JRC-Frontex Spaceborne SAR Small Boat Detection Campaign – Italy & Spain

Results of the Spaceborne SAR Small Boat Detection campaign carried out by the EC-JRC in cooperation with Frontex in Sardinia-Italy and Palomares Canyon – Spain in September and October 2009, respectively

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The mission of the JRC-IPSC is to provide research results and to support EU policy-makers in their effort towards global security and towards protection of European citizens from accidents, deliberate attacks, fraud and illegal actions against EU policies.
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1. – Introduction

1.1 – Scope

This report presents the key findings of the SAR Satellite Imagery Small Boat Detection Campaign, led by EC-JRC jointly with Frontex, carried out in Sardinia-Italy and in Palomares Canyon – Spain in September and October 2009, respectively.

This study addresses the feasibility of using Synthetic Aperture Radar (SAR) Satellite imagery for Small Boat Detection on open sea in Sardinia-Italy and Palomares Canyon-Spain. It also addresses spaceborne SAR Small Boat Detection on the beach.

To answer this statement of work, a multinational cross-disciplinary consortium with research and operational expertise in maritime surveillance was assembled with organisations highly involved in:

1. research expertise in SAR Satellite imagery processing and analysis (EC-JRC).
2. coordination and management of maritime surveillance campaigns (EU-Frontex).
3. operational patrolling of blue borders (Italian Authorities (Guardia Costiera and Guardia di Finanza), Spanish Authorities (Guardia Civil, Spanish Navy)).

1.2 – Objectives

The work was performed with the following objectives:

- To assess the feasibility of detection of Small Boats in Synthetic Aperture Radar (SAR) Satellite imagery (Radarsat2 and TerraSAR-X) on open sea and on the beach.
- To characterise the SAR signature of Small Boats in SAR Satellite imagery.
- To identify the limitations of current State-of-the-Art SAR Satellite technology for maritime surveillance, in particular for Small Boat detection.

1.3 – Context

Problem Statement – The European maritime area is one of Europe’s most important assets with regard to resources, security and ultimately prosperity of the Member States. A significant part of Europe’s economy relies directly or indirectly on it. It is not just the shipping or fisheries industries and their related activities. It is also shipbuilding and ports, marine equipment and offshore energy, maritime and coastal tourism, aquaculture, submarine telecommunications, blue biotech and the protection of the marine environment. The European maritime area faces several risks and threats posed by unlawful activities, such as drugs trafficking, smuggling, illegal immigration, organised crime and terrorism. Piracy in international waters also constitutes a threat to Europe since it can disrupt the maritime transport chain. These risks and threats can endanger human lives, marine resources and the environment, as well as significantly disrupt the transport chain and global and local security. It is anticipated that these risks and threats will endure in the mid and long run. In order to keep Europe as a world leader in the global maritime
economy, an effective integrated/interoperable, sustainable maritime surveillance system and situational awareness are needed.

A significant number of unlawful maritime activities, such as illegal immigration, drugs trafficking, smuggling, piracy and terrorism involve mainly small boats, because small boats are faster and more difficult to detect using conventional means. Hence, it is very important to find out the feasibility of using SAR Satellite images for small boat detection.

2. – Research Method

In order to find out the feasibility of using SAR Satellite imagery to detect small boats, two controlled experiments, one on open sea and the other one on the beach, were designed, set up and executed. The two controlled experiments are briefly described next.

2.1 – Controlled Experiment on Open Sea

The main objective of this controlled blind experiment was to find out if a small boat of known GPS position, deployed on open sea, could be detected using SAR satellite imagery. Knowing the GPS position of the small boat deployed on open sea at the time of the SAR Satellite passes it should be possible to check on the SAR Satellite image if the small boat had been detected or not. The experiment was blind in the sense that the EC-JRC was not supplied the GPS position of the small boat before running the vessel detection software (SUMO) and checking all detected targets and supplying the detected targets to Frontex.

The sequence of events of the controlled experiment was as follows:

1. - The EC-JRC checked the dates, times and locations of potential SAR satellite image acquisitions (Radarsat2 and TerraSAR-X) available over the Gulf of Cagliari and Porto Pino in Sardinia, Italy and in the Palomares Canyon in Spain and supplied them to the Italian and Spanish authorities, through Frontex.

2. - The Italian and Spanish authorities were asked to deploy a small boat on open sea during their normal patrolling activities at the time of the SAR satellite passes, within the SAR satellite image frame, with at least one member of staff carrying a GPS receiver to continuously measure the GPS position of the small boat during the SAR satellite pass.

3. - They were also asked to take note of the following information:
   a.) Sea State,
   b.) Wind Speed,
   c.) Weather conditions

2.2 – Controlled Experiment on the Beach

The detection of small boats on land at the beach is also important. For example, illegal immigration by sea coming from the coast of Africa towards Italy (Sardinia, Sicilia, Lampedusa, etc.), Spain (Canary Islands or the South of Spain) or from Turkey towards Greece usually involve a gathering of small boats at the beach several hours before the departure. If we could detect small boats on the beach using SAR satellite images, we could anticipate new waves of illegal immigrants and even prevent their departure by warning the authorities of the countries of origin. Any unusual gathering of small boats would trigger the alarm. The same is true for other illegal activities involving small boats, such as drugs trafficking and smuggling.
The main objective of this controlled experiment was to find out if a small boat of known GPS position, deployed on the beach, could be detected using SAR satellite imagery. Knowing the GPS position of the small boat deployed on the beach at the time of the SAR Satellite passes it should be possible to check on the SAR Satellite image if the small boat had been detected or not.

The sequence of events of the controlled experiment was the same as for the open sea experiment, except that a small boat was placed on the beach of Porto Canale, Sardinia, Italy.
3. – Experiments Set Up

In this section we describe the experiment set up, namely the experiment site selection, the SAR Satellite Imagery planning and the partners involved and their roles.

3.1 – Experiment Site Selection - Open Sea

Bearing in mind that most unlawful maritime activities involving small boats, such as illegal immigration, drugs trafficking, smuggling and terrorist activities can be better mitigated if the small boats are detected at an earlier stage while on open sea, the selection of open sea site scenarios for the experiment was an obvious option.

The open sea trials were carried out a few miles from the coast of Cagliari and Porto Pino to test the feasibility of detecting small immigrant boats at high sea during their trip from the coast of Africa towards Europe. These open sea scenarios help to prevent SAR Satellite imagery artefacts and effects due to the proximity of land coastal targets. The open sea sites selected were all located a few nautical miles away from the coast.

3.1.1 – Open Sea Sites in Sardinia-Italy

The open sea sites selected in Sardinia-Italy were at the Gulf of Cagliari area a few miles away from the coast and at the Porto Pino area as illustrated in fig.1 with yellow pin markers.

