**EO–SAR Change Detection Analysis Report**
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Location: **Delhi**
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1. **Introduction (study area description)**

The chosen Region of Interest (ROI) for this study is the Karachi Port, one of the busiest and most strategically significant maritime gateways in South Asia. As a major hub for commercial shipping, naval operations, and cargo logistics, Karachi Port experiences continuous vessel movement and infrastructural activity

2**. Datasets Used**

2.1 **Sentinel-1 (SAR)**

**Product:** Sentinel-1A GRD

**Polarization:** VV

**Spatial Resolution:** ~10 m

**Acquisition Dates:**

**Pre-event:** 2025-10-10

**Post-event:** 2025-10-22

**Source:** ASF Alaska Satellite Facility

2.2 **Sentinel-2 (Optical)**

**Product:** Sentinel-2 S2A/S2B

**Bands Used:** B02 (Blue), B03 (Green), B04 (Red), B08 (NIR) — 10 m

**Acquisition Dates:**

Pre-event: 2025-10-09

Post-event: 2025-10-12

2.3 **Region of Interest (ROI)**

**Format:** GeoJSON polygon

**Purpose of ROI Selection:**

To monitor ship movements, berth occupancy, and infrastructure changes, to detect abnormal vessel activity, potential illegal or unregistered ship movement, or operational anomalies.

**3.** **Data Acquisition (Automated)**

**Scripts / Notebooks Used:**

**data_acquisition_sentinel2.ipynb** – Uses Sentinelsat to programmatically download Sentinel-2 optical imagery

**data_acquisition_sentinel1.ipynb** – Uses ASF Search API (asf_search Python client) to download Sentinel-1 SAR imagery

**Authentication & API Access:**

**Sentinel-2:** Authenticates via Copernicus Data Space Ecosystem (CDSE) using OAuth Keycloak token with user-provided credentials.

**[Note:** Need to create an account on https://browser.dataspace.copernicus.eu/ ]

**Sentinel-1:** Authenticates with the ASF API using username and password, providing access to GRD products filtered by orbit and beam mode.

**[Note:** Need to create an account on https://urs.earthdata.nasa.gov/ ]

4. SAR Preprocessing (SNAP / QGIS)

| Step | Description | Example Output Filename |
|---|---|---|
| 1. Apply Orbit File | Improves geolocation accuracy by using precise orbit state vectors | S1A_IW_GRDH_1SDV_20251010T133537_Orb.data<br>S1A_IW_GRDH_1SDV_20251022T133537_Orb.data |
| 2. Thermal Noise Removal | Removes background thermal noise artifacts | S1A_IW_GRDH_1SDV_20251010T133537_Orb_tnr.data<br>S1A_IW_GRDH_1SDV_20251022T133537_Orb_tnr.data |
| 3. Radiometric Calibration ($\sigma^o$ VV) | Converts digital numbers (DN) to backscatter values | S1A_IW_GRDH_1SDV_20251010T133537_Orb_tnr_Cal.data<br>S1A_IW_GRDH_1SDV_20251022T133537_Orb_tnr_Cal.data |
| 5. Range–Doppler Terrain Correction | Corrects geometric distortions using SRTM DEM and produces a geocoded image | S1A_IW_GRDH_1SDV_20251010T133537_Orb_tnr_Cal_TC.data<br>S1A_IW_GRDH_1SDV_20251022T133537_Orb_tnr_Cal_TC.data |
| 6. subset images | Subset according to ROI | subset_of_S1A_IW_GRDH_1SDV_20251010T133537_Orb_tnr_Cal_TC.data<br>subset_S1A_IW_GRDH_1SDV_20251022T133537_Orb_tnr_Cal_TC.data |
| 7. Export GeoTIFF | Saves the final north-aligned, terrain-corrected SAR product for analysis | subset_of_S1A_IW_GRDH_1SDV_20251010T133537_Orb_tnr_Cal_TC.tif<br>subset_S1A_IW_GRDH_1SDV_20251022T133537_Orb_tnr_Cal_TC.tif |
| 8. Re-subset (pixel matching two images) | Based on the model making need both images need pixel matching | subset_pixel_of_S1A_IW_GRDH_1SDV_20251010T133537_Orb_tnr_Cal_TC.tiff<br>subset_pixel_S1A_IW_GRDH_1SDV_20251022T133537_Orb_tnr_Cal_TC.tiff |

