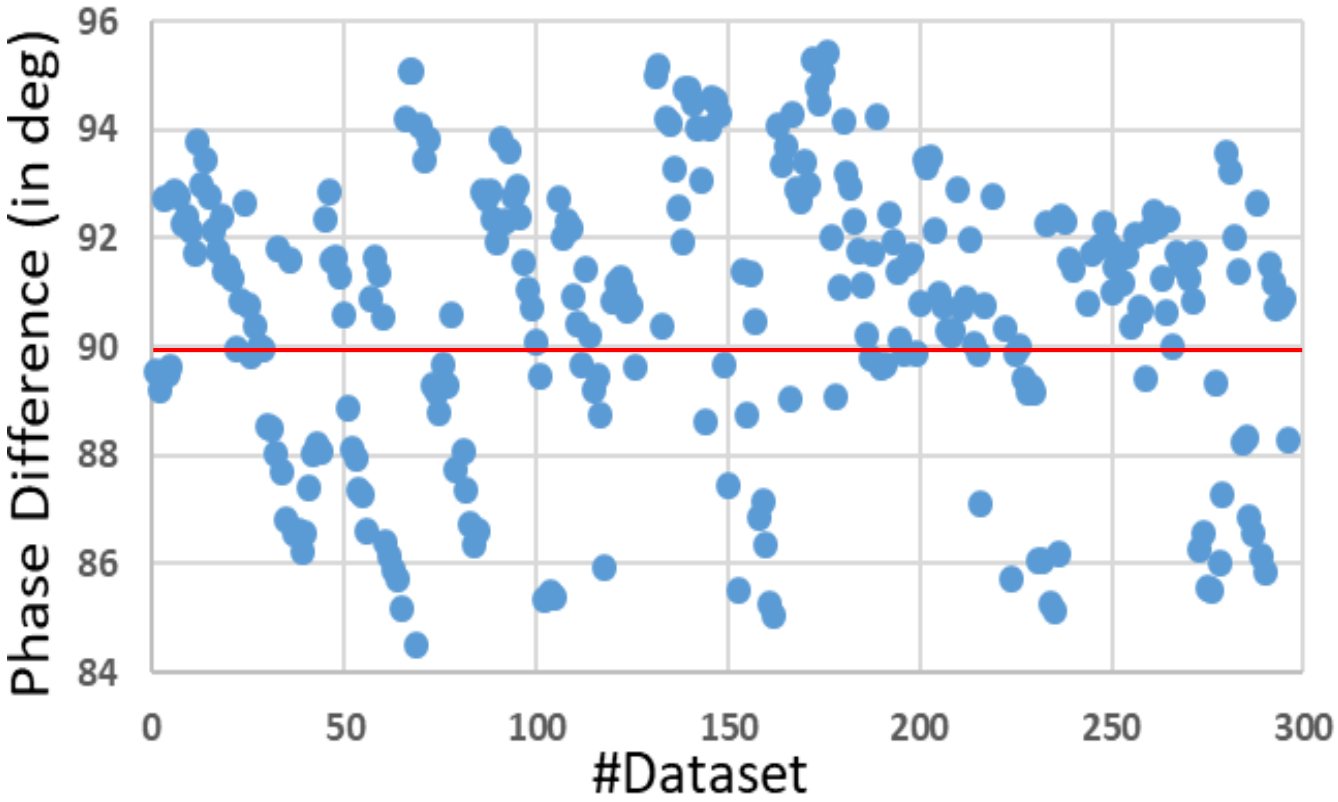
EOS-04 Polarimetric Calibration Model (Circular-Polarization) Validation

