SAR Image Simulation and Automatic Target Recognition

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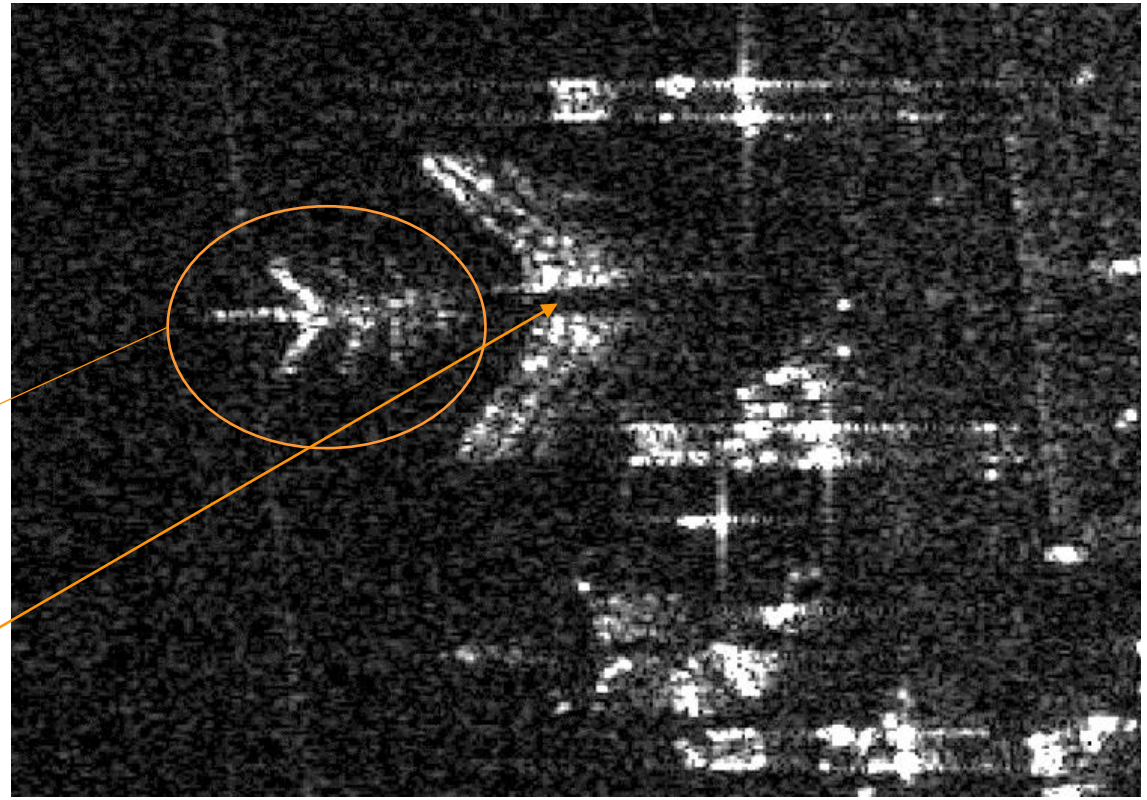
your information gateway

Interpretation of and Automatic Target Recognition in SAR imagery is neither simple nor intuitive

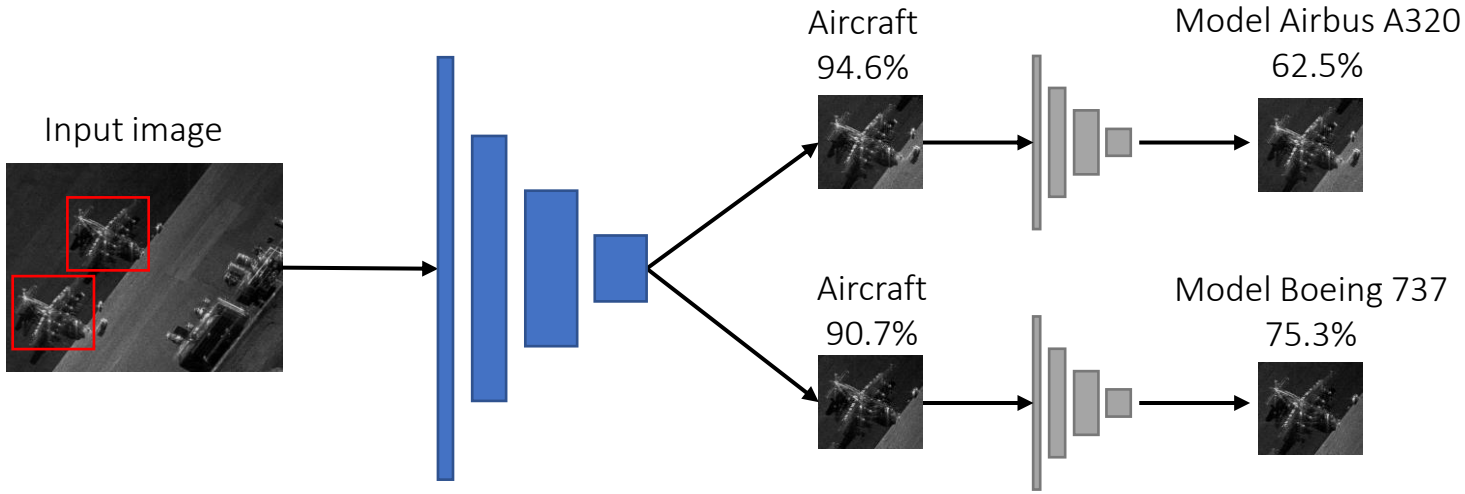


Full resolution COSMO-Skymed spotlight image of an airplane in an airport area

ATR: detection and classification

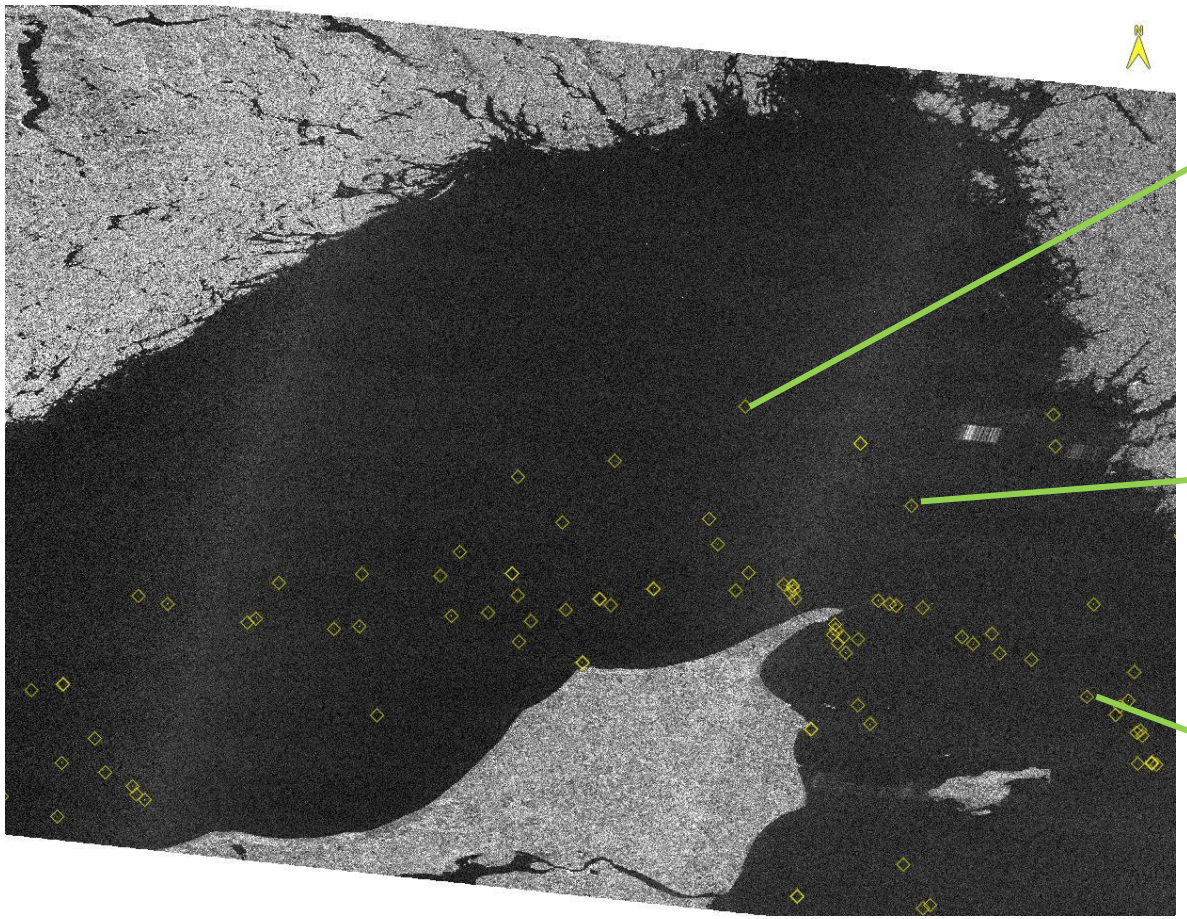
Detection expected output: a bounding box containing each and every object of a specific type (e.g. aircraft) inside the current image.

