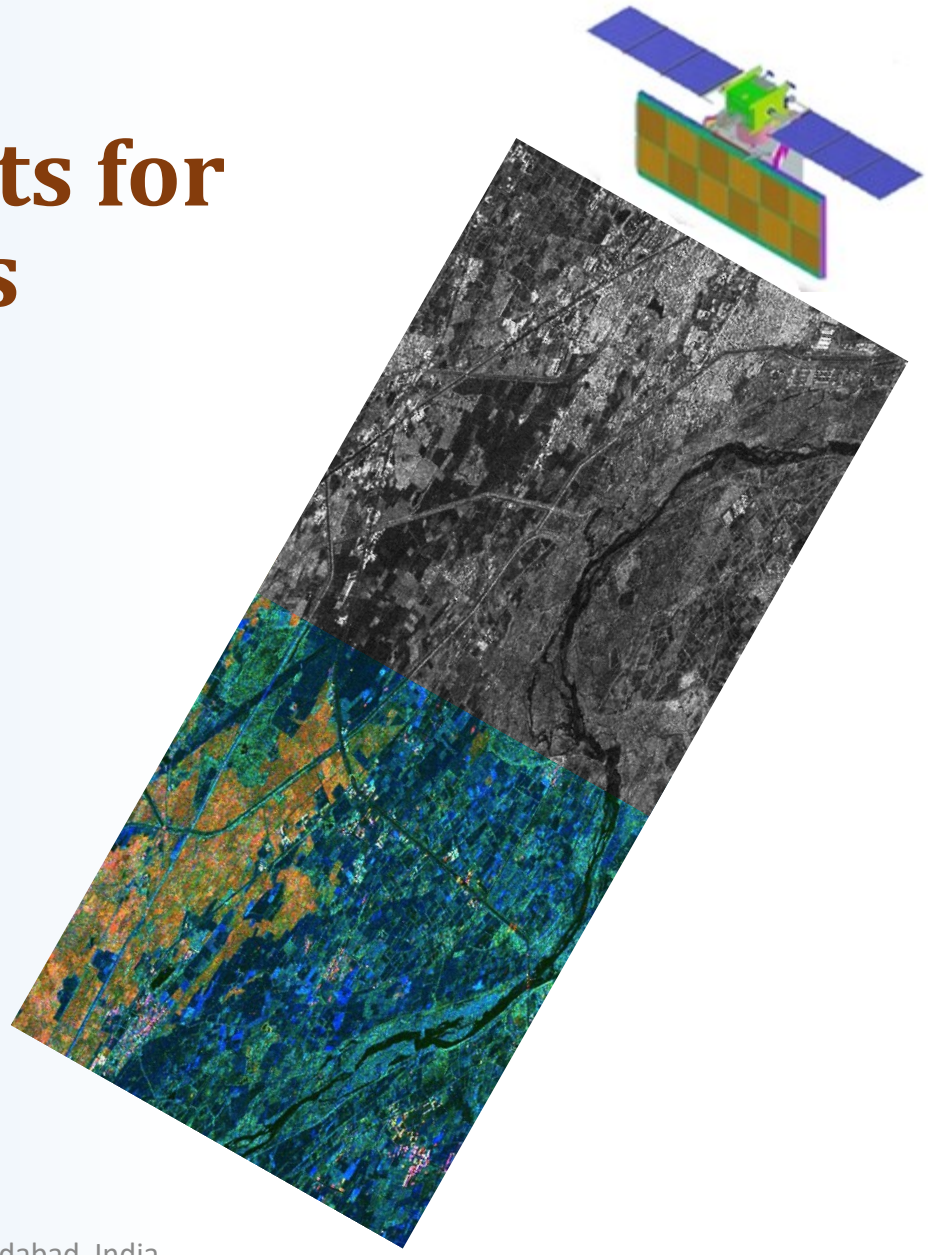
ISRO's SAR ship detection products for Maritime Domain Awareness



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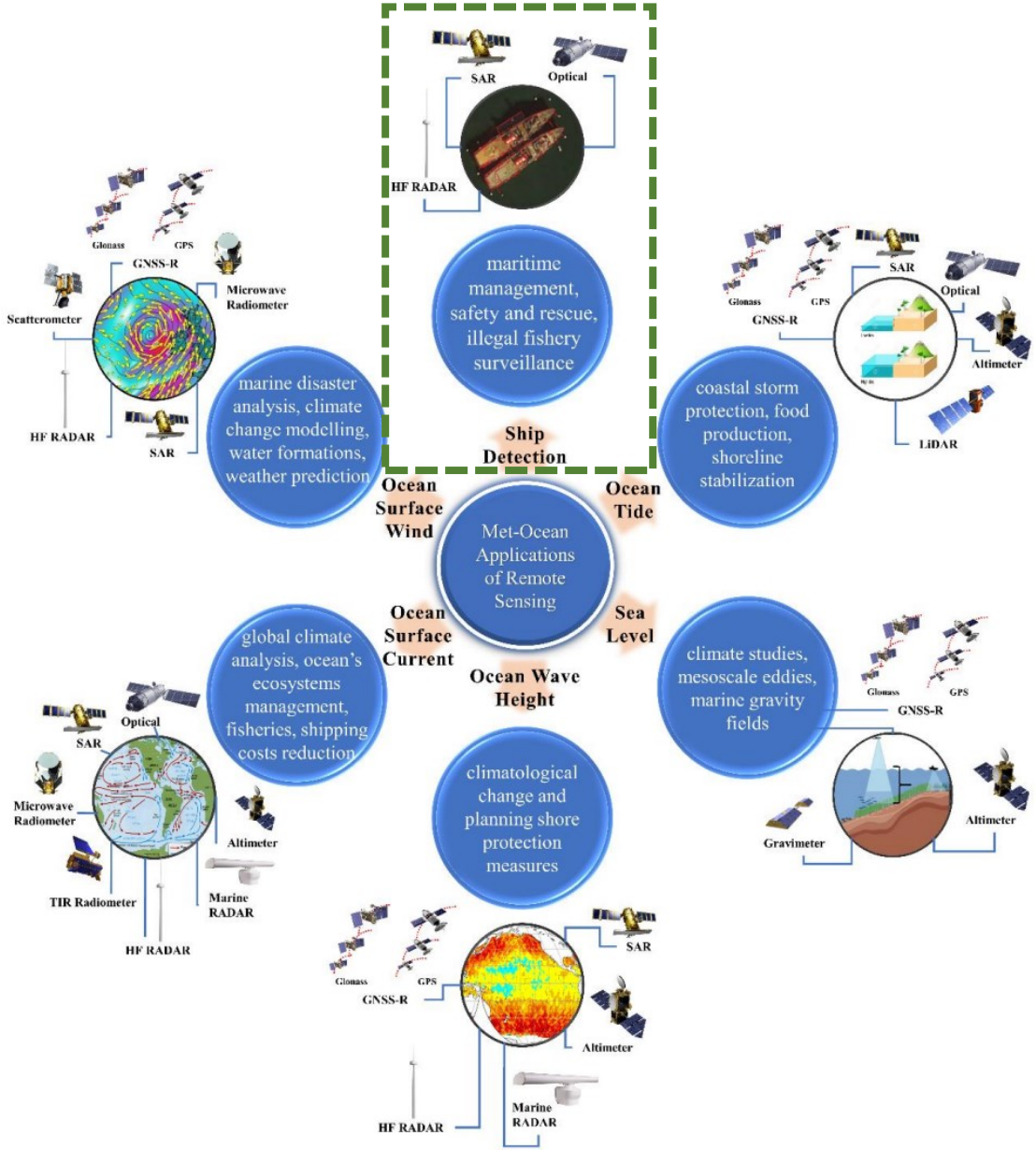
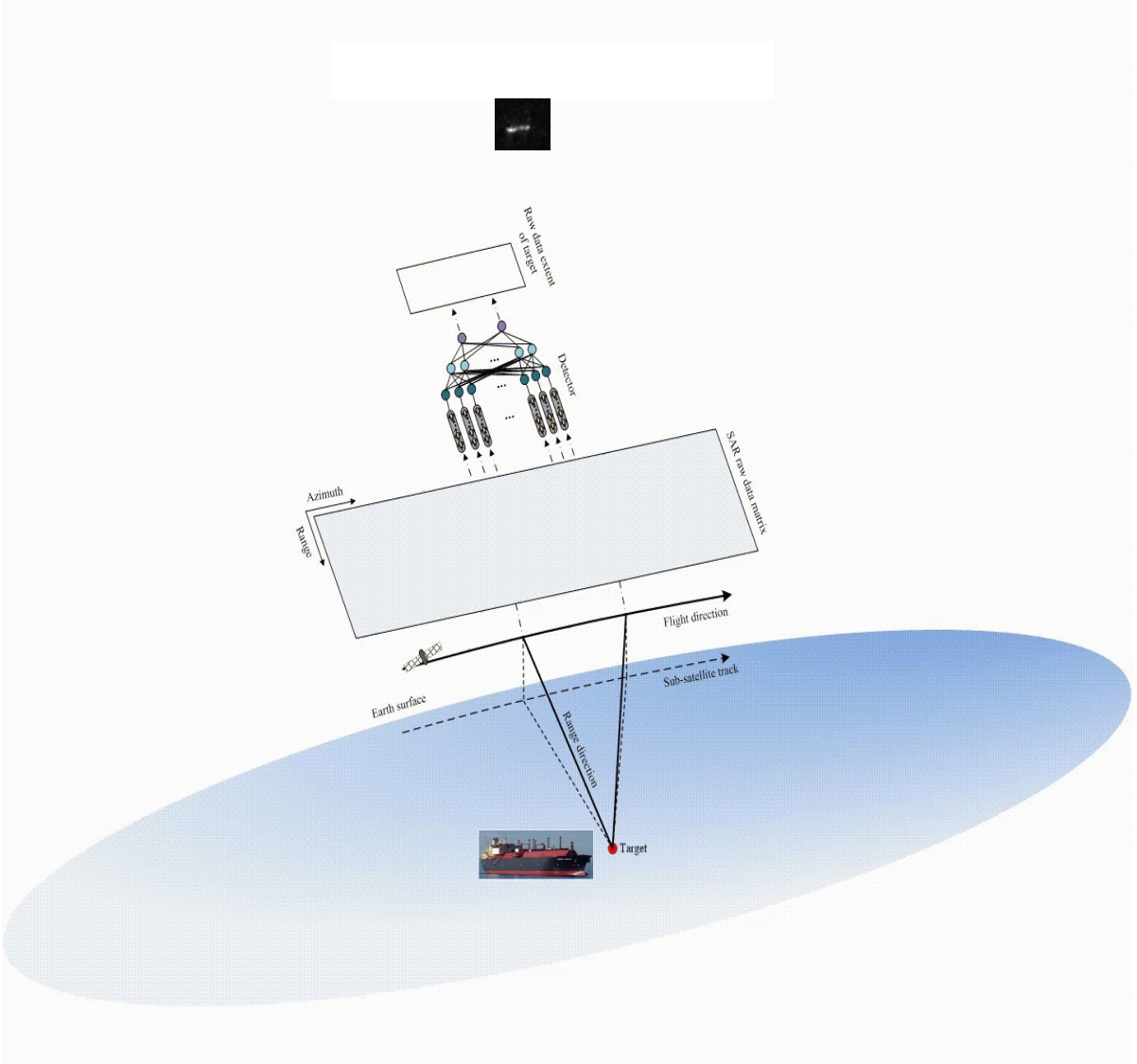
Space Applications Centre (SAC)
Indian Space Research Organization (ISRO)

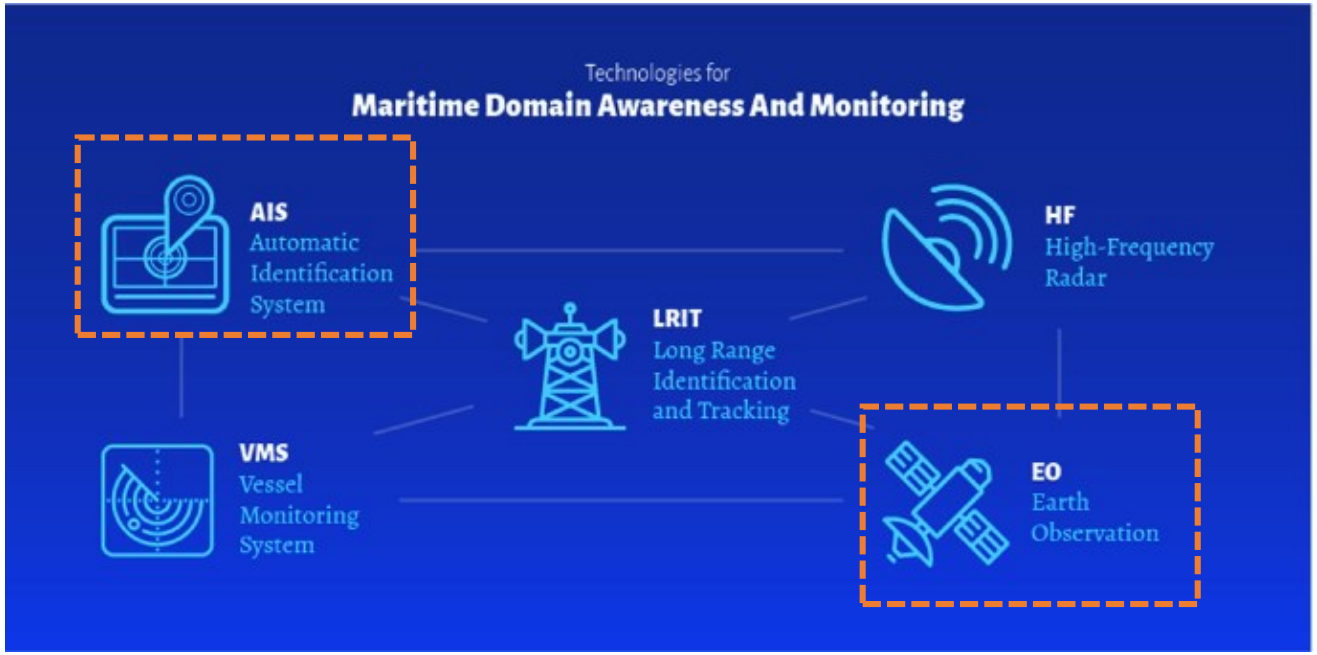
Co-Authors: **Jalpa Modi, Devang Mankad, V. M. Ramanujam**

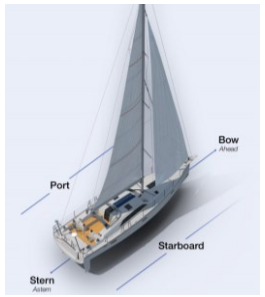
Met Ocean Applications of Remote Sensing





Maritime Domain Awareness(MDA) & Monitoring Systems





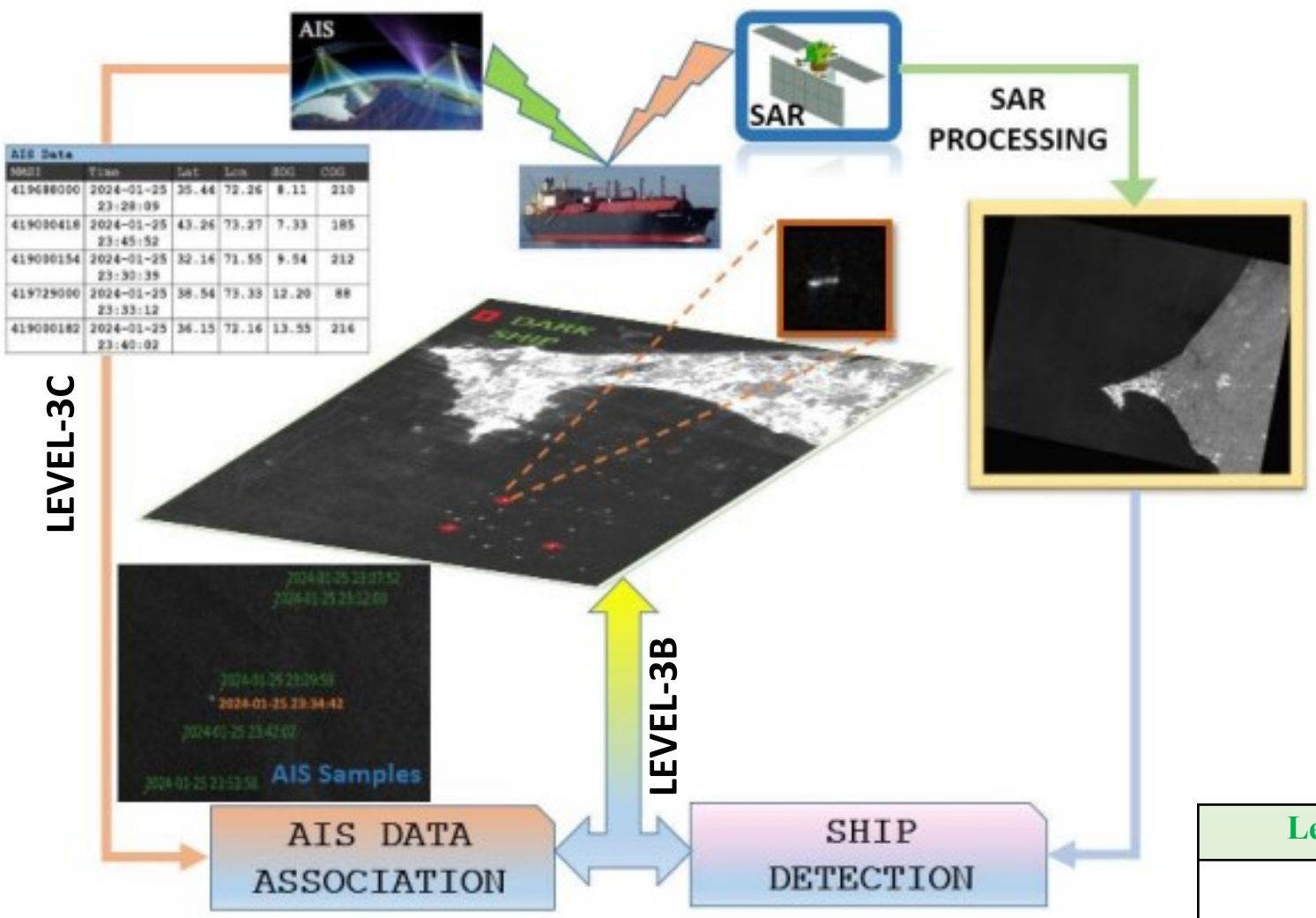
- VMS: **Vessel Monitoring System**
- LRIT: **Long Range Identification & Tracking of Ships**
- AIS: **Automatic Identification System**

VMS	LRIT	AIS
▪ a satellite-based fishing vessel monitoring system that provides ship information such as location, course and speed to fisheries authorities and at regular intervals. ▪ Generally transmit data at least every 60 minutes depending on law regulation specifications.	▪ an automated and satellite based vessel tracking system designed to collect and diffuse vessel position information received from vessels. ▪ use of LRIT systems is mandatory for vessels on international voyages including passenger ships carrying more than 12 passengers, high speed ships, offshore drilling and cargo ships over 300 tonnes. ▪ designed to ensure that ships provide daily position reports, at a basic frequency of once every 6 hours.	▪ a radio navigation equipment that emits VHF for a vessel that has been required by the International Maritime Organization (IMO) for the Safety of Life at Sea (**SOLAS**) & contains vessel information and vessel position. ▪ requires operating AIS transmitters on all international cargo vessels of more than 300 tons displacement, all cargo vessels of more than 500 tons displacement, and all passenger vessels. ▪ frequency of data transmit is 3sec-3 mins.