Figure 1 – Open sea experiment sites in Sardinia-Italy (Gulf of Cagliari, Porto Pino).
3.1.2 – Open Sea Sites in Spain

The open sea sites selected in Spain were at the Palomares Canyon area a few miles away from the coast, as illustrated in fig.2.

![Figure 2 – Open sea experiment site in Palomares Canyon – Spain.](image)

3.2 – Experiment Site Selection - Beach

The site selection for the trial on land was carried out taking into account the experiment requirements, including similarity of the scenario with the beaches on the coast of Africa from where illegal immigrants usually depart, the existence of other small boats spread over the beach, the distance from infrastructures to avoid SAR signature contamination and artefacts.

Bearing in mind the above mentioned considerations, a decision was made to carry out a controlled experiment on land at the beach of Porto Canale in Cagliari, near Giorgino. The site is illustrated in Fig. 3.
3.3 – SAR Satellite Imagery Planning

The Synthetic Aperture Radar (SAR) satellite imagery used in this experiment comprised Radarsat2 (using its Spotlight and Ultrafine modes) and TerraSAR-X (Spotlight and Stripmap). Figures 4 and 5 illustrate the Radarsat2 image modes and the TerraSAR-X image modes, respectively. Table-1 illustrates the SAR satellite Images and Modes used in the different days of the experiment. The SAR satellite images were acquired over the Gulf of Cagliari, Porto Pino, Porto Canale beach in Sardinia-Italy and over Palomares Canyon in Spain.

The Radarsat2 and TerraSAR-X image modes used in the present experiment will be briefly reviewed in the next paragraphs.

Radarsat2 - Spotlight Mode – The Spotlight Beams are intended for applications which require the best spatial resolution available from the RADARSAT-2 SAR system. In this mode the radar operates with the highest sampling rate, and so the ground swath coverage is limited to keep data rate within the recorder limits. Unlike the other modes, Spotlight images are also of fixed size in the along track direction.

The set of Spotlight Beams cover any area within the incidence angle range from 20 to 49 degrees. Each beam within the set images a swath width of at least 18 km. Spotlight images can only be generated in a single polarization, which can be either a linear co-polarization (HH or VV) or a linear cross-polarization (HV or VH).
Radarsat2 - Single Beam Mode – Single beam mode is a stripmap SAR mode. In Single Beam operation, the beam elevation and profile are maintained constant throughout the data collection period. The following Single Beam modes are available: Standard, Wide, Fine, Multi-Look Fine, Ultra-Fine, Extended High (High Incidence), Extended Low (Low Incidence), Standard Quad Polarization and Fine Quad Polarization. We selected Ultra-Fine because it is the best compromise between swath coverage and resolution.

Radarsat2 - Ultra-Fine – The Ultra-Fine Resolution Beams are intended for applications which require very high spatial resolution. In this mode the radar operates with the highest sampling rate, and so the ground swath coverage is limited to keep data rate within the incidence angle from 20 to 49 degrees. Each beam within the set images a swath width of at least 20 km. Ultra-Fine Resolution images can only be generated in a single cross-polarization, which can be either a linear co-polarization (HH or VV) or a linear cross-polarization (HV or VH).

The standard TerraSAR-X operational mode is the single receive antenna mode from which the following imaging modes can be retrieved: High Resolution Spotlight and Spotlight, StripMap, and ScanSAR. The single receive antenna mode uses a chirp bandwidth of up to 300 MHz.
The **SpotLight (SL)** imaging modes use phased array beam steering in azimuth direction to increase the illumination time, i.e. the size of the synthetic aperture. This leads to a restriction in the image / scene size. Thus, the scene size is technically restricted to a defined size: 10 km x 10 km for the SpotLight mode and 10 km x 5 km (width x length) in the HighResolution SpotLight (HS) mode.

This sophisticated imaging mode makes it possible to acquire data with up to 1 m resolution in the HighResolution SpotLight mode (acquired with a bandwidth of 300 MHz) and 2 m in the standard SpotLight mode.

**StripMap (SM)** is the basic SAR imaging mode as known e.g. from ERS-1 and other radar satellites. The ground swath is illuminated with continuous sequence of pulses while the antenna beam is fixed in elevation and azimuth. This results in an image strip with a continuous image quality (in flight direction). StripMap dual polarisation data have a slightly lower spatial resolution and smaller swath than the single polarisation data.

In StripMap mode, a spatial resolution of up to 3 m can be achieved. The standard scene size is 30 km x 50 m (width x length) in order to obtain manageable image files; however, acquisition length is extendable up to 1,650 km.

**Figure 5** – TerraSAR-X image modes. The Stripmap and Spotlight modes have been identified as the most suitable modes for this particular experiment.
The planning of all the SAR satellite images acquired during this campaign is illustrated in the sequence of figures given next (Fig.6 to Fig.14). In each figure, the red circle or square indicates the target area, and the tilted coloured box indicates the actually imaged area.

Table 1 – SAR satellite imagery acquired over Sardinia-Italy and Palomares Canyon-Spain.

<table>
<thead>
<tr>
<th>Date/Time</th>
<th>Area</th>
<th>Satellite / Mode</th>
<th>Polarization</th>
<th>Pass</th>
</tr>
</thead>
<tbody>
<tr>
<td>8-Sept-2009</td>
<td>Gulf of Cagliari, Sardinia-Italy</td>
<td>Radarsat2 Ultrafine</td>
<td>Single HH</td>
<td>Ascending</td>
</tr>
<tr>
<td>13-Sep-2009</td>
<td>Gulf of Cagliari, Sardinia-Italy</td>
<td>Radarsat2 Ultrafine</td>
<td>Single HV</td>
<td>Descending</td>
</tr>
<tr>
<td>15-Sep-2009</td>
<td>Gulf of Cagliari, Sardinia-Italy</td>
<td>Radarsat2 Ultrafine</td>
<td>Single HH</td>
<td>Ascending</td>
</tr>
<tr>
<td>19-Sep-2009</td>
<td>Porto Canale beach, Cagliari, Sardinia-Italy</td>
<td>Radarsat2 Spotlight TerraSAR-X Spotlight</td>
<td>Single HV</td>
<td>Ascending</td>
</tr>
<tr>
<td>22-Sep-2009</td>
<td>Porto Pino, Sardinia-Italy</td>
<td>Radarsat2 Ultrafine</td>
<td>Single HH</td>
<td>Ascending</td>
</tr>
<tr>
<td>23-Sep-2009</td>
<td>Porto Pino, Sardinia-Italy</td>
<td>Radarsat2 Ultrafine</td>
<td>Single HV</td>
<td>Descending</td>
</tr>
<tr>
<td>25-Sep-2009</td>
<td>Porto Pino, Sardinia-Italy</td>
<td>Radarsat2 Ultrafine</td>
<td>Single HH</td>
<td>Ascending</td>
</tr>
<tr>
<td>26-Oct-2009</td>
<td>Palomares Canyon-Spain</td>
<td>Radarsat2 Ultrafine</td>
<td>Single HH</td>
<td>Descending</td>
</tr>
<tr>
<td>28-Oct-2009</td>
<td>Palomares Canyon-Spain</td>
<td>Radarsat2 Ultrafine</td>
<td>Single HH</td>
<td>Ascending</td>
</tr>
</tbody>
</table>

Figure 6 – Radarsat2, Mode Ultrafine, single polarization HH, Ascending pass, 8Sep.2009, Gulf of Cagliari, Sardinia-Italy.
Figure 7 – Radarsat2, Mode Ultrafine, single polarization HV, Descending pass, 13Sep.2009, Gulf of Cagliari, Sardinia-Italy.

