NISAR Mission

Indian Science & Applications Plan

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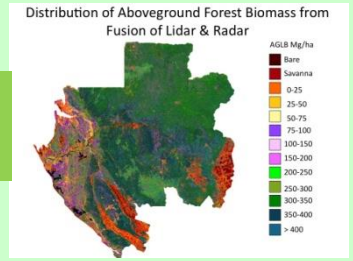
SAC/ISRO
2-6 March , 2020
Canberra, Australia

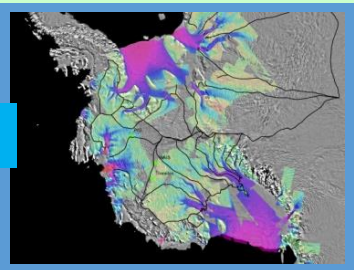
DESDynI Mission Concept: Earlier to 2011

Ecosystem Structure



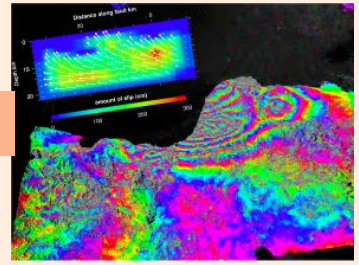
Biomass, Vegetation Structure, Effects of changing climate on habitats and CO_2, disturbance

Cryosphere



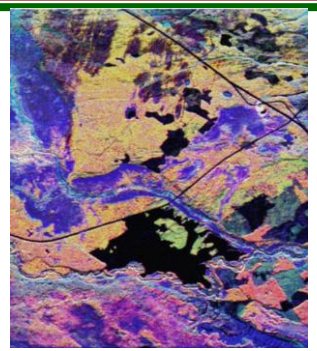
Ice velocity, thickness Response of ice sheets to climate change & sea level rise

Solid Earth

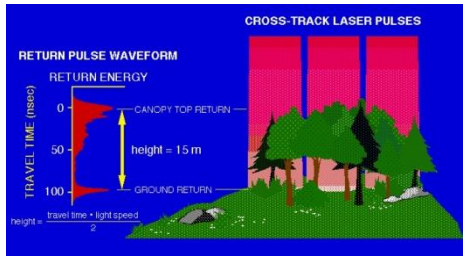


Surface Deformation Geo-Hazards Water Resource Management

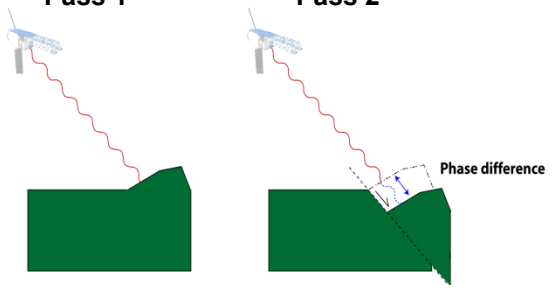
L-band Polarimetric SAR



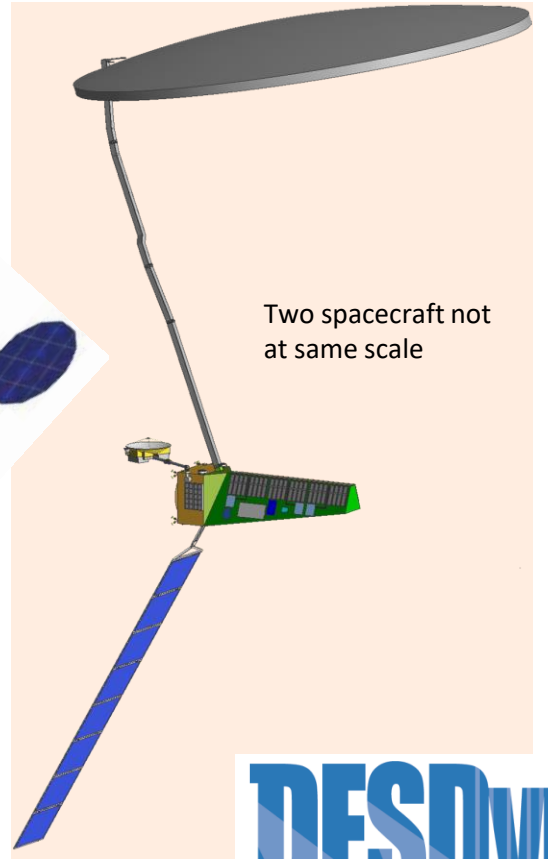
Multibeam Profiling LIDAR



L-band Repeat Pass InSAR



91-day repeat
~370 km orbit
25 m spot
5 beams



Two spacecraft not at same scale

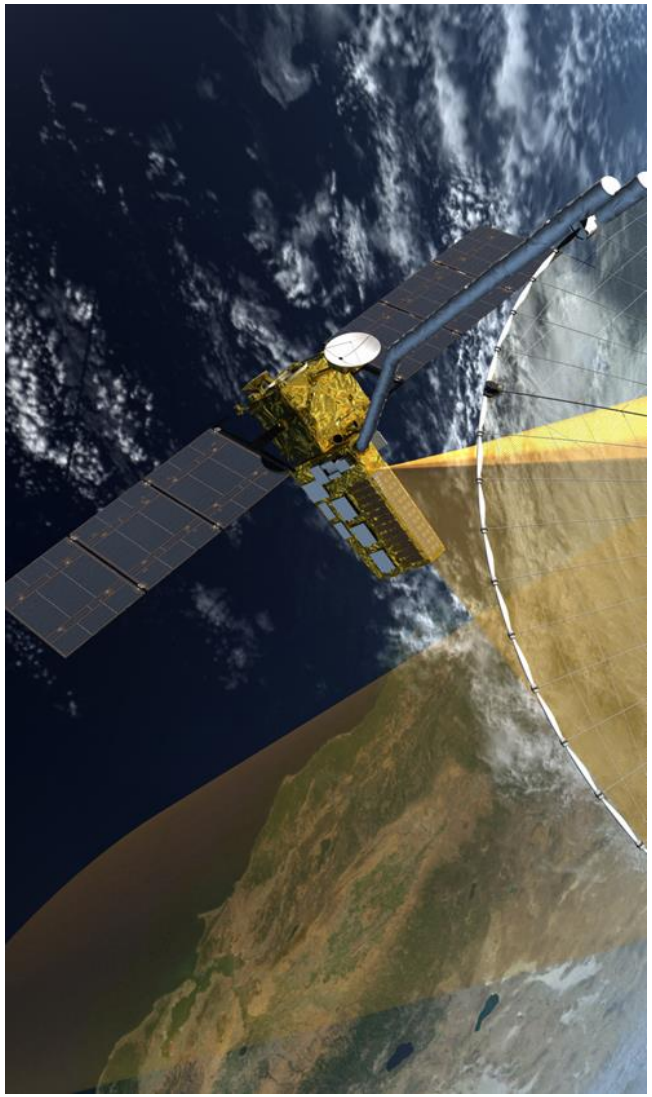
DESDynI

DEFORMATION, ECOSYSTEM STRUCTURE + DYNAMICS OF ICE

Mission Evolution and Objective

Mission Objective

- Global Science Mission along with specific local (Indian) applications
- Interferometric SAR observations for precise earth deformation measurements
- Biomass estimation
- Ice dynamics monitoring
- Indian geological & coastal processes monitoring
- Limited disaster monitoring



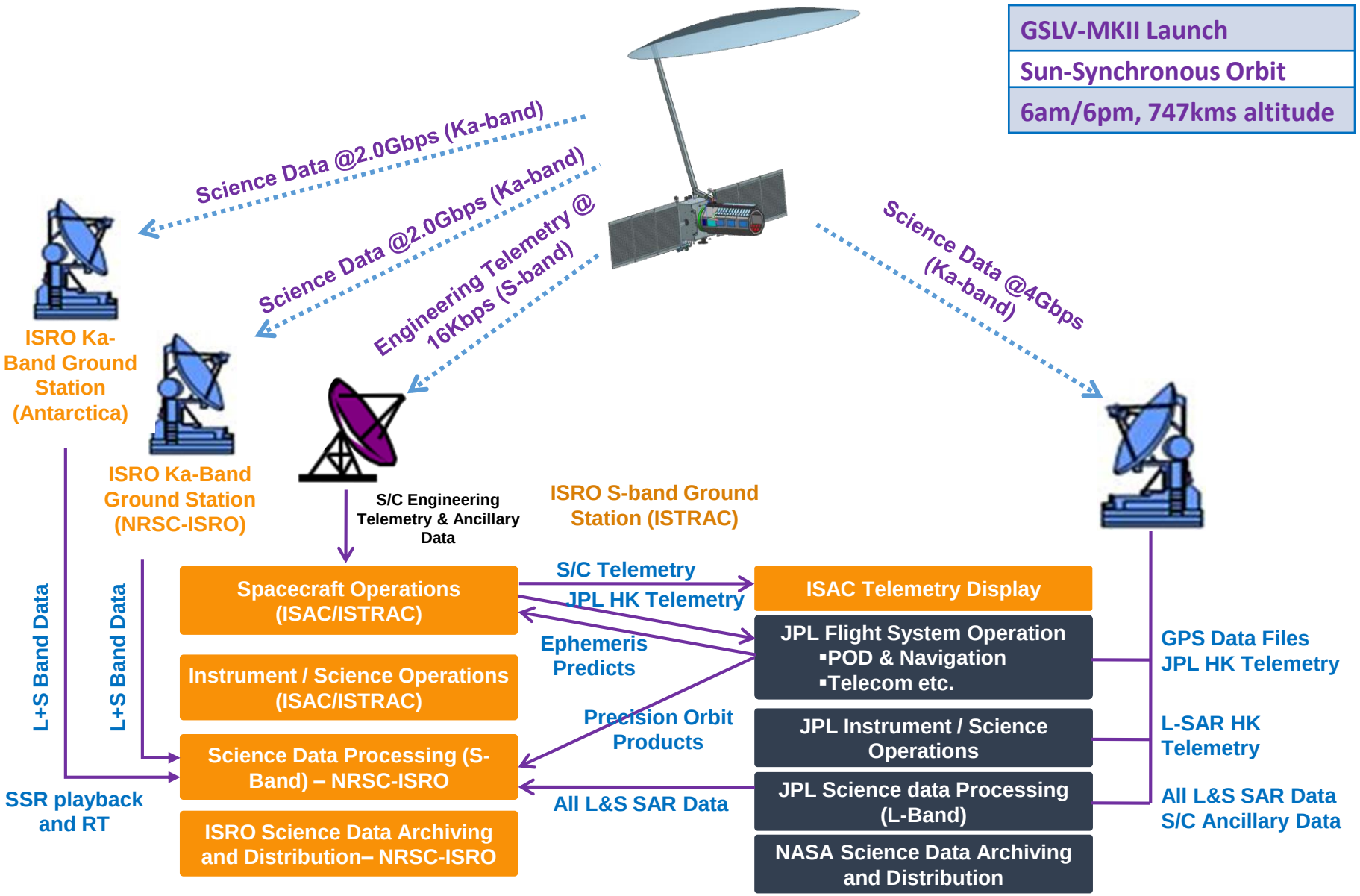
Mission Implementation Plan

NASA will be providing	ISRO will be providing
L-Band SAR science payload & integrated instrument structure	S-Band SAR science payload
GPS receiver	Spacecraft bus
Reflector Boom Assembly	Launch vehicle and services
Solid State Recorder	Spacecraft operations
Downlink of all science data to ground station	Downlink of selected science data and all spacecraft telemetry to ISRO ground stations
L-Band Science data processing	S-Band science data processing

Major Mission Specifications

Parameter	Specification
SAR payload frequencies	L-Band & S-Band
Payload operation modes	Polarimetric & Interferometric observations
Revisit period	12 days
Science Orbit altitude	747 Kms
Orbit Type	Dawn-Dusk (6AM -6PM) ; 6AM Descending
Orbit maintenance accuracy	250m x 375 m
Launcher (GSLV) Parameters	Max. Mass -2612 Kg into Injection orbit of 737 Kms Envelope – 4M PLF CG: Max 2m above interface plane
Mission Life	5 Years (JPL-3yrs nominal, extendable)

NISAR Mission System Architecture



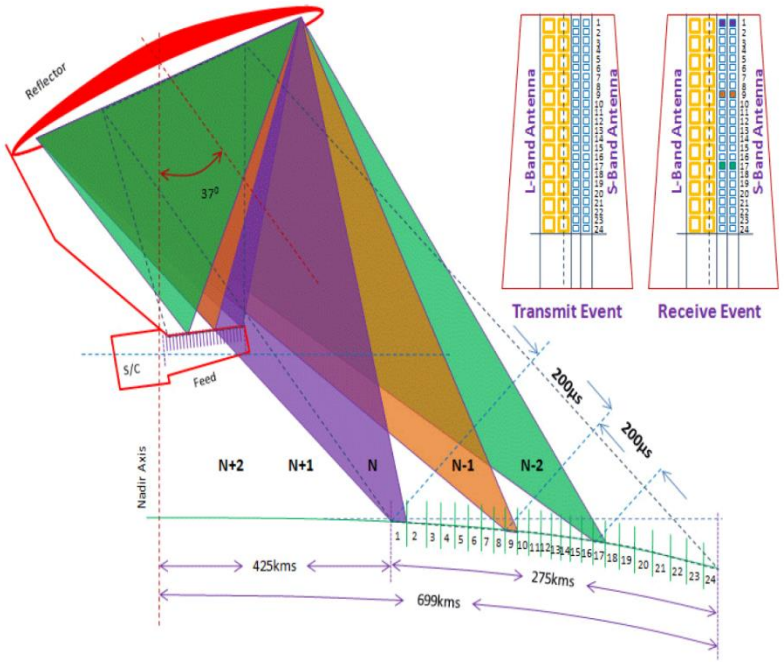
Sensor Specifications

Parameters	S-band	L-band
Orbit	747 km with 98° inclination	
Repeat Cycle	12 days with left look only	
Time of Nodal Crossing	6 AM / 6 PM	
Frequency	3.2 GHz ± 37.5 MHz	1.257 GHz ± 40 MHz
Available Polarimetric Modes	SP: HH or VV DP: HH/HV or VV/VH CP: RH/RV QQP: HH/HV and VH/VV	SP: HH or VV DP: HH/HV or VV/VH CP: RH/RV QP: HH/HV/VH/VV
Available Range Bandwidths	10 MHz, 25 MHz, 37.5 MHz, 75 MHz	5 MHz, 20 MHz, 40 MHz, 80 MHz (Additional 5 MHz in 20 & 40 MHz modes at other end of pass-band for ionosphere)
Swath Width	> 240 Km (except for QQP Mode)	> 240 Km (except for 80MHz BW)
Spatial Resolution	7m (Az); 3m-24m (Slant-Ra)	7m (Az); 3m-48m (Slant-Ra)
Incidence Angle Range	33 – 47deg	33 – 47deg
Noise Equivalent σ°	-25 dB (baseline) -20 dB(Threshold)	-25 dB (for required full-swath modes)
Ambiguities	< -20dB for all modes except QQP	< -23dB swath average in SP or DP modes < - 17dB swath average in QP mode
Data and Product Access	Free & Open	

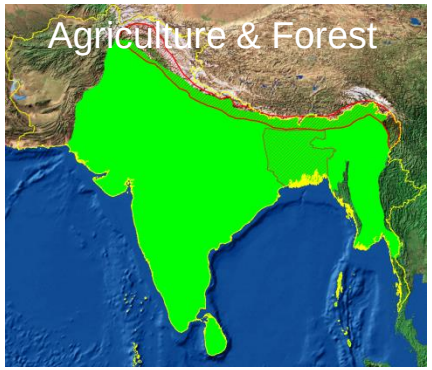
Sweep SAR Concept

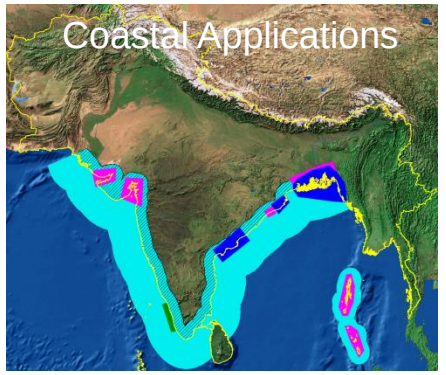
Transmit Event
All TRMs are active which illuminate a small aperture on reflector but a large footprint on ground

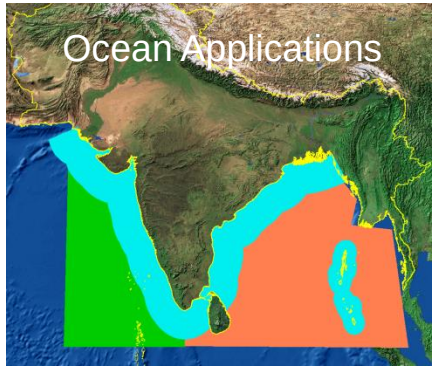
Receive Event
Data from each of the beam illuminates the full aperture area of the reflector which routes the echo signal in the designated TRM corresponding to given beam

