

# SENTINEL-1 SAR FOR OPERATIONAL MONITORING OF SOUTHERN AFRICA OCEANS

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## ABSTRACT:

The introduction of Synthetic Aperture Radar (SAR) through the Oceans and Coasts Monitoring Information system (OCIMS) has therefore become a critical tool for operational coastal and ocean monitoring in South Africa. Natural/man-made ocean phenomena can be observed using satellite Synthetic Aperture Radar (SAR) techniques, making it an integral part of large ocean area monitoring for maritime domain awareness. SAR is an active instrument on-board a satellite platform that transmits electromagnetic waves and measures the returning signal to infer what is happening on the ocean surface. The objective of this paper was to provide information and present options to the decision-makers around sustainability of commercial SAR data acquisition in support of OCIMS IVT. The OCIMS IVT tool identifies ships from multiple types of SAR data, which can provide locations of vessels that have switched off their AIS and oil slicks caused by vessels. Although open-data offerings, such as Sentinel-1, can be considered alternatives to commercial sensors, they present severe limitations for an operational service. To meet OCIMS requirements, and address the imperative to reduce costs, a hybrid of commercial acquisition being used in conjunction with an open data source such as Sentinel-1 is recommended. This would ensure that an operational service with the desired latency as well as increasing the revisit time over the EEZ.

## 1. INTRODUCTION

The South African Exclusive Economic Zone (EEZ) is roughly 1.5 million square kilometres and forms part of the economic resources and trade routes of South Africa. In terms of United Nations Convention on the Law of the Sea (UNCLOS) South Africa is required to take full responsibility for the administration, law enforcement, environmental protection and sustainable management of its EEZ (Anand, 2021, Rembe, 1980). The surveillance and the protection of South Africa's coastal waters and EEZ requires comprehensive knowledge, forecasting capability, and the ability to assess environmental impacts. Oil spills, harmful blooms, and coastal erosion are examples of the kinds of processes and incidents that take place, with great consequences for human health, economic activities, and the local, regional, and global environment (Mdakane and Kleynhans, 2022).

Considerable economic and social benefits are expected to accrue from technological advancements, forecast modelling, high frequency remote sensing observations and advanced assimilation techniques. These economic and social benefits include increased safety for merchant fleets, fisheries, and offshore aquaculture industries, better protection and management of coastal zones and the marine environment, and improvements in the monitoring of large-scale climate change (Buono et al., 2021, Findlay and Bohler-Muller, 2018, Weinert et al., 2021). In 2014, South Africa launched the Operation Phakisa's Oceans and Coasts Monitoring Information System (OCIMS) to deploy operational ocean monitoring services (Otto, 2019). The National Oceans and Coastal Information Management System (OCIMS) consists of multiple tools and services that provide decision support for the effective governance of South Africa's oceans and coasts, see Fig 1. In this paper, we focus on the

OCIMS Integrated Vessel Tracking (IVT) service which tracks vessel movements using integrated datasets such as AIS and Synthetic Aperture Radar (SAR).

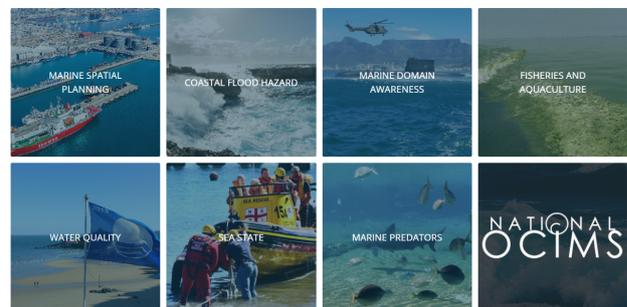


Figure 1. The National Oceans and Coastal Information Management System (OCIMS) tools and services ([www.ocims.gov.za](http://www.ocims.gov.za)).

