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JRC – Elbit Systems Coupled UAS and Spaceborne SAR Campaign in Israel

Results of the coupled UAS & Spaceborne SAR Small Boat Detection campaign carried out by the EC-JRC and Elbit Systems in Haifa-Israel in December 2010

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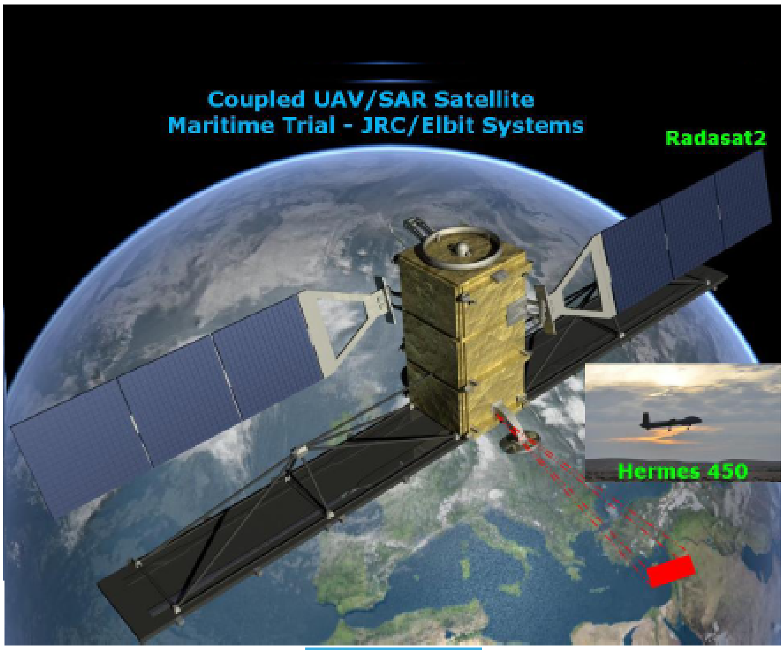
2012



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EXECUTIVE SUMMARY

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 assess emerging technologies to improve maritime surveillance, in particular the capability of detecting small boats. 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 coupled UAS and spaceborne SAR small boat detection campaign on open sea waters carried out by the EC-JRC in Haifa, Israel in collaboration with Elbit Systems on 8 Dec. 2010.

The results of this coupled UAS/Spaceborne SAR small boat detection experiment show the potential of UAS for maritime surveillance and that small boat detection in spaceborne SAR is possible under suitable conditions of sea state, wind speed and incidence angle. In fact, the experiment highlights how a UAS can fill in the maritime surveillance gap between ship-borne and land-based surveillance assets and spaceborne SAR. For instance, spaceborne SAR allows small boat detection under suitable sea and wind conditions. However, it neither allows classification nor identification of small boats. A UAS besides detection also allows classification and identification. Hence, since most unlawful activities in the maritime domain, such as illegal immigration, drugs trafficking, smuggling, terrorism and piracy involve small boats the potential of UAS for maritime surveillance is very high. However, Before UAS can be routinely used for maritime surveillance in non-segregated airspace, a significant number of key issues related to critical UAS systems have to be addressed, namely command and control issues, telecommunications (e.g. change over from Line of Sight (LOS) to Beyond Line of Sight (BLOS) Satcom), hand over of Air Traffic Control (ATC) between military and civil, collision avoidance systems, cross-border issues, flight plan modifications, contingency procedures, legal framework and regulations, etc.. Other interesting lines of research are UAS formation flying issues, patterns for optimal surveillance, onboard data fusion, full autonomy and endurance and altitude issues.

1. – Introduction

1.1 – Scope

This report presents the key findings of the coupled UAS and Spaceborne SAR Small Boat Detection Campaign, led by the EC-JRC and conducted jointly with Elbit Systems in Haifa, Israel in December 2010.

This study addresses the potential of Unmanned Aerial Systems (UAS) for maritime surveillance and the feasibility of using UAS as a complementary technology on an operational basis.

To answer this statement of work, a multinational cross-disciplinary consortium with research and operational expertise in maritime surveillance and Unmanned Aerial Systems (UAS) was assembled with organisations involved in:

1.- research in maritime surveillance using Spaceborne SAR imagery and in the processing and analysis of SAR imagery, as well as coordination and management of maritime surveillance campaigns (European Commission-JRC).
2.- experience with Unmanned Aerial Systems (UAS) campaigns (Elbit Systems).

1.2 – Main Objectives

The work was performed with the following main objectives:

- To acquire hands-on experience with UAS technologies, in particular with its possible applications to maritime surveillance.
- To assess the potential of UAS for maritime surveillance, including small boat detection, illegal immigration and drugs trafficking mitigation.
- To study the feasibility of using UAS as a complementary maritime surveillance technology on an operational basis together with currently used technologies.
- To identify the main limiting factors preventing the use of UAS in non segregated airspace and enabling factors that could help to facilitate the operational use of UAS for maritime surveillance.

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 Unmanned Aerial Systems (UAS) on an operational basis as a complementary maritime surveillance technology to currently used maritime surveillance assets, such as spaceborne SAR, coastal radars, ship-borne radars, etc.

2. – Research Method

In order to find out the potential and feasibility of using Unmanned Aerial Systems (UAS) for maritime surveillance, including small boat detection, a controlled experiment on open sea and along the coast was designed, set up and executed. The controlled experiment is briefly described next.

The controlled experiment consisted of a UAS (Hermes 450W from Elbit Systems) flight over the maritime area near the Port of Haifa in Israel at the approximate time of two SAR Satellite overpasses (Radarsat-2 and TerraSAR-X). The Hermes 450 took-off from Haifa in Israel and flew to the area of the experiment.

The experiment was comprised two phases, namely:

1.) the Coupled UAS/Spaceborne SAR Small Boat detection and
2.) the CONUSE and CONOPS phase.

These two phases are described next.

2.1 – Coupled UAS/Spaceborne SAR Small Boat Detection

One of the main objectives of this controlled experiment was to find out the potential of using UAS for maritime surveillance, in particular to find out if a UAS could fill in the gap between ship borne/land based maritime surveillance and spaceborne maritime surveillance, in particular the capability of detecting small targets. To that end, one small boat was deployed on open sea waters a couple of nautical miles southwest of the Port of Haifa. The UAS capabilities were then tested. The tests comprised flying over the above mentioned area and the detection, tracking and classification of the small boat deployed.

2.2 – UAS CONUSE and CONOPS Controlled Experiment

Another objective of this controlled experiment was to find out the potential of using UAS for maritime surveillance, the rationale behind it being testing the capabilities of UAS to detect, classify and identify targets on land (e.g. small boats, piers, etc.). To that end, the UAS acquired images of targets of opportunity to test the UAS capabilities. The tests comprised flying over the above mentioned area and the detection, tracking and classification of targets of opportunity, as well as an attempt to detect other moving and stationary targets.

3. – Experiment Set Up

This section describes 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

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 nautical miles off the coast of Haifa. This site was selected because it is under the jurisdiction of the Israeli Air Force, which made the authorisation to fly easier to obtain and reduced the risk of accidents involving people since the area is closed to the public. For the same reason the tests along the coast also took place in the same area.

3.1.1 – Open Sea Waters Site near Haifa, Israel

The open sea/coastal waters site selected in Haifa near the port of Haifa, a few nautical miles off the coast, is illustrated in fig.1 in Green. The UAS flight plan and the Italian Airforce military airbase are also illustrated in fig.1.

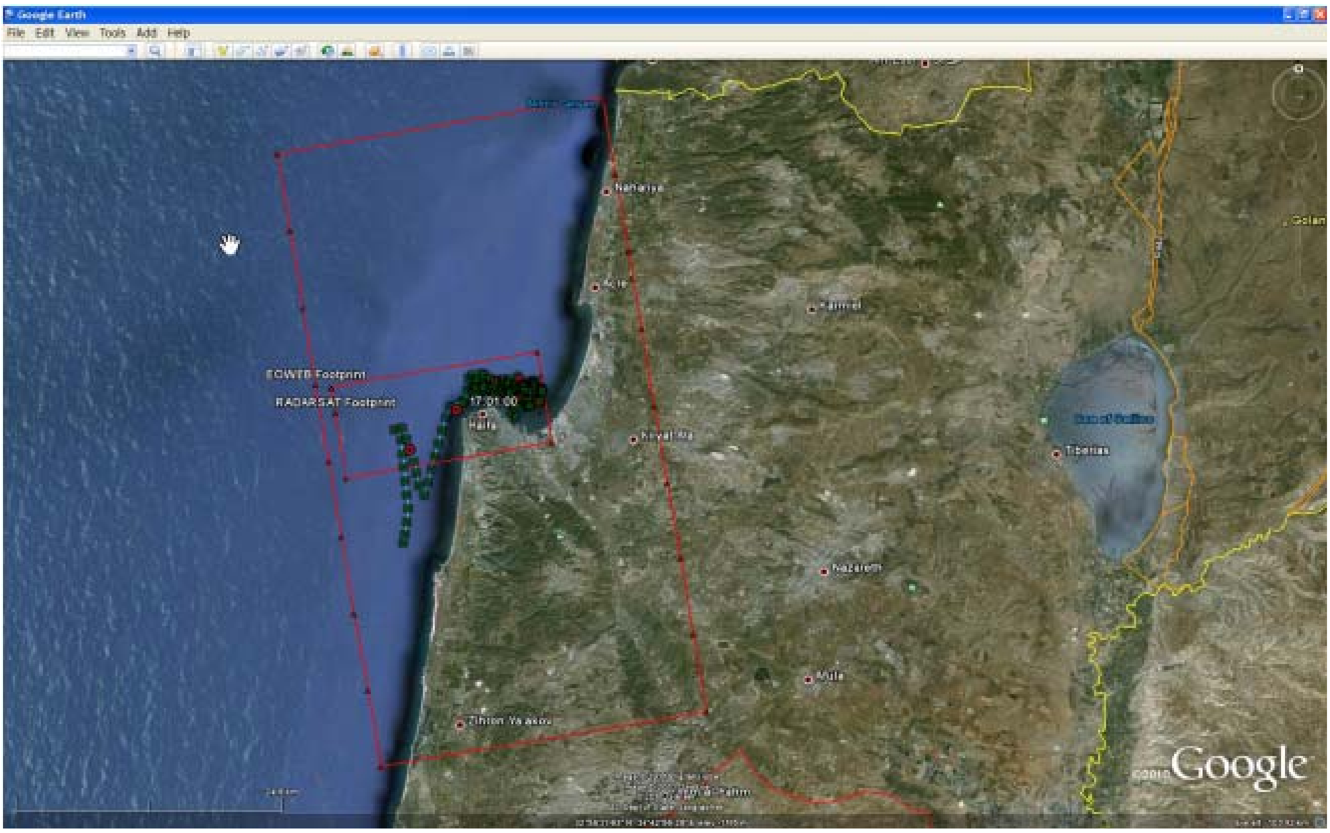

Figure 1 – Illustration of the site of the experiment in Haifa, Israel. The large rectangle in red is the footprint of the TerraSAR-X, Stripmap ordered to DLR. The small rectangle in red is the footprint of the Radarsat-2, Spotlight spaceborne SAR image ordered to MDA. Only the Radarsat-2 image was actually acquired. DLR was not able to acquire the TerraSAR-X image due to technical problems.

3.2 – SAR Satellite Imagery Planning

The Synthetic Aperture Radar (SAR) satellite imagery available at the time the planning was done comprised a Radarsat2 (Spotlight) and a TerraSAR-X (Stripmap). Figure 2 illustrates the TerraSAR-X, Stripmap SAR image footprint in red. The image was ordered to DLR, the German Aerospace Centre, but unfortunately, it was not possible to acquire it due to technical problems. Figure 3 illustrates the footprint of the Radarsart-2, Spotlight SAR image in red.

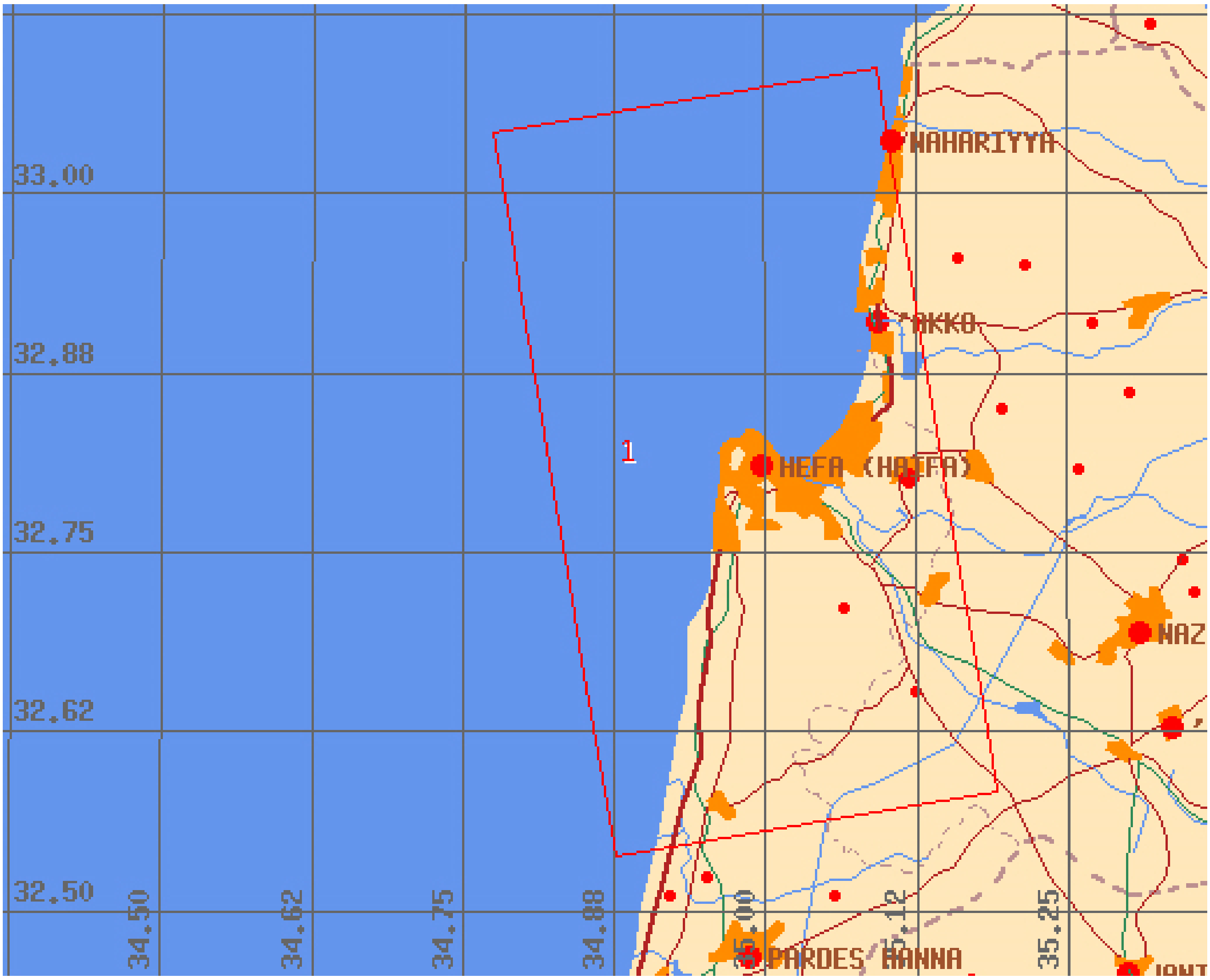

Figure 2 – The rectangle in red illustrates de footprint of the TerraSAR-X, Stripmap image ordered to DLR. Fortunately, due to technical problems DLR was not able to acquire this spaceborne SAR image. The approximate start date of acquisition was 2010-12-08T15:38:03.73.

