ANALYSIS OF THE LIMITS FOR THE DETECTION OF SMALL GARBAGE ISLAND IMMERSED IN CLUTTER RADAR

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Abstract – The aim of this work is to show the limits of the detection capacity of X-band radars, as the sea state changes, in order to identify, discriminate, characterize and track small floating aggregations of marine litter (Small Garbage Island - SGIs) consisting mainly of plastic. To this end, two distinct radar measurement campaigns were conducted with controlled releases at sea of SGI modules assembled in the laboratory. The measurement campaigns were carried out respectively in conditions of calm sea and almost no wind, in order to test the system in ideal conditions, and in rough sea conditions and presence of wind. The analysis of the data acquired during the experiments confirmed the ability of the X-band radars to detect the aggregations of floating waste on the sea surface, also demonstrating that the state of the sea that characterized the two measurement campaigns identifies the limits within which radars can be used for monitoring plastic marine litters.

Introduction

Although plastic is a very useful material, due to its progressive accumulation in oceans all over the world, it has become one of the great environmental, economic and social problems of our time [1]. Among the different types of waste present in the oceans, plastic is the most abundant material, it is estimated that 75 % of the waste that contaminates ocean habitats is made up of plastic [2–4]. Furthermore, plastic is omnipresent, due to its widespread use in every corner of the planet, and durable over time, since its degradation is extremely slow. Moreover, due to its great mobility, it can travel very far from its point of entry into the environment, since the degradation times of the plastic are much longer than its transport scales [4-7]. The impact of plastic on marine habitats and organisms is very worrying, so much so that it represents a serious threat to the biodiversity of the oceans [8].

To respond to the various problems associated with the dispersion and accumulation of plastic in the sea, the world scientific community is producing an important research effort aimed both at studying the impact of plastic on marine organisms and ecosystems, and at monitoring the movements and accumulations of plastic waste in the oceans. For a review of the different types of marine litter and plastic monitoring, readers are referred to [9-17].

This manuscript presents the results of a research activity for the study of the evolution of plastics floating on the sea surface based on the use of X-band radars. Marine litter monitoring techniques based on remote sensing are still in their infancy and are mainly based on technologies not developed specifically for marine plastics, X-band radar is one of them.

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Remote sensing techniques make it possible to provide uniform observation coverage of large areas of the ocean and coasts. However, due to the great variability of the specific characteristics of marine litter (e.g. size, shape, chemical composition, type and buoyancy), no remote sensing technique is capable of returning information with a sufficient level of accuracy. Therefore, to respond to particular observation needs, it is necessary to integrate different technologies.

Under favorable conditions (e.g. no cloud cover), photographic images can provide very detailed information on marine litter. The technologies available today make it possible to work at different resolutions, from a few cm of the cameras installed on board the aircraft, up to 30-50 cm of commercial satellite images at higher resolution.

Spectroscopy is based on the acquisition of the unique spectral signatures of the polymers that make up marine plastic waste. However, for a correct identification of plastics, it is necessary to create a database of the characteristic spectra of the different types of waste based on laboratory and local experiments.

Synthetic Aperture Radars (SAR), currently used in the oceanographic field to detect high-resolution information on the ocean surface (e.g. topography, roughness, surface waves, winds and currents), are among the most promising technologies for detecting marine litter as they allow observations to be made both day and night and in all weather conditions.

Raman spectroscopy is a relatively new technology which, unlike other detection methods, has the potential to detect particles suspended below the sea surface as well. This technology is still under development and its actual monitoring capabilities require fine-tuning both in the field and in the laboratory. For a review of remote sensing techniques for marine litter monitoring, readers are referred to [18-21].

X-band radars were born mainly as navigation support tools, however, thanks to their ability to detect targets at sea, they have also assumed a very important role in the oceanographic field, where they are used for remote monitoring of the physical state of the sea and reconstruction of the field of surface currents and bathymetry [22-25].

