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A robust symmetry-based approach to exploit TerraSAR-X dual-pol data for targets at sea observation

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Outline

Introduction

- Motivations
- State of Art

Methodology

- Symmetry property
- Data set

Results

- Symmetry on HH/HV
- Symmetry on VV/VH

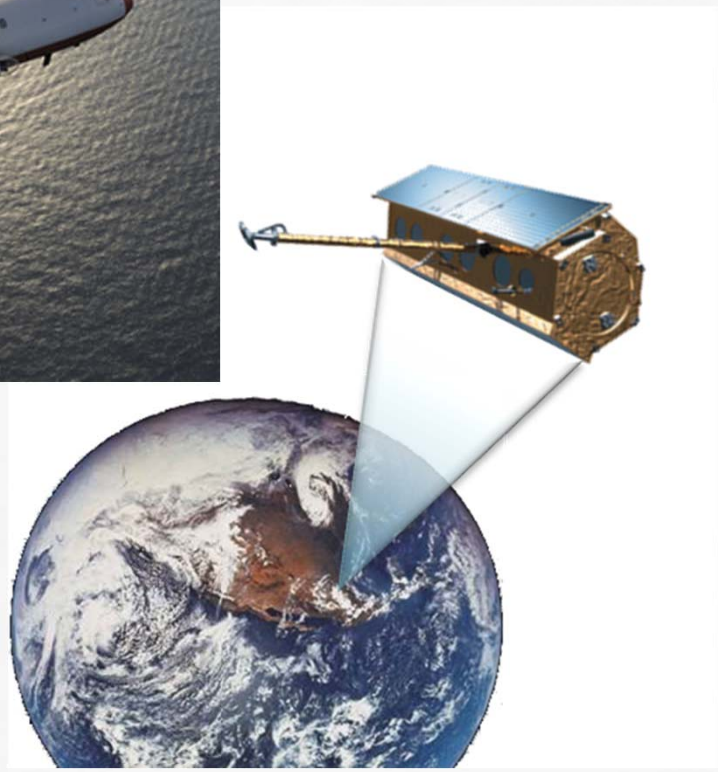
Conclusions

Introduction - Motivation

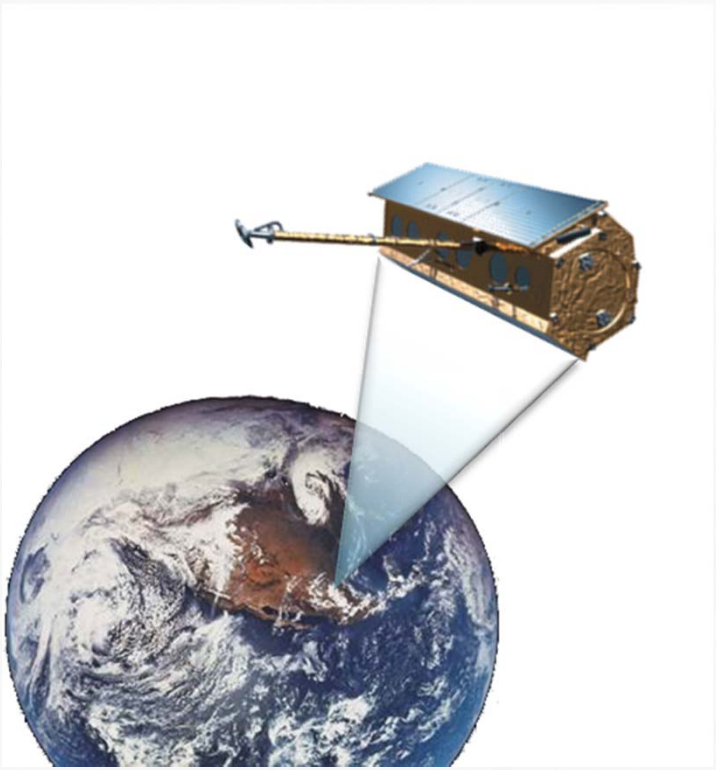
Target at sea monitoring finds its utmost importance in the field of maritime security.

- Ship traffic control
- Piracy and border control
- Oil pollution
- Platforms monitoring

Available methodologies for target at sea monitoring include:



Targets observation at sea by Synthetic Aperture Radar (SAR) offers:



PRO

- High resolution
- Wide area coverage
- 24hours – 7days capabilities
- Almost independent on weather conditions
- Single- and Multi-polarization

CONS

- Targets identification
- Revisit time
- Data processing

Robust, imaging mode independent and multi-frequency algorithm!

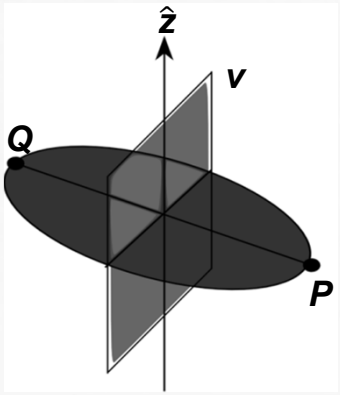
Methodology – Symmetry property

An Object $\boldsymbol{T}$ is defined symmetric

$\Leftrightarrow$

given a set of transformation $\boldsymbol{X} \in$ { rotation about some axis; mirror reflection in a plane; linear translation } ; $\boldsymbol{T'} = \boldsymbol{X}(\boldsymbol{T})$

$\Downarrow$

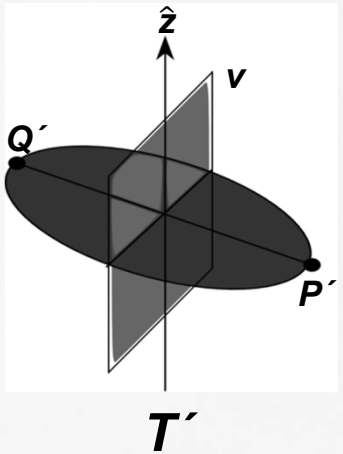


$\{\boldsymbol{P}, \boldsymbol{Q}\} \in \boldsymbol{T}$

$\{\boldsymbol{P'}, \boldsymbol{Q'}\} \in \boldsymbol{T'}$

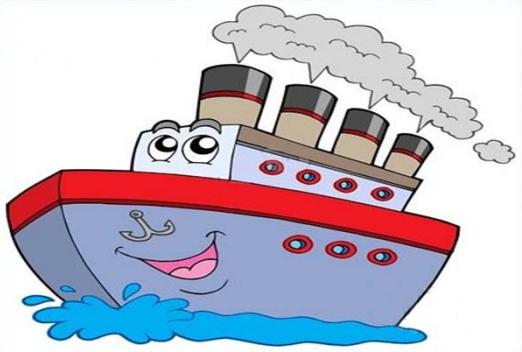
$\overline{\boldsymbol{PQ}} = \overline{\boldsymbol{P'Q'}}$

