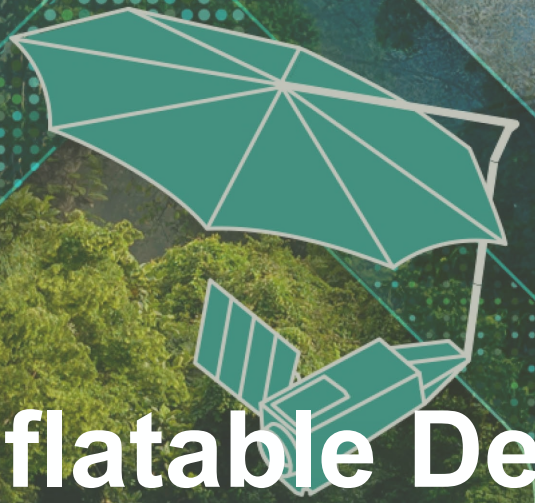

Automatic Refugee Inflatable Detection with Polarimetric SAR

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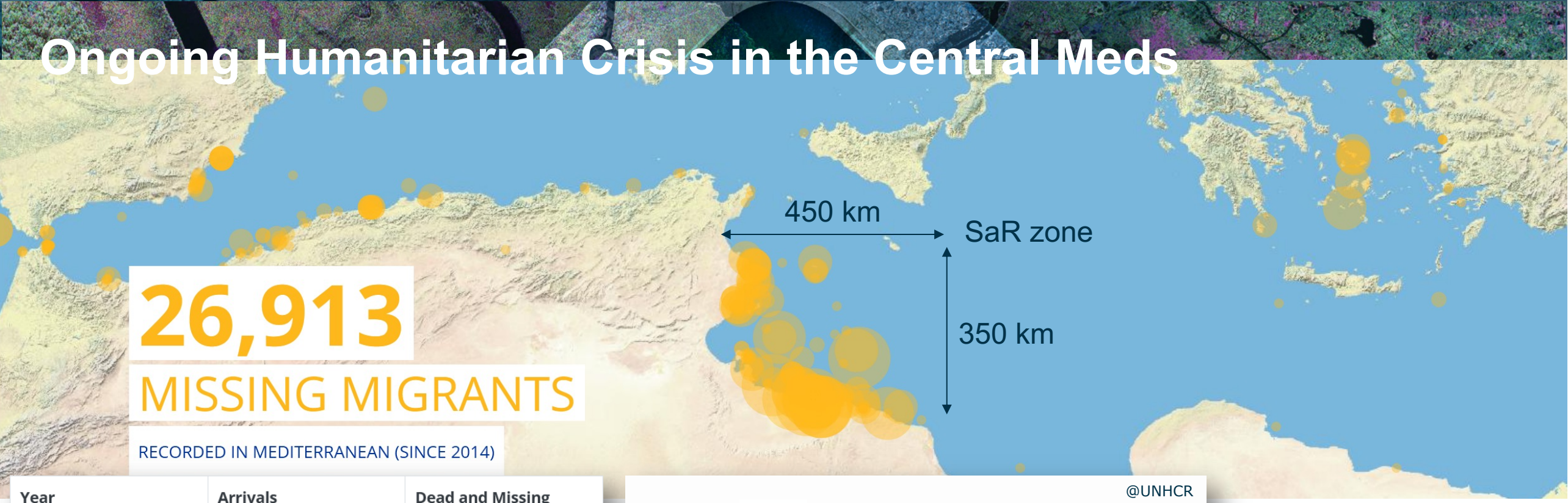
22/06/2023

Ongoing Humanitarian Crisis in the Central Meds



26,913

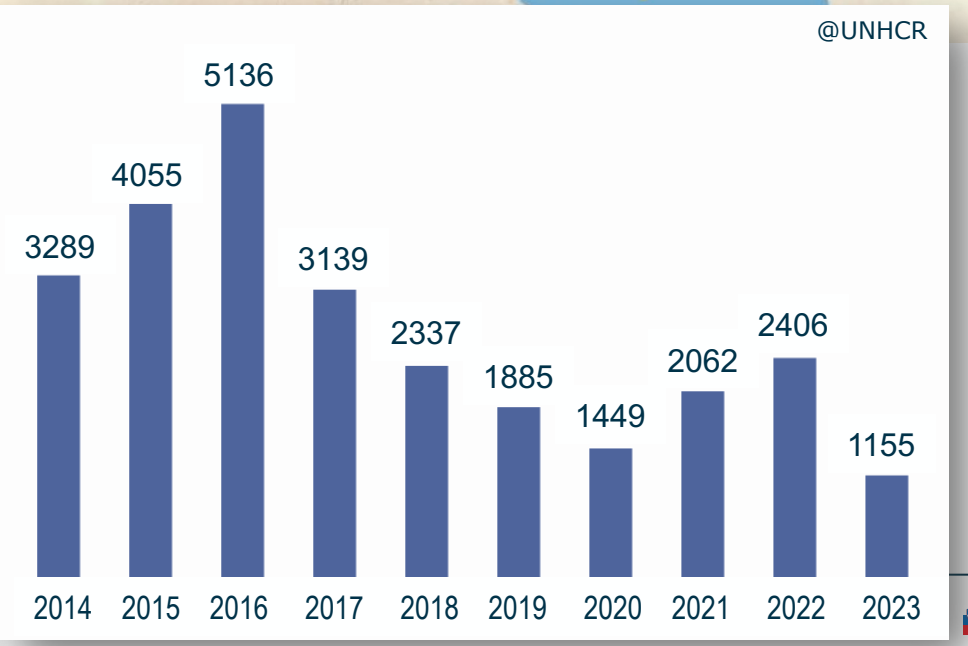
MISSING MIGRANTS

RECORDED IN MEDITERRANEAN (SINCE 2014)