The study of the intensity of the backscattered radar signal from plastic targets floating on the sea surface [26] has shown that in calm sea conditions and almost no wind, X-band radars are able to discriminate and characterize these kinds of objects. The purpose of this report is to identify the limits of the detection capability of X-band radars, as the state of the sea increases.

Material and methods

The radar used for the measurement campaign was a Consilium/Selesmar SRT Xband, 25 kW with a 9” feet antenna length and was purchased by the National Research Council (CNR) of Italy with funds of RITMARE project and installed on the roof of the “Scoglio della Regina” building in Livorno at coordinates Lat: 43_32021.1000N and Lon: 10_17058.9000E. The measurement campaigns were conducted in the stretch of sea in front of the IBE–CNR headquarters, located at the southern entrance of the port of Livorno.

The sea area on which the survey was conducted has a radius of about 0,98 nautical miles and is characterized by intense maritime traffic and by the presence of various signals (buoys, lighthouses, lights, etc.) which testify to the existence of navigation hazards. Figure 1 shows the study area on google map and the corresponding radar image.

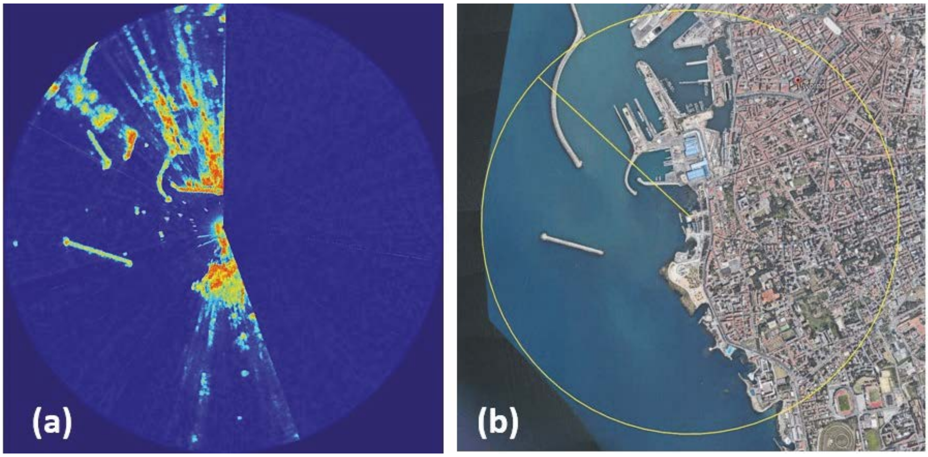

Figure 1 – Aerial image of the survey area (Google, images ©2019 CNES).

To verify the ability of an X-band radar to identify and track small aggregations of floating waste in the sea and to have repeatable and standardizable measurements, it was first of all necessary to manufacture in the laboratory 4 SGI modules with the following characteristics: a module/target T0, of the size 1 m x 1 m, consisting of mixed waste, which approximates the small aggregates of floating garbage; a module/target T1, measuring 1 m x 1 m, consisting mainly of plastic; a module/target T2 consisting of the union of three plastic bottles held together by a plastic band; a module/target T3 consisting of a single plastic bottle. For a detailed analysis on the construction methods of the modules used for the experiments, readers are referred to [26].

Two distinct measurement campaigns were conducted: the first in calm sea conditions, in order to verify the sensitivity of the radar in an ideal scenario; the second campaign in rough sea conditions (hs = 1,77 m) and presence of wind, in order to verify the upper limit of the target detection capability.

To evaluate the radar detection capabilities and understand the distance limits within which the radar is able to detect the presence of targets, in each of the measurement campaigns, three distinct target releases were made at three distances from the antenna: first release 0,12 nautical miles; second release 0,24 nautical miles, third release 0,39 nautical miles.

