

Detecting Coastal Aggregation Of Macro-Plastic Litter Using Satellite X-band SAR Imagery



E. Setale¹, A. Verlanti¹, A. Buono¹, M. Migliaccio¹, F. Nunziata²

¹ Università degli Studi di Napoli Parthenope, Naples, Italy; ² Università di Roma La Sapienza, Rome, Italy



SAPIENZA
UNIVERSITÀ DI ROMA

INTRODUCTION

In this study, the results obtained within the framework of the PRIN 2022 project «Multi-layer Approach to Detect and Analyze Coastal Aggregation of Macro-Plastic Litter (ECOMARE)» are presented. The goal is to develop a remote sensing approach combining X-band SAR (Synthetic Aperture Radar) and drone-based optical imaging for detecting macro-plastic litter. An experimental campaign was carried out in a Southern Italy lake. Results confirm the sensitivity of SAR, especially co-polarized channels, to plastic targets and highlight the benefits of integrating SAR and optical data for effective detection.

THEORETICAL BACKGROUND

The theoretical framework of this study is based on the electromagnetic interaction between microwave signals and floating plastic debris, driven by the dielectric contrast among air, plastic, and water. As shown in Fig. 1, various scattering mechanisms contribute to the radar backscatter from water surfaces partially covered with plastic. The air-water interface shows strong dielectric contrast, resulting in high reflectivity and signal attenuation into the water. In contrast, the air-plastic interface, due to the quasi-dielectric nature of plastics, produces weaker reflections and minimal attenuation. A significant contrast is again found at the plastic-water interface, enhancing backscatter. Plastic coverage also alters surface geometry, adding roughness and slope variations that affect radar returns, especially in calm conditions. These phenomena generate co- and cross-polarized backscatter components useful for detection. Environmental factors like wind-induced roughness and plastic wetness further influence the signal. Wet plastics, in particular, have dielectric properties closer to water, strengthening their electromagnetic response. This understanding supports the development of SAR-based algorithms to detect plastic debris among natural materials and open water.

