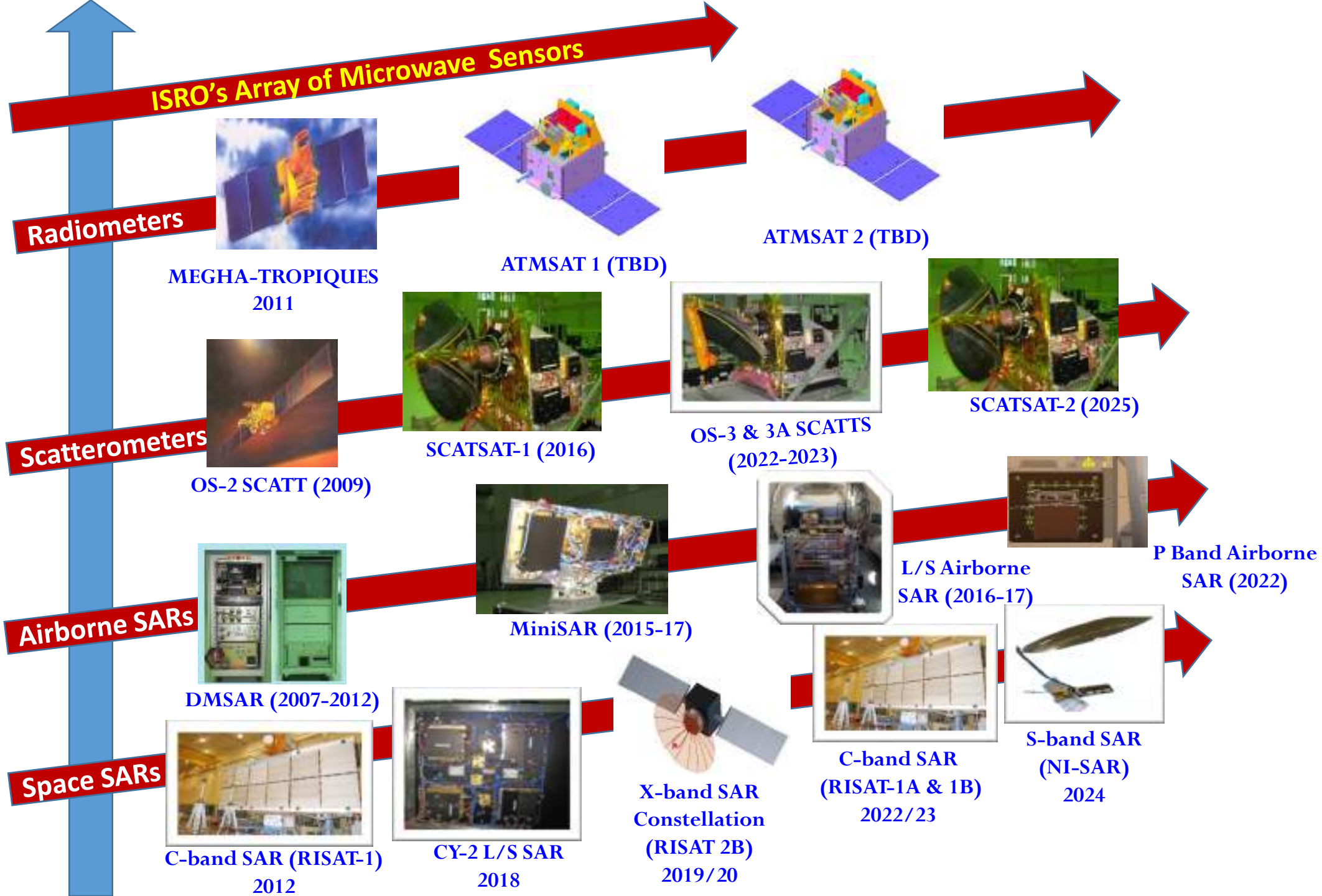
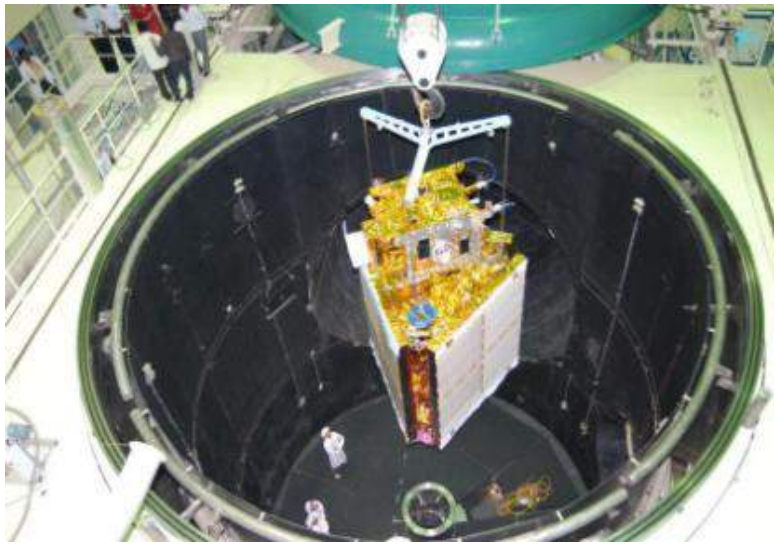
ISRO's SAR Endeavours : Past, Present and Future

Nilesh M Desai
Director-SAC,
ISRO


ISRO's Array of Microwave Sensors
Radiometers
MEGHA-TROPIQUES
2011
ATMSAT 1 (TBD)
ATMSAT 2 (TBD)
Scatterometers
OS-2 SCATT (2009)
SCATSAT-1 (2016)
OS-3 & 3A SCATTS
(2022-2023)
SCATSAT-2 (2025)
Airborne SARs
DMSAR (2007-2012)
MiniSAR (2015-17)
L/S Airborne
SAR (2016-17)
P Band Airborne
SAR (2022)
Space SARs
C-band SAR (RISAT-1)
2012
CY-2 L/S SAR
2018
X-band SAR
Constellation
(RISAT 2B)
2019/20
C-band SAR
(RISAT-1A & 1B)
2022/23
S-band SAR
(NI-SAR)
2024

Earth Observation Space-borne SARs

C-band SAR (RISAT-1) : 2012-2017

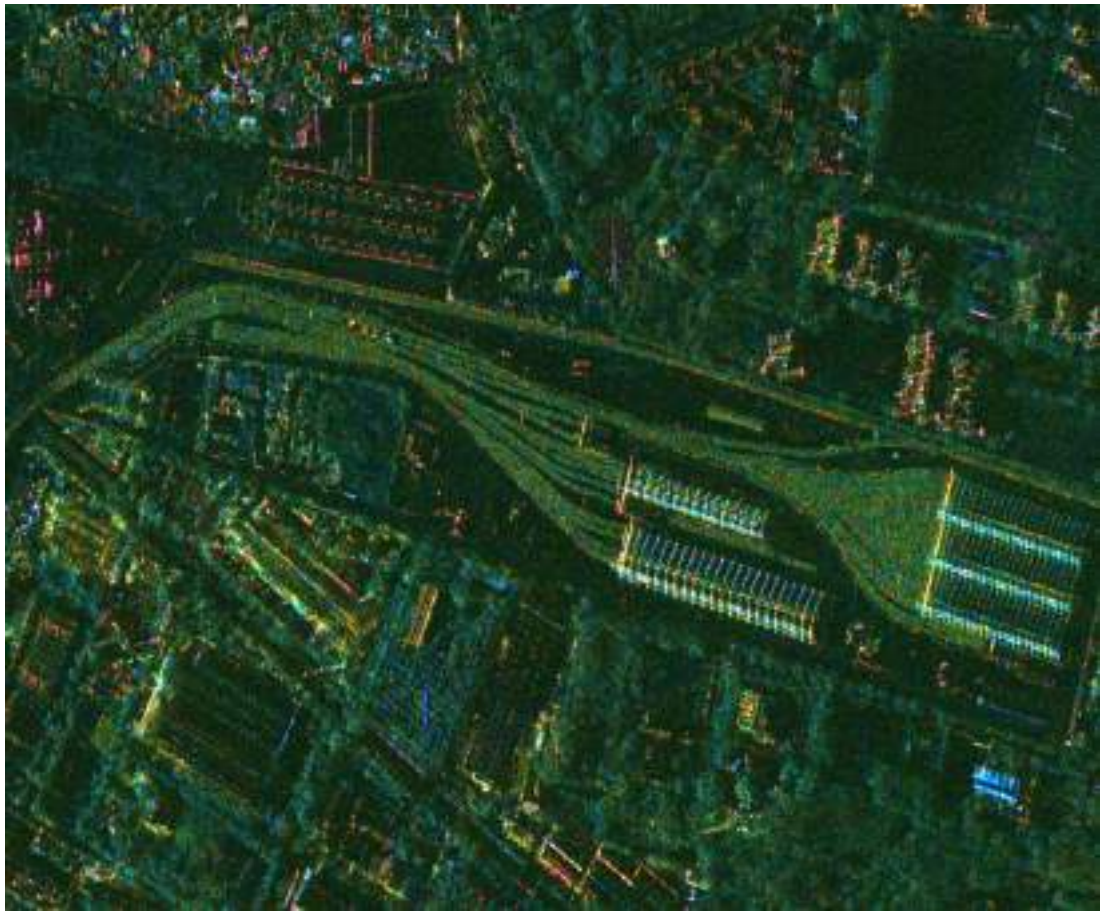


RISAT-1 in characterization tests

- Resolution: 2m – 50m
- Swath: 10km – 220km
- Repetivity: 25 days

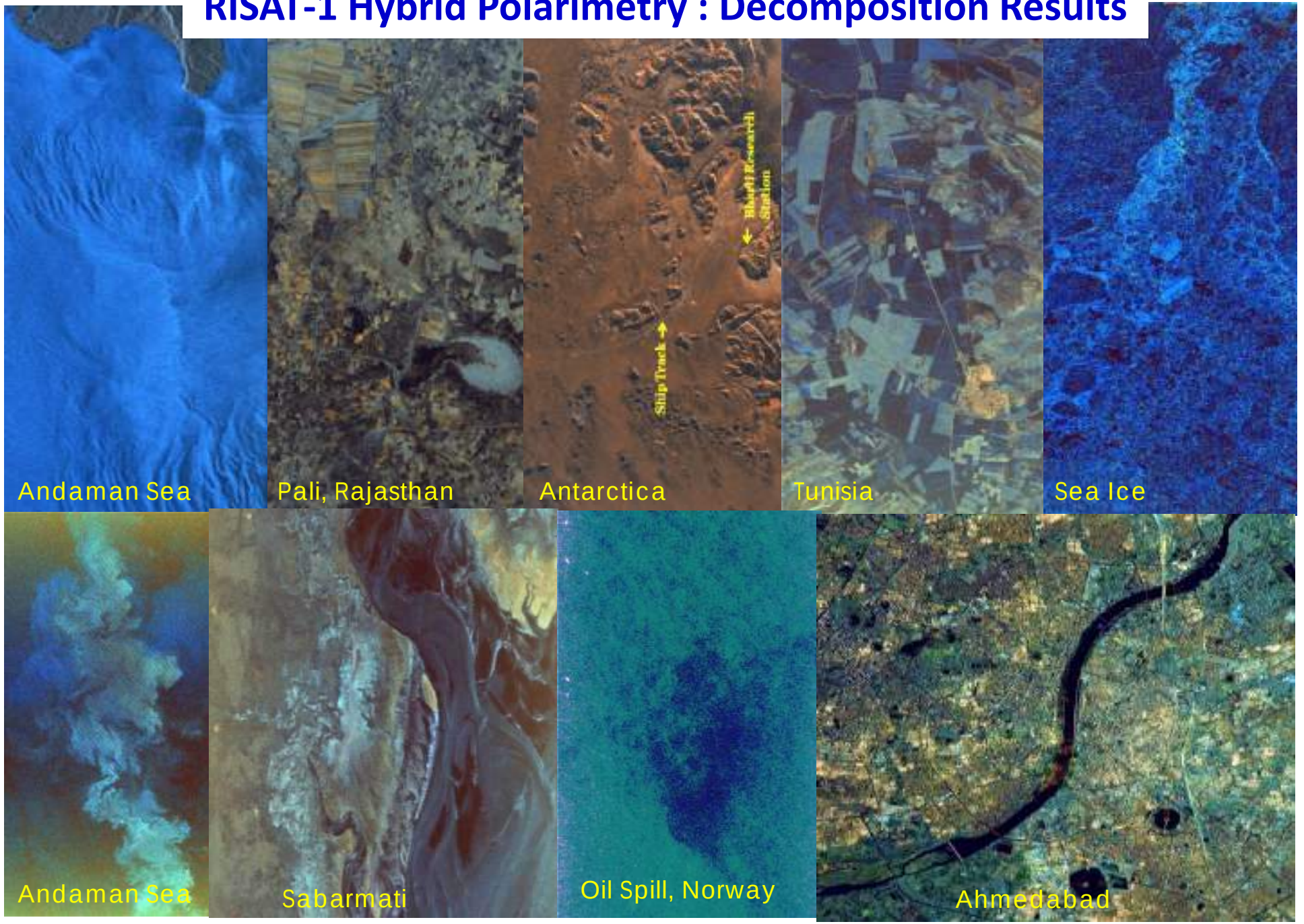
Satellite integrated with PSLV

- Indigenously developed Active Array SAR
- Multimode: Stripmap, ScanSAR and Spotlight
- Hybrid polarimetry mode alongwith Single/Dual pol



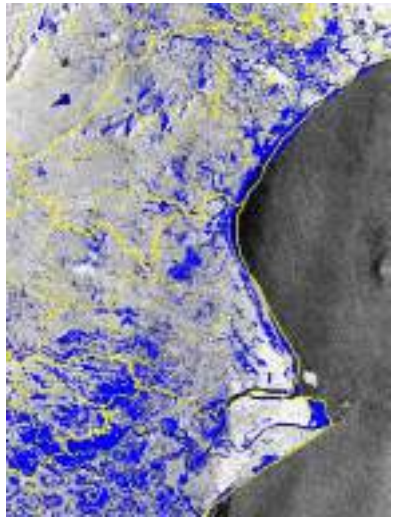
High Resolution Spotlight Mode
With Hybrid Polarimetry

RISAT-1 Hybrid Polarimetry : Decomposition Results

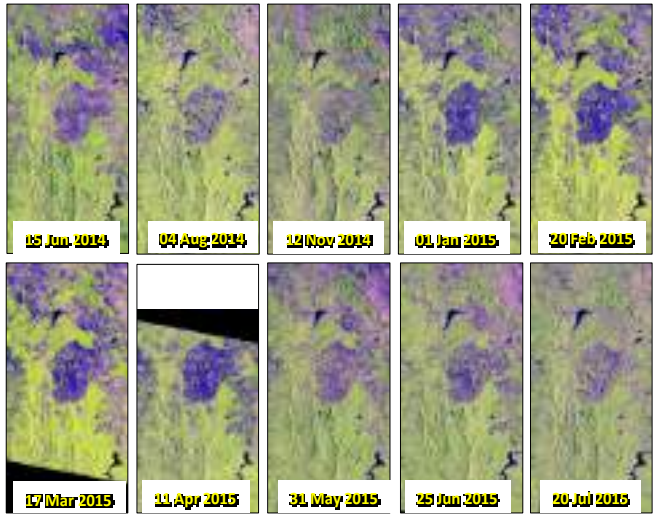


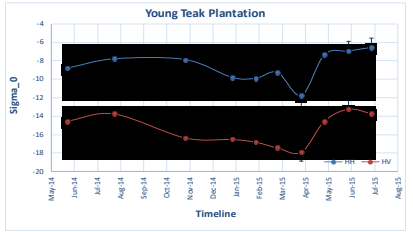
Glimpses of RISAT-1 Applications

Impact of Phailin Cyclone of Oct 2013

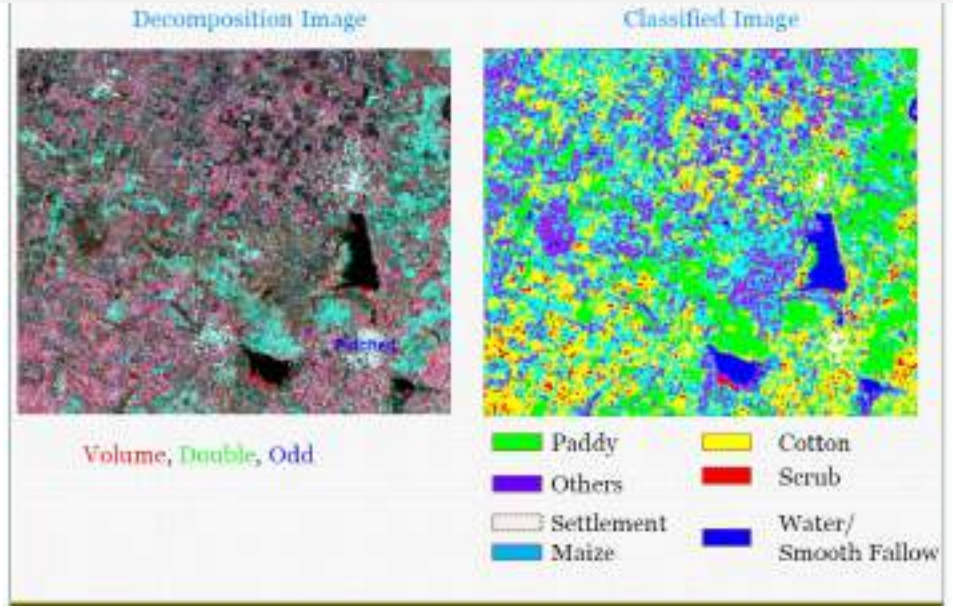


Forest phenology mapping to assess carbon flux



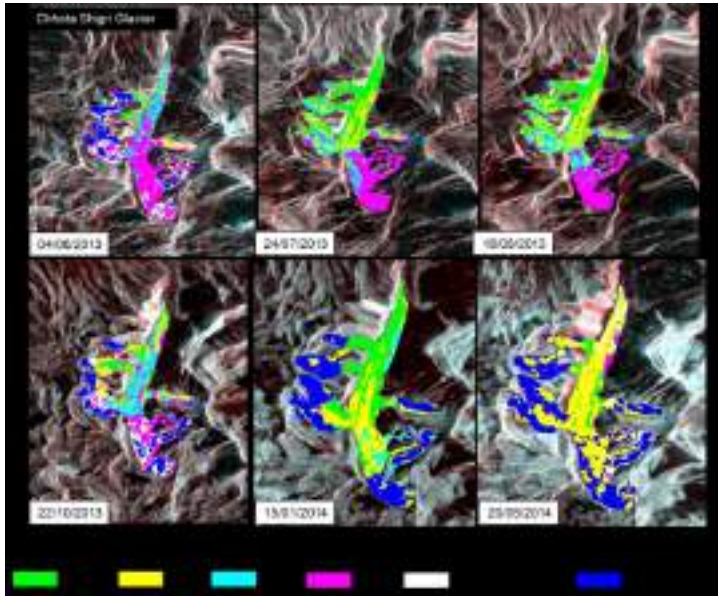


Discrimination of Rice, Cotton and Maize using RISAT-1 FRS-1 Hybrid Pol data

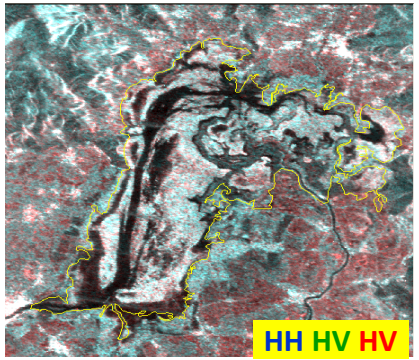


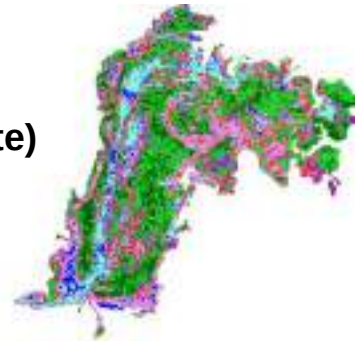
Flood affected area as on 14/10/13 (Superimposed on image)

