Open SAR Data Analysis Techniques vs. Intelligence

Can the wide availability of free satellite data, particularly in the SAR domain, truly support the research and analysis of intelligence-related information?

by Planetek Italia

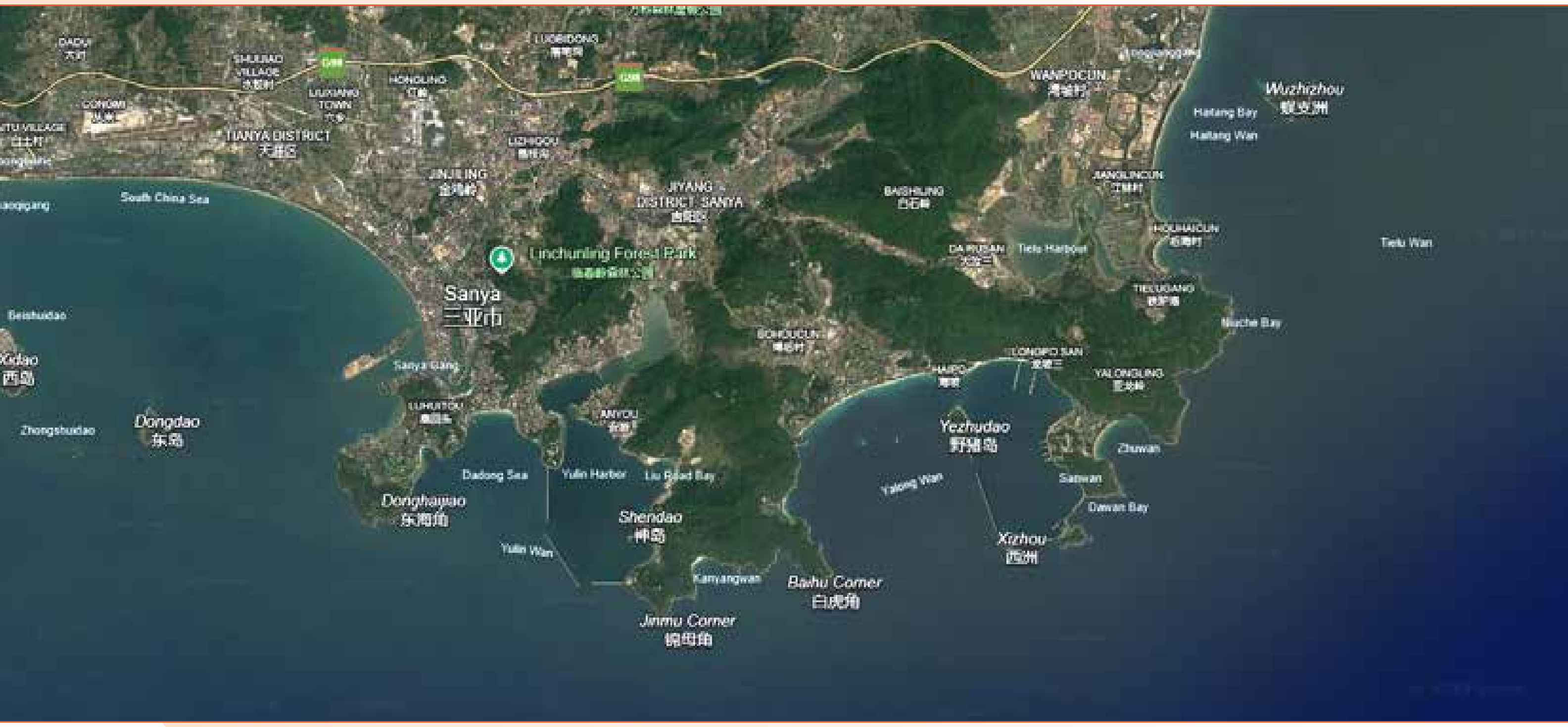

Fig. 1 – Geographical Overview of the Yulin Naval Base

The Earth observation missions from space carried out by the Copernicus constellation of the European Space Agency (ESA) have made a wide variety of data more readily available across the entire electromagnetic spectrum, with a notably high revisit frequency. In particular, the Sentinel-1 (SAR) constellation has been providing its products consistently and effectively since 2014, to the point where one may wonder whether it is possible to capitalize on such a highly reliable resource.

