The Use of Remote Sensing for Maritime Surveillance for Security and Safety in Cyprus

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ABSTRACT

Maritime surveillance is of critical importance for threat prevention and maintenance of national security and safety. Maritime traffic comprises worldwide navigation of millions of vessels. In this sense, the geostrategic position of Cyprus entails the need for effective monitoring of marine traffic. Remote Sensing is a technique, which enables maritime surveillance by means of space-based detection and identification of marine traffic. The advent of new satellite missions, such as Sentinel-1, enabled the acquisition of systematic datasets for monitoring vessels. Using the Copernicus Open Access Hub service, it is now feasible to access satellite data in a fully automated and near real-time mode and deliver vessel information through a web portal interface. Nevertheless, there is still a great need to understand the full potential of the information acquired from such sensors. In this paper, an overview of vessel tracking techniques using Sentinel acquisitions is carried out. Consequently, vessel detections via space imagery could be authenticated against Automatic Identification System (AIS) data, which provide the location and dimensions of ships that are legally operating in the Cyprus region.

Keywords: Remote Sensing, Maritime Surveillance, SAR, Sentinel-1, CFAR, Cyprus

1. INTRODUCTION

Maritime surveillance can be defined as the monitoring of human activities at sea. The surveillance is intended to support efforts related with security (e.g., irregular sea border crossing, and smuggling of illegal goods or substances), safety (e.g., Search and Rescue, and shipping traffic), and environmental and sustainability (e.g., fishing control, and pollution) aspects[1]. This paper focuses on monitoring marine traffic using Remote Sensing techniques, such as space-based detection and identification in the Cyprus region.

The advent of new satellite missions, such as Sentinel-1, enabled the acquisition of systematic datasets for monitoring vessels. Using the Copernicus Open Access Hub service, it is now possible to access satellite data in a fully automated and near real-time mode and deliver vessel information through a web portal interface. Following the Copernicus's "free, full and open" data access policy, all the images ("full") are made available to all users ("open") at no cost ("free") through the Copernicus Open Access Hub (formerly known as Sentinels Scientific Data Hub), while dedicated data access is provided to international partners (International Hub), collaborative ground segments (Collaborative Hub) and Copernicus Services (Copernicus Services Hub)[2]. Sentinel-1 operates in a predefined observation plan, which dictates the areas that will be monitored and the modes and polarisations that will be used[3].

Sentinel-1 is the SAR satellite constellation of the European Union's Copernicus programme for Earth Observation, operated by the European Space Agency (ESA). It consists of two units, Sentinel-1A launched on 3 April 2014 and Sentinel-1B launched on 25 April 2016, which entered into operation on 3 October 2014 and 26 September 2016, respectively. It uses a C-band instrument (frequency 5.405 GHz) and can operate in four acquisition modes: ExtraWide (EW), InterferometricWide (IW), Stripmap (SM) and Wave (WV) [4,5]. The data can be processed to various types of image product, and the Ground Range Detected High resolution (GRDH) product[4,5] is the one used in this study. The radar can transmit in vertical (V) or horizontal (H) polarisation, and can receive in H, V or in both of them simultaneously.

A Sentinel-1 product can therefore have one of the following combinations of polarisations: single channel HH, VV, HV or VH, or dual HH + HV or VV + VH, the first letter denoting the transmitted polarisation and the second one the received polarisation[4,5]. Additionally, SNAP (Sentinel Application Platform) software from ESA provide ocean object detection tool using Utilization of CFAR (Constant False Alarm Rate) algorithm to detect a sea object. The tool is called ocean object detection and allow rapid ship detection mapping. Thus, in this study, the aims are to detect ship position by using this tool[6]. Also, ship detection using SAR images could be validated against Automatic Identification System (AIS) data, which provide the location and dimensions of ships that are legally operating in the Cyprus region. The AIS system was initially developed for ship collision avoidance by broadcasting a ship's information to other ships and AIS base stations located along coast lines[1]. This information can be dynamic, including ship position, heading and speed, or static, including ship name, IMO number and size[7].

In the maritime domain, several algorithms and methods have been developed for ship detection using SAR data. The most common ship detector algorithm, as mentioned above, is the CFAR (Constant False Alarm Rate) detector, where the outcomes of the detection stage can be validated with the AIS data as the ground truth[8]. However, the AIS data are often not a reliable source of information because of the presence of some errors and uncertainties while reporting ships information, for example, error related to the ship position, heading or simply some data can be missing in the AIS report[9]. As well, ship detection with Sentinel-1 falls into the non-cooperative category and enables detection of vessels not carrying AIS or other tracking system on board, such as smaller fishing ships or ships that are found in the surveyed area illegally (illegal fishing, piracy etc.). Moreover, SAR is not reliant on solar illumination and is rather independent of weather conditions, therefore, enabling frequent monitoring[10].

