SAR vs AIS correlation for estimation of vessel detection performances and verification of reported velocity

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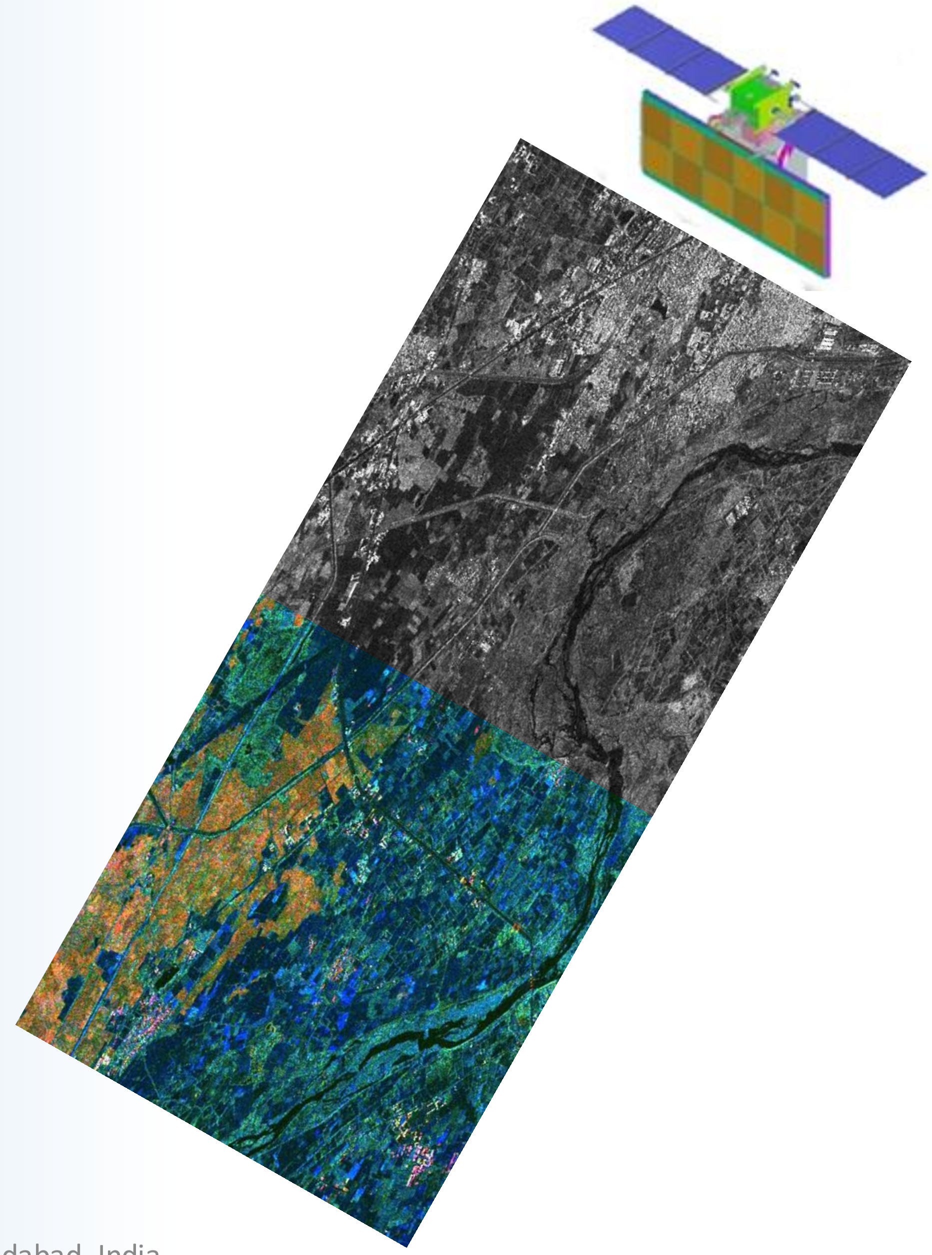
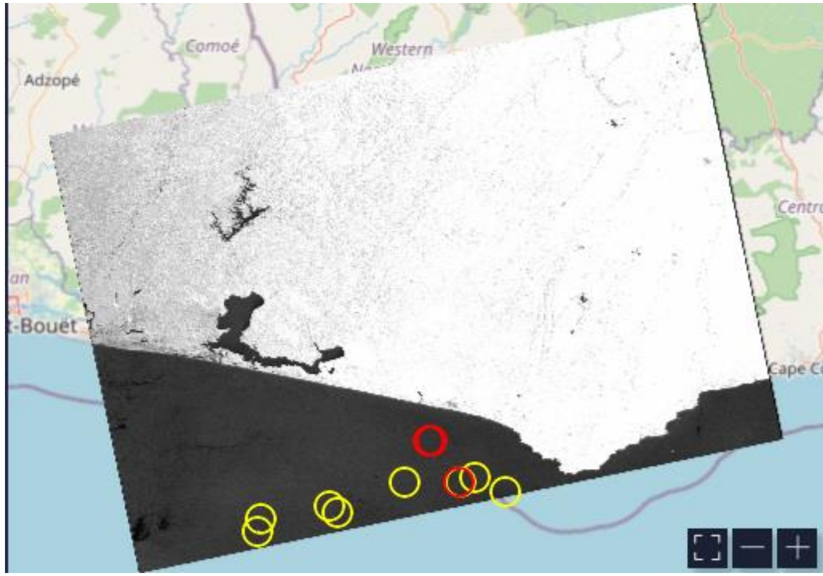


SAR vs AIS for maritime security - SAR

Spaceborne SAR imagery is based on Earth Observation techniques not requiring to instrument the target of interest.