Figure 8 – Radarsat2, Mode Ultrafine, single polarization HH, Ascending pass, 15Sep.2009, Gulf of Cagliari, Sardinia-Italy.
Figure 9 – Radarsat2, Mode Spotlight, single polarization HV, Ascending pass, 19Sep.2009, Porto Canale beach, Cagliari, Sardinia-Italy.

Figure 10 – Radarsat2, Mode Ultrafine, single polarization HH, Ascending pass, 22Sep.2009, Porto Pino, Sardinia-Italy.
Figure 11 – Radarsat2, Mode Ultrafine, single polarization HV, Descending pass, 23 Sep. 2009, Porto Pino, Sardinia-Italy.

Figure 12 – Radarsat2, Mode Ultrafine, single polarization HH, Ascending pass, 25 Sep. 2009, Porto Pino, Sardinia-Italy.
Figure 13 – Radarsat2, Mode Ultrafine, single polarization HH, Descending pass, 26Oct.2009, Palomares Canyon, Spain.

Figure 14 – Radarsat2, Mode Ultrafine, single polarization HH, Ascending pass, 28Oct.2009, Palomares Canyon, Spain.
3.4 – Partners Involved and their Roles

The partners involved in this experiment include:

3.4.1 - European Commission (EC) – Joint Research Centre (JRC)
- The main role of the EC-JRC was to design and set up the research study involved in the experiment. This comprised:
  a.) the definition of the objectives,
  b.) the research methods used,
  c.) the specification of the ground truth data collection,
  d.) the analysis of the data and
  e.) the conclusions of the experiment.

3.4.2 - Frontex (European Agency for the Management of Operational Cooperation at the External Borders of the Member States of the European Union)
- The main role of Frontex comprised:
  a.) the Coordination of the operations in the Coordination Centre in Cagliari,
  b.) the contacts with the Italian and the Spanish Authorities,
  c.) the supply of the ground truth data.

3.4.3 - Guardia Costiera – Italy
- The main role of Guardia Costiera comprised:
  a.) the deployment of a small rubber boat at the Beach of Porto Canale,
  b.) the deployment of a small rubber boat on open sea during the patrolling,
  c.) the collection of the ground truth data.

3.4.4 - Guardia di Finanza – Italy
- The main role of Guardia di Finanza comprised:
  a.) the deployment of a small rubber boat on open sea during the patrolling,
  b.) the collection of the ground truth data.

3.4.5 - Guardia Civil – Spain
- The main role of Guardia Civil comprised:
  c.) the coordination with the Spanish Navy,
  d.) the coordination with Frontex.
3.4.6 - Spanish Navy – Spain

- The main role of the Spanish Navy comprised:
  
e.) the deployment of a small rubber boat on open sea during the patrolling,
  f.) the collection of the ground truth data.
4. – Experiment Execution

4.1 – Open Sea - Modus Operandi

The modus operandi of the trial on open sea was as follows:

1.- JRC supplied Frontex and the Italian and Spanish authorities with spatial coverage (frames) of the SAR satellite images to be acquired, as well as the times of the SAR satellite passes.

2.- The Italian/Spanish authorities were given by Frontex the SAR satellite image frames and the time of the satellite passes and asked to deploy a small rubber boat within the SAR satellite image frame.

3.- The Italian/Spanish authorities deployed a small rubber boat within the above mentioned SAR satellite image frames at the time of the SAR satellite passes.

4.- The Italian/Spanish authorities supplied the following information:
   a.) the sea state
   b.) the wind speed
   c.) the drift
   d.) the weather conditions

5.- Relevant data (images, positions, sea/wind/conditions) were exchanged among concerned partners.

4.2 – Land Beach - Modus Operandi

The modus operandi of the trial on land at the Porto Canale beach was as follows:

1.- JRC supplied Frontex and the Italian authorities with the frames of the SAR satellite images to be acquired, as well as the times of the SAR satellite passes.

2.- The Italian authorities were given by Frontex the SAR satellite image frames and the time of the satellite passes and asked to deploy a small boat within the SAR satellite image frame at the beach of Porto Canale.

3.- The Italian authorities (Guardia Costiera) deployed a small boat within the above mentioned SAR satellite image frames at the time of the SAR satellite passes.

4.- The Italian authorities supplied the following information:
   a.) the weather conditions

5.- JRC supplied the processed SAR satellite images to Frontex and the Italian authorities and Frontex supplied the GPS position of the small rubber boat deployed at the time of the satellite passes and the above mentioned information, namely a.) the sea state, b.) the wind speed, c.) the drift, d.) the weather conditions.
4.3 – Ground Truth Data Collection

The ground truth data collected was the above mentioned data collected by the Italian/Spanish authorities during the experiment. On 19 Sep. 2009 a JRC team collected ground truth data at Porto Canale beach.

4.4 – Means Deployed by the Italian/Spanish Authorities

4.4.1 – Means Deployed by the Italian Authorities

The means deployed by the Italian authorities comprised the means deployed by the Guardia di Finanza and by the Guardia Costiera. The Guardia di Finanza means included a patrolling boat illustrated in Fig.15. Fig. 16 illustrates a small rubber boat used by Guardia Costiera.

![Figure 15 – Patrolling Boat used by Guardia di Finanza in the experiment.](image-url)
JRC asked to the Italian authorities to deploy the small wooden made boat illustrated in fig.17, but due to logistic limitations the Italian authorities deployed small rubber boats such as the one illustrated in fig.16.

Figure 16 – Small rubber boat deployed by Guardia Costiera in the experiment.

Figure 17 – Small wooden made boat apprehended to illegal immigrants.
The means deployed by Guardia Costiera comprised a patrolling boat illustrated in Fig. 18. The Guardia Costiera also deployed a small rubber boat at the Porto Canale beach for the land based controlled experiment. The small boat is illustrated in Fig. 19.

**Figure 18** - Patrolling Boat used by Guardia di Costiera in the experiment.

**Figure 19** - Small rubber boat deployed by Guardia Costiera at Porto Canale beach during the experiment.
4.4.2 – Means Deployed by the Spanish Authorities

The means deployed by the Spanish authorities comprised a patrolling vessel illustrated in fig.20 and a small rubber boat illustrated in fig.21.

