Progress in Automatic Ship Detection and Classification

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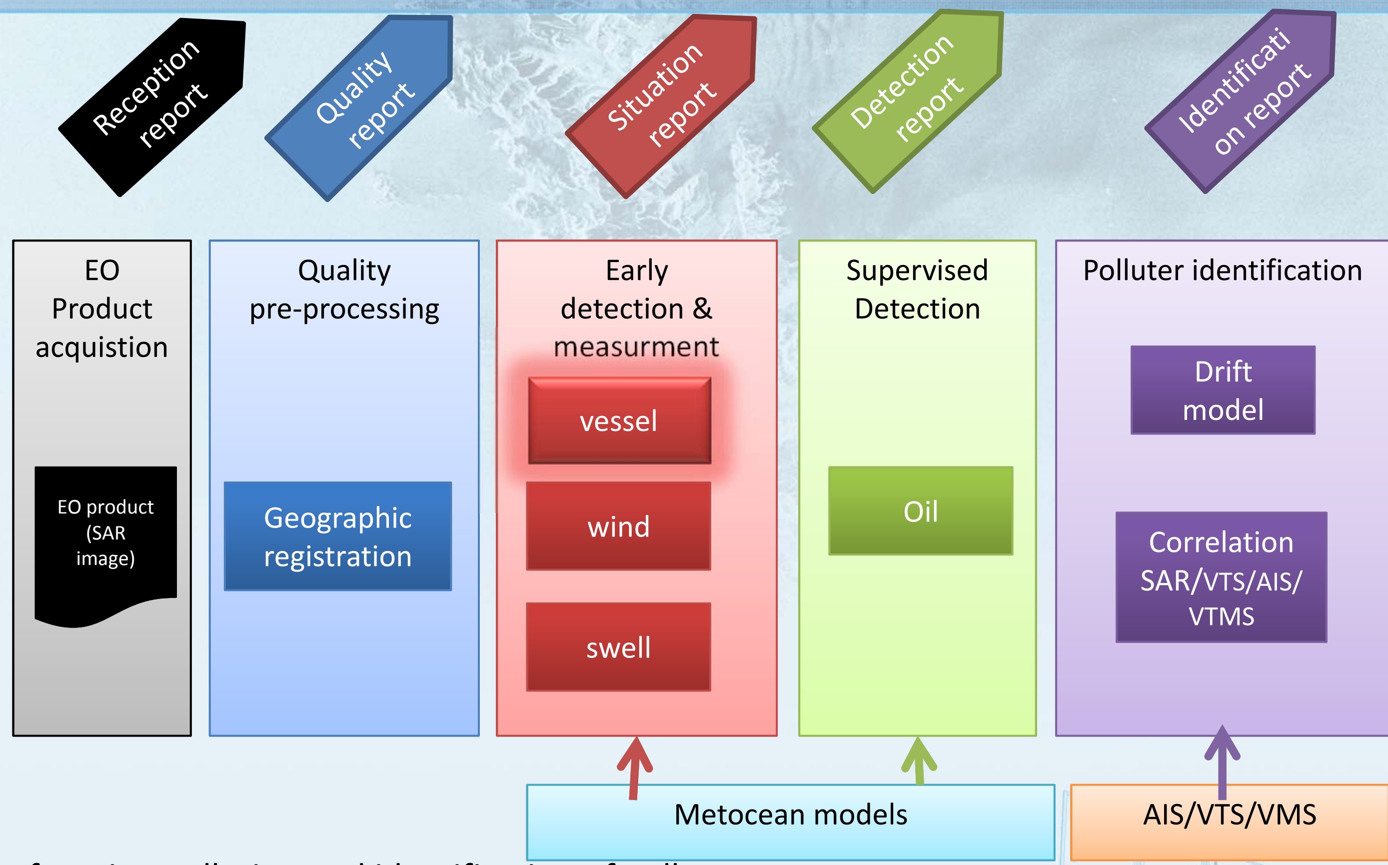
Plan of the presentation

- Context of ship detection versus marine applications
- Better estimation of characteristics of detected ships
- Using polarimetric information

Vessel detection versus marine applications

- The vessel detection is only a technical part of marine applications based on spaceborne SAR
- The vessel detection reports (VDR) usually have to be integrated into a full application chain, based on two kinds of SAR acquisitions modes (*):
  - High resolution / small coverage :
    - "One shot" observation of a limited area of interest with high reactivity
    - Focus on "expected" event : intelligence...
  - Medium resolution / wide coverage
    - Systematic monitoring of very large areas
    - Searching for unpredictable events : oil spill detection...
- The selection of optimal SAR acquisitions modes for vessel detection may not be possible due to requirements of the expected marine applications :
  - High reactivity => low incidence angle products in addition to high incidence angle
  - focusing on systematic monitoring of very large areas with a high revisit frequency => medium resolution products
- (*) The compromise between resolution / coverage will be updated with the Sentinel-1 mission

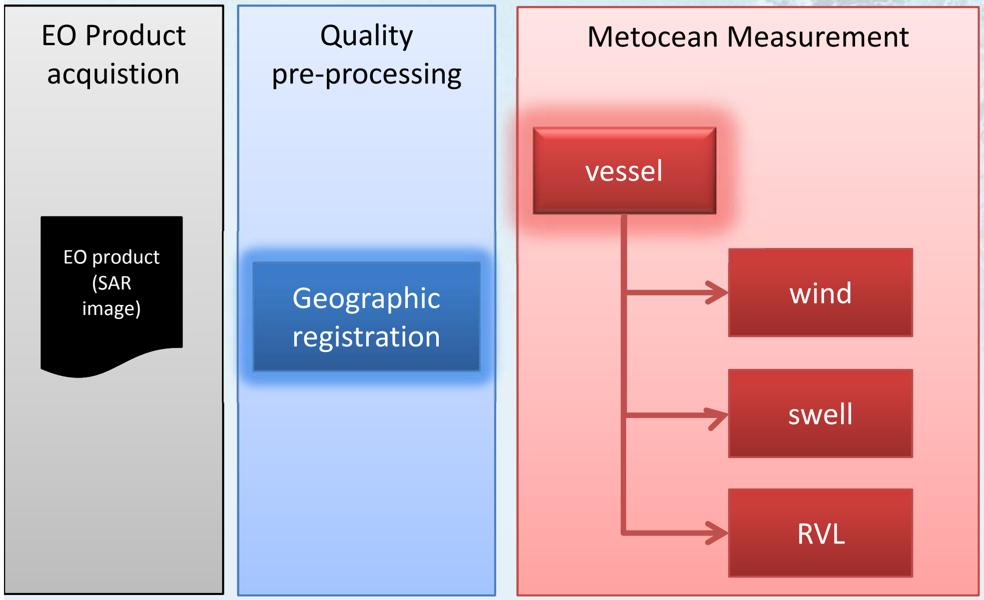
Example :
Pollution Detection Operational Service



Detection of marine pollution and identification of polluters
Wide swath / Medium resolution products (ASA/WSM, RS1-2/ScanSAR Narrow/Wide...)
SAR Vessel Detection is a by-product