2. METHODOLOGY

2.1 Study Area

The area of interest (AoI) of the study is part of the Cyprus' Exclusive Economic Zone (EEZ, which refers to 200 nautical miles, over which a nation has certain sovereign rights). Cyprus is located at the juncture of the World Island (Eurasia) with Africa. It is on the sea lane of the great maritime highway connecting the Mediterranean Sea through two sea gates--the Suez and Bab al-Mandab—with the Indian Ocean. From there, it links to two other sea gates. These are the Strait of Hormuz, leading to the Persian Gulf, and the Strait of Malacca, connecting to the Pacific[11]. The study periods used herein are 24 February 2020 and 02 March 2020, as shown from the satellites' metadata in Figure 1 and Figure 2 respectively. Figure 3 shows satellite image of Cyprus' Exclusive Economic Zone (EEZ) and also thumbnail backscattering images of Sentinel-1 imagery a) on 24 February 2020 and b) on 02 March 2020.

first_line_time	24-FEB-2020 03:51:22.982996
last_line_time	24-FEB-2020 03:51:47.981700
first_near_lat	35.81736373901367
first_near_long	34.23250580233104
first_far_lat	36.22178649902344
first_far_long	31.41541601699129
last_near_lat	34.31291198730469
last_near_long	33.87685017854811
last_far_lat	34.71928024291992
last_far_long	31.11173793256539

Figure 1. Main metadata of the study period on 24 February 2020.

first_line_time	02-MAR-2020 03:43:28.578227
last_line_time	02-MAR-2020 03:43:53.577806
first_near_lat	34.656639099121094
first_near_long	36.020653406314885
first_far_lat	35.06629620523973
first_far_long	33.21717292343347
last_near_lat	33.153578424813546
last_near_long	35.65770071486327
last_far_lat	33.563185604762396
last_far_long	32.917761922963386

Figure 2. Main metadata of the study period on 02 March 2020.