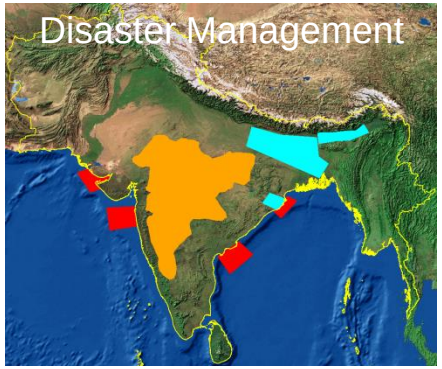


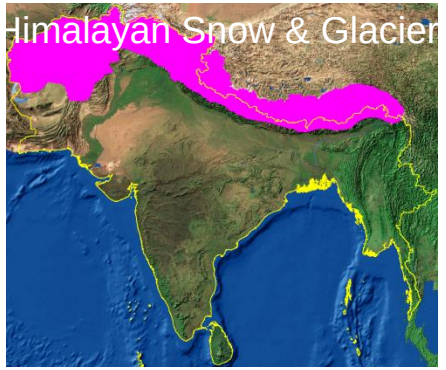
Indian Targets of Interest

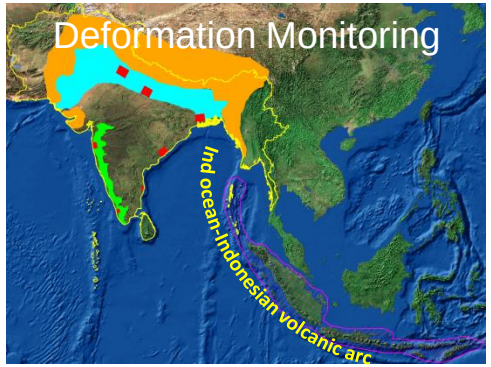


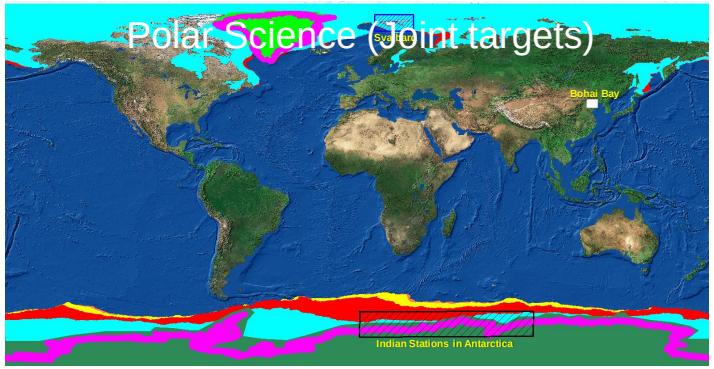












Background Land (Systematic Coverage)
S (DP/CP) 37.5/25 MHz;
L (QP) 40+5 MHz

Agriculture, Forest & Wetland
S (CP) 25 MHz;
L (QP) 40+5 MHz

Coasts / Coastal Ocean
S (CP) 25 MHz;
L (VV+VH) 20+5 MHz

Indian Ocean
S (DP-VV+HV) 10 MHz

Disaster Studies
S (CP) 25 MHz;
L (DP) 20+5 MHz

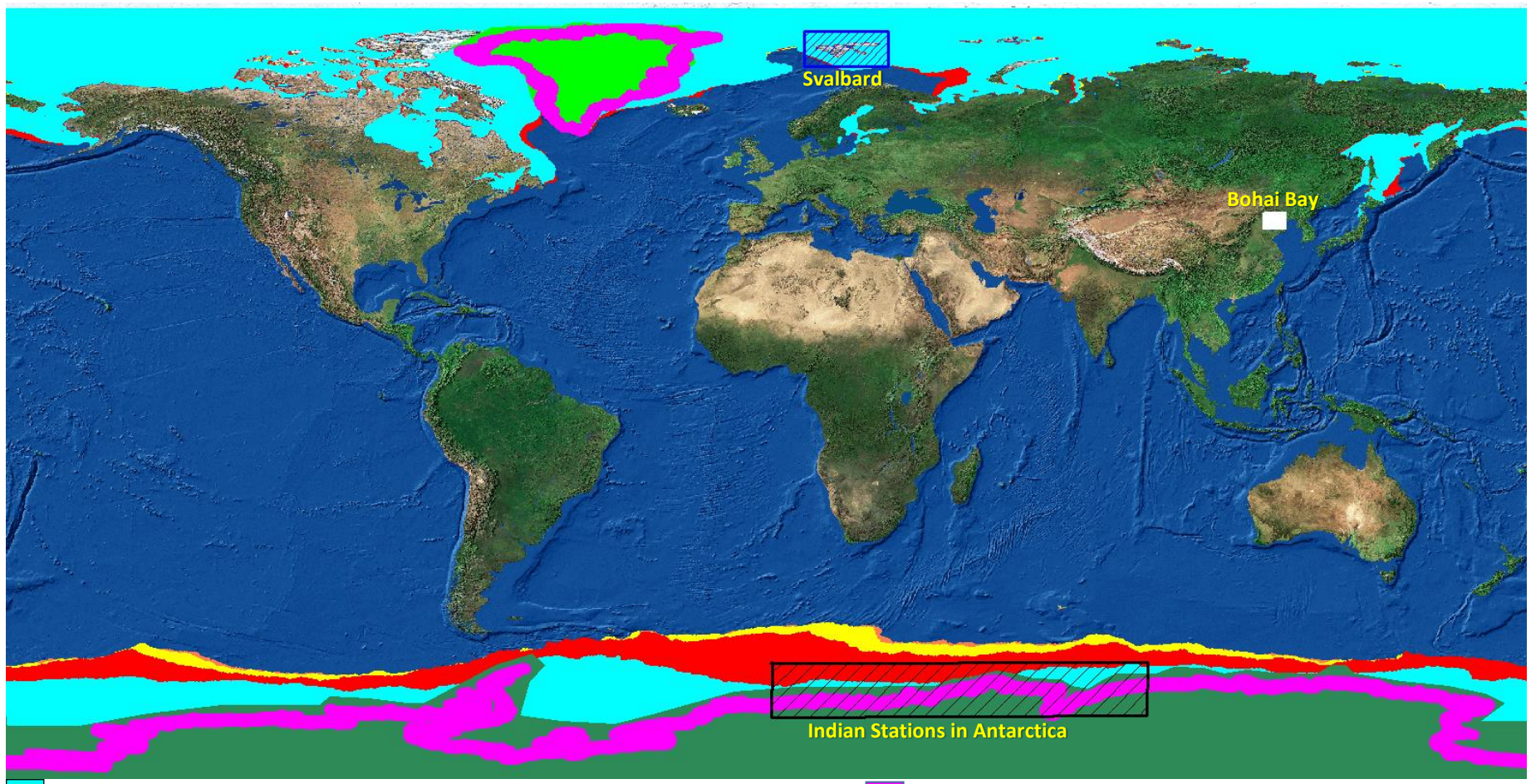
Himalayan Cryosphere
S (CP) 25 MHz;
L (QP) 40+5 MHz

Deformation Studies
S (DP) 35.5 MHz;
L (DP) 20+5 MHz

Polar Science
S (CP) 25 MHz;
L (DP) 20+5 MHz /
L(SP) 80 MHz / 5 MHz

NASA has interest in Himalayan cryosphere targets and Indian ocean-Indonesian volcanic arc target apart from Polar targets

Polar Cryosphere Targets

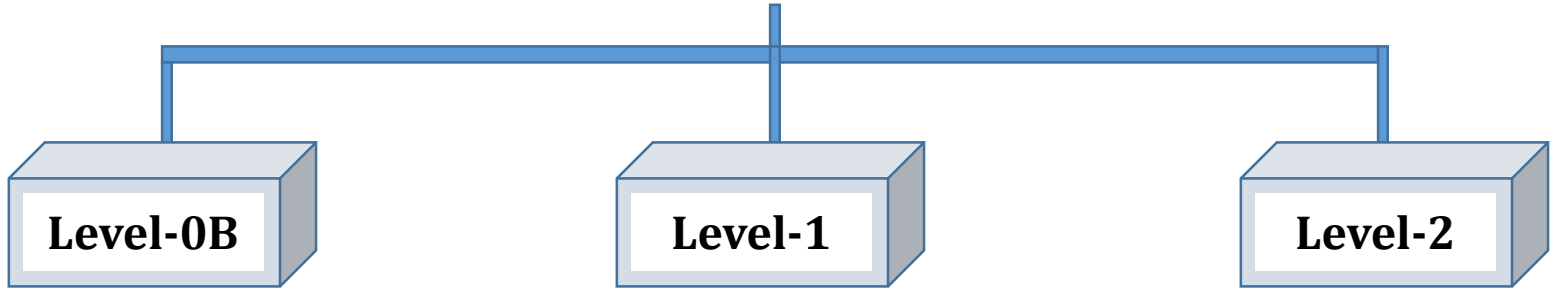


- Sea Ice Q1 (L- single-pol : 5 MHz) - same as NASA requirement
- Sea Ice Q2 (L- single-pol: 5 MHz) - same as NASA requirement
- Sea Ice Q3 (L- single-pol : 5 MHz) - same as NASA requirement
- Sea Ice Q4 (L- single-pol : 5 MHz) - same as NASA requirement
- Ice Characterization: S (CP) 25MHz & L(VV+VH) 20+5MHz; Sep-Apr, every 3days
- Land Ice Antarctica: S (CP) 25MHz; Jul-Sep, 2 sets of mosaics
  L (SP) 80 MHz, Half swath (same as NASA requirement)
- Priority Ice: L (SP) 80 MHz-half swath – same as NASA reqmt
- Svalbard Ice Characterization: S (CP) 25MHz & L(VV+VH)
  20+5MHz; Dec-Mar, every 12 days
- Bohai Bay Ice Characterization: S (CP) 25MHz & L(VV+VH)
  20+5MHz; Dec-Mar, every 12 days
- Land Ice Greenland: S (CP) 25MHz; Dec-Mar, 2 sets of mosaics
  L (SP) 80 MHz, Half swath (same as NASA requirement)

Data Products

NISAR SweepSAR Data Products

Basic Data Products Levels



➢ *RAW Signal Product : Individual Channel or Digital Beam Formed (DBF) data*

- *Unprocessed Radar echo data in I & Q format*
- *Stripping of Downlink frame format*
- *BAQ Decoding*
- *Along with Auxiliary data required for processing*

➢ *Products in Radar coordinates*

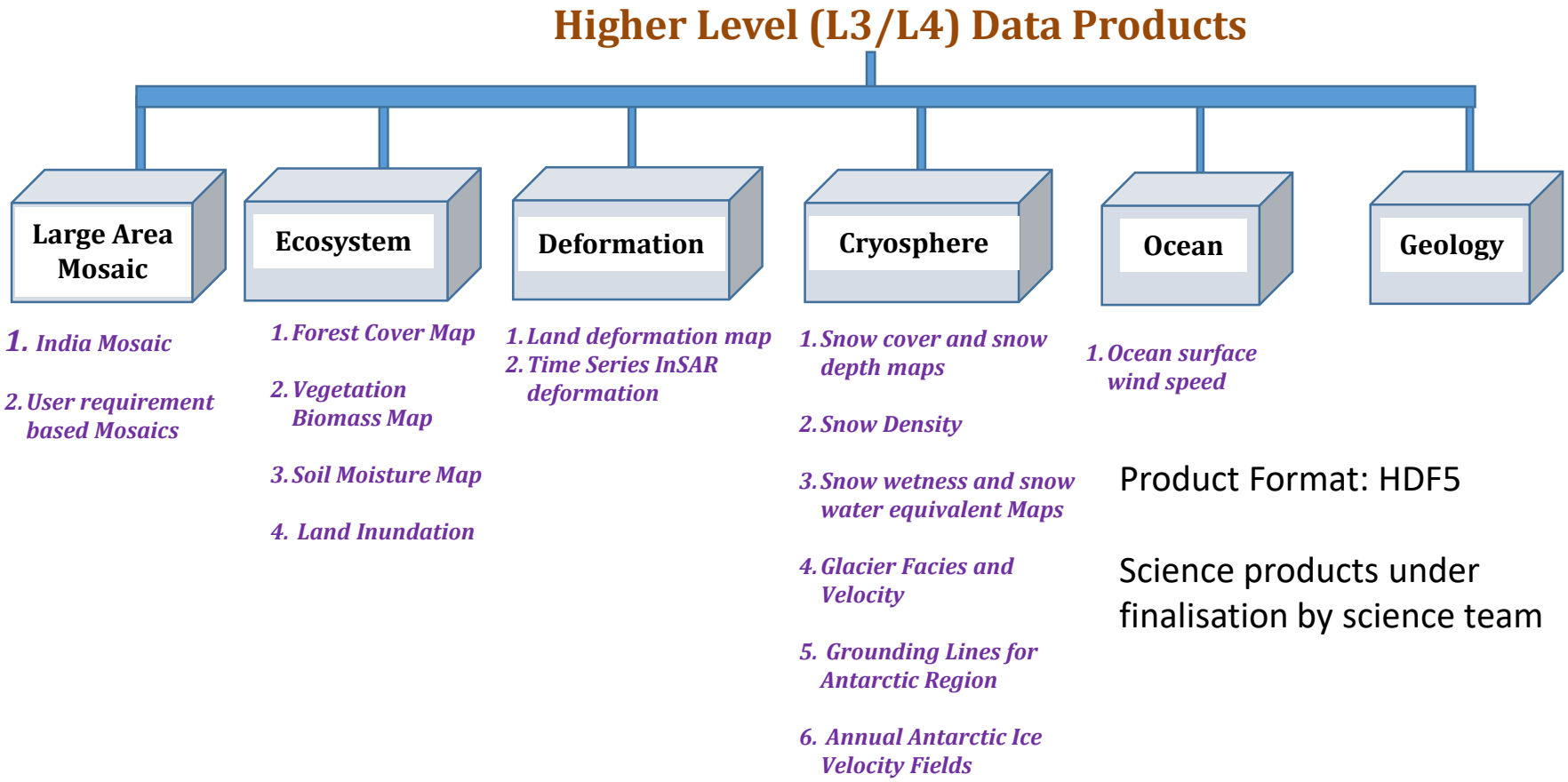
- *Geo-Tagging using satellite Ephemeris data*
- *Earth Geometry – Standard Ellipsoid*
- *Dense grid of Geo-Locations with product*

➢ *Geocoded Products*

- *Horizontal datum : WGS 84*
- *Map Projection : UTM, UPS for polar regions*
- *DEM : CARTODEM, NASA-DEM, TERRASAR DEM (90m), ARCTIC DEM*

NISAR Data Products Format HDF5 :: Contents	
1. Product File comprising ▪ Polarization wise RAW/ Processed SAR image ▪ Orbit and Attitude information ▪ Scene Processing Parameters & other Auxiliary parameters	2. Geolocation Grid Files
	3. Meta Data in XML/ASCII file
	4. Polarization wise Jpeg files

Higher Data Products



Product Format: HDF5

Science products under finalisation by science team

- **L1/L2/L3 Products will be operationally available from NRSC (nrsc.gov.in)**

Data Product Specifications

Level1: Single-Look Complex - Geo-Tagged Products

Level2: Geocoded Products

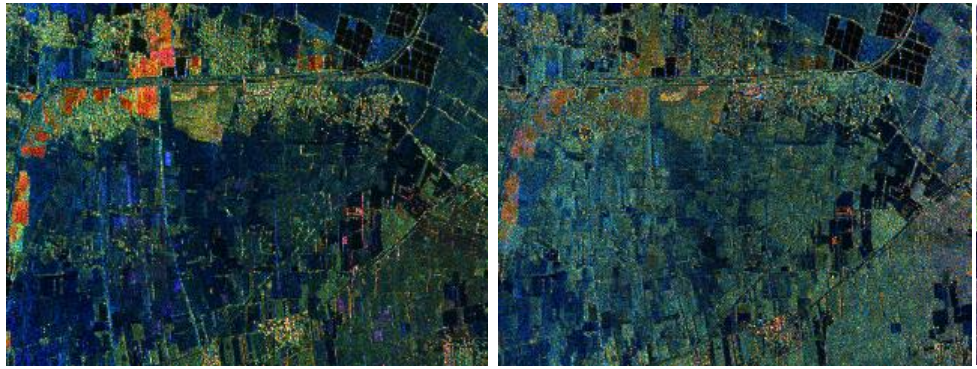
Format: GeoTiFF with Meta data

S.No.	Parameter	Specification		
1	Minimum Scene Size (considering worst case squint of ±15°)	5.5 km X full azimuth extent for roll bias 37 9.5 km X full azimuth extent for roll bias 51 14.5 km X full azimuth extent for roll bias 64 9.5Km X full azimuth extent for roll bias 40°		
2	Chirp Bandwidth	25 MHz	50MHz	75MHz
3.	SLC Resolution (m) (Azimuth X Slant Range)	2X6	2X3	2X2
4	SLC Pixel Spacing(m) (Azimuth X Slant Range)	~6* X 6	~3* X 3	~2*x2
5	L2 Pixel Spacing(m) (Azimuth X Slant Range)	6 X 6	3 X 3	2x2
6	Radiometric Resolution	~3dB-Single Look		
7	Radiometric Accuracy	2dB		
8	Geometric Accuracy (m)	<100m		
9	Polarimetry channel registration with in a band	Sub-pixel		
10	L&S Band Registration	Sub-Pixel		

L&S ASAR Images

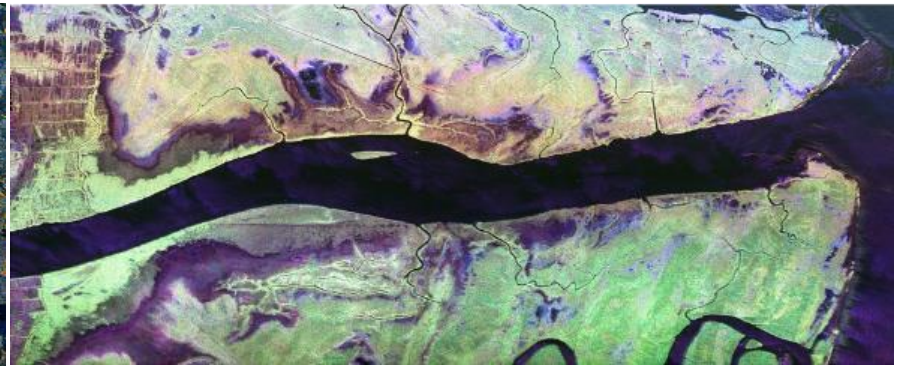
Agriculture/Soil Moisture Study

L-BAND Vijayawada, Circular Polarisation S-BAND



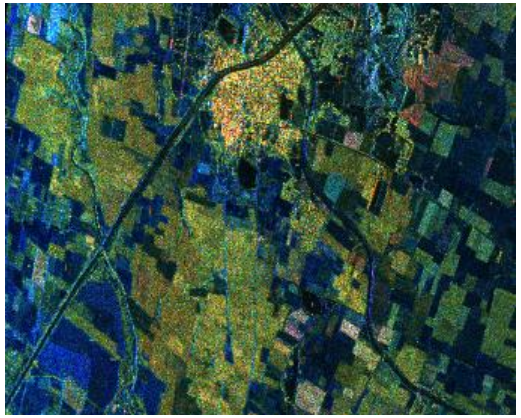
Wetland Mapping

S-Band Full Pol images over Krishna delta (HH,HV,VV)



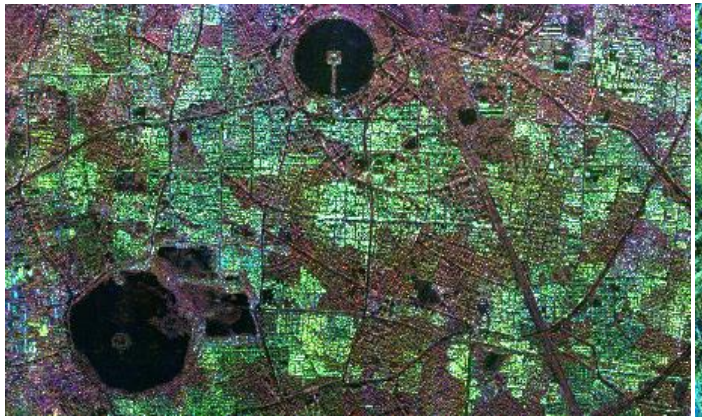
Agriculture/Soil Moisture

Guntur-L-Band,FP



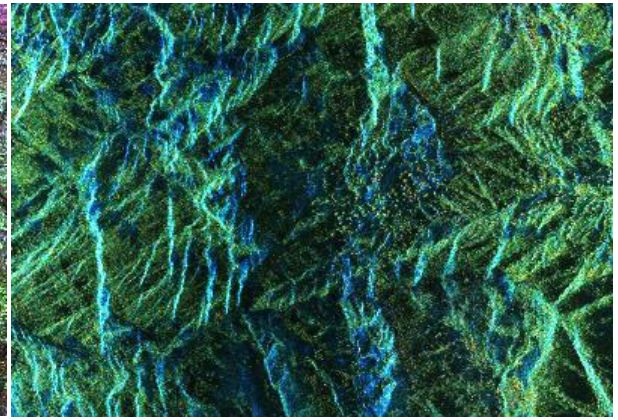
Urban

Ahmedabad-S-Band,FP



Forest

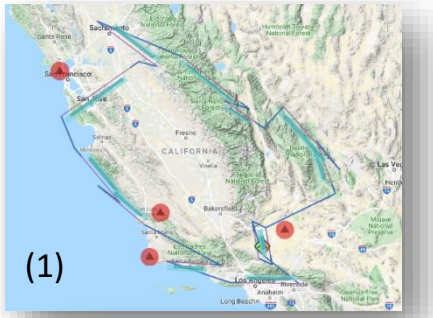
Narmada, L-Band ,CP



LS-ASAR US Campaign Summary of Flights

04 to 16 Dec 2019

(1)