AIS Data

Static Information (Information on ship characteristics)	Dynamic Information (Information on ship's movement)	Voyage Information (Information on current voyage)
MMSI(Maritime Mobile Service Identity), **IMO** Number, ship name, ship type, ship dimensions	Ship's position (longitude, latitude),Speed Over Ground(**SOG**), Course Over Ground(**COG**), Heading	Destination, Draught, Estimated time of arrival(**ETA**)

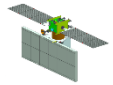
Quick workflow of the processing chain of Level-3B Data



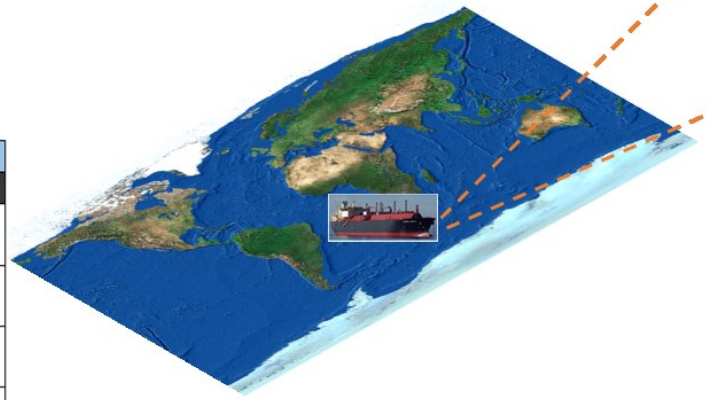
- RISAT-2B (Maritime)
- EOS04/09
- NISAR

Level	Product Type	Format
Level 3B	**Detected Ship in SAR + AIS Association**	KML vector layer for total detected ships , ship chips (PNG files), Metadata, & *AIS Information (if associated)

Quick workflow of the processing chain of Level-3C Data



EOS09 On-board AIS



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AIVDM PACKET

AIS DATA DECODER

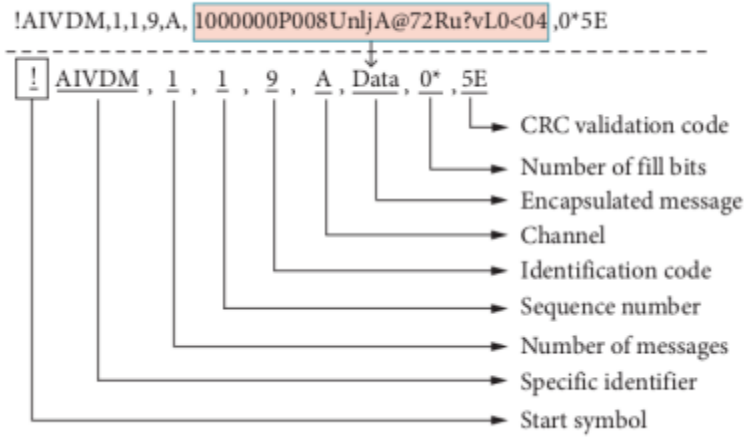
AIS Data

MMSI	Time	Lat	Lon	SOG	COG
419688000	2024-01-25 23:28:09	35.44	72.26	8.11	210
419000418	2024-01-25 23:45:52	43.26	73.27	7.33	185
419000154	2024-01-25 23:30:39	32.16	71.55	9.54	212
419729000	2024-01-25 23:33:12	38.54	73.33	12.20	88
419000182	2024-01-25 23:40:02	36.15	72.16	13.55	216

DATA PREPROCESSING

LEVEL-3C PRODUCT

Typical AIS AIVDM Packet



Level	Product Type	Format
Level 3C	AIS Information Product	KML vector layer having static and kinematic information from AIS receiver

RISAT-2B, EOS04/09 & NISAR Specifications

RISAT-2B-R1/R2 – Maritime Mode SPECIFICATIONS

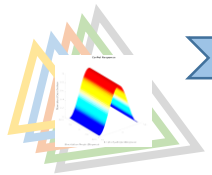
Parameters	Specifications
Band	X-band
Orbit	574 km with 98° inclination (polar sun-synchronous)
Frequency	9.6 GHz
Wavelength	3.125 cm
PRF	2000-2500 Hz
Available Polarization	VV
Swath Width	140-250 Km
Spatial Resolution	13.5m (Az); 1.5m (Slant-Ra)
Incidence Angle Range	55° – 60°
Noise Equivalent	-10 dB
Doppler Bandwidth Sampling	Aliased to get large Swath

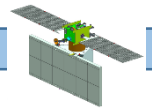
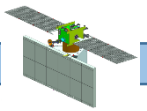
EOS04/09 (RISAT-1A/1B) SPECIFICATIONS

Parameters	Specifications
Band	C-band
Orbit	524 km with 98° inclination (polar sun-synchronous)
Repeat Cycle	17 days for EOS04 / ~9 days combining both EOS04/09.
Time of Nodal Crossing	6 am/6 pm
Frequency	5.4 GHz
Wavelength	5.5 cm
PRF	2800-3700 Hz
Available Polarization	Single Pol (SP), Dual Pol (DP), Circular Pol (CP) , Full Pol (FP)
Swath Width	10-223 Km
Spatial Resolution	1m-50m
Incidence Angle Range	11° – 55°
Noise Equivalent	-17 dB
Doppler Bandwidth Sampling	No aliasing
Systematic Coverage of Indian Landmass	6 am pass in MRS mode

NISAR SPECIFICATIONS

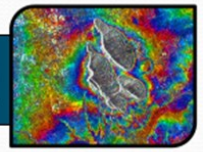
Parameters	Specifications	
Band	S-band	L-band
Orbit	747 km with 98° inclination (polar sun-synchronous)	
Repeat Cycle	12 days	
Time of Nodal Crossing	6 AM / 6 PM	
Frequency	3.2 GHz ± 37.5 MHz	1.257 GHz ± 40 MHz
Wavelength	9 cm	24 cm
Available Polarimetric Modes	Single Pol (SP), Dual Pol (DP), Quasi-Quad Pol (QQP), hybrid Circular Pol (CP) in S-band only, and Quad Pol (QP) in L-band only	
Range Bandwidths Options	10 MHz, 25 MHz, 37.5 MHz, 75 MHz	5 MHz, 20 MHz, 40 MHz, 80 MHz
Swath Width	> 240 Km (except for QQP Mode)	> 240 Km (except for 80 MHz BW)
Spatial Resolution	6.5m (Az); 2m-15m (Slant-Ra)	7m (Az); 2m-30m (Slant-Ra)
Incidence Angle Range	33°– 47°	33° – 47°
Noise Equivalent	Better than -25 dB (for required full-swath modes)	
Pointing	Left (South) pointing	
Pointing Control	< 273 arc seconds	
Orbit Control	< 500 meters	
Data and Product Access	**Free & open access**	



2020  2022  2025 (NISAR+EOS09) 

EOS04/09 & NISAR Coverage for Ocean Applications

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



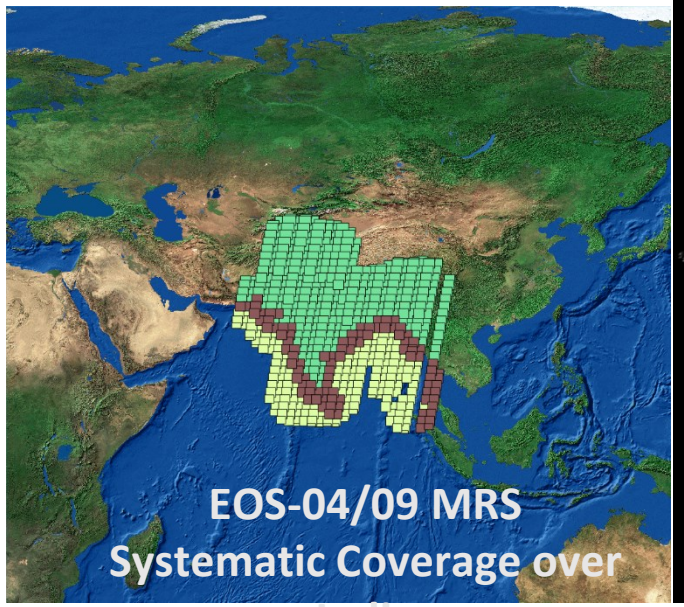
Land Deformation: 2.1 Inter-seismic / Co-seismic deformations; 2.2 Landslides; 2.3 Land subsidence; 2.4 Volcanic deformations

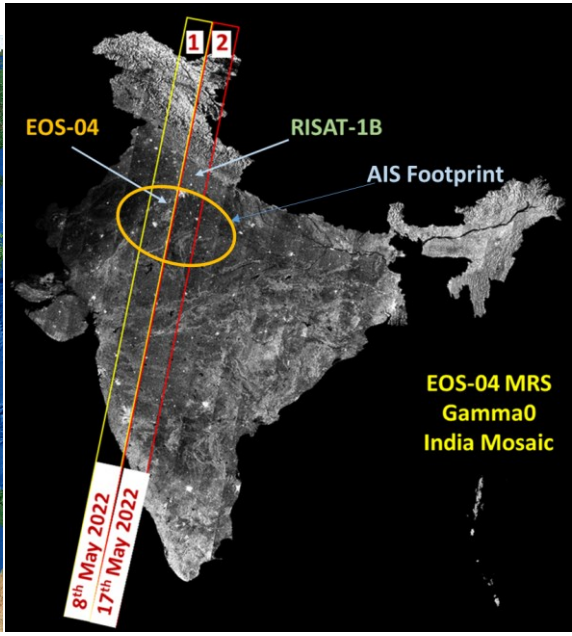
Cryosphere: 3.1 Polar Ice Shelf / Ice sheet; 3.2 Sea Ice Dynamics; 3.3 Mountain snow/ glacier 3.4 Glacier dynamics/ hazard (Himalayan Region); 3.5 Climate response to glaciers; 3.6 Sea–Ice advisory on safer marine navigation in Antarctica region

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

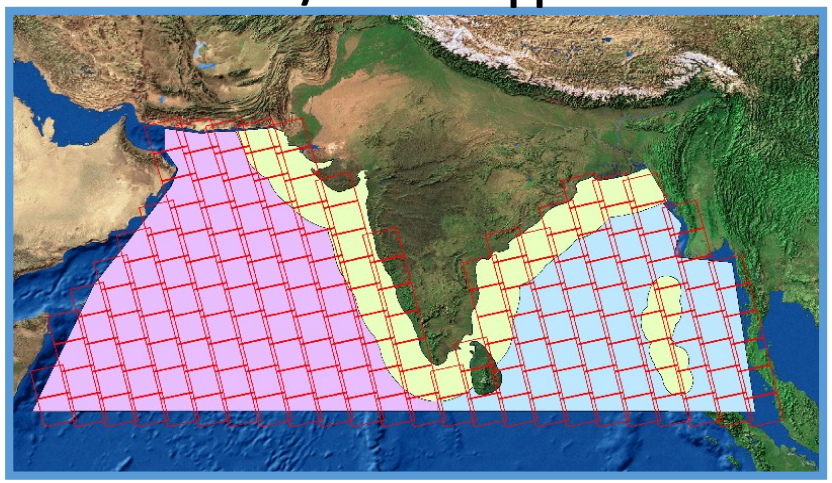
Disaster Response: 5.1 Floods; 5.2 Forest fire damage assessment; 5.3 Coastal oil spill; 5.4 Earthquakes / Others

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

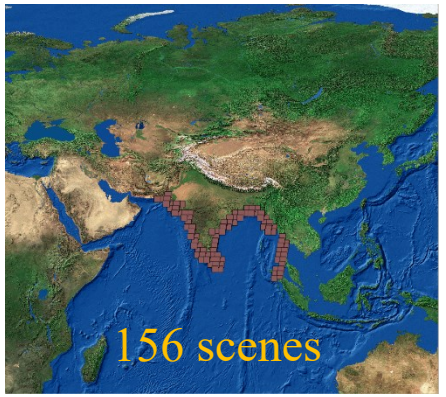




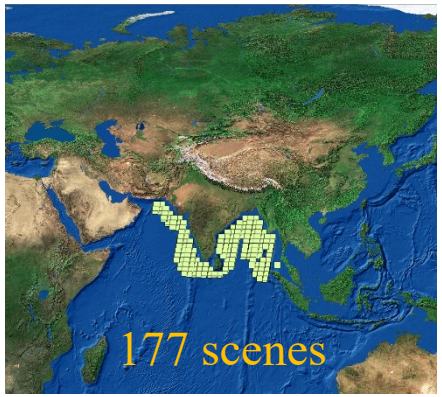
NISAR targeted AOI for Ocean/Coastal Applications



Coastal Scenes

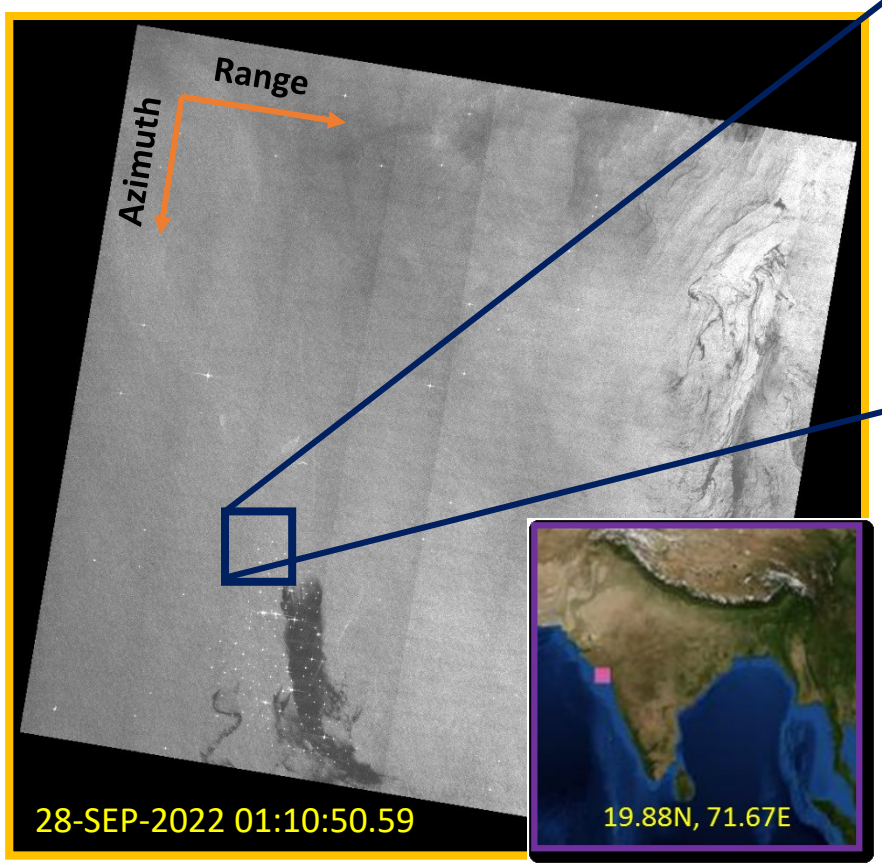


Oceanic Scenes

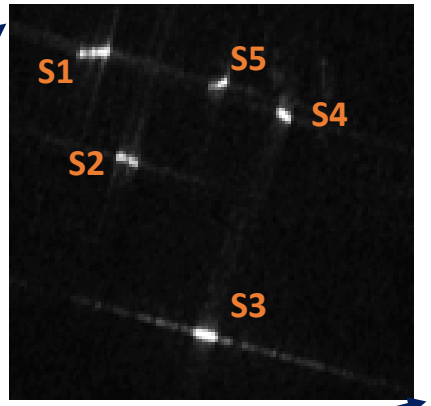


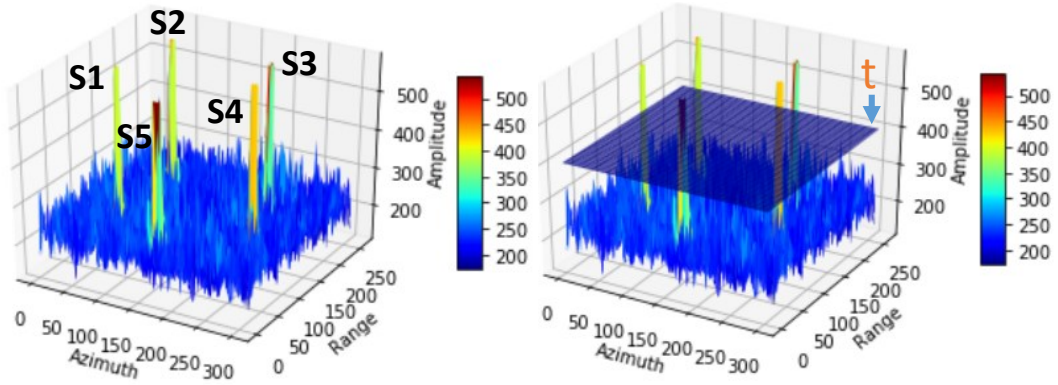
Basic Concept of Ship Detection in SAR Images

- Identify pixels that do not fit to the statistical properties of the sea clutter keeping constant the probability of false alarm throughout the input image

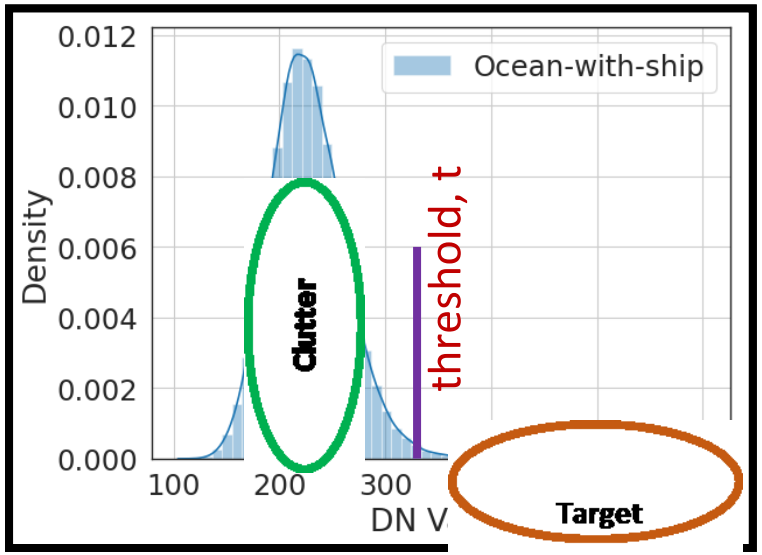


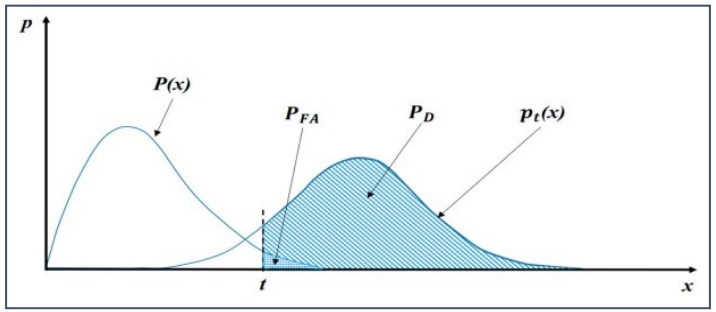
SUB IMAGE





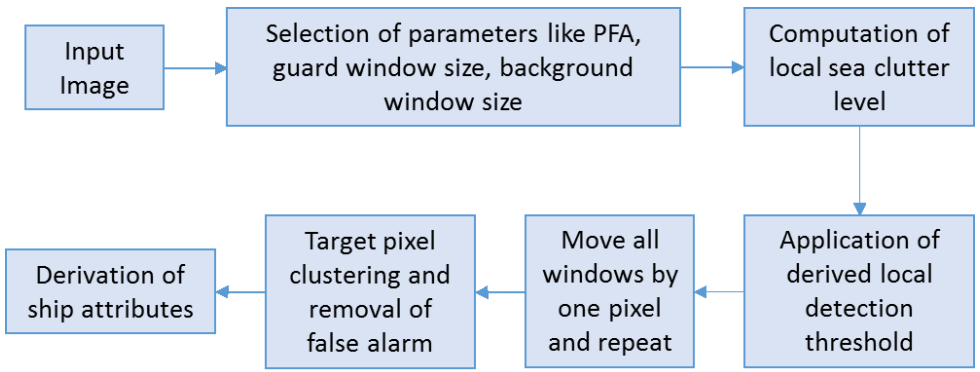
S1,S2,S3,S4,S5 are ships

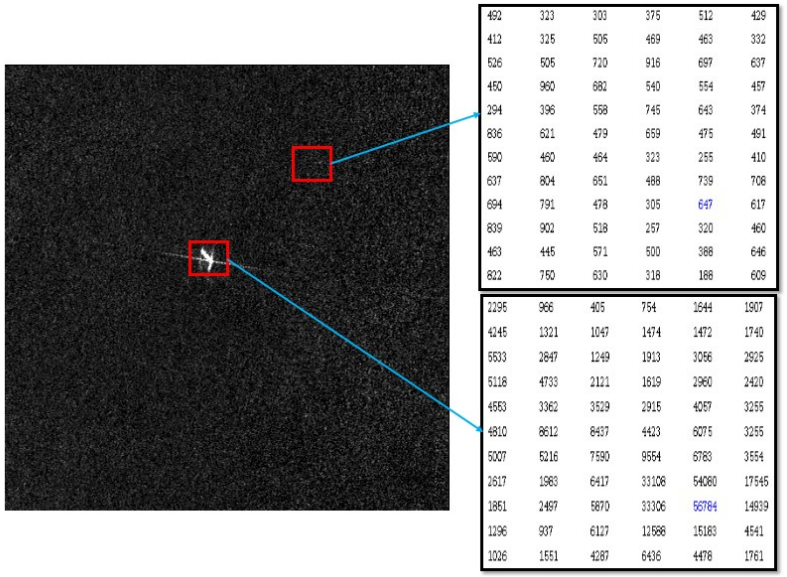


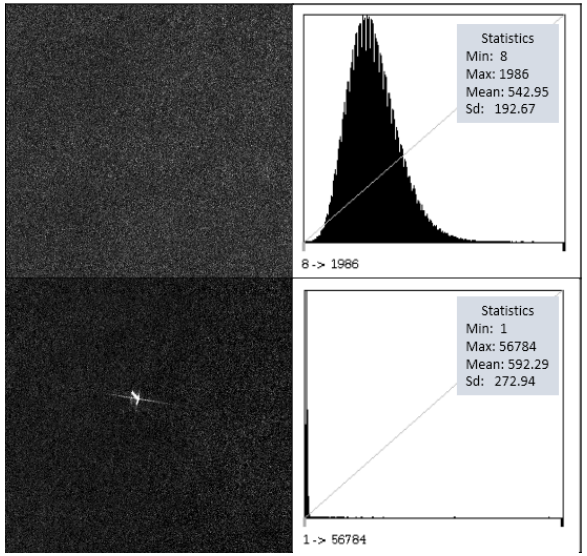


$PFA = \int_t^{\infty} p(x)$	$PFA = 1 - \int_0^t p(x)$
$PD = \int_t^{\infty} pt(x)$	$1 - PFA = \int_0^t p(x)$

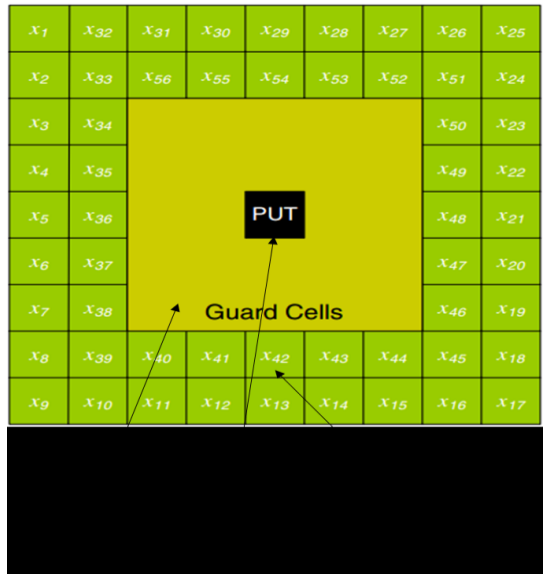
Algorithm flowchart for Level-3B ship detection data product



