High-Resolution Primary Signal Processing in Over-the-Horizon Radars (OTHR) developed by Vlatacom Institute

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November 22, 2023.

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Introduction

- Maritime surveillance of vessels at long distances is up-to-date research topic!

- **The focus** –>> High-resolution algorithms in High Frequency Surface Wave Radars (HFSWRs)…

NEW ALGORITHMS DEVELOPED BY VLATACOM INSTITUTE!

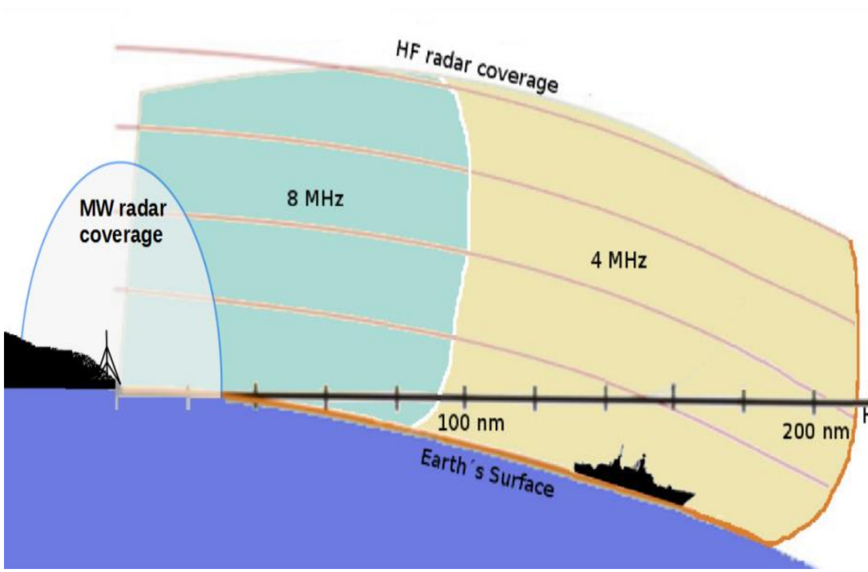
vessel location estimation…

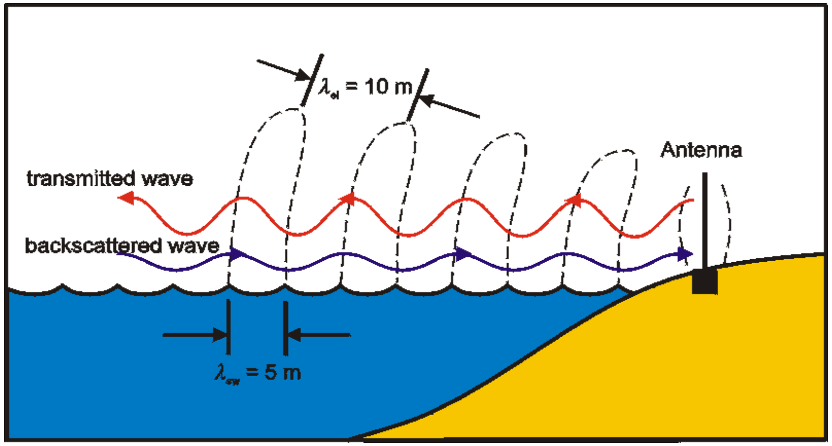
Introduction

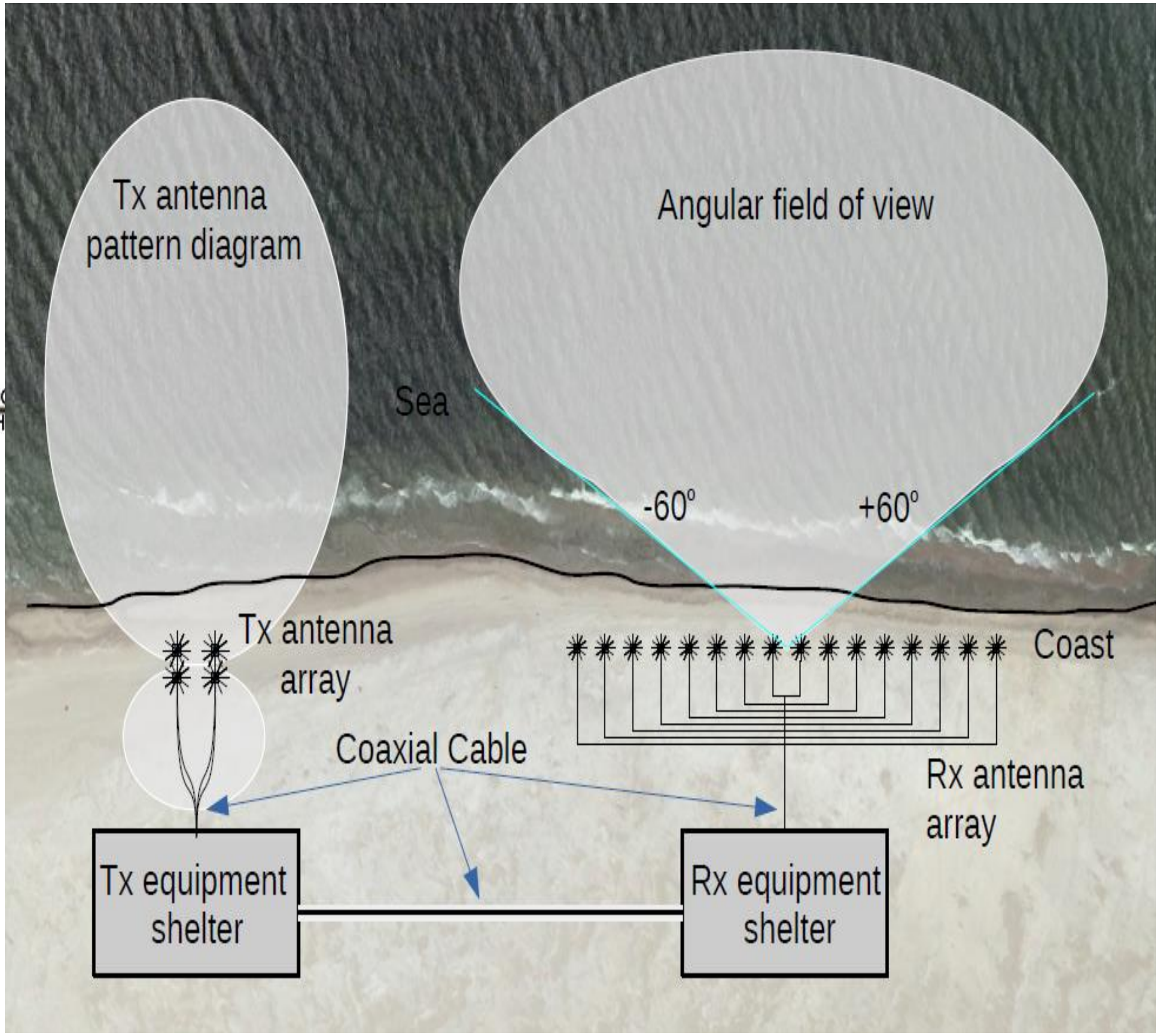
- The proposed algorithm is based on a **high-resolution** estimate of the range-Doppler (RD) map
- A **numerically efficient** Image Processing method for detection on the range-Doppler map is also proposed…
- Azimuth estimation is performed by a high-resolution MUSIC-type algorithm that is executed for all targets detected on the range-Doppler map.