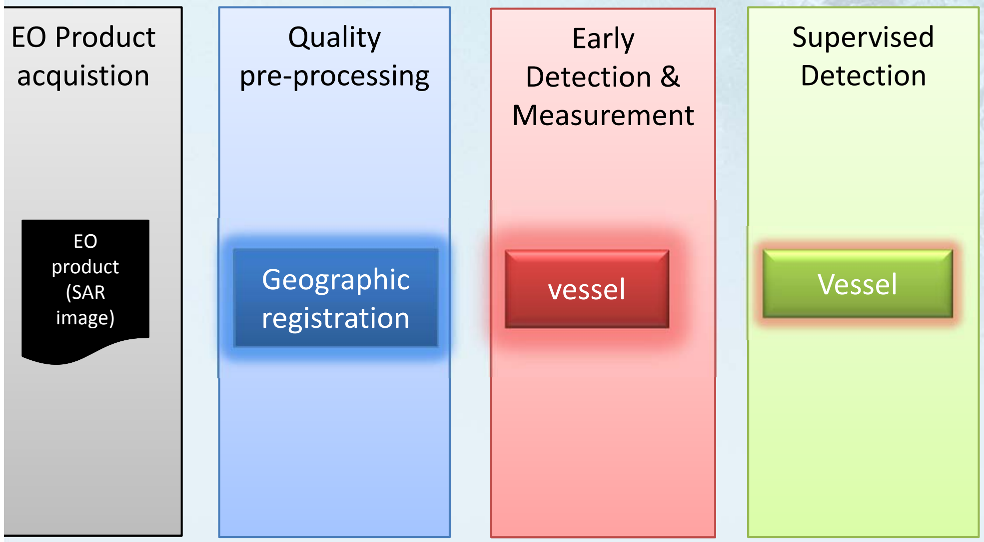
- Automatic processing is needed for NRT processing
- Optimal characterisation of the detected echoes is needed for an appropriate polluter identification
- Low false alarm rate is expected

Example :
Metocean measurement



- Wide swath / Medium resolution products (ASA/WSM, RS1-2/ScanSAR Narrow/Wide...)
- SAR Vessel Detection is an internal by-product
- Fully automated processing needed due to operational requirements and the volume of data
- No characterisation of the detected echoes is needed
- Medium/High false alarm rate is acceptable
- Automatic geographic registration is a expected

Example:
Abnormal marine activity on limited area of interest



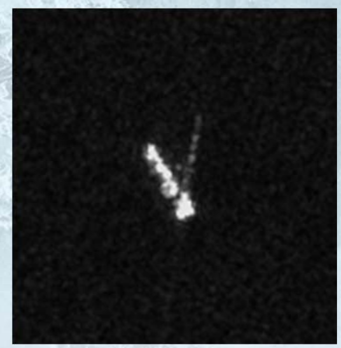
- For instance : detection of « go fast »
- Narrow Swath / High Resolution products
- Systematic vessel detection is an internal by-product
- Only the characterisation of a limited number of vessels of interest is needed
- Very low false alarm rate is needed
- Supervised/manual detection and characterisation of the vessels of interest is needed

- Note: we will not develop a vessel detection algorithm in human operators head

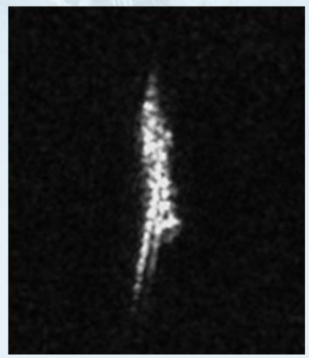
BETTER CHARACTERISATION OF THE DETECTED ECHOES

Characterisation of vessel in high resolution products is not a challenge
Example : RS2 / Multi Look Fine , 10m resolution

03 : NORGAS TRADER
Pavillon : Singapour
Type : Transport de gaz liquéfié
Dimensions : 119 m x 18 m
Dimensions SAR: auto 145 m, manuelle 135 m
Code MMSI : 563662000



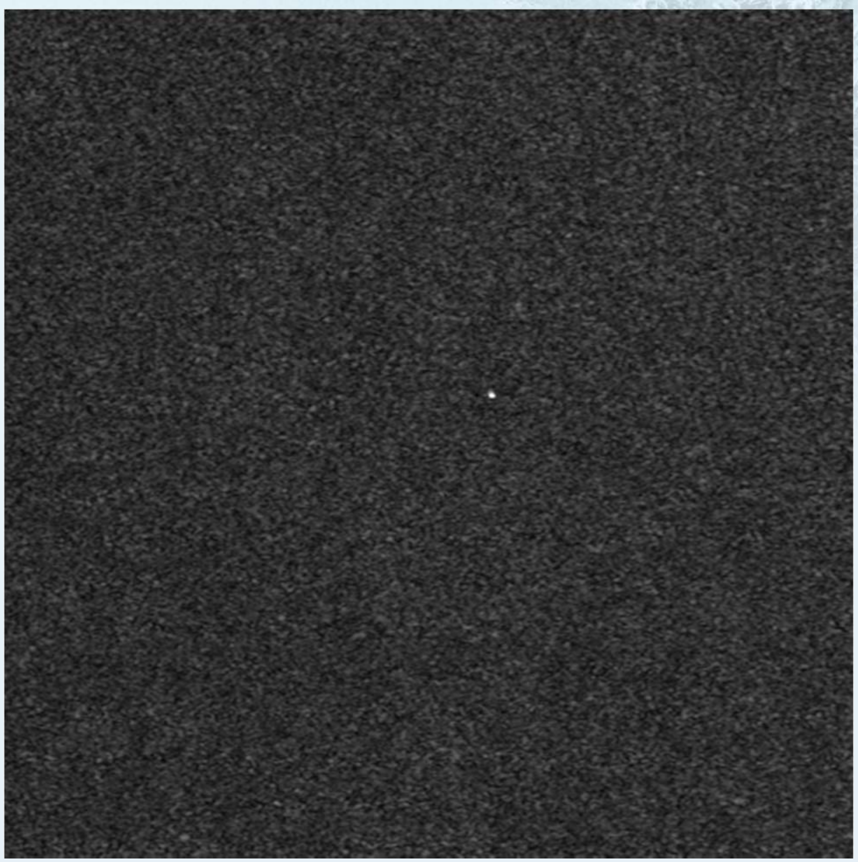
04 : GRAND SAPPHIRE
Pavillon : Panama
Type : Transport de véhicule
Dimensions : 199 m x 32 m
Dimensions SAR: auto 402 m, manuelle 206 m
Code MMSI : 372516000



05 : HARMEN OLDENDORFF
Pavillon : Liberia
Type : Minéralier
Dimensions : 225 m x 32 m
Dimensions SAR: auto 348 m, manuelle 221 m
Code MMSI : 636090932

