OSIRIS

"Optical and Sar data and system Integration for Rush Identification of Ship models"

a Maritime Situational Awareness System

ESA GSTP

ESA-IPL-POE-SBo-sp-RFP-1008-2015

FP meeting

5th December, 2018

ESA-ESRIN - Frascati
Via Galileo Galilei
00044 Frascati (Roma)
building XYZ, floor ???, room ???

Claudio Di Paola PM & TM (MapSat), Andrea Marchetti (CNR IIT), Emanuele Salerno (CNR - ISTI), Alessandro Greco (SisTer)

Agenda

- *Project description*
  - *Project overview*
  - *Project initial objectives*
  - *Data*
  - *Developed functionalities*
  - *Results*
- *Prototype - Live demo*
  - *Sentinel 1A/1B full chain*
- *Discussion about future developments*

ESA attendees:
Joost van Bemmelen
Michele Iapaolo
Gordon Campbell
Andrea Della Vecchia
Guenther Landgraf
Philippe Mougnaud
Jose Antonio Rodriguez Vazquez
Antonio Romeo

Consortium attendees:
Claudio Di Paola (MapSat)
Andrea Marchetti (CNR-IIT)
Emanuele Salerno (CNR-ISTI)
Alessandro Greco (SisTer)

Consortium (1)

MapSAT is an Italian company, which was formed on 23rd March 2015 in Milan. It took control of MARSEC (Mediterranean Agency for Remote Sensing and Environmental Control) starting on September 2015.
MARSec has provided Satellite and Ground Station services in the field of Maritime for:

- CleanSeaNet maritime safety project of EMSA (with Telespazio)
- the control of fishing vessels of JRC-Ispra,
- the control of the illegal immigration (with Almaviva) as part of the SATM project of the Interior Ministry.

LEOP satellite missions: 10+ years expertise
2004: TERRA, AQUA
2005: EROS-A
2006: RadarSat-1
2009: EROS-B

The chart describes the relationship between subjects that are involved in the project.

Consortium (2)

CNR-IIT
The Institute of Informatics and Telematics of CNR (National Research Council of Italy) carries out activities of research, assessment, technology transfer and training in the field of Information and Communication Technologies and of Computational Sciences.

Within this sub-contractor it is also incorporated a team of the CNR-ISTI.

CNR-ISTI
The Institute of Information Science and Technologies (ISTI) is one of the 108 Institutes of the National Research Council of Italy (CNR).
The Institute is located in the CNR Research Area of Pisa.
ISTI is committed to producing scientific excellence and to playing an active role in technology transfer.
The domain of competence covers Computer Science, Information Engineering, related technologies and a wide range of applications.

SISTER
Sistemi Territoriali srl was established in 1991 as a spin-off of the CNR.
Today, Sister provides consulting and professional services to public and private companies in the field of GIS, Business Intelligence Systems, Big Data, Open Data, Social Network Analysis, Semantic web.

The chart describes the relationship between subjects that are involved in the project.

Project Overview

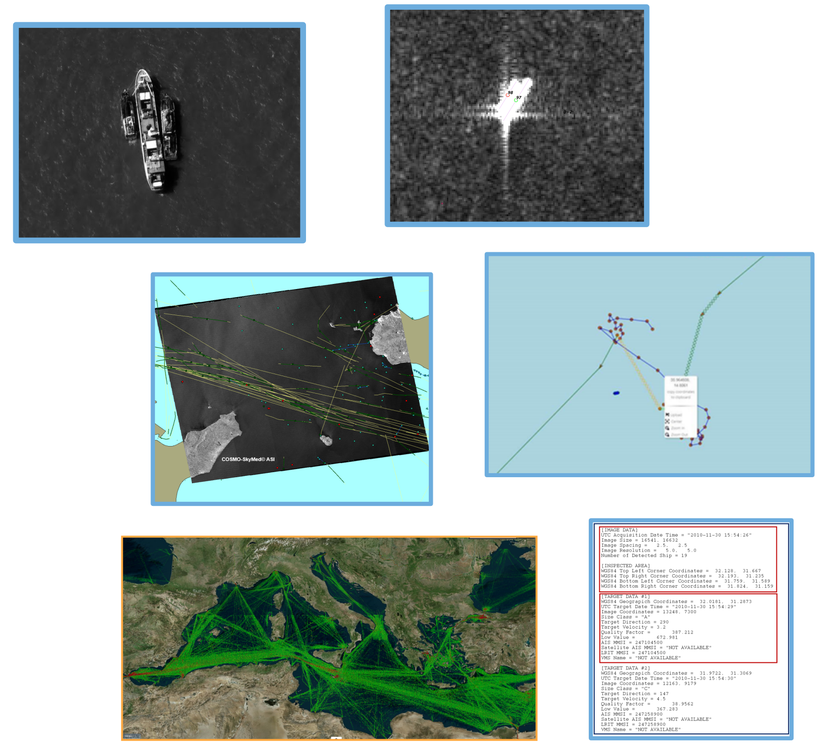
Companies and Research Institutes collaborated on development of effective maritime awareness system based on smart analysis of satellite imagery and complementary data sources.

Project General Objectives:

The project aim at demonstrating as an optimized planning of complementary satellite sensors, RADAR and Optical together an algorithms library able to extracted accurate information from EO multi-mission data and integrate them with legacy system data (AIS), can provide valid support for the decision making process in the maritime domain.

Project Key Words:

Sensors: SAR satellites, EO satellites, AIS data (Satellite and Terrestrial)



Initial Objectives (1)

The main technical objectives of the ITT/RFP consist at least of following target services:

1. **Data Acquisition, Gathering and Fusion**
2. **Processing and Final Services**
3. **User Interface**

1. Data Acquisition, Gathering and Fusion

a. Copernicus Rolling Archive, Tasking and daily synchronization of Cosmo Sky-Med SAR VHR and EROS-B EO VHR satellite mission

b. AIS data Fusion
- AIS terrestrial data source
- SAT-AIS satellite data source

c. Knowledge data integration
- VTS and LRIT (Closed information data source e.g.: Ministry of Interior, Coastal Guard, Frontex, EMSA)
- OSINT data source

Initial Objectives (2)

2. <u>Processing and Final Services</u>

d. Ship Detection
- Detection and Showing targets (vessels) present in a given AOI.
- Showing all vessels which are not transmitting any messages associated to their location (not-cooperative vessels)

e. Ship “Identification”
- Estimate of main physical characteristics (length, width…)
- Classification for types of vessels (course classification and fine classification)

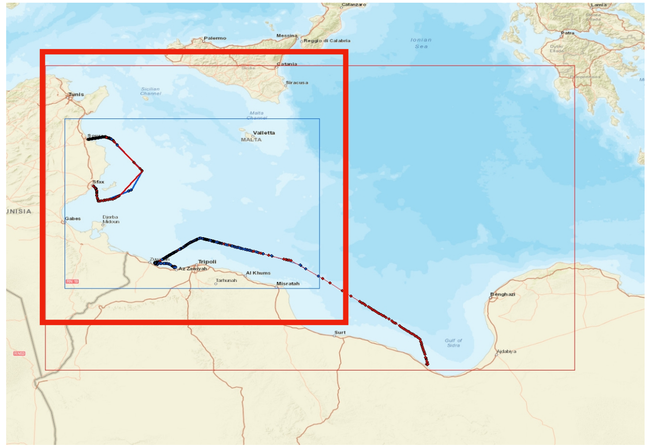
f. Ship moving data extraction (hearing, speed)
- Estimation of average speed and heading

g. Route Prediction
- Estimation of the expected upcoming route
- Detection of vessel behavior (e.g.: cooperative/not cooperative, rendezvous, stationary vessel…)

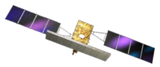
3. <u>User Interface</u>

h. Web user interface to inquire the requests and to visualize the outputs.

AIS and Remote Sensing data source







Data source	ExactEarth	EROS-B	CSK	S1	S2
Type	S-AIS (& T-AIS)	VHR-PAN	VHR-SAR	HR-SAR	HR-MS
Constellation	world coverage	1	4	2	2
Status	active	active	active	active	active
Data access Policy	Archive RT https (getting xml or Json)	Archive On-demand Tasking	Archive On-demand Tasking	Rolling Archive carpet mapping	Rolling Archive carpet mapping
AoI Revisit Time	continuous	2 days	DAILY	plan	plan

Data Collection

Provider	**ExactEarth Europe Limited + VesselTracker**	**AstraPaging L.t.d.**	**e-GEOS**	**ISI**	**ESA - Copernicus** **Open Access Data Hub**
data source	**S-AIS + T-AIS**	**T-AIS**	**CSK**	**EROS-B (Pan)**	**Sentinel 1A/B, 2A/B**
data gathering	**2016-07-23** **2018-07-31 (also up today)**	**2016-10-19** **2017-12-24**	**10 Stripmap Himage**	**41.8 Archive,** **52 Tasking,** **26 Orbits Reserved**	**Rolling Archive**

open sea sat-AIS

more antennas along the African coast (acquired on enlarged area)

multi-source integration for better coverage

RoI and AoIs

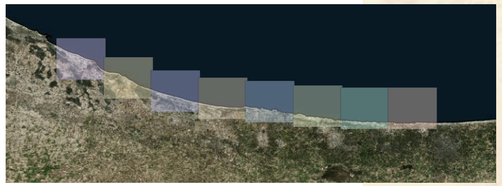
~~AoI 4~~
~~name: Sicily Channel~~
~~target type: dynamic~~
~~daily synch: no~~
~~CSK: Stripmap Himage~~

AoI 4
name: Isola Ferdinandea
target type: dynamic
daily synch: no
E2: mosaic

AoI 3
name: Malta
target type: static
daily synch: yes
CSK: StripMap Himage
E2: mosaic

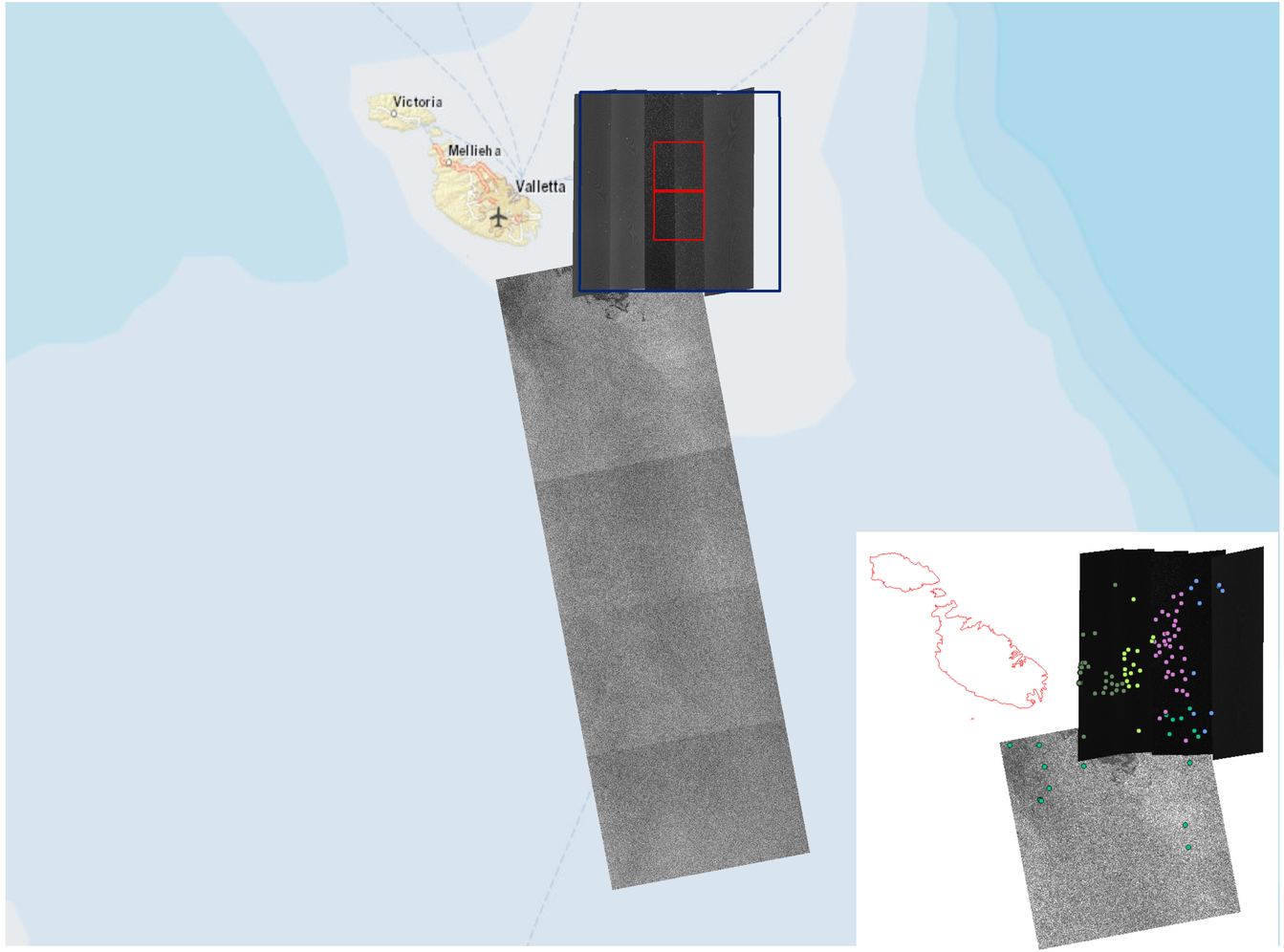
AoI 5
name: DeepField
target type: static
daily synch: no
E2: mosaic

AoI 1
name: Libya shoreline
target type: static
synch: no
E2: mosaic



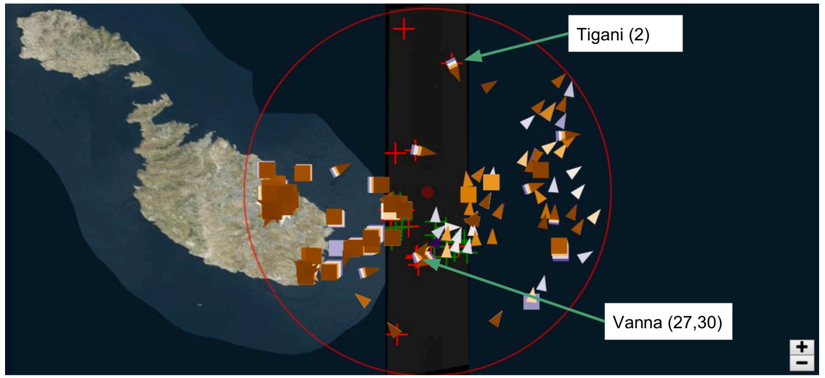
AoI 2
name: SaR
target type: dynamic
daily synch: yes
CSK: Stripmap Himage
E2: mosaic

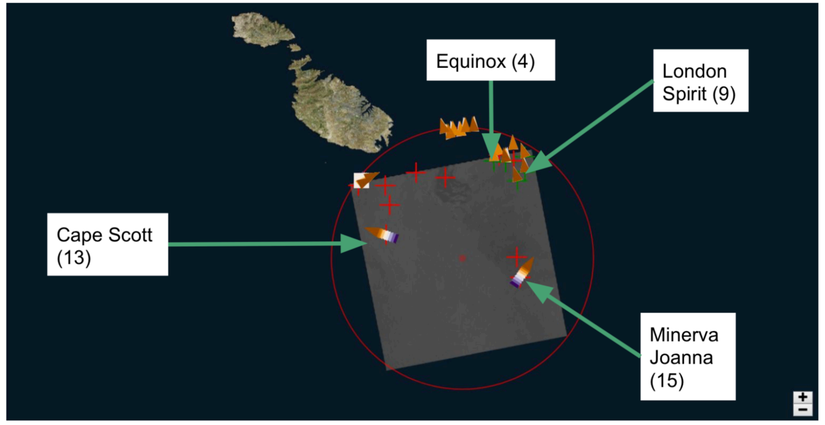
SAR-Optical Daily Synchronization: Malta