→ **Less computation…**

Introduction to OTHRs

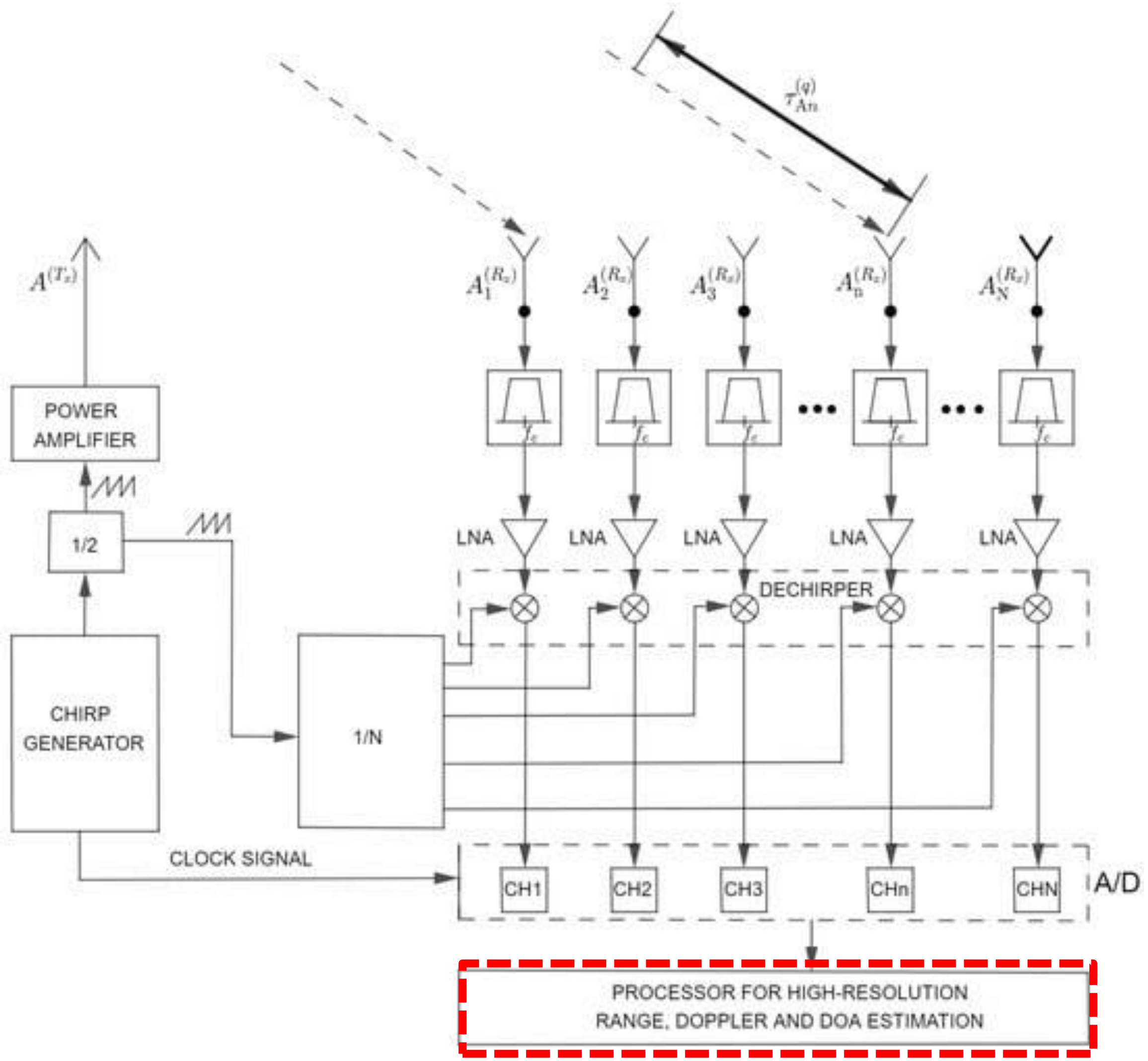




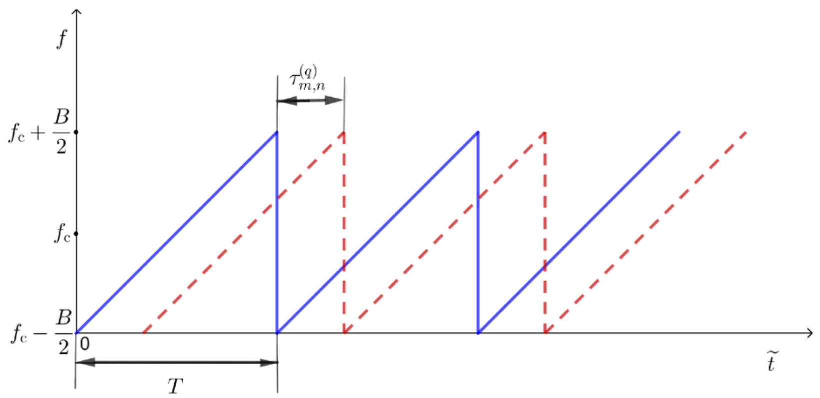


System and signal model

System model

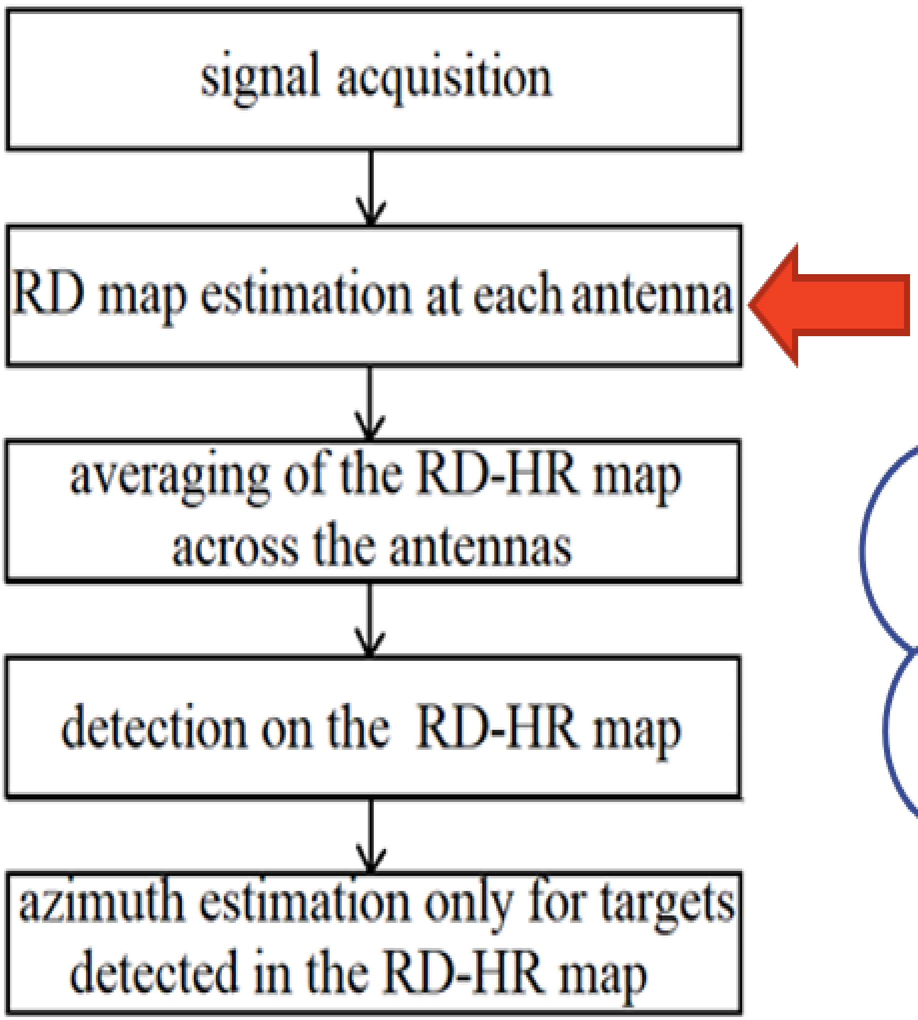


Signal model



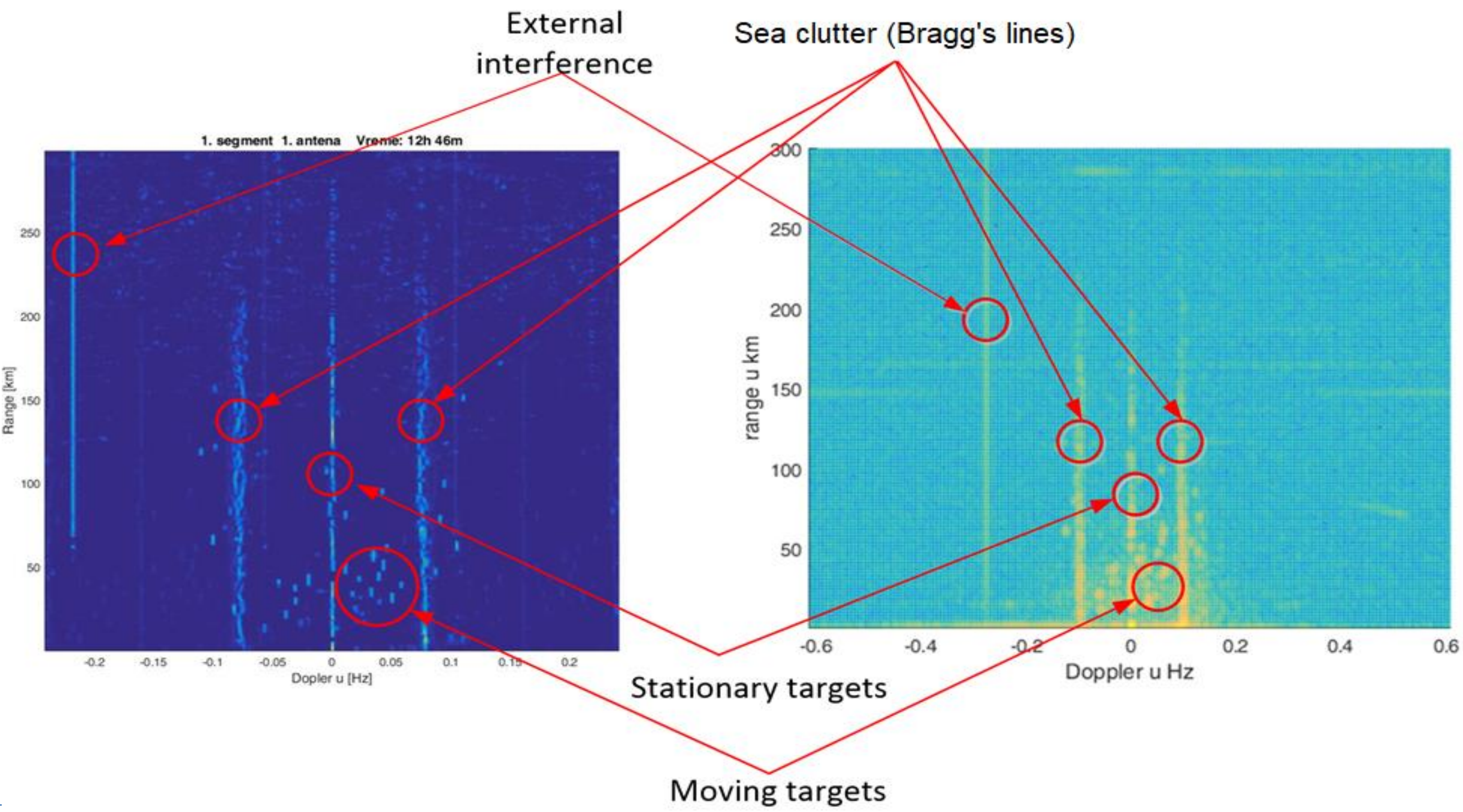
The developed algorithms are based on the high-resolution evaluation of the Range-Doppler (RD-HR) map...

The overview of the high-resolution algorithm for vessel detection in HFSWR

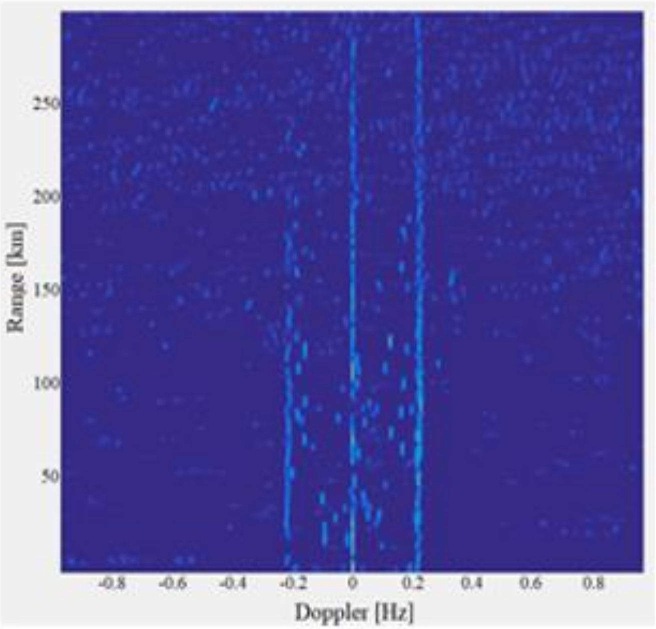


The proposed algorithm has five steps, but the most computationally demanding task is step two – RD-HR map estimation at each antenna.