Détection de la flèche

Characterising the vessel in medium resolution products is the real challenge



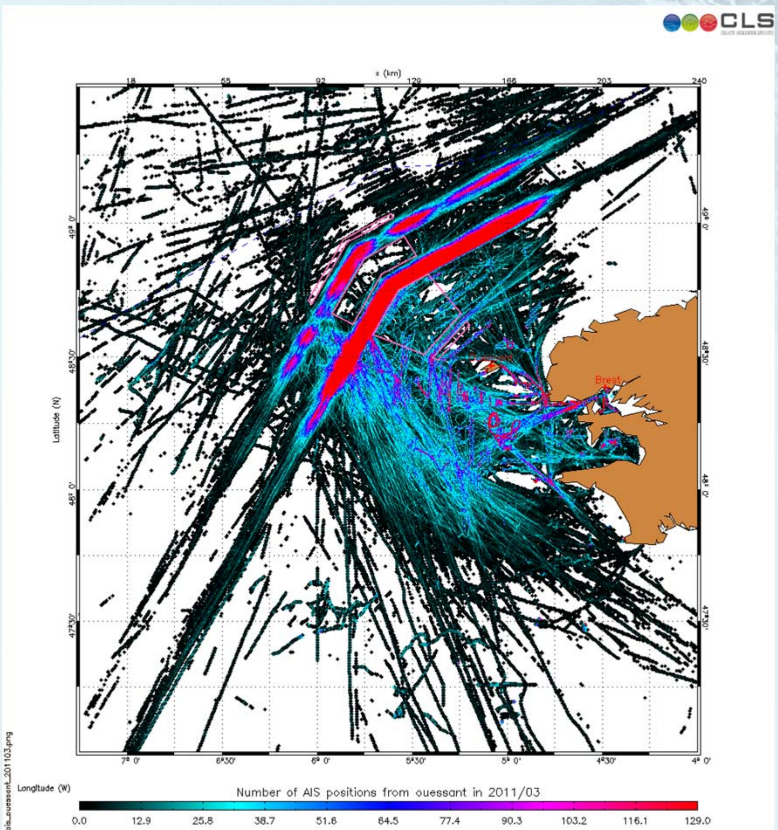
- Standard techniques of length estimation :
  - Measurement of the shape of the detected echoes
  - Not best suited for medium resolution products
    - The biggest vessels have an extension of few pixels
    - For most of the vessels, the length is below the resolution of the product

Characterising the vessel in medium resolution products is the real challenge

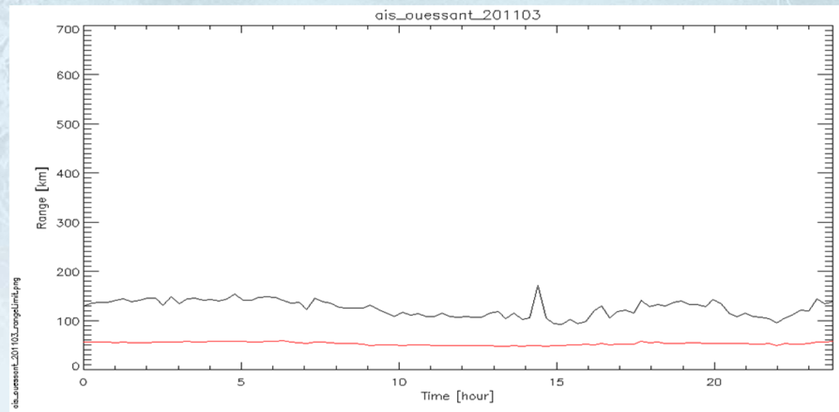
- New technique of length estimation
  - Fused length estimation based on both geometric and radiometric measurements
- Geometric measurement
  - Measurement of the shape of the echo (as usual)
- Radiometric measurement
  - Inversion of a model of vessel RCS with respect to its length
  - Literature of the domain [Skolnik, Vachon97]
  - Obtained using AIS "ground truth"

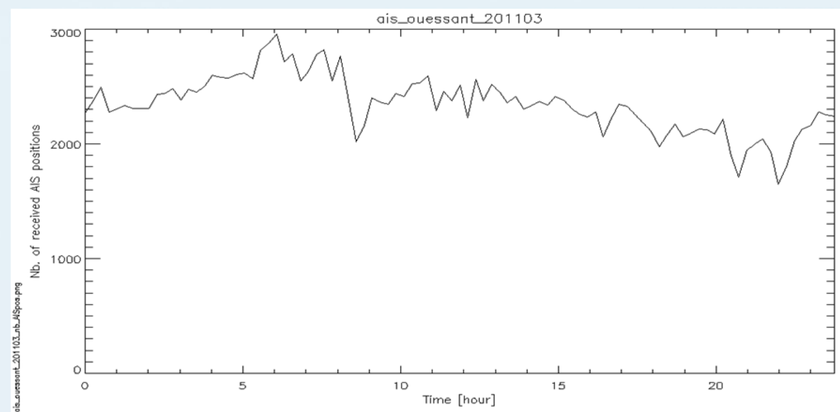
Characterisation of AIS data as « ground truth »

