DETECTING SUSPICIOUS ACTIVITIES AT SEA USING SYNTHETIC APERTURE RADAR (SAR) SATELLITE IMAGERY AND AIS DATA

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1. **ABSTRACT:** Nowadays, ship detection using remote sensing images is considered one of the most important aspects of maritime surveillance systems, as it enables the monitoring of a range of maritime activities such as shipping traffic, safety and security at sea, cargo transportation, maritime defence, fisheries control, oil spill detection, etc. In this paper, a methodology is proposed to collect, process and analyse Sentinel-1 Synthetic Aperture Radar (SAR) data for maritime activity, which are further correlated with relevant AIS (Automatic Identification System) datasets, to identify vessels that may not require AIS or related systems or vessels involved in illegal activities. The rapid development of remote sensing science and the wide variety of freely available satellite data and related tools have contributed to this goal. All datasets are stored and visualized through a developed portal specifically designed to host spatial data. Geoportal is easily accessible by many users, offering a wide range of services such as download, visualization, and analysis. Geoportal is expected to be a valuable tool that can provide easy access to accurate high resolution spatial data to a wide range of individuals, scientists, decision makers and other stakeholders.

2. INTRODUCTION

Forming a comprehensive picture of human activities at sea can be considered as a complicated and demanding task [1]. Vessel detection process as an integral part of maritime surveillance, plays a very important role in port management and environmental protection in terms of shipping traffic, safety and security at sea, cargo transportation, maritime defence, fisheries control, marine environment pollution monitoring, etc. [2, 3]. Today a wide variety of tools and methods are used for maritime surveillance purposes, using either cooperative systems (in which ships can report information about their identities and position, together with additional information from other on-board systems) such as the Automatic Identification System (AIS), Long Range Identification and Tracking (LRIT) and Vessel Monitoring System (VMS), or non-cooperative systems, which do not require any action from the side of ships. The latter most commonly use cameras or radars installed on platforms (e.g. satellites, airplanes, etc.). Satellites and their sensors can provide cost-effective, reliable and widespread maritime surveillance, regardless of weather conditions and geographical limitations [1].

Ship detection using SAR satellite datasets can be included in non-cooperative systems, allowing the tracking of vessels that may not require AIS or related technologies (e.g. smaller fishing vessels) or vessels that are sailing illegally (e.g. piracy, illegal fishing activities, etc.). [4]. Furthermore, SAR datasets are widely used to detect vessels in extreme weather conditions in search and rescue missions [3].

In this paper, a methodology is proposed to collect, process and analyse Sentinel-1 SAR data for maritime activity, which are further correlated with relevant AIS datasets, to identify vessels that may not require AIS or related systems or vessels involved in illegal activities. The rapid development of remote sensing science and the wide variety of freely available satellite data and related tools (e.g. satellite images and value adding products) have contributed to this goal. Section 3 presents the materials and methods used. Section 4 describes the geoportal in which the vessel tracking datasets are collected, stored and visualized, taking advantage of the vast capabilities provided by the use of satellite products and World Wide Web data. Conclusions and main findings are summarized in the last section.

3. MATERIALS AND METHODS

This section provides a detailed overview of the proposed methodology for vessel detection and the data and tools used. The flow chart of the overall methodology followed is described in Figure 1.

3.1 Data description

The Sentinel-1 SAR data used are freely available through the Alaska Satellite Facility (ASF) Vertex interface [5]. ASF hosts the NASA Distributed Active Archive Center (DAAC) and processes, archives, and distributes SAR data from various satellites, including Copernicus Sentinel-1, ALOS PALSAR, European Remote Sensing Satellite-2 (ERS-2), SMAP, European Remote Sensing Satellite-1 (ERS-1), etc. [6]. Thirty (30) SAR images were downloaded from the ASF Vertex interface, Level 1 (L1) Ground Range Detected (GRD), from July 01 to December 31, 2021. All GRD datasets consist of focused SAR data that have been detected, multi-looked and projected to ground range using the Earth ellipsoid model World Geodetic System 84 (WGS84) [7]. The SAR data used in this study are provided in Interferometric Wide swath (IW) and polarization VV +VH[1].