Glacier facies classification



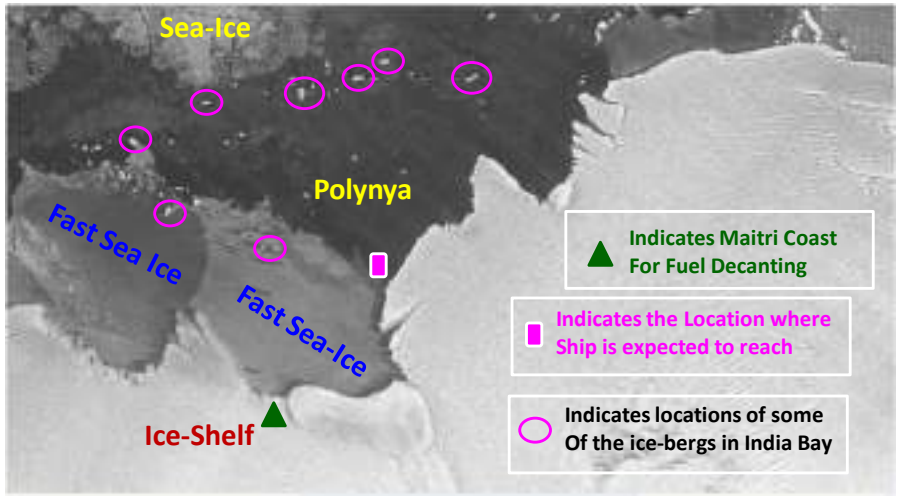
Wetland monitoring for ecosystem assessment (Wular Lake (Ramsar site)





Color	Class Names	Area (ha)
	Area Outside Wular wetland	21995.3
	Water	580.802
	Lowdensity Trapa	2249.63
	Mediumdensity Trapa	809.093
	Highdensity Trapa	1369.52
	Matured Medium Willow	1543.67
	Matured Dense Willow	1767.68
	Grass Land	1206.32
	Habitation	947.7
	Paddyfields	168.091
	Fallow	739.951

Discrimination of Sea Ice and Polar Ice Features



RISAT-1A (EOS-4) C-band SAR : Launched in Feb 2022

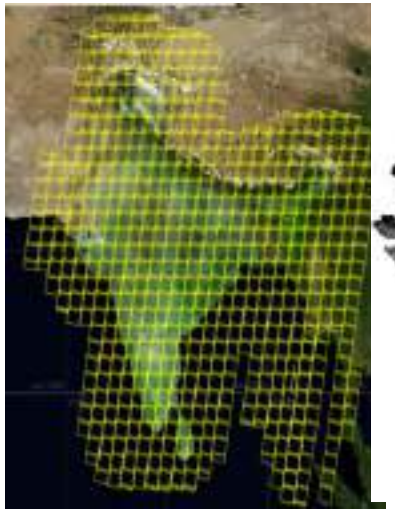
- SAR @ 5.4 GHz using 6mx2m Planar Phased Array Antenna
- Single/Dual/Hybrid / Full (Quad) Polarizations
- Off-Nadir Coverage of 100km – 650km either side of the flight track
- Off-Nadir Coverage with only electronic beam steering – Onboard computation based antenna beam generation
- Imaging Modes: FRS-1, FRS-2, MRS-6/8 beam, CRS, HRS
- System Design with Numerous Programmability features

RISAT-1A Data Products

Capabilities of EOS-04(follow-on mission of RISAT-1):

- **Imaging Modes**: Stripmap, ScanSAR and Sliding-Spotlight (FRS-1, FRS-2, MRS, CRS and HRS)
- **Polarizations**: Single, Dual, Compact (CP) & Full (FP)
- **Swath Coverage**: 15 Km to 223 Km
- **Spatial Resolutions**: 1m to 50m

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

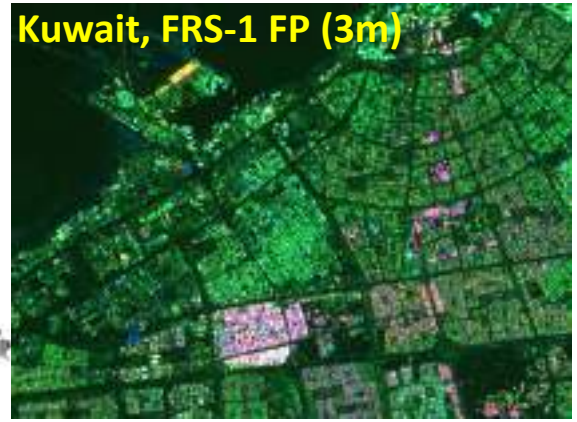


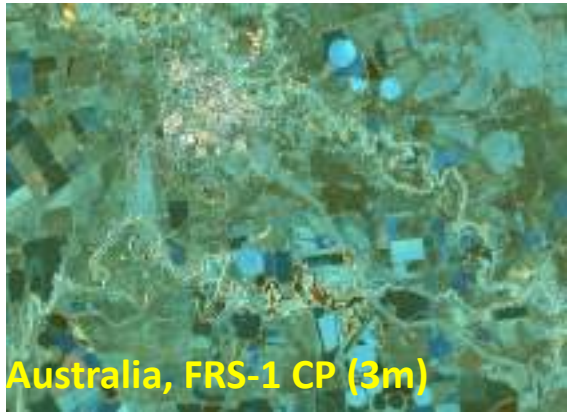
Systematic Collections in ScanSAR mode

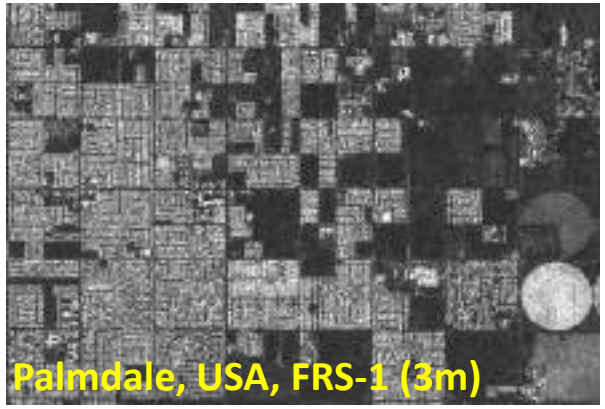
Levels of Data Products	
Level -0	Raw Signal Product (Generic Binary)
Level-1	Slant Range Geo-Tagged Product Ground Range Products (CEOS/GeoTiff)
Level-2 GEOREF	Enhanced Terrain corrected Geo Referenced Product (GeoTiff)
Value Added Products	
Level-1C	Geo-tagged Polarimetric products
Level-3A	Geo-referenced Polarimetric products
Mosaic	Large Area Mosaic Full Strip Mosaic India Mosaic (for systematic coverage)
Projection: UTM/ Polyconic (Level-2) Datum : WGS84 (Level-2) Resampling : CC (Level-2)	

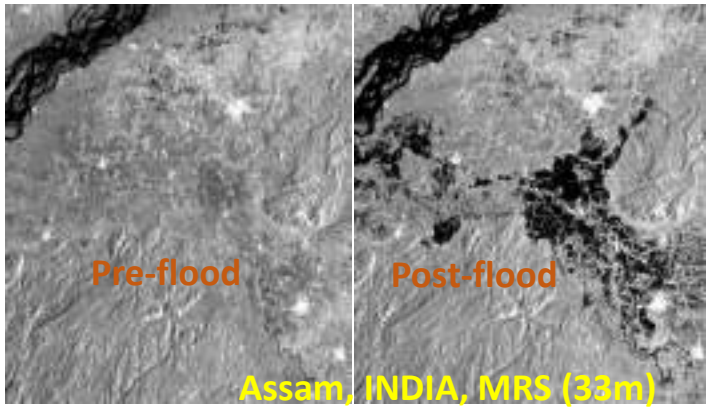
Product Specifications	Value
Geo-location Accuracy(RMSE)	<50 m
Radiometric Resolution (SLC)	3.1 dB
PSLR	-17 dB
Relative Radiometric Accuracy	1 dB
Absolute Radiometric Accuracy	± 1 dB

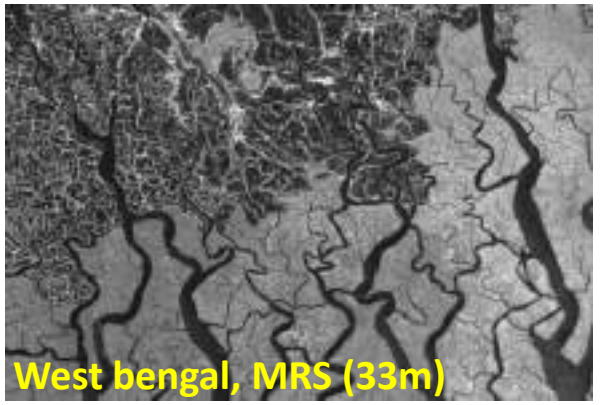
Sample EOS-04 Images

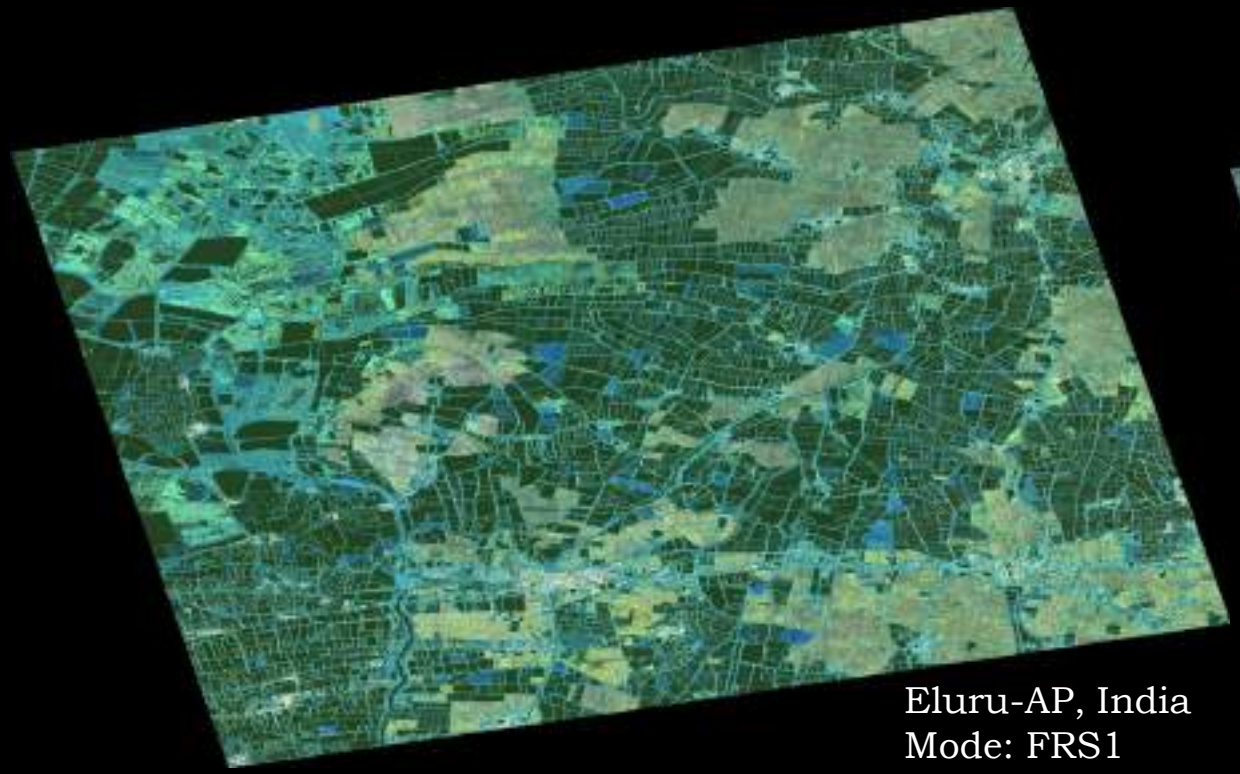




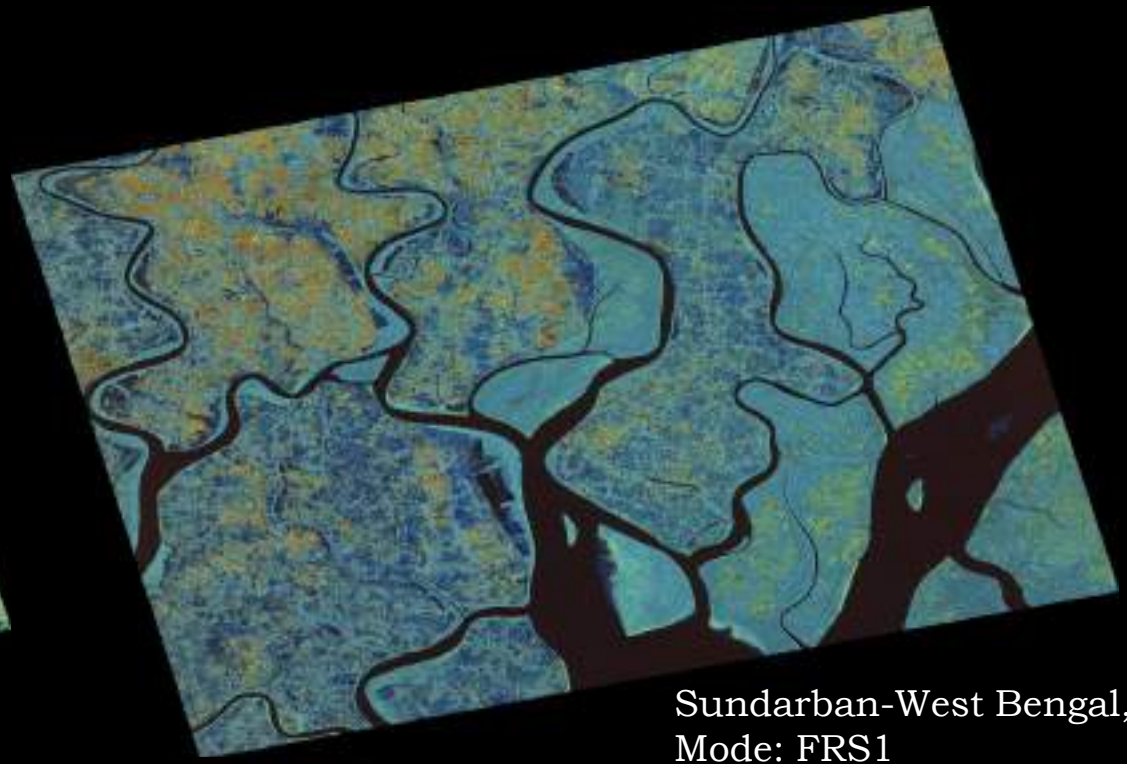




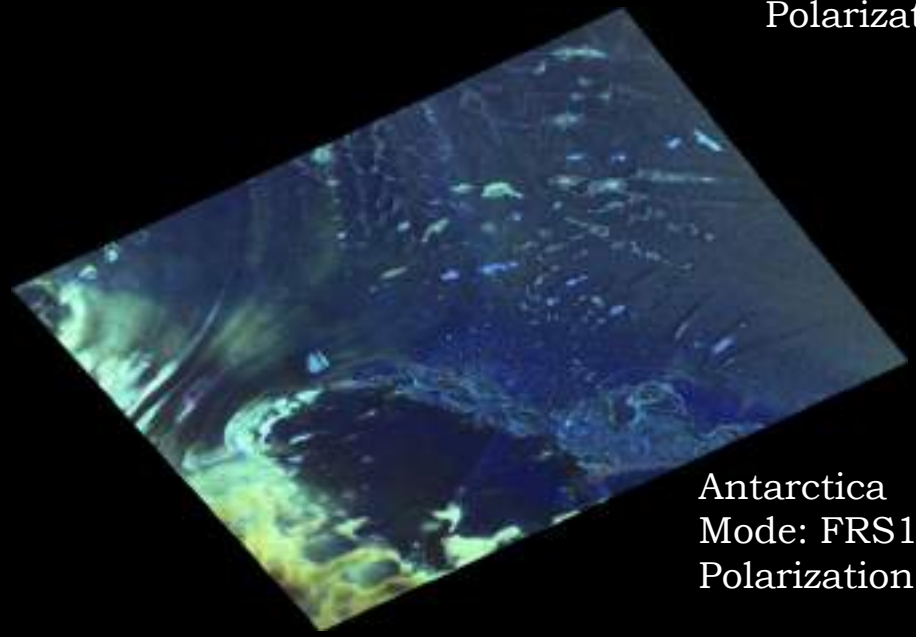




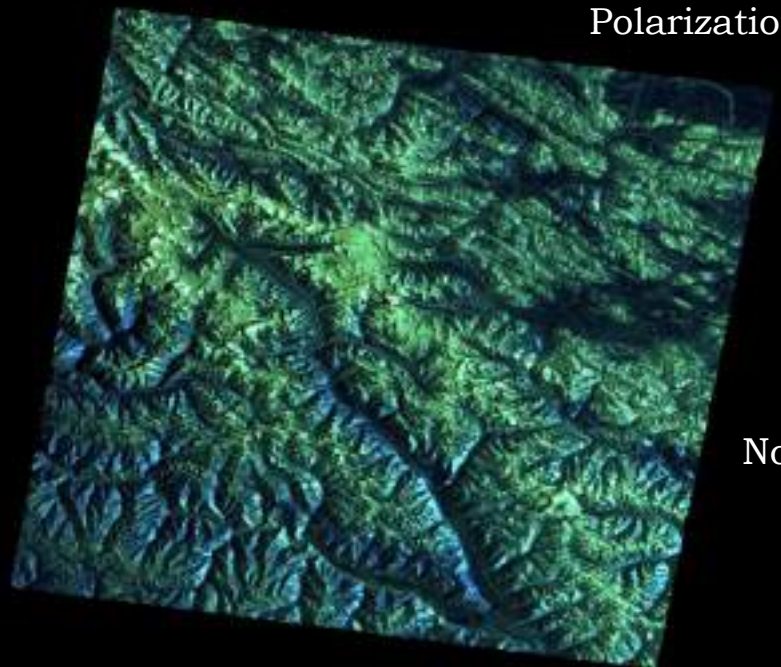
Eluru-AP, India
Mode: FRS1
Polarization: CP