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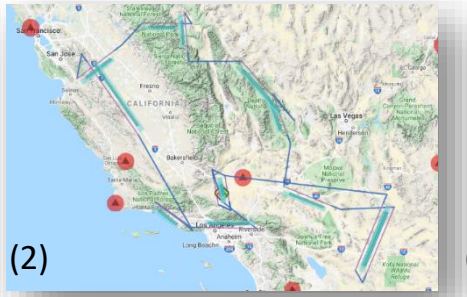

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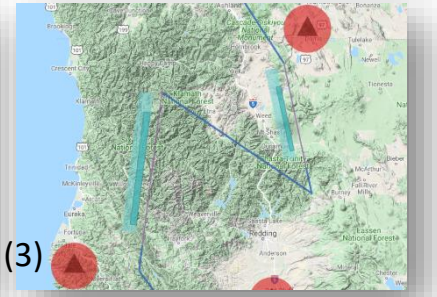

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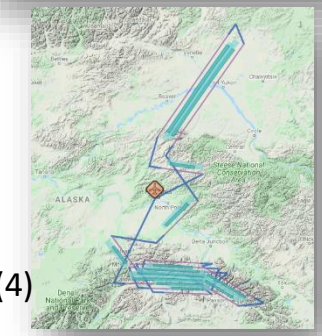
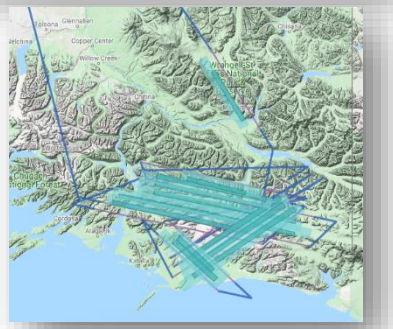


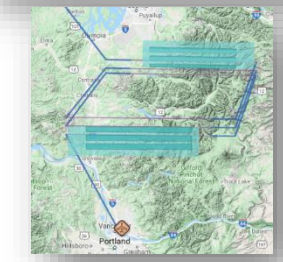
(5)



(6)

(7)

(8)

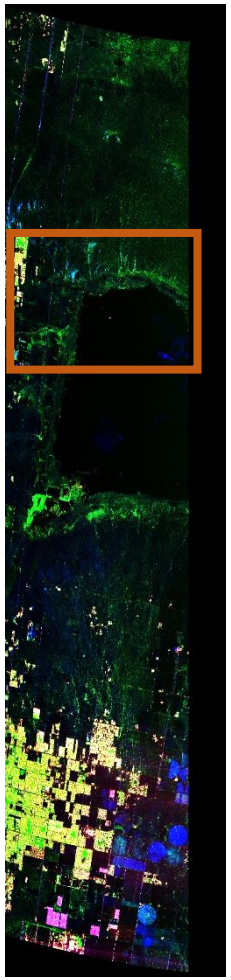


(9)

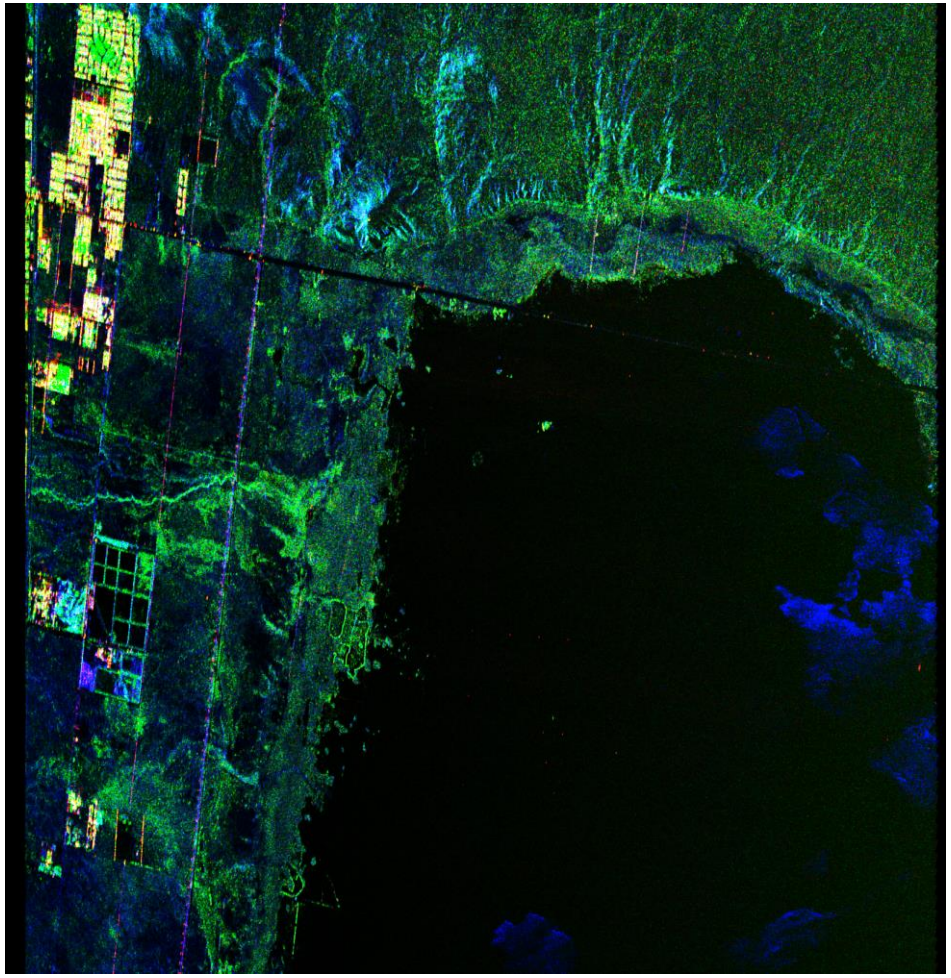
SN	Date	Lines	Area Covered
1	4-Dec-2019	11/12	CA
2	5-Dec-2019	14/16	CA
3	9-Dec-2019	2/2	Palmdale to Fairbanks
4	10-Dec-2019	10/12	Alaska
5	11-Dec-2019	12/12	Alaska
6	12-Dec-2019	14/13	Alaska
7	14-Dec-2019	7/7	Alaska
8	15-Dec-2019	6/6	Nr Seattle
9	16-Dec-2019	13/13	Portland to Palmdale

2TB+2TB = 4TB Data collected in L+S Band

Full Pol Image - Freeman decomposition

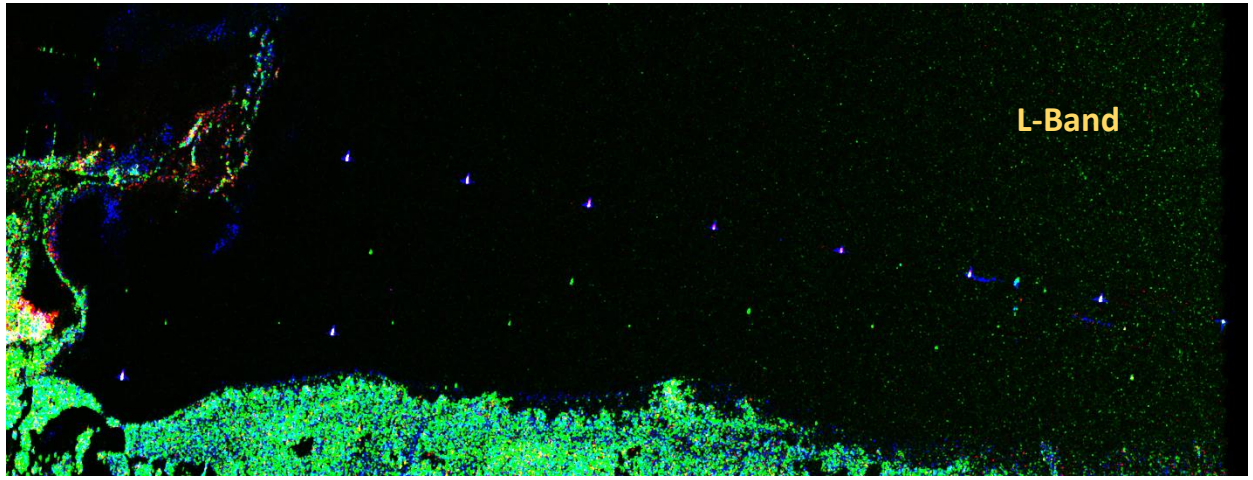


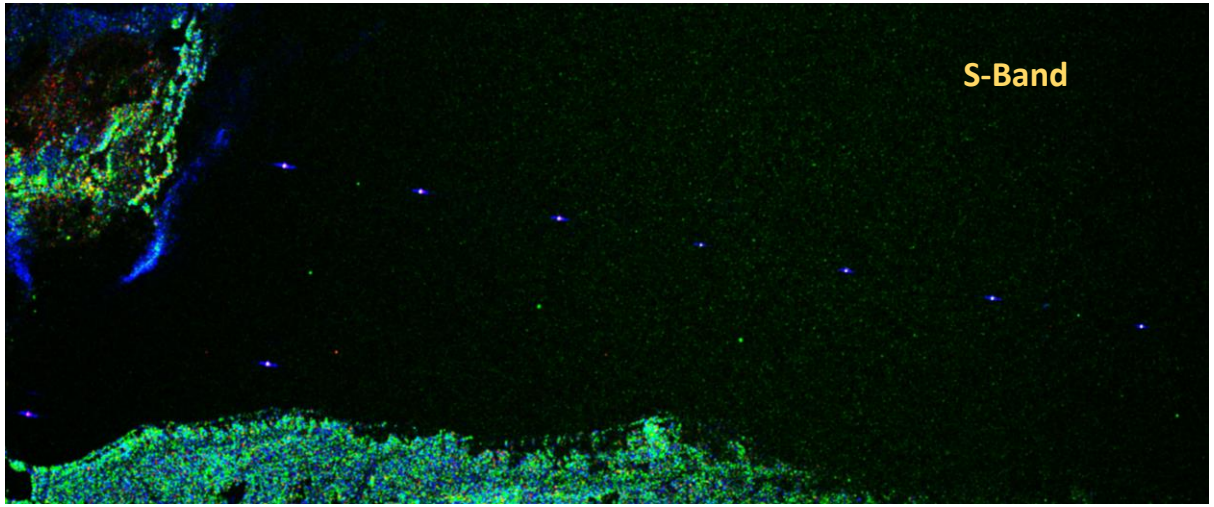
SITE-ID 1702N –Rosamond Calibration Site -L Band



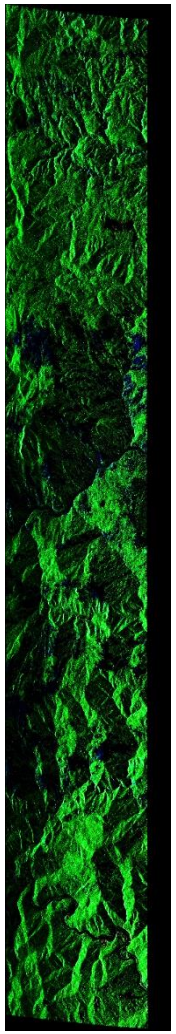
R-Even Bounce, G- Volumetric, B-Odd Bounce Targets

SITE-ID 1702N –Rosamond Calibration Site -L and S Band

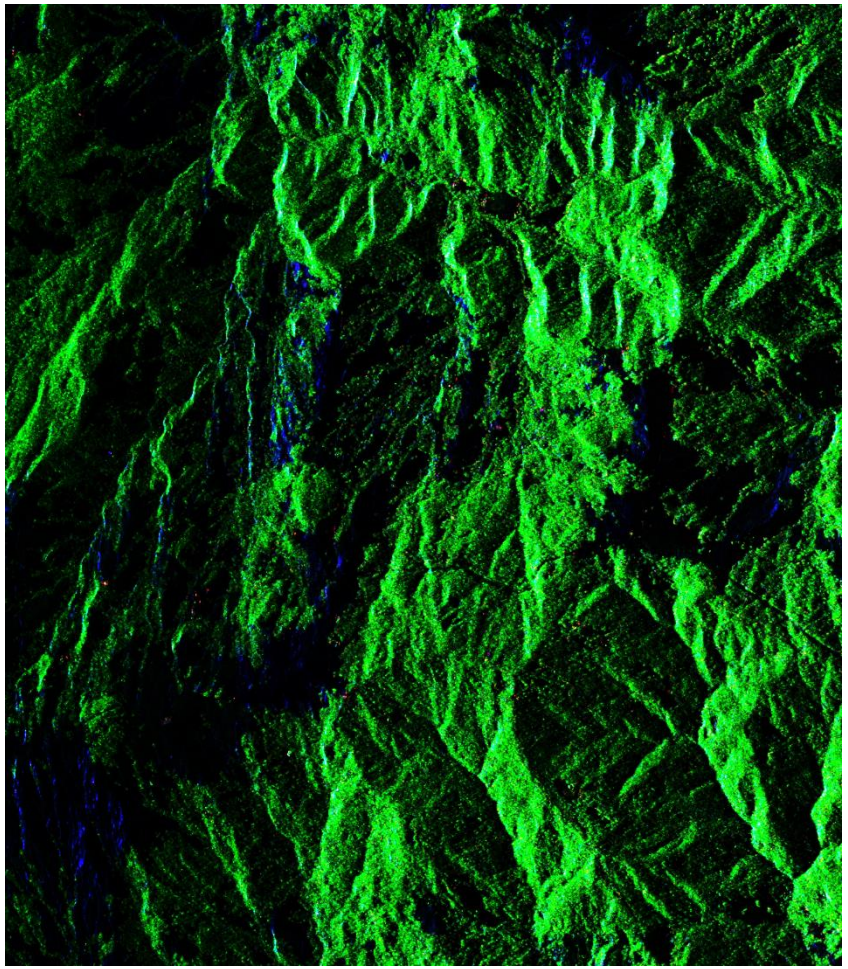




SITE-ID 24513 –Eel River Landslide Site -L Band



SITE-ID 24513 –Eel River Landslide Site -L Band



NISAR Global Objectives

Key Scientific Objectives

- Understand the response of ice sheets and glaciers to climate change and the interaction of sea ice and climate
- **Understand the dynamics of carbon storage and uptake in wooded, agricultural, wetland, and permafrost systems**
- Determine the likelihood of earthquakes, volcanic eruptions, and landslides

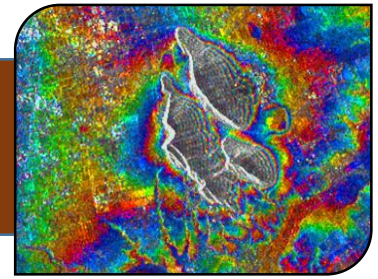
Key Applications Objectives

- Understand societal impacts of dynamics of water, hydrocarbon, and sequestered CO_2 reservoirs
- Enhance agricultural monitoring capability in support of food security objectives
- NISAR data to explore the potentials for urgent response and hazard mitigation

To be accomplished in partnership of ISRO and NASA through the joint development and operation of a space-borne, dual-frequency, polarimetric, synthetic aperture radar (SAR) satellite mission with repeat-pass interferometry capability

NISAR: Science Plan of ISRO

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

Major operation modes identified for NISAR L- and S-band

	Mode	Primary Science Target	Frequency	Polarisation	Band Width (MHz)	Resolution (Az × Ra)	Swath (Km)
L-Only	L1	*Background Land*	L-Band	DP: HH + HV	20+5	6.9m×7.5m	242
	L2	*Land Ice*	L-Band	SP: HH	80	6.9m×1.9m	121 (Half)
	L3	*Sea Ice dynamics*	L-Band	SP: VV	5	6.9m×30m	242
	L4	*Sea Ice characterization*	L-Band	DP: VV + VH	20+5	6.9m×7.5m	242
	L5	*Urban areas, Himalayas*	L-Band	DP: HH + HV	40+5	6.9m×3.8m	242
	L6	*Indian / US Agriculture*	L-Band	QP: HH+HV+VH+VV	40+5	6.9m×3.8m	242
	L7	*Experimental compact pol*	L-Band	CP: RH + RV	20+20	6.9m×7.5m	242
S-Only	S1	*Land Ice/ Vegetation/ Coastal land*	S-Band	Quasi-Quad Pol (QQP)	37.5	6.4m × 4m	122 (Half)
	S2	*Ecosystem/ Ocean/ Polar Cryosphere*	S-Band	DP: HH+HV / VV+VH	10	6.4m ×15m	244
	S3	*Agriculture/ Sea Ice/ Land Ice / Himalayas*	S-Band	CP: RH+RV	25	6.4m × 6m	244
	S4	*Background Land/ Glacial Ice*	S-Band	DP: HH+HV	37.5	6.4m × 4m	244
	S4x	*Land Ice / Himalayas (High Resolution)*	S-Band	CP: HH+HV	37.5	6.4m × 4m	244
	S5	*Deformation*	S-Band	SP: HH (or SP: VV)	25	6.4m × 6m	244
	S6	*Deformation/ Urban area – Max Resolution*	S-Band	SP: HH (or SP: VV)	75	6.4m × 2m	244
Joint Mode	L1+S3	*Background Land systematic coverage*	L + S	L: DP HH + HV S: CP RH + RV	20+5 25	6.9m×3.8m 6.4m × 6m	244
	L1+S4	*Systematic coverage & Deformation*	L + S	L: DP HH + HV S: DP HH + HV	20+5 37.5	6.9m×3.8m 6.4m × 4m	244
	L4+S3	*Coastal ocean/ Sea Ice characterization*	L + S	L: DP VV + VH S: CP RH + RV	20+5 25	6.9m×7.5m 6.4m × 6m	244
	L6+S3	*Indian Agriculture/ Himalayan snow, glacier*	L + S	L: QP HH+HV+VH+VV S: CP RH + RV	40+5 25	6.9m×3.8m 6.4m × 6m	244
	L5+S4x	*Glacial Ice - Himalayas*	L + S	L: DP HH+HV S: CP RH + RV	40+5 37.5	6.9m×3.8m 6.4m × 4m	244
	L3+S2	*Ocean*	L + S	L: SP VV S: DP VV + VH	5 10	6.9m×30m 6.4m ×15m	244
	L5+S6	*High Res.Urban/ Deformation, Urgent Response*	L + S	L: DP HH + HV S: SP HH (or SP: VV)	40+5 75	6.9m×3.8m 6.4m × 2m	244.

