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Performance Assessment of HF-Radar Ship Detection using two WERA Systems

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Introduction

- Nowadays, **Integrated Maritime Surveillance** (**IMS**) systems have acquired great Importance.
- Need for early-warning tools.
- Great attention is paid to **low-power HFSW radars**.
- **WERA** (**WEllen RAdar**) is such a system.

The analysis of HF data is of primary importance:

1) Raw data (i.e. statistical analysis of clutter and noise),
2) Detection stage (i.e. prob. of detection and false alarm),
3) Tracking stage (i.e. track maintenance, RMSE).

Outline

The WERA system

The NURC BP09 experiment

Performance assessment

Detection statistics

Conclusions and future perspectives

The WERA system:
General information and system setup

Principal task:

Remote sensing and oceanic applications.

Aimed task:

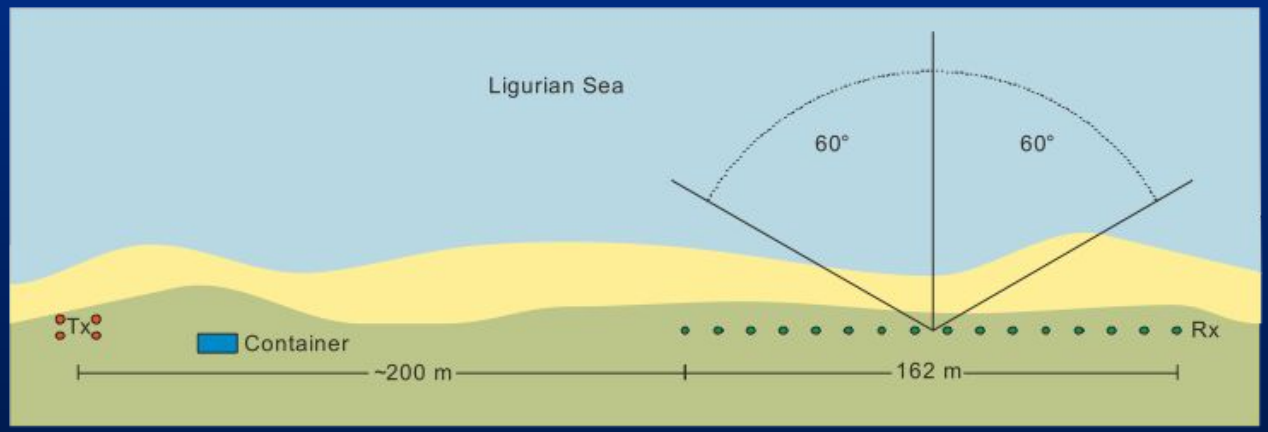
Long-range early-warning tool for maritime surveillance.

Pros:

Low-power system,
Coverage well beyond the optical horizon.

Cons:

Sea clutter and interference sources,
Low range/azimuth resolution.



http://ifmaxp1.ifm.uni-hamburg.de/info.shtml.