The purpose of the Integrated Vessel Tracking (IVT) Decision Support Tool (DeST) is to improve Maritime Domain Awareness for South Africa. The IVT tool provides a general overview of South African waters with real-time positional updates any vessels nearby or in our EEZ. The positions are updated either via near-real time terrestrial Automatic Identification System (AIS), satellite AIS, Vessel Monitoring System (VMS), terrestrial radar or satellite Synthetic Aperture Radar (SAR), see illustration in Fig 2. One of the core principles of the IVT tool is that it aggregates as many different types of maritime data as possible to prevent duplication of data purchases across stakeholders. This provides a better MDA picture at any given moment which allows stakeholders to make the best possible decision with the most up-to-date information at any given moment. Until recently monitoring and surveillance approaches included: the use of patrol ships; transponder-based identifica-

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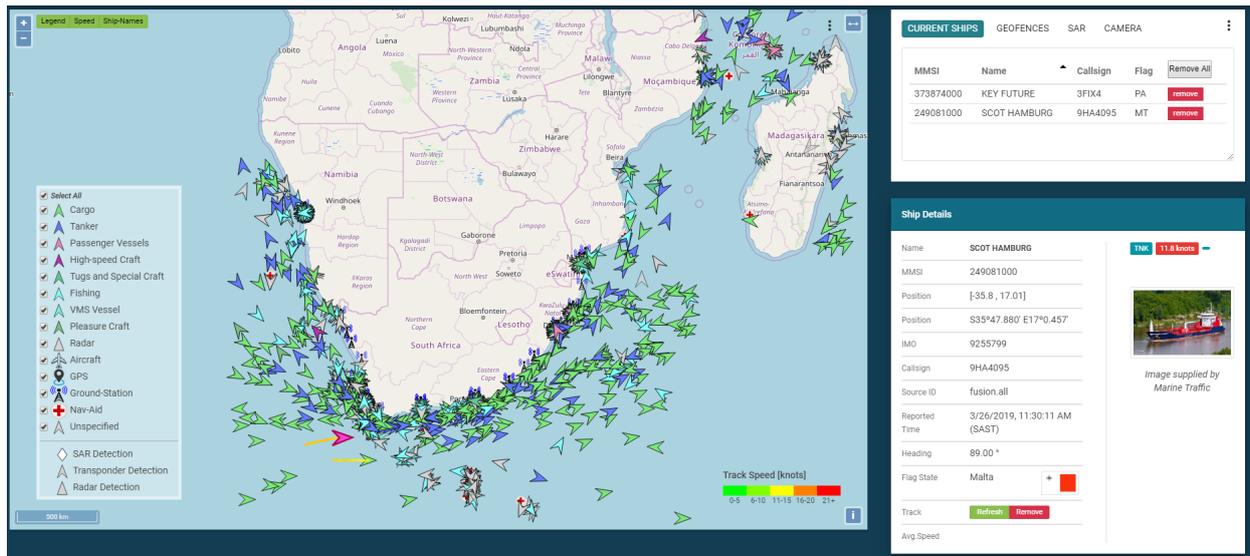


Figure 2. The OCIMS Integrated Vessel Tracking tool.

tion such as Vessel Monitoring System (VMS) and Automatic Identification System (AIS); and aircraft and helicopters in specific instances. In the open ocean areas, monitoring was done predominantly by means of AIS to display the vessel locations.

The use of Synthetic Aperture Radar (SAR) on an operational basis has become a critical tool for operational coastal and ocean monitoring and its use has been widely adopted (Franceschetti and Lanari, 2018). Significant research and development have gone into the development of SAR processing, specifically for vessels and oil-slick monitoring within South Africa in the last 10 years. From the research, the CSIR developed a state-of-the-art SAR processing chain for OCIMS IVT and Bilge Dump services. The OCIMS IVT integrates SAR remote sensing data for monitoring vessels positions and oil pollution over vast ocean areas (Schwegmann et al., 2016, Mdakane et al., 2017). SAR is an active microwave sensor capable of taking measurements day or night and almost independently from atmospheric conditions (Fitch, 2012). However, not all available SAR offerings are suitable for the observational requirements of an operational OCIMS.

The purpose of this paper is to provide an overview and analysis of available sensors that could support Systematic OCIMS IVT user requirements and to further investigate the utility of open-data for use in operational ocean and coasts monitoring in South African. To this end, the first instance provided a brief overview of satellite based SAR data, and its usefulness for OCIMS IVT. Secondly, we investigate the Phakisa Maritime Domain Awareness and OCIMS SAR technical requirements, as a subset of the broader Satellite SAR Sensor portfolio requirements. Lastly, an updated review is provided for the suitability of available sensors that could meet the OCIMS technical requirements for SAR data.