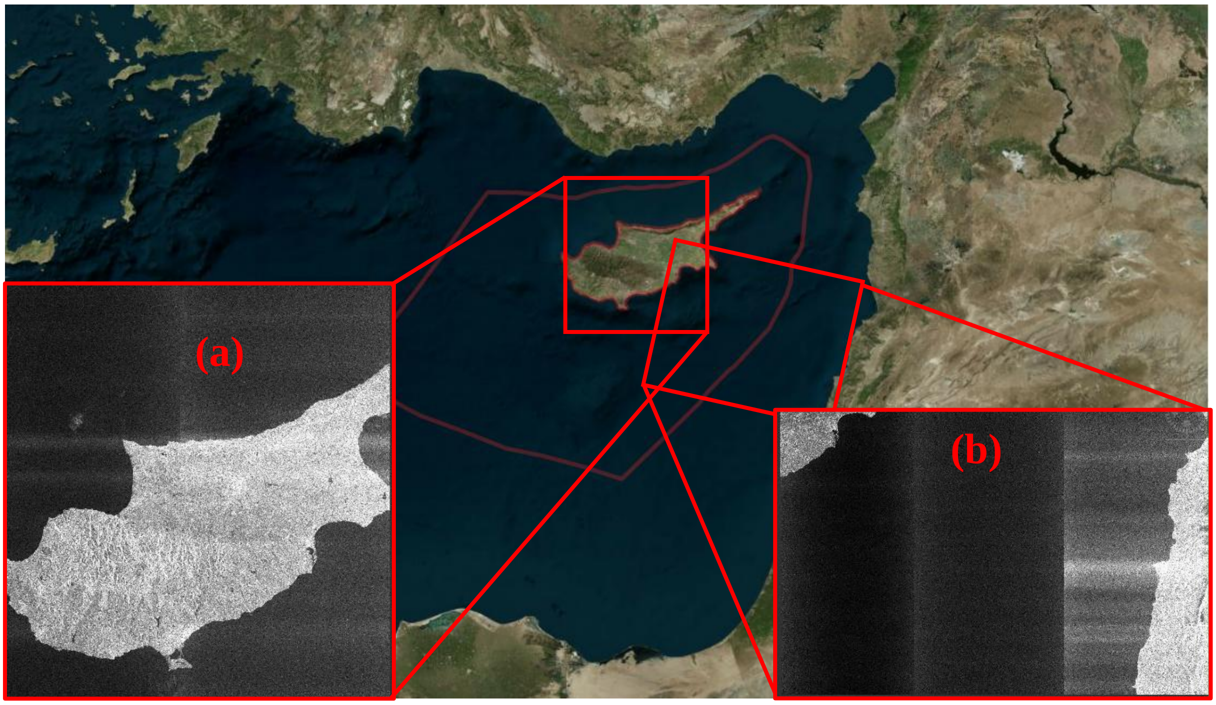

Figure 3. Satellite image of Cyprus' Exclusive Economic Zone (EEZ) and also thumbnail backscattering images of Sentinel-1 imagery a) on 24 February 2020 and b) on 02 March 2020.

2.2 Methods

The main idea for this study is to detect ships in the Cyprus' Exclusive Economic Zone (EEZ). Data from Sentinel-1 from the Copernicus Open Access Hub was used through the online interface. The methodology was formulated in order to be used within the Sentinel application platform (SNAP), a common architecture for all Sentinel satellite toolboxes. The processing graph in 'xml' format allows the processing of Sentinel-1 GRD using the command line graph processing framework, which allows for batch processing of large datasets[12].

The overall methodology adopted in this study consists of fifteen (15) processing steps briefly described below (see Figure 6):

Step 1: Select Areas of Interest from Copernicus Open Access Hub (Figures 4 and 5)

Figure 4. Select Area of Interest (on 24 February 2020) from Copernicus Open Access Hub used in this study.

Figure 5. Select Area of Interest (on 02 March 2020) from Copernicus Open Access Hub used in this study.

Step 2: Download data from Sentinel-1 via the Copernicus Open Access Hub using the online interface by specifying the following parameters:

Sensing period: (2 periods) From 24/02/2020 to 24/02/2020 and from 02/03/2020 to 02/03/2020
Check Mission: Sentinel-1
Satellite Platform: S1A*
Product Type: GRD (Ground-range-detected product)

Step 3: Using SNAP (Sentinel Application Platform) software. Opening Amplitude_VH to visualize the band.

Step 4: Thermal noise Removal: Thermal noise removal reduces noise effects in the inter-sub-swath texture, in particular, normalizing the backscatter signal within the entire Sentinel-1 scene and resulting in reduced discontinuities between sub-swaths for scenes in multi-swath acquisition modes[12].

Step 5: Apply orbit file which provides accurate satellite position and velocity information. Based on this information, the orbit state vectors in the abstract metadata of the product are updated[10].

Step 6: Remove GRD (Ground Range Detected) Border Noise: Remove noisy pixels from GRD images, regardless of their acquisition mode, polarization, or resolution and can cope with challenging features within the image scenes that typically affect other approaches[13].

Step 7: Subset: Since our Area of Interest (AoI) is quite small and there is no need to process the whole image, we start with sub-setting the scene to a more manageable size. This will reduce the processing time in further steps and is recommended when the analysis is focused only over a specific area and not the complete scene[10].

Step 8: Add vector mask in order to avoid detection of false targets (ships) on land the SNAP Ocean Object detection includes a land masking function[10]. Our mask was ESRI Shapefile which represents Cyprus' Exclusive Economic Zone (EEZ).

Step 9: Run ship detection algorithm. It consists of four (4) stages briefly described below:

Land-Sea Mask: The first stage is masking the land areas to avoid false target detections on land[10]. Therefore, it has been chosen to import into our product our vector mask with the name EEZ.shapefile.

Calibration: Calibration is the procedure that converts digital pixel values to radiometrically calibrated SAR backscatter[12].

Adaptive Thresholding: Adaptive thresholding is a frequently used method for target detection in SAR imagery. The underlying assumption is that targets appear bright on dark background. The adaptive thresholding algorithm is applied in the moving window. For each pixel under test (central pixel) a new threshold value is calculated based on the statistical characteristics of its local background: if the pixel value is above the threshold the pixel is classified as target pixel[10].

Object Discrimination: This stage is used to filter out false targets based on minimum and maximum size limits[10]. In this study, 30 m and 600 m were determined for minimum and maximum target size. These values were selected based on ship size estimation

Step 10: Terrain correction: Terrain corrections are intended to compensate for the distortions arising due to the sensor's side looking geometry so that the geometric representation of the image will be as close as possible to the real world[12].