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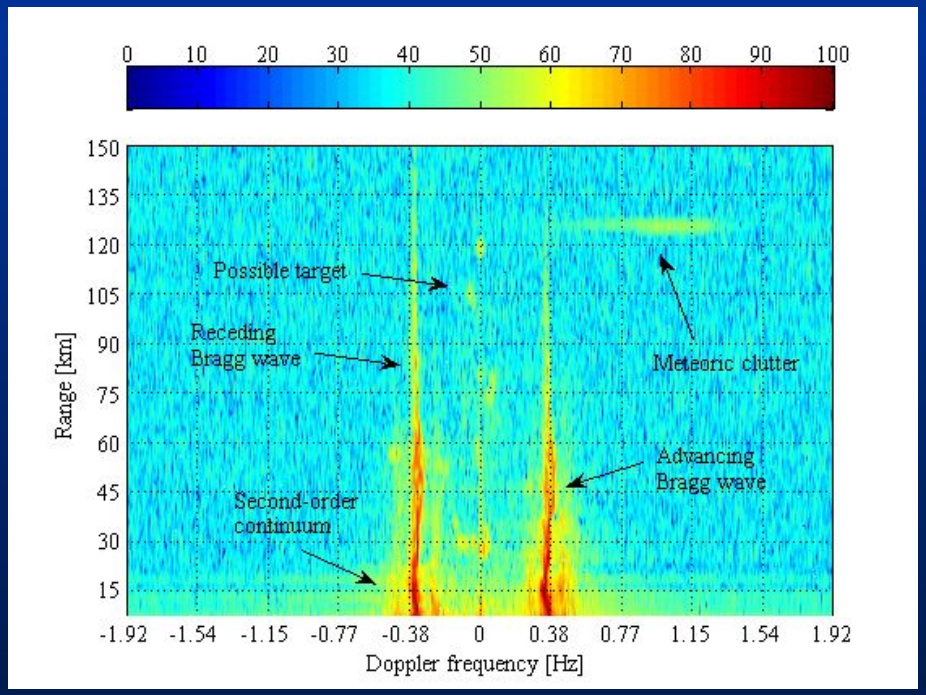
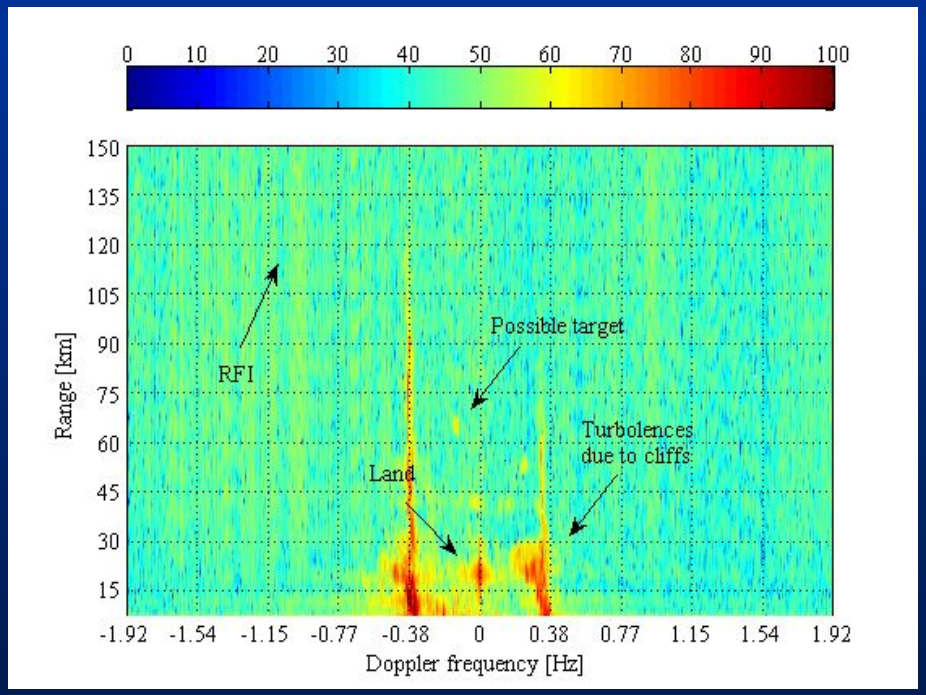
The WERA system:
The range-Doppler spectrum

Sea clutter and **interference sources** can mask ship echoes.

Sea clutter is mainly described by **first-order Bragg scattering**.

$$f_{Bragg} = \pm\sqrt{\frac{g}{\pi\lambda_0}} = \pm\sqrt{\frac{gf_0}{\lambda c}},$$





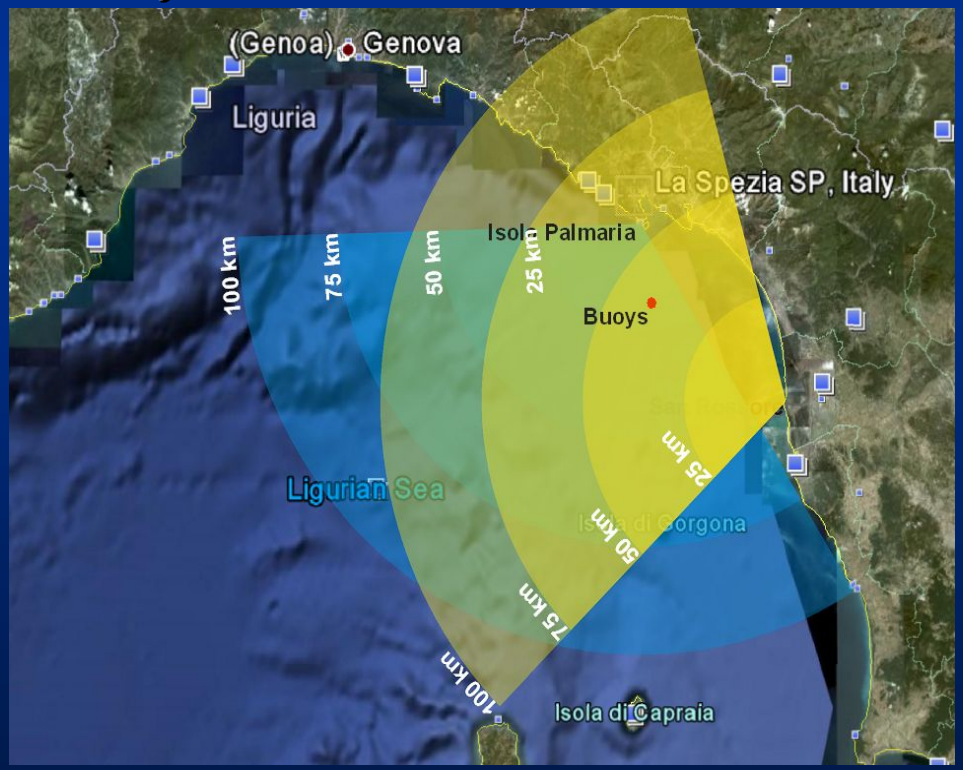
The WERA system:
The CFAR detection algorithm