SAR derived vessel detection allows non cooperative maritime monitoring allowing collecting information on :

- Vessels locations: from location of the echoes
- Vessel size, heading and type: from shape of the echo assuming the spatial resolution is sufficient
- Vessel speed: when wakes are observables considering azimuth displacement of the echo vs the wake (or other methods)



Pros:

- Non cooperative

Cons:

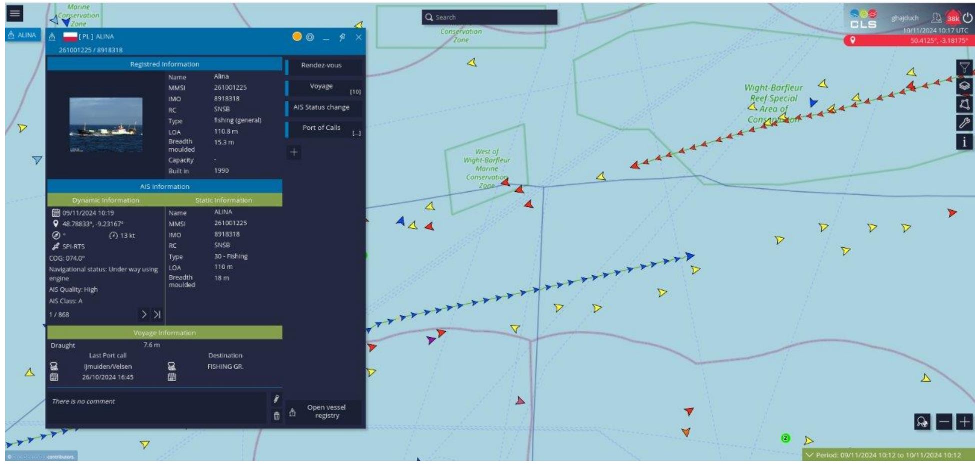
- Revisit of observation limited by the constellations (non continuous)
- Performances depends on acquisition geometry (decreasing at low incidence angle), polarisation (not optimal in VV...)
- Performances depends on vessel size vs spatial resolution of the images

SAR vs AIS for maritime security - AIS

AIS (Automatic Identification System) is based on emitters on board vessels transmitting information on their positions and destinations

AIS allows collecting <u>collaborative</u> information on:

- Vessel ID (name, MMSI, IMO number, call sign)
- Vessel location, heading, course over ground, speed (from GNSS receivers)
- Vessel size and type (as static information)
- Destination and ETA (as provided by captain)
- …



Pros:

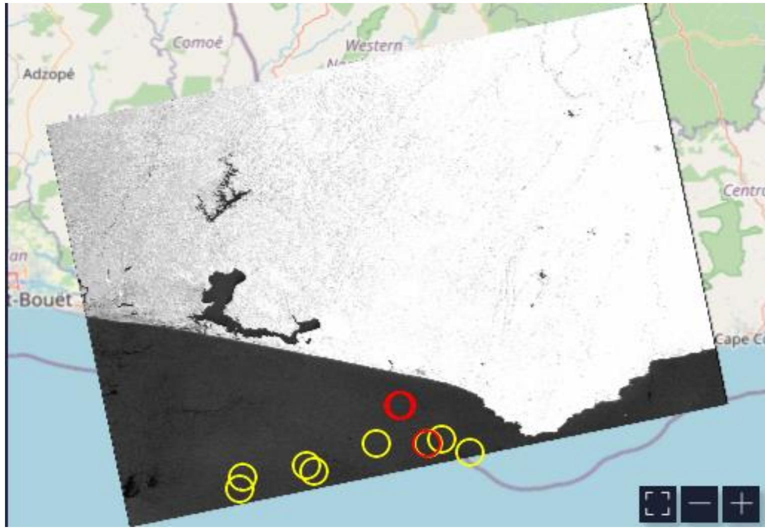
- Continuous information on the traffic (assuming availability of a reception nework)