[Note: re-subsetting was needed for the same pixel matching of pre- and post-imagery]

5. Optical Preprocessing (QGIS/Python)

| Step | Description | Example Output Filename |
|---|---|---|
| 1. Band composite | B2, B3, B4, B8 | S2_merged_RGBNIR_pre.tiff<br>S2_merged_RGBNIR_post.tiff |
| 4. resample/ROI Clipping | Clipped to Karachi Port polygon | S2_merged_20251009_CLIP_pre.tiff<br>S2_merged_20251012_CLIP_post.tiff |

**6. Change Detection Methods**

6.1 **Sentinel2 (PCA-based change detection)**

**Difference Image Calculation:** You compute diff = post - pre across multiple bands, which is a standard first step in change detection.

**Principal Component Analysis (PCA):** PCA is applied to the multi-band difference image to reduce dimensionality and highlight the most significant variance, which typically corresponds to areas of change.

**Thresholding and Morphological Filtering:** After PCA, a threshold is applied to isolate significant changes, followed by binary morphological operations to remove noise.

**Object Filtering:** Region-based filtering is applied to focus on features of interest (ships in this case).

**6.2 Sentinel-1 (Method 1- Object-Based Unified Change Detection (OBCD))**

Data Preparation: Preprocessed Sentinel-1 VV SAR images (pre-event and post-event) were loaded and converted to dB scale for consistent backscatter representation. Very low backscatter areas were masked to avoid false detections in water or shadows.

Pixel-Level Analysis: Computed absolute difference between pre-event and post-event images. Identified pixel-level changes exceeding a percentile threshold (e.g., 96th percentile).

Object Segmentation:

High-intensity regions in each image were segmented using thresholding and morphological operations to isolate individual objects (ships, bright infrastructure). Connected components labeling was applied to identify objects in pre- and post-event images.

Object-Based Change Detection:

Appearance: Objects present in post-event but absent in pre-event.

Disappearance: Objects present in pre-event but absent in post-event.

Intensity Change: Objects present in both images whose mean backscatter changed above a threshold.

Post-Processing: Small objects below a minimum area (e.g., 50 pixels) were removed to reduce noise. Morphological opening and closing cleaned up the binary mask.

Output & Visualization: Produced a binary change mask highlighting detected changes. Changes were overlaid in red on the post-event SAR image for visual inspection.

**7. Quality Checks**

**7.1 Edge Cases Identified:** Small vessels are occasionally missed due to thresholding or despeckling. Very bright objects near shorelines can be misclassified as land changes when they are actually water reflections.

**7.2 False Detections Observed:** Some water areas appear as false positives due to speckle noise or residual SAR artifacts. Temporary bright spots (e.g., moving ships, wakes) are sometimes flagged as persistent changes. Areas with minimal difference between pre-/post-images but extreme local contrast occasionally trigger change detection.

**7.3 Usability Challenges:** Large image sizes increase processing time, especially during object-based labeling and morphological cleaning. Threshold values (percentiles for bright/dark detection) require tuning per ROI or image scene.

8. **Recommendations (Product & Workflow Improvements)**

8.1 **Technical Workflow Improvements: Automated Preprocessing Pipelines**, Integrate a sequential preprocessing workflow: download → calibration → speckle filtering → coregistration → change

detection. **Quality Control Metrics** Include automatic metrics like the number of detected objects, total changed area, and signal-to-noise ratio. **Batch Processing & Logging,** enable batch processing of multiple ROIs with clear logs of thresholds used and outputs generated. Store intermediate outputs (despeckled images, masks) for reproducibility and debugging.

8.2 **Product / UI Improvements (tool):** Interactive Visualization, ability to switch layers between sensors interactively, hovering over the map shows lat/lon, pixel values, or changes intensity, statistics Panel, Filter Changes, batch Processing, change Animation, automatic reporting.

9. **Conclusion:**

This assignment demonstrates a complete, reproducible workflow integrating Sentinel-1 SAR and Sentinel-2 optical imagery for cross-sensor ship change detection and port activity monitoring at Karachi Port.