Ship detection in Cyprus EEZ using Sentinel 1 data

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ABSTRACT

Marine Spatial Planning (MSP) is a key tool in managing the interaction of activities in the coastal and marine environment. It analyzes and allocates human activities to achieve the ecological, economic, and social goals established through a political process. Under this project, data was collected for various activities such as tourism, aquaculture, fisheries, renewable energy, ship routes, etc. This study focuses on the data referring to ship detection. Ship routes in Cyprus EEZ were created using position signals of ships in the EEZ for a temporal resolution of 15 minutes. These signals are compared to the positions of these ships using the radar backscatter derived from Sentinel-1A and Sentinel-1B satellite images, which have a temporal resolution of 6 days. The radar backscatter for a certain period calculated using the Google Earth Engine platform, was then compared to the ship signals provided. This research is supported by the project entitled "Cross border Cooperation for Implementation of Marine Spatial Planning referred as THAL-CHOR 2" and is Co-funded by the European Regional Development Fund (ERDF) and by national funds of Greece and Cyprus under the Cooperation Programme Interreg V-A Greece-Cyprus 2014-2020.

Keywords: Remote Sensing, Cyprus, Ship detection, Marine Spatial Planning, Sentinel-1, Google Earth Engine

1. INTRODUCTION

Marine Spatial Planning (MSP) refers to a public process, investigating and dealing with the spatial and time-based distribution of human activities in marine areas for achieving the ecological, economic and social intentions which are usually identified over a political process [1,2]. It is a key tool in managing the interaction of activities in the coastal and marine environment. MSP is increasingly recognized as an important management tool that provides a comprehensive framework for managing multiple activities within the marine environment [3,4].

Satellite and Earth observation data have a key role to play in studying the marine and coastal environment [5]. They are used to monitor many maritime activities and applications, including sustainable fishing, marine ecosystem protection, natural resource extraction, commerce, trade, traffic monitoring, among others, as they are an effective way of obtaining frequent data on a synoptic scale regarding the state of oceans and coasts. Remote sensing data from Synthetic Aperture Radar (SAR) sensors are used extensively as they operate independently of sunlight and weather conditions. In addition, SAR time series images can form a temporal dataset, which is accomplished by examining the phase difference between multiple images of the same area, acquired from different sensor positions, to conduct the detection of points with stable temporal characteristics [6]. The advantage of the SAR temporal series exploited in this work is the ability to conduct the detection of points with stable temporal characteristics [7].

Globally, there are an estimated 150,000 merchant ships (vessels that transport cargo or passengers), with the international shipping industry responsible for the carriage of 90% of world trade and 60% of the world's oil and fuel supplies [8]. Most ship transits occur within distinct shipping routes. Consequently, identifying the movement of maritime vessels is seen as an essential step to effectively mitigating threats due to maritime shipping [9]. Due to the economic efficiency of shipping as a mode of transport as well as the volume and distance over which material is transported, there is an urgent need to identify potential conflicts between shipping. Satellite data can assist in the visualization patterns of vessel behavior and identify potential threats to support marine spatial planning at national scales [10]. Evaluating the spatial information on the movement of maritime vessels spatial options is essential for developing strategies for selecting spatial management measures [11].

Ship detection is an essential factor for maritime traffic monitoring [12] andmaritime surveillance applications. Research has focused on how ships can be detected using Spaceborne Synthetic Aperture Radar (SAR) images [13]. This is due to the ability of SAR to provide data regardless of sunlight weather conditions, in contrast with the optical sensors, which provide data only during the day and for weather without clouds [14]. Furthermore, SAR images are considered ideal for ship detection because the variation of backscatter properties of each object can provide distinctive features for reliable scene understanding and interpretation [12, 15].

During the THAL-CHOR 2 project, SAR images from newly launched Sentinel-1 satellites, equipped with medium resolution SAR sensor, will be used to verify MSP data referring to ship detection [16-18]. The Sentinel-1 mission is the European Radar Observatory and is composed of a constellation of two satellites, Sentinel-1A and Sentinel-1B which were launched in 2014 and 2016 respectively. Sentinel-1A and Sentinel-1B satellites have the same orbit plane but with 180o orbital phasing difference and a temporal resolution of 6 days [19]. Table 1 presents details about acquisition modes, spatial resolution, and coverage [16].