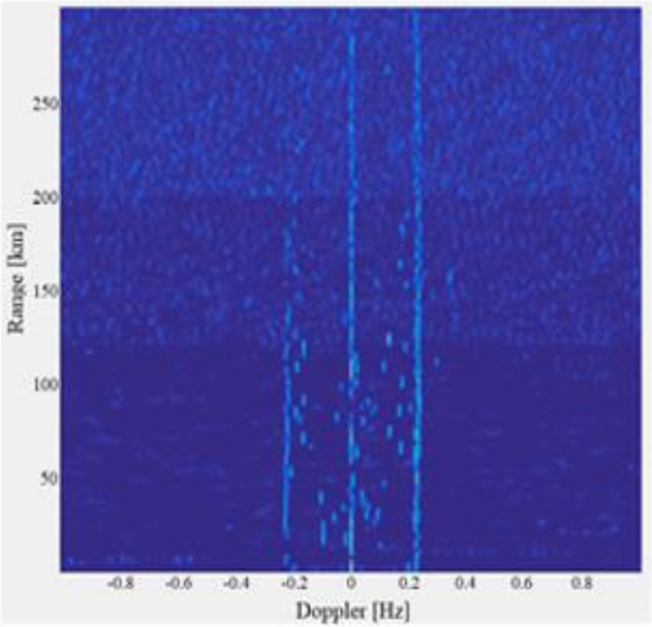
HIGH RESOLUTION RANGE-DOPPLER MAP (LEFT) vs FFT BASED RANGE-DOPPLER MAP (RIGHT)



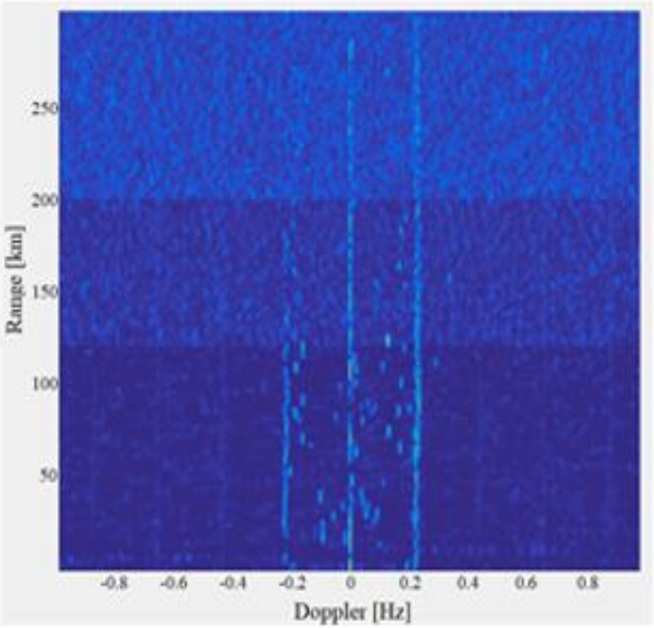
Non-uniform Range-Doppler map estimation



Uniform obtained RD-HR map

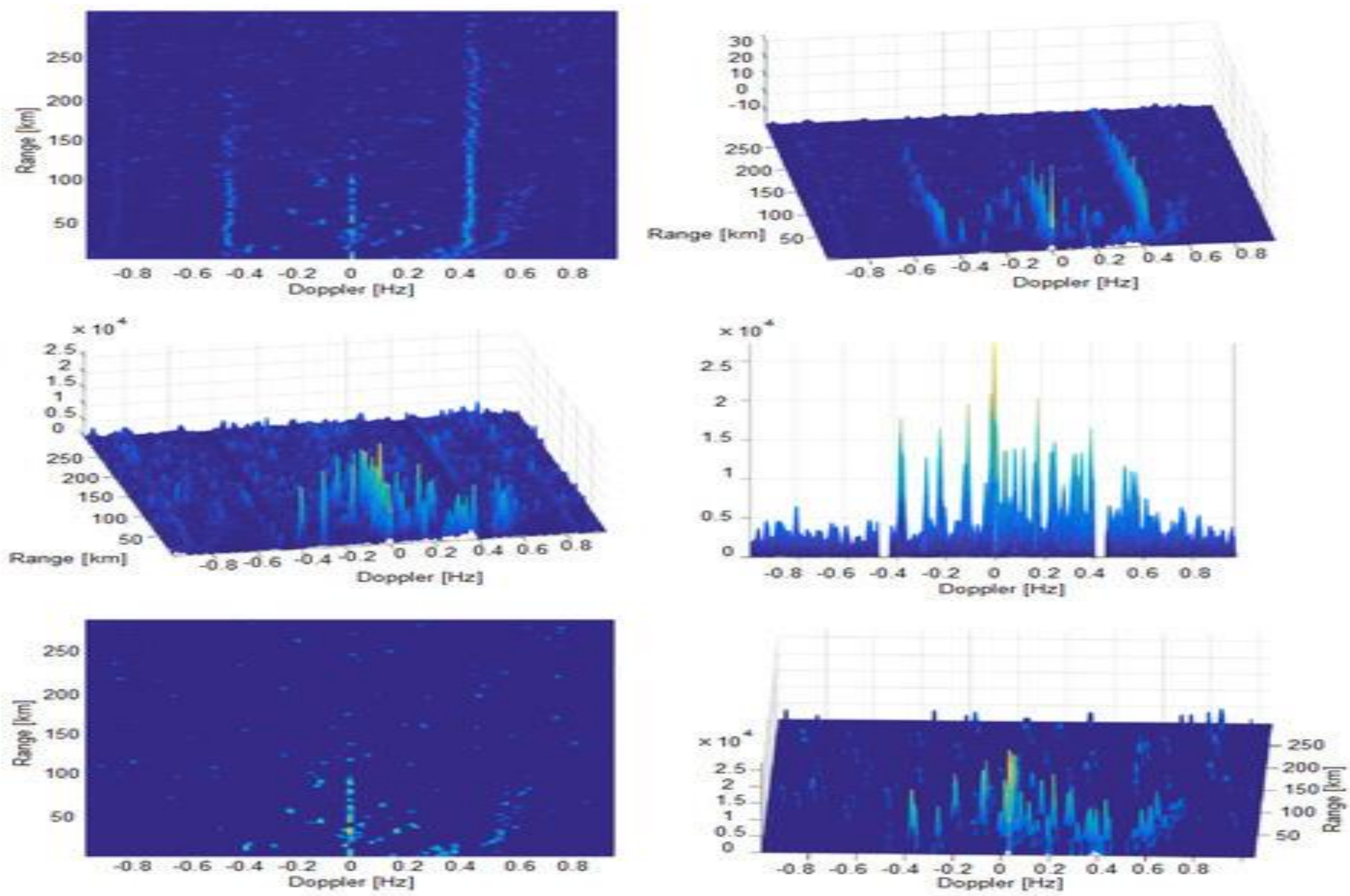


Non-uniform obtained RD-HR map (pattern88)



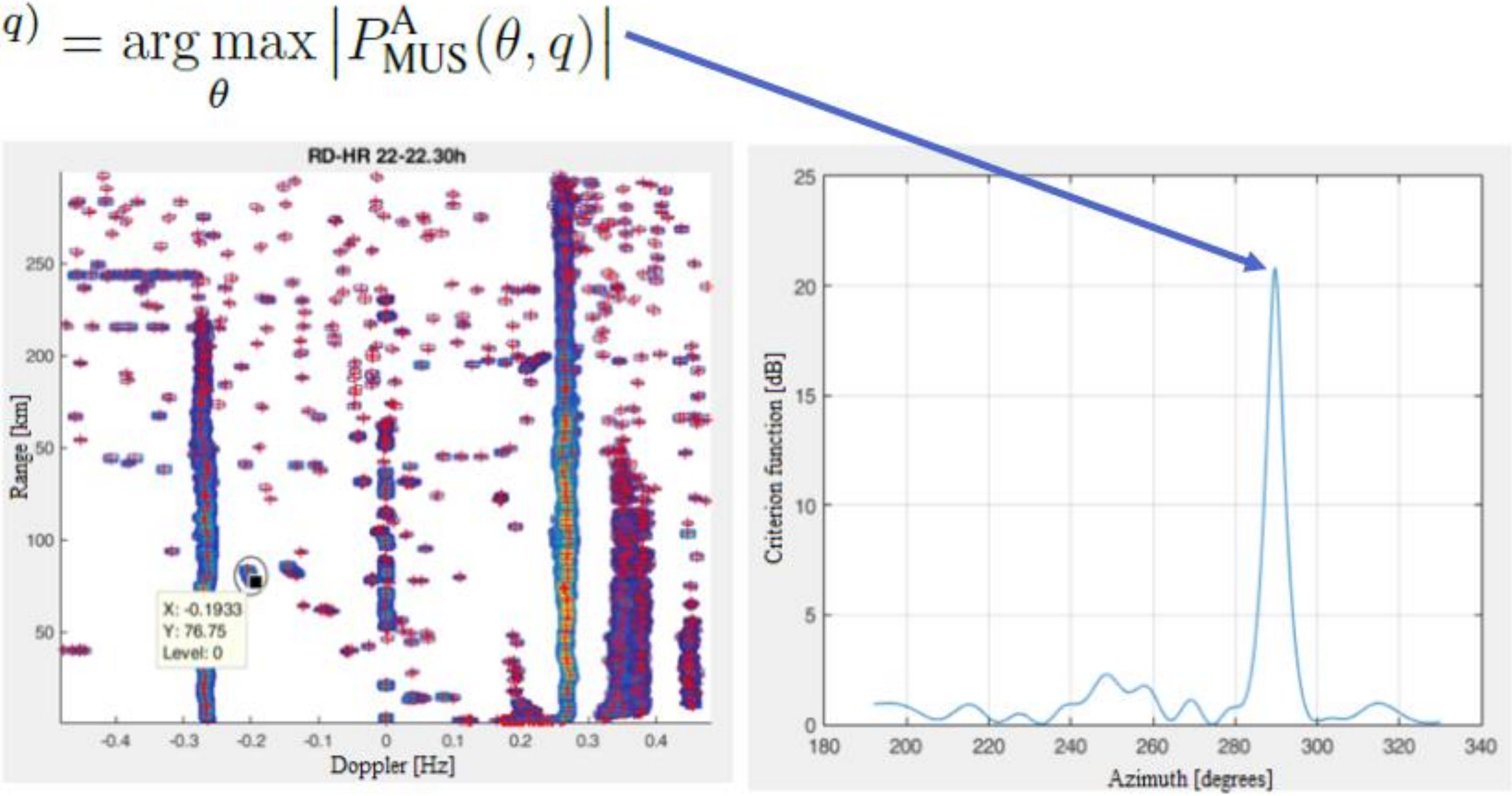
Non-uniform obtained RD-HR map (pattern56)