Year	Arrivals	Dead and Missing
2023	72,585	1,246
2022	189,620	2,965
2021	151,417	3,188
2020	99,907	2,326
2019	128,663	2,087
2018	146,949	2,380
2017	187,499	3,140
2016	389,976	5,305

@IOM

@UNHCR



@IOM

last updated:
June 12th 2023

Vision

Automatic Refugee Inflatable Detection with Polarimetric SAR

I. Creation of a Martitime Refugee Disaster Charter

Recognition of the ongoing humanitarian disaster by supra-national bodies to secure fundings for satellite data

II. Collection of satellite data

Continuous acquisition of real-time high-resolution radar data

III. Automatic data analysis and dissemination

AVessel Detection System searches for refugee boats in distress; Detections are visualized via an interactive webmap to support search and rescue missions

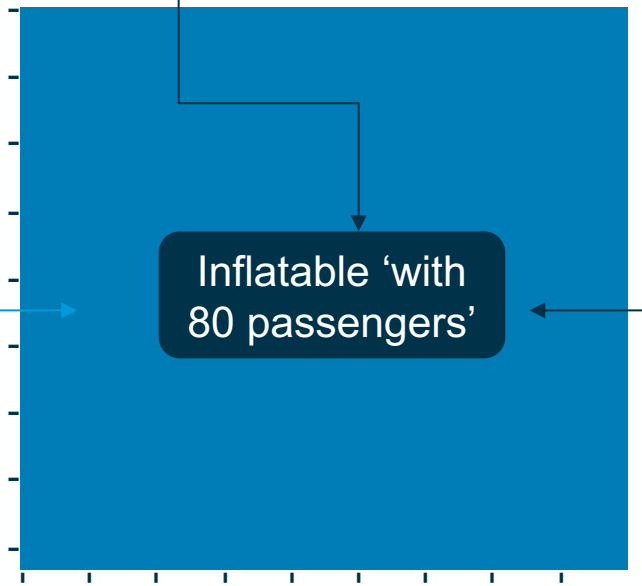
Icons by the Noun Project

Scope of our Research

Data Simulation Approach

Data collection campaign (03/2022 – 07/2022)
~50 TSX dual pol StripMap with different **polarizations, incidence angles and boat orientations**

Archive data with **different wave heights**
TSX dual-pol Stripmap in categories of different polarizations (HH VV, HV HH, VH VV) and incidence angles (low, medium, high)



How to **simulate 80 passengers**?
(experiments with a handheld radar sensor)

SAR test dataset with different polarizations and incidence angles

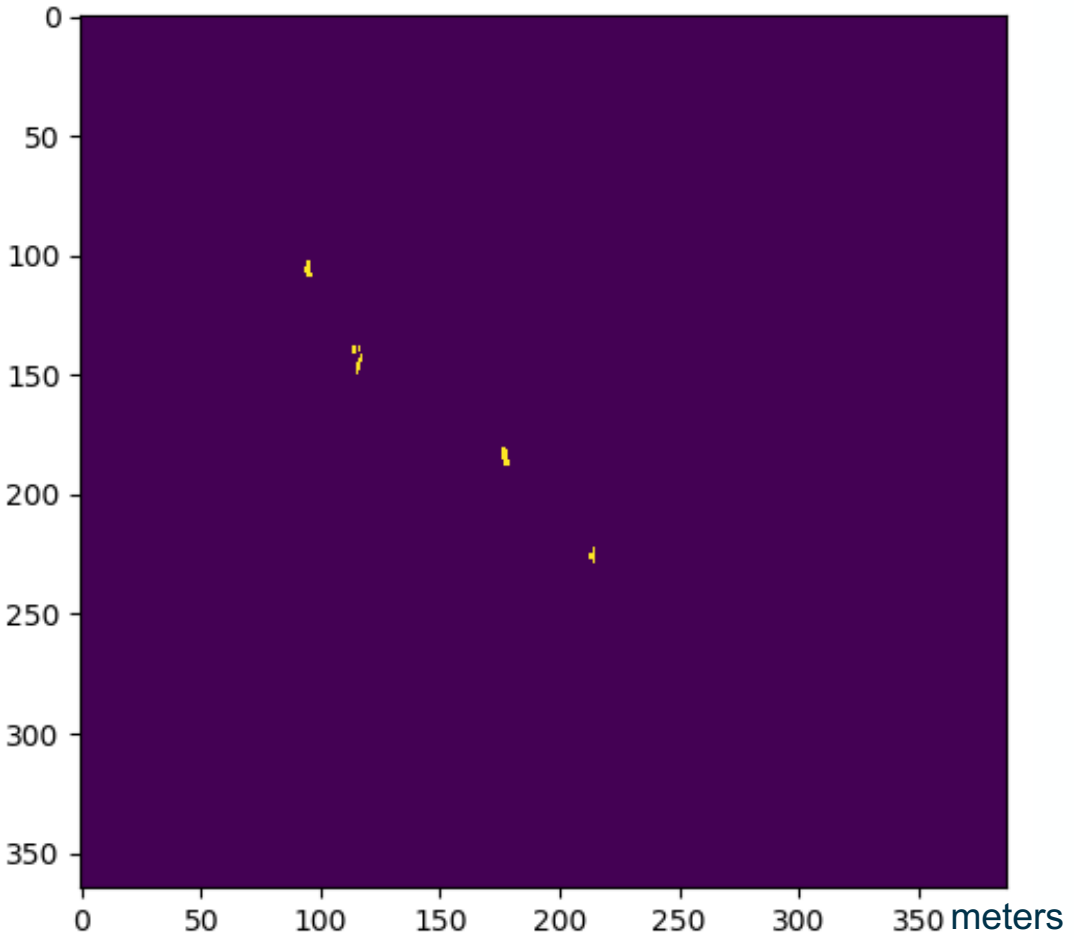
Data Simulation Approach

Polarization		HH VV			HV HH		VH VV	
Incidence Angle	Low	Low	Medium	High	Medium	High	Medium	High
Wave Direction	Cross	Up/Down	Up/Down	Up/Down	Up/Down	Up/Down	Up/Down	Up/Down
Wave Height (m)								
0.4–0.8 (BFT3)	✓	✓	✓	✓	✓	✓	✓	✓
0.8–1.5 (BFT4)	✓	✓	✓	✓	✓		✓	✓
1.5–2.5 (BFT5)		✓			✓	✓	✓	✓
2.5–3.5 (BFT6)			✓	✓				
3.5–4.5 (BFT7)						✓		
4.5–6.5 (BFT8)	✓							