**Figure 20** – Patrolling vessel deployed by the Spanish Navy at Palomares Canyon, Spain, during the experiment.

**Figure 21** – Small rubber boat deployed by the Spanish Navy at Palomares Canyon, Spain, during the experiment.
5. – Preliminary Data Analysis

5.1 – Review of the SUMO Detector

The SAR images acquired during this maritime surveillance campaign were analysed both visually and using an automatic ship detection software package developed at JRC by the fisheries control group, SUMO (Search for Unidentified Maritime Objects). A detailed description of SUMO can be found in Schwartz et al. in [1] and Kourtì et al. in [2]. SUMO uses a conventional approach known in the literature as Constant False Alarm Rate (CFAR) [4]. Basically it detects bright clusters over a local background.

In the results section of [2], Kourtì et al. note that apart from the detection algorithm, their exercise is similar to that of Vachon et al., [3]. The results of Kourtì et al. clearly indicated that wooden and fibreglass vessels do not show up well in SAR imagery. Several other detection problems are mentioned: weather effects (high wind speed generates noisy backgrounds creating detection problems); incidence angle effect (the near swath ocean clutter is brighter than the far swath clutter); and image errors (bright spots at the edges of different beam modes). We report their conclusions by quoting from the paper: Results from different studies confirm that fishing vessels longer than 26 m length have a 92% probability of being detected on ScanSAR imagery. ScanSAR imagery offers a good compromise between resolution and covered area. The comparison of the detected vessels positions with VMS position reports match well. More than 73% of the vessels could be unambiguously identified in the Flemish Cap study and 92% in the North Sea. Only in the Azores, where fibreglass and wooden vessels predominate, was it difficult to detect the vessels subject to VMS. The mean distance between detected position and VMS position was about 0.3 nautical miles. Other observations of interest in the paper are: trawling vessels have larger wakes; azimuthal travelling vessels are brighter than range travelling ones.

The main thrust of the paper by Schwartz et al. is the study of algorithms for identifying and removing the two main types of false alarms produced by the SUMO detector. Their analysis revealed that most false alarms arise from two circumstances:

- Large objects, like oil rigs, which for certain aspect angles have bright ship-like sidelobe patterns
- Very local wind turbulence effects which can produce bright ship-like noise patterns.

Schwartz et al. note that false alarms in the first category could easily be eliminated if the locations of the large objects are mapped and the SAR image registered with the map. However, that is not possible owing to the lack of precise satellite orbit parameters. Schwartz et al. also comment that modelling and predicting the sidelobe patterns is not an option. Hence an ad hoc method is employed. It involves simply grouping together any detected pixels which are less than 8 pixels apart. In this way the false alarms due to sidelobes are incorporated into the main detection. The distance of 8 pixels was selected heuristically. It was considered suitable for the detection problem at hand since ships in the open sea are usually more than 300 m apart which corresponds to a distance of 12 pixels.

For the second type of false alarm, Schwartz et al. note that local wind turbulence effects are normally contained within a 100x100 pixel area. Three characteristics of such effects are listed.
The last of these was found to be best for discrimination purposes. It states that the number of local maxima close to the threshold value T2 is large. Therefore, a 100x100 pixel image chip is taken from around each detection and the number of local maxima above T2 is counted. If that number is larger than 750, the detection is rejected as a false alarm. Test data was used in setting the threshold at 750. Schwartz et al. report that this algorithm separates false alarms from true detection well and provides quantitative performance data.

5.2 – SAR Satellite Imagery Processing

The high resolution SAR satellite images were analysed visually, since the resolution is good enough to allow visual analysis. The medium/lower resolution SAR satellite images (Ultrafine and Stripmap) were processed using JRC vessel detection software, Search for Unidentified Maritime Objects (SUMO). Different SUMO thresholds were used, namely a normal threshold and progressively lower thresholds. The objective of using lower thresholds was to increase sensitivity of the detector. In fact, lowering the threshold increased the number of targets detected. However, the increased detection has a main drawback, the number of false alarms also increased. The results are presented next.

Figures 24, 25 and 26 are the output of the SUMO processing for the SAR image acquired on 8 September 2009. In Fig. 24 a normal threshold was used. As it can be seen, only four targets were detected, a large ship and three medium size boats.

In order to increase the sensitivity of the detector, the threshold was lowered. The SUMO output is given in Fig.25. Two extra boats were detected. One in green is likely a false alarm. The second in blue is likely a medium size boat.

A third threshold was used to increase even further the sensitivity of the detector. The result is presented in Fig.26. The number of detected targets increased significantly, however, most of the new detections are likely false alarms.

The results of the SUMO processing were compared with the ground truth data supplied by the Italian authorities (Guardia di Finanza and Guardia Costiera). No target was detected in the GPS coordinates supplied by the Italian authorities. The small boat deployed was not detected.
Figure 22 – SAR satellite image (8Sep2009) processed using SUMO and a normal threshold. Radarsat-2 images © MDA 2009/2010.

Figure 23 – SAR satellite image (8Sep. 2009) processed using SUMO and a lower threshold.
Figure 24 - SAR satellite image (8Sep. 2009) processed using SUMO and a lower threshold.

Figure 27 shows the area where the experiment was carried out on 13 Sep. 2009, including the footprint of the SAR image.

Figure 28 and 29 are the output of the SUMO processing for the SAR image acquired on 13 September 2009. In Fig. 28 a normal threshold was used. As it can be seen, only one target was detected, apparently, a medium size boat or a false alarm.

Figure 29 is the result of running SUMO with a lower threshold. Seven medium size and one large size boats were detected.

The results of the SUMO processing were compared with the ground truth data supplied by the Italian authorities (Guardia di Finanza and Guardia Costiera). No target was detected in the GPS coordinates supplied by the Italian authorities. The small boat deployed was not detected.
Figure 25 – SAR satellite planning for 13Sep2009.

Figure 26 - SAR satellite image (13Sep2009) processed using SUMO and a normal threshold. **Radarsat-2 images © MDA 2009/2010.**
Figure 27 - SAR satellite image (13Sep. 2009) processed using SUMO and a lower threshold. Radarsat-2 images © MDA 2009/2010.

Figure 30 and 31 illustrate the output of the SUMO detector for the SAR image acquired on 15 September 2009. In Fig. 30 a normal threshold was used. As it can be seen, nine targets were detected. Apparently, they correspond to medium size boats. Some of the targets might be false alarms.

Figure 31 is the result of running SUMO with a lower threshold. Thirty targets were detected. A significant number of these detected targets are likely false alarms.

The results of the SUMO processing were compared with the ground truth data supplied by the Italian authorities (Guardia di Finanza and Guardia Costiera). No target was detected in the GPS coordinates supplied by the Italian authorities. The small boat deployed was not detected.
Figure 28 - SAR satellite image (15Sep. 2009) processed using SUMO and a normal threshold. Radarsat-2 images © MDA 2009/2010.