Pol Cal Validation for Corner Reflectors

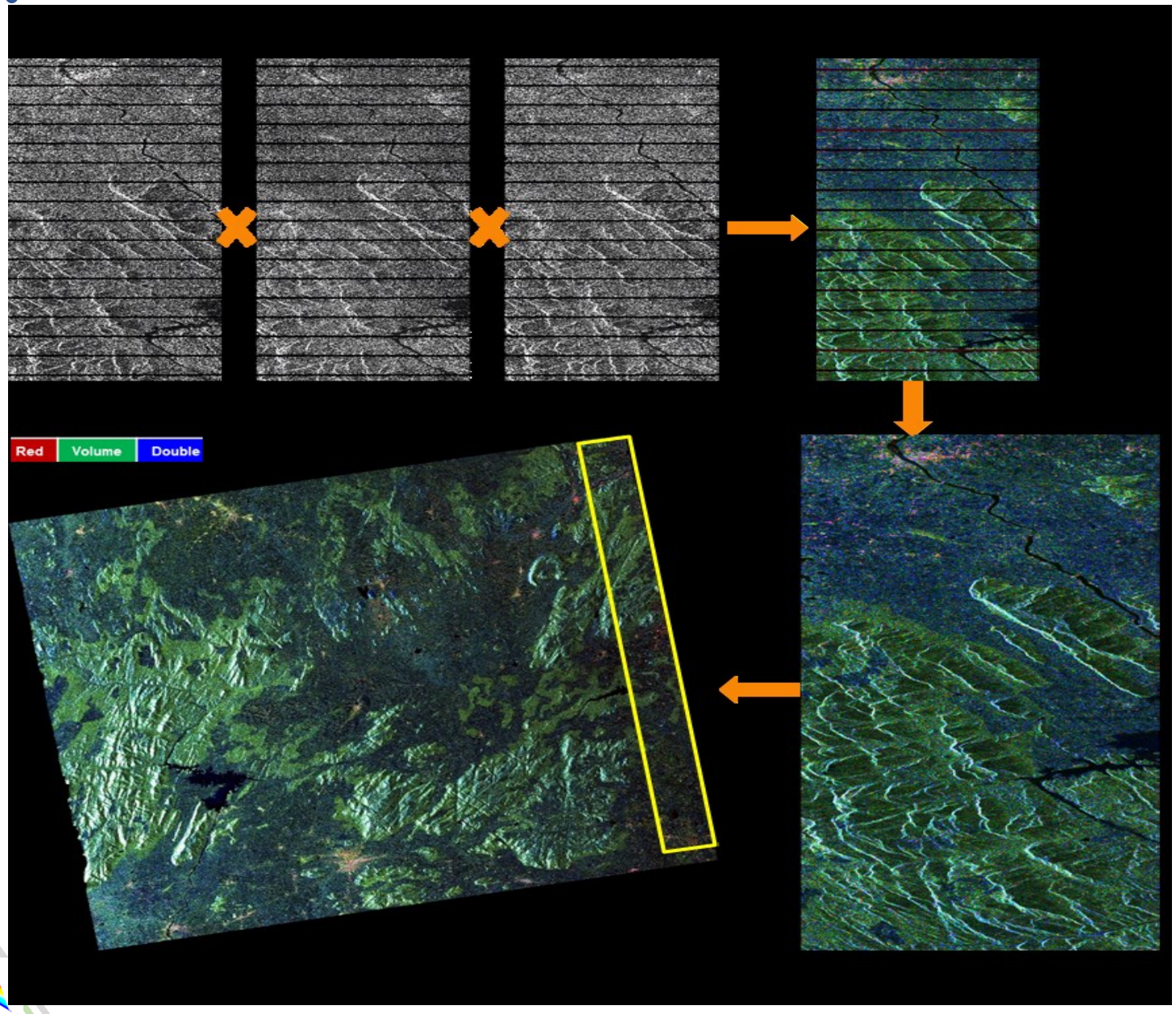


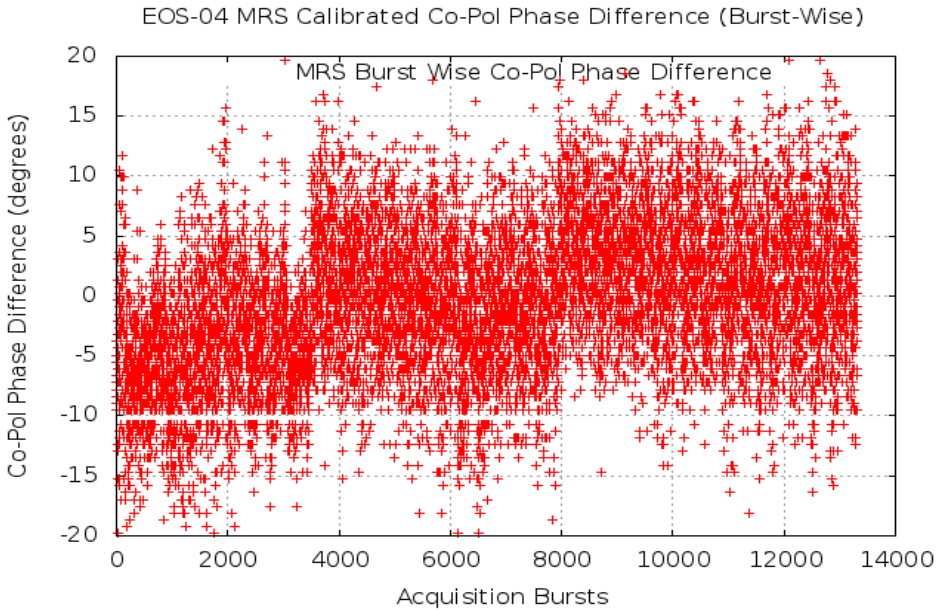


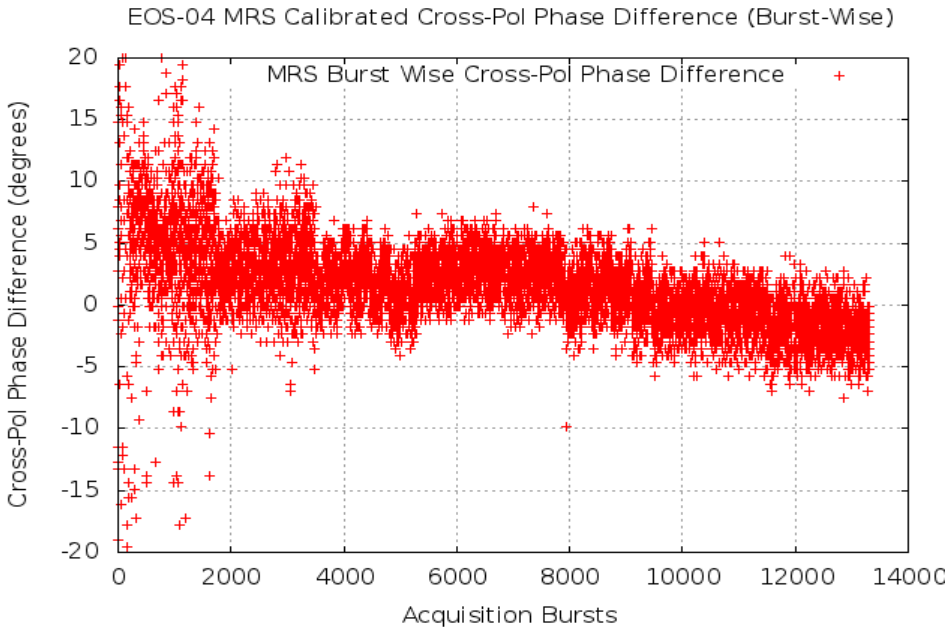