The European Marine Observation and Data Network (EMODnet) is a broad network of organizations supported by the EU's integrated maritime policy. Its main objective is to collect observations and marine data from various sources and process them appropriately, making the information freely available to the general public. Through the official website of EMODnet, access is provided to the following seven (7) thematic fields: Bathymetry, Biology, Chemistry, Geology, Human activities, Physics, and Seabed Habitants [8]. The EMODnet data used in the current study are based on average vessel density for all vessel types and by vessel type. The following vessel types are provided through the EMODnet portal: Other, Fishing, Service, Dredging or underwater ops, Sailing, Pleasure Craft, High speed craft, Tug and towing, Passenger, Cargo, Tanker, Military and Law Enforcement, Unknown and All vessel types. The datasets cover a time period from 2017 to 2022 and are provided in two formats: a) raster and, b) Web Map Service (WMS). Both available formats are based on AIS datasets collected by the Collecte Localization Satellites (CLS) and ORBCOMM. Data show vessel density in 1x1km cell. Vessel density can be expressed as hours per square kilometer per month.

[1] VV: vertical transmit, vertical receive; VH: vertical transmit, horizontal receive.

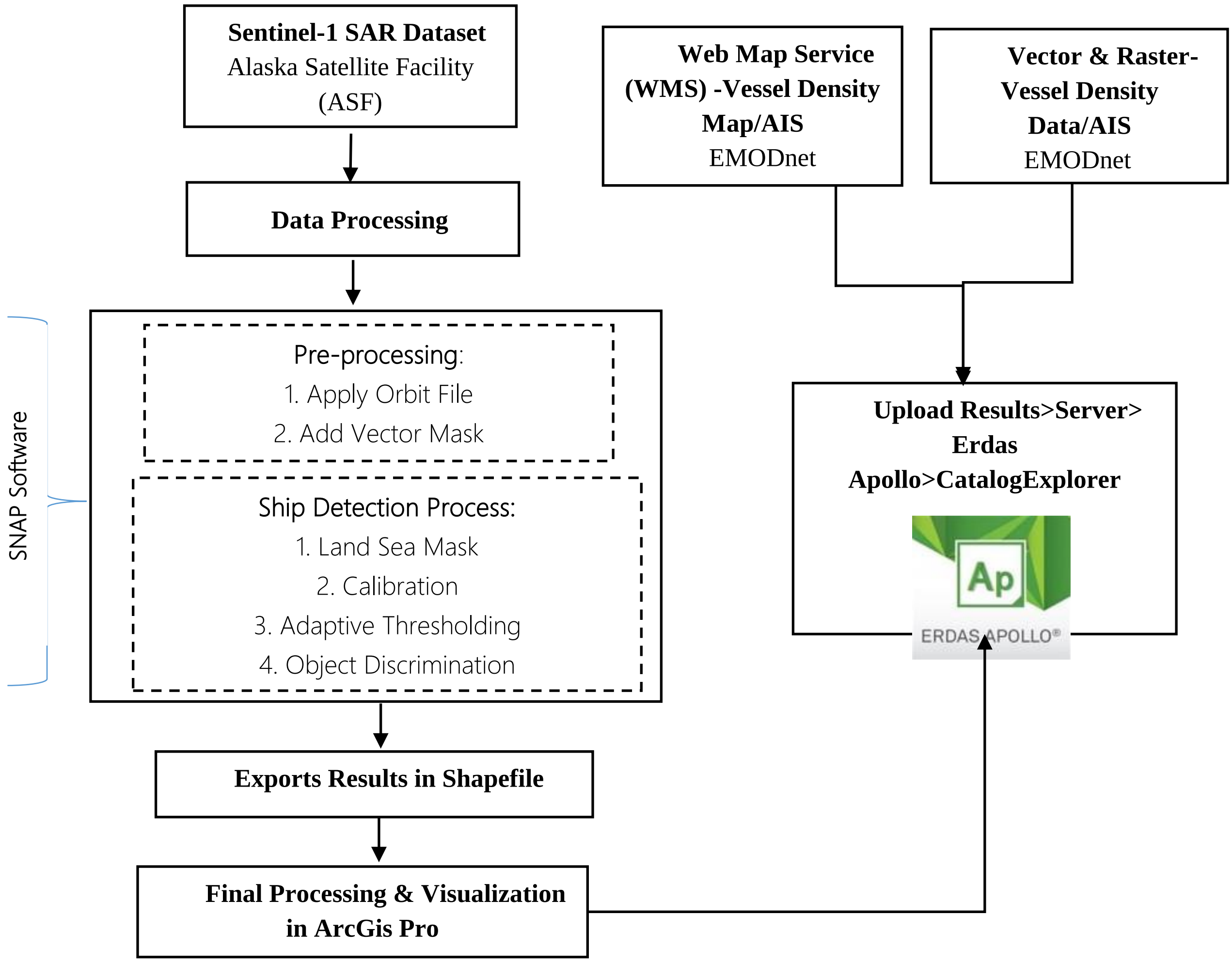

Figure 1: Methodology Flowchart

3.2 Methodology description

The Sentinel Application Platform (SNAP) software is used for SAR image processing and target (vessel) detection. SNAP is freely available through the ESA (European Space Agency) Science Toolbox Exploitation Platform (STEP). It is a collection of executable tools and interfaces (Application Programming Interfaces-APIs), which have been developed to facilitate the use, viewing and processing of a variety of remote sensing data [9]. The platform runs in a Java environment and is available on the organization's official page on the following operating systems: Windows 64-Bit, Mac OS X, and Unix 64-bit [10]. In this study, the latest version of SNAP 9.0.0 (29.06.2022 15:00 UTC) for Windows 64-bit operating system was selected to process the thirty (30) SAR images.

The vessel detection process of the thirty (30) SAR images through SNAP software consists of the following sub-steps, including [4]:

A. Pre-processing: Image pre-processing is an essential part of the Sentinel-1 SAR GRD products in order to reduce orbit errors or speckle noise. Sentinel-1 datasets have some issues with their orbit information in the metadata. To address this issue, the orbit data of the Sentinel-1 images must be updated with the latest orbit file data. This process is called Apply orbit file.