The **3D Ordered Statistics (3D-OS) CFAR** test statistic based on the **Neyman-Pearson Criterion** is used.

A. Dzvonkovskaya, K.-W. Gurgel, H. Rohling, and T. Schlick, **“HF Radar WERA Application for Ship Detection and Tracking”**, European Journal of Navigation, vol. 7, no. 3, December 2009.

The NURC BP09 experiment

- NATO Undersea Research Centre (NURC), Italy
- Institute of Oceanography, University of Hamburg, Germany
- Department of Information Engineering, University of Pisa, Italy



	Palmaria	San Rossore
Longitude	9° 50' 36'' E	10° 16' 52'' E
Latitude	44° 2' 30'' N	43° 40' 53'' N
True North Angle Φ	296.2°	12.0°
Range resol. ΔR	1.50 – 2.40 km	
Chirp bandwidth B	100.00 – 62.50 kHz	
Range cells N_{RC}	100	
Azimuth resol ΔΘ	8.0°	
Azimuth cells N_{AC}	121	
Frequency f_0	12.190 – 12.565 MHz	
Chirp time T	0.26 s	
Samples per file	128	
Files per hour	103	

Problem statement:
Key Assumptions

Use of **AIS data as ground-truth information**.

AIS-transponders carrying ships are the only ones present in the region of interest.

The information exchanged by ships are reliable and not corrupted by errors.

Ship Identifiers (MMSI) refer each to a different vessel.

AIS contacts are interpolated on WERA detector timestamps.
The interpolated route is the true one.

Problem statement:
The WERA and AIS data

The WERA data
latitude, longitude, day, time, range/bearing/range rate w.r.t. the sensor position.

$$\mathbf{X} = \{\mathbf{X}_1, \ldots, \mathbf{X}_n, \ldots, \mathbf{X}_N\},$$

where:

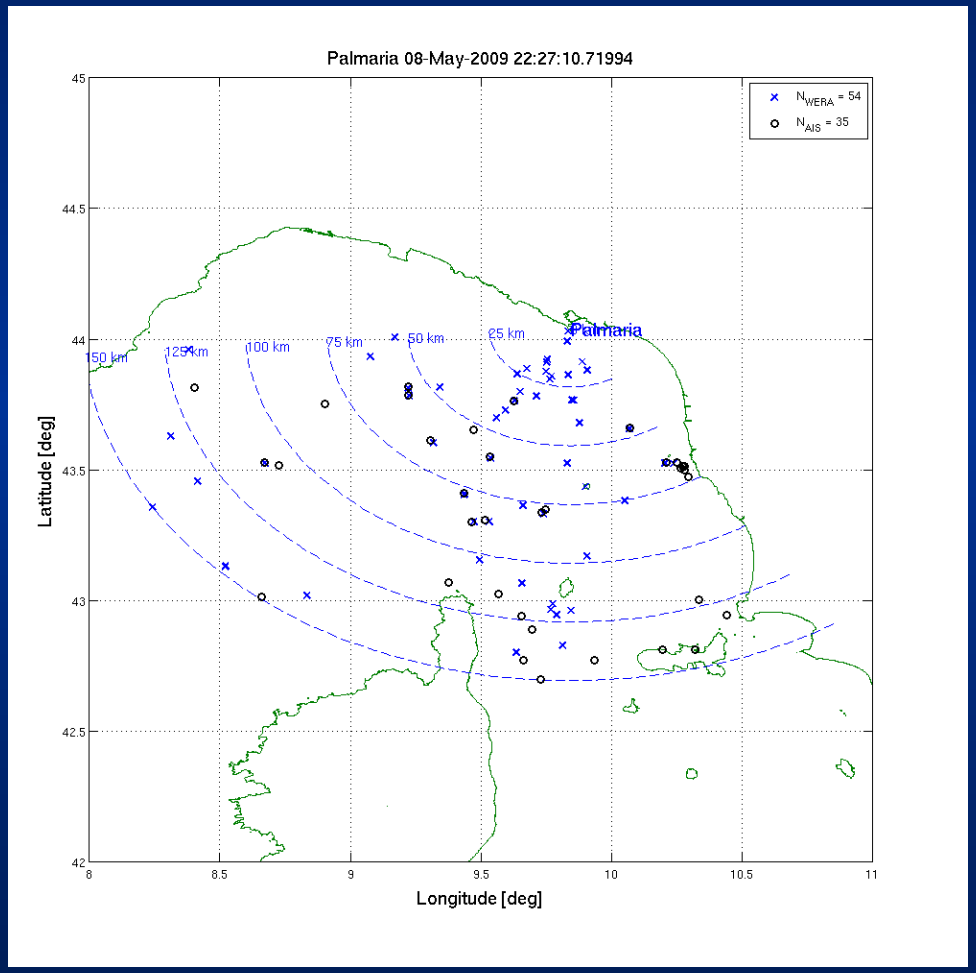
$$\mathbf{X}_n = \{\mathbf{x}_n^1, \ldots, \mathbf{x}_n^M\},$$

The AIS data
dynamic (latitude, longitude, course over ground, speed over ground, epoch time) and **static** (i.e. type, dimensions, MMSI):

$$\mathbf{Y} = \{\mathbf{Y}_1, \ldots, \mathbf{Y}_l, \ldots, \mathbf{Y}_L\},$$

Problem statement:
Association and filtering procedure 1/4

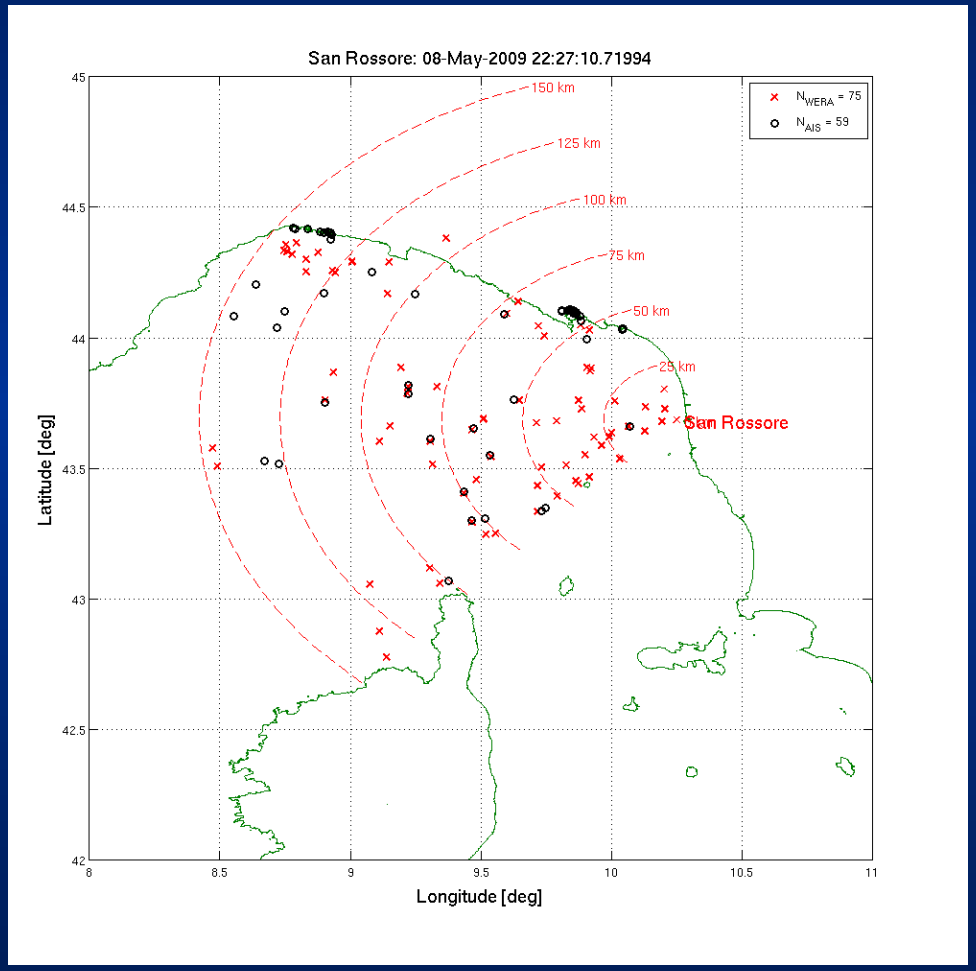
1) Linear interpolation of Y on X timestamps.