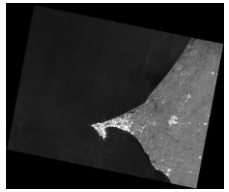


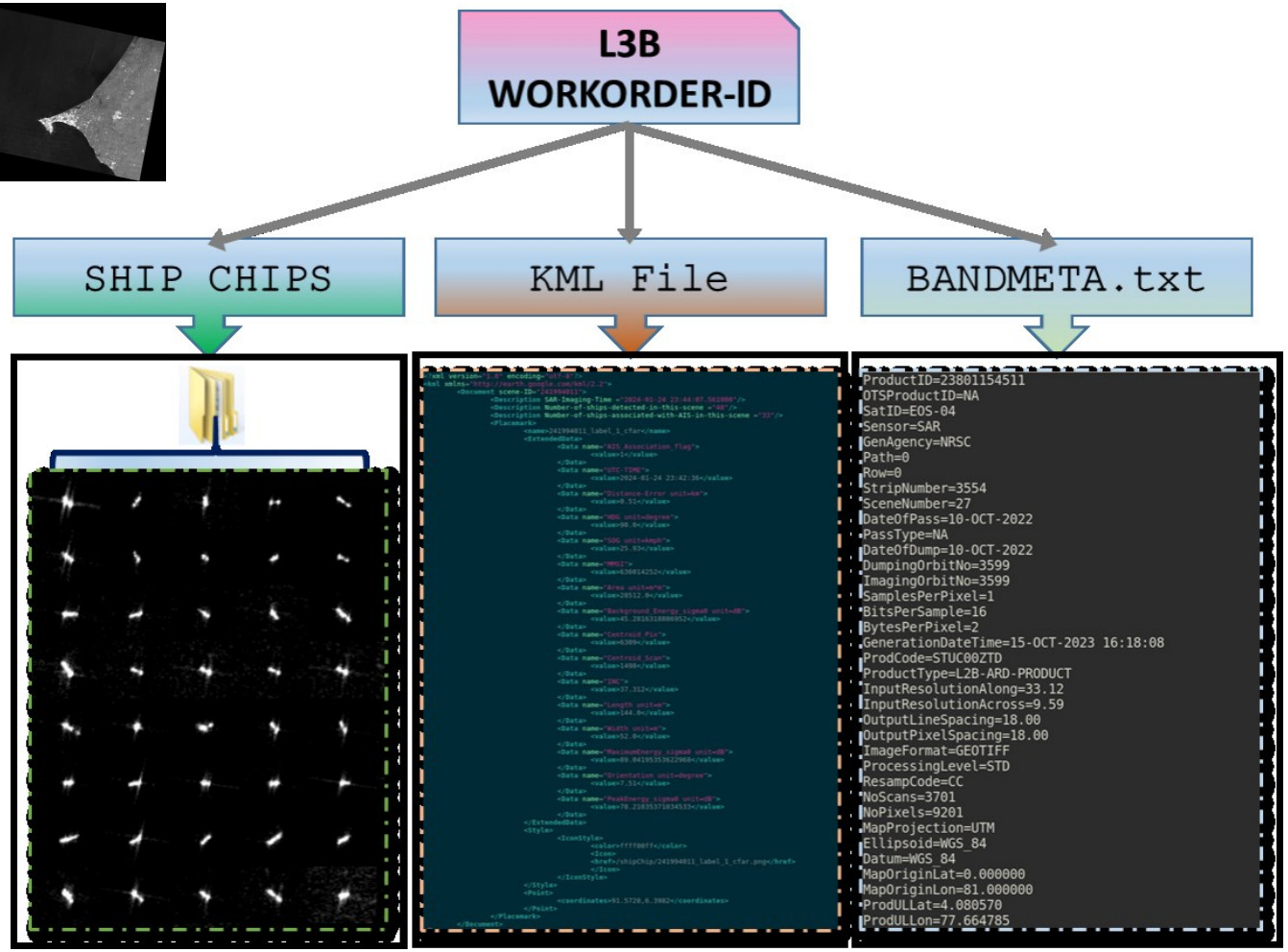


- m_c & m_t represents background and test window mean
- $Detection\ threshold,\ t = \alpha * m_c$
- $\alpha = N * \left(P_{FA}^{-\frac{1}{N}} - 1\right)$, $P_{FA} = Probability\ of\ false\ alarm, N = \text{Number of cells in background window}$
- $m_t \underset{no-ship}{\overset{ship}{>}} Detection\ threshold$
- CA-CFAR (Cell Averaging-Constant False Alarm Rate) is a statistical based approach for detection of ship pixels in SAR images.
- Variants of CFAR are possible based on different treatment given to background pixels. In case, of CA-CFAR (most widely used operationally) variant, background pixels are averaged as shown in above equation.
- PUT defines minimum detectable ship size, Guard window define maximum expected ship size to be detected, & Background window define pixels used to estimate background (ocean clutter).
- All the parameters are to be fine tuned for a particular sensor. Typical values of parameters for EOS04 are: PUT=3, Guard Window=17, Background Window=25, PFA=1e-6.
- As PFA increases, detectability increases, but false alarm also increases, so PFA has to be adjusted according to the dataset.
- alpha (α) is constant for the dataset, & threshold adapts to the background pixels.



Content of Ship Detected Data Product (Level-3B)



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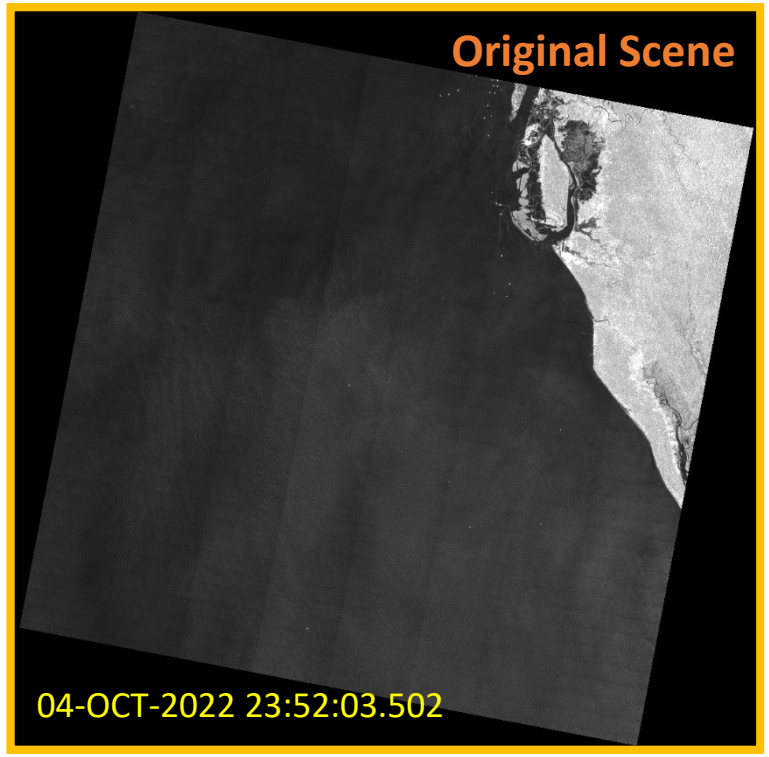
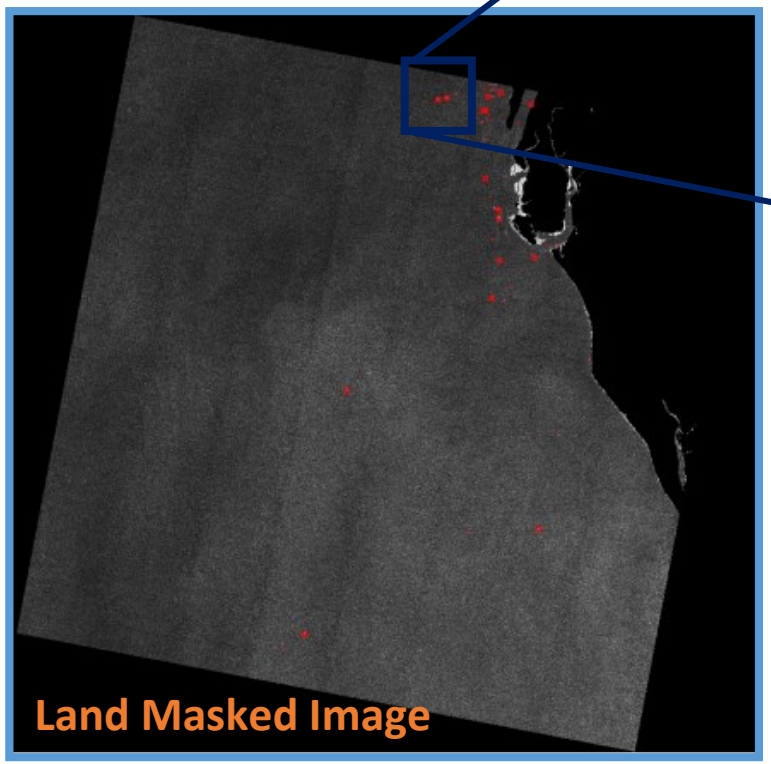
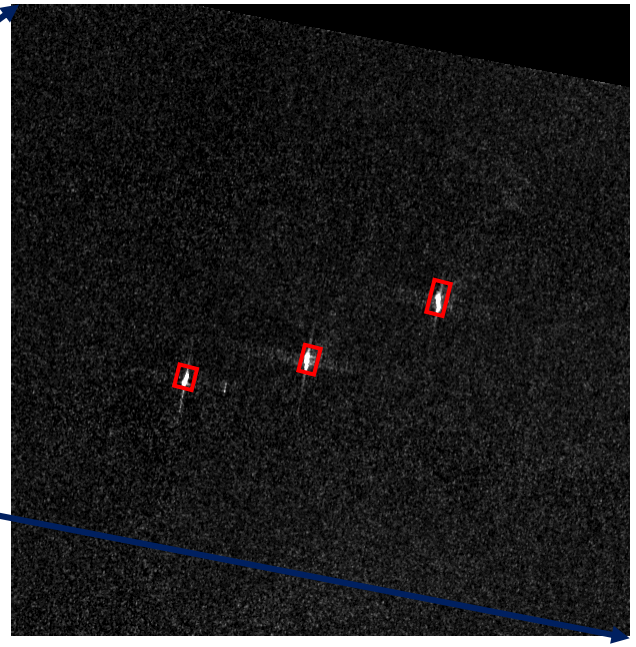
Example of KML Product

Example of Ship Detection in Coastal Scene – Case: 1



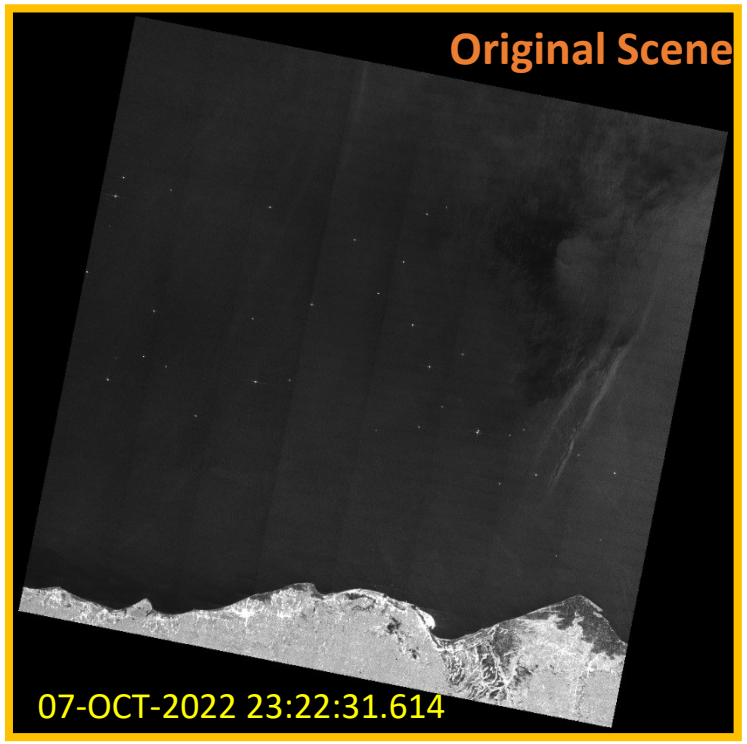
EOS04 Data



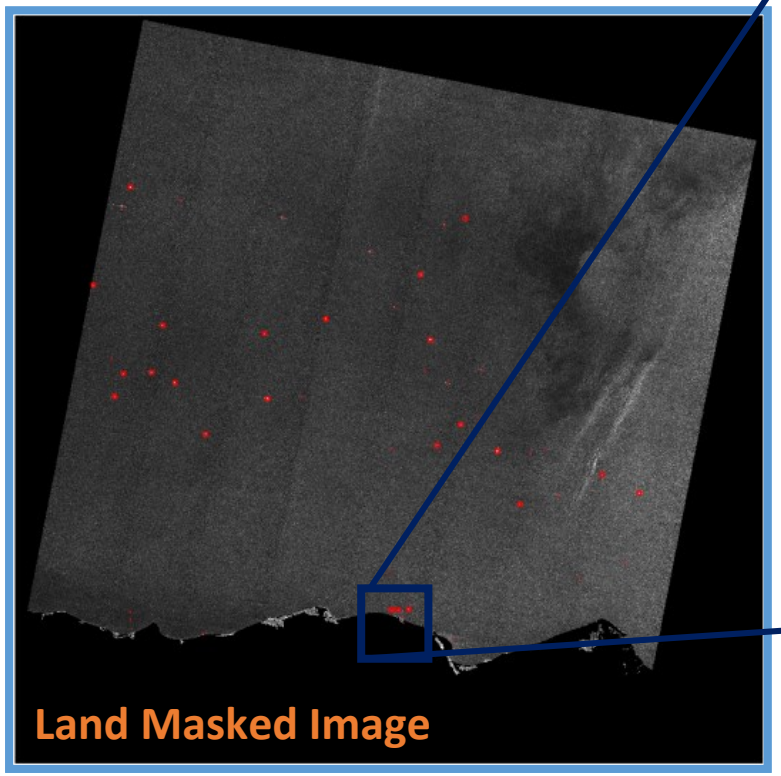


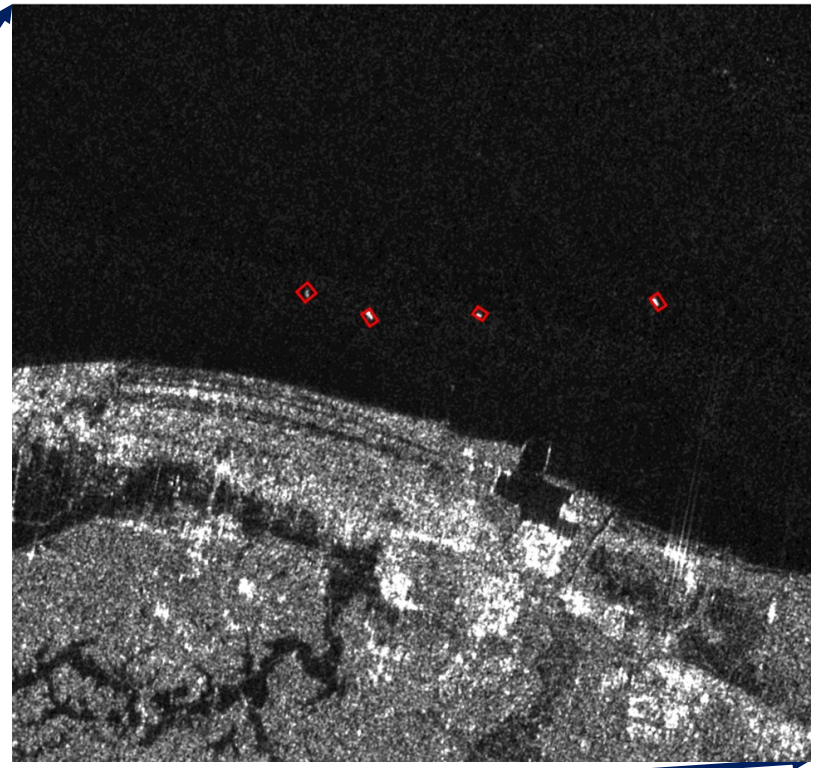
Detected ships with bounding boxes on zoomed region

Example of Ship Detection in Coastal Scene – Case: 2



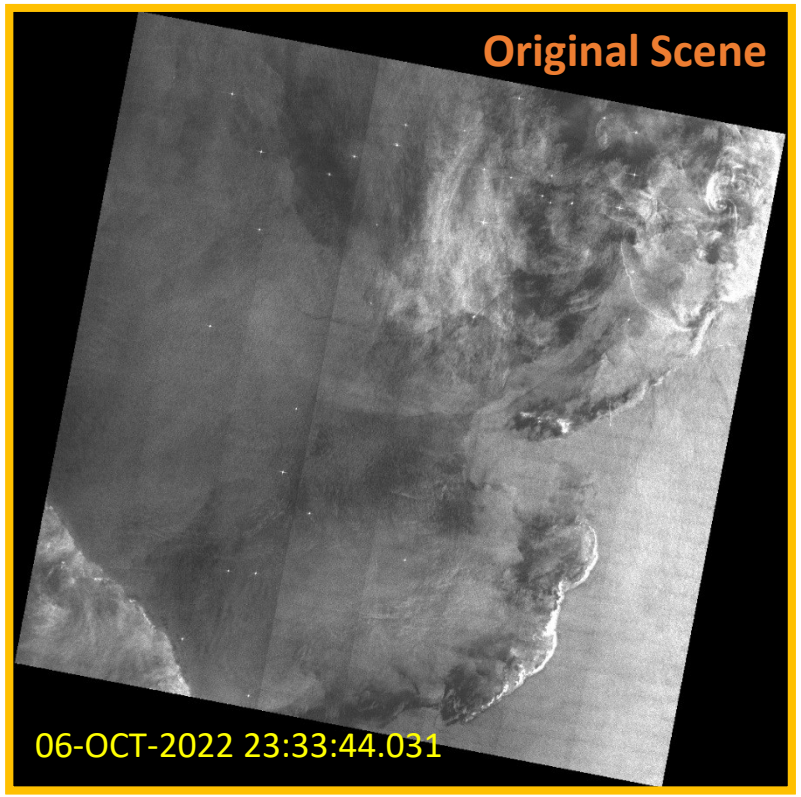
EOS04 Data

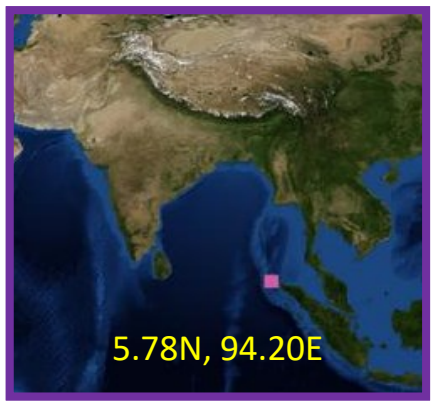




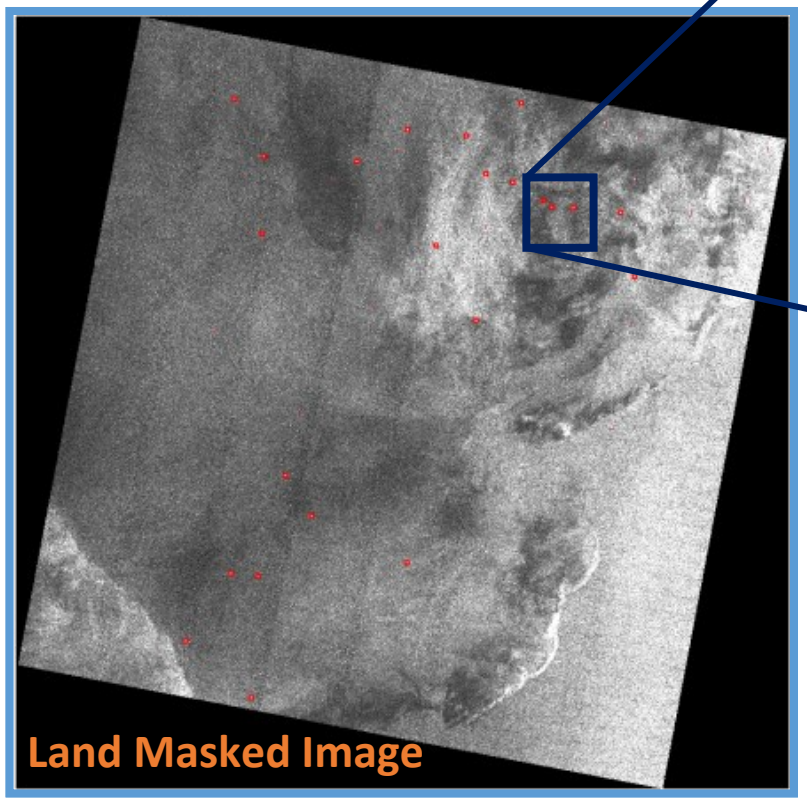
Detected ships with bounding boxes on zoomed region