Table 1: Acquisition modes, spatial resolution and coverage

Modes	***Swath (Km)***	***Spatial resolution (m)***
Strip map (SM)	*80*	*5 x 5*
Interferometric Wide swath (IW)	*250*	*5 x 20*
Extra-Wide swath (EW)	*400*	*20 x 40*
Wave (WV)	*20 x 20*	*5 x 5*

In this study, the routes of ships in Cyprus EEZ were compared by using position signals of ships in the EEZ for a temporal resolution of 15 minutes with the positions of these ships using the radar backscatter derived from Sentinel-1A and Sentinel-1B satellite images using the Google Earth Engine platform.

2. STUDY AREA AND METHODOLOGY

The study area selected is the Cyprus Exclusive Economic Zone (EEZ, which refers to 200 nautical miles, over which a nation has certain sovereign rights). Cyprus is an island located among three continents: Europe, Africa and Asia. The implementation of an exact MSP is essential for all coastal countries especially for Cyprus, an island with a geostrategic position in the area of eastern Mediterranean [1]. In Cyprus, the geographical location and the massive area of its EEZ (compared to its land size) are two very important reasons for the formation of a precise and integral MSP [20]. The terrestrial area of the island is 9.251 km² and the area of the EEZ is more than ten times larger than the land area, the EEZ area is 98.240 km² [20]. Figure 1 indicates the study area.

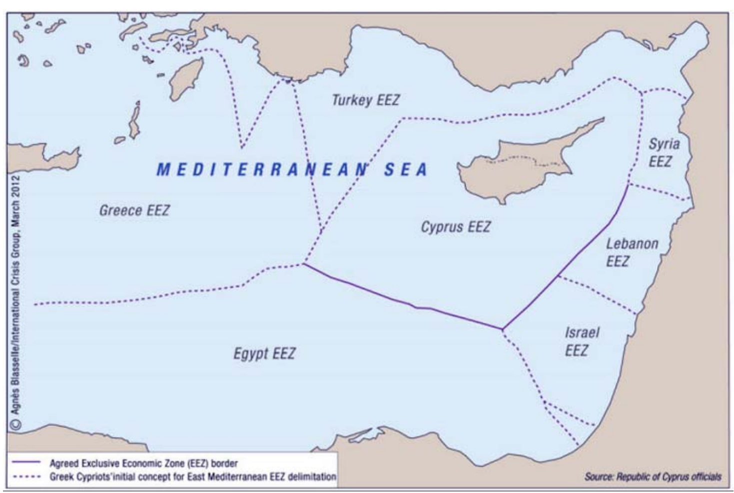

Figure 1 Study area location (source: Republic of Cyprus)

2.1 Resources

In this study, both the Google Earth Engine and automatic identification system were used. Google Earth Engine (GEE) is a planetary-scale platform for scientific analysis and visualization of geospatial datasets. The Earth Engine has archived all the satellite imagery into a public data archive that includes historical earth images for more than forty years [21]. Google has launched GEE, which processes big geospatial data [22]. In this platform, the open source images acquired by several satellites, including Sentinel-1, are accessible and can be efficiently imported and processed in the cloud without the necessity of downloading the data to local computers. Moreover, several image-driven products and many remote sensing algorithms, including classification algorithms and cloud masking methods, are available in this platform [22, 23].

The Automatic Identification System (AIS) system is an automatic tracking system defined by the International Maritime Organization (IMO). This system is a maritime safety and navigation system, while the information it provides is very useful in predicting the routes of ships and avoiding collisions. This system includes information about the name of the vessel, MMSI ID of the ship, ship type, size and the current time. It also includes information for the ship's position, speed, direction, destination and expected time of arrival [24]. In this study, position signals of ships from AIS system were used in the Cyprus EEZ for a temporal resolution of 15 minutes.