Pol Cal Validation for Homogeneous Targets



EOS-04 Wide Swath ScanSAR Polarimetric Data Product







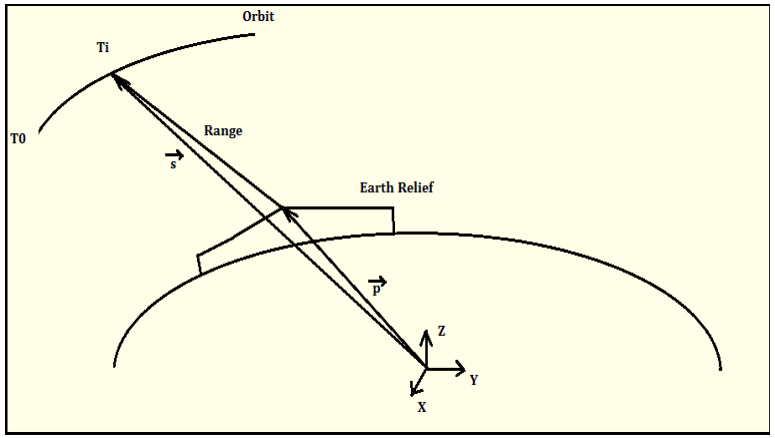
EOS-04 Geometric Calibration Model

SAR Doppler Equation :