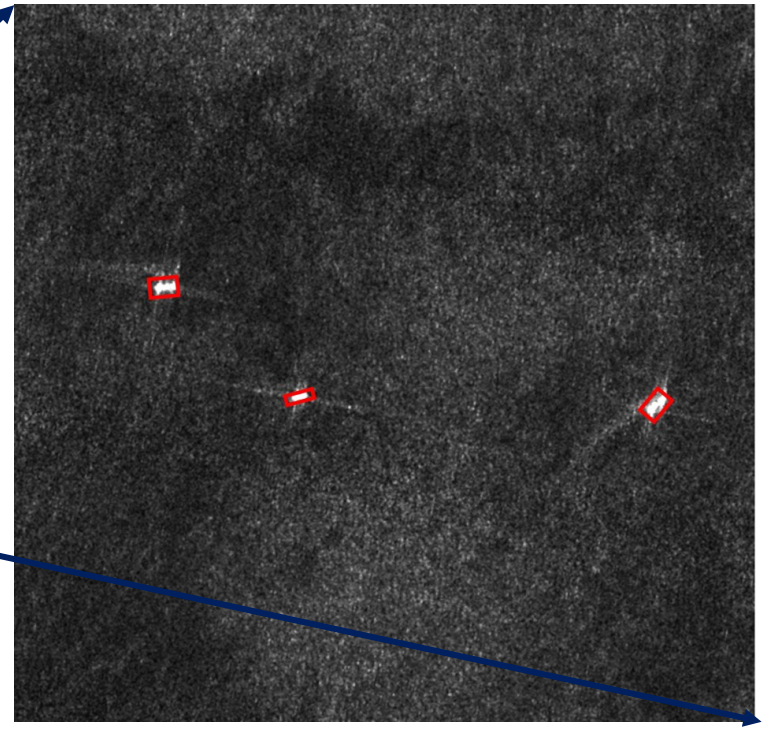
Example of Ship Detection in Deep Ocean – Case: 1