## 2. METHODOLOGY

SAR processing converts a large SAR image into a list of ships and possible oil-slick detections via several steps including pre-processing, prescreening and discrimination stages. Pre-processing and prescreening ensure that discrimination only sees

a limited number of likely vessels/oil-slick samples whilst discrimination typically used advanced machine learning techniques to separate ships from look-alikes. Dual polarization is used to better discriminate targets from false alarms. In a fully operational system, the access time for the most recent observations also becomes important. The natural variability of marine parameter requires near-real-time acquisition of satellite data very important in coastal monitoring applications (Mdakane et al., 2020). The next sections investigate OCIMS IVT requirements and the satellite SAR sensors for the task.

### 2.1 OCIMS IVT Requirements

For a successful systematic vessel detection and tracking capability, OCIMS IVT tool identified the following prerequisites:

**Coverage:** Systematic monitoring of the entire EEZ with a minimum Minimum 7-day coverage for the entire SA EEZ (> 90%).

**Tasking Capability** Capability to monitor areas of high interest and to fill gaps in systematic observations (tasked acquisitions).

**Spatial Resolution** Identifying vessels of at least 50m or larger.

**Applicable Frequency Bands:** Ability to identify bilge dumps and simultaneously map these to vessels responsible for the dump.

**Acquisition Time:** Near real-time data with a maximum 30-minute latency for image delivery from time of acquisition.

**Temporal Resolution** Resolution requirements of 400km+ swath width, minimum 40m spatial resolution and 3-day temporal resolution.

**Other:** Monitoring of other coastal (e.g., coastal erosion) and ocean (e.g., sea state) parameters along the South African EEZ.

## 2.2 An Overview of SAR Satellites for Ocean Monitoring

The growth in the use of SAR data is related to its ability to operate over a wide surveillance area during both day and night, independent of cloud cover and weather conditions, thereby allowing for efficient and cost-effective monitoring and surveillance tools and services. Several SAR sensors are available globally, both commercially as well as through open data policies. Table 1 presents commonly used SAR frequency bands and their applications (Schmullius and Evans, 1997, Topouzelis, 2008, Gens, 2008). From the table, C and X SAR sensors are identified as the most applicable sensors for ocean surveillance.

Frequency band	Frequency range	Application Example
VHF	300KHz – 300MHz	Foliage/Ground penetration, biomass
P-Band	300MHz – 1 GHz	Biomass, soil moisture, penetration
L-Band	1GHz – 2GHz	Agriculture, forestry, soil moisture
C-Band	4 GHz – 8GHz	Ocean, agriculture
X-Band	8 GHz – 12GHz	Agriculture, ocean, high resolution radar
Ku-Band	14 GHz – 18GHz	Glaciology (snow cover mapping)
Ka-band	27 GHz – 47 GHz	High resolution radars

Table 1. Commonly used SAR frequency bands and their applications.

## 2.3 SAR Sensors for Ocean Monitoring

To identify potential SAR data sources that could meet the OCIMS requirements outlined in section 2.1, several spaceborne SAR sensors were investigated based on their technical specifications. Detailed technical descriptions of all selected SAR satellites that were considered for OCIMS IVT are presented in Table 2.

Sensor <sup>1</sup>	Band	Latency	Swath	Resolution	Tasking	Cost	Total
ALS-2	3	3	5	4	2	5	3.7
SEN-1	5	4	4	4	2	5	4.0
RDST-2	5	4	5	4	5	4	4.5
TSR-X	4	4	2	5	5	3	3.8
CSM	4	4	2	5	5	3	3.8
KST-5	4	4	2	5	5	3	3.8

Suitability scale: from poorly = 2 to ideally = 5 suitable, and 1 = not suitable/applicable  
ALS-2:ALOS-2, SEN-1:SENTINEL-1, RDST-2:RADARSAT-2,  
TSR-X:TerraSAR-X, CSM:Cosmo-SkyMed, KST:KompSAT-5

Table 2. Sensor Analysis for each OCIMS Requirement.