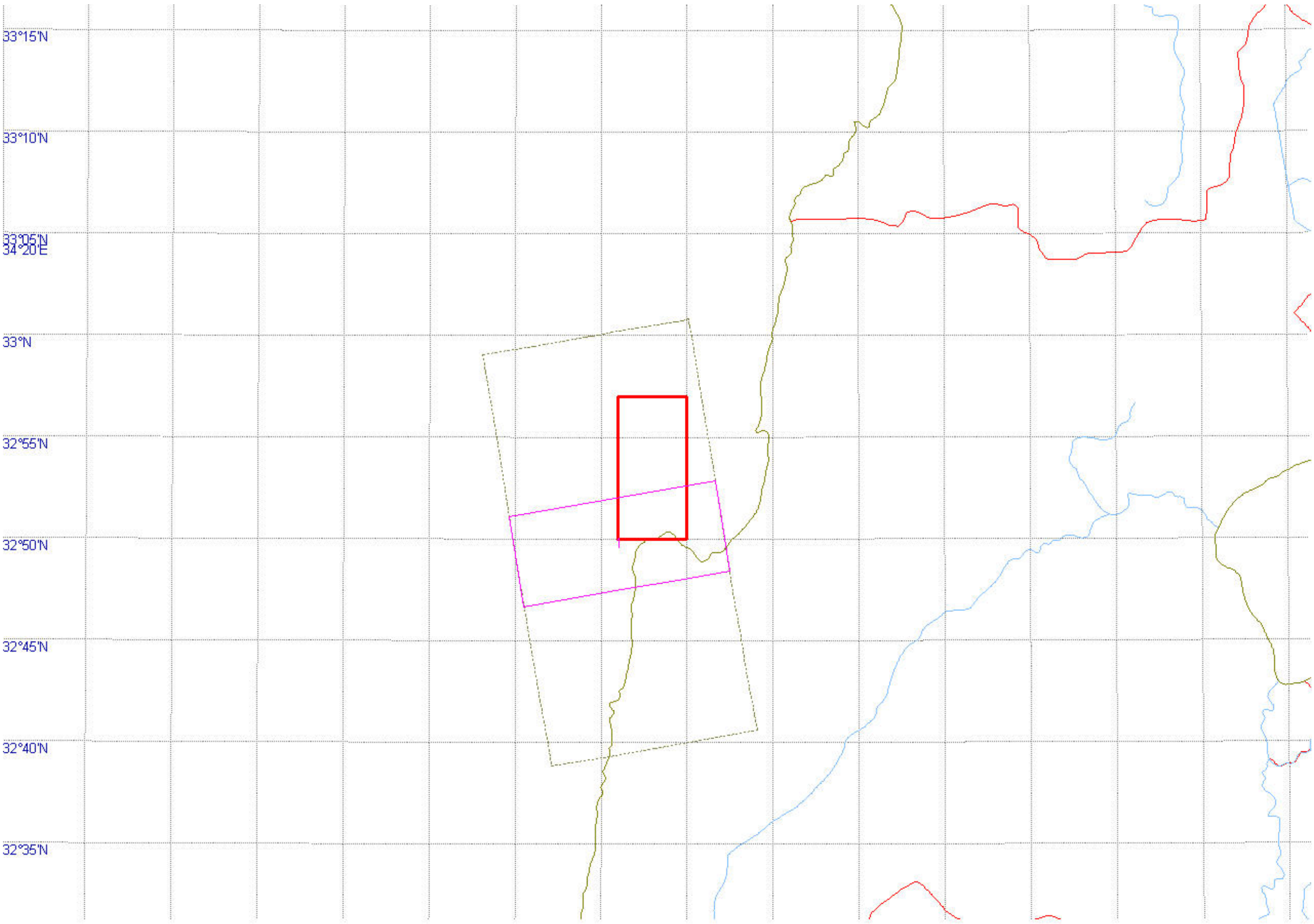

Figure 3 – The rectangle in pink illustrates de footprint of the Radarsat-2, Spotlight SAR image ordered to MDA. Fortunately, due to technical problems DLR was not able to acquire this spaceborne SAR image. The approximate start date of acquisition was 2010-12-08T15:47:40.00 UTC.

Table-1 illustrates the SAR satellite images and image modes used in the different days of the experiment.

Table 1– TerraSAR-X, Stripmap and Radarsat2- Spotlight High Resolution 08-Dec.-2010.

#	**Satellite**	**Evening Satellite Pass**
1	TerraSAR-X, Stripmap	2010-12-08T15:38:03.73 UTC
2	Radarsat-2, Spotlight	2010-12-08T15:47:40.00 UTC

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 ser 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).

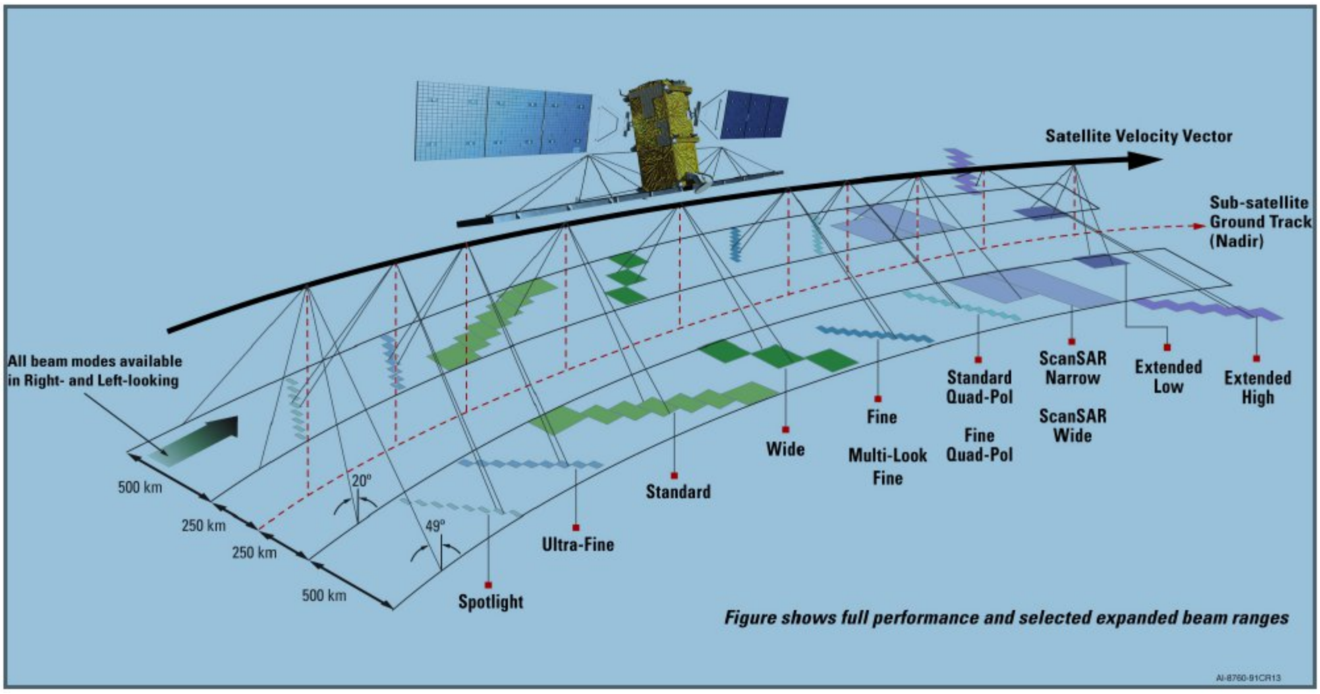

Figure 4 – Radarsart2 image modes. The Ultrafine and the Spotlight modes have been identified as the most suitable modes for this particular experiment.

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.

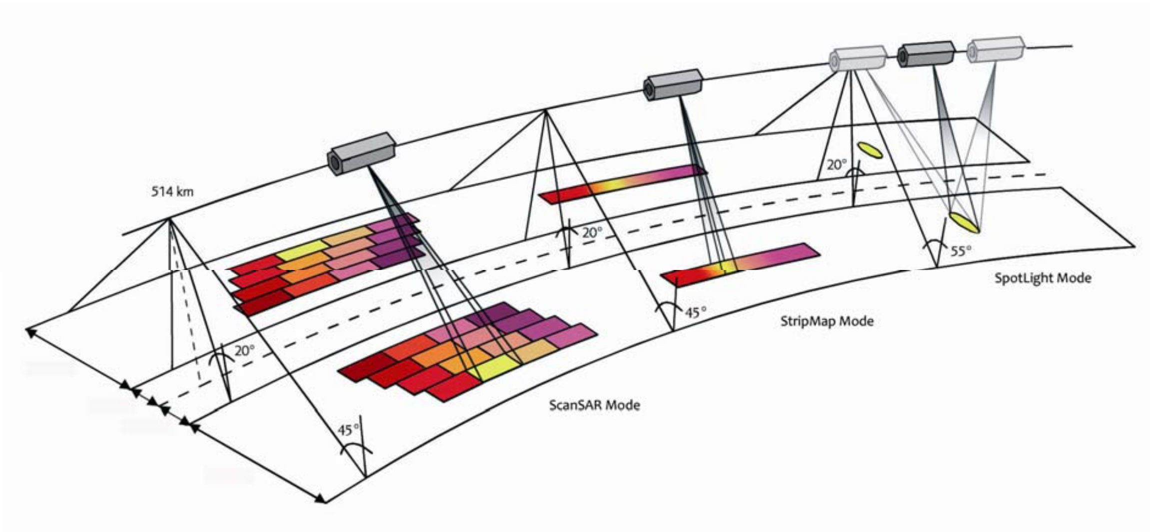

Figure 5 – Radarsart2 image modes. The Ultrafine and the Spotlight modes have been identified as the most suitable modes for this particular experiment.

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.

3.3 – Partners Involved and their Roles

The partners involved in this experiment comprised the European Commission (EC) – Joint Research Centre (JRC) and Elbit Systems from Haifa, Israel. The role of each partner is briefly described next.

3.3.1 - European Commission (EC) – Joint Research Centre (JRC)

– The main role of the EC-JRC was the planning, set up, execution and the analysis of the data together with Elbit Systems. 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 the conclusions of the experiment.

3.3.2 – Elbit Systems

– The main role of Elbit Systems comprised:

a.) the deployment and operation of the boat used as target.
b.) the deployment and operation of the UAS Hermes 450.
c.) the contacts with the Israeli authorities, namely the Israeli Air Force and Civil Aviation Authority.
d.) the collection of ground truth data.
e.) The analysis of the data and conclusions of the experiment.

4. – Experiment Execution

4.1 – Modus Operandi

The modus operandi of the trial was as follows:

1.- JRC supplied Elbit Systems with the footprint (frame) of the spaceborne SAR images to be acquired (TerraSAR-X-Stripmap and Radarsat-2, Spotlight), as well as the time of the SAR satellite passes.

2.- The boat was deployed about 2 nautical miles Southwest of the Port of Haifa. The boat was about 12-meter long. The boat had a crew of 3 people plus one JRC staff.

3.- The boat left from the port of Haifa and travelled a couple of nautical miles to reach the test site. Once the test site was reached the boat was stationary at the time of the satellite SAR overpass. After the satellite overpasses the boat was steered at different speeds to test the tracking capabilities of the UAV.

4.2 – Ground Truth Data Collection

The ground truth data collected comprised:

a.) the sea state.
b.) Data from the UAS sensors.
b.) the weather conditions and wind speed.
e.) Photos and movies of the boats involved in the experiment.

4.3 – Means Involved in the Experiment

The means involved in the experiment comprised two satellite SAR images, namely a TerraSAR-X-Stripmap and a Radarsat-2, Spotlight and one 12-meter long boat.

4.3.1 – Boat Deployed During the Experiment

Figures 6 illustrate the boat deployed as target during the experiment.

Figure 6 – The 12-meter boat deployed during the experiment at the Port of Haifa, Israel.

4.3.2 – Hermes 450 – System Overview

The Hermes® UAV system is a mature and operationally proven system with accumulated experience with the Israel Defense Forces operations and with other users worldwide. It features a fully redundant architecture leading to a high level of safety and reliability, a high level of autonomy, modern, high performance state-of-the-art payloads and a small logistic footprint. Figure 7 shows the main elements of the Hermes UAV System.

4.3.3 – The Air Vehicle

Hermes® 450W is a modern UAV design featuring highly efficient aerodynamics, composite structure, and a high level of system redundancy and autonomy. Its compact size and high maximum/empty weight ratio enable very high mission effectiveness, delivering potent payloads, high endurance and a modest logistic footprint.

The Hermes® 450 is in production and has accumulated over 150,000 flight hours with the Israeli Air Force and other users around the globe. The Hermes® 450W uses the higher power delivered by the AR802W engine to achieve higher gross weight with the same platform, greatly increasing payload and fuel carrying capability, a shorter takeoff run and expanded flight envelope.

The AR802W engine is a derivative of the AR802 rotary engine, with widened rotor and housing. The result is a 30% gain in power to nearly 70HP. Coupled to an Electronic Fuel Injection system the engine is highly efficient and has improved maintenance figures.

Following is a summary of the physical characteristics of the Hermes 450W air vehicle is given in Table 2:

Table 2 – Summary of Hermes 450 main characteristics.