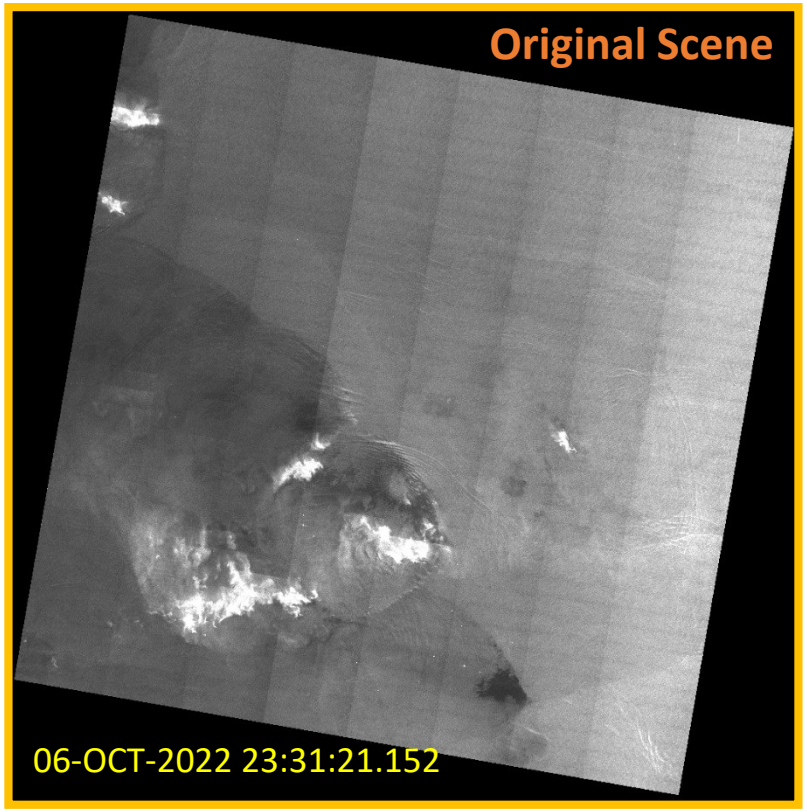
EOS04 Data



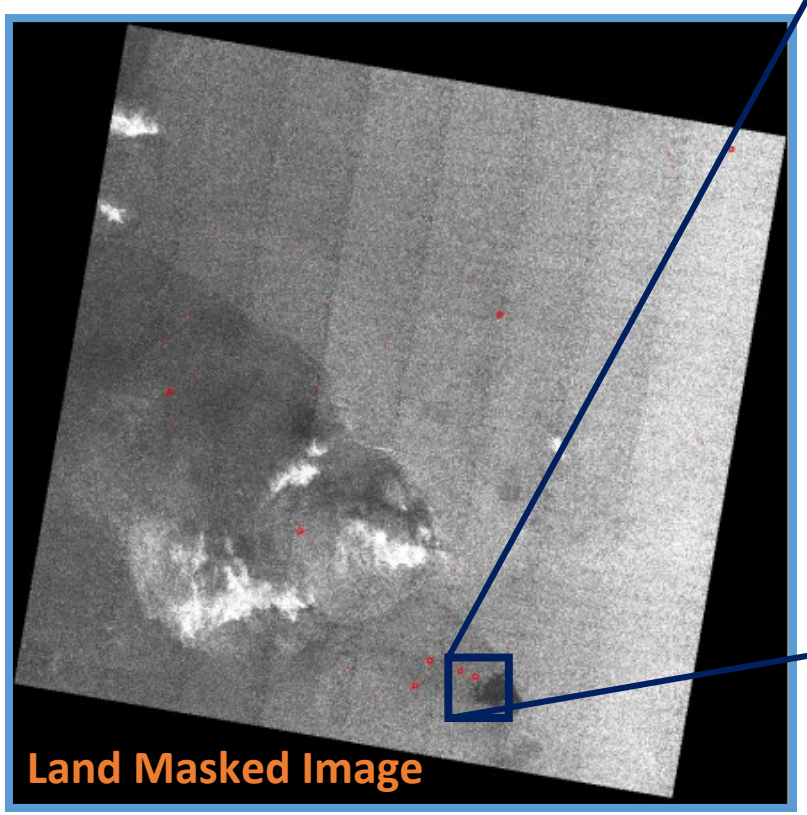


Detected ships with bounding boxes on zoomed region

Example of Ship Detection in Deep Ocean – Case: 2

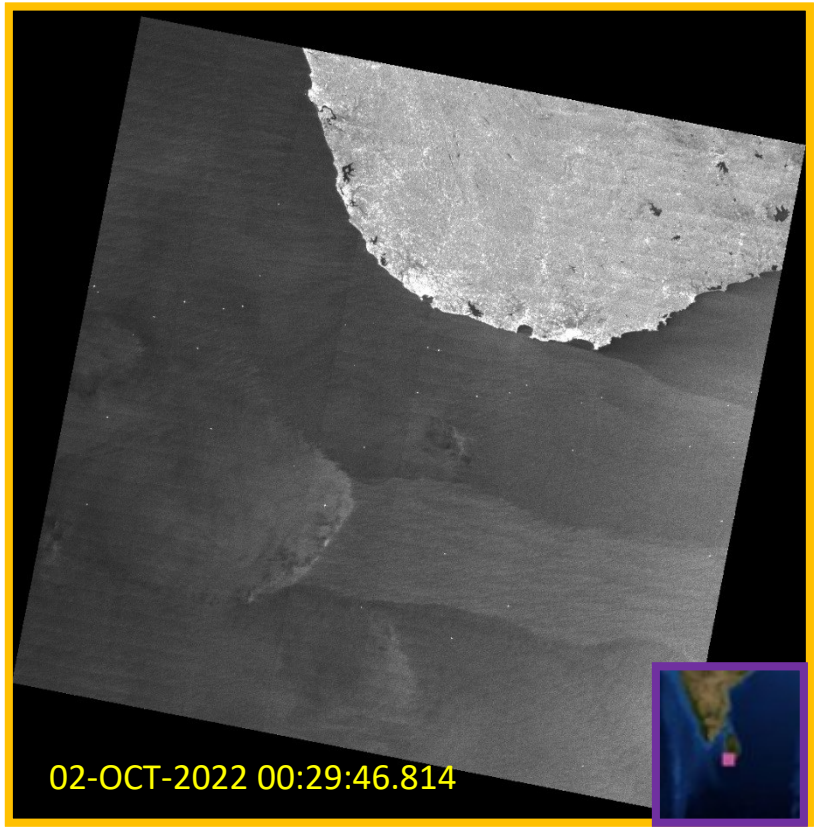


EOS04 Data

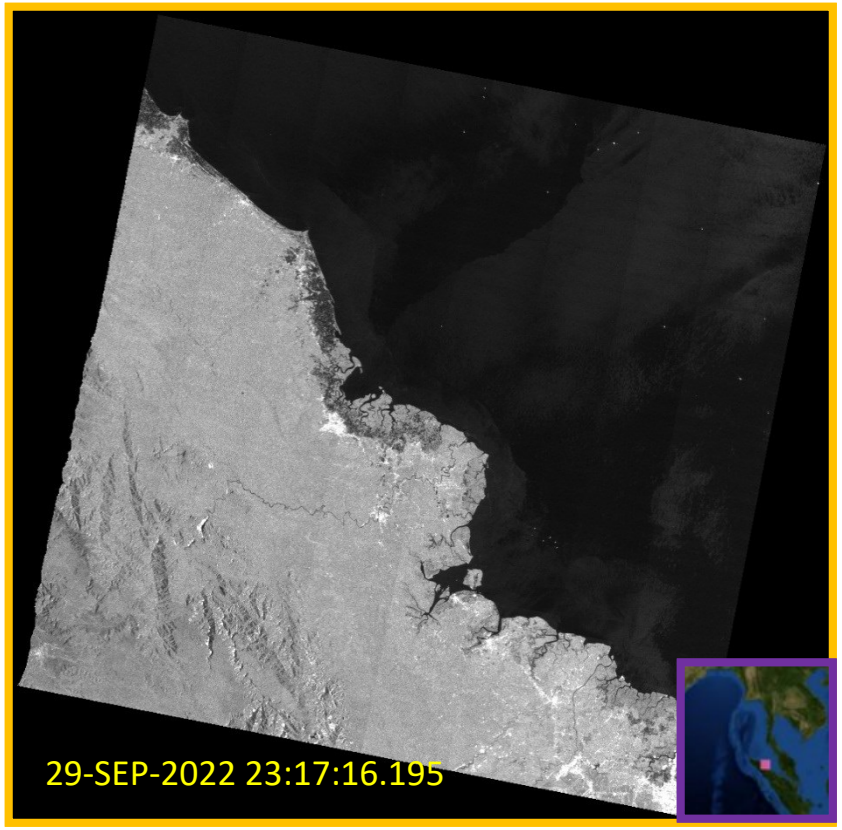


Detected ships with bounding boxes on zoomed region

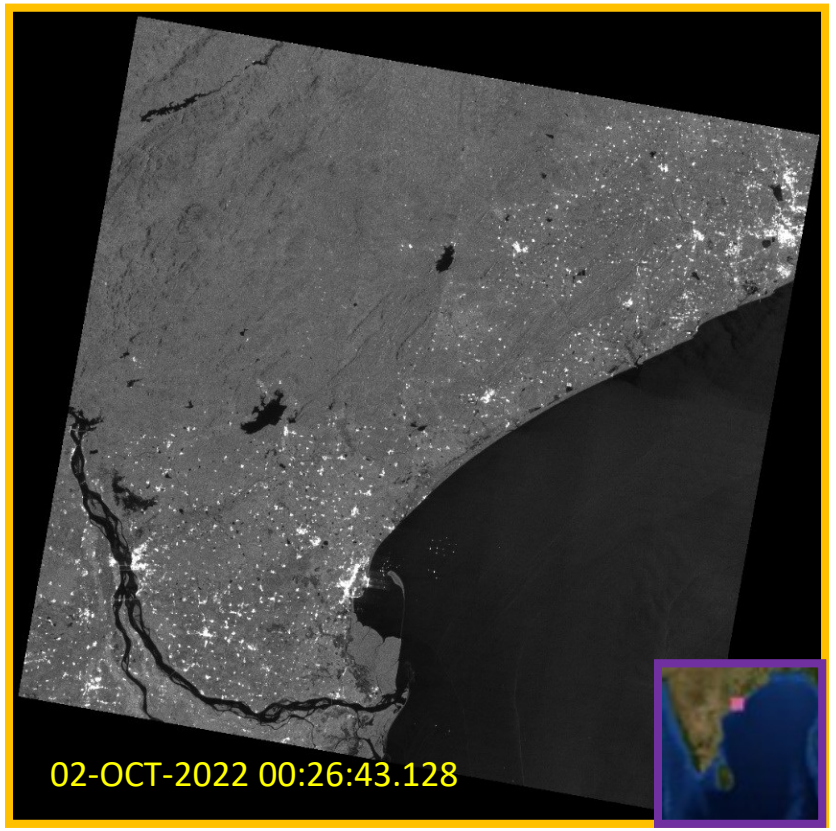
Few more Coastal Cases



Number of ships (Observed)	62



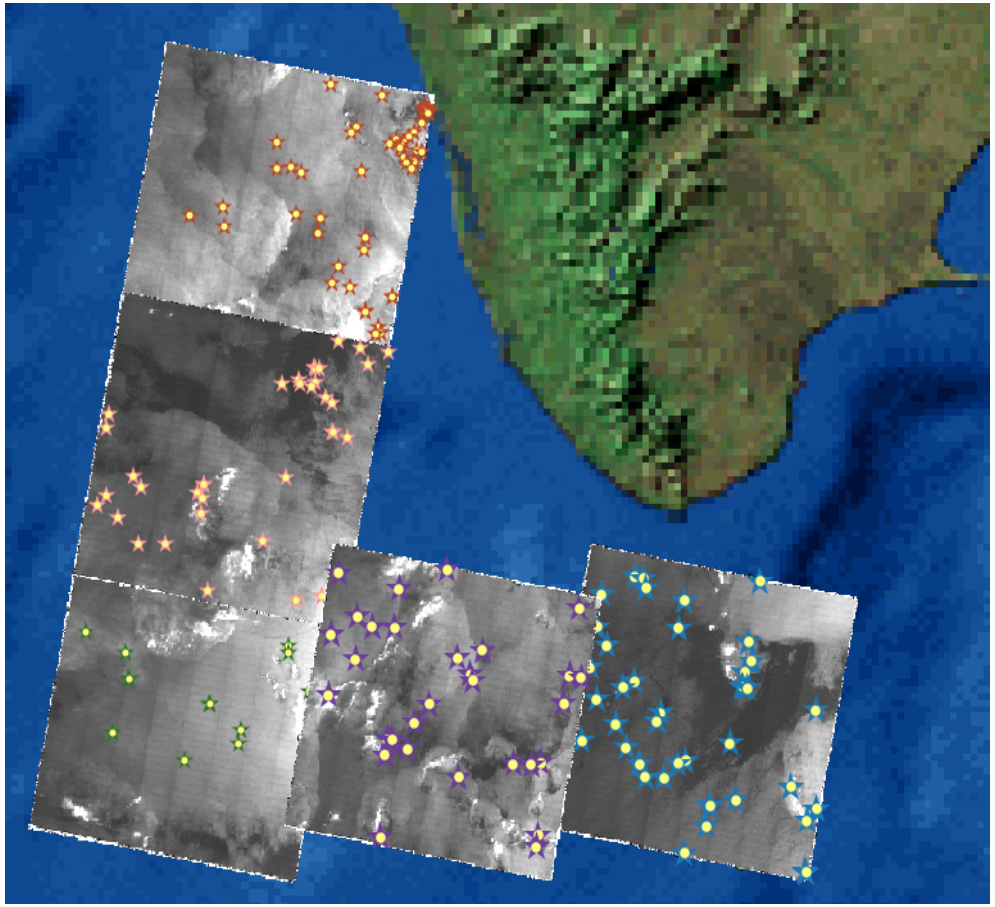
Number of ships (Observed)	72

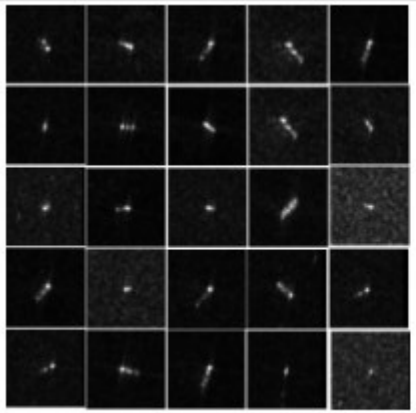


Number of ships (Observed)	106

EOS04 Data

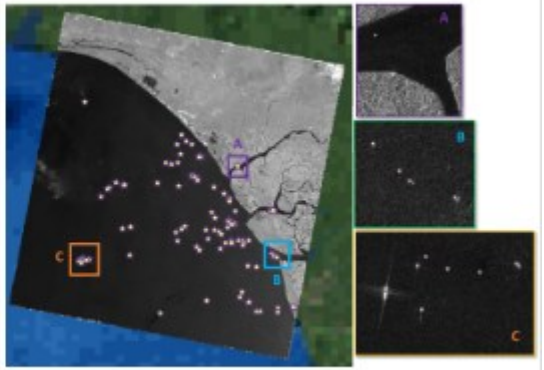
Few more Ocean Cases



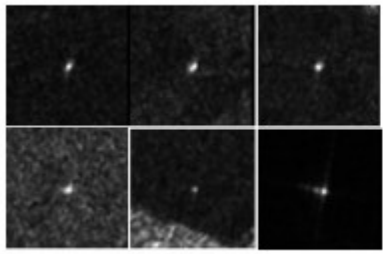


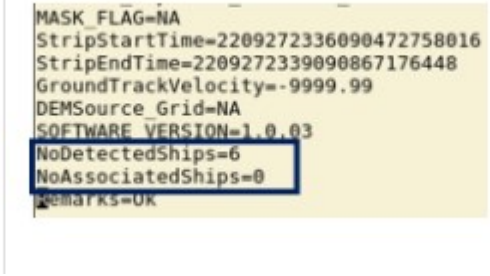
shipChips

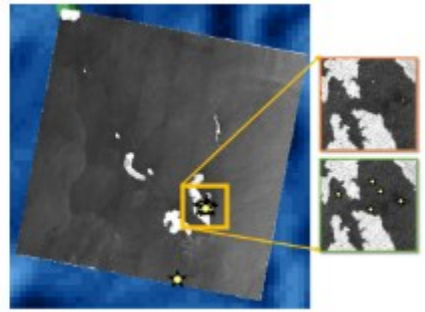
BAND_META.txt



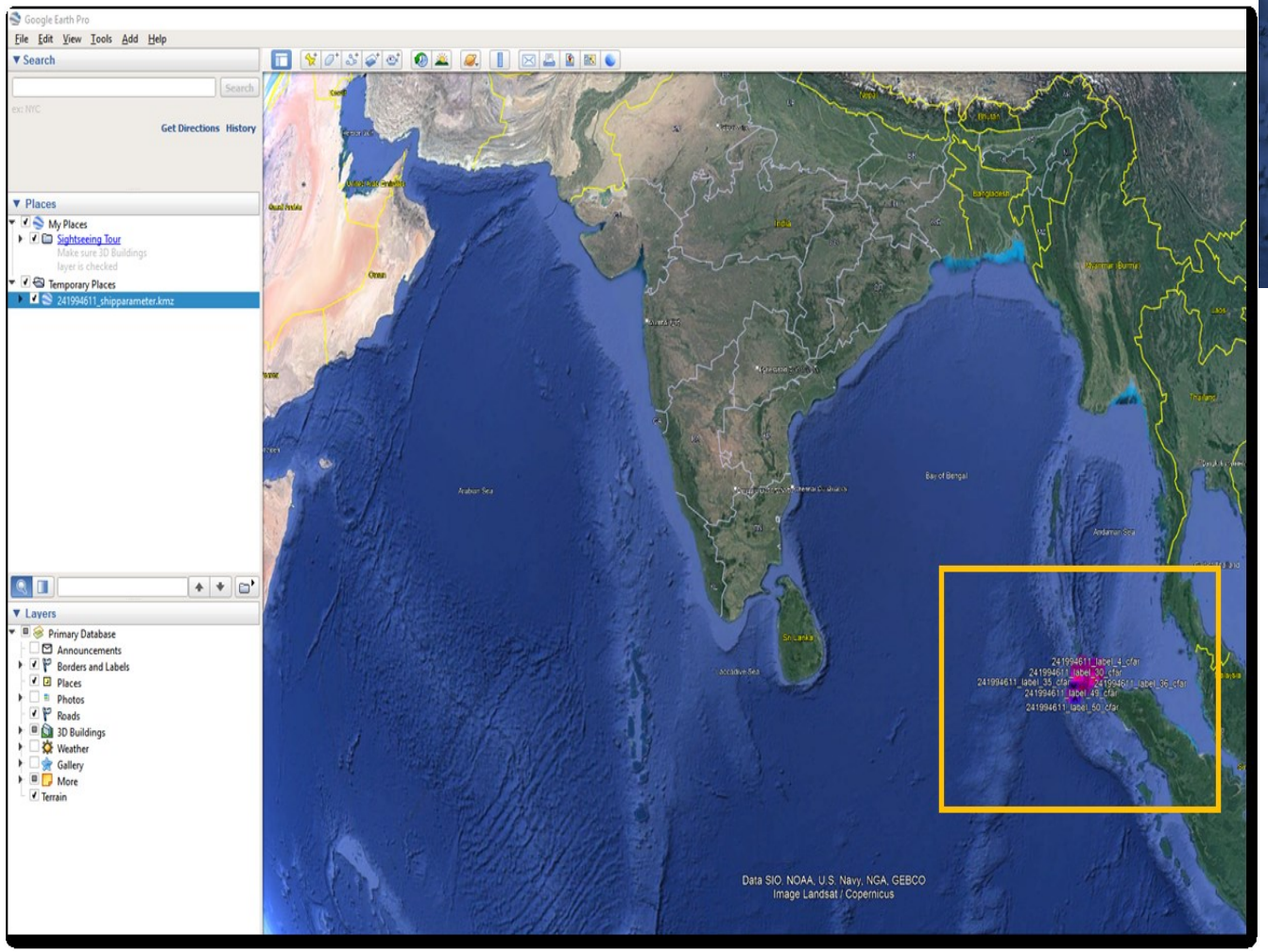
KML

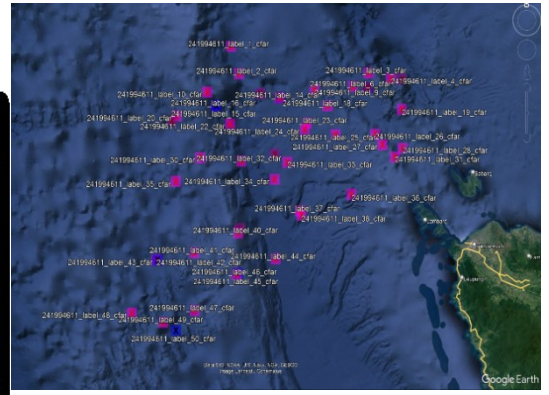


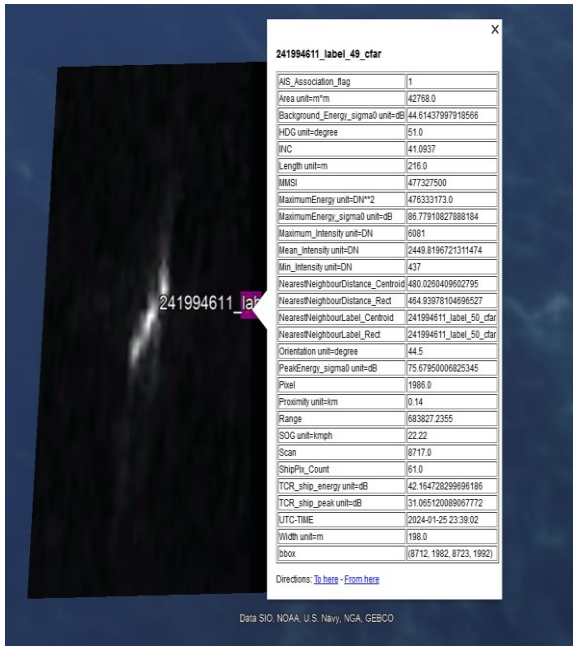


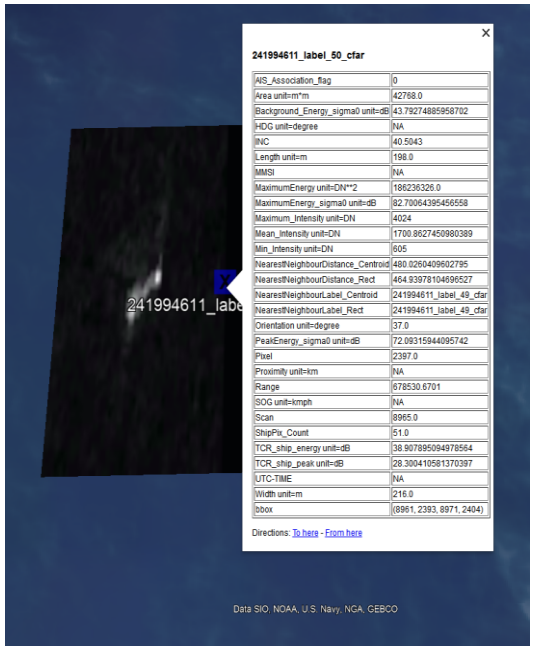


Verification of KML loaded on Google Earth







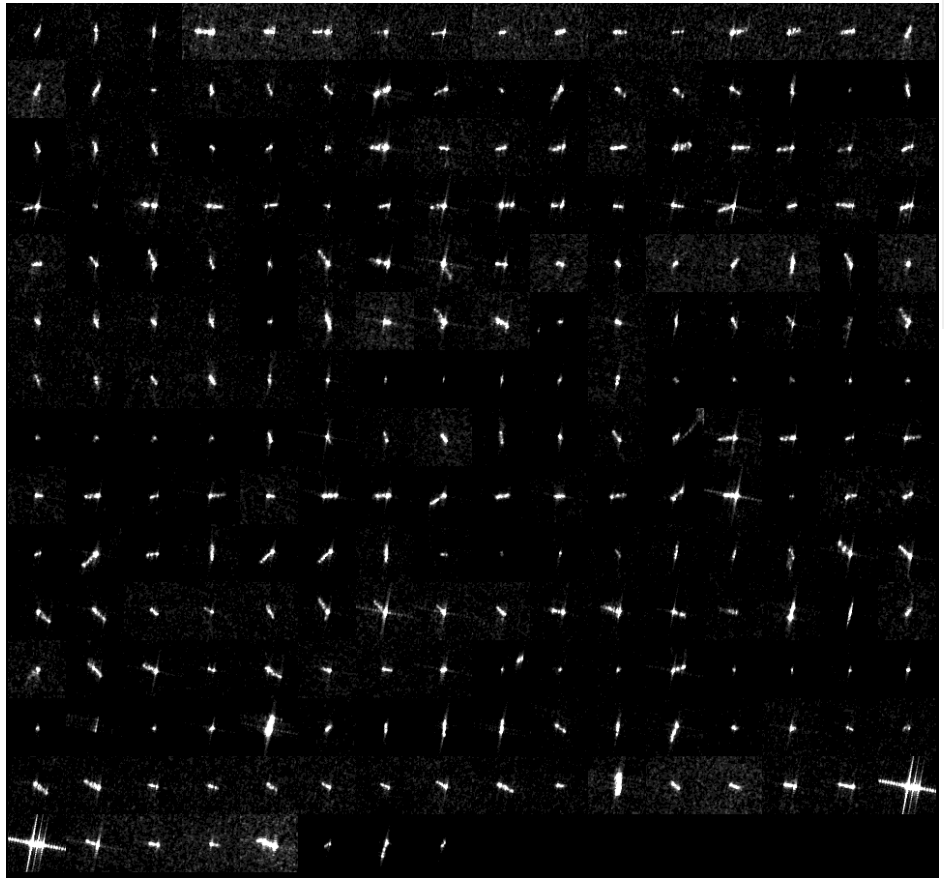


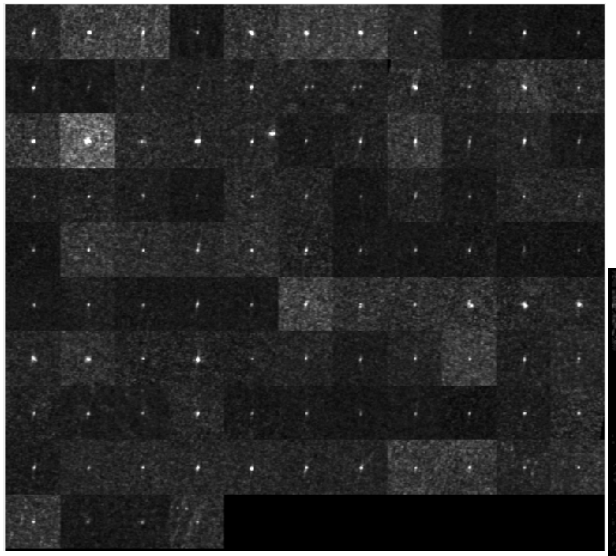
Examples of detected ships derived using EOS04 Data

EOS04 Data

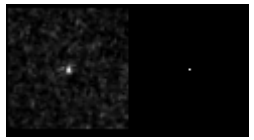
1 Pixel = 18m in EOS04 Systematic Coverage

Medium Sized(5 to 50 Pixels)



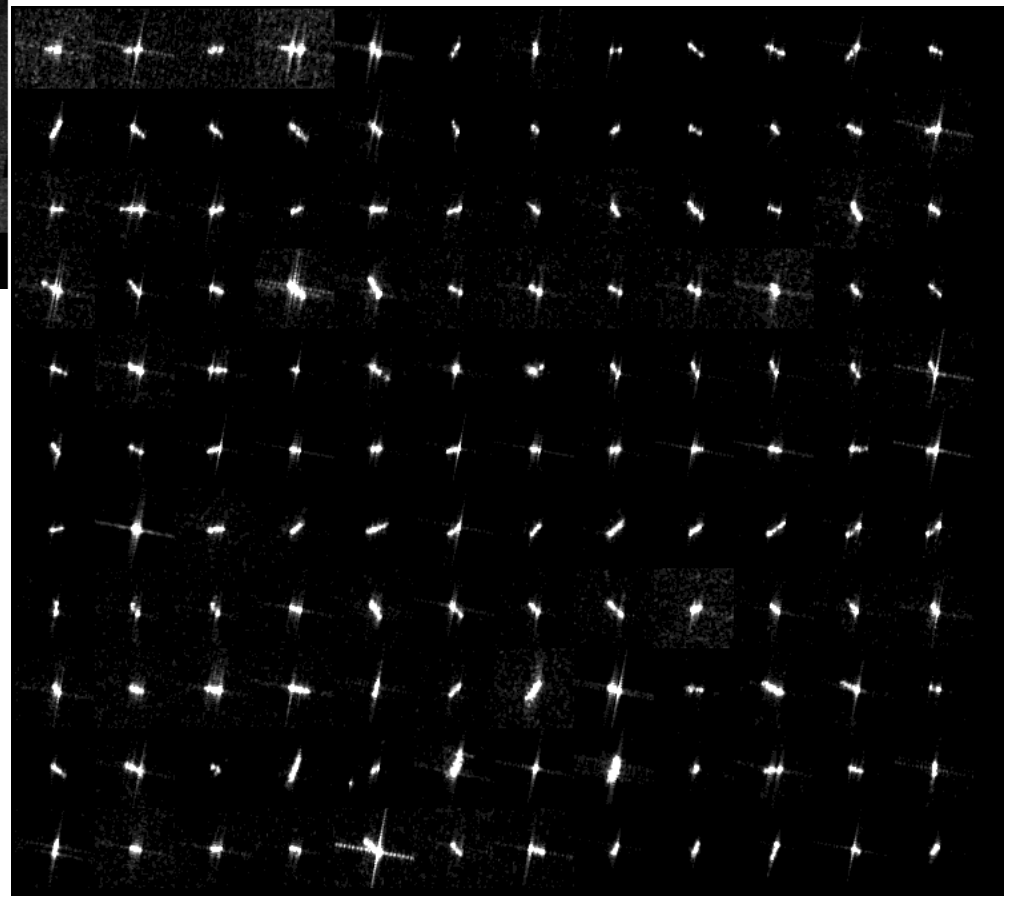


Small Sized(<5Pixel)

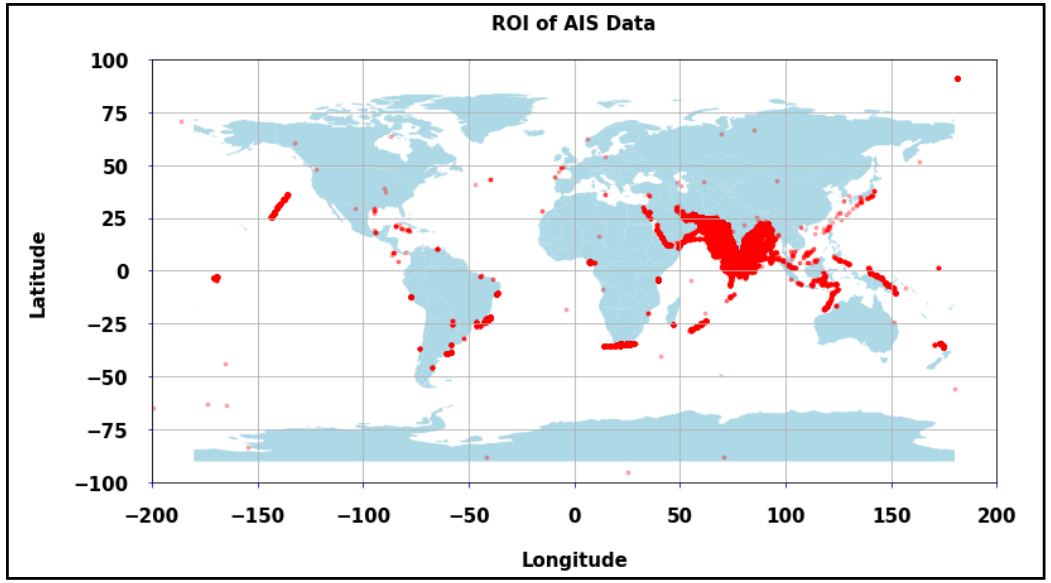


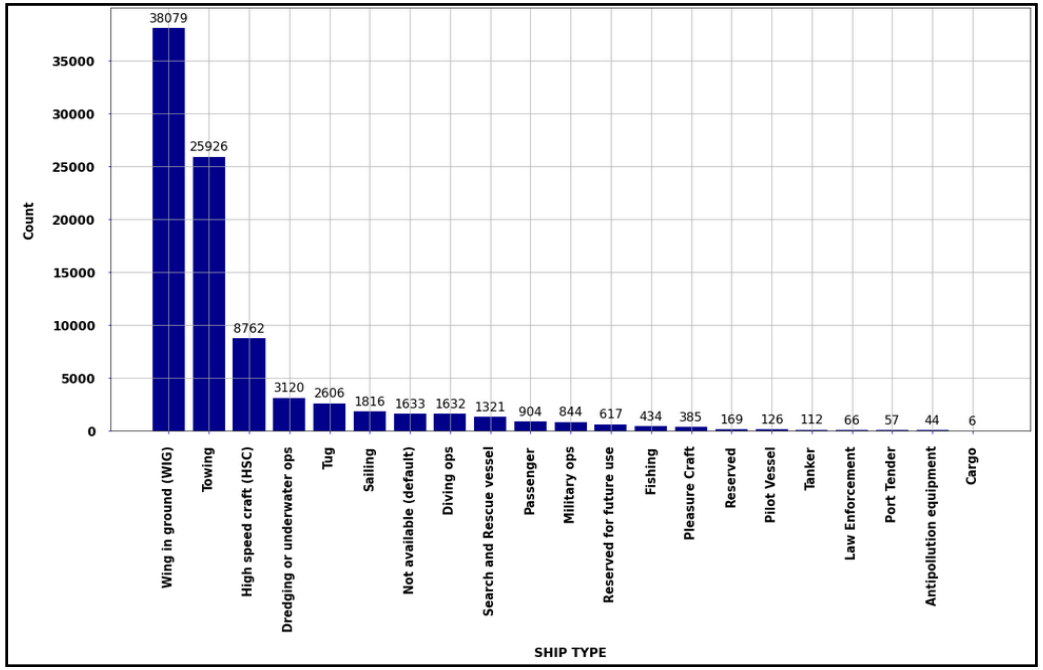
Minimum size detected ship of 1 pixel
Target Peak: 1068 DN
TCR ship-peak: 16.37 dB
Incidence Angle: 33.5°
Range: 625055.2862 m
Label: 23801157461_label_43_cfar

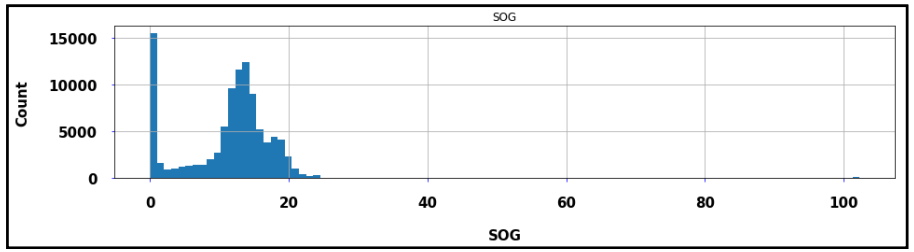
Large Sized(>50 Pixels)

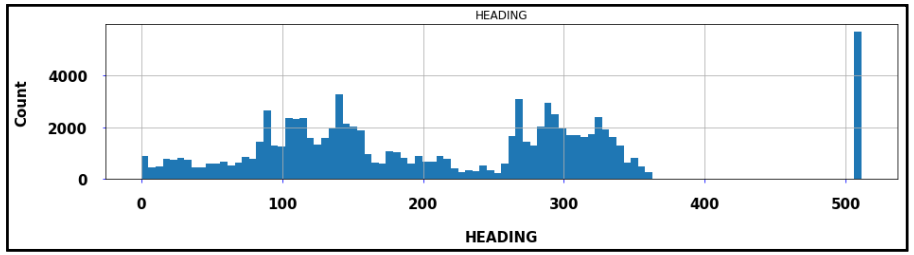


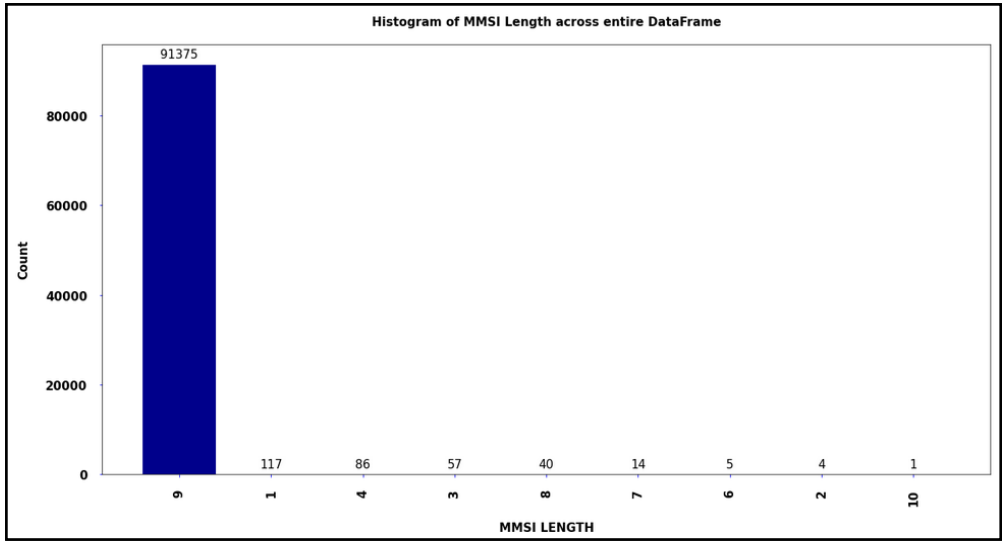
Need of AIS Data Filtering (Abnormalities in AIS)?











AIS messages being repeated multiple times?

