JRC Scientific and Technical Reports

JRC - SAR Satellite Small Boat Detection Campaign – Algarve - Portugal

Results of the Spaceborne SAR Small Boat Detection campaign carried out by the EC-JRC in the Algarve-Portugal in December 2009

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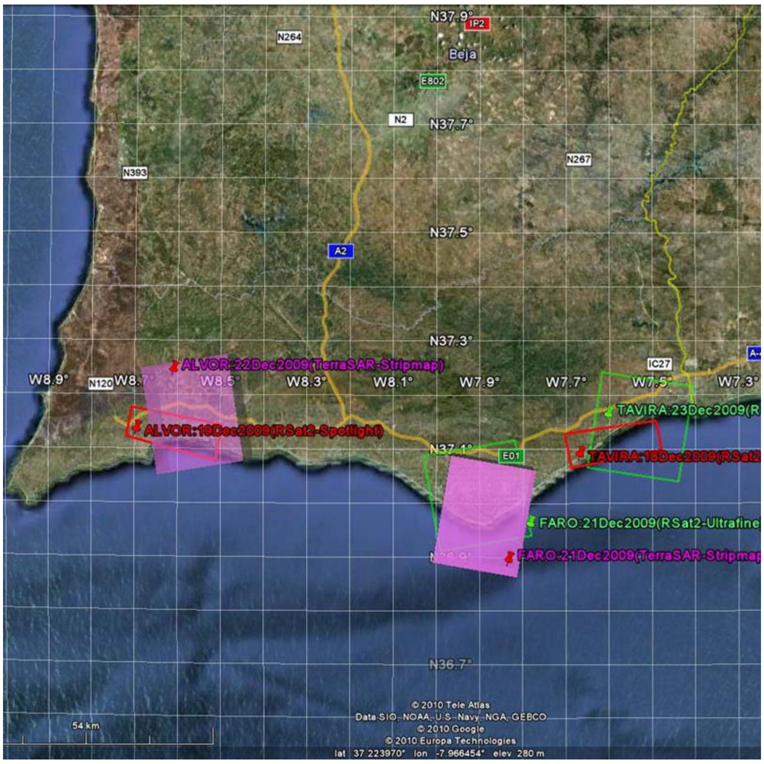

EUR 24945 EN - 2011

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JRC **66631**

EUR **24945 EN**
ISBN **978-92-79-21265-9**
ISSN **1831-9424 (online), 1018-5593 (print)**
doi:**10.2788/717**

Luxembourg: Publications Office of the European Union, 2011

Printed in Italy

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1. – Introduction

This report presents the key findings of the SAR Satellite Imagery Small Boat Detection Campaign, carried out by the EC-JRC in the Algarve-Portugal from 17 to 23 December 2009.

1.1 – Scope

This study addresses the feasibility of using Synthetic Aperture Radar (SAR) Satellite imagery for Small Boat Detection, in particular on inland sea waters.

To answer this statement of work, the European Commission (EC) – Joint Research Centre (JRC) set up a small boat detection campaign in the Algarve-Portugal. In previous small boat detection campaigns carried out by the EC-JRC in Algeria-Italy (2008) and in cooperation with Frontex and national authorities in Sardinia-Italy and Palomares Canyon–Spain (2009), the trials took place on open sea and on land (beach). In order to reduce the effect (sea clutter) of the sea state to the minimum possible, this time the experiment took place on inland sea waters where the sea state does not play an important role.

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), in particular on inland sea waters.
- To try 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, a controlled experiment using targets of opportunity was designed, set up and executed. The controlled experiment is briefly described next.

2.1 – Controlled Experiment on Inland Sea Waters

The main objective of this controlled experiment was to find out if small boats used as targets of opportunity, could be detected using spaceborne SAR imagery. Knowing the approximate GPS position of a set of small boats, targets of opportunity, and collecting in-situ ground truth data at the time of the SAR Satellite passes it should be possible to find out if small boats can be detected using spaceborne SAR imagery. In order to maximize the probability of detection, inland sea waters were chosen to minimize the effect (sea clutter) of the sea state on the detection.

The controlled experiment involved the following steps:

1. – The EC-JRC selected several areas in the Algarve-Portugal, where a significant number of small boats were available on inland sea waters. Fig.1 illustrates the selected areas, namely Alvor, Faro and Tavira.

2. – The next step comprised the selection of the spaceborne SAR images (Radarsat2-Spotlight and Ultrafine, TerraSAR-X- Spotlight and Stripmap) available between 17 and 23 Dec. 2009 covering the above mentioned locations.

3. - The EC-JRC collected in-situ ground truth data in the Algarve-Portugal in all the selected locations on the dates and at the times of the satellite passes. The Ground Truth data included photos, films, the approximate position of the small boats and the weather conditions.

4. – The EC-JRC analysed the SAR satellite images acquired with the Ground Truth data collected during the experiment.

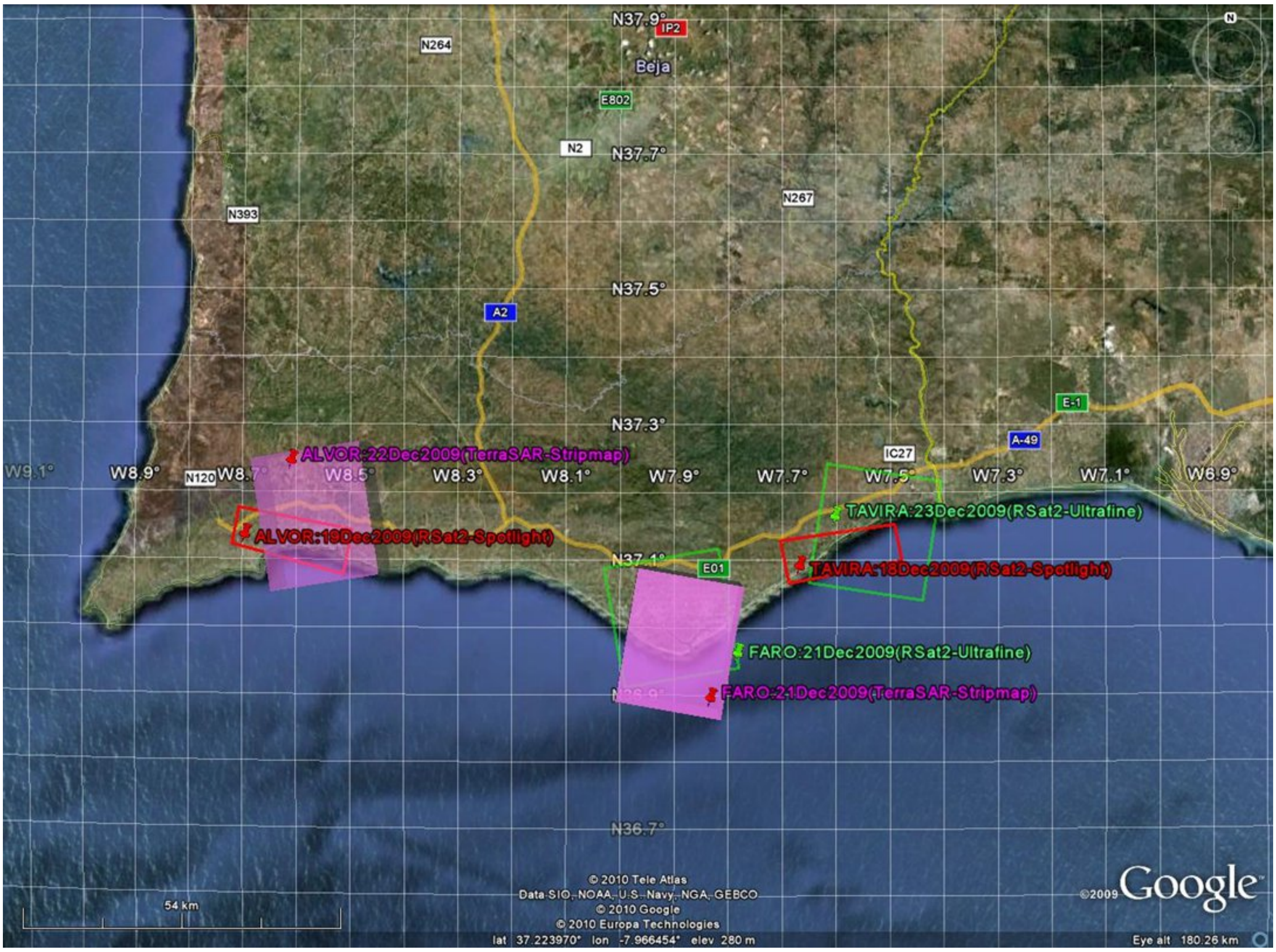

Figure 1 – The selected locations for the experiment in the Algarve-Portugal were: Tavira, Alvor and Faro. The images and image modes, as well as the dates of acquisition of all spaceborne SAR images acquired are indicated in the map above.

3. – Experiments Set Up

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

3.1 – Experiment Site Selection – Inland Sea Waters

The previous JRC small boat detection campaigns (Algeria, Sardinia and Palomares Canyon) took place mainly on open sea where the sea clutter is relatively high. Bearing in mind that sea clutter plays an important role in SAR imagery small boat detection, making it more difficult, the selection of inland sea water site scenarios for the experiment was an obvious option. By selecting inland sea waters where the sea is flat most of the time the sea clutter effect was minimised.

3.1.1 – Site Selection Criteria

The main criteria used for site selection were the following:

1.) – The sites should have inland sea waters somehow naturally protected from tides and currents in order to minimise the effect of the sea state (clutter) in SAR Small Boat detection.

2.) – The sites should have a reasonable number (over 20) of Small Boats with sizes ranging from 5 up to 20 meters.

3.) – A significant number of Small Boats should be spread over the area, moored on sea at reasonable distances apart from each other to avoid SAR signature contamination.

4.) – The sites should have easy access to facilitate the collection of Ground-Truth data.

3.1.2 – Inland sea waters in Tavira (Santa Luzia)

Santa Luzia in Tavira-Algarve was the first location selected for the experiment. The area was selected due to the inland sea waters and the availability of small boats that could be used as targets of opportunity. The spaceborne SAR image acquired over Santa Luzia was a Radarsat2-Spotlight. The frame (footprint) of the SAR image acquired covering Santa Luzia is illustrated in Figure.2.

Figure 2 – The first spaceborne SAR image was acquired over Tavira (Santa Luzia) above illustrated. The image was a Radarsat2-Spotlight.

Figure.2, a Google Earth image, illustrates the area of Santa Luzia in Tavira-Algarve. As it can bee seen, a significant number of small boats can be found moored in inland sea waters. The small boats are not packed nor too close to each other, which is essential to avoid SAR signature contamination.

Figure 3 -The Google Earth image above illustrates the area of Santa Luzia in Tavira-Algarve, over which the first spaceborne SAR image was acquired on 18 Dec. 2009.

3.1.3 – Inland sea waters in Alvor-Algarve

The second inland sea waters site selected for the experiment was in Alvor-Algarve, illustrated in Figure. 4. The area was selected due to the inland sea waters and the availability of small boats that could be used as targets of opportunity. The spaceborne SAR image acquired over Santa Luzia was a RAdarsat2-Spotlight. The frame (footprint) of the SAR image acquired covering Santa Luzia is illustrated in Figure.4.

Figure 4 -The Google Earth image above illustrates the area of Alvor- Algarve, over which the second spaceborne SAR image was acquired on 19 Dec. 2009.

As it can be seen in Figure.5, a large number of small boats with sizes ranging from 3 meter up to 15 meter can be found in Alvor on inland sea waters. The small boats were not packed, which is important to prevent SAR signature contamination. The area was selected due to the inland sea waters and the availability of small boats spread over the area that could be used as targets of opportunity. Besides the small boats on sea water, there were also several small boats on land.

Figure 5 -The Google Earth image above illustrates the area of Alvor in the Algarve, over which the second spaceborne SAR image was acquired on 19 Dec. 2009.

3.1.4 – Inland sea waters in Faro-Algarve

The third inland sea waters site selected for the experiment was in Faro-Algarve, illustrated in Figure. 6. The area was selected due to the inland sea waters and the availability of small boats that could be used as targets of opportunity. The spaceborne SAR images acquired over Faro were a Radarsat2-Ultrafine on 21 December 2009 and a TerraSAR-Stripmap on 21 December 2009. The frames (footprints) of the SAR images acquired covering Faro are illustrated in Figure.6.

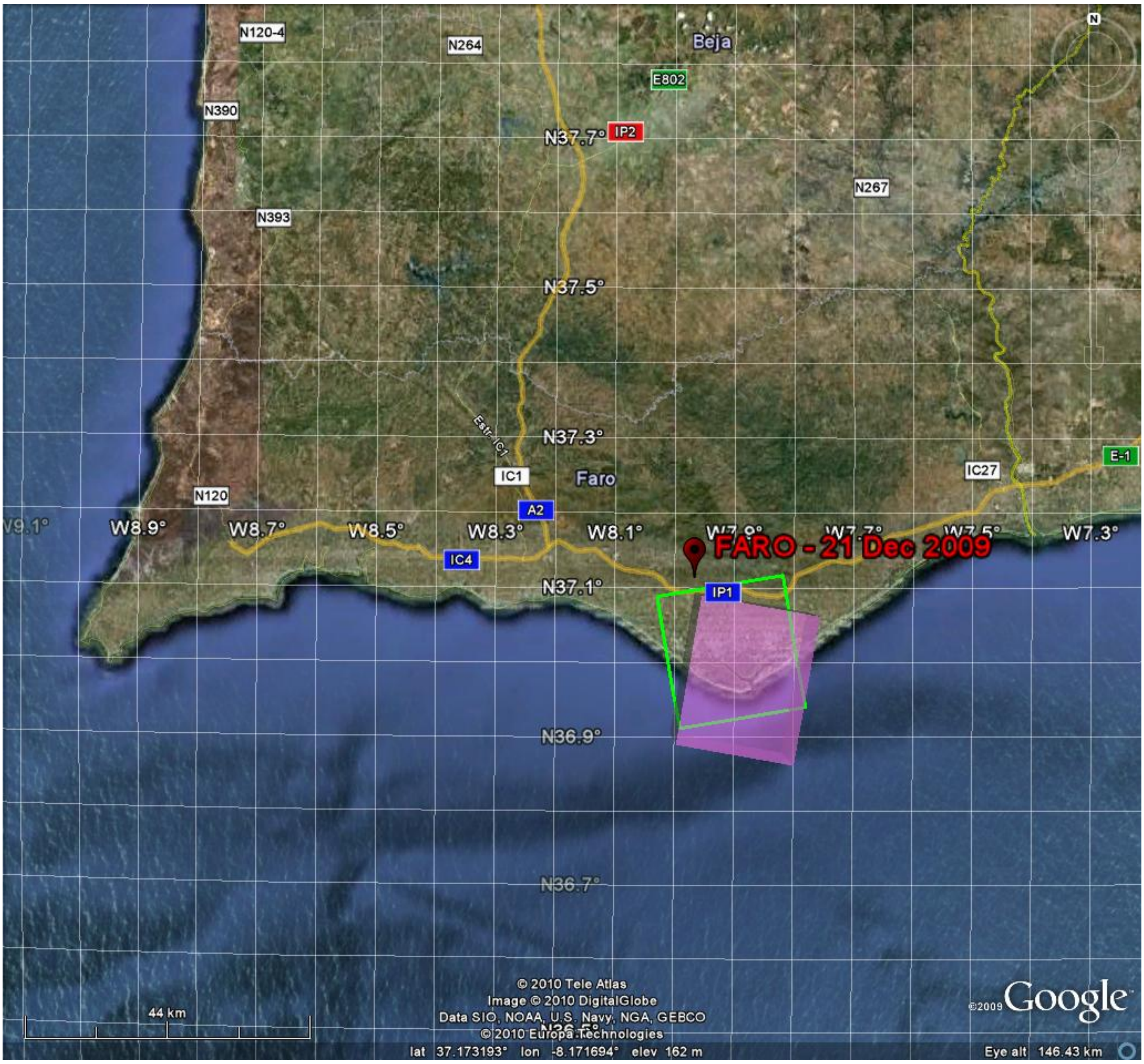

Figure 6 -The Google Earth image above illustrates the area of Faro- Algarve, over which the third and fourth spaceborne SAR images were acquired on 21 Dec. 2009.

As it can be seen in Figure.7, a large number of small boats with sizes ranging from 3 meter up to 10 meter can be found in Faro on inland sea waters. The small boats were spread over the area near the marina of Faro. The small boats were not packed or too close to each other, which is important to prevent SAR signature contamination. The area was selected due to the inland sea waters and the availability of small boats spread over the area that could be used as targets of opportunity. Besides the small boats on sea water, there were also several small boats moored at the marina of Faro.

Figure 7 -The Google Earth image above illustrates the area of Faro (São Pedro) in the Algarve, over which the third and fourth spaceborne SAR images were acquired on 21 Dec. 2009.

3.1.5 – Inland sea waters in Alvor / Portimão-Algarve

The fourth area covered included Alvor and Portimão. Figure.8 illustrates the image frame (footprint) of the SAR image acquired over Alvor-Portimão. The area was selected due to the inland sea waters and the availability of small boats that could be used as targets of opportunity. The spaceborne SAR images acquired over Alvor-Portimão was a TerraSAR-Stripmap on 22 Decembre 2009. The Alvor area was illustrated in Figure.5. The Portimão-Ferragudo area is illustrated in Figure.9.

Figure 8 -The Google Earth image above illustrates the area of Alvor/Portimão- Algarve, over which the fifth spaceborne SAR image was acquired on 22 Dec. 2009.

As it can be seen in Figure.9, a large number of small boats with sizes ranging from 3 meter up to 10 meter can be found in Ferragudo-Portimão on inland sea waters. The small boats were spread over the area near Ferragudo. The small boats were not packed or too close to each other, which is important to prevent SAR signature contamination. The area was selected due to the inland sea waters and the availability of small boats spread over the area that could be used as targets of opportunity. Besides the small boats on sea water, there were also several small boats on land near Ferragudo.

Figure 9 -The Google Earth image above illustrates the area of Portimão/Ferragudo in the Algarve, over which the fifth spaceborne SAR image was acquired on 22 Dec. 2009.

3.1.6 – Inland sea waters in Tavira (Cacela Vellha)-Algarve

The fifth area covered was Cacela-Velha in Tavira-Algarve. Figure.10 illustrates the image frame (footprint) of the SAR image acquired over Alvor-Portimão. The area was selected due to the inland sea waters and the availability of small boats that could be used as targets of opportunity. The spaceborne SAR image acquired over Cacela-Velha in Tavira-Algarve was a Radarsat2-Ultrafine on 23 December 2009.

Figure 10 -The Google Earth image above illustrates the area of Cacela Velha, Tavira-Algarve, over which the sixth spaceborne SAR image was acquired on 23 Dec. 2009.

As it can be seen in Figure.11, a significant number of small boats with sizes ranging from 3 meter up to 15 meter can be found in Cacela-Velha, Tavira-Algarve on inland sea waters. The small boats were spread over the area near Cacela-Velha. Some of the small boats were moored to different piers, other were moored on inland sea waters. Most of the small boats were not packed or too close to each other, which is important to prevent SAR signature contamination. However, some of the boats were close to each other. The area was selected due to the inland sea waters and the availability of small boats spread over the area that could be used as targets of opportunity. Besides the small boats on sea water, there were also several small boats on land.

Figure 11 -The Google Earth image above illustrates the area of Cacela Velha, Tavira in the Algarve, over which the fifth spaceborne SAR image was acquired on 22 Dec. 2009.

3.2 – Experiment Site Selection - 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.

Although the main purpose of this controlled experiment was not the detection of small boats on land, in virtually all sites there were some small boats on land.

3.3 – SAR Satellite Imagery Planning

The Synthetic Aperture Radar (SAR) satellite imagery used in this experiment comprised Radarsat2 (Spotlight and Ultrafine) and TerraSAR-X (Spotlight and Stripmap). 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 Alvor, Faro and Tavira in the Algarve-Portugal.

The planning of all the SAR satellite images acquired during this campaign is illustrated in the sequence of figures given next (Fig.12 to Fig.17).

Table 1 – SAR satellite imagery acquired over the Algarve-Portugal.

Date/Time	Area	Satellite / Mode	Polarization	Pass
PORTUGAL (Algarve)				
18-Dec.-2009	Tavira (Sta. Luzia) – Algarve	Radarsat-2 / Spotlight	Single HH	Ascending
19-Dec.-2009	Alvor - Algarve	Radarsat-2 / Spotlight	Single HV	Descending
21-Dec.-2009	Faro – Algarve	Radarsat-2 / Ultrafine	Single HH	Ascending
21-Dec.-2009	Faro – Algarve	TerraSAR-X / Stripmap	Dual HV/HH	Descending
22-Dec.-2009	Alvor – Algarve	TerraSAR-X/ Stripmap	Dual HV/HH	Ascending
23-Dec.-2009	Tavira – Algarve	Radarsat-2 / Ultrafine	Single HV	Descending

Figures 12 and 13 illustrate the planning for Radarsat2-Spotlight, single polarization HH, Ascending pass, 18 December 2009 (Time-18:23:44), Santa Luzia, Tavira-Algarve, Portugal.

Figures 14 and 15 illustrate the planning for Radarsat2 - Spotlight, single polarization HH, Descending pass, 19 December 2009 (Time-06:38:54), Alvor-Algarve, Portugal.

Figures 16 and 17 illustrate the planning for Radarsat2 - Ultrafine, single polarization HH, Ascending pass, 21 December 2009 (Time-18:36:11), Faro-Algarve, Portugal.

Figures 18 and 19 illustrate the planning for TerraSAR-X - Stripmap, dual polarization HV, Descending pass, 21 December 2009 (Time-06:38:14), Faro-Algarve, Portugal.

Figures 20 and 21 illustrate the planning for TerraSAR-X - Stripmap, dual polarization HH, Ascending pass, 22 December 2009 (Time-18:31:42), Alvor-Algarve, Portugal.

Figures 22 and 23 illustrate the planning for Radarsat2 - Ultrafine, single polarization HH, Descending pass, 23 December 2009 (Time-06:22:13), Tavira-Algarve, Portugal.

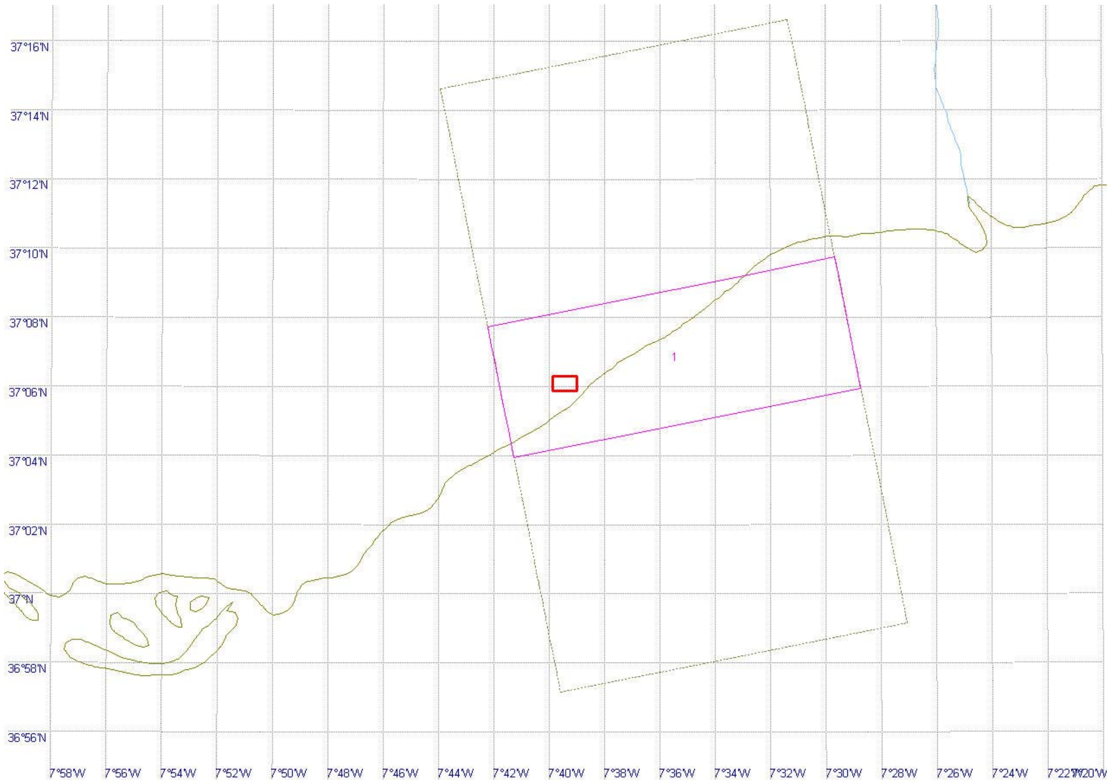

Figure 12 – Radarsat2, Mode Spotlight, single polarization HH, Ascending pass, 18 December 2009 (Time-18:23:44), Santa Luzia, Tavira-Algarve, Portugal.

Figure 13 – Radarsat2, Mode Spotlight, single polarization HH, Ascending pass, 18 December 2009 (Time-18:23:44), Santa Luzia, Tavira-Algarve, Portugal.

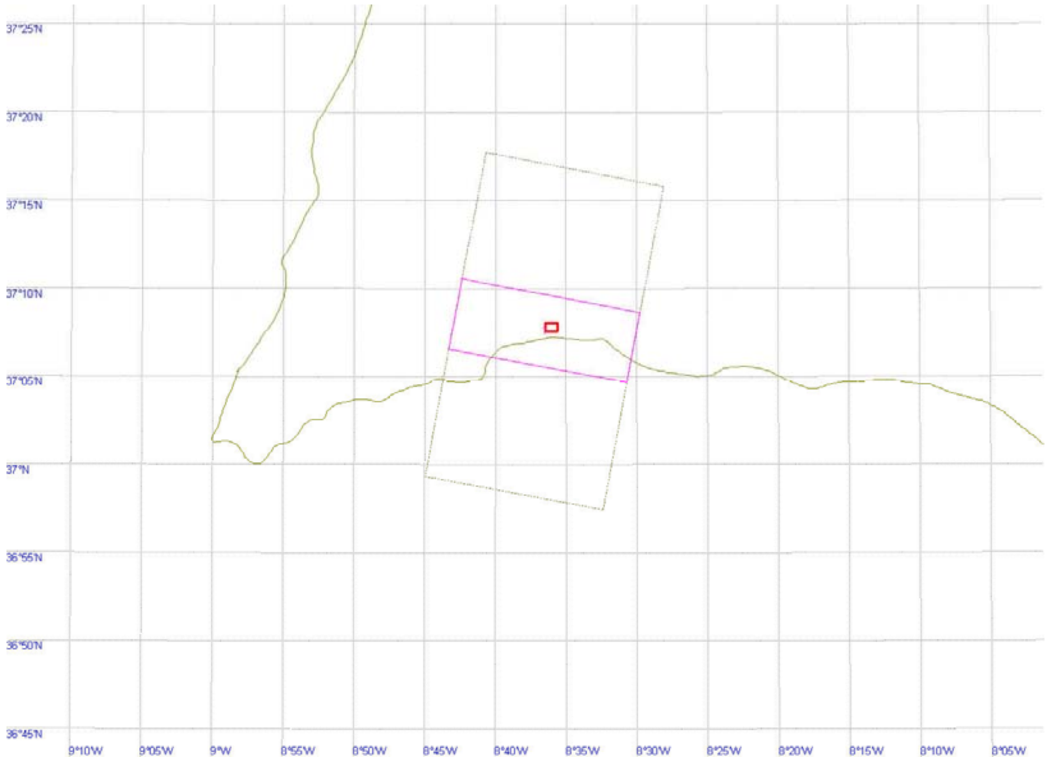

Figure 14 – Radarsat2 - Spotlight, single polarization HH, Descending pass, 19 December 2009 (Time-06:38:54), Alvor-Algarve, Portugal.

Figure 15 – Radarsat2 - Spotlight, single polarization HH, Descending pass, 19 December 2009 (Time-06:38:54), Alvor-Algarve, Portugal.

Figure 16 – Radarsat2 - Ultrafine, single polarization HH, Ascending pass, 21 December 2009 (Time-18:36:11), Faro-Algarve, Portugal.

Figure 17 – Radarsat2 - Ultrafine, single polarization HH, Ascending pass, 21 December 2009 (Time-18:36:11), Faro-Algarve, Portugal.

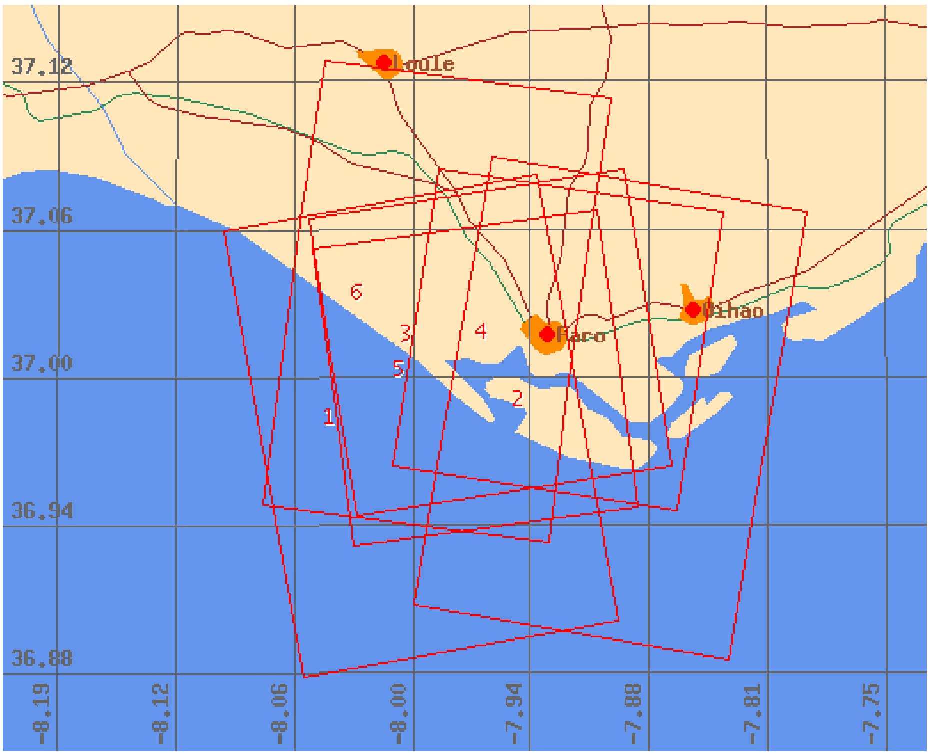

Figure 18 – TerraSAR-X - Stripmap, dual polarization HV, Descending pass, 21 December 2009 (Time-06:38:14), Faro-Algarve, Portugal.

Figure 19 – TerraSAR-X - Stripmap, dual polarization HV, Descending pass, 21 December 2009 (Time-06:38:14), Faro-Algarve, Portugal.

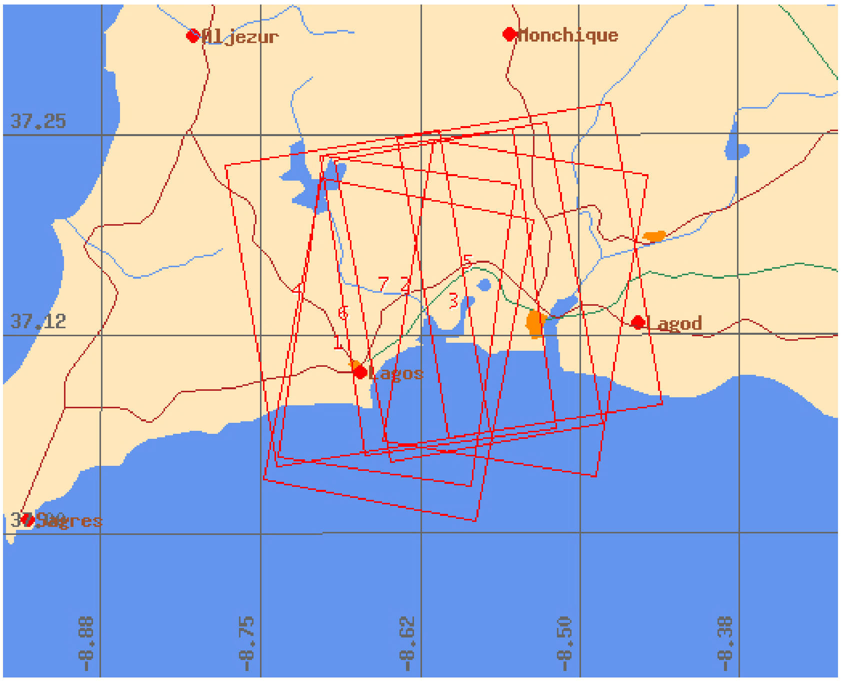

Figure 20 – TerraSAR-X - Stripmap, dual polarization HH, Ascending pass, 22 December 2009 (Time-18:31:42), Faro-Algarve, Portugal.

Figure 21 – TerraSAR-X - Stripmap, dual polarization HH, Ascending pass, 22 December 2009 (Time-18:31:42), Faro-Algarve, Portugal.

