Calibration and Validation of
EOS-04 Hybrid Polarimetric ScanSAR Data

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Introduction

Over past many years, Synthetic Aperture Radar (SAR) imaging has received considerable attention due to its unique capabilities to provide day and night measurements, almost independent of atmospheric conditions.

Polarimetric SAR data has the potential to exploit many applications including:

(i) Agriculture (crop classification, soil moisture, crop assessment)

(ii) Oceanography (surface currents and wind field retrieval)

(iii) Forestry (forest monitoring, classification)

(iv) Disaster monitoring (oil spill detection, disaster assessment)

(v) Strategic applications (ship detection, target recognition/classification).

Capabilities of EOS-04 (follow-on mission of RISAT-1 – C-band SAR):

- Imaging Modes: Stripmap, ScanSAR and Sliding-Spotlight
- Polarizations: Single, Dual, Compact (CP) & Full (FP)
- Swath Coverage: 10 Km to 223 Km
- Spatial Resolutions: 1m to 50m
- Interferometric Mode - Experimental
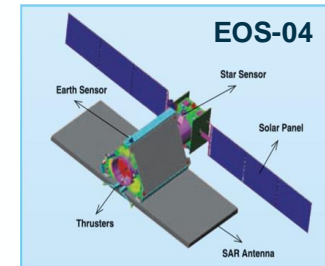
EOS-04

Earth Observation Satellite - 4 (EOS-04)

State-of-the-Art:

- RISAT-1(C-band) launched by ISRO in 2012 is first of its kind in Earth Observation Satellite to have Hybrid Polarimetry on-board.
- ScanSAR mode of Operation of EOS-04 offering Hybrid and Full polarimetric measurements to the user community.
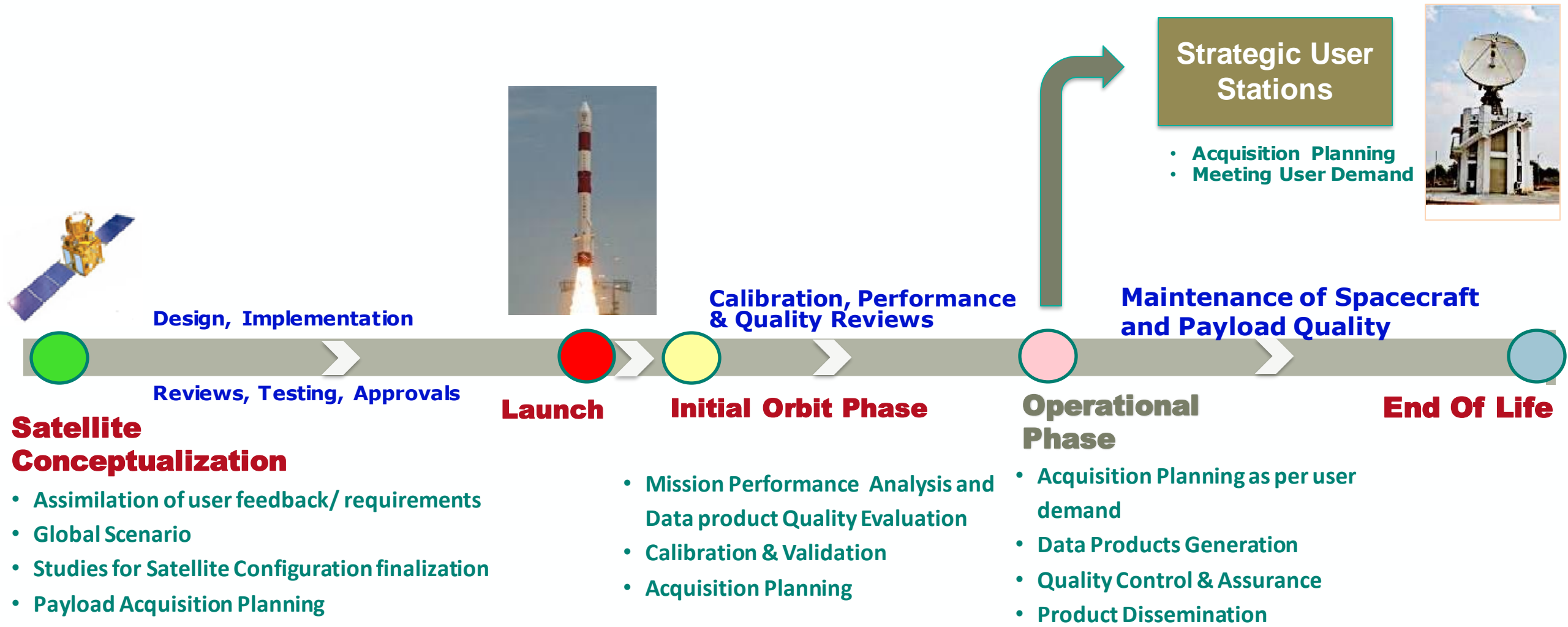
Motivation:

To provide calibrated and validated data products to support User community with the continuity to exploit Hybrid Polarimetric data having long term stability and data integrity.

Objective:

❑ Performing SAR Calibration and Validation of EOS-04 Stripmap and ScanSAR Hybrid polarimetric data.

❑ To implement different polarimetric decomposition techniques by deriving Stokes Parameters and performing sensitivity analysis on standard radar targets.

Strategic User Stations

- Acquisition Planning
- Meeting User Demand

Design, Implementation

Calibration, Performance & Quality Reviews

Maintenance of Spacecraft and Payload Quality

Reviews, Testing, Approvals

Launch

Initial Orbit Phase

Operational Phase

End Of Life

Satellite Conceptualization

- Assimilation of user feedback/ requirements
- Global Scenario
- Studies for Satellite Configuration finalization
- Payload Acquisition Planning

- Mission Performance Analysis and Data product Quality Evaluation
- Calibration & Validation
- Acquisition Planning