Figure 29 - SAR satellite image (15Sep. 2009) processed using SUMO and a lower threshold. Radarsat-2 images © MDA 2009/2010.
Figure 32 illustrates the SAR Satellite imagery planning for the experiment at the beach of Porto Canale. The footprints of all Radarsat2-Spotlight SAR satellite images available during the period of the experiment are shown in different colours. The selected image was the one on 19 September 2009.

![Figure 30 – SAR satellite Radarsat2 image planning for 19 Sep. 2009 at Porto Canale beach in Sardinia-Italy.](image)

Figure 33 illustrates the approximate position of the small boat deployed by the Italian Guardia Costiera on 19 September at the beach of Porto Canale over a google Earth image of the Porto Canale beach.

Figure 34 shows several members of staff of the Italian Guardia Costiera holding the small boat the time of the SAR satellite pass (19:06h).
Figure 31 – Google Earth image of the Porto Canale beach with the location where the small rubber boat was deployed on 19 Sep. 2009.

Figure 32 – Small rubber boat deployed at the Porto Canale beach at the time of the SAR satellite pass on 19 Sep. 2009.
Figure 35 illustrates the Radarsat2-Spotlight SAR image acquired over Porto Canale beach on 19 September 2009 by 19:06h. Within the red circle there is a bright spot in the same position where the Guardia Costiera deployed the small boat. The small green circle also corresponds to a bright spots where several small boats were deployed. However, it is not clear if it corresponds to one or more small boats.

The results of the experiment at the beach of Porto Canale seem to suggest that there is some potential for the detection of small boats on the beach using SAR spaceborn imagery. At least, it might be worth to carry out new experiments to investigate the probability of detection using several small boats of different types (e.g. shape, size, materials, etc.).

Figure 33 - SAR satellite image Radarsat2-Spotlight acquired over Porto Canale beach on 19 Sep. 2009. Radarsat-2 images © MDA 2009/2010.

Figure 36 illustrates the SAR Satellite imagery planning for the experiment at the beach of Porto Canale. The footprints of all TerraSAR-X-Spotlight SAR satellite images available during the period of the experiment are shown in different colours. The selected image was the one on 19 September 2009.

Figure 37 illustrates the quick-view of the TerraSAR-X image acquired on 19 September 2009 delivered by DLR, the German Aerospace Centre. Since the incidence angle was out of the optimal performance range interval, the actual full SAR image was not delivered by DLR. The quick-view does not allow to check the small boat detection.
Figure 34 – TerraSAR-X-Spotlight SAR satellite image planning for 19 Sep. 2009.

Figure 35 – Preview of the TerraSAR-Spotlight acquired over Porto Canale beach on 19 Sep. 2009. The actual full image was not delivered by DLR because the incidence angle was out of the optimal performance range interval.
Figure 38 illustrates the Radarsat-2 image acquired on 22 September 2009 delivered by MDA and processed using SUMO and a lower threshold. Several targets with a wide range of sizes were detected.

Figure 36 - SAR satellite image (22Sep. 2009) processed using SUMO and a lower threshold. Radarsat-2 images © MDA 2009/2010.
Figure 39 illustrates the Radarsat-2 spaceborne SAR image outline acquired on 23 September 2009, delivered by MDA and processed using SUMO and a normal threshold. Several targets of different sizes were detected.

Figure 37 - SAR satellite image outline (Radarsat-2, 23Sep. 2009) with detections from SUMO and a normal threshold.
Figure 40 illustrates the Radarsat-2 spaceborne SAR image outline acquired on 23 September 2009, delivered by MDA and processed using SUMO and a lower threshold. Several targets of different sizes were detected.

Figure 38 - SAR satellite image outline (Radarsat-2, 23Sep. 2009) with detections from SUMO and a lower threshold.
Figure 41 illustrates the Radarsat-2 spaceborne SAR image outline acquired on 25 September 2009, delivered by MDA and processed using SUMO and a lower threshold. Several targets of different sizes were detected.

**Figure 39** - SAR satellite image outline (Radarsat-2, 25Sep. 2009) with detections from SUMO and a lower threshold.
Figure 42 illustrates the Spaceborne SAR imagery planning for October 2009 near Palomares Canyon in Spain.

Figure 40 - SAR satellite image planning for Oct. 2009 near Palomares Canyon – Spain.
Figure 41 - SAR satellite image (26Oct. 2009) processed using SUMO and a normal threshold. Radarsat-2 images © MDA 2009/2010.

Figure 42 - SAR satellite image (26Oct. 2009) processed using SUMO and a lower threshold. Radarsat-2 images © MDA 2009/2010.
Figure 43 - SAR satellite image (28Oct. 2009) processed using SUMO and a normal threshold. Radarsat-2 images © MDA 2009/2010.

Figure 44 - SAR satellite image (28Oct. 2009) processed using SUMO and a lower threshold. Radarsat-2 images © MDA 2009/2010.
5.3 – Ground Truth Data

Tables 2 and 3 give the ground truth data collected by the Italian and Spanish authorities during the experiments, namely the GPS position of the small boats deployed, the sea state, the wind speed and the drift. The area, date and time and the satellite modes are also given.

Table 2 – Ground Truth data supplied by the Italian/Spanish Authorities.

<table>
<thead>
<tr>
<th>Date/Time</th>
<th>Area</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Satellite/Mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>8-Sep-2009</td>
<td>Gulf of Cagliari, Sardinia-Italy</td>
<td>38° 56' 00&quot;N</td>
<td>09° 18' 00&quot;E</td>
<td>Radarsat2 Ultrafine</td>
</tr>
<tr>
<td>13-Sep-2009</td>
<td>Gulf of Cagliari, Sardinia-Italy</td>
<td>38° 54' 00&quot;N</td>
<td>09° 14' 00&quot;E</td>
<td>Radarsat2 Ultrafine</td>
</tr>
<tr>
<td>15-Sep-2009</td>
<td>Gulf of Cagliari, Sardinia-Italy</td>
<td>38°49'00&quot;N</td>
<td>09°13'00 E</td>
<td>Radarsat2 Ultrafine</td>
</tr>
<tr>
<td>19-Sep-2009</td>
<td>Porto Canale beach, Cagliari, Sardinia-Italy</td>
<td>Porto Canale Beach</td>
<td>Porto Canale Beach</td>
<td>Radarsat2 Spotlight TerraSAR-X Spotlight</td>
</tr>
<tr>
<td>22-Sep-2009</td>
<td>Porto Pino, Sardinia-Italy</td>
<td>38°54'1.0&quot;N</td>
<td>8°30'3.0&quot;E</td>
<td>Radarsat2 Ultrafine</td>
</tr>
<tr>
<td>23-Sep-2009</td>
<td>Porto Pino, Sardinia-Italy</td>
<td>38°56 N</td>
<td>8.5</td>
<td>Radarsat2 Ultrafine</td>
</tr>
<tr>
<td>25-Sep-2009</td>
<td>Porto Pino, Sardinia-Italy</td>
<td>38°900556</td>
<td>8.500278</td>
<td>Radarsat2 Ultrafine</td>
</tr>
<tr>
<td>26-Oct-2009</td>
<td>Palomares Canyon-Spain</td>
<td>37º02'30.96&quot;N</td>
<td>01º36'58.92&quot;W</td>
<td>Radarsat2 Ultrafine</td>
</tr>
<tr>
<td>28-Oct-2009</td>
<td>Palomares Canyon-Spain</td>
<td>37º00' 54&quot;</td>
<td>01º 31’ 0.6”</td>
<td>Radarsat2 Ultrafine</td>
</tr>
</tbody>
</table>

Table 3 - Ground Truth data supplied by the Italian/Spanish Authorities.