Physical Characteristics	
• Length	6.1 m
• Wingspan	10.5 m
• Fuselage diameter	0.508 mm
• Max. takeoff weight	550 kg
• Max. internal fuel weight (including oil)	115 kg
• Max. payload weight	150 kg

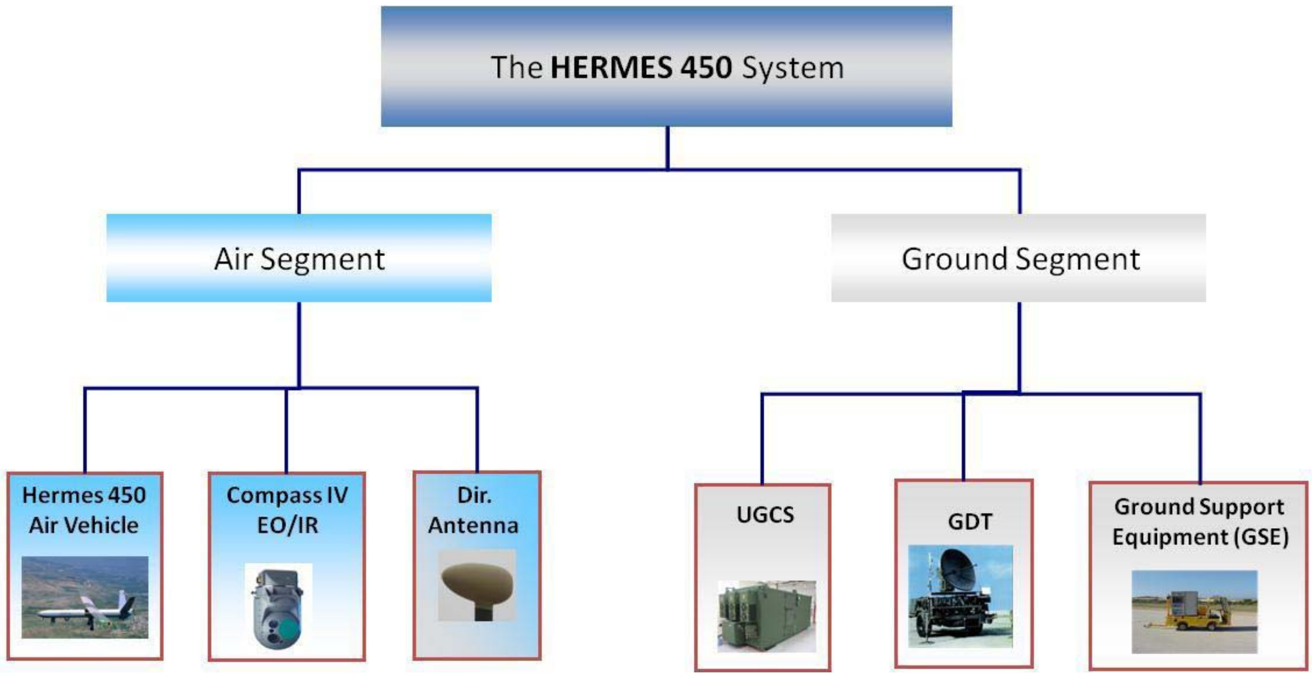

Figure 7 – Elements of the Hermes UAV System.

4.3.4 – Ground Control Station (GCS)

The GCS is a transportable system designed to perform and support all Hermes® UAV family ground Based activities operational activities. These activities include mission planning, pre-flight check, takeoff and landing, UAV flight control, mission control, payloads and systems control, as well as post-mission debriefing. An embedded or appended training capability is optional.

Remote communication of video and telemetry to a C4I center via SATCOM or WAN infrastructure is optional.

The GCS provides a user friendly, comfortable, effective, and protected environment for carrying out UAV missions.

The GCS is housed in a shelter with operator consoles of advanced human engineering design that provide an ergonomic operational environment. The shelter is based on the NATO ACE III shelter with a side door.

As Israel's leading C4I provider, Elbit Systems has incorporated Hermes® GCS advanced C4I capabilities including comprehensive mission planning, tactical database management and tactical coordination with supported forces and command elements.

The Hermes® GCS is uniquely capable of performing two UAV missions concurrently, with two UAVs, each of which is controlled via a separate Ground Datalink Terminal (GDT).

The Hermes® GCS requires minimal operating personnel, i.e., mission commander and mission operator.

Figure 8 – The UAS Hermes 450 Ground Control Station (GCS).

4.3.5 – The EO Payload

The CoMPASS, Compact Multi Purpose Advanced Stabilized System, is a day and night surveillance system that includes a 3rd generation 3-5 μm zoom FLIR camera, a color zoom TV CCD camera, and automatic tracking capabilities.

The CoMPASS enables the following:

- Day and night stabilized LOS observation with capabilities of target detection, recognition and identification in various weather conditions
- Automatic and manual tracking of targets
- Slaving CoMPASS Line of Sight (LOS) to external systems
- LOS information
- Target Laser designation&Ranging or only Target Laser Ranging
- Laser Target Marker

CoMPASS, the EO/IR system for UAV applications, is the most advanced payload version of the CoMPASS family, featuring reduced weight, high degree of modularity and flexibility, space-saving packaging and advanced operational and video processing features.

The CoMPASS based STA, Stabilized Turret Assembly, is a single LRU housing:

- 3rd generation 3-5 µm FLIR zoom Camera.
- Color Zoom TV CCD Camera
- Laser Target Designator
- Laser Target Marker
- Electronic Boards

Figure 9 – CoMPASS Stabilized Turret Assembly (STA).

5. – Preliminary Data Analysis

5.1 – SAR Satellite Imagery Processing

The high resolution spaceborne SAR image was analysed visually because the resolution is good enough to allow visual analysis and the site is too close to the coast, which makes automatic processing more difficult and prone to error due to artefacts caused by land targets.

The Hermes 450 images were also analysed visually.

5.2 – Ground Truth Data

This section briefly describes the Ground Truth data, namely the GPS positions of the boat deployed as target during the experiment, a photo of the boat, as well as other relevant ground truth data collected.

5.2.1 – GPS coordinates of the boat deployed

Table 5 gives the GPS coordinates of the boat deployed during the experiment at the time of the Radarsat-2 satellite overpass.

Table 3 – Ground Truth data collected at the time of the satellite pass (15:47:40 UTC=17:47:40 LT) on 8 December 2010.

Date: 8 Dec.2010 **Time:** 15:47:40 UTC=17:47:40 LT / **Pass:** Ascending		**Satellite/Mode:** Radarsat-2 / Spotlight **Polarisation :** HH	
Boats	**Type / Size**	**Latitude**	**Longitude**
Elbit's 12-meter Boat		32˚ 51.830" N 32°51'49.80"N 32.863833° N	34˚ 57.961" E 34°57'57.66"E 34.966017° E

5.2.1 – HERMES 450 Ground Truth Data

Table 4 shows the 12-meter Elbit´s Boat as detected by the IR sensor of the Hermes 450.

Table 4 – Hermes 450 Ground Truth Data.

Date: 8 Dec.2010 **Time:** 15:47:40 UTC=17:47:40 LT		**Platform:** Hermes 450	
UAV	**Type / Size**	**Latitude**	**Longitude**
UAV Hermes 450		17:47:30h 32.84489947 N 17:48:00h 32.85089687 N	17:47:30h 34.98564048 E 17:48:00h 34.99338667 E
Elbit's 12-meter Boat **UAV Image**		32˚ 51.830" N 32°51'49.80"N 32.863833° N	34˚ 57.961" E 34°57'57.66"E 34.966017° E

5.3 – Weather Conditions and Sea State

The weather conditions in Haifa are summarized in Table 5 bellow.

Table 5 – Wind speed, wind direction and Temperature.

Time (IST)	Temp.	Dew Point	Humidity	Pressure	Visibility	Wind Dir	Wind Speed	Gust Speed	Precip	Events	Conditions
5:50 PM	**21.0** °C	**13.0** °C	60%	**1017** hPa	-	North	**11.1** km/h / **3.1** m/s	-	N/A		Clear

Figure 10 gives the weather data (Temperature, Barometric Pressure, Wind Speed and Wind Direction) for Haifa, Israel on 8 Dec. 2010.

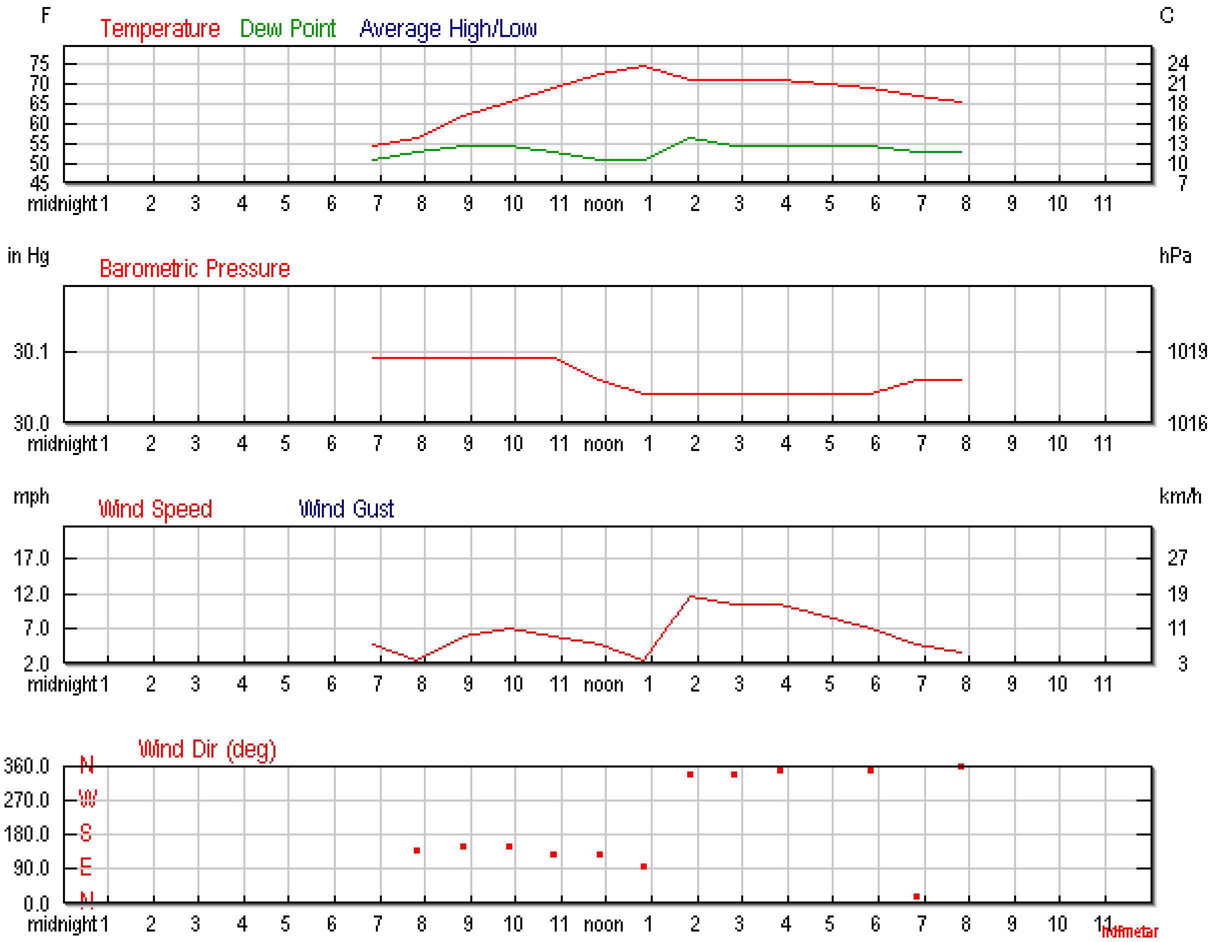

Figure 10 – Weather data (Temperature, Barometric Pressure, Wind Speed and Wind Direction) for Haifa, Israel on 8 Dec. 2010.

5.4 – Verification of the Results

This section briefly describes the verification of the targets detected in the spaceborne SAR image and in the Hermes 450 UAV using the ground truth data collected during the experiment.

5.4.1 – Overview of the UAV Trajectory and the SAR Imagery Footprint

Figure 11 gives an overview of the UAV trajectory, the footprint of the SAR imagery and the area of the experiment near the port of Haifa. The UAV trajectory is depicted in blue. The large red rectangle is the footprint of the TerraSAR-X, Stripmap. The smaller red rectangle is the footprint of the Radarsat-2, Spotlight image.

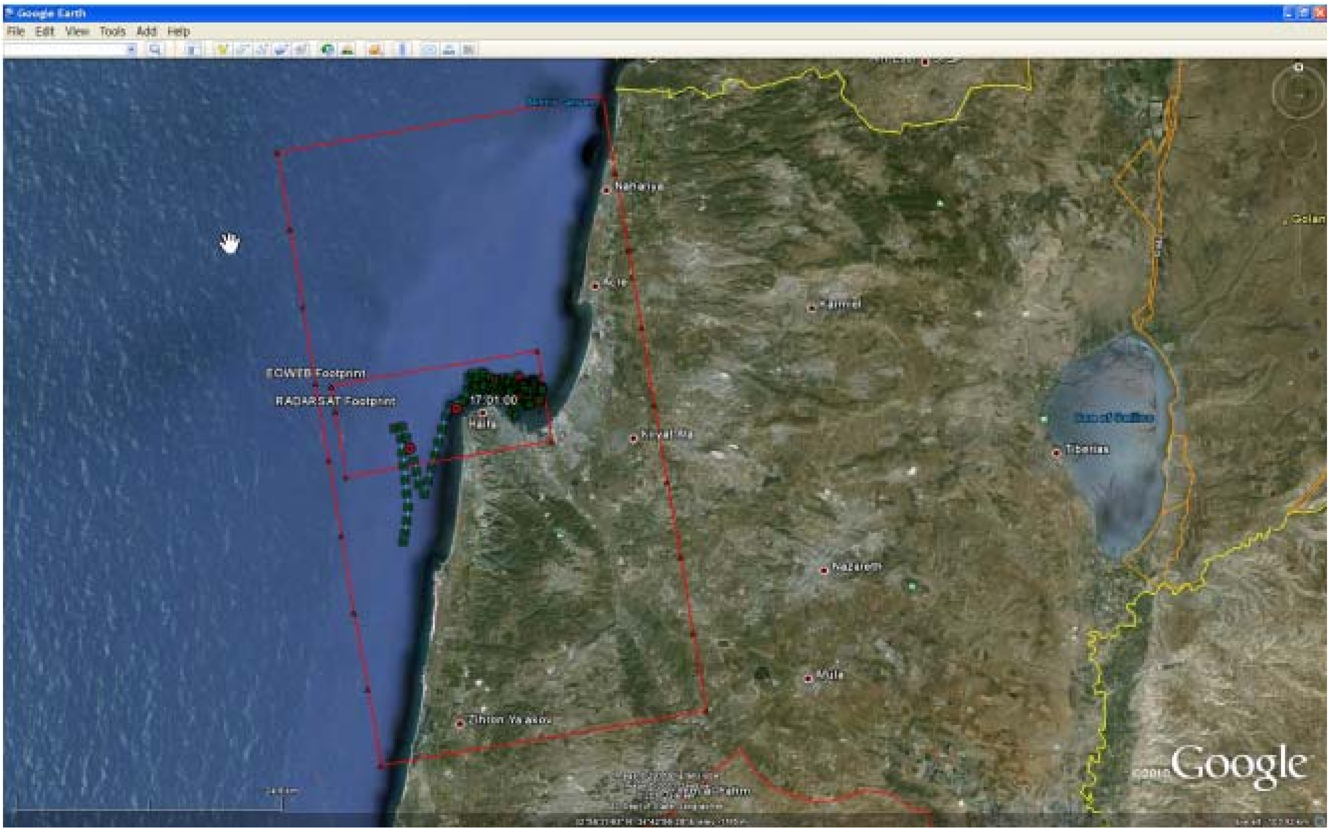

Figure 11 – Google Earth UAV trajectory during the experiment and footprinst of the SAR imagery ordered for the experiment.

Figure 12 is a zoom in of the previous image, which allows a more detailed view of the UAV trajectory and of the port of Haifa. Figure 13 is a zoom in of figure 12. It shows in more detail the UAV trajectory during the entire experiment and the port of Haifa in Israel.