2.2 Methodology

The methodology used in this study is featured in Figure 2 and explained in steps 1-7.

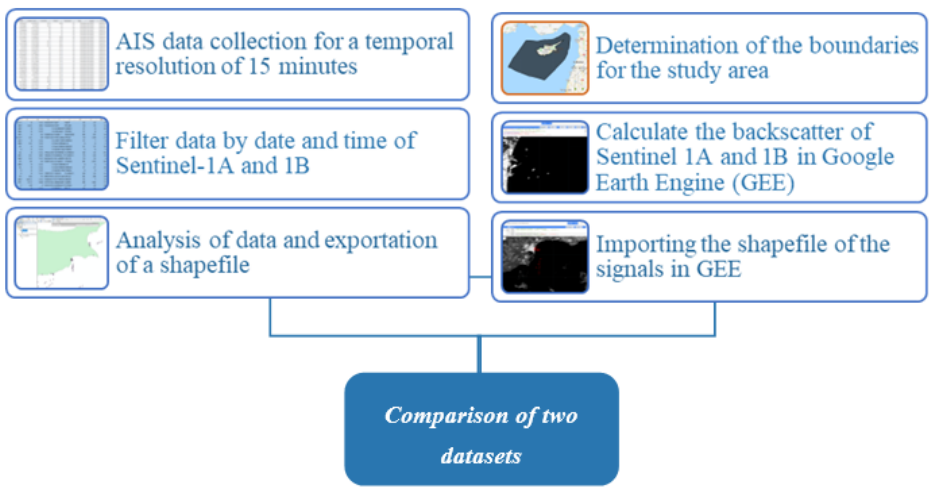

Figure 2 Flow chart of the proposed method

Step 1: The AIS data for the ships used the EEZ of Cyprus for one month (January 2019).

Step 2: The boundaries of the study area were identified by inserting a shapefile in GEE platform.

Step 3: Specification of the criteria based on which the images were acquired and calculation of the radar backscatter for these criteria.

- Instrument mode : IW
- Polarisation: VH
- Orbit properties: Descending
- Bounds: EEZ
- Date: 1/1/2019 – 31/1/2019

Step 5: A list of images was created with the images that responded to the criteria and the AIS data were filtered based on the date and time of these images.

Step 6: In ArcMap GIS a shapefile with the positions of the ships was created based on the AIS data

Step 7: The shapefile with the positions of the ships was imported in GEE and these points were compared with the backscatter of SAR images.

3. RESULTS

To make the result more distinguishable, a specific date was used as an example. The results are shown in figures 3 and 4. Most of the positions of the ships from the AIS system agree with the ships that were detected by the backscatter of the Sentinel-1 images. The orange coloured dots are the AIS data, while the white marks indicate the backscatter SAR data. In some cases there are more than one orange coloured dots in a small area due to the fact that the position of ships recorded was for a particular timeframe where satellite data was available (i.e. 03:00-04:00). Since the temporal resolution is 15 minutes, a ship can be shown up to four times.