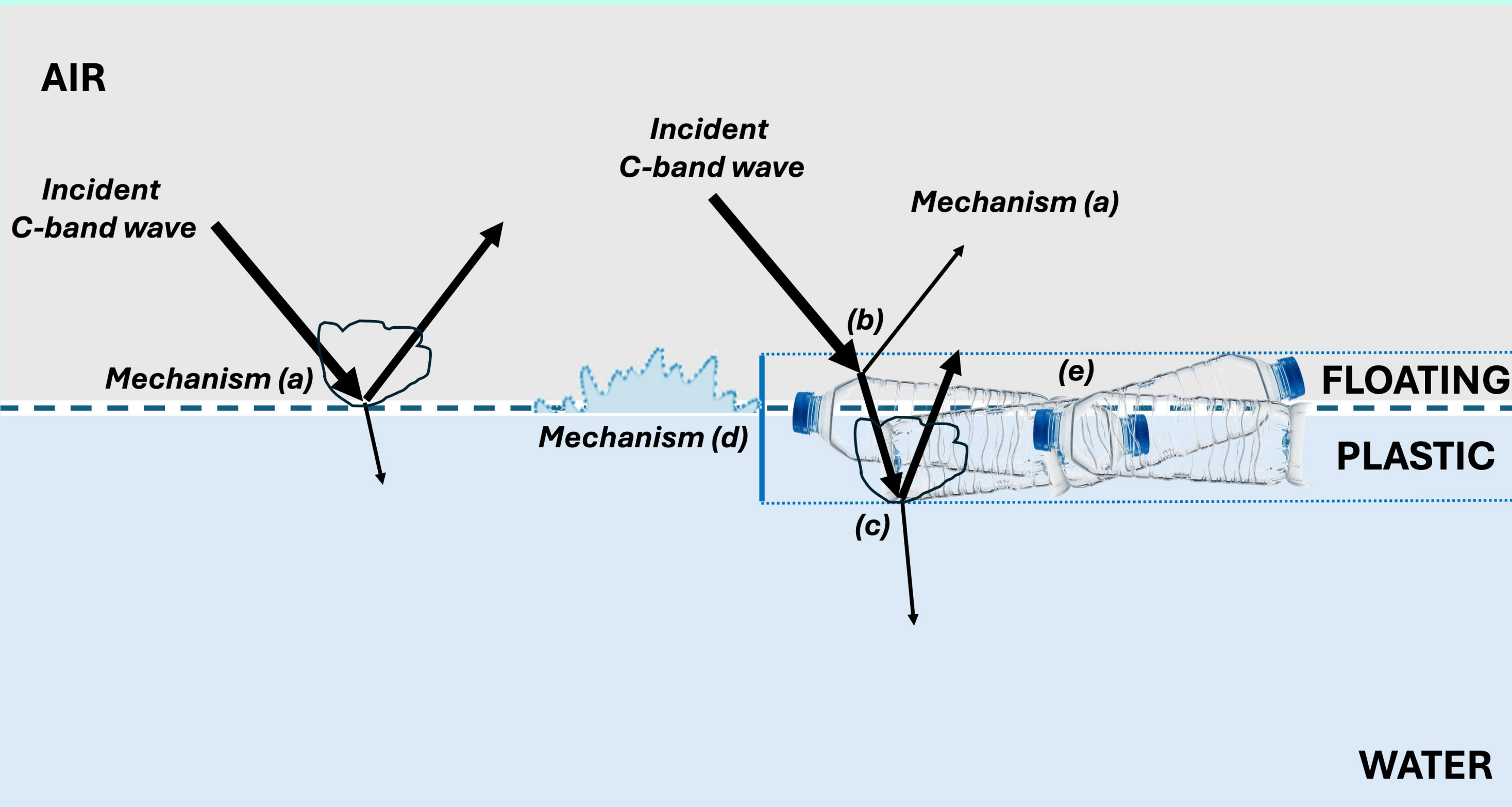


Fig. 1 – Basic scattering mechanisms expected to be in place when the incident C-band electromagnetic wave interact with the floating plastic –free and floating plastic-covered water surface.

EXPERIMENTAL CAMPAIGN

The proposed approach explores the potential of microwave remote sensing to detect floating macro-plastic litter by analyzing its interaction with radar signals and dielectric properties. Focusing on the study areain Fig. 2 — Calore Lake in Southern Italy — dual-polarimetric X-band SAR data from the COSMO-SkyMed Second Generation (CSG) satellite are used to distinguish plastic and natural debris based on their backscatter features. An excerpt of the dual-polarized X-band Synthetic Aperture Radar (SAR) dataset acquired by the CSG satellite over the Calore Lake is shown in Fig. 3. The data were collected in Spotlight-2B mode with HH and HV polarizations at a spatial resolution of 21 cm × 44 cm. The scene captures two floating targets, i. e., a controlled plastic aggregation and natural debris anchored in calm water conditions, enabling analysis of their radar backscatter response.



Fig. 2 – Calore lake where the plastic target and accumulated natural debris can be observed in the upper and lower part of the visible orthomosaic image, respectively.