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possible to capitalize on such a highly reliable resource.
Imagery Intelligence (IMINT) has traditionally relied on high-resolution optical data, but the advancement of satellite radar sensors like Sentinel-1 has significantly expanded surveillance capabilities, especially under adverse weather conditions or at night. This article illustrates the use of a Sentinel-1 SAR time series to monitor naval activities at the Yulin naval base in the South China Sea, from January 2024 to June 2025, using the Copernicus Data Space Ecosystem.

Yulin Naval Base – Geographical Context and Strategic Significance

• Overview

The Yulin naval base, located on the southern coast of Hainan Island (China), is one of the most strategic naval hubs of the People's Liberation Army Navy (PLAN). The base faces the South China Sea, near the Qiongzhou Strait, southeast of Sanya, and is composed of two distinct sections:

• Yulin Ovest (Longpo) – intended for the surface fleet (Shandong aircraft carrier);

• Yulin Est – Headquartes for destroyers and frigate as well as a semi-underground base reserved for nuclear submarine in particular the Type 094 (SSBN)and Type 093A (SSN).

• Strategic Significance

Its geographical location and military assets make it a site of significant strategic interest, enabling it to fulfill roles in protection, surveillance, and power projection across all three domains: air, surface, and undersea warfare.

• Submarine nuclear deterrence: the eastern section of the base hosts Type 094 SSBNs, equipped with JL-2 and future JL-3 ballistic missiles, representing the maritime cornerstone of China's nuclear triad.

• Naval power projection: Yulin West hosts the aircraft carrier Shandong, Type 055-class destroyers, and amphibious units, enabling long-range naval and air operations.

• Control of the South China Sea: the base supports naval and aerial patrols and strengthens China's claims over the artificial islands.

• Multilayered defense: protected by HQ-9 SAM systems, coastal radar surveillance, and layered air defense systems.

Multi-temporal Monitoring of Chinese Naval Activities

The multi-temporal monitoring of naval activities at the Chinese naval base on Yulin Island was conducted using 41 Synthetic Aperture Radar (SAR) images from the Sentinel-1 satellite, acquired during the specified period. The images were processed through a dedicated workflow designed to optimize data quality and result accuracy.
The data were downloaded from the ESA website, and the tools used for the analysis included ERDAS Imagine, Radar ToolBox, Spatial Modeler, and Google Earth.
The main objective of the monitoring was to analyze movements and naval activities at the Yulin base, leveraging Sentinel-1's ability to acquire images regardless of weather conditions or sunlight. This enabled the creation of a detailed temporal dataset useful for analyzing behavioral patterns and operational anomalies.

Data Processing Workflow

P To ensure accurate analysis, a tailored pipeline was implemented for the multi-temporal analysis of radar backscatter in decibel scale. The workflow focused on relative radiometric quality, avoiding unnecessary steps for the type of analysis conducted.
The adopted workflow was as follows:

• Calibration: applied to obtain normalized radar backscatter values (σ^0) in VV polarization.

• Orbit Correction.

• Speckle Filtering: using the Lee Sigma 5x5 filter.

• Linear to dB Conversion:

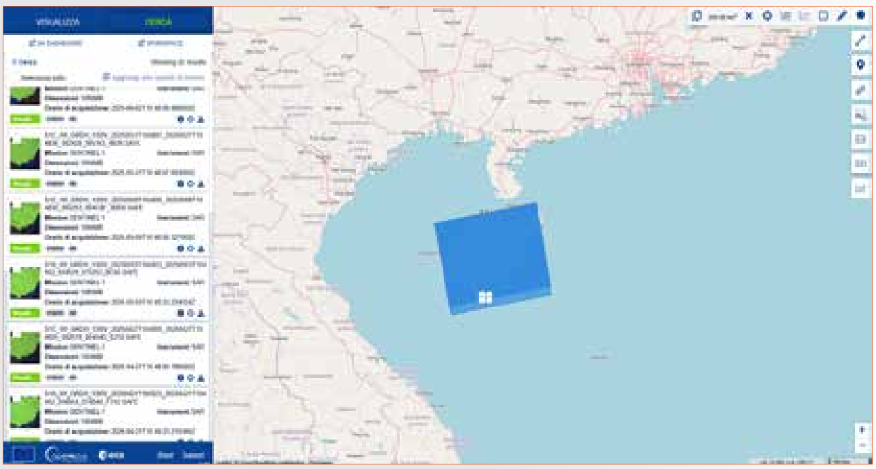

Fig. 2 - Copernicus Data Space Ecosystem

converting σ^0 values to decibel (dB) scale.
• Terrain Correction (Range-Doppler): geometric correction based on the SRTM 1Sec DEM.
• Subset (AOI Yulin): spatial cropping of the area of interest. In particular:
• Calibration
The calibration function for Sentinel-1 is used to convert the raw values (DN, digital number) contained in SAR images into physically interpretable radar backscatter values, that is, the normalized power of the signal reflected from the Earth's surface toward the sensor.
• Orbit update
Sentinel-1 is equipped with precise orbits, but ephemerides can be retroactively updated through files provided by the European Space Agency (ESA). These updates improve the geometric accuracy of the images, reduce geolocation errors, and enable accurate pixel-wise comparison between images acquired on different dates.
• Subset (AOI)
To focus on the Yulin naval base and reduce the computational load, a geographic subset was applied to the images. This process limited the analyzed area to the portion containing the base and the surrounding waters of strategic interest, eliminating irrelevant information.
• Speckle filtering
The SAR radar signal is affected by speckle, a coherent noise caused by multiple wave interference. To improve the visual and quantitative quality of the data, an adaptive filter, such as the Lee 5x5 filter, was applied, reducing noise and preserving structural details.
• Co-registration and ortho-correction
Pixel-wise co-registration was performed to align all images (pixel by pixel in relation to time) to a common geometry, which is essential for temporal comparison. Subsequently, ortho-correction was applied to correct geometric distortions introduced by the acquisition angle and topography, ensuring that the images are accurately georeferenced.
• VV Signal Transformation
Sentinel-1 dual-polarization SAR images include VV and VH polarizations. For the analysis of naval activities, the VV channel was used, as it is more sensitive to targets with complex geometries, such as ships. The amplitude values were converted to logarithmic intensity expressed in dB, as this allows for a clearer comparison between pixels and greater sensitivity in detecting temporal variations, emphasizing the relative differences between values, which is useful for identifying anomalies or patterns in the dataset.
• Stack generation
The generation of a SAR image stack serves to combine multiple radar images acquired at different times into a single coherent dataset, facilitating multi-temporal analysis. The "stack" is therefore a common basis on which to perform comparisons over time, pro-