To define the radar's ability to detect SGIs, an analysis of the intensity of the radar signal received and reflected by the modules released into the sea was carried out. The radar worked for the entire duration of the measurement campaigns, recording the raw data which were subsequently analyzed in the laboratory. The step-by-step sequence of the radar data analysis procedure used to identify the targets in the first measurement campaign is given below:

1. Identification of the targets on the radar image using photographic images. This phase is essential to have spatial and temporal references to ensure the exact identification of the targets;

2. Extraction of mobile sub-areas containing the targets under investigation for each of the targets T0, T1, T2 and T3. Due to the presence of surface currents and wind, targets are subject to drift/leeway; therefore, it would be necessary to define mobile subareas that are able to "follow" the targets taking into account their speed;
3. Measurement of the maximum intensity value detected for each sub-area containing the targets T0, T1, T2 and T3 at each instant of time.

In the second measurement campaign, the intensity of the backscattered signal from the SGI is scarcely distinguishable from the average clutter of the sea (thus making it difficult to identify and recognize the modules), in this case the investigation was therefore focused only on the analysis of the sea average clurrer, in order to identify the upper limit of detection of targets using X-band radar technology.

Figure 2 contains the radar and photographic images relating to the first release of the first measurement campaign, and clearly shows that all the SGI modules (T0, T1, T2, T3), are clearly visible and distinguishable from the other targets in the area (e.g. signaling beacons: Buoy 1, Buoy 2, Buoy 3; boat and port infrastructures).

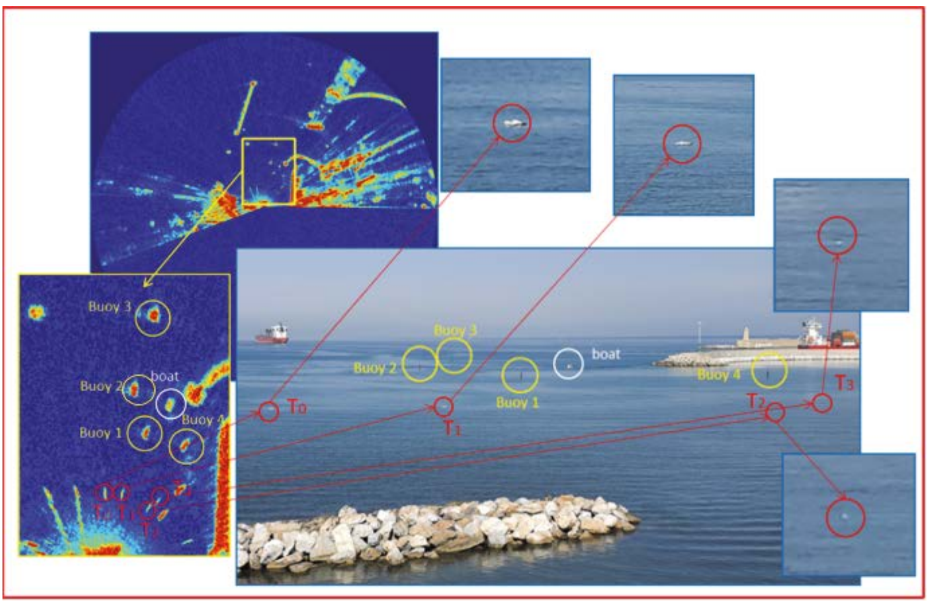

Figure 2 – Radar and photographic representations of the first release of the targets in calm sea conditions and no wind.

For an in-depth analysis of the radar signal received and reflected by the targets, readers are referred to [26].

Results

Figure 3 (a) shows the trend over time of the radar intensities of targets T0, T1, T2 and T3 normalized with respect to the maximum radar intensity recorded during the second release of the first measurement campaign. Figure 3 (b) shows the trend of the radar intensities of the targets related to the third release (unlike the previous two releases, only targets T0, T1 and T2 are visible, while target T3 was not detectable by the radar). The black line at the bottom of Figures 3 (a) and 3 (b) represents the average value of a sub-area containing only the clutter extracted in the vicinity of the area where the targets were released. The high intensity values highlighted by the arrows in Figure 3 (a) and 3 (b) for the target curves T1 (red line), T2 (green line) and T3 (yellow line) are due to the entry into the sub-area of the inflatable dinghy used for the releases; it follows that these extremely high intensity values are associated with the radar signal of the boat and not with that coming from the targets. Given the high radar reflectivity of the inflatable dinghy, this occurrence was recorded by the radar as a sudden rise (spike) in the radar intensity of the areola containing the targets until the inflatable dinghy left the sub-area.