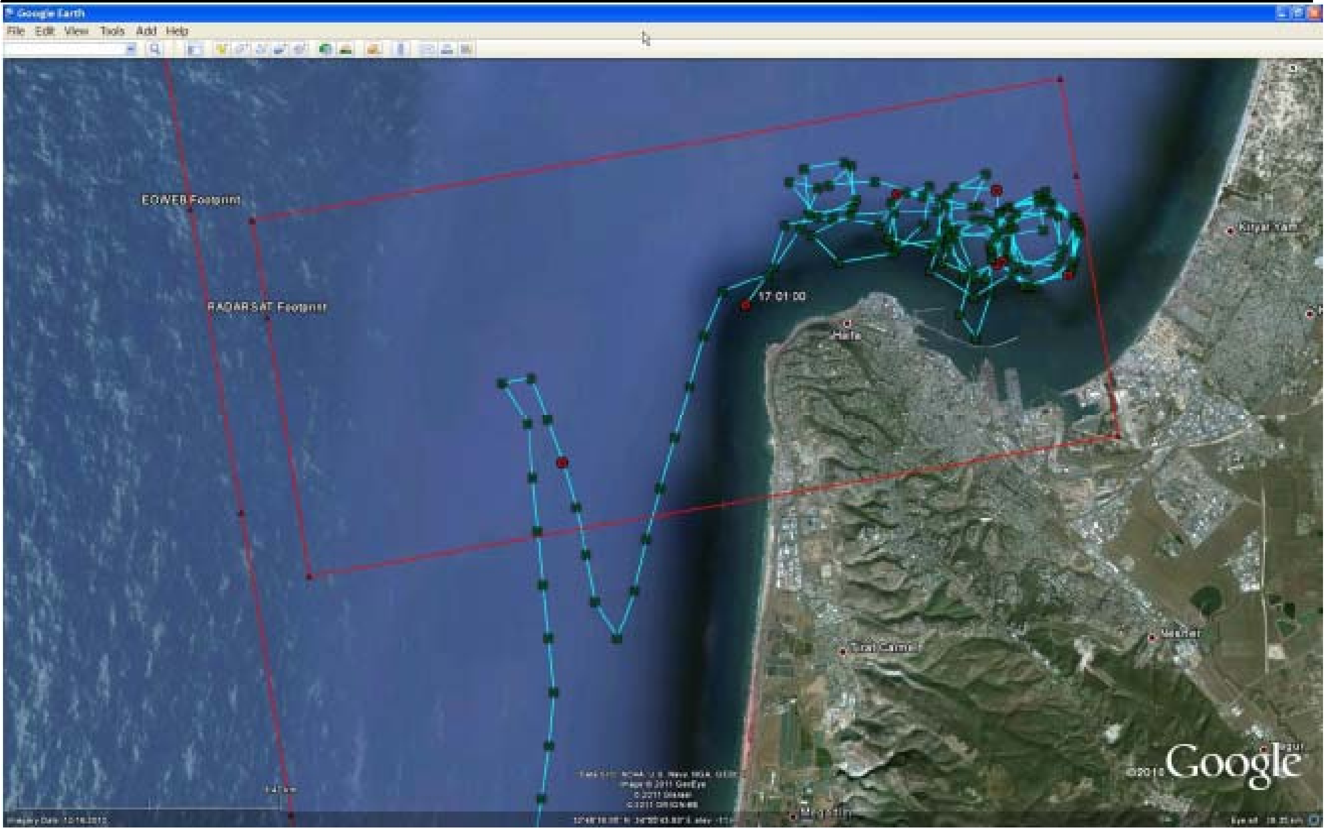

Figure 12 – Zoom in of the previous figure, showing a more detailed view of the UAV trajectory and of the port of Haifa in Israel.

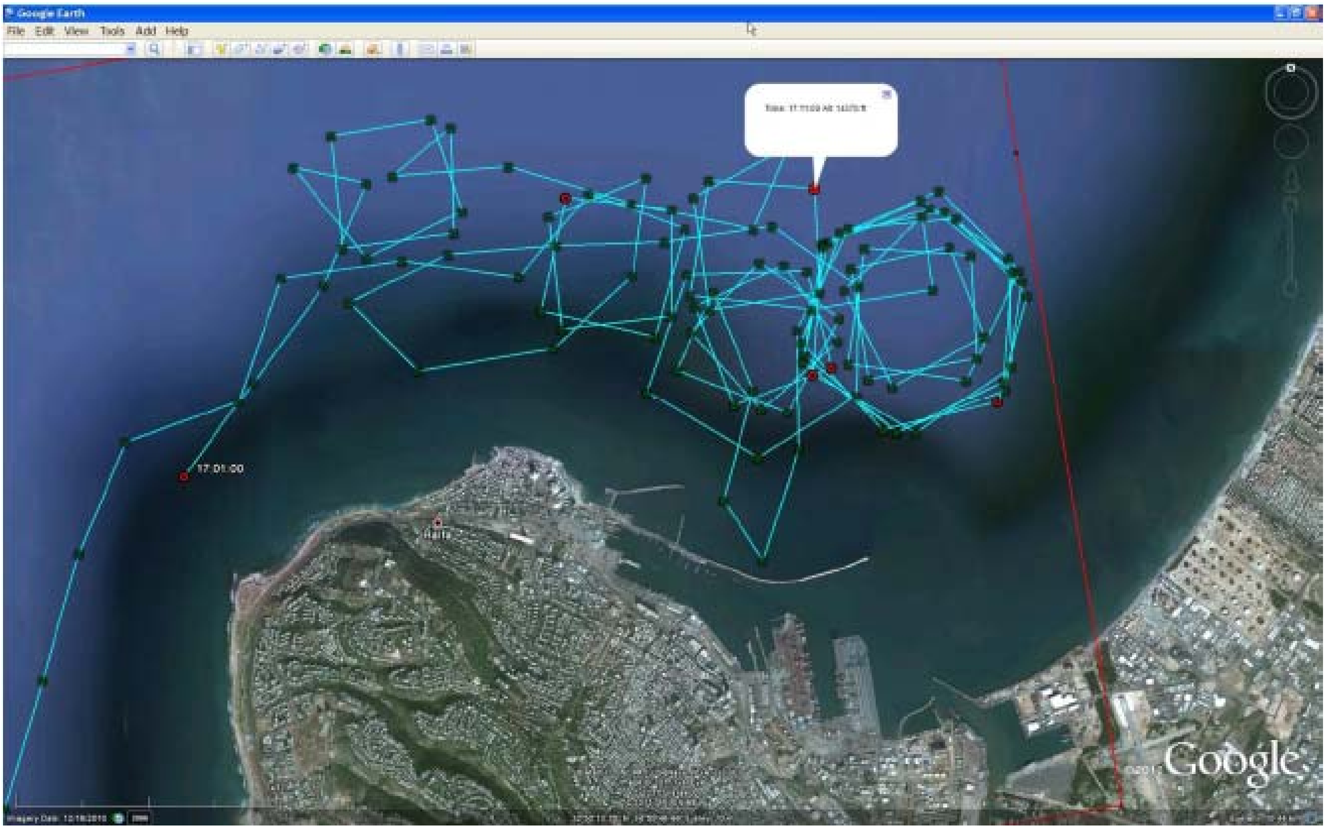

Figure 13 – Zoom in of the previous figure, showing a even more detailed view of the UAV trajectory and of the port of Haifa in Israel.

5.4.2 – Targets Detected in the Radarsat-2, Spotlight Image

Figure 14 illustrates the position of the Elbit's boat used as target in the experiment at the approximate time of the SAR Satellite pass by 15:47 UTC (17:47 LT). The small photo of the boat shows the approximate position of the boat. The two small planes show the positions of the UAV immediately before and after the SAR Satellite pass.

Figure 14 – Google Earth positions of the elbit's boat and the UAV (Hermes450) at the approximate time of the SAR Satellite overpass by 17:47:40 UTC.

Figure 15 shows the corresponding SAR image (Radarsat-2, Spotlight) acquired during the experiment. Pins 1 and 2 represent the positions of the UAV before and after the SAR satellite overpass. Pin 3 illustrates the position of the Elbit´s boat deployed at the time of the satellite overpass. At this scale the SAR signature of the boat is not distinguishable from the sea clutter background. However, zooming in the SAR image the SAR signature can clearly be seen, as illustrated in figure 12. The SAR image in figure 12 also shows several SAR signatures of large ships in the area at the time of the satellite overpass.

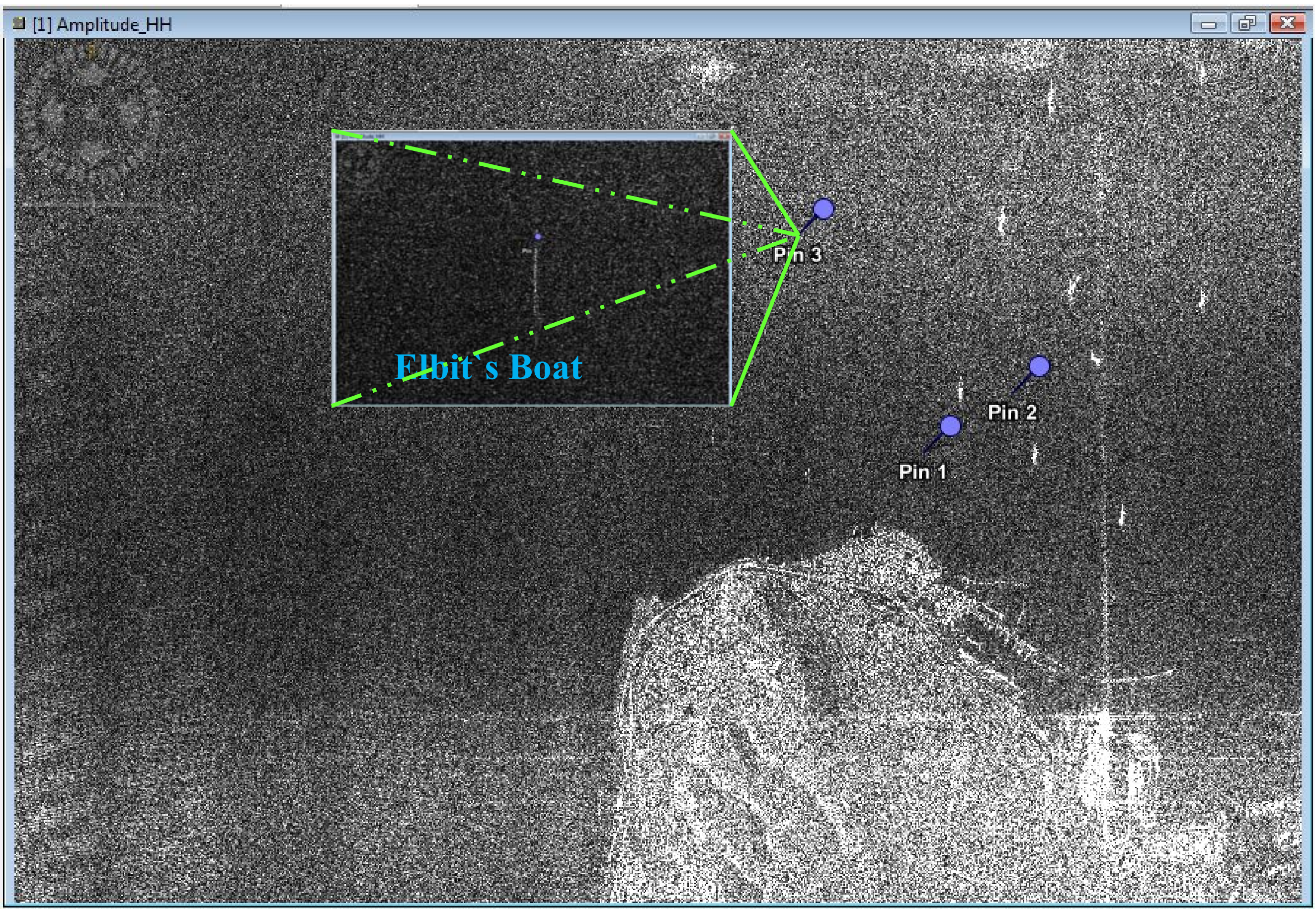

Figure 15 – On the background the SAR image with the two UAV positions before and after the satellite overpass (Pin1 and Pin2) and the Elbit´s Boat position (Pin3). The small window over the SAR image shows a zoom in of the SAR image where the SAR signature of the Elbit´s Boat can clearly be seen. The top right are of the SAR image also shows SAR signatures of several large ships in the area at the time of the SAR satellite overpass.

Figure 16 shows the corresponding SAR image (Radarsat-2, Spotlight) acquired during the experiment and the UAV IR images of some of the targets. Pins 1 and 2 represent the positions of the UAV before and after the SAR satellite overpass. Pin 3 illustrates the position of the Elbit´s boat deployed at the time of the satellite overpass. At this scale the SAR signature of the boat is not distinguishable from the sea clutter background. However, zooming in the SAR image the SAR signature can clearly be seen, as illustrated in figure 13. On the top left the UAV IR image of the Elbit's Boat. The SAR image in figure 13 also shows several SAR signatures of large ships in the area at the time of the satellite overpass. On the centre left the UAV IR image of a large ship. On the centre right the UAV IR image of a large ship. On the bottom right the UAV IR image of a large ship.

All the UAV images were acquired at night in complete darkness from altitudes in the order of 5,500 meters. Nonetheless, the quality and detail of the UAV images allows classification of the targets and in some cases the identification. As it can be seen the potential of UAV for maritime surveillance is very promising.

During the experiment the UAV detected all the boats and ships in the area and tracked some of the boats/ships to test the tracking capability. The capability of detection and tracking targets is a critical capability for maritime surveillance.