Sundarban-West Bengal, India
Mode: FRS1
Polarization: CP



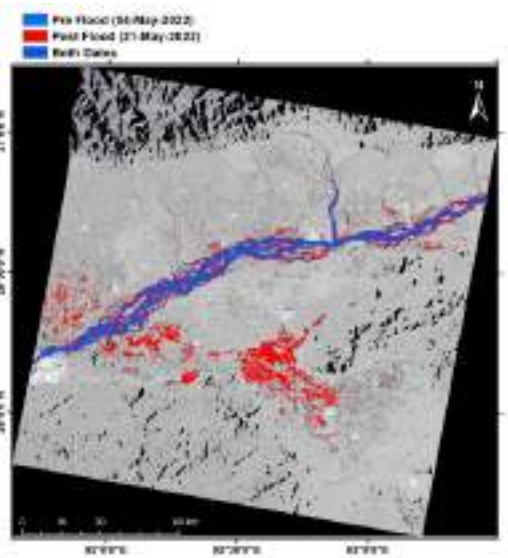
Antarctica
Mode: FRS1
Polarization: CP



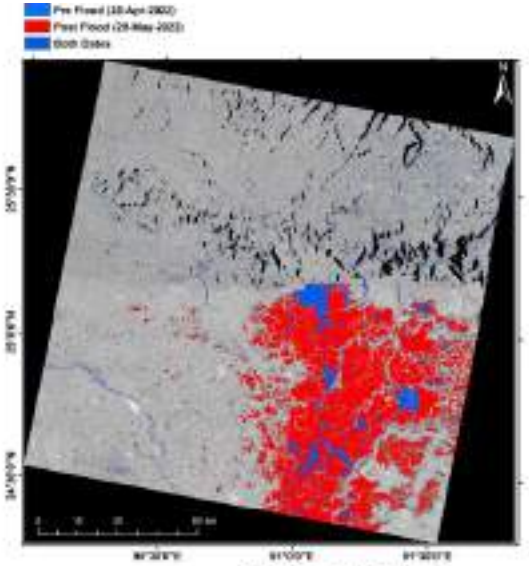
North Terong Glacier-
Himalaya, India
Mode: MRS
Polarization: CP

Initial results from RISAT-1A (EOS-4)

Flood inundation assessment



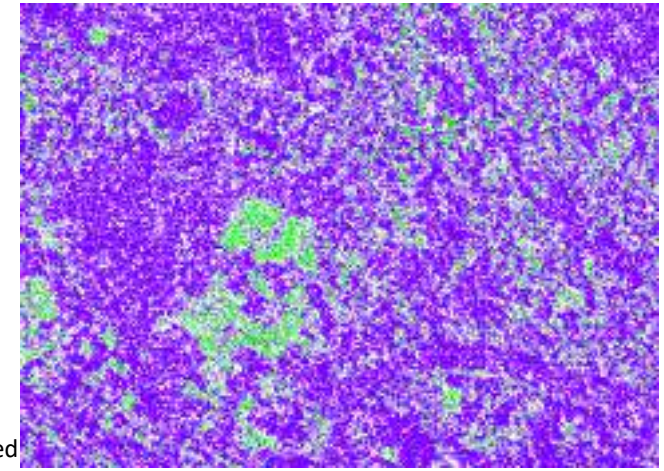
Assam Flood



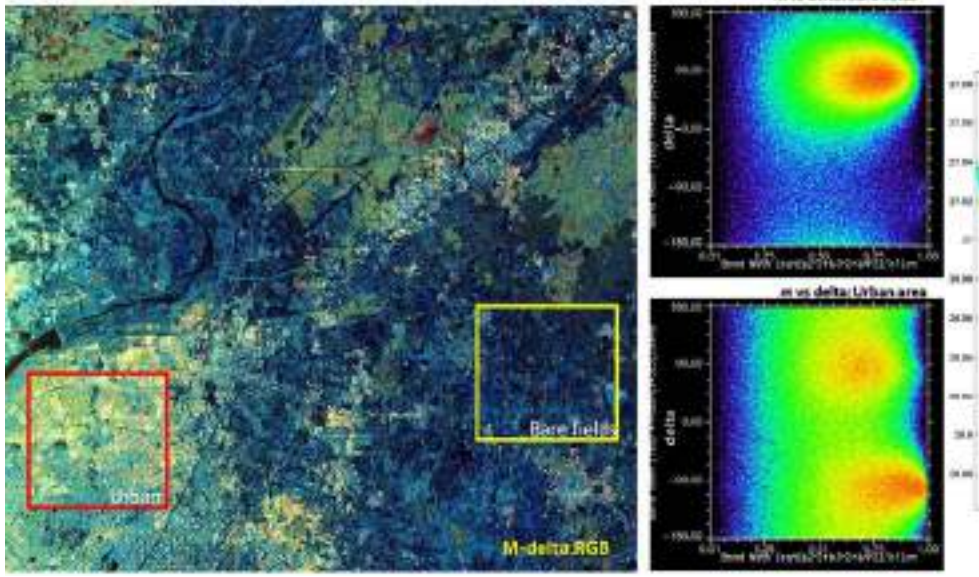
Bangladesh Flood

Calibration campaign @ Little Rann of Kutchh

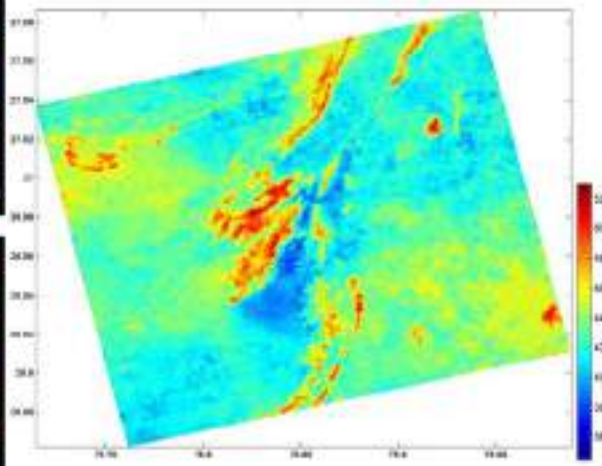
Machine learning based Crop classification



Evaluation of Polarimetric parameters

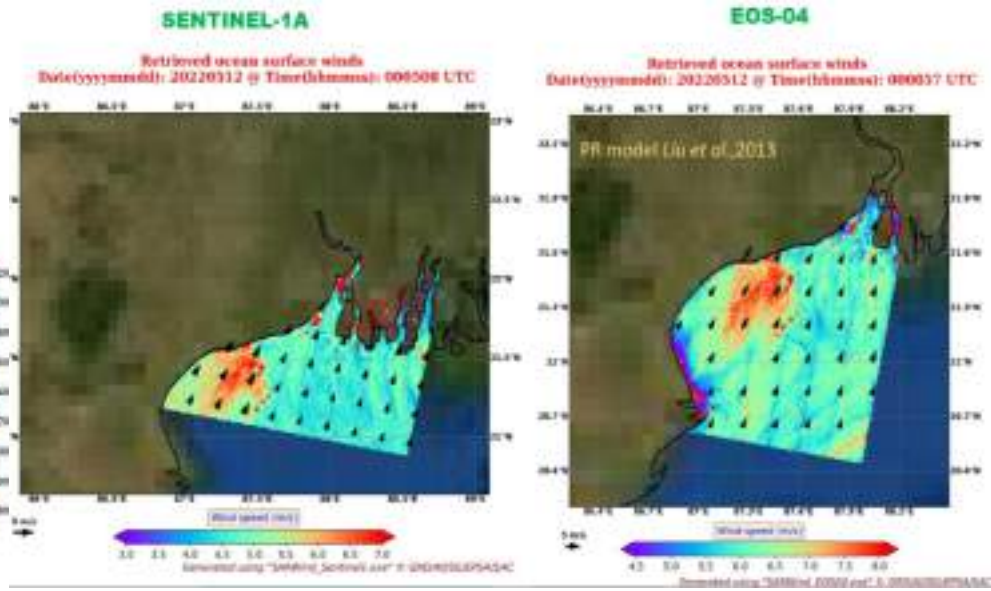


Repeat pass InSAR: First results from EOS-4



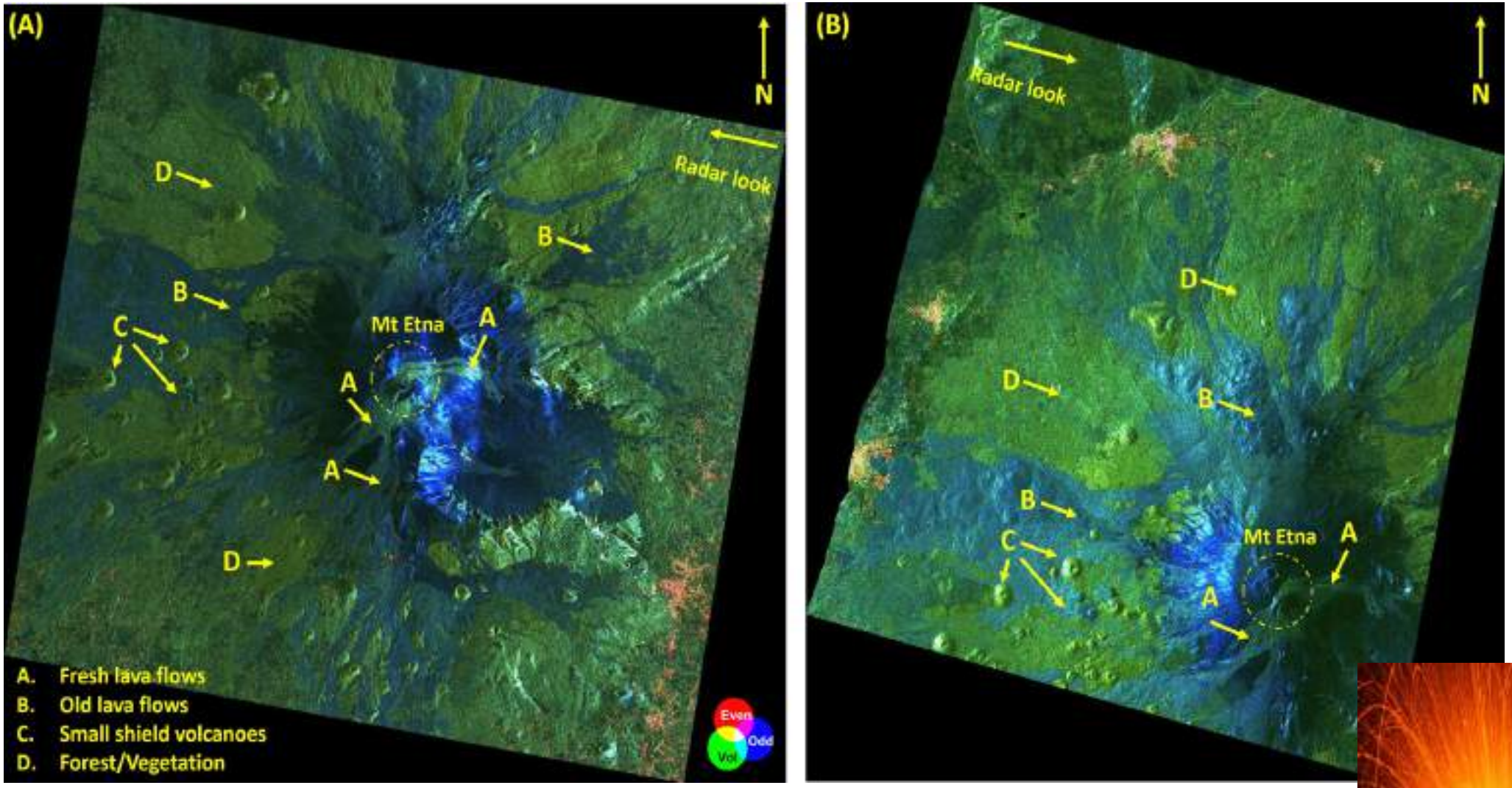
DEM from RISAT-1A

Comparison of ocean surface wind speeds using Sentinel-1A and EOS-4 data 12th May, 2022



RISAT-1A : Full-polarimetry studies of Mt. Etna

Recent eruptions (2021-2022) captured



Yamaguchi 4-component (Y4U) decomposition derived from RISAT 1A full-pol C-band images acquired over Mt Etna in different look directions (A and B)

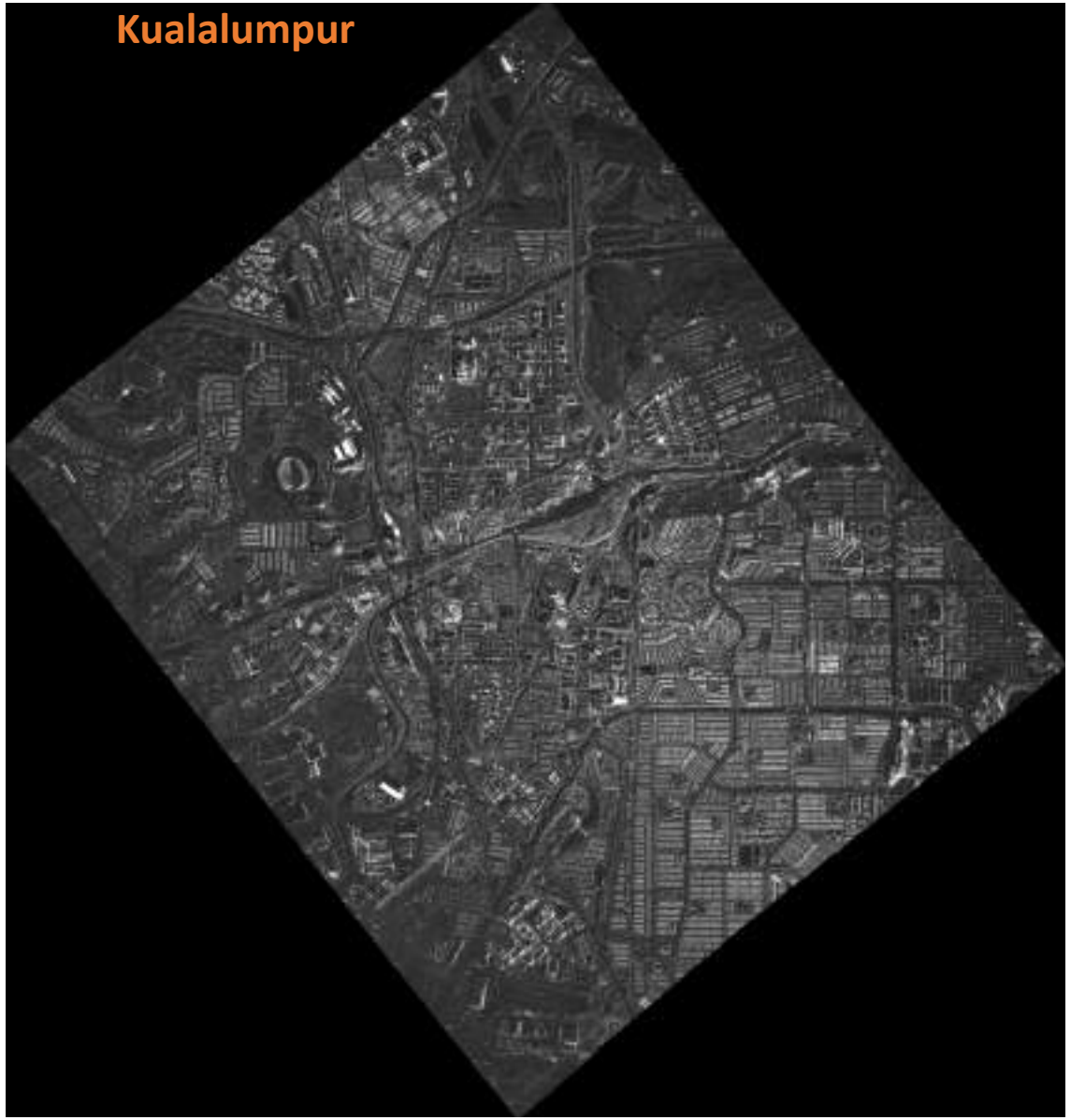
RISAT-2B X Band SAR Constellation

- ❖X–band SAR mission for high resolution target detection applications.
- ❖High Agility SAR for improved revisit.
- ❖Single Polarization and multi-mode capability.