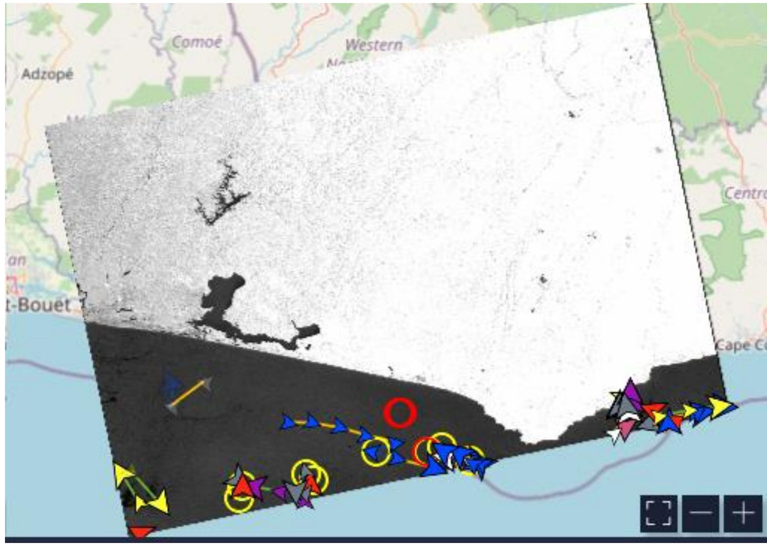
Cons:

- Coastal AIS receivers can be unaivalable
- Spaceborne AIS receivers can be saturated, or not collecting information at a given time
- AIS system can be switched off
- GNSS information can be spoofed
- AIS information can be inaccurate (invalid size, type, ETA...)

SAR vs AIS for maritime security - Complementarities

		AIS	
		Reported	Not Reported
SAR	Detected	Nominal	AIS switched off ? AIS spoofing ? GNSS spoofing ? Azimuth ambiguity unresolved No Receiver ?
	Not Detected	Bad SAR detection rate ? Bad SAR detection setting ? AIS spoofing ? GNSS spoofing ?	Nominal





SAR

- Bad detection rate: for instance due to low incidence angle, polarisation and high wind
- Bad detection setting: for instance for detection of small vessels in difficult weather conditions

AIS

- AIS switched off: on purpose or not ?
- AIS spoofing: on purpose to hide illegal activity ?
- GNSS spoofing: affecting other vessels around ?
- No receivers:

Basic association from SAR derived vessel detection to AIS

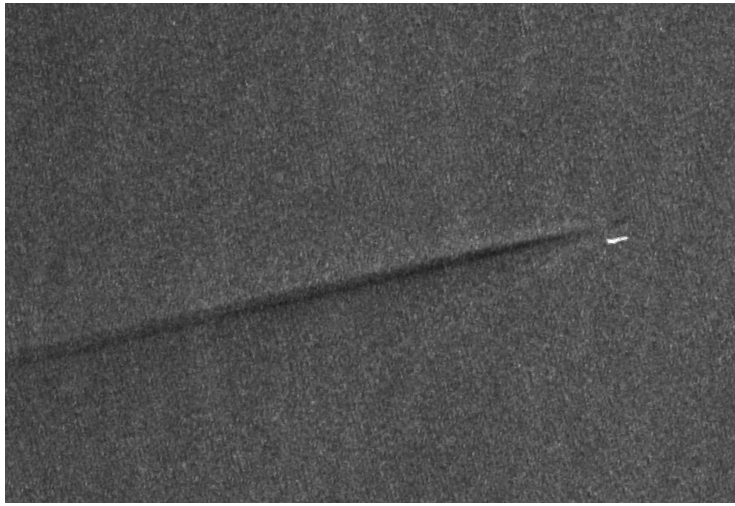
Basic method: from SAR to AIS

For each SAR detected vessel:
- Look for AIS position in the vicinity
- Test azimuth shift of AIS location vs SAR derived location
- Keep the echoes vs AIS being the closest

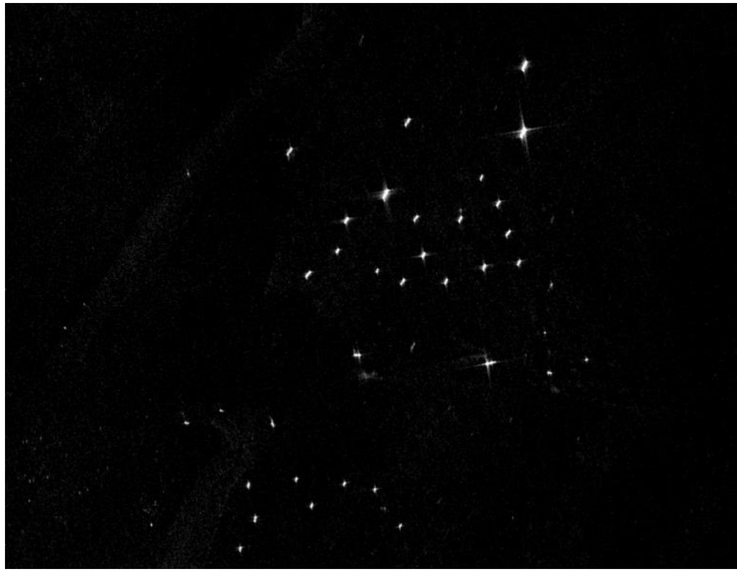
For all associations:
- Remove duplicated associations

Main drawbacks:
1- multi stage associations with potential duplicates
2- issues with dense areas
3- issues with azimuth ambiguities that may not be rejected near to image edge
4- may tend to associate SAR to nearest reported AIS location even if the real vessel switched its AIS off