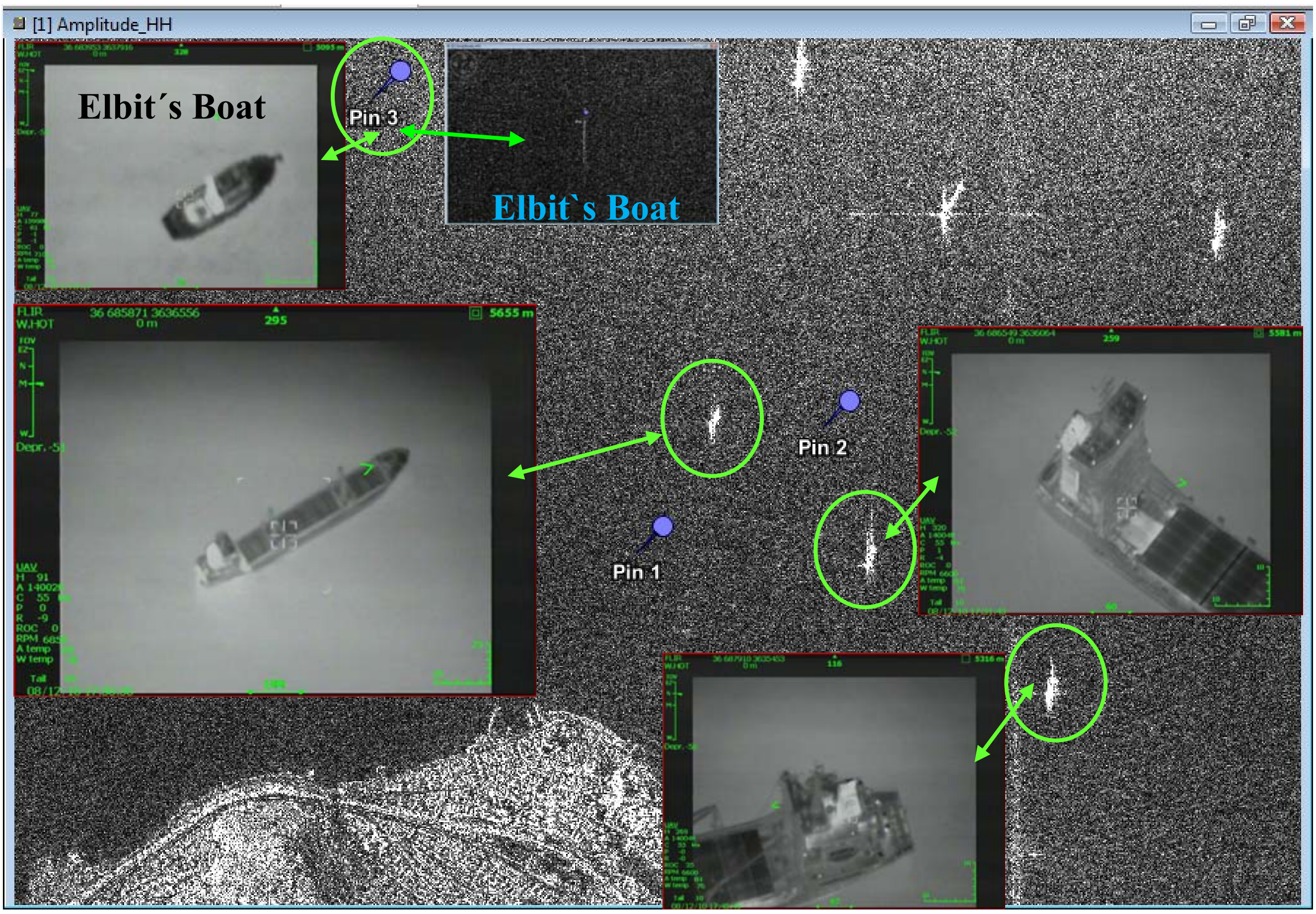

Figure 16 – Zoom-in of figure 15 with the UAV images of some targets. On the top left the UAV IR image of the Elbit's Boat. On the centre left the UAV IR image of a large ship. On the centre right the UAV IR image of a large ship. On the bottom right the UAV IR image of a large ship.

Figure 17 shows a comparison of the SAR and UAV images with an optical photo taken in Haifa, Israel a couple of hours before the SAR satellites overpass. Most of the large ships were detected in the SAR image and some of these ships can be identified in the optical photo. Some of the ships in the photo left the area before the SAR satellites overpass.

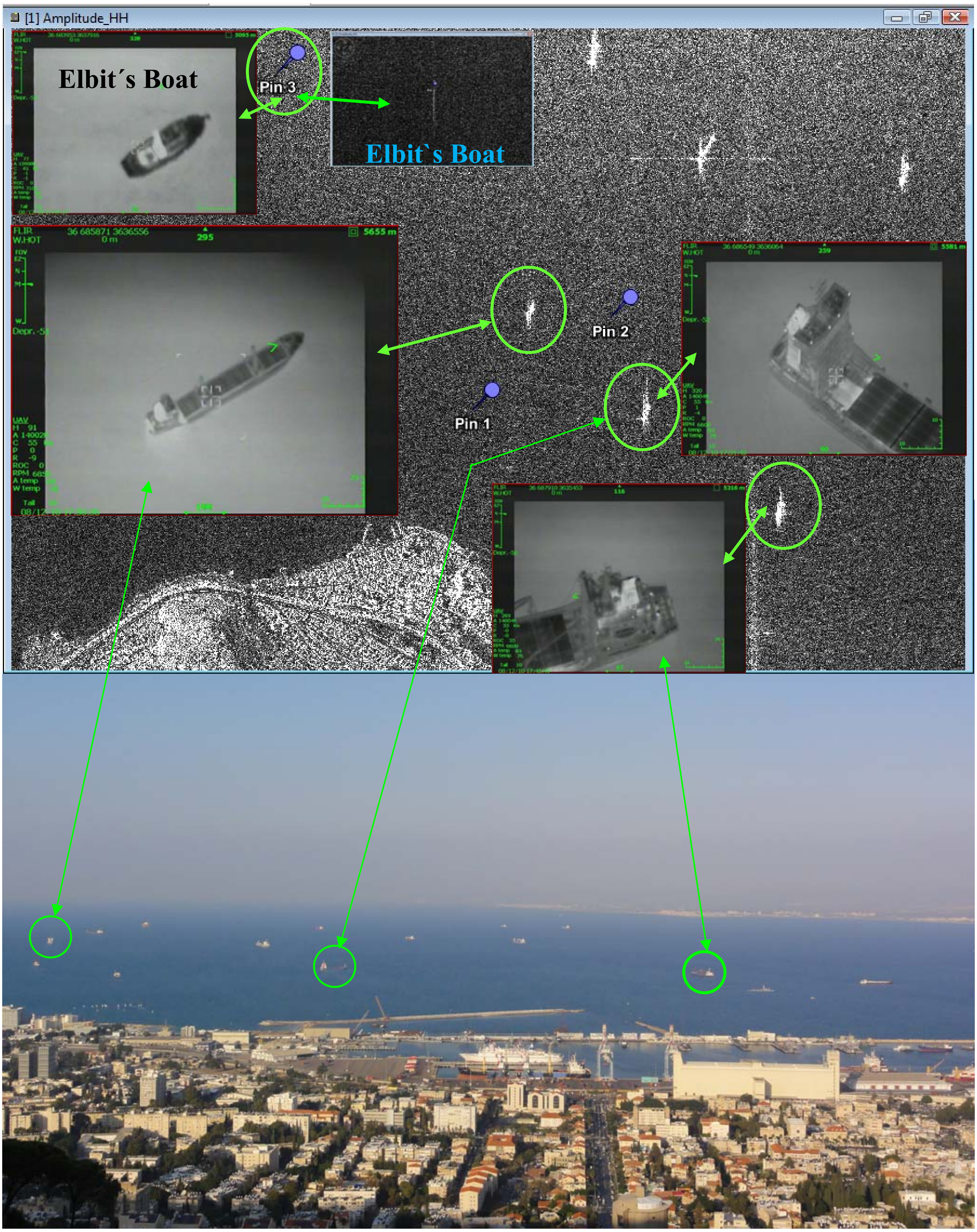

Figure 17 – Photo taken in Haifa Israel a couple of hours before the SAR satellites overpass. This phot shows the large ships moored in the area. Most of these large ships were detected in the Radarsat-2 image. As expected their positions and orientations were slightly different at the time of the satellite overpass.

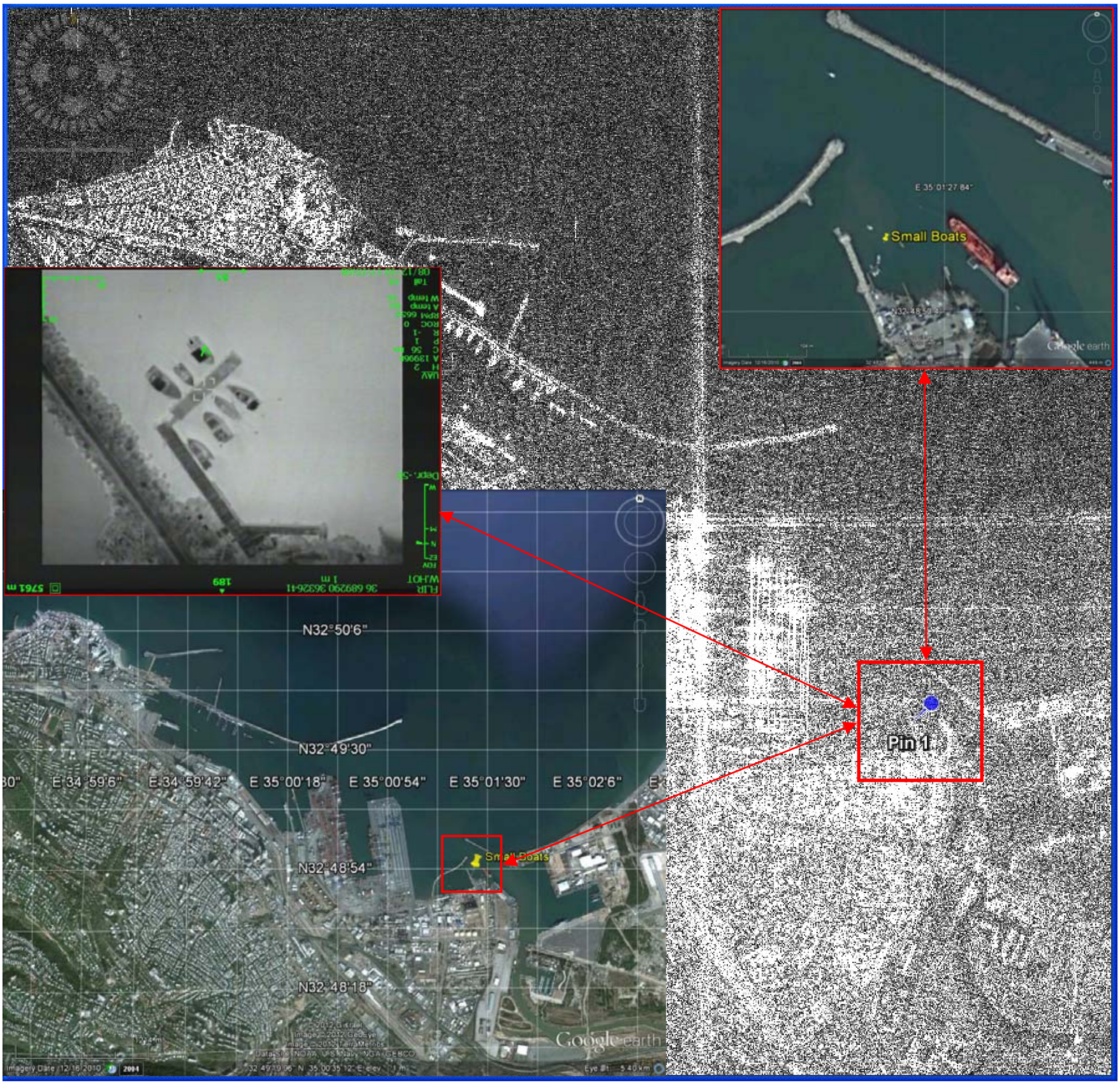

Figure 18 – Photo taken in Haifa Israel a couple of hours before the SAR satellites overpass. This phot shows the large ships moored in the area. Most of these large ships were detected in the Radarsat-2 image. As expected their positions and orientations were slightly different at the time of the satellite overpass.

Figure 18 illustrates the SAR image and the corresponding google earth image of a small pier in the port of Haifa. In the SAR image, due to several artefacts it is not possible to detect the 7 small boats moored to the small pier. The UAR IR image of the same area clearly shows the 7 small boats with impressive detail, taking into account that the image was acquired from an altitude of about 5,500 meters.

A zoom in of the same UAV IR image is shown in figure 19. As it can be seen, although the image was acquired from an altitude of about 5,500 meters, the 7 small boats can be clearly seen with enough detail to allow classification of the type of boat. A UAV flight at lower altitude would probably giver a lot more detail and eventually allow the identification of the small boats.

Figure 19 – UAV IR image of a small pier in the port of Haifa, Israel where 7 small boats can be seen with enough detail to allow classification. This image was acquired from an altitude of about 5,500 meters in the dark.

5.5 – Quantitative Analysis of the Spaceborne SAR Image

In order to allow a quantitative analysis of the data, the spaceborne SAR image was calibrated using ESA's NEST software package, version 4B. The input was the SAR image acquired and the output was 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°)).

5.5.1 – Radarsat-2-Spotlight, 08Dec.2010 (15:47:40 UTC), Haifa, Israel

Figure 20 illustrates the Intensity band of a subset of the Radarsat-2,Spotlgiht image (08Dec.2010).

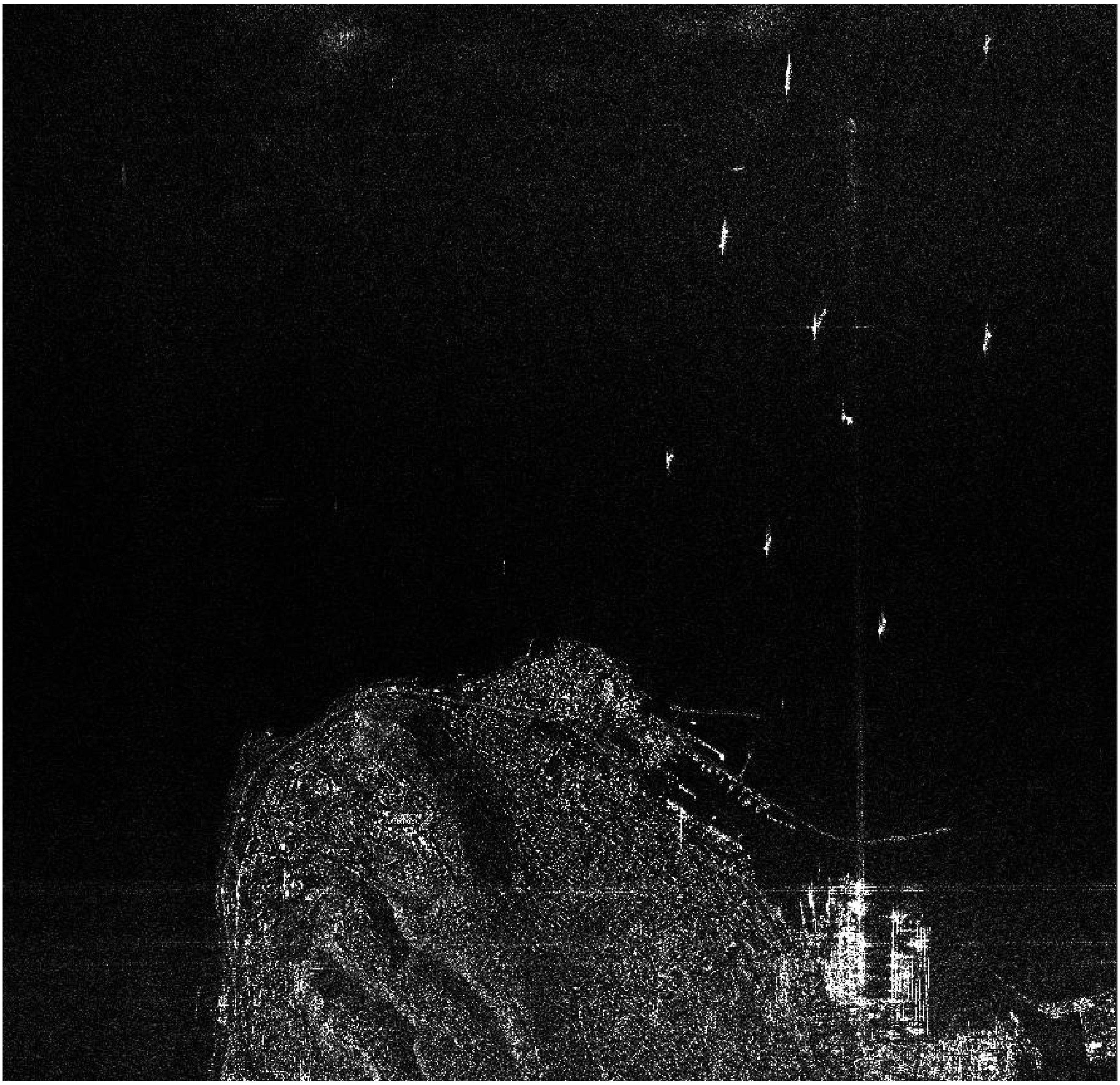

Figure 20 – Radarsat-2, Spotlgiht image (08Dec.2010) – Sigma Naught (Intensity) band.