ISRO Science Plan Document

ISRO Science Plan document of NISAR was prepared and released in February 2016.

Subsequent to the formation of ISRO Science team for NISAR in July 2019, and changes in the NISAR observation strategy, the science Plan document is being revised.

- ❑ Observation in Left-look mode only (restriction in North pole observation)
- ❑ Transition at mode change (2 seconds data loss)
- ❑ NISAR Product framing and File sizing restriction
- ❑ Dithering problem in quad/full pol mode (reduced swath)

Science Data Products

Ecosystem:

1. Forest cover map at 25m pixel every 24 days
2. Forest AGB at 100m pixel within 20% error every 120 days
3. Surface soil moisture map at 100m pixel with 20% error every 12days
4. land inundation map at 25m pixel within 20% error every 12 days
5. Crop type/cover map at 25m pixel within 20% error every 12 days (selected region)

Solid Earth:

1. Geocoded Line of Sight (LOS) deformation
2. Time series InSAR deformation at selected calibration sites

Cryosphere:

1. Dry/wet snow map
2. Snow Wetness/ SWE (R&D product)
3. Snow Density (R&D product)
4. Glacier Facies
5. Glacier Velocity (R&D product)

Polar Ice

6. Annual Antarctic Ice velocity fields
7. Regular (every cycle) velocity fields for identified parts of Antarctica and Greenland
8. Grounding line position data for the Antarctic region within two Indian stations

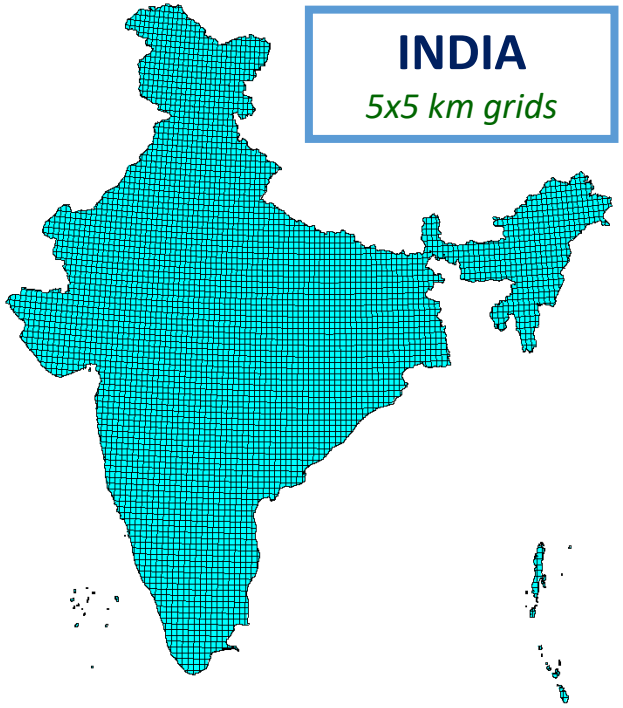
Ocean:

1. Coastal wave height/direction;
2. Coastal bathymetric maps (over selected sites);
3. Coastal oil spill (event based)

Forest Related Studies and Status

New National Forest Inventory design

India has a comprehensive protocol for forest inventory. Forest Survey of India (FSI) is responsible for National Forest Inventory.



Sampling of grids on 5 yr cycle

1st yr – all 1s 2nd yr- all 3s 3rd yr – all 5s
4th yr – all 2s 5th yr- all 4s 6th yr- all 1s

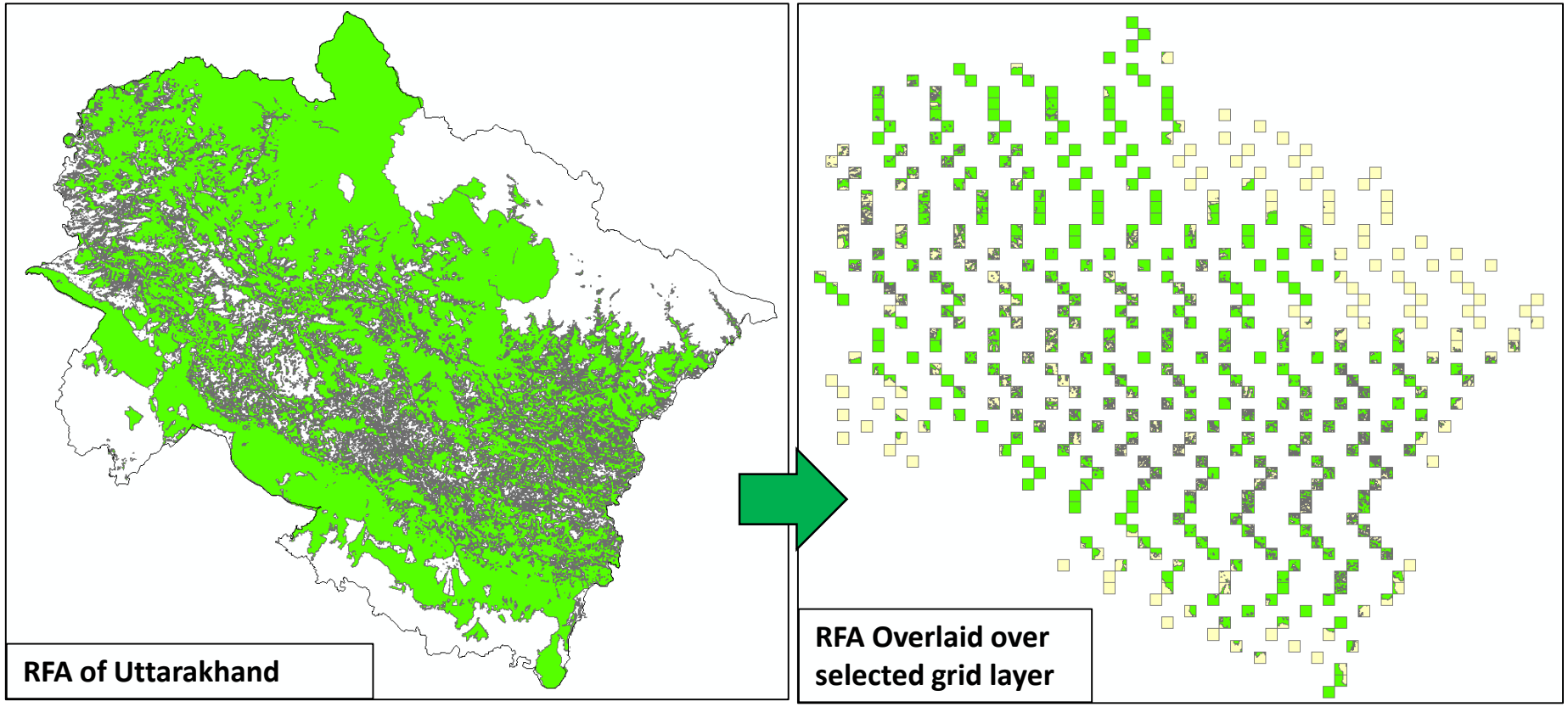
5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1
2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2
3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3
4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4
5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1
2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2
3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3

- **Addressing information needs of:**
  - MoEF & CC
  - Niti Aayog
  - Finance Commission
  - UNFCCC
  - REDD+
  - SFDs
  - GFRA

Around 7,000 forested grids & 10,000 tree outside forests (TOF) grids are being inventoried/ year

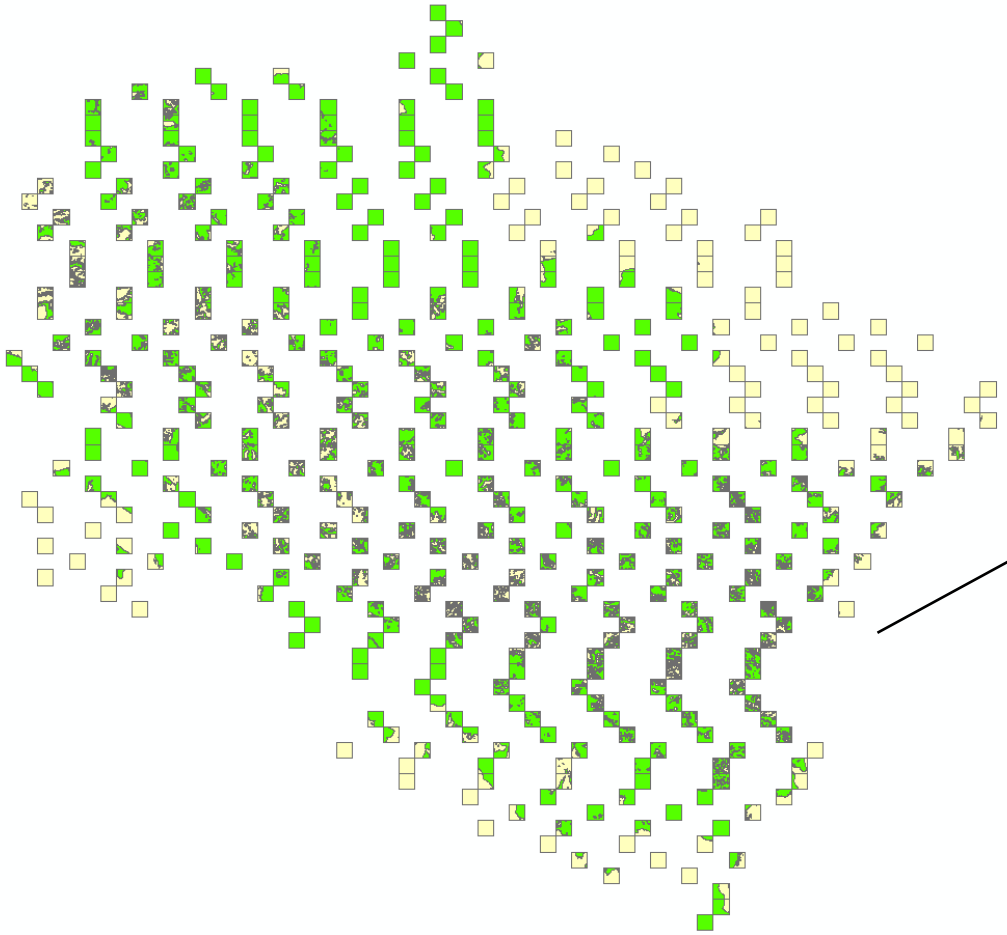
- **Reducing time of revisit from 20 years to 05 years**

Forest Inventory – e.g. from Uttarakhand

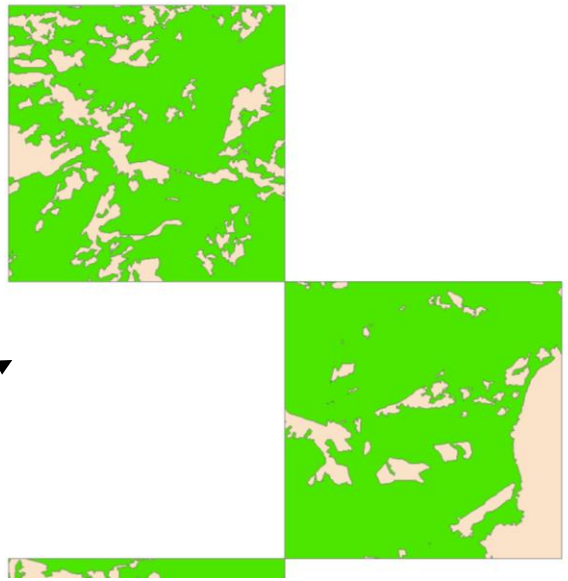


RFA: Recorded Forest Area

Forest Inventory – e.g. from Uttarakhand



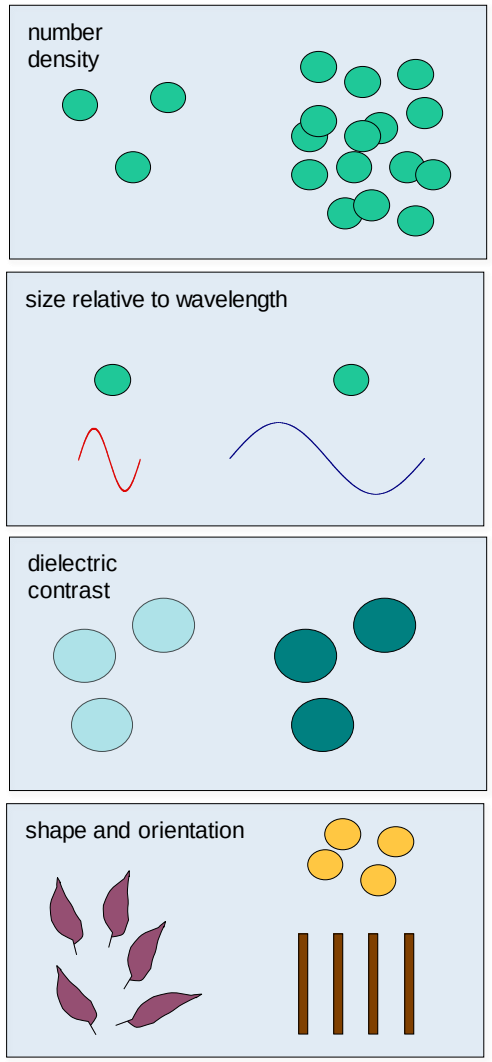
RFA Overlaid over selected grid layer



Forested and non-forested polygons are delineated

SAR Interaction with Forest Vegetation

Sources of scattering within a volume



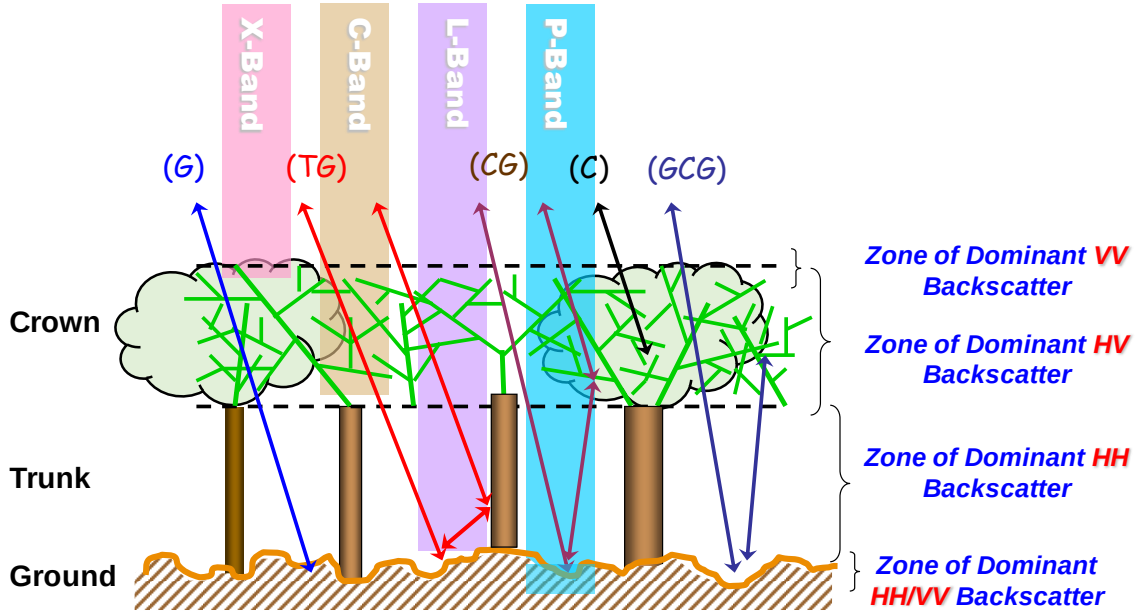
K – band - **Leaves**

X – band - **Leaves, twigs and small branches**

C – band - **Leaves, and small and secondary branches**

L – band - **Primary and secondary branches, trunks and ground**

P – band - **Mostly within main branches, trunks, ground And interaction with trunks-ground**



G: direct backscatter from ground; *TG*: trunk-ground backscatter; *CG*: crown-ground backscatter; *C*: direct backscatter from crown; *GCG*: ground-canopy-ground backscatter

Forest Above-Ground Biomass

Generally referred to the dry phyto-mass (vegetation mass) over forest ground, including litter, fallen trees and deadwood. Expressed in tons per Hectare (t/Ha)

Forest (FAO FRA 2000): Land spanning more than 0.5 hectares with trees higher than 5 meters and a Canopy Cover of more than 10 percent, or trees able to reach these thresholds in situ. It does not include land that is predominantly under agricultural or urban land use.

The FSI defines forest cover as 'all lands more than one hectare in area, with a ***Tree Canopy Density*** of more than 10%, irrespective of ownership and legal status'.