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DONG FANG HONG 3,MMSI-413332930,2021-08-07 23:09:41,15.5567,115.142,47,11
DONG FANG HONG 3,MMSI-413332930,2021-08-07 23:09:41,15.5567,115.142,47,11
DONG FANG HONG 3,MMSI-413332930,2021-08-07 23:09:41,15.5567,115.142,47,11
GASLOG GEORGETOWN,MMSI-310800000,2021-08-07 23:27:59,15.9067,115.802,21,15
GASLOG GEORGETOWN,MMSI-310800000,2021-08-07 23:27:59,15.9067,115.802,21,15
GASLOG GEORGETOWN,MMSI-310800000,2021-08-07 23:27:59,15.9067,115.802,21,15
GASLOG GEORGETOWN,MMSI-310800000,2021-08-07 23:27:59,15.9067,115.802,21,15
GASLOG GEORGETOWN,MMSI-310800000,2021-08-07 23:27:59,15.9067,115.802,21,15
GASLOG GEORGETOWN,MMSI-310800000,2021-08-07 23:27:59,15.9067,115.802,21,15
TRANG AN 08,MMSI-457193000,2021-08-07 23:28:03,16.2733,108.548,156,11
TRANG AN 08,MMSI-457193000,2021-08-07 23:28:03,16.2733,108.548,156,11
TRANG AN 08,MMSI-457193000,2021-08-07 23:28:03,16.2733,108.548,156,11
TRANG AN 08,MMSI-457193000,2021-08-07 23:28:03,16.2733,108.548,156,11
TRANG AN 08,MMSI-457193000,2021-08-07 23:28:03,16.2733,108.548,156,11
TRANG AN 08,MMSI-457193000,2021-08-07 23:28:03,16.2733,108.548,156,11
TRANG AN 08,MMSI-457193000,2021-08-07 23:28:03,16.2733,108.548,156,11
NAN HAI 220,MMSI-413022000,2021-08-07 23:32:59,20.8133,115.717,42,0
NAN HAI 220,MMSI-413022000,2021-08-07 23:32:59,20.8133,115.717,42,0
NAN HAI 220,MMSI-413022000,2021-08-07 23:32:59,20.8133,115.717,42,0
NAN HAI 220,MMSI-413022000,2021-08-07 23:32:59,20.8133,115.717,42,0
SBI TANGO,MMSI-538006140,2021-08-07 23:39:00,20.9533,110.853,327,0
SBI TANGO,MMSI-538006140,2021-08-07 23:39:00,20.9533,110.853,327,0
SBI TANGO,MMSI-538006140,2021-08-07 23:39:00,20.9533,110.853,327,0
SBI TANGO,MMSI-538006140,2021-08-07 23:39:00,20.9533,110.853,327,0
SBI TANGO,MMSI-538006140,2021-08-07 23:39:00,20.9533,110.853,327,0
NAN HAI 220,MMSI-413022000,2021-08-07 23:39:12,20.8133,115.717,42,0
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NAN HAI 220,MMSI-413022000,2021-08-07 23:39:12,20.8133,115.717,42,0
NAN HAI 220,MMSI-413022000,2021-08-07 23:39:12,20.8133,115.717,42,0
GRAND PIONEER,MMSI-352935000,2021-08-07 23:42:04,19.3583,119.187,215,14
GRAND PIONEER,MMSI-352935000,2021-08-07 23:42:04,19.3583,119.187,215,14
GRAND PIONEER,MMSI-352935000,2021-08-07 23:42:04,19.3583,119.187,215,14
GRAND PIONEER,MMSI-352935000,2021-08-07 23:42:04,19.3583,119.187,215,14
GRAND PIONEER,MMSI-352935000,2021-08-07 23:42:04,19.3583,119.187,215,14
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PTI HUDSON,MMSI-477854700,2021-08-07 23:50:46,13.8117,115.483,225,11
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PTI HUDSON,MMSI-477854700,2021-08-07 23:50:46,13.8117,115.483,225,11
PTI HUDSON,MMSI-477854700,2021-08-07 23:50:46,13.8117,115.483,225,11
PTI HUDSON,MMSI-477854700,2021-08-07 23:50:46,13.8117,115.483,225,11
MAERSK HAVANA,MMSI-563069900,2021-08-07 23:54:58,15.245,116.023,41,22
MAERSK HAVANA,MMSI-563069900,2021-08-07 23:54:58,15.245,116.023,41,22
MAERSK HAVANA,MMSI-563069900,2021-08-07 23:54:58,15.245,116.023,41,22
MAERSK HAVANA,MMSI-563069900,2021-08-07 23:54:58,15.245,116.023,41,22
MAERSK HAVANA,MMSI-563069900,2021-08-07 23:54:58,15.245,116.023,41,22
MAERSK HAVANA,MMSI-563069900,2021-08-07 23:54:58,15.245,116.023,41,22
MAERSK HAVANA,MMSI-563069900,2021-08-07 23:54:58,15.245,116.023,41,22
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DIGNITY ACE,MMSI-311002900,2021-08-07 23:55:00,13.075,113.382,225,17
DIGNITY ACE,MMSI-311002900,2021-08-07 23:55:00,13.075,113.382,225,17
DIGNITY ACE,MMSI-311002900,2021-08-07 23:55:00,13.075,113.382,225,17
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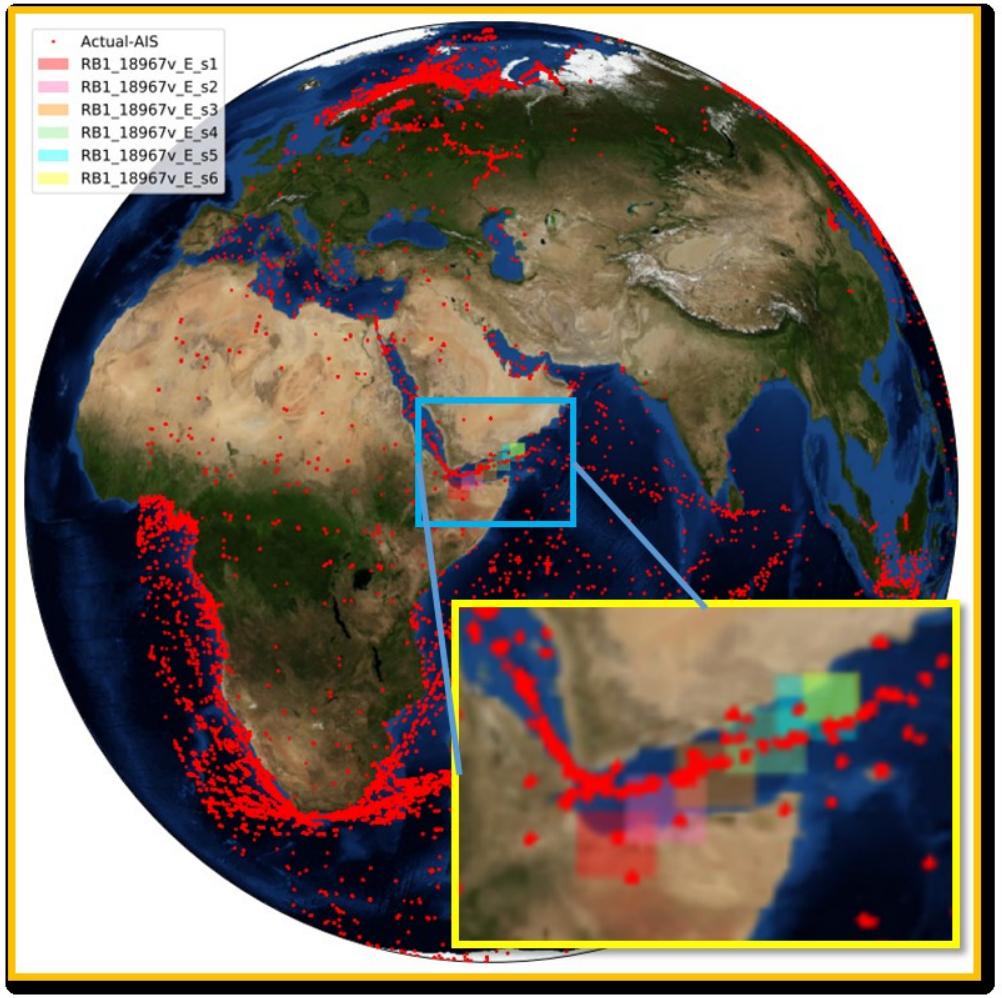
2	DIGNITY ACE	MMSI-311002900	2021-08-07 23:55:00	13.075	113.382	225	17
3	DIGNITY ACE	MMSI-311002900	2021-08-07 23:55:00	13.075	113.382	225	17
4	DIGNITY ACE	MMSI-311002900	2021-08-07 23:55:00	13.075	113.382	225	17
5	DIGNITY ACE	MMSI-311002900	2021-08-07 23:55:00	13.075	113.382	225	17
6	DIGNITY ACE	MMSI-311002900	2021-08-07 23:55:00	13.075	113.382	225	17
7	DIGNITY ACE	MMSI-311002900	2021-08-07 23:55:00	13.075	113.382	225	17
12	GASLOG GEOR...	MMSI-310800000	2021-08-07 23:27:59	15.9067	115.802	21	15
13	GASLOG GEOR...	MMSI-310800000	2021-08-07 23:27:59	15.9067	115.802	21	15
14	GASLOG GEOR...	MMSI-310800000	2021-08-07 23:27:59	15.9067	115.802	21	15
15	GASLOG GEOR...	MMSI-310800000	2021-08-07 23:27:59	15.9067	115.802	21	15
16	GASLOG GEOR...	MMSI-310800000	2021-08-07 23:27:59	15.9067	115.802	21	15
17	GASLOG GEOR...	MMSI-310800000	2021-08-07 23:27:59	15.9067	115.802	21	15
50	TRANG AN 08	MMSI-457193000	2021-08-07 23:28:03	16.2733	108.548	156	11
51	TRANG AN 08	MMSI-457193000	2021-08-07 23:28:03	16.2733	108.548	156	11
52	TRANG AN 08	MMSI-457193000	2021-08-07 23:28:03	16.2733	108.548	156	11
53	TRANG AN 08	MMSI-457193000	2021-08-07 23:28:03	16.2733	108.548	156	11
54	TRANG AN 08	MMSI-457193000	2021-08-07 23:28:03	16.2733	108.548	156	11
55	TRANG AN 08	MMSI-457193000	2021-08-07 23:28:03	16.2733	108.548	156	11
56	TRANG AN 08	MMSI-457193000	2021-08-07 23:28:03	16.2733	108.548	156	11

Multiple messages corresponding to same MMSI at same time stamp was observed.

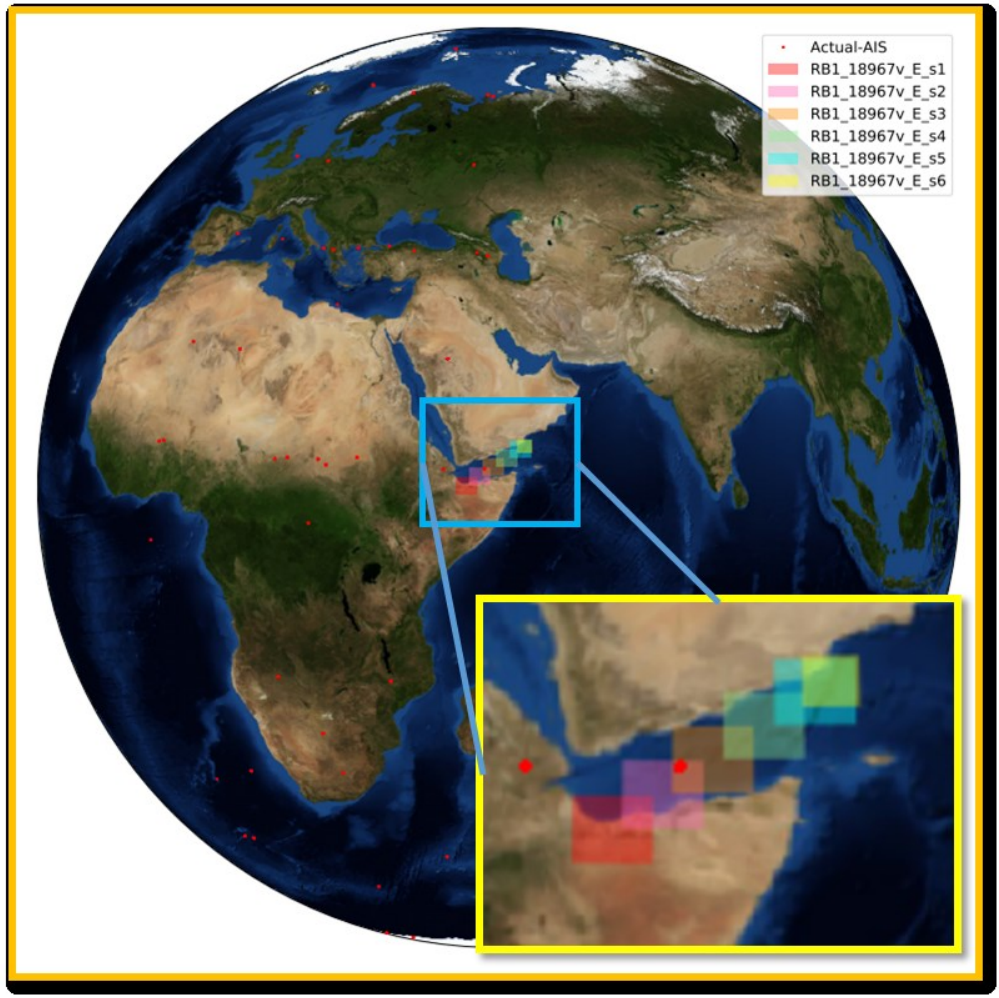
Experience in EOS01(RISAT-2B) Maritime Mode SAR Data & NOVASAR AIS Data

NOVASAR AIS DATA BEFORE APPLYING FILTER| STRIP ID -18967



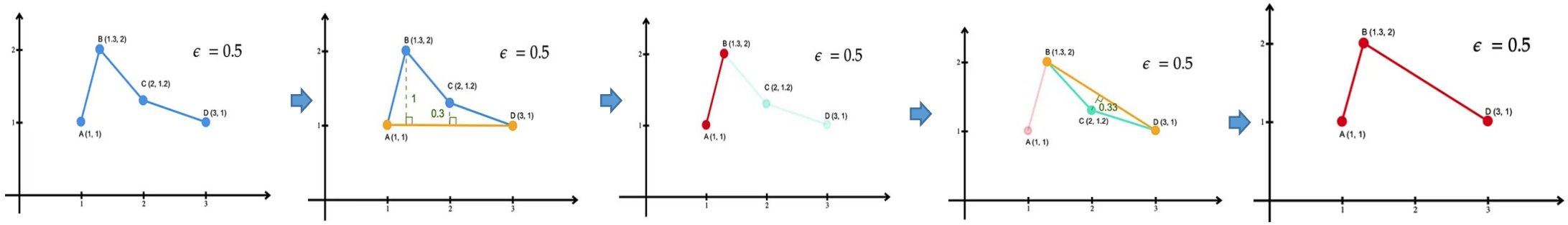
AIS Data[SAR-time – 2 hours: SAR-time + 2 hours]

NOVASAR AIS DATA AFTER APPLYING FILTER | STRIP ID -18967

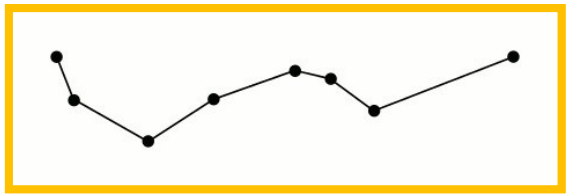


Douglas Peucker Algorithm for Trajectory Compression

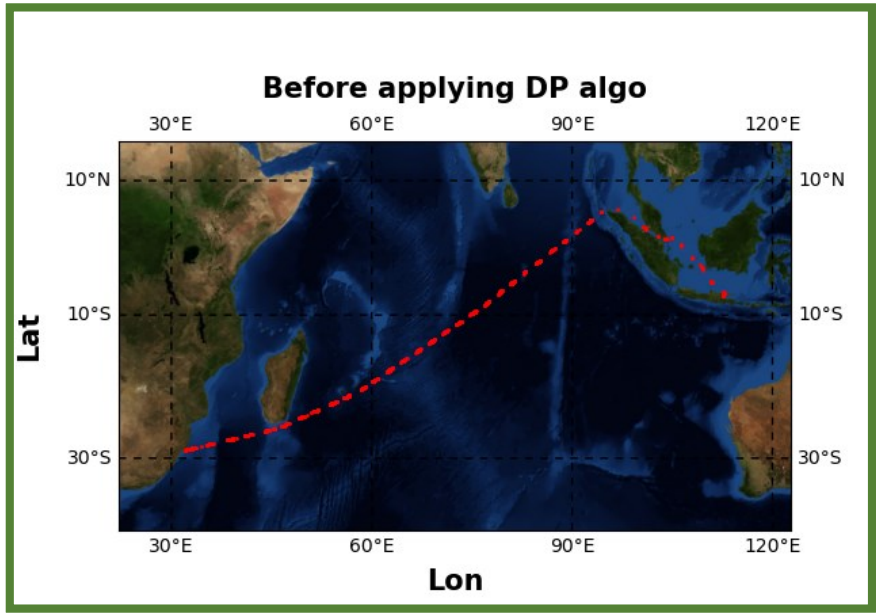
- Douglas–Peucker (DP) is a cartographic/line generalization/waypoint simplification algorithm also known as polynomial approximation algorithm.
- It basically reduces the number of points in a curve/line without losing the shape of the curve/line, based on some tolerance parameter 'epsilon' (ε).
- The algorithm starts by identifying the start and end points of the polyline which are called as the anchor point and the floating point, respectively. It works iteratively.
- It first draws a line joining the first and the last point of the curve, it then checks which point in between is the farthest away from the line using "perpendicular distance" to calculate the distance from the point to the line. If the point is closer than the threshold (ε), then the point is removed, if not then the curve is split into two parts:
  - From the 1st point up to the outlier, including the outlier.
  - The outlier and the remaining points.
- It has extensive applications in time series data analysis where in data is smoothened out without losing much information.

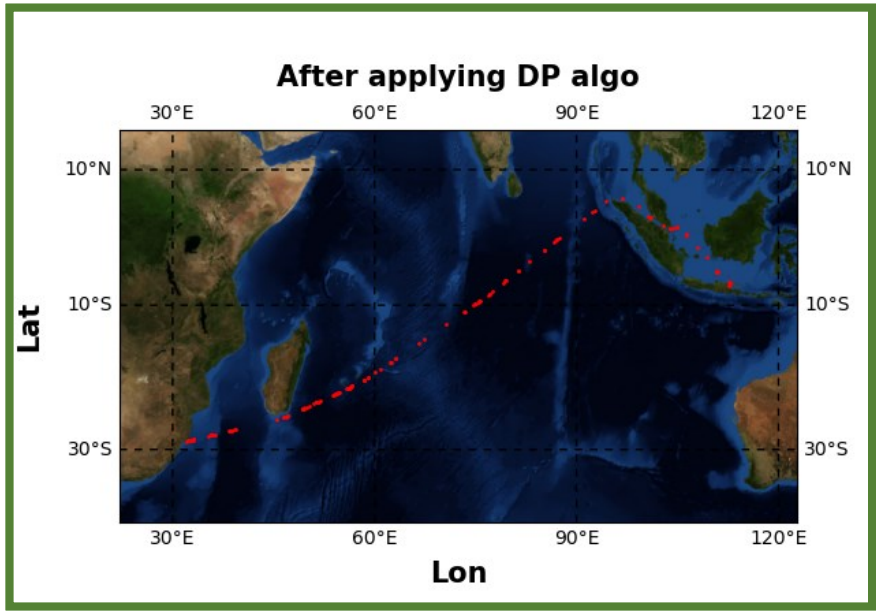


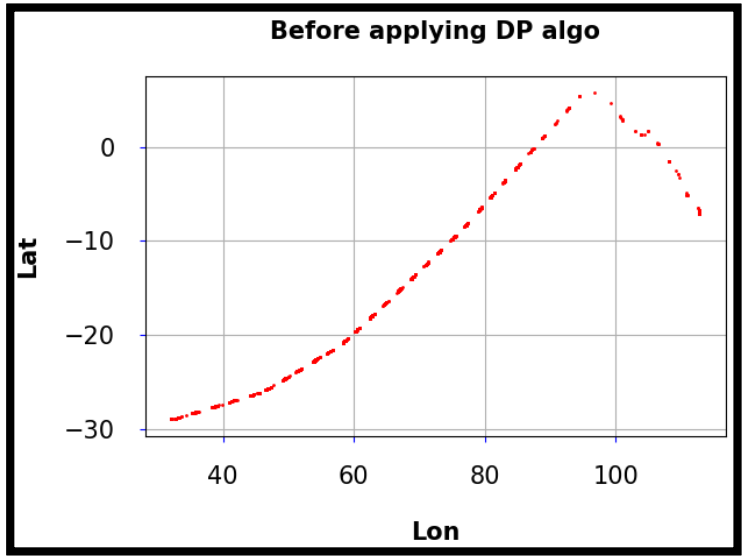
Example



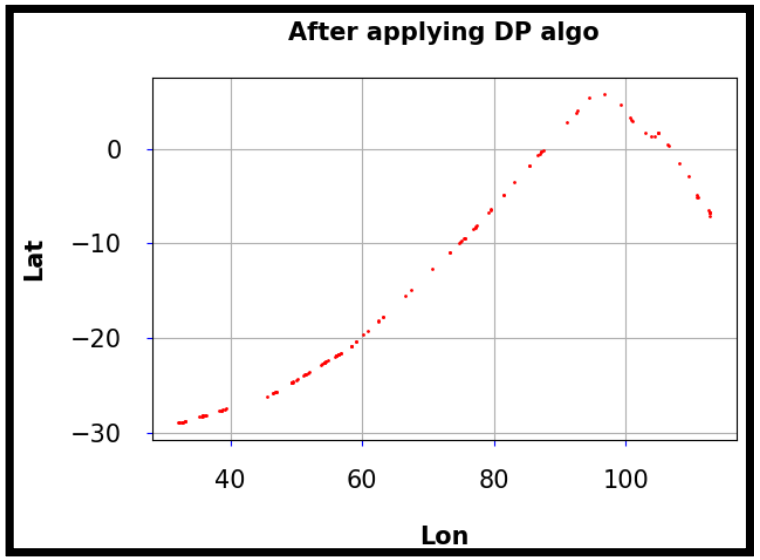
Application of DP Algorithm on MMSI: 419065000 SHIP-TYPE: Towing Vessel