Figure 21 illustrates the Sigma Naught Coefficient of the Radarsat-2, Spotlgiht image (08Dec.2010) expressed in terms of intensity and decibel (dB).

Figure 21 – Radarsat-2, Spotlgiht image (08Dec.2010) **-** On the left, the Sigma Naught (σ°) (intensity) and on the right, the Sigma Naught (σ°) (dB).

Figure 22 illustrates the Radar Brightness (Beta Naught (β°)), and the radiometric normalisation (Gamma Naught (γ°)) of the Radarsat-2, Spotlgiht image (08Dec.2010) expressed in dB.

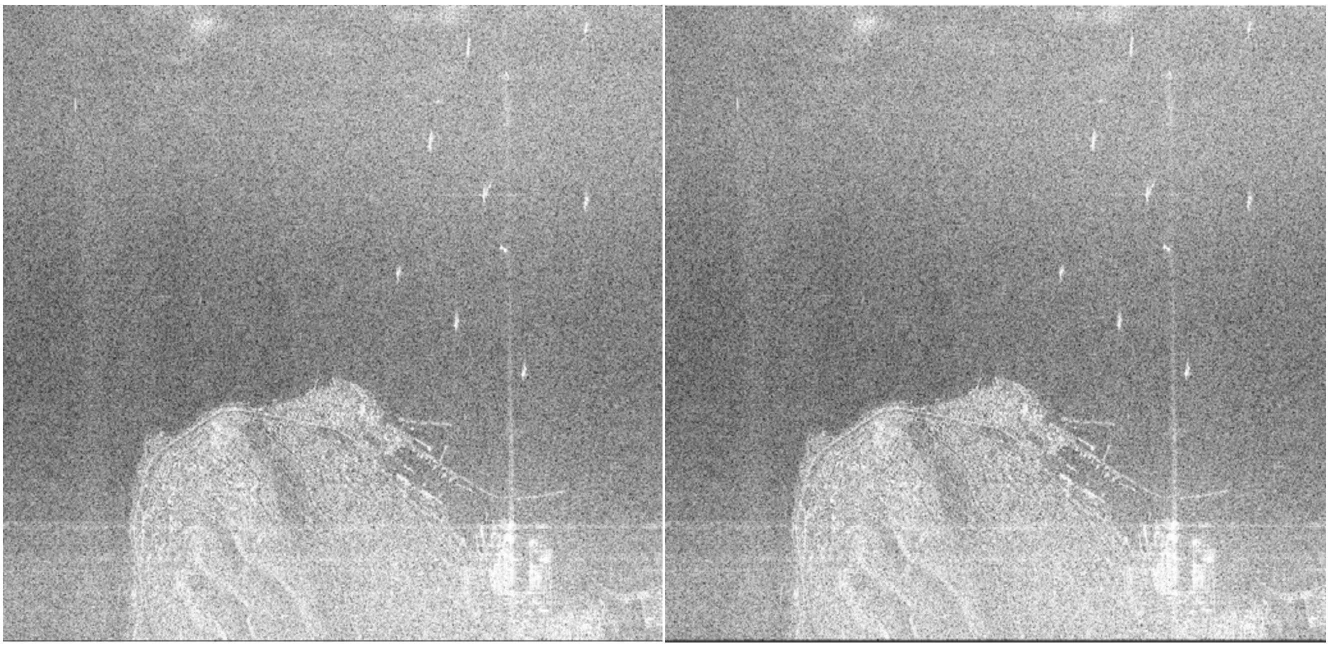

Figure 22 – Radarsat-2, Spotlgiht image (08Dec.2010) **-** On the left, the Beta Naught (β°) and on the right, the Gamma Naught (γ°) (dB).

Figure 23 shows the Sigma Naught (σ°) in dB after some colour manipulation and the histogram of the Sigma Naught (σ°) image.

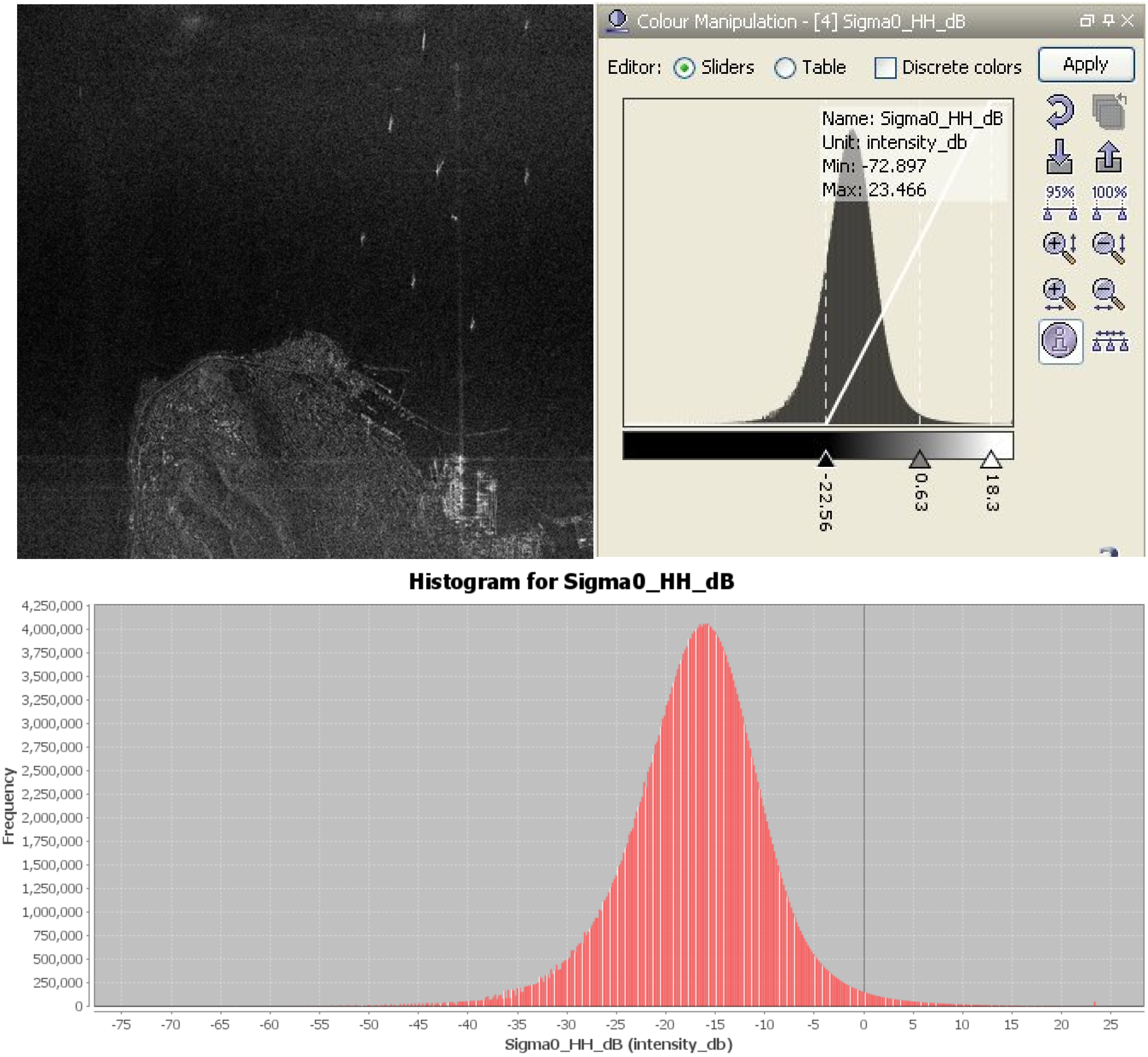

Figure 23 – Radarsat-2, Spotlgiht image (08Dec.2010) **-** On the top left the Sigma Naught (σ°) after colour manipulation to enhance the targets and on the top right, the corresponding histogram. On the bottom, we can see the histogram of the image.

Table 6 gives the statistics of the Sigma Naught (σ°) Radarsat-2, Spotlgiht image (08Dec.2010). The Sigma Naught (σ°) range from -72.897 dB up to 23.465 dB. The Mean value is -16.855 dB, the Median is -16.594 dB and the standard deviation is 7.077 dB.

Table 6 – Statistics of the Radarsat-2, Spotlgiht image (08Dec.2010) (15:47:40 UTC)

Statistics	Values	Unit
Only ROI-Mask pixels considered: Number of pixels total: Number of considered pixels: Ratio of considered pixels:	No 322394283 322394283 100.0 %	
Minimum: Maximum:	-72.8974609375 23.4655818939209	intensity_db intensity_db
Mean: Median: Std-Dev: Coefficient of Variation:	-16.855686580177853 -16.59462338617847 7.07796800831575 0.7888765273432338	intensity_db intensity_db intensity_db intensity_db

Checking the radar backscattering coefficient of some targets (small boat and some large ships) detected in the Radarsat-2, Spotlight image, we get values ranging from -0.379 dB up to 23.455 dB. The analysis of the Sigma Naught values (σ°) of the targets and the area around the targets shows a significant contrast.

5.6 – Summary of the Preliminary Analysis of the Spaceborne SAR Image

This experiment involved two spaceborne SAR images, namely a TerraSAR-X, Stripmap and one Radarsat-2, Spotlight. The TerraSAR-X image was not delivered by DLR due to technical problems. The Elbit's boat deployed during the experiment was detected in the Radarsat-2, Spotlight image. Several other targets, including a set of large ships were also detected. Table 7 summarises the characteristics of the SAR image acquired and the targets detected.

Table 7 – List of SAR Satellite Images acquired during the experiment and detected boats.

ISRAEL (HAIFA)				
Date / Time	**Place**	**Satellite / Mode**	**Ground Truth Data**	**Detected Boats**
08.Dec.2010 (PM)	**Haifa - Israel**	**Radarsat-2 / Spotlight**	**GPS/Photos/Movies**	**1 small boat deployed + 9 large ships.**

Table 8 gives the minimum and maximum Sigma Naught (σ°) of the targets detected in each SAR image.

Table 8 – Minimum and maximum Sigma Naught (σ°) of the targets detected in each SAR image.

Date /Time UTC (LT)/Pass	Satellite / Image Mode / Polarisation	Sigma Naught (σ°) Min / Max
29.Oct.2010/5:28UTC(7:28AM LT) / DES	**Radarsat-2/ Spotlight / HH**	**--0.379 dB / 23.455 dB**

The SAR signatures of the boats deployed were very weak. Some possible reasons to explain such weak signatures are the sea state, the wind speed, the incidence angle and the type and materials. Another possible reason is the processing at DLR.

6. – Preliminary Conclusions

The analysis of the results of this coupled UAS/Spaceborne SAR experiment shows a promising potential for the use of UAS for maritime surveillance. UAS can be integrated into the airborne building block of maritime surveillance systems to complement the existing assets, increase system performance and improve the overall maritime domain awareness. The main perceived maritime security and safety threats comprise piracy, terrorist and military threats, weapons proliferation/smuggling, drugs trafficking, illegal immigration, unlawful use of containers, attacks to critical infrastructures and illegal fishing. The main maritime security and safety gaps include a lack of technologies with the capability of detecting small targets (e.g. small boats), a lack of wide area and persistent maritime surveillance, a lack of coordination and information sharing, limited interoperability, a lack of containers security, a lack of persistent surveillance of critical infrastructures and early warning systems. Unmanned Aircraft Systems (UAS) are an emerging technology with strong potential to mitigate the above mentioned threats by filing in the main maritime security and safety gaps listed earlier. For instance, the wide range of potential applications of UAS to maritime surveillance includes, but is not limited to:

- — detection, classification and identification of small boats,
- — persistent maritime surveillance,
- — use as communications relays,
- — persistent surveillance of critical infrastructures,
- — early warning systems,
- — COMINT and ELINT collection, etc..

Table 11 illustrates the mapping of maritime security/safety threats vs gaps and summarises the main potential applications of UAS to maritime surveillance.

The above mentioned potential applications of UAS to the Maritime Domain will be addressed in turn in more detail next.

- — <u>Detection, classification and identification of small boats</u> – The capability of detecting, classifying and identifying small targets (e.g. small boats) is among the key technologies required to improve maritime domain awareness. This capability is critical to mitigate piracy, illegal immigration, drugs trafficking, weapons smuggling, illegal fishing, terrorism and critical infrastructure. Unmanned Aircraft Systems (UAS) provide this capability more efficiently and at a lower cost than any other existing technology.

- — <u>Persistent maritime surveillance</u> – With the continuous improvements of UAS technologies, such as platforms, sensors, collision avoidance systems, command and control systems, telecommunications, etc., UAS are increasing their autonomy, endurance and flexibility. These characteristics are very important for persistent maritime surveillance. UAS can be launched from land, ships, aircraft and technologies to launch UAS from submarines are currently under development. UAS have distinct advantages over other existing technologies for persistent maritime surveillance in terms of autonomy/endurance (the Global Surveyor has an autonomy of 1 week), cost (e.g. as the autonomy of UAS increases, the number of staff required to operate UAS decreases), risk (e.g. if the UAS crashes the crew is not at risk), flexibility (e.g. they can be launched from a ship reducing the time to reach potential threats), etc..

• — Communications relays – UAS are being used as communication relays, mainly in military context, but have the potential to play a similar role in Civil context in several situations, such as to replace satellite communications or as a redundant system over any location on Earth. The main advantages of using UAS as communication relays is that airborne communication relays mitigate kinetic and noise jamming threats to satellite communications uplinks by providing an alternative set of links either directly to surface-based terminals or to satellites beyond the range of threats. They are less susceptible to noise jamming threats than satellites because an adversary has to detect, geolocate and track the airborne asset and operate within line of sight of the receive antenna main beam.

• — Persistent surveillance of critical infrastructures – The security of critical infrastructures, such as nuclear power plants, refineries, ports, etc. requires persistent surveillance. UAS can play an important role in providing persistent surveillance over critical infrastructures and over a wide area around the critical infrastructure. Some advantages of UAS over other existing technologies, such as ground-based assets (e.g. video cameras, alarm systems, manned aircraft, etc.), comprise the security of the UAS (e.g. hardly can be damaged or switched off as any ground-based asset), the area covered by a UAS (e.g. it is larger than the area covered by any ground-based asset), the cost (e.g. UAS is cheaper than manned aircraft with similar capability), etc..