Stacked positions

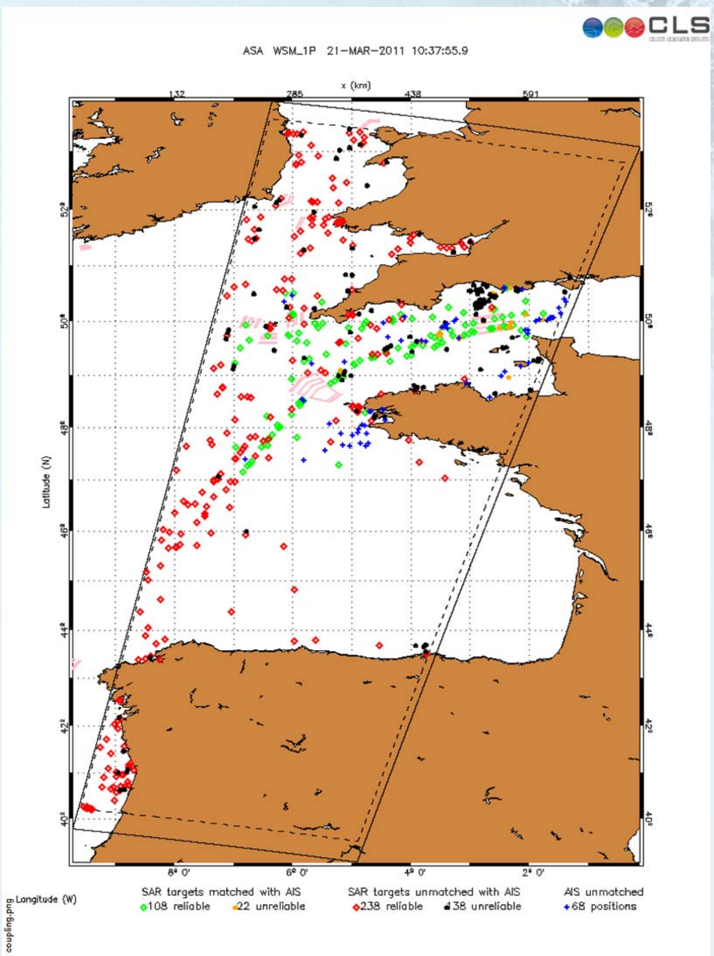


Characterisation of the receiver performances





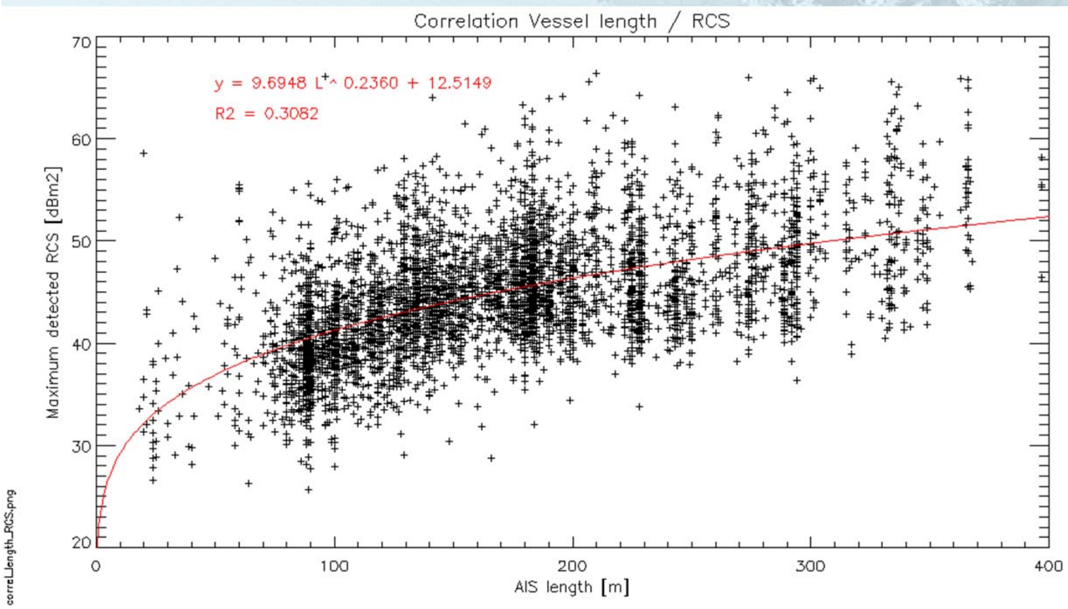
SAR / AIS correlation



- *Color code:*
  - *Green: reliable SAR targets matched with AIS position*
  - *Orange: unreliable SAR targets matched with AIS position*
  - *Red: Reliable SAR targets unmatched with AIS position*
  - *Black: Unreliable SAR targets unmatched with AIS position*
  - *Blue: AIS position unmatched*
- *2 main issues*
  - *Many red points: range of AIS reception or false alarms or vessels not equipped ?*
  - *Many blue points: non detection by SAR image*
- *Need for a comprehensive understanding of:*
  - *AIS data reception for each station: range, angular aspect, sea state/atmosphere dependency…*
  - *Non detection linked to the SAR image itself*

Characterisation : RCS model of vessels

- Modelling of vessel backscattering

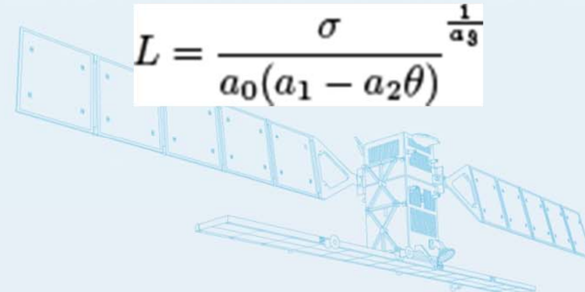


Coupling between SAR & AIS
Empirical modelling of vessel RCS with respect to it’s size and incidence angle

σ = g(L, **θ**)

L = h(**σ, θ**)

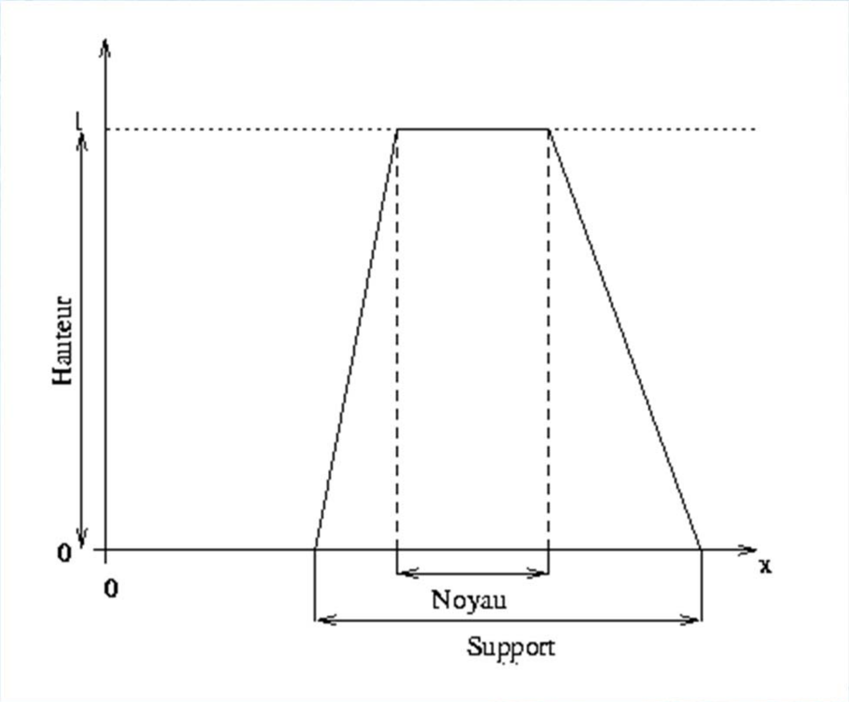
$$L = \frac{\sigma}{a_0(a_1 - a_2\theta)}^{\frac{1}{a_3}}$$



Applies to the max RCS of the vessel:
-Ensures that there is no dependency on the echo segmentation
-Implies that the RCS model has to be tuned to each product type

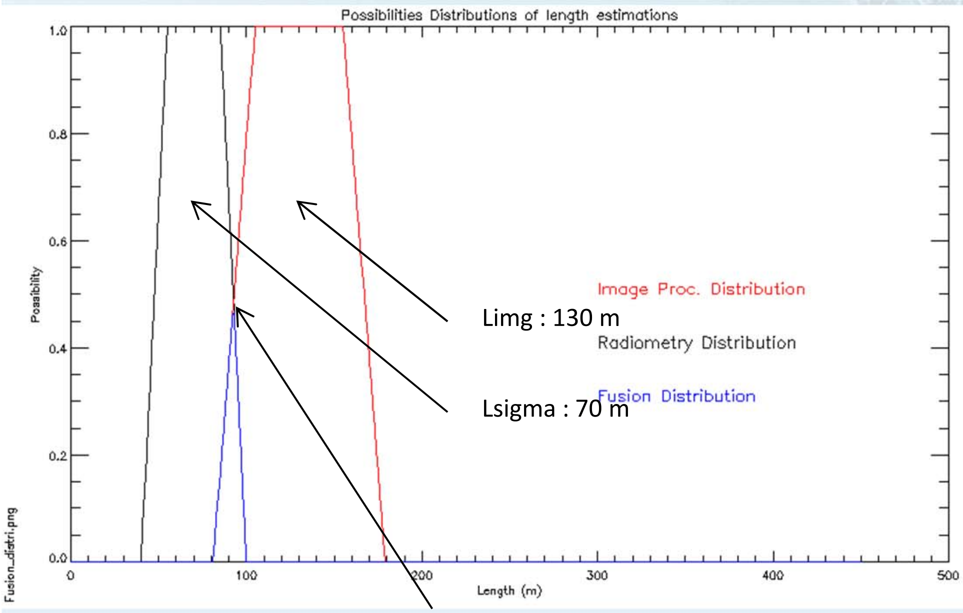
Data Fusion & Distribution of possibilities