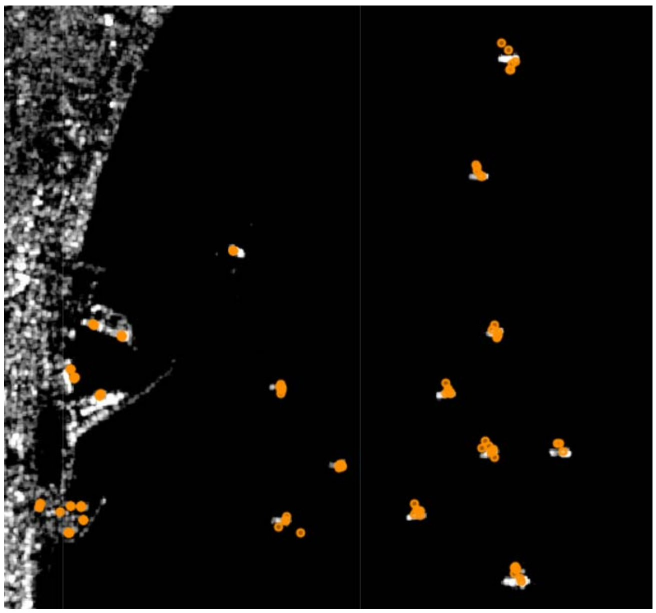

Figure 3: Port of Larnaca, Sentinel-1B backscatter for 6/1/2019

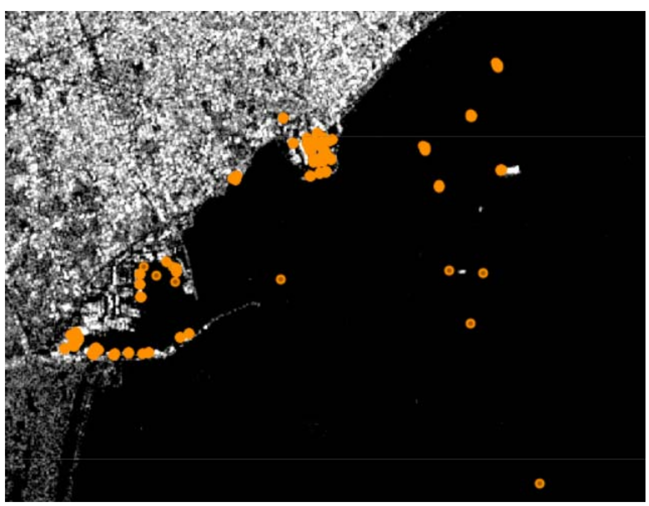

Figure 4: Port of Limassol, Sentinel-1B backscatter for 6/1/2019

Furthermore, using a larger time-series, it is possible to detect the areas where the ships were anchored. Figure 5 indicates the anchor areas detected from the time series analysis. Areas with higher number of ship conflicts aships are recorded in red boxes. As is evident, the primary areas related to ship detection are the Limassol port (a), the coastal area of ships awaiting to dock at the Limassol port (b), the coastal area near Zygi (c) and the Larnaca port (d).