Step 11: Colour Manipulation

Step 12: Results - Ship detection: Open band using Sigma_VH and Sigma_VV. We can see the red circles representing targets.

Step 13: Ship Extraction: Export results to an ESRI Shapefile (.shp) format that is more manageable and can be processed and visualized further in software such as QGIS.

Step 14: Visualization in QGIS

Step 15: Comparison of results is performed

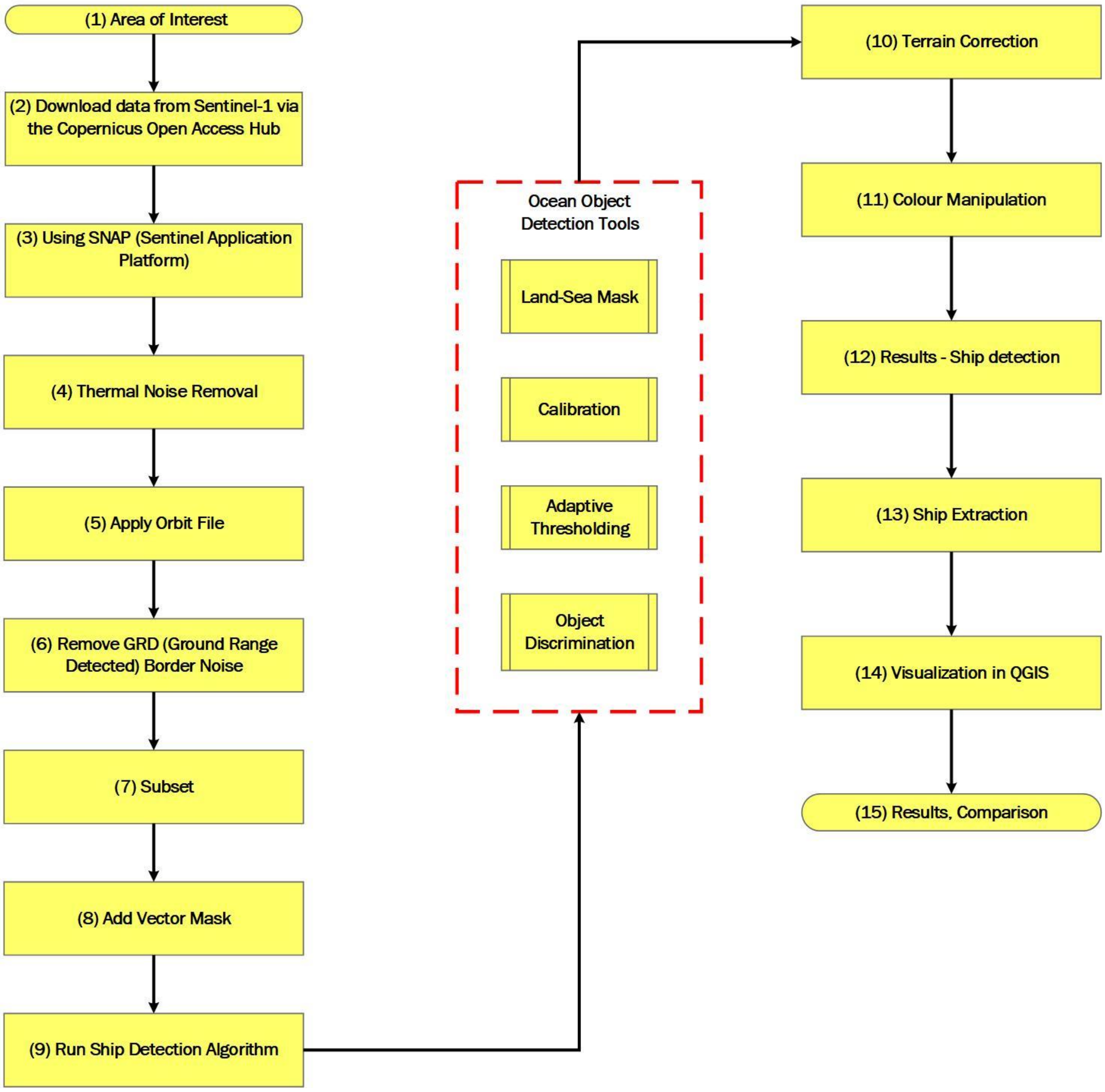

Figure 6: Methodology

3. RESULTS

In the ship detection process, using ocean object detection tool in SNAP, ship was extracted from Sigma Nought VH. The results show that the objects are detected as shown in Figure 7 and Figure 8. In SAR images using SNAP viewer ships tend to appear as bright pixels in a darker local background. We can see the bright targets (ships) within the red circles (Figures 7, 8) in the Areas of Interest on 24 February 2020 and on 02 March 2020.