Classification expected output: for each bounding box a label identifying the class inside the specific type.

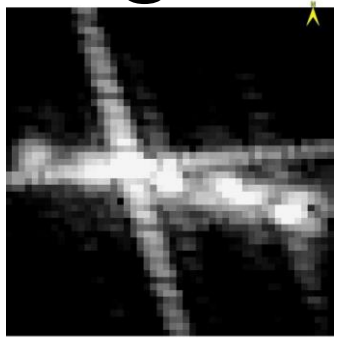


AIS-assisted generation of training datasets

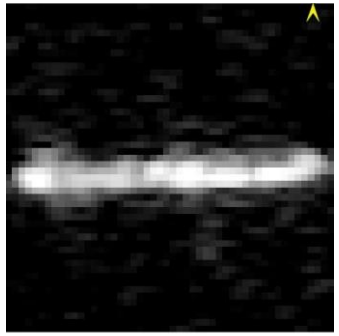
Sentinel-1



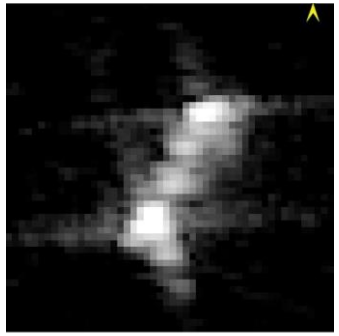
Cargo



Passenger



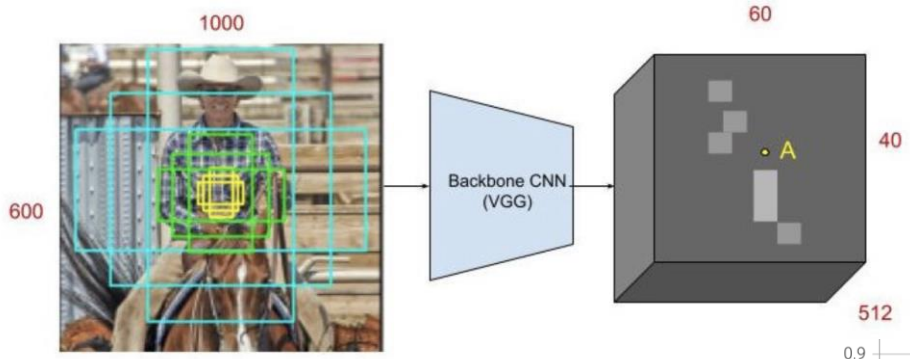
Tanker



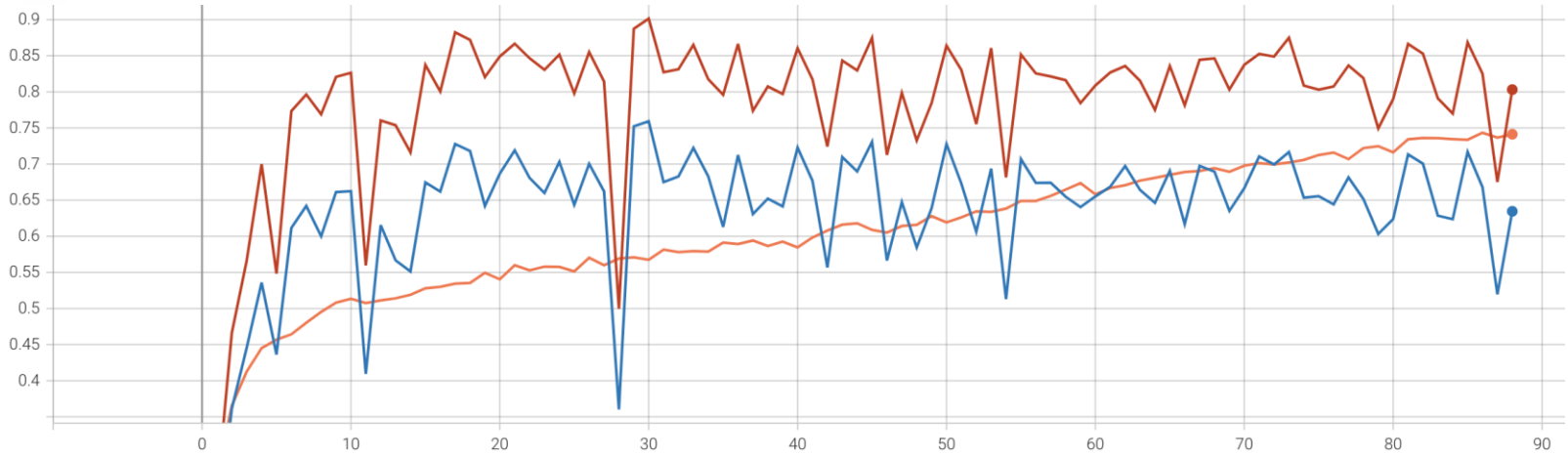
-> Deep Learning training based on automatically extracted datasets

Selected architecture for detection:

Faster R-CNN ResNet50 V1



Best validation mAP @0.50 IoU: 0.90



Training

Validation whole dataset

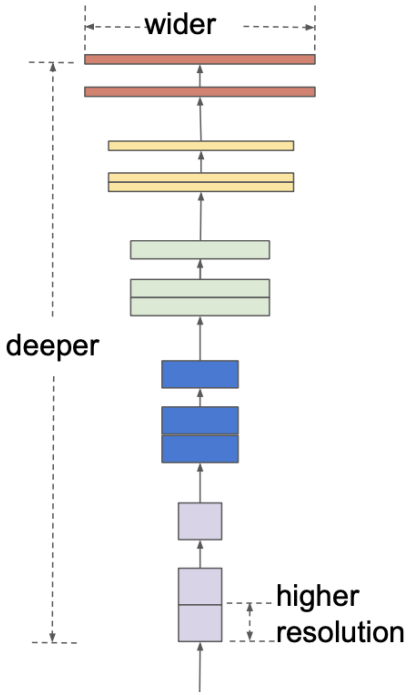
Validation Offshore

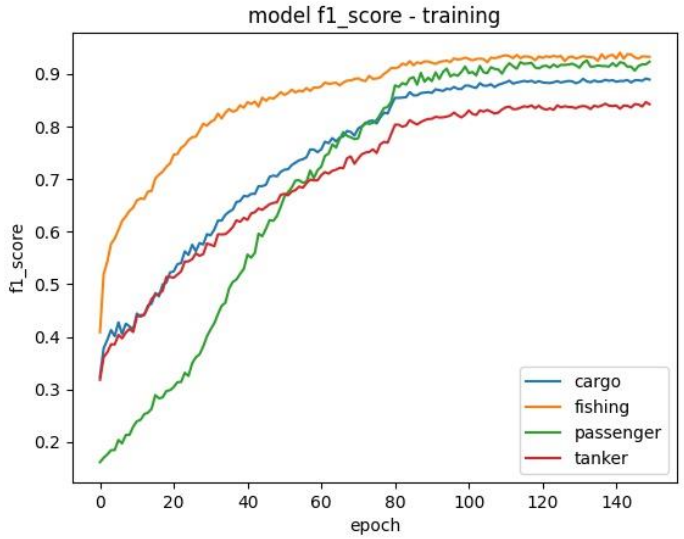
Comparison with State of the Art

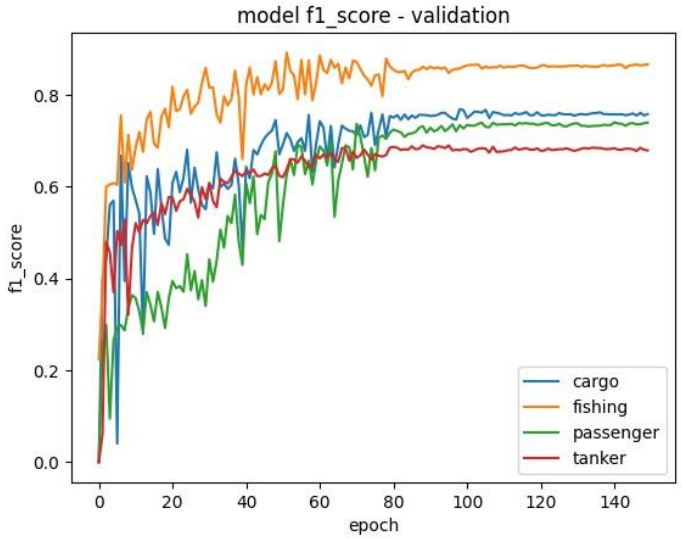
No.	Method	P_d	P_f	P_m	Recall	Precision	mAP	F1
1	Faster R-CNN without FPN [75]	87.49%	18.45%	12.51%	87.49%	81.55%	84.62%	0.84
2	Faster R-CNN [100]	91.91%	17.18%	8.09%	91.91%	82.82%	89.99%	0.87
3	OHEM Faster R-CNN [101]	88.83%	10.75%	11.17%	88.83%	89.25%	86.84%	0.89
4	CARAFE Faster R-CNN [102]	91.84%	16.74%	8.16%	91.84%	83.26%	89.78%	0.87
5	SA Faster R-CNN [103]	92.78%	17.10%	7.22%	92.78%	82.90%	90.89%	0.88
6	SE Faster R-CNN [104]	92.24%	17.28%	7.76%	92.24%	82.72%	90.22%	0.87
7	CBAM Faster R-CNN [105]	92.64%	18.58%	7.36%	92.64%	81.42%	90.50%	0.87
8	PANET [106]	91.51%	18.03%	8.49%	91.51%	81.97%	89.25%	0.86
9	Cascade R-CNN [78]	89.43%	12.10%	10.57%	89.43%	87.90%	88.02%	0.89
10	OHEM Cascade R-CNN [101]	84.68%	5.52%	15.32%	84.68%	94.48%	83.51%	0.89
11	CARAFE Cascade R-CNN [102]	90.50%	10.52%	9.50%	90.50%	89.48%	88.99%	0.90
12	SA Cascade R-CNN [103]	88.49%	11.68%	11.51%	88.49%	88.32%	86.92%	0.88
13	SE Cascade R-CNN [104]	89.97%	12.66%	10.03%	89.97%	87.34%	88.48%	0.89
14	CBAM Cascade R-CNN [105]	89.83%	11.93%	10.17%	89.83%	88.07%	88.12%	0.90
15	Libra R-CNN [107]	92.04%	18.48%	7.96%	92.04%	81.52%	90.09%	0.86
16	Double-Head R-CNN [108]	93.18%	17.67%	6.82%	93.18%	82.33%	91.34%	0.87
17	Grid R-CNN [109]	90.77%	13.24%	9.23%	90.77%	86.76%	88.43%	0.89
18	DCN [110]	91.64%	17.82%	8.36%	91.64%	82.18%	89.45%	0.87
19	EfficientDet [111]	83.88%	24.00%	16.12%	83.88%	76.00%	80.37%	0.80
20	Guided Anchoring [112]	87.83%	9.88%	12.17%	87.83%	90.12%	86.15%	0.89
21	HR-SDNet [6]	89.90%	12.50%	10.10%	89.90%	87.50%	88.37%	0.89
22	SSD-300 [76]	41.00%	11.03%	59.00%	41.00%	88.97%	37.69%	0.56
23	SSD-512 [76]	58.33%	6.24%	41.67%	58.33%	93.76%	56.73%	0.72
24	YOLOv3 [113]	37.98%	4.39%	65.02%	34.98%	95.61%	33.98%	0.51
25	RetinaNet [77]	77.66%	4.68%	22.34%	77.66%	95.32%	76.15%	0.86
26	GHM [114]	88.43%	11.16%	11.57%	88.43%	88.84%	86.20%	0.89
27	FCOS [115]	74.98%	5.80%	25.02%	74.98%	94.20%	73.59%	0.84
28	ATSS [116]	42.34%	7.59%	57.66%	42.34%	92.41%	40.95%	0.58
29	FreeAnchor [117]	91.91%	23.15%	8.09%	91.91%	76.85%	88.67%	0.84
30	FoveaBox [118]	75.99%	4.14%	24.01%	75.99%	95.86%	75.01%	0.85

Selected architecture for classification:

EfficientNet





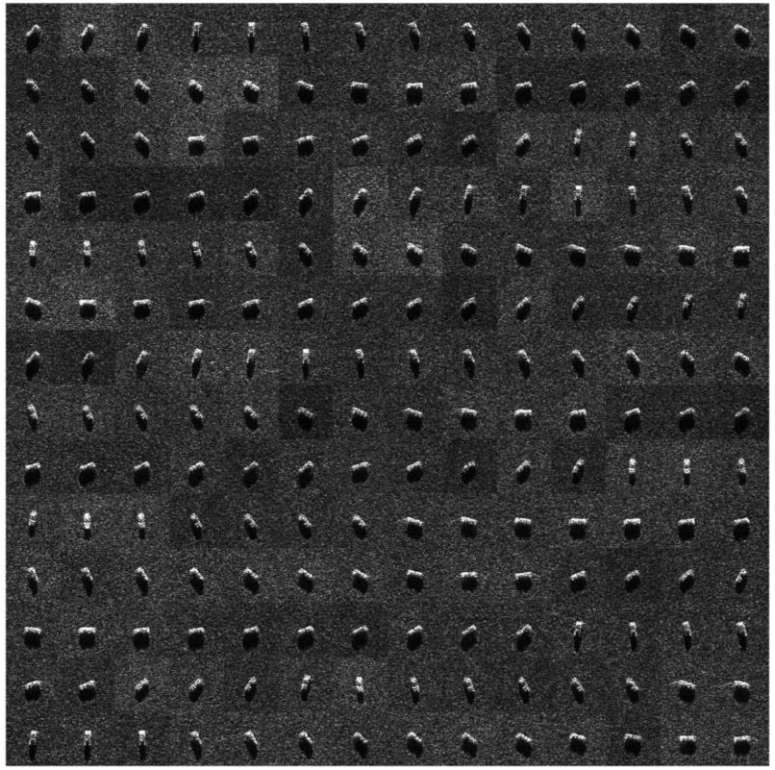


Best val F1-score @ epoch 137: 77.83%

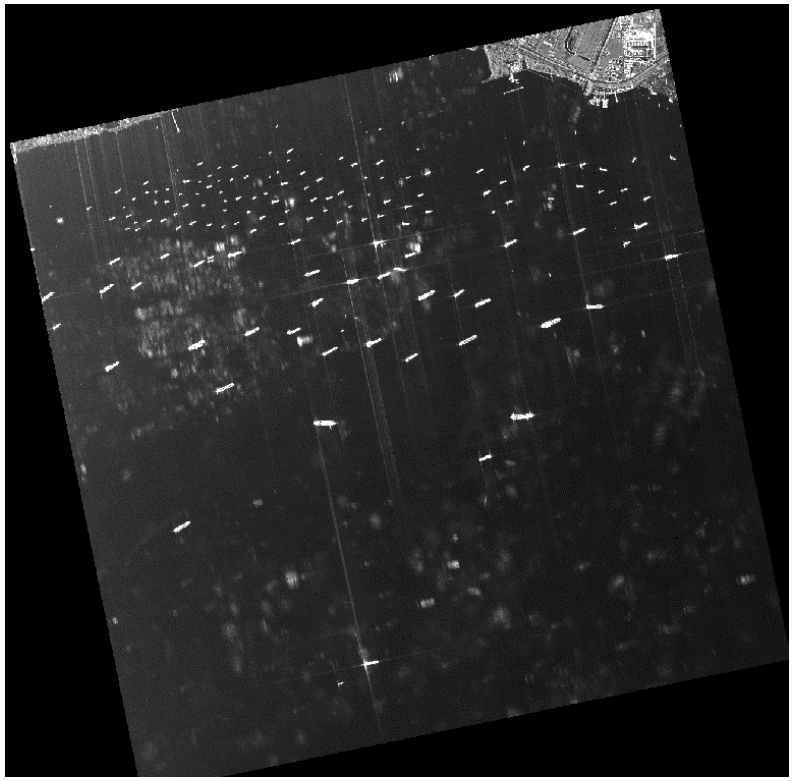
Comparison with State of the Art

Method	OpenSARShip				
	Recall (%)	Precision (%)	F1 (%)	LR+	*Accuracy* (%)
LeNet-5 [87]	65.15±1.12	60.54±2.47	62.73±1.52	5.37±1.20	65.74±1.50
AlexNet [81]	68.51±3.04	65.52±1.23	66.94±1.51	6.71±1.15	70.22±0.68
VGG-11 [83]	73.21±0.96	68.64±1.49	70.85±1.07	7.29±1.11	73.42±0.75
VGG-13 [83]	72.59±1.29	67.24±1.75	69.79±0.92	6.43±1.08	73.03±0.86
VGG-16 [83]	68.61±5.33	64.63±2.52	66.53±3.77	6.89±1.23	70.05±1.35
VGG-19 [83]	60.03±5.18	59.85±5.27	59.89±4.89	7.20±2.54	66.05±1.52
GoogLeNet [118]	69.73±2.70	68.80±1.81	69.21±1.19	7.44±1.09	73.80±1.32
ResNet-18 [90]	73.76±1.61	69.40±1.92	71.49±1.04	7.71±1.86	74.64±0.68
ResNet-34 [90]	71.43±2.72	68.11±1.73	69.69±1.47	7.07±1.13	73.40±1.09
ResNet-50 [90]	71.67±1.71	66.79±1.27	69.13±1.04	6.30±0.73	72.82±0.75
ResNet-101 [90]	70.51±2.33	67.21±2.86	68.79±2.26	7.68±1.88	70.85±0.58
ResNet-152 [90]	68.88±2.01	63.74±1.70	66.18±0.95	5.75±1.05	69.02±0.70
ResNext-50-32x4d [91]	70.30±2.14	66.04±2.15	68.06±1.19	6.42±1.62	71.65±0.67
ResNext-101-32x8d [91]	70.78±2.77	67.05±1.93	68.81±1.21	6.78±1.86	72.61±0.93
Wide-ResNet-50 [91]	73.45±1.96	67.64±1.95	70.40±1.26	6.67±1.45	73.28±1.17
Wide-ResNet-101 [91]	72.12±2.77	67.37±1.46	69.62±1.27	6.83±1.61	73.04±0.73
DenseNet-121 [109]	72.55±3.88	69.56±2.17	70.93±1.60	7.77±1.99	74.65±0.68
DenseNet-161 [109]	72.54±3.39	67.77±1.46	70.02±1.51	6.82±1.23	73.39±0.79
DenseNet-169 [109]	71.40±1.80	68.83±1.50	70.07±1.00	7.34±1.05	74.31±0.76
DenseNet-201 [109]	72.07±3.33	68.29±1.98	70.07±1.73	7.69±2.16	72.96±0.66
MobileNet-v1 [110]	66.30±2.87	63.49±2.40	64.83±2.03	5.85±1.47	69.91±1.08
MobileNet-v2 [111]	66.01±4.05	61.80±2.55	63.82±3.15	6.18±0.94	65.83±0.81
MobileNetv3-Large [112]	65.12±2.53	60.75±1.72	62.84±1.73	5.48±0.94	66.13±0.92
MobileNetv3-Small [112]	67.23±1.59	61.85±1.69	64.42±1.41	5.52±0.70	66.71±0.87
SqueezeNet-v1.0 [113]	71.47±1.31	66.73±1.70	69.01±1.28	6.61±1.03	72.15±1.25
SqueezeNet-v1.1 [113]	67.42±4.67	65.67±1.87	66.45±2.61	7.39±2.44	70.89±1.11
Inception-v3 [114]	67.13±1.41	63.03±1.63	65.00±1.20	6.14±0.89	65.99±1.08
Inception-v4 [115]	69.26±3.16	67.43±2.39	68.28±1.97	7.53±1.64	72.44±0.70
Xception [116]	71.56±3.00	68.60±1.67	70.00±1.29	7.47±1.60	73.74±0.86
Wang *et al.* [61]	57.72±1.37	58.72±4.76	58.12±2.67	7.42±1.06	69.27±0.27
Hou *et al.* [71]	69.33±2.00	69.44±2.42	66.76±1.64	6.74±1.76	67.41±1.13
Huang *et al.* [117]	74.74±1.60	69.56±2.38	72.04±1.68	7.39±1.43	74.98±1.46
HOG-ShipCLSNet	**77.87±1.14**	**72.42±1.06**	**75.04±0.68**	**7.83±0.62**	**78.15±0.57**