TSX SAR archive data with

- different wave heights
- dual-pol channel combinations and
- incidence angles

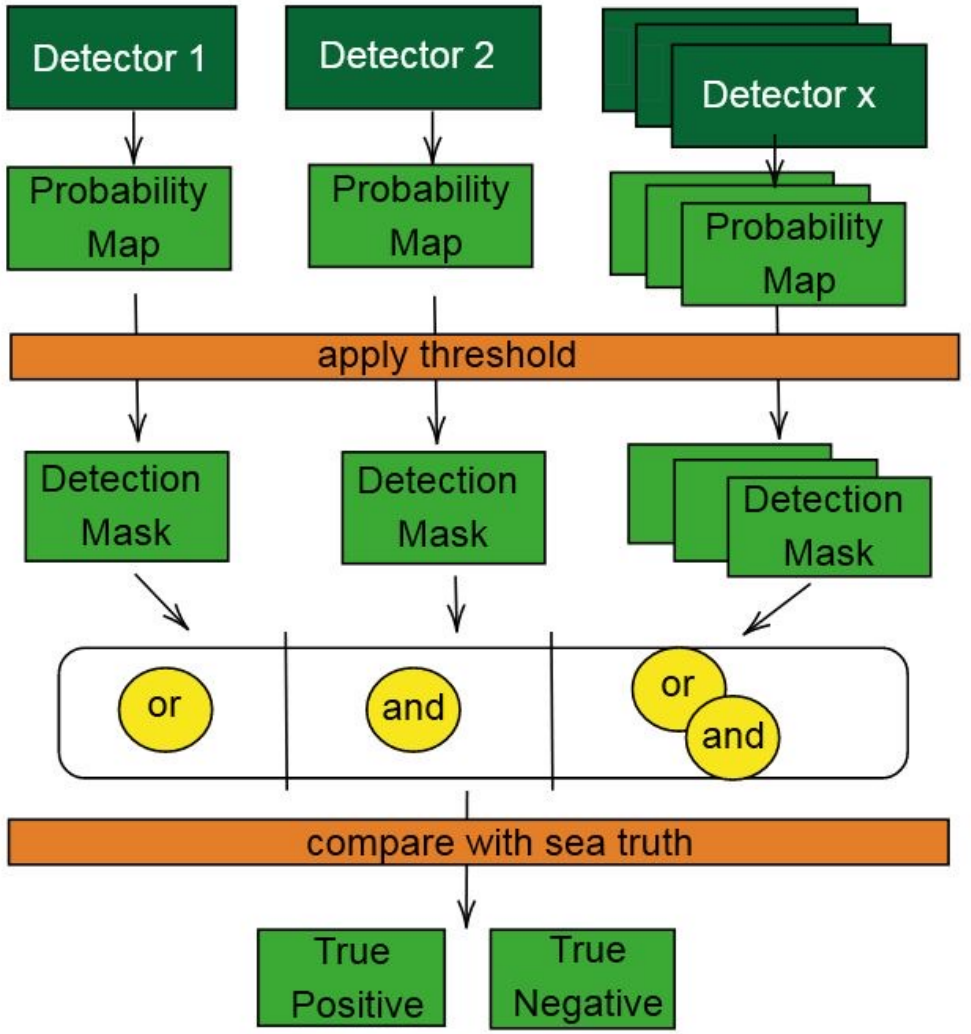
Data Simulation Example



Example of a ground truth map

- Yellow pixels: the positive true pixels of four different acquisitions from the rubber inflatable
- Purple pixels: represent the ocean surface

Detector Fusion

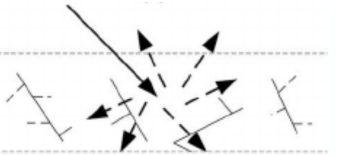


Dual-Pol Detector Development

Automatic Refugee Inflatable Detection with Polarimetric SAR

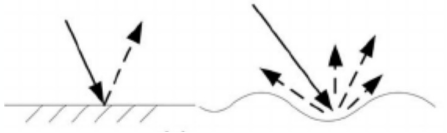
original iDPolRAD:
volume scattering detector

$$PolRatio1 : \frac{\langle |cross\text{-}pol|^2 \rangle_{test} - \langle |cross\text{-}pol|^2 \rangle_{train}}{\langle |co\text{-}pol|^2 \rangle_{train}} * \langle |cross\text{-}pol|^2 \rangle_{test}$$



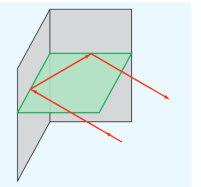
inverse iDPolRAD:
surface scattering detector

$$PolRatio2 : \frac{\langle |co\text{-}pol|^2 \rangle_{test} - \langle |co\text{-}pol|^2 \rangle_{train}}{\langle |cross\text{-}pol|^2 \rangle_{train}} * \langle |co\text{-}pol|^2 \rangle_{test}$$



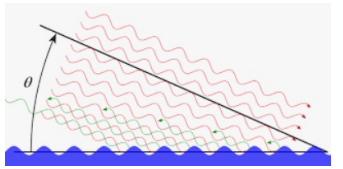
iDPolRAD with co-pol:
dihedral scattering detector

$$PolRatio3 : \frac{\langle |HH|^2 \rangle_{test} - \langle |HH|^2 \rangle_{train}}{\langle |VV|^2 \rangle_{train}} * \langle |HH|^2 \rangle_{test}$$