$\boldsymbol{P} \equiv \boldsymbol{P'} \quad \boldsymbol{Q} \equiv \boldsymbol{Q'}$



Methodology – Symmetry property

Symmetry has been widely used in PolSAR application, i.e. Decomposition, Calibration



- Man-made metallic target
- Not symmetric
- **C** has 9 non-0 elements

$$C = \begin{pmatrix} \langle |S_{hh}|^2 \rangle & \sqrt{2}\langle S_{hh}S_{hv}{}^* \rangle & \langle S_{hh}S_{vv}{}^* \rangle \\ \sqrt{2}\langle S_{hv}S_{hh}{}^* \rangle & \langle |S_{hv}|^2 \rangle & \sqrt{2}\langle S_{hv}S_{vv}{}^* \rangle \\ \langle S_{vv}S_{hh}{}^* \rangle & \sqrt{2}\langle S_{vv}S_{hv}{}^* \rangle & \langle |S_{vv}|^2 \rangle \end{pmatrix}$$

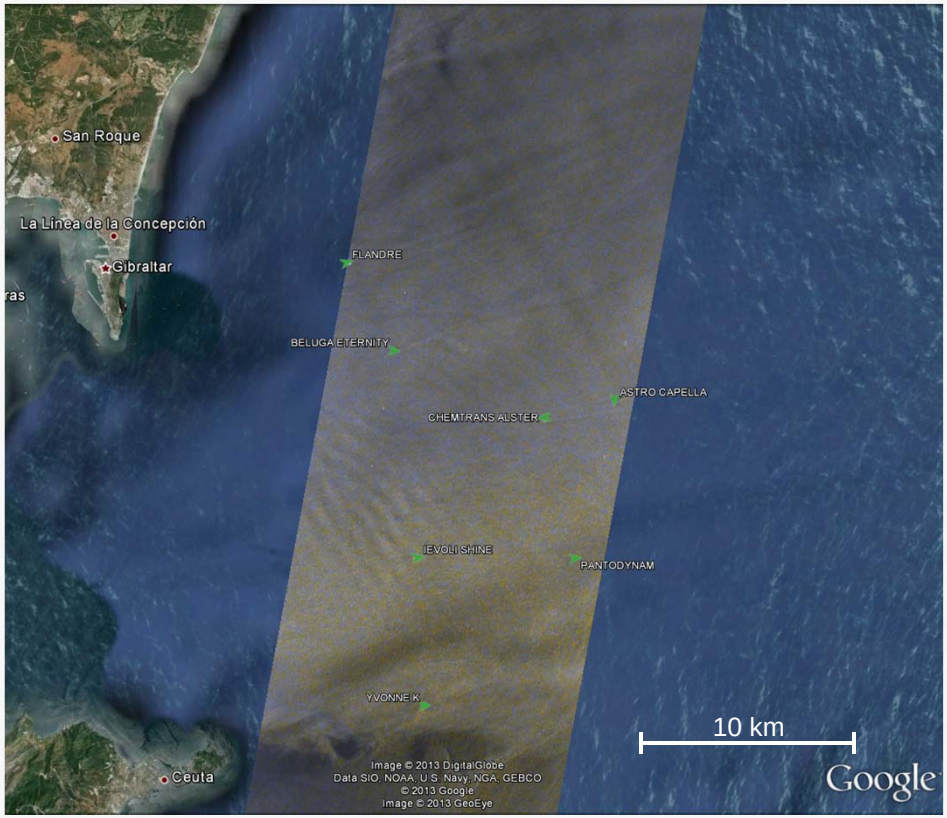
VS

- Natural distributed target
- Symmetric
- **C** has 5 non-0 elements

$$r = \left|\langle S_{xx}S_{xy}{}^* \rangle\right| \quad x, y \in \{h, v\}$$

$$C = \begin{pmatrix} \langle |S_{hh}|^2 \rangle & 0 & \langle S_{hh}S_{vv}{}^* \rangle \\ 0 & \langle |S_{hv}|^2 \rangle & 0 \\ \langle S_{vv}S_{hh}{}^* \rangle & 0 & \langle |S_{vv}|^2 \rangle \end{pmatrix}$$

Methodology – Data set



Coherent Dual-Pol TS-X **HH/HV** $\ominus$ = 30.51

Time: 2009-07-15 at 06:30 UTC

Wind: 5.1 m/s SW

Targets: 8; Ground truth: 7 Ships(AIS)

Coherent Dual-Pol TS-X **VV/VH** $\ominus$ = 39.7

Time: 2011-08-30 at 14:15 UTC

Wind: 2.2 m/s SE

Targets: 50; Ground truth: 21 (10 AIS)