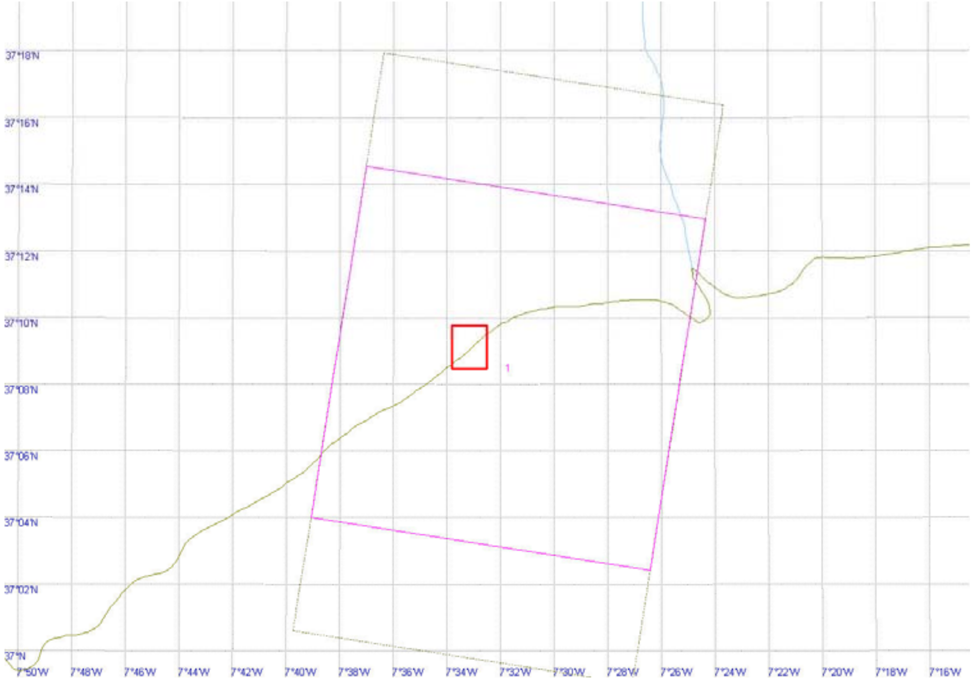

Figure 22 – Radarsat2 - Ultrafine, single polarization HH, Descending pass, 23 December 2009 (Time-06:22:13), Tavira-Algarve, Portugal.

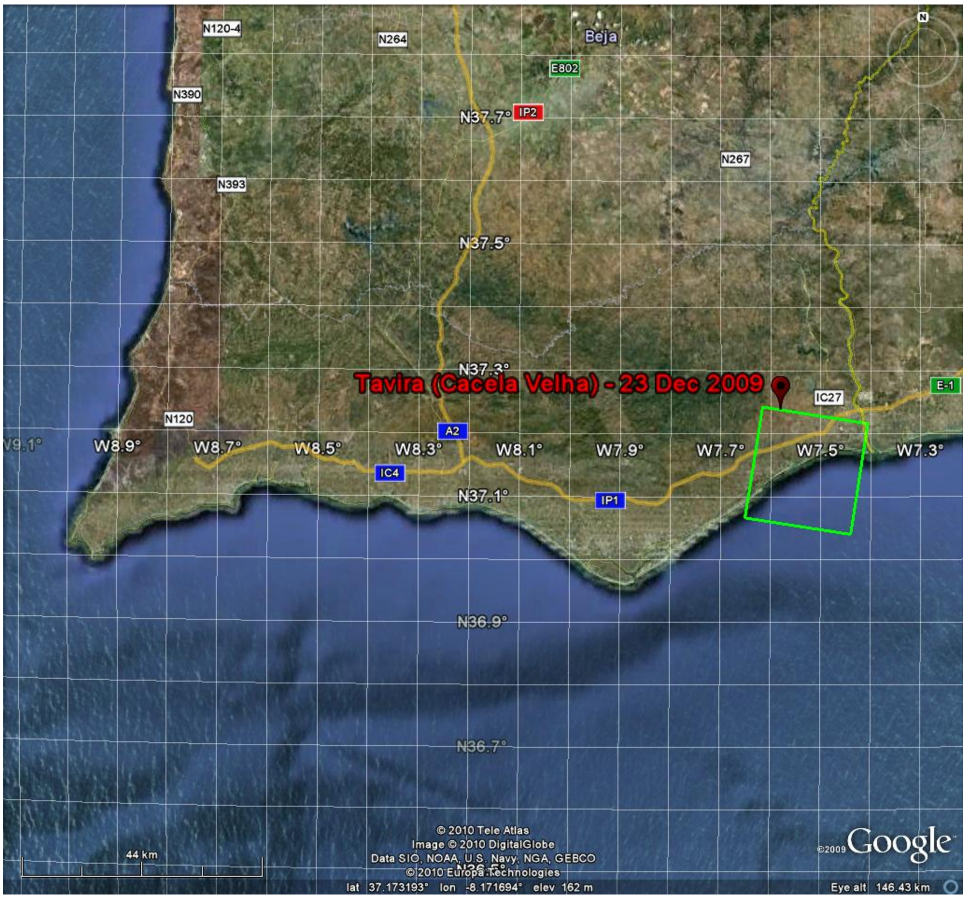

Figure 23 – Radarsat2 - Ultrafine, single polarization HH, Descending pass, 23 December 2009 (Time-06:22:13), Tavira-Algarve, Portugal.

3.4 – Partners Involved and their Roles

This experiment was carried out by EC-JRC. Frontex was contacted to take part in this experiment, but due to planning and budget constraints Frontex was not able to take part in this experiment.

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 ground truth data collection,
d.) the analysis of the data and
e.) the conclusions of the experiment.

4. – Experiment Execution

4.1 – Inland Sea Waters - Modus Operandi

The modus operandi of the trial was as follows:

1.- JRC collected in-situ ground truth data and weather information in the area of the selected sites at the time of the satellite passes, namely:

a.) Photos of the targets of opportunity (small boats),
b.) Movies of the targets of opportunity (small boats),
c.) the sea state
d.) the wind speed
e.) the weather conditions

Since it was dark at the time of the satellite passes, ground truth information was also collected during daylight before or after the satellite passes for Ascending passes and Descending passes, respectively.

4.2 – Ground Truth Data Collection Limitations

The ideal ground truth data would comprise a flight over the area covered by the footprint of the satellite image during the satellite pass complemented by ground truth data collected on the ground. Unfortunately, a flight is very expensive and in this case, since at the time of the satellite passes it was dark, a flight would be useless. The only feasible ground truth data collection was on the ground before, during and after the satellite passes.

For Satellite Descending passes early in the morning (between 6:15AM and 6:45AM), the ground truth data was collected during the satellite pass using photos with flash and movies using camcorders with low light modes. This was followed by photos and movies at sunrise. The scenarios hardly change at this time in December.

For Satellite Ascending passes in the evening (between 18:15 and 18:45), the ground truth data was collected before the satellite pass during daylight and at the time of the satellite pass using photos with flash and movies using camcorders with low light modes. The scenarios hardly change at this time in December.

4.3 – Means Deployed

In this experiment, apart from digital cameras, camcorders and a GPS receiver, no other means were deployed. The main idea behind this experiment was to use targets of opportunity, namely small boats moored on Inland Sea Waters close by land.

5. – Preliminary Data Analysis

This section describes the analysis of the SAR Satellite images.

5.1 – SAR Satellite Imagery Processing

The high resolution SAR satellite images were analysed visually, since the resolution is good enough to allow visual analysis. The lower resolution SAR satellite images were also analysed visually because they cannot be processed using JRC vessel detection software, SUMO, due to the fact that the inland sea waters are surrounded by land.

5.2 – Analysis of the SAR Satellite Imagery

The visual analysis of the SAR Satellite images was carried out with the following main objectives:

1. – To check if individual, targets of opportunity, namely small boats could be detected using SAR Satellite imagery, such as Radarsat2 (Spotlight and Ultrafine) and TerraSAR-X (Spotlight and Stripmap).

2. – If possible, to estimate the probability of small boat detection using SAR Satellite imagery, namely Radarsat2 (Spotlight and Ultrafine) and TerraSAR-X (Spotlight and Stripmap).

3. – to understand the potential of using spaceborne SAR for small boat detection and to identify its main limiting factors.

The results of the analysis of the SAR Satellite images acquired during this experiment will now be described in turn, next.

5.2.1 – Radarsat2-Spotlight, 18 December 2009, Santa Luzia, Tavira-Algarve.

The SAR Satellite image acquired over Santa Luzia, Tavira-Algarve, Portugal, was a Radarsat2-Spotlight, single polarization HH, Ascending pass, 18 December 2009 (Time-18:23:44).

Santa Luzia in Tavira-Algarve was the first location selected for the experiment. The area was selected due to the inland sea waters and the availability of small boats that could be used as targets of opportunity. The spaceborne SAR image acquired over Santa Luzia was a Radarsat2-Spotlight. The frame (footprint) of the SAR image acquired covering Santa Luzia is illustrated in Figure.1.

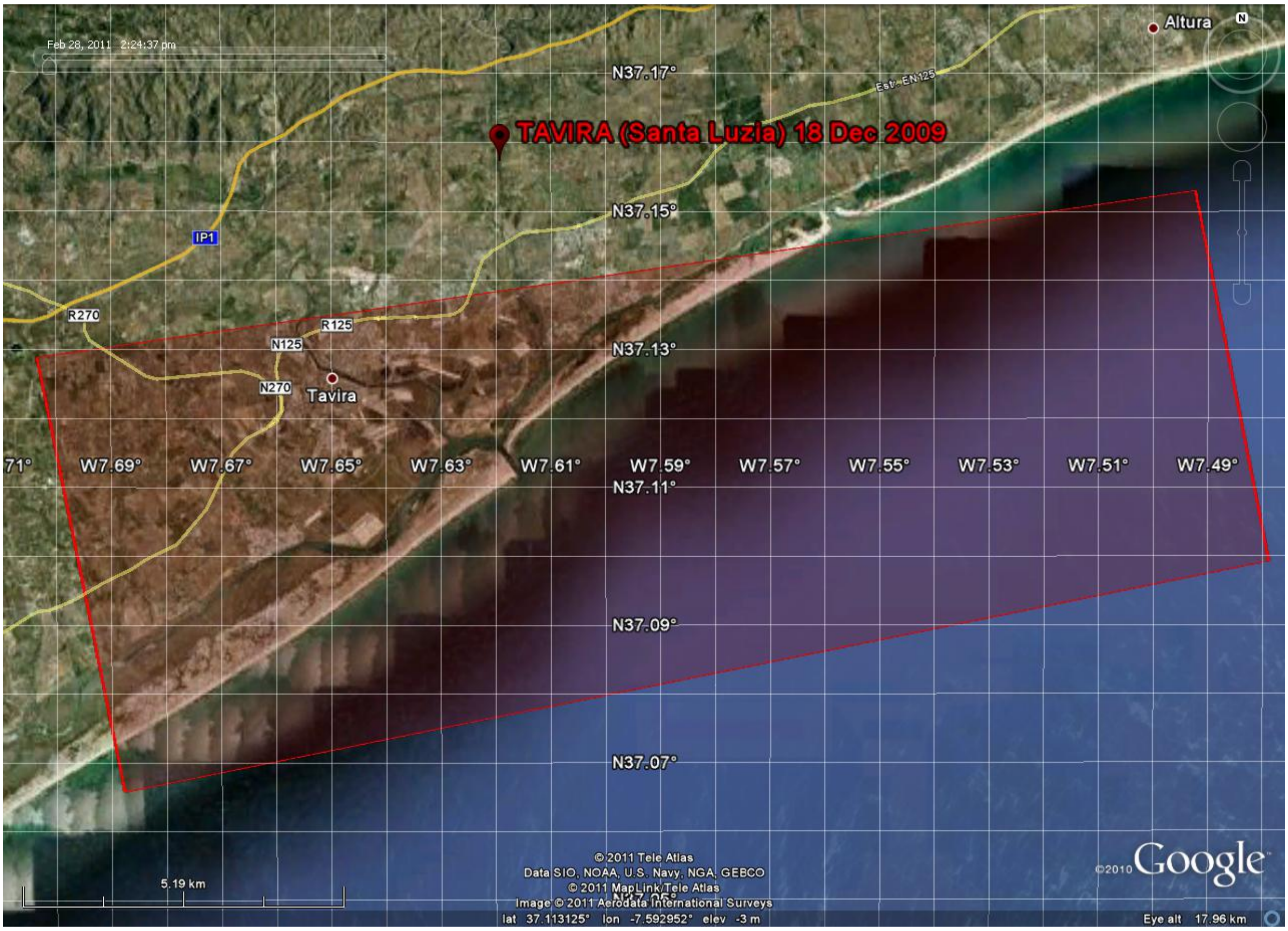

Figure 24 – Footprint of the Radarsat2-Spotlight image acquired over Santa Luzia, Tavira-Algarve on 18 Dec. 2009 by 18:24h.

The SAR image was calibrated using NEST, an ESA software package. An overview of the Santa Luzia area in the Radarsat2-Spotlight image is given in Figure 25. As it can be seen, there are several targets of opportunity detected. Most small boats moored on sea not too close to other targets have been detected. Some of the bright spots in the image correspond to sets of small boats too close to each other. There was SAR signature contamination. The small boats moored to piers also have contaminated SAR signatures by the backscattering from other nearby boats and the piers.

Figure 25 shows an overview of the entire are covered by the Radarsat2-Spotlight divided into five zones to facilitate the comparison of the ground truth data with the SAR image. Zone 1 in green is the zone located East of the first pier. Zone 2 in blue is the zone covering the first pier. Zone 3 in magenta covers the area between the second and the third pier. Zone 4 in yellow covers the area between the third and the fourth piers. Zone 5 in red covers the area West of the fourth pier.

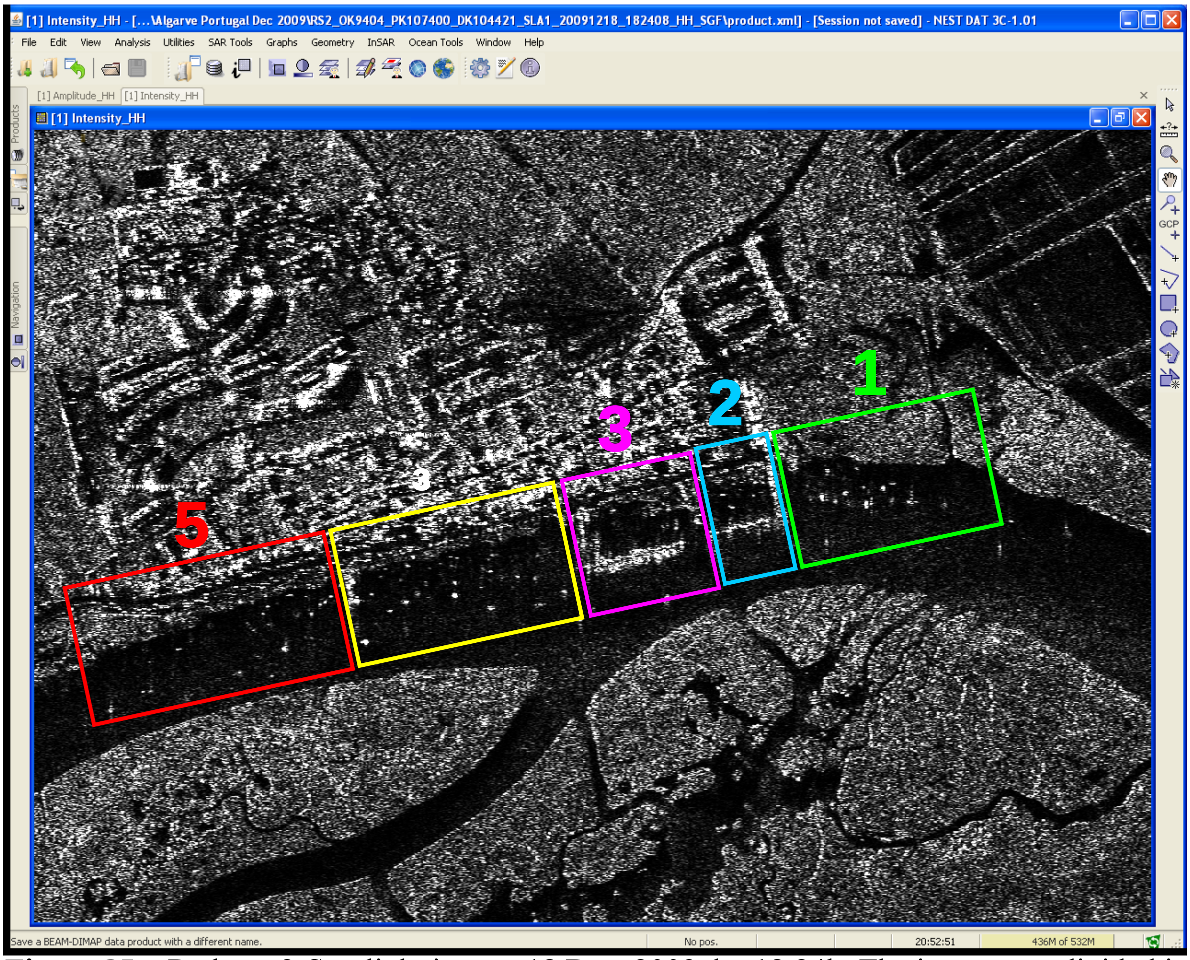

Figure 25 – Radarsat2-Spotlight image, 18 Dec. 2009, by 18:24h. The image was divided into 5 zones to facilitate the comparison with the ground truth data.

Figure 26 illustrates ground truth data collected in Santa Luzia and the corresponding SAR Radarsat2-Spotlight image. As it can be seen, most targets of opportunity (small boats) were detected as isolated targets. The brightest spots seem to be contaminated SAR signatures with contributions from different targets.

Figures 27 and 28 show photos taken at the first pier (Zone 2 in blue) before the satellite pass and approximately at the time of the satellite pass, respectively. The corresponding Radarsat2-Spotlight image shows that several targets of opportunity have been detected. However, since the targets are too close to each other and to the pier, the resulting SAR signatures are contaminated and do not allow to isolate the signatures of the different targets.

Figure 29 shows several photos taken before and at the approximate time of the satellite pass at the first pier. As it can be seen, several targets of opportunity have been detected.

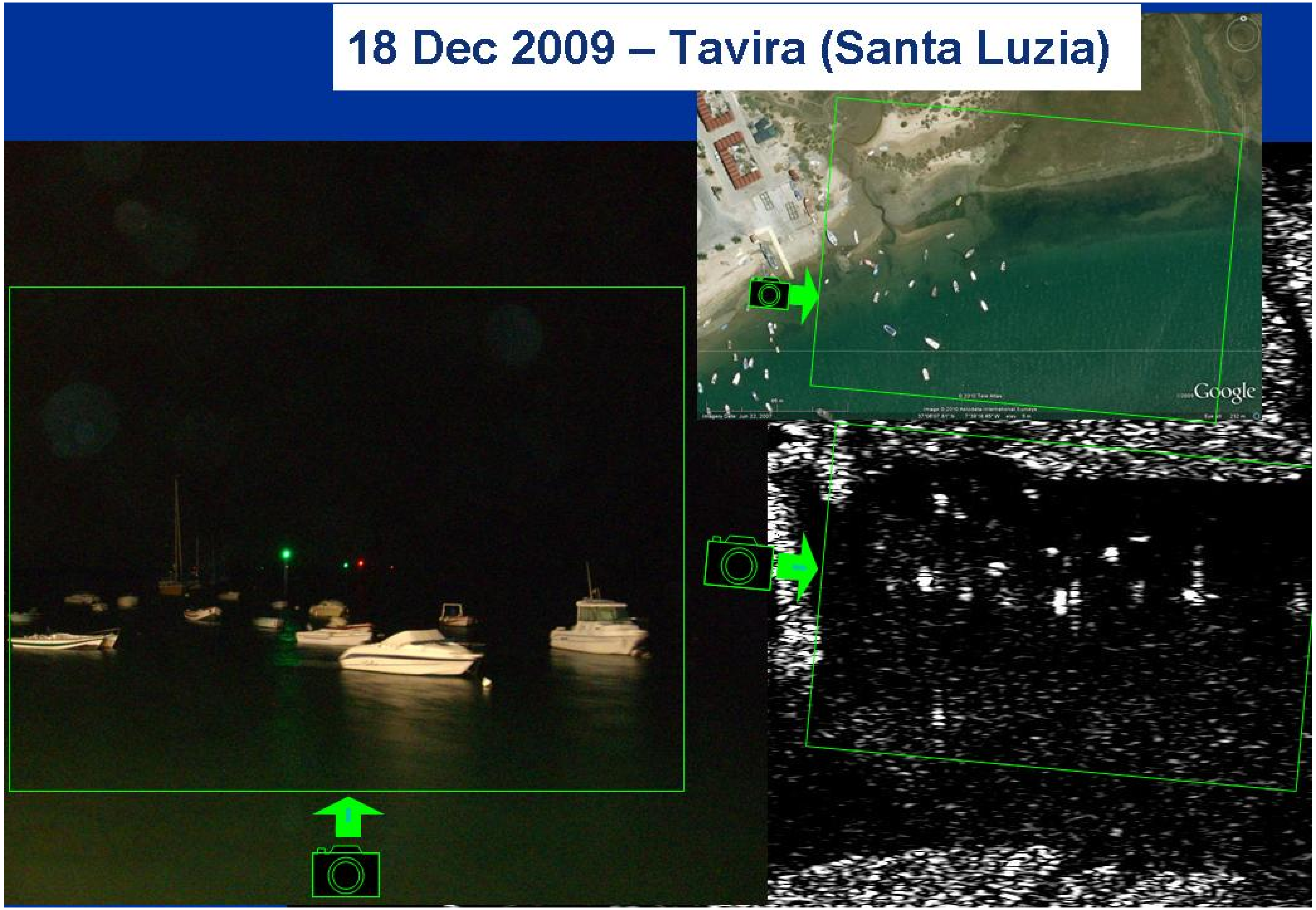

Figure 26 – On the left a photo taken at the time of the Satellite pass at the first pier (Zone 1 in green in Fig.25). On the top left a Google Earth image of the area. On the bottom left the corresponding area in the Radarsat2-Spotlight image. Several targets of opportunity have been detected.

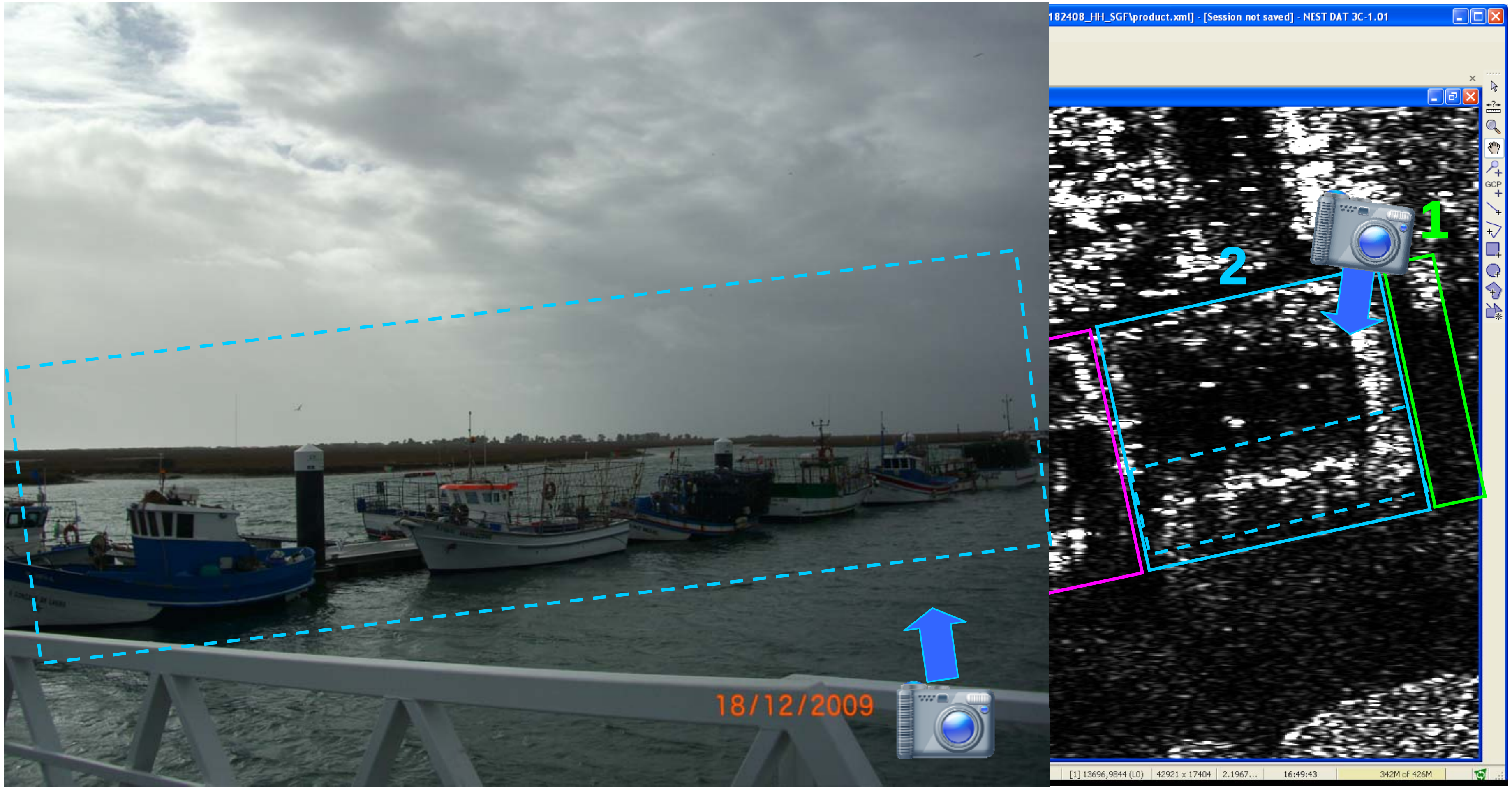

Figure 27 – On the left a photo taken before the satellite pass at the first pier (Zone 2 in blue). On the right the Radarsat2-Spotlight image with the zone 2 in blue. Several targets of opportunity have been detected. However, since the targets are too close to each other and to the pier, the resulting SAR signatures are contaminated and do not allow to isolate the signatures of the different targets.

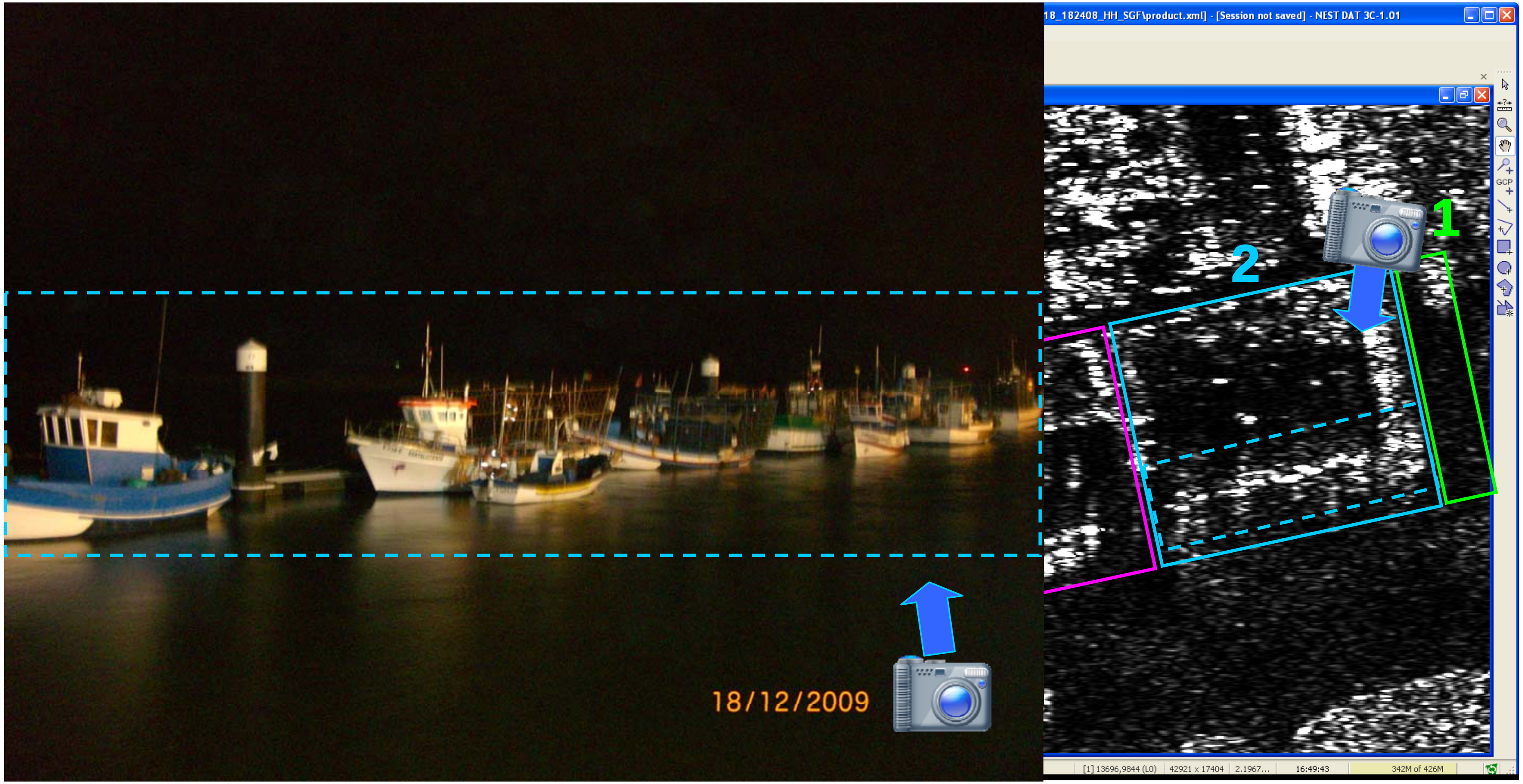

Figure 28 – On the left a photo taken at the first pier (Zone 2 in blue) at the approximate time of the satellite pass. On the right the Radarsat2-Spotlight image with the zone 2 in blue. Several targets of opportunity have been detected. However, since the targets are too close to each other and to the pier, the resulting SAR signatures are contaminated and do not allow to isolate the signatures of the different targets.

Figure 29 – On the top left two photos taken at the first pier (Zone 2 in blue) at the approximate time of the satellite pass. On the bottom left three photos taken at the same pier before the satellite pass. On the right the Radarsat2-Spotlight image.

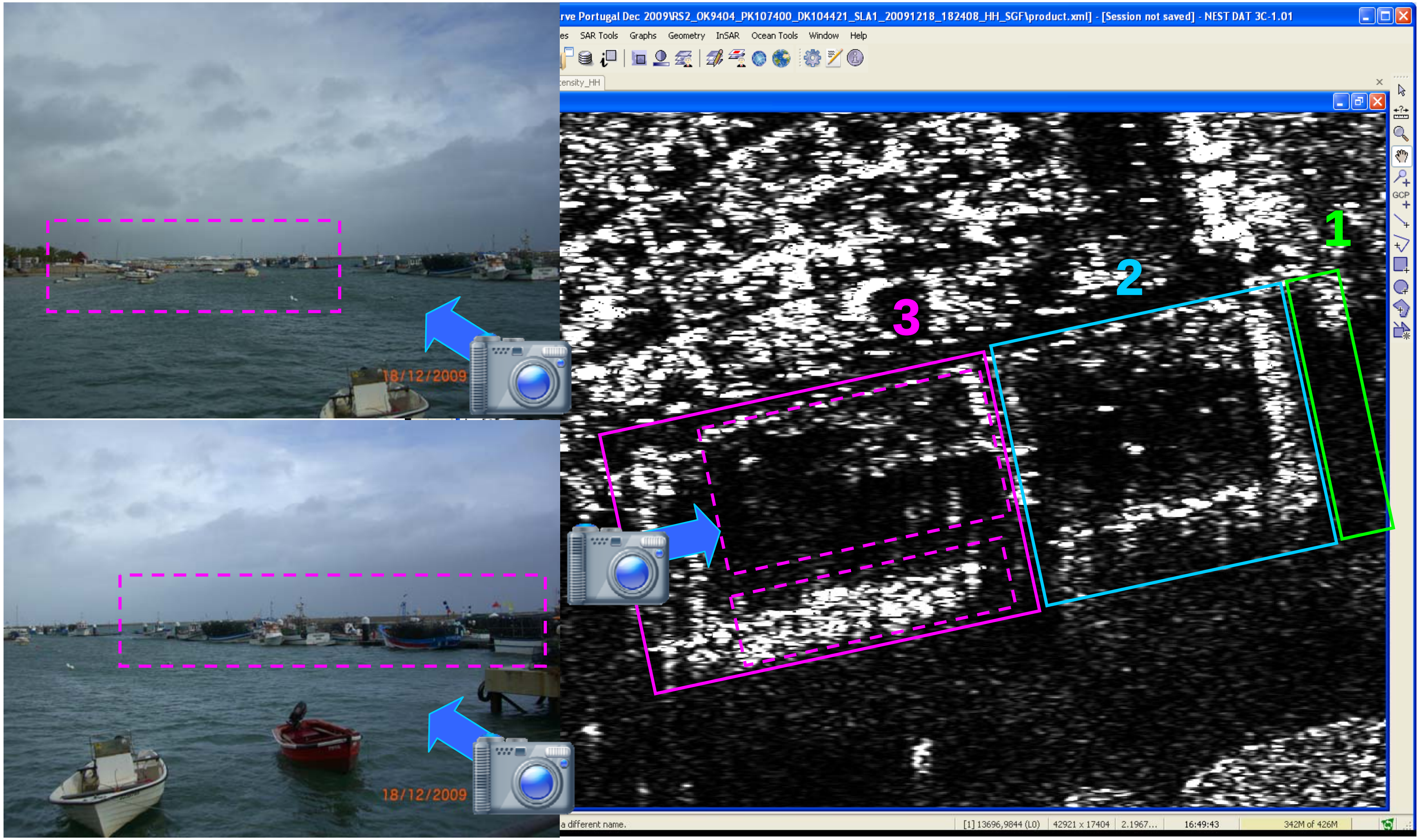

Figure 30 – On the left two photos taken from the third pier towards the second pier (Zone 3 in magenta) before the satellite pass. Several targets of opportunity were detected.