• — Early warning systems – UAS have the potential to be used as part of an integrated system of systems for early warning. A UAS can provide information about a given area at a fraction of the cost of alternative means. Formation flying of UAS can cover a wide maritime area. It is reasonable to assume that in a foreseeable future with the advent of UAS with increased autonomy, the operations cost of UAS will likely decrease, making them increasingly more attractive.

• — COMINT and ELINT collection – SIGNal INTelligence (SIGNINT) can be divided into two categories, namely COMINT and ELINT. COMINT stands for Communication Intelligence and ELINT for Electronic Intelligence. Collection of COMINT is passive. Exploitation of COMINT requires a human operator, which implies COMINT UAS are suitable for COMINT and ELINT collection in different scenarios,

The relatively reduced amount of data collected and analysed during this experiment and the lessons learned do not allow drawing final conclusions about the feasibility of using Unmanned Aerial Systems (UAS) for maritime surveillance. However, this experiment allowed hands-on experience with UAS technologies and significantly improved the awareness for its applications to maritime surveillance and related issues involved, including its potential, the feasibility, as well as the limiting and enabling factors. These different aspects will now be analysed in turn in the next sections.

Table 11 illustrates the mapping of the main maritime security threats and gaps, as well as the main priorities in terms of the different technologies involved in maritime surveillance. For each maritime threat, the technologies required to fill in each gap is indicated and its priority is expressed in a range of numbers (1 to 3, 1 = Maximum Priority, 2 = Medium Priority, 3 = Low Priority) and colours (Red = Maximum Priority, Orange = Medium Priority, Green = Low Priority). The main technologies involved in maritime surveillance are listed on the bottom of figure 4 and are reproduced here for convenience of the reader: 1.- Reporting Systems, 2.- Sensors, 3.- Platforms, 4.- Communications, 5.- Data Fusion & Sharing, 6.- Intelligence and 7.- Databases. For example, the mitigation of the main threat Piracy requires filling in several maritime security gaps (e.g. lack of persistent surveillance, lack of wide-are maritime surveillance, lack of small boat detection, lack of Early Warning Systems, and lack of Information Sharing with maximum priority (1- Red) and among the required technologies listed are UAS, LTAAV, GEO-HR, etc. Concerning the remaining two gaps (Limited Interoperability and Containers Security) they are less relevant to mitigate Piracy, hence the priority for Limited Interoperability is 2-Orange and for Containers Security is 3- Green.

Table 9 – The Main Maritime Security and Safety Threats vs Gaps and the technologies that can be used to mitigate them.

Maritime Security Main Threats / Gaps

Gaps→ / ↓Threats	Lack of Risk Assessment Capability	Lack of Persistent Surveillance	Lack of Wide-Area surveillance	Lack of Small Boat Detection	Lack of Early Warning Systems	Lack of Information Sharing	Limited Interoperability	Lack of Containers Security
• Piracy	UAS, LTAV,GEO-HR + ...	UAS, LTAV,GEO-HR + ...	SAR, GEO-HR + ...	UAS, USV, LTAV + ...	UAS, LTAV, + ...	Coordination &Sharing + ...	Interoperabilty Optimisation + ...	
	1, 2, 3, 5, 6, 7	1, 2, 3, 5, 6, 7	1, 2, 3 5, 6	1, 2,3	1,2,3,4,5,6	4,5,6,7	1,2,3,4,5,6,7	1,2,3,4,5,6,7
• Terrorism	UAS, LTAV,GEO-HR + ...	UAS, LTAV, GEO-HR + ...	SAR, AIS GEO-HR + ...	UAS, USV, LTAV + ...	Intelligence + ...	Inteligence + ...	Interoperabilty Optimisation + ...	Intelligence + ...
	1, 2, 3, 5, 6, 7	1, 2, 3, 5 6	1, 2, 3 5, 6	1, 2,3	1,2,3,4,5,6	4,5,6,7	1,2,3,4,5,6,7	1,2,3,4,5,6,7
• Weapons of Mass Destruction Smuggling	UAS, LTAV,GEO-HR + ...	UAS, LTAV,GEO-HR + ...	SAR, AIS + ...	UAS, USV, LTAV + ...	Intelligence + ...	Inteligence + ...	Intelligence + ...	Intelligence + ...
	1, 2, 3, 5, 6, 7	1, 2, 3, 5 6	1, 2, 3 5, 6	1, 2,3	1,2,3,4,5,6	4,5,6,7	1,2,3,4,5,6,7	1,2,3,4,5,6,7
• Drugs Trafficking	UAS, LTAV,GEO-HR + ...	UAS, LTAV,GEO-HR + ...	SAR, AIS + ...	UAS, USV, LTAV + ...	Intelligence + ...	Inteligence + ...	Intelligence + ...	Intelligence + ...
	1, 2, 3, 5, 6, 7	1, 2, 3, 5 6	1, 2, 3 5, 6	1, 2,3	1,2,3,4,5,6	4,5,6,7	1,2,3,4,5,6,7	1,2,3,4,5,6,7
• Illegal Immigration	UAS, LTAV,GEO-HR + ...	UAS, LTAV,GEO-HR + ...	SAR, AIS + ...	UAS, USV, LTAV + ...	Intelligence + ...	Inteligence + ...	Intelligence + ...	Intelligence + ...
	1, 2, 3, 5, 6, 7	1, 2, 3, 5 6	1, 2, 3 5, 6	1, 2,3	1,2,3,4,5,6	4,5,6,7	1,2,3,4,5,6,7	1,2,3,4,5,6,7
• Critical Infrastructure Security	UAS, LTAV,GEO-HR + ...	UAS, LTAV,GEO-HR + ...	SAR, AIS + ...	UAS, USV, LTAV + ...	+ ...	Inteligence + ...	Intelligence + ...	Intelligence + ...
	1, 2, 3, 5, 6, 7	1,2, 3, 6	1, 2, 3 5, 6	1, 2,3	1,2,3,4,5,6	4,5,6,7	1,2,3,4,5,6,7	1,2,3,4,5,6,7
• Illegal Fishing	UAS, LTAV,GEO-HR + ...	AIS+SAR, UAS,LTAV+ ...	SAR,AIS, GEO-HR+ ...	UAS, USV, LTAV + ...	Intelligence + ...	Inteligence + ...	Intelligence + ...	
	1, 2, 3, 5, 6, 7	1, 2, 3, 5 7	1, 2, 3 5, 6	1, 2,3	1,2,3,4,5,6	4,5,6,7	1,2,3,4,5,6,7	
• Unlawful Use of Containers (Security)	UAS, LTAV,GEO-HR + ...	GPS Tracking + ...			Intelligence + ...	Inteligence + ...		GPS, Intrusion Detection, Seal
	1, 2, 3, 5, 6, 7	4, 6, 7	1, 2, 3 5, 6	1, 2,3	1,2,3,4,5,6	4,5,6,7	1,2,3,4,5,6,7	1,2,3,4,5,6,7

(-)	Priority	(+)	Not Relevant

SURVEILLANCE TECHNOLOGIES	1- Reporting Systems	2-Sensors	3-Platforms	4-Communications	5-Data Fusion & Sharing	6-Intelligence	7-Databases

6.1 – Hands-on experience with UAS technologies and its applications to maritime surveillance

This coupled UAS/Spaceborne SAR campaign was a unique opportunity to acquire further hands–on experience with UAS technologies and learn about the main issues related to its applications to maritime surveillance. From the planning phase up to the execution of the UAS flight and landing there are several factors that need to be carefully analysed and taken into account. A summary of the main issues identified in this experiment is given next.

1.- Selection of the Experiment Area /Authorisation to Fly – For the time being UAS can only be flown in restricted areas usually under control of national authorities, often the military. This is due to the risks that a UAS can pose to human life and property. In the present case, an area under the authority of the Israeli Civil Aviation Authority was selected. The authorisation to fly was not easy to obtain because the selected area is under the authority of the Civil Aviation Authority. Figure 24 indicates the area of the experiment in Haifa, Israel.

2.- UAS Communications Issues – The Hermes 450 was flown in Line-of-Sight (LOS) since it was close to the coast. For BLOS (Beyond Line-of-Sight) operation satellite communications are required.

3.- Synthetic Aperture Radar (SAR) – The specific model Hermes 450W used in the experiment had no SAR sensor installed. However, a SAR sensor can be installed. A SAR sensor is important for maritime surveillance since it allows 24/7 operations regardless of the weather conditions.

4.- Automatic Identification System (AIS) Receiver – The Hermes 450 used in this experiment was not equipped with an AIS receiver. For maritime surveillance operations an AIS receiver is a very important tool since it allows the automatic identification of most ships allowing the UAS to concentrate on non-identified ships.

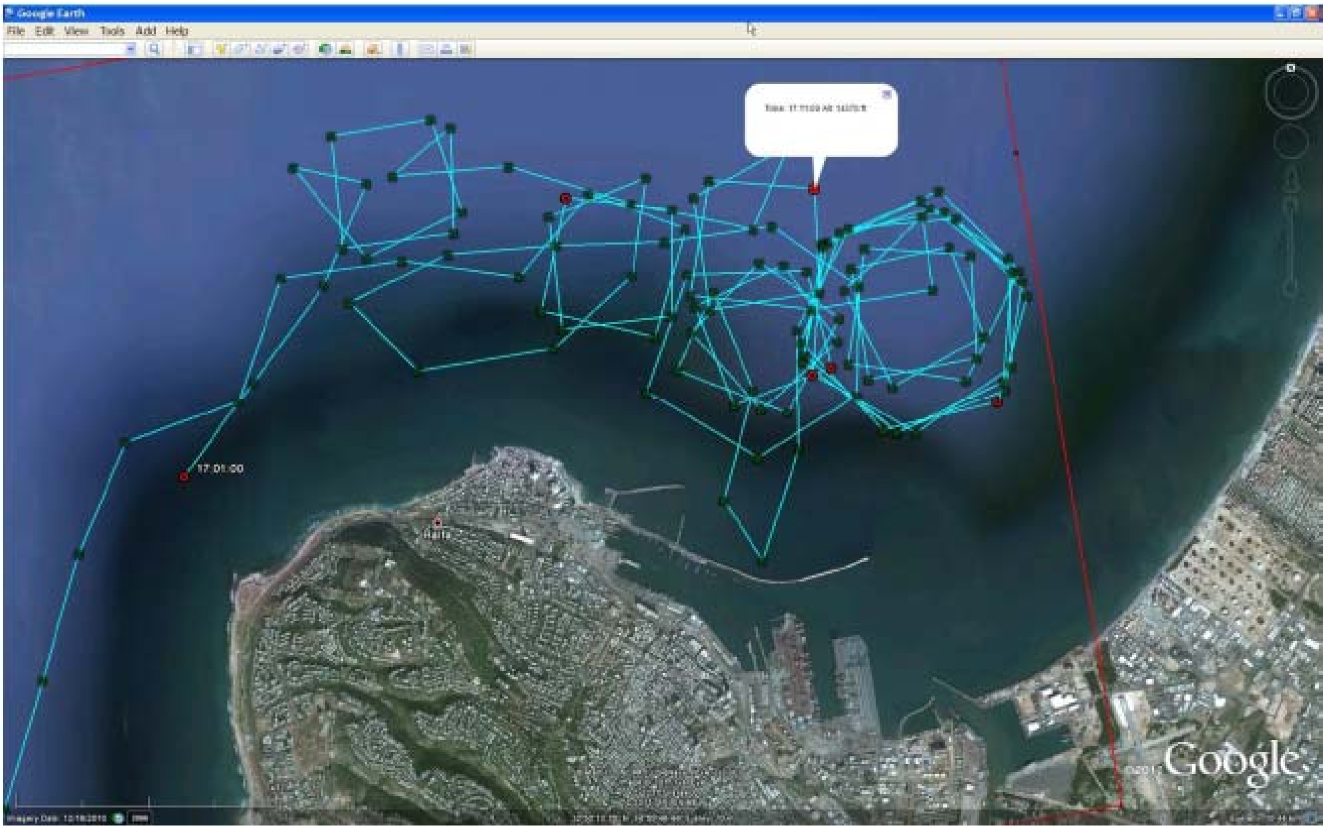

Figure 24 – The area of the experiment is indicated by the GPS Trajectory of the UAV.

6.2 – Potential of UAS for Maritime Surveillance

UAS technologies are relatively recent and involve a wide range of fields spanning from aeronautics and sensors technologies to satellite communications and other engineering disciplines. Innovations in each of the fields involved are emerging by the day. UAS still have a long way to go before they become mature and their use fully operational. For the time being UAS are mainly used for military applications. However, a large number of non-military UAS applications have been identified by stakeholders and there are several studies and demonstration flights foreseen for the near future.

Maritime surveillance is one of the most challenging and promising fields of application of UAS. The challenges are due to the very demanding conditions under which the UAS must operate over sea and the requirements for safe operation.

The present UAS experiment has unveiled some of the potential of UAS for maritime surveillance. The UAS tests performed during this experiment include:

1 – Detection of a Small rubber Boat and a Fishing Ship,
2 – Tracking of a Small Boat and a Fishing Ship,
3 – Classification of a Small Boat and a Fishing Ship,
4 – Identification of a Small Boat and a Fishing Ship,
5 – Detection and Tracking of People on the Beach,

Despite the operational requirement that prevented the UAS from flying bellow 3km, the experiment has confirmed the capability of UAS for small boat detection, tracking and classification, as well as the capability for people detection and tracking. Concerning the identification of the targets, the characteristics of the images acquired during this mission suggest that flying at lower altitudes the UAS images would allow the identification of the targets. The UAS images can be seen from Figure 15 to 20.

6.2.1 – Advantages of UAS for maritime Surveillance

Some of the advantages of using UAS for maritime surveillance have been described in the literature and are summarized bellow.

- 1.- One potential benefit of UAS is that they could fill in a gap in current maritime surveillance by improving coverage.
- 2.- The range of UAS is a significant asset when compared to border agents on patrol or stationary surveillance equipment.
- 3.- Eletro-Optical InfraRed (EOIR) sensors (cameras) can identify small size objects from very high altitudes (high resolution).
- 4.- UAS can provide precise and near-real-time imagery to a ground control operator, who would then disseminate that information so that informed decisions regarding the deployment of border patrol agents can be made quickly.
- 5.- Long endurance UAS used along the border can fly for more than 30 hours up to several days without having to refuel, compared with manned helicopter's average flight time of just over 2 hours.
- 6.- The ability of UAS to loiter for prolonged periods of time has important operational advantages over manned aircraft.
- 7.- The longer flight times of UAS means that sustained coverage over a previously exposed area may improve maritime security.
- 8.- The range of UAVs is a significant asset when compared to border agents on patrol or stationary surveillance equipment. Nevertheless, the extended range and endurance of UAVs may lessen the burdens on human resources at the borders.
- 9.- UAS accidents do not risk the lives of pilots, as do the helicopters and aircraft currently used by Coast Guards for border patrolling.

6.2.2 – Possible Drawbacks of using UAS for maritime Surveillance

UAS also have disadvantages; some of them are briefly described next.