   A land sea mask is also created and uploaded to the software to cover the land area. Thus, vessel detection process will be focused only on the sea area. After this pre-processing stage, Sentinle-1 datasets are ready for the vessel detection process.

B. Ocean Vessel Detection (i.e.: Vessel Detection Process): This part is the main part of the overall process and includes a number of sub-steps as follows:

   1. Use of vector mask. This operation can be done using the already uploaded vector mask, instead of the default SRTM (Shuttle Radar Topography Mission) option provided by the software. The use of the vector mask is considered better in cases of complex coastlines to avoid detecting false targets.
   2. Sentinel-1 GRD products as raw products can be depicted as an amplitude image. Therefore, it is necessary in this step to convert the amplitude image into a calibrated product for quantitative use of the SAR data. The Sigma-nought image was then chosen as a calibrated product.
   3. The type of adaptive algorithm used by the software to perform the pre-overlay process is the two-parameter Constant False Alarm Rate (CFAR) detector. This type is considered a commonly used method for target detection in SAR images. The idea is that targets appear brighter compared to the darker surrounding area [11]. The Probability of False Alarm (PFA) is then calculated. Acceptable PFA values are in range 0-1. In real implementation, the CFAR detector is performed using the Adaptive Thresholding operator. For each pixel there are three windows namely: target window, guard window and background window (Fig.2). First, the target window size is determined, which is the size of the target window in meters and must be set to the size of the smallest target to be detected. The guard window size is then determined, which is the size of the guard window in meters and must be set to the size of the largest target to be detected. Finally, the background window size is determined, which is the size of the background window in meters, which must be sufficiently larger than the size of the guard window to ensure accurate calculation of local statistics. In this study, 30, 500, and 800 m were determined for the target window, guard window and background window respectively.
   4. Finally, the discrimination process is performed using the Object discrimination operator. The user sets the minimum and maximum target size in meters, which ensures that targets with a size smaller or larger than the specified threshold will be rejected respectively. 20 and 600 m were determined for minimum and maximum target size. Those values were chosen based on expert judgments and preliminary tests.