- Acquisition Planning as per user demand
- Data Products Generation
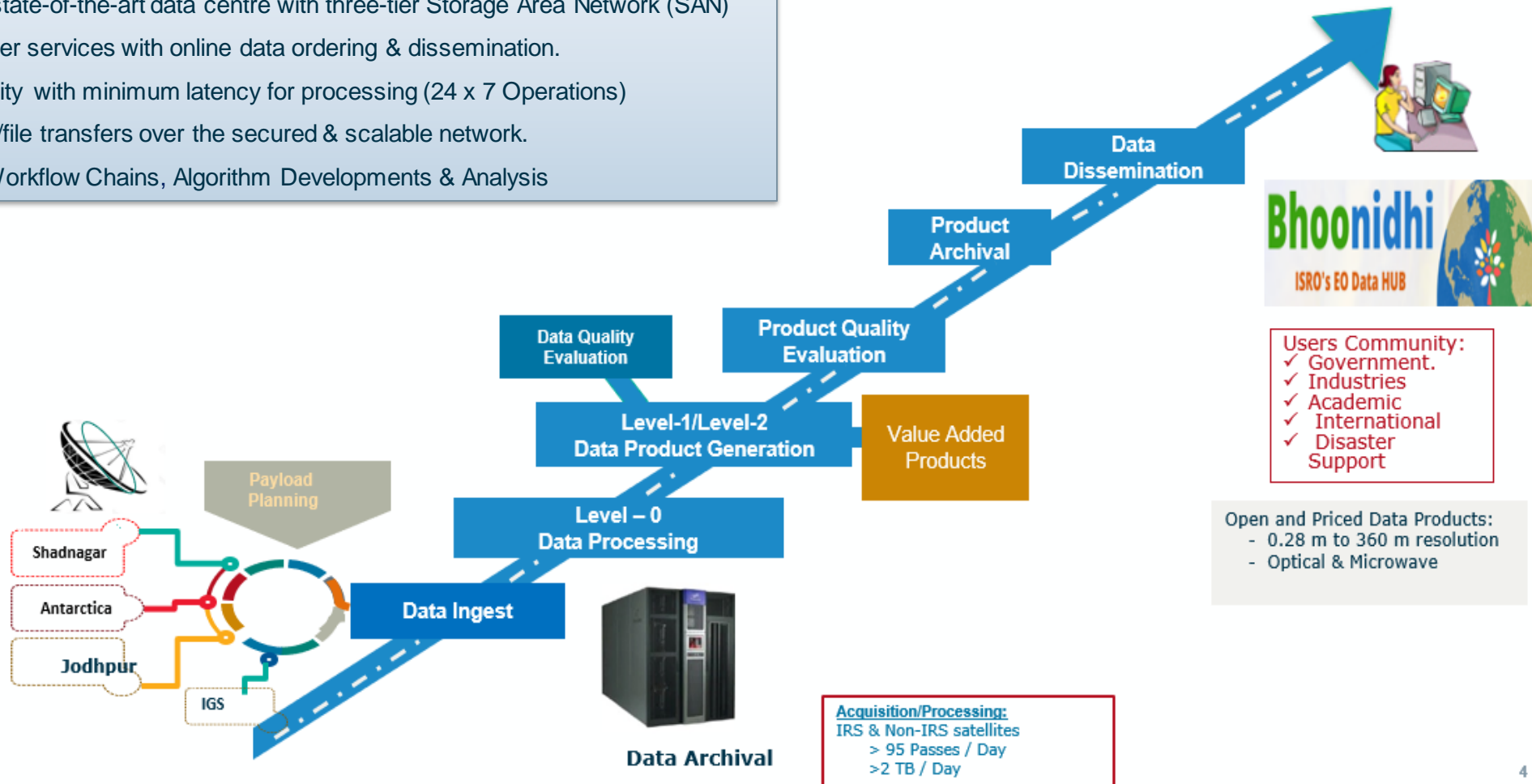- Quality Control & Assurance
- Product Dissemination

ISRO EO DATA PROCESSING for EOS-04

Integrated Multi-Mission Ground Segment for EO Satellites (IMGEOS)

Salient Features:

- World class state-of-the-art data centre with three-tier Storage Area Network (SAN)
- Enhanced user services with online data ordering & dissemination.
- Data availability with minimum latency for processing (24 x 7 Operations)
- Efficient data/file transfers over the secured & scalable network.
- Automated Workflow Chains, Algorithm Developments & Analysis

IMGEOS

Antarctica

Jodhpur

Shadnagar

Antarctica

Jodhpur

IGS

Payload Planning

Data Ingest

Level – 0 Data Processing

Level-1/Level-2 Data Product Generation

Data Quality Evaluation

Value Added Products

Product Quality Evaluation

Product Archival

Data Dissemination

Data Archival

Bhoonidhi
ISRO's EO Data HUB

Users Community:
- ✓ Government.
- ✓ Industries
- ✓ Academic
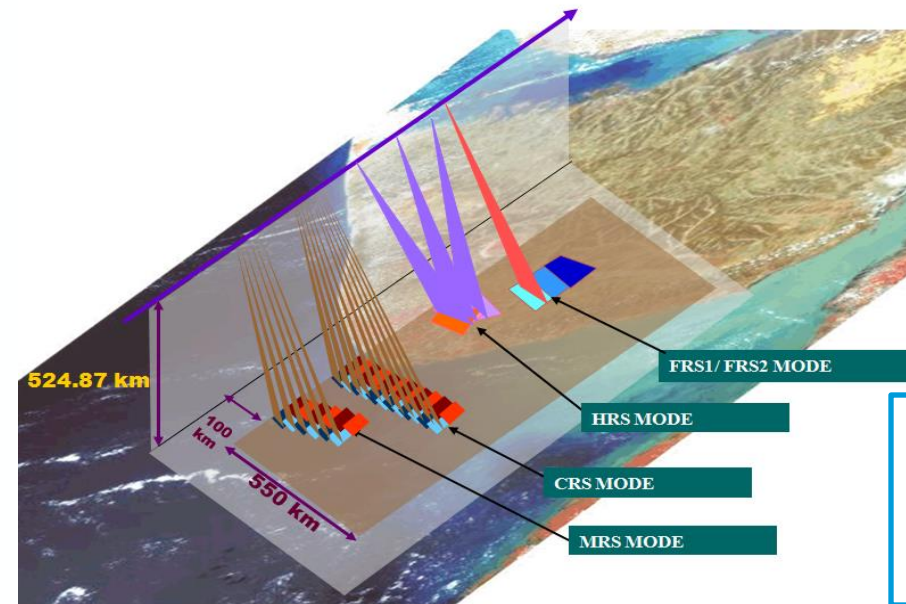- ✓ International
- ✓ Disaster Support

Open and Priced Data Products:
- 0.28 m to 360 m resolution
- Optical & Microwave

Acquisition/Processing:
IRS & Non-IRS satellites
> 95 Passes / Day
>2 TB / Day

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eesa
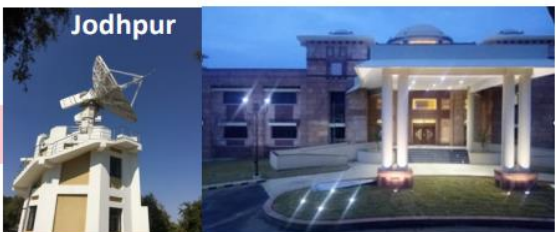
EOS-04 Imaging Modes:

- ❖ Fine Resolution StripMap (FRS-1)
- ❖ Coarse Resolution ScanSAR(CRS)
- ❖ Medium Resolution ScanSAR(MRS)
- ❖ Full Polarimetric StripMap (FRS-2)
- ❖ High Resolution Spotlight(HRS)

524.87 km
100 km
550 km

FRS1/FRS2 MODE
HRS MODE
CRS MODE
MRS MODE

EOS-04 (C-band SAR) has come up with:

- ✓ Medium Resolution ScanSAR (MRS) – 8 beams
- ✓ Course Resolution ScanSAR(CRS) - 12 beam configuration
- ✓ Swath Coverage :163 km and 223km for MRS and CRS respectively
- ✓ Spatial resolution: 8 to 50m