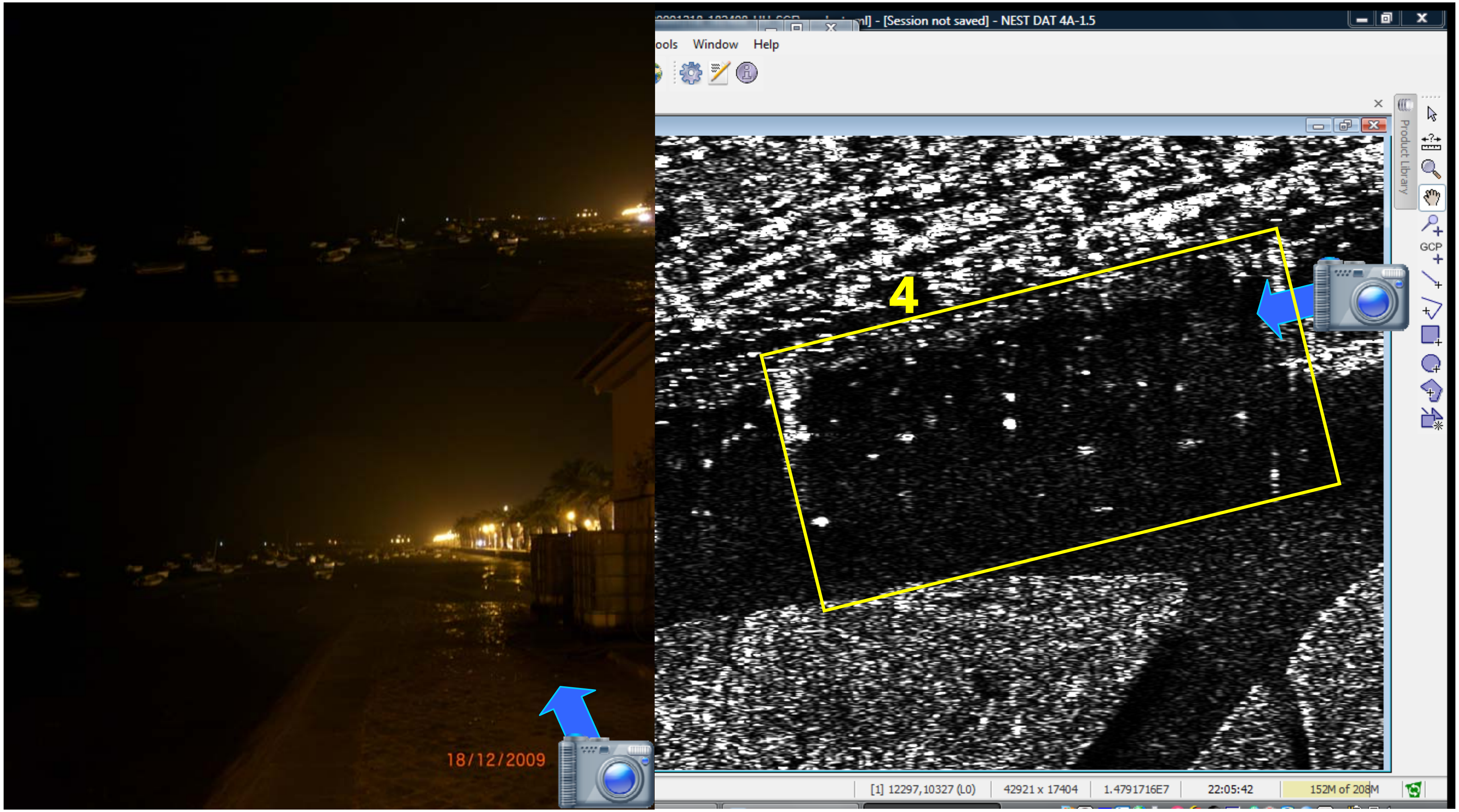

Figure 31 – On the left two photos taken from the third pier towards the fourth pier (Zone 4 in yellow) at the approximate time of the satellite pass.

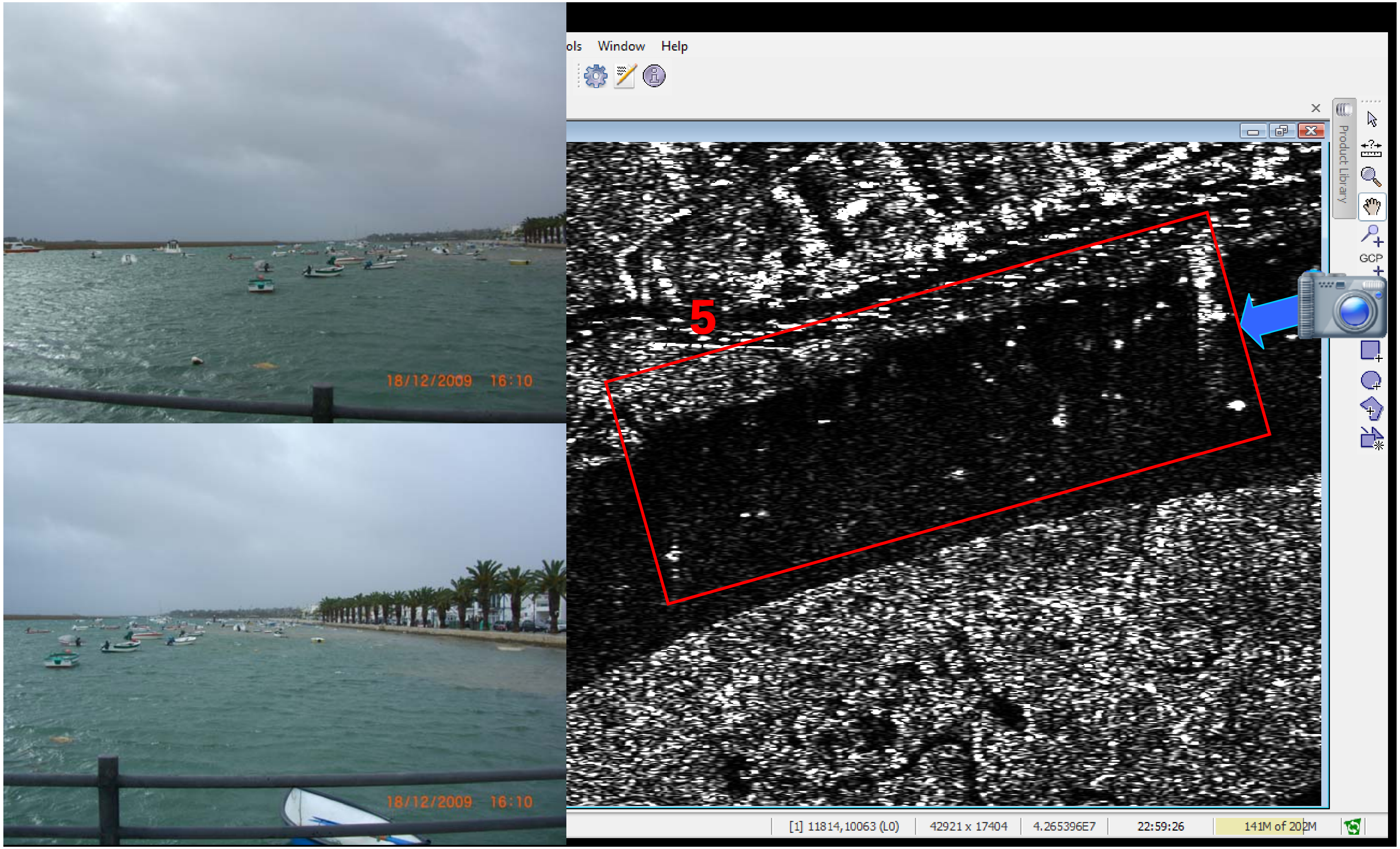

Figure 32 – On the left two photos taken from the fifth pier towards the West (Zone 5 in red) before the satellite pass.

Figure 30 shows several photos of Zone 3 in magenta taken from the third pier before the satellite pass. As it can be seen, several targets of opportunity were detected.

Figure 31 shows two photos of Zone 4 in yellow taken at the approximate time of the satellite pass from the third pier towards the second pier. Looking at the Radarsat2-Spotligh image (Zone 4), several targets of opportunity can be seen.

Figure 32 shows several photos taken from the fourth pier towards West before the satellite pass. As it can be seen, several targets of opportunity were detected.

5.2.2 – Radarsat2-Spotlight, 19 December 2009, Alvor-Algarve.

The SAR Satellite image acquired over Alvor-Algarve, Portugal, was a Radarsat2-Spotlight, single polarization HH, Descending pass, 19 December 2009 (Time-06:38:54).

Alvor-Algarve was the second location selected for the experiment. The area was selected due to the inland sea waters and the availability of small boats that could be used as targets of opportunity. The spaceborne SAR image acquired over Alvor was a Radarsat2-Spotlight. The frame (footprint) of the SAR image acquired covering Alvor is illustrated in Figure 33.

The SAR image was calibrated using NEST, an ESA software package. An overview of the Alvor area in the Radarsat2-Spotlight image is given in Figure 34. As it can be seen, several targets of opportunity were detected. Most small boats moored on sea not too close to other targets have been detected. Some of the bright spots in the image might correspond to sets of small boats too close to each other. In those cases there was SAR signature contamination. The small boats moored to piers also have contaminated SAR signatures by the backscattering from other nearby boats and the piers.

Figure 34 shows an overview of the entire are covered by the Radarsat2-Spotlight divided into two zones to facilitate the comparison of the ground truth data with the SAR image. Zone 1 in green includes the first pier and the North area of the image. Zone 2 in blue includes the second pier and the South part of the image.

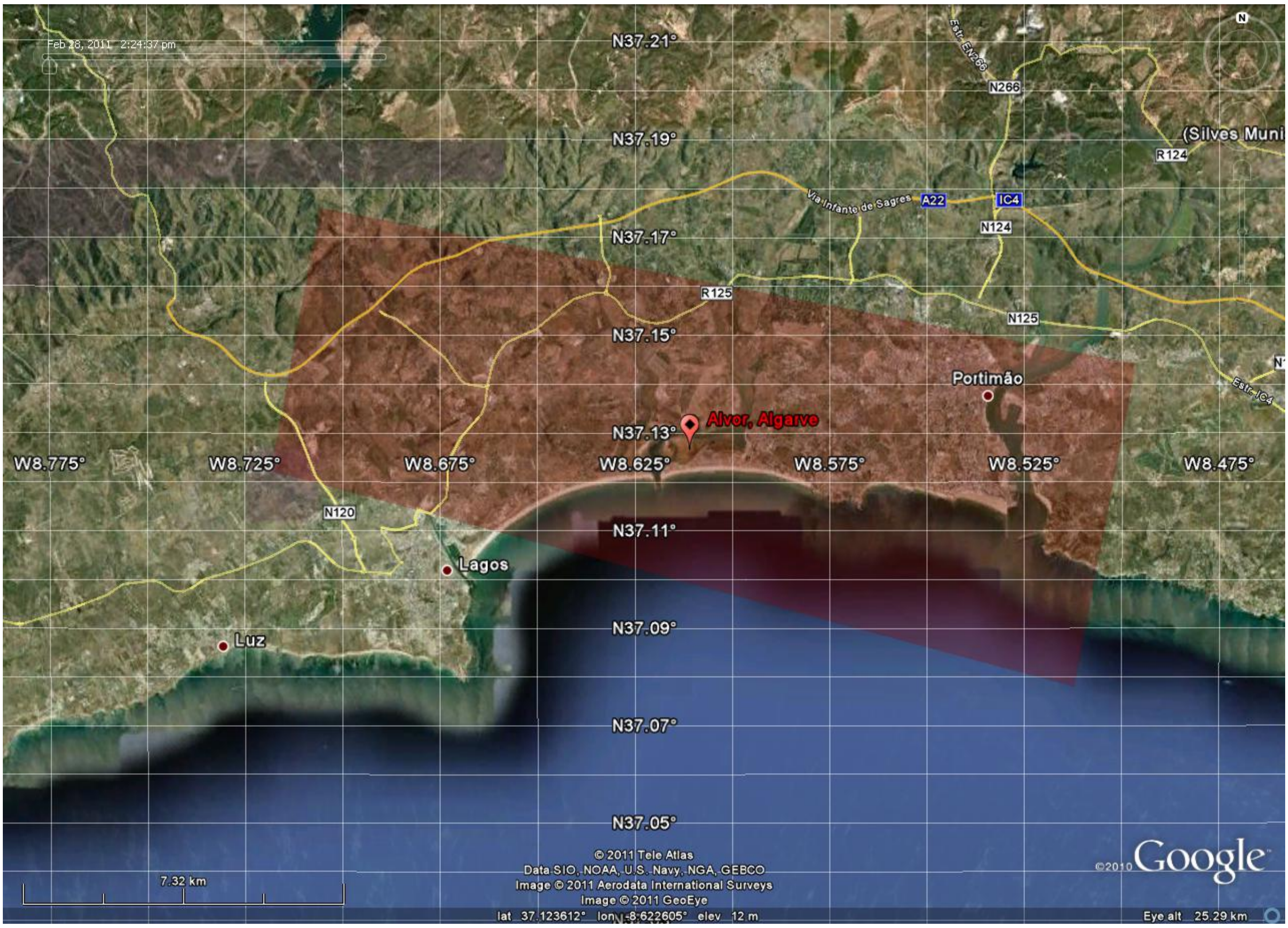

Figure 33 – Footprint of the Radarsat2-Spotlight image acquired over Alvor-Algarve on 19 Dec. 2009 by 06:39h.

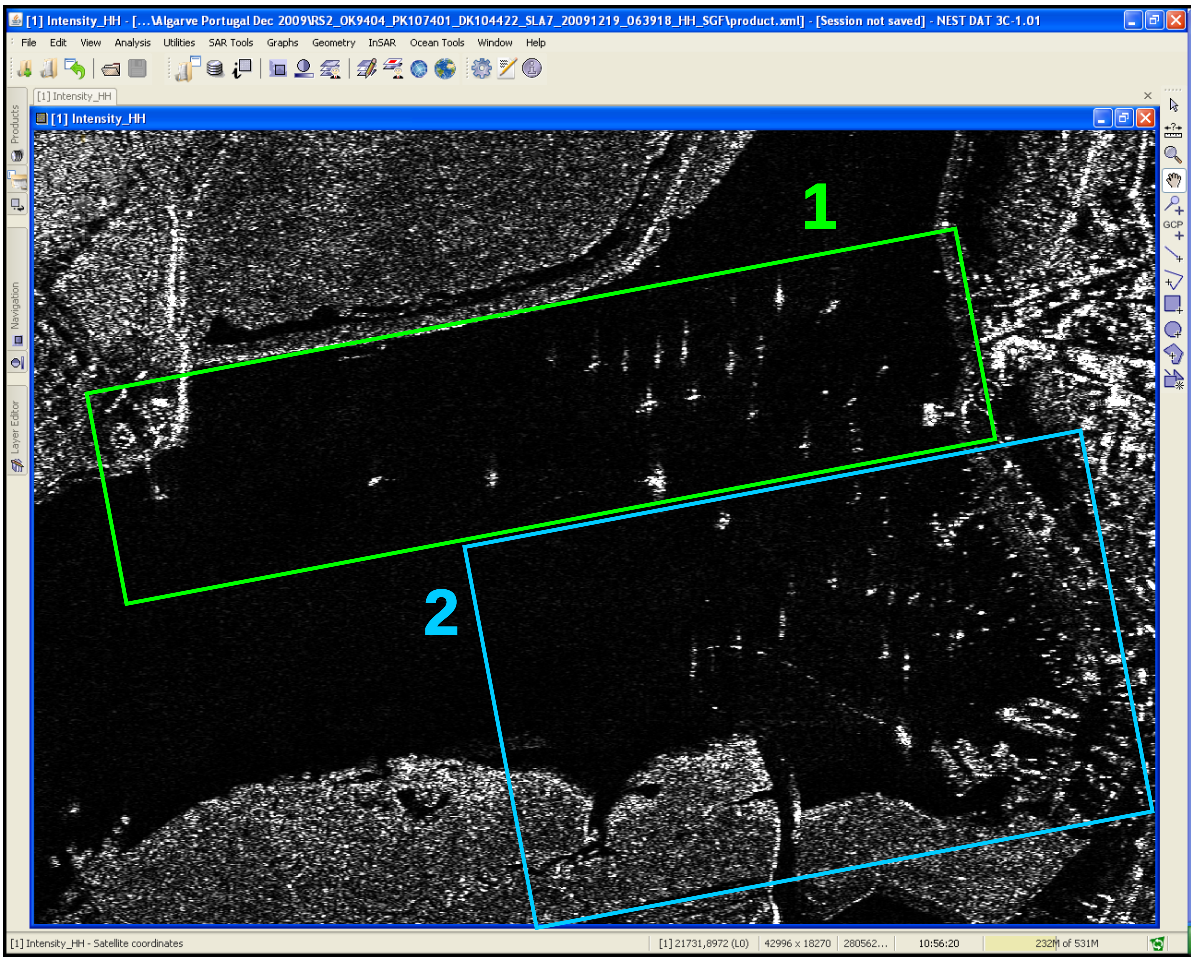

Figure 34 – Radarsat2-Spotlight image, 19 Dec. 2009, by 06:39h. The image was divided into 2 zones to facilitate the comparison with the ground truth data.

Figures 35 to 37 illustrate the comparison of several photos taken in Alvor at the time of the satellite pass with the Radarsat2-Spotlight SAR image for the area covered by Zone 1 in green.

Figures 38 to 40 illustrate the comparison of several photos taken in Alvor at the time of the satellite pass with the Radarsat2-Spotlight SAR image for the area covered by Zone 2 in blue.

As it can be seen, comparing the photos with the SAR image show that most small boats were detected.

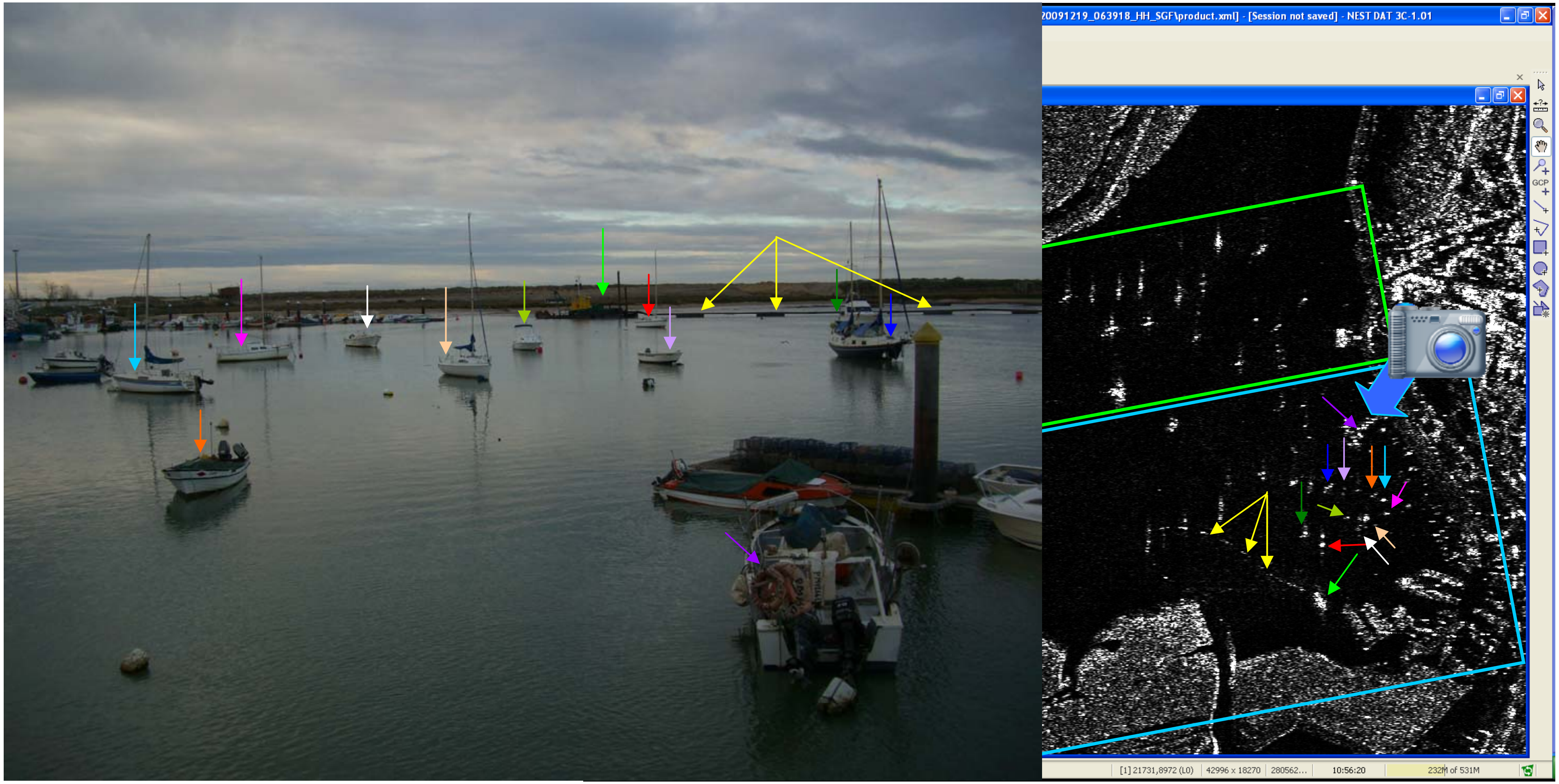

Figure 35 – On the left a photo taken from the second pier in Zone 2 in blue. On the right we can see the corresponding Radarsat2-Spotlight. As it can be seen, most targets of opportunity were detected. The arrows in yellow indicate a barrier detected.

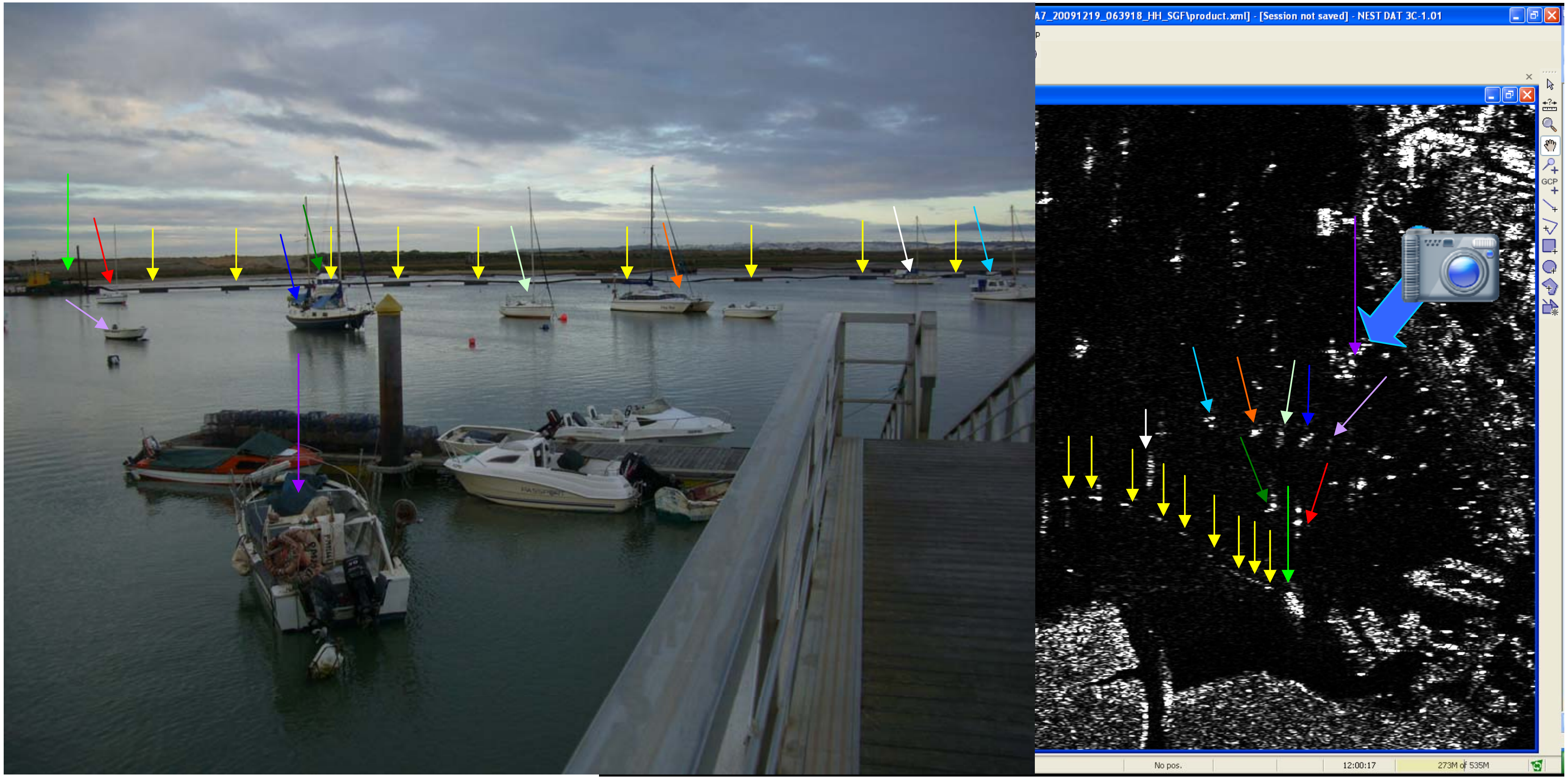

Figure 36 – On the left a photo taken from the second pier in Zone 2 in blue. On the right we can see the corresponding Radarsat2-Spotlight. As it can be seen, most targets of opportunity were detected. The arrows in yellow indicate a barrier detected.

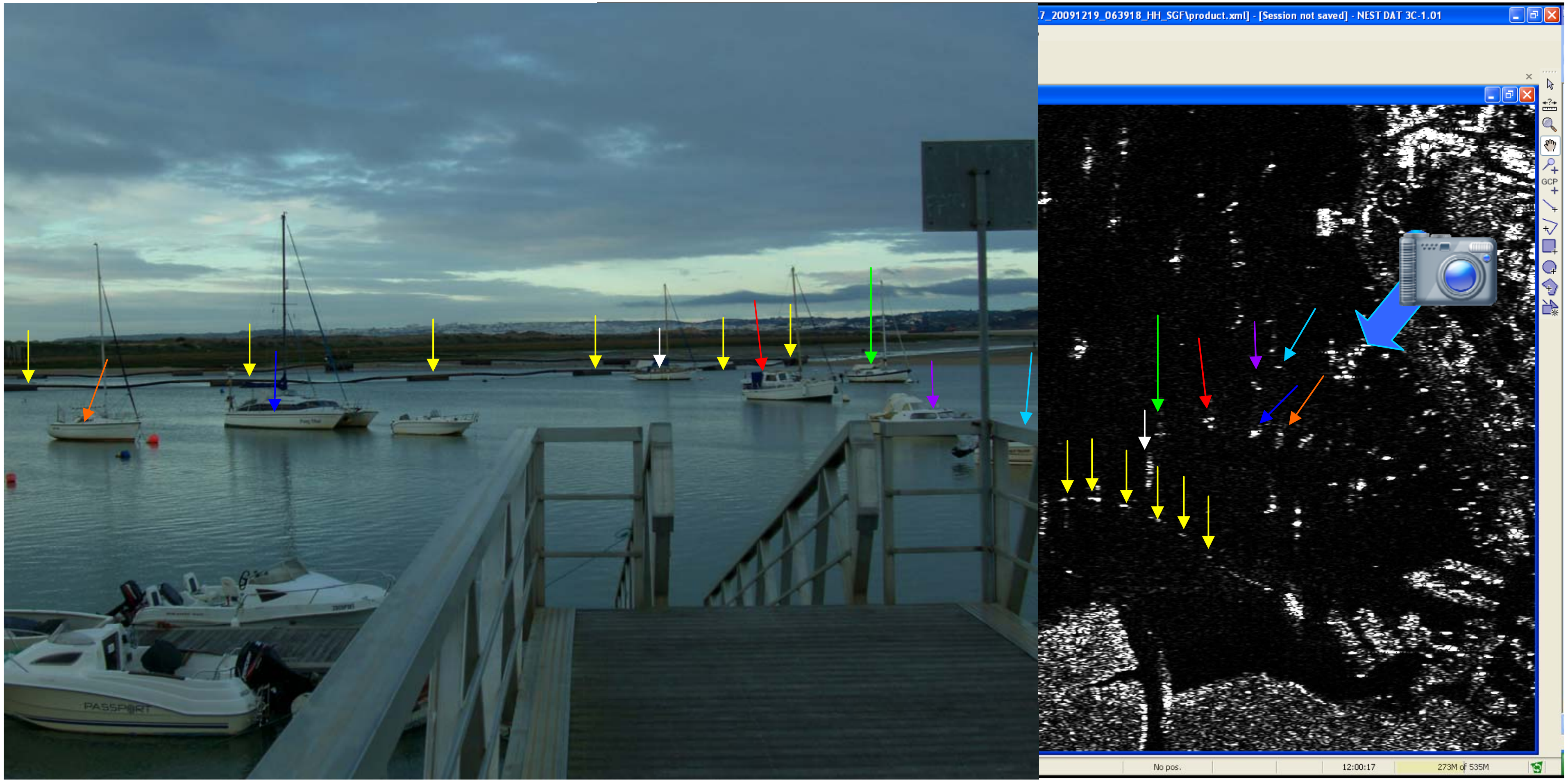

Figure 37 – On the left a photo taken from the second pier in Zone 2 in blue. On the right we can see the corresponding Radarsat2-Spotlight. As it can be seen, most targets of opportunity were detected. The arrows in yellow indicate a barrier detected.

Figure 38 – photo taken from the second pier in Zone 2. In Figure 39 we can see the corresponding Radarsat2-Spotlight. As it can be seen, most targets of opportunity were detected. The arrows indicate which small boats correspond to which bright spots.

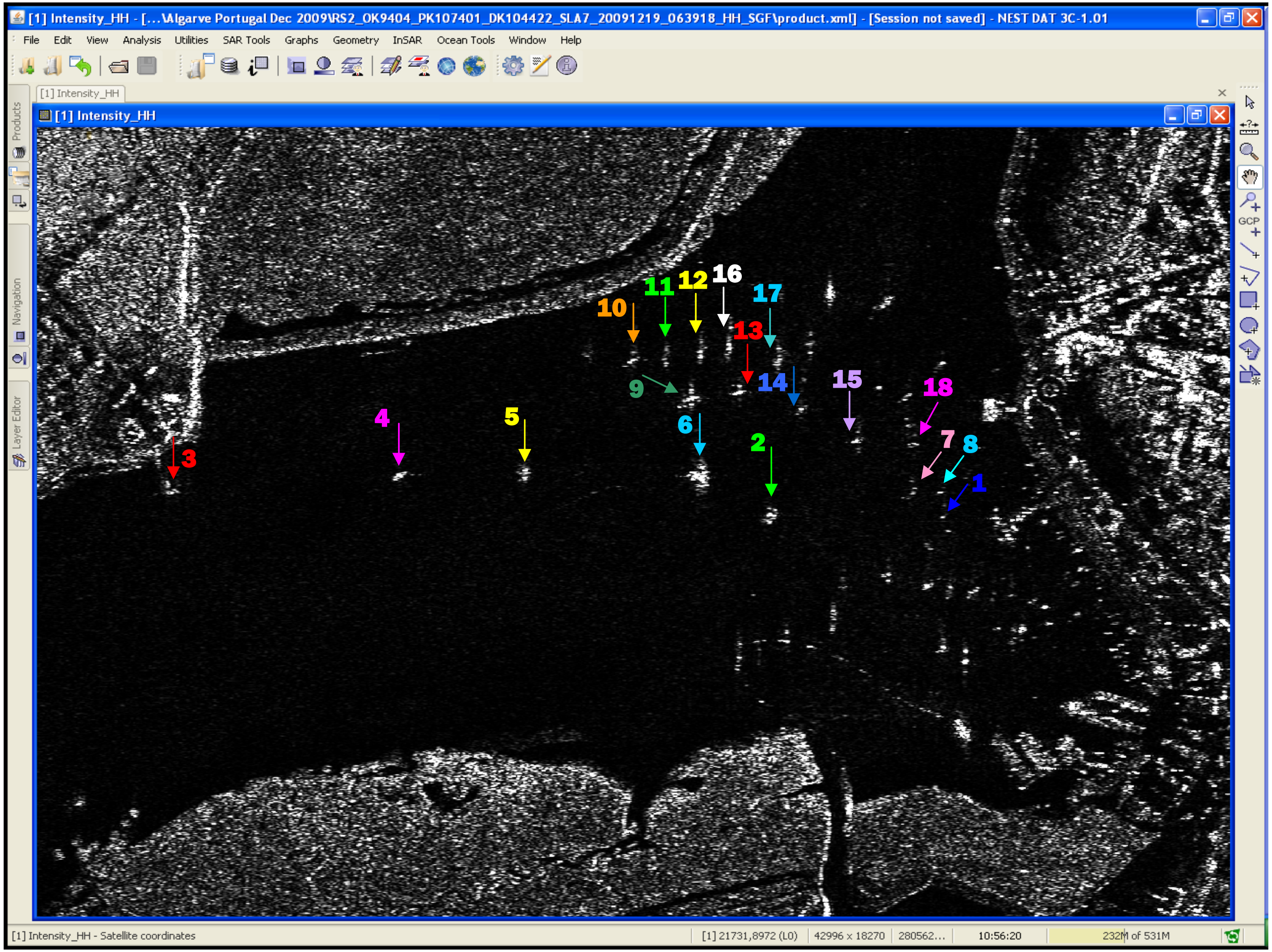

Figure 39 – Radarsat2-Spotlight SAR image of Alvor-Algarve. The arrows with different colours indicate which bright spots correspond to which small boats in figure 38.