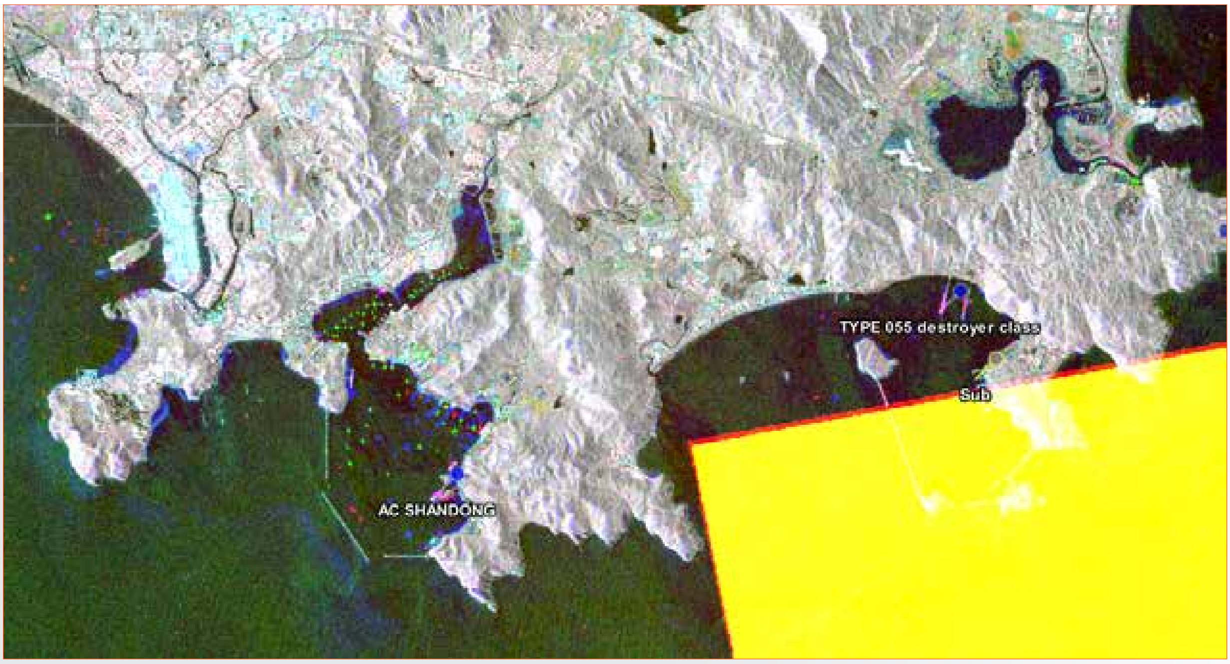

Fig. 3 – Multitemporal stack (the yellow area is a temporal decorrelation between images, due to the variation in the field covered during the 18 months)

file extractions, or advanced analyses such as interferometry, change detection, and classification.

Time series analysis

In order to observe the temporal variations that occurred in the area of interest, the analysis was carried out in two phases. The first phase involved gathering information from open sources (OSINT and SOCINT) and searching for evidence in the time series. The second phase, on the other hand, was guided by IMINT evidence processed from 41 SAR images, which made it possible to highlight the changes that had occurred over time thanks to the composition of statistics and averages of the images over time.

• Phase 1, OSINT indications

Different multispectral images were created by associating RGB colors (additive synthesis) with data from different SAR products. The images obtained allowed us to observe specific periods during which the information gathered in the OSINT (Open Source Intelligence) sector clearly showed the occurrence of events collected in the OSINT report. This method allowed us to validate the information gathered, showing the numerous naval activities observed during the 18 months of analysis, with intense movement of military ships throughout the period. In particular, the presence of the Shandong aircraft carrier at berth was monitored closely over time, accurately determining its presence or absence in port. The same was observed for other large military ships, such as the Type 055 destroyers moored in the eastern part of the base and the Type 052 destroyers.