The review results from Table 2 demonstrated that Sentinel-1 and Radarsat-2 meet most of the technical requirements for OCIMS. Advanced Land Observing Satellite-2 (ALOS-2) showed good spatial coverage (490 km) and dual polarisation (both HH+HV and VV+VH available) but was not considered due to L-bands poor performance in oil spill monitoring (Wang et al., 2019). All the X-band satellites (TerraSAR, ComsoSkyMed and KompSAT) showed a common disadvantage of a small spatial coverage ( $\approx 200km$ ) thus a high number of images would be required to meet systematic operational monitoring of Southern Africa oceans. However, their spatial resolution ( $\approx 20m \times 20m$ ) makes them ideal for vessel classification and monitoring smaller fishing vessels. Sentinel-1 and RADARSAT-2 were shown to be better options overall, meeting frequency, scene coverage, spatial and temporal resolution requirements. Radarsat-2 showed better temporal resolution with an ability to be tasked on demand, however this is a cost. Sentinel-1's open-data policy makes it the most cost-effective C-band sensor with acceptable swath coverage, temporal and spatial coverage ( $\approx 40m$ ). It is however, not suitable for operational monitoring/tracking of

<sup>1</sup> Only ScanSAR sensors were considered for maximum coverage.

<sup>2</sup> Copernicus Sentinel-1B has been unavailable since 23 December 2021 due to a spacecraft malfunction.

vessels with its high acquisition latency ( $> 2hrs$ ) and inability to task images for emergency situations.

At this time, there was no sensor that able to meet all OCIMS IVT requirements (i.e., the so called perfect SAR sensor), mainly due to cost and near-real time requirements. However, spaceborne SAR is continually improving and numerous sensors are planned to be launched to address these problem, this includes the launch of multiple SAR sensors on miniaturised satellites (e.g., CubeSats). The next section looks the application of Radarsat-2 and Sentinel-1 in OCIMS IVT.

## 2.4 Radarsat-2 and Sentinel-1 for OCIMS Integrated Vessel Tracking

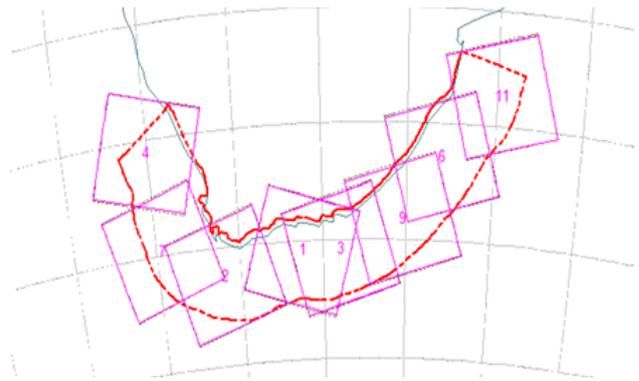


Figure 3. SAR Radarsat-2 image footprints over a one-week period covering the EEZ along South African coastline.

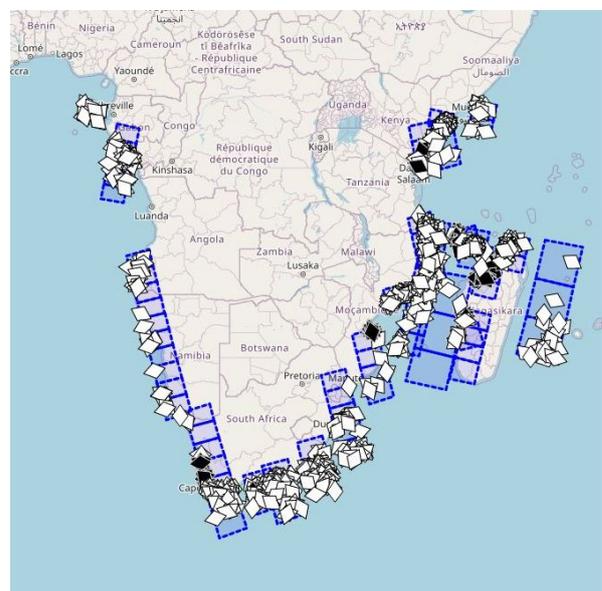


Figure 4. OCIMS Integrated Vessel Tracking System showing Vessels Detected from using only SAR Sentinel-1 and Radarsat-2 (Note: Radarsat-2 data only covers SA EEZ).