CPI-coherent plot of WERA and AIS contacts at Palmaria.

Problem statement:
Association and filtering procedure 2/4

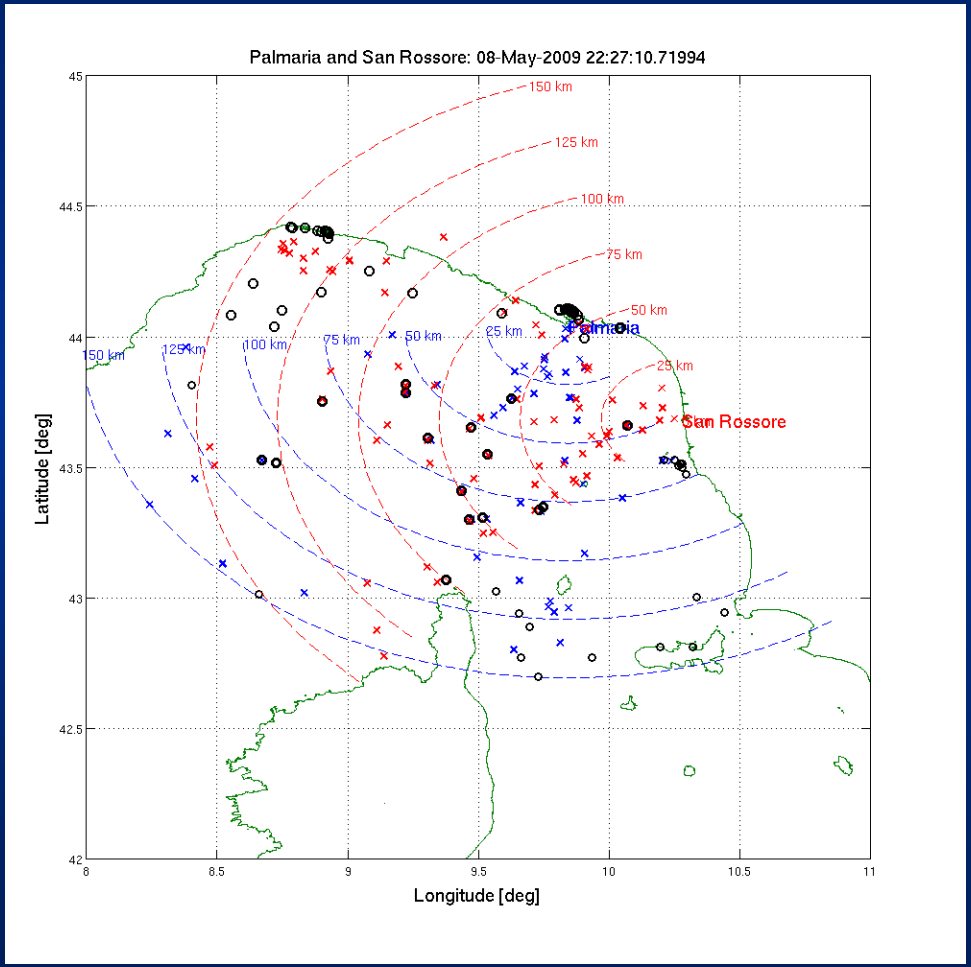
1) Linear interpolation of Y on X timestamps (cont'd).



CPI-coherent plot of WERA and AIS contacts at San Rossore.

Problem statement:
Association and filtering procedure 3/4

1) Linear interpolation of Y on X timestamps (cont'd).



CPI-coherent plot of WERA and AIS contacts at Palmaria and San Rossore.