The detailed overall vessel detection process can be found in the tutorial provided by ESA and Serco Italia S.p.A [4].

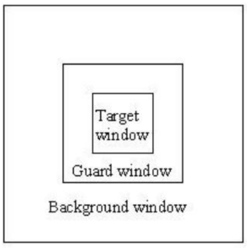

Figure 2. Moving window setup for Adaptive Thresholding operator

The *Product Explorer* interface displays the final product of the detection process, where the targets are identified in red (Fig.3). This product is one of the thirty SAR images downloaded by ASF and represents a specific day and time (e.g. Date: 07.08.2021, Start time: 04.22.25, Stop time: 04.22.50). The process is repeated for all SAR images. Finally, we export the results to an ESRI Shapefile (.shp) format that is more manageable and can be processed and visualized further in a Geographic Information System (GIS). In the ArcGisPro environment, all products are consolidated into six individual products, one for each month (i.e.: July to December).

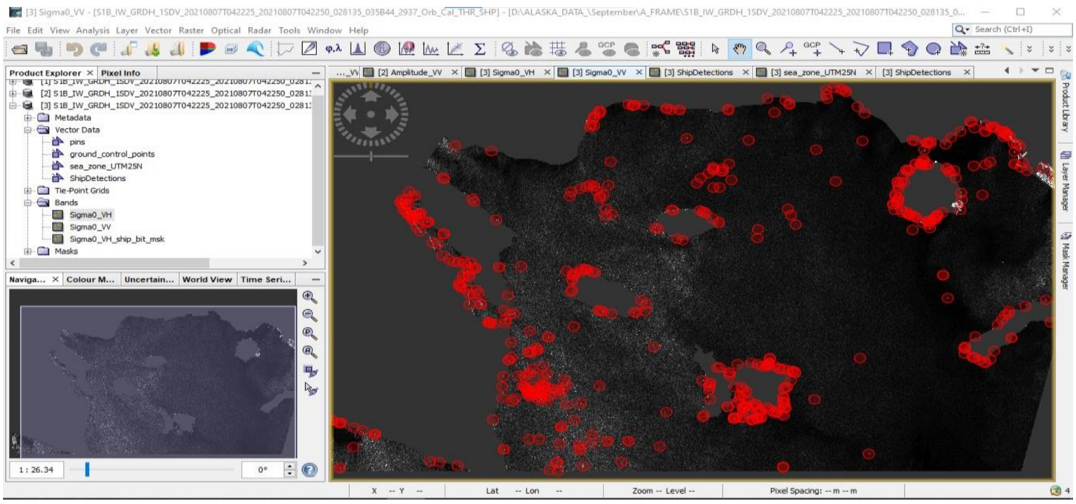

Figure 3. Vessel detection results. SNAP environment

4.DISTRIBUTION, SYNTHESIS AND VISUALIZATION OF MARITIME DATA THROUGH GEOSPATIAL PORTAL

Geoportal is accessible through internet and VPN (Virtual Private Network) connection, offering a wide range of online services and maritime data to all interested parties. Hexagon's Erdas Apollo software was used for its development. Erdas Apollo essentially provides a portal that stores, distributes, processes and downloads large volume of geospatial information. The Catalog Explorer is the web-client (Image Web Server-IWS) of the software and is used for distribution, synthesis and visualization of the maritime geospatial data. The database can be regularly updated and deliver into any client, on any device. All available datasets are provided through the portal in Web Map Service (WMS), vector and raster formats. Datasets can be found via the following path (Tools→Browse Catalogs) (Fig.4).