Target detection on the RD-HR map



Azimuth estimation for targets detected on the RD-HR map

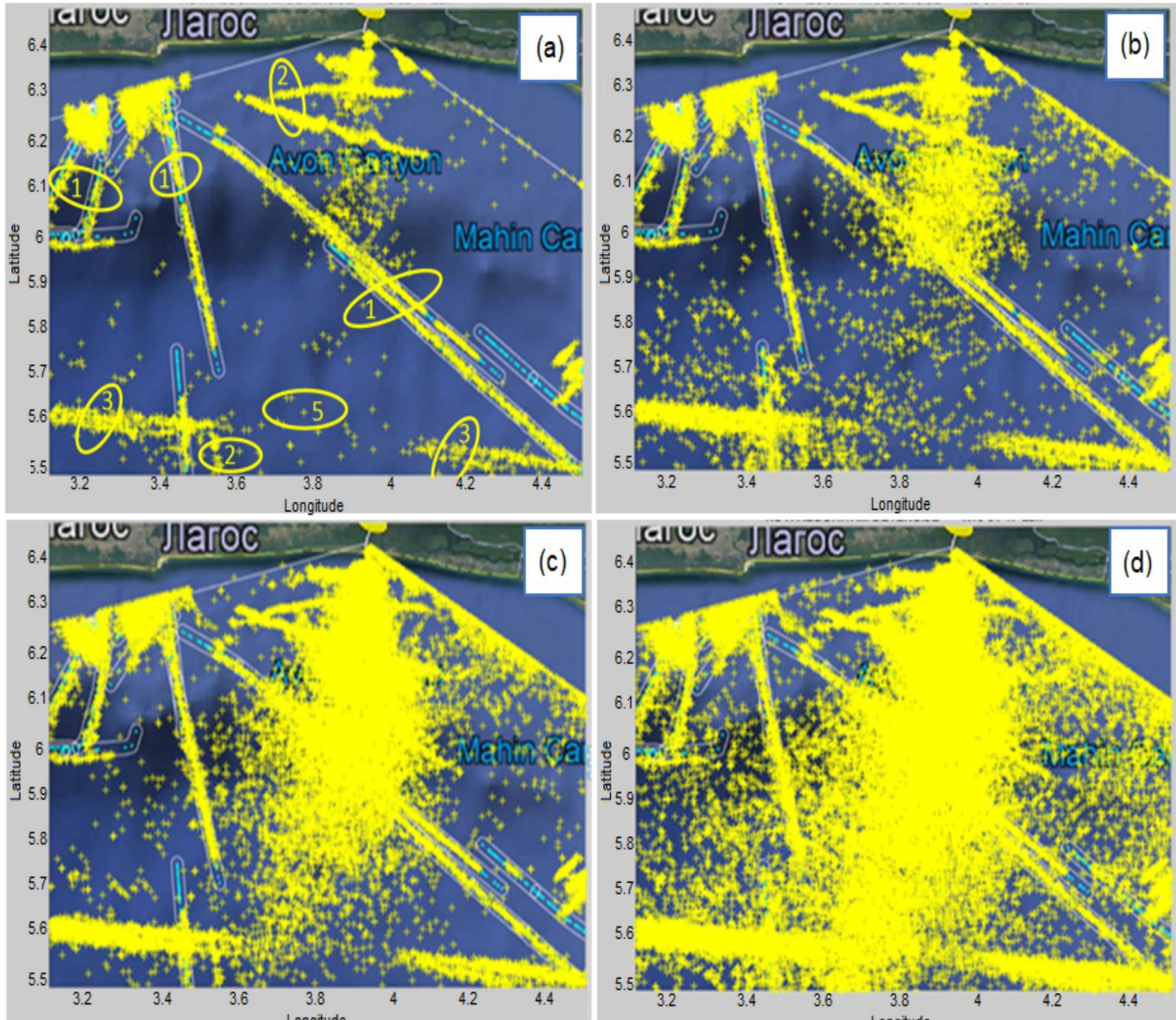
$$\hat{\theta}^{(q)} = \arg\max_{\theta} \left| P^{\mathrm{A}}_{\mathrm{MUS}}(\theta, q) \right|$$



The analysis of all vessel’s detections

The display of all vessel’s detections (yellow markers) in a small part of the area, with AIS data as a benchmark (light blue tracks) in a time interval of 5 h for different detection parameters of the proposed algorithm:

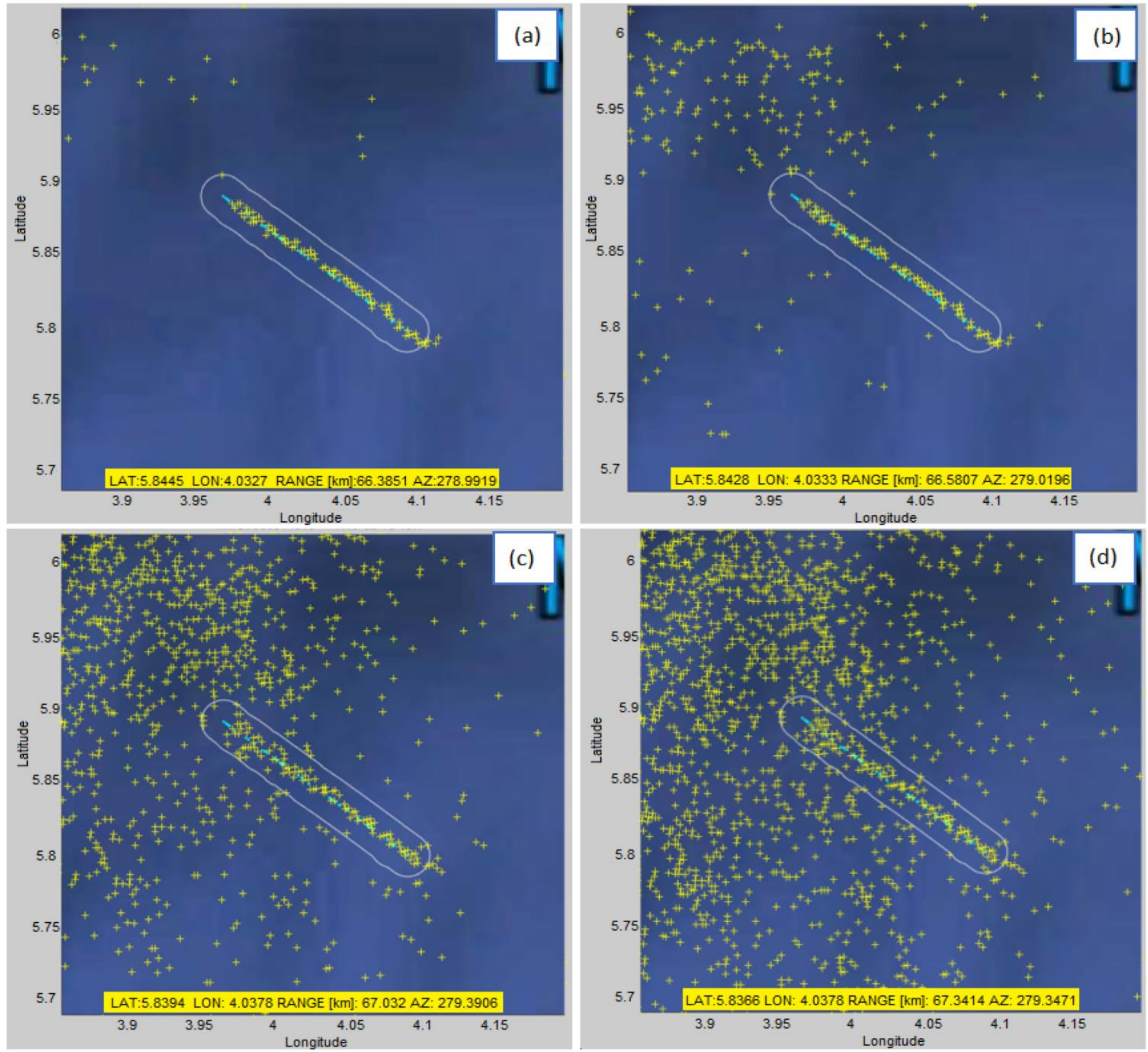
(a) K=5 and normalized threshold = 0.2
(b) K=5 and normalized threshold = 0.1
(c) K=10 and normalized threshold = 0.2
(d) K=10 and normalized threshold = 0.1.