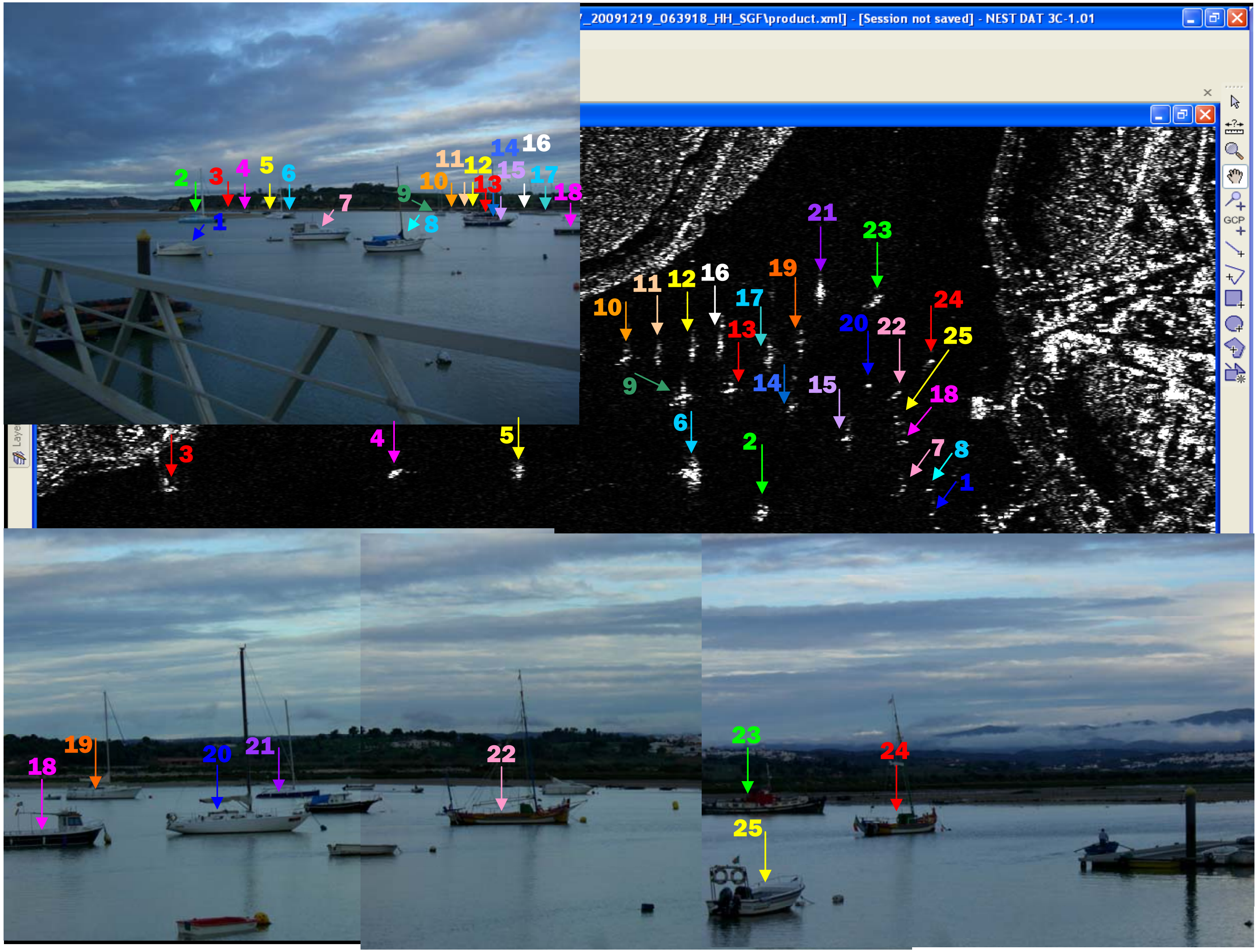

Figure 40 – Four Photos of Alvor region compared to the Radarsat2-Spotlight SAR image.

5.2.3 – TerraSAR-X - Stripmap, 21 December 2009, Faro-Algarve.

Faro-Algarve was the third location selected for the experiment. The area was selected due to the inland sea waters and the availability of small boats that could be used as targets of opportunity. The SAR Satellite image acquired over São Pedro, Faro-Algarve, Portugal, was a TerraSAR-X - Stripmap, dual polarization HV, Descending pass, 21 December 2009 (Time-06:38:14), Faro-Algarve, Portugal..The frame (footprint) of the SAR image acquired covering Faro is illustrated in Figure 41.

The SAR image was calibrated using NEST, an ESA software package. An overview of the Faro area in the TerraSAR-Stripmap image is given in Figure 42. As it can be seen, several targets of opportunity were detected. Most small boats moored on sea not too close to other targets have been detected. Some of the bright spots in the image might correspond to sets of small boats too close to each other. In those cases there was SAR signature contamination. The small boats moored to piers also have contaminated SAR signatures by the backscattering from other nearby boats and the piers.

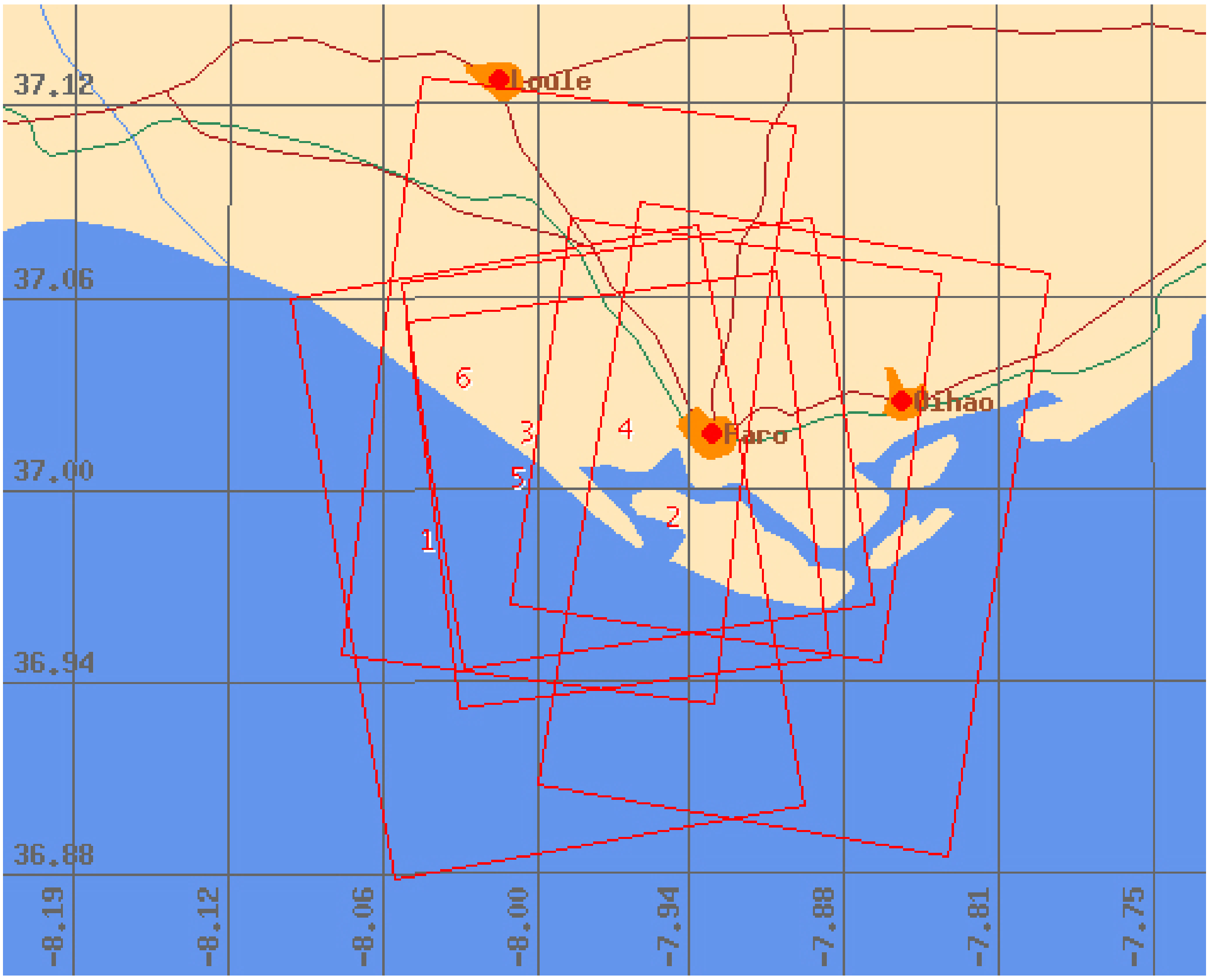

Figure 41 – Footprint of the Radarsat2-Spotlight image acquired over Faro-Algarve on 21 Dec. 2009 by 06:39h.

Figure 42 illustrates the footprint of the TerraSAR-X-Stripmap image acquired over São Pedro-Faro. As it can be seen, a significant number of target of opportunity (small boats) were detected. The brightest spots seem to be contaminated SAR signatures with contributions from different targets.

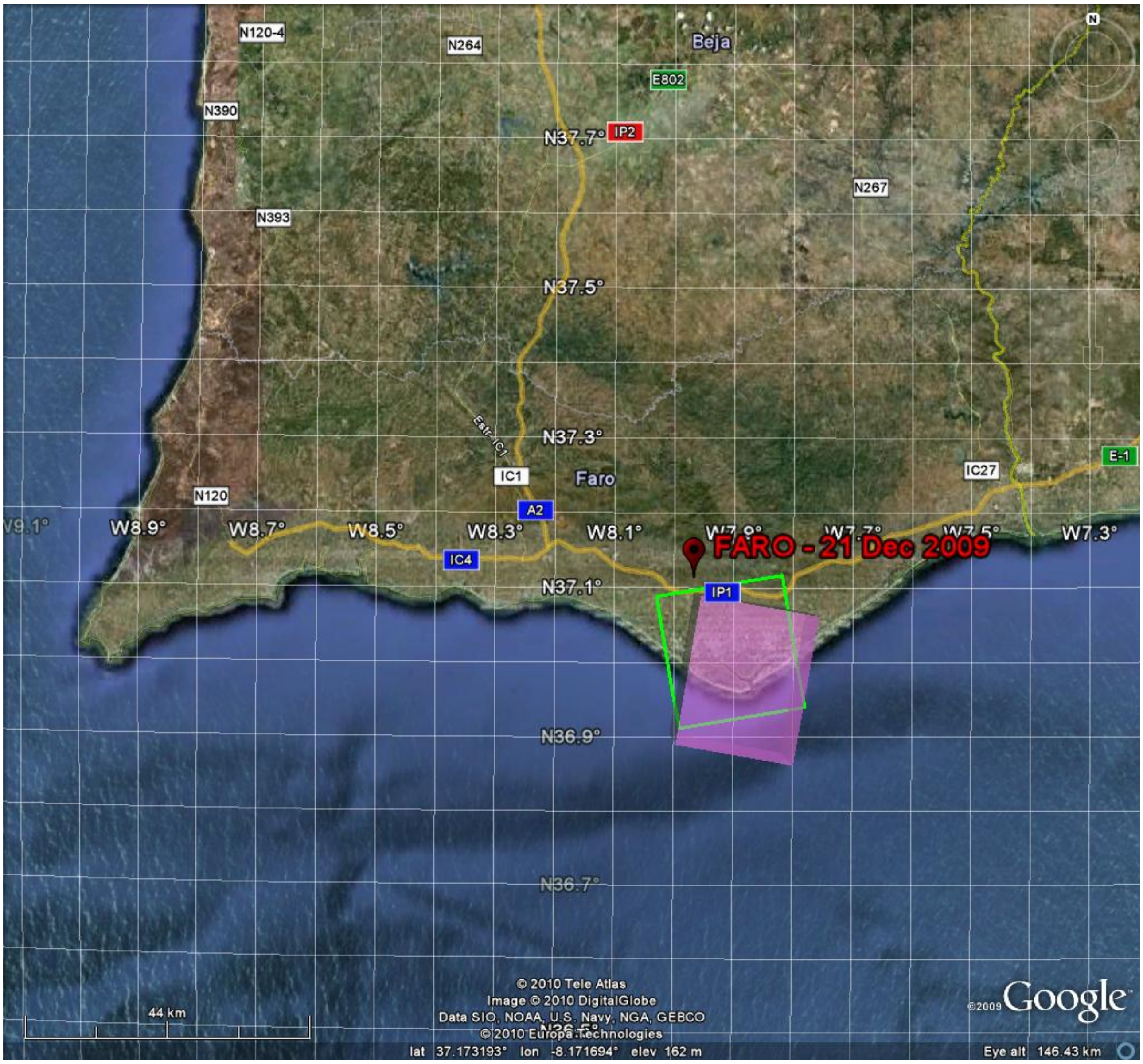

Figure 42 – The TerraSAR image footprint is illustrated in magenta.

Figure 43 illustrates the TerraSAR-Stripmap SAR image acquired over São Pedro, Faro. The area was divided into two zones to facilitate the analysis of the SAR image. Several targets of opportunity were detected in both zones; however, due to the lower resolution of the Stripmap mode (about 3 meters) it is difficult to isolate the different targets. The image also shows some artefacts and azimuth ambiguities.

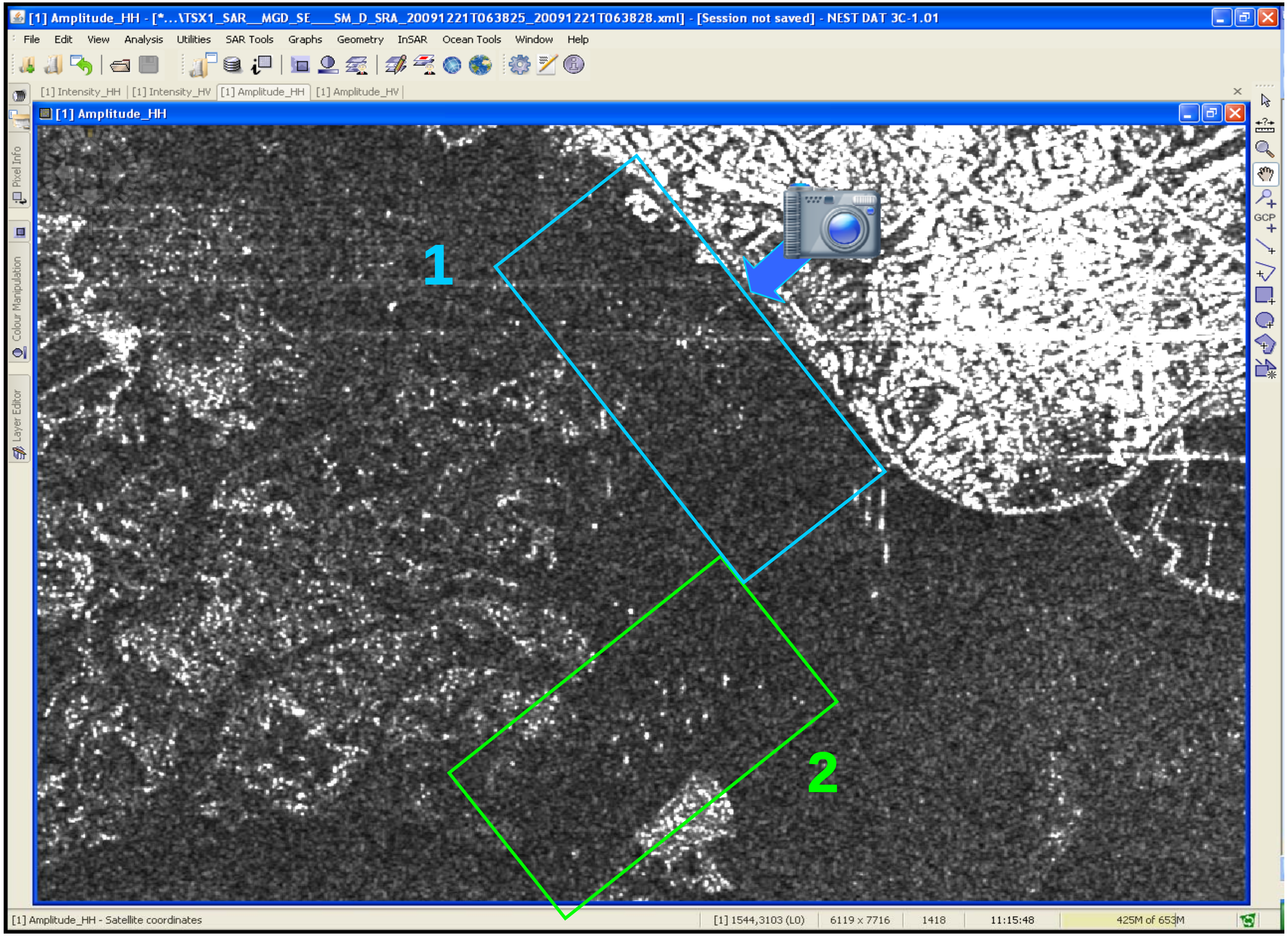

Figure 43 – Area of São Pedro-Faro covered by the SAR image footprint. The area was divided into two zones.

Figure 44 –Photo taken after the satellite pass São Pedro-Faro, Algarve. This area corresponds to zone 1 in blue.

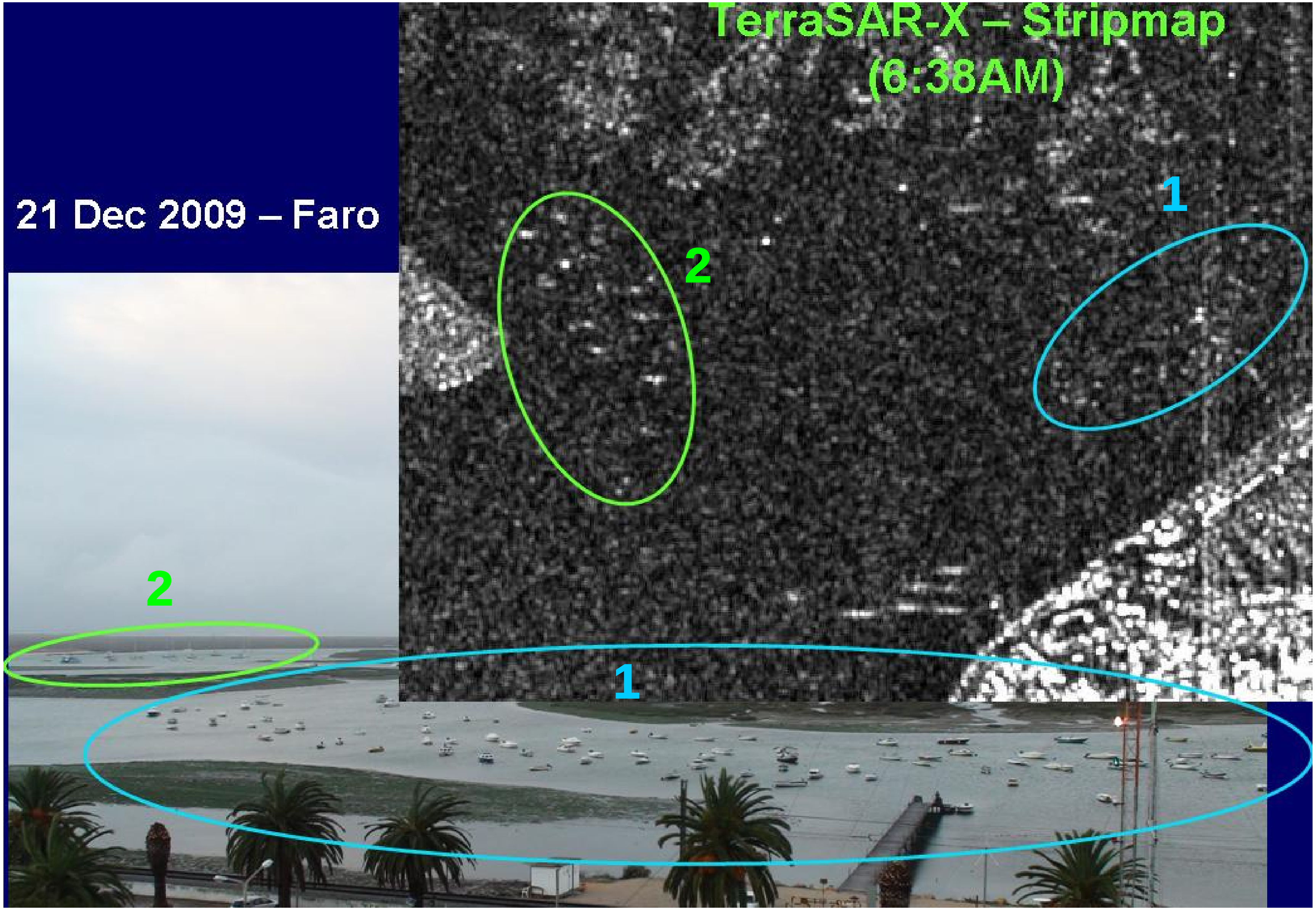

Figure 45 – At the top right we have a subset of the TerraSAR-X-Stripmap acquired on 21Dec.2009 over São Pedro, Faro-Algarve. On the bottom a photo taken after approximately at the time of the satellite pass.

5.2.4 – Radarsart2-Ultrafine, 21 December 2009 Faro-Algarve.

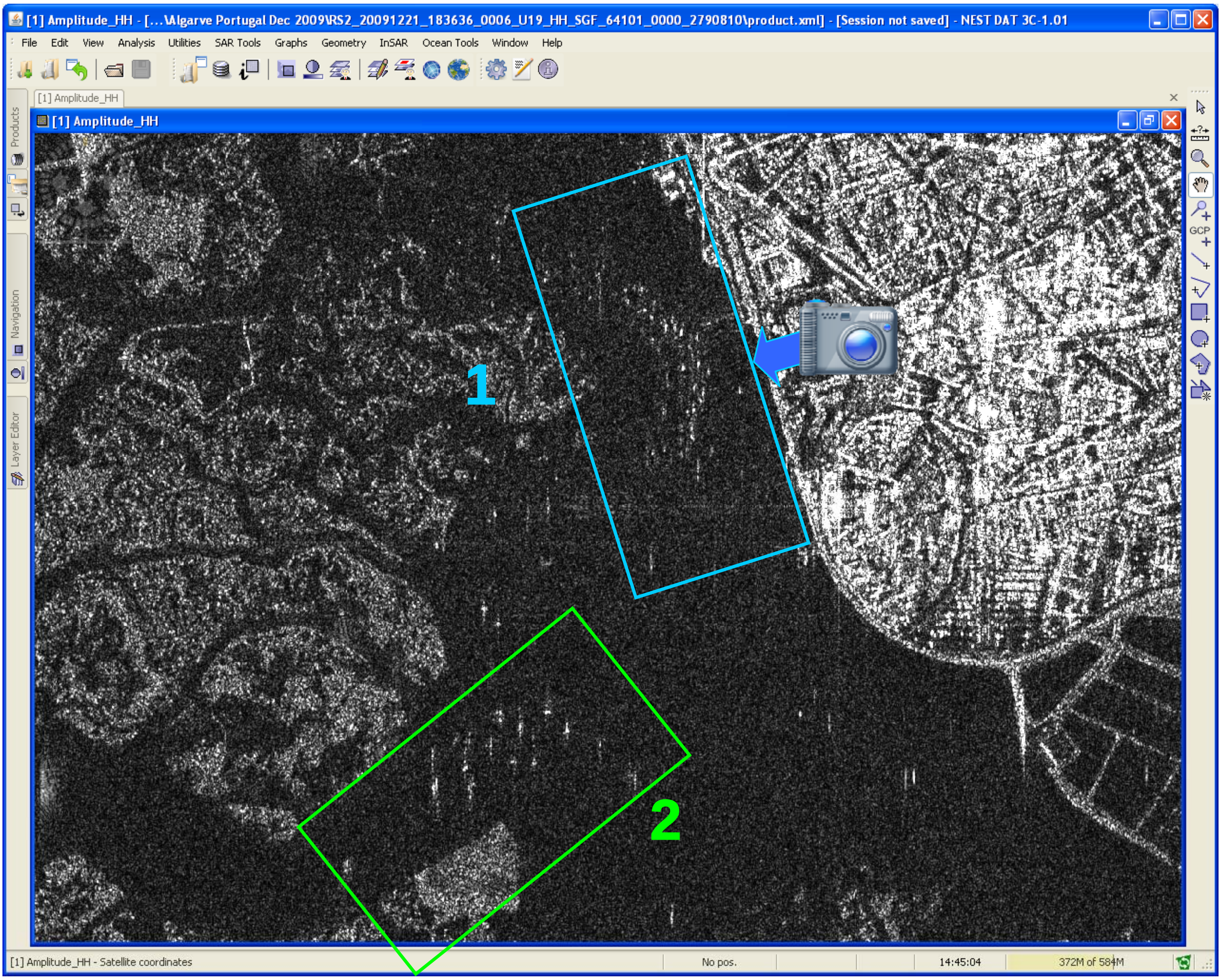

Figure 46 – Area of São Pedro-Faro covered by the Radarsat2-Ultrafine SAR image footprint. The area was divided into two zones.

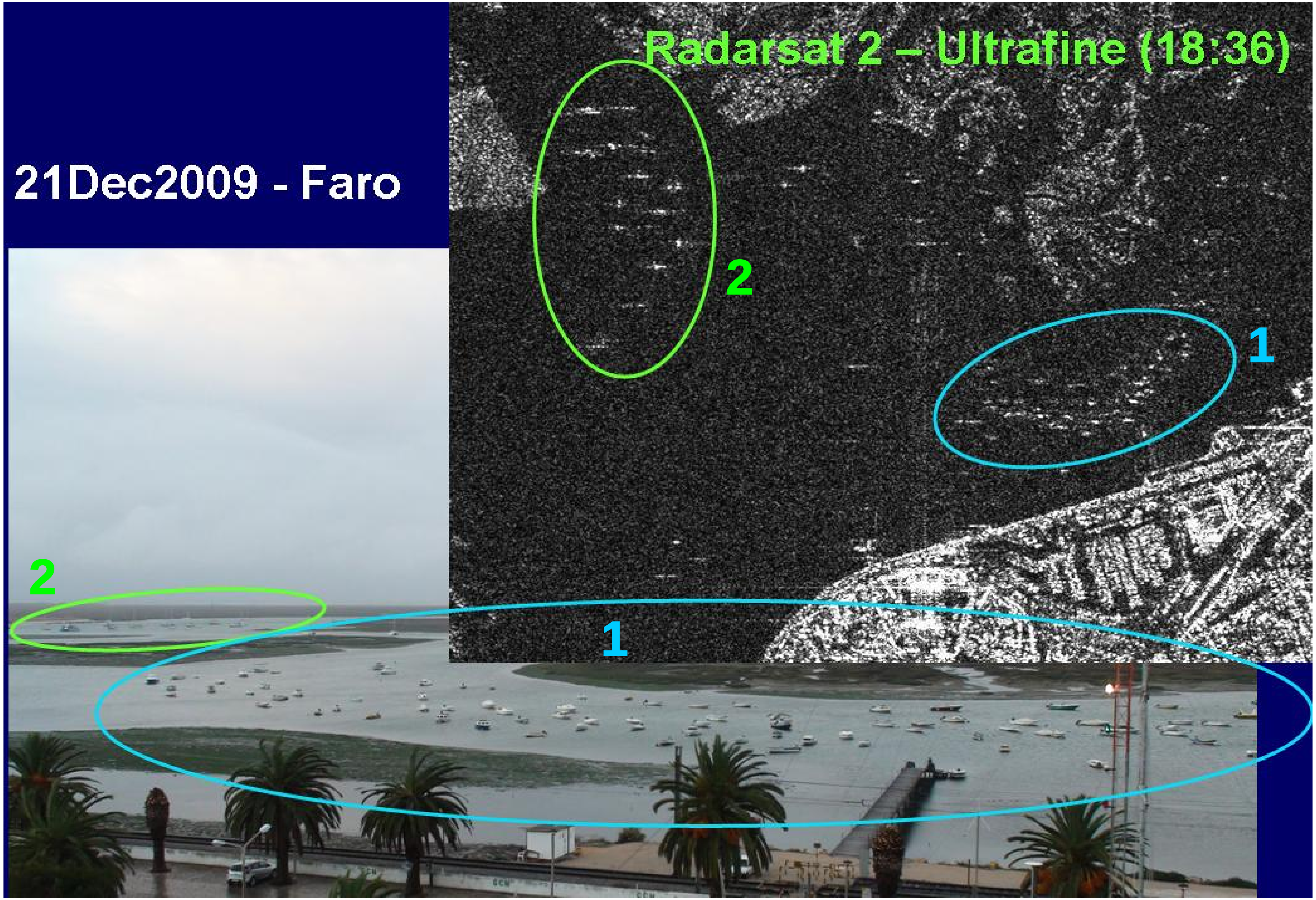

Figure 47 – On the top right we have a subset of the Radarsat2-Ultrafince image acquired on 21Dec.2009 over São Pedro, Faro-Algarve. At the bottom a photo taken after approximately at the time of the satellite pass.

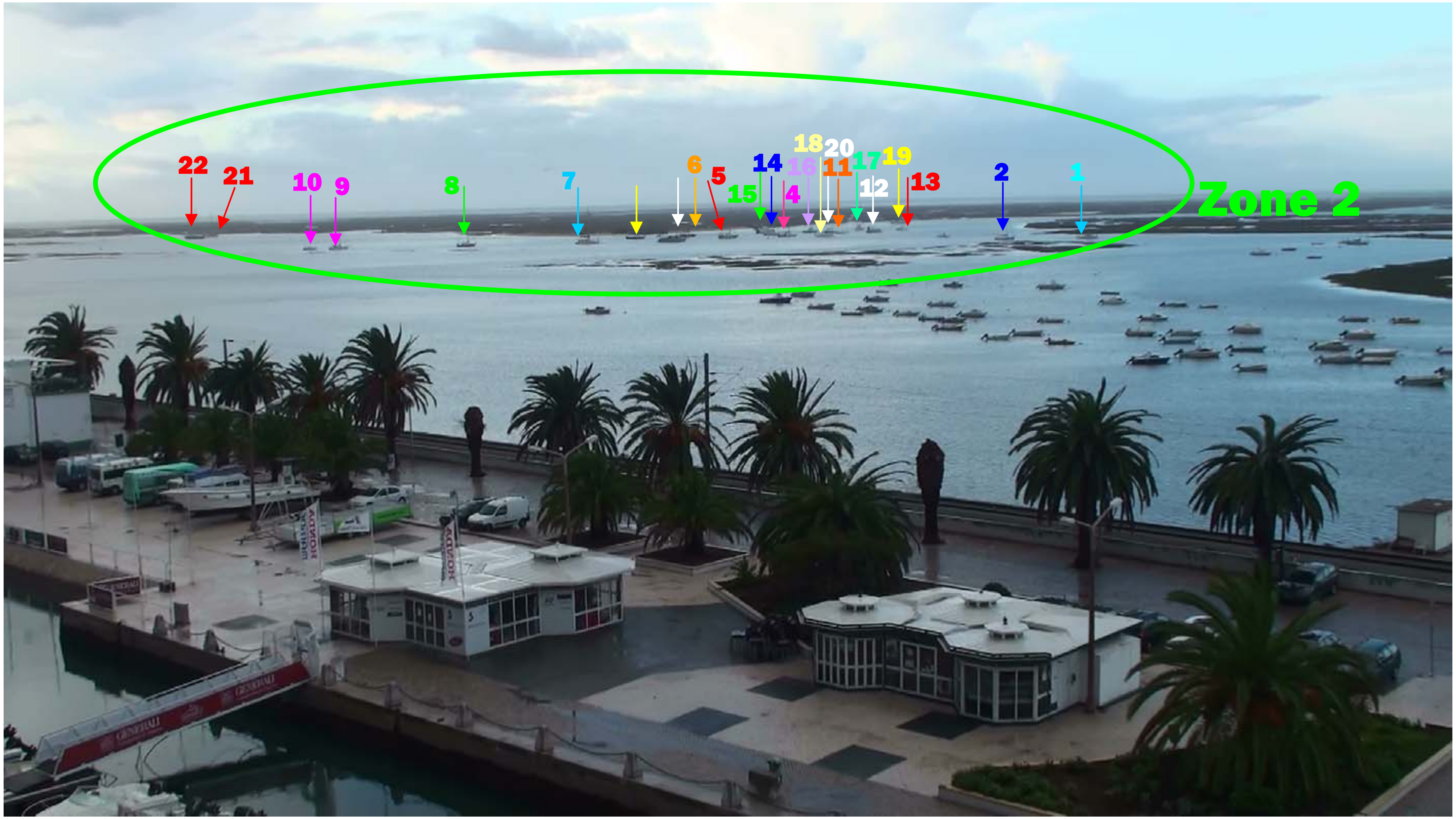

Figure 48 – Photo of Zone 1 covered by the Radarsat2-Ultrafine SAR image of 21 Dec. 2009. Each boat has an identification number used to compare with SAR image in figure 49.