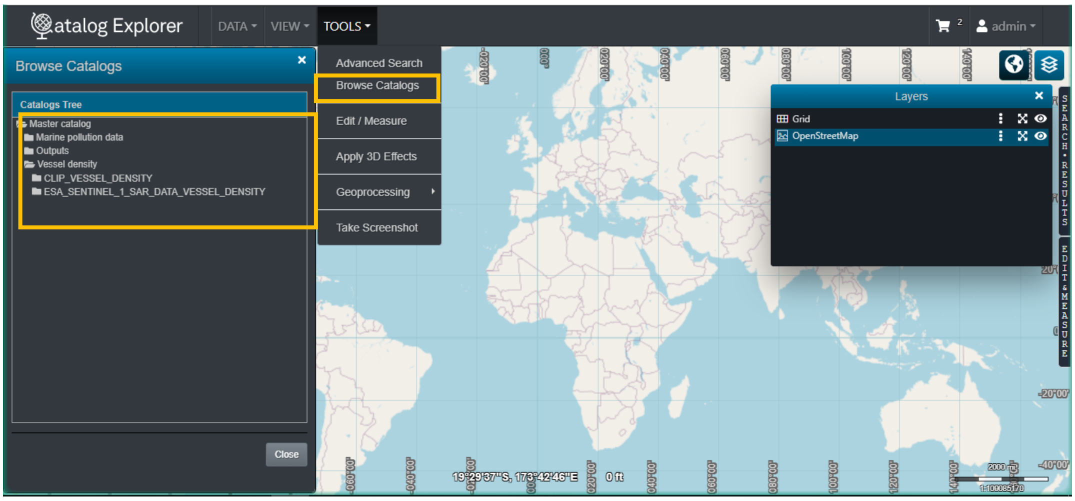

Figure 4. Geospatial portal interface

Authorized users can select any folder to view and/or download. The available data in each folder are displayed to the right of the main user interface. The visualized data are also added to the Layers tab (Fig.5).

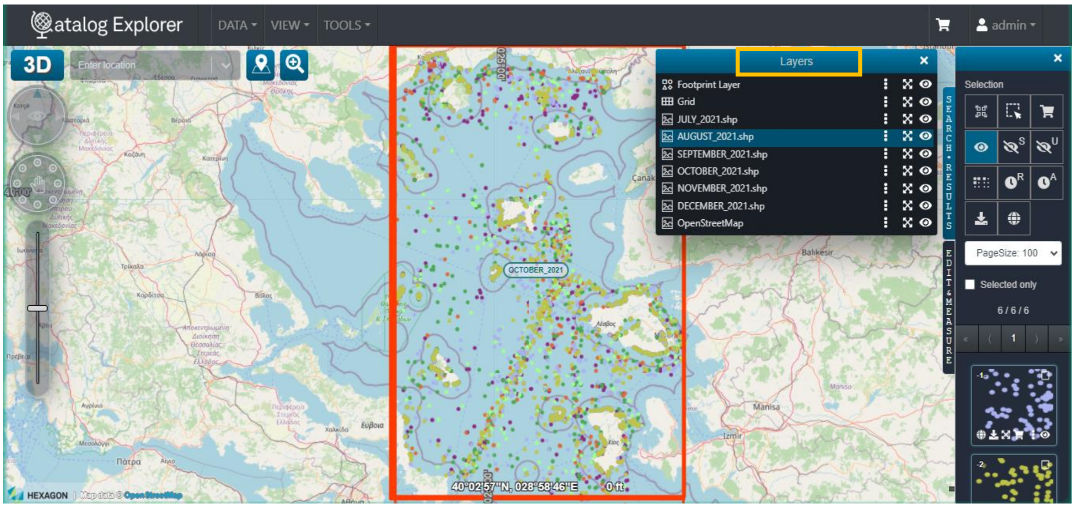

Figure 5. Visualization of ESA Sentinel-1 SAR data for the months July 2021 to December 2021.