Azimuth shift due to radial speed



Dense areas



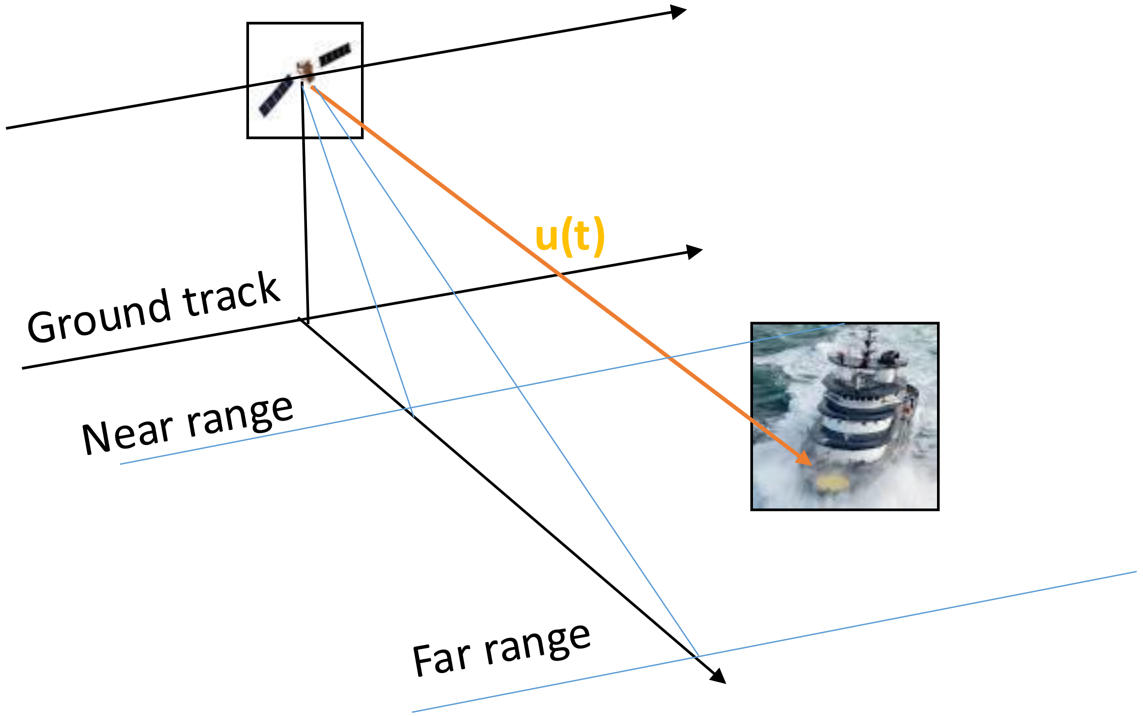
Association from AIS to SAR

To overcome those limitations the proposed method is not to compare straigth away AIS locations vs SAR ones, but first to reconstruct the locations vessels from AIS as seen by SAR.

Thus considering:

1- Specific SAR observation time
2- Interpolation of vessel's location at that time
3- Azimuth offset due to radial speed
4- Prediction of location of azimuth ambiguities

Step 1: determination of SAR observation times



For each vessel of interest, based on AIS information

Observation verctro from s/c to target: **u(t)**

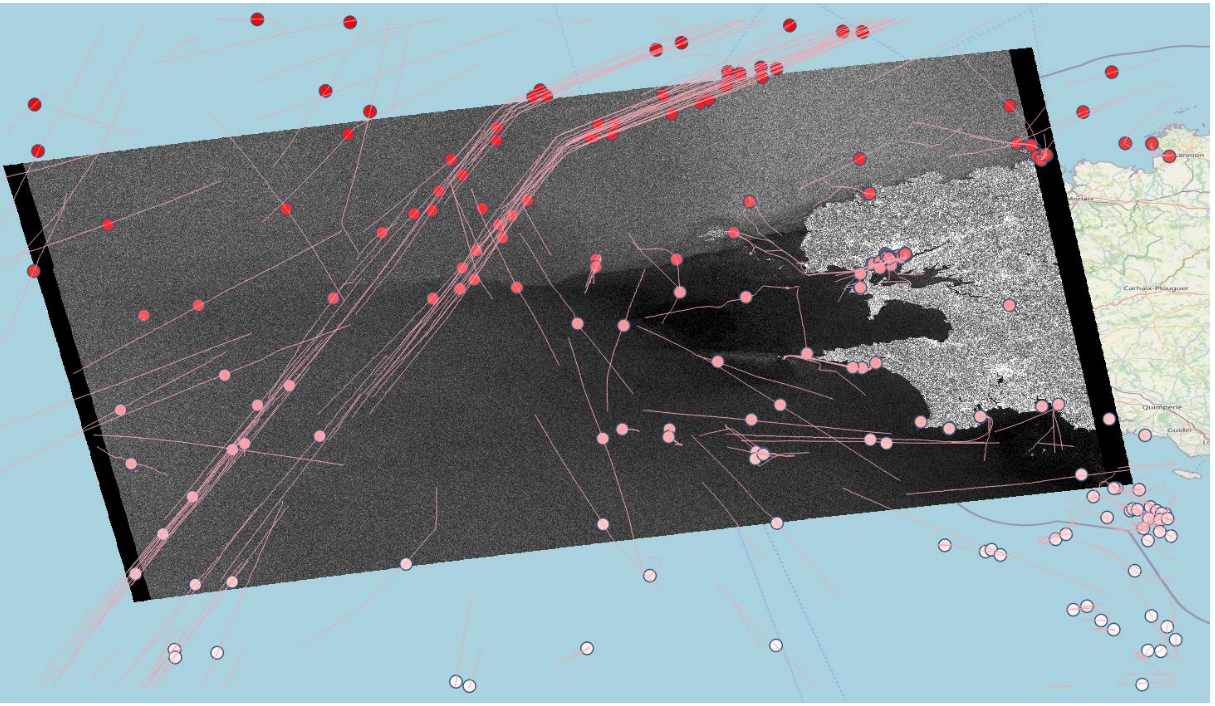
Observation time t0 is obtained as:

t0 = Argmin(norm(u(t)))

<u>The SAR image is not required for this computation.</u>
<u>Only the orbit information is required.</u>

(Here only for vessel on the right side of the track and with a pointing of 90° right)

Step 2: interpolation of vessel positions



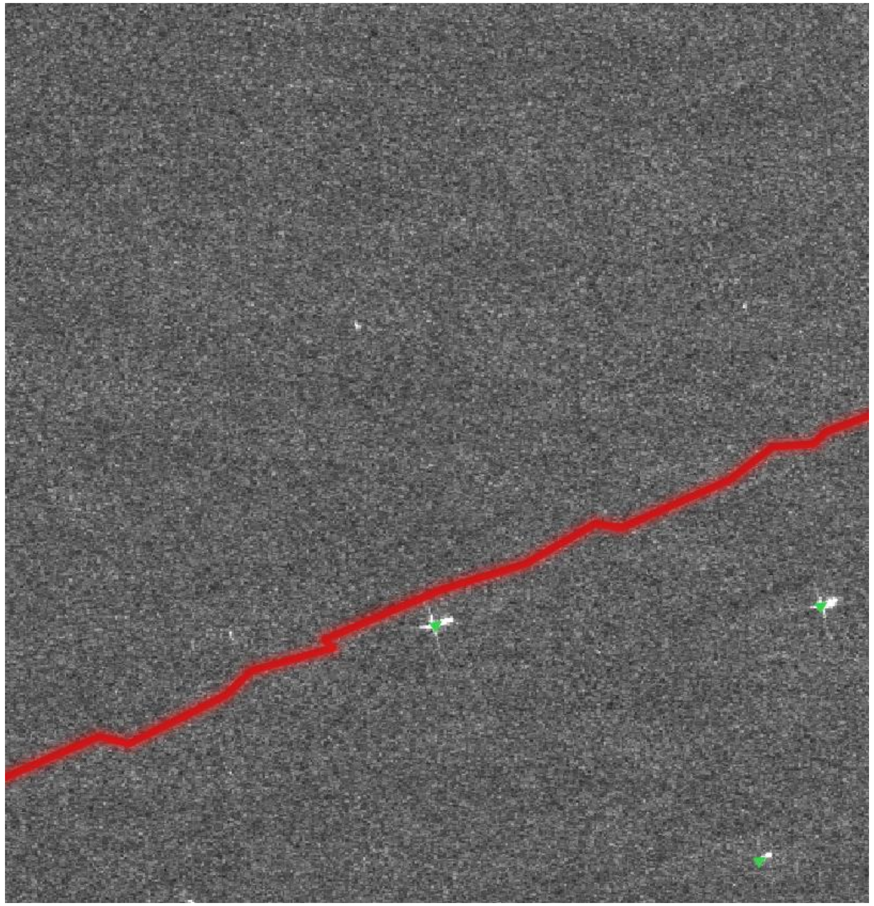
Color scale from white to red as increasing observation date

The positions of the vessels can be interpolated at their respective observation times.

As the observation times are performed from orbit information, they can be computed even for vessels potentially observed before or after the image of interest.

The time shift between date of prediction and latest AIS message is kept as an indicator of accuracy of the interpolation.

Step 3: Computation of azimuth shift



The location of the echo in SAR image is shifted in azimuth direction due to Doppler effect.