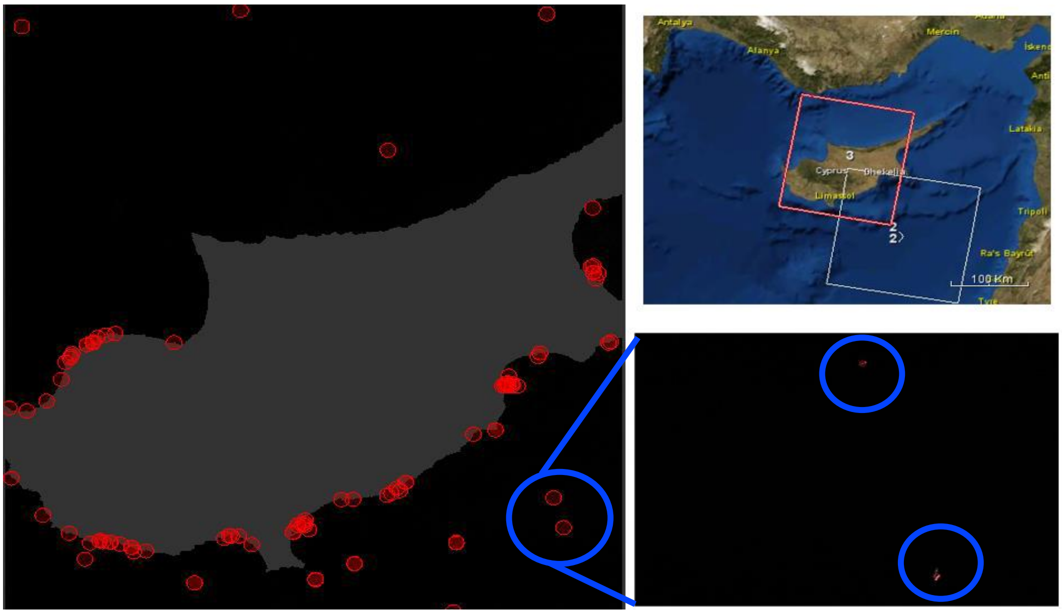

Figure 7. Ships detection results in SNAP viewer for Area of Interest **(**on 24 February 2020). Targets (ships) within the red circles.

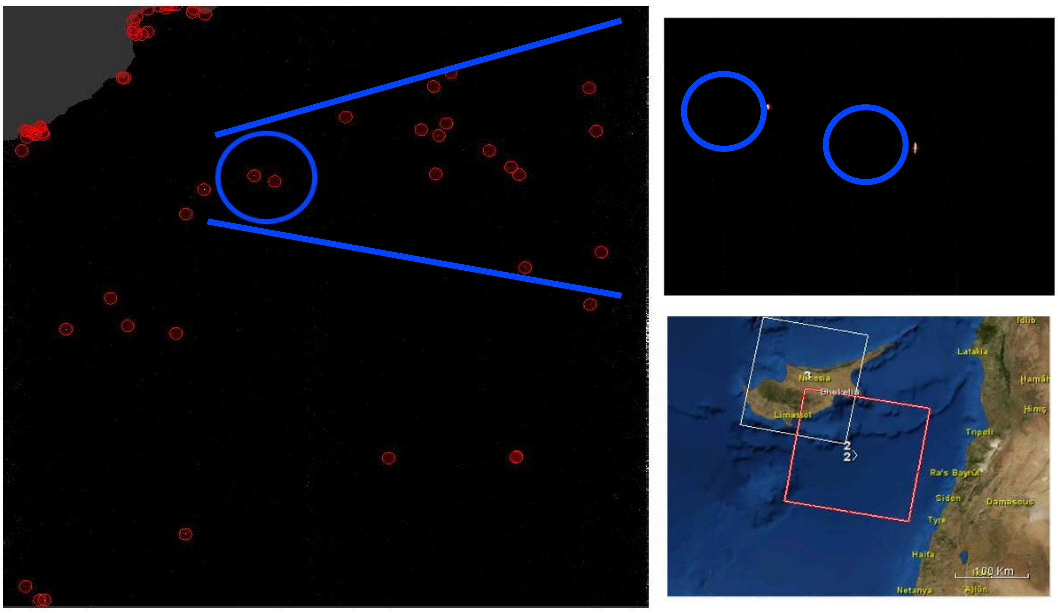

Figure 8. Ships detection results in SNAP viewer for Area of Interest **(**on 02 March 2020). Targets (ships) within the red circles.