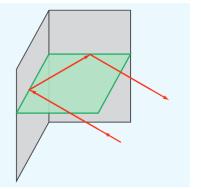
'inverse PolRato3':
Bragg scattering detector

$$PolRatio4 : \frac{\langle |VV|^2 \rangle_{test} - \langle |VV|^2 \rangle_{train}}{\langle |HH|^2 \rangle_{train}} * \langle |VV|^2 \rangle_{test}$$



T22 detector:
double bounce
(diplane or dihedral)

$$T_{22} = \frac{1}{2}\langle |S_{HH} - S_{VV}|^2 \rangle = \frac{1}{2}\langle |S_{HH}|^2 \rangle + \frac{1}{2}\langle |S_{VV}|^2 \rangle - \langle Re\{S_{HH}S_{VV}^*\} \rangle$$



Dual-Pol Detector Testing

Polarization		HH VV		HV HH		VH VV		
Incidence Angle	Low	Medium	High	Medium	High	Medium	High	avg
PMF	0.787	0.888	0.976	0.996	0.906	0.945	0.995	**0.928**
PWF	0.779	0.882	0.975	0.997	0.912	0.941	0.995	**0.926**
PNF	0.670	0.822	0.956	0.994	0.881	0.871	0.986	**0.883**
PolEntropy	0.834	0.813	0.534	0.046	0.279	0.559	0.373	**0.491**
PolRatio1/3	0.529	0.768	0.947	0.913	0.689	0.714	0.939	**0.786**
PolRatio2/4	0.554	0.599	0.849	0.983	0.900	0.768	0.936	**0.799**
SubCorr_HH	0.565	0.688	0.744	0.900	0.608			**0.701**
SubCorr_VV	0.528	0.557	0.684			0.604	0.481	**0.571**
SubCorr_cross				0.785	0.531	0.483	0.537	**0.584**
CACFAR_HH	0.600	0.775	0.975	0.980	0.943			**0.854**
CACFAR_VV	0.628	0.695	0.915			0.798	0.946	**0.797**
CACFAR_cross				0.972	0.701	0.766	0.909	**0.837**
PolSym				0.999	0.920	0.895	0.991	**0.951**
avg	**0.647**	**0.749**	**0.856**	**0.869**	**0.752**	**0.759**	**0.826**	

Area under Curve (AUC) from Receiver Operating Characteristics (ROC) curves

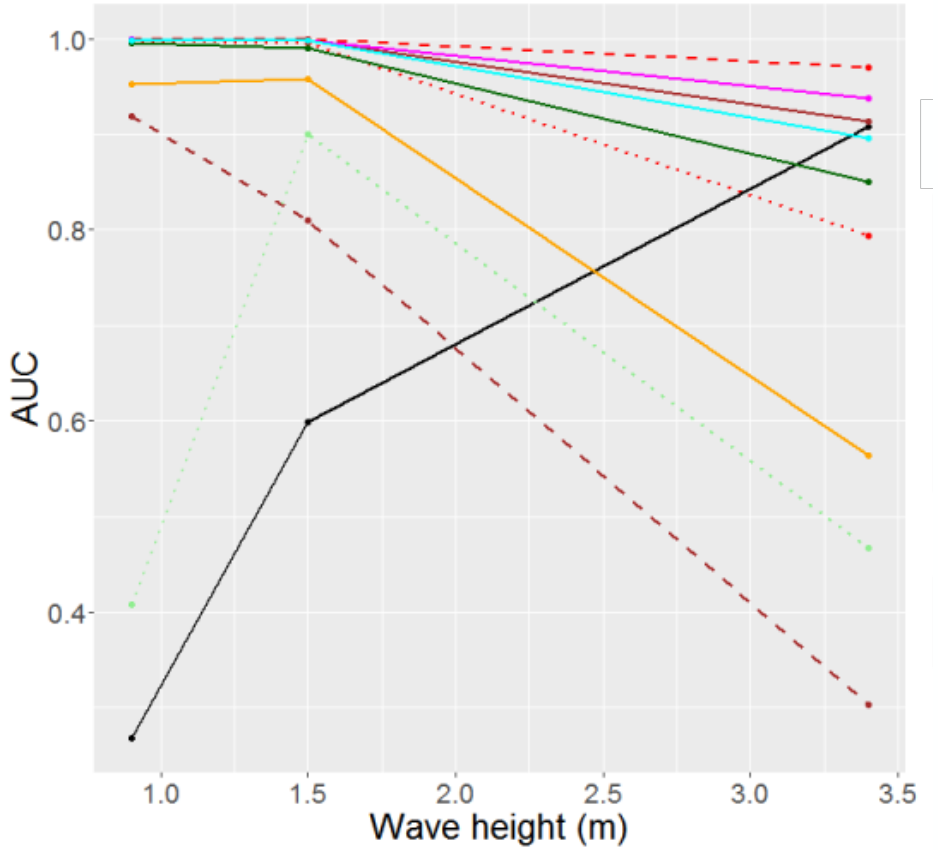
Area under curve (AUC) for detectors under test with different sensor parameters

PMF = Pol. Match Filter
PWF = Pol. Whitening Filter
PNF = Polarimetric Notch Filter
PolEntropy = Pol. Entropy detector
PolRatio1 = iDPolRAD
PolRatio2 = inverse iDPolRAD
PolRatio3 = HH over VV
PolRatio4 = VV over HH
SubCorr = Sub-look correlation
CACFAR = Const. False Alarm Rate
PolSym = Symmetry detector