Forest cover of India - 2017

Class	Area (Sq km)	% of Geog. Area
Very Dense Forest	98,158	2.99
Moderately Dense Forest	3,08,318	9.38
Open Forest	3,01,797	9.18
Total Forest Cover*	**7, 08,273**	**21.54**
Scrub	45, 979	1.40
Non-Forest	25, 33,217	77.06
Total Geographic Area	**32,87,469**	**100**

* Includes 4,921 sq km of Mangrove cover

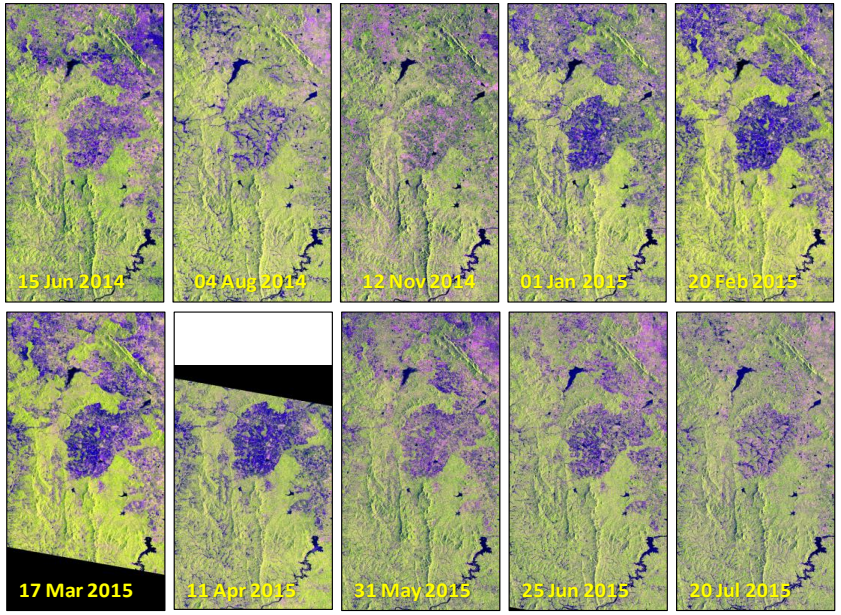






Effect of Leaf-on and Leaf-off on SAR Data

SAR data acquired over Leaf-off period is more suitable for AGB Estimation



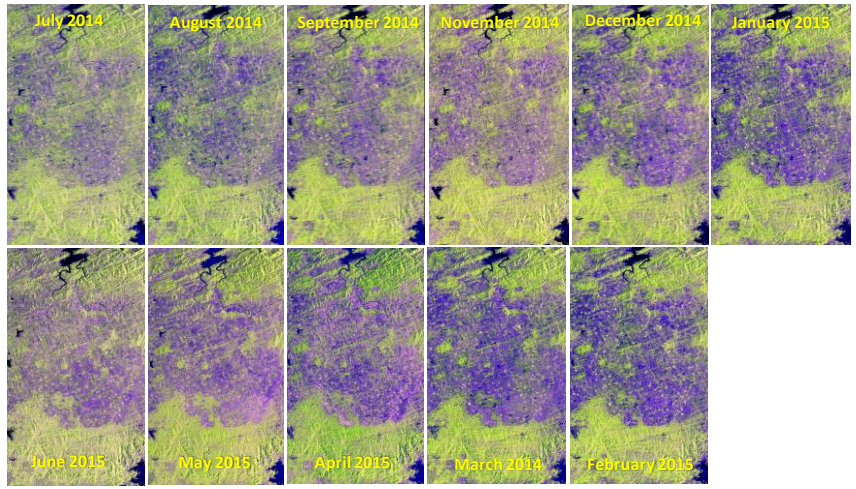
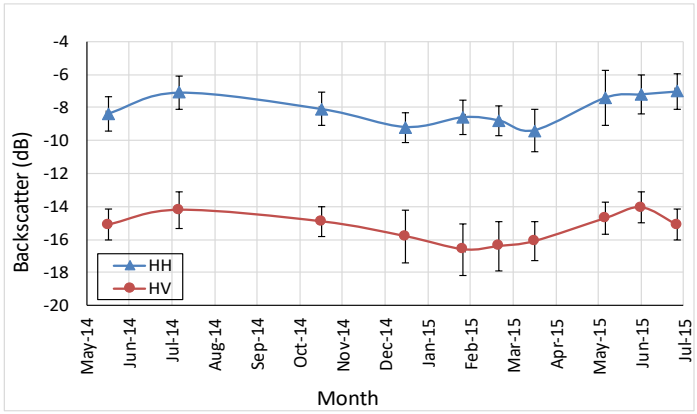
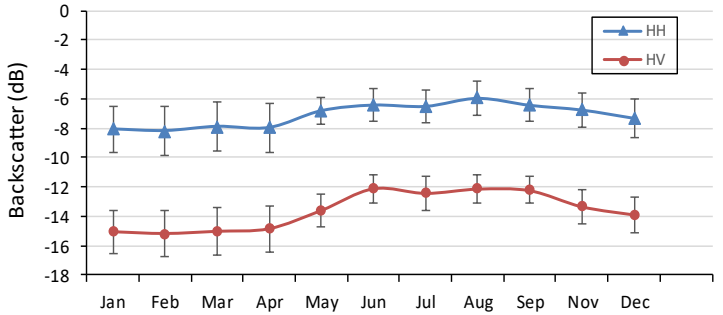


Fig.: RISAT-1 MRS time series images over deciduous forests in Shimoga, KAR (Top) and Narmada, GUJ - Bottom



Temporal C-band SAR backscatter over Decidous Forests



FCC Images (time series)

R: HH backscatter

G: HV backscatter

B: HH/HV ratio backscatter

RISAT-1 MRS Data

Inc Angle (θ): 36.7°

Output Pixel Spacing: 18m

- **L-band backscatter sensitivity to aboveground forest biomass have been studied over the past 30 years**
- **L-band radar backscatter is dominated by three scattering terms: volume, volume-surface, and surface**
- **L-band HV backscatter has strong sensitivity to AGB up to ~100 Mg/ha with low to moderate impacts of soil moisture compared to co-polarization channels.**
- **The algorithm is based on a physically based EM model with reduced parameters to include biomass, soil moisture, and roughness in a semi-empirical formulation.**

$$s^0 = s^0_{vol} + G_{surf} s^0_{vol\_surf} + G_{vol} s^0_{surf}$$

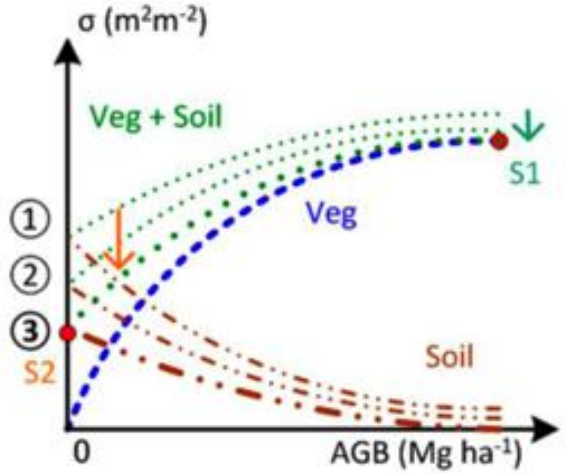
s^0_{vol} : vegetation

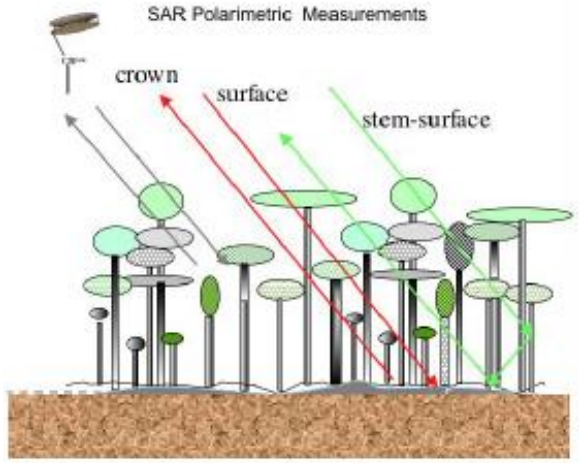
$s^0_{vol\_surf}$: vegetation

s^0_{surf} : soil

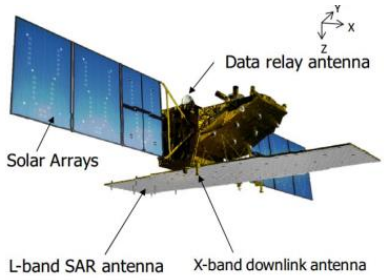
$G_{surf} = |R|^2 \exp(-k^2 s^2 \cos^2 q)$: soil

$G_{vol} = \exp(-2a)$: vegetation





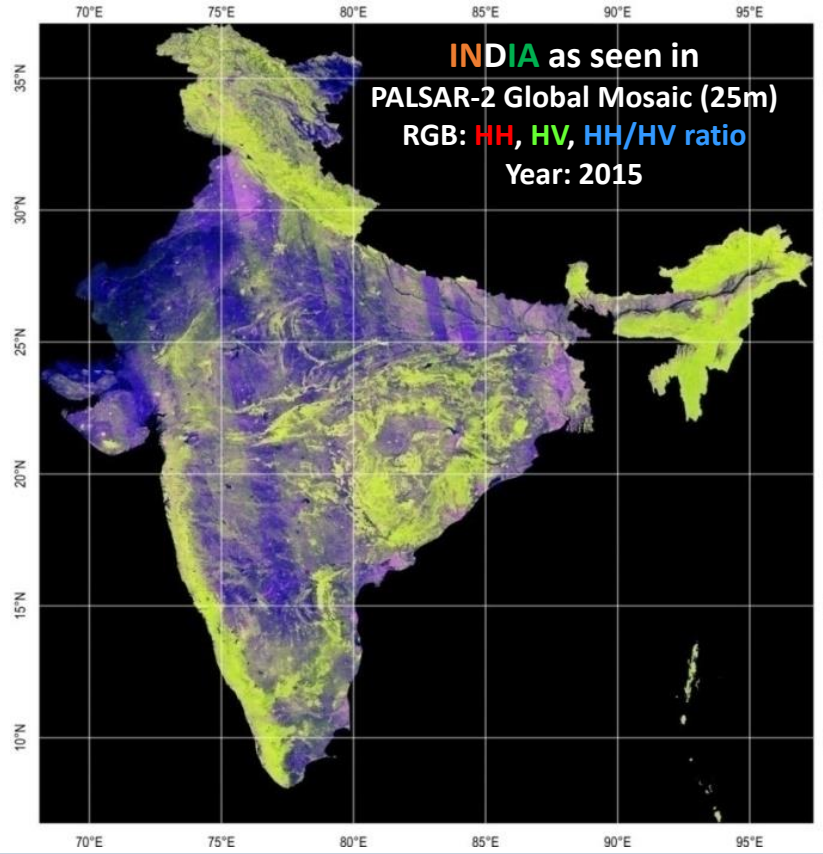
Available SAR data for Forest cover/ biomass estimation

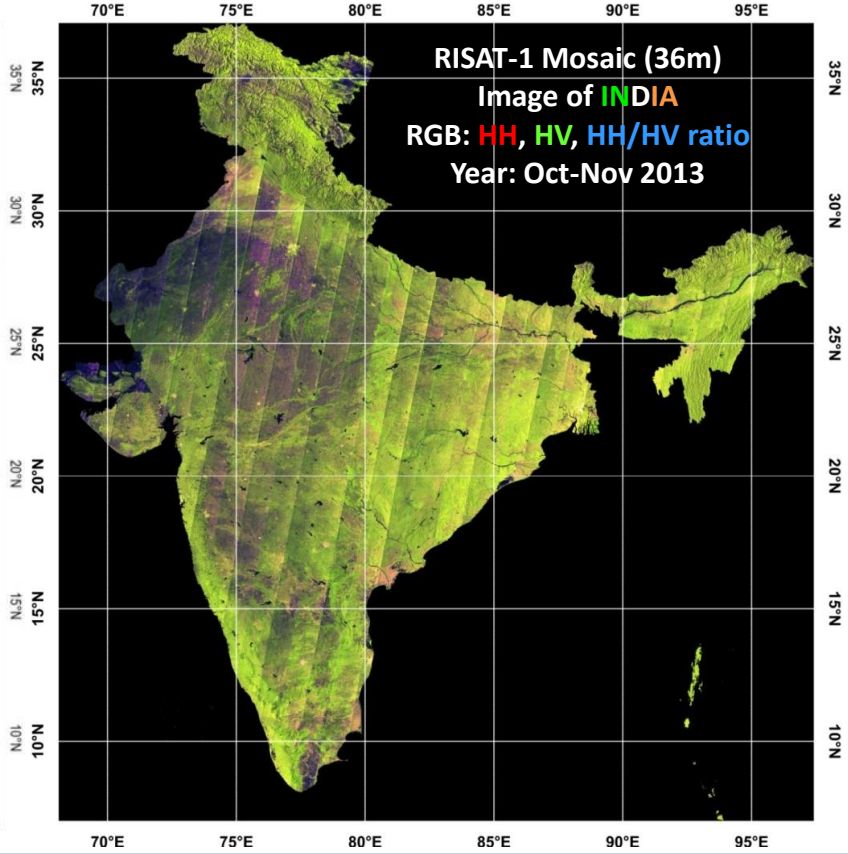


ALOS-2 PALSAR-2 (JAXA)

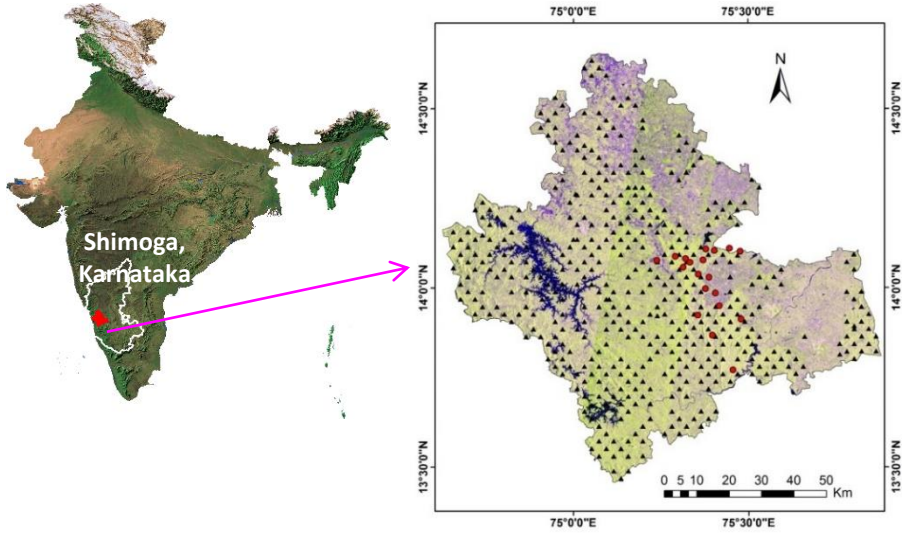
Today, ALOS PALSAR-1/2 provides most suitable data for forest cover and biomass retrieval. Global mosaic product of SAR data in HH+HV polarization at 25m grid spacing is available for the years 2007-10 from ALOS-PALSAR-1 and for the years 2015-17 from ALOS-PALSAR-2 in public domain.

C-band SAR data from Indian RiSAT-1, Canadian Radarsat-2 and ESA's Sentinel-1A are also useful for forest applications



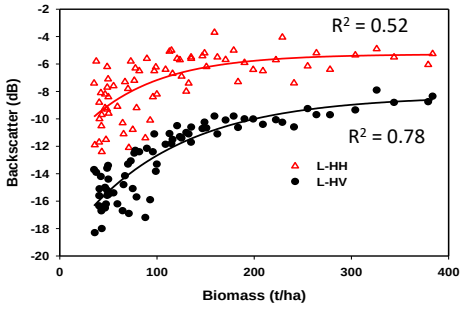


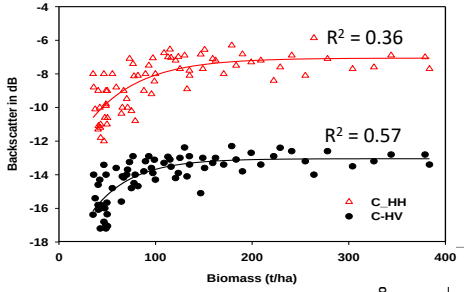
Estimation of Above-ground Biomass – Comparison of C and L-band

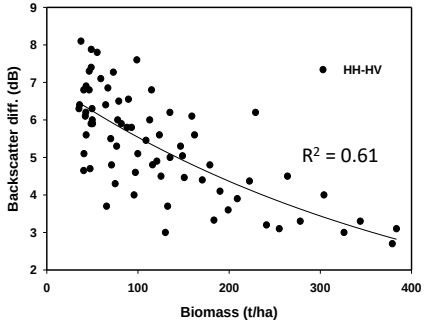


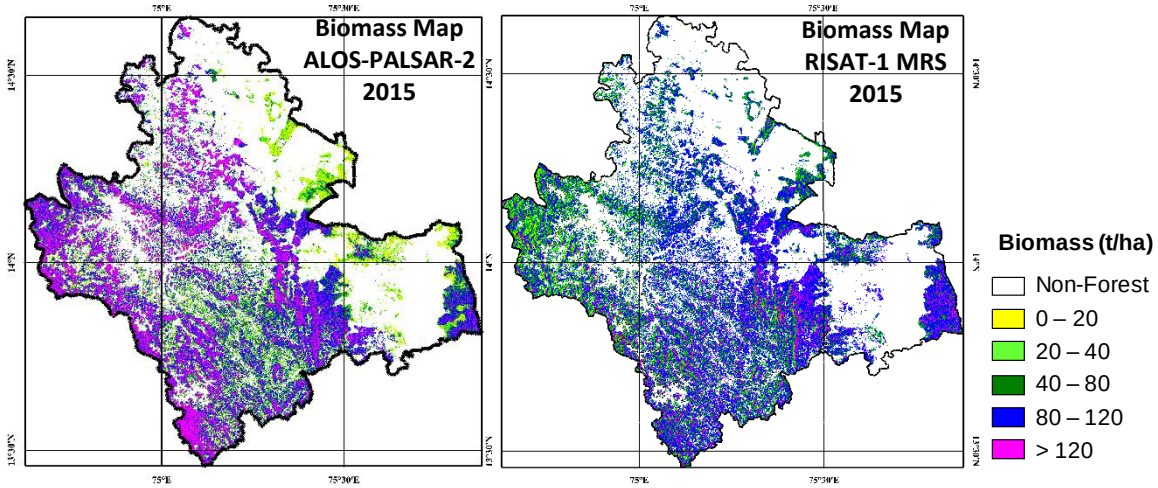
▲ Field data (from FSI) used for model development

● Field data used for model validation



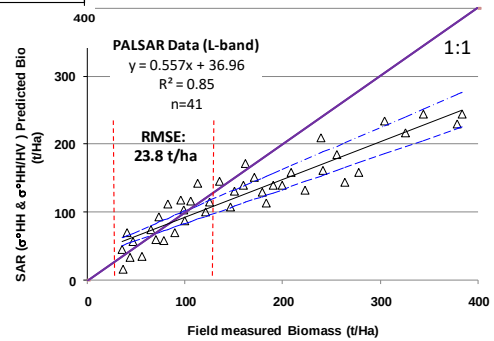


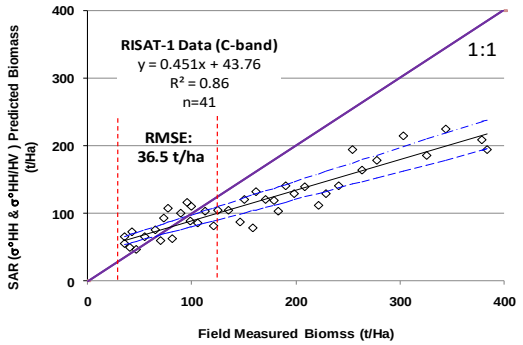




(Deciduous forest dominated by teak (*Tectona grandis*) vegetation)