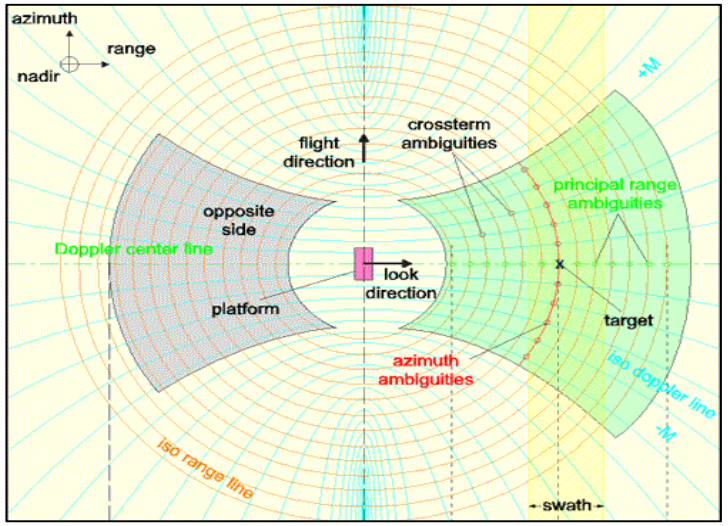
$$F_1(i,j) = f_{dc}(i,j) - \frac{2(\vec{p} - \vec{s}(i))(\vec{p}^{\bullet} - \vec{s}^{\bullet}(i))}{\lambda |\vec{p} - \vec{s}(i)|}$$

SAR Range Equation :

$$F_2(i,j) = R_0 + \Delta r \cdot j - |\vec{p} - \vec{s}(i)|$$



Coordinate System for SAR viewing Geometry



Iso- Range and Iso- Doppler lines specifying location of target

where,

f_{dc} = Doppler centroid frequency

$\vec{p}$ & $\vec{p}^{\bullet}$ = position and velocity vector of target

$\vec{s}(i)$ & $\vec{s}^{\bullet}(i)$ = position and velocity vector of satellite at scan line *s(i)*

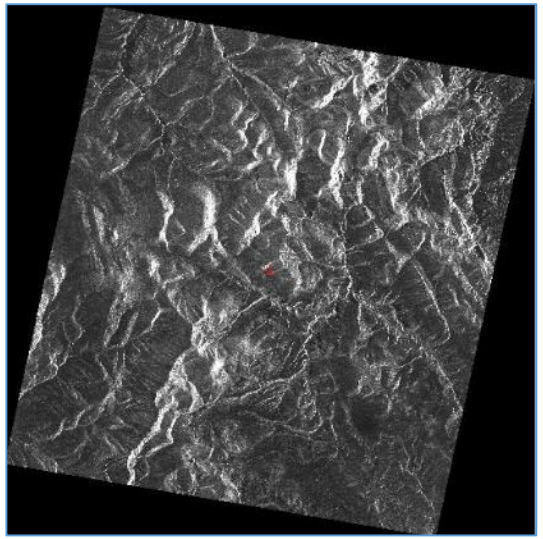
λ = wavelength

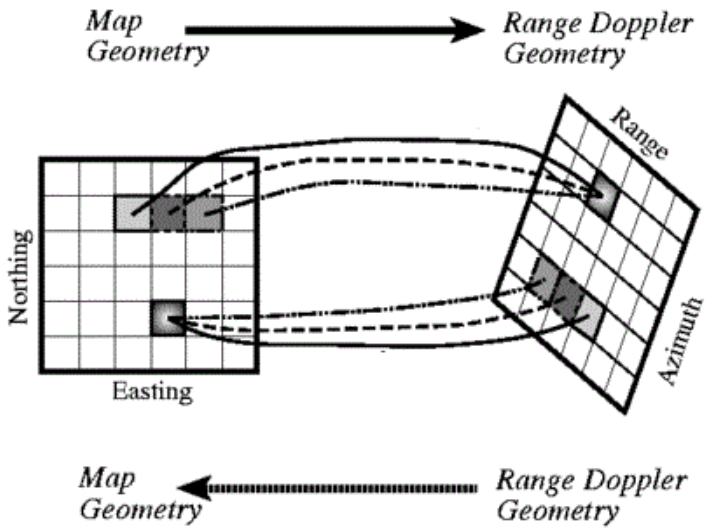
i = scan

j = pixel

R_0 = Minimum Range

Δr = Range Sampling

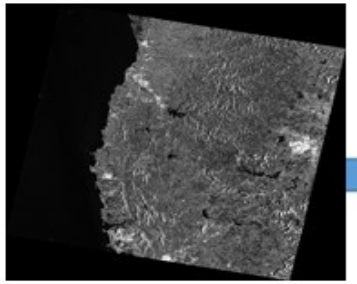




Geocoded Image (Map Projected) ⇄ Inverse Map Projection / Map Projection ⇄ Geographic Coordinates (latitude, longitude) ⇄ SAR Geolocation ⇄ Signal Processed Image (Slant)