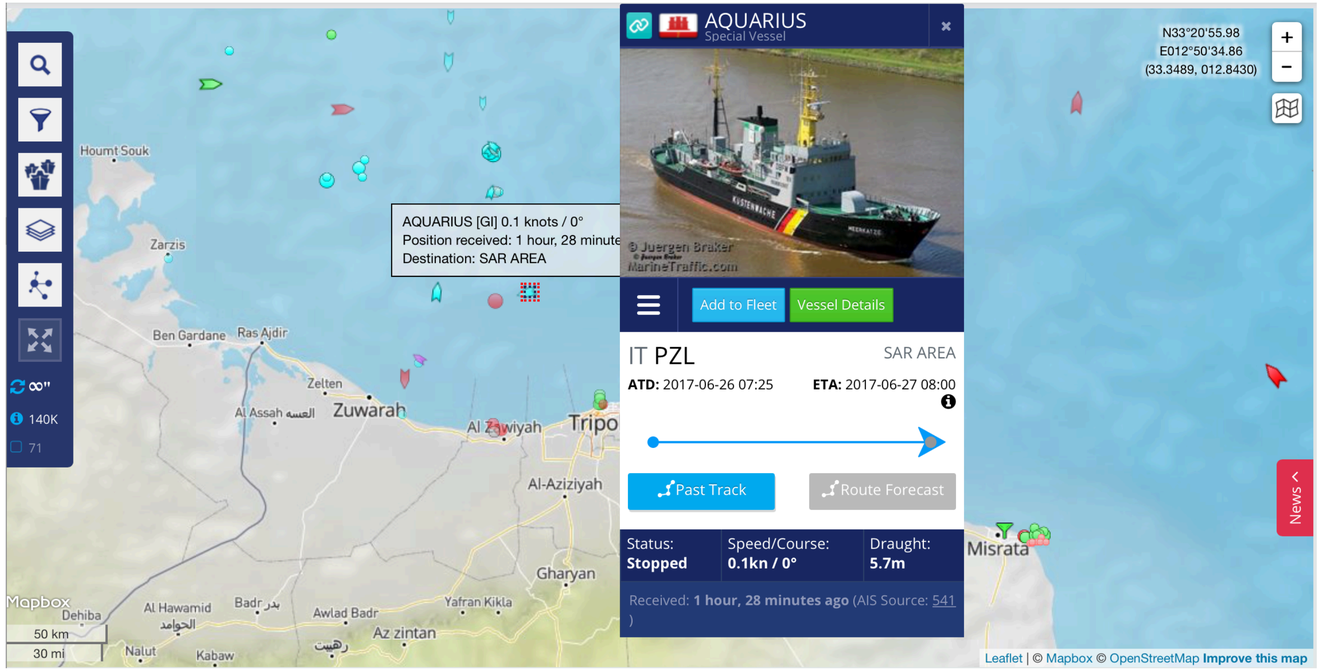
2017_0817
Partial overlapping

We didn't find anything match among vessels





SAR-Optical Daily Synchronization: SaR zone



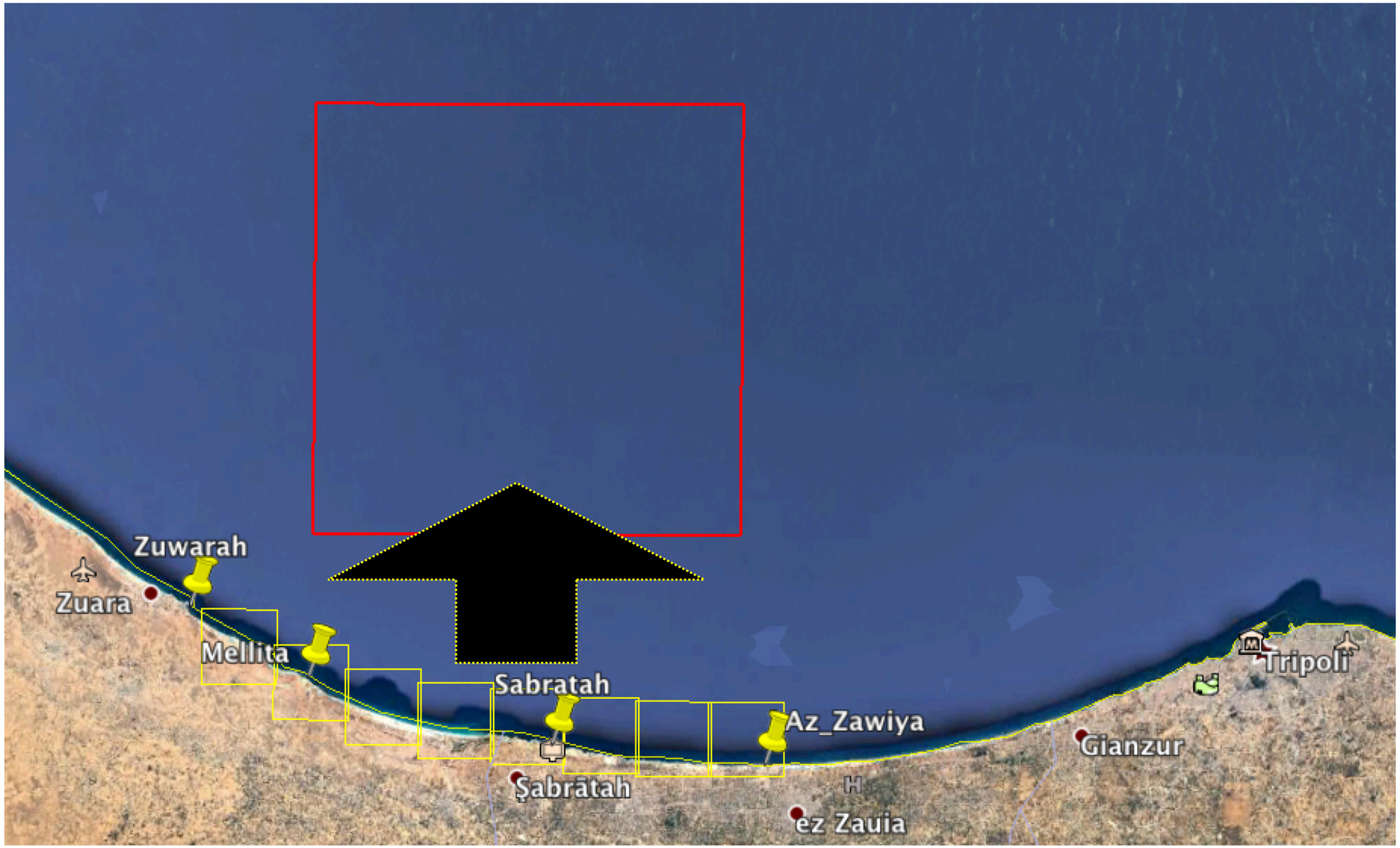
AQUARIUS (SAR) - MMSI: **236527000**

start data-time: 20170620 CEST08:00
end data-time: 20170628 CEST08:00

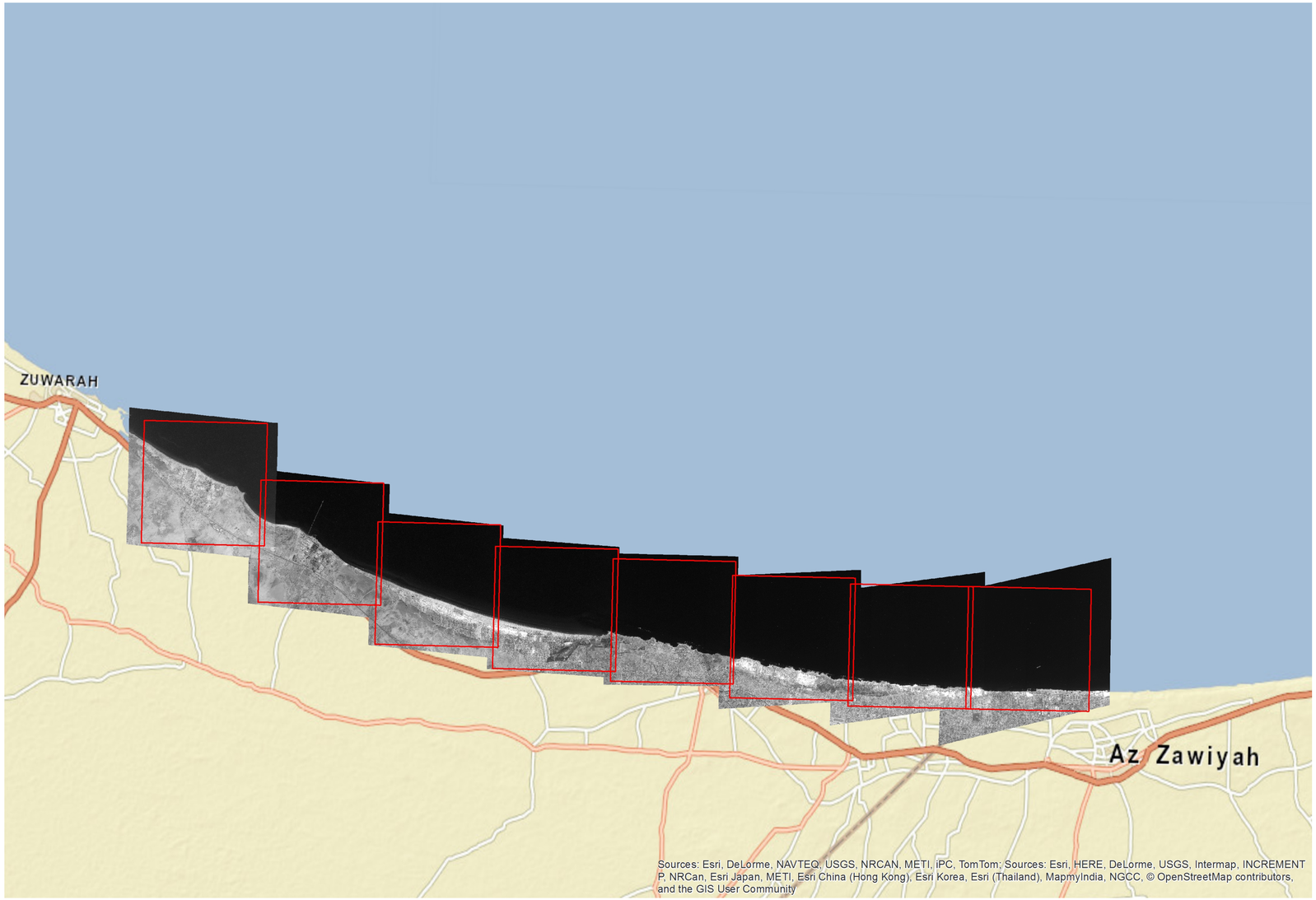
SAR-Optical Daily Synchronization: SaR zone

New AoIs:
SaR zone (red) and
Libyan coast/harbors (yellow)

How illegal immigration ships moves?



SAR-Optical Daily Synchronization: SaR zone

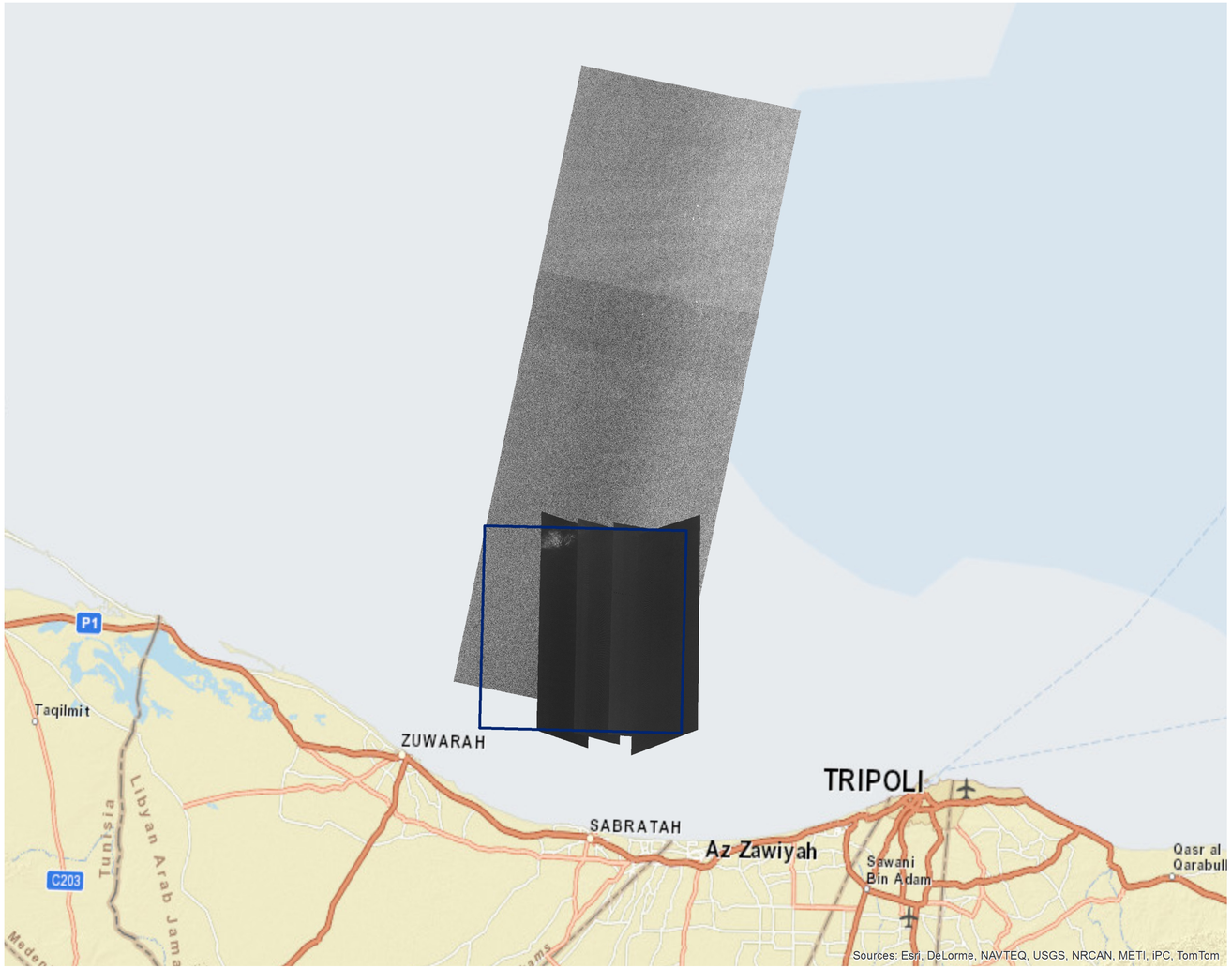


2017_0831
Libya harbors

We found only a fishing ship in the shoreline area

SAR-Optical Daily Synchronization: SaR zone

TEST Scenario: from Libya harbors to Daily Synchronization over the SaR-Zone



2017_0821
a good geospatial overlapping

We didn't find anything
into overlapped area

What were the reasons?

SAR-Optical Daily Synchronization: SaR zone

Codice per **Ong**, governo spaccato | Plauso di Mattarella per **Minniti**
TGCOM - 07 ago 2017
Le nuove regole - "Chi non ha firmato il Codice di condotta non potrà far parte del sistema di salvataggio che risponde all'Italia", ha detto l'altro giorno il ministro **Minniti**, e infatti la nave Prudence di Medici senza Frontiere - una delle **Ong** che non ha sottoscritto il documento - non è entrata nelle acque territoriali italiane per ...

[Il retroscena] Il Governo si spacca sulle **Ong**, **Minniti** ad un passo ...
Tiscali.it - 07 ago 2017

Marco **Minniti** era pronto a farsi da parte. Arriva il sostegno del ...
L'Huffington Post - 07 ago 2017

Migranti, il Colle e Gentiloni 'blindano' **Minniti**: "Grande lavoro e ...
Editoriali - La Repubblica - 07 ago 2017

Migranti, Delrio critica **Minniti**: «Guerra agli scafisti, non alle **Ong**»
Approfondimenti - Corriere della Sera - 07 ago 2017

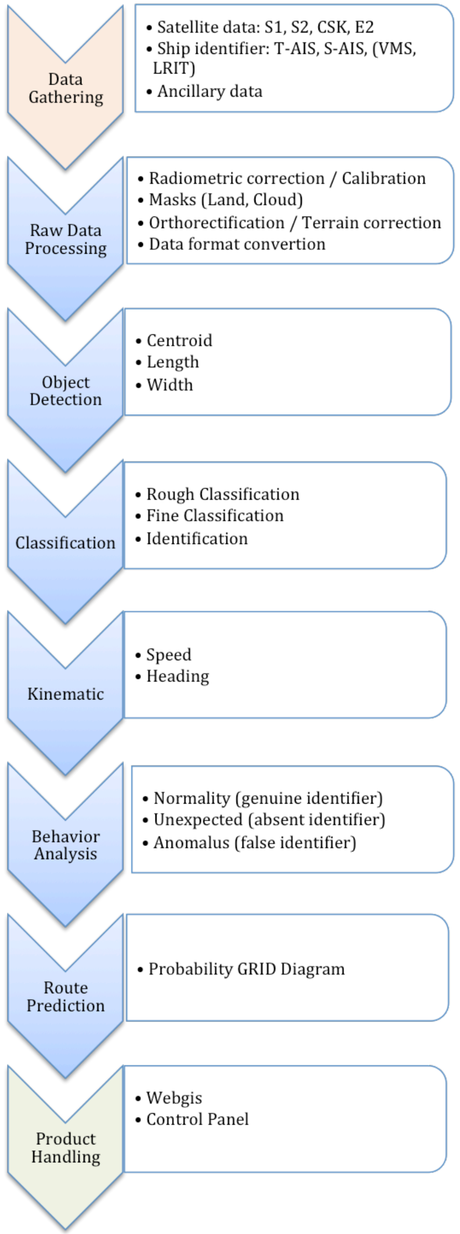

Corriere della…


Tiscali.it

La Repubblica


L'Huffington …

What were the reasons?