Collection of extensive and VHR training datasets is not simple



Sample dataset taken from the MSTAR database

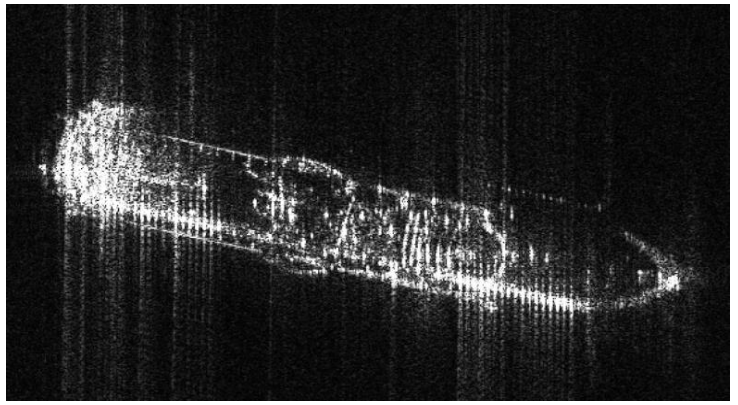


COSMO-Skymed spotlight image

An efficient solution: use a SAR image simulator

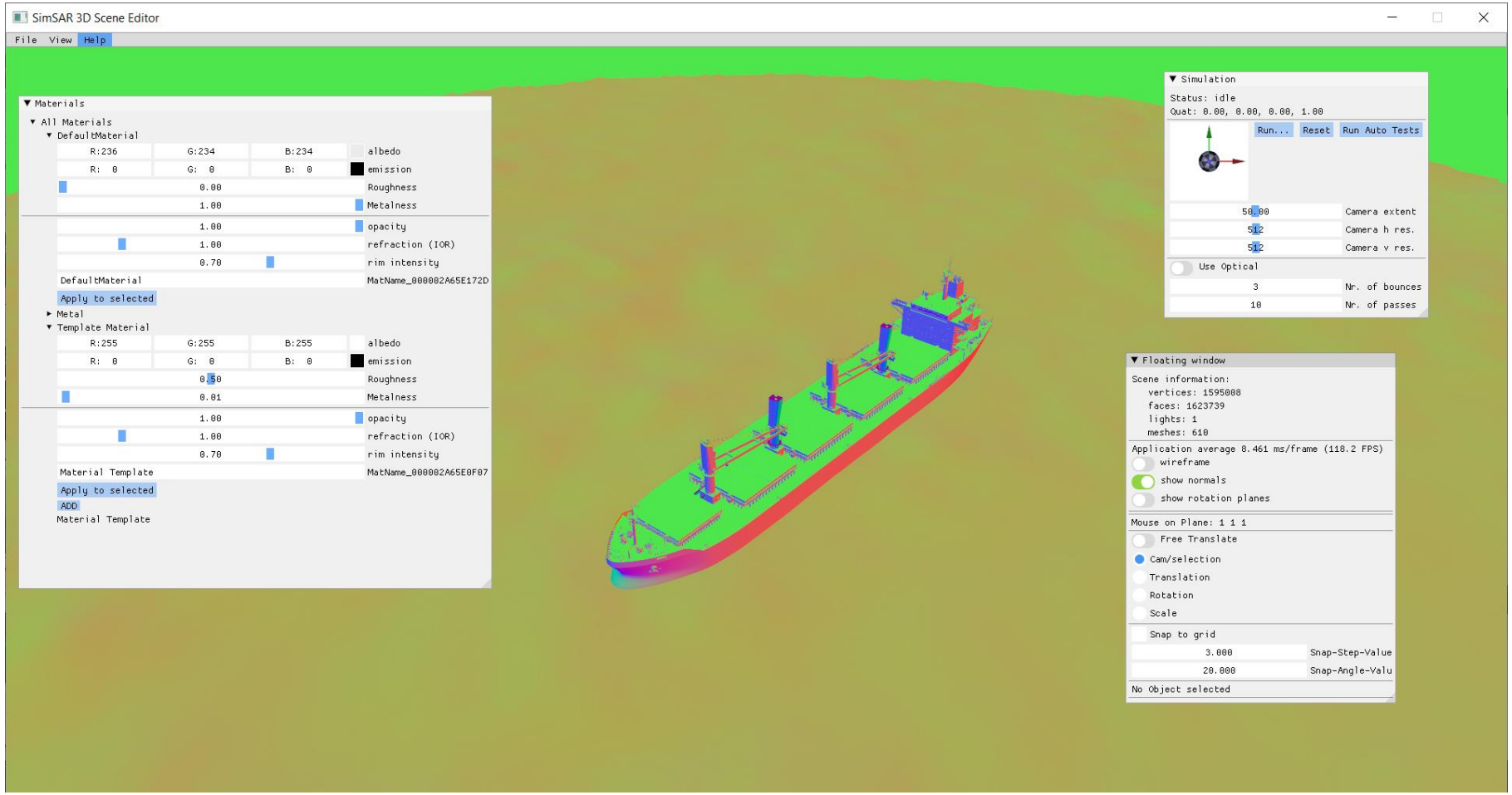
Aida Diva
passenger ship

Aida Diva, Capella Space SAR image, 0.5m resolution

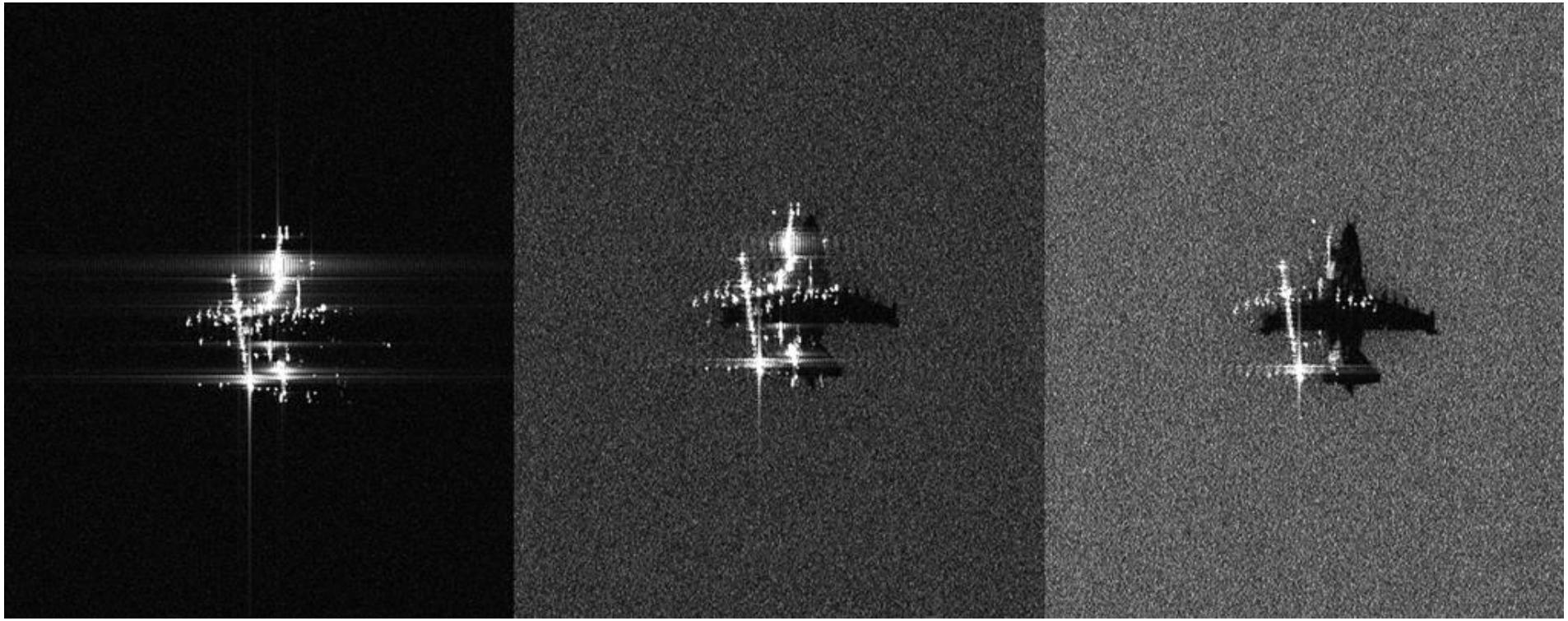


Aida Diva, simulated with same parameters of Capella Space SAR image

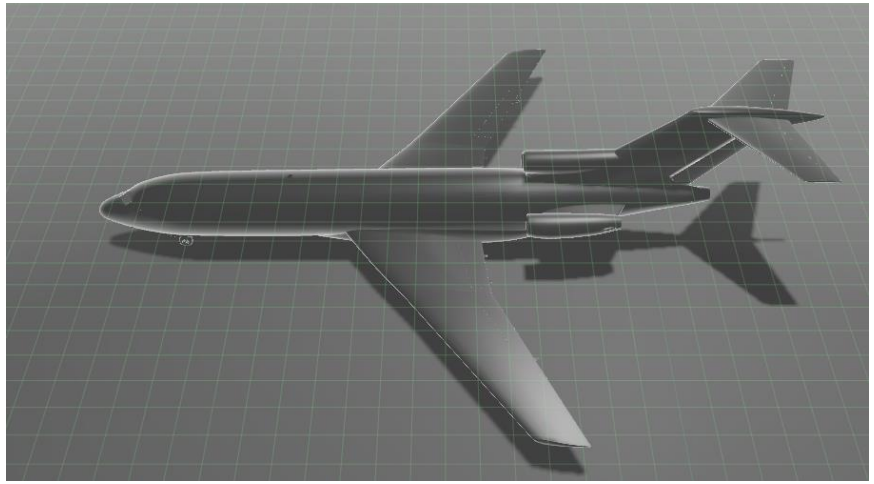
Definition of SAR-specific materials



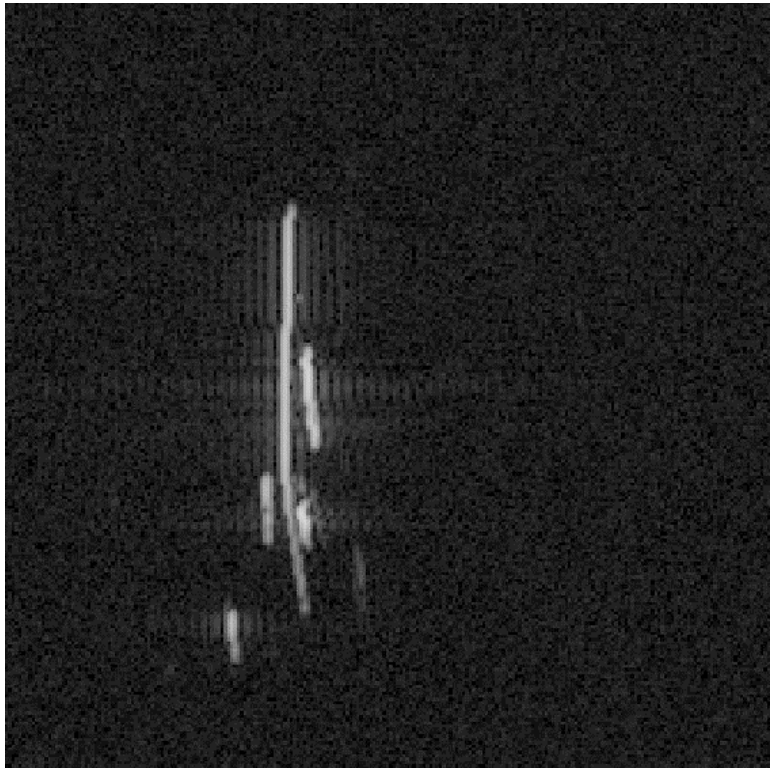
Simulation of different background roughness



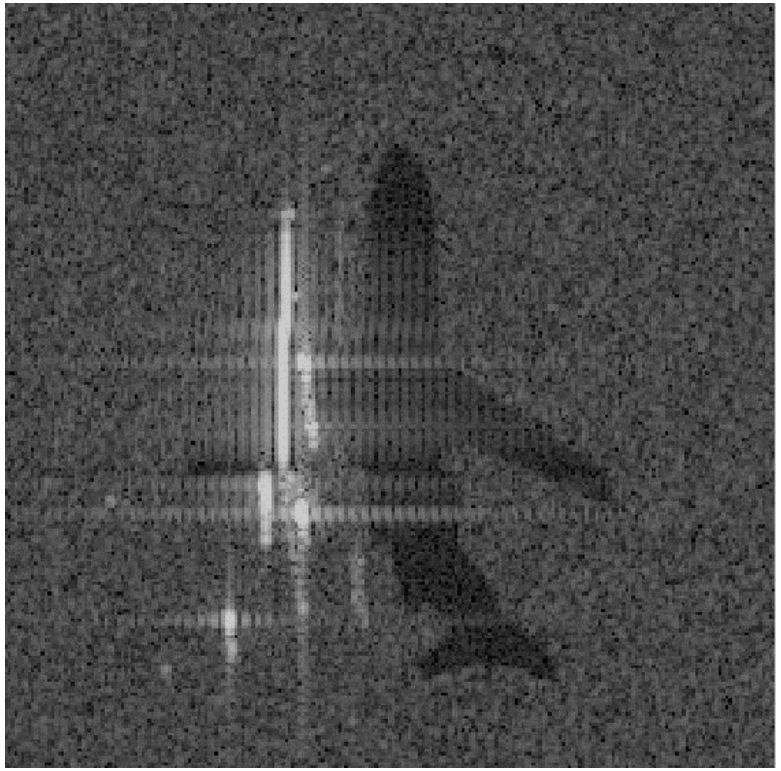
Simulation of different carrier frequencies