Copernicus DEM

EOS-04 Geometric Calibration Validation and Correction Framework



EOS-04 Map Projected image in equal MapX MapY

Determine Phase Correlation based ΔMapX; ΔMapY shifts with COPERNICUS 30m DEM

ΔMapX
ΔMapY

Determine corrected MapX MapY for EOS-04 Map Projected Image using Δ MapX and Δ MapY

Using Inverse Map Projection ;determine Latitude Longitude for corrected MapX MapY for Image Grid

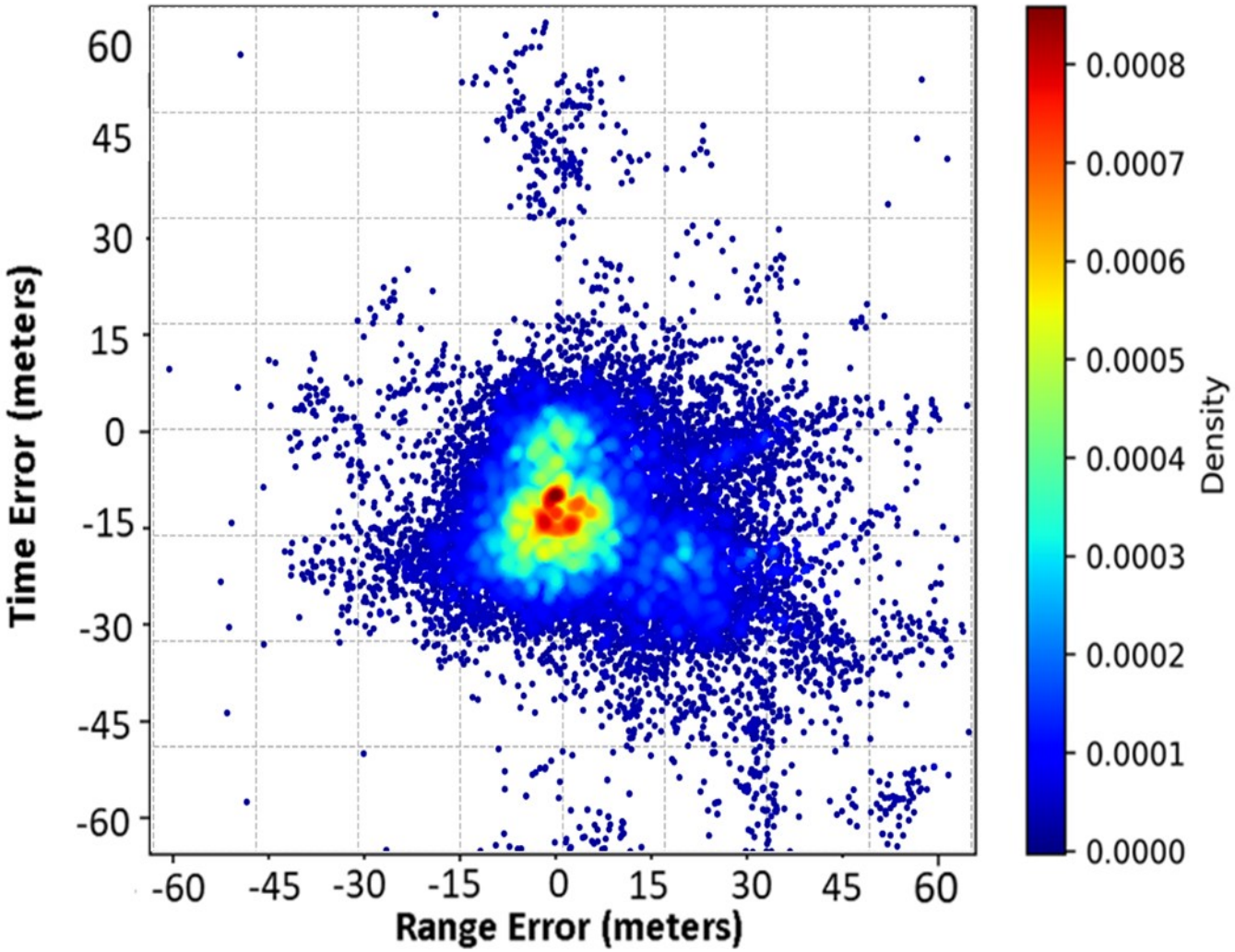
Using SAR Geolocation algorithm ;determine Scan Pixel for corrected Latitude Longitude for Image Grid