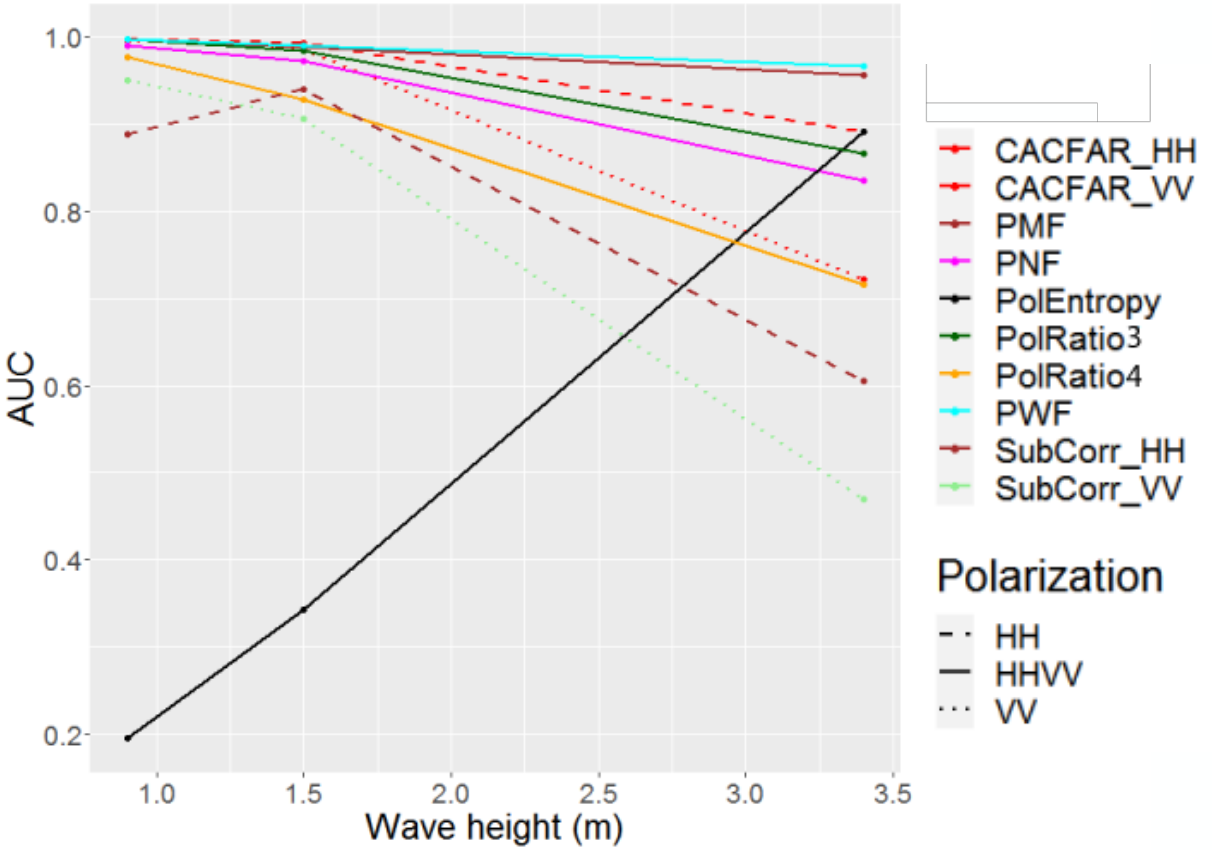
Detector Performance at Difference Sea States: Entropy