Boeing 727



L-band

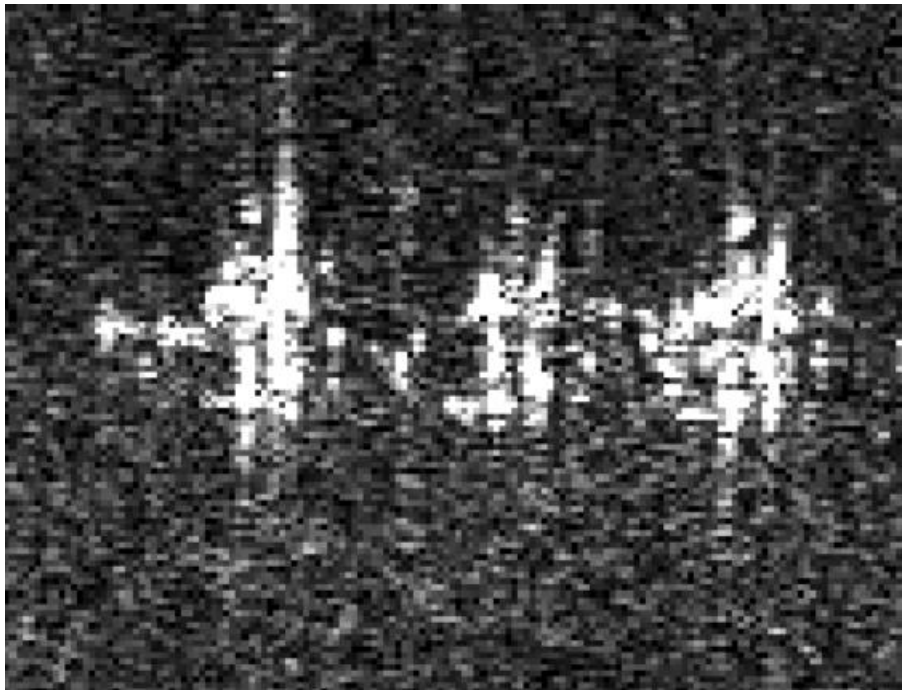


X-band

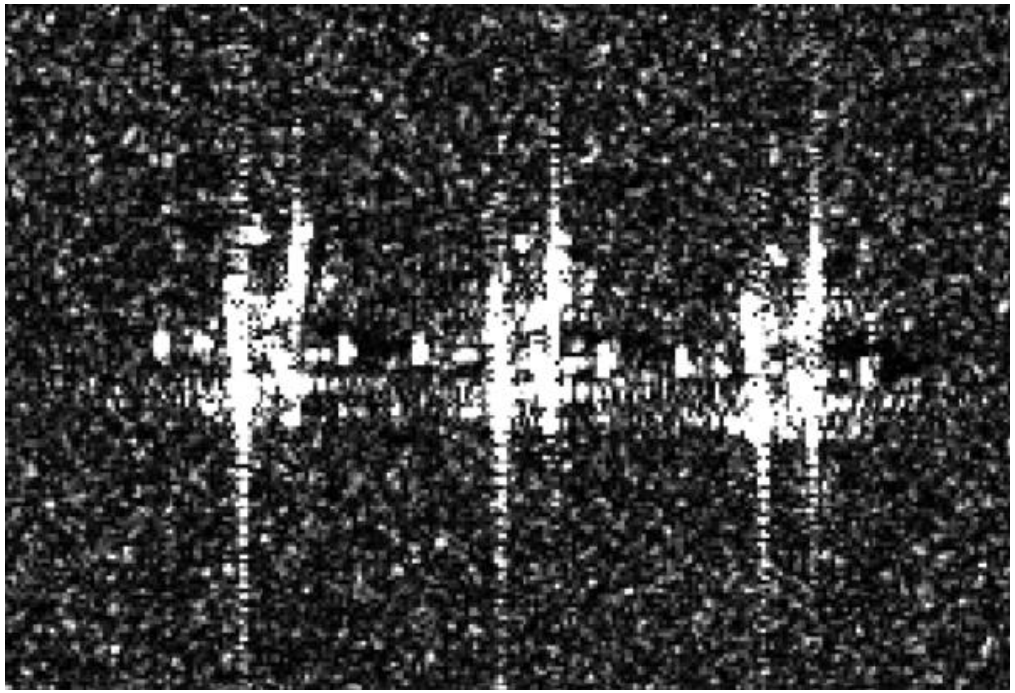
Verification of hypotesis

Social media, based on visual analysis of Very-High resolution Capella Space images, reported the presence of Russian Su-25 ground attack airplanes in the Luninets airbase in Belarus on February 22.