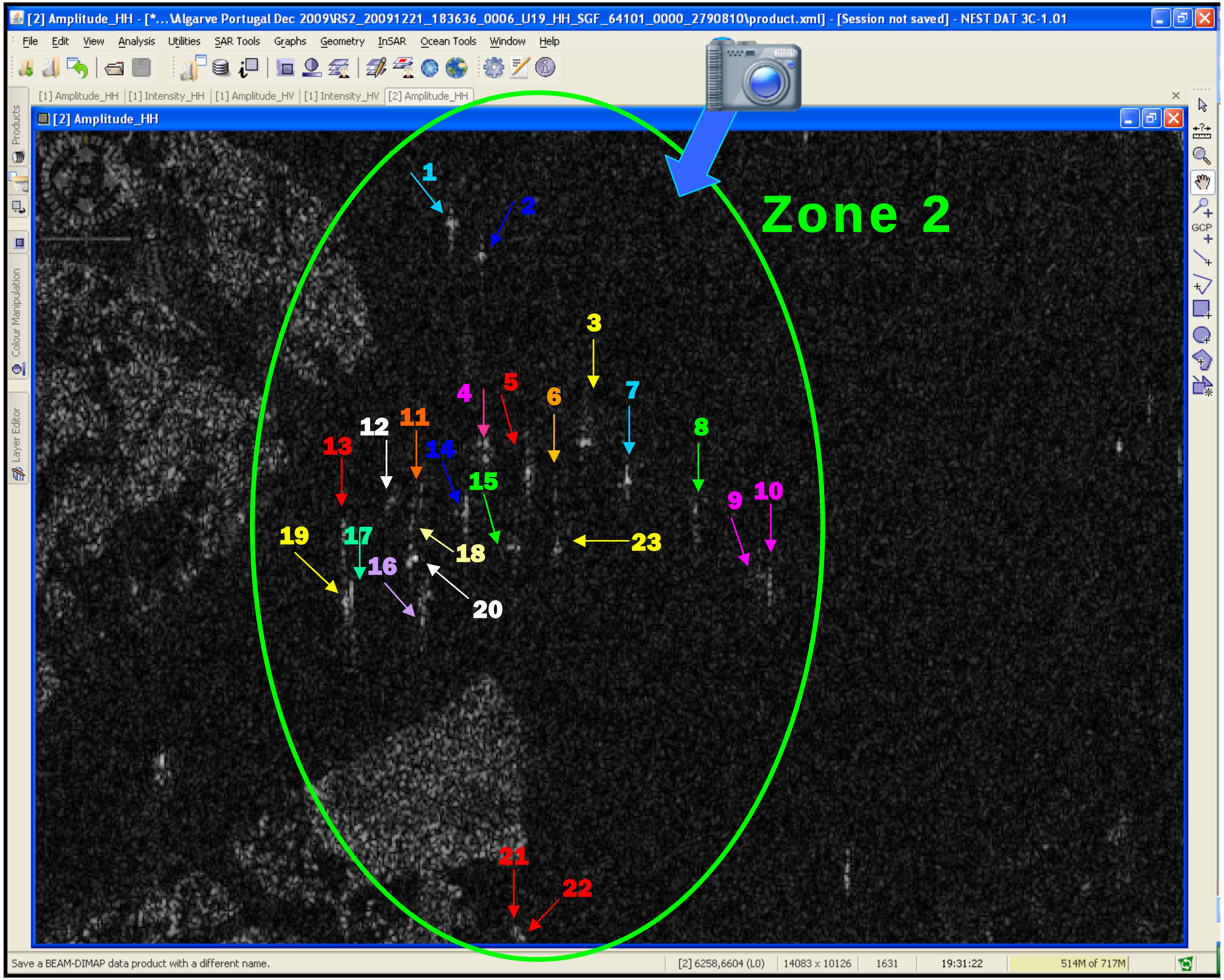

Figure 49 – Radarsat2-Ultrafine SAR image acquired on 21 Dec. 2009 over Faro, Algarve. The targets of opportunity correspond to the small boats in figure 48.

5.2.5 – TerraSAR-X - Stripmap, 22 December 2009, Alvor-Algarve.

On 22 December 2011 a TerraSAR-X-Stripmap was acquired over Alvor-Algarve. The area was selected due to the inland sea waters and the availability of small boats that could be used as targets of opportunity. The SAR Satellite image acquired over Alvor-Algarve, Portugal, was a TerraSAR-X - Stripmap, dual polarization HH, Ascending pass, 22 December 2009 (Time-18:31), Alvor-Algarve, Portugal. The frame (footprint) of the SAR image acquired covering Alvor is illustrated in Figure 50 and 51.

The SAR image was calibrated using NEST, an ESA software package. An overview of the Alvor area in the TerraSAR-Stripmap image is given in Figure 52. As it can be seen, several targets of opportunity were detected. Most small boats moored on sea not too close to other targets were detected. Some of the bright spots in the image might correspond to sets of small boats too close to each other. In those cases there was SAR signature contamination. The small boats moored to piers also have contaminated SAR signatures by the backscattering from other nearby boats and the piers.

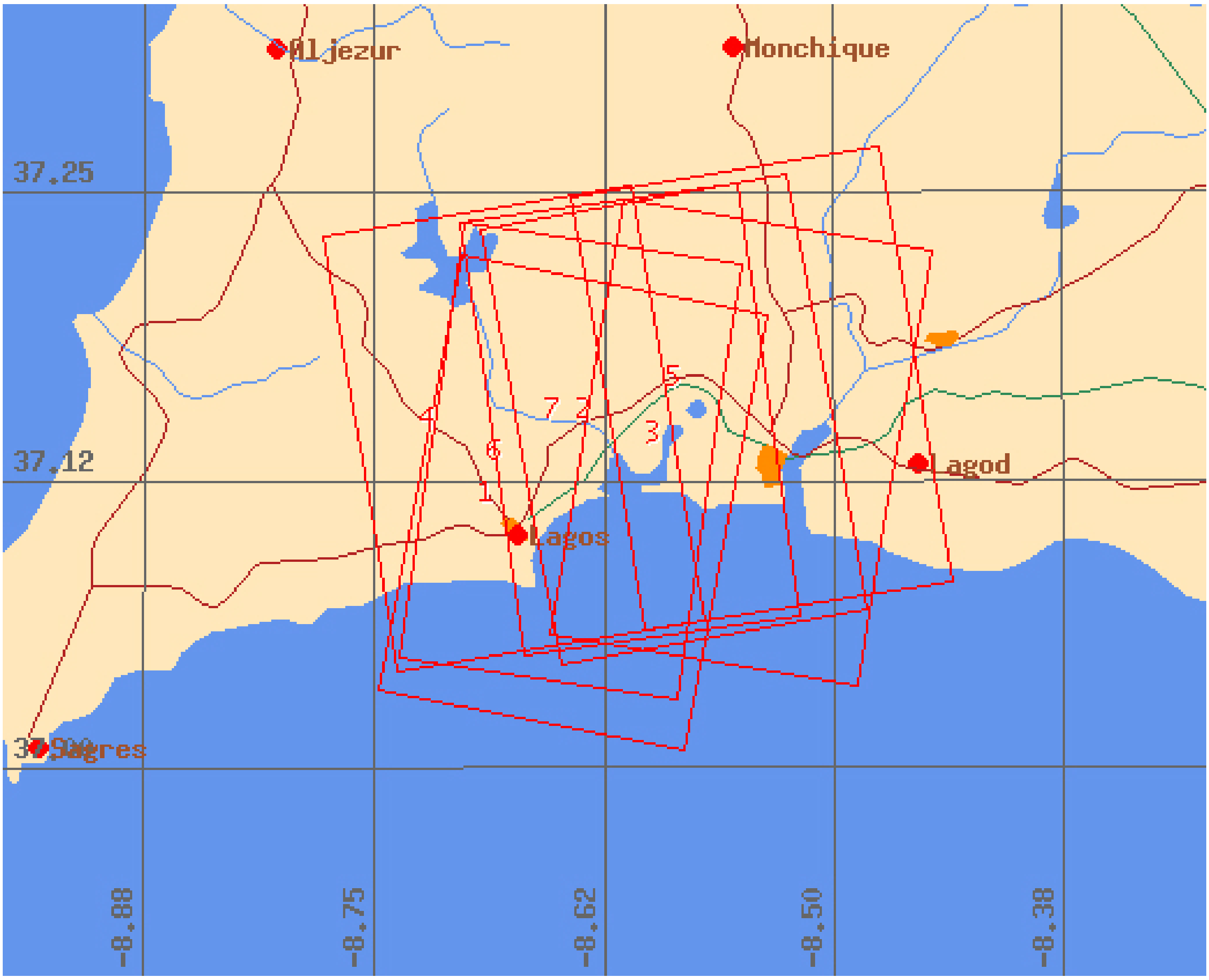

Figure 50 – Footprint of the Radarsat2-Spotlight image acquired over Alvor-Algarve on 19 Dec. 2009 by 06:39h.

Figure 51 - The TerraSAR image footprint is illustrated in magenta.

Figure 52 illustrates the TerraSAR-Stripmap SAR image acquired over Alvor. The area was divided into two zones to facilitate the analysis of the SAR image. Several targets of opportunity were detected in both zones; however, due to the lower resolution of the Stripmap mode (about 3 meters) it is more difficult to isolate the different targets. The image also shows some artefacts and azimuth ambiguities.

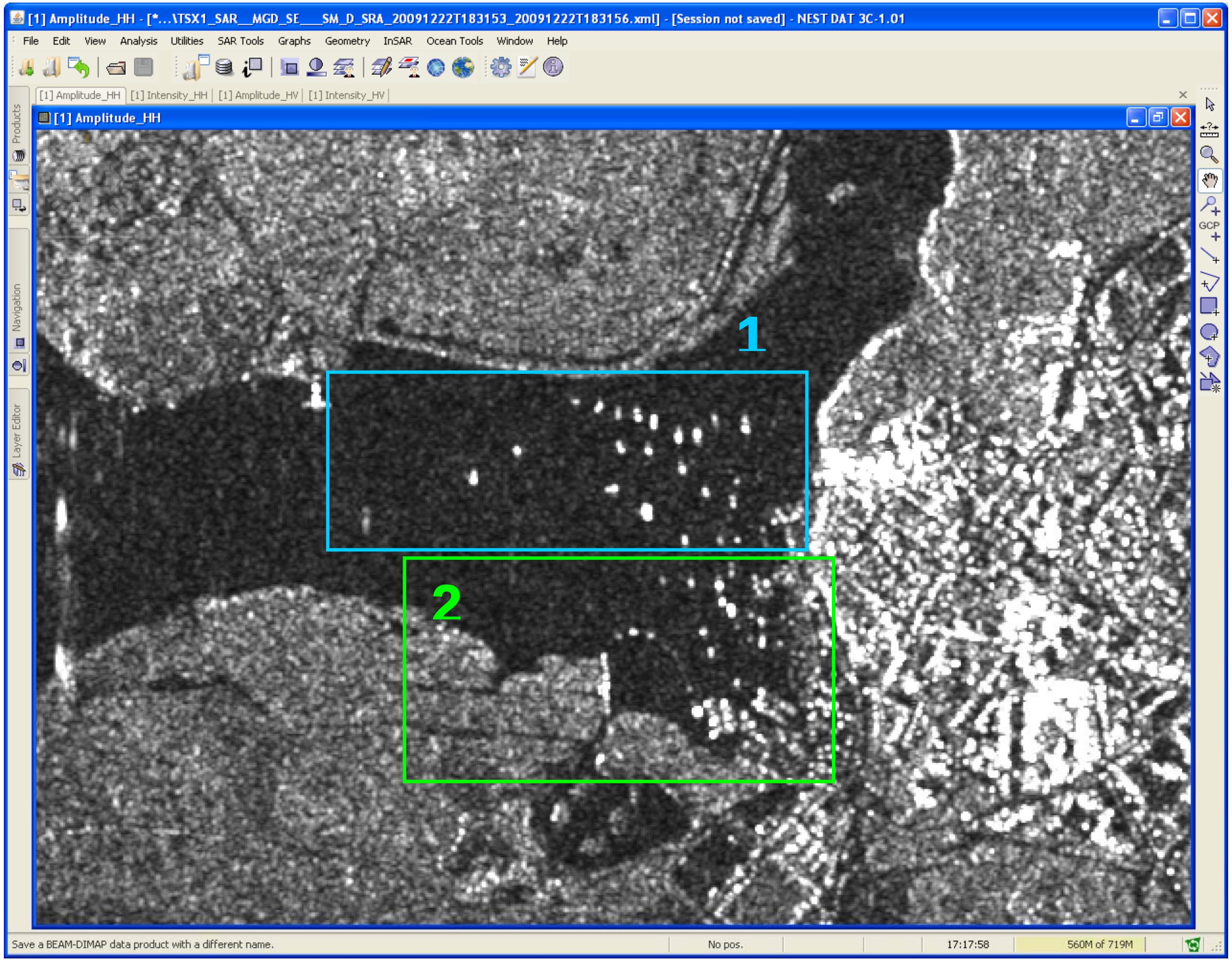

Figure 52 – Alvor area covered by the TerraSAR image footprint. The area was divided into two zones.

Figure 53 – Photo taken in Alvor approximately at the time of the satellite pass.

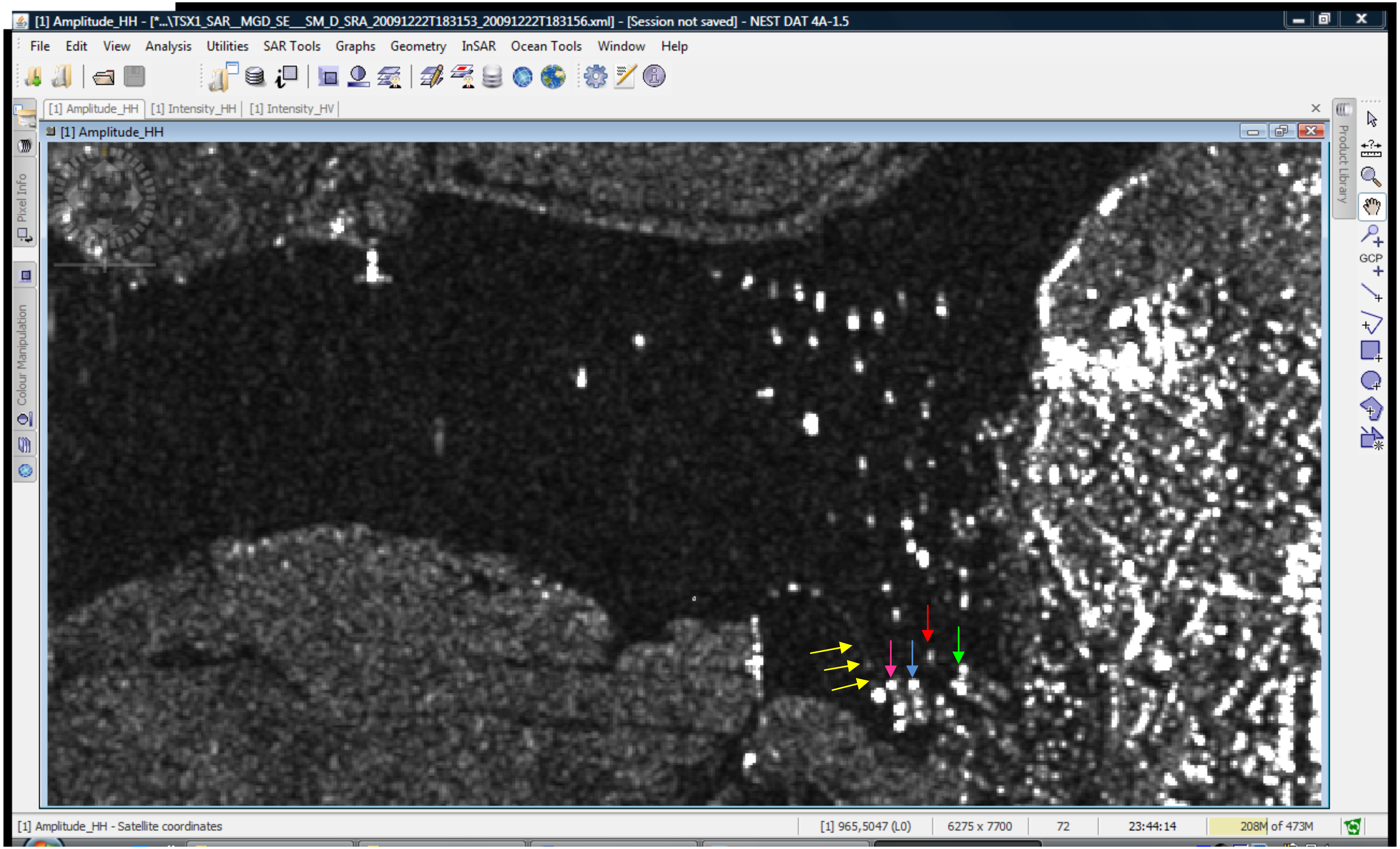

Figure 54 – TerraSAR-X-Stripmap acquired over Alvor-Algarve on 22 Dec. 2011.

Figure 55 – Photo taken in Alvor approximately at the time of the satellite pass.

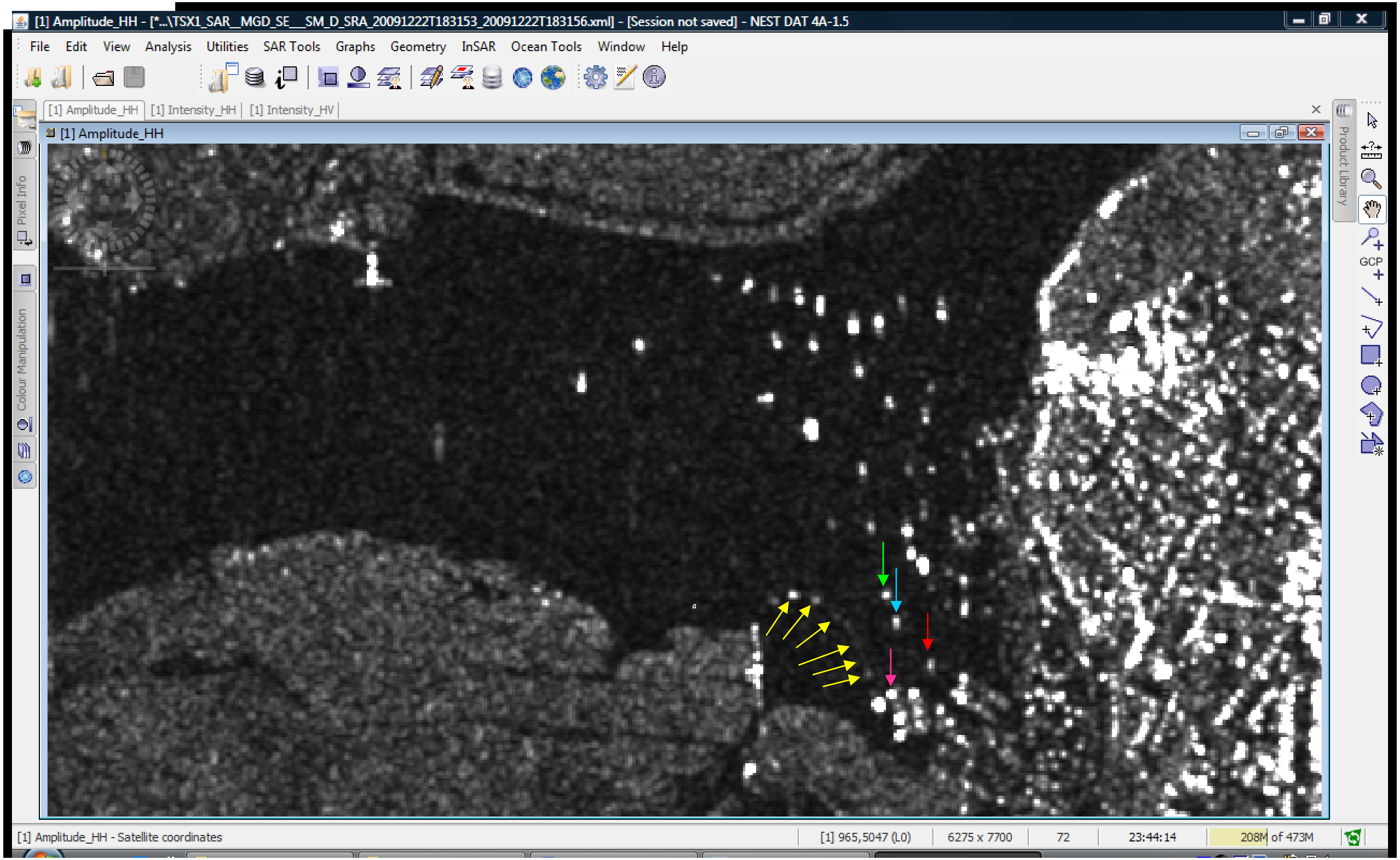

Figure 56 – TerraSAR-X-Stripmap acquired over Alvor-Algarve on 22 Dec. 2011.

Figure 57 – Photo taken in Alvor approximately at the time of the satellite pass.

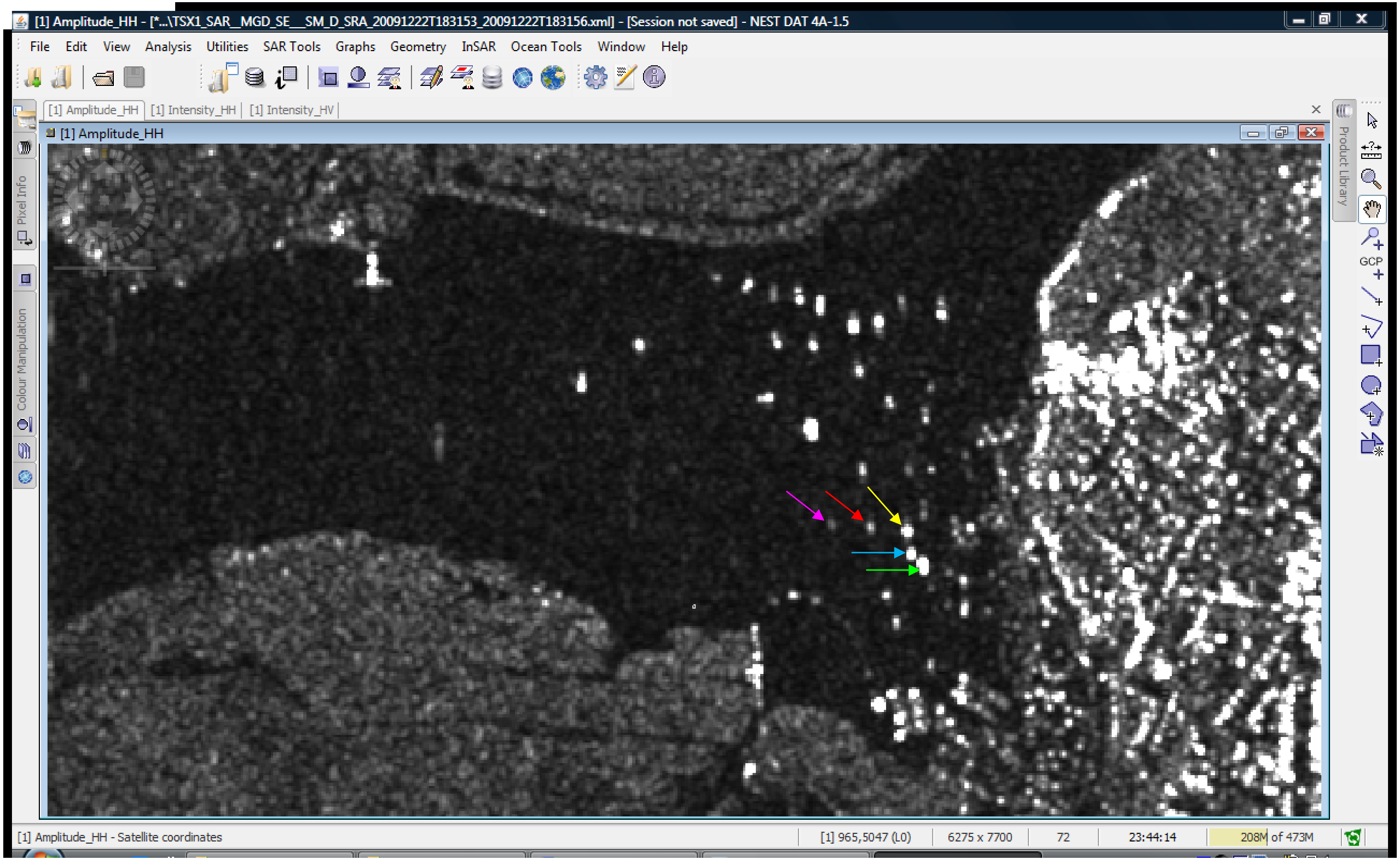

Figure 58 – TerraSAR-X-Stripmap acquired over Alvor-Algarve on 22 Dec. 2011.

Figure 59 – Photo taken in Alvor approximately at the time of the satellite pass.

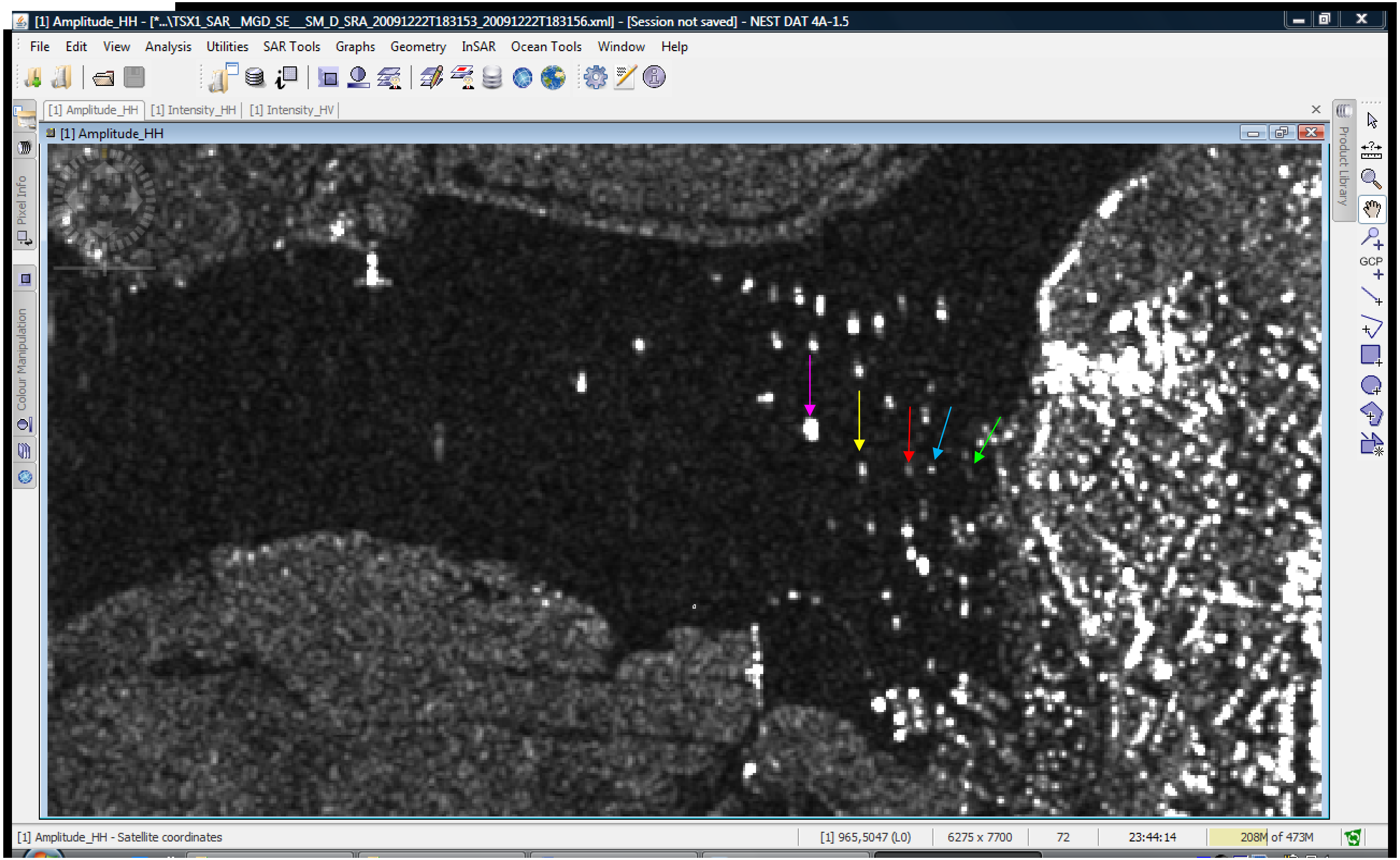

Figure 60 – TerraSAR-X-Stripmap acquired over Alvor-Algarve on 22 Dec. 2011.

Figure 61 – Photo taken in Alvor approximately at the time of the satellite pass.

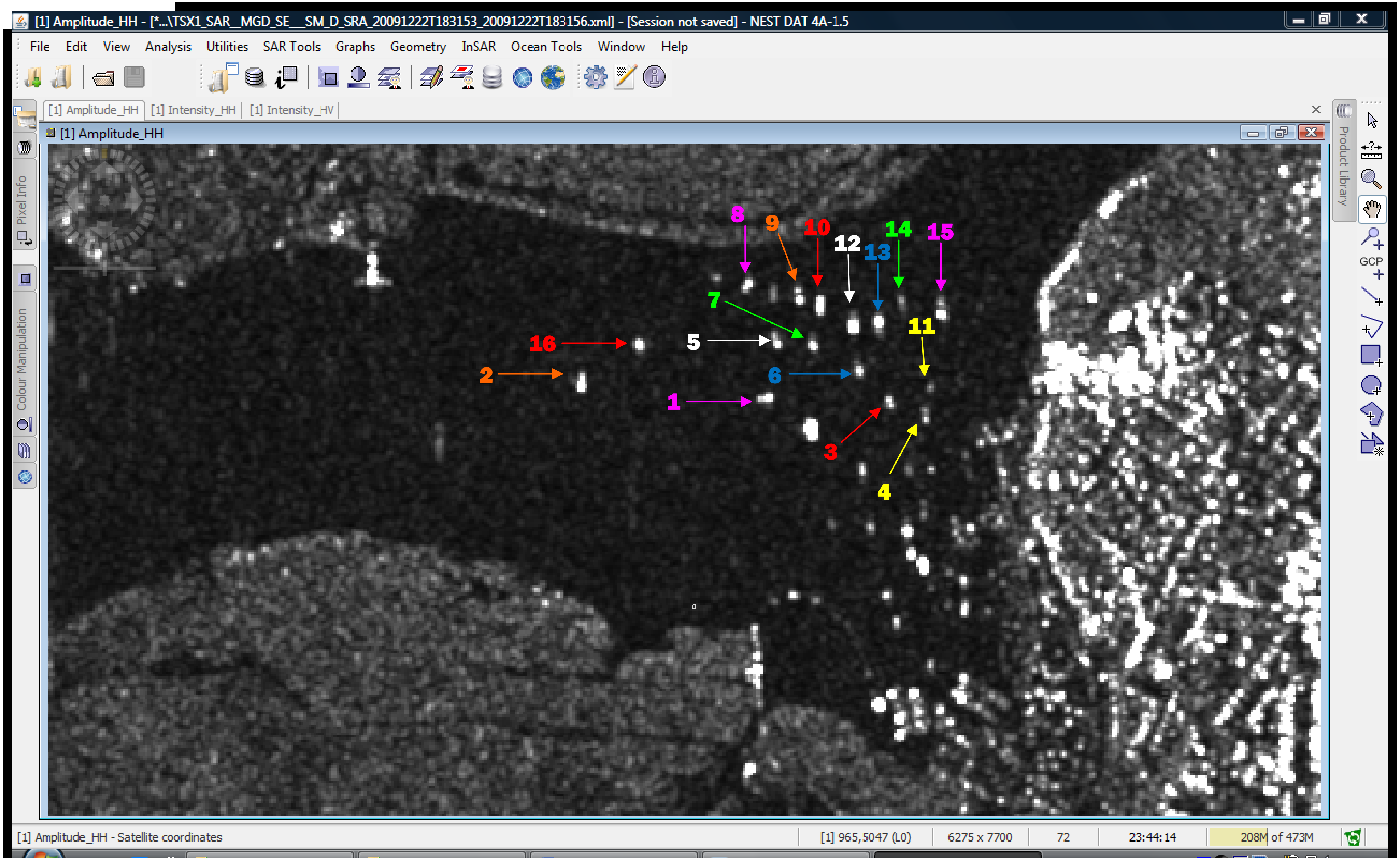

Figure 62 – TerraSAR-X-Stripmap acquired over Alvor-Algarve on 22 Dec. 2011.