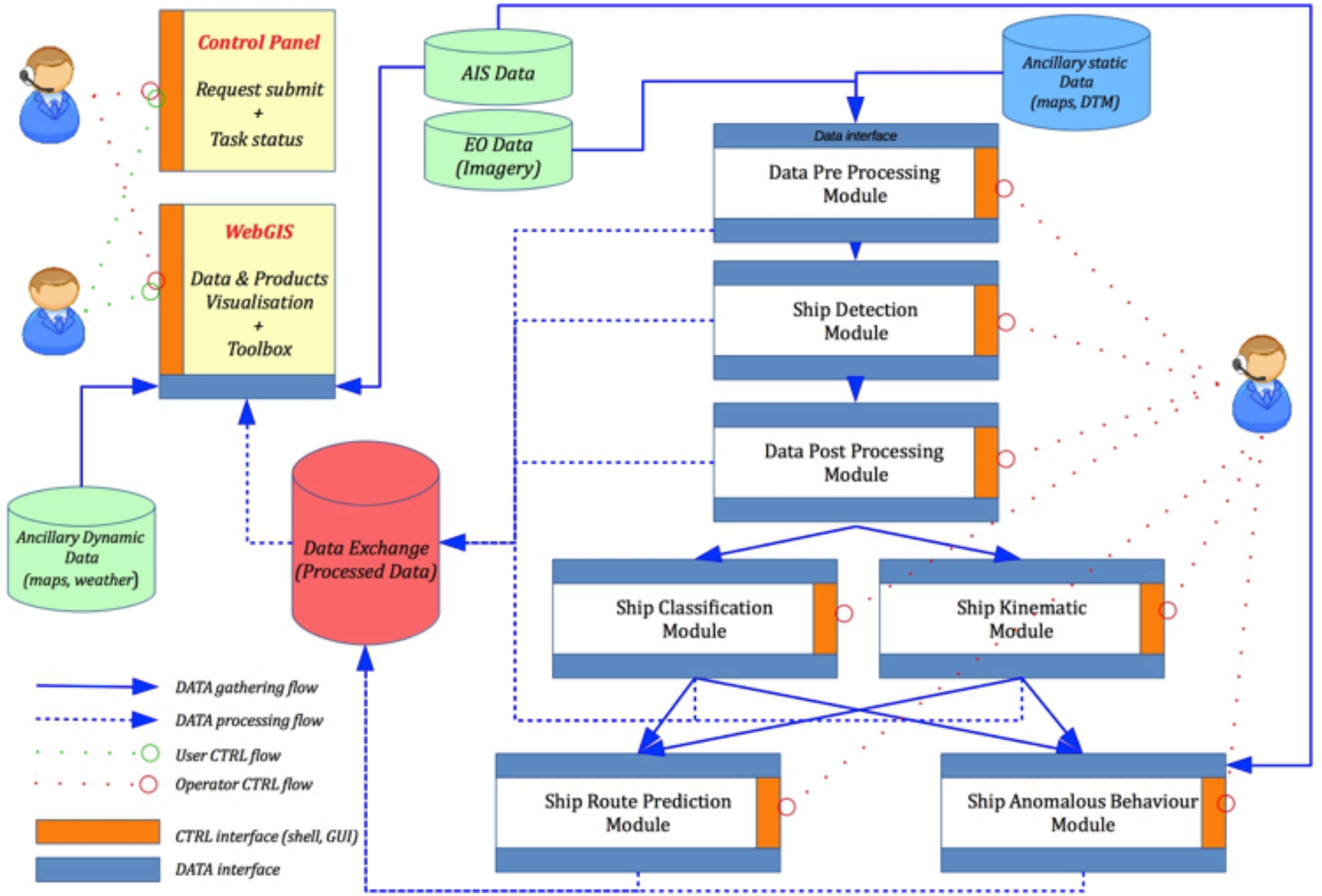
Actions flow

```
/home/user/ownCloud/Shared/OSIRIS_REPOSITORY/yyyy_mmdd

DATE (yyyy_mmdd)
  |
  |_____ IDs (semplified)
          |
          |_____ ID_RAW_DATA
          |
          |_____ DPP
          |        |_____ metadata.csv
          |        |_____ ID.tif (UTM)
          |        |_____ ID.16bit_4326.tif
          |
          |_____ SD
          |        |_____ detection.csv
          |        |_____ POLYGON (ship_detection.shp, scene_contour.shp) (*)
          |
          |_____ DPE
          |        |_____ crops.csv
          |        |_____ CROPS.zip (zipped folder with SdI.tif)
          |
          |_____ SC
          |        |_____ classification.csv
          |
          |_____ SKE
          |        |_____ kinematic.csv
          |
          |_____ SRP
          |        |_____ route_prediction.json
          |
          |_____ SBA
          |        |_____ behaviour_analysis.csv (ship w highest score)
          |        |_____ behaviour.json
          |
          |_____ DO
                   |_____ ID_full.xml (*)
                   |_____ updating the webGIS CP (eventually sending an e-mail)
```

CSV fields specification and ownCloud file-system structure

Software Architecture

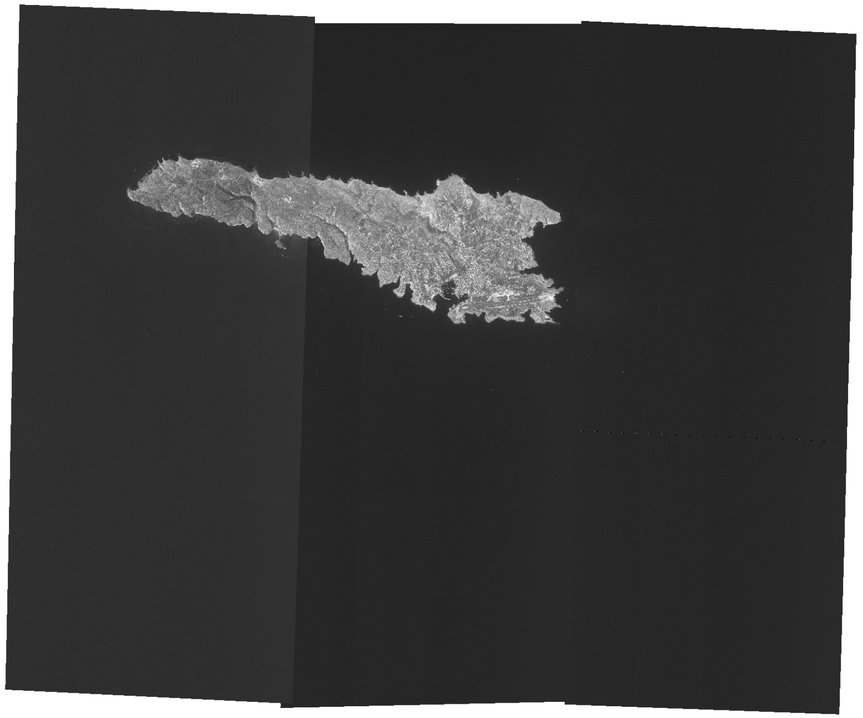


- planning, gathering and processing the data.

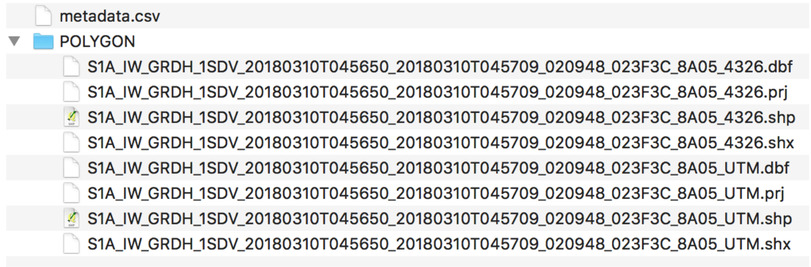
- DPP - a module for data pre-processing
- SD - a module for object detection (searching for vessel on the acquired images, their size measurement as width and length);
- SC - a module for vessel classification (fishing, cargo…);
- SKE - a module for kinematic extraction;
- SBA - a module for AIS data fusion (cooperative and not cooperative)
- SRP - a module for route prediction (to track the past route and to estimate the next route);

- CP - a user interface to handle the monitoring service;
- WG - a webGIS module for data visualization and handling;

Results: DPP module



- ***Land Mask***
- ***Geotiff reprojected 4326 and downsampled***
- ***Metadata extraction (csv format)***
- ***Contour polygons (UTM + 4326)***

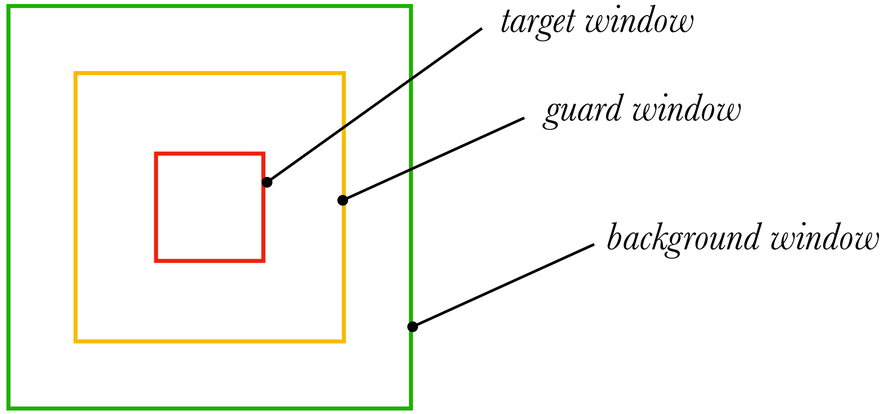


METADATA

ID	URIa	URIp	Sat	OP	SST	SET	PxS	SFDir	SSAmp	SAlt	SLAng
S1A_IW_GRDH_1SDV_20170817T165511_20170817T165536_017966_01E248_AED5	null	null	S1A	null	2017-08-17 16:55:11.558740	2017-08-17 16:55:36.556284	10.0	347.065	7596.104	7072.158	39.2361613533

Results: SD module

SNAP CFAR



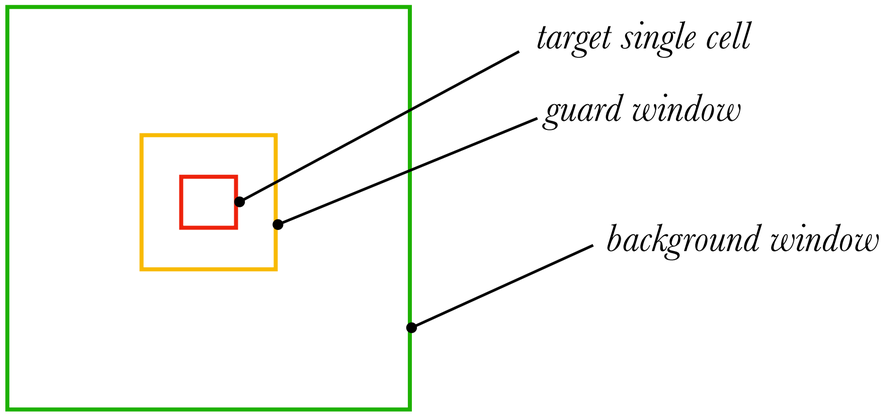
$$x_t > \mu_b + \sigma_b \quad \Leftrightarrow \text{target}$$
$$\mu_t > \mu_b + \sigma_b$$

$$PFA = \frac{1}{2} - \frac{1}{2} * erf\left(\frac{t}{\sqrt{2}}\right)$$

PDF: Gaussian distribution

in both cases:
- *the bigger BWS, the bigger the probability to detect big vessel*
- *PFA best value is a trade-off between ghost detection and missing vessel*

CA-CFAR2D



$$x_t > \alpha * \mu_b$$

$$PFA = \left(\frac{N}{\alpha\beta^2}\right)^N \frac{1}{(N-1)!} \int_{-\infty}^{\infty} T^{N-1} e^{-\left[(N/\alpha)+1\right]T/\beta^2} dT$$

PDF: Erlang

Threshold is less sensitive to background noise

Results: SD module

SAR data: SNAP vs OSIRIS

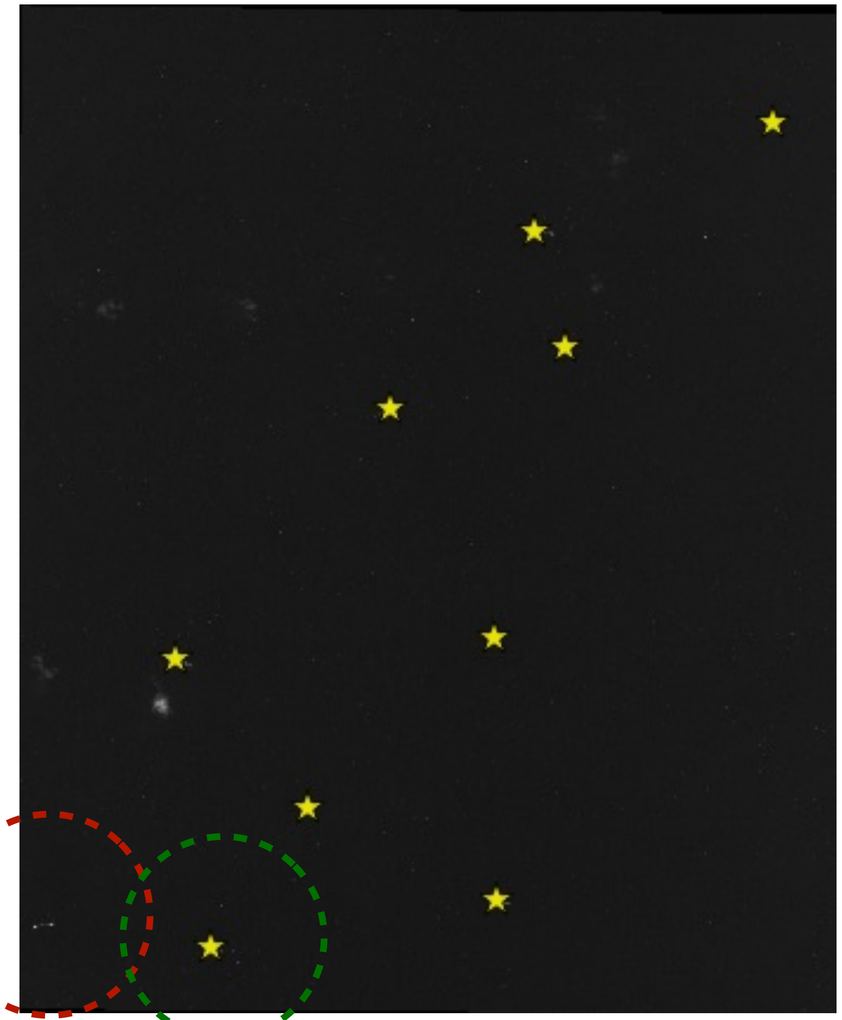
	Target	Ghost (azimuth ambiguity)	False Positive range ambiguity	Duplicated target	Detected ship	Processing Time RM(VM)	
SNAP-6 Object Detection	**46**	**11**	**6 (?)**	**3**	**32/26**	**6' (30')**	*weak on local threshold calculation*
OSIRIS CA-CFAR2D	**27**	**1**	**0**	**0**	**26**	**- (50')**	*weak on complex computation* *Python —> Matlab* *VM —> R.M.*

strong/bright ghost

S1A_IW_GRDH_1SDV_20180720T045700_20180720T045725_022873_027B01_32EC

Results: SD module

Electro Optical data: what happened? The same behavior!