In the oceans, vessel traffic monitoring is especially important for security, economy, tourism, and safety for all coastal countries that are responsible for their EEZs. The OCIMS IVT system identifies, locates and monitors vessel within a pre-defined area using multiple datasets including SAR Data and Automatic Identification System (AIS) data. Table 2 provided a comparison of the specifications of the available SAR sensors as well as an indication of the suitability of Sentinel-1 and Radarsat-2

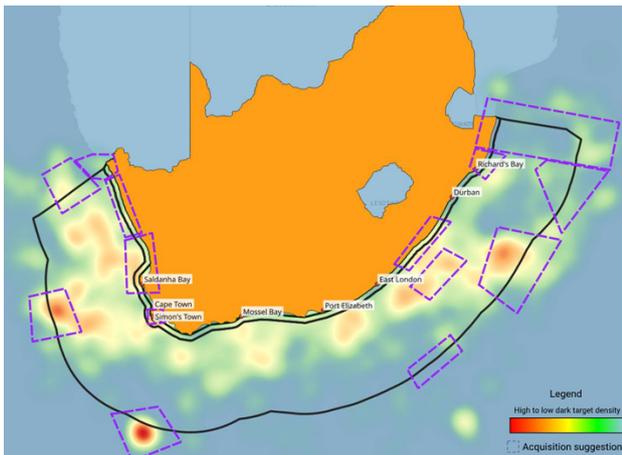


Figure 5. Normalised Number of Dark Targets in 2018.

data for use with OCIMS operational service requirements, see section 2.1.

In 2018, for the first time, a South African operational system integrated satellite SAR data through the South African Space Agency (SANSa). In 2019 SANSa further improved the monitoring on SA EEZ by providing direct access to SAR imagery (reducing latency to under 30 minutes). Figure 3 shows the Radarsat-2 image footprints over a one-week period covering ( $\approx 100\%$ ) of the South African EEZ. In 2020, the coverage area was increased to Southern Africa Regions and Sentinel-1 data was integrated to OCIMS IVT operational monitoring service, see Figure 4. The next section looks at the operation of OCIMS using Radarsat-2 and Sentinel-1 to evaluate the system's effectiveness.

### 3. RESULTS AND DISCUSSION

#### 3.1 SAR Dark Targets

AIS transmits location and vessel type information via an on-board AIS transponder and is mandatory internationally. However, vessels cannot always be identified or located using AIS on-board as they can turn off their AIS transponder or falsely report/artificially create information location and vessel type information. This behaviour is referred to as "spoofing" and is normally associated with vessels that are engaged in illicit activities. If AIS transponders are either malfunctioning, turned off, being spoofed, not installed or out of range, SAR images become essential for detecting vessels (called dark targets) in these areas of interest regardless of the status of any transponder device located on the vessel.

Using historic data from detected vessels that were not matched to an AIS position (dark targets), an SAR analysis tool is used to identify hot-spots and understand the behaviour and motives of these vessels. Figure (5) presents a SAR analysis that identified multiple dark target hot-spots. The analysis raises a few questions such as, why these areas have a high number of dark-targets? Could it be caused by a) lack of terrestrial AIS data reception or b) vessels turning off their AIS. Using SAR imagery and post analysis, we are able to monitor where is the SA EEZ is vulnerable, particularly, in the Marine Protected Area where strict rules apply. The hot-spots from the analysis can be used as a guide to where the satellite tasked to capture these areas over a period. to focus these areas for a better understand of why vessels switch off (or do not have) AIS.

#### 3.2 SAR Analysis: Commercial vs Open Data

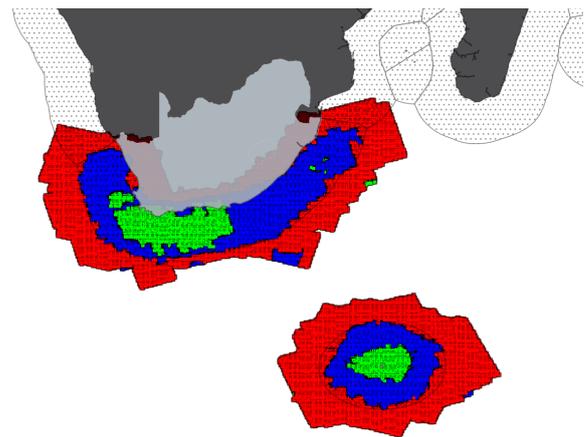


Figure 6. SAR Image Coverage in 2018 (Radarsat-2 only). Where Green, Blue and Red represent High, Medium, Low coverage respectively.