Users can also open the Feature Properties tab of each point by simply clicking on a point. This table actually displays information about the attributes of a selected SAR point (Fig.6).

Finally, a Web Map Service (WMS) is also provided. WMS displays average monthly vessel density data for all vessel types and by vessel type (Fig. 7).

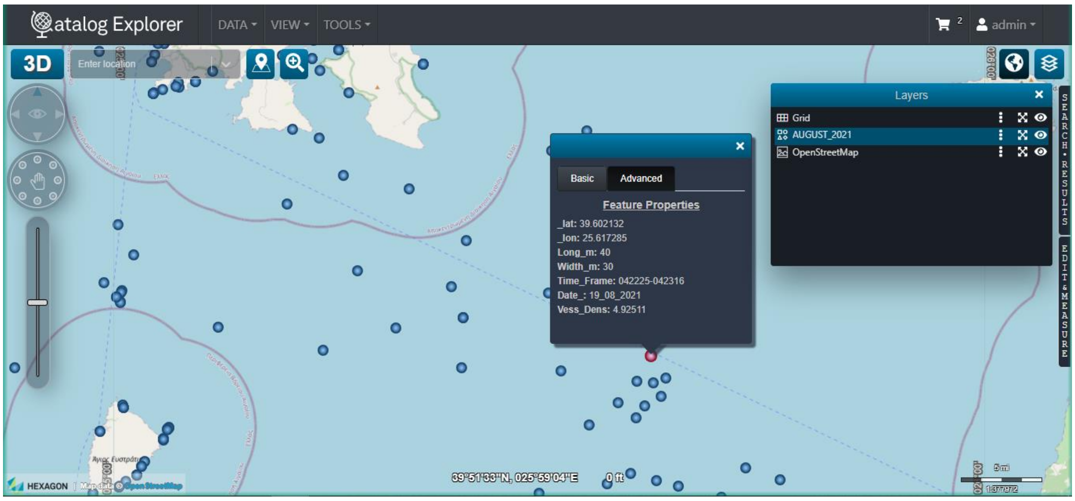

Figure 6. Table of Feature Properties of a SAR point[2]

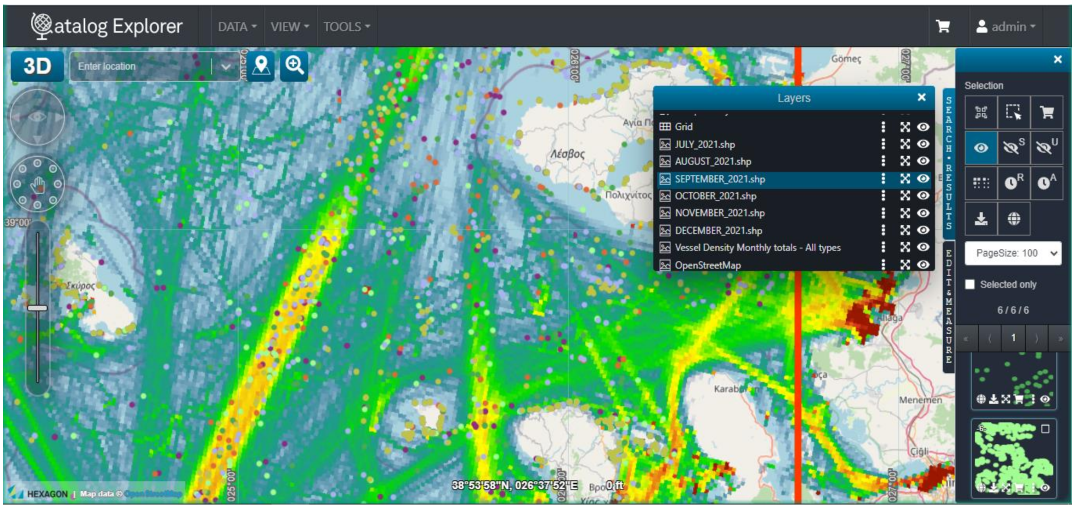

Figure 7. WMS of monthly average vessel density and Sentinel-1 SAR data (July 2021-December 2021).