- *no false positive*
- *1 false negative (a missing detection of a weak ship in shadow)*

Results: DPE module

Extracts crops around detected target with two options:

- *constant box dimension*
- *variable box dimension (depending on ship length)*

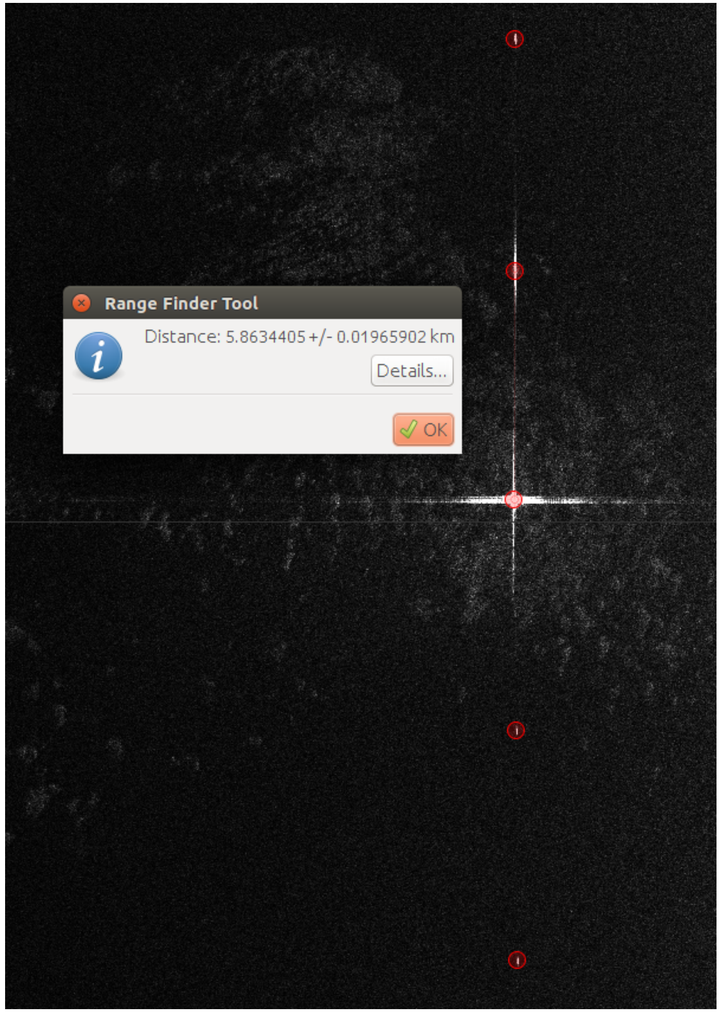
Filtering the output of SNAP detection on Sentinel-1

- *ghost detection (azimuth ambiguity - distance and sub-swath)*
- *remove duplicates (set with distance)*

crops.csv

CROPS.zip

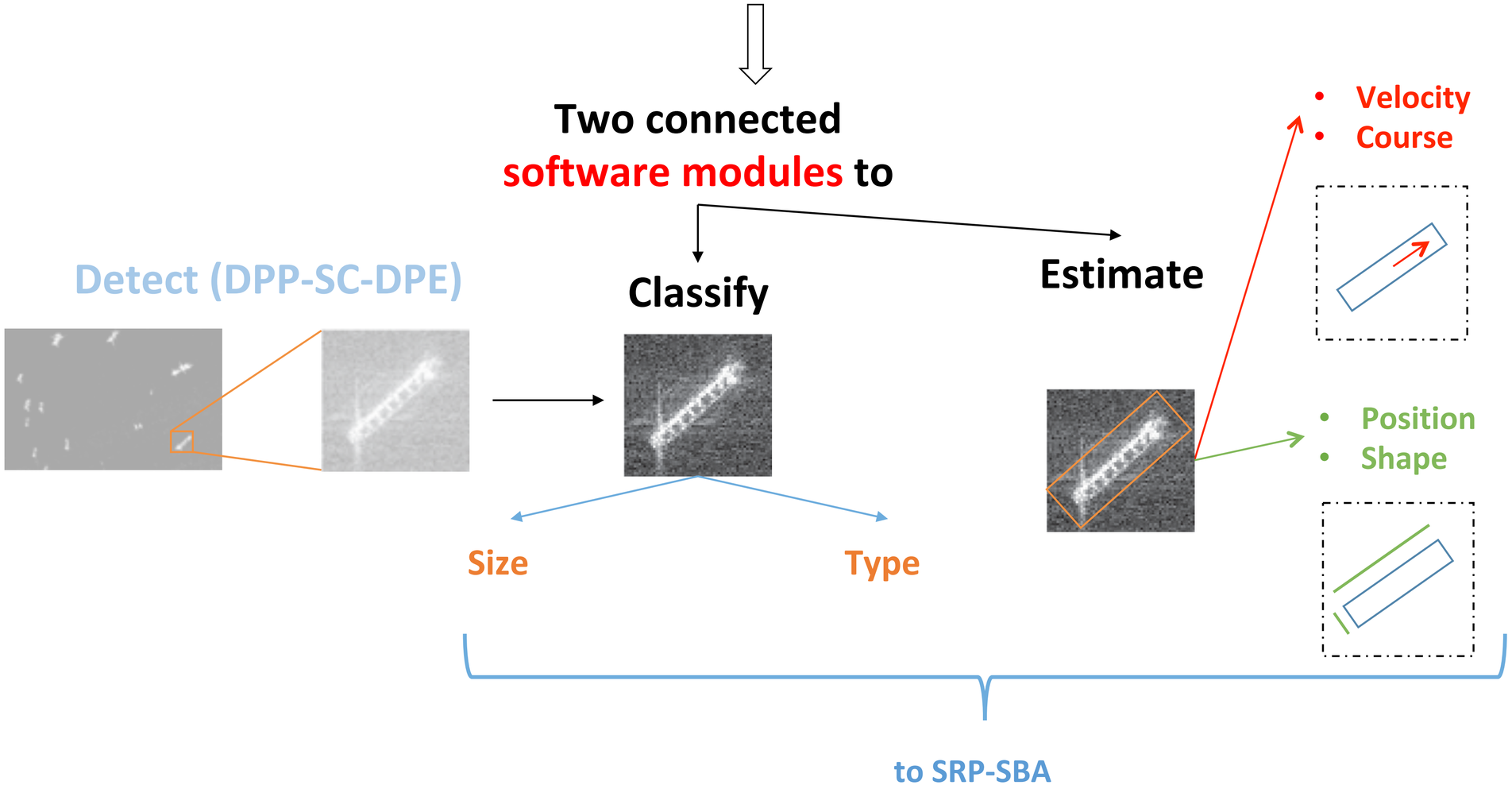
ghosts



In Sentinel-1 imagery, ghosts are also called azimuth ambiguities.
Typically they are placed in azimuth direction :
at 5200, 4700 and 5800 meters from the real target, respectively for sub-swath IW1, IW2 and IW3.

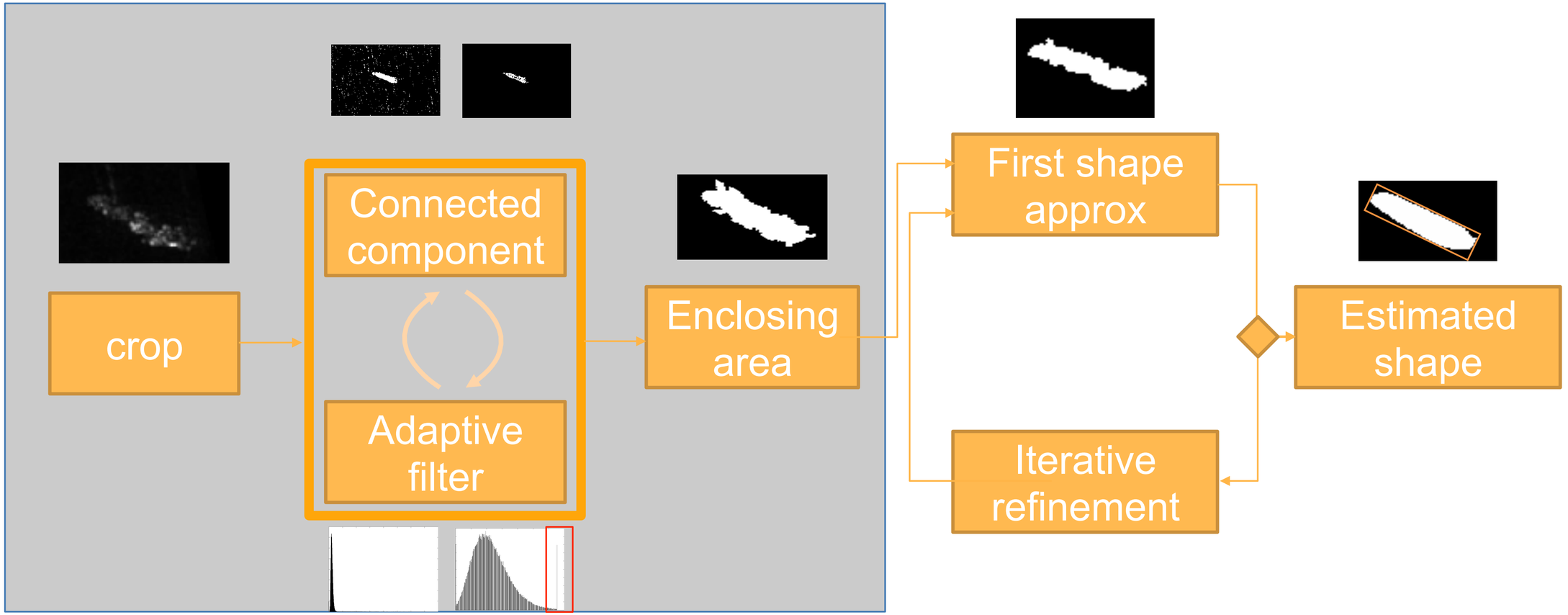
Results: SC and SKE modules

Ship Classification and Kinematics Estimation (SC-SKE)



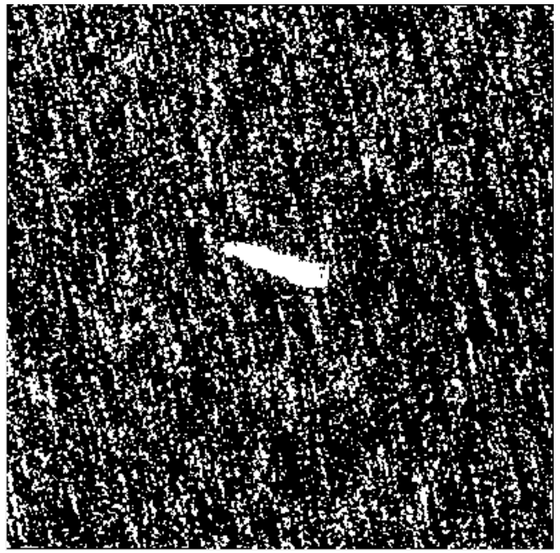
Results: SC module

Algorithm

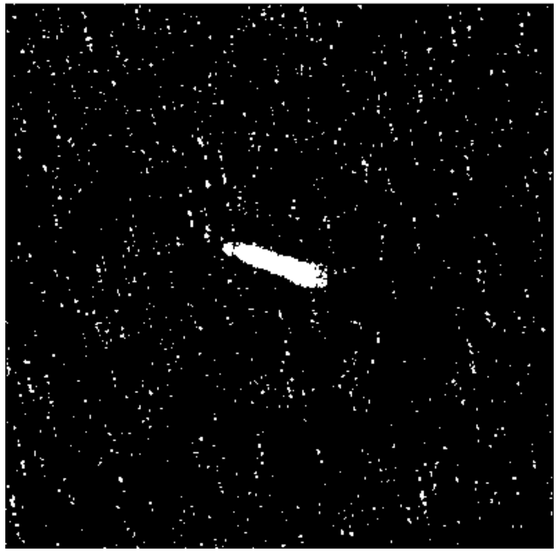


Results: SC module

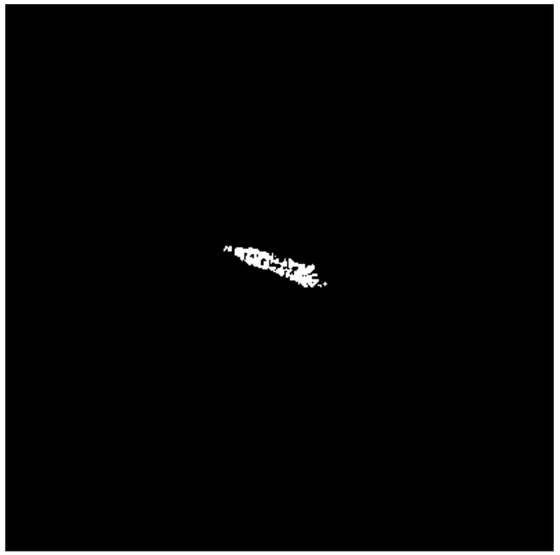
Max size connected component extraction



Threshold 1



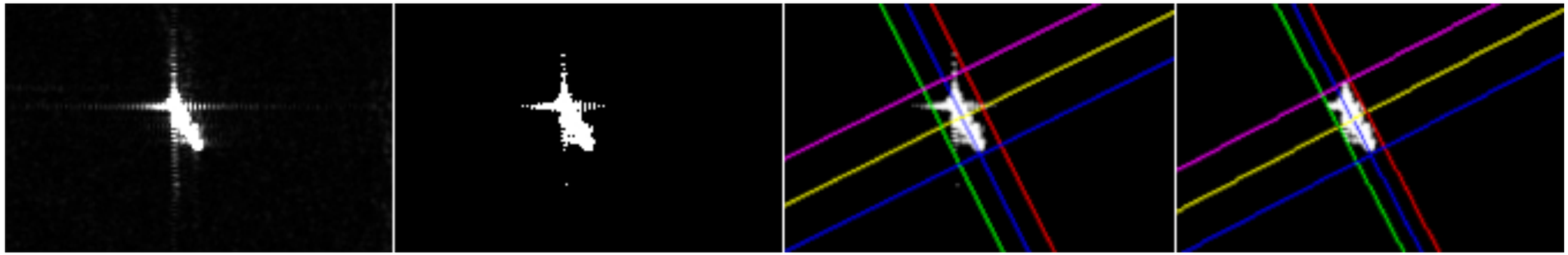
Threshold 2



Threshold 3

Results: SC module

Refined ship footprint extraction



Input image | 1st approximation footprint | 1st iteration refinement | MER and output image

Sentinel 1 data, 8-bit depth (heavily saturated to demonstrate how the algorithm works)

Results: SC module

Refined ship footprint extraction

Input image

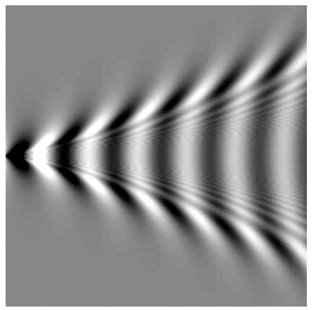
1st approximation footprint

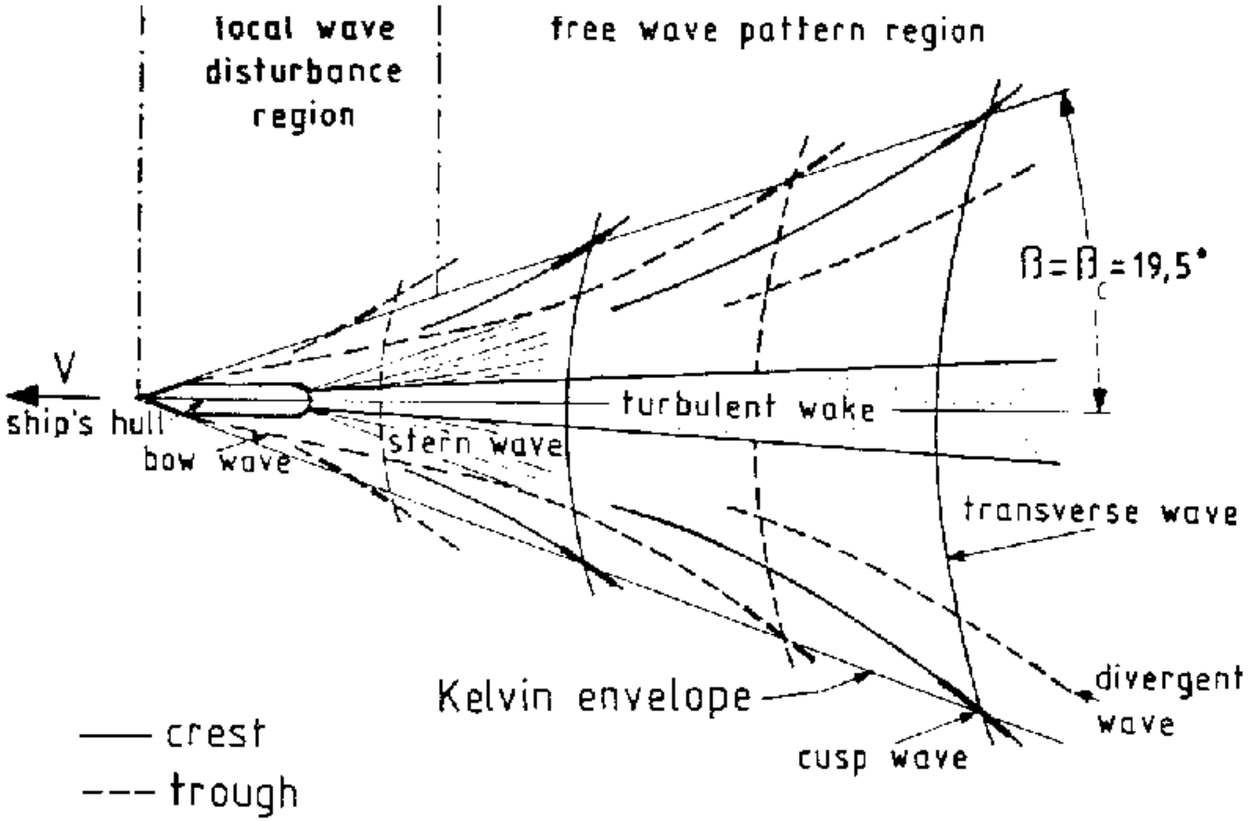
Output image overlaid with the final footprint (red, MER not shown