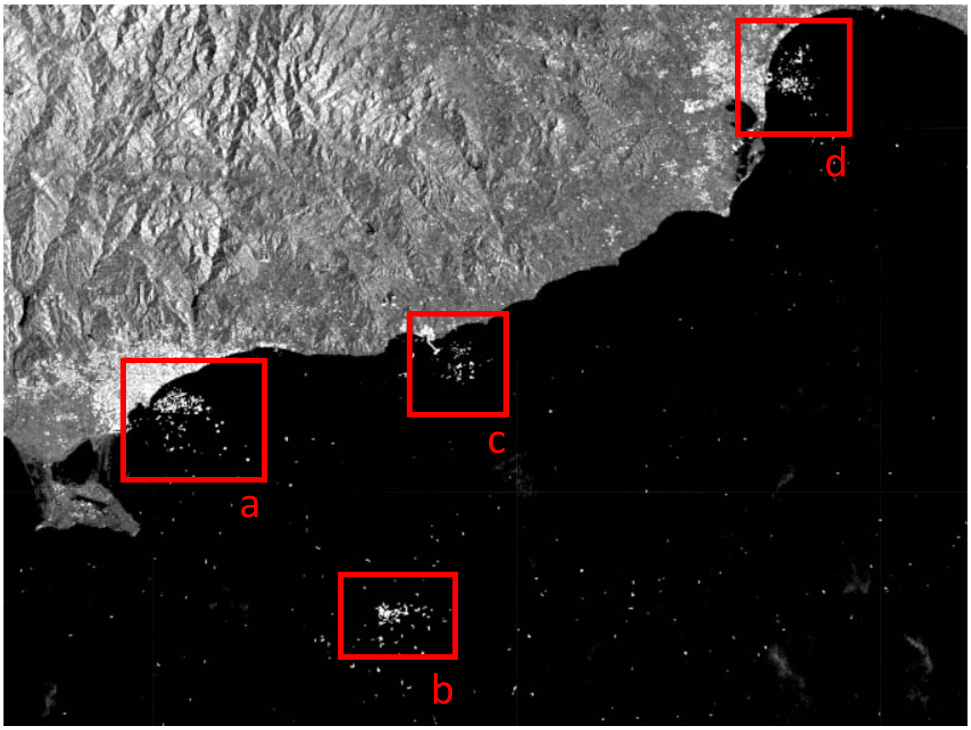

Figure 5 Anchor areas which are detected from the time-series analysis

4. CONCLUSIONS

This study demonstrated how the use of Google Earth Engine can be used to create a time series SAR images from Sentinel 1 for monitoring marine traffic, under the project THAL-CHOR 2. The use of Sentinel-1 satellite imagery and the analysis of these data in the GEE platform were valuable tools and very promising for the marine traffic monitoring. Furthermore, the comparison of the Sentinel-1 satellite images with the AIS data was shown a good correlation and this fact can be used in future works, such as the detection of illegal vessels in the area. Also, they can be used to identify anchors areas, which provide important information for decision making in marine spatial planning.

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REFERENCES

[1] Evagorou, E., Mettas, C., Agapiou, A., Themistocleous, K. and Hadjimitsis, D. [2018] "Bathymetry mapping with remote sensing methods for supporting Marine Spatial Planning in Cyprus". Geophysical Research Abstracts, Vol. 20, EGU2018-3492.

[2] Hadjimitsis, D.G, Agapiou, A, Themistocleous, K., Mettas, C., Evagoras, E., Soulis, G., Xagoraris, Z., Pilikou, M., Aliouris, K. and Ioannou, N. (2016). Maritime Spatial Planning in Cyprus. *Open Geosciences*, 8(1), pp. 653-661. doi:10.1515/geo-2016-0061.

[3] Ehler, C.: Conclusions: Benefits, lessons learned, and future challenges of marine spatial planning, Mar. Policy, 32(5), 840–843, doi:10.1016/j.marpol.2008.03.014, 2008.

[4] Douvere, Fanny. (2008). The importance of marine spatial planning in advancing ecosystem-based sea use management. Marine Policy. 32. 762-771. 10.1016/j.marpol.2008.03.021.

[5] Ouellette, William & Getinet, Wondifraw. (2016). Remote sensing for Marine Spatial Planning and Integrated Coastal Areas Management: Achievements, challenges, opportunities and future prospects. Remote Sensing Applications: Society and Environment. 4. 10.1016/j.rsase.2016.07.003.

[6] Fornaro, G.; Pauciullo, A. [2018]. Interferometric and Tomographic SAR. In Novel Radar Techniques and Applications, Edited by; Klemm, R., Nickel, U., Gierull, C., Lombardo, P., Griffiths in Klemm, Richard.

[7] Vaduva, C., Danisor, C. and Datcu, M. (2018). "Joint SAR image time series and PSInSAR data analytics: An LDA based approach". Remote Sensing. 10. 1436. 10.3390/rs10091436.

[8] UNCTAD, 2016, UNCTAD. (2016). United Nations Conference on trade and Development (UNCTAD) Review of Maritime Transport. United Nations Publication

[9] Robards, M., Silber, G., Adams, J., Arroyo, J. Lorenzini, D., Schwehr, K. and Amos, J. (2016). Conservation science and policy applications of the marine vessel Automatic Identification System (AIS)-A review. Bulletin of Marine Science -Miami-. 92. 75-103. 10.5343/bms.2015.1034.

[10] Metcalfe, K., Bréheret, N., Chauvet, E., Collins, T., Curran, B.K., Parnell, R.J., Turner, R.A., Witt, M.J and Godley, B.J. [2018]. "Using satellite AIS to improve our understanding of shipping and fill gaps in ocean observation data to support marine spatial planning". *J Appl Ecol*. 2018; 55: 1834– 1845. https://doi.org/10.1111/1365-2664.13139

[11] Ocean Leadership: Science Requirements for Marine Spatial Planning, [2009]. Accessed: https://oceanleadership.org/ocean-leadership-science-requirements-for-marine-spatial-planning/

[12] Liang, Y., Sun, K., Zeng, Y., Li, G. and Xing, M.: An Adaptive Hierarchical Detection Method for Ship Targets in High-Resolution SAR Images, Remote Sens., 12(2), 303, doi:10.3390/rs12020303, 2020.