Standard Data Products	
Level -0	Raw Signal Product (Generic Binary)
Level-1	Slant Range Geo-Tagged Product Ground Range Products (CEOS/Geotiff)
Level-2 Georef	Enhanced Terrain corrected Geo Referenced Product (Geotiff)
Value Added Products	
Level-1C	Geo-tagged Polarimetric products
Level-3A	Geo-referenced Polarimetric products
Mosaic	India Mosaic (for systematic coverage) Large Area Mosaic

Projection: UTM (Level-2)
Datum : WGS84 (Level-2)
Resampling : CC (Level-2)

Parameters	Specifications
Altitude	524.87 km
Orbit	Sun synchronous (6 AM -descending / 6 PM equatorial crossing)
Frequency	5.4 GHz ± 37.5 MHz
Polarization Combination	Single / Dual / Full /Hybrid polarimetry
Antenna Roll Bias (deg)	± 36°
Range Coverage (Km)	100-650 (either side of flight track)
Look Angle (deg)	11.5 - 49.6
Incidence Angle (deg)	12.4 – 55.5

EOS-04	FRS-1 (StripMap)	FRS-2 (StripMap)	MRS (ScanSAR)	CRS (ScanSAR)
Swath (km) * Full Pol	25 Km (*20)	25 km (*20)	160 km (*115)	223 km (*168)
Polarization	Single, Dual Circular, Full Pol	Single, Dual, Circular, Full Pol	Single, Dual, Circular, Full Pol	Single, Dual, Circular, Full Pol
Resolution Az. x Slant Range(m)	3 x 2	3 x 4	33 x 8	50 x 8
Worst Sigma Naught (dB)	≤ -18	≤ -19	≤ -18	≤ -18
Off-Nadir (km) * Full Pol	100 – 650 (*100-400)	100-650 (*100 – 400)	100 – 650 (*100 – 400)	100 – 650 (*100 – 400)

Product Specifications	Value
Geo-location Accuracy(RMSE)	<50 m
Radiometric Resolution (SLC)	3.1 dB
PSLR	-17 dB
Relative Radiometric Accuracy	1 dB
Absolute Radiometric Accuracy	± 1 dB

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EOS-04 Data Products and Dissemination

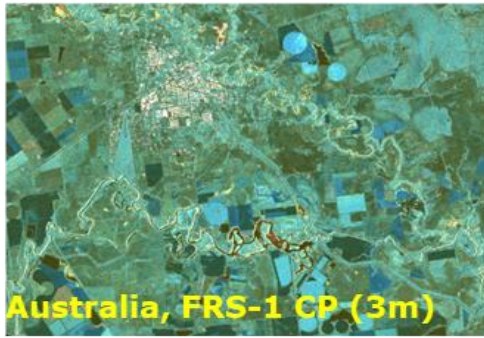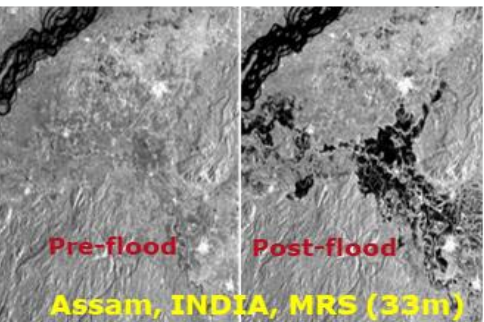

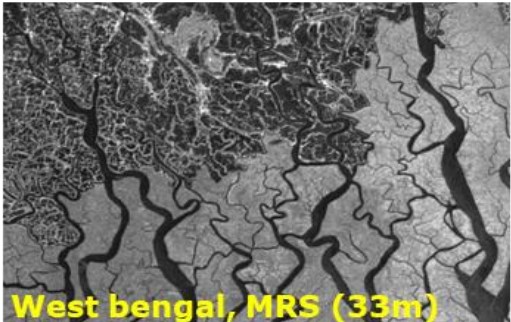Sample EOS-04 Images

Kuwait, FRS-1 FP (3m)

Odisha, India, FRS-1(3m)

Australia, FRS-1 CP (3m)

Palmdale, USA, FRS-1 (3m)

Pre-flood   Post-flood
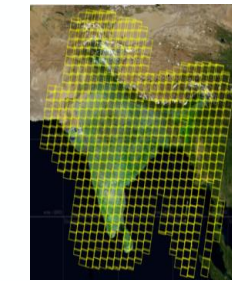
Assam, INDIA, MRS (33m)

West bengal, MRS (33m)

ISRO's EO data hub — Home Applications Contact Us nrsc

https://bhoonidhi.nrsc.gov.in

BHOONIDHI

We enable access to our extensive archive of Remote Sensing data from 44 satellites, including Indian and Foreign Remote Sensing sensors acquired since 1988. We also facilitate the Regional distribution of Sentinel and LandSat-8 data in India.

eased!!   Upagrah Orbit Viewer for satellite tracking released!!

VISTA
Visualize at Full Resolution

Bhoonidhi
STATS

Bhoonidhi
Browse & Order

Bhoonidhi
API

UPAGRAH
Orbit Viewer

Data products available to User community in Bhoonidhi Web Portal for Ordering

Full India Mosaic

Systematic Collections in ScanSAR mode (33m) in 17days over India

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SAR Cal-Val Activities at ISRO- PAN India CR Network

ISRO has established permanent and campaign mode Calibration Sites with an objective:

- To perform radiometric, geometric and polarimetric calibration of space borne and airborne SAR sensors operating in:
  - Multi-frequency (L, S, C and X bands)
  - Multi-polarizations (Single/Dual/Hybrid/Full Pol)
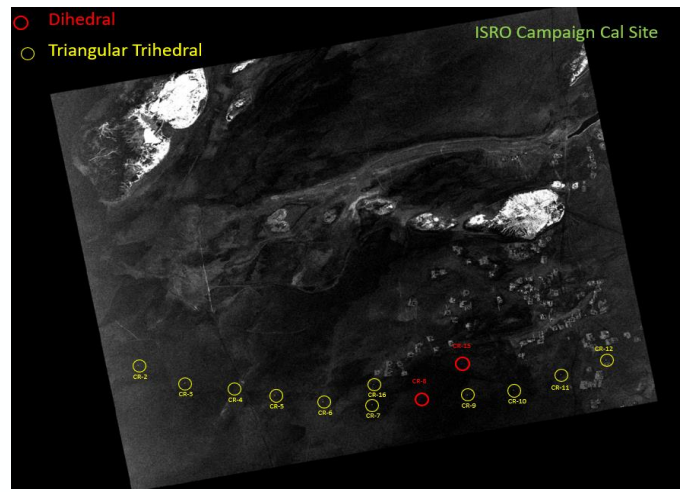- To derive SAR Image Quality Metrics for data product validation

Permanent Sites: NRSC-IMGEOS, SAC-Ahmedabad, Antarctica
Campaign mode Sites: Desalpur, Amarapur, IIST Campus

ISRO-IMGEOS Cal-Val Site

EOS-04 Fine Resolution Stripmap data

75cm Square Trihedral
40cm Square Trihedral
125cm Square Trihedral
IMGEOS Cal Site