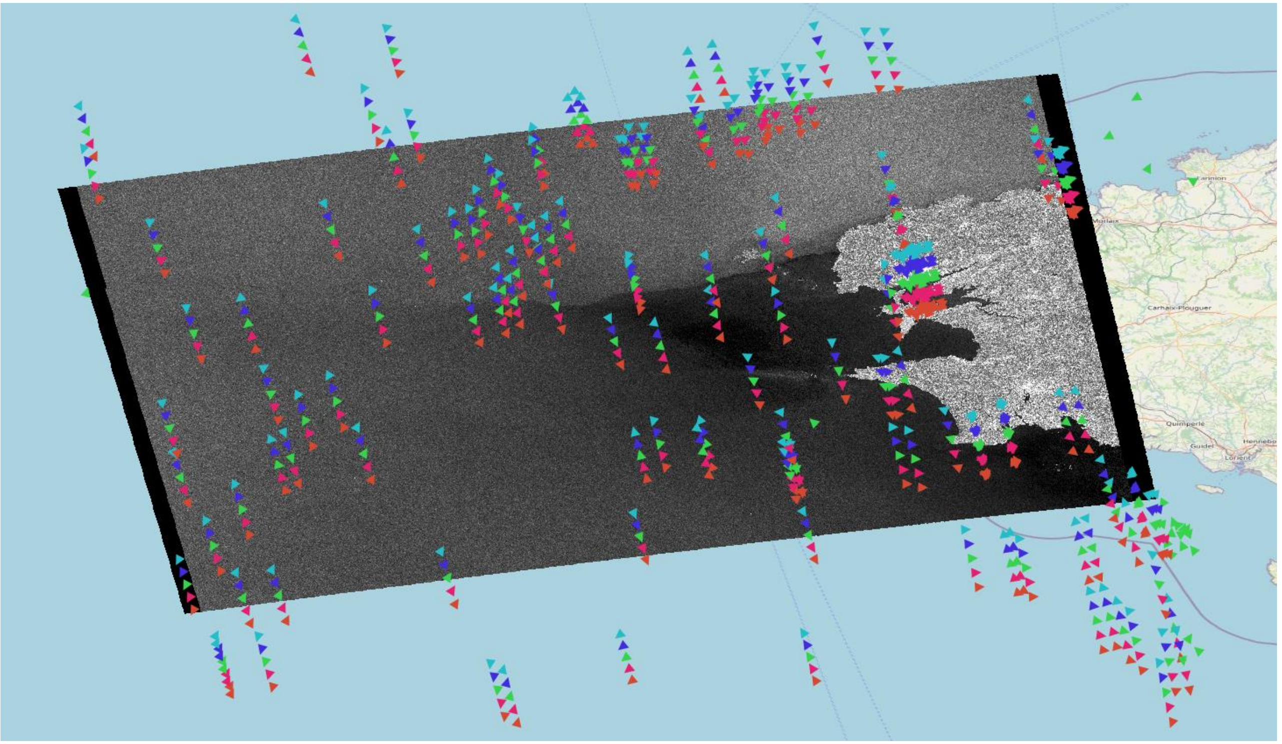
The shift is equal to

Delta = norm(u(t0)) * <**u(t0), v(t0)**> / V

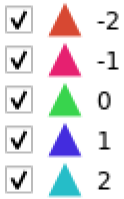
u(t0): observation vector s/c to vessel
v(t0): speed of the vessel
V: speed of the spacecraft

Norm(u(t0)): distance from s/c to vessel

Step 4: computation of azimuth ambiguities



Color code is ambiguity rank (0 = main echo)



The potential location of azimuth ambiguities is derived from distance to satellite, satellite velocity, PRF and radar frequency

Delta(k) = norm(u) / norm(V) * c/2*PRF/F

This allows predicting location of azimuth ambiguities within the image even from vessel located outside.

Finally, the location of the detected vessels within the SAR image can be directly compared with predicted observation of AIS.

The residual offset can be kept as a quality indicator.

Benefits of advanced method

Main benefits compared to basic SAR vs AIS comparison

Better matching of location as compensating the proper azimuth shift for each reported location by AIS.

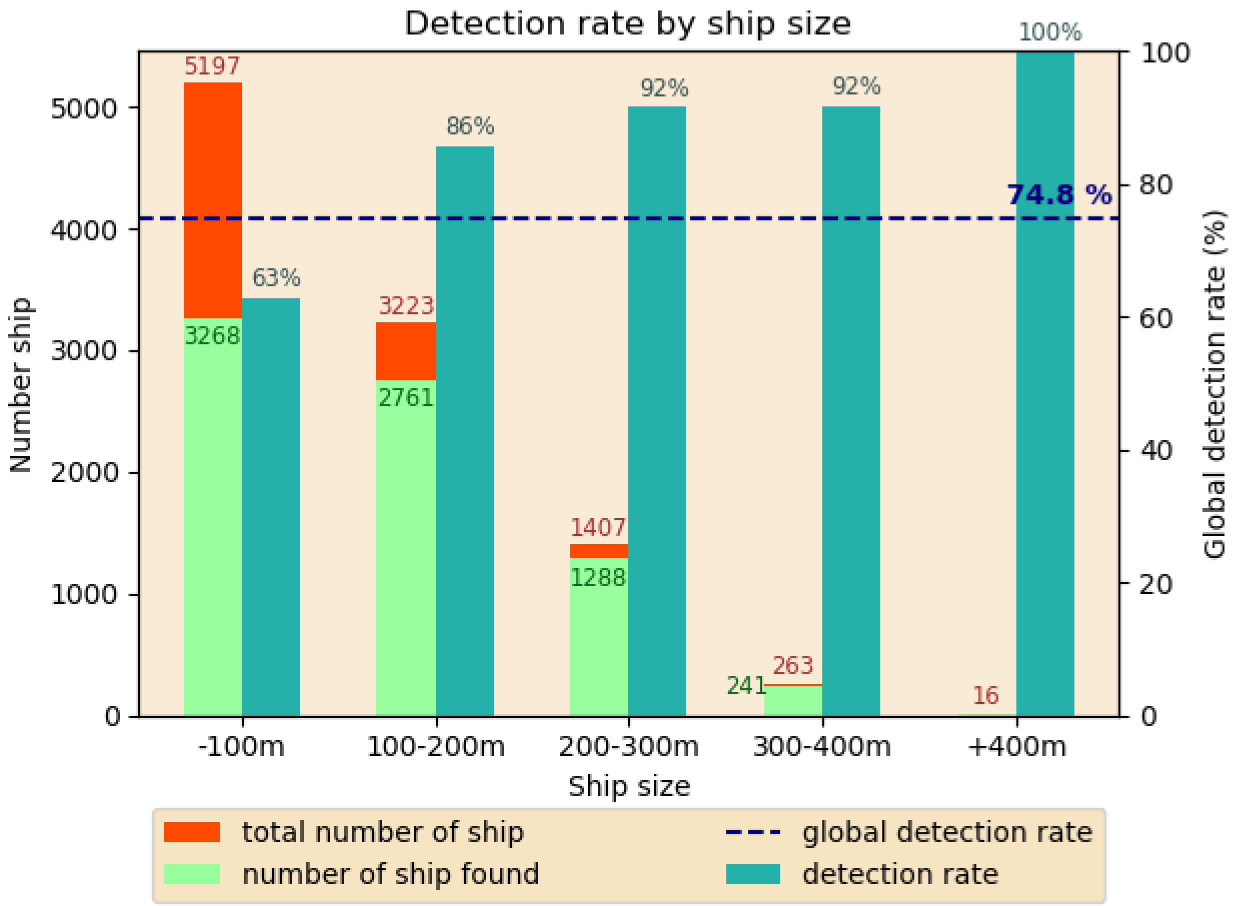
Allows direct matching to closest candidate (no need to remove duplicates)