**3.2.1 Image Coverage Analysis** In 2018, OCIMS IVT procured Radarsat-2 data that met most of the requirements (excluding cost effecting requirement) of system and set a benchmark for an almost ideal system. The data allowed weekly coverage of regions of interest, that allowed over 90% coverage and with a high control of areas of interest. Regions of interest (high priority areas) are observable on Fig 6 with the colour green and less priority areas (regions outside the SA EEZ) as red.

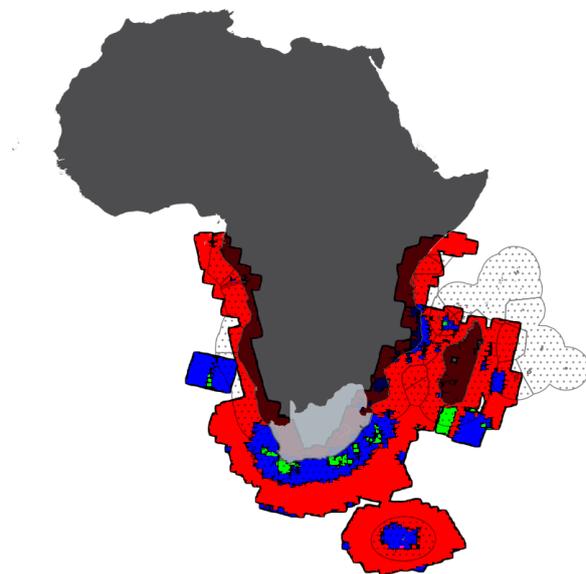


Figure 7. SAR Image Coverage in 2019 (Hybrid version = Reduced Radarsat-2 + Sentinel-1). Where Green, Blue and Red represent High, Medium, Low coverage respectively.

In 2019, the sustainability of SAR data acquisition was questioned and less data was procured with the data to be complemented by open data offerings such Sentinel-1. Further analysis during the period showed that coverage decreased significantly for regions of interest (green regions) compared to 2018 SAR coverage over the same area (SA EEZ), see Fig 7. However, the coverage was still considered "good enough" as it showed an

average coverage for SA EEZ (Blue), while there was significant change on the "red" areas (regions outside SA EEZ).

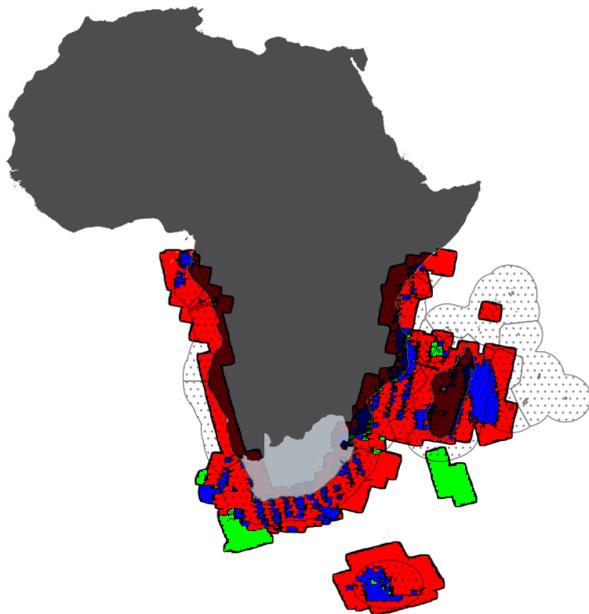


Figure 8. SAR Image Coverage in 2021 (Only Sentinel-1). Where Green, Blue and Red represent High, Medium, Low coverage respectively.

With the cost cutting measures forced by COVID-19 pandemic, commercial SAR was halted and only open data (Sentinel-1) was available. The coverage significantly decreased compared years 2018 and 2019, see Figs(6 and 7), where SAR coverage within the EEZ was mostly "red" (low coverage) and only a few areas showed "blue" (average coverage). These results show that open data alone does not meet the SAR requirements for OCIMS IVT as the coverage is too low.

SAR data may critical for dark target detection, but, it also has major limitations for operational uses. A drawback for all SAR satellites (particularly, non-commercial) is their temporal coverage which has long been considered as being insufficient to meet almost operational needs where persistent observation is required. Figure 3 shows that the EEZ can be fully covered every week, which is not possible with current open data sources such the Sentinel-1 constellation. This however is set to change with Multiple spaceborne SAR systems for maritime applications employing the wide swath mode temporal coverage becoming available in the coming years.