Impulse Response Function for point target
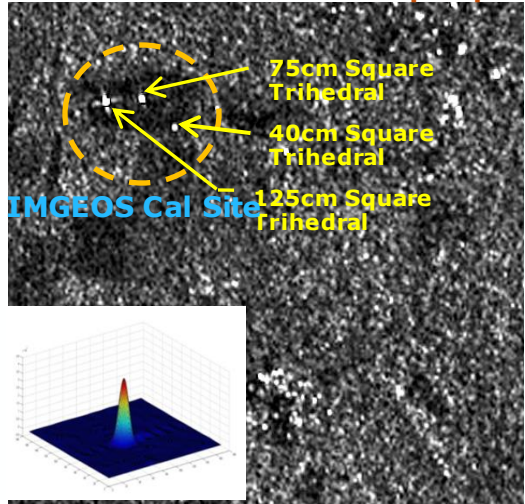
Indigenously developed Wideband Active Radar Calibrator (ARC) (L, S, C & X band)

Dihedral
Triangular Trihedral
ISRO Campaign Cal Site

CRs deployed in ISRO Cal Site in Campaign Mode

CR deployed at Antarctica during 2021-2022

Orientation of 100cm Dihedral CR

2m CR
New 2m CR
0.90m CR
SAC-Bopal CAL-VAL Site
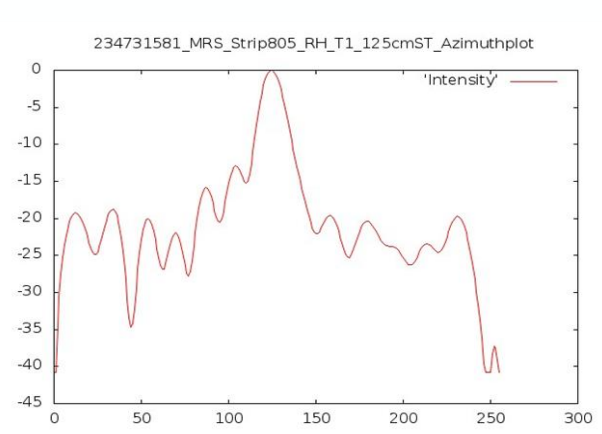
CRs deployed at SAC/ISRO

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Geometric Accuracy and Point Target Analysis of ScanSAR Data
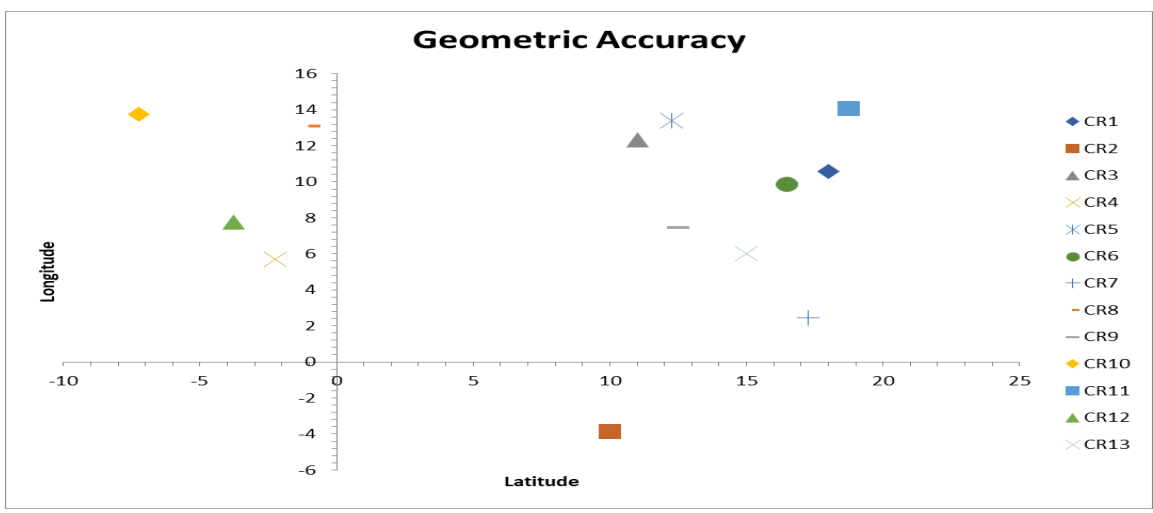
Impulse Response Function of Point Target
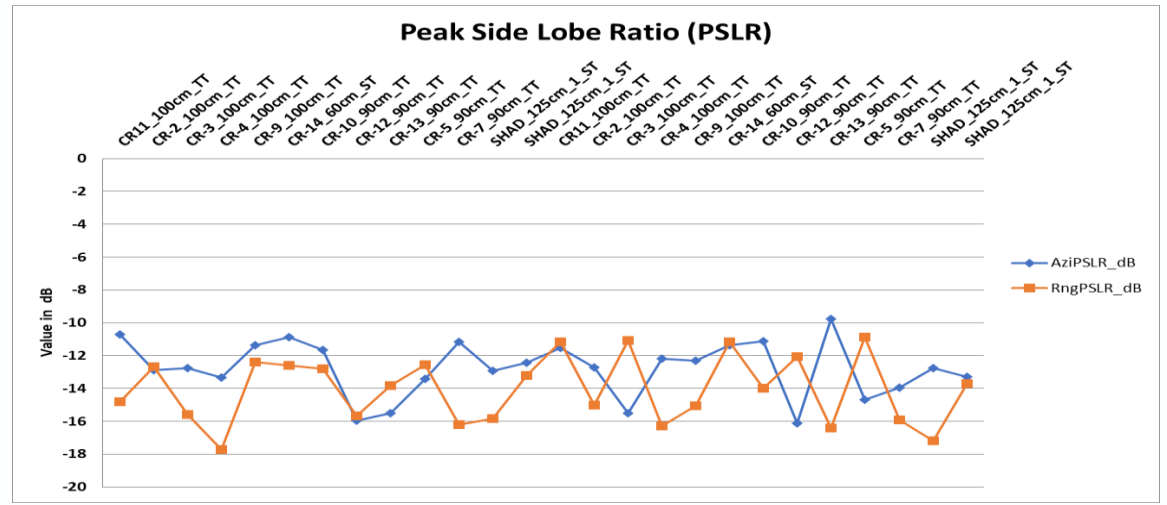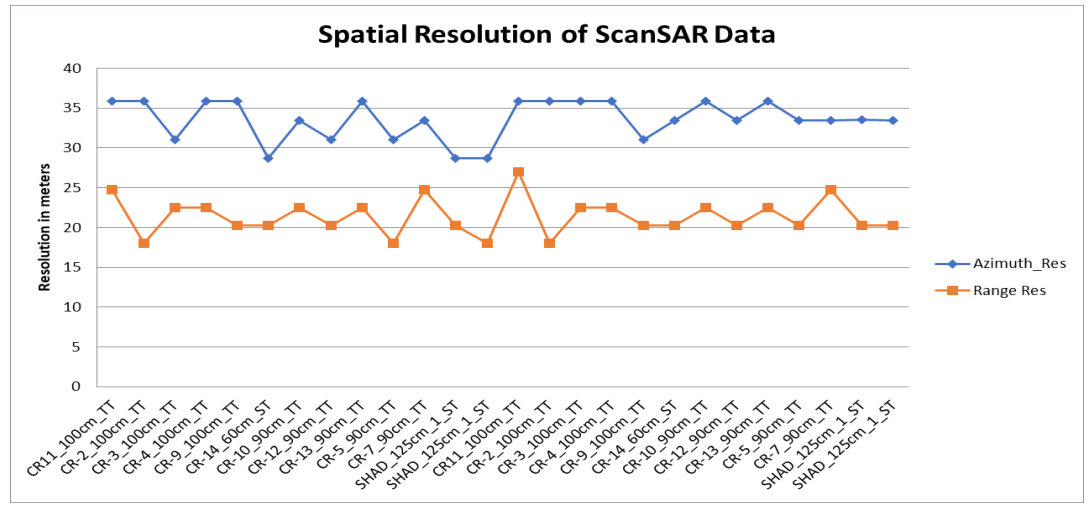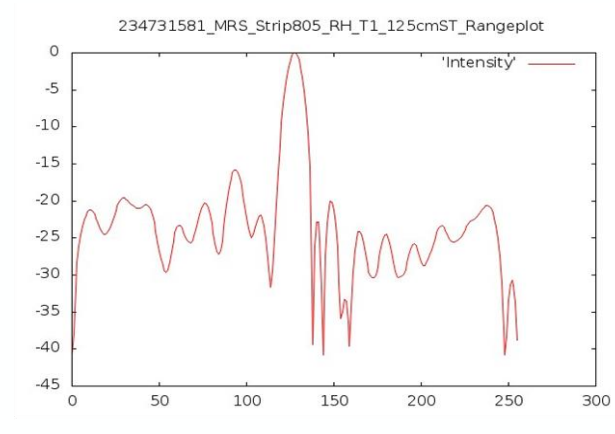
Methodology / Algorithm Implemented