Sentinel 1 data, 16-bit depth (partially saturated only for visibility)

Results: SKE module

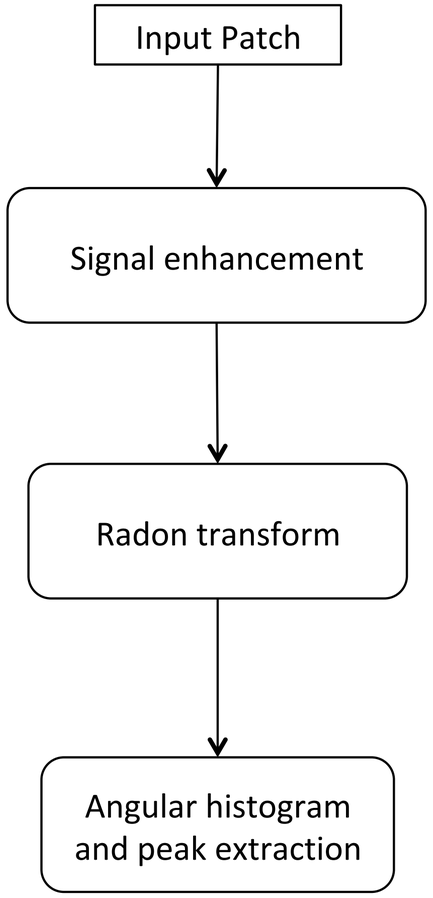
Wake pattern

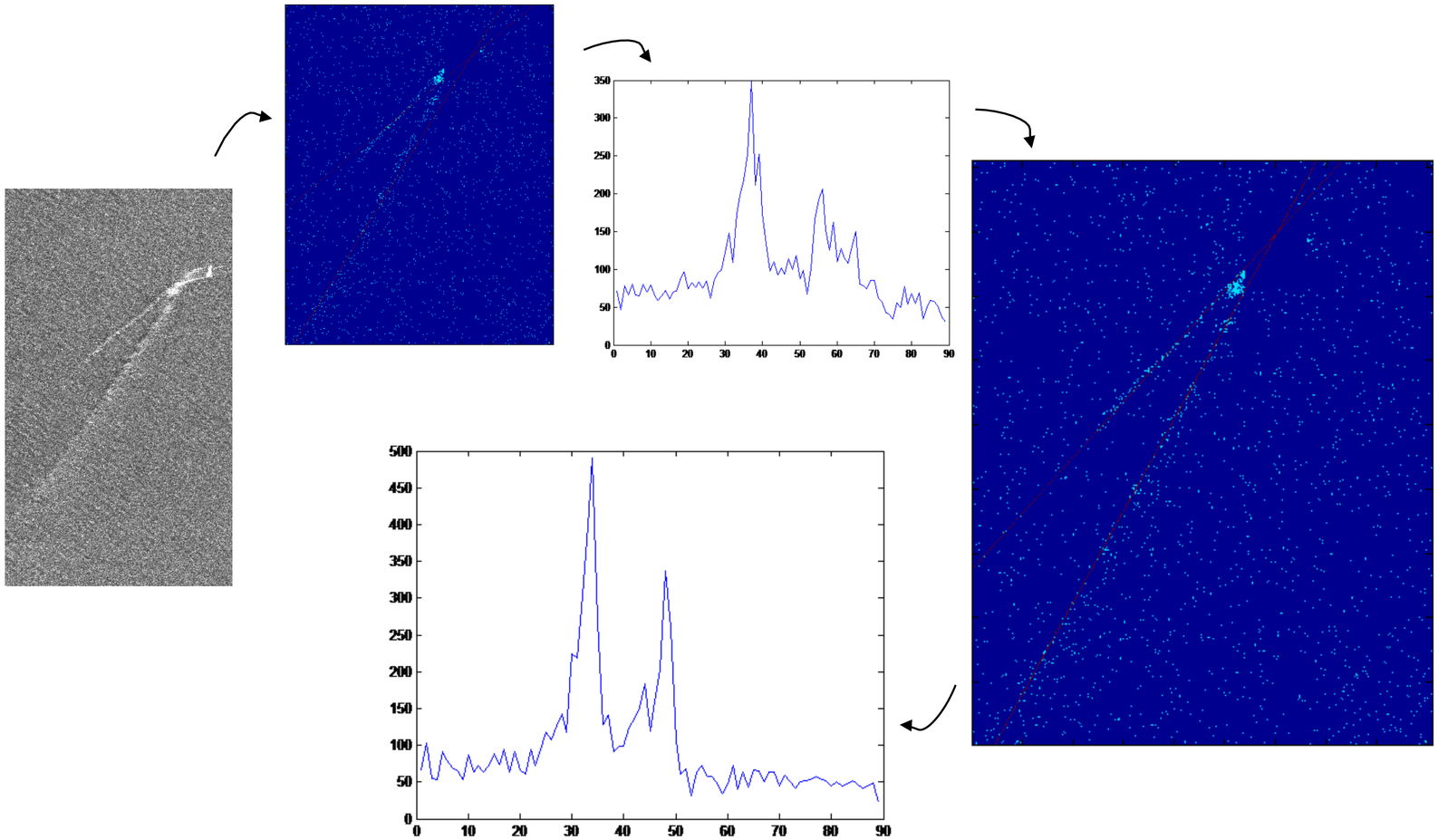




Results: SKE module

Wake detection

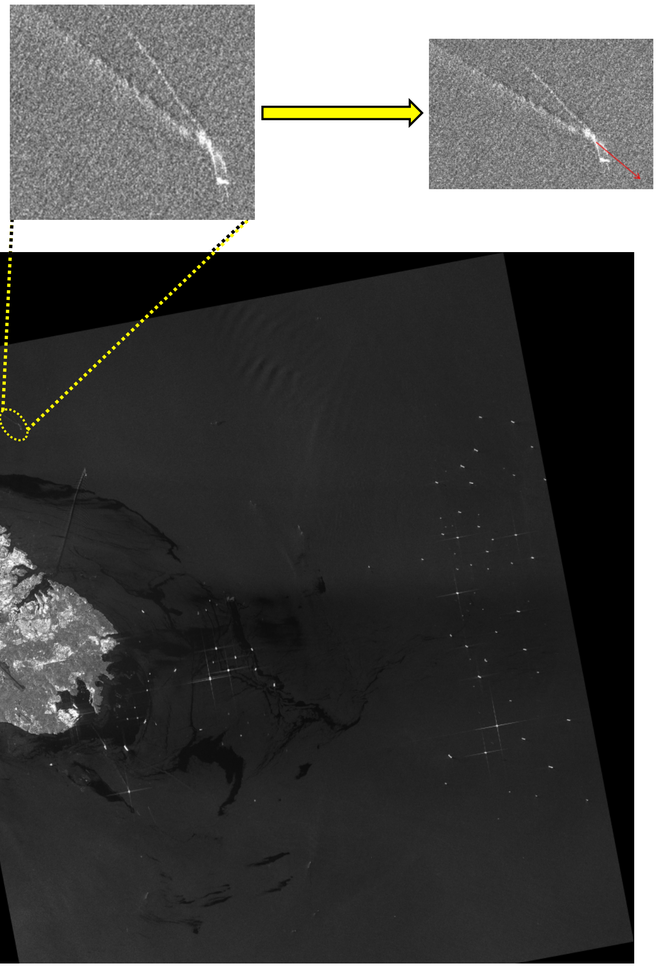




Results: SKE module

Velocity – 1: through azimuth shift

Wake analysis

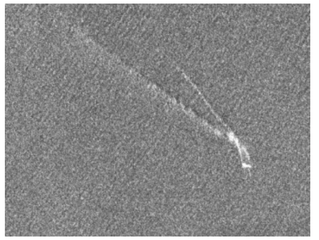


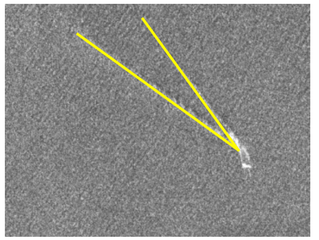
Velocity Estimation - 1

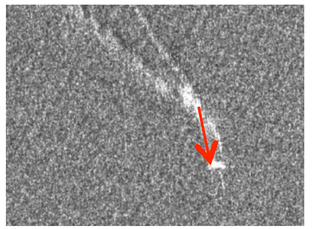
Wake detection

Estimate the azimuth shift △ as the separation between the wake tip and the ship centroid

$v\downarrow radial = \Delta \cdot V\downarrow satellite / Satellite\ to\ target\ range$



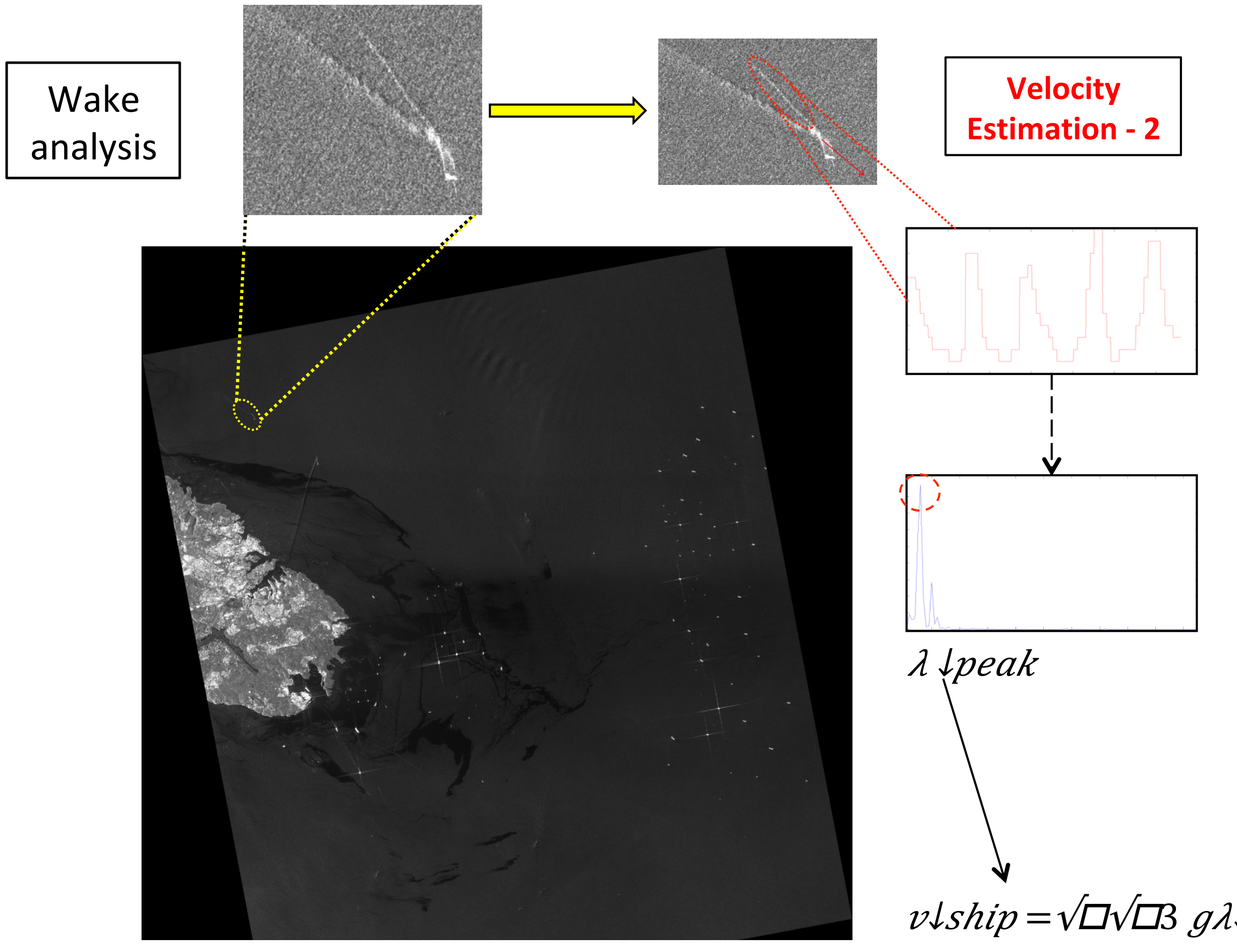


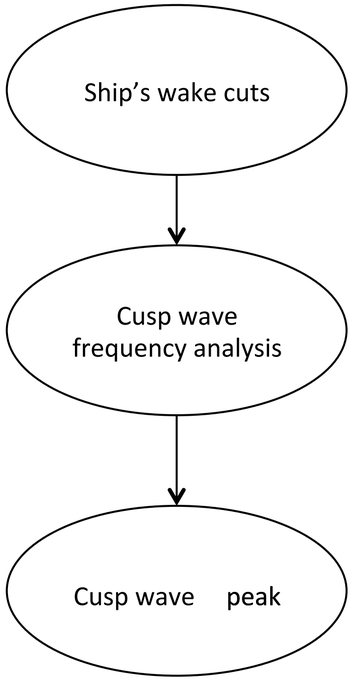


If the ship course is known, the complete velocity vector $v\downarrow ship$ is easily estimated