Polarization: co-pol

Incidence angles: high



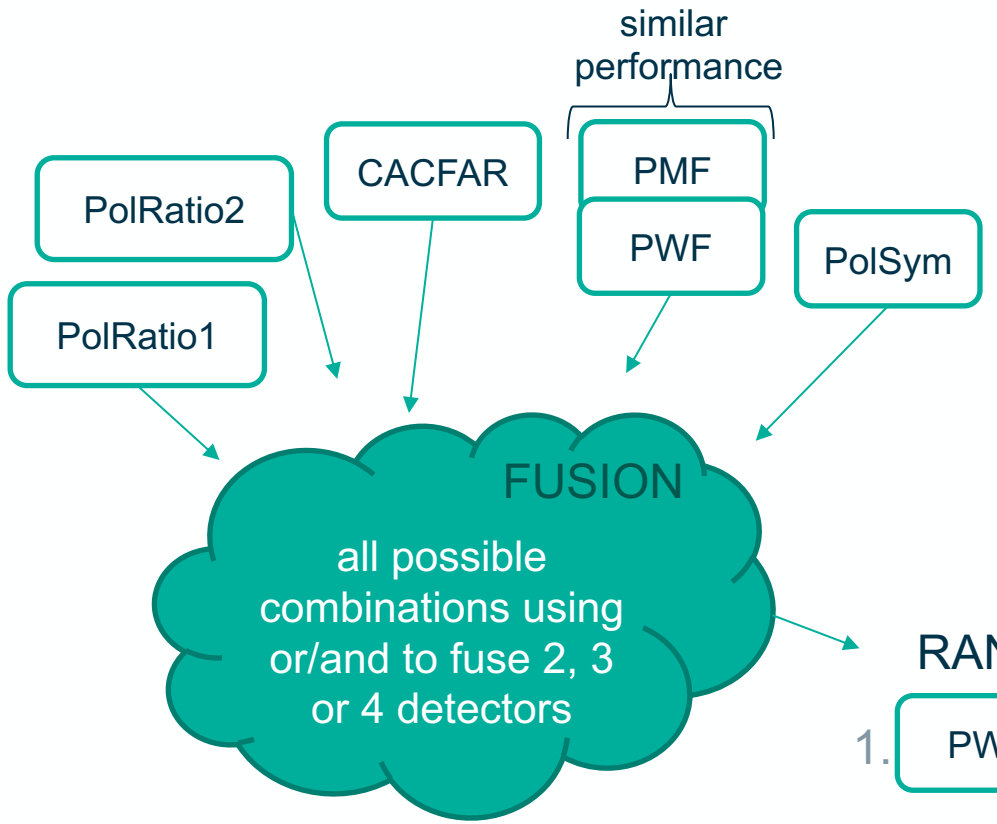
Boat orientation: 45° to the LoS



Boat orientation: 90° to the LoS

Dual-Pol Detector Fusion

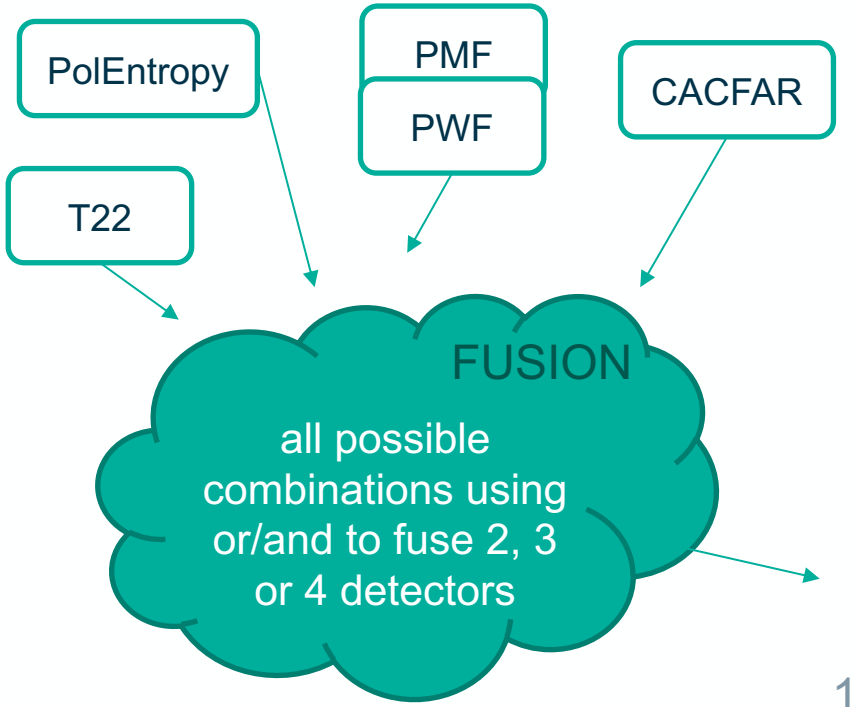
Automatic Refugee Inflatable Detection with Polarimetric SAR



RANKING

1. PWF
2. PolSym
3. PolRatio_OR

DUAL CROSS-POL (HV HH, VH VV)



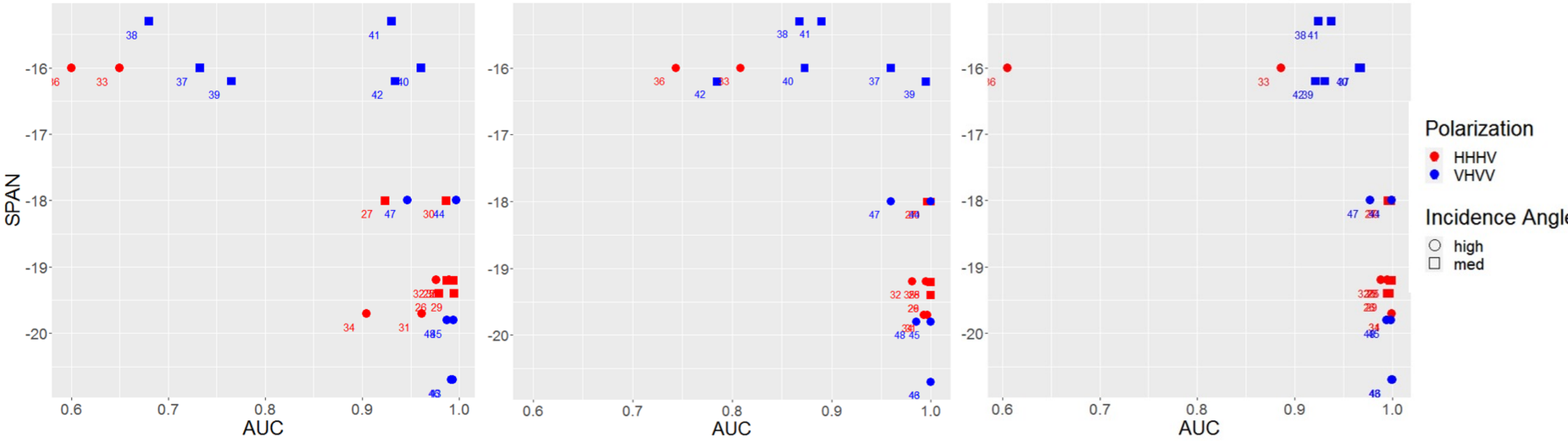
RANKING

1. HT22_AND
2. PWF

DUAL CO-POL (HH VV)