The analysis of one vessel's detections

The display of all detections
of the selected vessel
in a time interval of 1 hour
for different detection
parameters of the
proposed algorithm:

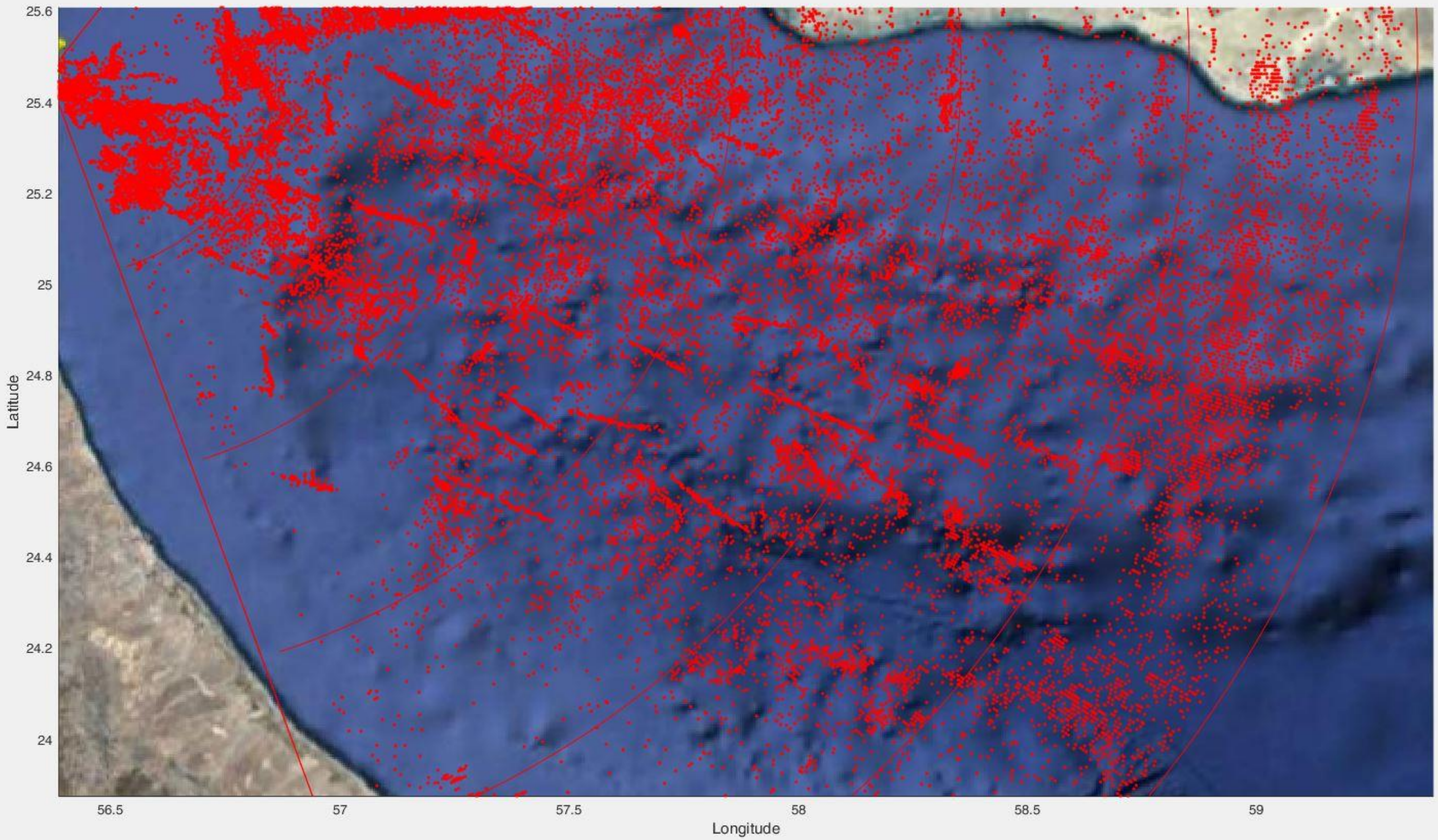
a) K = 5 and γ = 0.2
b) K = 5 and γ = 0.1
c) K = 10 and γ = 0.2
d) K = 10 and γ = 0.1



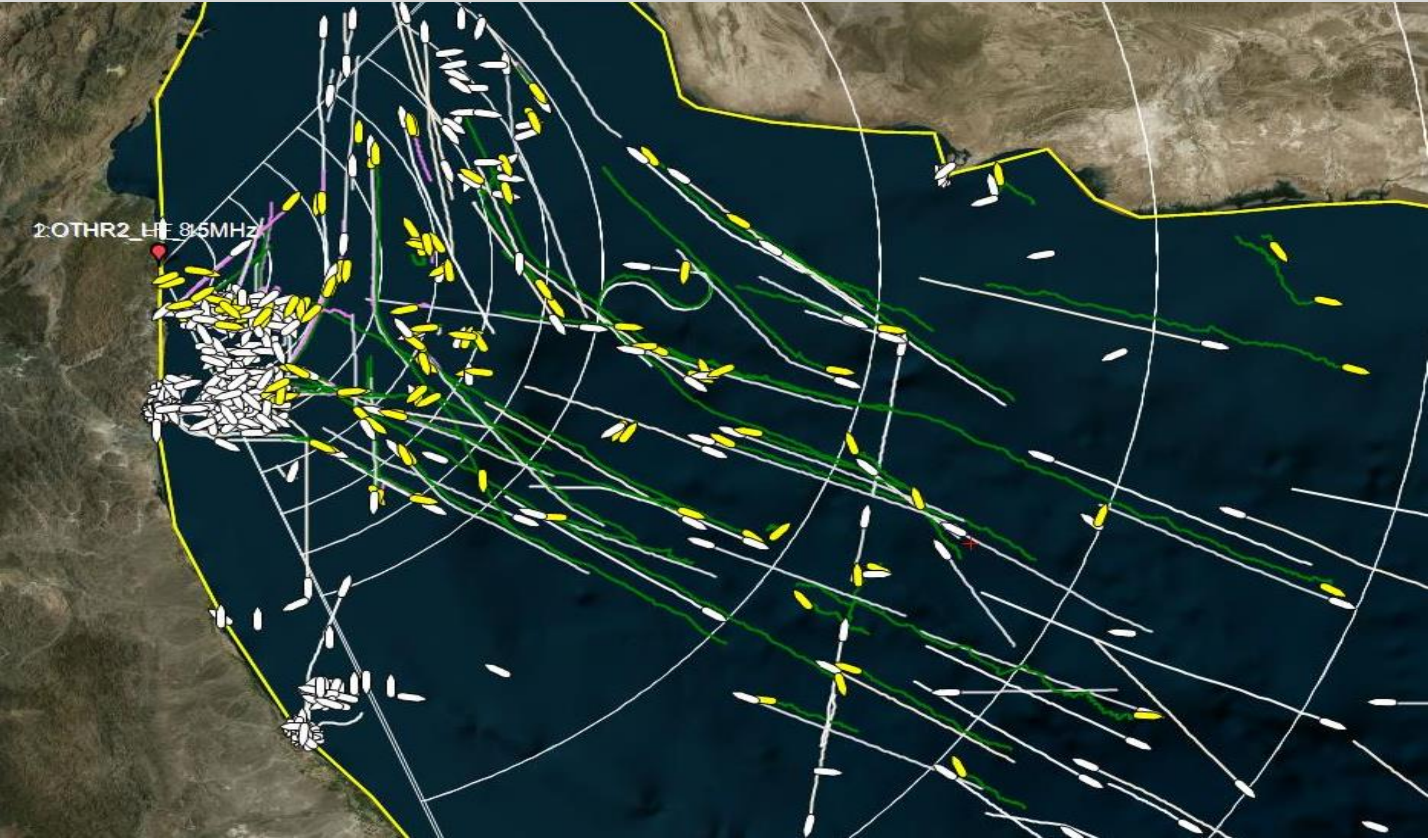
High target resolvability rate

The display of two vessels (rounded in red) that were very close to each other (**left**) and zoomed display of these vessels (**right**).