Verification of hypotesis

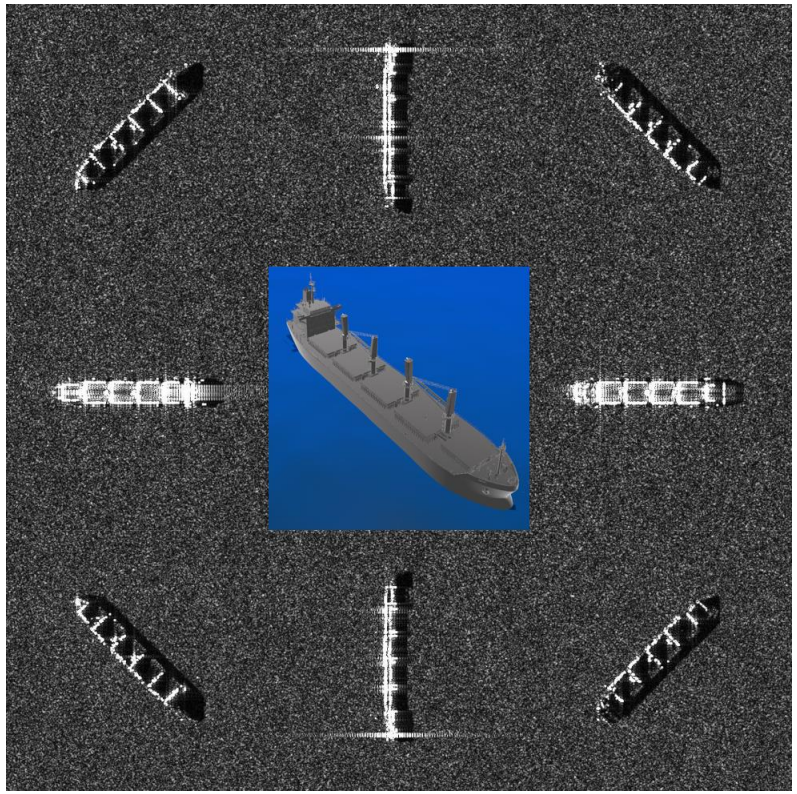


Capella Space 0.5m resolution

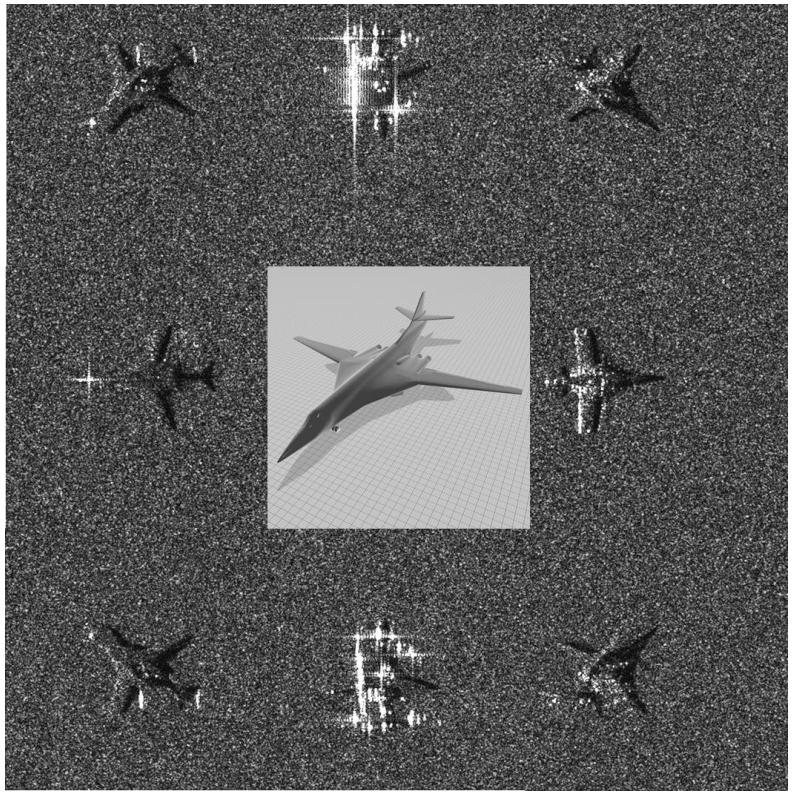


Simulated Su-25

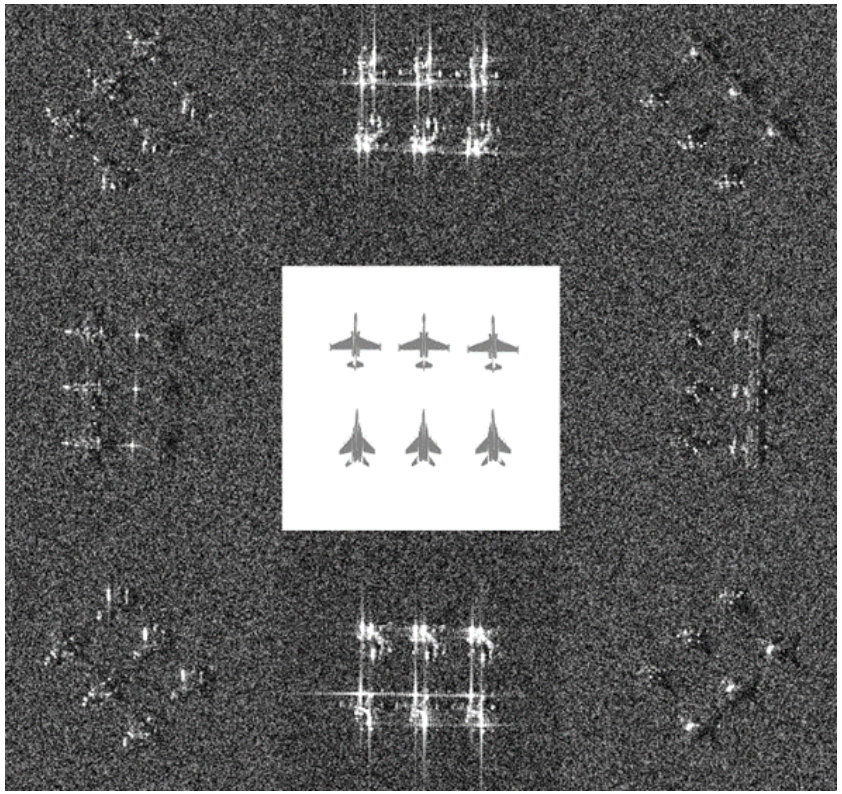
Simulation of different orientations / incidence angles