Model Validation



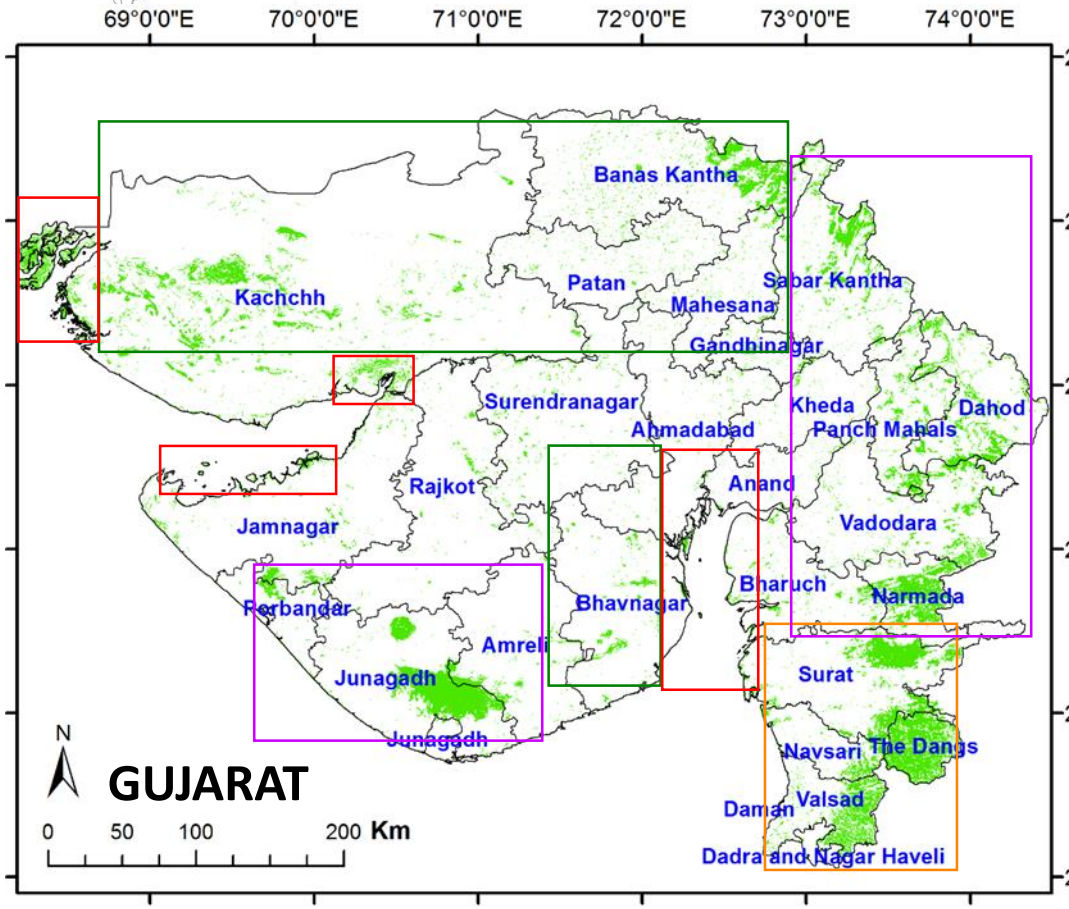


$$Y_{BIOMASS\ (t/Ha)} = A + (B * \sigma^0_{HV}) + (C * \sigma^0_{HH/HV})$$

σ^0 is backscattering coefficient in dB and A, B and C are the model coefficients

Estimation of forest above-ground biomass of Gujarat & Karnataka

According to the estimate by the Forest Survey of India (FSI) for the year 2015, forest area of Gujarat is 21664.99 km^2 of which 14837.6 km^2 area is reserved forest, 2888.85 km^2 is protected forest and 4388.98 km^2 area is unclassified forest. This Constitutes **11.05%** of the geographical area of the state



1. Tropical Moist Deciduous Forests (Type 3B): These forests are found in the southernmost part of the state in the districts of Surat, Valsad and Dangs. These forests form the main source of commercial timber in the state..

2. Littoral and Swamp Forests (Type 4B): These mangrove forests are distributed over 15 districts of the State and are represented by 15 mangrove species.

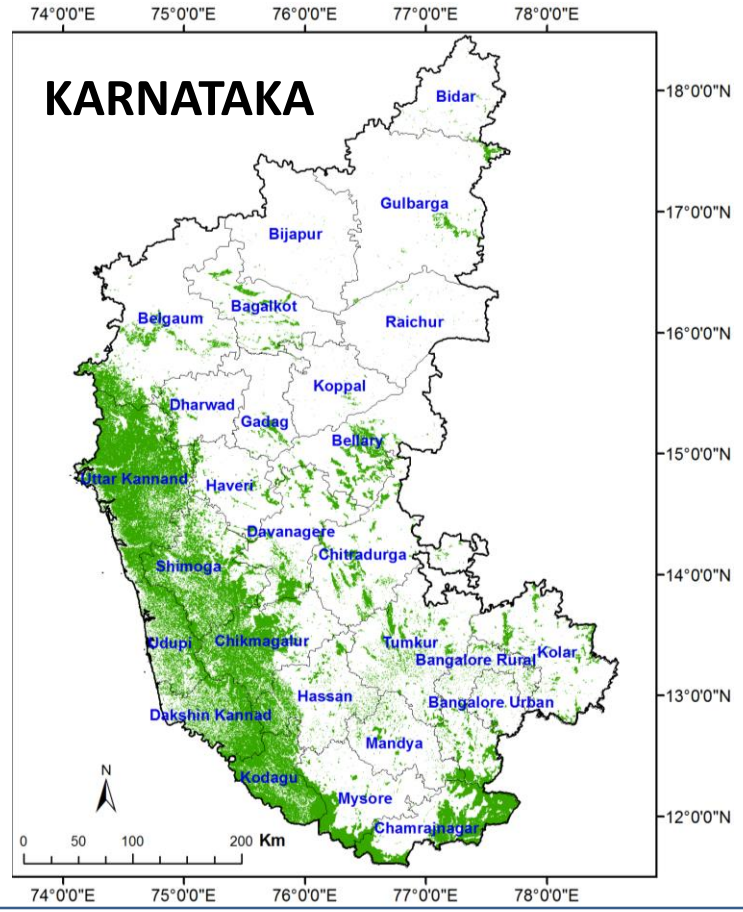
3. Tropical Dry Deciduous Forests (Type 5A): These forests are found in the central part of the state in the districts of Bharuch, Vadodara, Panchmahals, Sabarkantha and parts of Saurashtra in the districts of Amreli, Junagadh and Jamnagar.

4. Northern Tropical Thorn Forests (Type 6B): These forests are found are found in districts of Banaskantha, Rajkot and parts of Bhavnagar, Junagadh and Kachchh.

Different vegetation types show different sensitivities to SAR backscatter and hence are dealt with separately for generating coefficients for AGB estimation models

Estimation of forest above-ground biomass of Gujarat & Karnataka

As per the estimates of the Forest Survey of India (FSI, 2015), the forest cover in Karnataka state is **41,973** km^2, which is **21.88**% of the state's geographical area. In terms of forest canopy density classes, the state has 4502 km^2 under very dense forest, 20,444 km^2 under moderately dense forest and 12,604 km^2 under open forest



Evergreen-semi evergreen forest (Type 2B): These are dense forests found in the western slopes of the Western Ghats

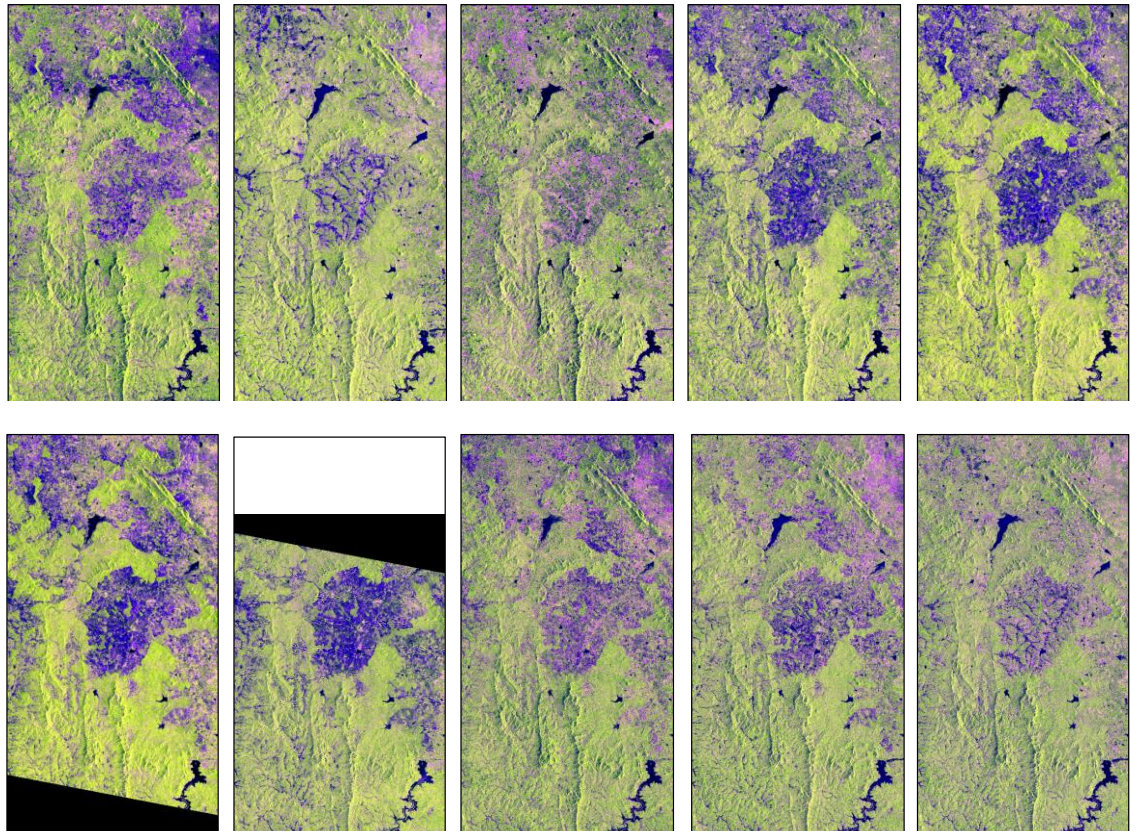
Moist deciduous forest (Type 3B): These forests mostly occupy the eastern slopes of the Western Ghats in Karnataka. They are spread across the wet north-eastern parts of the peninsula. These forests are dominated by sal *(Shorea robusta)* and teak *(Tectona grandis)* trees along with rosewood *(Dalbergia sisoo)* trees.

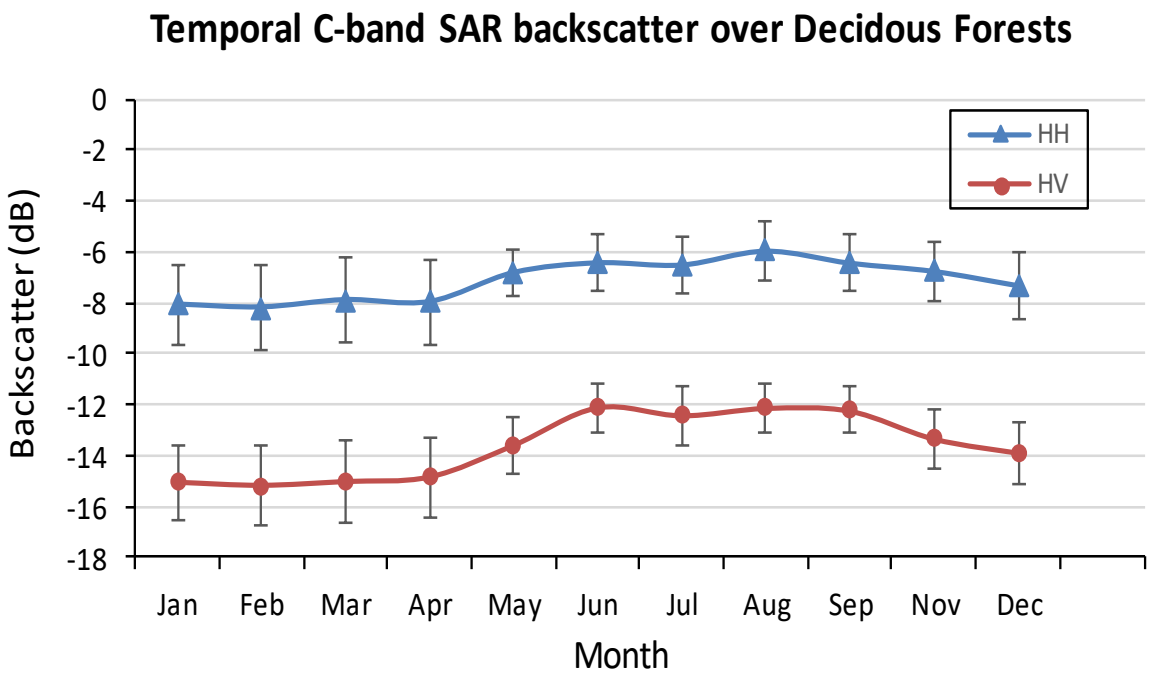
Dry deciduous forests (Type 5B): The dry deciduous forests dominate the lee side of the Western Ghats. The most significant tree found in the dry deciduous forests is sal *(Shorea robusta).*

Scrub and thorny forest (Type 6A): These forests are seen in the arid parts of the Deccan plateau located in the north eastern part of the state. These forests receive less than 750mm (30 inches) annual rainfall. There is no rainfall in this region during the months of Nov-April. These forest type is characterised by thorny trees, spiny and xerophytic shrubs and dry grassland.

Un-wooded forest: These are grasslands and wastelands in Karnataka. In the heavy rainfall regions of the state the grasslands occur at high altitudes. Often the high altitude grasslands of Karnataka are interspersed with pockets of *shola* forests.

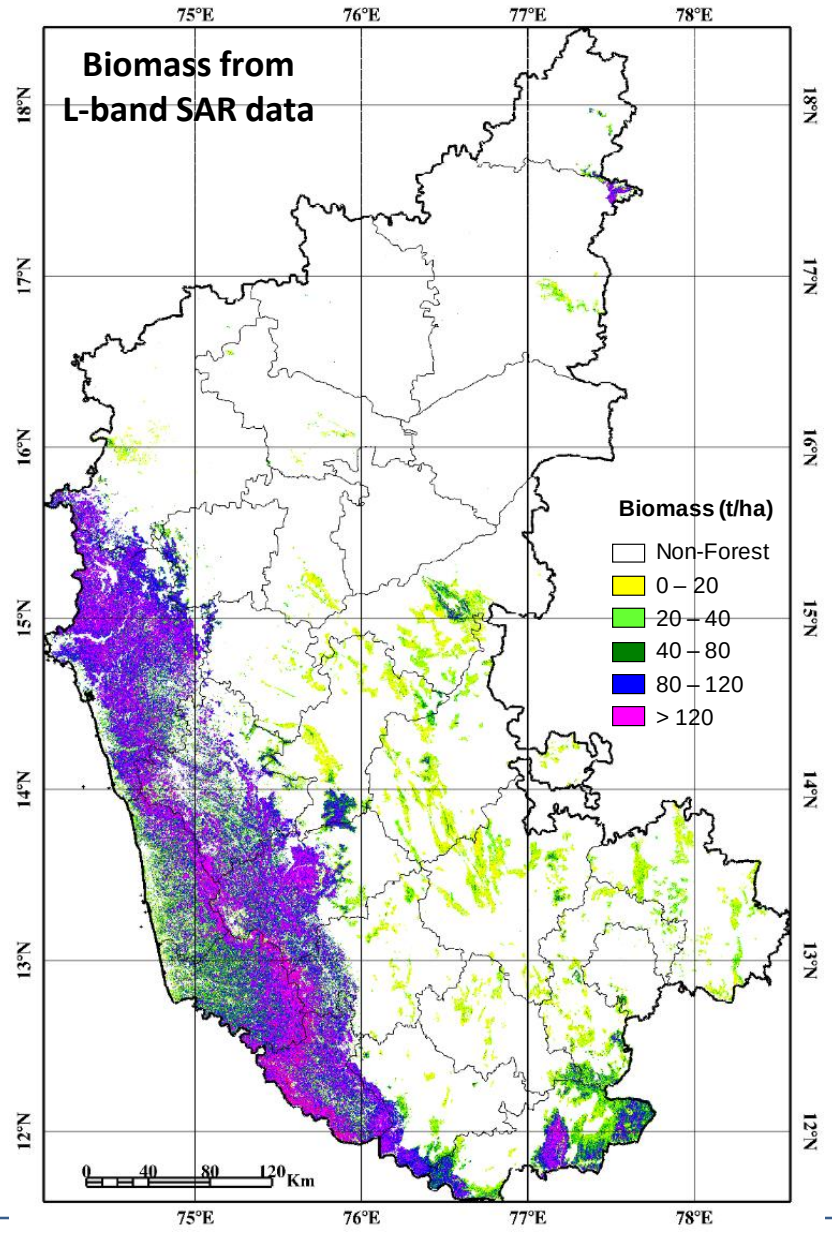
FOREST PHENOLOGY MONITORING

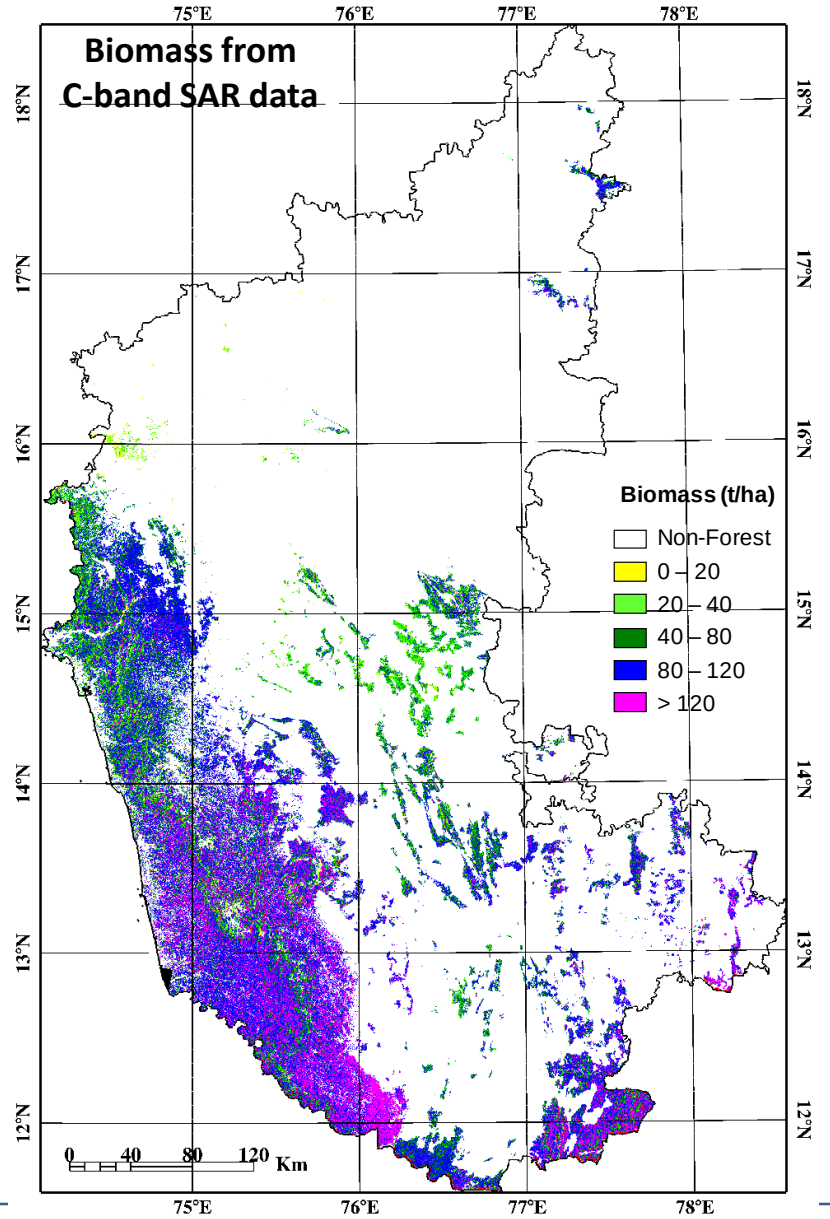




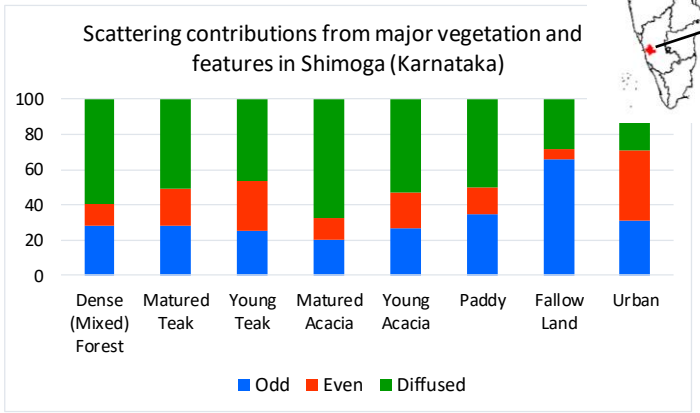
Forest phenology is monitored to estimate the annual growth rate, the leaf-off and leaf –on onsets and peaks all of which help in assessing forest parameters. Phenology monitoring also helps is determining the SAR acquisitions for above ground biomass estimation for the different physiographic zones of India.