Results: SKE module

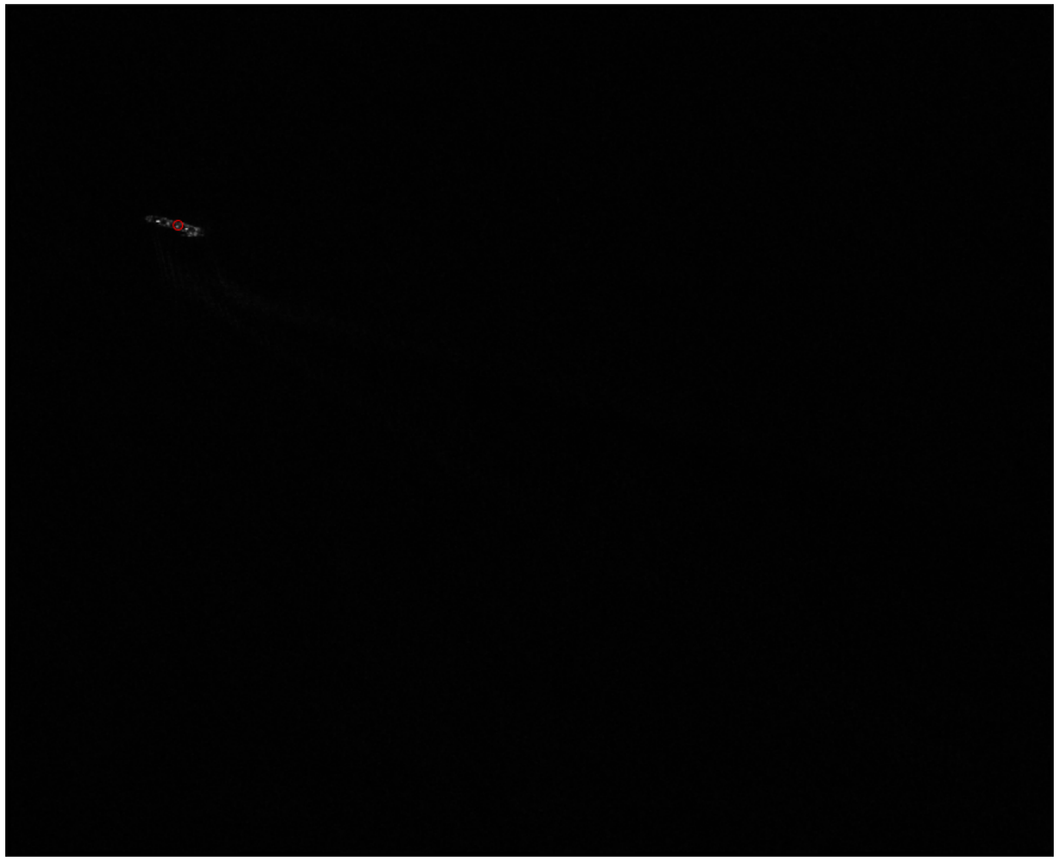
Velocity – 2: through cusp wave length





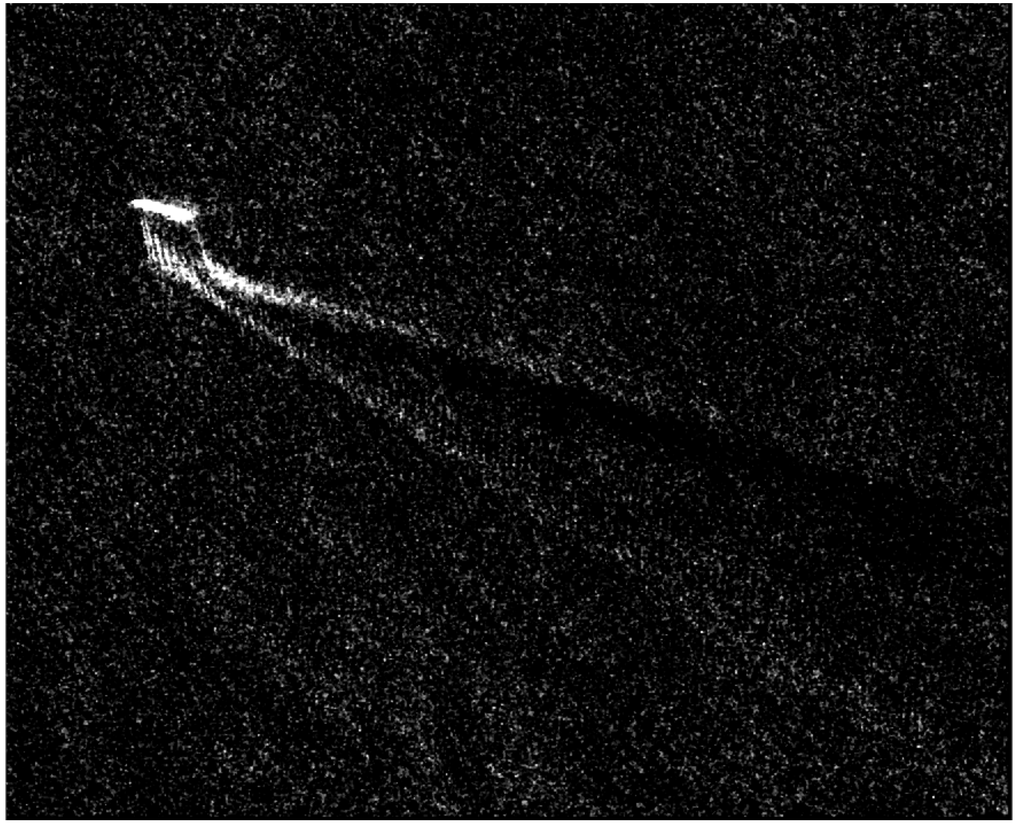
Results: SKE module

SKE Example – 1: input image and target



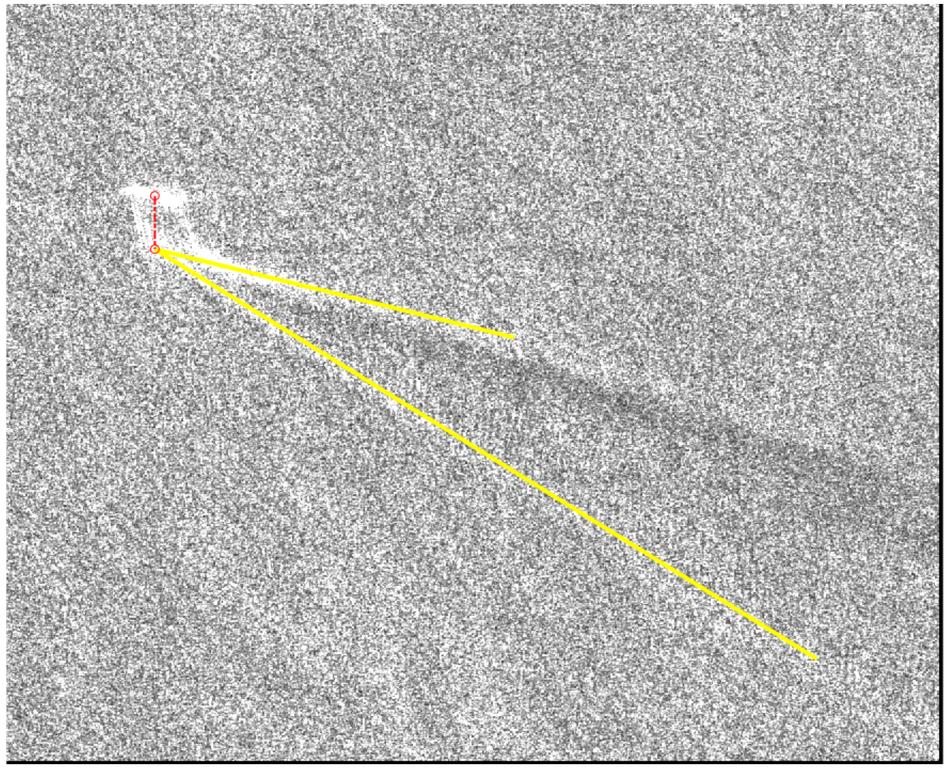
Results: SKE module

SKE Example – 2: wake enhancement



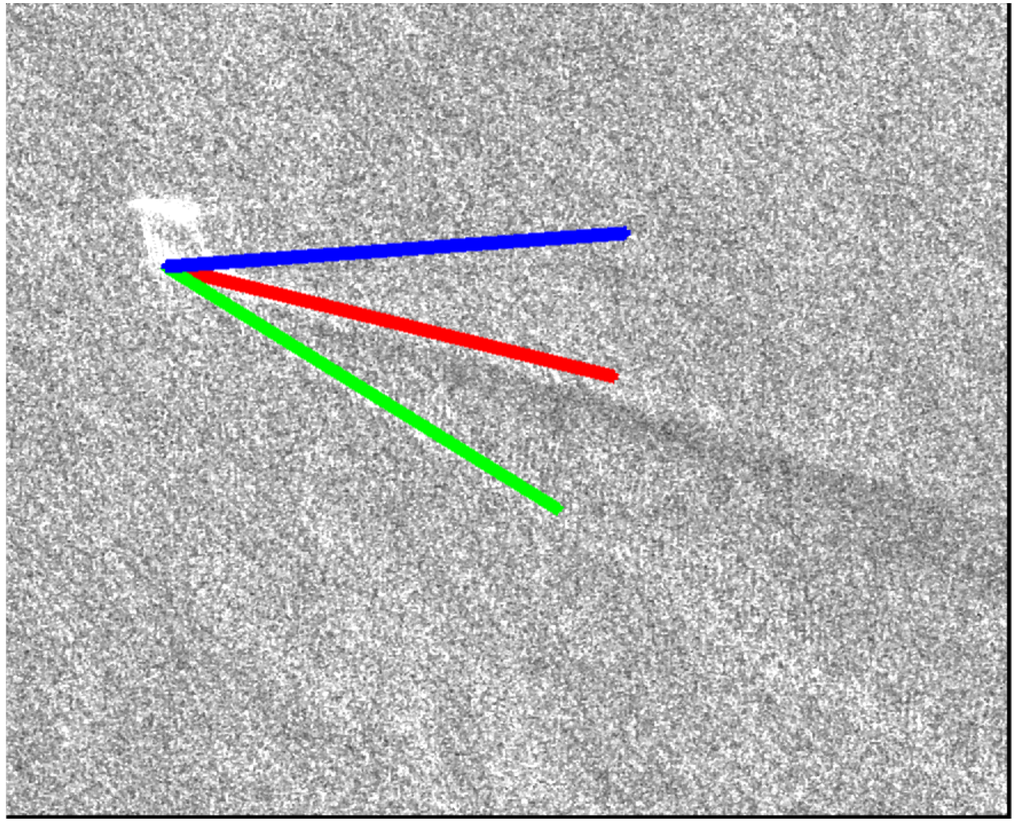
Results: SKE module

SKE Example – 3: wake extraction and azimuth shift estimation



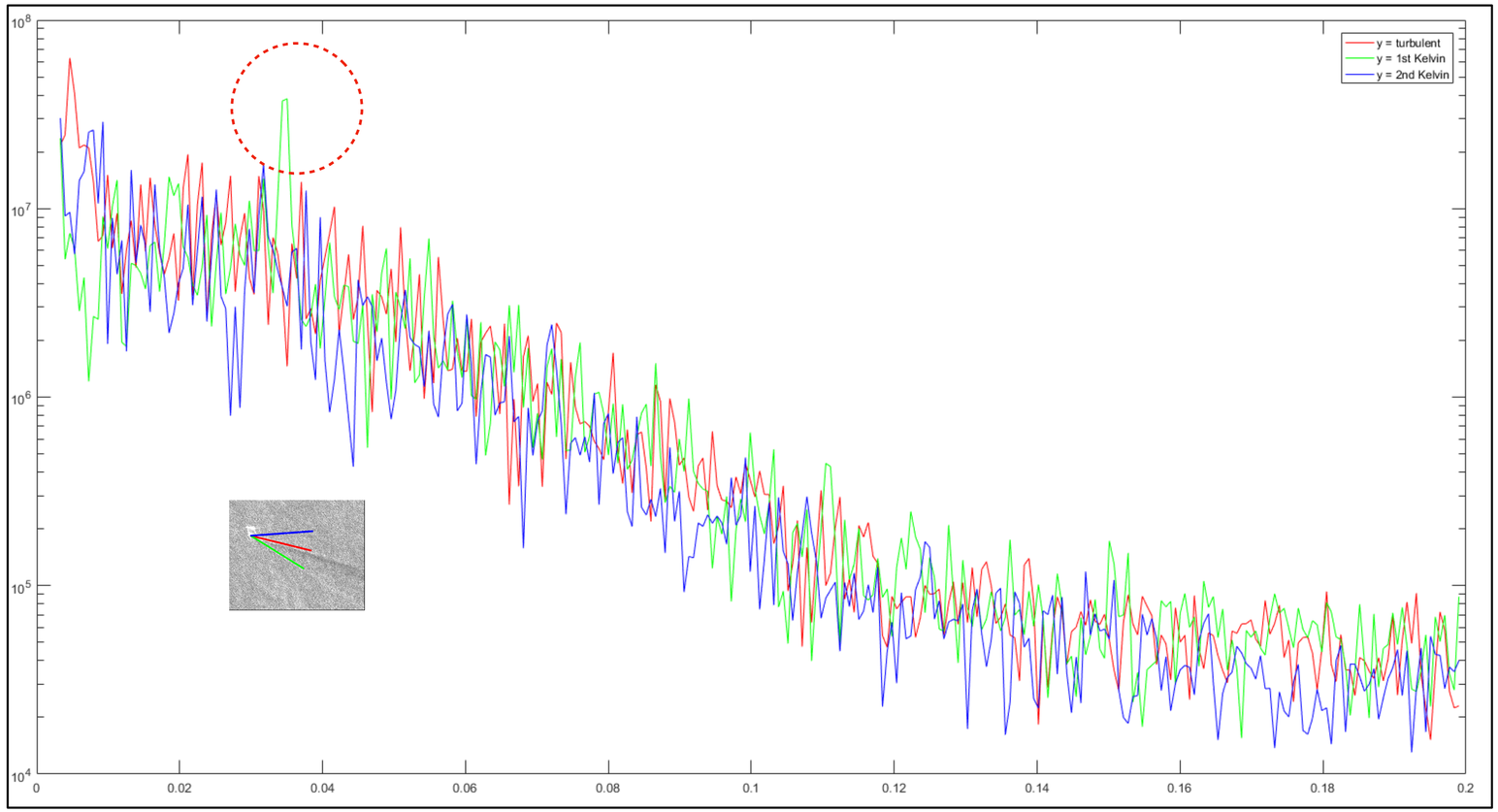
Results: SKE module

SKE Example – 4: Fourier analysis 1



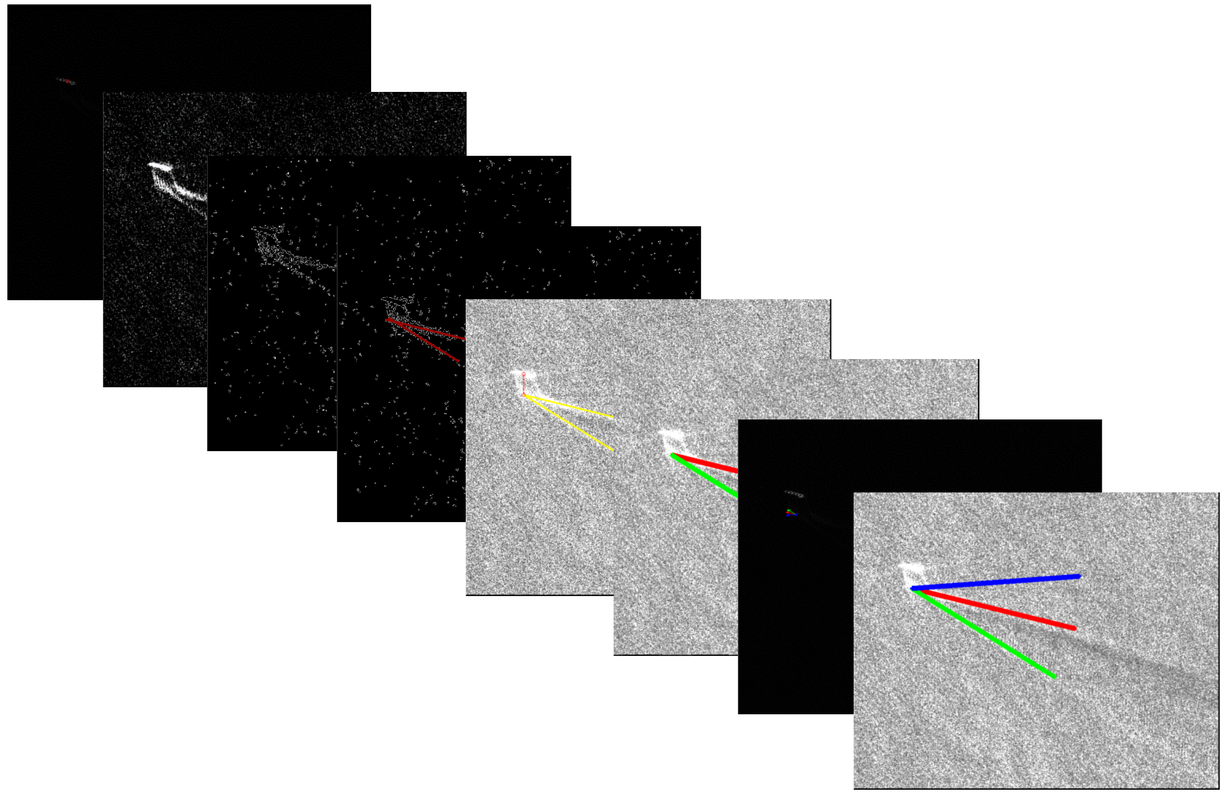
Results: SKE module

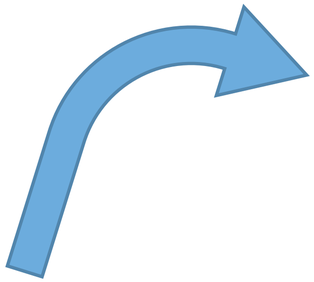
SKE Example – 5: Fourier analysis 2



Results: SKE module

SKE Example – 6: END





Kinematic.csv

SdI, SSA (A.S.), SSA(F.A.), SSO

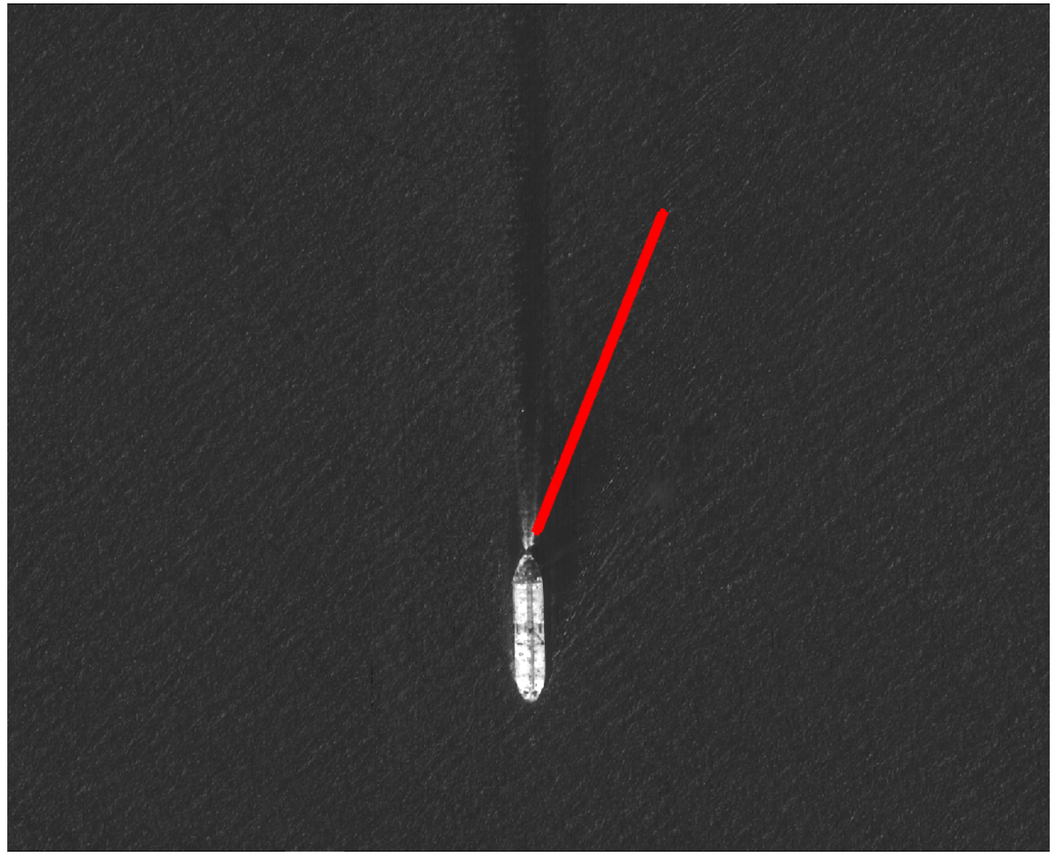