- 1 estimation of length = 1 sensor
- Here we have two imprecise sensors
  - One sensor based on geometric measurement
  - One sensor based on radiometric measurement
- Each measurement is characterised by a distribution of possibilities
  - Support corresponding to possible values
  - Kernel corresponding to truthful values
  - Max = 1 for truthful values
  - Min = 0 for unrealistic values
- The distribution is defined based on :
  - The measurement itself and its variability
  - Limits of ship lengths
- Fusion operator
  - T-norm of Zadeh = minimum



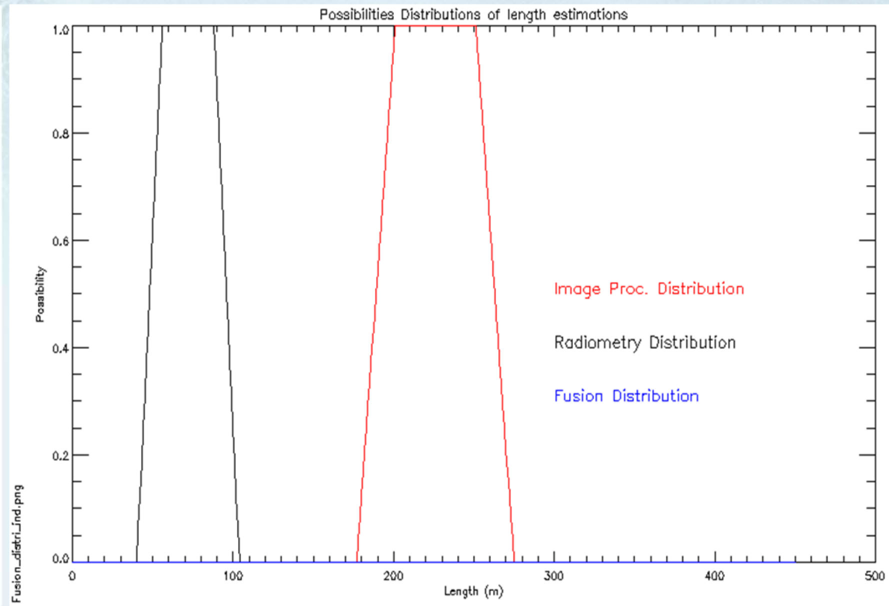
Data Fusion & distribution of possibilities

Concording sensors



Lfus : 90 m

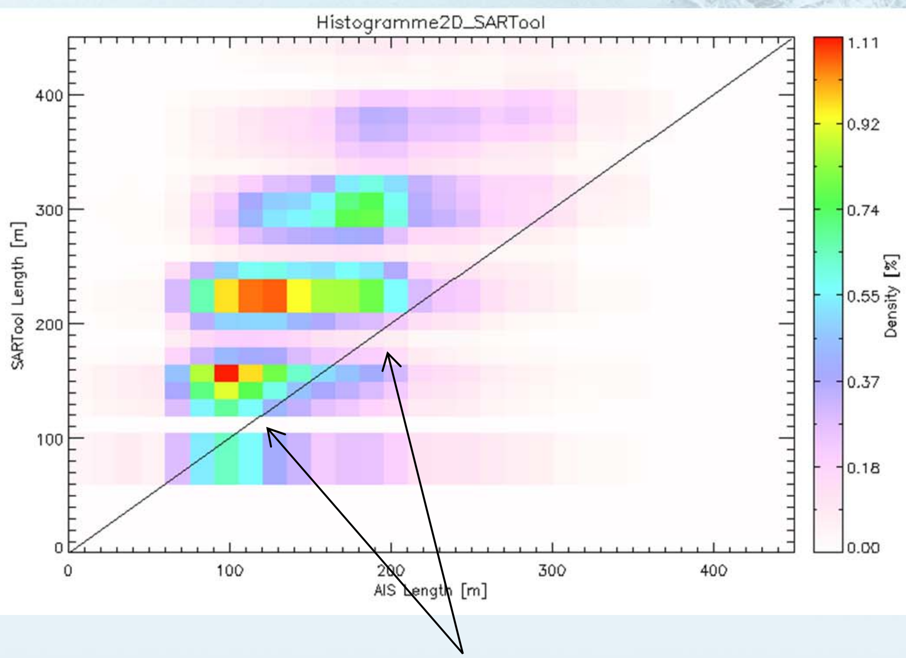
Contradictions between sensors



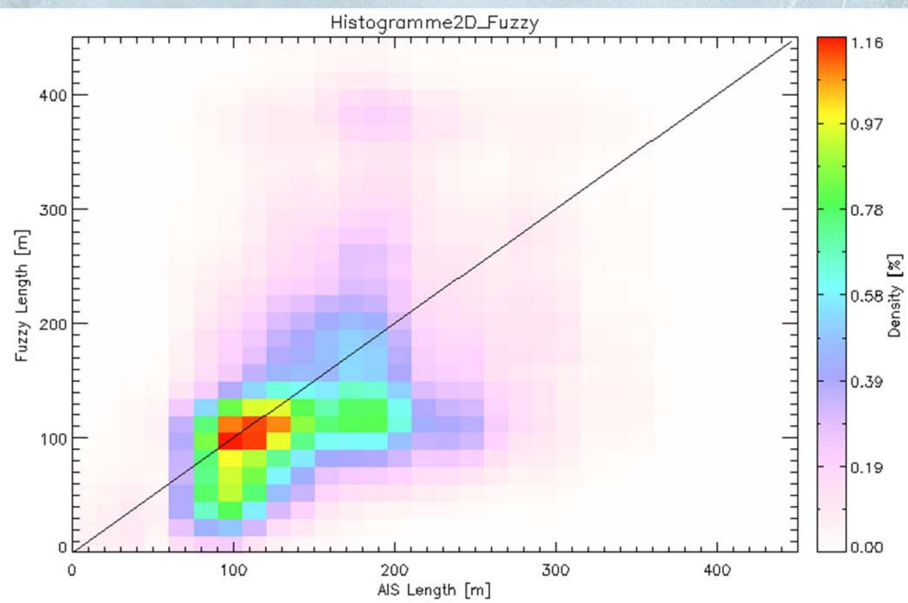
Solved by considering confidence of each measurement