5.2.6 - Radarsat2 - Ultrafine, 23 December 2009 Tavira-Algarve.

On 23 December 2009 a Radarsat2-Ultrafine was acquired over Cacela Velha-Algarve. The area was selected due to the inland sea waters and the availability of small boats that could be used as targets of opportunity. The SAR Satellite image acquired over Cacela Velha-Algarve, Portugal, was a single polarization HH, Descending pass, 23 December 2009 (Time-06:22:13), Tavira-Algarve, Portugal. The frame (footprint) of the SAR image acquired covering Cacela Velha, Tavira is illustrated in Figure 63 and 64.

The SAR image was calibrated using NEST, an ESA software package. An overview of Cacela Velha area in the Radarsat2-Ultrafine image is given in Figure 65. As it can be seen, the sea state made it difficult to detect targets of opportunity. Several targets of opportunity were detected, but they can hardly be distinguished from sea clutter due to the sea state. The detected targets look like small stripes. Most small boats moored on sea not too close to other targets were detected as small stripes. The wind speed was higher than in the previous days. The Radarsat2 SAR image also shows longer stripes on open sea. These longer stripes are the waves breaking.

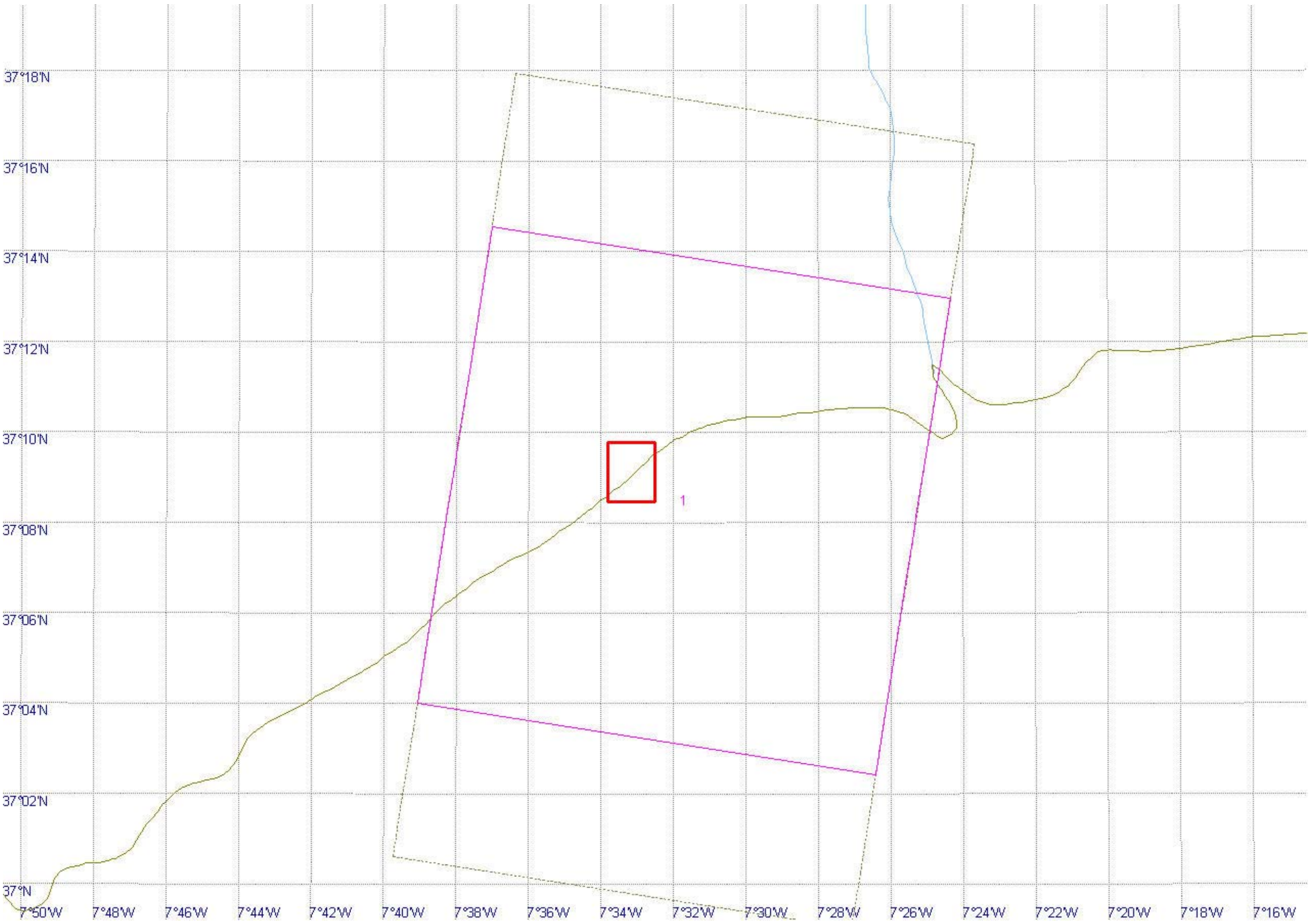

Figure 63 – Footprint of the Radarsat2-Ultrafine image acquired over Cacela Velha-Algarve on 23 Dec. 2009 by 06:22h.

Figure 64 - The Radarsat2-Ultrafine image footprint is illustrated in green.

Figure 65 illustrates the Radarsat2-Ultrafine SAR image acquired over Cacela Velha, Tavira, Algarve. The area was divided into two zones to facilitate the analysis of the SAR image. Several targets of opportunity were detected in both zones; however, due to the lower resolution of the Stripmap mode (about 3 meters) it is more difficult to isolate the different targets. The image also shows some artefacts and azimuth ambiguities.

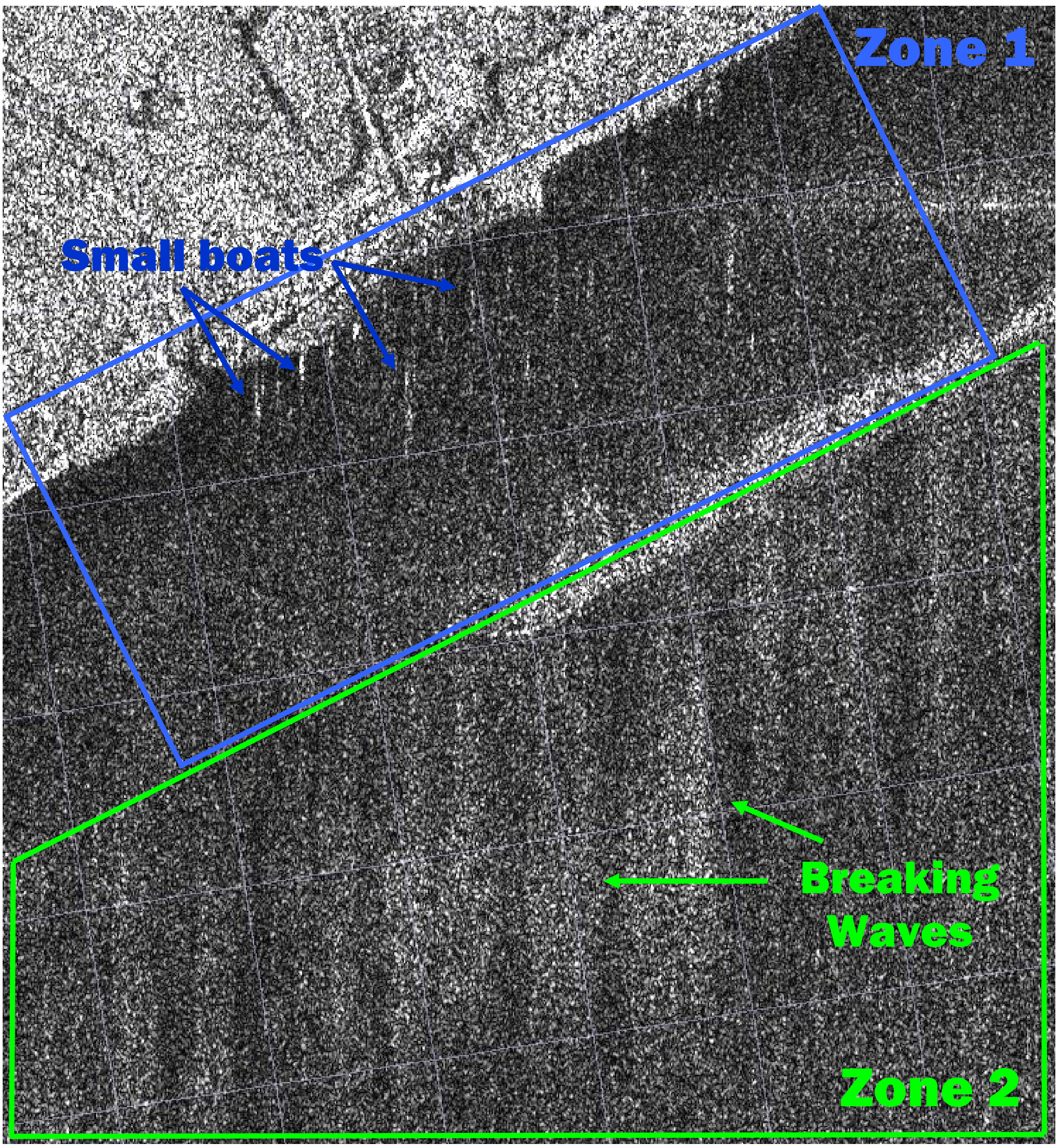

Figure 65 – Cacela Velha, Tavira-Algarve area covered by the Radarsat2-Ultrafine image footprint. The area was divided into two zones. In Zone 1 the small stripes are likely small boats. In Zone 2 the large stripes are likely breaking waves.

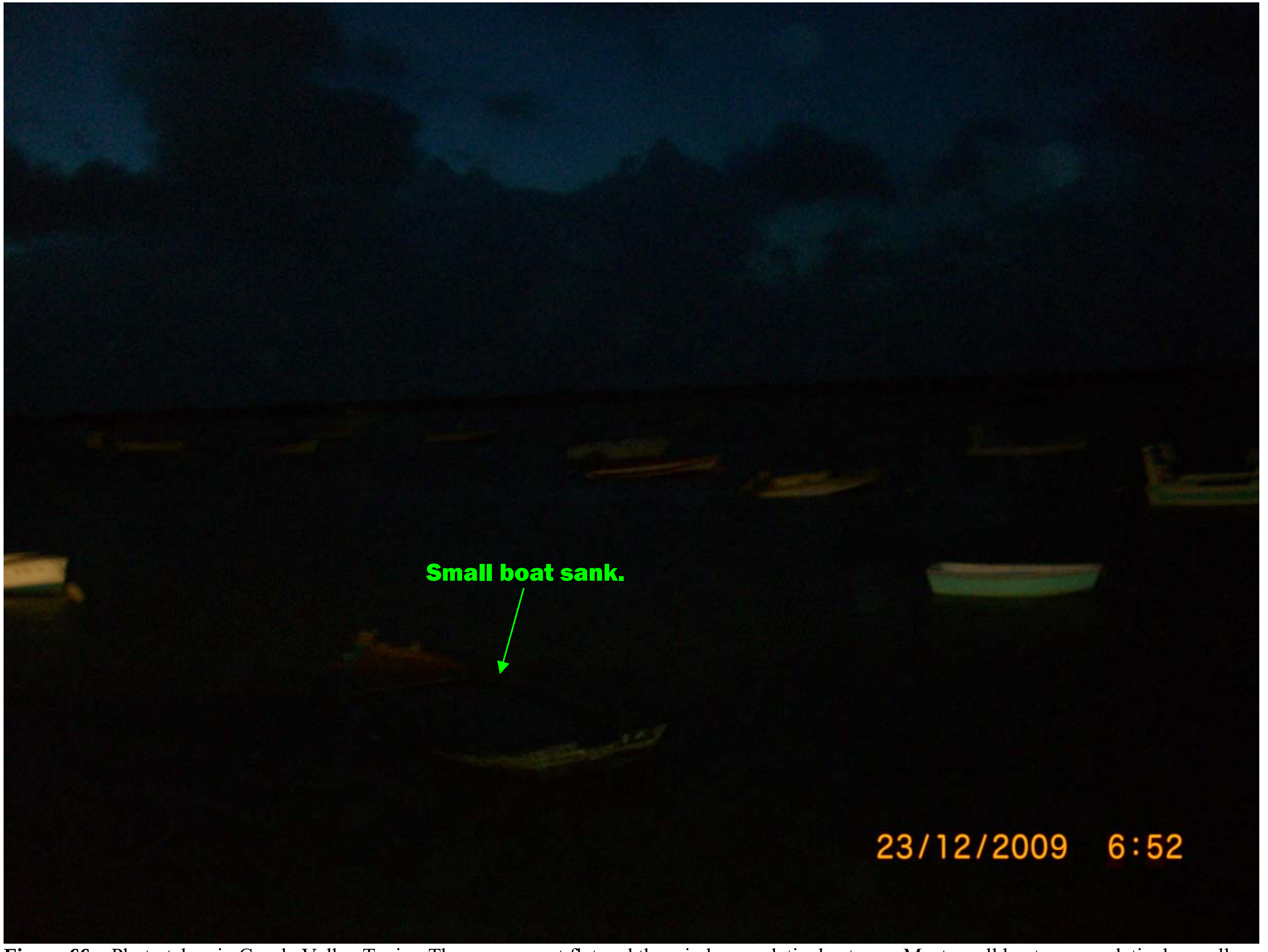

Figure 66 – Photo taken in Cacela Velha, Tavira. The sea was not flat and the wind was relatively strong. Most small boats were relatively small boats (e.g. between 2 and 4 meter), some of which sank.

Figure 67 – Due to the sea state and the relatively strong wind several small boats sank.

Figure 68 – This photo illustrates the waves breaking on the top and the relatively rough sea surface due to the wind.

Figure 69 – Overview of Cacela Velha, Tavira and the small boats used as targets of opportunity.

For each area covered in the experiment, an empirical probability of detection was estimated by dividing the number o small boats detected in that area in each SAR satellite image by the number of small boats counted from the ground truth data in the same area. It should be noted that this probability of detection is purely empirical and has an error associated. It gives a rough idea about the probability of detection of small boats using spaceborne SAR under the conditions (e.g. sea state, wind, weather, etc.) observed at the time of the SAR satellite passes during the experiment. A better estimate of the probability of detection would require a large number of similar experiments under different conditions (e.g., sea states, wind speed, geographical locations, weather conditions, etc.) representative of the possible scenarios.

Table 2 – Empirical probability of small boat detection using spaceborne SAR on inland sea waters.

Date / Time	Place	Satellite / Mode	Ground Truth Data	Detected Boats	Ground Truth	Empirical Probability
PORTUGAL (Algarve)						
18-Dec.-2009 18:23:44	Tavira (Sta. Luzia) – Algarve	Radarsat-2 / Spotlight	GPS/Photos/Movies	20 (Section 1)	31	20 (Section 1) / 31 = 64.5% ± Error
19-Dec.-2009 06:38:54	Alvor - Algarve	Radarsat-2 / Spotlight	GPS/Photos/Movies	50	65	50/65 = 76.9% ± Error
21-Dec.-2009 18:36:11	Faro – Algarve	Radarsat-2 / Ultrafine	GPS/Photos/Movies	66	120	66 / 120 = 55% ± Error
21-Dec.-2009 06:38:14	Faro – Algarve	TerraSAR-X / Stripmap	GPS/Photos/Movies	45	110	45 / 110 = 40.9% ± Error
22-Dec.-2009 18:31:42	Alvor – Algarve	TerraSAR-X/ Stripmap	GPS/Photos/Movies	32	68	32/68 = 47.1% ± Error
23-Dec.-2009 06:22:13	Tavira (Cacela Velha) – Algarve	Radarsat-2 / Ultrafine	GPS/Photos/Movies	NA	???	???

6. – Preliminary Conclusions

This chapter gives a quantitative analysis for each spaceborne SAR image acquired and describes the preliminary conclusions of this spaceborne SAR small boat detection experiment.

6.1 – Quantitative Analysis of the Spaceborne SAR Images

In order to allow a quantitative analysis of the data, all the spaceborne SAR images were calibrated using ESA’s NEST software package, version 4B. The inputs were the SAR images acquired and the outputs were the Radiometric Calibration (Sigma Naught (σ°)) expressed in terms of intensity and in decibel (dB), the Radar Brightness (β°) and the Radiometric Normalisation (gamma naught (γ°)).

6.1.1 – Radarsat2-Spotlight,18Dec.2009(18:23h), Tavira-Algarve

Figure 70 illustrates the Amplitude and Intensity bands of the Radarsat2-Spotlgiht image (18Dec.2009).

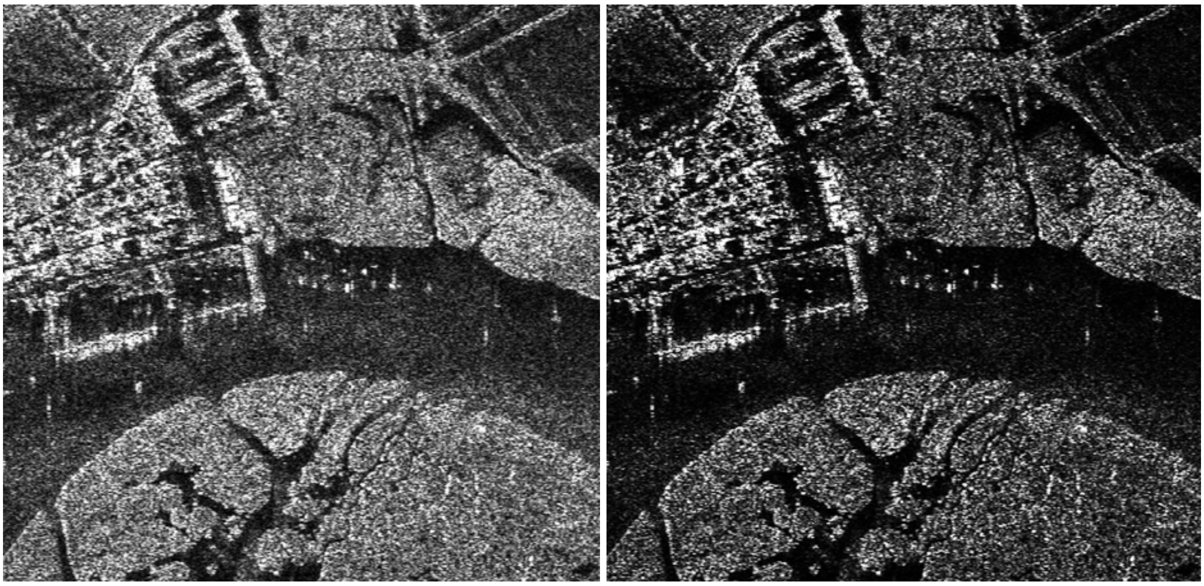

Figure 70 – Radarsat2-Spotlight 18Dec.2009 - On the left, the Amplitude band. On the right the Intensity band.

Figure 71 illustrates the Sigma Naught Coefficient of the Radarsat2-Spotlgiht image (18Dec.2009) expressed in terms of intensity and decibel (dB).

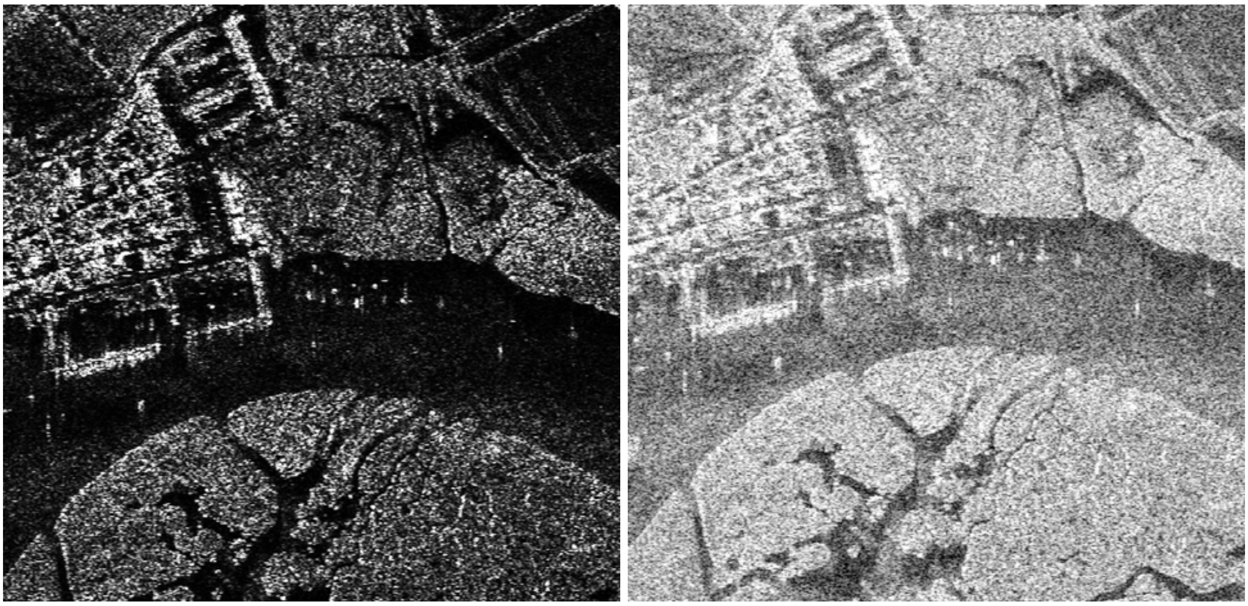

Figure 71 – Radarsat2-Spotlight 18Dec.2009 - On the left, the Sigma Naught (σ°) (intensity) and on the right, the Sigma Naught (σ°) (dB).

Figure 72 illustrates the Radar Brightness (Beta Naught (β°)), and the radiometric normalisation (Gamma Naught (γ°)) of the Radarsat2-Spotlgiht image (18Dec.2009) expressed in dB.

Figure 72 – Radarsat2-Spotlight 18Dec.2009 - On the left, the Beta Naught (β°) and on the right, the Gamma Naught (γ°) (dB).

Figure 73 shows the Sigma Naught (σ°) in dB after some colour manipulation and the histogram of the Sigma Naught (σ°) image.

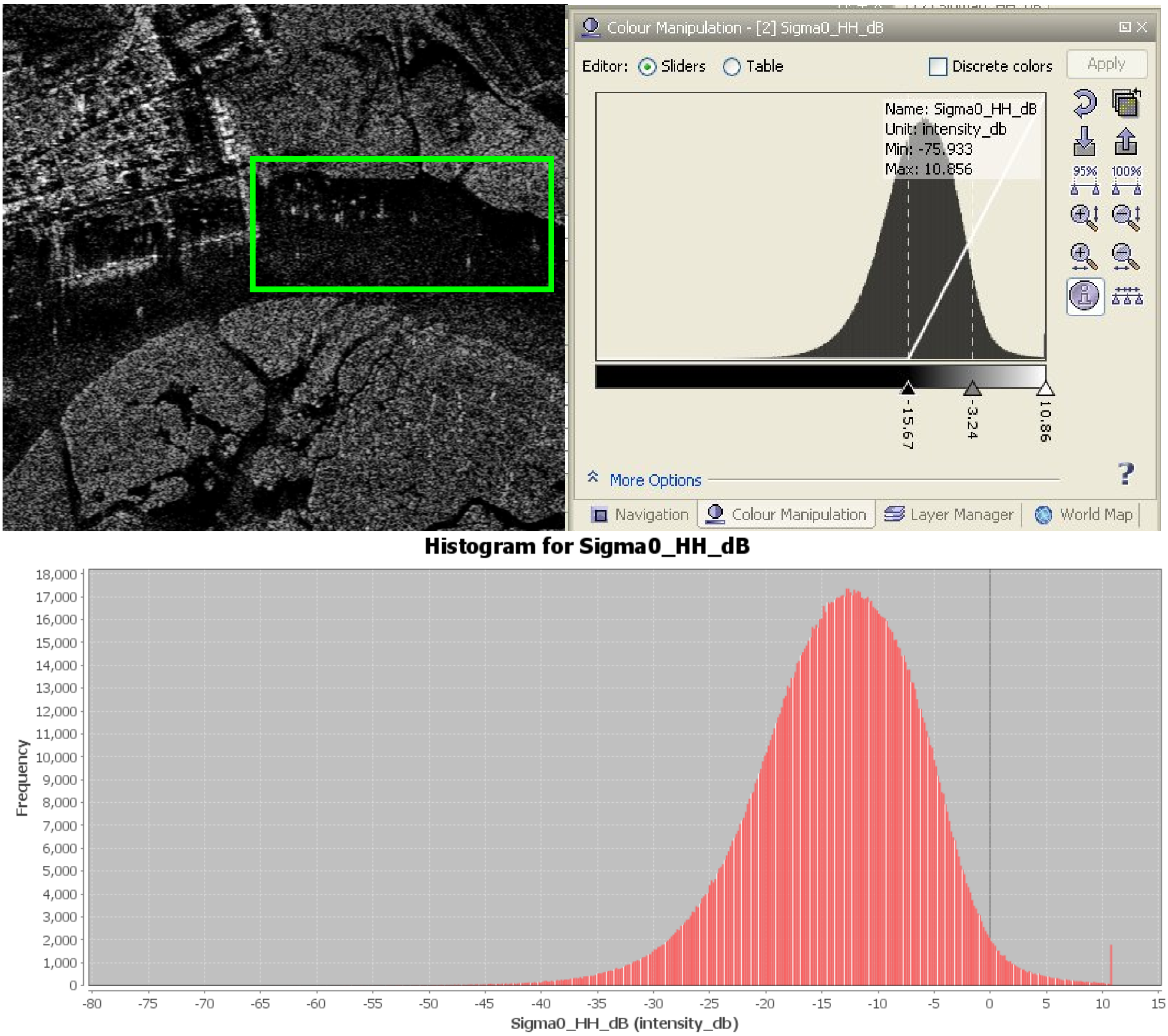

Figure 73 – Radarsat2-Spotlight 18Dec.2009 - On the top left the Sigma Naught (σ°) after colour manipulation to enhance the targets and on the top right, the corresponding histogram. On the bottom, the histogram of the image.

Table 3 gives the statistics of the Sigma Naught (σ°) Radarsat2-Spotlight image (18Dec.2009). The Sigma Naught (σ°) range from -75.9 dB up to 10.8 dB. The Mean value is -13.5 dB, the Median is -13.2 dB and the standard deviation is 7.4 dB.

Table 3 – Statistics of the Radarsat2-Spotlight 18Dec.2009 (18:23h)

Statistics	Values	Unit
Only ROI-Mask pixels considered:	No	
Number of pixels total:	1819510	
Number of considered pixels:	1819510	
Ratio of considered pixels:	100.0 %	
Minimum:	-75.93343353271484	intensity_db
Maximum:	10.85602855682373	intensity_db
Mean:	-13.53262000280064	intensity_db
Median:	-13.214486319571733	intensity_db
Std-Dev:	7.384050585565769	intensity_db
Coefficient of Variation:	-0.5456481121107789	intensity_db

Checking the radar backscattering coefficient of the targets (small boats) detected in section 1 (in Green), we get values ranging from -3.6 dB up to 8.2 dB. The analysis of the Sigma Naught values (σ°) of the targets and the area around the targets shows a significant contrast.

6.1.2 – Radarsat2-Spotlight,19Dec.2009(06:38h), Alvor-Algarve

Figure 74 illustrates the Amplitude and Intensity bands of the Radarsat2-Spotlgiht image (19Dec.2009)

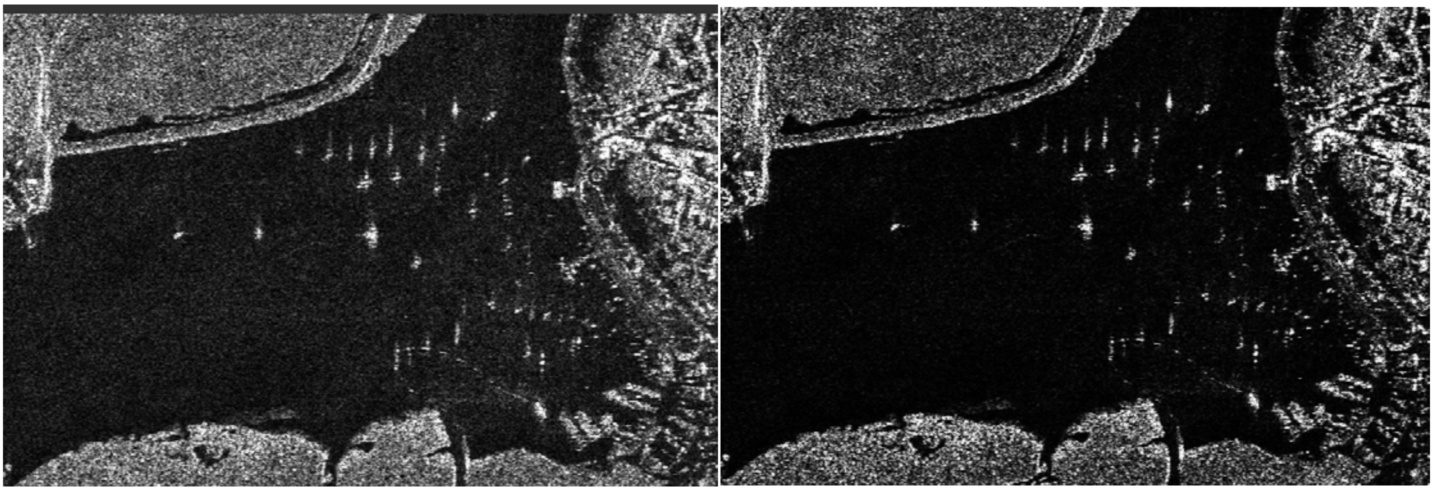

Figure 74 – Radarsat2-Spotlight 19Dec.2009 - On the left, the Amplitude band. On the right the Intensity band.

Figure 75 illustrates the Sigma Naught Coefficient of the Radarsat2-Spotlgiht image (19Dec.2009) expressed in terms of intensity and decibel (dB).

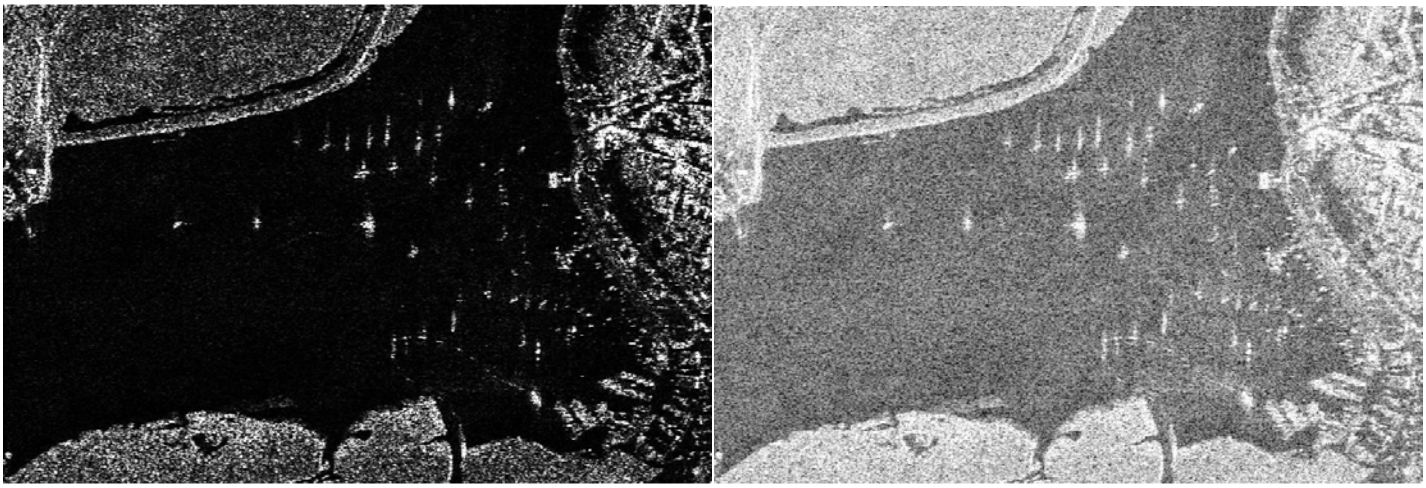

Figure 75 – Radarsat2-Spotlight 19Dec.2009 - On the left, the Sigma Naught (σ°) (intensity) and on the right, the Sigma Naught (σ°) (dB).

Figure 76 illustrates the Radar Brightness (Beta Naught (β°)), and the radiometric normalisation (Gamma Naught (γ°)) of the Radarsat2-Spotlgiht image (19Dec.2009) expressed in dB.