<table>
<thead>
<tr>
<th>Date/Time</th>
<th>Area</th>
<th>Sea State</th>
<th>Wind Speed</th>
<th>Drift</th>
</tr>
</thead>
<tbody>
<tr>
<td>8-Sep-2009</td>
<td>Gulf of Cagliari, Sardinia-Italy</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>13-Sep-2009</td>
<td>Gulf of Cagliari, Sardinia-Italy</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>15-Sep-2009</td>
<td>Gulf of Cagliari, Sardinia-Italy</td>
<td>Sea 3</td>
<td>south/west</td>
<td>drift south/west</td>
</tr>
<tr>
<td>19-Sep-2009</td>
<td>Porto Canale beach, Cagliari, Sardinia-Italy</td>
<td>Beach</td>
<td>Beach</td>
<td>Beach</td>
</tr>
<tr>
<td>22-Sep-2009</td>
<td>Porto Pino, Sardinia-Italy</td>
<td>Sea 2 (0,10 -0,5 m)</td>
<td>east/south/east 2 ( 4-6 knots )</td>
<td>east/south/east</td>
</tr>
<tr>
<td>23-Sep-2009</td>
<td>Porto Pino, Sardinia-Italy</td>
<td>Sea 2</td>
<td>north/east 4</td>
<td>drift north/east</td>
</tr>
<tr>
<td>25-Sep-2009</td>
<td>Porto Pino, Sardinia-Italy</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>26-Oct-2009</td>
<td>Palomares Canyon-Spain</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>28-Oct-2009</td>
<td>Palomares Canyon-Spain</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
</tbody>
</table>
5.4 – Verification of the Results

Table-4 gives a summary of all SAR images acquired during the two campaigns in Sardinia-Italy and Palomares Canyon in Spain. The table gives the detected ships of all sizes using different SUMO thresholds. A visual inspection and analysis of the SAR images was also performed. While no small boats were detected at sea exactly at the ground truth locations, in two and maybe three cases, depending on interpretation, a small target was detected near enough to the reported ground truth position to accept it.

<table>
<thead>
<tr>
<th>Date / Time</th>
<th>Place</th>
<th>Satellite / Mode</th>
<th>Ground Truth Data</th>
<th>Detected Ships</th>
<th>Small Boat?</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ITALY (Sardinia)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>08-Sep-2009</td>
<td>Gulf of Cagliari</td>
<td>Radarsat-2 / Ultrafine</td>
<td>GPS</td>
<td>t1-[4]; t2-[6]; t3-[22]</td>
<td>No</td>
</tr>
<tr>
<td>13-Sep-2009</td>
<td>Gulf of Cagliari</td>
<td>Radarsat-2 / Ultrafine</td>
<td>GPS</td>
<td>t1-[1]; t2-[3]; t3-[9]</td>
<td>No</td>
</tr>
<tr>
<td>15-Sep-2009</td>
<td>Gulf of Cagliari</td>
<td>Radarsat-2 / Ultrafine</td>
<td>GPS</td>
<td>t1-[9]; t2-[33]</td>
<td>No</td>
</tr>
<tr>
<td>18-Sep-2009</td>
<td>Gulf of Cagliari</td>
<td>TerraSAR-X-Stripmap</td>
<td>GPS – Flight Data</td>
<td>±</td>
<td></td>
</tr>
<tr>
<td>19-Sep-2009</td>
<td>Sardinia Cagliari</td>
<td>Radarsat-2 / Spotlight TerraSAR-X/Spotlight</td>
<td>GPS – Flight Data</td>
<td>±</td>
<td></td>
</tr>
<tr>
<td>22-Sep-2009</td>
<td>Porto Pino</td>
<td>Radarsat-2 / Ultrafine</td>
<td>GPS</td>
<td>t1-[11]; t2-[14]; t3-[25]</td>
<td>No</td>
</tr>
<tr>
<td>23-Sep-2009</td>
<td>Porto Pino</td>
<td>Radarsat-2 / Ultrafine</td>
<td>GPS</td>
<td>t1-[1]; t2-[3]; t3-[12]</td>
<td>+/-</td>
</tr>
<tr>
<td>25-Sep-2009</td>
<td>Porto Pino</td>
<td>Radarsat-2 / Ultrafine</td>
<td>GPS</td>
<td>t1-[30]; t2-[32]; N/A</td>
<td></td>
</tr>
<tr>
<td><strong>SPAIN (Almeria)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>26-Oct-2009</td>
<td>Almeria (SP)</td>
<td>Radarsat-2 / Ultrafine</td>
<td>GPS</td>
<td>t1-[1]; t2-[5]; t3-[31]</td>
<td>No</td>
</tr>
<tr>
<td>28-Oct-2009</td>
<td>Almeria (SP)</td>
<td>Radarsat-2 / Ultrafine Cosmo-SkyMed</td>
<td>GPS</td>
<td>t1-[3]; t2-[5]; t3[12]</td>
<td>+/-</td>
</tr>
</tbody>
</table>
Figures 44 to 52 illustrate the positions of the small boats deployed by the Italian and Spanish authorities during the experiments in each of the SAR images.