Results of fuzzy logic size estimation : ASA/WSM/VV

Geometric criteria only



Fused Geometric & Radiometric

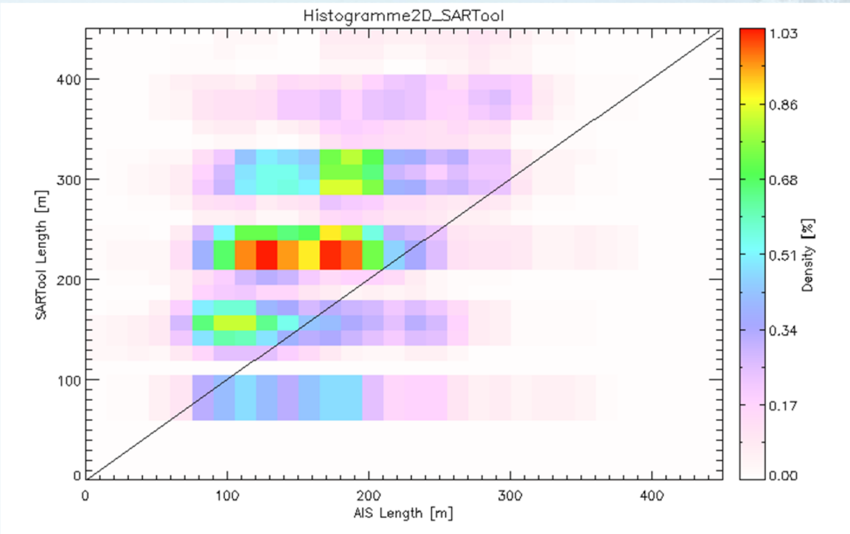


- Geometric approach with step effect : related to the geometric estimation + pixel spacing.
- Overestimation of the length

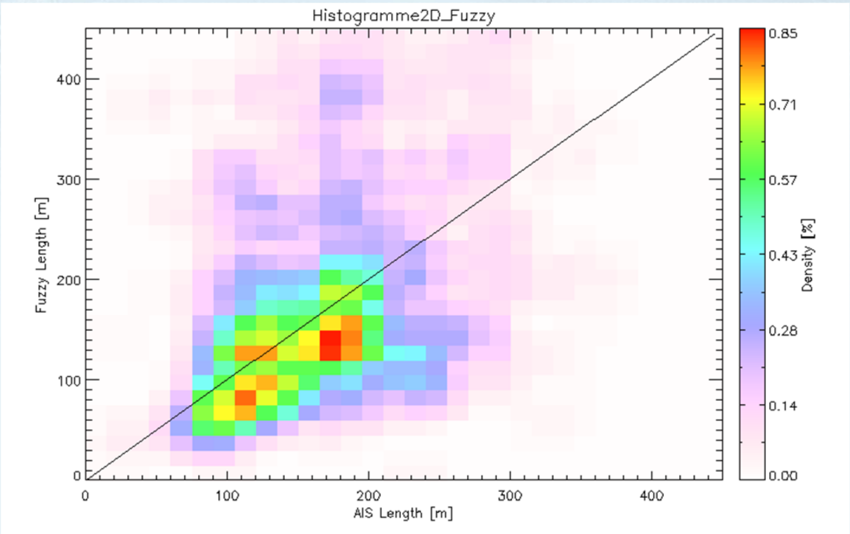
- Improvement of length estimation (better fit of the data, no step effect)
- Effective fusion for medium resolution products
- 6447 vessels for the test, 1930 for the learning of the RCS law and fusion.