Bulk-carrier

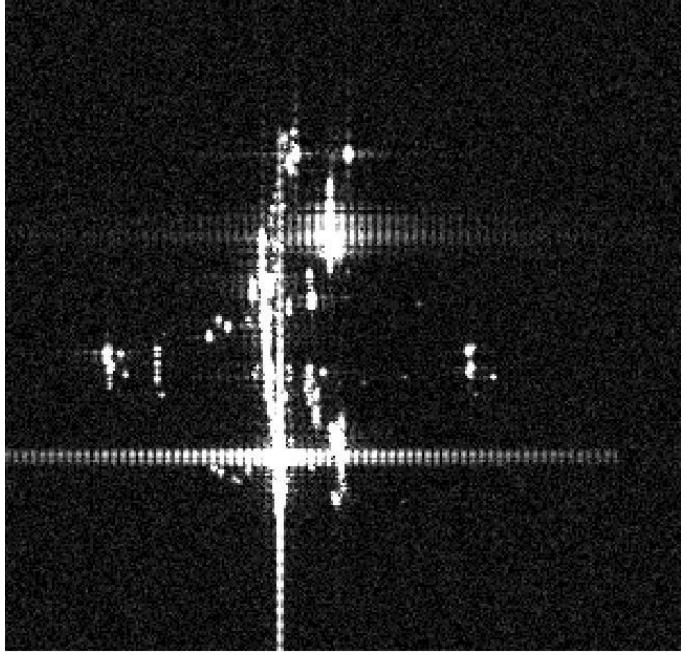


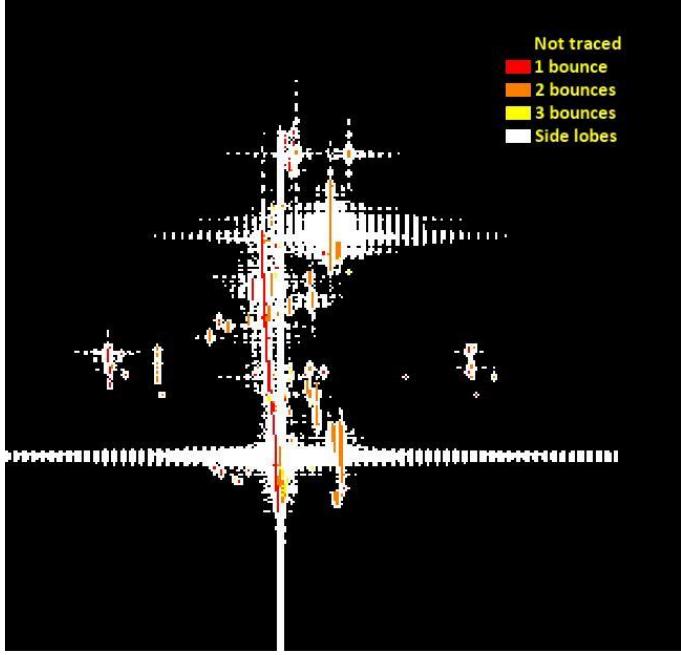
Tu-160

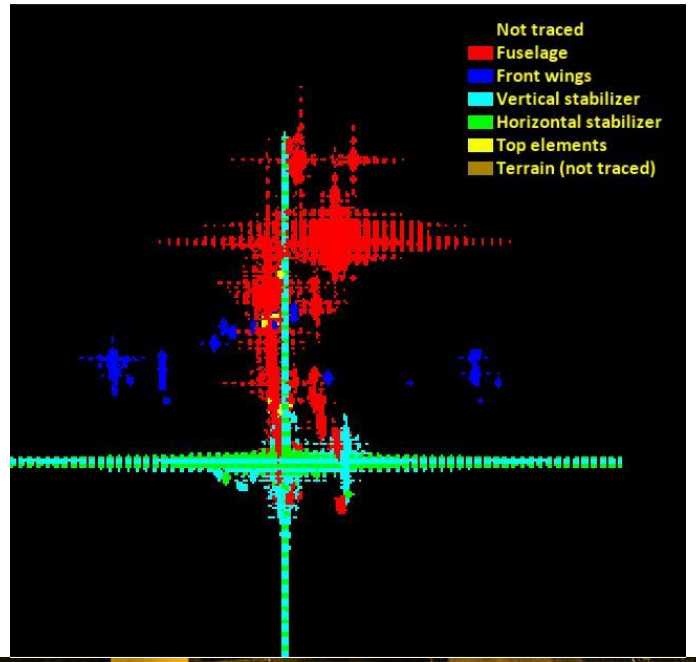


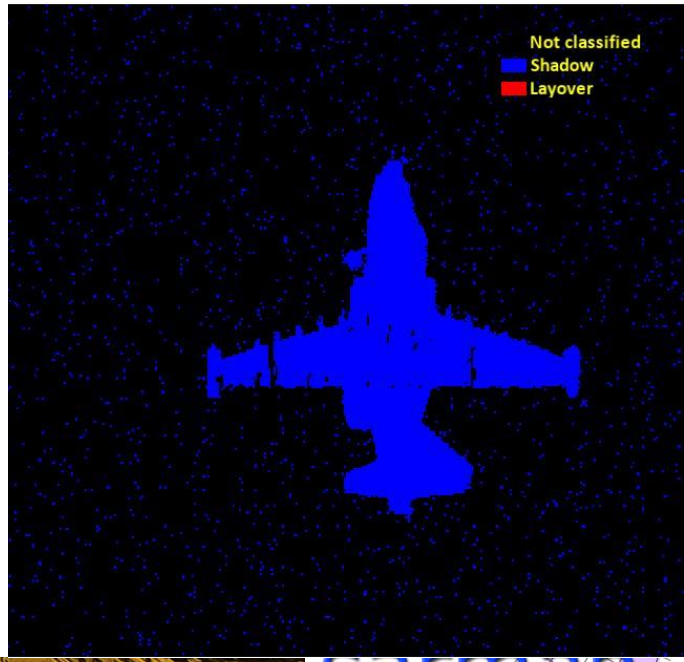
Su-25 and Mig-29

The simulation can provide several details on the scattering mechanisms

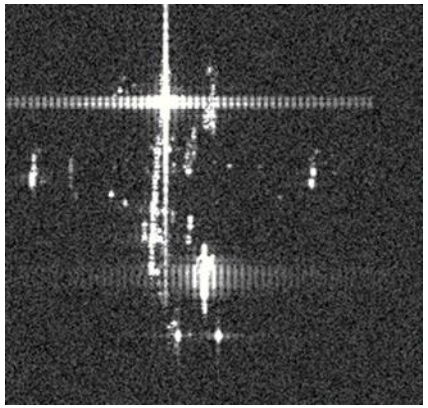


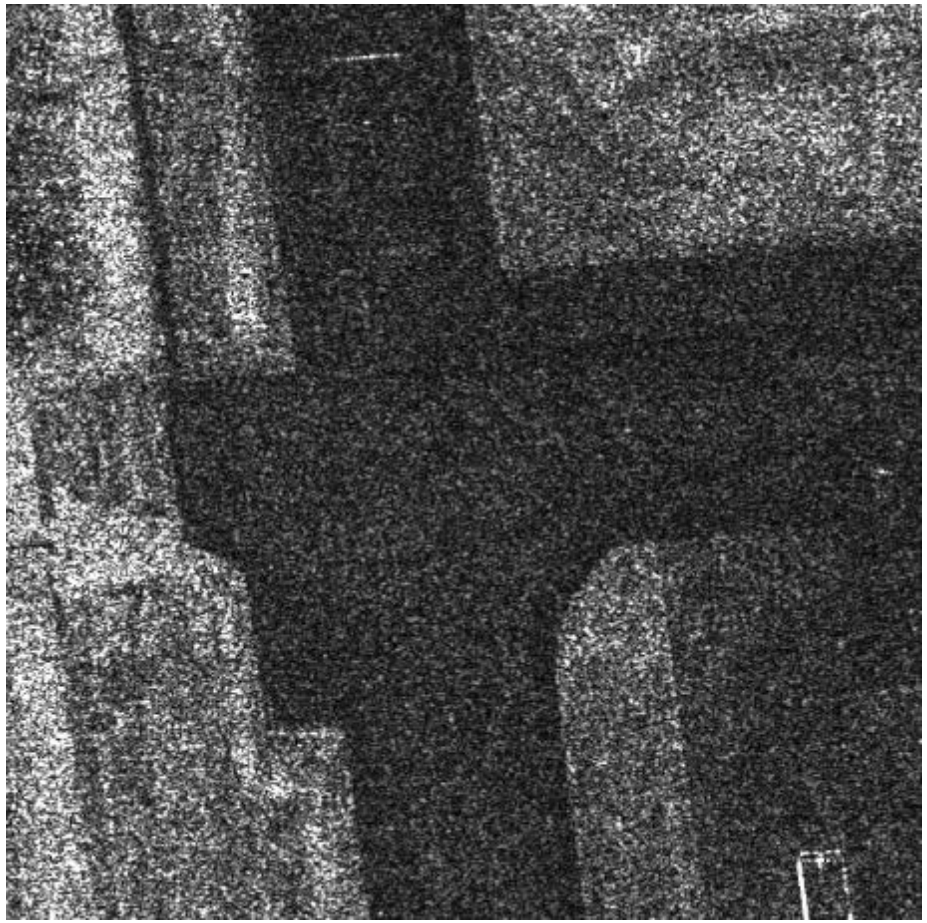


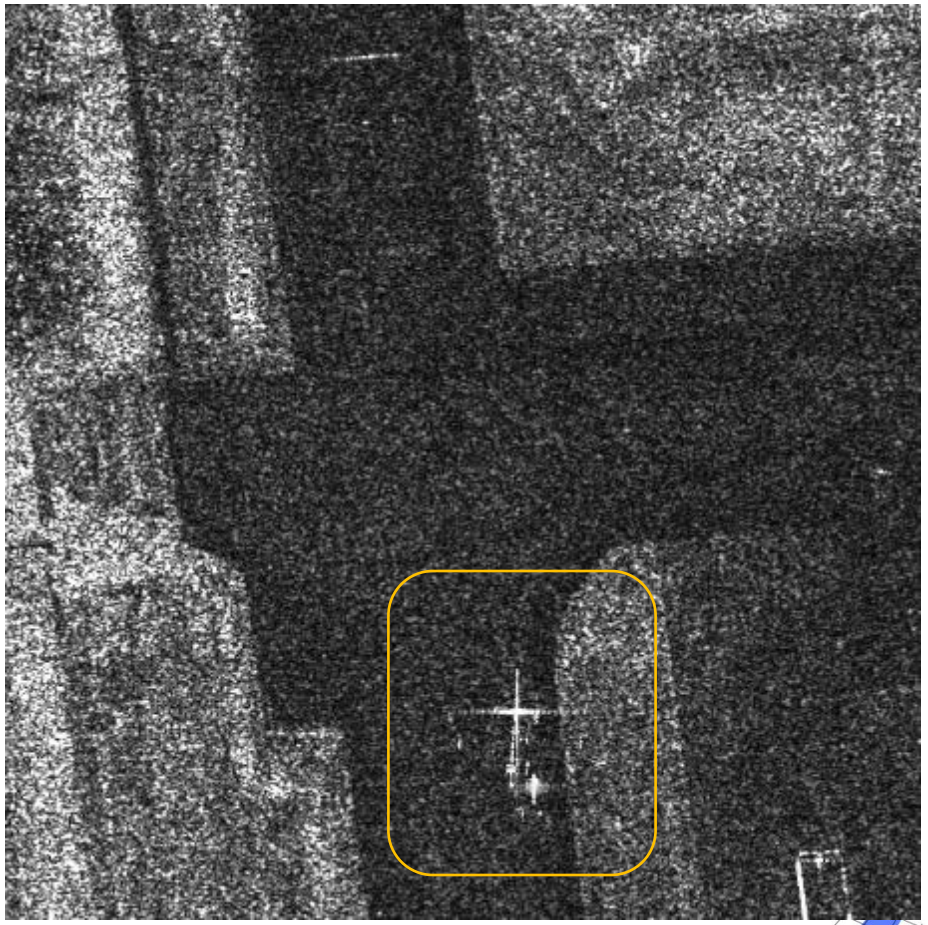




Generation of detection datasets via «augmented reality»

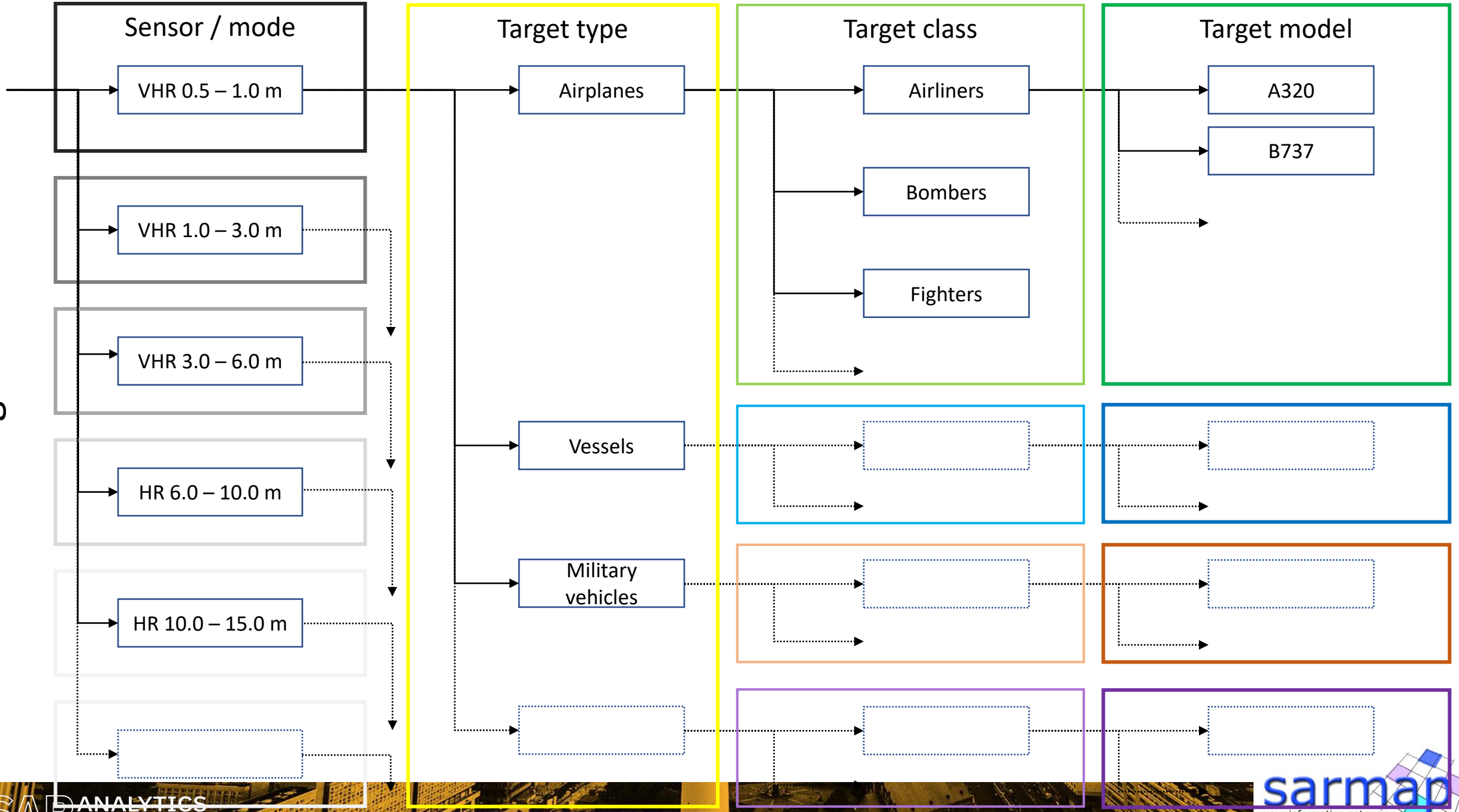






Easier and more efficient than simulating complex scenes

The Big Picture



Thanks a lot for your attention!