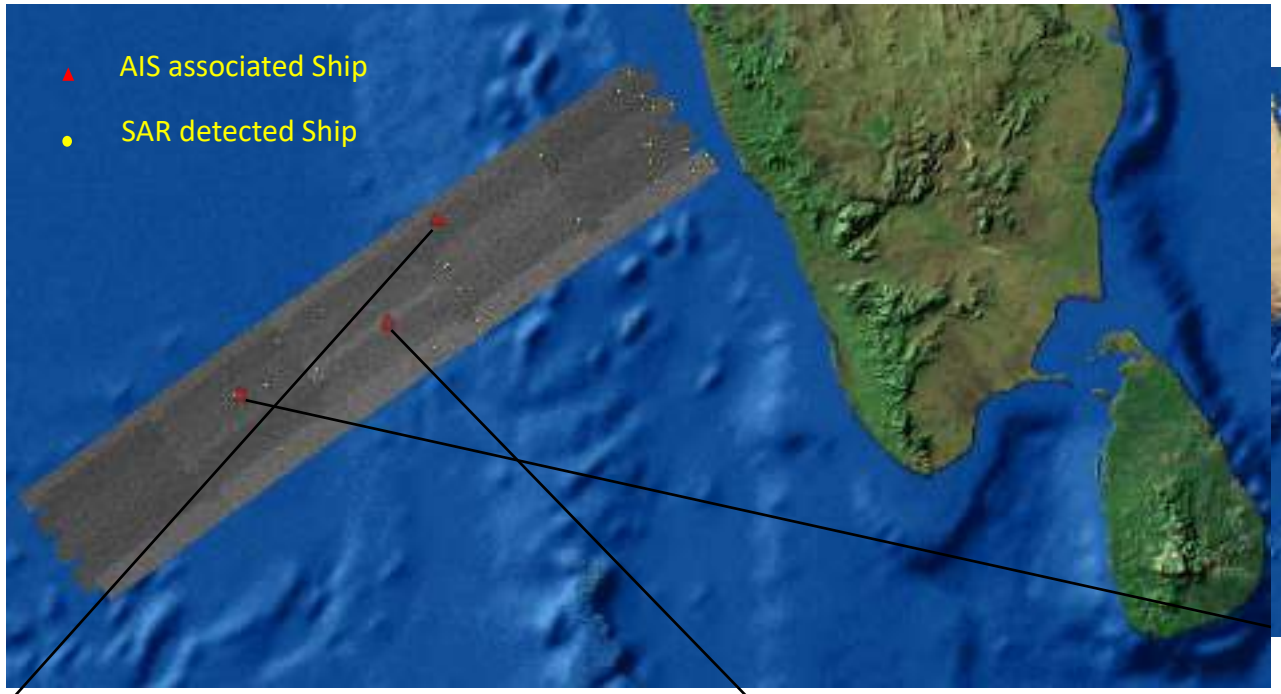
Imaging Modes

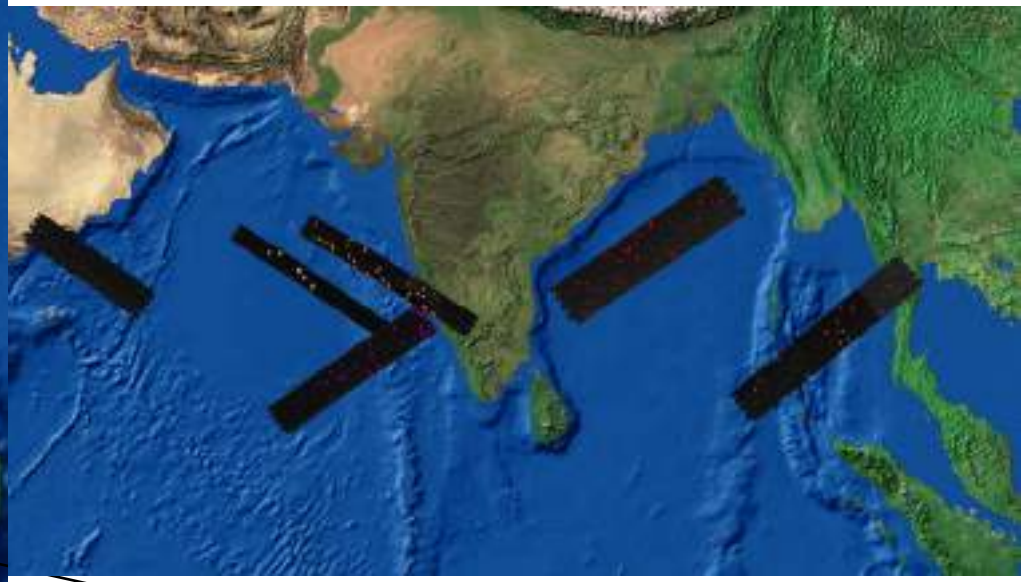
a) StripMap Mode
b) Super StripMap Mode
c) Spot Mode (Fixed Spot)
d) Fine Spot Mode (Fixed Spot)
e) Mosaic Mode (Mosaic-1 and Mosaic-3)
f) Sliding Spot-10 /20
g) Sliding Finespot-10 / 20

RISAT-2B Spotlight imaging



Maritime Mode Imaging Experiments





Oil Product Tanker (MMSI – 636092135)

Parameter	AIS
Dimension of Ship (m)	229x33

Container Ship (MMSI – 477598400)

Parameter	AIS
Dimension of Ship(m)	366x52

LPG Tanker (MMSI – 21968300)

Parameter	AIS
Dimension of Ship(m)	160x26

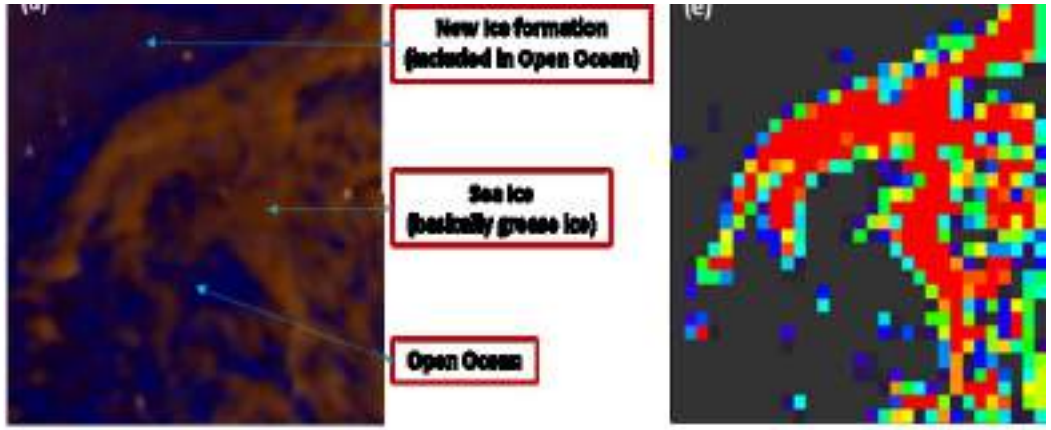
High Resolution Wideswath SAR for Maritime Imaging/Detection (Proposed) + RISAT-2B Follow-on (Proposed)

- ***Constellation of High Resolution Wideswath(upto ~300-350km)*** SAR Capable of detecting ships of length minimum 20m with high reliability is being studied for Maritime targets Imaging/Detection Applications.
- Capable of >10 minutes of payload operation per orbit.
- X Band SAR With AIS & ADS-B
- Constellation planned for high revisits near Indian Region
- SAR Configuration with deployable Offset reflector antenna being planned
- Being planned for ~2026/2027 (if approved)

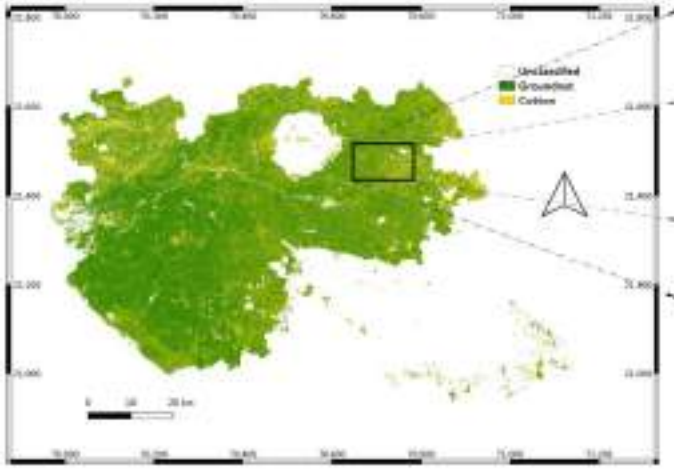
- Apart from this follow-on for RISAT-2B with similar/slightly enhanced capabilities too is being planned (under approval)

Some salient results using international SAR missions

High resolution Sea-ice concentration using Sentinel-1 SAR data

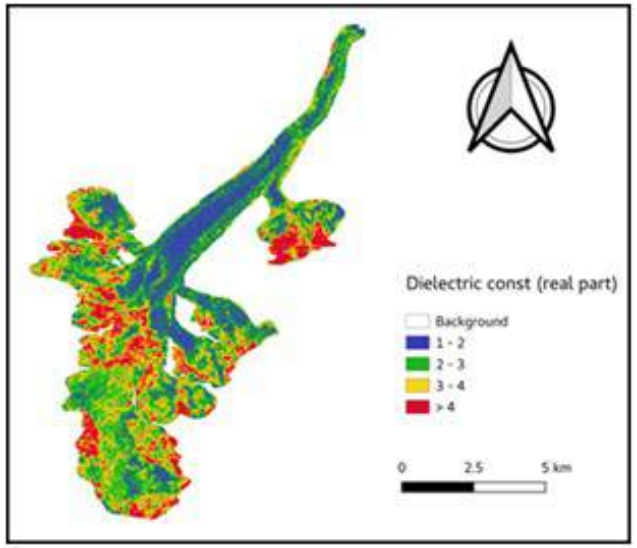


Sentinel-1 Dual-pol (limited polarimetry) based groundnut / cotton classification

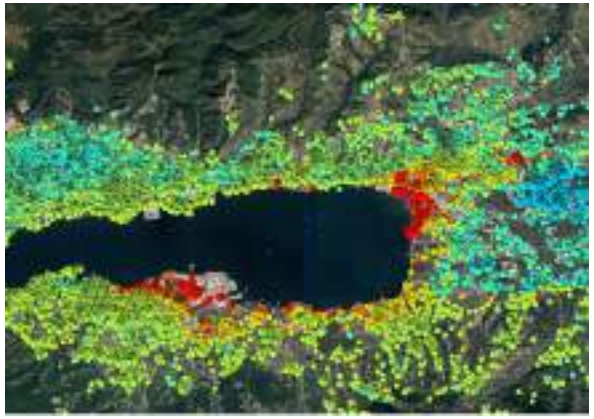


Method	Classification Overall Accuracy	Relative Deviation
POLSAR(PRVI)	92.8%	4%
σ0 (VH)	86.2%	8%

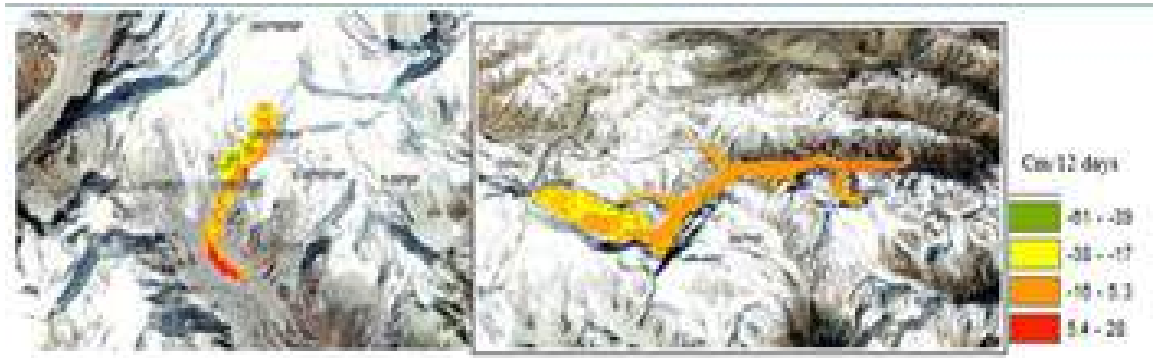
Snow parameters retrieval using L-band full-pol PALSAR-2 data



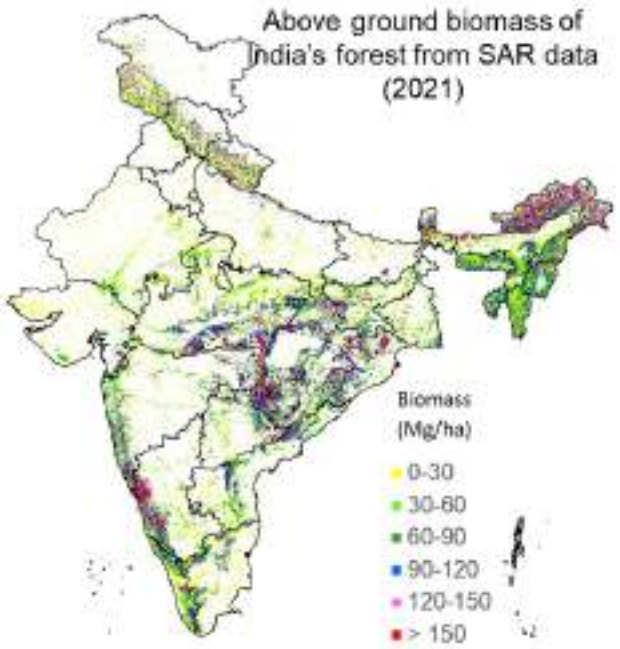
PS-DS-InSAR technique for deformation estimation



InSAR based LOS Velocities for Rathong and Zemu Glaciers Sikkim (cm/12 Days)

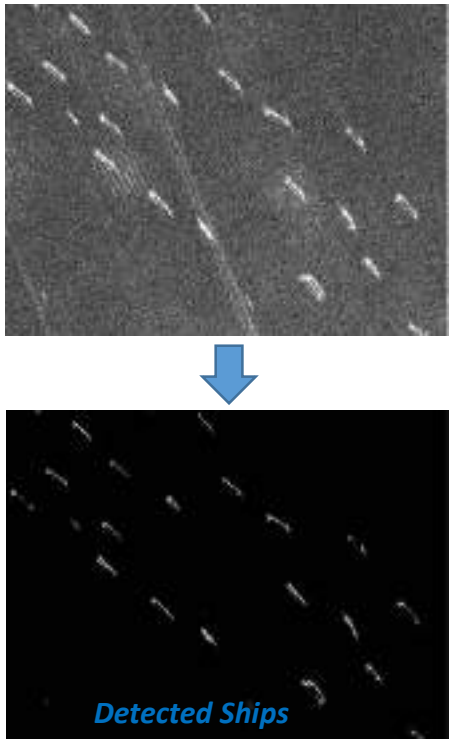


Some more salient results …

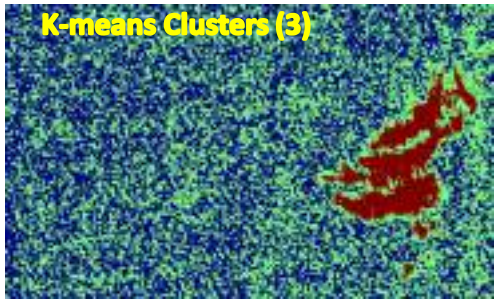


Adaptive CFAR algorithm based Ship detection

RISAT-1 RH-HRS 1m

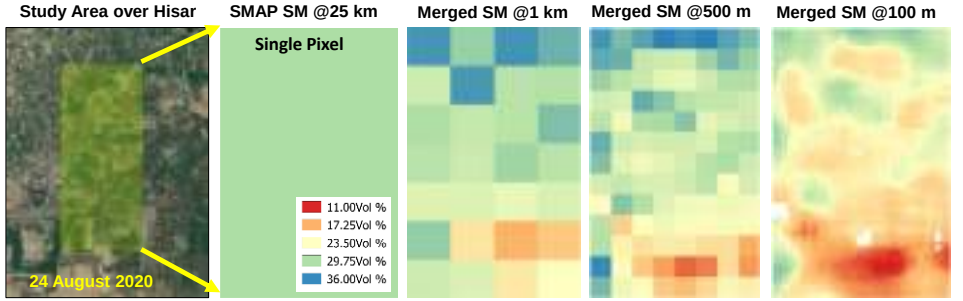


Machine learning based oil spill detection using SAR data



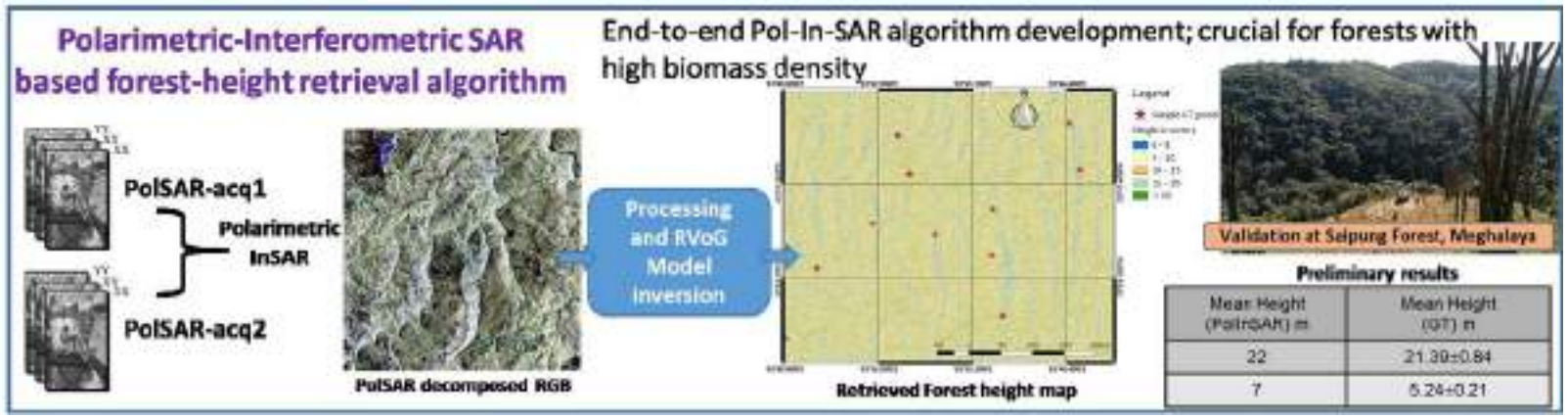
Oil spill Accuracy	93.33%
Look-alike Accuracy	86.66%