✓ EOS-04 Hybrid polarimetric Single Look Complex (SLC) data corresponding to Stripmap and ScanSAR in performing validation of polarimetric parameters using point target and distributed targets.

✓ ScanSAR SLC data contains burst wise complex data for each polarization.

Stokes Vector: (RH-RV Case, BSA Convention)

$$S_0 = \langle |RH|^2 + |RV|^2 \rangle$$

$$S_1 = \langle |RH|^2 - |RV|^2 \rangle$$

$$S_2 = 2\Re \langle RH \cdot RV^* \rangle$$

$$S_3 = -2\Im \langle RH \cdot RV^* \rangle$$

Stokes Parameters: (RH-RV Case, BSA Convention)

Degree of Polarization: $m = \dfrac{\sqrt{S_1^2 + S_2^2 + S_3^2}}{S_0}$

Relative RH-RV Phase: $\delta(\deg) = \tan^{-1}\left(\dfrac{S_3}{S_2}\right)$

Degree of Circularity: $\sin 2\chi = \dfrac{S_3}{mS_0}$

Scattering mechanism: $\alpha(\deg) = \dfrac{1}{2}\tan^{-1}\left(\dfrac{\sqrt{S_1^2 + S_2^2}}{-S_3}\right)$

m-delta (δ) Decomposition:

$$B = f_{odd} = \sqrt{S_0 \times m \times \frac{1+\sin\delta}{2}}$$

$$R = f_{even} = \sqrt{S_0 \times m \times \frac{1-\sin\delta}{2}}$$

$$G = f_{diffused} = \sqrt{S_0 \times (1-m)}$$

m-chi (χ) Decomposition:

$$B = f_{odd} = \sqrt{S_0 \times m \times \frac{1+\sin 2\chi}{2}}$$

$$R = f_{even} = \sqrt{S_0 \times m \times \frac{1-\sin 2\chi}{2}}$$

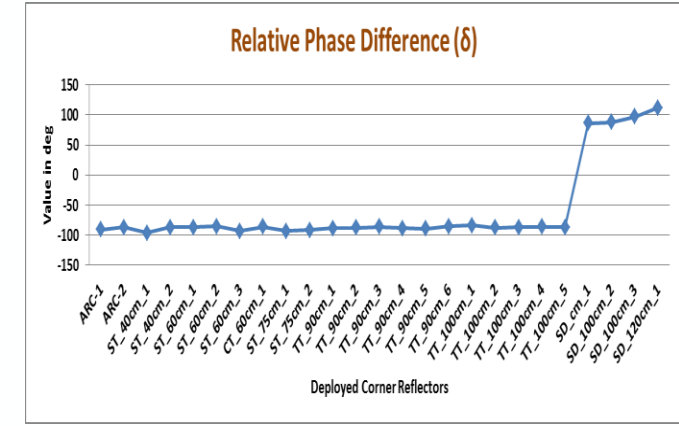$$G = f_{diffused} = \sqrt{S_0 \times (1-m)}$$

m-alpha (α) Decomposition:
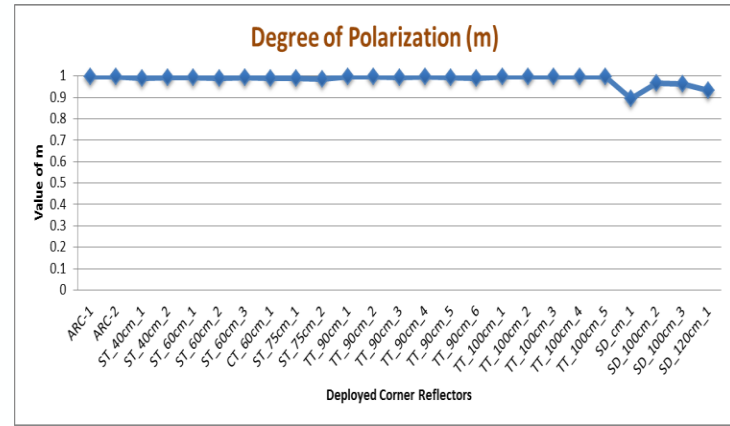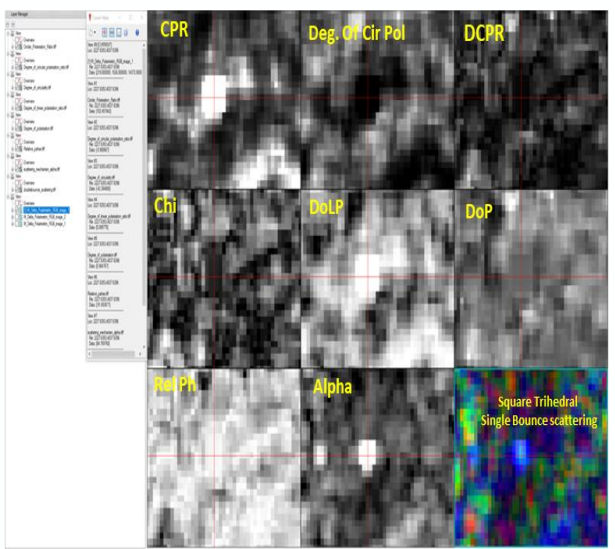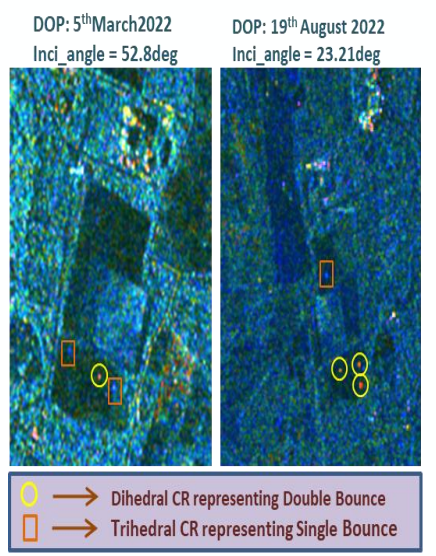
$$B = f_{surface} = \sqrt{S_0 \times m \times \frac{1-\cos 2\alpha}{2}}$$

$$R = f_{dihedral} = \sqrt{S_0 \times m \times \frac{1+\cos 2\alpha}{2}}$$

$$G = f_{volume} = \sqrt{S_0 \times (1-m)}$$

Details of Datasets:

Imaging Mode: Medium Resolution ScanSAR(MRS)

Fine Resolution Stripmap (FRS-1)

Standard Radar Targets: Trihedral/Dihedral Corner Reflectors

Level of the data product: Single Look Complex (SLC)

Study Area: Calibration data acquired over ISRO Cal-Val site

Software: In-house developed Cal-Val Software

Raney et al., PolinSAR, 2008;
Charbonneau, et.al., PolinSAR, 2009

Raney et al., JGR, Vol. 117, E00H21, 2012

Cloude, et al., IEEE GRS Letters, 9(1), Jan 2012

Hybrid Pol Parameter for Stripmap CR Data

DOP: 5th March 2022
Inci_angle = 52.8deg

DOP: 19th August 2022
Inci_angle = 23.21deg

Dihedral CR representing Double Bounce
Trihedral CR representing Single Bounce

Relative phase in deg
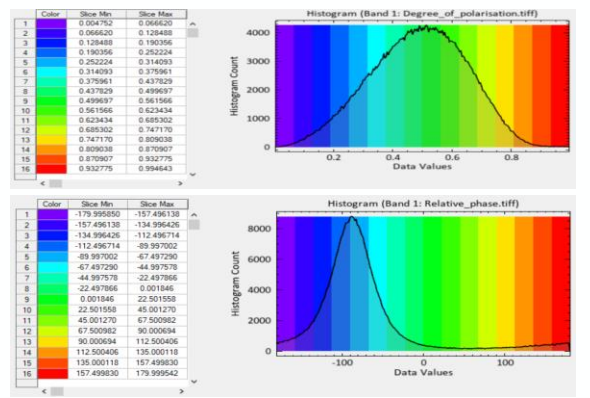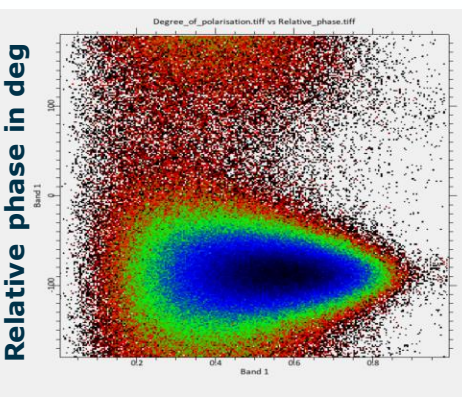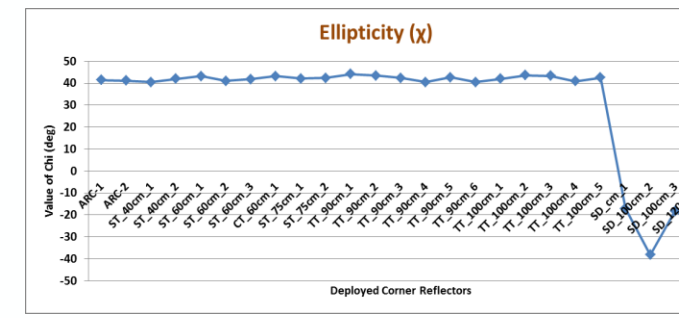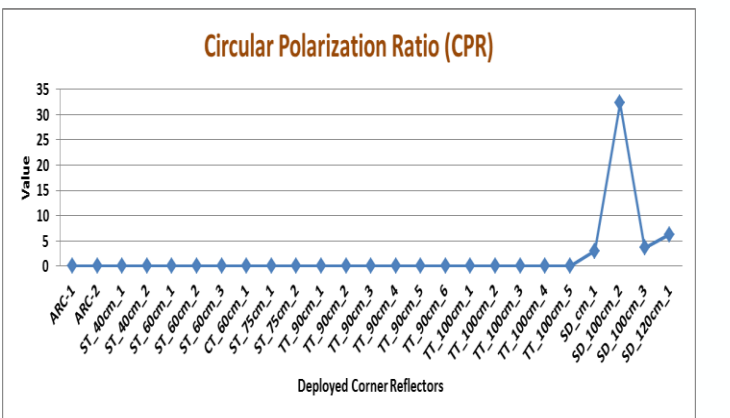
Degree of Polarization

Distribution of Degree of Polarization and Relative phase of EOS-04 Hybrid Polarimetric calibration parameters over Heterogeneous terrain

CPR — Deg. Of Cir Pol — DCPR
Chi — DoLP — DoP
RelPh — Alpha — Square Trihedral Single Bounce scattering