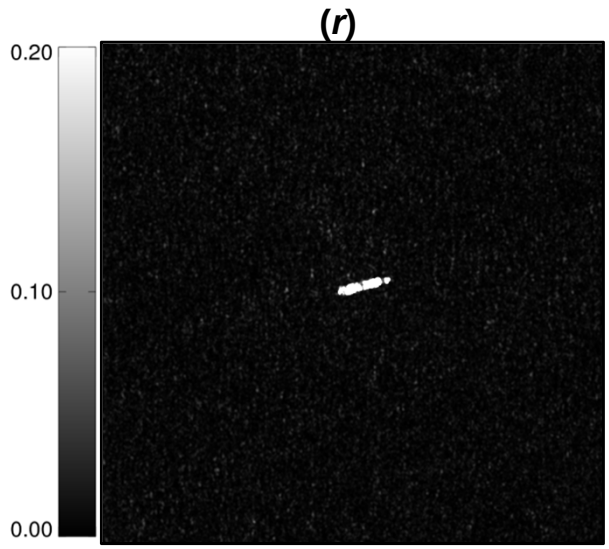
Results – Symmetry on HH/HV

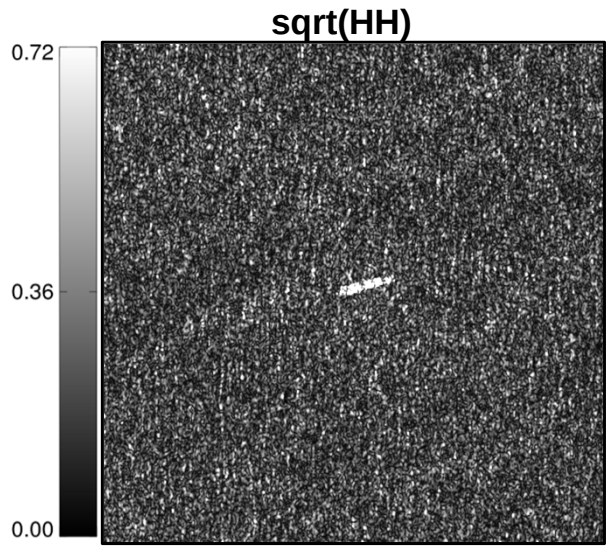
Two case studies: almost same incidence angle but different oceanic processes.

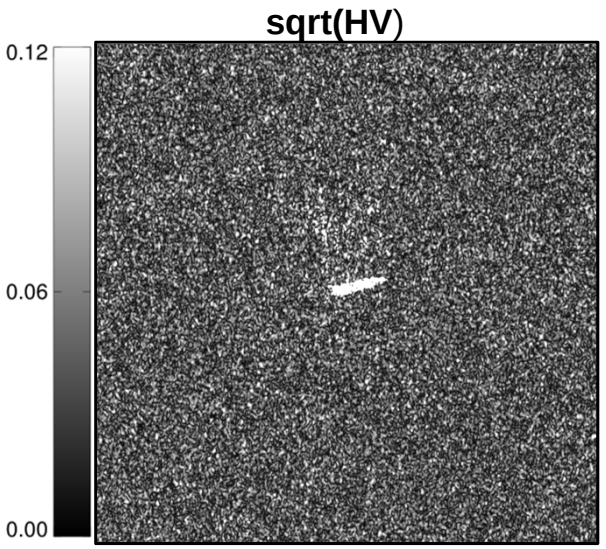
[Left] Ship and internal waves. [Right] Ship and calm water.

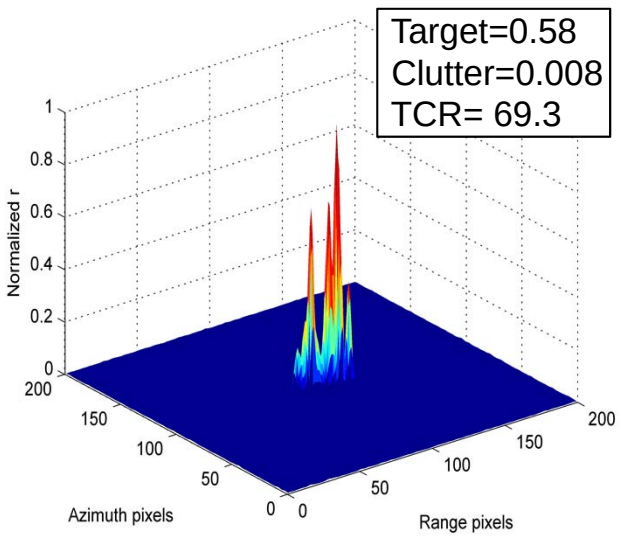
Different performances between Co- and Cross-pol are expected!!