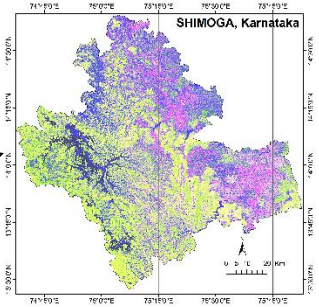
Estimation of forest above-ground biomass of Gujarat & Karnataka



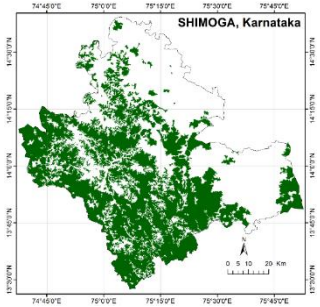


Extraction of Forest Cover from Polarimetric SAR Data

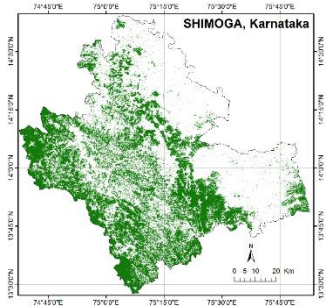




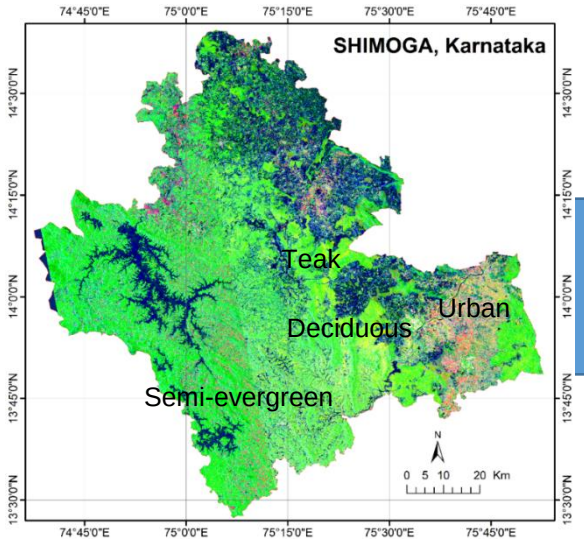
ALOS-PALSAR-2 dual-pol RGB Image, 2017



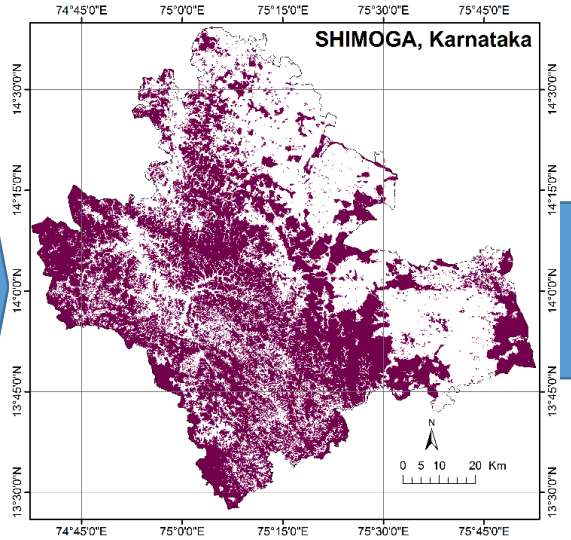
Forest Cover generated from ALOS-PALSAR-2 dual-pol data, 2017 (Shimada, 2010)



Forest Cover generated from Landsat data (Hensen – 2000)



Polarimetric decomposition RGB image of ALOS PALSAR-2 Polarimetric data, 2017 (forests in green colour)



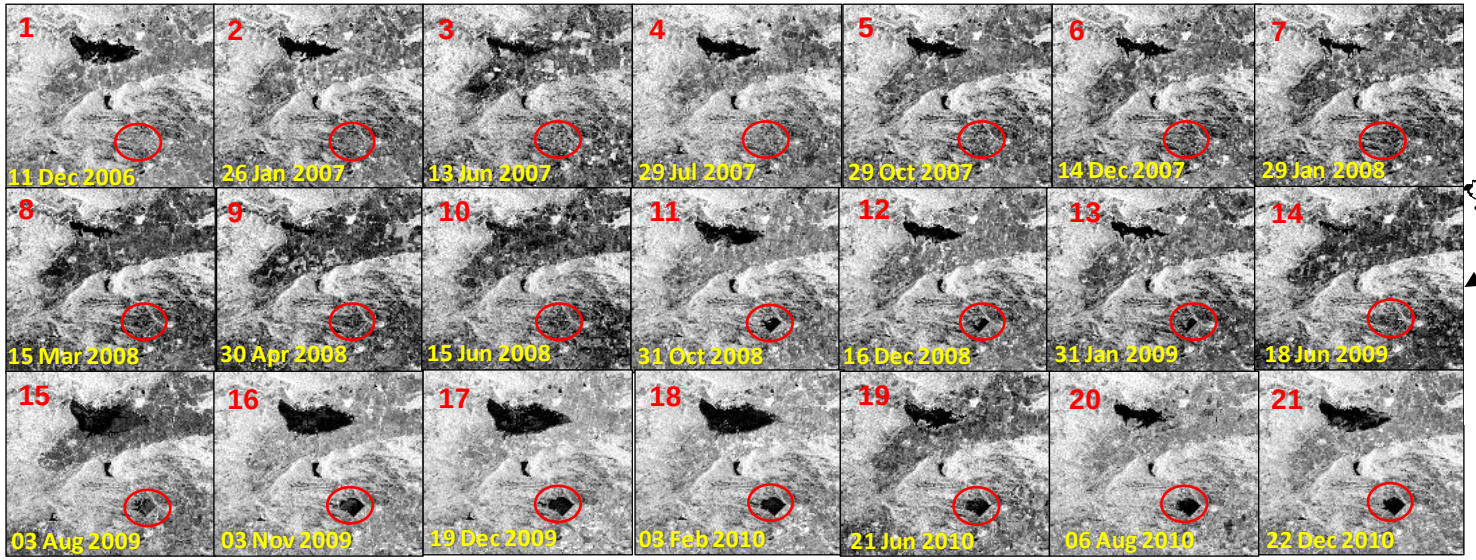
Forest cover generated from ALOS PALSAR-2 Polarimetric data, 2017

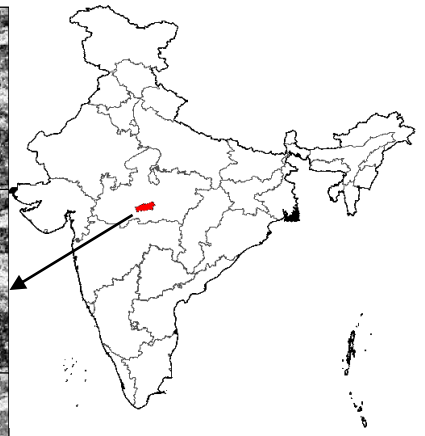
Comparison of forest cover extracted from various datasets over Shimoga dist., Karnataka

Forest Cover	Area (in km²)	Diff. from ISFR	% GA
ALOS PALSAR-2 Polarimetric data	4,322	(+) 2	50.98
ALOS-PALSAR dual-pol data	4,259	(-) 61	50.23
Landsat Data (Hensen, 2000)	3,851	(-) 169	45.42
Forest Cover reported by ISFR, 2017	4,320	0	50.96

GA: Geographical Area = 8,478 sq km
ISFR: India State of Forest Report

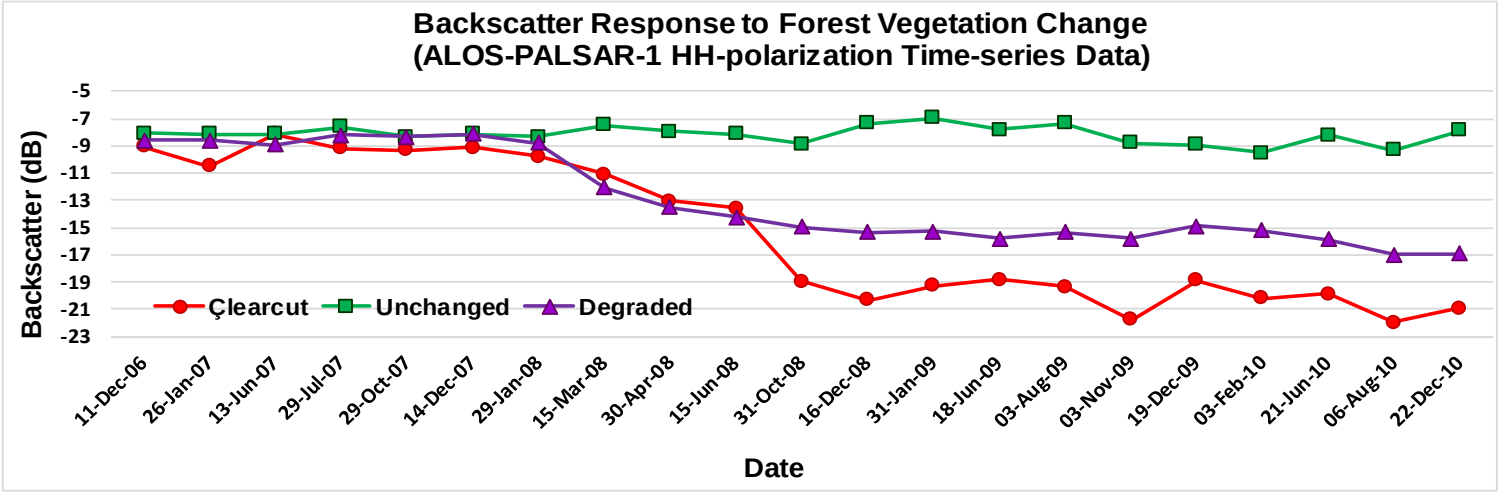
Monitoring Forest Disturbance from Time-Series SAR Data





Part of Hoshangabad Dist., M.P.

ALOS PALSAR time-series HH-pol image over a part of Hoshangabad Dist. MP, showing a patch of forest has been removed for construction of a reservoir and also regions where forest vegetation has been degraded



Characteristic SAR backscatter change due to forest degradation and forest clear-cut. This helps generating threshold for forest vegetation change detection

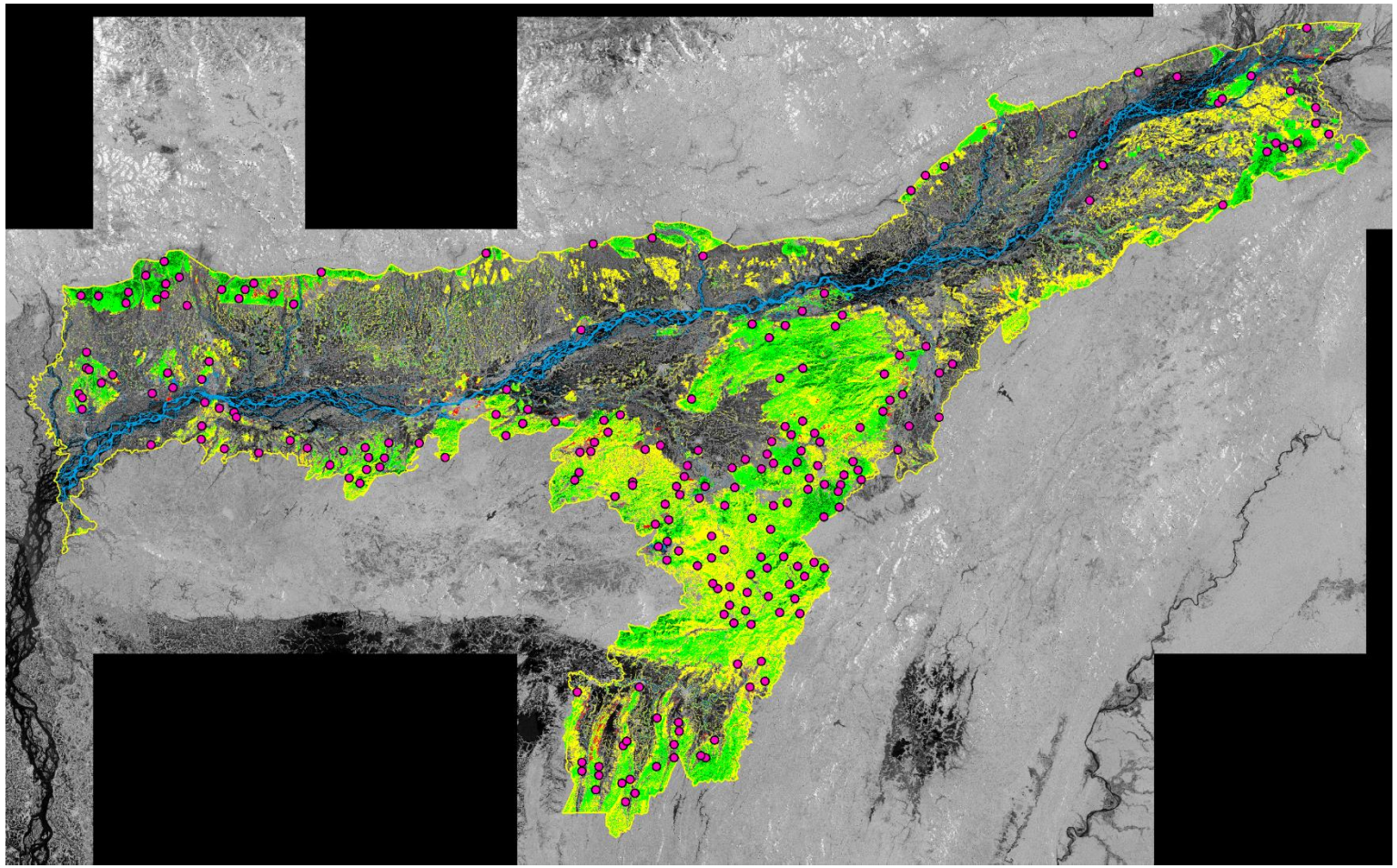
ASSAM

L-band SAR
Grey Image
HV Pol

Forest Cover (FnF)
FSI-2017

Forest Density
FSI-2017
- Water
- Scrub
- Open Forest
- Mod. Dense Forest
- Very Dense Forest

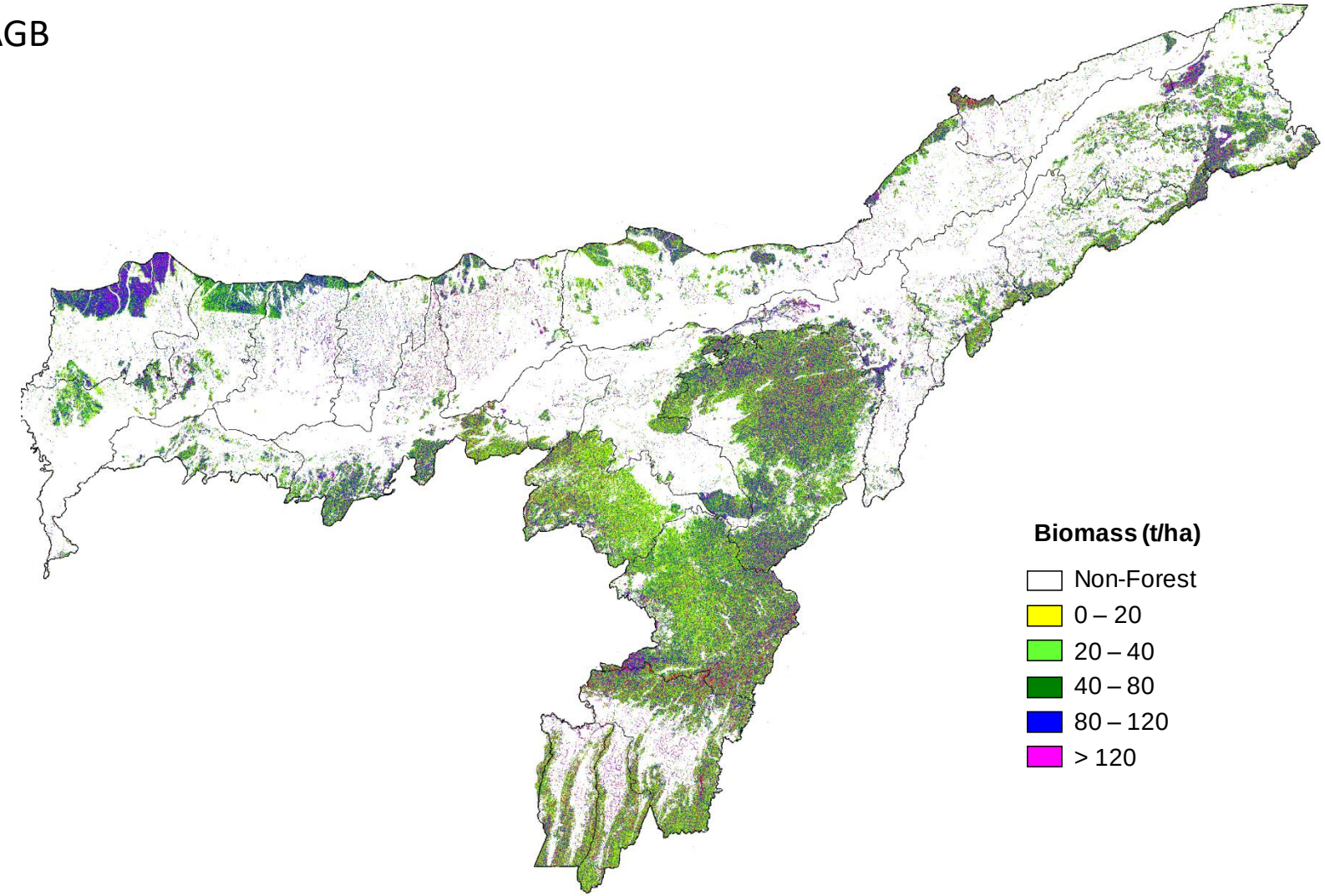
Inventory Plots
0.1 Ha (FSI-2016)
219 plots