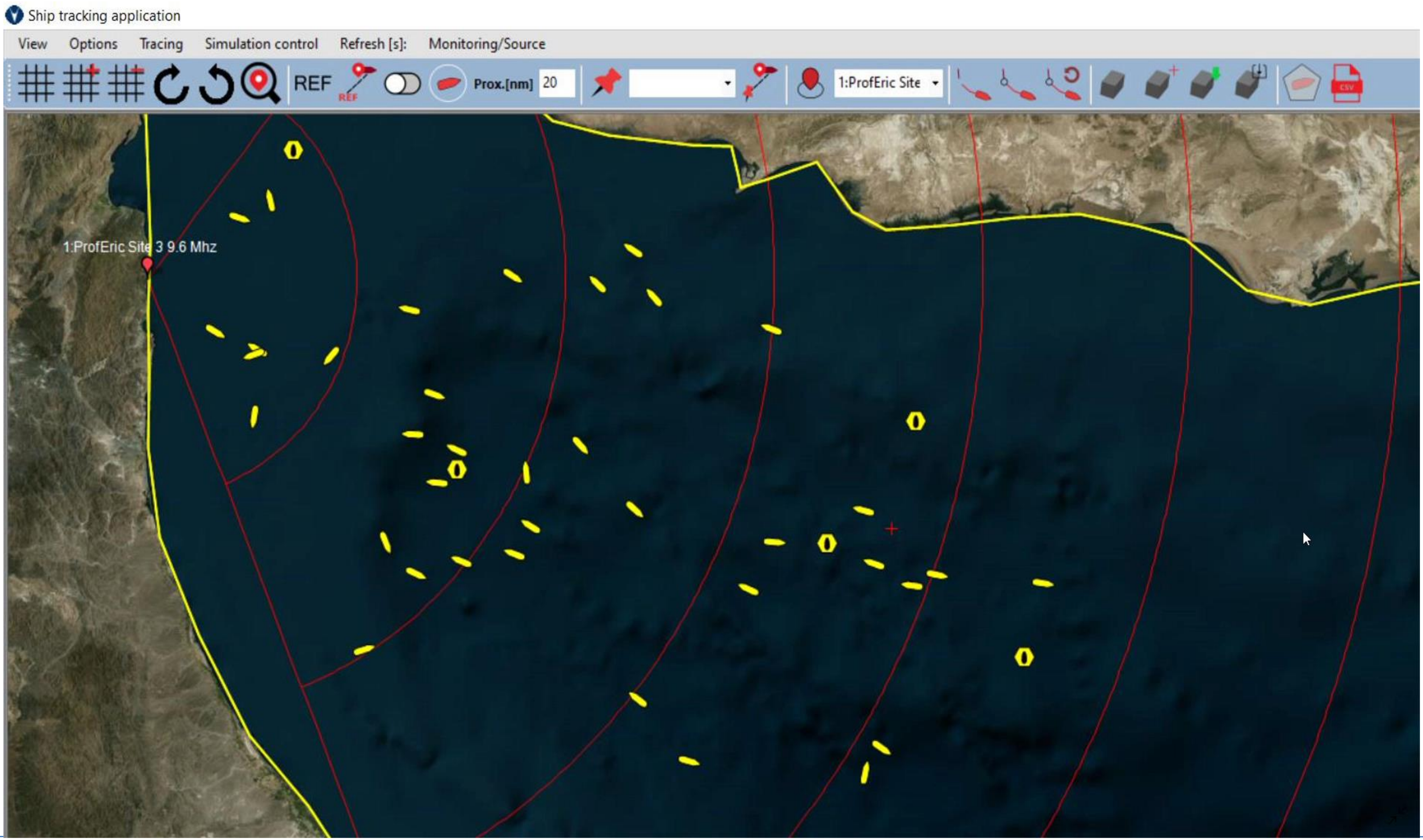
Detection results up to 300 km



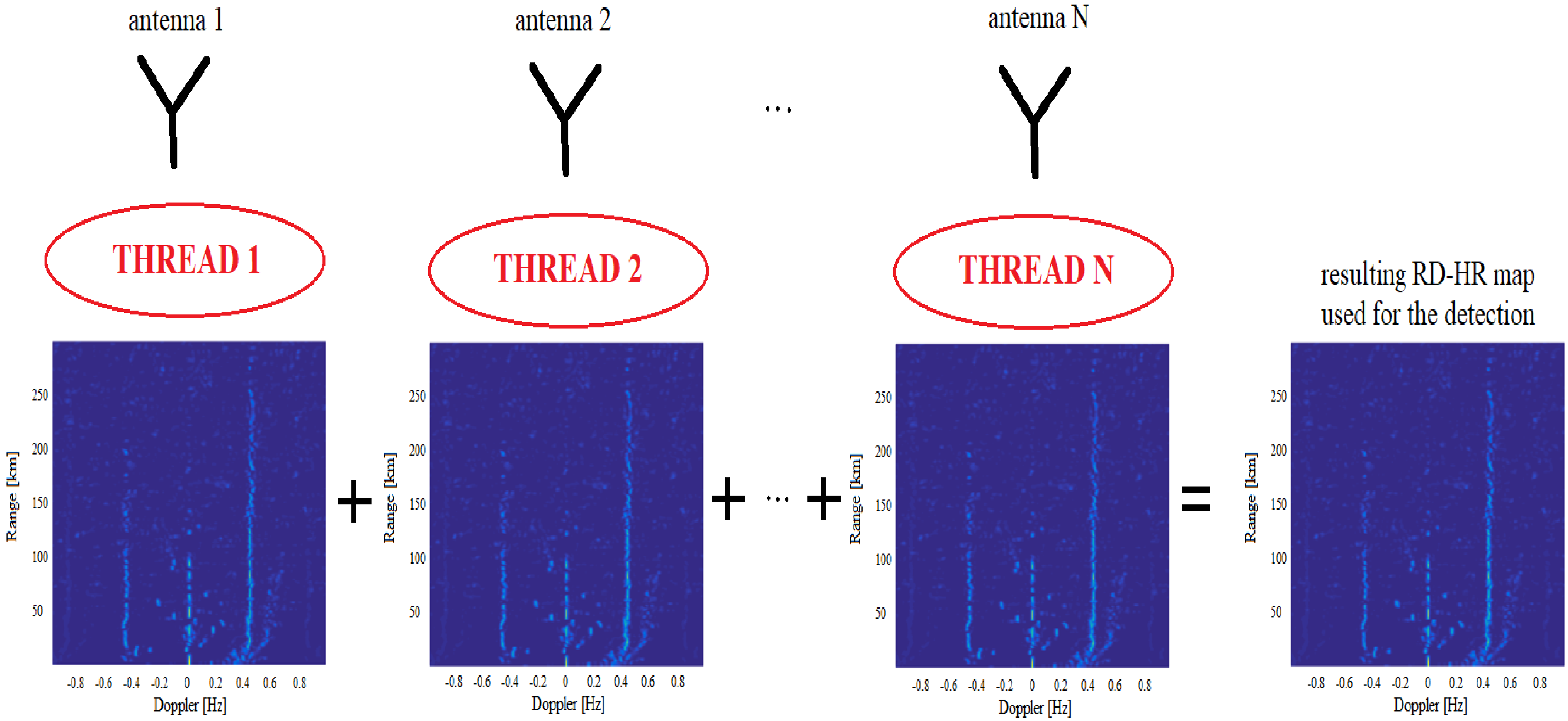
The comparison of tracks (colored) with AIS (white)



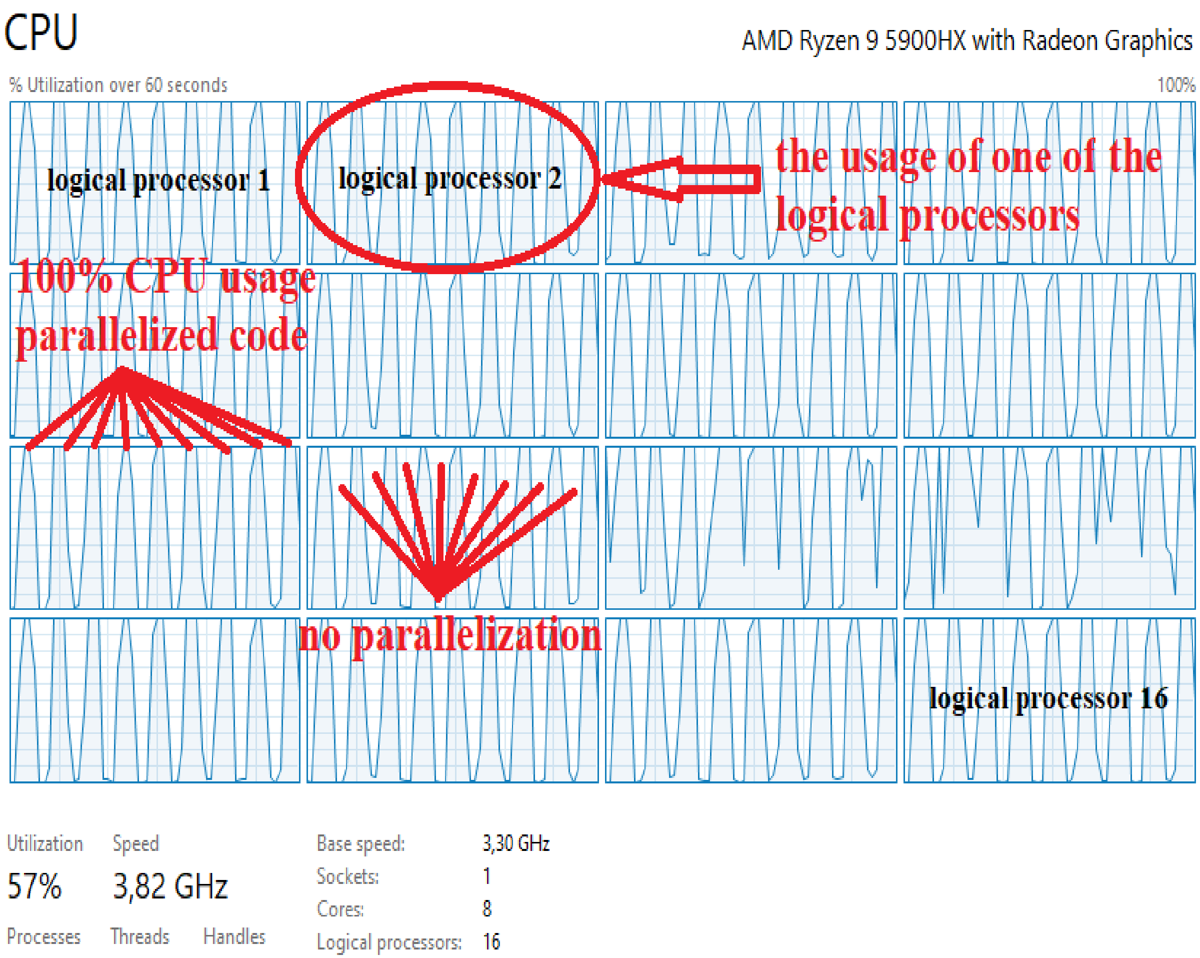
Tracking results (VIDEO)