Geoportal supports single file download or mass file download by selecting the output format from a dropdown menu (e.g. e.g. IMG, NTIF, ECW, JPEG2000, GeoPackage, SHP, LAS). Spatial information can also be extracted from a specific area either by typing the coordinates (Longitude & Latitude) of the area of interest when these are known or by digitizing using the appropriate tools within the platform. The selected files are downloaded as a zip file.

[2] Attributes of the detected target (i.e. vessel): lat: Latitude, lon: Longitude, Long: (m), Width (m), Time frame: HH/MM/SS, Date: DD/MM/YY, and Vessel density: hours per square kilometer per month.

5. RESULTS AND DISCUSSION

Correlation of Sentinel-1 SAR data and AIS data can be done by importing the WMS link and Sentinel-1 SAR vector data as thematic layers in the main user interface. SAR datasets derive information from the average vessel density data provided in raster format. Through WMS layer (see points outside the grid) and/or Feature Properties table (see Field named Vess_Dens) of the SAR vector data, users can see if a density value is detected or not (Fig. 6 &7).

The majority of the detected points are along the coastline and this probably cannot be directly related to the detection of vessels that may not require AIS or related systems or vessels involved in suspicious activities due to limitations in the primary data provided by EMODnet. Both the WMS link and the raster average vessel density data do not provide sufficient information (i.e. no data) along the coasts, resulting in near-shore targets not being detected by AIS but detected via ESA Sentinel-1 imagery.

Targets detected beyond the coastline may potentially be seen as vessel that may not require AIS or related systems (e.g. smaller fishing vessels) or vessels engaged in suspicious activities at sea (piracy, illegal fishing activities, etc.). A more detailed AIS thematic layer can lead to more accurate results.

In addition to maritime data, the geoportal also hosts and visualizes environmental data related to marine eutrophication (chlorophyll, nitrates, ammonium and phosphate), making it a valuable tool for long-term marine and environmental policies and strategies (e.g. reorganization of Traffic Separation Schemes-TSSs, appropriate environmental management in sensitive marine areas with increased vessel traffic, instructions for proper operation of ships to prevent marine pollution, revision of the marine pollution response network using datasets from vessel traffic, etc.).

6. CONCLUSIONS

In this paper, a methodology is proposed to collect, process and analyse Sentinel-1 SAR data for maritime activity, which are further correlated with relevant historical AIS datasets of the same time period, to identify vessels that may not require AIS or related systems or vessels involved in illegal activities. SAR datasets are independent of weather conditions and geographical limitations, thus allowing tracking on a regular basis. The rapid development of remote sensing science and the wide variety of freely available satellite data and related tools have contributed to this goal.

Target (vessel) detections are collected, stored and visualized through a developed portal specifically designed to host spatial data. The database can be regularly updated and deliver into any client, on any device. Although there are studies in the international literature on ship detection using satellite SAR datasets or self-reporting systems (e.g. AIS, etc.) [12, 13, 14, 15], there is not a single portal that provides visualization, download and analysis services of processed data. As a result, a wide range of individuals, scientists, decision makers and other stakeholders have a web-based tool with which they can combine visualized vessel position data from two different sources (i.e. Satellite and AIS datasets). In combination with the environmental data provided, the online geoportal can serve as a tool for the adoption of strategies and policies related to vessel traffic and preservation and restoration of the quality of the marine environment.