Performance Comparison: Best Dual Cross-Pol Detectors

Automatic Refugee Inflatable Detection with Polarimetric SAR

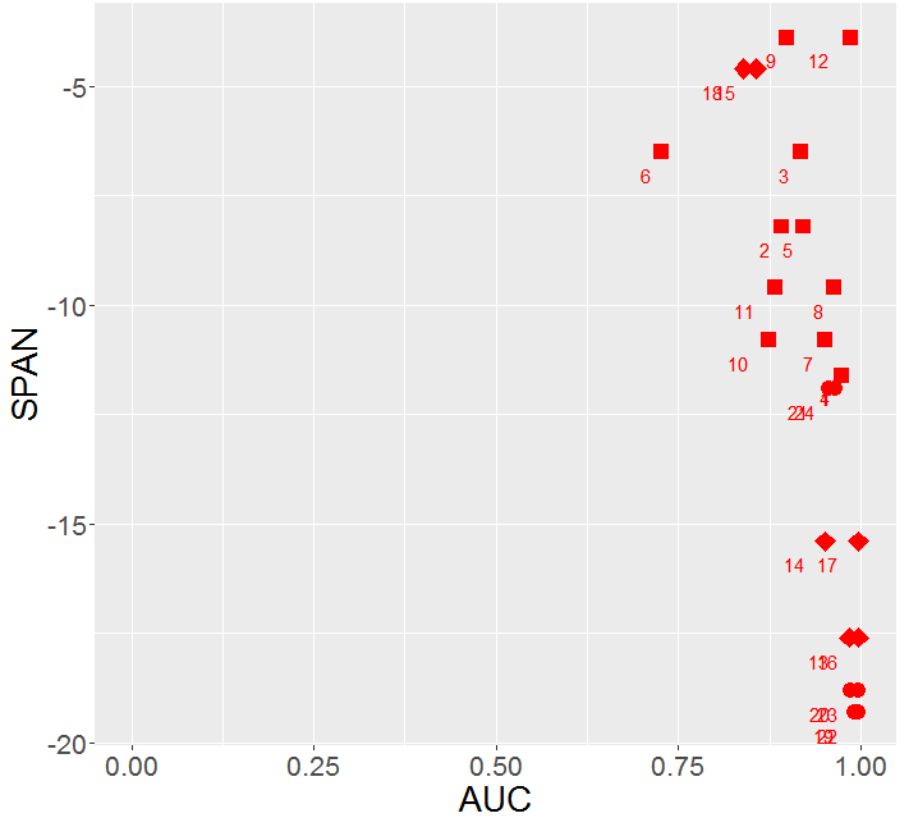


PolRatio_OR
(Fusion of iDpolRAD and inverse iDPolRAD)

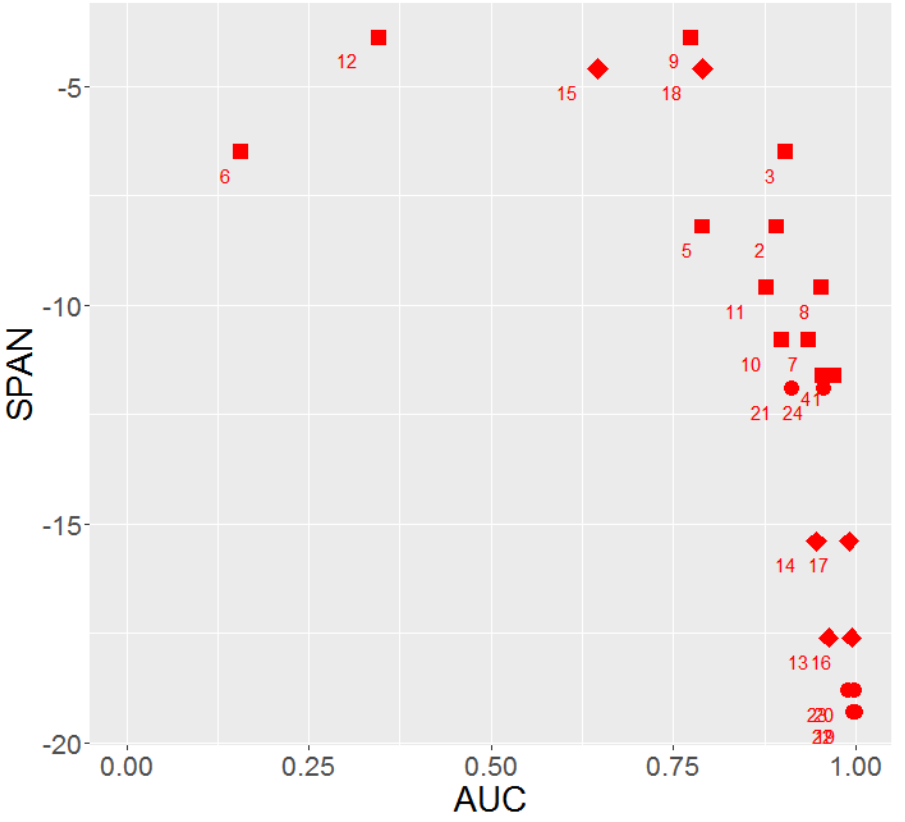
Symmetry Detector

PWF

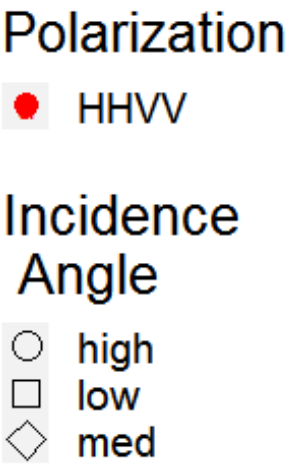
Performance Comparison: Best Dual Co-Pol Detectors



HT22_AND
(Fusion of entropy detector and T22 detector)