Problem statement:
Association and filtering procedure 4/4

2) For each timestamp, a WERA contact is associated to an AIS contact.

$$(\mathbf{x}_n \rightarrow \overline{\mathbf{y}}_n) : d(\mathbf{x}_n, \overline{\mathbf{y}}_n) = \min_{i,j} \left\{ d\left(\mathbf{x}_i, \overline{\mathbf{y}}_j\right) \right\},$$

where:

$$d(\mathbf{x}_n, \overline{\mathbf{y}}_n) \triangleq \sqrt{(e_{\mathbf{x}} - e_{\overline{\mathbf{y}}})^2 + (n_{\mathbf{x}} - n_{\overline{\mathbf{y}}})^2}$$

3) A **validation gate** filters out possible false alarms and labels survived contacts as true detections.

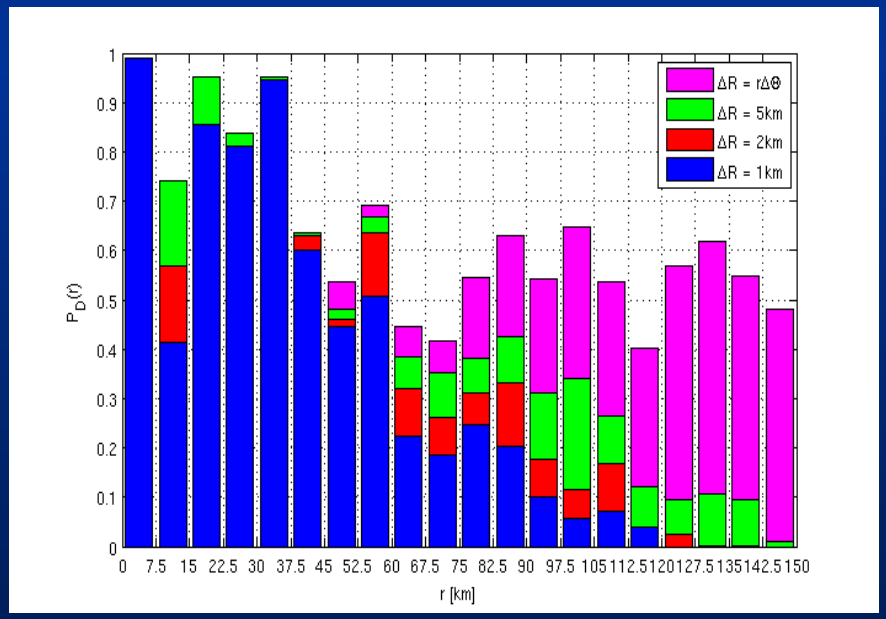
ΔR_1 = 1 km (blue line),
ΔR_2 = 2 km (red line),
ΔR_3 = 5 km (green line),
$\Delta R_4 = r \cdot \Delta\Theta$, where r = 0, 7.5, 15, …, 150 km (magenta line).

Detections Statistics:
Probability of Detection 1/2

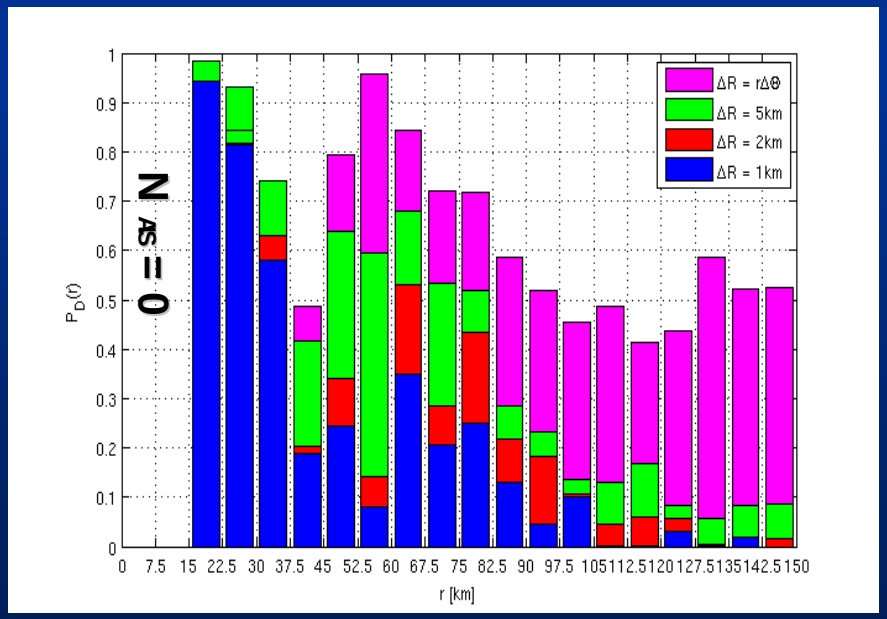
The **probability of detection** (P_D) is estimated using:

$$P_D \cong \frac{N_{Filtered}}{N_{AIS}},$$

N_{AIS} = 2.082·10^6 at Palmaria
N_{AIS} = 4.660·10^6 at San Rossore



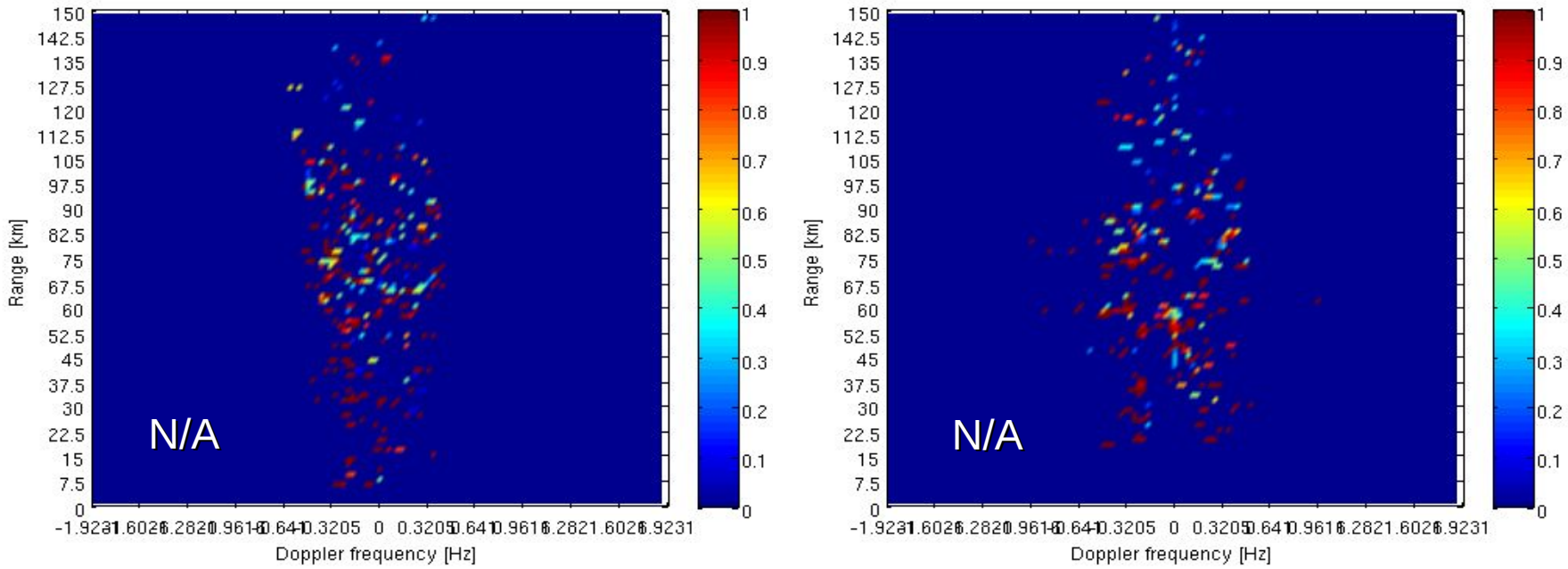
P_D at Palmaria site.



P_D at San Rossore site.

Detections Statistics:
Probability of Detection 2/2

P_D vs range/Doppler at Palmaria and San Rossore sites.