Field Scale Soil Moisture Retrieval over Agricultural Cropland



Polarimetric-Interferometric SAR based forest-height retrieval algorithm

End-to-end Pol-In-SAR algorithm development; crucial for forests with high biomass density



Preliminary results

Mean Height (PolInSAR) m	Mean Height (GT) m
22	21.39±0.84
7	6.24±0.21

Microwave Data Analysis Software (MIDAS)

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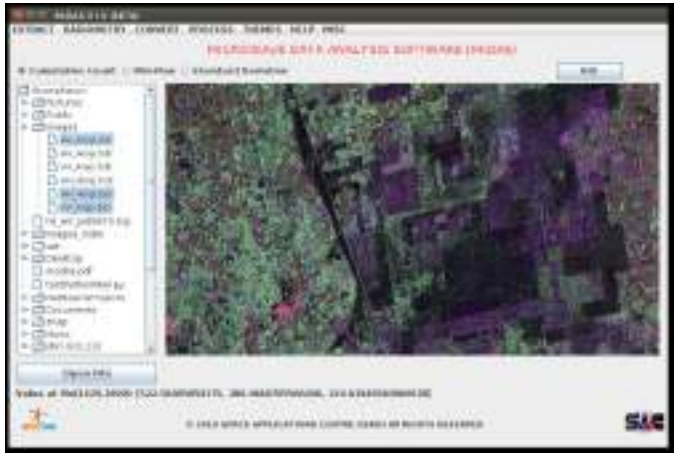
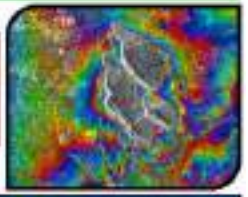


NASA-ISRO SAR (NISAR)

- **L-band SAR: JPL/NASA**
- **S-band SAR: SAC/ISRO**
- **High-resolution (6m), wide-swath(240km) based on SweepSAR concept**
- **12-day repetivity**
- **Planned launch Jan-2024**

Ecosystem Structure: 1.1 Agriculture biomass & Crop monitoring; 1.2 Forest biomass; 1.3 Forest disturbance; 1.4 Mangroves / Wetlands; 1.5 Alpine vegetation; 1.6 Vegetation phenology; 1.7 Soil moisture; 1.8 Ecosystem stress assessment

Land Deformation: 2.1 Inter-seismic / Co-seismic deformations; 2.2 Landslides; 2.3 Land subsidence; 2.4 Volcanic deformations

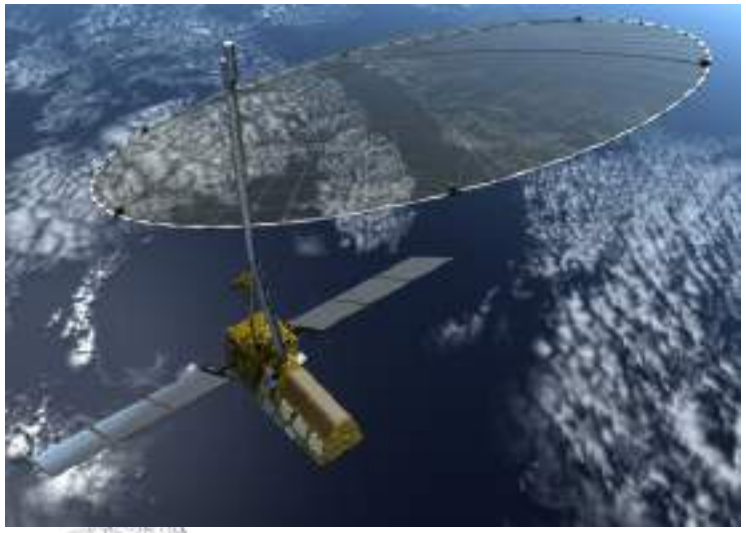


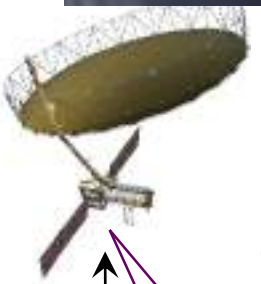
Cryosphere: 3.1 Polar Ice Shelf / Ice sheet; 3.2 Sea Ice Dynamics; 3.3 Mountain snow/ glacier 3.4 Glacier dynamics/ hazard (Himalayan Region); 3.5 Climate response to glaciers; 3.6 Sea–Ice advisory on safer marine navigation in Antarctica region

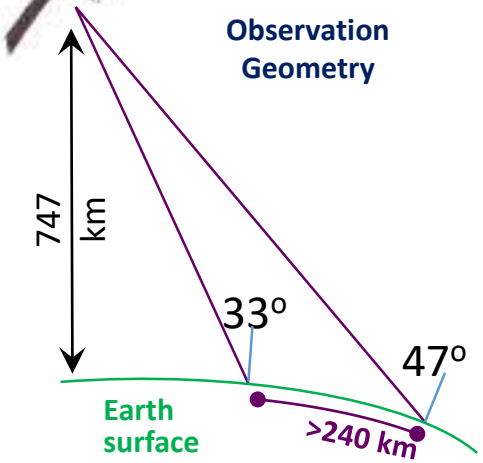
Coasts & Ocean: 4.1 Coastal erosion / shoreline change; 4.2 Coastal subsidence and vulnerability to sea-level rise; 4.3 Coastal bathymetry; 4.4 Ocean surface wind; 4.5 Ocean wave spectra; 4.6 Ship detection; 4.7 Coastal watch services; 4.8 tropical cyclone

Disaster Response: 5.1 Floods; 5.2 Forest fire damage assessment; 5.3 Coastal oil spill; 5.4 Earthquakes / Others

Geological Applications: 6.1 Structural & Lithological mapping; 6.2 Lineament mapping; 6.3 Paleo-Channel study; 6.4 Geomorphology; 6.5 Land degradation mapping; 6.6 Geo-archaeology; 6.7 Mineral explorations



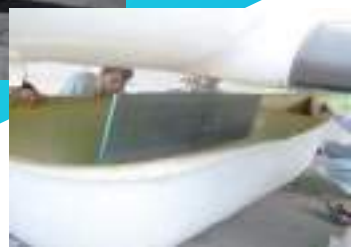




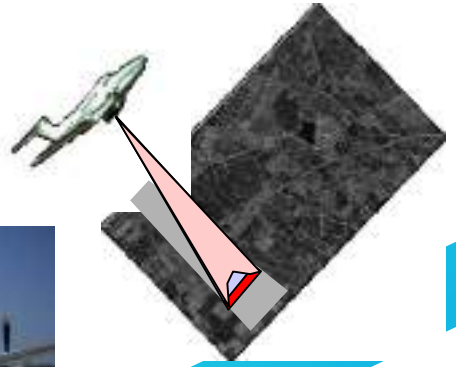
Earth Observation Airborne SARs

India's First Airborne Synthetic aperture radar which was a precursor to RISAT-1

ASAR
1989-1993

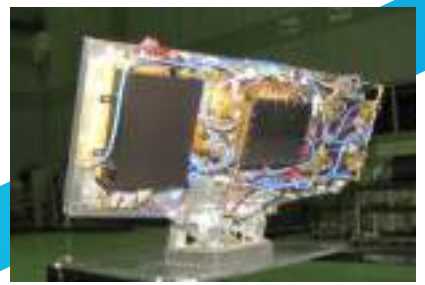


C-And X-Band SAR for disaster management applications



DM Airborne SAR
2007-2011

Miniaturized X-Band SAR for high resolution imagery. Entire Dual-Pol SAR in less than 8 Kg.



X-Band Minisar

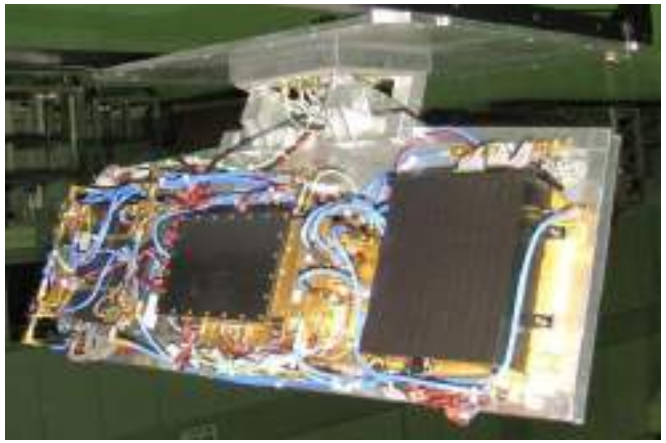
Airborne Dual-Band SAR at L & S-Band. Technology demonstration for the upcoming Joint NASA-ISRO mission NISAR

L & S-Band SAR

First Fully Polarimetric P-Band SAR being developed in India. Technology development for future Spaceborne/ Planetary mission

P-Band SAR

MiniSAR: X Band Airborne SAR



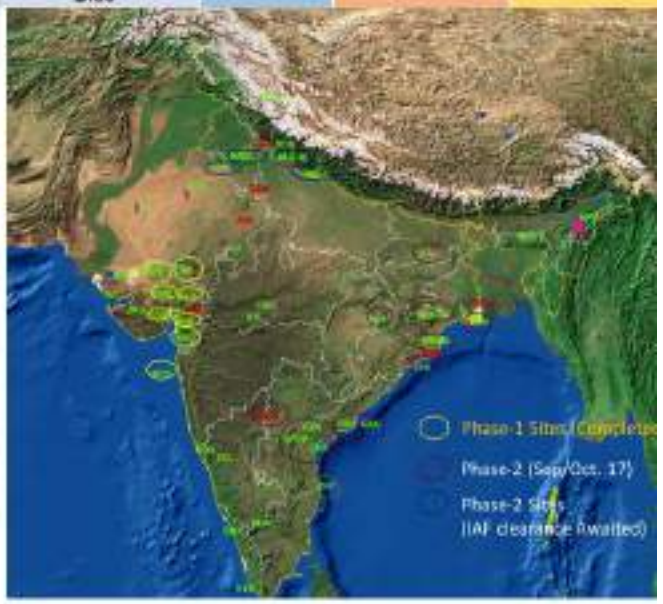
SIZE : 260mm X 590mm X110mm; Weight : 6kg

- ❖Miniaturized Airborne SAR @ 9.6GHz
- ❖Single/Dual/Circular polarization
- ❖Spatial resolution of 30cm
- ❖Swath 5kms

L&S-band Airborne SAR

- **Precursor of NISAR to demonstrate hardware performance and deliver NISAR analogue (dual frequency L+S) products to science community**
- **Successful flight campaigns in India and the US**

Platform	Beech craft B-200, 8.0kms Height, 120m/s speed			
Operating Frequency	1250MHz (L) & 3200MHz (S)			
Chirp Bandwidth	10MHz	25MHz	50MHz	75MHz
Resolution - (Az X SL)	2m X 15m	2m X 6m	2m X 3m	2m X 2m
Polarization Modes	Single	Quasi-Quad	Dual	Compact	Full Pol
Imaging Swath (S+L) / Antenna Roll Bias	5.9km @ 37°	10km @ 51°	15km @ 64°	



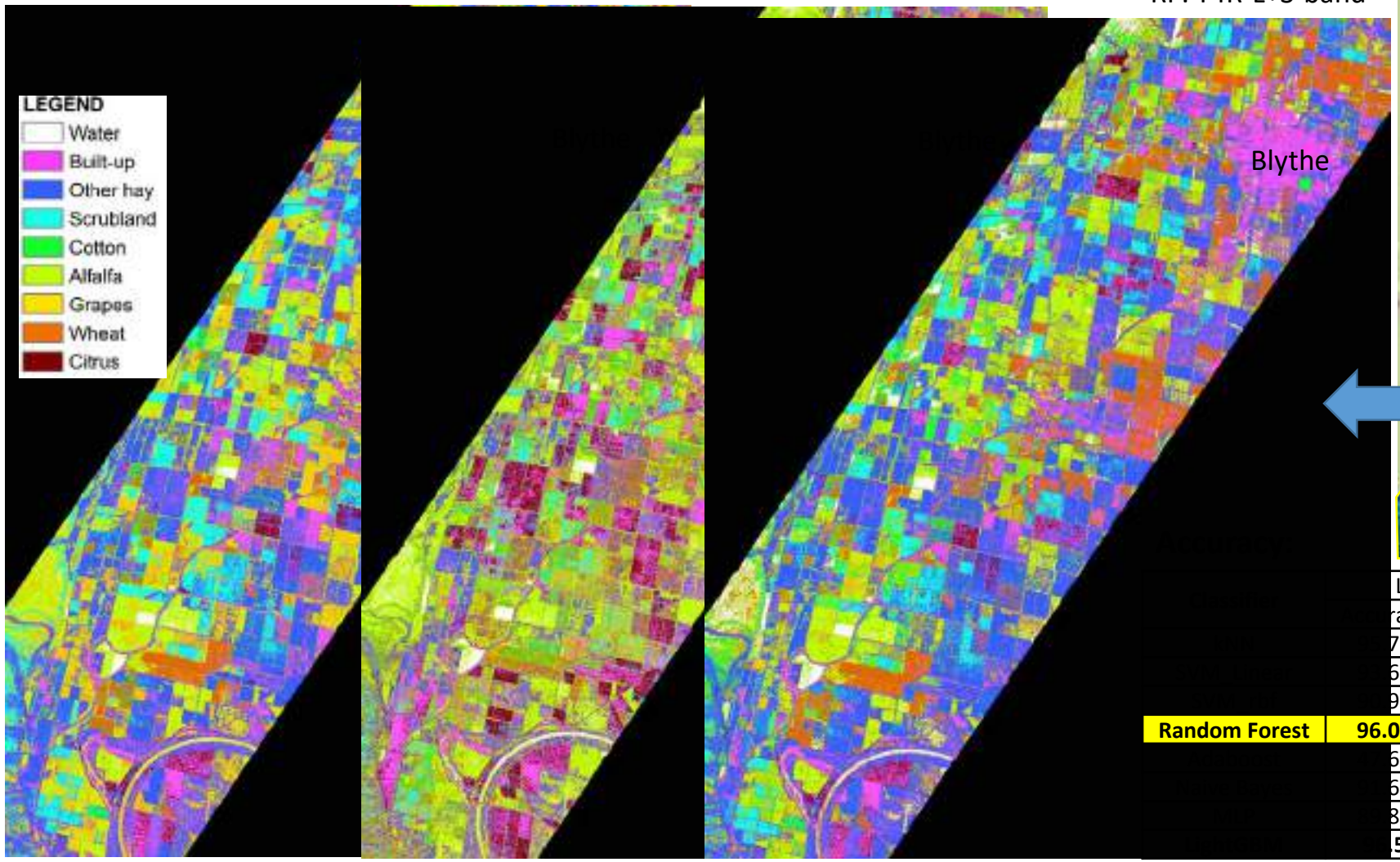
L&S-band ASAR: Crop Classification on Blythe, USA

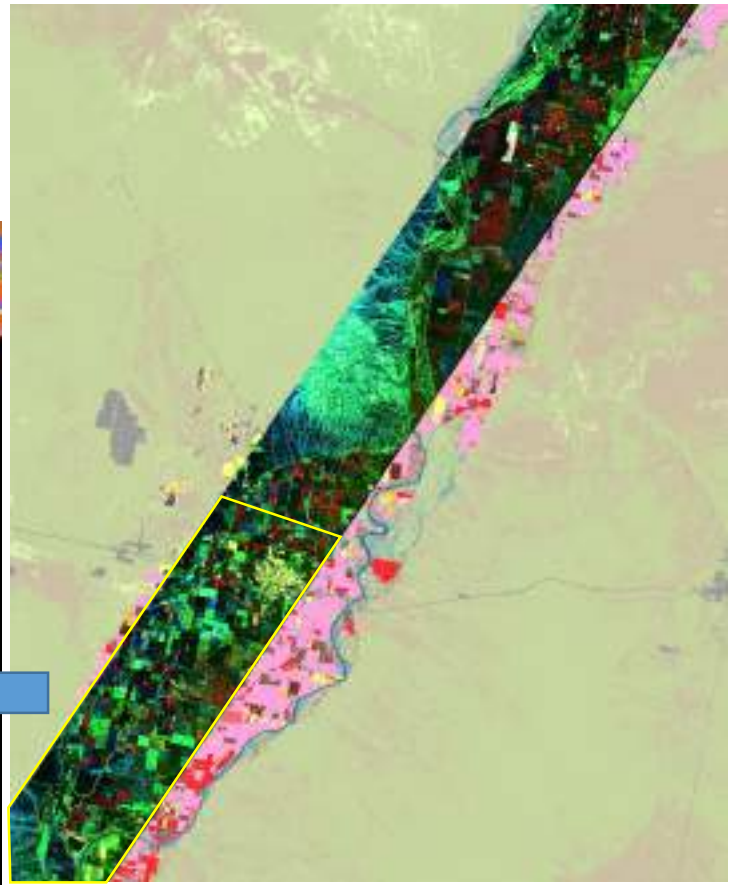
Comparison of L, S and L+S Band results using Random Forest classifier