⋮

13, 4.35, 12.10 , 283.801

⋮

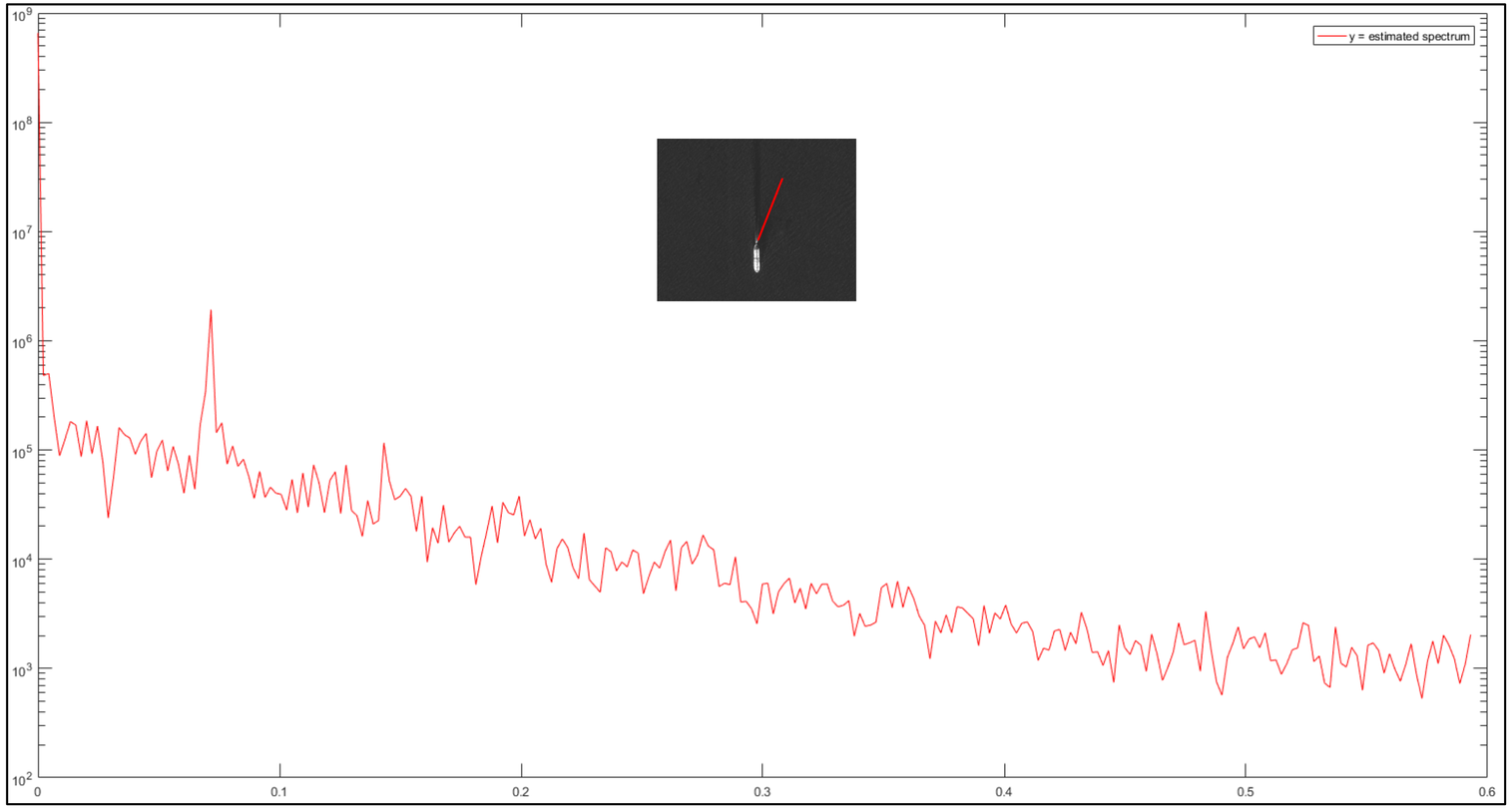
Results: SKE module

Interactive SKE Processing – Optical input:
Rayleigh envelope extraction



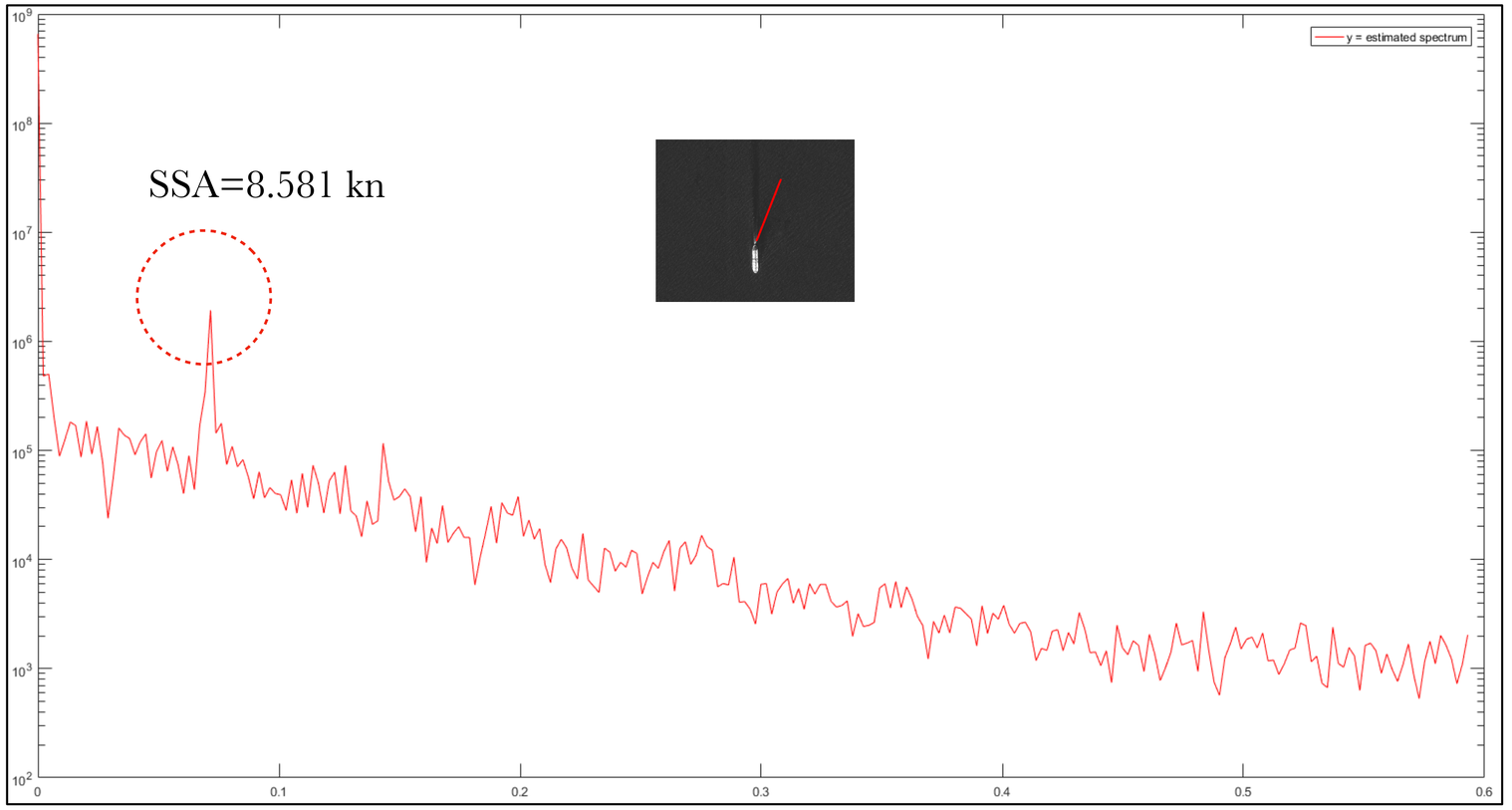
Results: SKE module

Interactive SKE Processing – Optical input:
Cusp-wave Fourier analysis



Results: SKE module

Interactive SKE Processing – Optical input:
Cusp-wave peak detection



Results: SBA module

Coordinates (SD)
Size (width-length) (SC)
Speed (SKE)
Acquisition Interval

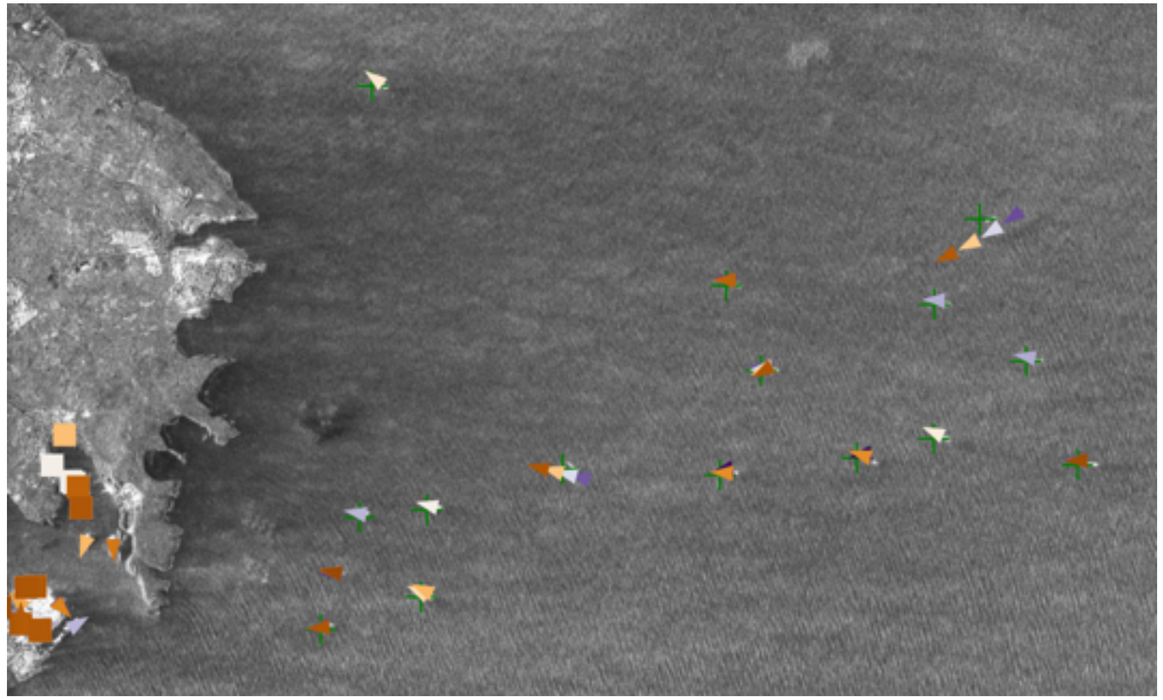
MMSI (best match - if any)
AD (anomaly detection)
PMS (position matching score)
TMS (type matching score)
SMS (speed matching score)
MS (matching score - overall)
SAL (length - from AIS data)
SAW (width - from AIS data)
SAH (heading - from AIS data)