● 1.- There have been concerns regarding the high accident rate of UAS, which can be multiple times higher than that of manned aircraft. Because UAS technology is still evolving, there is less redundancy built into the operating system of UAS than of manned aircraft and until redundant systems are perfected mishap rates are expected to remain high.

● 2.- If control systems fail in a manned aircraft, a well-trained pilot is better positioned to find the source of the problem because of his/her physical proximity. If a UAS encountered a similar system failure, or if a UAS landing was attempted during difficult weather conditions, the ground control pilot would be at a disadvantage because he or she is removed from the event. Unlike a manned pilot, the remote pilot would not be able to assess important sensory information such as wind speed.

● 3.- Inclement weather conditions can also impinge on a UAS surveillance capability, especially UAS equipped with only an EO camera and Forward Looking Infrared Radar (FLIR), because cloudy conditions and high humidity climates can distort the imagery produced by EO and FLIR equipment. The effects of extreme climatic or atmospheric conditions on sensors reportedly can be mitigated with the outfit of one synthetic aperture radar (SAR) system and a moving target indicator (MTI) radar. However, adding SAR and MTI to a UAS platform would increase the costs associated with using UAS.

● 4.- Depending on the type of UAS, the costs of operating a UAS can be higher than the costs of operating a manned aircraft. This is because some types of UAS require a significant amount of logistical support and specialized operator and maintenance training. Operating one UAS may require a crew of up to 20 support personnel. The high comparative costs of operating some sophisticated types of UAS may be offset somewhat by their comparatively lower unit costs.

6.3 – Main Limiting Factors Preventing the Use of UAS

Several pre-requisites must be satisfied to render the UAS a viable, cost-effective and regulated alternative to existing resources. Major civil and commercial market barriers include:

- — Single European Sky
- — Sense and Avoid technologies
- — Command and Control Technologies Reliability
- — Communications (Bandwidth, LOS, BLOS)
- — Lack of airspace regulation that covers all types of UAV systems (encompassing 'sense and avoid', airspace integration and airworthiness issues)
- — Affordability - price and customization issues (e.g. commercial off-the-shelf, open modular architecture)
- — Lack of efforts to establish joint customer requirements (although this is gradually changing)
- — Liability for civil operation
- — Capacity for payload flexibility
- — Lack of sufficient secure non-military frequencies for civil operation
- — Perceived reliability (e.g. vehicle attrition rate vs. manned aircraft)
- — Operator training issues
- — Recognition/customer perception of the UAV market
- — Technology developments for multi-mission capability

6.4 – UAS Key Enabling Technologies

Figure 25 illustrates the components of a typical UAV System, showing some of the capabilities needed and the enabling technologies required for performing a given mission. Any UAV mission involves many capabilities and technologies. Due to the depicted system complexity the main key players, such as the US Department of Defense (DoD) and other agencies have started to use the term Unmanned Aerial System (UAS) in place of UAV.

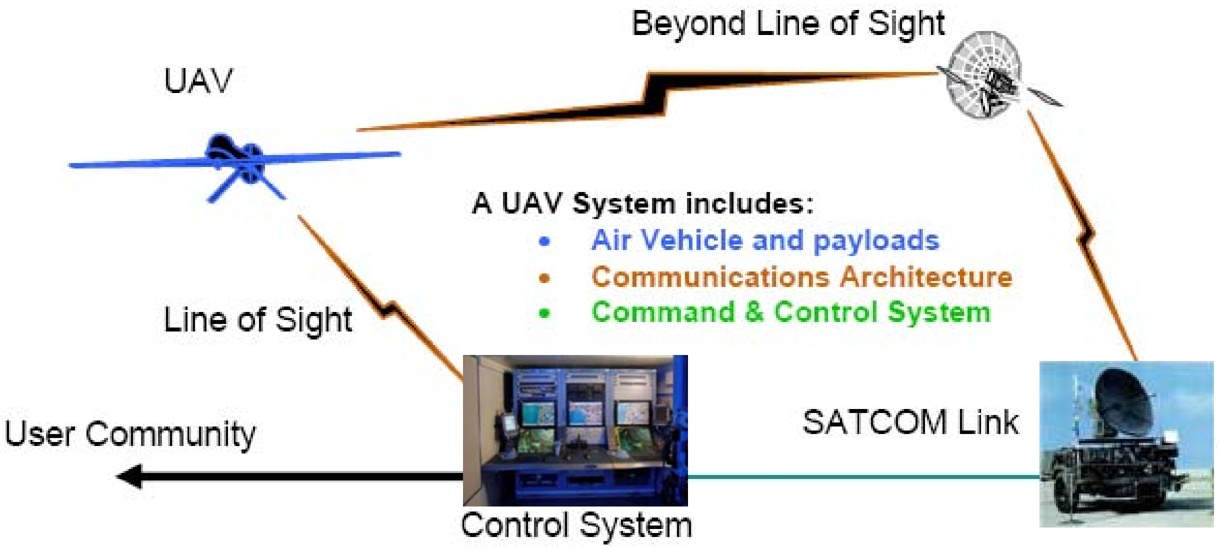

Figure 25 – Unmanned Aerial Vehicle System. Enabled by: Autonomous Mission Management, Reliable Flight Systems, Navigation Accurate Systems, Terrain Avoidance, Power and Propulsion

Some UAS key enabling technologies are listed below.

- — Autonomous Mission Management
- — Collision Avoidance
- — Intelligent System Health Monitoring
- — Reliable Flight Systems
- — Sophisticated Contingency Management
- — Intelligent Data Handling and Processing
- — Over-the-Horizon Communication
- — Network-Centric Communication
- — Open Architecture
- — Power and Propulsion
- — Navigation Accurate System Technology
- — Enhanced Structures

Table 12 gives a more detailed description of other critical technologies for emerging autonomous UAV systems both civil and military. Most of the technologies mentioned in Table 12 apply both to civil and military UAV systems.

Table 10 – Key Enabling Technologies (from SG/75 study on autonomous systems).

Critical Technologies	
Decision Making Software: • Fuzzy-based decision making • Knowledge-based system • Case-based reasoning • Self-learning techniques • Decision tree evaluation • Reasoning/Inferring • Probabilistic/stochastic reasoning Prediction Algorithms: • Predictive path/intent algorithms • Short reaction algorithm • Effectiveness evaluation Status Assessment Software: • Internal status analysis • Self-orientation Situation Analysis Software: • Situation analysis • Environmental analysis • External status analysis Modelling Software: • Air vehicle modelling algorithms • Sensor modelling algorithms • Scenario generation • Threat system modeling • Attack simulation • Mission success optimisation model • Simulation	Sensor Processing Software: • Sensor fusion • Area of interest identification • Automatic target recognition Adaptive and Self-learning Systems: • Failure self-compensation Attack Planning Software: • Attack plans and tactical alternatives • Plan change impact identification Weapon Engagement Procedure Software: • Weapon engagement algorithms Mission Plan Update Software: • Route planning system • Payload plan management system • Mission Success Optimisation model Path Optimisation Software: • Optimal trajectory planning • Path Optimisation System Targeting Software: • Target tracking • Target prioritisation Platform Technologies: • Obstacle detection and avoidance (airborne) • Obstacle detection and avoidance (ground) • Improved autopilot • Speech recognition

Figure 26 summarises system element designs needed to transition from current to next-generation autonomous UAV systems for civilian and military UAS.

Platforms	• Unreliable	• Safe, reliable
	• Short duration	• Long endurance
	• Vulnerable	• Survivable
	• Restricted airspace	• Controlled airspace
	• Single mission	• Multi-mission
Payloads	• Sensors only	• Weapons and sensors
Onboard Processing	• Vehicle and payload management	• Mission and contingency management
	• Signal processing	• Data Fusion; ATR
Communications	• Stovepipe	• Interoperable, net capable
	• Jam resistant	• Robust; secure; anti-jam
Mission Control	• Operator intensive	• Autonomous; intuitive HSI
	• Pre-planned	• Adaptive
	• Single vehicle	• Coordinated multi-vehicle
Support and Training	• Unique	• Common autonomic logistics

Figure 26 – System Element Designs Needed to Transition from Current to Next-Generation Autonomous UAV Systems.

These new paradigms are a combination of system attributes and technological capabilities. For instance, the data fusion, secure anti-jam, and coordinated multi-vehicle control require technological development as well as specific system development to bring full maturity to unmanned systems.

Finally, very small Micro UAVs (MAVs) and relatively large, sophisticated UCAV systems are examples of the range of UAVs that are applying the new platforms, payloads, onboard processing, communications, etc. to create next generation automated UAVs. It is with these new platforms, payloads, etc. that both UCAVs and MAV will be able to address similar operational challenges including:

- — **Mixed operation with other assets**:
  - Deconfliction, collision avoidance, C4I integration.
- — **Operation over populated areas**:
  - Safety issues.
- — **Need to reduce reliance on communications**:
  - UCAV – countermeasures.
  - MAV – limited size and power.
  - Limited line of sight environment.
- — **Need a fully integrated system**:
  - MAV propulsion/power generation still critical.
  - Operator machine interface critical.
  - All weather operations.
  - Survivability.

6.5 – Mission Readiness

6.5.1 – Mission Readiness Summary

This section summarises civil UAV mission readiness. The purpose of Mission Readiness is to assess the readiness status of the different technologies involved in UAS. In the present case this civil UAV mission readiness based on technology maturation forecasts that meet or exceed the desired, or required, capabilities identified by the user community.

Figure 27 summarises the mission readiness time forecasts for the different technologies. The technologies annotated with an asterisk (*) are shown within the figure with maturation forecasts based on development targets expressed in the US Department of Defences' UAV Roadmap document.

The purpose of the chart is to be able to identify when the capability to fly a particular mission can be expected as a function of time. The left-most end is the least probable and the right end the most probable timeframe.

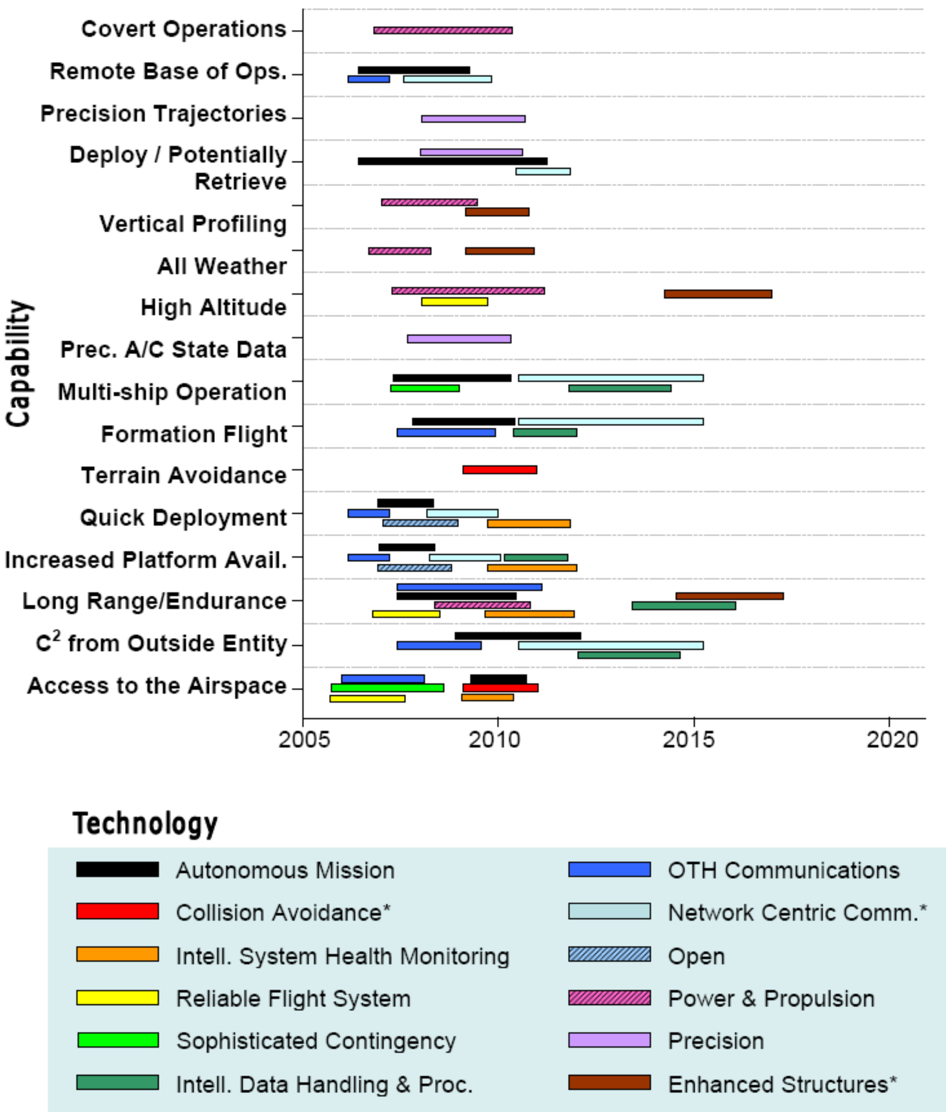

Figure 27 – Technology Maturation Summaries in Terms of Mission-Derived Capabilities.

6.6 – 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 conditions using different methods. It is not possible to draw final conclusions based on a limited number of small boat detection experiments, which are not representative of the multiple possible scenarios.

6.7 – 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 by the EC-JRC together with Elbit Systems in Haifa-Israel comprised the deployment of a UAS (Hermes-450) and one small 12-meter boat. A Radarsat-2, Spotlight image was acquired and several images collected by the Hermes-450. The experiment unveiled the potential of UAS for maritime surveillance, in particular for detection, tracking, classification and possible identification of small targets. The UAS was able to detect, track and classify small targets, such as small boats. For low UAS altitude flights identification may be possible in some cases. The small 12-meter boat was detected in the spaceborne SAR image.

The small boat detection trials carried out by the JRC were very successful since most small boats deployed during the experiments were detected in different sea states, wind speeds and geographical locations. The several small boat detection campaigns conducted by the EC-JRC seem to suggest that the probability of detection of small boats in spaceborne SAR images strongly depends on factors, such as the sea state, the wind speed, the type of boat (shape and materials), the weather conditions, among other factors. The results of the experiments conducted thus far are not enough to draw final conclusions about the feasibility of using spaceborne SAR imagery for small boat detection. However, the experiments have an overall positive outcome because they indicate that under suitable sea state and wind speed conditions it is possible to detect small boats using spaceborne SAR. The estimation of the probability of detection of small boats in spaceborne SAR images requires a large number of experiments under different circumstances (e.g. sea state, wind speed, characteristics of the targets, image type and mode, etc.).

Future plans include additional UAS experiments to asses its potential for maritime surveillance.

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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 Unmanned Aerial Systems (UAS) for small boat detection, tracking, classification and identification, as well as to study the potential of UAS for maritime surveillance. Since 2010 the EC-JRC has carried out a number of UAS maritime surveillance campaigns to study the potential of UAS for maritime surveillance, in particular for small boat detection. This report presents the results and conclusions of the JRC – Elbit Systems Coupled UAS and Spaceborne SAR campaign carried out in Dec. 2010 in Haifa, Israel.

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