For Every Image Grid Point, determine Δ Scan and Δ Pixel error, using original and corrected Latitude Longitude

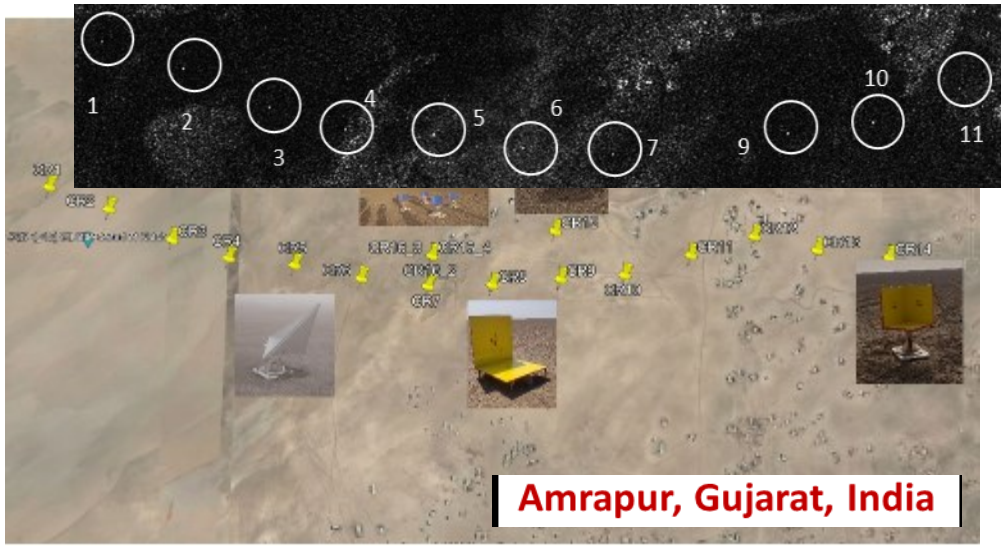
Mean Δ Scan error gives Along Track (Time) error
Mean Δ Pixel error gives Across Track (Range) error