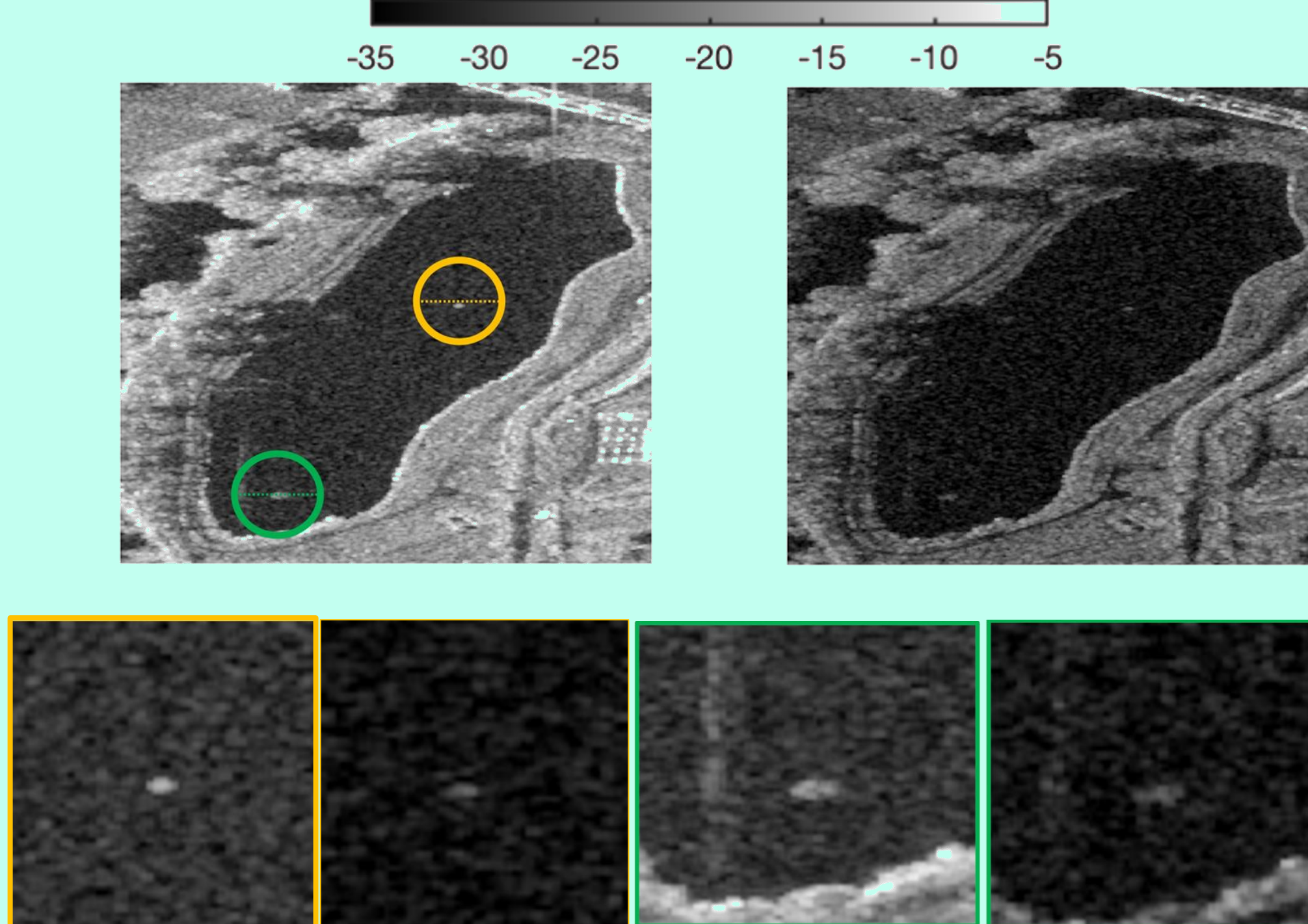


Fig. 3 – Multi-polarization NRCS SAR images. The plastic target and the natural debris are highlighted with orange and green circles, respectively.

EXPERIMENTAL RESULTS

As shown in Fig. 4, the NRCS signatures of the plastic and natural targets in both co- and cross polarized channels provide different Target-to-Clutter Ratio (TCR) values. The plastic target appears more compact and exhibits a higher backscattering response, whereas the natural debris shows a broader and more irregular backscattering pattern. In Fig. 5 the statistical distribution of water clutter is shown: the co- and cross-polarized NRCS values follow a log-normal distribution, suggesting a global threshold Constant False Alarm Rate (CFAR) approach for target detection. The effectiveness of the proposed approach is demonstrated in Fig. 6, where the binary detection maps generated from HH- and HV-polarized SAR imagery are depicted. Both targets are successfully identified in co- and cross-polarized channels; however, the co-polarized channel results in a better detection characterized by fewer false alarms.