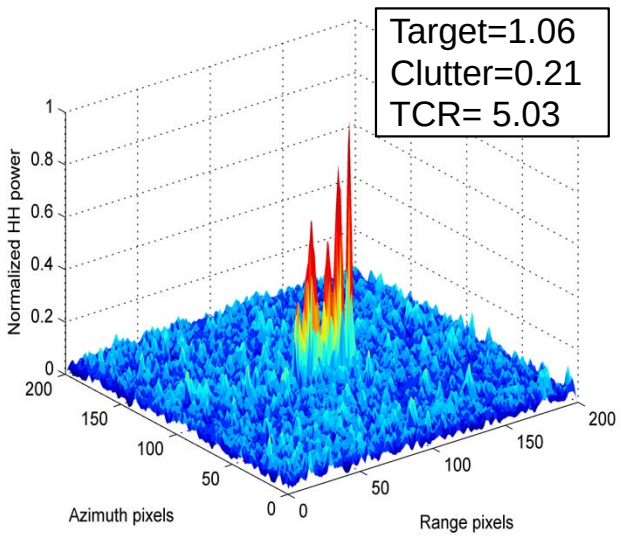
Results – Ievoli Shine

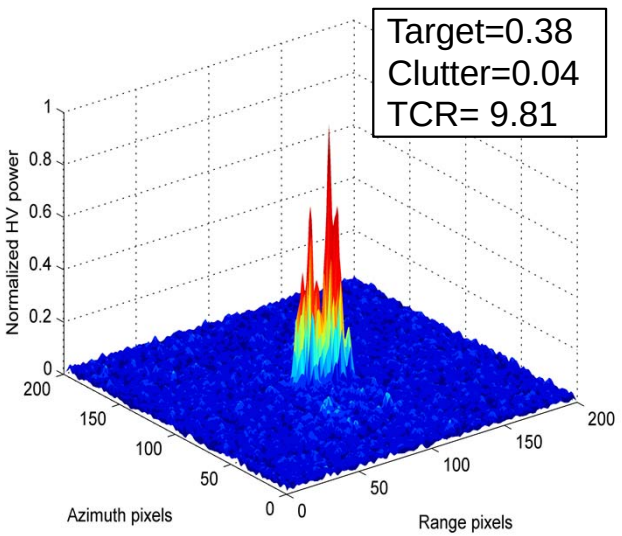




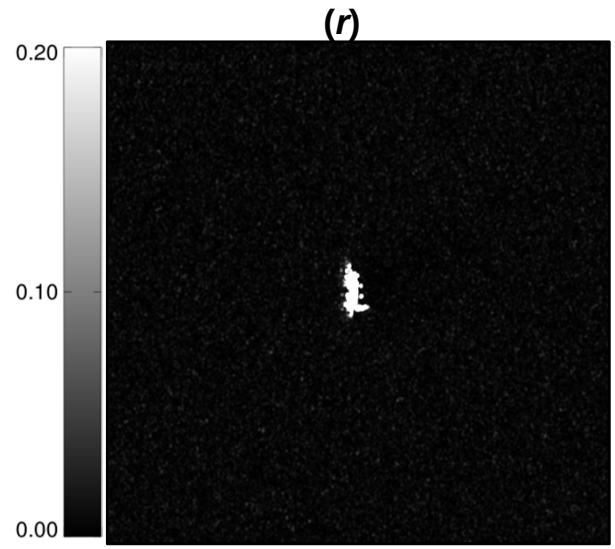


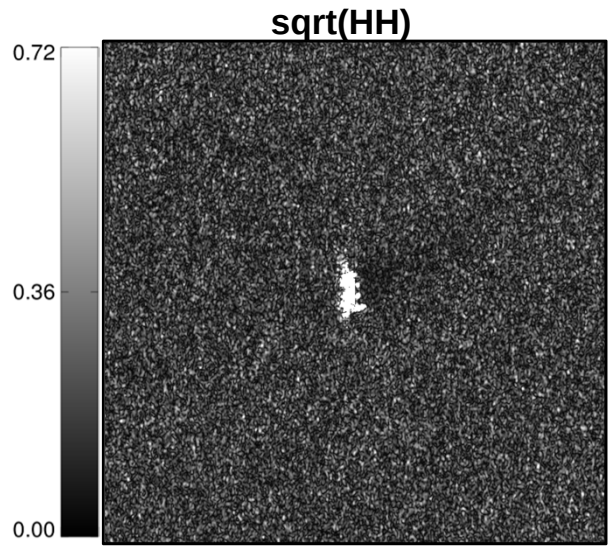


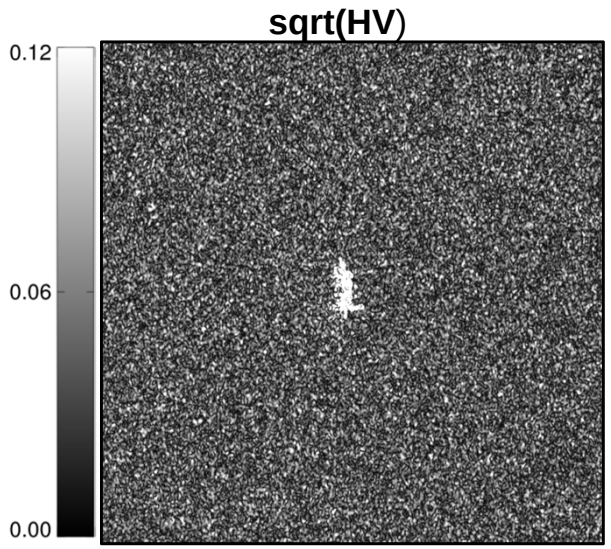


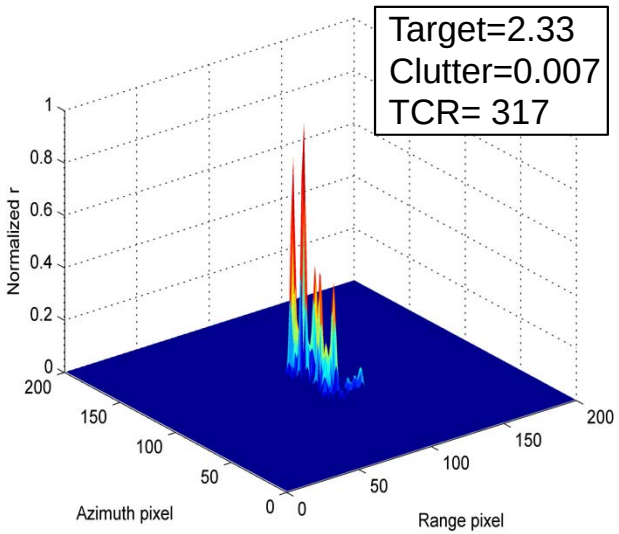