Figure 45 – Radarsat2 – Ultrafine image, acquired on at the Gulf of Cagliari. The image shows the boats detected in green and blue and the GPS position 38° 56' 00"N, 09° 18' 00"E (in yellow) of the small boat deployed by the Italian authorities on 8-Sep-2009. Radarsat-2 images © MDA 2009/2010.
Figure 46 - Radarsat2 – Ultrafine image, acquired on at the Gulf of Cagliari. The image shows the boats detected in green and blue and the GPS position 38° 54' 00"N, 09°14'00"E (in yellow) of the small boat deployed by the Italian authorities on 13-Sep-2009. Radarsat-2 images © MDA 2009/2010.
Figure 47 - Radarsat2 – Ultrafine image, acquired on at the Gulf of Cagliari. The image shows the boats detected in green and blue and the GPS position 38°49'00"N,09°13'00E (in yellow) of the small boat deployed by the Italian authorities on 15-Sep-2009. Radarsat-2 images © MDA 2009/2010.
Figure 48 - Radarsat2 – Spotlight image, acquired over the beach of Porto Canale. The image shows the small semi-rigid boat deployed by the Italian authorities detected in red on 19-Sep-2009. Within the green circle we can see another bright spot which corresponds to the GPS coordinates of a second small boat. Radarsat-2 images © MDA 2009/2010.
Figure 49 - Radarsat2 – Ultrafine image, acquired in Porto Pino. The image shows the boats detected in green and blue and the GPS position 38°54’01”N, 8°30’03”E (in yellow) of the small boat deployed by the Italian authorities on 22-Sep-2009. Radarsat-2 images © MDA 2009/2010.
Figure 50 - Radarsat2 – Ultrafine image, acquired in Porto Pino. The image shows the boats detected in green and blue and the GPS position 38°56’ 00”N, 09°13’00”E (in yellow) of the small boat deployed by the Italian authorities on 23-Sep-2009. Radarsat-2 images © MDA 2009/2010.
Figure 51 - Radarsat2 – Ultrafine image, acquired in Porto Pino. The image shows the boats detected in green and blue and the GPS position 38°54’02”N, 08°30’01” (in yellow) of the small boat deployed by the Italian authorities on 25-Sep-2009. Radarsat-2 images © MDA 2009/2010.
Figure 52 - Radarsat2 – Ultrafine image, acquired near Palomares Canyon-Spain. The image shows the boats detected in green and blue and the GPS position 37°02’30.96”N, 01°36’58.92”W (in yellow) of the small boat deployed by the Spanish authorities on 26-Oct.-2009. Radarsat-2 images © MDA 2009/2010.
5.5 – Analysis of the Results

During the experiment in Sardinia-Italy and Palomares Canyon-Spain, eight SAR images were acquired over open sea and two at the beach of Porto Canale.

First, the eight cases over sea are discussed here. In each image, the small targets nearest to the test boat location were considered as candidates for being the test boat. In no case did the test boat location exactly coincide with a small target. However, the quoted test boat locations are expected to have a considerable uncertainty. The actual test boat location (ground truth) should have been recorded exactly at the time of satellite overpass. However, some ground truth reports have come in with a different time, or with no time at all. Therefore, some ground truth reports are considered more reliable than others. Even if the timing is correct, a measured location of a small boat at sea easily has an error of 10-100 meters. For these reasons, it is not unlikely that a small target that is found up to a few hundred meters away from the reported test boat location is actually the test boat. There are two such cases, 15 and 23 Sept, where a small target is found at a distance of respectively 280 m and 570 m from the test boat ground truth. These are deemed as...
possible detections of the test boat. In one other case, 28 Oct, the patrol boat is found in the image as a larger target, with a small target alongside it. Although the quoted test boat position is 3 km away from this small target, the quoted location is actually outside the image. In this case it is also not unlikely that the small detection is in fact the test boat.

The measure for how strongly a target reflects radar is the Radar Cross Section (RCS). Its unit is square meters (m²), and it can be understood as an effective physical size of the target as seen by the radar. The RCSs of the presumed detected test boats have been measured from the images. A target can be detected if its RCS is high enough to lift its reflection out of the surrounding background noise and clutter. The local image background can therefore be characterised by a minimum detectable RCS, which is the smallest RCS that can be detected above the local background noise and clutter level. Also this number has been computed for the test boat locations in the images. (NB: RCS is finally given in units of dBm² which means 10 x the 10-logarithm of the RCS in m² – although awkward at first sight, this is the customary way.)

The eight cases over sea, as discussed above, are summarised in Table 5. The table first lists the two images in HV polarisation, then the six in HH polarisation. The columns of the table are: Date of the image; Incidence angle (ref. section 3.3); Minimum detectable Radar Cross Section at test boat location; Radar Cross Section of assumed detected test boat; Distance between ground truth position and assumed detected test boat; Wind speed; Sea state; Assessed reliability of ground truth; and Total number of small boat detections in the image. A small boat (as opposed to a medium-sized or large one) is a boat that is unresolved or marginally resolved in range, and has an RCS in HH of less than 12 dBm², or in HV of less than 3 dBm².

Table 5 – List of SAR Satellite Images acquired during the experiment.

<table>
<thead>
<tr>
<th>Date</th>
<th>Inc (deg)</th>
<th>RCS min (dBm²)</th>
<th>RCS det (dBm²)</th>
<th>Dist (km)</th>
<th>Wind (kn)</th>
<th>Sea (m)</th>
<th>GT rel</th>
<th># Det</th>
</tr>
</thead>
<tbody>
<tr>
<td>HV</td>
<td>09 13</td>
<td>37</td>
<td>-5.1</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>09 23</td>
<td>30</td>
<td>-4.8</td>
<td>-4.1</td>
<td>0.57</td>
<td>4 Bf</td>
<td>0.1-0.5</td>
<td>+ 1</td>
</tr>
<tr>
<td>HH</td>
<td>09 08</td>
<td>47</td>
<td>1.0</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>09 15</td>
<td>43</td>
<td>3.4</td>
<td>4.6</td>
<td>0.28</td>
<td>4-6</td>
<td>0.1-0.5</td>
<td>+ 9</td>
</tr>
<tr>
<td></td>
<td>09 22</td>
<td>35</td>
<td>9.0</td>
<td>-</td>
<td>-</td>
<td>4-6</td>
<td>0.1-0.5</td>
<td>+ 0</td>
</tr>
<tr>
<td></td>
<td>09 25</td>
<td>48</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>2-3 Bf</td>
<td>0.1-0.5</td>
<td>- 9</td>
</tr>
<tr>
<td></td>
<td>10 26</td>
<td>31</td>
<td>8.2</td>
<td>-</td>
<td>-</td>
<td>11</td>
<td>0.5</td>
<td>o 31</td>
</tr>
<tr>
<td></td>
<td>10 28</td>
<td>45</td>
<td>1.0</td>
<td>4.5</td>
<td>3.0</td>
<td>12</td>
<td>0.5</td>
<td>o 9</td>
</tr>
</tbody>
</table>

On 25 Sep, the test boat was outside the image by 10 km. Accepting that the cases of 15 and 23 Sept, and possibly 28 Oct, are positive detections, then the detection score is 2 – 3 out of 7, i.e. 28 % - 43 %. If those cases where the ground truth is deemed unreliable are not taken into account, the we have 2 detections out of 4 cases, i.e. 50 % detection score.