Furthermore, to making the ship detection results look better were exported as CSV file and in ESRI Shapefile (.shp) format. This is more manageable and can be processed and visualized further with software, such as QGIS. Figure 9 shows the results as CSV format for Area of Interest **(**on 24 February 2020) and Figure 10 shows the results as CSV format for Area of Interest **(**on 02 March 2020) and Figure 11 shows results in QGIS. The results indicate that ship detection using ocean object detection tools by Sentinel-1 ocean object detection in SNAP tools, enables detection of vessels not carrying AIS or other tracking system.

Target	Detected_x:Integer	Detected_y:Integer	Detected_lat:Double	Detected_lon:Double	Latitude	Longitude
target_000	(1793	257)	1793	257	35.78780513	33.9671357
target_001	(9159	162)	9159	162	35.91699918	33.16723265
target_002	(14412	598)	14412	598	35.96046341	32.58511204
target_003	(5616	3873)	5616	3873	35.52546314	33.47643936
target_004	(693	5403)	693	5403	35.30593744	33.97702384
target_005	(684	6935)	684	6935	35.16776355	33.94568441
target_006	(734	6958)	734	6958	35.16653718	33.93980427
target_007	(680	7104)	680	7104	35.15242869	33.94252107
target_008	(680	7114)	680	7114	35.15156455	33.94237351
target_009	(551	7139)	551	7139	35.1471317	33.9557539
target_010	(620	7286)	620	7286	35.13505762	33.94519514
target_011	(12170	8723)	12170	8723	35.19441491	32.66507606
target_012	(12386	8763)	12386	8763	35.19434348	32.6404245
target_013	(262	8944)	262	8944	34.97965785	33.94859259
target_014	(316	8979)	316	8979	34.97741867	33.94203597
target_015	(1960	9242)	1960	9242	34.98135844	33.75937155
target_016	(10756	8970)	10756	8970	35.14969055	32.81409845
target_017	(12593	8829)	12593	8829	35.19158247	32.61715788
target_018	(12689	8954)	12689	8954	35.18178752	32.60428528
target_019	(12696	8966)	12696	8966	35.18086243	32.60329606
target_020	(12702	8975)	12702	8975	35.18015401	32.6024144
target_021	(12846	9020)	12846	9020	35.1782598	32.58631271
target_022	(12852	9030)	12852	9030	35.17745383	32.58546348
target_023	(13204	9264)	13204	9264	35.16181924	32.54334497
target_024	(2004	9336)	2004	9336	34.97368286	33.75261912
target_025	(13232	9329)	13232	9329	35.1564464	32.53907522
target_026	(13253	9375)	13253	9375	35.15264308	32.53583406
target_027	(13366	9484)	13366	9484	35.14452829	32.52164518
target_028	(2634	10049)	2634	10049	34.91998062	33.66975432
target_029	(2631	10108)	2631	10108	34.91457797	33.66878741
target_030	(2501	10120)	2501	10120	34.9113152	33.68262369

Figure 9. Ships detection CSV results for Area of Interest **(**on 24 February 2020).