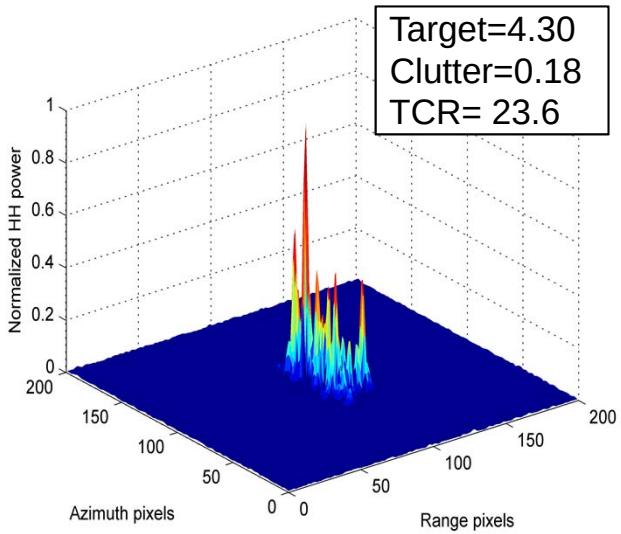
Results – Beluga Eternity

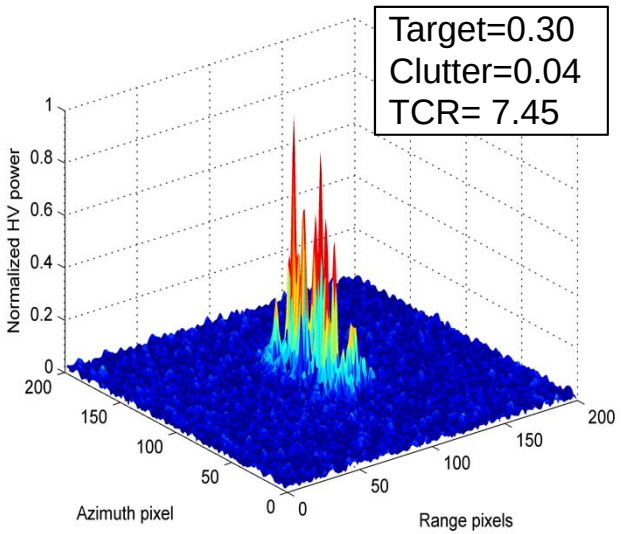






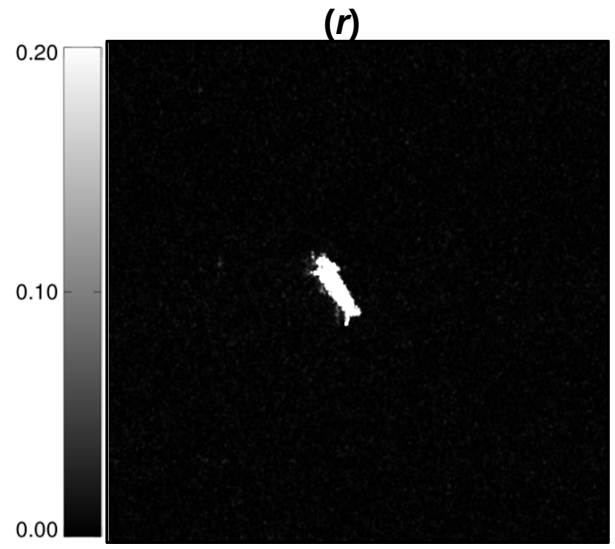


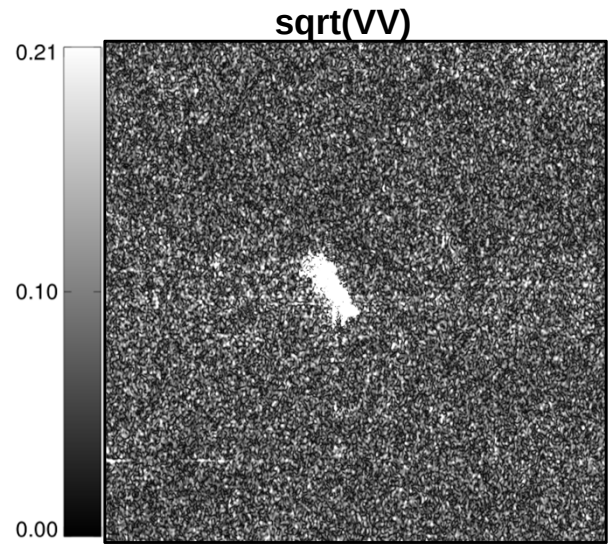


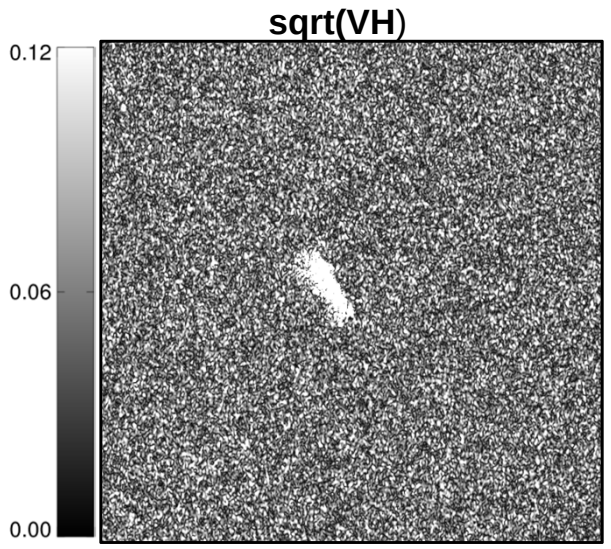


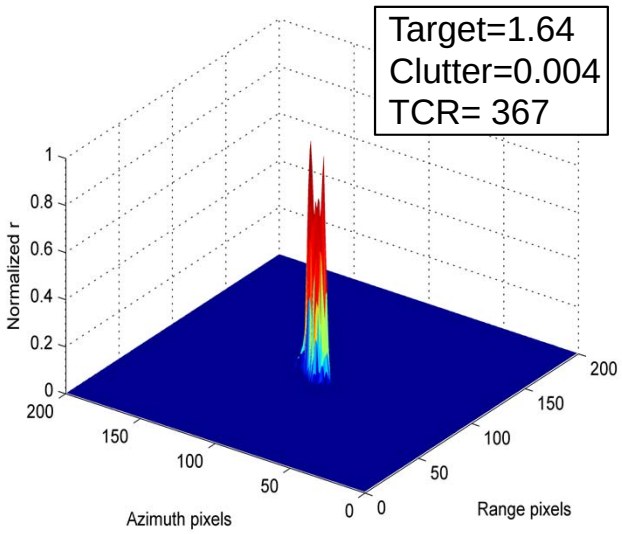