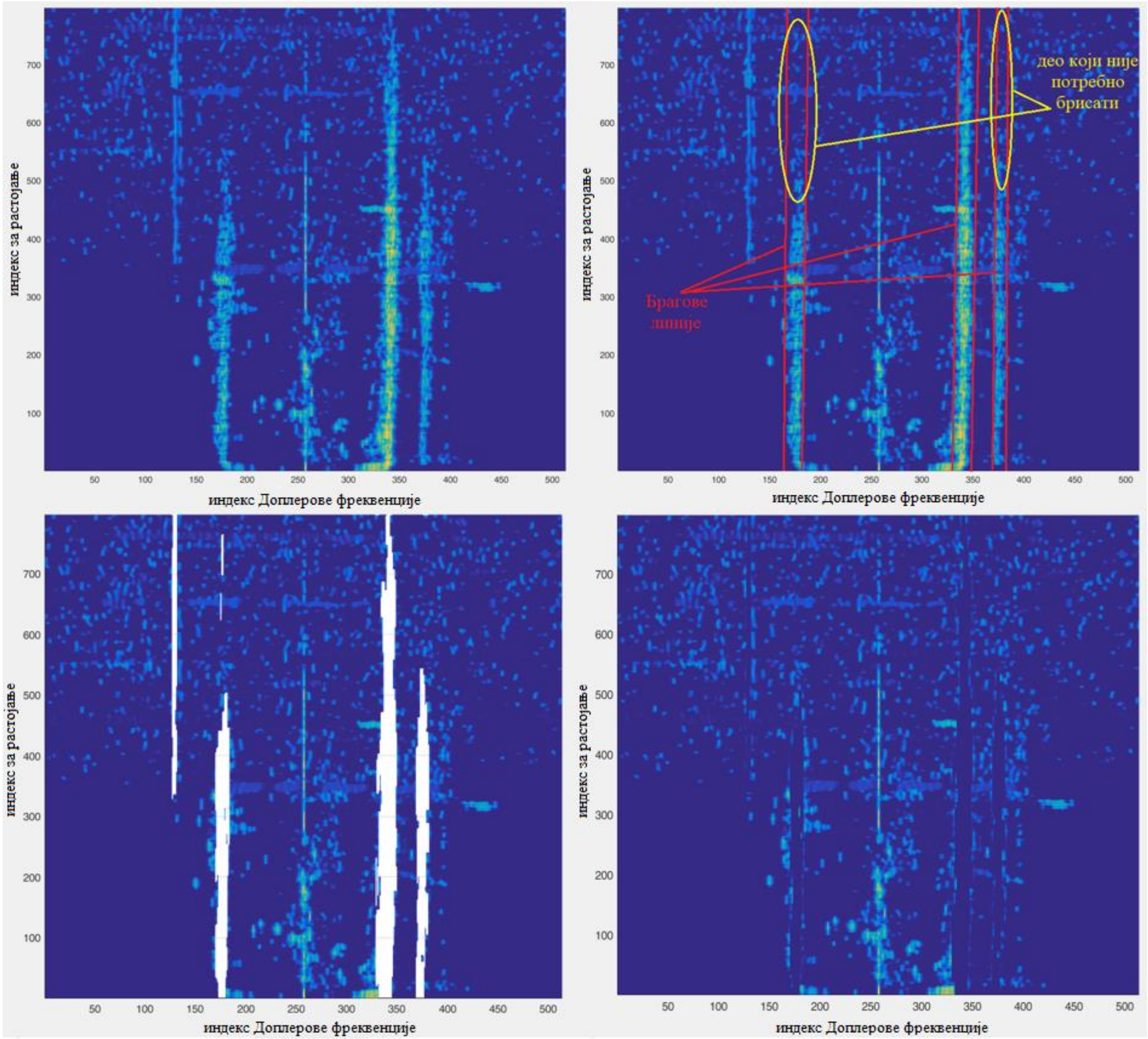
Less execution time of the algorithm



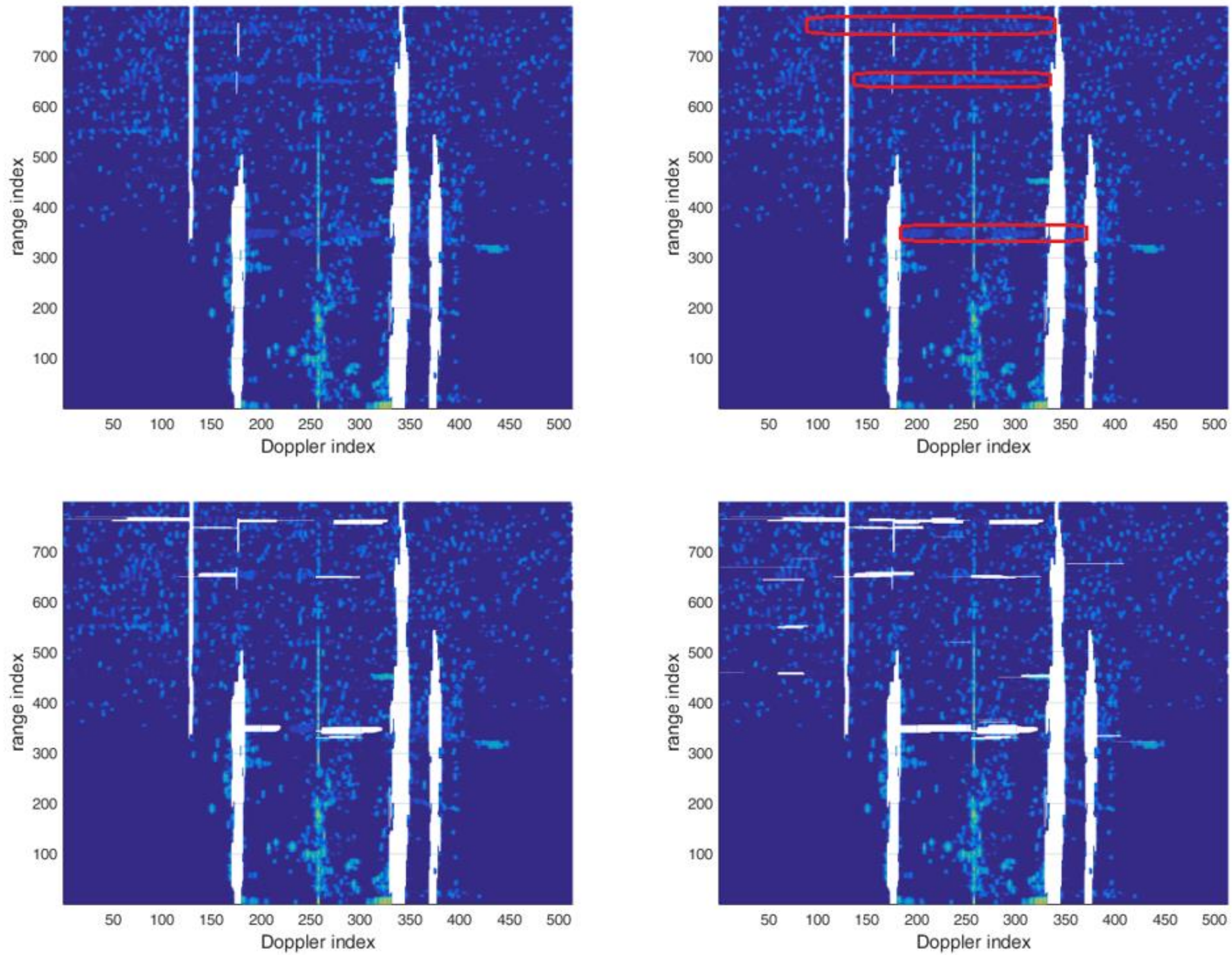
Execution time reduction



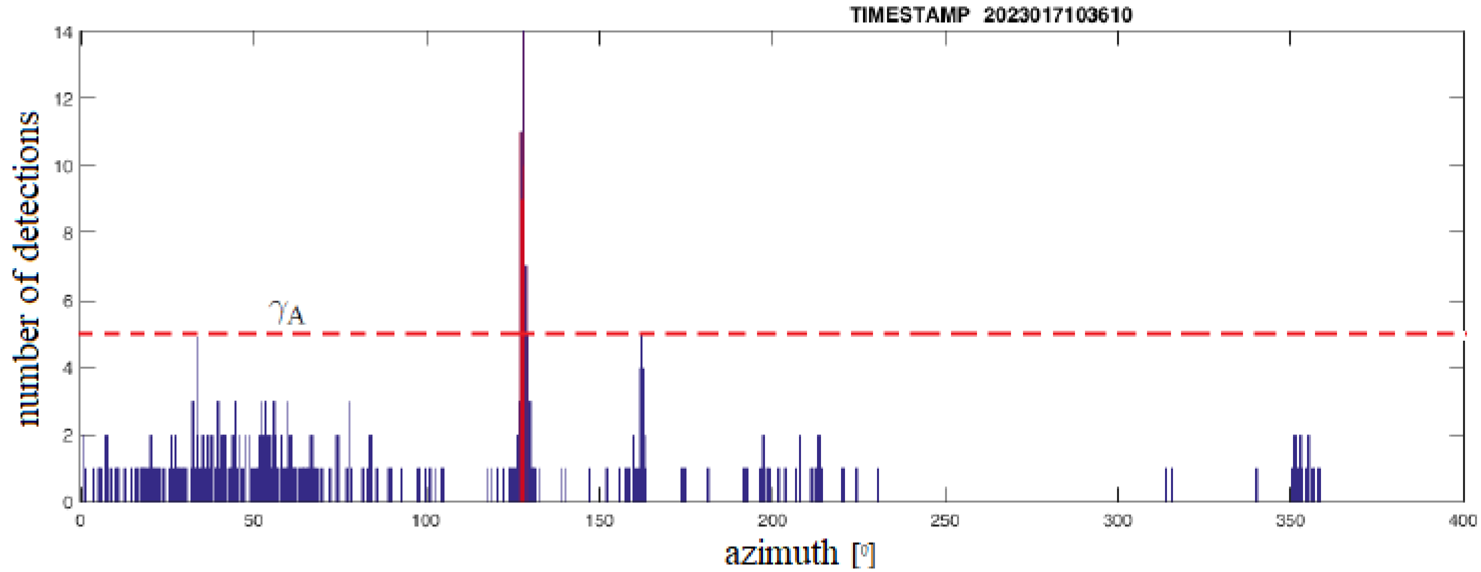
Sea clutter and RFI supression

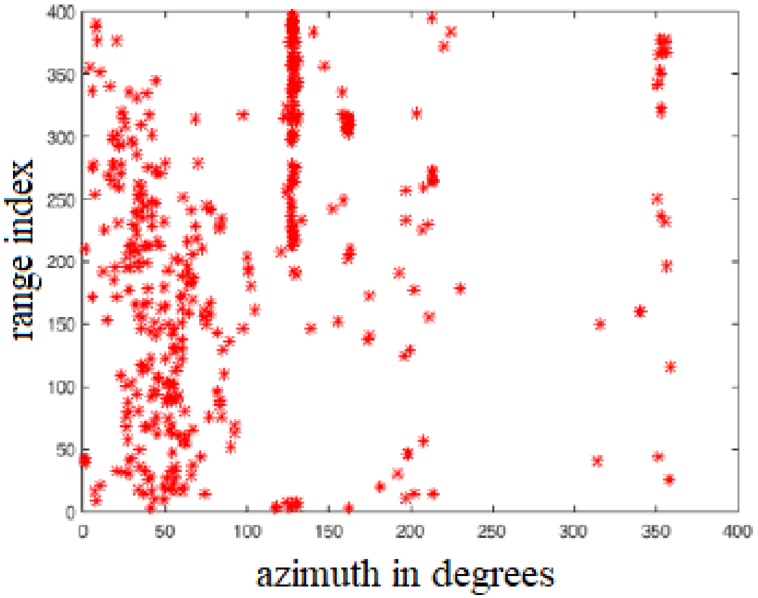


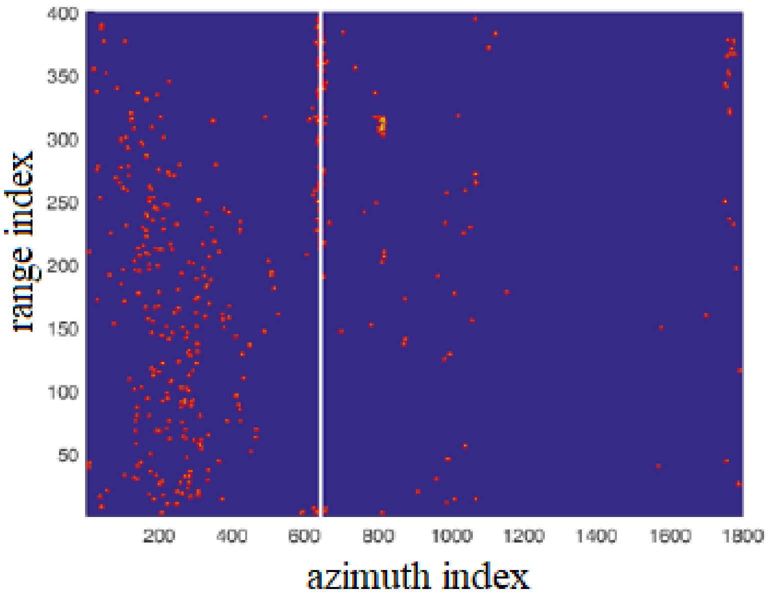
Ionospheric interference supression



The suppresion of interference grouped by azimuth



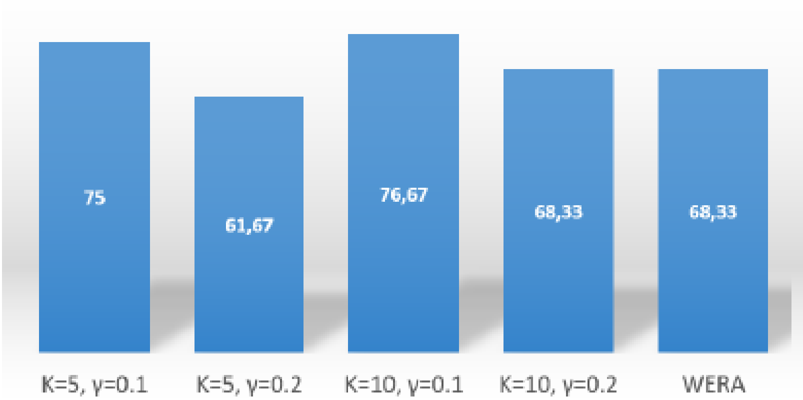




New algorithm VS WERA comparison

The ratio of total number of detections and detections within vessel contours for all vessels

Period of time	$K=5$ $\gamma=0.1$	$K=5$ $\gamma=0.2$	$K=10$ $\gamma=0.1$	$K=10$ $\gamma=0.2$	WERA
17h	5.97	2.66	10.57	6.01	18.5
18h	12.53	6.21	19.97	12.10	26.2
19h	7.46	3.09	14.40	7.76	25.6
20h	5.83	2.28	13.99	5.70	34.8
21h	4.06	1.83	9.20	4.54	24.09
22h	3.54	1.77	7.98	4.23	20.31



The percentage of detection success of high-resolution algorithm and WERA algorithm

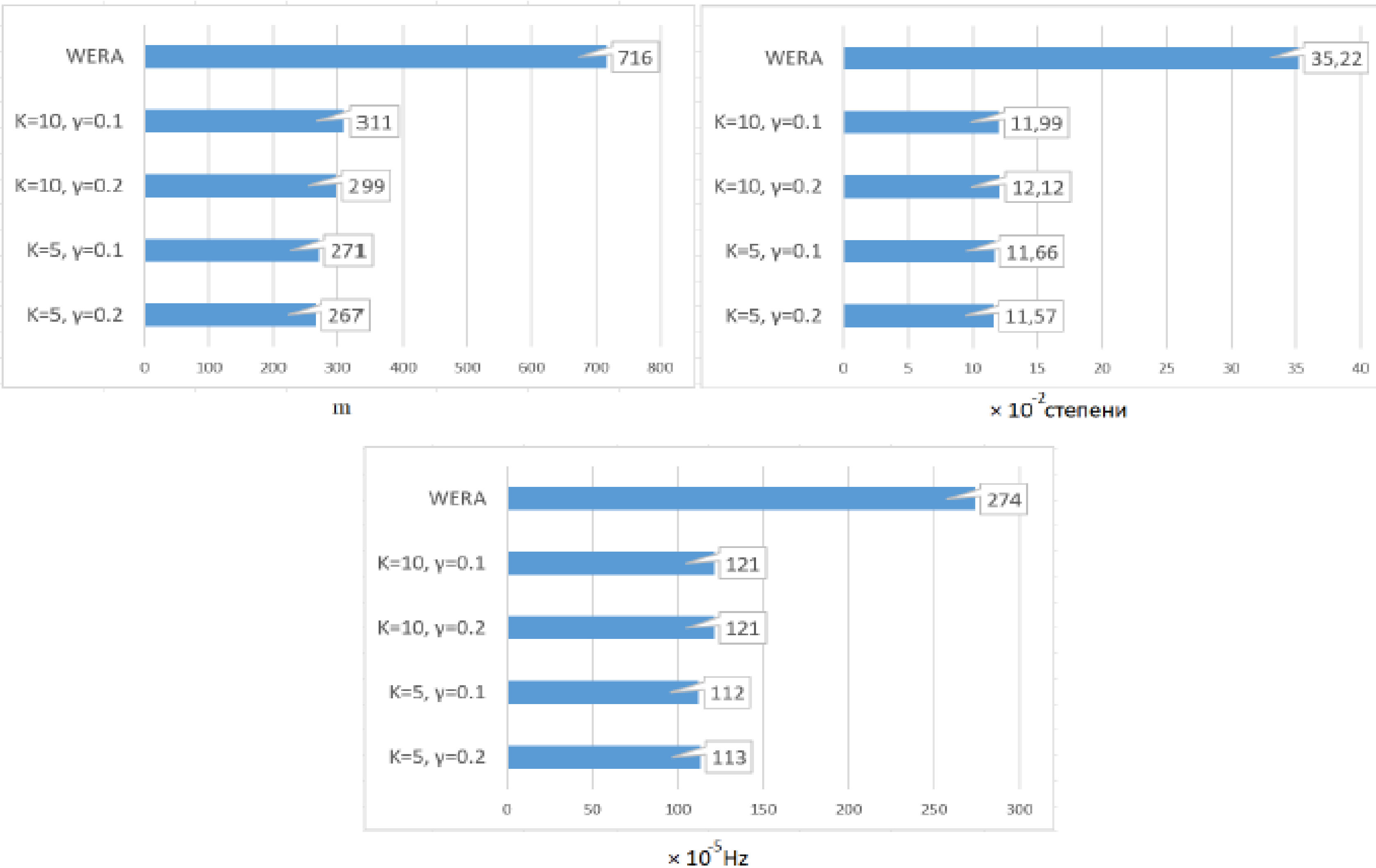
New algorithm VS WERA comparison

P_d and P_f of two arbitrarily selected vessels in a time interval of one hour

Algorithm parameters	P_d	P_{fa}	P_{fae}
$K = 5, \gamma = 0.2$	0.7238	$21/1{,}689{,}555$ *	$48/1{,}759{,}737$ *
$K = 5, \gamma = 0.1$	0.7238	1.0417×10^{-4}	1.1536×10^{-4}
$K = 10, \gamma = 0.2$	0.7524	4.5278×10^{-4}	4.6257×10^{-4}
$K = 10, \gamma = 0.1$	0.8381	7.6470×10^{-4}	7.7625×10^{-4}
WERA	0.7212	$24/1{,}689{,}555$ *	$57/1{,}759{,}737$ *

Algorithm parameters	P_d	P_{fa}	P_{fae}
$K = 5, \gamma = 0.2$	0.2095	1.7061×10^{-4}	1.7565×10^{-4}
$K = 5, \gamma = 0.1$	0.2952	5.6351×10^{-4}	5.7442×10^{-4}
$K = 10, \gamma = 0.2$	0.3238	5.3808×10^{-4}	5.4040×10^{-4}
$K = 10, \gamma = 0.1$	0.3714	1.3330×10^{-3}	1.3331×10^{-3}
WERA	0.2833	2.4630×10^{-3}	2.7119×10^{-3}

New algorithm VS WERA comparison



RMSE for range (**top left**), azimuth (**top right**) and Doppler frequency (**down**)

Advantages

- ✓ Better ship detectability…
- ✓ Ability to detect some ships, which are not visible at all using the currently used primary signal processing algorithms
- ✓ The proposed detector is more suitable for detection in high resolution range-Doppler map than classical CFAR