ShipDetections:String	Detected_x:Integer	Detected_y:Integer	Detected_lat:Double	Detected_lon:Double	Latitude	Longitude
target_000	(33.83075117540663	34.96093144813737)	11780	233	34.96093145	33.83075118
target_001	(33.858686908852455	34.94257786724139)	11494	389	34.94253284	33.85867749
target_002	(33.78311366301148	34.977026936858756)	12239	131	34.97702694	33.78311366
target_003	(33.82493841876927	34.953309727154924)	11818	324	34.95330973	33.82493842
target_004	(33.75360760081525	34.982405176271904)	12512	117	34.98240518	33.7536076
target_005	(33.758899564195474	34.9813958272514)	12463	120	34.98139583	33.75889956
target_006	(33.768971658476076	34.979077343310465)	12369	130	34.97908489	33.76891709
target_007	(33.73558877061148	34.98100576982691)	12670	159	34.98096828	33.73552499
target_008	(33.752280140037385	34.97378938054525)	12508	212	34.97375189	33.75221632
target_009	(33.70086957001005	34.977377430641454)	12973	250	34.97733992	33.70080593
target_010	(33.66460732048816	34.96359214988511)	13272	453	34.96355462	33.66454386
target_011	(33.6542838340417	34.95390751267437)	13347	573	34.95386245	33.65427485
target_012	(33.68894827802851	34.921791233786756)	12979	868	34.9217537	33.68888486
target_013	(33.67160639322557	34.91715298426594)	13126	944	34.91711545	33.67154306
target_014	(33.65100238409793	34.93296987017706)	13339	804	34.93297739	33.65094806
target_015	(33.647103689191574	34.92573061637298)	13361	888	34.92573062	33.64710369
target_016	(33.65366025449253	34.91945192804801)	13291	946	34.91945944	33.65360598
target_017	(34.513702228516635	34.70008985685455)	5126	1994	34.70008986	34.51370223
target_018	(33.59484209693134	34.81748337201105)	13635	2135	34.81748337	33.5948421
target_019	(33.6013648974855	34.81584615732172)	13574	2143	34.81580115	33.60135557
target_020	(34.88915085441975	34.605032470357564)	1551	2420	34.60499546	34.88908718
target_021	(34.45730303531224	34.67282111869171)	5581	2376	34.67277608	34.45729323
target_022	(34.47349844808212	34.57584085093268)	5244	3394	34.57580366	34.47343496
target_023	(34.197013601681604	34.632527409502714)	7851	3215	34.63249011	34.19695019
target_024	(34.88470278140762	34.49556650804803)	1371	3603	34.49556651	34.88470278
target_025	(34.44558103693822	34.54888111306038)	5443	3728	34.54884393	34.44551755
target_026	(34.399793533434654	34.56996711093216)	5898	3573	34.56996711	34.39979353
target_027	(33.340091894268475	34.727186217091436)	15757	3488	34.7271411	33.34008355
target_028	(33.33995837646374	34.726464339966)	15757	3496	34.72641922	33.33995003

Figure 10. Ships detection CSV results for Area of Interest **(**on 02 March 2020)

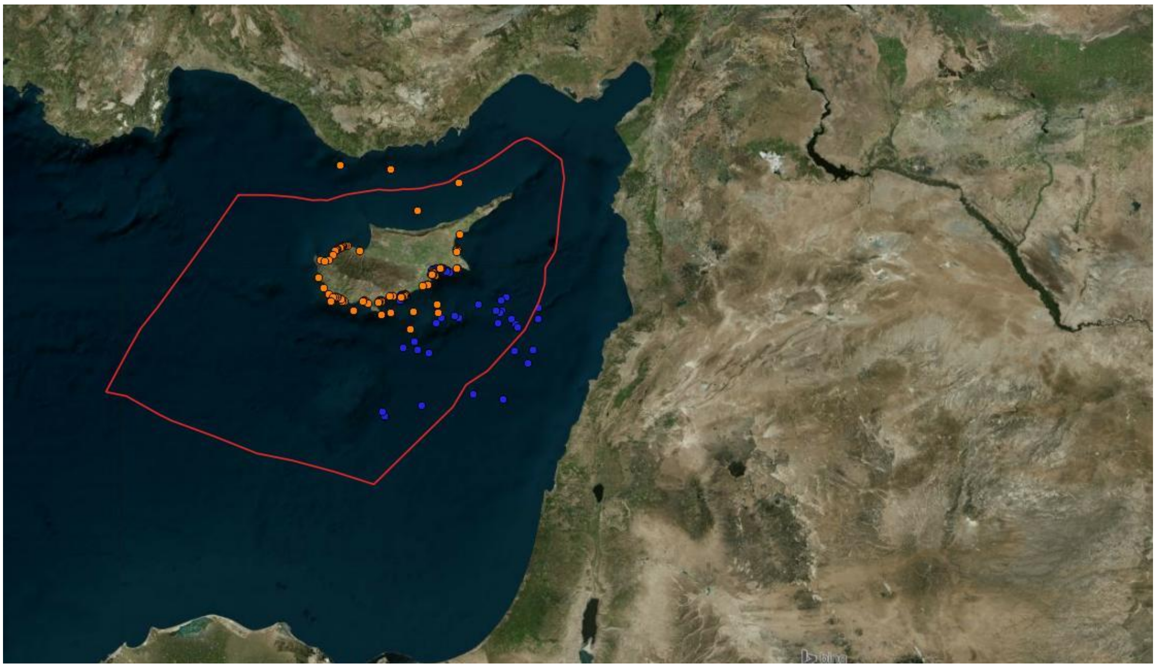

Figure 11. Ships detection results for Area of Interest on 24 February 2020 (blue points) and for Area of Interest on 02 March 2020 (orange points).