[13] Liao, M., Wang, C., Wang, Y. and Jiang, L.: Using SAR images to detect ships from sea clutter, IEEE Geosci. Remote Sens. Lett., 5(2), 194–198, doi:10.1109/LGRS.2008.915593, 2008.

[14] Wang, Z., Yang, T. and Zhang, H.: Land contained sea area ship detection using spaceborne image, Pattern Recognit. Lett., 130(xxxx), 125–131, doi:10.1016/j.patrec.2019.01.015, 2020.

[15] Wang, S., Wang, M., Yang, S. and Jiao, L.: New Hierarchical Saliency Filtering for Fast Ship Detection in High-Resolution SAR Images, IEEE Trans. Geosci. Remote Sens., 55(1), 351–362, doi:10.1109/TGRS.2016.2606481, 2017.

[16] Pelich, R., Longepe, N., Mercier, G., Hajduch, G. and Garello, R.: Performance evaluation of Sentinel-1 data in SAR ship detection, Int. Geosci. Remote Sens. Symp., 2015-Novem, 2103–2106, doi:10.1109/IGARSS.2015.7326217, 2015.

[17] Vachon, P. W., Wolfe, J., Greidanus, H., Avenue, C. and Ka, C.: ANALYSIS OF SENTINEL-1 MARINE APPLICATIONS POTENTIAL Defence R & D Canada – Ottawa European Commission – Joint Research Centre TP 670 , Via E . Fermi 2749 , 21027 Ispra (VA), Italia, , (May), 1734–1737, 2012.

[18] Themistocleous K., Mettas C., Evagorou E. & Hadjimitsis D.G. (2019) The use of satellite remote sensing and UAV for the mapping of coastal areas for the use of marine spatial planning, Proc. SPIE 11156, Earth Resources and Environmental Remote Sensing/GIS Applications X, 1115610 (3 October 2019); https://doi.org/10.1117/12.2533064

[19] Geudtner, D., Torres, R., Snoeij, P., Davidson, M. and Rommen, B.: Sentinel-1 System capabilities and applications, Int. Geosci. Remote Sens. Symp., 1457–1460, doi:10.1109/IGARSS.2014.6946711, 2014.

[20] Hadjimitsis, D., Agapiou, A., Mettas, C., Themistocleous, K., Evagorou, E., Cuca, B., Papoutsa, C., Nisantzi, A., Mamouri, R.-E., Soulis, G., Xagoraris, Z., Lysandrou, V., Aliouris, K., Ioannou, N. and Pavlogeorgatos, G.: Marine spatial planning in Cyprus, Third Int. Conf. Remote Sens. Geoinf. Environ., 9535(March 2021), 953511, doi:10.1117/12.2195655, 2015.

[21] Mutanga, O. and Kumar, L.: Google earth engine applications, Remote Sens., 11(5), 11–14, doi:10.3390/rs11050591, 2019.

[22] Gorelick, N., Hancher, M., Dixon, M., Ilyushchenko, S., Thau, D., & Moore, R. (2017). Google Earth Engine: Planetary-scale geospatial analysis for everyone. *Remote Sensing of Environment*, 202, 18–27.

[23] Kumar, L., & Mutanga, O. (2018). Google Earth Engine applications since inception: Usage, trends, and potential. *Remote Sensing*, 10(10), 1509.

[24] Mao, S., Tu, E., Zhang, G., Rachmawati, L., Rajabally, E. and Huang, G.-B.: An Automatic Identification System (AIS) Database for Maritime Trajectory Prediction and Data Mining, , 241–257, doi:10.1007/978-3-319-57421-9_20, 2018.