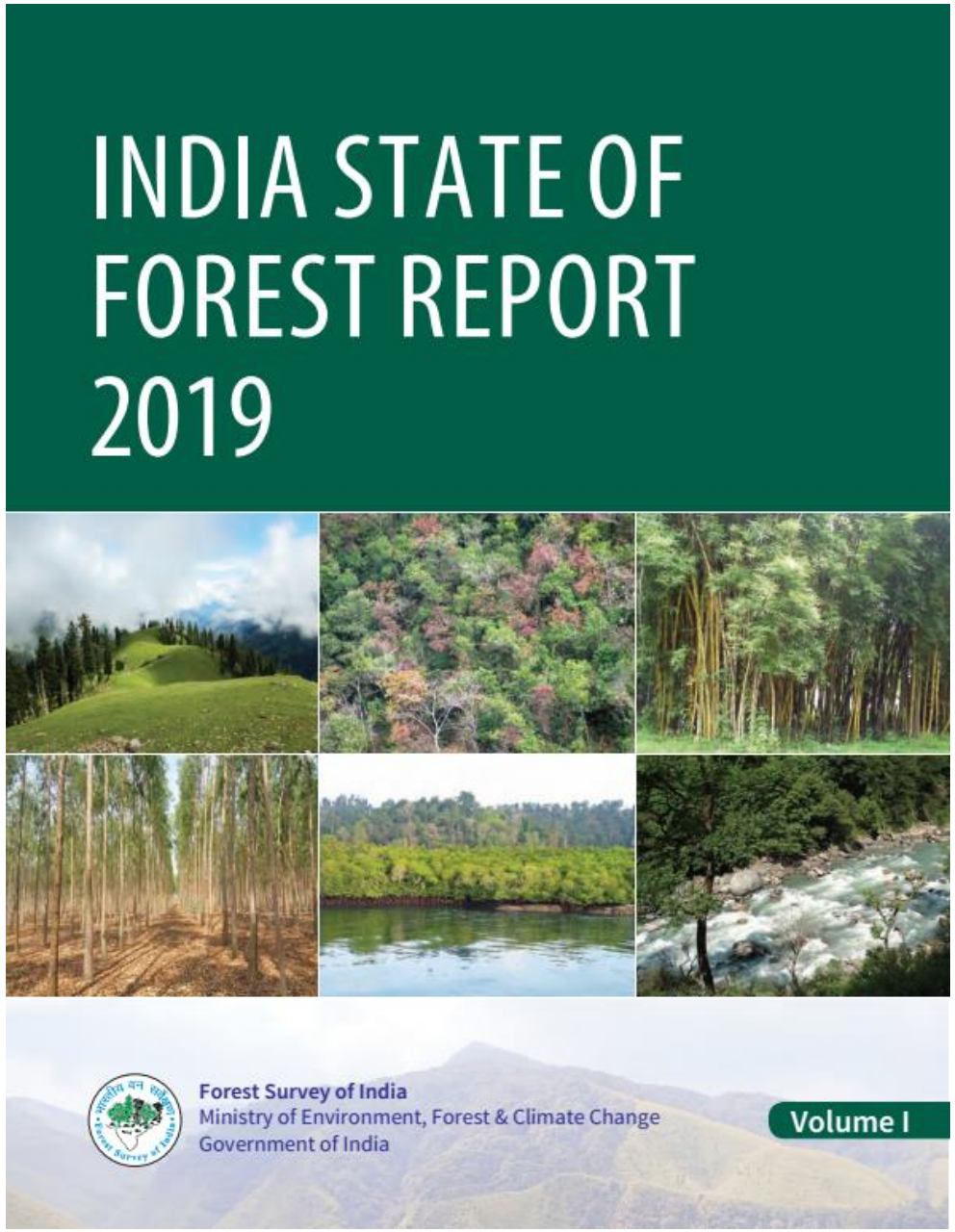
ASSAM

Forest AGB

2017



Interesting Outcome of SAC-FSI MOU



9

Chapter

Carbon Stock in India's Forests

9.1 INTRODUCTION

Climate change poses a serious threat to the ecosystems and the quality of human life all over the world. It is for this reason that the parties to the United Nations Framework Convention on Climate Change (UNFCCC) have undertaken wide ranging policy measures, actions and programmes to address the issues of climate change adaptation and mitigation. India as a Party to the Convention is required to periodically communicate greenhouse gas inventory for the country from all the sectors including Land Use, Land-Use Change and Forestry (LULUCF) as National Communication (NATCOM). Accordingly, India has furnished its initial National Communication in 2004, second National Communication in 2012, first Biennial Update Report (BUR-I) in 2016 and second Biennial Update Report (BUR-II) in 2018 to the UNFCCC. Apart from the international reporting periodic forest carbon assessment helps in monitoring flow of carbon in different pools in the forests of the country and is an important indicator of ecosystem services from forests.

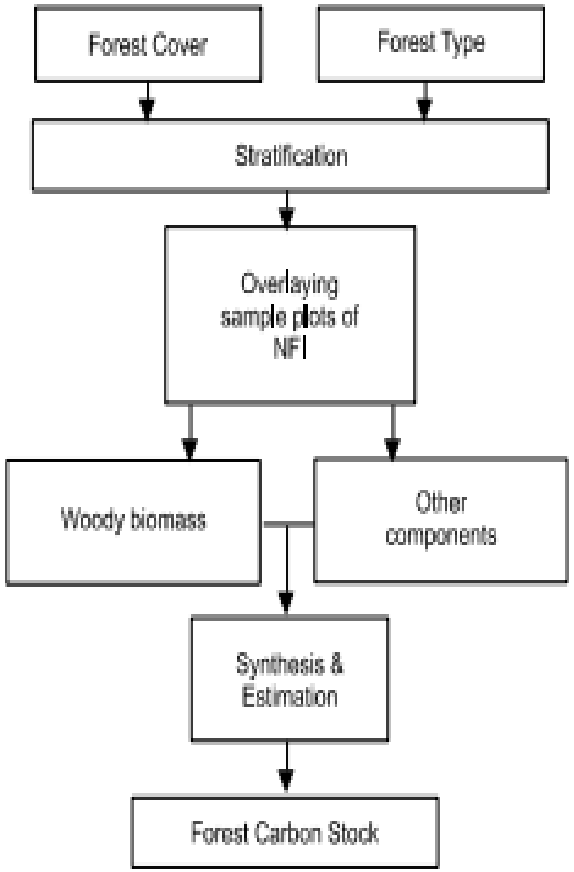
SAC Team :

1. **C Patnaik**
2. **Dr Anup Das**

HOD , Deepak Putrevu

GD, Dr Arundhati Misra

FIGURE 9.3 Schematic diagram showing methodology of forest carbon assessment



9.3.3 *Estimation of Biomass and Carbon in different pools*

FSI has developed volume equations of forest and TOF species. Through a special study done for different forest types, biomass equations have also been developed for important species. Using forest type specific volume equations and biomass equation, biomass in different pools have been determined. Specific gravity and carbon content in biomass for different forest types/species as available in different literature including IPCC Guidelines (2006)[4] have been used in estimation of forest carbon. Methods for biomass/carbon in different pools are described in short in the following sub sections.

9.3.3.1 *Above Ground Biomass (AGB) of trees having dbh ≥ 10 cm and bamboo*

Forest inventory data collected from around 9628 sample plots in the last two years as per the new sampling design has been used for calculation of AGB of trees above dbh 10 cm. At each sample plot all trees of diameter 10 cm and above were measured. The woody volume of trees for each sample plot was calculated using volume equations developed by FSI for various species. The volume equation provides above ground woody volume i.e. above ground volume, which includes volume of main stem measured upto 10 cm diameter and volume of all branches having diameter 5 cm or more. Data of specific gravity and percentage carbon content of most of the tree species have been obtained from different published literature. For few species, percentage carbon content was ascertained by experimentation and for remaining an average of all other species was used. Standard formulae were used to calculate biomass and carbon content.

The estimates of bamboo biomass and its carbon stock has been calculated from NFI data. For estimating volume of the bark, the double bark thickness of trees measured during forest inventory and volume equation of trees have been used. Using species-wise, dbh and bark thickness, bark volume was calculated which is duly adjusted for 'bark void factor'. With the help of the specific gravity of bark,

[4] IPCC Guidelines for National Green House Gas Inventories (2006), Intergovernmental Panel on Climate Change

BOX 3

Above Ground Forest Biomass Estimation of Assam and Odisha using Synthetic Aperture Radar (SAR) Data

Global estimation of carbon and biomass is linked to environment and climate change. As one of the largest carbon sinks on land, forest ecosystems account for 80% of the terrestrial carbon stock and plays an important role in mitigating climate change. Forest biomass determination is useful in modelling ecosystem dynamics and estimate carbon stock sequestered in the forests. Traditional methods for biomass estimation do not provide its spatial distribution. Therefore, satellite data analysis is required for better estimation of forest carbon stocks and AGB at regional to national level. An appropriate combination of multisource data, such as the field measurement and the monitoring through Remote Sensing can potentially improve spatially explicit estimation of biomass over large areas. Forest biomass occurs in different stories of vegetation and Optical remote sensing data cannot penetrate the tree canopy. These limitation can be overcome by using Synthetic Aperture Radar (SAR) data. SAR due to its higher sensitivity to vegetation growth variables has emerged as the most suitable tool for retrieval of vegetation parameters specific to forests. Forest vegetation shows distinct scattering mechanism in SAR data, such as direct back scattering from crown (branch and leaves), crown-ground scattering, trunk-ground scattering and the direct scattering from the forest floor. The upcoming NASA-ISRO Synthetic Aperture Radar (NISAR) mission is a joint project between NASA and ISRO to co-develop and launch a dual-frequency Synthetic Aperture Radar on an Earth observation satellite. In this regard, an attempt has been made by FSI under joint collaboration with Space Application Centre (SAC), ISRO, Ahmedabad for estimation of AGB for Assam State. Global 25 m resolution Phased Array Type L-band Synthetic Aperture Radar (PALSAR) mosaic with forest inventory data at sample plots available with FSI has been used for AGB estimation. Forest inventory data has been used for training and validation of AGB map. A Multivariate Linear Regression Model (MLR) based on backscatter values and ratios of PALSAR global mosaic polarizations have been used to estimate AGB of Assam State.

Figure 1 Methodology for estimation of AGB

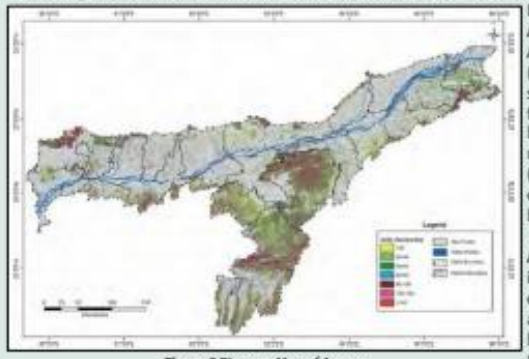


Figure 2 Biomass Map of Assam

An overview of methodology of this study is shown in Figure 1. Forest Inventory data collected from more than 200 sample plots across the forested area of the State of Assam have been used in conjunction with the dual polarised L-band data of ALOS PALSAR-2. The HV polarisation shows a better correlation with the forest biomass and this has been used along with the HH/HV ratio for the study. Approximately 70% of the inventory data was used to build the model and the remaining 30% was used to validate the model. The total biomass available in the forests of Assam has been divided into seven biomass classes. The biomass map depicting biomass classes in tonnes per hectare is shown in Figure 2. The study shows acceptable correlation between the SAR data and forest inventory data with a R^2 value 0.48. The study paves way for developing a biomass map of the country.

Similar study has also been carried for Odisha State by National Remote Sensing Centre (NRSC), ISRO, Hyderabad for spatial estimation of AGB using field inventory data collected from RS stratification based network of ~8,000, 0.1 ha plots using Microwave RS data synergistically with optical RS, bio-climatic parameters and topographic information. Spatial estimates of AGB are prepared using a K-NN approach with a random forest distance measure to relate field measure AGB. The forest cover layer generated by the Forest Survey of India (FSI) for ISFR 2017 was used to arrive at area weighted AGB for the analysis. The modelled relationship had a R^2 of 0.83 with an RMSE of 30%. The Forest Above Ground Biomass map is shown in Figure 3.

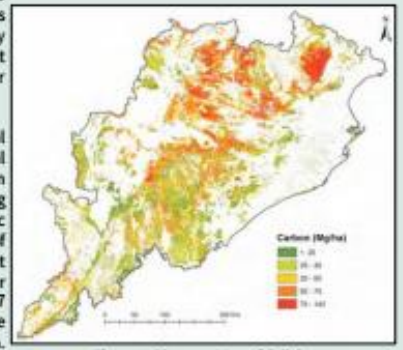


Figure 3 Biomass Map of Odisha

Above 70% of forest cover in India falls in Tropical Semi-Evergreen, Tropical Moist Deciduous and Tropical Dry Deciduous Forest Type. More than 30% areas have this Forest Types fall in the category of Open Forest, which need to be improved in order to achieve NDC targets. Among these forest types Tropical Dry Deciduous and Tropical Moist Dry Deciduous may be taken up. This can also be seen from the above table that the per hectare carbon stock for open forest is 59.67 tonnes per hectare whereas for moderately dense forest it is 85.07 tonnes per hectare, implying significant gain in carbon sequestration rate if Dry Deciduous Open Forest is converted to Dry Deciduous Moderately Dense Forest.

FIGURE 9.6 Density wise carbon stock per ha in different pools

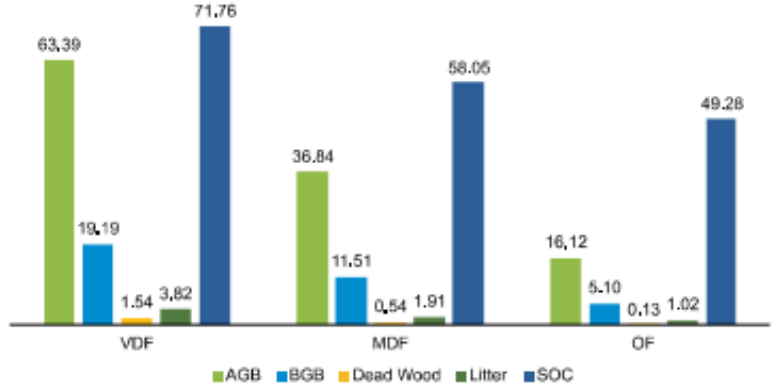
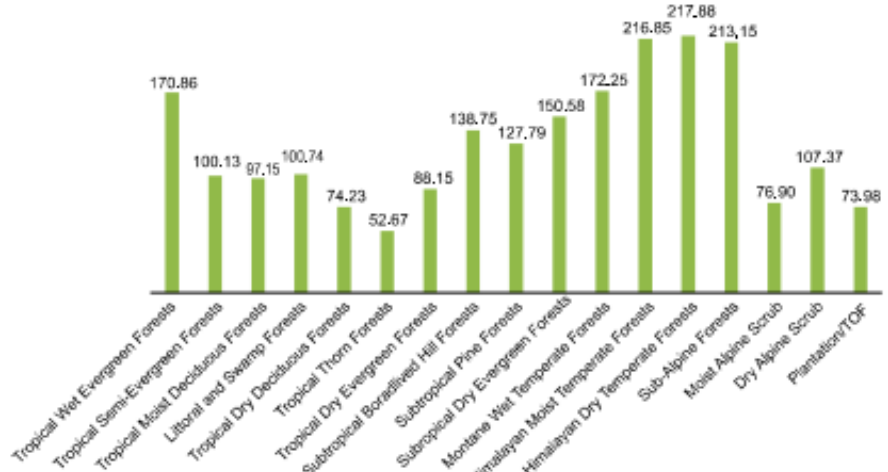


FIGURE 9.7 Forest Type wise carbon stock per ha



CAL/VAL Status Update

NISAR Cal-Val Plan: Validation Parameters

THEME	Parameter	ROI	Validation Plan
Oceanography	Coastline change	Andhra Coast	To be validated using optical and *in-situ* data
	Ship detection	North Indian Ocean	To be validated using optical/DG-Shipping Corporation data
	Oil-spill/dark spot detection	Indian coastal region	To be validated using optical/ *in-situ* (if possible) data
Mountain, Snow & Glacier	Glacier ice-velocity product	Bench-mark glaciers	
Geological Studies	Mineral map	Selected sites in Rajasthan, Jharkhand etc.	To be validated through structural data collection in the field Mineral potential of structures validation using geochemical analysis (XRD and Spectroscopy) For paleo-channel studies, GPR, DGPS and resistivity survey on paleo-channels and also detailed ground truth data collection
Coastal applications	Coastal land cover map	Coastal regions in Gujarat, Maharashtra and Andhra	Using ground truth data and ancillary data (published thematic map)
Ecosystems agriculture	Radar vegetation index Radar Roughness index Surface Soil moisture content Vegetation optical depth	Selected regions in Gujarat, Indo-Gangetic plains, sites in Tamil Nadu etc.	Validation through vegetation water content and ancillary data Through ground truth data (vegetation and soil moisture) Through in-situ measurements and other sensors Validation through biomass and backscattering model
Hydrology studies	Soil moisture, flood inundation	Kosi, Godavari , Mahanadi delta, Bikaner Rajasthan	Soil moisture measurements, Ground truth data for inundation, resistivity survey for perched aquifers.
Ecosystems forests	Forest Cover and Change Detection where change >50%	Selected forests in India	By ground truth and published information from respective ministries
Soil moisture	Surface Soil Moisture (SSM)	Selected core study sites over India (Gujarat, Karnataka, MP, UP and Raj. etc.)	To be validated using in-situ soil moisture stations, field campaign and satellite data products with models


Thank you