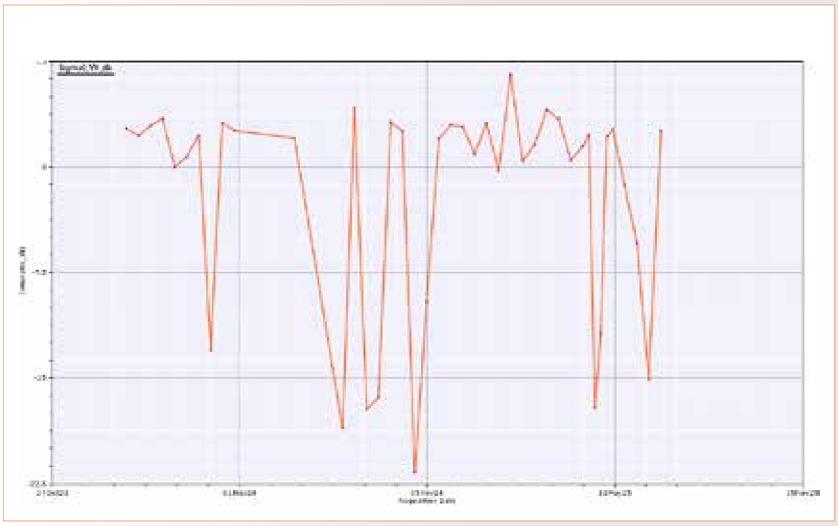

Fig. 4 Timeline of the movements of the aircraft carrier Shandong

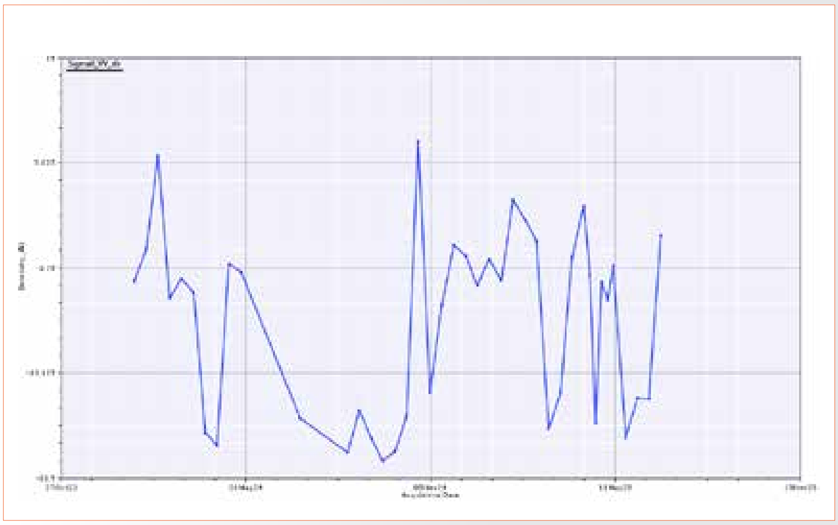

Fig. 5 Time chart of destroyer movements

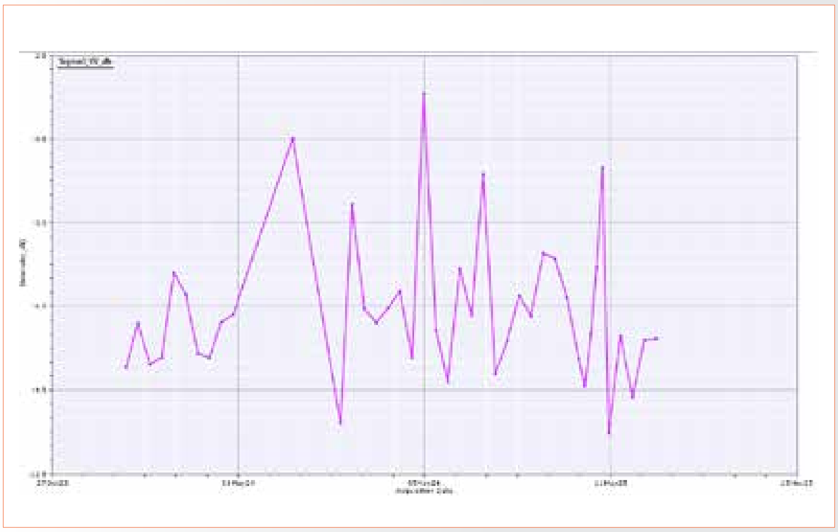

Fig. 6 Time chart of submarine movements

Both classes were characterized by great dynamism and periods similar to the absence of the Shandong aircraft carrier. The docks that typically house some Chinese nuclear submarines (Type 094 and Type 093A) also showed a certain amount of activity, often correlated in time with the naval activities of larger military ships (aircraft carriers and destroyers).

• Phase 2, evidence emerging from multitemporal stacks
With the help of the numerous images collected, statistics were compiled which, thanks to band composition, made it possible to highlight the construction of new moorings inside. In particular, the following statistics were generated:

• The CoV (Coefficient of Variation) applied to a stack of SAR images is a normalized statistic that measures how much a pixel varies over time, relative to its average. It is a very useful tool in multi-temporal SAR analysis to highlight dynamic areas, such as ships, construction sites, moving objects, or operational activities. CoV= σ/μ, where σ is the standard deviation of pixel values in the stack (in the time domain), μ is the average of the same values over time. The higher the CoV in the pixel, the greater the variation over time.

• The Minimum calculates, for each pixel in the stack, the minimum value of backscatter (σ^0) that that pixel has assumed over time. The value represents the weakest radar return observed for each pixel among all images in the series.

• The Maximum calculates the maximum value observed over time for each pixel in the time stack. The Maximum value shows you the point of maximum radar reflectivity in each pixel throughout the time series. It is very useful for: Identifying highly reflective objects that have appeared at least once (e.g., ships, containers, radar, metals) and highlighting areas of episodic or intense activity.

Analysis of the results

The analysis of the images highlighted the following main aspects:

• Operational Pattern: The images showed an increase in naval activity during certain specific periods, probably related to exercises or planned operations.

• Presence of ships of interest: It was only possible to identify specific types of military ships, thanks to their size and the specific moorings of the naval units (Aircraft Carrier Shandong, Type 055 destroyer class, and observation of the presence/absence of submarines) in known docks.