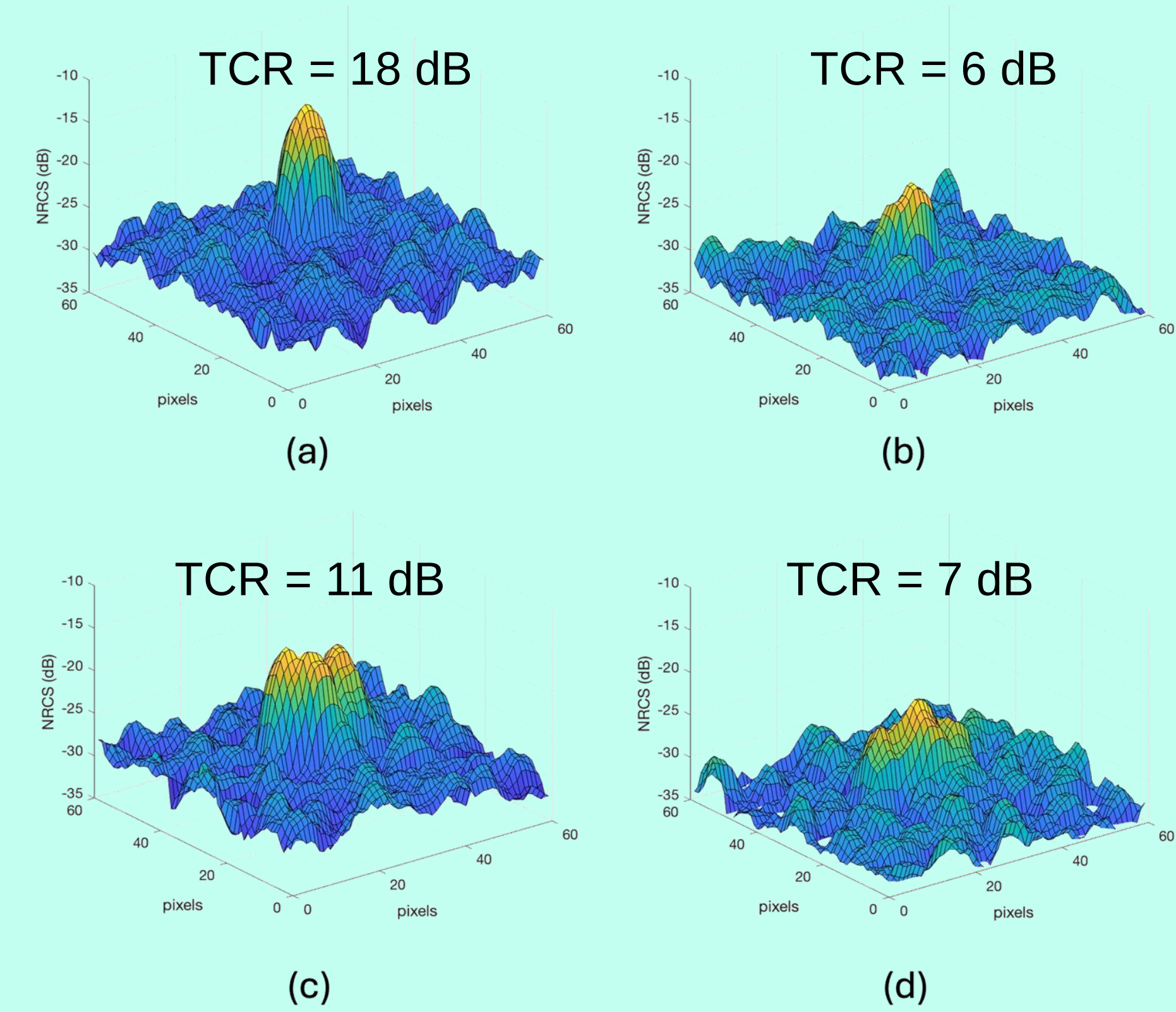


Fig. 4 – Multi-pol NRCS signatures. (a) and (b) refer to the plastic target observed under the HH and HV channel, respectively; while (c) and (d) refer to the natural target observed under the HH and HV channel, respectively.