Results – Symmetry on VV/VH

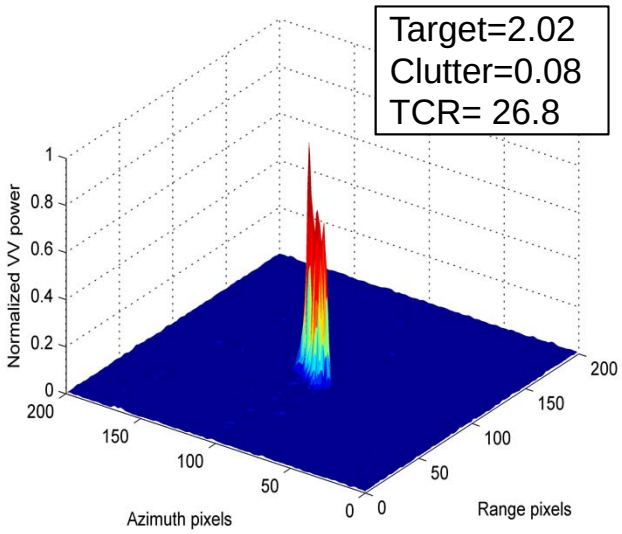
Results – Yasa Bodrum

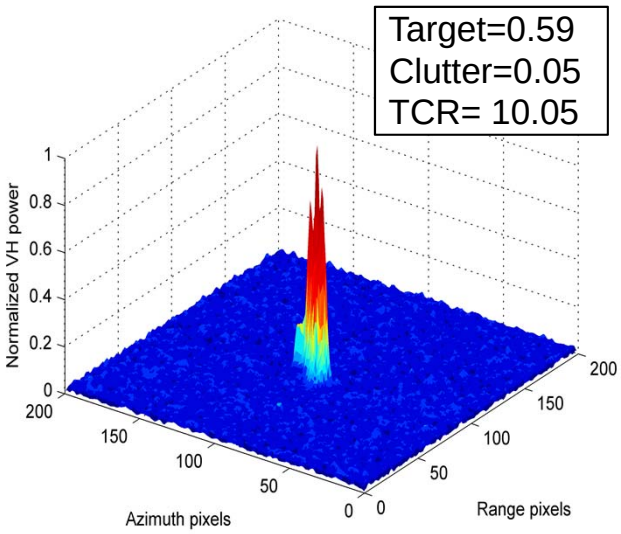




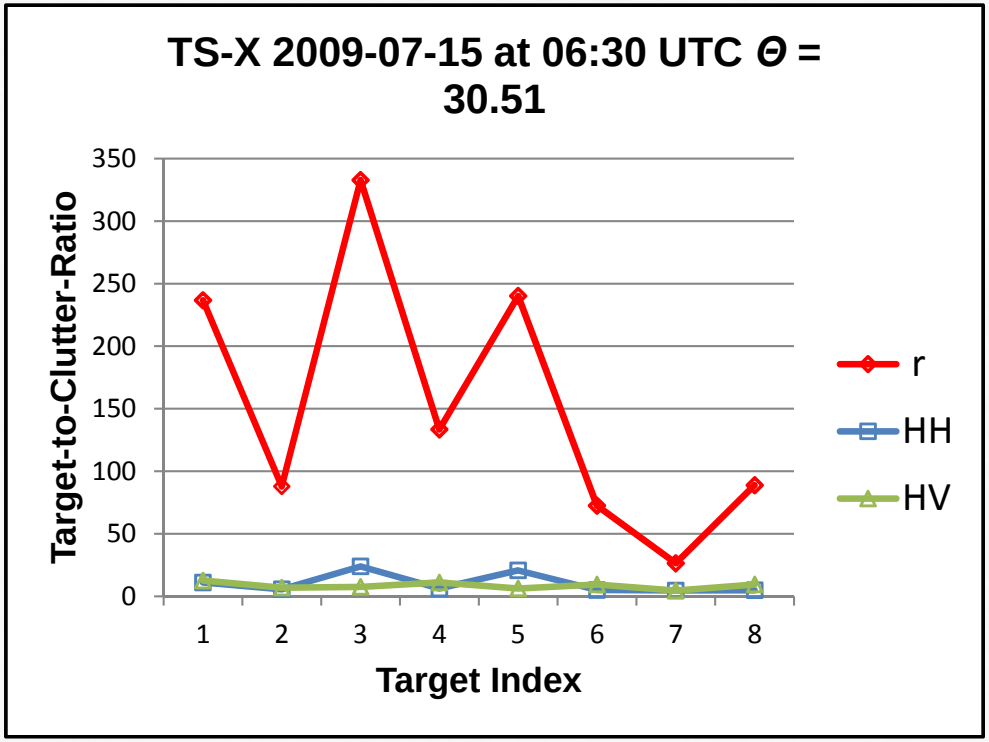


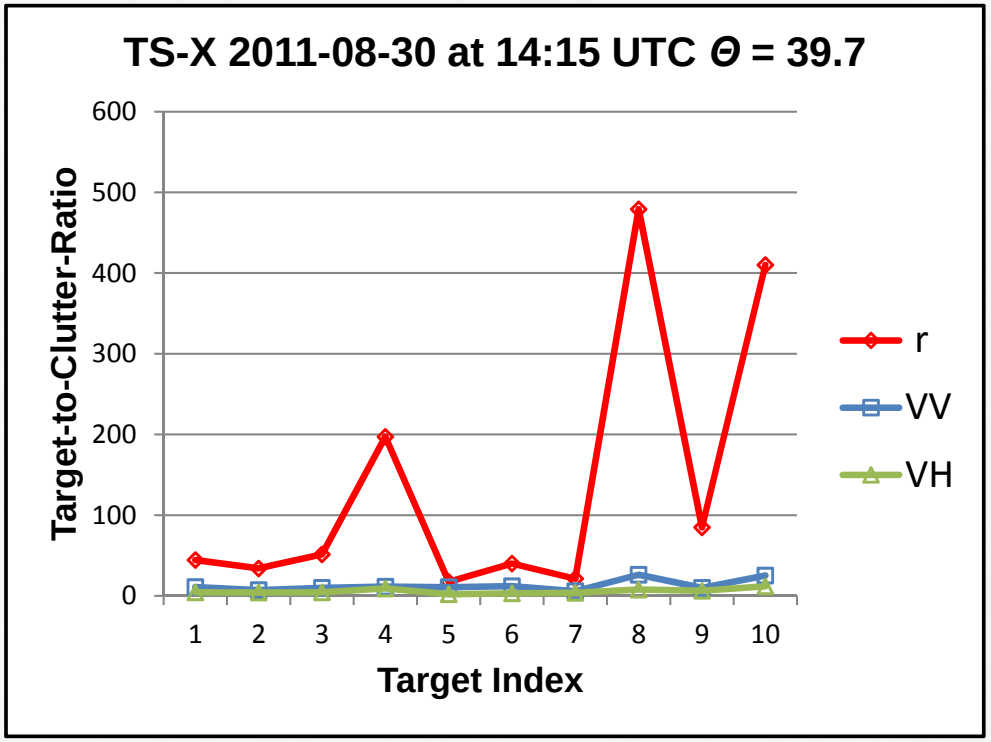






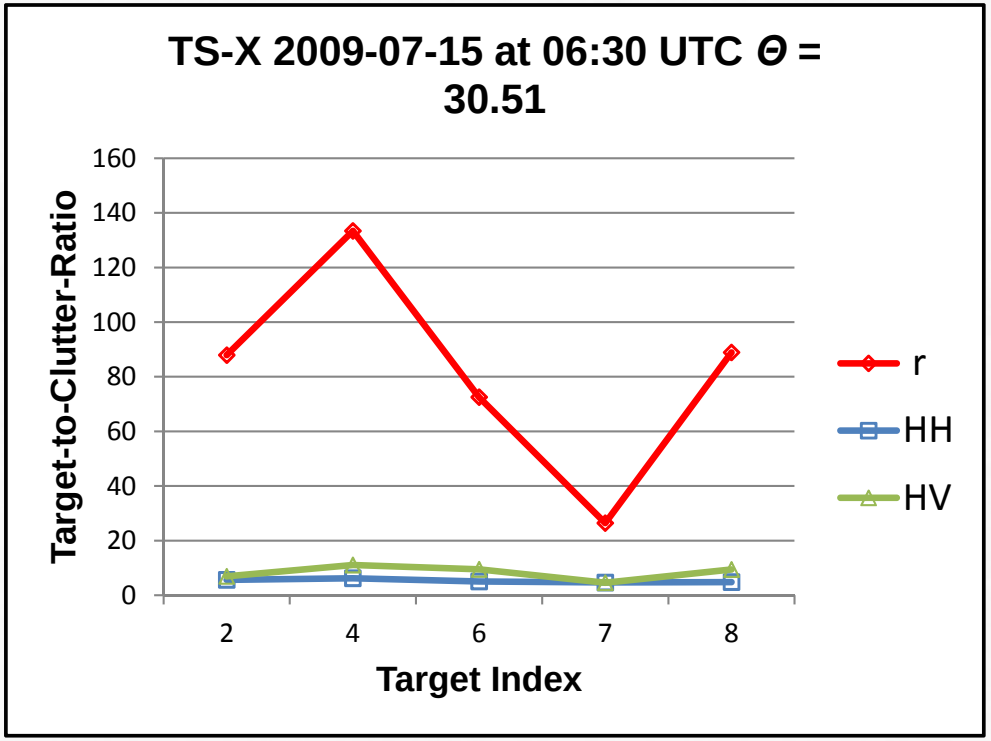