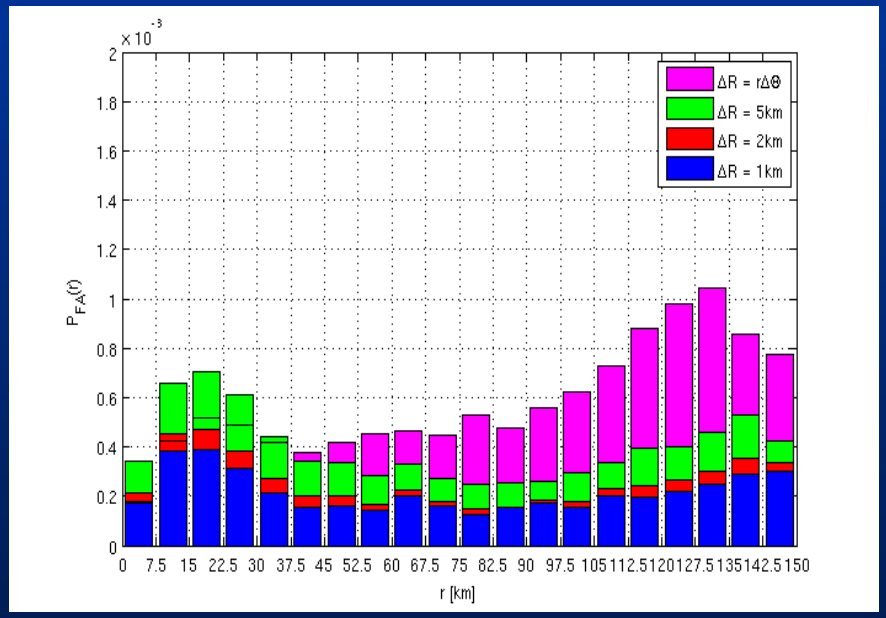
Detections Statistics:
Probability of False Alarm

The **probability of false alarm** (P_{FA}) is estimated using:

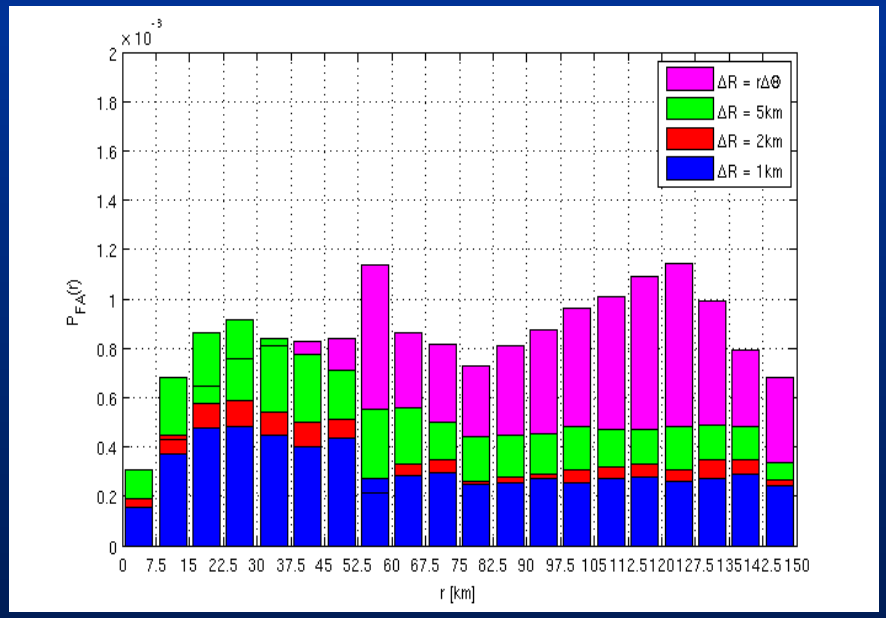
$$P_{FA} \cong \frac{N_{WERA} - N_{AIS}}{N_{Trials}} \leq \frac{N_{WERA} - N_{Filtered}}{N_{Trials}},$$

$$N_{Trials} = N_{Days} N_{CPI} N_{AC} N_{RC},$$

$N_{Trials} = 777.6 \cdot 10^6$



P_{FA} at Palmaria site.



P_{FA} at San Rossore site.

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Conclusions and perspectives

What we did:

1) use AIS ata as groun-truth information,
2) interpolate the AIS contacts according to WERA CPI timestamps.
3) associate a WERA contact to each single AIS contact,
4) filter the WERA contacts according to range gates,
5) obtain P_D and P_{FA}

Results:

1) P_D decreases with range,
2) P_D is almost the same for ΔR = 1,2,5 km.
3) Doppler shifts of ships are mostly between the two Bragg frequencies,
4) P_{FA} is almost constant over range (CFAR property).

Ongoing...

1) single-sensor vs fused detections from HF-radars,
2) comparison to other available data (e.g. SAR images),
3) estimation of position and speed errors,
4) different radar and ship parameters (e.g. speed and size).

Acknowledgements

We would like to sincerely acknowledge Prof. K.-W. Gurgel for kindly providing us the WERA data and for his help and suggestions.

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