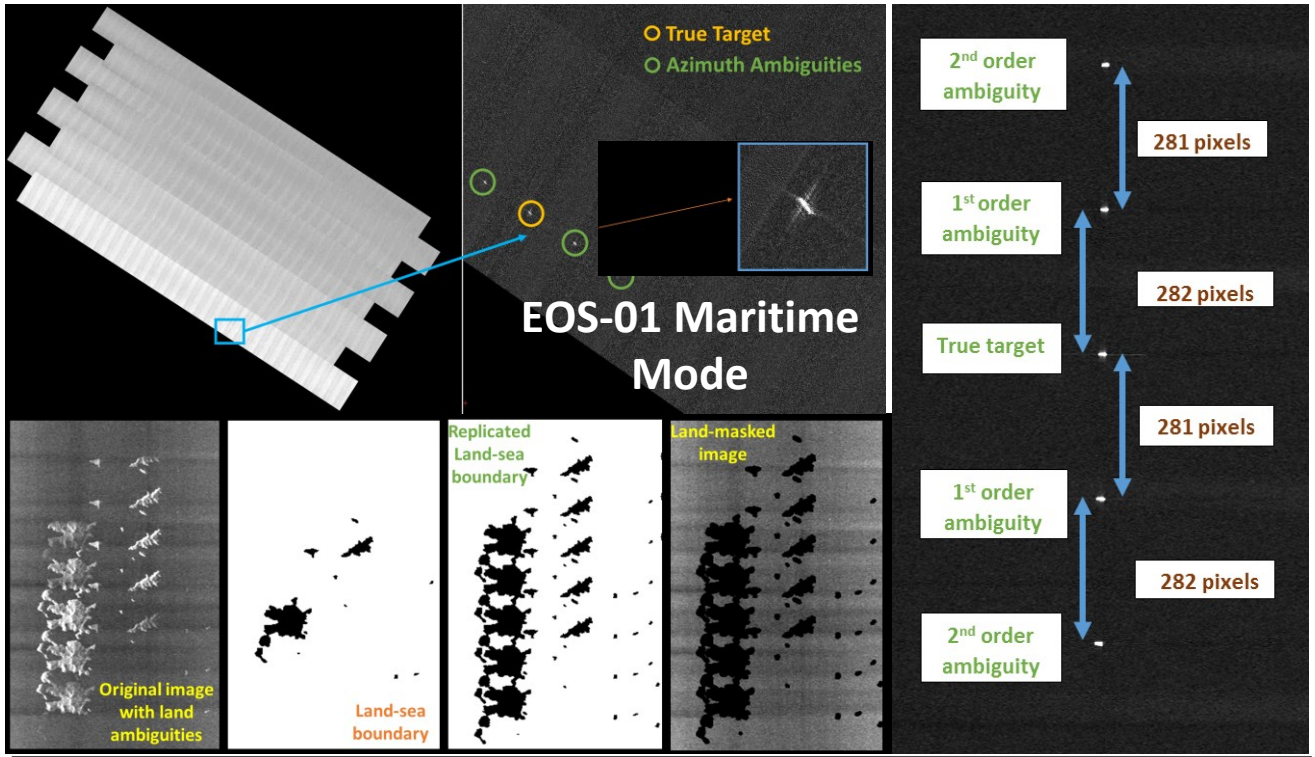


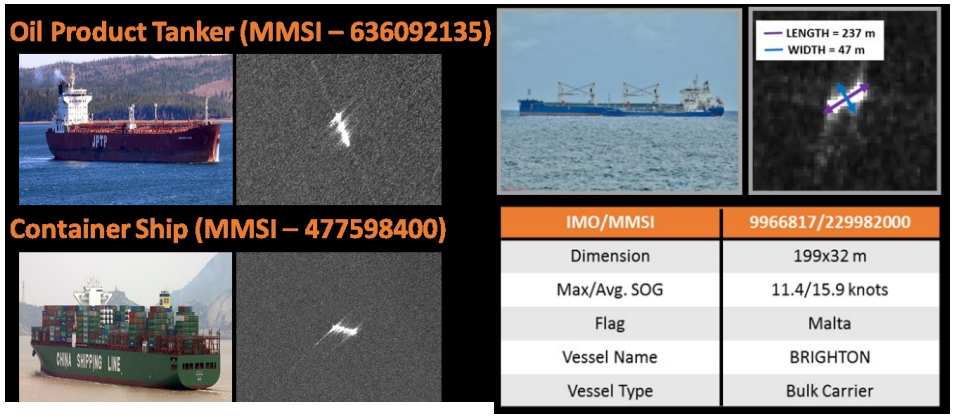


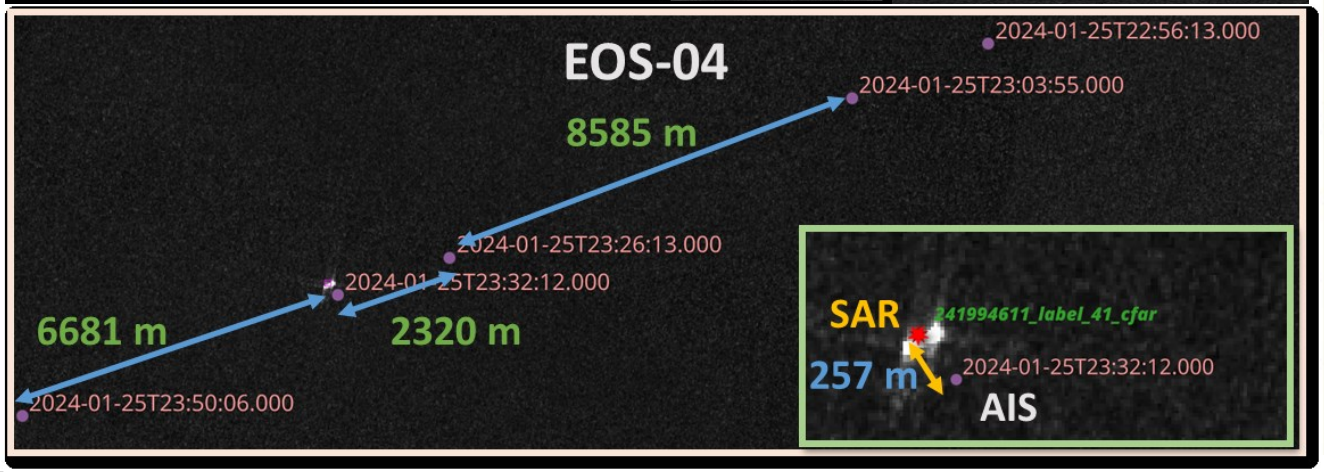
MMSI	419065000
#points before DP	2648
#points after DP	132

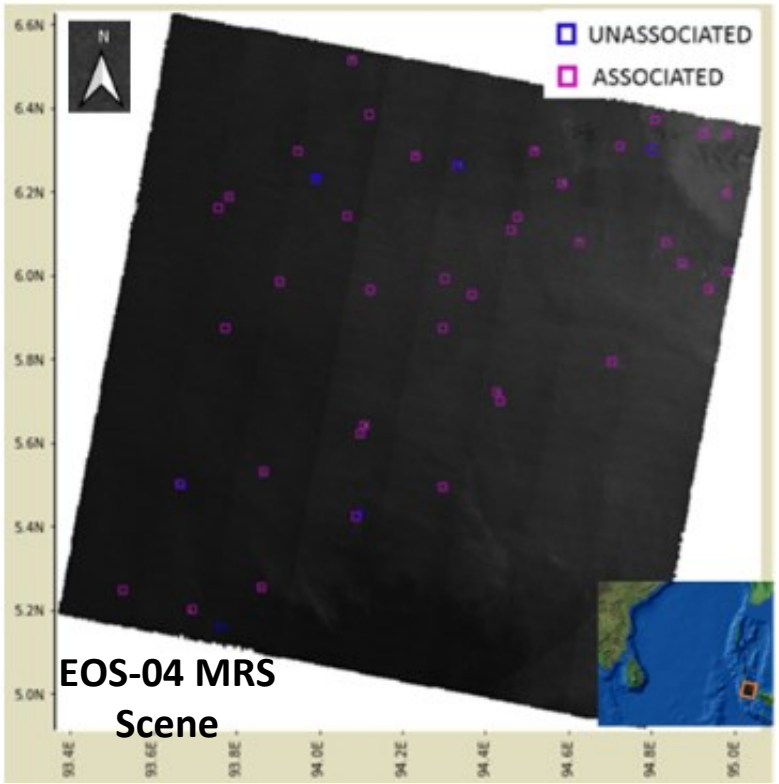


Example of EOS-01/EOS04 SAR SHIP-AIS Association

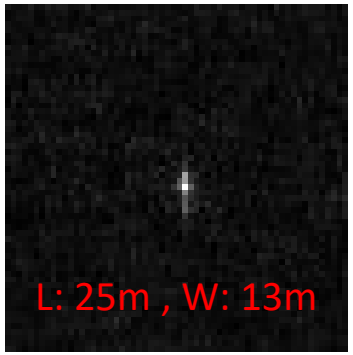




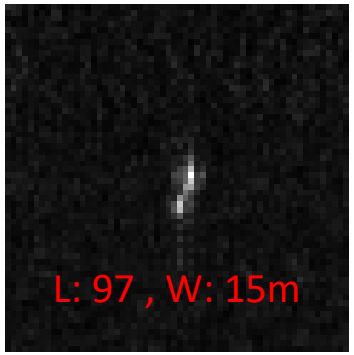




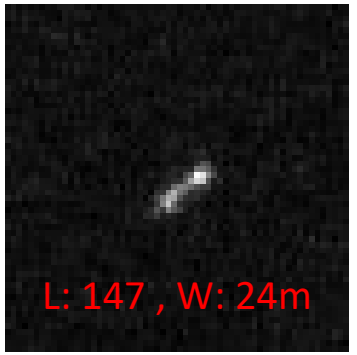
AIS Associated Ship Chip samples with their dimensions – EOS01(RISAT-2B)



RB1_18967v_W_s4S005



RB2_11527v_W_s1S006



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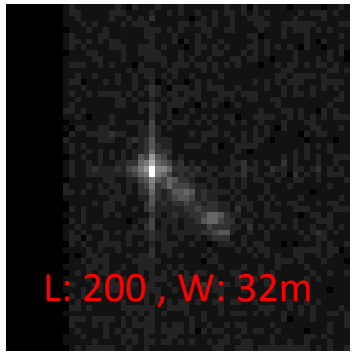

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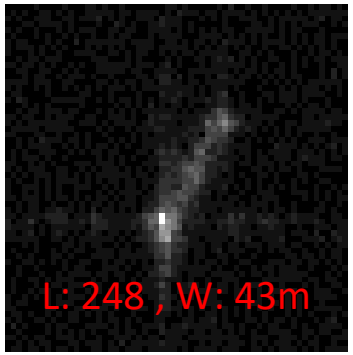

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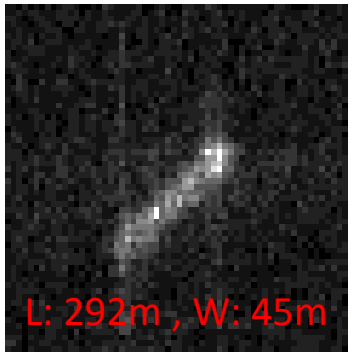

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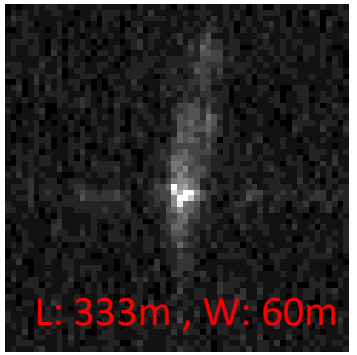
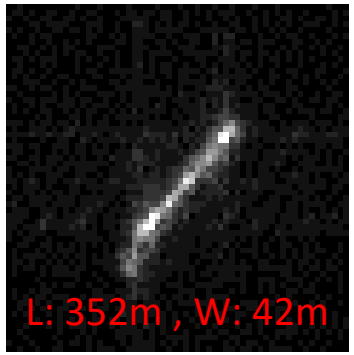
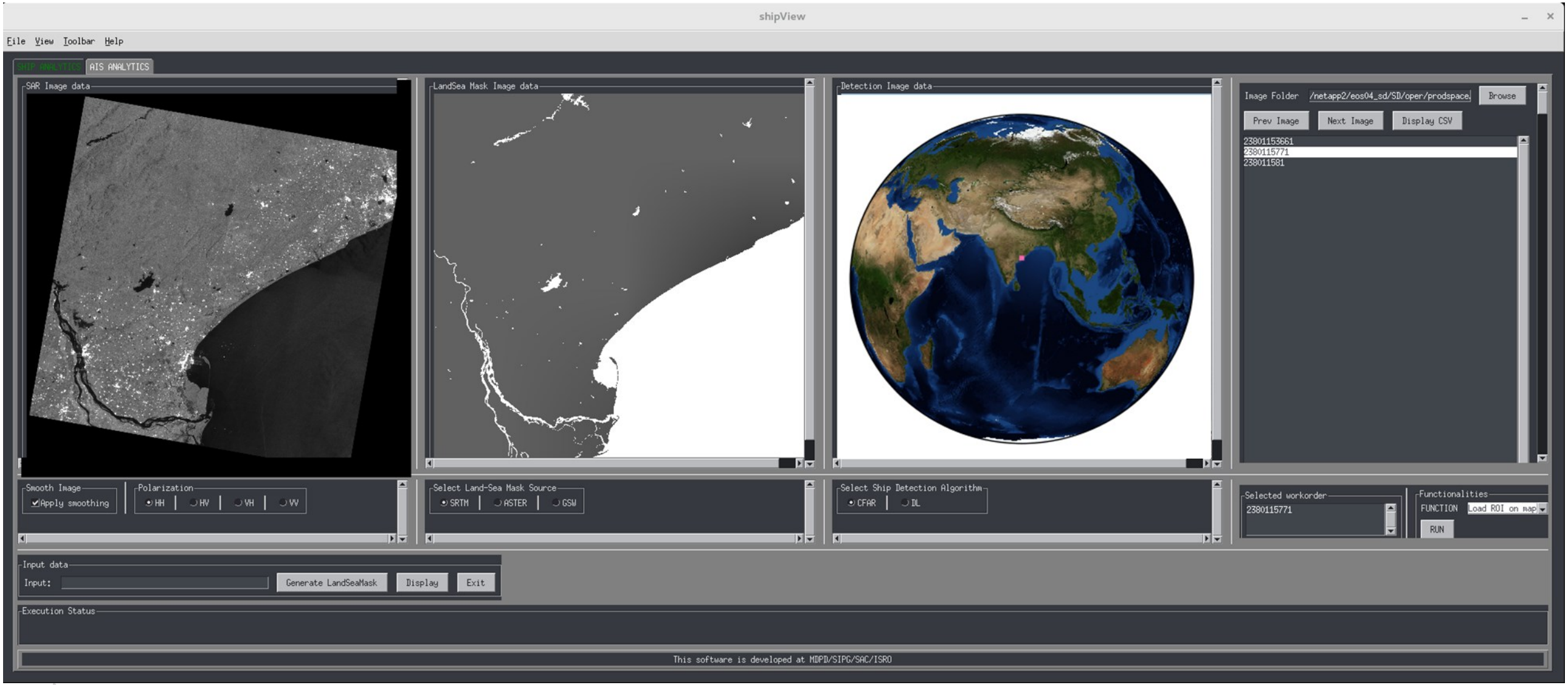


RB2_11527v_W_s3S005

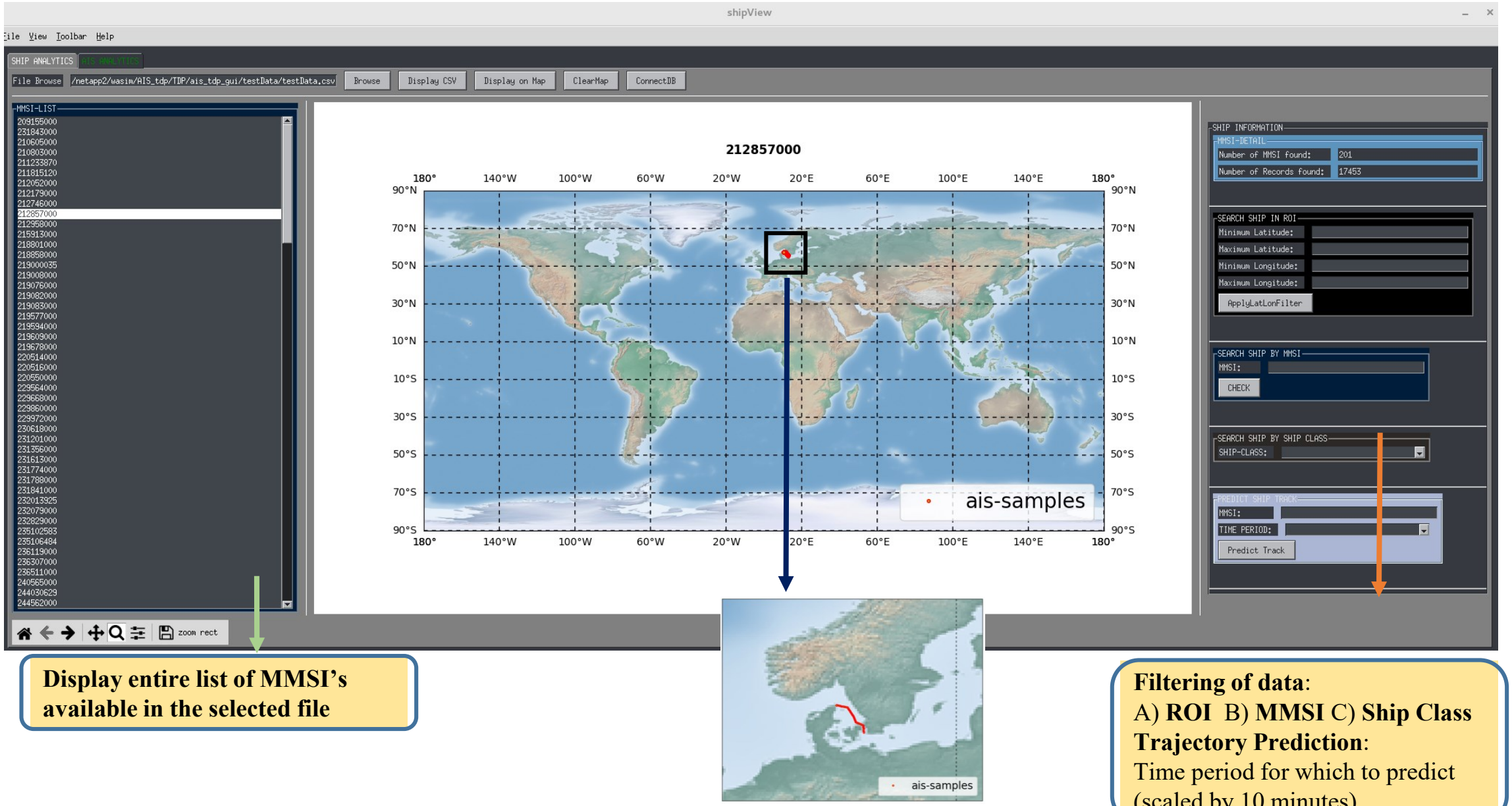


RB2_11221v_W_s3S003

GUI Framework for SAR Ship Detection/AIS Analytics



GUI Framework for SAR Ship Detection/AIS Analytics

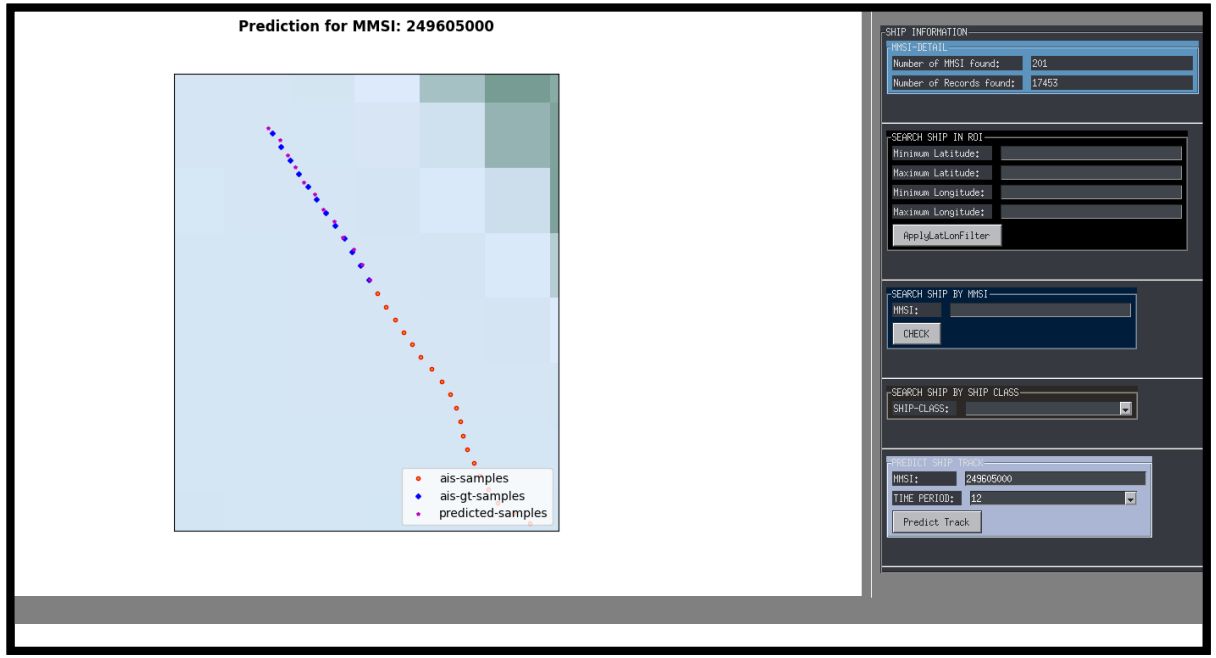


Display entire list of MMSI's available in the selected file

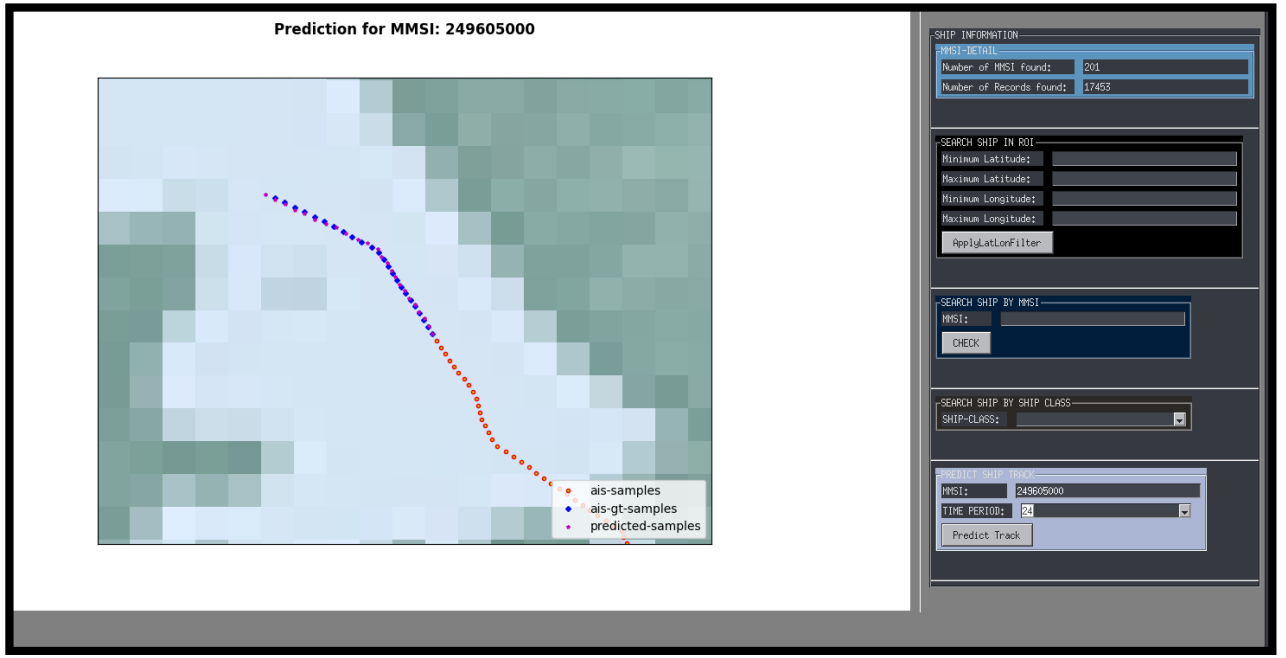
Filtering of data:
A) **ROI** B) **MMSI** C) **Ship Class**
Trajectory Prediction:
Time period for which to predict (scaled by 10 minutes)