Results of fuzzy logic size estimation : ASA/WSM/HH

Geometric measurement



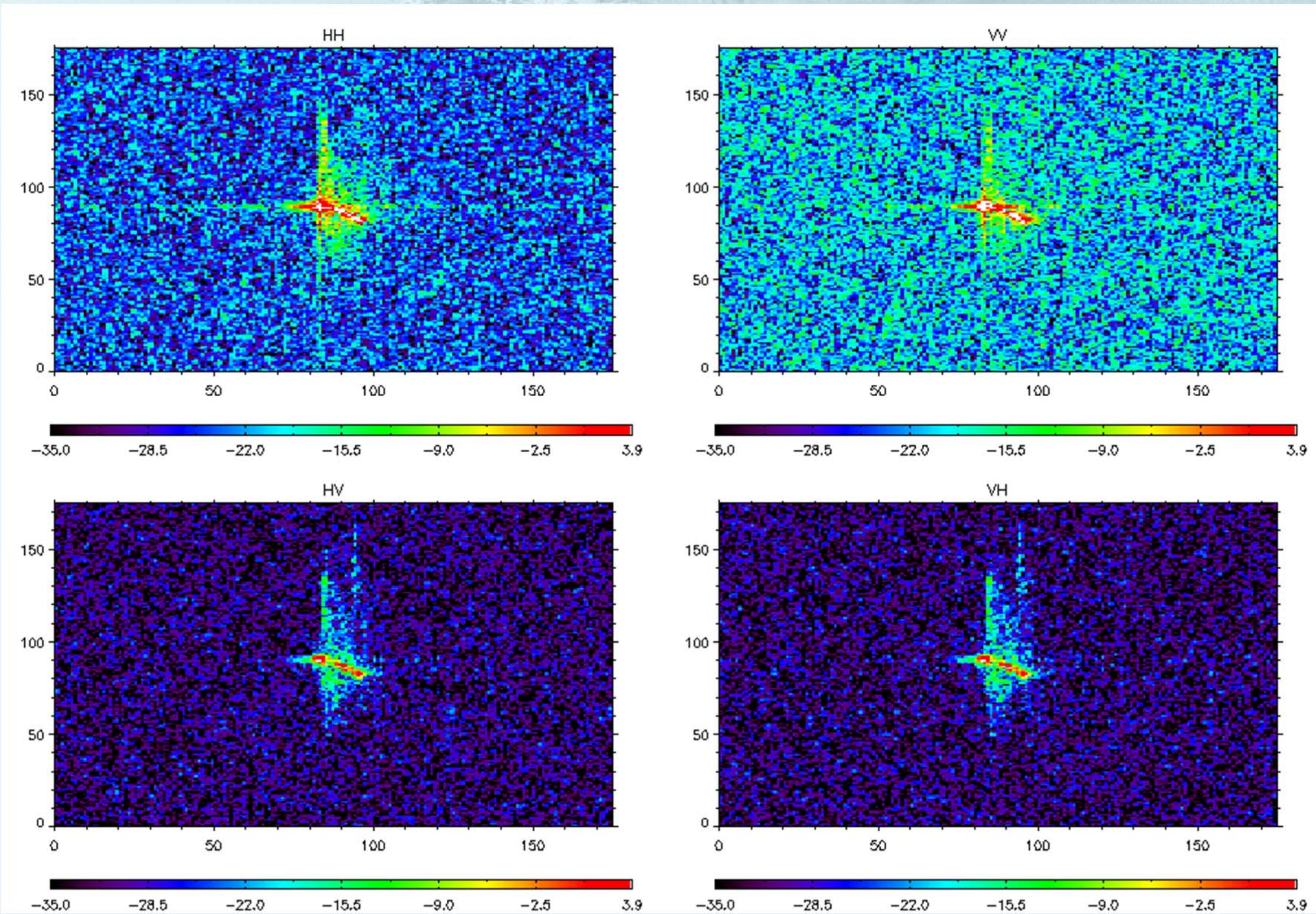
Fused geometric & radiometric



762 vessel for the test
290 vessels for learning

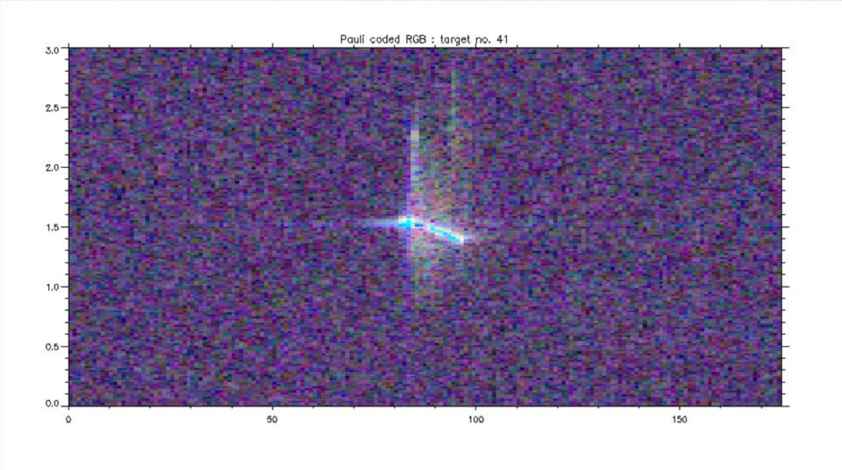
POLARIMETRIC DETECTION

Polarimetric signature of a vessel imaged in RS2 Fine Quad Pol mode

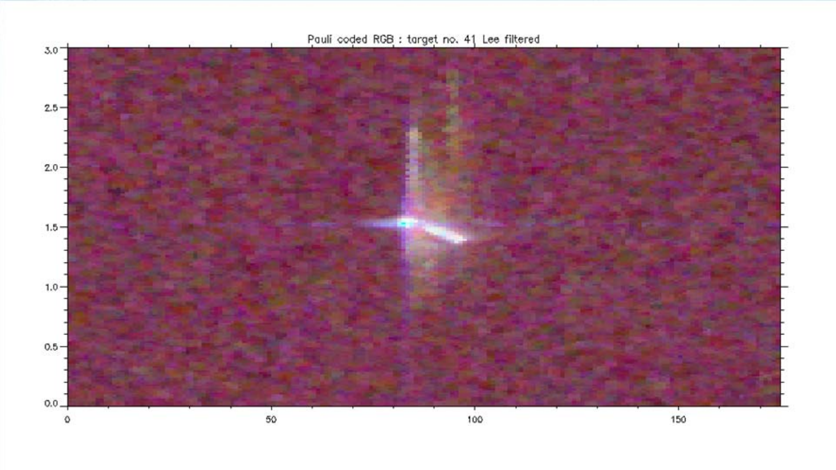


Pauli decomposition

Pauli RGB

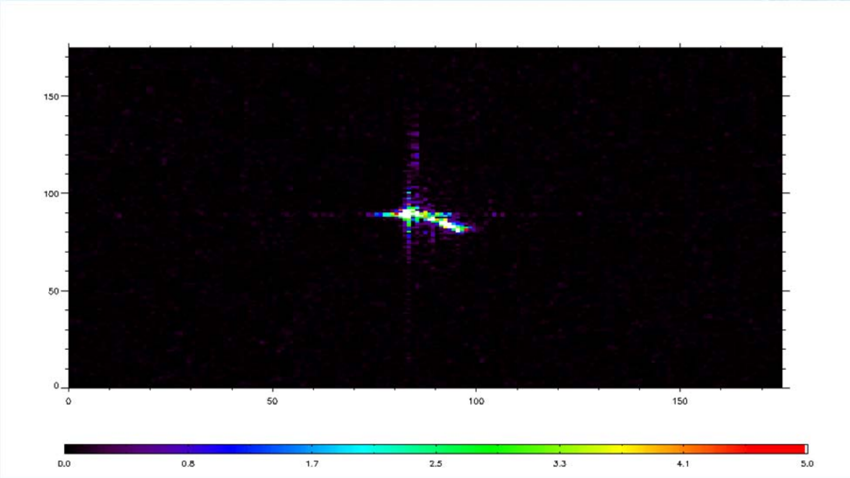


Pauli RGB with lee filtering

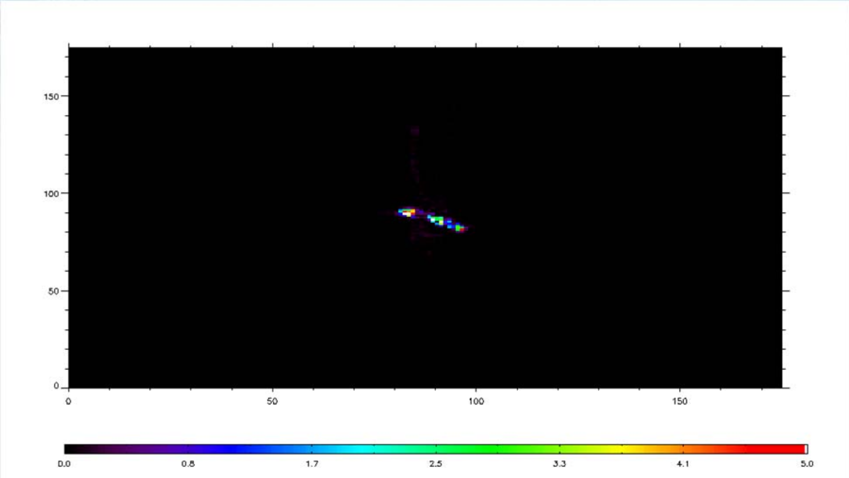


Co-pol and cross-pol power

Synthesis of co-pol power from Muller Matrix

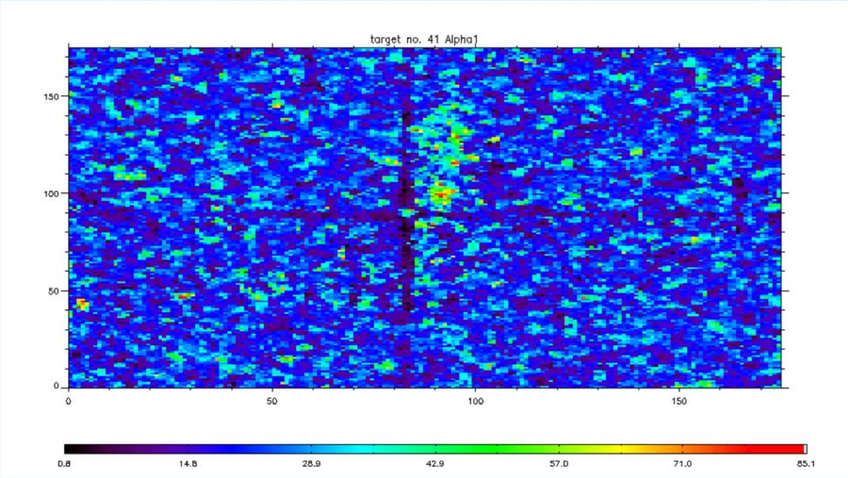


Synthesis of x-pol power from Muller Matrix

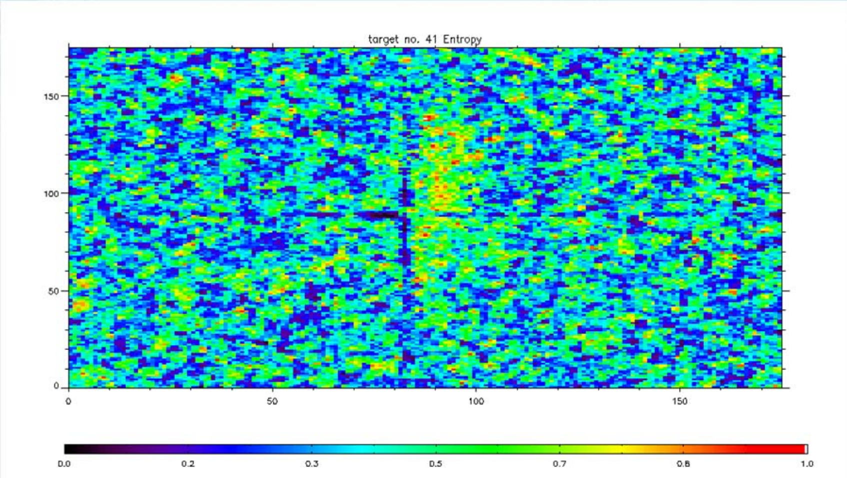


H/A/alpha polarimetric decomposition

alpha1



entropy



Optimization of Polarimetric Contrast Enhancement

- SAR based ship detection usually assumes a high contrast between a bright target and the sea clutter -> CFAR principle
  - Not valid for small target « lost » in sea clutter (low contrast)
- Full polarimetric data enables the generation of the target/clutter signature in any polarisation basis $P_b = \boldsymbol{h}^t [K]_b \, \boldsymbol{g}$
  - **K** polarimetric Kennaugh matrix and **g-h** the receiving and transmitting antenna polarisation state
- OPCE-like method optimizes the contrast (Kostinski et al 77-78) – recent fast implementation by Yang et al. 2004

$$\text{maximize} \quad \left(\frac{\boldsymbol{h}^t [K]_a \boldsymbol{g}}{\boldsymbol{h}^t [K]_b \boldsymbol{g}} \right)$$

$$\text{subject to} \quad g_1^2 + g_2^2 + g_3^2 = 1$$

$$h_1^2 + h_2^2 + h_3^2 = 1.$$

- Ideas to be developed/tested in the coming months
  - Build a comprehensive polarimetric database from RS2 quad-pol images
    - Various detected ships, incidence angle, sea state …
  - Extract a limited (if possible) set of g-h polarisation state optimizing the ship-to-clutter ratio