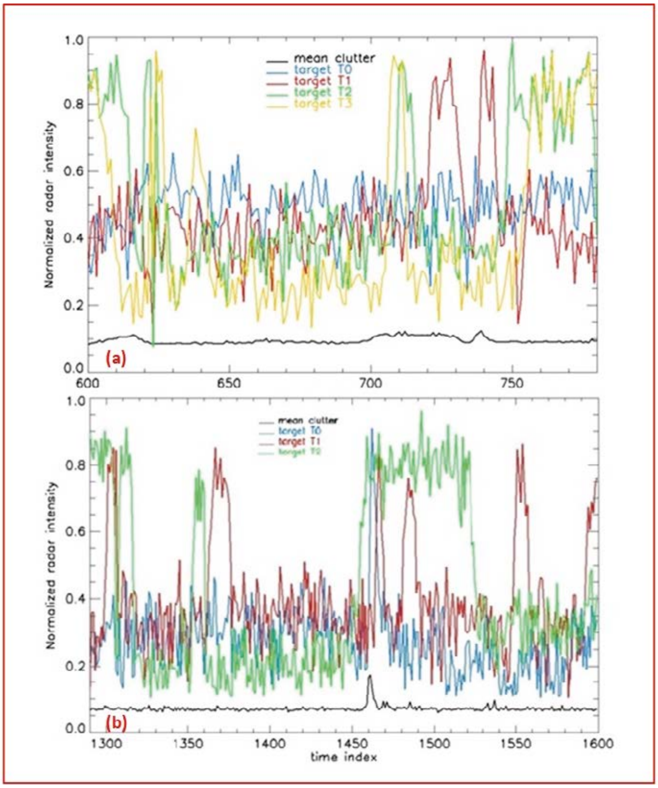

Figure 3 – Radar intensities of the targets related: to the second release (a) and the third release (b) of the first session of measures.

As already anticipated in “materials and methods”, due to the poor distinction of the backscattered signal from the targets compared to the average sea clutter, during the second measurement campaign the investigation was limited exclusively to the analysis of the marine clurrer, in order to identify the upper detection threshold of the targets through the X-band radar. In particular, Figure 4 compares the average clutter of the sea for the first measurement campaign (black line) and the average clutter for the second measurement campaign (red line). The image clearly shows that the average clutter of the sea relating to the second measurement campaign, conducted in rough sea conditions, has increased until it assumes values comparable to the intensity of the radar signal backscattered by the SGI modules during the second and third release of the first measurement campaign (respectively: 0,24 and 0,39 nautical miles). In the case of targets closer to the radar (0,12 nautical miles), the intensity of the backscattered signal from the SGI is barely distinguishable from the average clutter of the sea, also making it difficult to identify and recognize the modules in this case.