Prediction of azimuth ambiguities with two benefits:

- Comparison of azimuth ambiguities observed in SAR vs the one predicted by AIS -> reenforce trust on SAR/AIS association
- Identification of azimuth ambiguities from vessel out of the SAR image

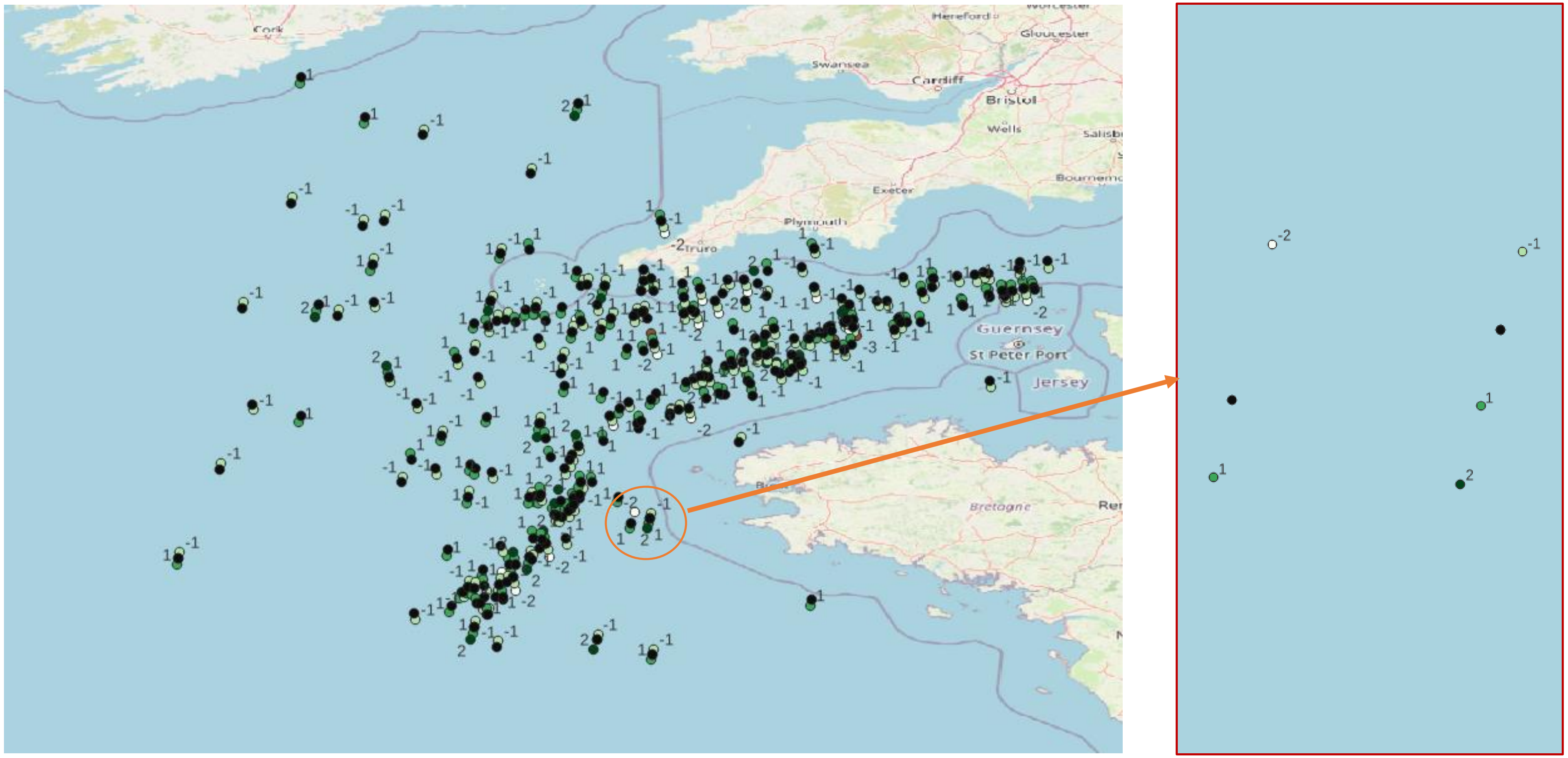
Example of evaluation of performances

Evaluation of ship detection performance on Sentinel-1 GRDH VV
(all wind conditions and incidence angle combined)



Other applications: analysis of azimuth ambiguities (S1)

Selection of SAR images acquired at very low wind on a main traffic lane



	Rank 1	Rank 2	Rank 3	Rank > 3	Total
+	144	26	3	2	175
-	165	20	4	0	189
Total	309	46	7	2	**364****

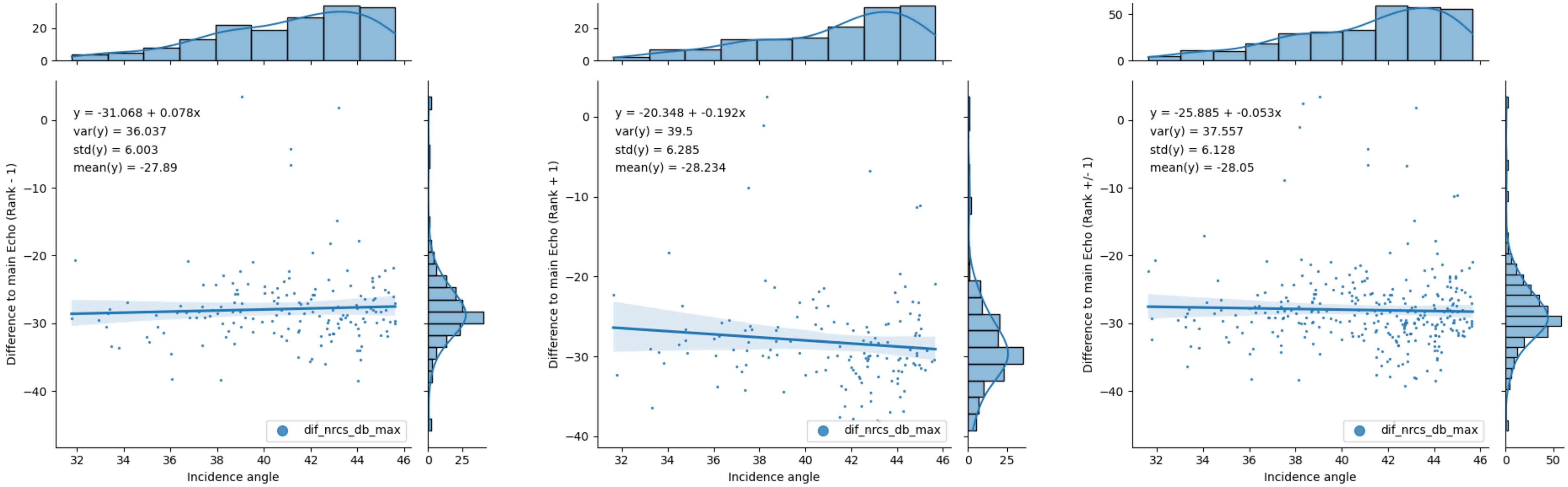
**total number of <u>associated</u> azimuthal ambiguities

Contribution of M.Berniere (CLS, 2023)

Other applications: analysis of azimuth ambiguities (S1)

Difference in nrcs max (dB)

Rank -1 Rank +1 Rank +/-1



Values do not seem to vary much on the range of incidence angle.
Overall average difference with main echo (in terms of nrcs max) around 28 dB

Benefit compared to analysis using CR or TP: allows capturing measurment over full incidence angle range on few products

Contribution of M.Berniere (CLS, 2023)

Conclusion

We demonstrated a specific methodology for SAR derived vessel detection and AIS.

This methodology takes into account the specificities of SAR imagery (Doppler shift, azimuth ambiguities) to predict the location of vessels artefacts in SAR imagery considering AIS information, spacecraft orbit and SAR characteristics.

This methodology can be used to perform a finer validation of performances of vessel detection and (not demonstrated here) of speed estimation.

The proper management of azimuth ambiguity information can be used for assessment of attenuation from main echo to ambiguous echoes:

- Of interest for automatic rejection of azimuth ambiguities in SAR derived vessel detection
- Of interest for characterisation of azimuth ambiguity level as indicator of the SAR system performances in real case scenario.