• Structure Patterns: Several expansion projects for naval

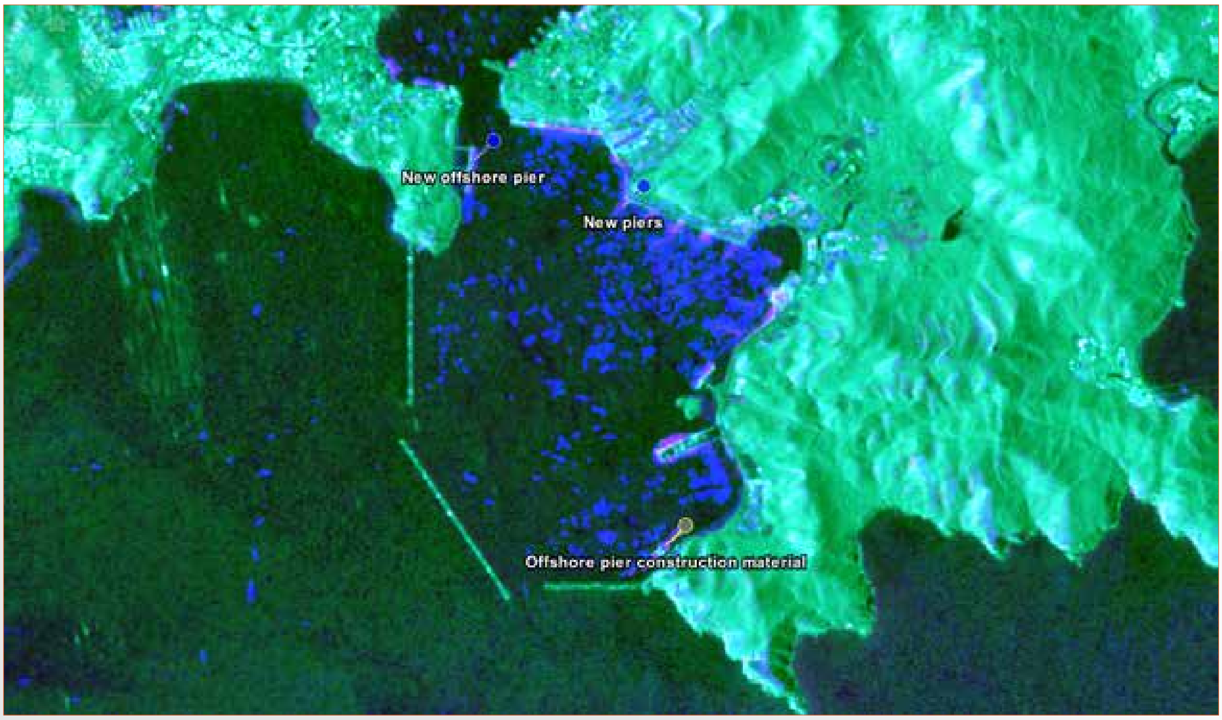

Fig. 7 - Band composition CoV, Min, Max. Elements of interest

vessel mooring structures were observed during the observation period.

Conclusions and prospects

Sentinel-1 data has proven to be very useful and effective for monitoring naval targets, given the strong contrast between the sea surface and complex metallic targets. The high observation frequency (revisit time) allows for accurate monitoring over long periods for strategic assessment. However, operational or tactical use is not feasible due to the spatial resolution characteristics of the images and the time interval between acquisitions. It is certainly a very useful tool for studying the tactics, techniques, and procedures (TTPs) of a naval base, allowing continuous monitoring of larger units and submarines over time if their traditional moorings are known. A system that activates an alarm requiring higher-performance products (in the SAR and EO domains) can certainly be integrated in order to fill the gaps in spatial and temporal resolution and, at the same time, activate an additional monitoring chain in other intelligence domains to identify any changes of military interest.

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KEYWORDS

SAR; SERIE TEMPORALE; OPEN DATA; OPEN SOURCE; ESA - COPERNICUS

ABSTRACT

A multi-temporal analysis of Sentinel-1 images (VV polarization) was conducted to monitor activity at the Chinese naval base in Yulin between January 2024 and June 2025. By constructing a time series of radar backscatter in decibels, variations compatible with the presence or absence of naval units were detected. The observed reflectivity peaks are consistent with events documented by OSINT sources, indicating strategic movements and periods of high operational activity.

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