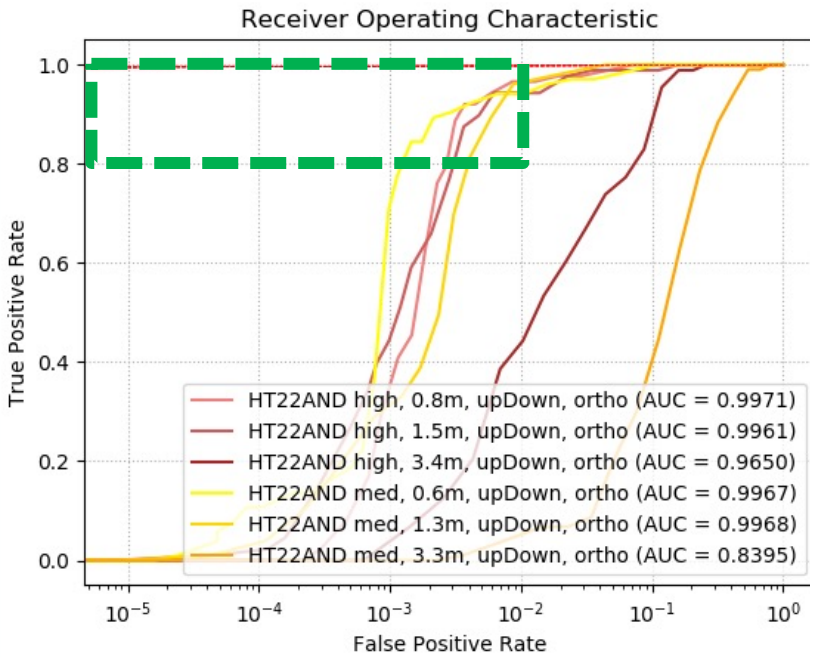
PWF



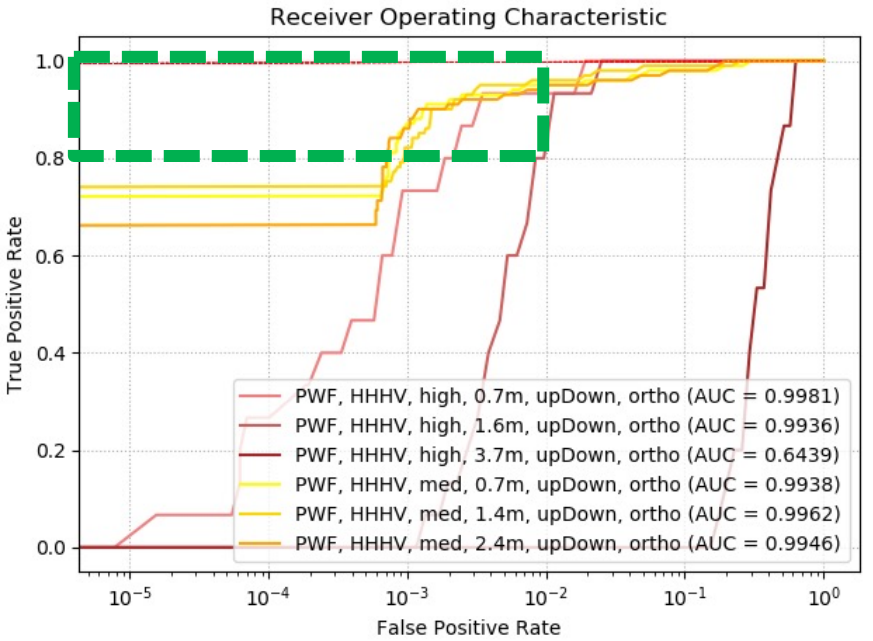
Detector Performance at Different Sea States: Polarization

Automatic Refugee Inflatable Detection with Polarimetric SAR

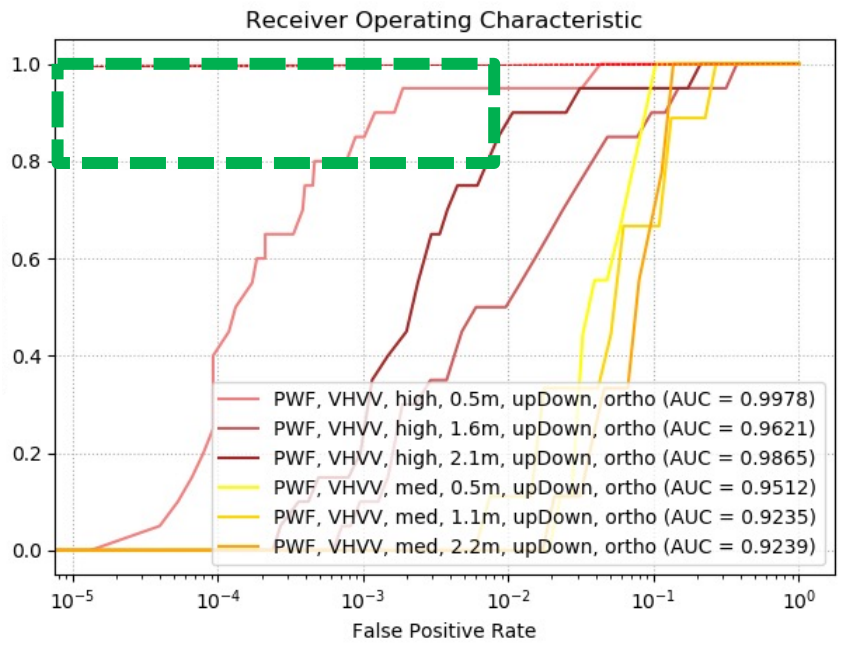
HH VV: HT22_AND



HV HH: PWF



VH VV: PWF



Max. wave height with:
P(d) > 80%
P(fa) < 1%

1.5 m, 1.3 m

2.4 m,1.6 m

0.5 m

Recommendations

- Preferred incidence angle: **medium or high**, not low
- Preferred vessel orientation: no significant impact
- Best detector performance at P(d) = 90%:

P(d): Probability of detection

P(fa): Probability of false alarm

Polarization	Best Detector	P(fa) (%)	wave height (m)
HV HH	**PWF***	0.11	2.4
HH VV	**HT22_AND****	0.59	1.5
VH VV	PWF*	1.07	2.1

* The PMF (Novak et al., 1989) and the PNF (Marino et al. 2010) show similar results

** Fusion of entropy detector (H) with the T22 double bounce detector

Future work:

- The introduction of **blob analyses and size filtering** of the detection results
- The implementation of an **a-priori wind field estimation** to better interpret the detection results
- Collect quad-pol high-res (e.g. Stripmap mode) multi-band SAR data of a fully occupied rubber inflatable

Automatic Refugee Inflatable Detection with Polarimetric SAR

Thank you for listening!

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22/06/2023