RF: Y4R-L-band

RF: Y4R-S-band

RF: Y4R-L+S-band

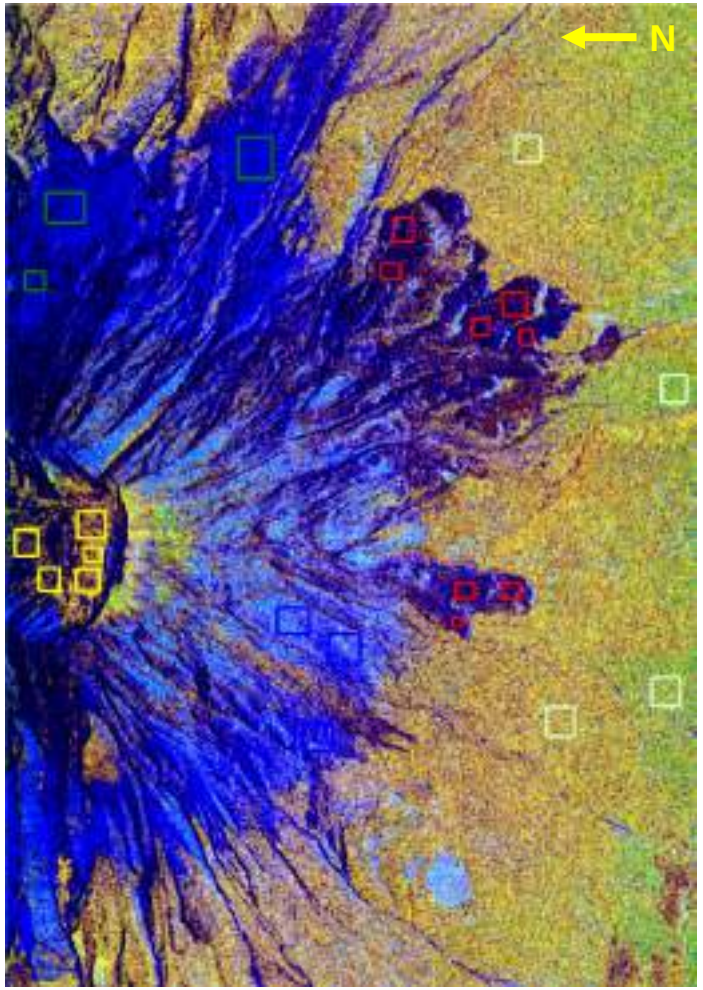




		L-Band		S-Band		L+S - Band	
		racy	Kappa	Accuracy	Kappa	Accuracy	Kappa
		75	0.95	82.58	0.80	95.75	0.95
		69	0.93	80.79	0.78	95.44	0.95
		95	0.90	82.22	0.80	90.95	0.90
Random Forest	**96.01**	**0.95**	**85.52**	**0.84**	**98.47**	**0.98**
		62	0.41	53.77	0.48	33.17	0.25
		63	0.91	79.21	0.77	92.90	0.92
		80	0.89	81.55	0.79	92.02	0.91
		5	**0.95**	**85.6**	**0.82**	**98.8**	**0.98**

L&S-band ASAR: Polarimetric characterization and classification of St. Helens Volcano, USA

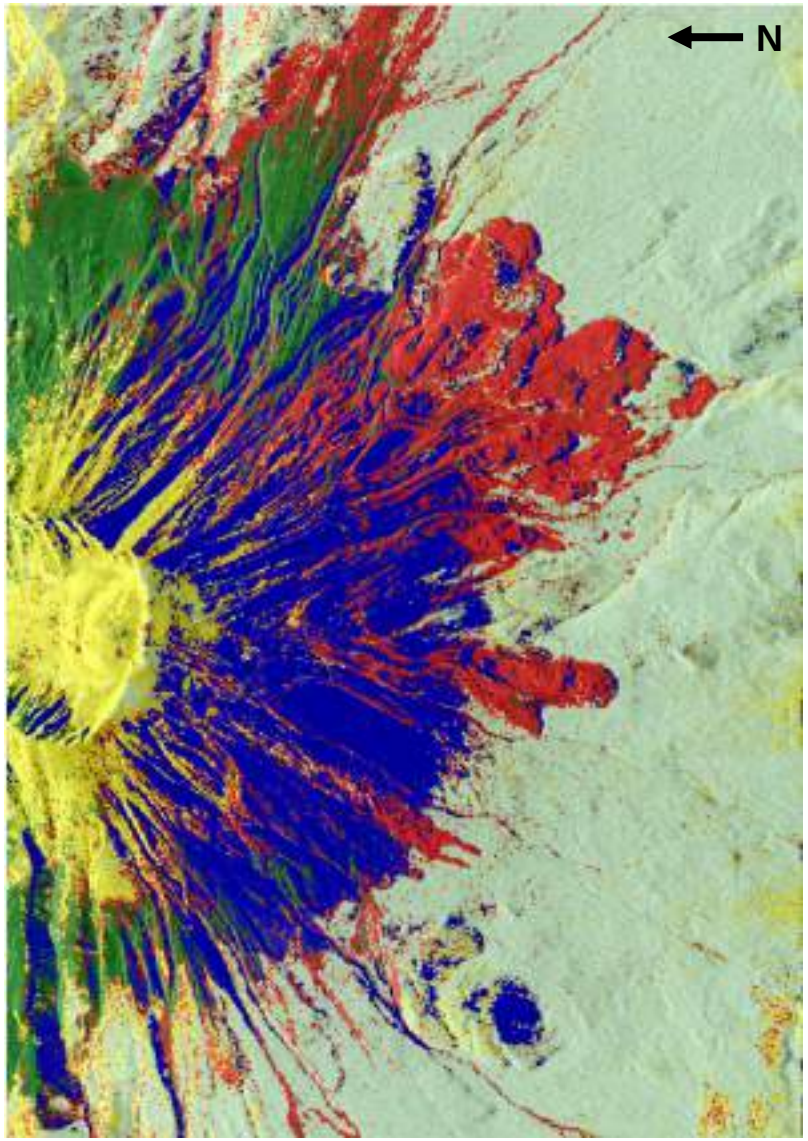
Input Image



L_Entropy; *L_Alpha*; *L_Anisotropy*

L+S Polarimetric Products
(12 channels)

Classified Image (SVM-RBF)

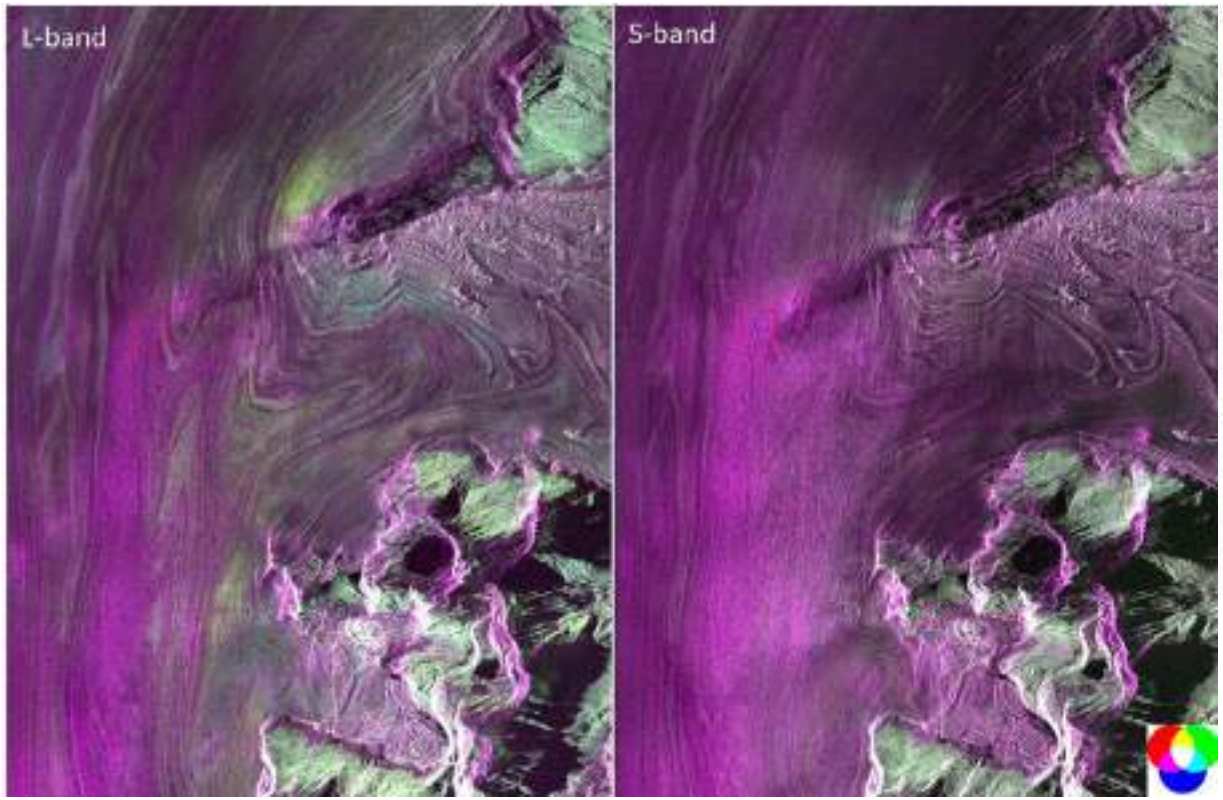


**Classified image superimposed on L-band span data*

Confusion Matrix

Class	Producer Accuracy	User Accuracy
Mudflow and Rock Flow Deposits	93%	93%
Old Volcanic Flows	95%	95%
Young Volcanic Flows (?)	97%	98%
Caldera Avalanche Debris	94%	95%
Forest	97%	96%
Overall Accuracy	95%	
Kappa Coefficient	0.94	

L&S-band ASAR: Cryosphere studies

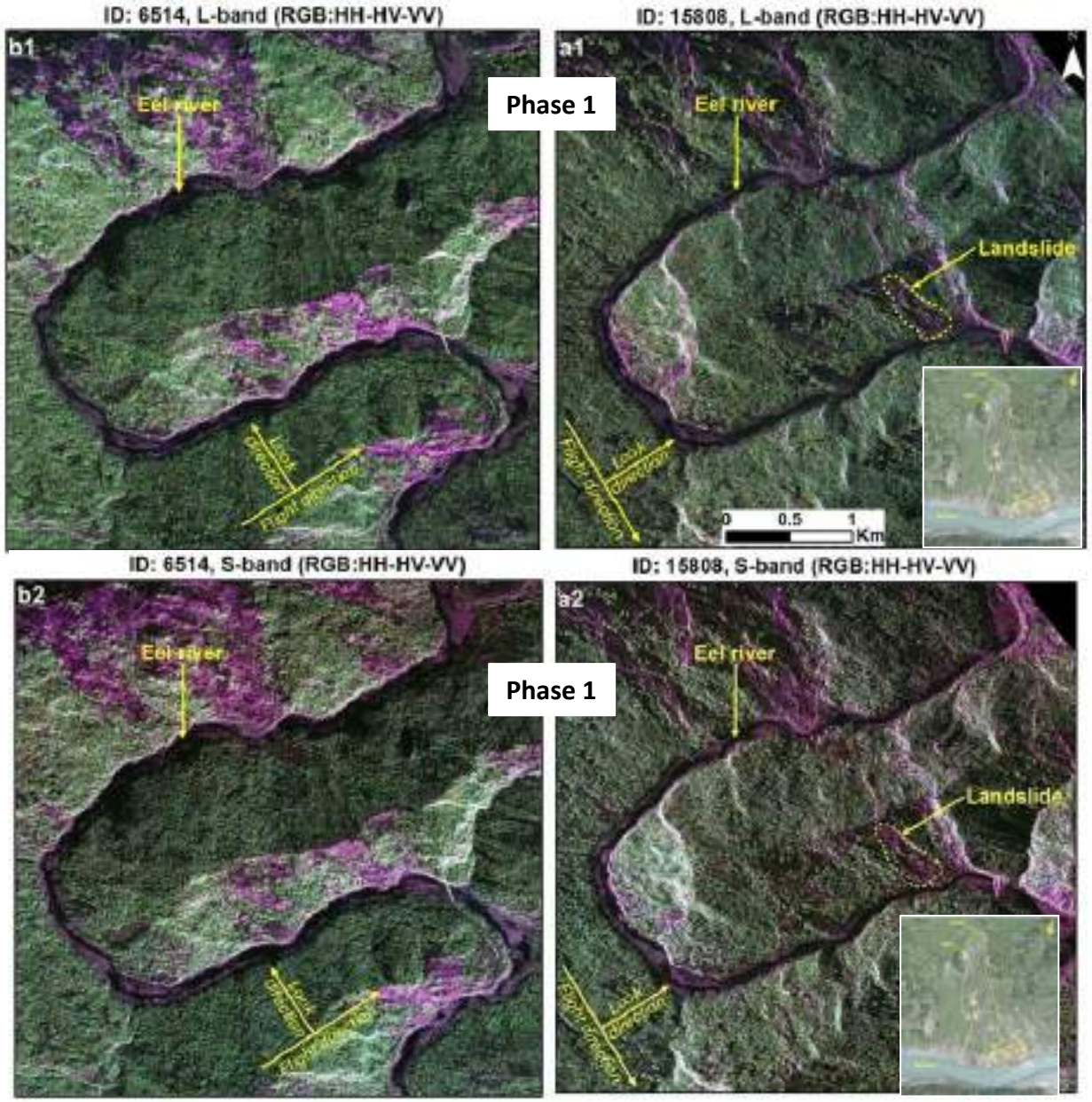


Bering Glacier 11 Dec 2019

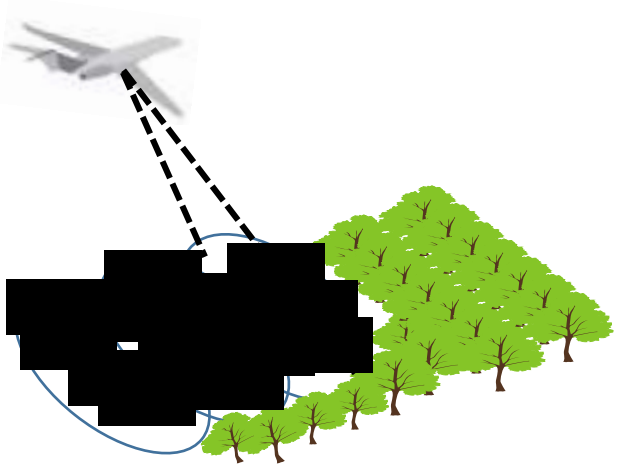
R: HH-VV, even, G: 2*HV, volume, B: HH+VV, odd

S-band retains better surface features such as crevasses and L-band due to its higher penetration, gives enhanced information from deeper snow/ice regions

L&S-band ASAR: Eel river landslide studies



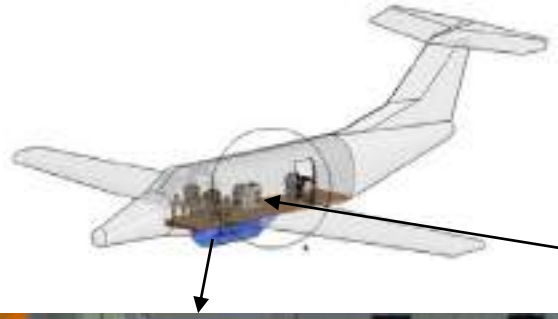
P-Band Airborne SAR



- Full Polarimetric P-Band SAR developed in India
- Applications in the field of Forestry, root-zone soil moisture
- Center Frequency : 450 MHz
- Resolution [slant range x azimuth] : 4m x 4 m with 8 looks

Option 1 :Integrated payload with belly mounted antenna

NES_0 <-40 dB

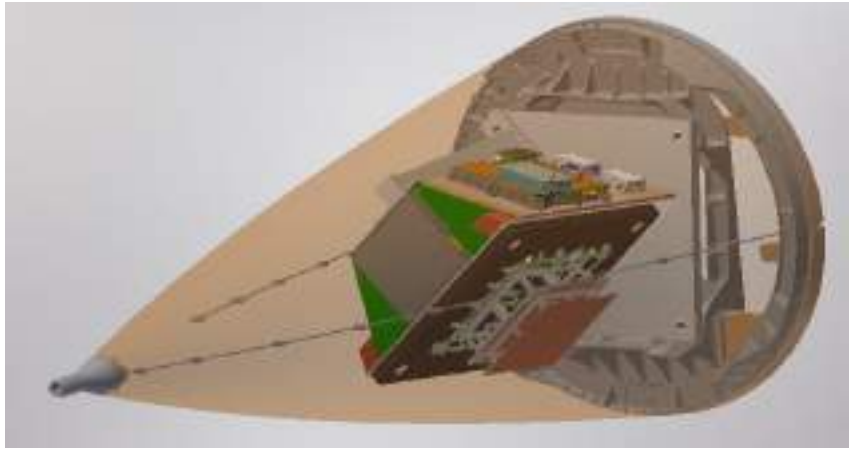


1.5m x 0.5m
Antenna to mounted in belly

Payload Electronics

Option 2 :Integrated payload inside nose cone

NES_0 <-36 dB



SYNTHETIC APERTURE RADARS FOR PLANETARY EXPLORATION

TECHNOLOGY DEVELOPMENTS

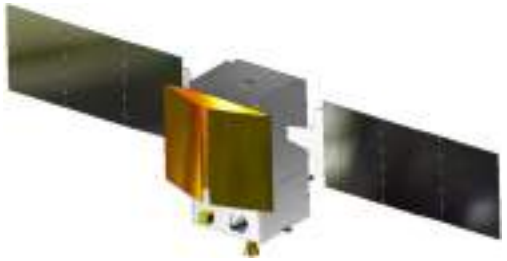
- First Full Pol, simultaneous L&S band imaging SAR for unambiguous detection/ Quantification of water ice.
- Highest Resolution : 4m

CHANDRAYAAN-2
DF-SAR

2019

S- Band SAR and Radiometer in one instrument
Res:40m,FULL POL,
Pass to Pass Interferometry

VENUS MISSION
VSAR



Under Approval

P- Band SAR, S&K Band Radiometer in one instrument
Res:40m,FULL POL

MOM-2 SAR

Under Approval

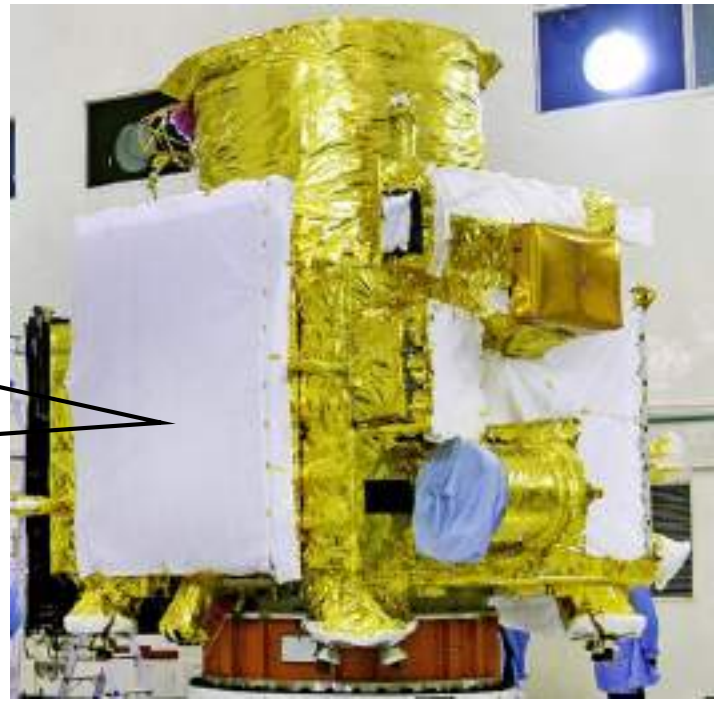
Chandrayaan-2 Dual Frequency SAR

- ***First Full-Pol Dual-Frequency (L & S) SAR instrument for lunar imaging.***
- ***High Resolution (2m slant range) capability, one order better than previous lunar radars.***

Science Objectives:

- Unambiguous detection and quantitative estimation of water-ice in the lunar polar regions.
- Dielectric constant and Surface roughness estimation over lunar surface.
- High resolution lunar geological/ morphological mapping and polarimetric characterization in the polar and non-polar regions.