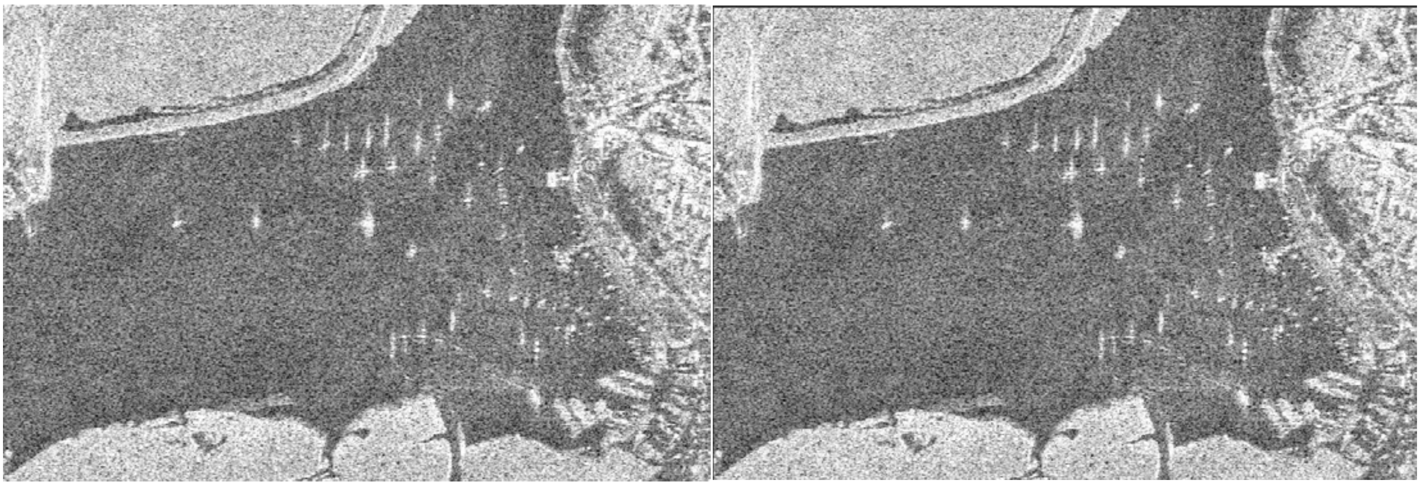

Figure 76 – Radarsat2-Spotlight 19Dec.2009 - On the left, the Beta Naught (β°) and on the right, the Gamma Naught (γ°) (dB).

Figure 77 shows the Sigma Naught (σ°) in dB after colour manipulation and the histogram of the Sigma Naught (σ°) image.

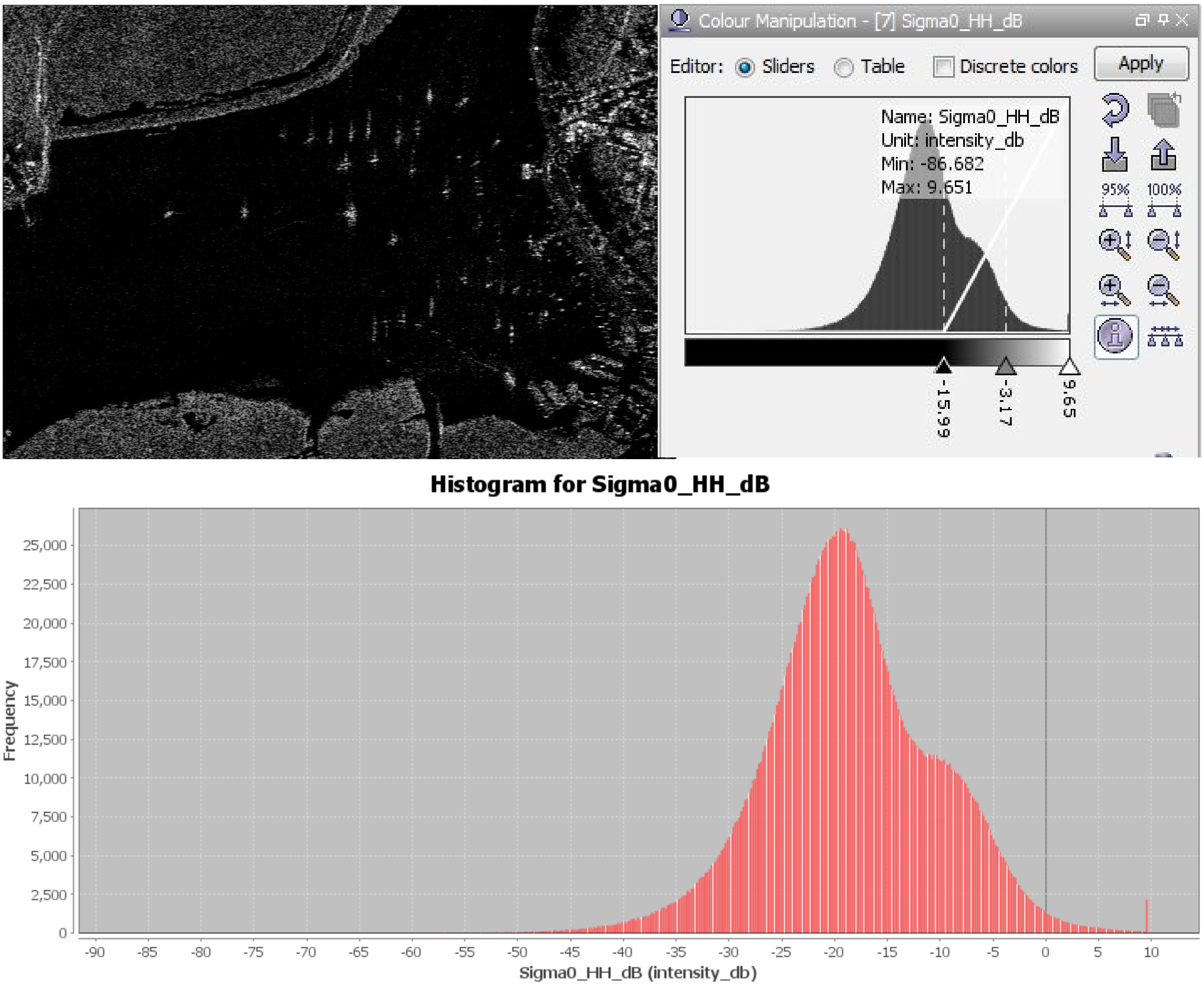

Figure 77 – Radarsat2-Spotlight 19Dec.2009 - On the top left the Sigma Naught (σ°) after colour manipulation to enhance the targets and on the top right, the corresponding histogram. On the bottom, the histogram of the image.

Table 4 gives the statistics of the Sigma Naught (σ°) Radarsat2-Spotlight image (19Dec.2009). The Sigma Naught (σ°) range from -86.6 dB up to 9.6 dB. The Mean value is -18.4 dB, the Median is -18.9 dB and the standard deviation is 8.0 dB.

Table 4– Statistics of the Radarsat2-Spotlight 18Dec.2009 (18:23h)

Statistics	Values	Unit
Only ROI-Mask pixels considered:	No	
Number of pixels total:	2311296	
Number of considered pixels:	2311296	
Ratio of considered pixels:	100.0 %	
Minimum:	-86.68241882324219	intensity_db
Maximum:	9.651137351989746	intensity_db
Mean:	-18.45416563799943	intensity_db
Median:	-18.947887137532234	intensity_db
Std-Dev:	8.00514712962392	intensity_db
Coefficient of Variation:	-0.4337852794279831	intensity_db

Checking the radar backscattering coefficient of the targets (small boats) detected in Figure 77, we get values ranging from -5.6 dB up to 9.6 dB. The analysis of the Sigma Naught values (σ°) of the targets and the area around the targets shows a significant contrast.

6.1.3 – Radarsat2-Ultrafine,21Dec.2009(18:36h), Faro-Algarve

Figure 78 illustrates the Amplitude and Intensity bands of the Radarsat2-Ultrafine image (21Dec.2009).

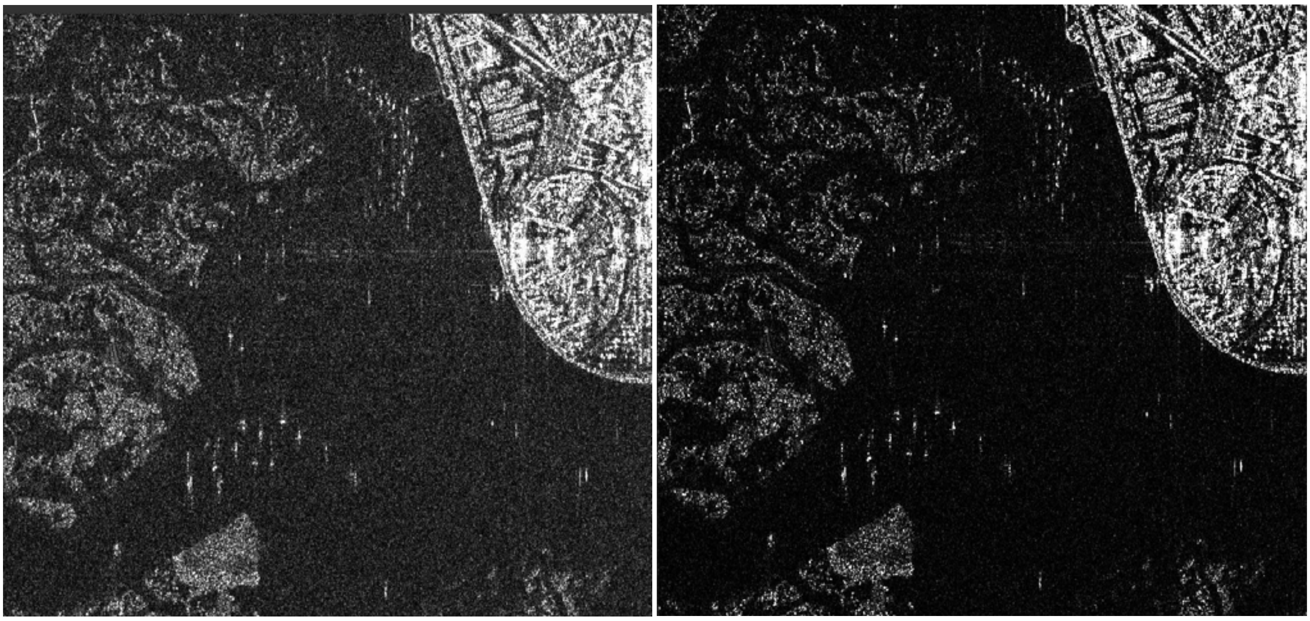

Figure 78 – Radarsat2-Ultrafine 21Dec.2009 - On the left, the Amplitude band. On the right the Intensity band.

Figure 79 illustrates the Sigma Naught Coefficient of the Radarsat2- Ultrafine image (21Dec.2009) expressed in terms of intensity and decibel (dB).

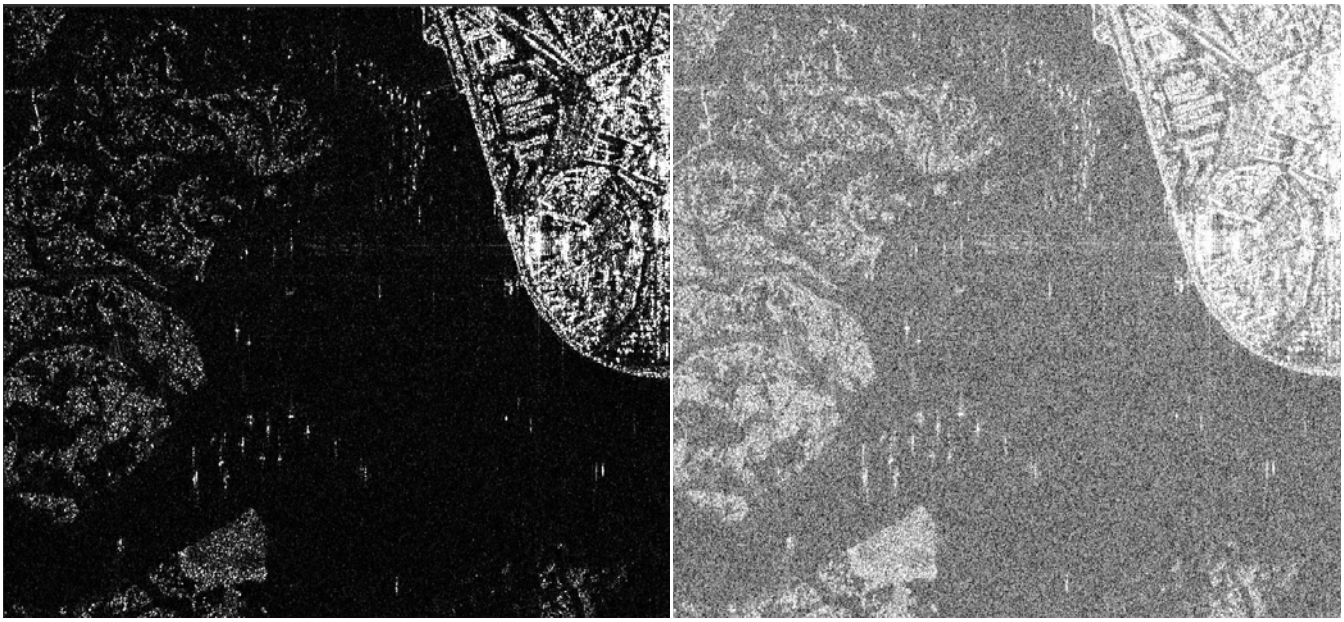

Figure 79 – Radarsat2-Spotlight 21Dec.2009 - On the left, the Sigma Naught (σ°) (intensity) and on the right, the Sigma Naught (σ°) (dB).

Figure 80 illustrates the Radar Brightness (Beta Naught (β°)), and the radiometric normalisation (Gamma Naught (γ°)) of the Radarsat2- Ultrafine image (21Dec.2009) expressed in dB.

Figure 80 – Radarsat2-Ultrafine 21Dec.2009 - On the left, the Beta Naught (β°) and on the right, the Gamma Naught (γ°) (dB).

Figure 81 shows the Sigma Naught (σ°) in dB after colour manipulation and the histogram of the Sigma Naught (σ°) image.

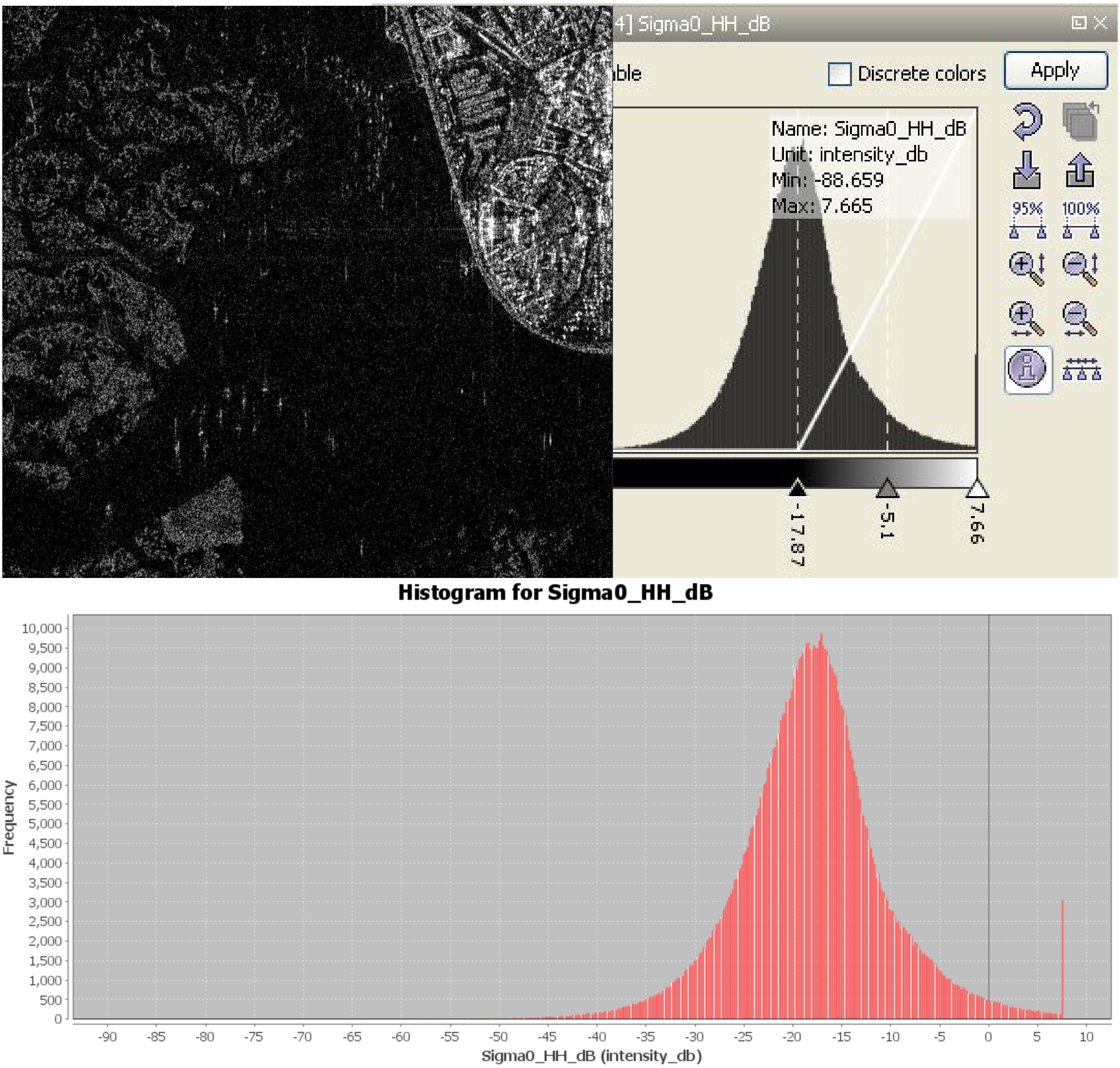

Figure 81 – Radarsat2-Ultrafine 21Dec.2009 - On the top left the Sigma Naught (σ°) after colour manipulation to enhance the targets and on the top right, the corresponding histogram. On the bottom, the histogram of the image.

Table 5 gives the statistics of the Sigma Naught (σ°) Radarsat2- Ultrafine image (21Dec.2009). The Sigma Naught (σ°) range from -88.6 dB up to 7.6 dB. The Mean value is -17.9 dB, the Median is -18.1 dB and the standard deviation is 7.4 dB.

Table 5– Statistics of the Radarsat2- Ultrafine image 21Dec.2009 (18:36h)

Statistics	Values	Unit
Only ROI-Mask pixels considered:	No	
Number of pixels total:	743256	
Number of considered pixels:	743256	
Ratio of considered pixels:	100.0 %	
Minimum:	-88.65936279296875	intensity_db
Maximum:	7.664803504943848	intensity_db
Mean:	-17.96751725640685	intensity_db
Median:	-18.109436305239797	intensity_db
Std-Dev:	7.417398112424511	intensity_db
Coefficient of Variation:	-0.41282237366339297	intensity_db

Checking the radar backscattering coefficient of the targets (small boats) detected in Figure 81, we get values ranging from -6.9 dB up to 7.2 dB. The analysis of the Sigma Naught values (σ°) of the targets and the area around the targets shows a significant contrast.

6.1.4 – TerraSAR-X-Stripmap,21Dec.2009(06:38h), Faro-Algarve

Figure 82 illustrates the Amplitude and Intensity bands of the Radarsat2-Ultrafine image (21Dec.2009

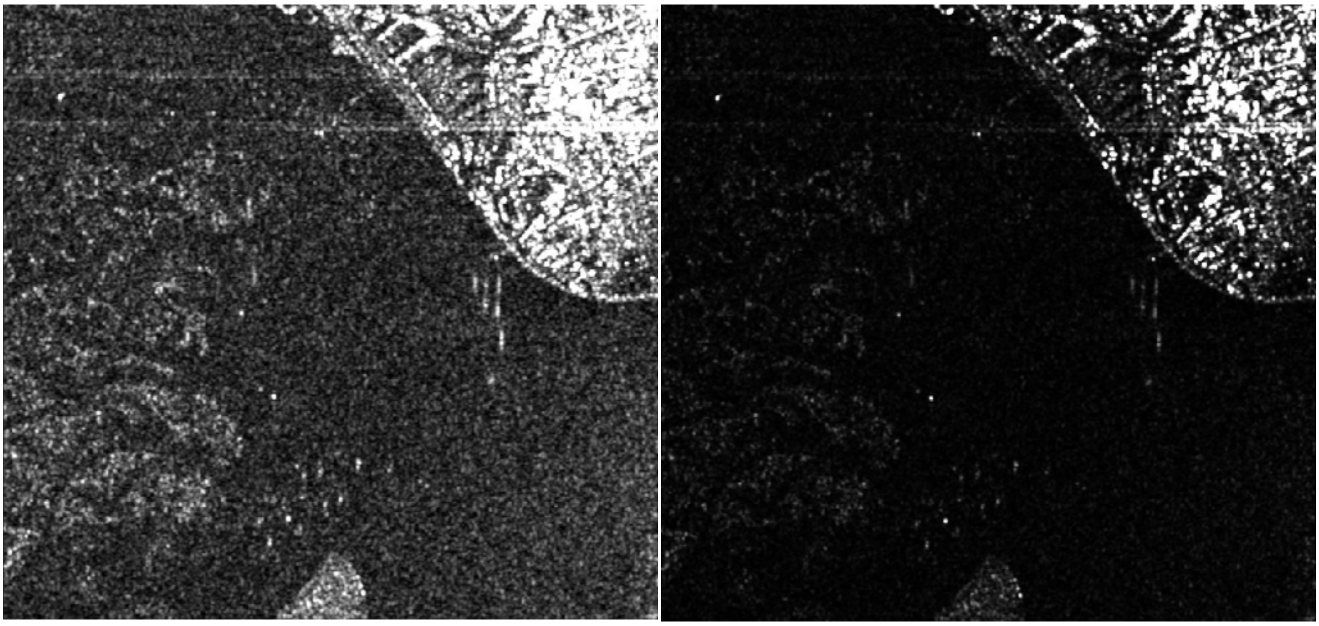

Figure 82 – TerraSAR-X-Stripmap 21Dec.2009 - On the left, the Amplitude band. On the right the Intensity band.

Figure 83 illustrates the Sigma Naught Coefficient of the Radarsat2- Ultrafine image (21Dec.2009) expressed in terms of intensity and decibel (dB).

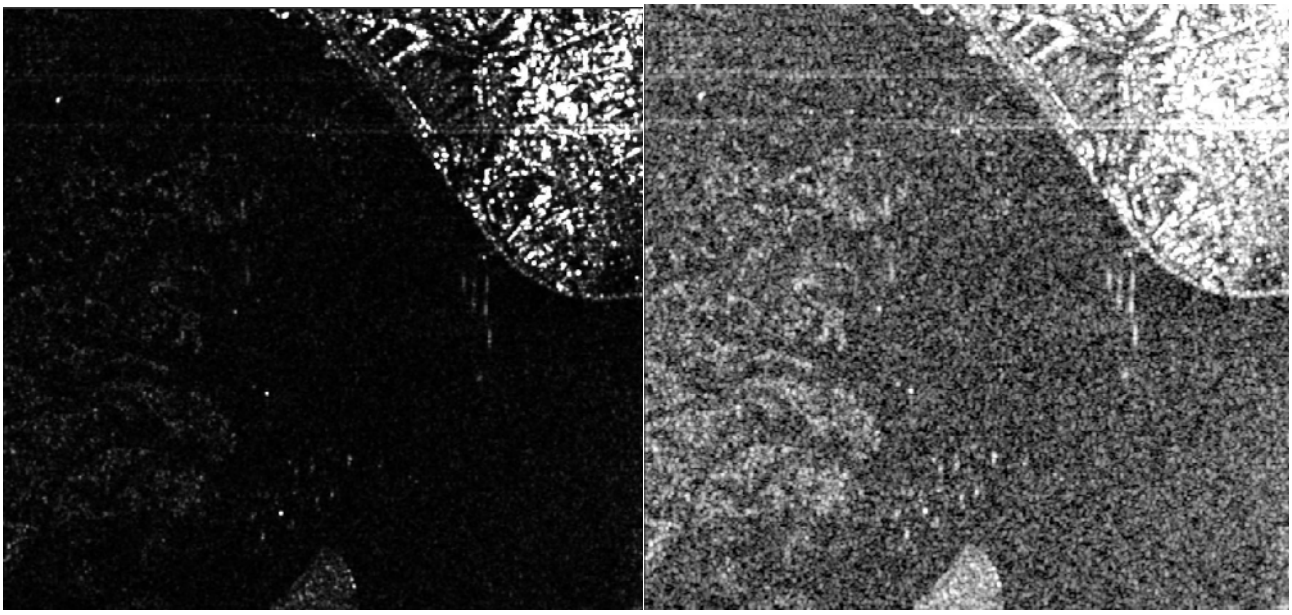

Figure 83 – TerraSAR-Stripmap 21Dec.2009 - On the left, the Sigma Naught (σ°) (intensity) and on the right, the Sigma Naught (σ°) (dB).

Figure 84 illustrates the Radar Brightness (Beta Naught (β°)), and the radiometric normalisation (Gamma Naught (γ°)) of the Radarsat2- Ultrafine image (21Dec.2009) expressed in dB.

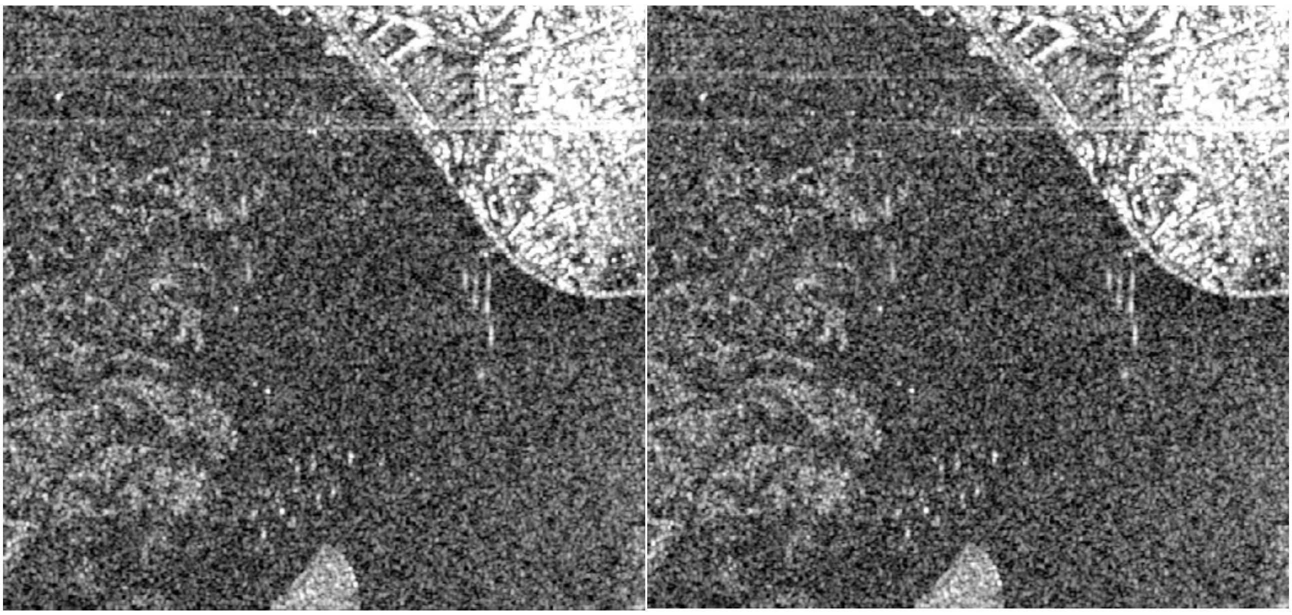

Figure 84– TerraSAR-X-Stripmap 21Dec.2009 - On the left, the Beta Naught (β°) and on the right, the Gamma Naught (γ°) (dB).

Figure 85 shows the Sigma Naught (σ°) in dB after colour manipulation and the histogram of the Sigma Naught (σ°) image.

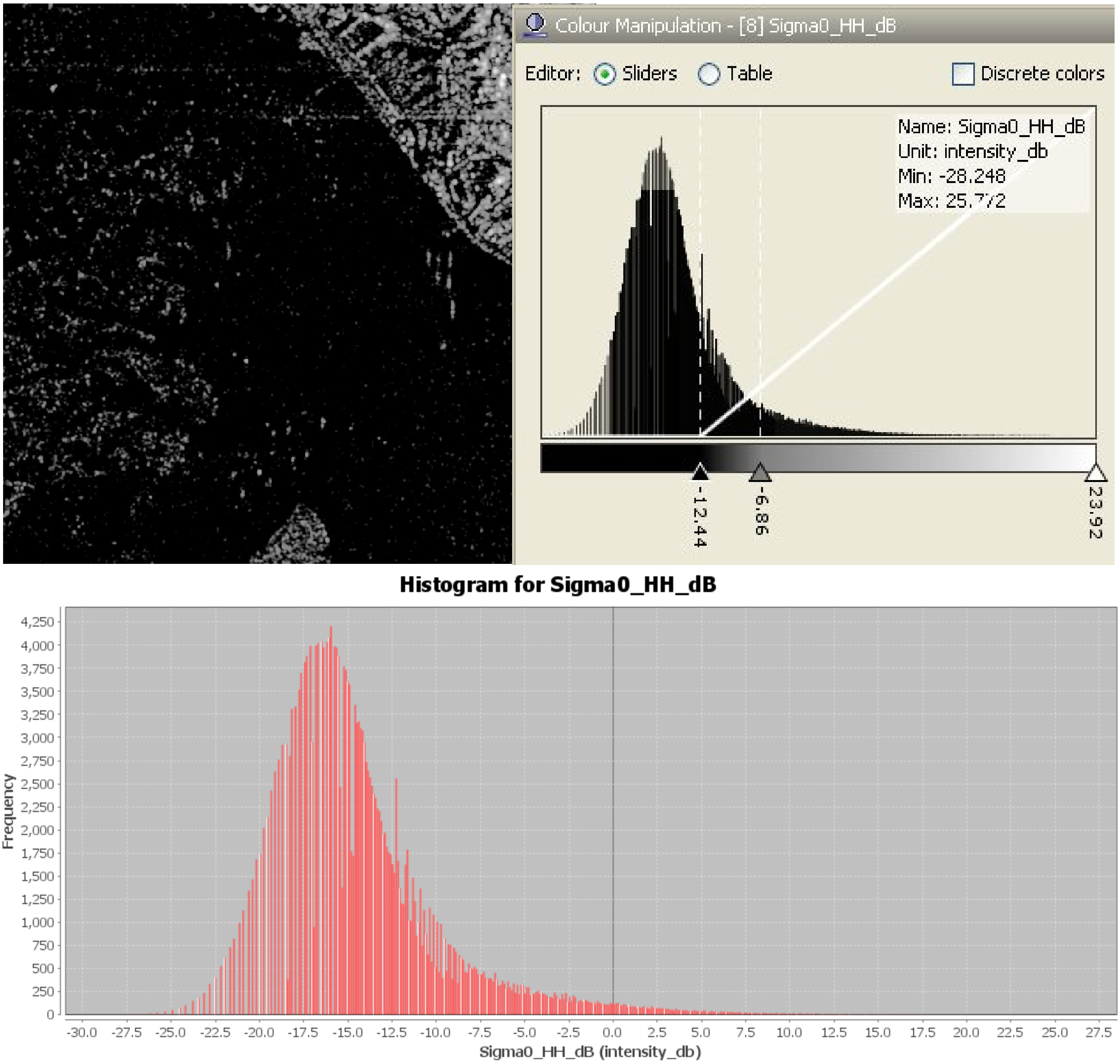

Figure 85 – TerraSAR-X-Stripmap 21Dec.2009 - On the top left the Sigma Naught (σ°) after colour manipulation to enhance the targets and on the top right, the corresponding histogram. On the bottom, the histogram of the image.

Table 6 gives the statistics of the Sigma Naught (σ°) TerraSAR-X-Stripmap image (21Dec.2009). The Sigma Naught (σ°) range from -28.2 dB up to 25.7 dB. The Mean value is -13.9 dB, the Median is -14.9 dB and the standard deviation is 4.8 dB.

Table 6– Statistics of the TerraSAR-X- Stripmap image 21Dec.2009 (06:38h)

Statistics	Values	Unit
Only ROI-Mask pixels considered:	No	
Number of pixels total:	239875	
Number of considered pixels:	239875	
Ratio of considered pixels:	100.0 %	
Minimum:	-28.24794578552246	intensity_db
Maximum:	25.77244758605957	intensity_db
Mean:	-13.998393852971347	intensity_db
Median:	-14.905907500285089	intensity_db
Std-Dev:	4.837982556388935	intensity_db
Coefficient of Variation:	-0.34560911221767954	intensity_db

Checking the radar backscattering coefficient of the targets (small boats) detected in Figure 85, we get values ranging from -7.8 dB up to 2.2 dB. The analysis of the Sigma Naught values (σ°) of the targets and the area around the targets shows a significant contrast.

6.1.5 – TerraSAR-X-Stripmap,22Dec.2009(18:31h), Alvor-Algarve

Figure 86 illustrates the Amplitude and Intensity bands of the TerraSAR-X-Stripmap image (22Dec.2009).