- ✓ The nature of the MUSIC-based criterion function is more suitable for application of such kind of detectors, especially for close ranges in the RD-HR map
- ✓ Numerically efficient !

Implementation

Published papers related to new developed high-resolution algorithms

1. D.Golubović, M. Erić, and N. Vukmirović, "High-Resolution Doppler and Azimuth Estimation and Target Detection in HFSWR: Experimental Study," *Sensors* vol. 22, 3558, 2022. DOI: https://doi.org/10.3390/s22093558

2. D. Golubović, M. Erić, and N. Vukmirović, "High-Resolution Method for Primary Signal Processing in HFSWR," *2022 30th European Signal Processing Conference (EUSIPCO 2022)*, Belgrade, Serbia, pp. 912-916, 2022. doi: 10.23919/EUSIPCO55093.2022.9909894.

3. D. Golubović, N. Vukmirović, Z. Loncarević, M. Marković, and M.Erić, "Execution Time Improvement using CPU Parallelization and Non-Uniform High-Resolution Range-Doppler Map Estimation in HFSWR," *9th International Conference on Electrical, Electronic and Computing Engineering (IcETRAN 2022)*, pp. 717-722, Novi Pazar, Serbia, 2022.

4. D. Golubović, N. Vukmirović, M. Erić, and M. Simić-Pejović, "Method for Noise Subspace Determination in HFSWR's High-Resolution Range-Doppler Map Estimation," *10h International Conference on Electrical, Electronic and Computing Engineering (IcETRAN 2023)*, East Sarajevo, Republic of Srpska, 2023.

5. D.Golubović, "Visokorezoluciona primarna obrada signala kod izahorizontnih radara u visokofrekventnom opsegu,"doktorska disertacija, 2023.

Conclusion

- In this presentation, we demonstrated how new developed algorithms for primary signal processing in HFSWR work in real situations → we achieved great detectability!
- The contributions → high-resolution method for estimating the RD-HR map, computationally more efficient non-uniform variant, compensation of the Doppler shift before high-resolution azimuth estimation, more convenient detection algorithm…
- The chalenge → future improvements in order to have better detection of small targets…

Thank you for your attention!

Any questions?

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