Accepting three detections, then where the test boat was detected in HH (2x), its RCS is 4.5 dBm². Where it was detected in HV (1x), RCS is -4.1 dBm². Where the test boat was not detected in HH (3x), in 2 cases the minimum detectable RCS is 8.2 and 9.0, which is higher than 4.5, so indeed the test boat would not have been detected. In one case the minimum detectable RCS is 1.0, so in that case the test boat should have been detected. However, in that case the ground truth time was not reported back, so there is uncertainty in the ground truth position. Where the test boat was not detected in HV (1x), the minimum detectable RCS is -5.1, only just below the -4.1 that was detected. So indeed it could have been missed.
The above analysis on RCS and minimum detectable RCS seems to indicate that the small boats may be detectable in calm conditions (low sea clutter) but not anymore when wind or waves are a bit higher.

In the eight sea images, the total number of small boats detected (with reasonable threshold settings) was 72, so on average 9 per image. This does not imply that for each image there are 9 false alarms – these detection may have been real small boats, other than the test boat. But it does mean that it is difficult to find the small boat that one is looking for.

Concerning the two high resolution images (Spotlight) acquired on 19 Sep. 2009 over the Porto Canale beach, the TerraSAR-X-Spotlight image was not delivered because the incidence angle was out of the full performance range. The RAdarsat2-Spotlight was delivered and a visual analysis shows that the Small rubber boat deployed by the Guardia Costiera was detected. This is encouraging; however, considering the statistical nature of the radar detections, no firm conclusion should be drawn based on a single experiment. Additional experiments are needed to assess the feasibility of detecting small boats using spaceborne SAR images.
6. – Preliminary Conclusions

The relatively reduced amount of data collected and analysed does not allow drawing final conclusions about the feasibility of using SAR Satellites for small boat detection. But the trial has given some indications. The SAR image acquired over the beach of Porto Canale suggests that it is feasible to detect small boats (>6m) on land (e.g. beach). However, further detection campaigns are needed before final conclusions can be drawn. Concerning the trials on open sea, in none of the eight SAR images a detection was found exactly at the reported test boat position. However, based on a more accommodating but reasonable analysis of the uncertainties in the trials, a detection score of 30-50 % for the small boats is indicated, with calm sea conditions needed for positive detection.

Further small boat detection campaigns are needed to evaluate the feasibility of detection of small boats using spaceborne SAR imagery. Future campaigns should include different scenarios, different types of boats (e.g. size, shape, material, etc.) and different environmental and weather conditions.

6.1 – Small Boat Detection in SAR Satellite Imagery

The use of spaceborne SAR imagery for small boat detection requires additional small boat detection experiments under different environments using different methods. It is not possible to draw broad conclusions based on a limited number of small boat detection experiments, which are not representative of the multiple possible scenarios.

6.2 – Characterisation of SAR Small Boat Signatures

The characterisation of SAR small boat signatures is a challenging task. In the three cases in this trial where it was assumed that the test boat was detected, its RCS in HH polarisation was 4.5 dBm2 (two cases) and in HV polarisation -4.1 dBm2 (one case). Any attempt to characterize SAR signatures of small boats requires a large number of SAR signatures. Additional small boat detection experiments are required to generate a large amount of data to be analysed.
6.3 – Limitations of current State-of-the-Art SAR Satellite technology

The main limitations of current State-of-the-Art spaceborne SAR imagery for maritime surveillance, in particular aimed at small boat detection, are:

1. - SAR satellites repeat cycles do not allow the coverage of the same area at the required time intervals. Constellations of SAR satellites could be a solution.

2. - The conflict between resolution and image swath. High resolution is required to detect small boats. However, the high resolution images have small swaths. Maritime surveillance with high resolution images would require a large number of images to cover wide maritime areas, which is very expensive and for the time being technically not feasible. Intelligence data can play an important role by indicating an approximate position of suspicious non cooperative targets, therefore reducing the surveillance area, which can then be imaged using high resolution images.

3. - Spaceborne high resolution SAR imagery acquisition times are long enough to allow significant motion of the target during the acquisition time degrading the quality of the image. Further research efforts are needed to develop new sensors and platforms. As far as sensors are concerned, shorter integration times are needed to prevent the blurring effect caused by the motion of the targets. Regarding the platforms, more platforms are needed to allow lower repeat cycles and improved coverage.
7. – Plans for Future Work

The controlled experiments carried out in Sardinia-Italy and Palomares Canyon-Spain comprised the deployment of small boats on open sea and on land (beach). The open sea trials did not produce any small boat detection. The trial at the beach of Porto Canale led to the detection of the small boat deployed. These results are not enough to draw final conclusions about the feasibility of using spaceborne SAR imagery for small boat detection. Several factors can affect the detection of small boats, including the sea state, the wind speed, the size, shape and materials of the boats, etc.

Our future plans include additional small boat detection experiments taking into account several factors, including:

1. new methods – besides deploying a single small boat on open sea, we will try to deploy several small boats and to use targets of opportunity.
2. different environments – besides the open sea deployments, it would be useful to use other environments, such as inland waters and environments with different sea states, wind speeds and drifts.
3. it would also be useful to use different types and modes of SAR images.

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REFERENCES


The European maritime area is one of Europe’s most important assets with regard to resources, security and ultimately prosperity of the Member States. A significant part of Europe’s economy relies directly or indirectly on it. It is not just the shipping or fisheries industries and their related activities. It is also shipbuilding and ports, marine equipment and offshore energy, maritime and coastal tourism, aquaculture, submarine telecommunications, blue biotech and the protection of the marine environment. The European maritime area faces several risks and threats posed by unlawful activities, such as drugs trafficking, smuggling, illegal immigration, organised crime and terrorism. Piracy in international waters also constitutes a threat to Europe since it can disrupt the maritime transport chain. These risks and threats can endanger human lives, marine resources and the environment, as well as significantly disrupt the transport chain and global and local security. It is anticipated that these risks and threats will endure in the mid and long run. In order to keep Europe as a world leader in the global maritime economy, an effective integrated/interoperable, sustainable maritime surveillance system and situational awareness are needed.

A significant number of unlawful maritime activities, such as illegal immigration, drugs trafficking, smuggling, piracy and terrorism involve mainly small boats, because small boats are faster and more difficult to detect using conventional means. Hence, it is very important to find out the feasibility of using SAR Satellite images for small boat detection. This report describes the results of the JRC/Frontex joint spaceborne SAR maritime surveillance campaign aimed at small boat detection in Sardinia-Italy and Palomares Canyon-Spain. The relatively reduced amount of data collected and analysed does not allow drawing final conclusions about the feasibility of using SAR Satellites for small boat detection. But the trial has given some indications. A SAR image acquired over the beach of Porto Canale suggests that it is feasible to detect small boats (>6m) on land (e.g. beach). However, further detection campaigns are needed before final conclusions can be drawn. Concerning the trials on open sea, in none of the eight SAR images a detection was found exactly at the reported test boat position. However, based on a more accommodating but reasonable analysis of the uncertainties in the trials, a detection score of 30-50 % for the small boats is indicated, with calm sea conditions needed for positive detection.
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