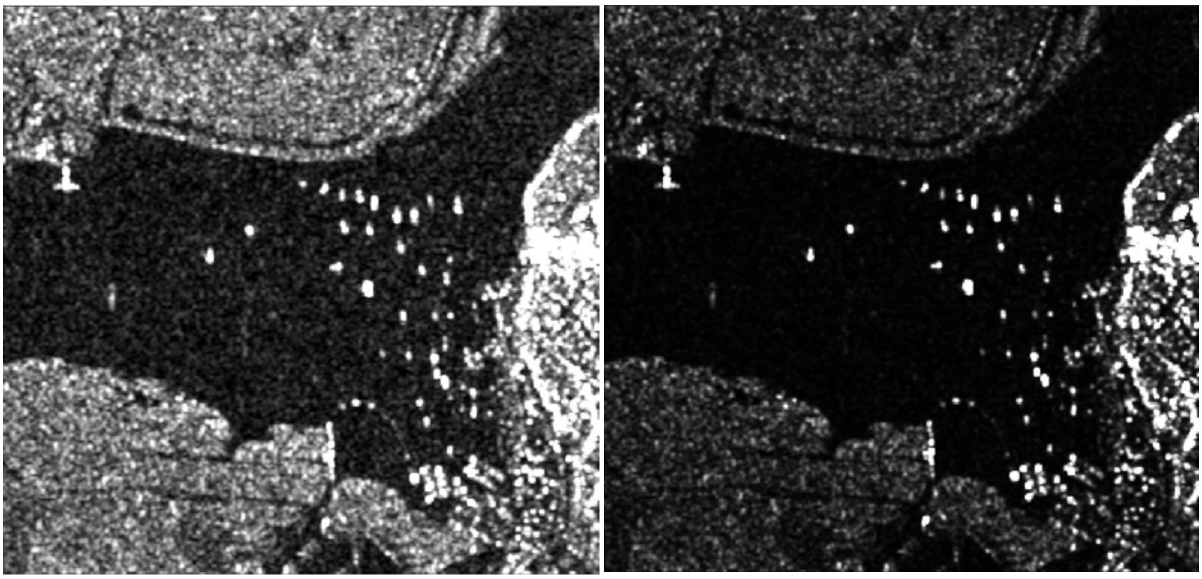

Figure 86 – TerraSAR-X-Stripmap 22Dec.2009 - On the left, the Amplitude band. On the right the Intensity band.

Figure 87 illustrates the Sigma Naught Coefficient of the TerraSAR-X-Stripmap image (22Dec.2009) expressed in terms of intensity and decibel (dB).

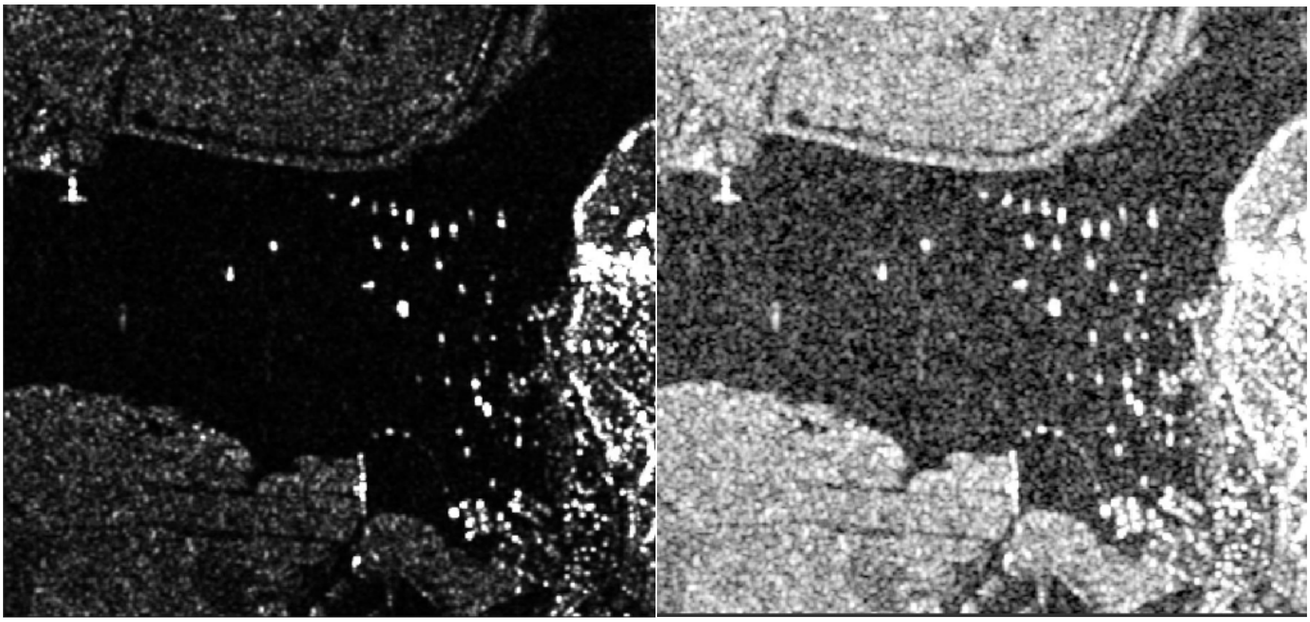

Figure 87 – TerraSAR-Stripmap 22Dec.2009 - On the left, the Sigma Naught (σ°) (intensity) and on the right, the Sigma Naught (σ°) (dB).

Figure 88 illustrates the Radar Brightness (Beta Naught (β°)), and the radiometric normalisation (Gamma Naught (γ°)) of the Radarsat2- Ultrafine image (21Dec.2009) expressed in dB.

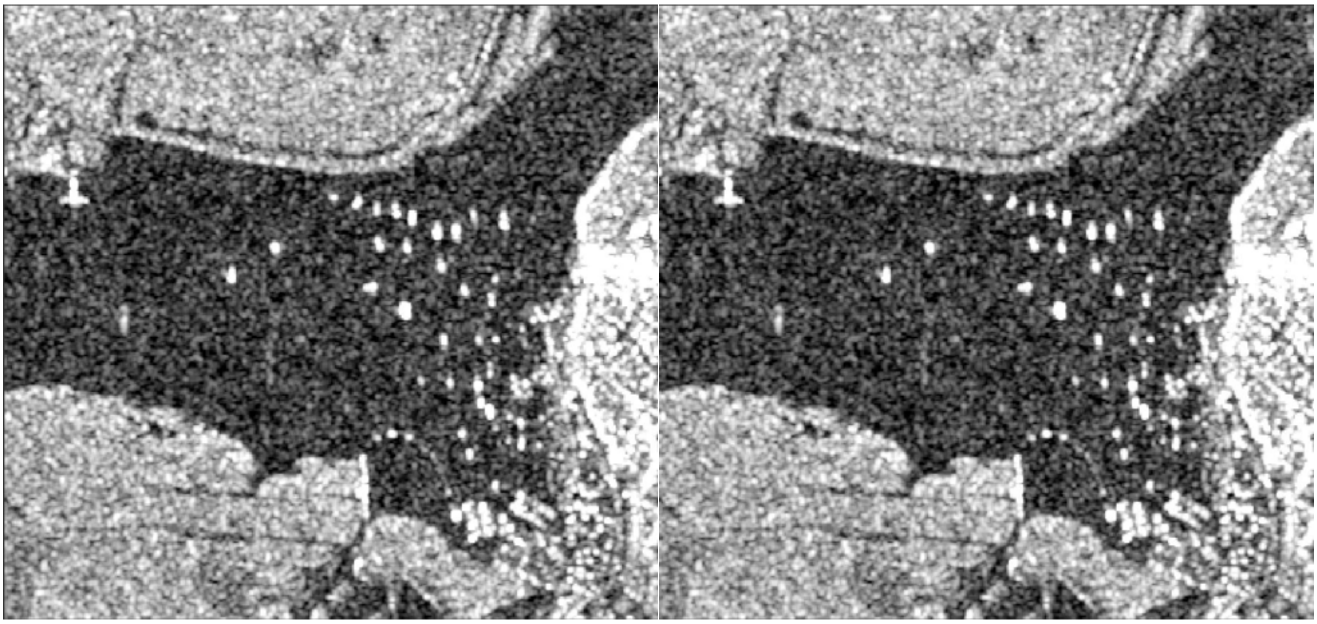

Figure 88 – TerraSAR-X-Stripmap 22Dec.2009 - On the left, the Beta Naught (β°) and on the right, the Gamma Naught (γ°) (dB).

Figure 89 shows the Sigma Naught (σ°) in dB after colour manipulation and the histogram of the Sigma Naught (σ°) image.

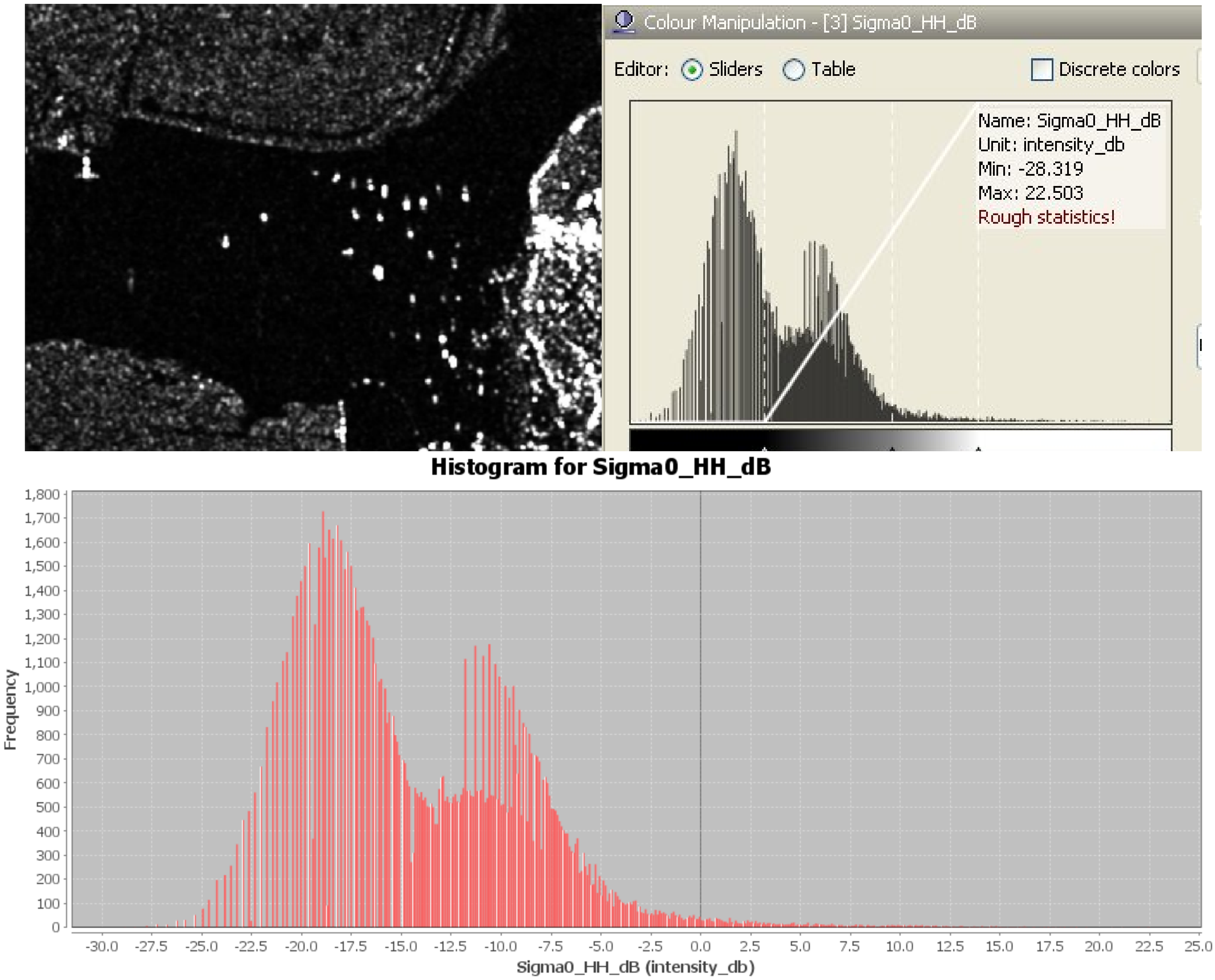

Figure 89 – TerraSAR-X-Stripmap 22Dec.2009 - On the top left the Sigma Naught (σ°) after colour manipulation to enhance the targets and on the top right, the corresponding histogram. On the bottom, the histogram of the image.

Table 7 gives the statistics of the Sigma Naught (σ°) TerraSAR-X-Stripmap image (22Dec.2009). The Sigma Naught (σ°) range from -28.9 dB up to 22.5 dB. The Mean value is -13.6 dB, the Median is -14.1 dB and the standard deviation is 5.5 dB.

Table 7– Statistics of the TerraSAR-X-Stripmap image 22Dec.2009 (18:31h)

Statistics	Values	Unit
Only ROI-Mask pixels considered:	No	
Number of pixels total:	111780	
Number of considered pixels:	111780	
Ratio of considered pixels:	100.0 %	
Minimum:	-28.916440963745117	intensity_db
Maximum:	22.50277328491211	intensity_db
Mean:	-13.626439732212658	intensity_db
Median:	-14.153502497822046	intensity_db
Std-Dev:	5.555574795420939	intensity_db
Coefficient of Variation:	-0.40770370353947594	intensity_db

Checking the radar backscattering coefficient of the targets (small boats) detected in Figure 89, we get values ranging from -6.5 dB up to 14.5 dB. The analysis of the Sigma Naught values (σ°) of the targets and the area around the targets shows a significant contrast.

6.1.6 – Radarsat2-Ultrafine,23Dec.2009(06:22h), Tavira-Algarve

Figure 90 illustrates the Amplitude and Intensity bands of the Radarsat2-Ultrafine image (23Dec.2009).

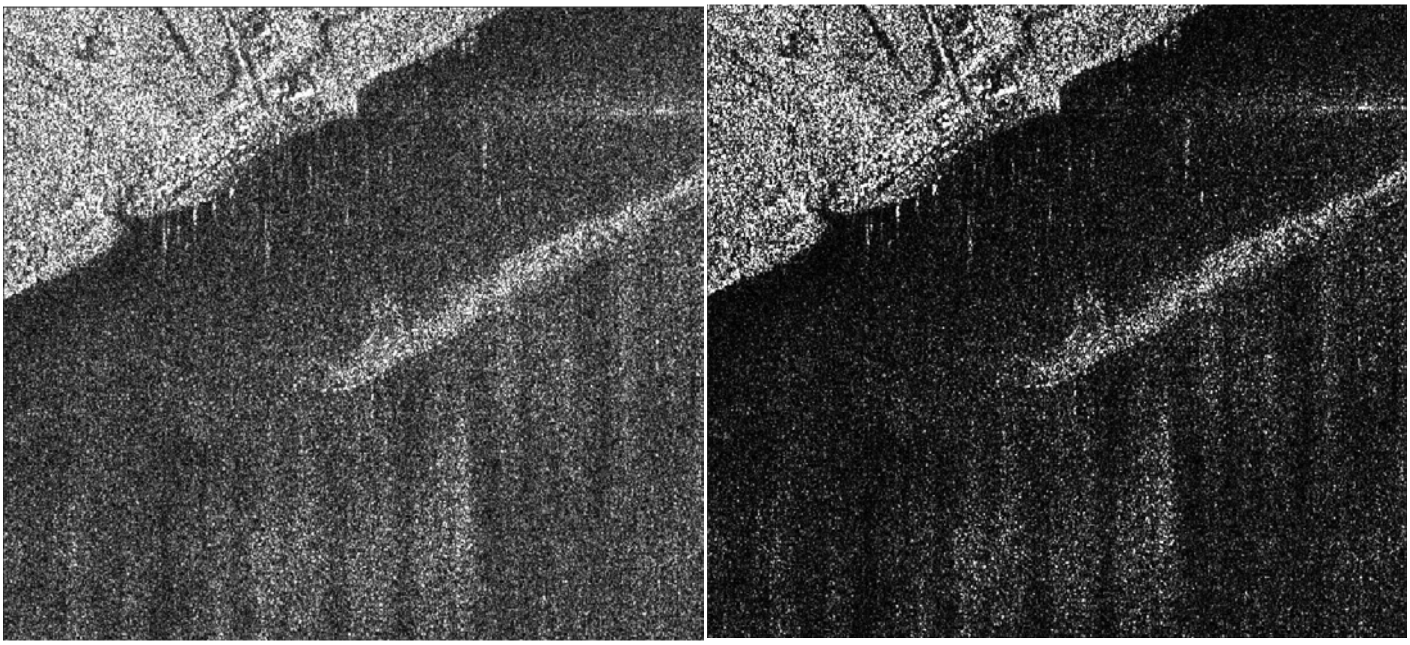

Figure 90 – RAdarsat2-Ultrafine 23Dec.2009 - On the left, the Amplitude band. On the right the Intensity band.

Figure 91 illustrates the Sigma Naught Coefficient of the Radarsat2- Ultrafine image (23Dec.2009) expressed in terms of intensity and decibel (dB).

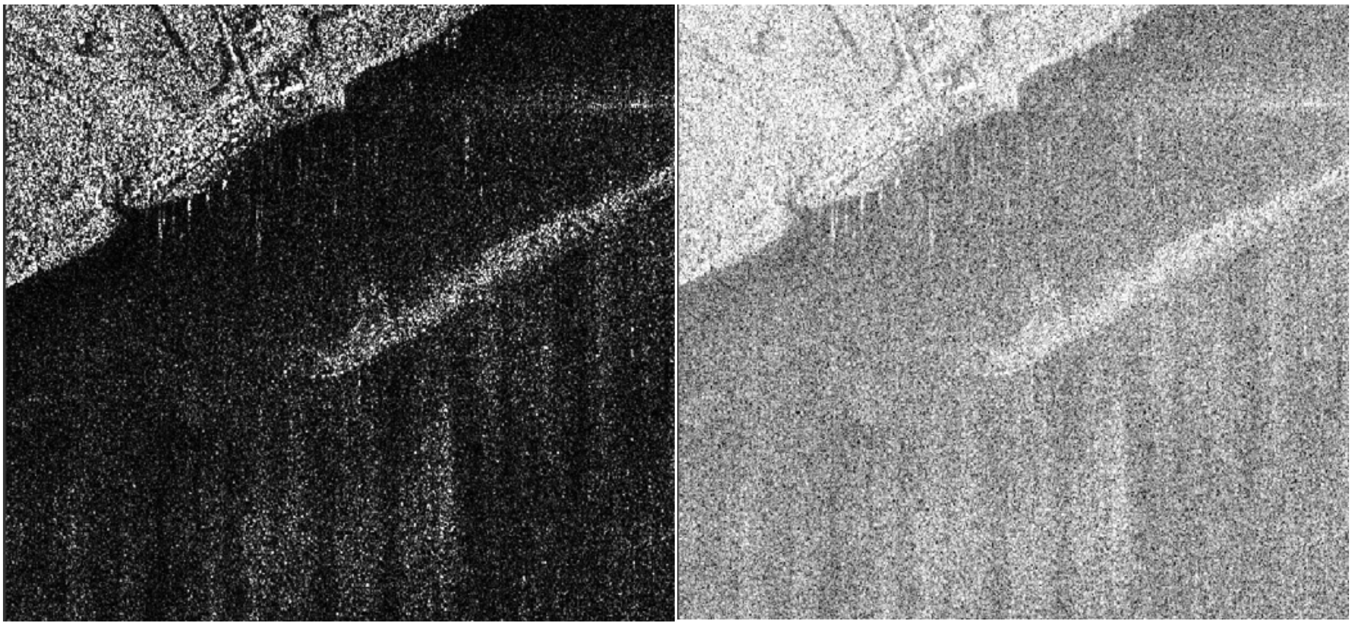

Figure 91–Radarsat2-Ultrafince 23Dec.2009 - On the left, the Sigma Naught (σ°) (intensity) and on the right, the Sigma Naught (σ°) (dB).

Figure 92 illustrates the Radar Brightness (Beta Naught (β°)), and the radiometric normalisation (Gamma Naught (γ°)) of the Radarsat2- Ultrafine image (21Dec.2009) expressed in dB.

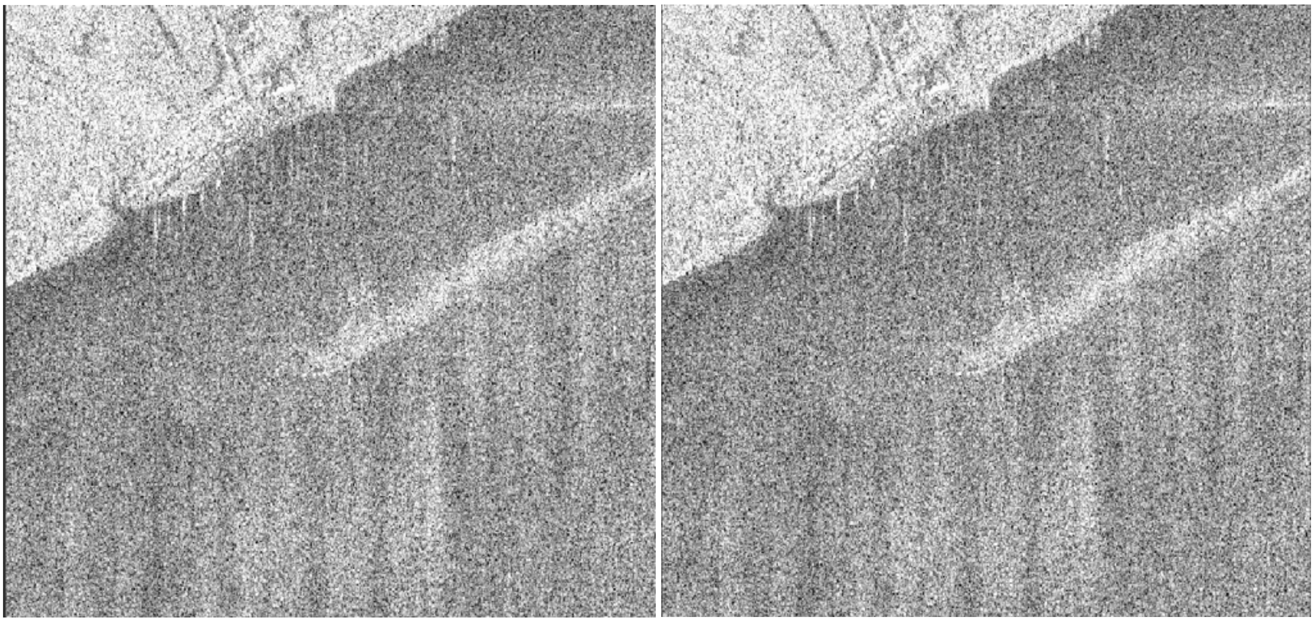

Figure 92 – RadarSAt2-Ultrafine 23Dec.2009 - On the left, the Beta Naught (β°) and on the right, the Gamma Naught (γ°) (dB).

Figure 93 shows the Sigma Naught (σ°) in dB after colour manipulation and the histogram of the Sigma Naught (σ°) image.

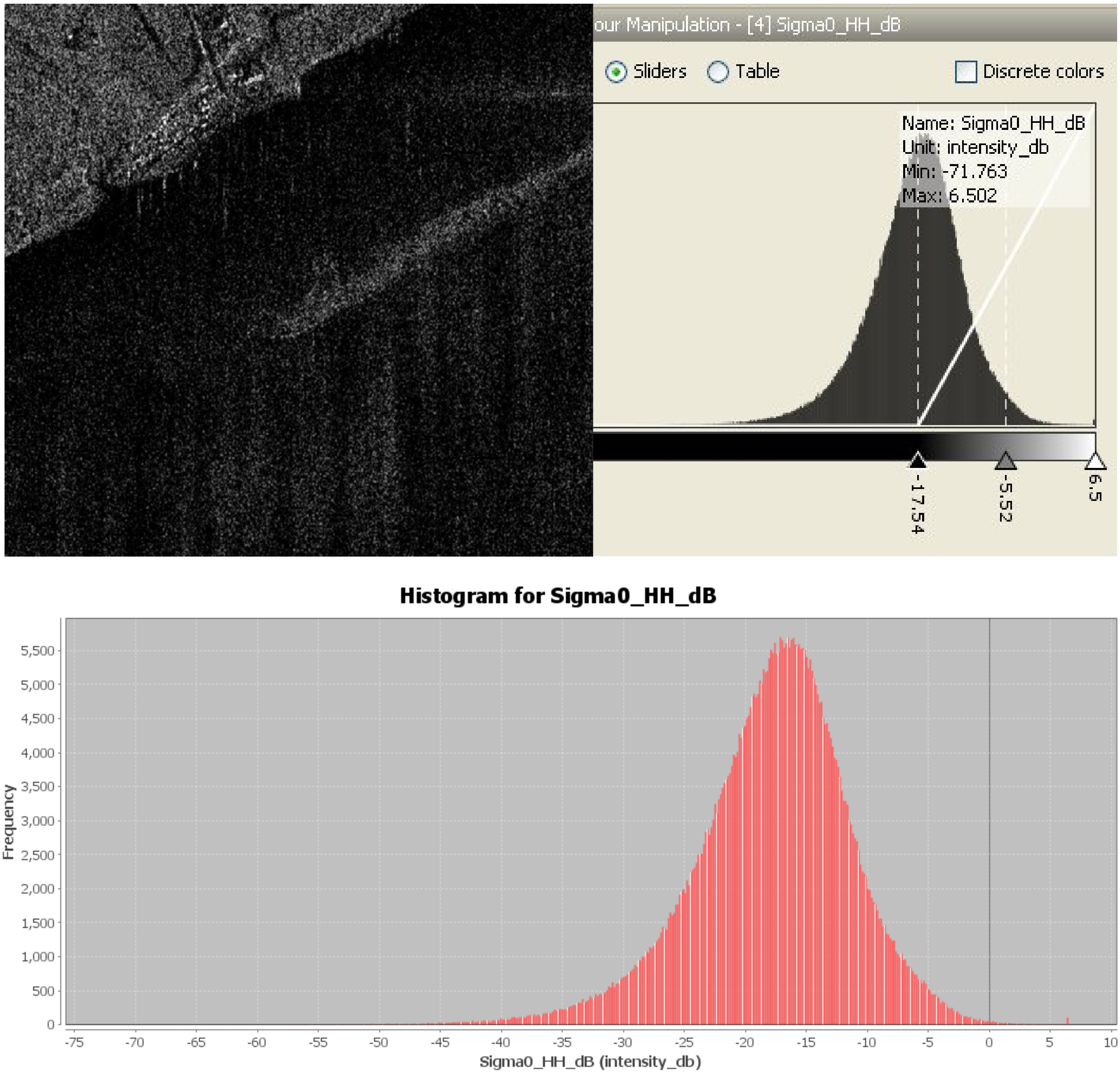

Figure 93 – Radarsat2 –Ultrafine 23Dec.2009 - On the top left the Sigma Naught (σ°) after colour manipulation to enhance the targets and on the top right, the corresponding histogram. On the bottom, the histogram of the image.

Table 8 gives the statistics of the Sigma Naught (σ°) Radarsat2- Ultrafine image (21Dec.2009). The Sigma Naught (σ°) range from -71.8 dB up to 6.5 dB. The Mean value is -17.8 dB, the Median is -17.2 dB and the standard deviation is 6.4 dB.

Table 8– Statistics of the Radarsat2- Ultrafine image 23Dec.2009 (18:22h)

Statistics	Values	Unit
Only ROI-Mask pixels considered:	No	
Number of pixels total:	506503	
Number of considered pixels:	506503	
Ratio of considered pixels:	100.0 %	
Minimum:	-71.76331329345703	intensity_db
Maximum:	6.501696586608887	intensity_db
Mean:	-17.801960942314274	intensity_db
Median:	-17.28791372778135	intensity_db
Std-Dev:	6.405616448135778	intensity_db
Coefficient of Variation:	-0.35982609699681883	intensity_db

Checking the radar backscattering coefficient of the targets (small boats) detected in Figure 77, we get values ranging from -2.6 dB up to 9.6 dB. The analysis of the Sigma Naught values (σ°) of the targets and the area around the targets shows a significant contrast.

6.2 – Small Boat Detection in SAR Satellite Imagery

This spaceborne SAR Small Boat detection experiment 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), in particular on inland sea waters.
- To try 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.

Using spaceborne SAR for small boat detection is a challenging task because it is a complex problem, which involves several variables, such as the sea state, the wind speed, the incidence angle, the resolution, the image mode, the bands used, the type and shape of boat, etc.

The results of this small boat detection experiment on inland sea waters show that under suitable conditions it is possible to detect small boats on inland sea waters using spaceborne SAR images. In all six spaceborne SAR images acquired during this experiment it was possible to detect small boats on inland sea waters. However, several difficulties were identified, namely:

1.- It is difficult to estimate the probability of detection. In order to be able to estimate an improved empirical probability of detection, a significant number of experiments under different conditions (e.g. sea state, wind speed, weather, etc.) are required.

2.- The sea state and wind speed play a very important role in spaceborne SAR small boat detection. The difference between the SAR images acquired on 23 Dec. 2009 with a relatively high sea state and wind speed compared to the images acquired in all previous days is clear. In order to quantify the correlation between the sea state and wind speed with the probability of detection a significant number of experiments under different conditions and scenarios is needed.

6.3 – Characterisation of SAR Satellite Small Boat Signatures

The characterisation of the SAR signatures of small boats as a function of boat shape, size or material is a very challenging task. The characteristics of the SAR signatures depend on a large number of variables, such as the size, shape, material, incidence angle, sea state, wind speed, etc.. Most of these variables are random. Possibly, only a very large number of experiments under different conditions would allow the identification of a possible statistical correlation between all or some of the variables involved, if such correlation exists.

De-correlation effects due to long acquisition time of the SAR satellite imagery have been identified in virtually in all spaceborne SAR images acquired during the experiment. For instance, analysing the Radarsat2/Spotlight image acquired over Tavira (Santa Luzia) on 18 Dec. 2009 by 18:24h, illustrated in Figures 25 to 32, we can see several targets blurred due to the long integration time. The same blurring effect can be seen analysing the Radarsat2/Spotlight image acquired over Alvor on 19 Dec. 2009, by 06:39h, presented in Figures 34 to 40. Analysing the next three images, namely the Radarsat2/Ultrafine (21-Dec.-2009, 18:36, over Faro), TerraSAR-X/Stripmap (21-Dec.-2009, 06:38, over Faro), TerraSAR-X/Stripmap (22-Dec.-2009, 18:31, over Alvor), the same effect can also be seen. But it is less evident due to the lower resolution of these three spaceborne SAR images.

A particular case is the last SAR image, Radarsat2/Ultrafine (23-Dec.-2009, 06:22) acquired over Tavira (Cacela Velha) and illustrated in Fig. 65. In this case, the blurring effect is more evident due to a rougher sea state and higher wind speed. Instead of focused targets the boat’s SAR signatures are short stripes.

6.4 – Limitations of current State-of-the-Art SAR Satellite technology

The main limitations of current State-of-the-Art SAR Satellite technology are relatively well known. The main limitations include:

1.- Large image integration times, which leads to blur of the targets. This is especially important for small boats because when compared to bigger targets they are less stable for the same sea state.

2.- Low repeat cycle. Spaceborne SAR platforms are not readily available. There is a limited number of SAR satellites in orbit. Hence, spaceborne SAR images are only available in limited windows in time.

3.- Inadequate resolution/swath. The high resolution images (e.g. Spotlight and Ultrafine or Stripmap) have relatively small swaths, which are not suitable for maritime surveillance of wide areas.

7. – Plans for Future Work

Based on the several spaceborne SAR experiments aimed at small boat detection carried out by JRC thus far [1], no final conclusions can be drawn. The detection of small boats using SAR satellites is a complex problem, which involves several variables, such as the sea state, the wind speed, the incidence angle, the resolution, the image mode, the bands used, the type and shape of boat, etc. A comprehensive assessment of the feasibility of using spaceborne SAR for small boat detection requires a significant number of experiments using different types of images (e.g., different satellite images on different bands/modes, with several incidence angles, acquired under different scenarios (e.g. different sea states, wind speeds, etc.).

Another important line of research is the correlation between the different variables involved in the spaceborne SAR detection of small boats, namely the role of the sea state, wind speed, boat shape and material, incidence angle, image mode, etc. Equally important is the improvement of the Ground Truth data.

Acknowledgements

– The authors would like to thank the EC-JRC for funding the present SAR Satellite Small Boat Detection Campaign. They also would like to express their gratitude to Dario Tarchi for reviewing the present scientific report and for his comments and suggestions.

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European Commission

EUR 24945 EN – Joint Research Centre – Institute for the Protection and Security of the Citizen
Title: **JRC - SAR Satellite Small Boat Detection Campaign – Algarve - Portugal**
Author(s): Victor M.G. Silva & Harm Greidanus
Luxembourg: Publications Office of the European Union
2011 – 97 pp. – 21 x 29.7 cm
EUR – Scientific and Technical Research series – ISSN **1831-9424 (online), 1018-5593 (print)**
ISBN **978-92-79-21265-9**
doi:**10.2788/717**

Abstract

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. Since 2008 the EC-JRC has carried out a number of SAR Small Boat detection experiments to assess the feasibility of using Spaceborne SAR for Small Boat detection. This report presents the results and conclusions of the Spaceborne SAR Small Boat detection campaign in inland sea waters carried out by the EC-JRC in the Algarve-Portugal in December 2009.

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LB-NA-24945-EN-N

JRC
EUROPEAN COMMISSION

Publications Office

ISBN 978-92-79-21265-9

9 789279 212659