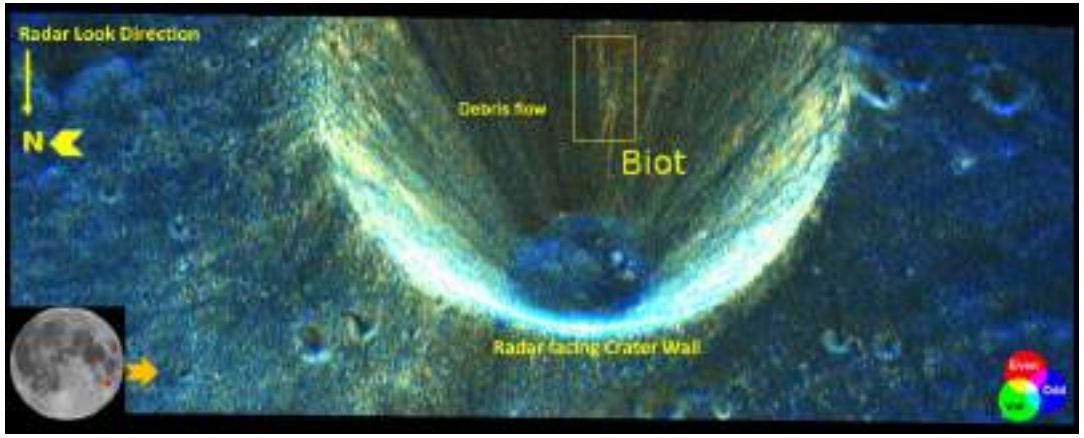
DFSAR Instrument during characterization



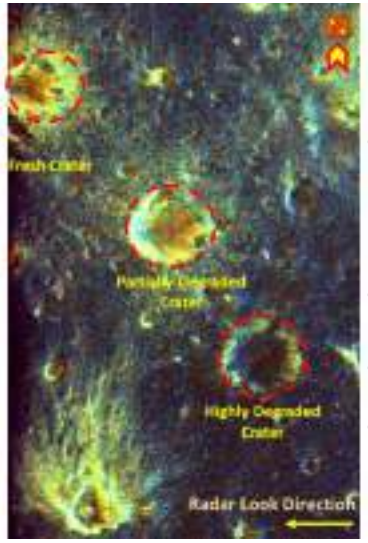
Imaging Geometry

Science Results from Chandrayaan-2 Dual Frequency SAR

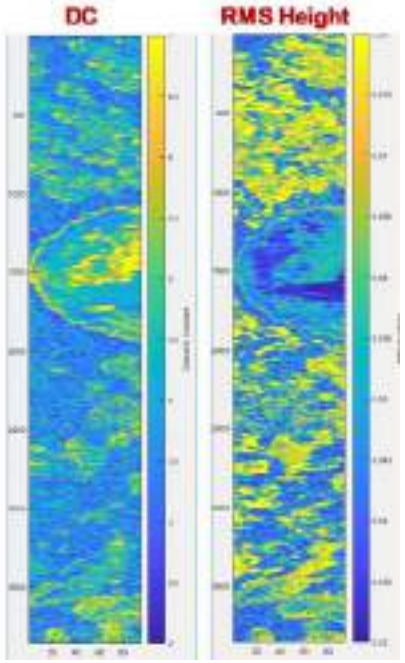
- Polarimetric characterization of various impact craters *[PSJ, 2021]*
- Physical model-based estimation of lunar dielectric constant and surface roughness.
- Novel methodology developed for unambiguous detection of water-ice rich regions. Testing over multiple PSR anomalous regions is in progress.
- Characterization of lunar volcanic features, impact melts and crater-ejecta.
- SAR based characterization of past and future landing sites



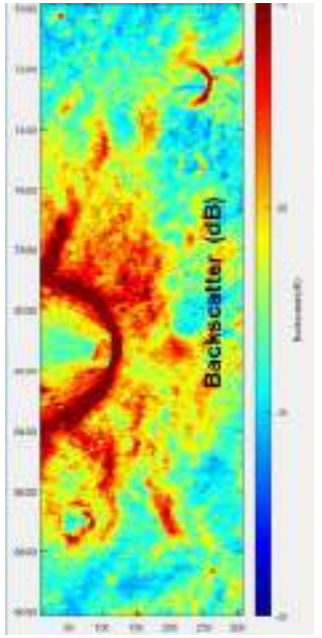
First L-band acquisition of Moon



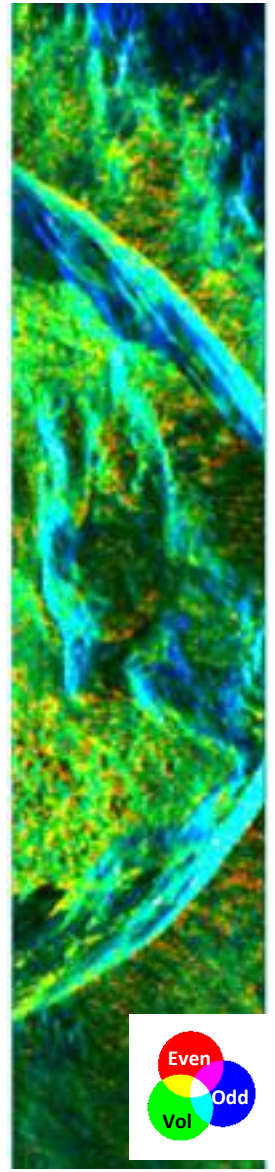
L-band CP decomposed image



High resolution (25m) DC and RMS over non-polar Gardner Crater

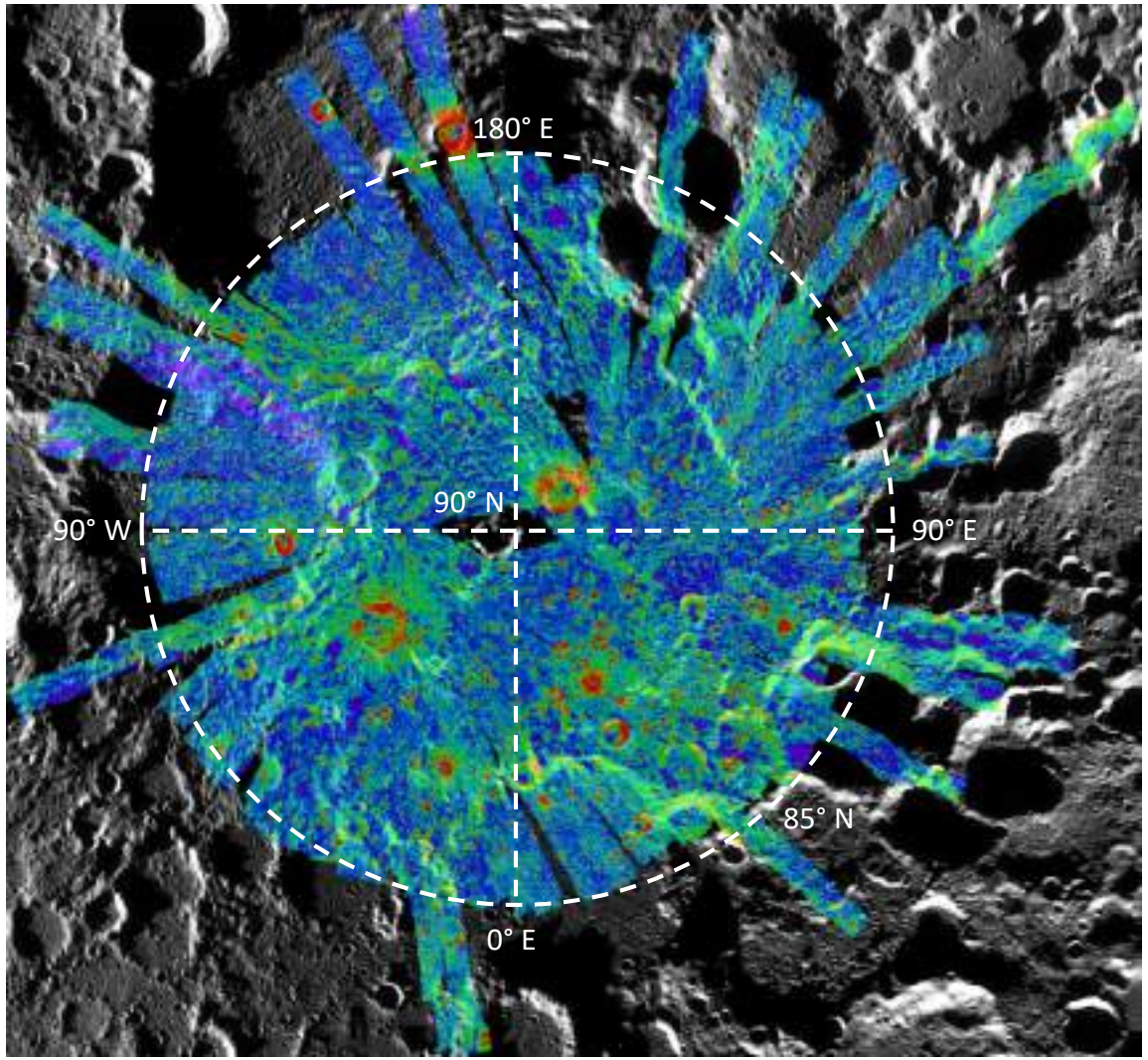


L band HV-Pol

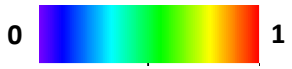


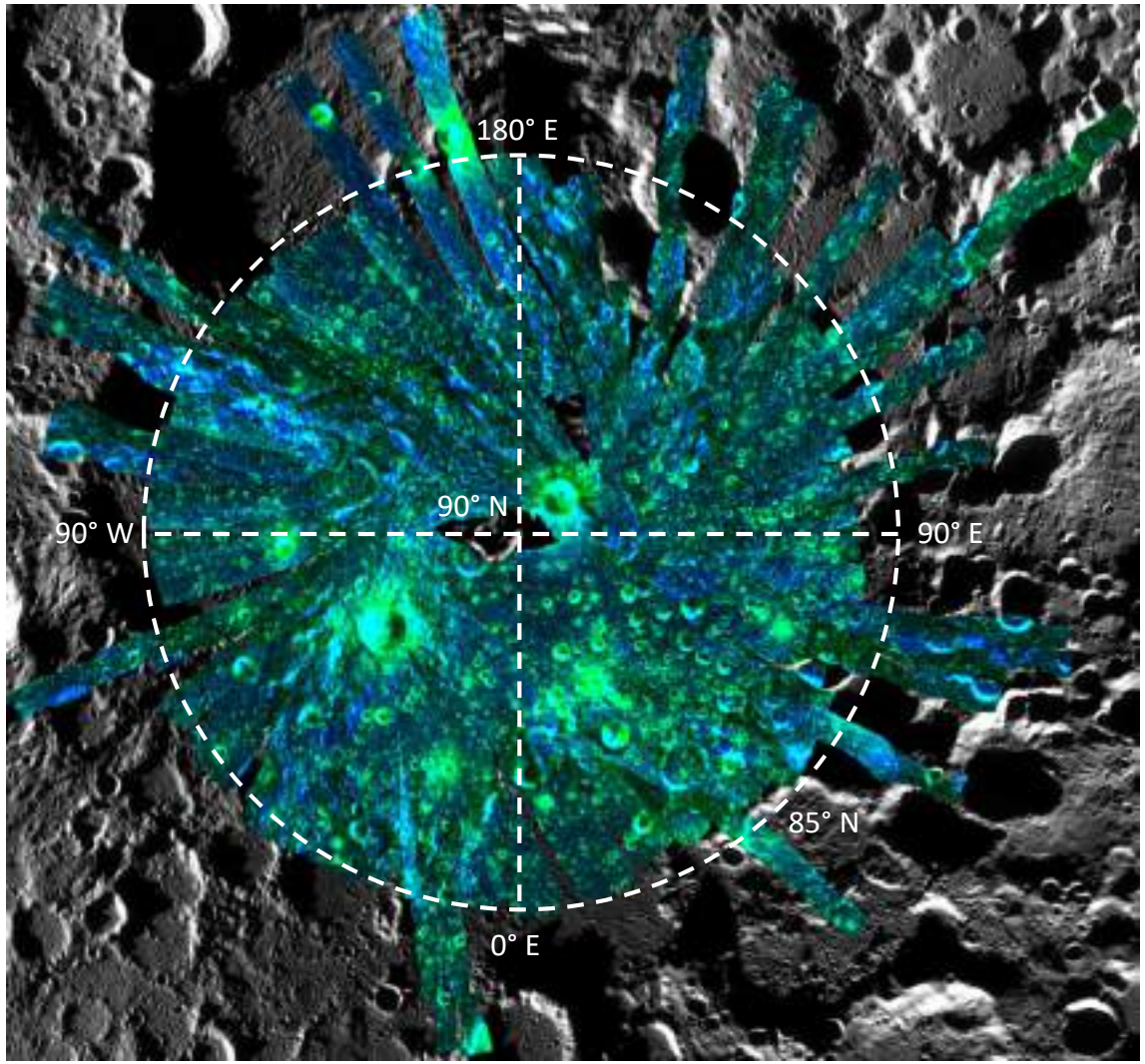
Polarimetric Decomposed image of Giordano Bruno (a non-polar Young) crater

DFSAR Polarimetric Mosaics of Lunar North-Pole, using L-band data



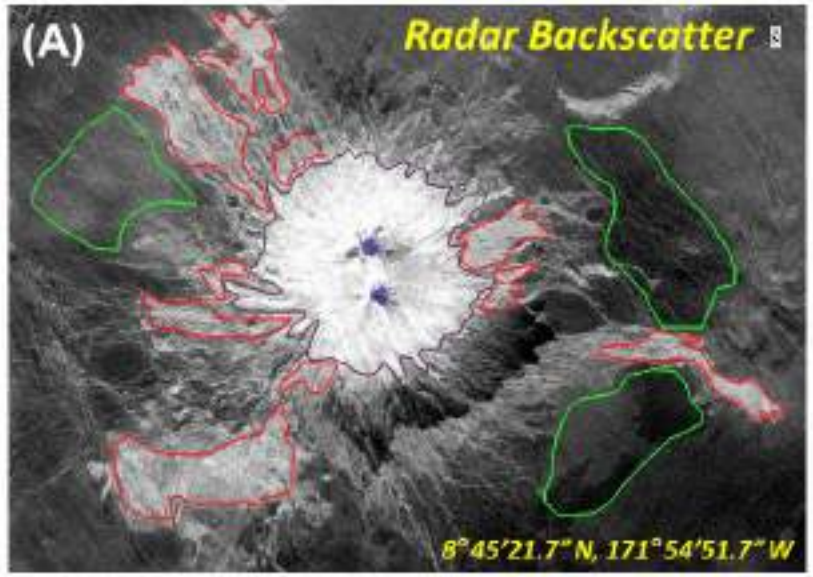
Circular Polarization Ratio (CPR)

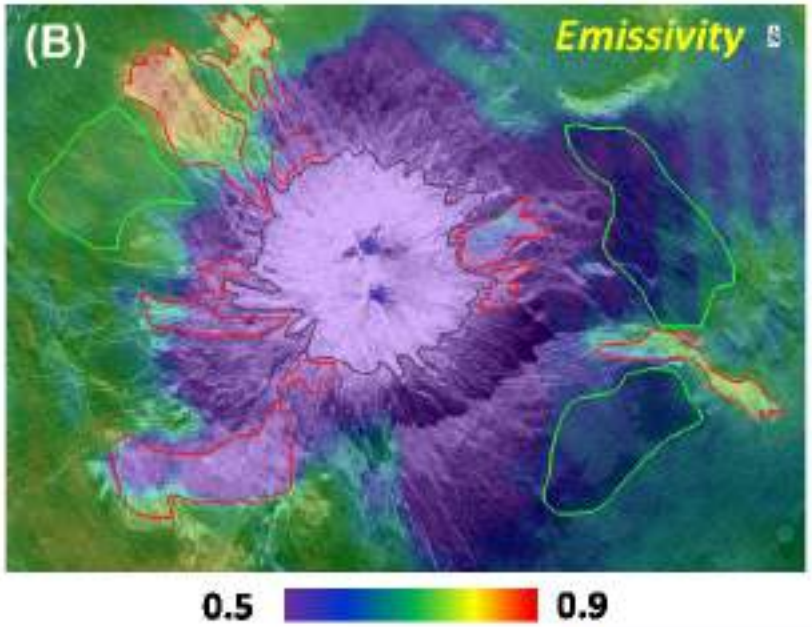




Polarimetric Decomposition (Y4R)