Future research efforts include the addition of relevant meteorological datasets (i.e. wind speed and direction), to identify and assess areas of high potential risk for marine pollution caused by vessel activity (e.g. oil spill detection), as well as the integration of real-time AIS data and Artificial Intelligence (AI) algorithms for better management of environmental protection and maritime and spatial issues.

7. ACKNOWLEDGMENTS

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8. REFERENCES

[1] European Maritime Safety Agensy (EMSA), "Surveillance", https://emsa.europa.eu/20years/en/surveillance, 2022, accessed Dec. 15, 2023.

[2] Bioresita, F., Pribadi, C.B., and Firdaus, H.C."Ship detection in Madura Strait and Lamong Gulf using Sentinel-1 SAR Data". *Digital Press Physical Sciences and Engineering*, no 1 (2018): 13–23. http://dx.doi.org/10.29037/digitalpress.11224

[3] ESRI, "Ship Detection (SAR)", https://www.arcgis.com/home/item.html?id=705f4c04ac3043be806529047b79abfd, 2022, accessed Dec. 15, 2023.

[4] Serco Italia SPA, "Ship detection with Sentinel-1 – Gulf of Trieste (version 1.3)", Retrieved from RUS Lectures at https://eo4society.esa.int/wp-content/uploads/2021/04/OCEA01_ShipDetection_Trieste.pdf

[5] Alaska Satellite Facility (ASF), "Data Search Vertex", 2023, https://search.asf.alaska.edu/, accessed May 10, 2023.

[6] Alaska Satellite Facility (ASF), "Datasets Available from ASF DAAC", 2023, https://asf.alaska.edu/datasets-available-from-asf/, accessed Jun. 10, 2023.

[7] European Space Agency (ESA), "Sentinel-1 Data Products-Level, https://sentinel.esa.int/web/sentinel/user-guides/sentinel-1-sar/product-types-processing-levels/level-1, 2023, accessed May 10, 2023.

[8] EMODnet, "What is EMODnet", https://emodnet.ec.europa.eu/en/about_emodnet, 2023, accessed May 15, 2023.

[9] Science Toolbox Exploration Platform, SNAP Overview", https://step.esa.int/main/doc/online-help/, 2023, accessed March 16, 2023.

[10] Science Toolbox Exploration Platform, "SNAP Download", https://step.esa.int/main/download/snap-download/, 2023, accessed March 16, 2023.

[11] Hicham Madjidi, Toufik Laroussi, and Faiçal Farah. "CFAR Ship Detection in SAR Images Based on the Generalized Rayleigh Mixture Models". In International Conference of Advanced Technology in Electronic and Electrical Engineering (ICATEEE), p. 1-5. 2022. doi: 10.1109/ICATEEE57445.2022.10093718.

[12] Galdelli, A., Mancini, A., Ferrà,C., Tassetti, A.N. "A Synergic Integration of AIS Data and SAR Imagery to Monitor Fisheries and Detect Suspicious Activities". *Sensors, no* 21 (2021): doi: https://doi.org/10.3390/s21082756

[13] Marzuki, M., Rahmania, R., Kusumaningrum, P., Akhwady, R., Sianturi, D., Firdaus, Y., Sufyan, A., Hatori, C., Chandra, C. "Fishing boat detection using Sentinel-1 validated with VIIRS Data" *Earth and Environmental Science*, 925 (2021):10.1088/1755-1315/925/1/012058.

[14] Fitriani, S.P., Gaol, J.L., Kushardono, D. "Fishing-Vessel Detection Using Synthetic Aperture radar (SAR) Sentinel-1 (Case Study: Java Sea)". *International Journal of Remote Sensing and Earth Sciences, no 2 (2018):25-36*

[15] Grover, A., Kumar, S., Kumar, A. "Ship Detection Using Sentinel-1 SAR Data". *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences, no IV-5 (2018): https://doi.org/10.5194/isprs-annals-IV-5-317-2018*