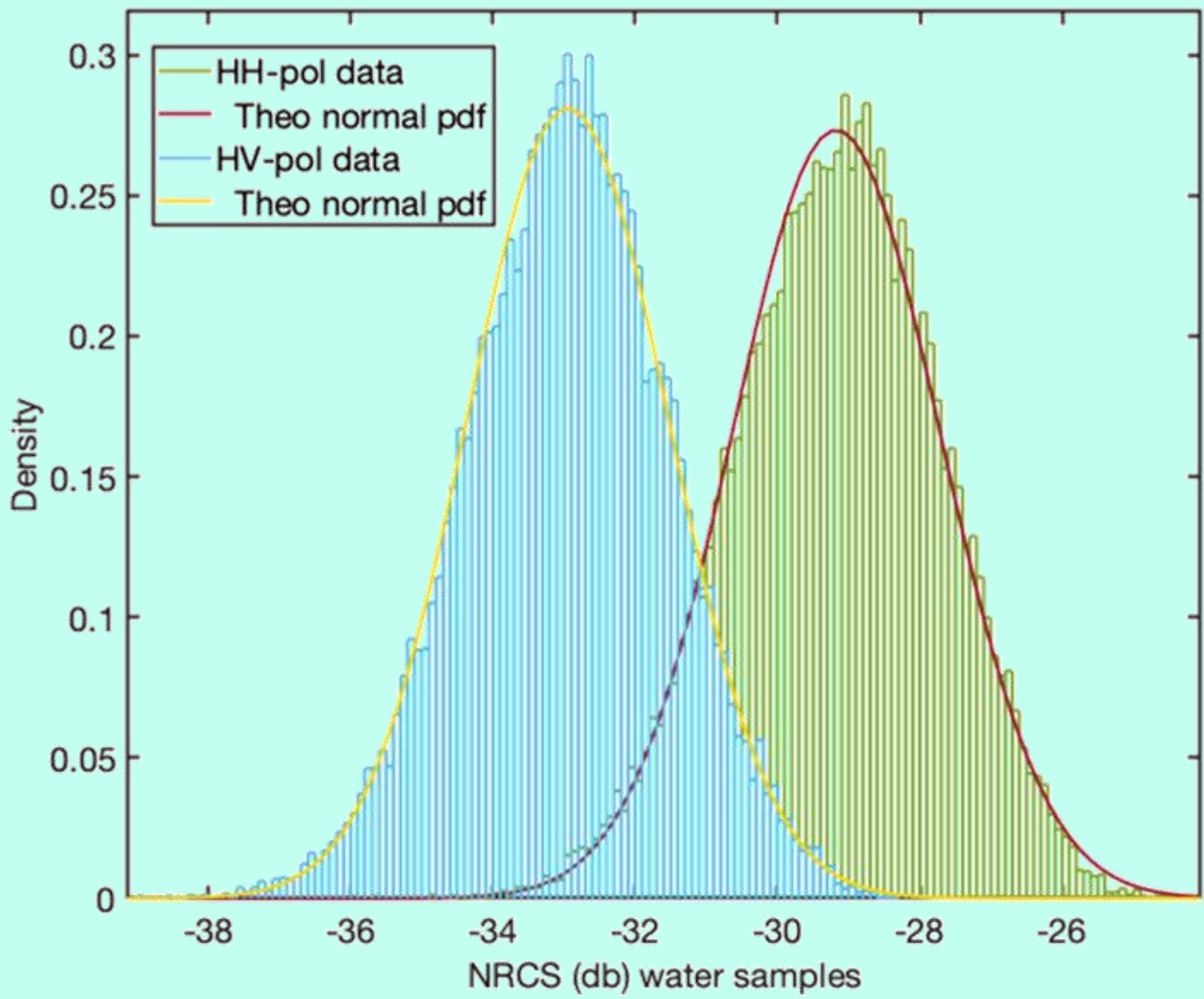


Fig. 5 – Multi-polarization NRCS statistical analysis of water clutter.