Characterization of Venusian Volcano, Sapas Mons, using Magellan data



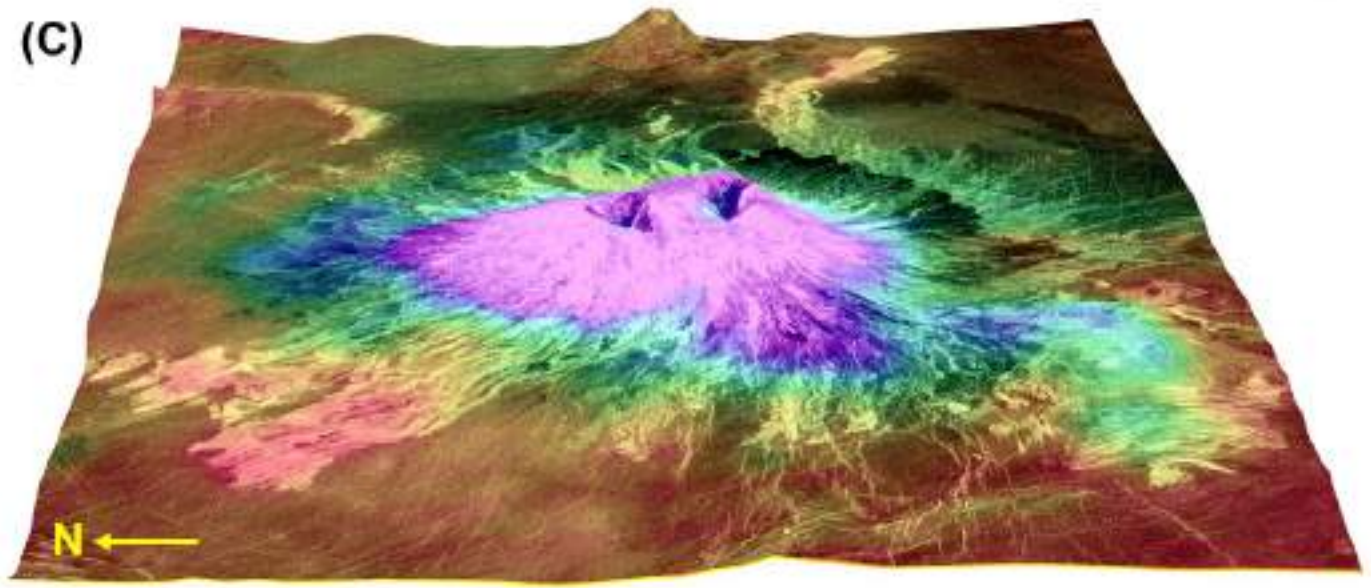


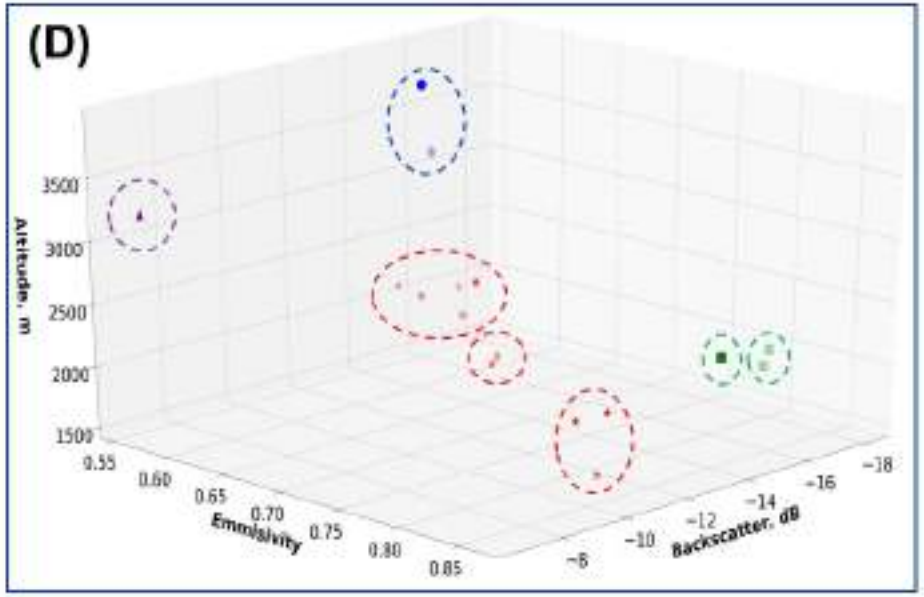
Young Lava Flow
Ferroelectric material

Older Lava Flow
Doesn't faced extensive chemical weathering due to lower elevation

Collapsed dome
Fine grain debris

Background Regional lava flow
Basaltic composition





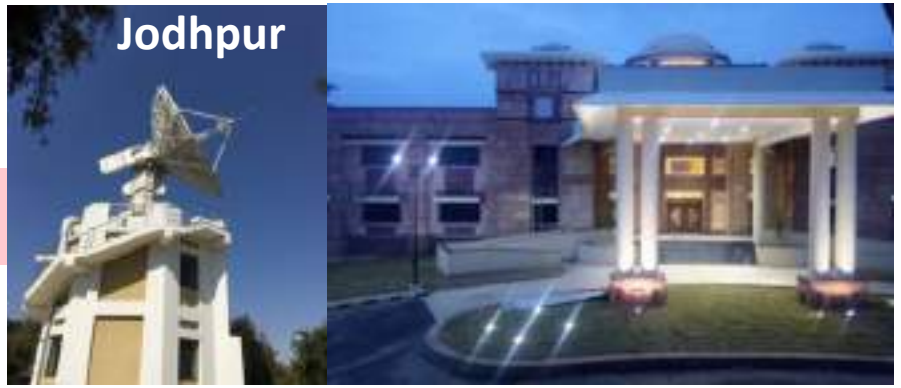
ISRO's Ground Stations

Data Reception
Shadnagar
Antarctica
Jodhpur

Data Processing & Dissemination
IMGEOS

IMGEOS Data Centre
(Compute Cloud, Storage, Networks)

Network with Indian and International Ground Stations



ISRO EO DATA PROCESSING

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

Data Dissemination

Bhoonidhi
ISRO's EO Data HUB

Product Archival

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

Product Quality Evaluation

Data Quality Evaluation

At IMGEOS, data is being acquired processed, archived and disseminated for both Indian Remote Sensing (IRS) and Non-IRS category of Satellites.

Level-1/Level-2
Data Product Generation

Value Added Products

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

Payload Planning

Level – 0
Data Processing

Shadnagar

Antarctica

Jodhpur

IGS

Data Ingest

Data Archival

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

ISRO Ground Segment for Microwave SAR missions

Indian Remote Sensing(IRS) SAR Missions

Past:

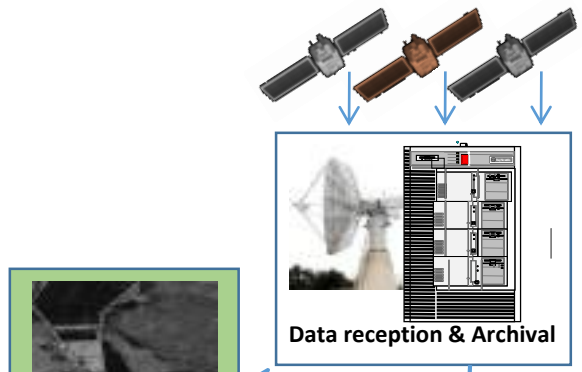
- Airborne SLAR(C-band)
- Airborne Disaster Management SAR(C-band)
- RISAT-1(C-band)
- Airborne MiniSAR(X-band)

Present:

- Airborne L&S band SAR
- RISAT-2B Constellation Mission(X-band)
- EOS-04 (C-band)

Future:

- NISAR (L and S band)
- RISAT-1B (C-band)



Web Portals & Services

National and International Users

- G-Governance
- Societal Applications
- SD Goals
- Strategic Applications
- Natural Resource Management

Non-IRS & Collaborative SAR Missions

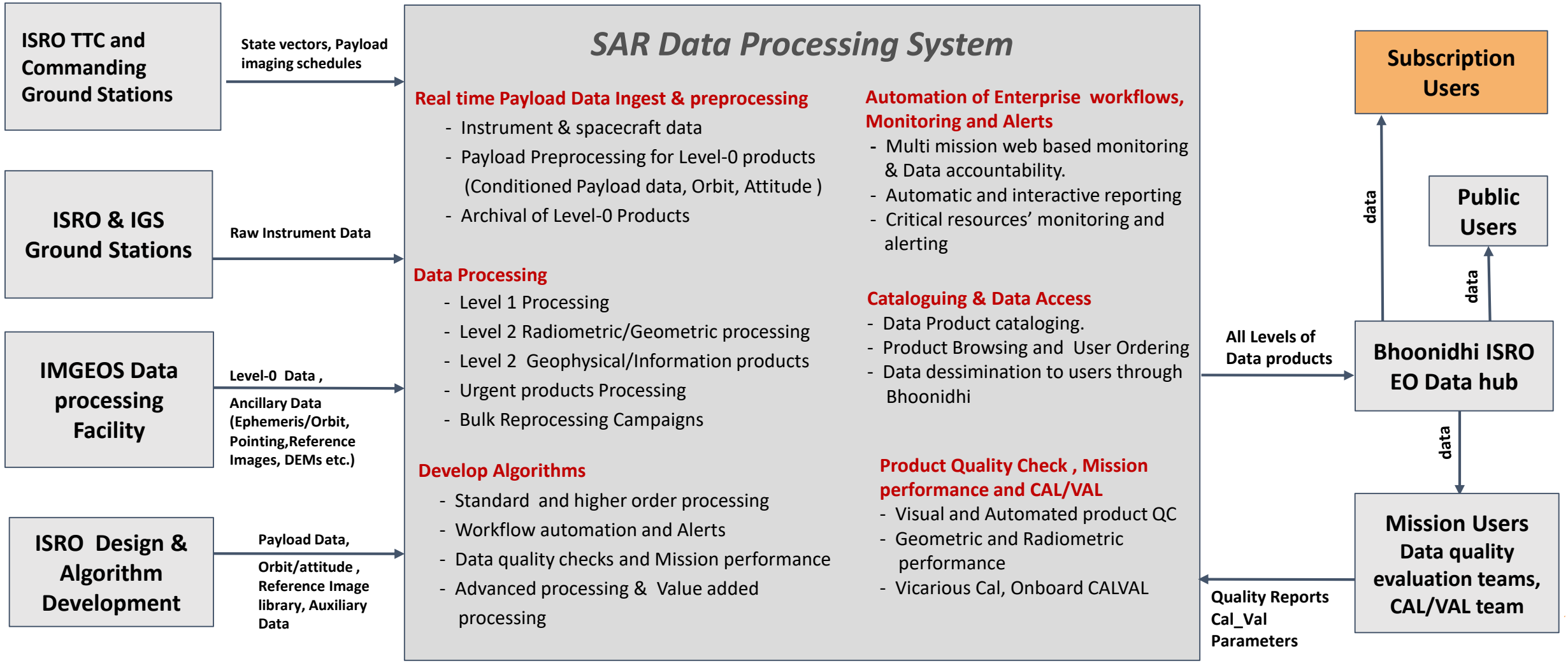
- ERS-1/2 (C-band) - ESA
- RISAT-2 (X-band) - IAI
- NovaSAR (S-band) - SSTL

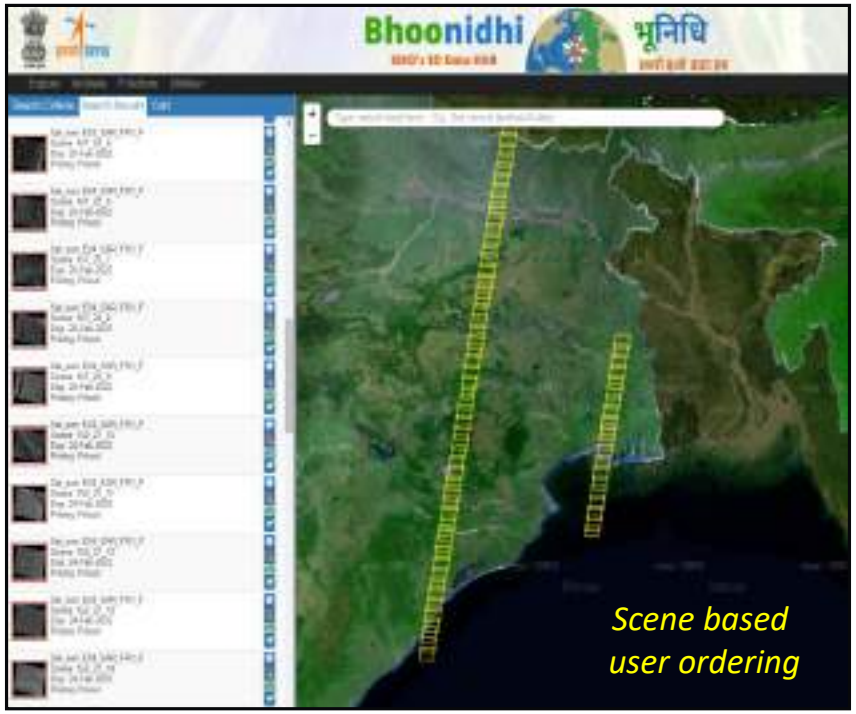
SAR Remote Sensing Applications

Agriculture & Soils | Forestry & Ecology | Water Resources | Ocean | Geology | Urban & Land

Disaster Management Support

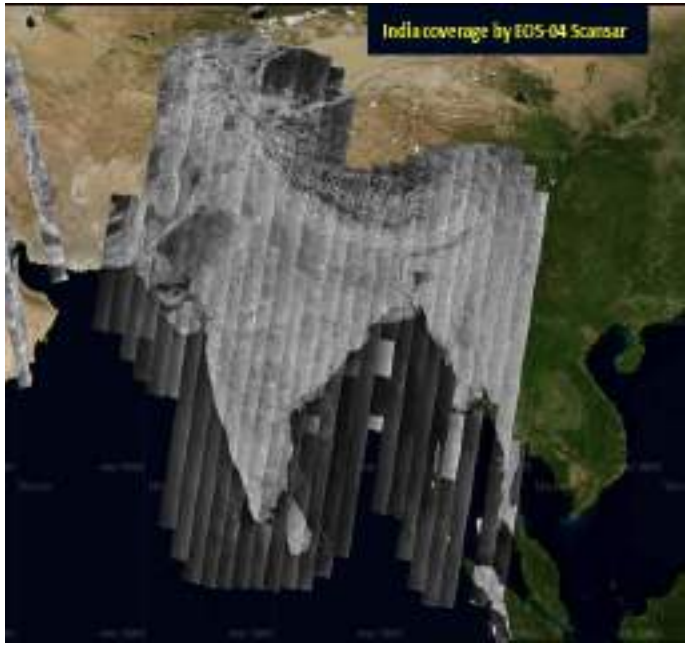
IMGEOS- Ground Segment – SAR Data Processing System Architecture





Functionalities & Capabilities of ISRO's EO Data Hub:

- Open & commercial access for satellite data products across spatial and spectral resolutions; tools for near real time data visualization for geospatial and science applications
- Disaster support by quick data identification and delivery; disaster specific data processed and published on highest priority
- SAR data hosted at Bhoonidhi from EOS-04, NovaSAR and Sentinel-1 missions
- Various AOI based & Resolution based search options.
- Map based visualization
- On demand product generation of Level-1 and Level-3 (polarimetry) products for EOS-04



Bhoonidhi Vista

- Showcases how India looked in the past few hours or days by EO sensors in native resolution.
- First hand valuable visual insights for change detection and quick analysis for fast response for disaster monitoring and to examine data suitability for EO applications and further analysis.

ISRO's Cal-Val Facilities

ISRO has established permanent and campaign mode Calibration Sites with objectives:

- 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

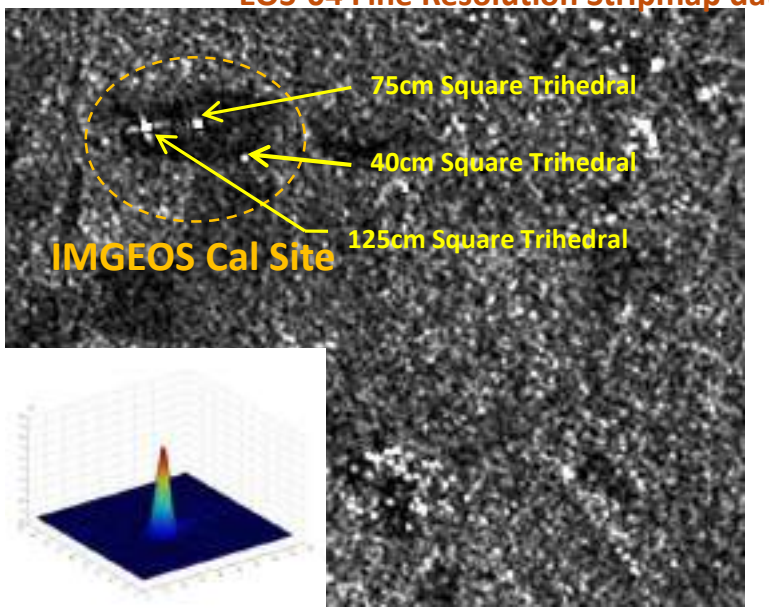
Permanent Sites: NRSC-IMGEOS, SAC-Ahmedabad, Antarctica
Campaign mode Sites: Desalpur, Amarapur, IIST Campus

CR deployed at Antarctica during 2021-2022

Corner Reflectors deployed at SAC

Indigenously developed
Wideband Active Radar Calibrator
(ARC)
(L, S, C & X band)

EOS-04 Fine Resolution Stripmap data



Impulse Response Function for point target

Thank You!!