$$MS = pms\_weight*PMS + tms\_weight*TMS + sms\_weight*SMS$$

$$AD = MS > threshold\ ?\ false : true$$

Results: SBA module

SBA Viewer



WebGIS Viewer

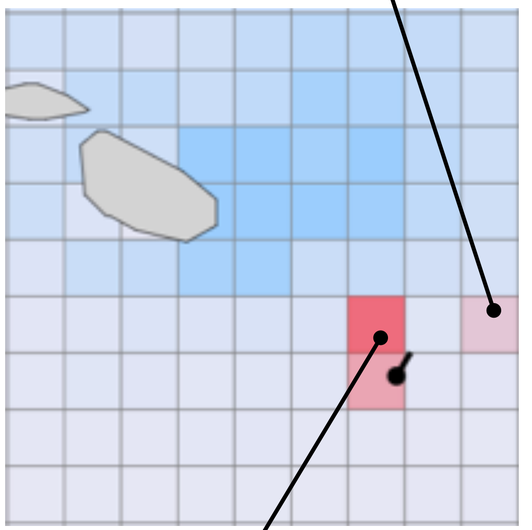
Results: SRP module

Coordinates (SD)
Type (SC)
Heading(SKE)
Speed (SKE)
Day of year
Time of day

K-nearest neighbors

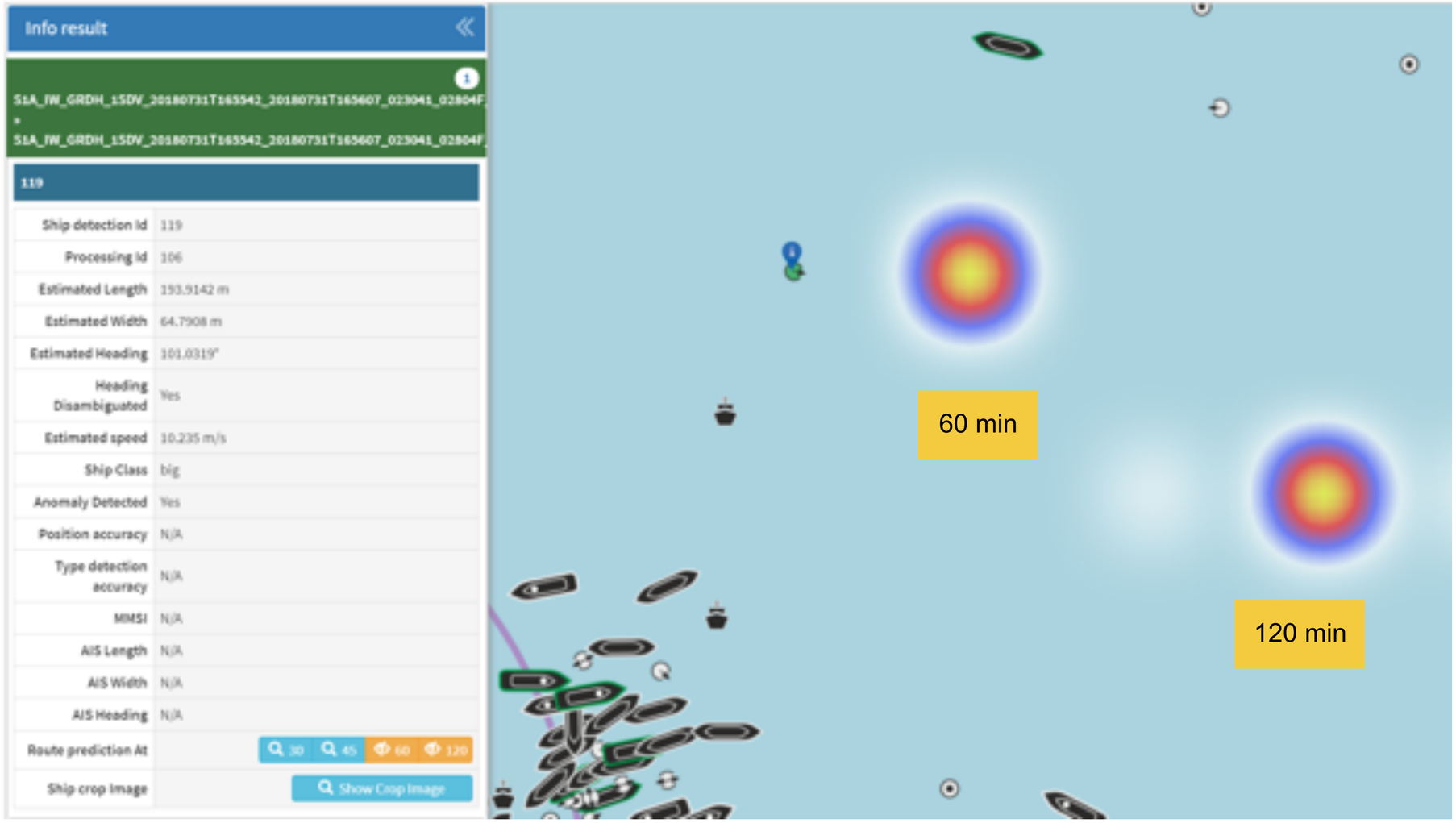
SRP

time interval set
30 45 60 120



Precision > 0.70 in all cases
inversely proportional to time interval

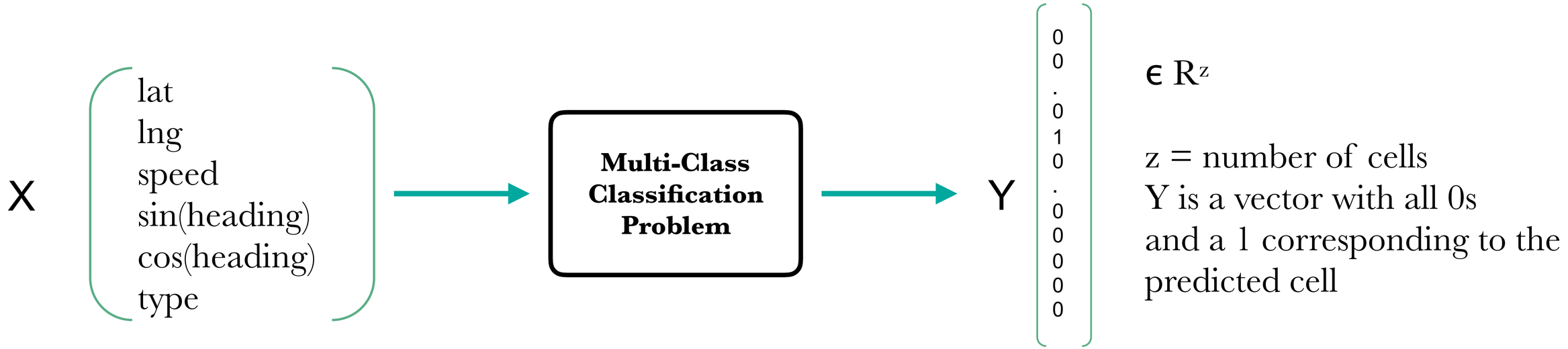
Results: SRP module



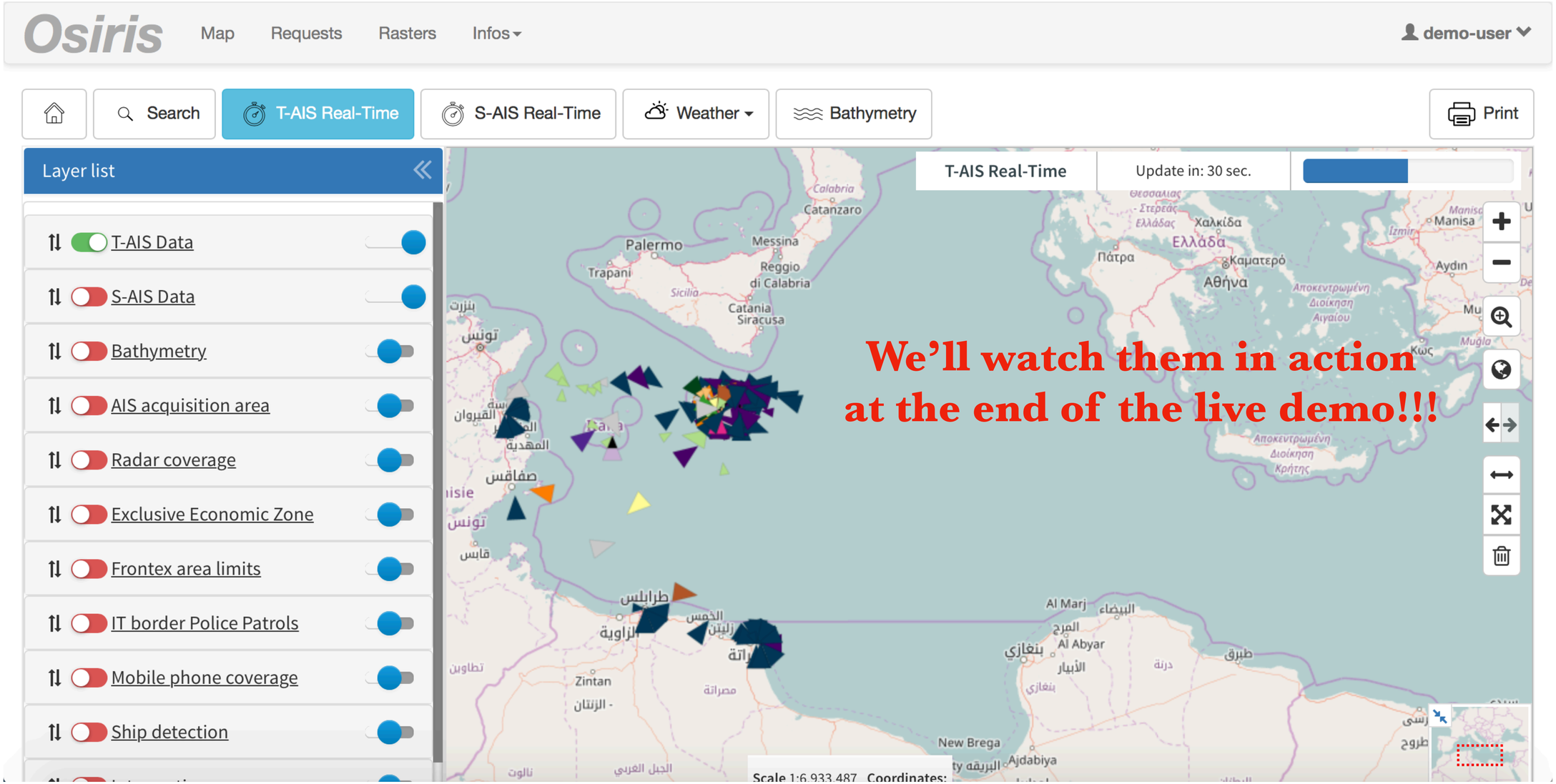
Results: SRP module

Ship Route Prediction was defined as a Multi-class Classification Algorithm

- K-Nearest Neighbor was applied



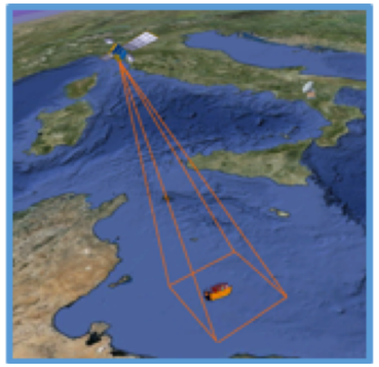
Results: CP & WG modules



Claudio Di Paola PM & TM (MapSat), Andrea Marchetti (CNR IIT), Emanuele Salerno (CNR - ISTI), Alessandro Greco (SisTer)

Full Chain

Acquisition Plan
or
Copernicus Rolling Archive

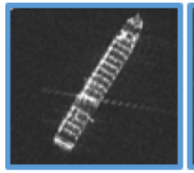


Imaging & Pre-Processing

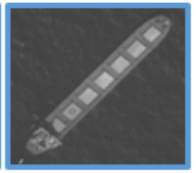
CP: user request handling

Ground Station activities
&
DPP

SAR image



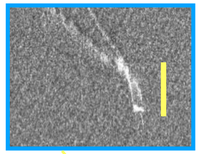
Optical image

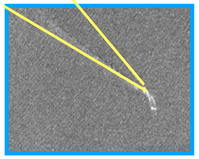


Detection & Classification

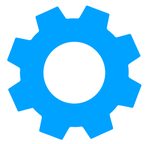
SD: Target Detection
&
SC: Vessel Classification

SAR image



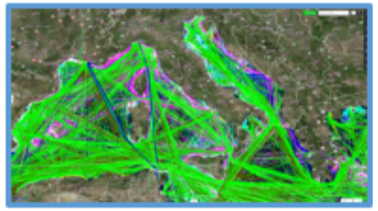


Optical image



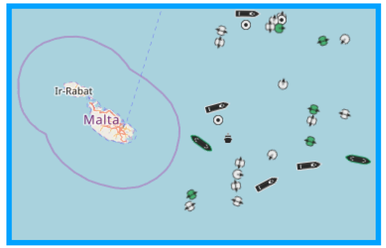
Kinematic

SKE: Speed and fine heading



AIS Data Fusion

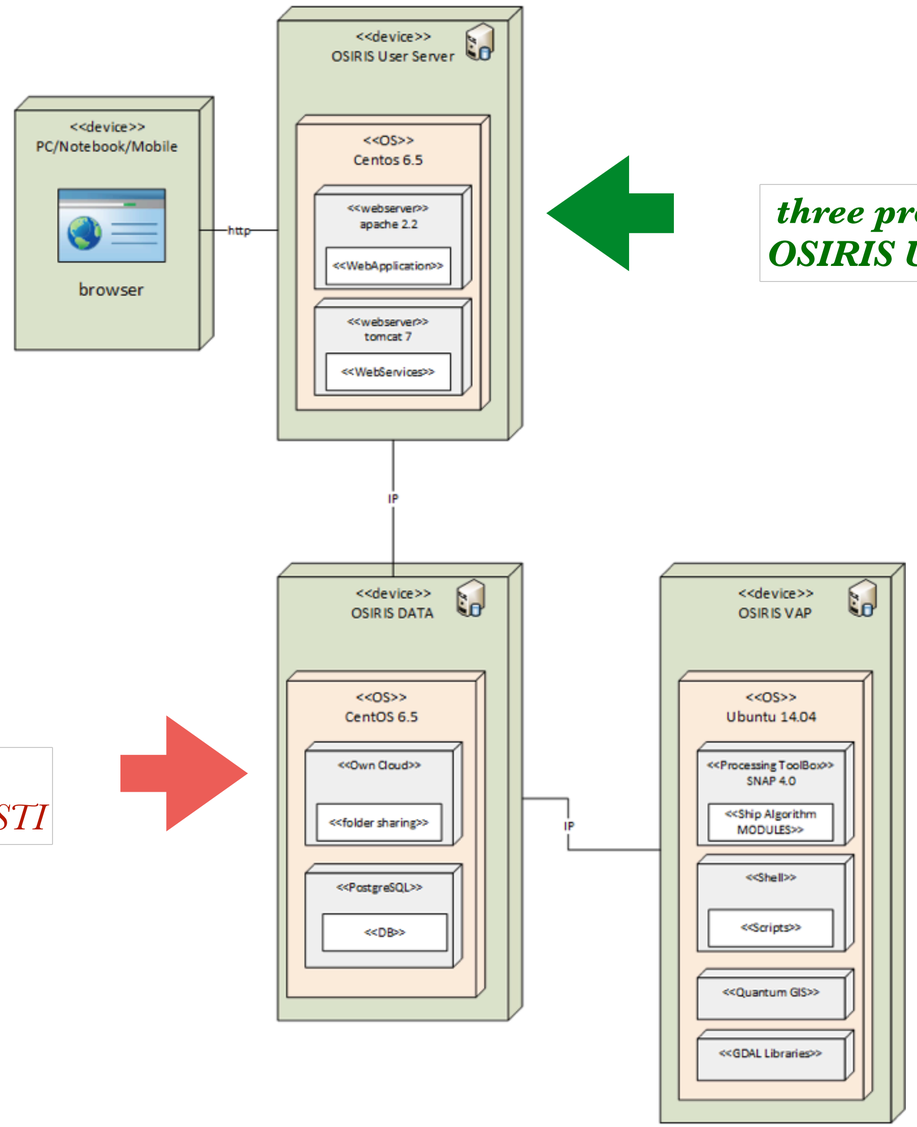
SBA: cooperative and not cooperative targets
&
SRP: route prediction



Report

WG: report handling

Prototype Deployment



three processing machines
OSIRIS US: WG/CP *@SisTer*

three processing machines
OSIRIS DS: ownCloud *@CNR-ISTI*

three processing machines
OSIRIS VAP-1: DP/SD/DPE *@MapSat*
OSIRIS VAP-2: SC/SKE *@CNR-IIT*
OSIRIS VAP-3: SRP/SBA *@CNR-ISTI*

Live Demo

Sentinel 1 full chain

Prototype Analysis and Future Developments

	SAR		Electro Optical	
	OSIRIS status	**future development**	**OSIRIS status**	**future development**
DPP	consolidated	nothing	Good	cloud mask in Pan images
SD - SNAP	consolidated	(ghost and azimut ambiguity)	n/a	n/a
SD - OSIRIS	Good	reduce processing time	Good	reduce processing time
DPE	Good	reduce numbers of matching tests	Good	reduce numbers of matching tests
SC	Good	Increase ground-truth set to refine classification	Good	Effectiveness of geometrical features for finer classification
SKE	Good	Error analysis based on further experiments	n/i	stereo pairs
SBA	Good	ground-truth set to refine matching performance	Good	the same
SRP	Good	algorithm improvement to increase performance	Good	the same
WG	Good	-	Good	-
CP	Good	-	Good	-

Thanks for your attention

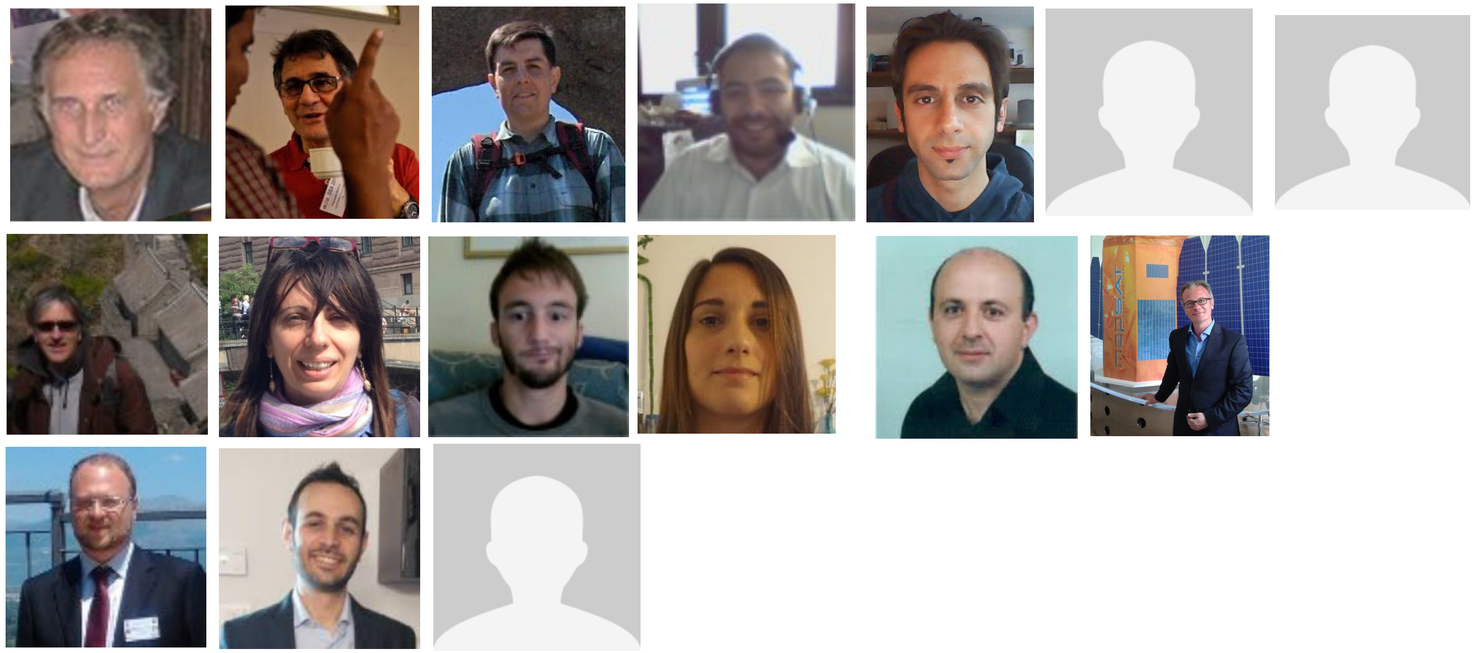
Team @ work

CNR-IIT
Andrea Marchetti
Andrea D'Errico
Clara Bacciu
Angelica Lo Duca

CNR-ISTI
Emanuele Salerno
Marco Righi
Marco Reggiannini
Massimo Martinelli
Marco Tampucci
Luigi Bedini

MapSat
Claudio Di Paola
Costanzo Mercurio

Sistemi Territoriali S.r.l.
Alessandro Greco
Bruno Zizi
Antonino Mistretta (2016-2017)



Claudio Di Paola (PM MapSat), Andrea Marchetti (CNR IIT), Emanuele Salerno (CNR - ISTI)

Indicazioni di Michele

di solito la presentazione finale è organizzata in modo da avere

una breve introduzione sul progetto (obiettivi iniziali, svolgimento, risultati ottenuti) - circa 30min -
seguita da una dimostrazione (possibilmente live demo) delle funzionalità sviluppate e offerte dal prototipo - 30 / 45 min -
e una discussione finale su futuri sviluppi.
In totale un paio di ore al massimo.

Description
The **OSIRIS Prototype platform**, operating on satellite data (both optical and radar) and on AIS data, provides the following main functions:

– a webGIS module for data visualization and handling;
– a user interface to handle the monitoring service;
– a module for object detection (searching for vessel on the acquired images, their size measurement as width and length);
– a module for vessel classification (fishing, cargo…), and for vessel recognition;
– a module for route prediction (to track the past route and to estimate the next route);
– modules to planning, gathering and processing the data.

During the Final Presentation the current prototype will be presented and demonstrated, followed by discussions on possible future steps.

Feel free to forward the invitation to anyone potentially interested.

Michele