**3.2.2 Ship Detection Analysis** Figures (9 and 10) show the number of vessels detection performance (vessel detection performance) between the years 2020 and 2021, respectively. The results show a significant decrease in vessels detected in 2021, compared to 2020. These results are expected as the data coverage has significantly decreased, as showed in Fig 8. However, these results further show the importance of spatial coverage and temporal coverage for an operation monitoring system.

Important information on the use of Open Data for operational MDA monitoring efforts was observed from the analysis. The spatial and temporal coverage is of high importance when evaluating if the dataset can be used for operational monitoring of large areas. Considering the very significant progress done

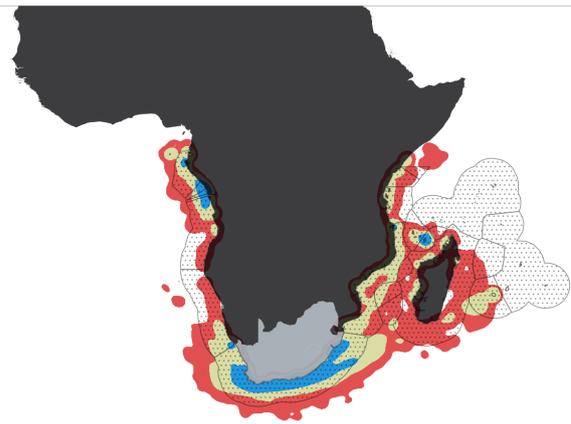


Figure 9. SAR Ship Detections in 2020. Where Blue, Yellow and Red represent High, Medium, Low vessel detections respectively.

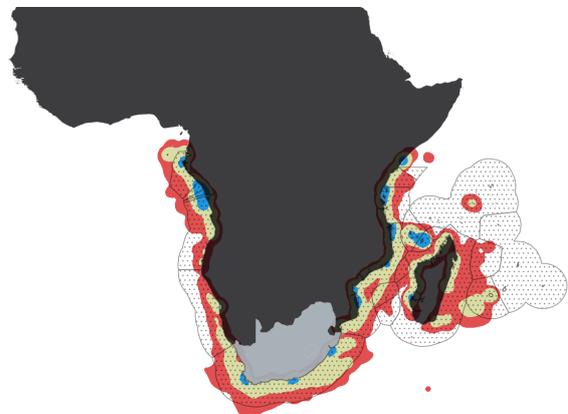


Figure 10. SAR Ship Detections in 2021.

by the OCIMS and the SAR community, and considering the unique capacity of SAR to monitor our environment with high resolution, regardless of cloudy and dusty conditions and solar illumination, it is evident that operation marine security and environmental management cannot afford to not include SAR data sources.

#### 4. CONCLUSION

The main objective of this paper was to provide information and present options to the decision-makers around sustainability of commercial SAR data acquisition in support of OCIMS. Although Sentinel 1A and B provide alternatives to commercially acquired C- band sensors, it does present severe limitations for an operational service. All the Sentinel images obtained from the sentinel portals over South Africa took more than 2 hours to receive at CSIR and can take up to 24 hours. This does not conform to the near real time requirement of a latency of less than 30 minutes. The downloading of Sentinel 1 images from the Sentinel hubs was also constrained by the data throttling policies of Sentinel, restricting the number of images that can be downloaded per day. The revisit time delay of 6 to 12 days would not be critical if the service was only used for the analysis of historical data. However, for operational applications such as OCIMS, the revisit latency, together with the reception

latency, is too long, as it increases the uncertainty of vessel location and reduces the chance of vessel identification.

However, despite the limitations of Sentinel-1 in supporting an operational service such as OCIMS, it could be considered as a complementary dataset for operational monitoring of our oceans and coasts. Sentinel 1 is also not a taskable data source and cannot be used for hot spot monitoring, emergency acquisitions and monitoring specific areas of interest. The need for having access to a programmable SAR data source that allows for acquiring data that fully meets OCIMS requirements is a crucial component of a fully operational OCIMS. To meet OCIMS needs and address the imperative to reduce costs would require a hybrid of commercial acquisition being used in conjunction with an open data source such as Sentinel 1 A B. This would ensure that an operational service with the desired latency as well as increasing the revisit time over the EEZ.

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