Degree of Polarization (m)
Relative Phase Difference (δ)
Circular Polarization Ratio (CPR)
Ellipticity (χ)
Degree of Circular Polarization
Degree of Linear Polarization
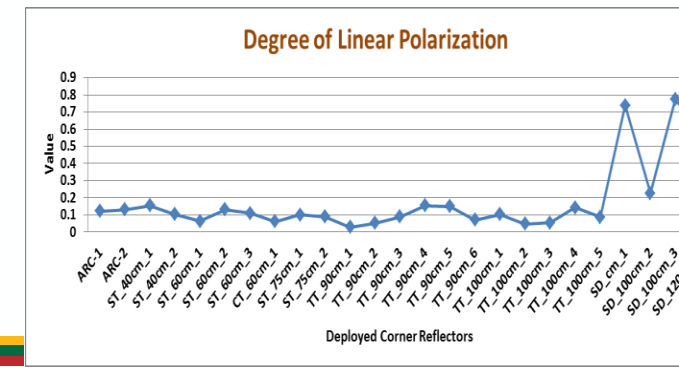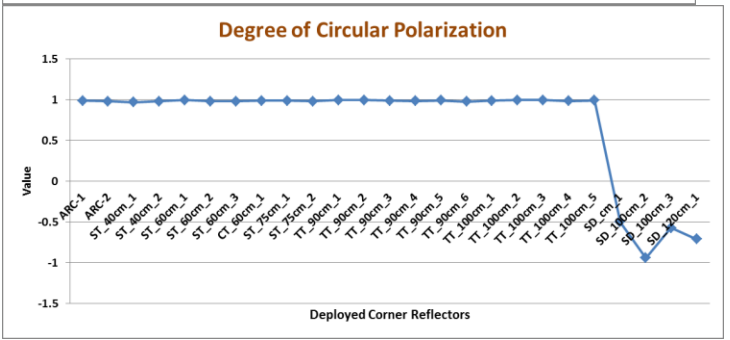
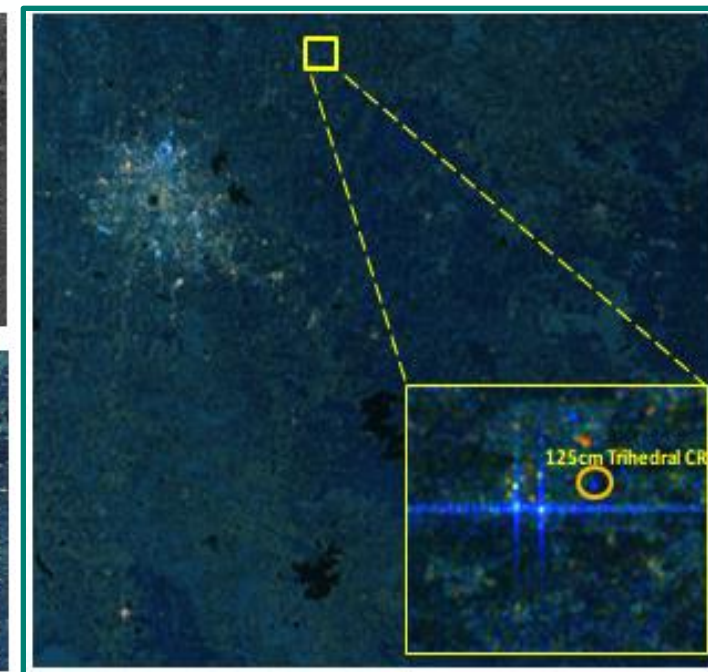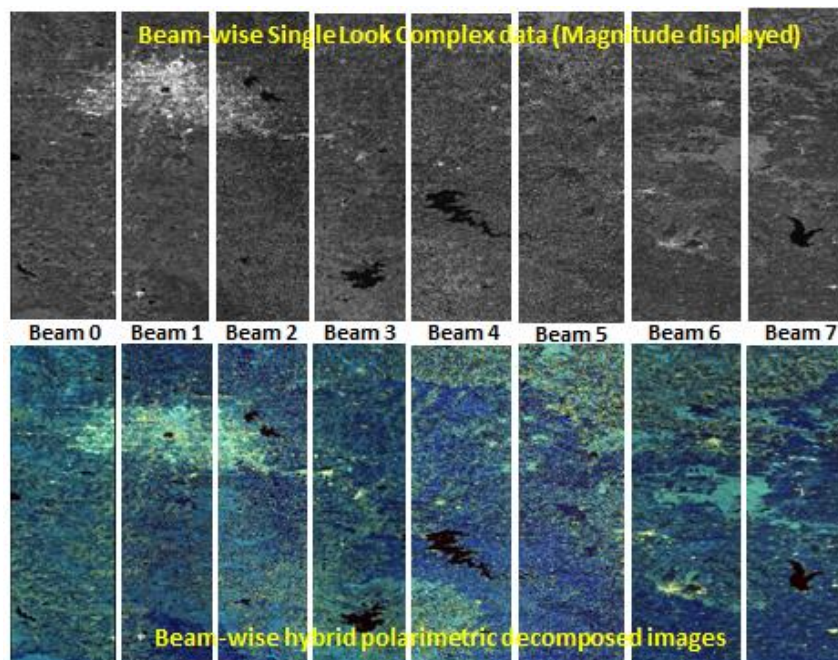# Hybrid Pol Parameter for ScanSAR Point Target Data

Mosaicking of Burst Data:

Handling of intricacies related to extracting/processing of ScanSAR (8 to 12 beams) SLC data, while mosaicking in slant range domain (by preserving phase) to form a complete scene:

- ✓ Number of bursts
- ✓ First valid line
- ✓ Number of valid samples
- ✓ Minimum range of burst buffer
- ✓ Start and End Time of beam(seconds)

Typical Values derived from Standard Radar Targets

Stokes Child Parameters	Value
Degree of Polarization(m)	0.9958
Relative phase (δ) in deg	93.379
Ellipticity (χ) in deg	-42.87
Circular Polarization Ratio(CPR)	0.0034
Degree of Linear Polarization	0.074
Degree of Circular Polarization	-0.9972

Beam-wise Single Look Complex data (Magnitude displayed)

Beam 0 Beam 1 Beam 2 Beam 3 Beam 4 Beam 5 Beam 6 Beam 7
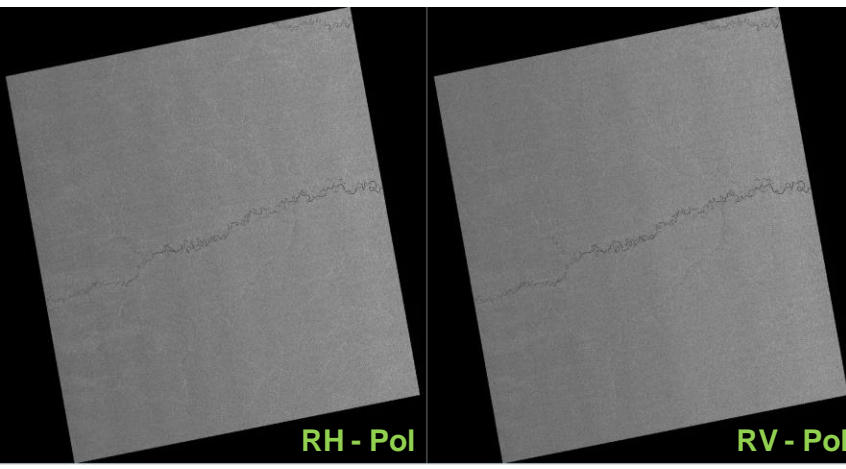
Beam-wise hybrid polarimetric decomposed images