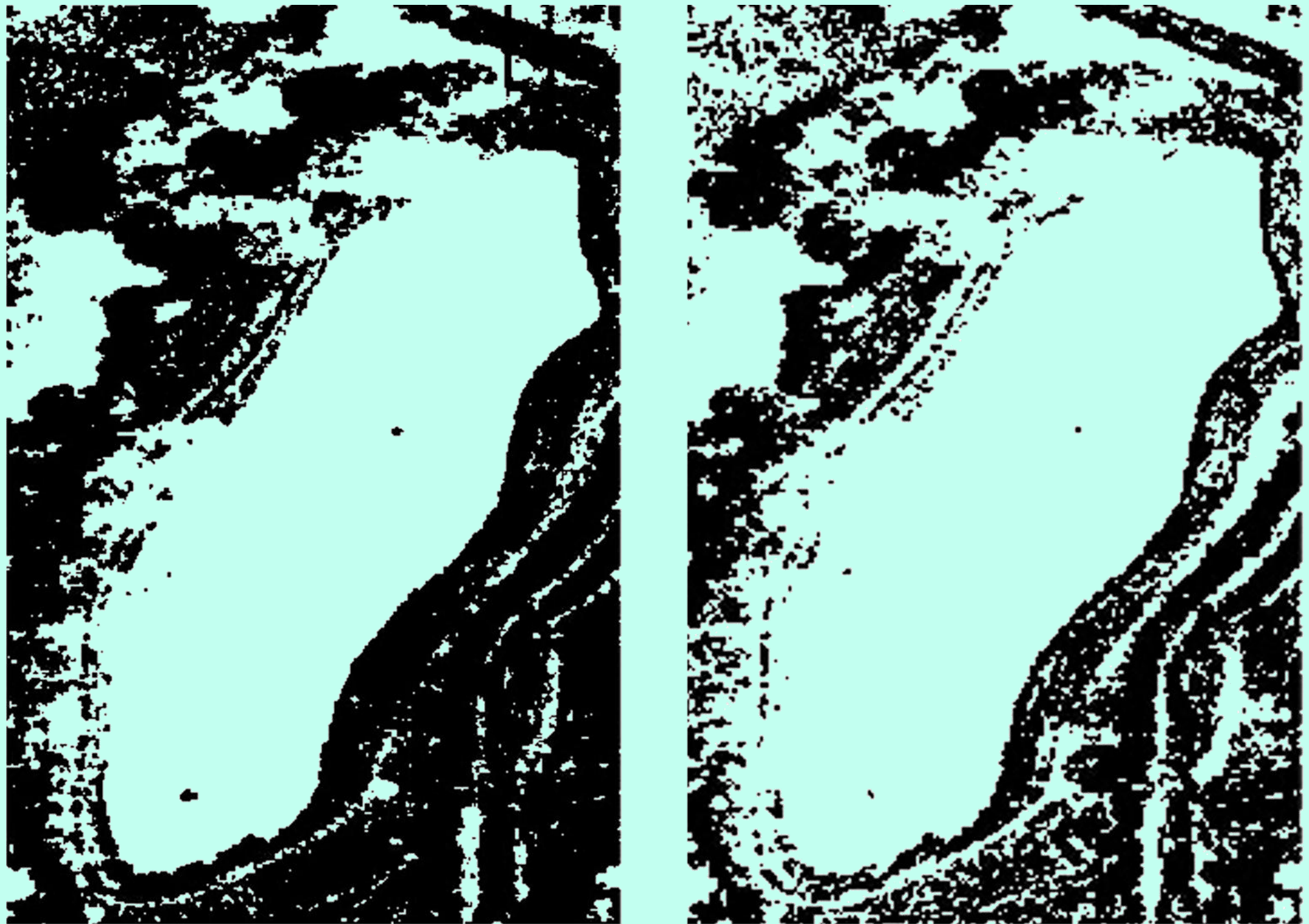


Fig. 6 - Detection maps obtained processing the co- (left) and the cross-polarized (right) NRCS using the CFAR approach.

CONCLUSIONS

This study confirms the effectiveness of dual-pol X-band SAR imagery for detecting and distinguishing floating plastic litter from natural debris over inland water bodies. The HH channel provides the largest TCR with the plastic target resulting in a TCR larger than the natural target one. A CFAR algorithm is implemented to discriminate in an objective way the targets from the surrounding water. The detection masks show that both HH and HV channels can detect the targets, with the best performance achieved by the HH channel that, due to the larger TCR and a better-defined target’s signature, results in well-distinguishable target’s spots and negligible false alarms.

ACKNOWLEDGMENTS

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