  - Apply this set of vector and apply a CFAR-based method on the simulated power

Conclusion

- Automatic vessel detection is usually only a part of marine applications
  - Help to operators in order to perform iIdentification of polluters, or IUU activities...
- Multiple possibilities to measure vessel characteristics
  - Each of them with different reliabilities
  - Interest to combine/fuse them in order to improve the overall accuracy
- Still lots to be done with polarimetric information
  - Even if full polarimetric data will not be systematically available
- Interest of interfacing echo (not vessel) detection with metocean measurement in order to improve their overall performance and accuracy
  - Toward and integrated wind-wave-current +VESSEL inversion

The End

THANK YOU

Bibliography

- [Skolnik] Skolnik, Merrill Ivan. Radar handbook. McGraw-Hill, 1990.
- [Vachon97] Vachon, PW, JWM Campbell, CA Bjerkelund, FW Dobson, et MT Rey. « Ship detection by the RADARSAT SAR: Validation of detection model predictions ». Canadian Journal of Remote Sensing 23, n°. 1 (1997): 48–59.

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- Part of the results int this presentation where obtained in the framework of the FP7 DOLPHIN Project:
    - http://www.gmes-dolphin.eu/team

Appendix : Minimum detectable ship length for Sentinel-1 HH and HV

Sentinel-1 : ESA’s Radar Observatory Mission for GMES Operational Services, SP-1322/1, March 2012

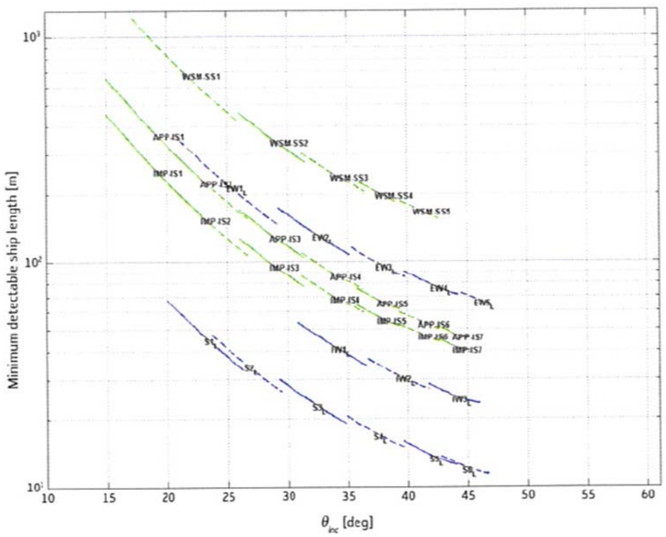

Figure 12.4. Minimum detectable ship length for Sentinel-1 HH (blue) and Envisat ASAR HH (green).
HH, $U = 12\ m\ s^{-1}$, $\varphi = 0°$; $\nu = 4$; PFA = 2.5e-009; PD = 0.9; margin = 3 dB.

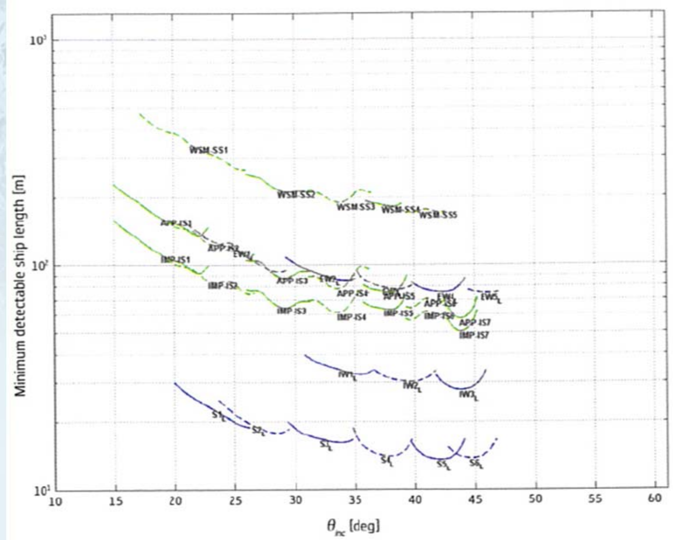

Figure 12.5. Minimum detectable ship length for Sentinel-1 HV (blue) and Envisat ASAR HV (green).
HV, $U = 12\ m\ s^{-1}$, $\varphi = 0°$; $\nu = 4$; PFA = 2.5e-009; PD = 0.9; margin = 3 dB.