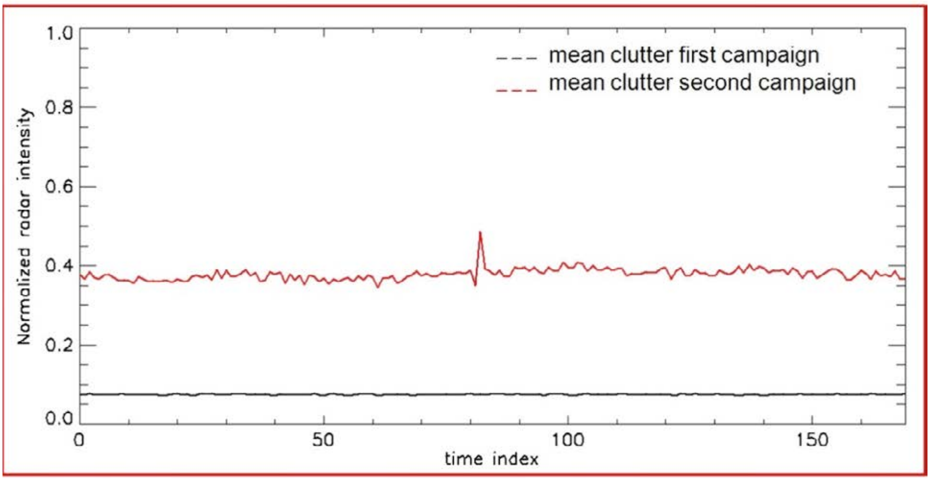

Figure 4 – Comparison between the average clutter of the sea during the first measurement campaign (black line) and that of the second measurement campaign (red line).

Discussion

As regards the identification and recognition of SGI modules, the following can be stated. During the first measurement campaign, characterized by calm sea and almost no wind: all targets, T0, T1, T2 and T3 (Figure 3), are clearly visible from the radar and can be clearly distinguished with respect to the average sea clutter.

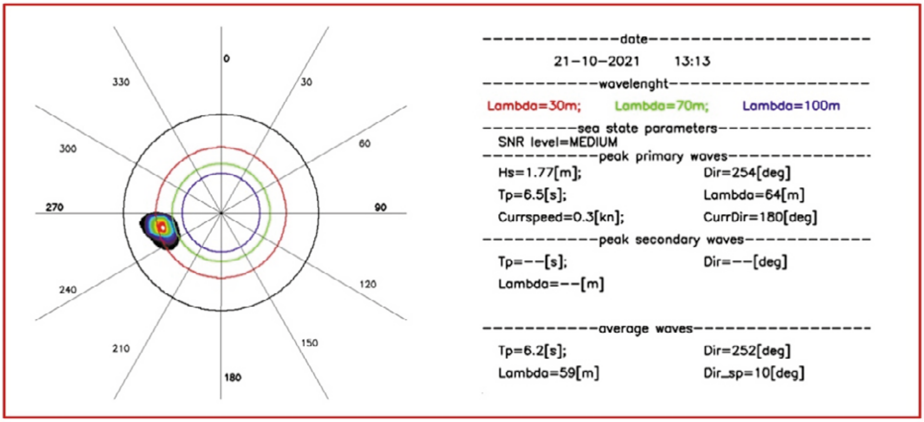

Figure 5 – Energy spectrum and sea state relating to the second measurement campaign.

In the conditions of the second measurement campaign, characterized instead by a sea state with hs = 1.7 m (as shown in Figure 5), the average sea clutter assumes values comparable to the intensity of the radar signal backscattered by the targets and detected during the first measurement campaign, it follows that the conditions of the second measurement campaign identify the sea state limit threshold beyond which the intensity of the backscattered signal from the targets mixes with the average clutter of the sea, making it difficult or ineffective to use radar for SGI monitoring purposes.

Conclusions

The purpose of the radar measurement campaigns illustrated in this work is: verifying the ability of an X-band radar to detect the presence of floating targets on the sea surface, mainly or exclusively made of plastic; define the limits of its use in terms of distance from the antenna, evaluating the performance of the radar system as the sea conditions increases; identify the sea state limit threshold beyond which the intensity of the backscattered signal from the targets is comparable with the average clutter of the sea, making the use of radar ineffective for SGI monitoring.

The results of the experiments showed that in calm sea conditions, the characteristics of the signal reflected by the SGIs are different, and therefore discriminable, from those reflected by other targets. In fact, in calm sea conditions and with almost no wind, the empirical data showed that the X-band radar distinguishes the targets of the experiment within the maximum distance of 0.39 nautical miles from the receiving antenna. Beyond this distance, the intensity of the signal received by the radar is very attenuated and no longer recognizable. In the sea state conditions that characterized the second measurement campaign, the average sea clutter is comparable with the signal backscattered by the targets; it follows therefore that these conditions can be identified as the limit threshold beyond which the monitoring of marine litter with an X-band radar is ineffective.

The conditions under which the two measurement campaigns were conducted therefore identify the limit thresholds within which it is possible to use the X-band radar for monitoring marine litter.

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