Furthermore, using a larger time-series, it is possible to detect the areas where the ships are frequently travelling and the concentration of marine traffic in the Cyprus EEZ (figure 12).

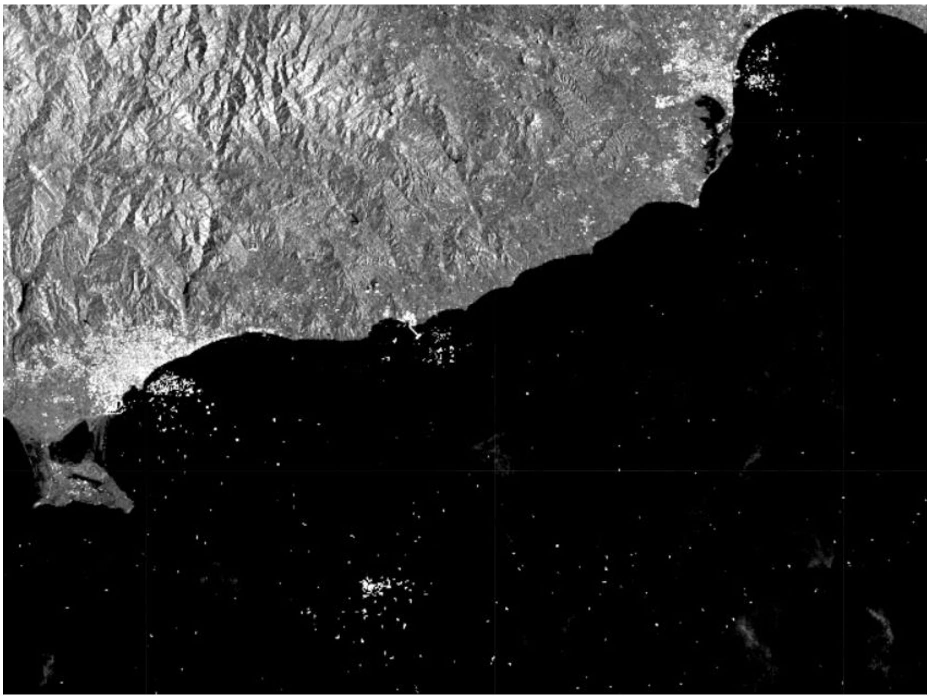

Figure 12. Ships detected using time series analysis

4. CONCLUSIONS

Ship detection is part of maritime surveillance that is in the focus of this paper using Sentinel 1. The free, full, and open nature of the Sentinel-1 SAR images gives access to unprecedented volumes of data. This presents opportunities, but these will not come to fruition unless the challenges that also come with the huge data volume are confronted[1]. The surveillance is intended to support efforts related with security. In this study, Sentinel-1 results show that using ocean object detection SNAP tools are suitable to use for rapid sea mapping. The procedure uses fast-delivery data from the synthetic aperture radars on Sentinel-1, with automatic download and processing for object detection[14].

Furthermore, the availability of repeated observations allows ship detections: most of these detections are ships of interest and some of them of no interest to maritime surveillance purposes. Overall, observations are planned in the near future to study different periods of time and different study areas in order to evaluate the above results and the satellites' sensitivity and time series analysis.

The study at hand represents an initial approach to ship detection with publicly available tools. Within the 'EXCELSIOR' project, the results will later be compared to more sophisticated methods as developed by DLR. The technology to run high-performance ship detection algorithms directly at the receiving ground station and thus keeping the time between acquisition and information delivery minimal will be introduced to the Cyprian partners within this project. The benefit in accuracy and time saving can then be quantified.

ACKNOWLEDGMENTS

This paper is under the auspices of the activities of the 'ERATOSTHENES: Excellence Research Centre for Earth Surveillance and Space-Based Monitoring of the Environment'- 'EXCELSIOR' project that has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No 857510 and from the Government of the Republic of Cyprus through the Directorate General for the European Programmes, Coordination and Development. From 1st of October 2019, the ERC group (Department of Civil Engineering and Geomatics) at the Cyprus University of Technology is on the way to be upgraded to ERATOSTHENES Centre of Excellence (ECoE) through 'EXCELSIOR' H 2020 Widespread Teaming project (www.excelsior2020.eu).

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