Example of AIS Trajectory Prediction

MMSI: 249605000



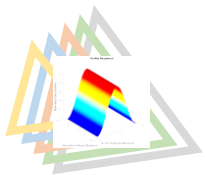
Prediction for next 2 hours



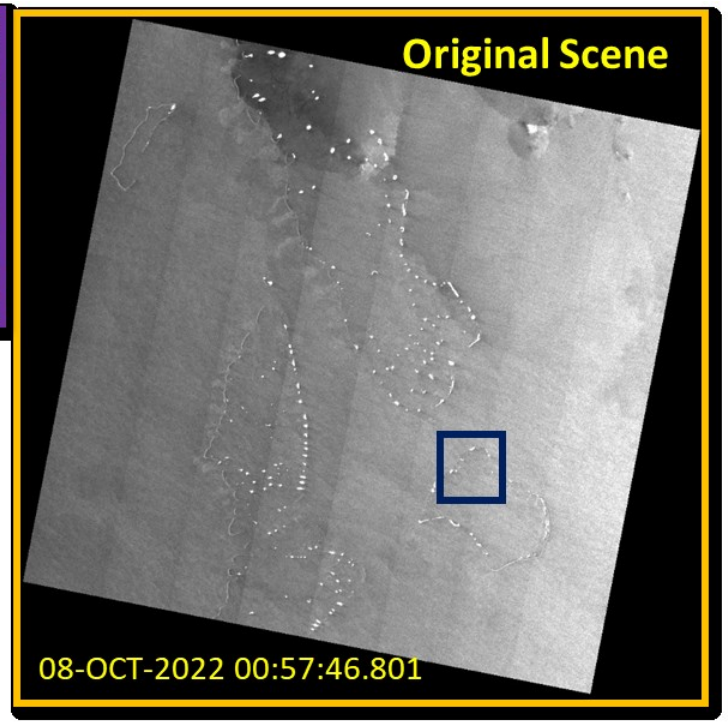
Prediction for next 4 hours

Thank You

For any queries, please contact: **Wasim** (**wasimakram@sac.isro.gov.in**)



Type of False Alarm – Case: 1 – Improper Island Masking



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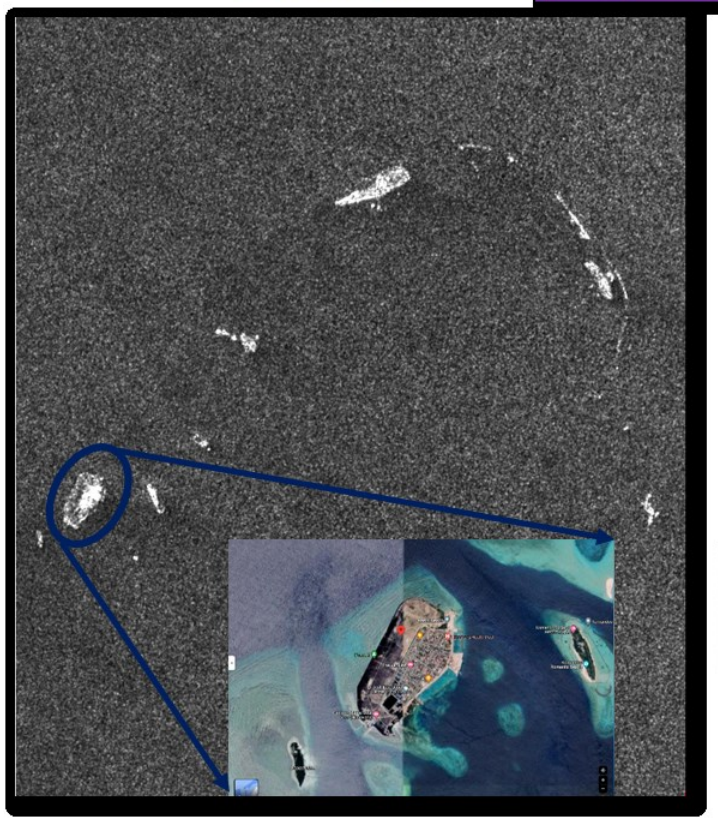
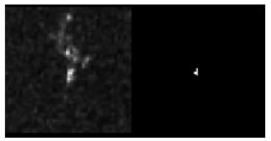
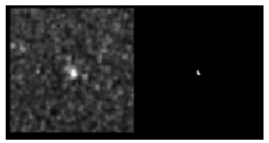
Sub-Image

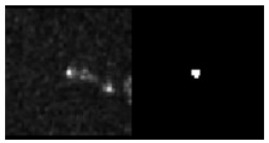




F.A. 1

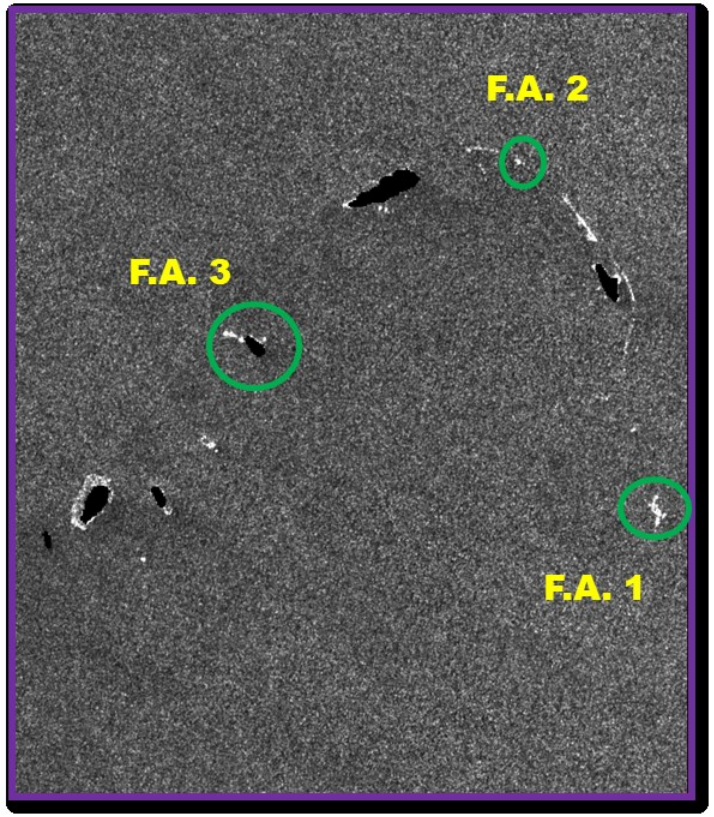


F.A. 2

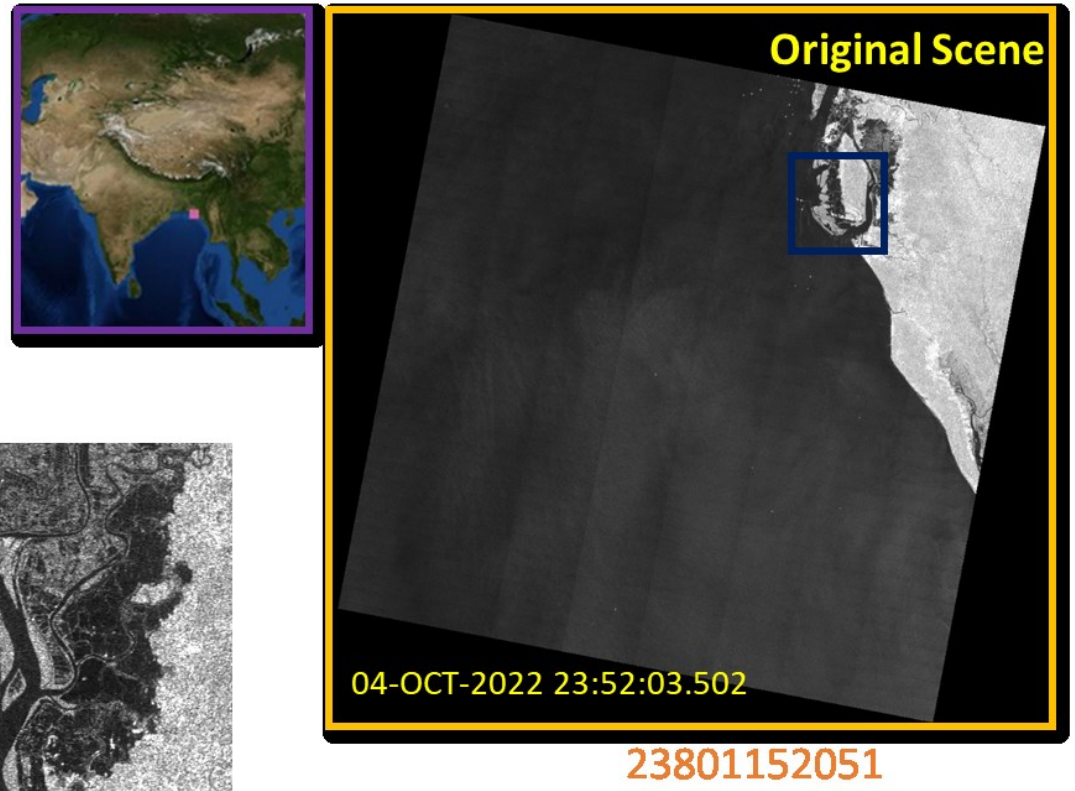


F.A. 3

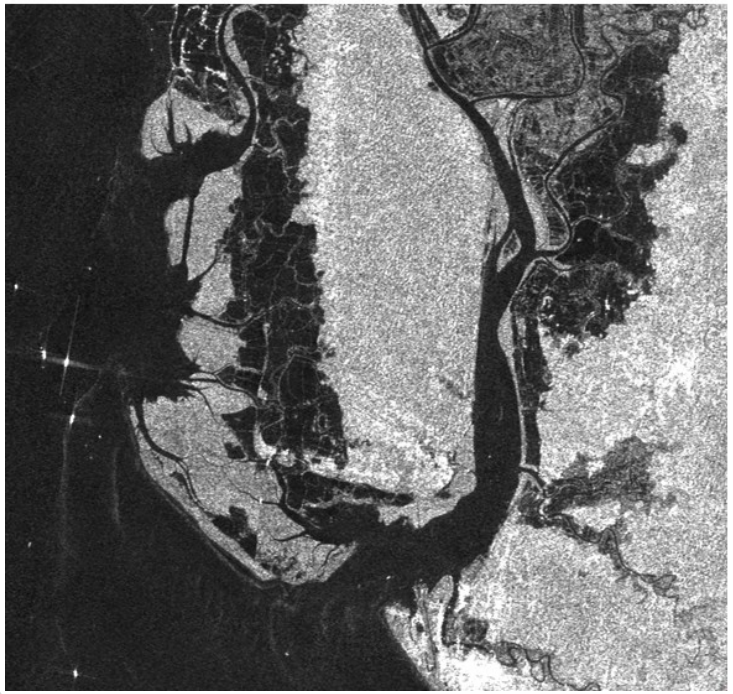
Land-masked sub image



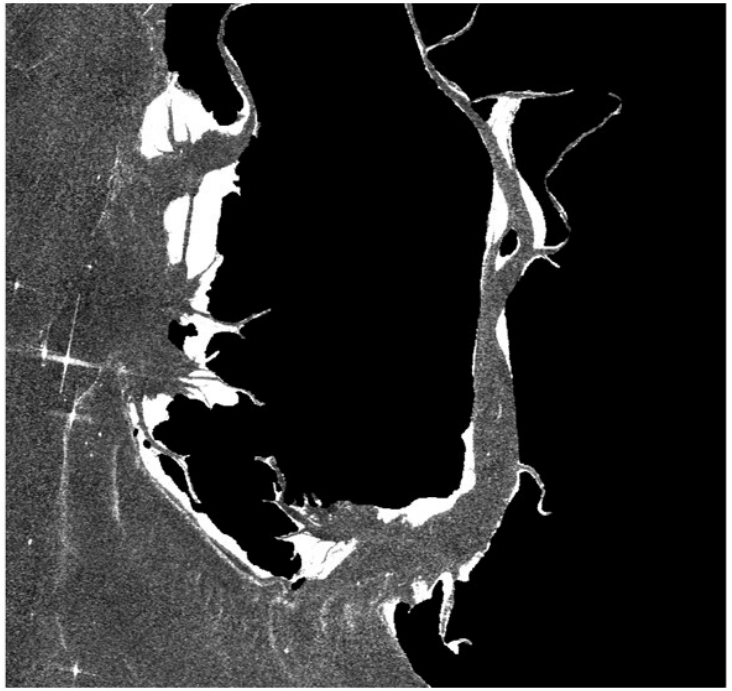
Type of False Alarm – Case: 2 – Improper Land Masking/Rain Seasonal Impact



Sub-Image



Land-masked sub image



Type of False Alarm – Case: 3 – Side Lobes

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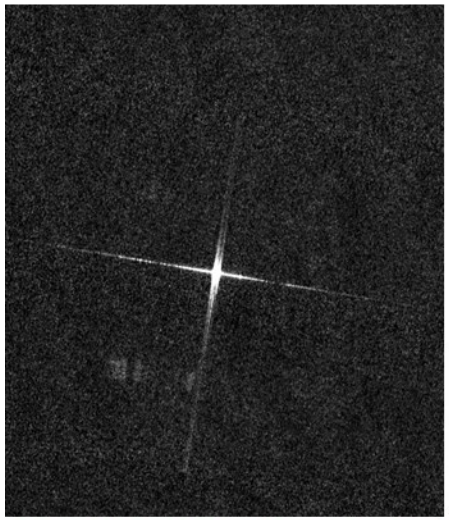
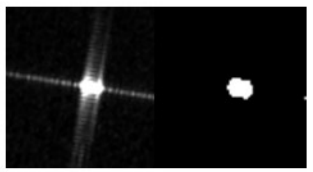
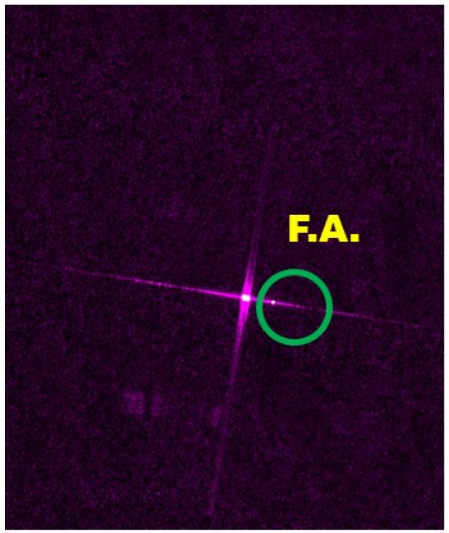
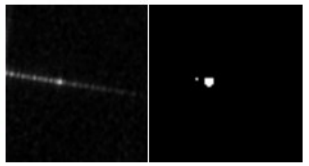
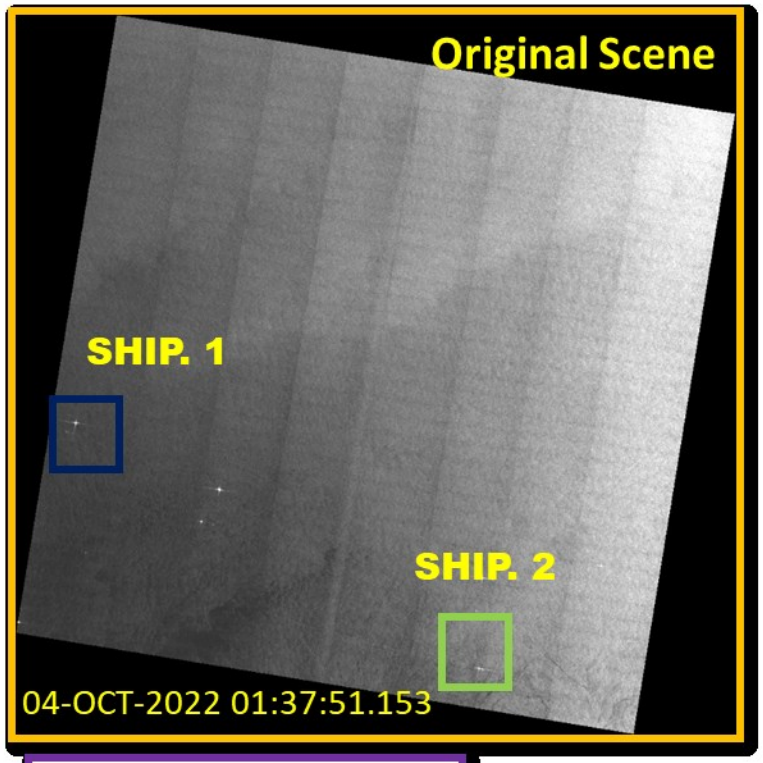
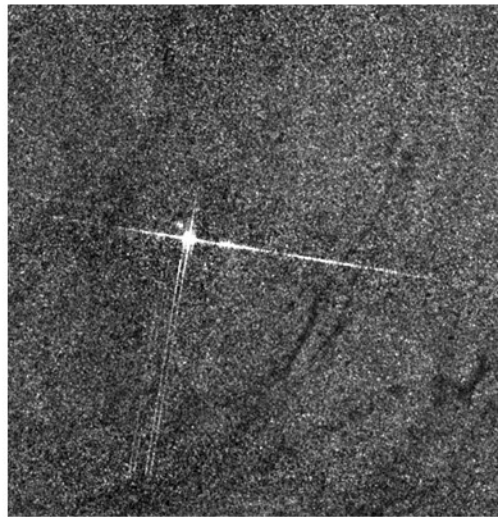


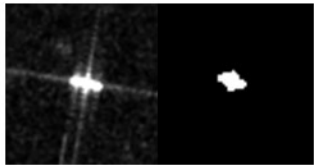


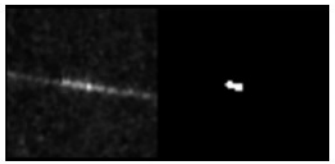


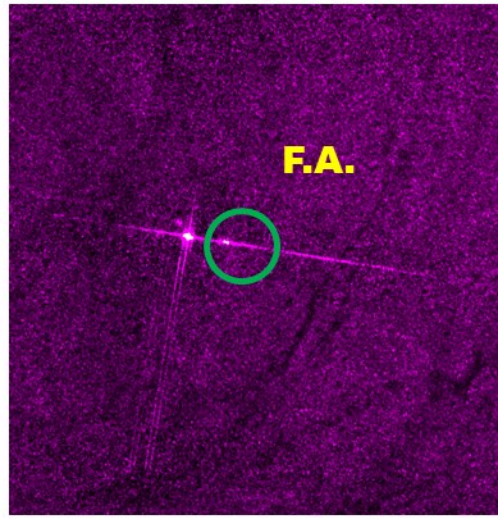




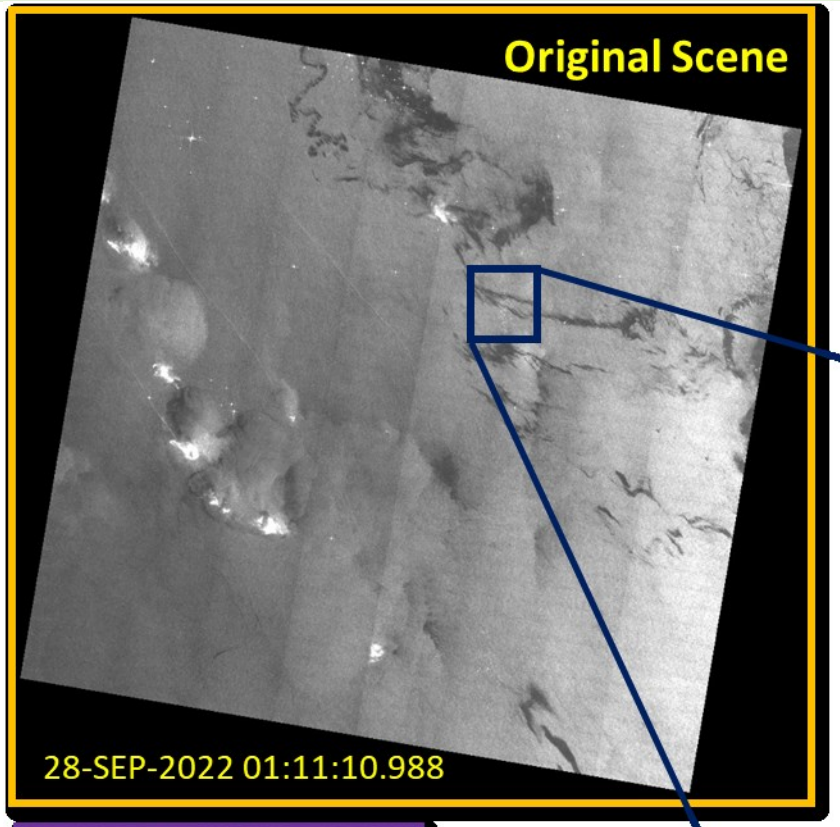








Type of False Alarm – Case: 4 – Range Ambiguity



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