Target-to-Clutter-Ratio summary for the data set analyzed

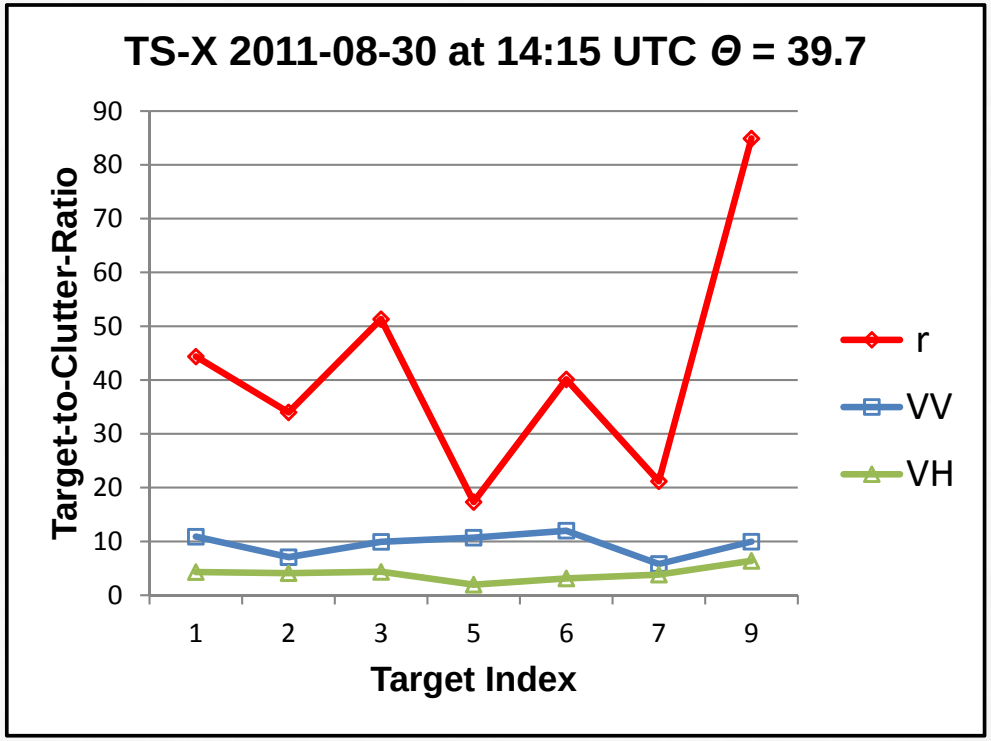




Only targets with valid AIS report have been considered (target size: 12m<*lenght*<332m)!

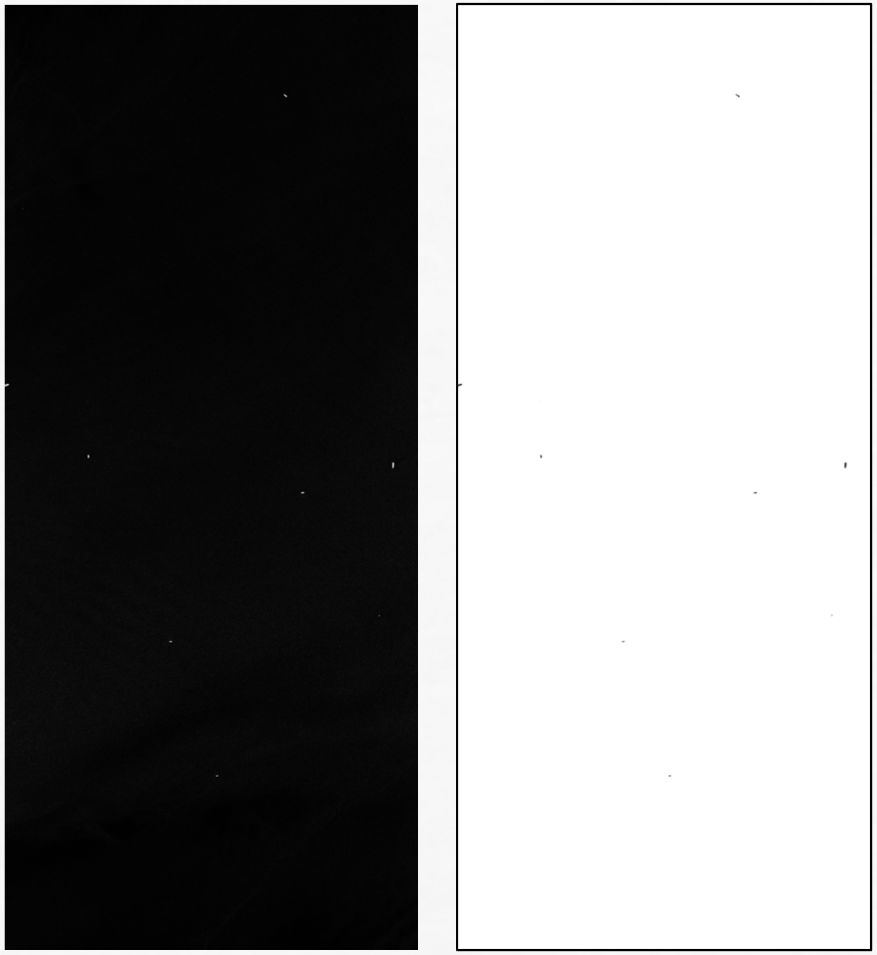
Target-to-Clutter-Ratio summary for the data set analyzed