125cm Trihedral CR

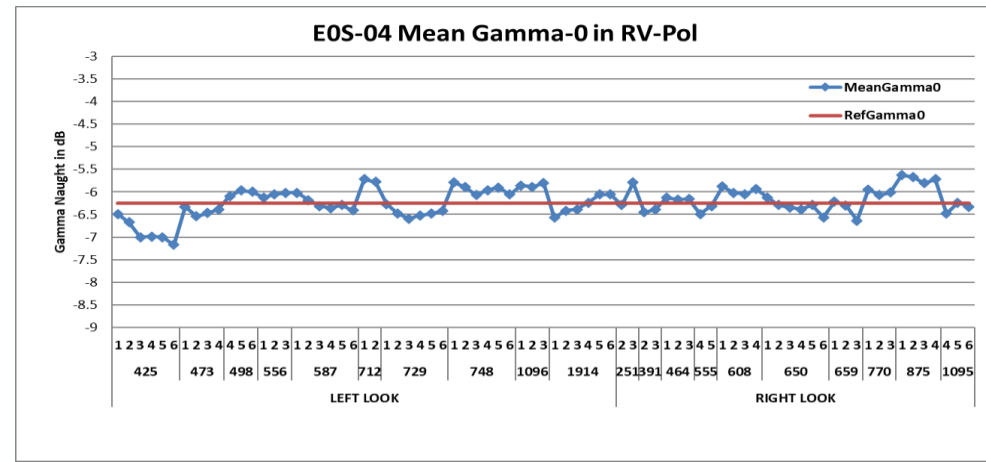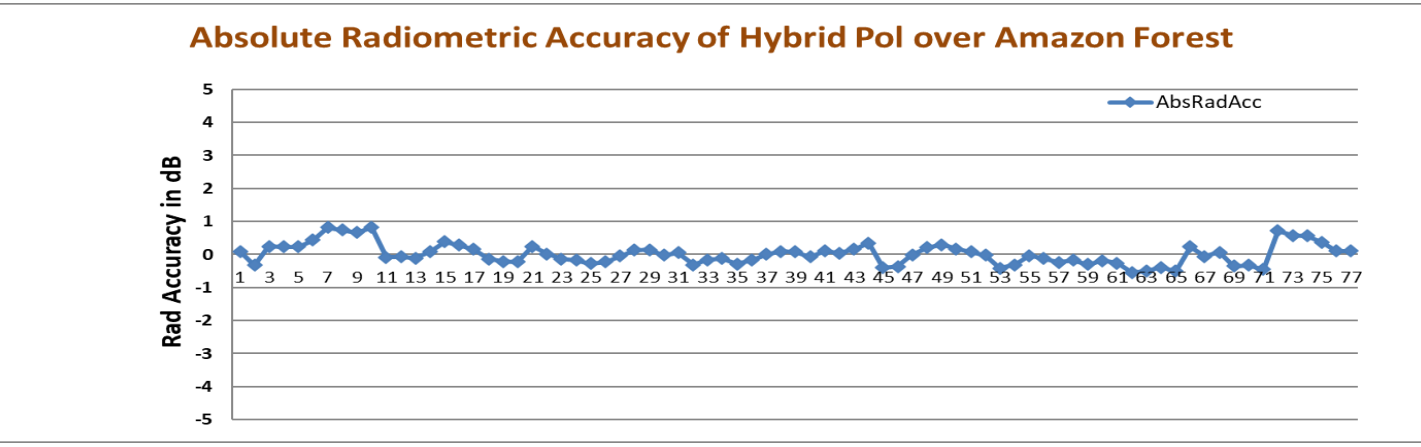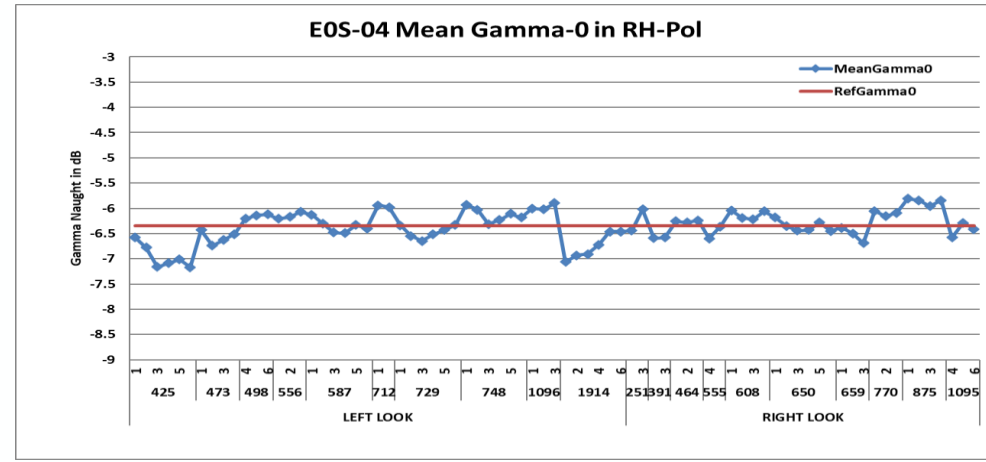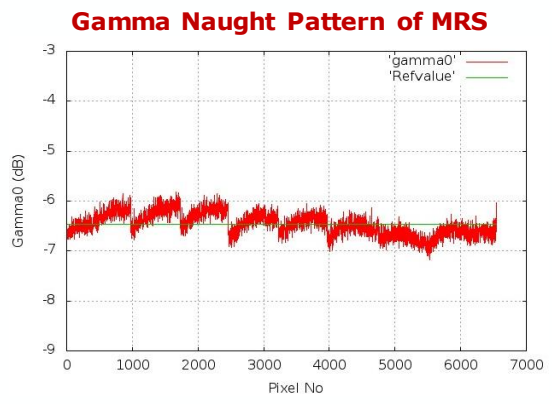**Mosaicked scene in SLC domain**

Observations:

- The relative phase component for burst data with overlap and without overlap between bursts is around 3 deg which is in acceptable range for exploiting MRS Hybrid Pol Data.
- Significant improvement is observed between Calibrated and Un-Calibrated data with $\pm$ 4 to 6 deg variation in Relative phase and 2 to 3 deg in Ellipticity.
- Stokes vector and its derived value added parameter based decompositions are well demonstrated with corner reflectors as they aid in characterizing target properties based on dominant basic scattering mechanism.

EOS -04 ScanSAR MRS Data Over Amazon – EAP Analysis (Distributed Target Analysis)

Gamma 0 analysis is performed on ScanSAR MRS Hybrid Pol Data acquired over Amazon Rain Forest to estimate Elevation Antenna Profile.

RH - Pol

RV - Pol

Date Of Pass=07-JUL-2022 Imaging Orbit No=2176
ASCENDING / LEFT , Incidence Angle=31.95438

Gamma Naught Pattern of MRS

E0S-04 Mean Gamma-0 in RH-Pol

Absolute Radiometric Accuracy of Hybrid Pol over Amazon Forest

E0S-04 Mean Gamma-0 in RV-Pol

Absolute Radiometric Accuracy is within ± 1 dB as per the specification

Conclusion

- ISRO's Ground Segment Activities and Payload capabilities of EOS-04 with its unique Hybrid Polarimetric feature in ScanSAR imaging mode is discussed.

- ISRO's SAR Calibration and Validation Facility and its Activities

- Radiometric, Geometric and Polarimetric calibration and Validation performed using Point Target and Distributed Target Analysis and the image quality metric are as per specifications.

- Absolute Radiometric Accuracy is within $\pm$ 1 dB as per the specification

- EOS-04 Hybrid polarimetric data has been analyzed and processed for different standard point targets like corner reflectors using Stokes parameter based decomposition techniques.

- Stokes vector and its derived value added parameter based decompositions are well demonstrated with corner reflectors as they aid in characterizing target properties based on dominant basic scattering mechanism.

- Significant improvement is observed between Calibrated and Un-Calibrated data with $\pm$ 4 to 6 deg variation in Relative phase and 2 to 3 deg in Ellipticity.

- EOS-04 operational Hybrid Polarimetric Level-3A data products (M-delta and M-chi decomposed data products) can be used to exploit land and ocean applications

- Calibration and Validation of ScanSAR mode Hybrid Polarimetric data products will upscale polarimetric based applications having larger swath coverages.

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Acknowledgements:

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