Generate Level-2 Map Projected image incorporating Time and Range errors

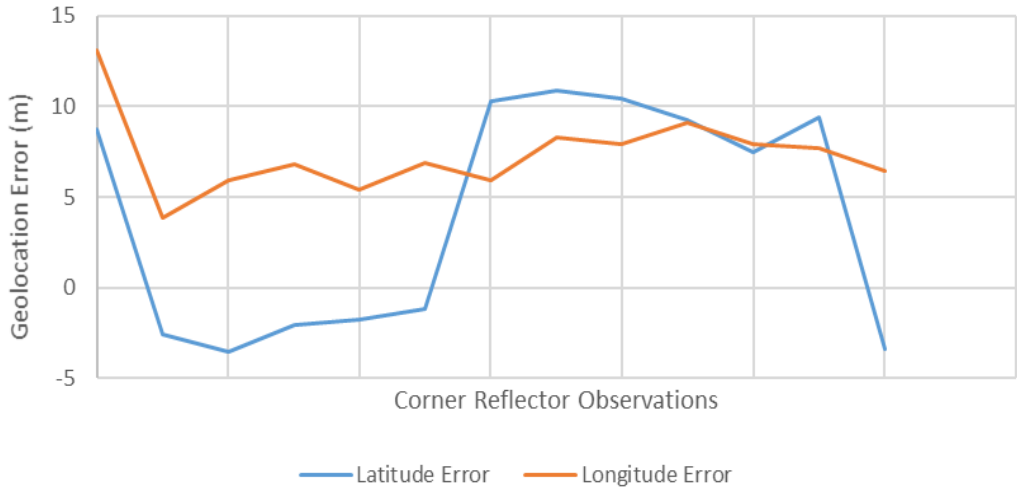
Long Term Geolocation-Error Statistics

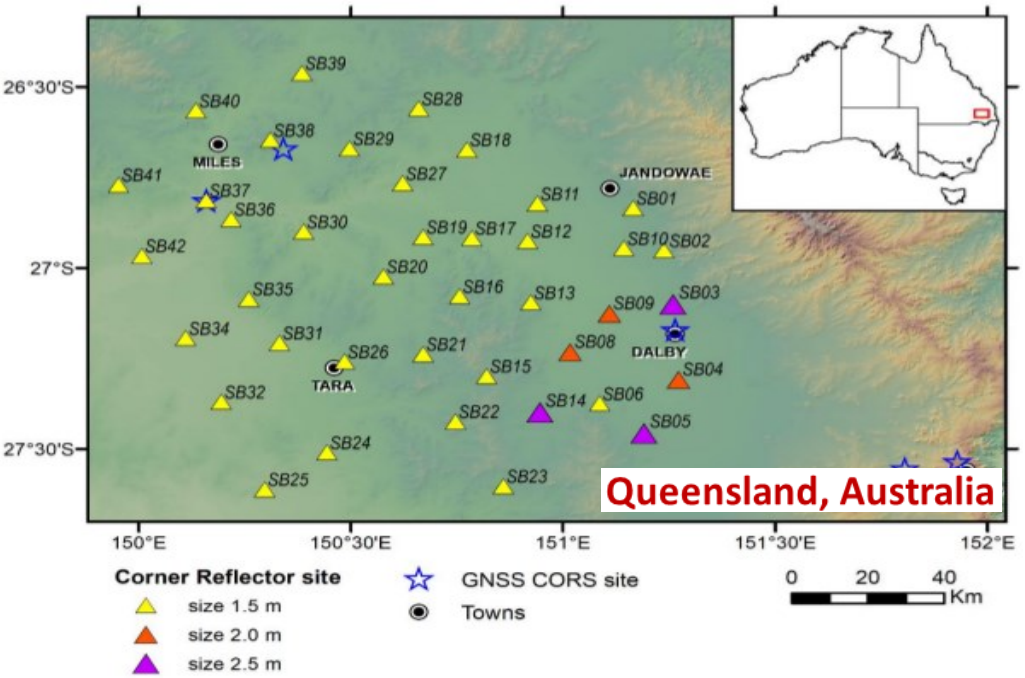


EOS-04 Geometric Calibration Validation for Corner Reflectors

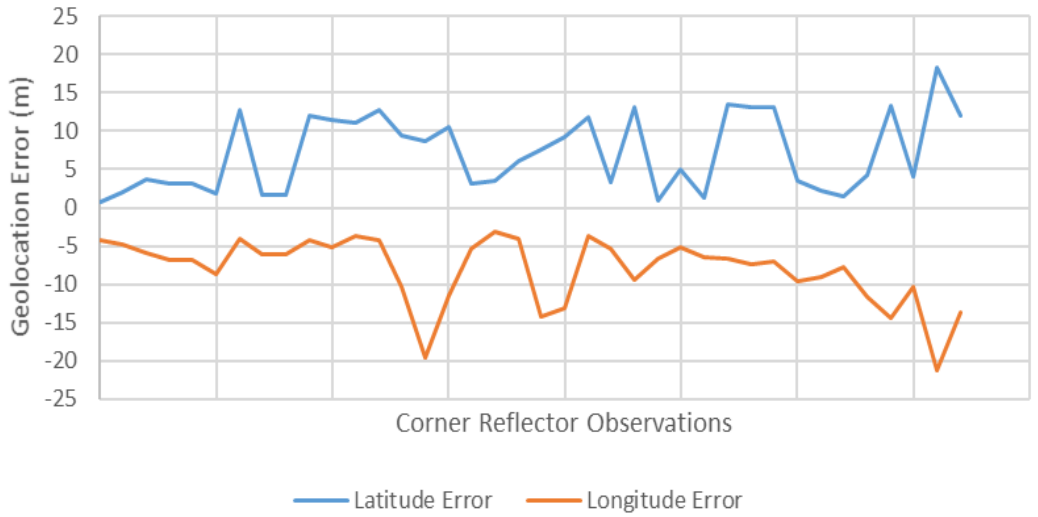


Geolocation-Error Statistics for Amrapur Corner Reflectors





Geolocation-Error Statistics for Queensland Corner Reflectors



Thank You

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