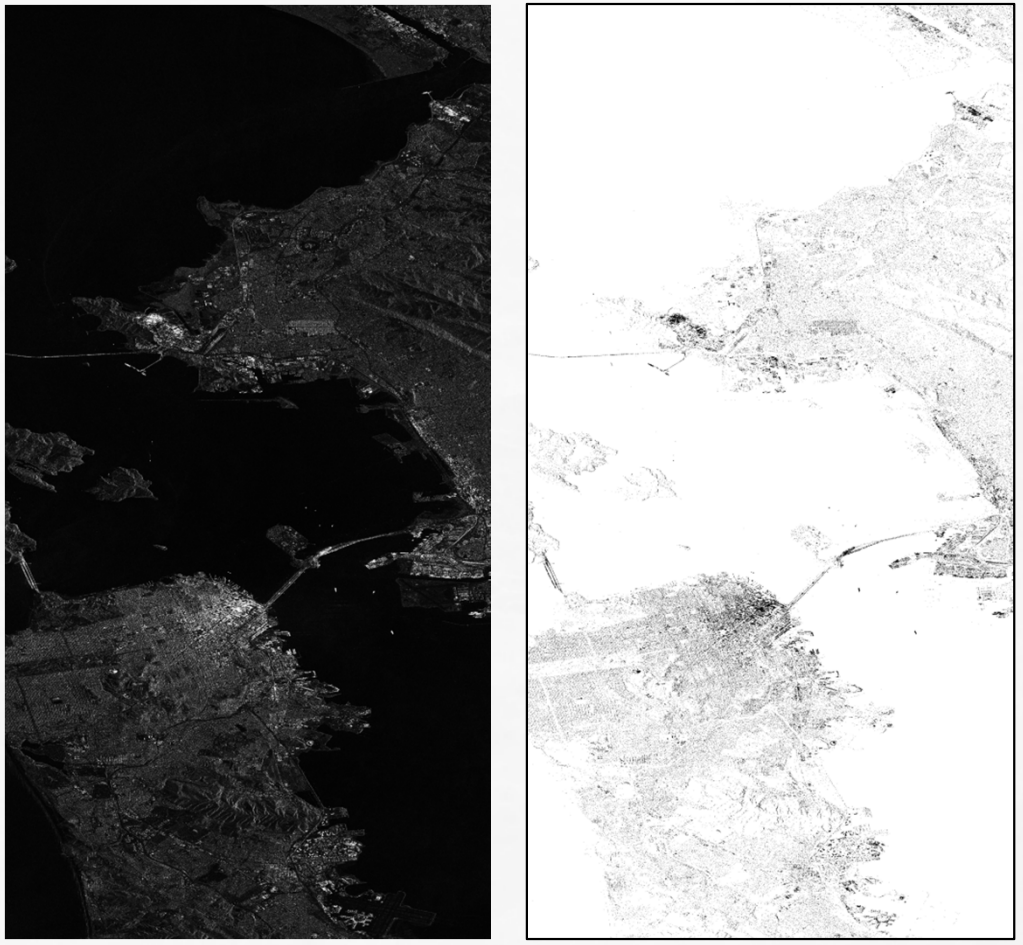


Charts for targets with measured TCR < 200

Results – Detection



[Left] *r* image processed with 3x3 moving window.
[Right] Logical true-false output.



[Left] *r* image processed with 3x3 moving window.
[Right] Logical true-false output.

Standard TS-X dual-pol data (10000 x 24000 pixels) processed in few minutes!

Results – Validation

TERRASAR-X DUAL-POLARIMETRIC DATA SET. [Ref]

ID	Data & time (UTC)	Location	Polarization	Inc.angle (°)	Wind speed (m/s)	Wind dir.
IMG-1	2009-07-11; 18:14	Gibraltar	HH-HV	34.73	2.7	SE
IMG-2	2011-08-30; 14:15	San Francisco	VV-VH	39.69	2.2	SE
IMG-3	2009-07-15; 06:29	Gibraltar	HH-HV	30.51	5.1	SW
IMG-4	2009-09-21; 18:06	Spain	VV-VH	20.00	5.5	SE
IMG-5	2012-03-29; 23:57	Gulf of Mexico	VV-VH	43.00	5.0	SE
IMG-6	2012-04-12; 16:49	Naples	HH-HV	28.16	3-5	SW
IMG-7	2011-10-06; 09:28	South Korea	VV-VH	39.68	10-12	NW

SUMMARY OF THE RESULTS OBTAINED BY PROCESSING THE SAR DATA. [Ref]

ID	Targets	Ground truth	Detected targets	False negatives	False positives
IMG-1	70	57	68	2	0
IMG-2	50	21	48	2	0
IMG-3	8	7	8	0	0
IMG-4	7	5	5	2	0
IMG-5	14	7	12	2	0
IMG-6	13	0	12	1	0
IMG-7	29	4	22	7	0

[Ref] D. Velotto, F. Nunziata, M. Migliaccio and S. Lehner, “Dual-polarimetric TerraSAR-X SAR data for target at sea observation”. *IEEE Geoscience and Remote Sensing Letters, In print*, DOI: 10.1109/LGRS.2012.2231048.

Conclusions

- Ocean clutter has been proved to follow the polarimetric symmetry at X-band in both cross-polarization combination (HH/HV and VV/VH).
- *r* is an effective and efficient measure of the departure from the reflection symmetry, acting as clutter suppression while enhancing targets at sea.
- *r* outperforms single polarization TCR independently of radar geometry and oceanic process (wind, waves, etc.)
- Target detection method proposed is fast with an overall detection performance of 97% (validated with ground truth data).
- Multi-frequency approach for target at sea detection.

Thanks for your attention!