SHIP SURVEILLANCE WITH TERRASAR-X SCANSAR

A. Gabban(1), H. Greidanus(2), A.J.E. Smith(3), L. Anitori(4), F.-X. Thoorens(5) and J. Mallorqui(6)

(1) Joint Research Centre (JRC), Italy, andrea.gabban@jrc.it
(2) Joint Research Centre (JRC), Italy, harm.greidanus@jrc.it
(3) TNO Defence, Security and Safety, The Netherlands, arthur.smith@tno.nl
(4) TNO Defence, Security and Safety, The Netherlands, laura.anitori@tno.nl
(5) Joint Research Centre (JRC), Italy, francois-xavier.thoorens@jrc.it
(6) Universitat Politecnica de Catalunia, Spain, mallorqui@tsc.upc.edu

ABSTRACT

During the last years, the demand for vessel surveillance has increased both for fisheries control and for maritime security and safety. In order to overcome the limitations posed by conventional systems, surveillance with satellite SAR is being adopted more frequently because of its possibility to provide ship detection over wide swaths and under many conditions. Up to now, different satellite sensors have been available for vessel surveillance. Nevertheless, considering revisit and coverage requirements, the availability of additional satellite sensors is of interest. Thus, this study evaluates the quality of the new TerraSAR-X (ScanSAR mode) and gives a preliminary impression about its performance for vessel detection. For the study, two images were acquired over The Netherlands' Western sea board in April 2008. Concurrent information on vessel positions was available from AIS and (limited) VMS. On both the acquisitions, weather and sea conditions were quite calm, resulting in very low background sea clutter enabling recognition of quite weak features. The two ScanSAR images have a resolution of 16 m, incidence angles around 39 degrees and HH polarisation. They were analysed with automatic ship detection software ("SUMO") and also manually inspected.

The images contain many ships and also platforms and windmills. Generally speaking, ship detection is limited by noise, clutter, in-homogeneities, features and artefacts in the image background, which hamper detection of the weakest targets or cause false alarms. Specifically these images show, concerning natural features on the sea surface: "cloud"-like wind in-homogeneities; sharp and more diffuse sea water fronts; shoals, banks and possibly some sea bottom topography; small-scale striations perpendicular to the coast; and waves breaking on the shore. Concerning image quality, a critical evaluation shows: striping parallel to the range direction with a period of about 2.5 km, and additionally as 1-pixel wide lines; azimuth ambiguities of strong targets at around 5 km offset; in one image, also range ambiguities at about 57 km offset; and km-long sidelobes in range and azimuth from a few very bright ships. The measured ENL is around 5-6 except in some bands parallel to the azimuth direction where it reaches 9-10; while this shows that optimum use has been made of the available raw data, such a variation of ENL within the image is undesirable for some automatic ship detection algorithms that work with a pre-defined ENL value. When comparing image geolocation, only using data in the main image tiff file, to GCPs in Google Earth, inaccuracies of up to 700 m are found.

Although the effects mentioned above lead to false alarms (or, equivalently, necessitate a higher threshold setting leading to less detection sensitivity), the ships present in the images appear mostly with good contrast and, for the larger ones, well-defined outlines. In many cases wakes of the turbulent and Kelvin type are associated. In case of the AIS-carrying – larger – vessels, there is mostly no difficulty in detecting them, and the length and heading estimated from the SAR image compares mostly well with the AIS values. For the VMS-equipped fishing vessels, 4 out of 14 vessels with a length below 20 m could be seen.

Based on this limited sample, as preliminary conclusion it can be said that the TerraSAR-X ScanSAR images are well suitable for vessel detection over wide areas in calm conditions.
1  INTRODUCTION:

During the last years, the demand for maritime surveillance has increased continuously, in particular for fisheries control, maritime security and maritime safety. One of the main challenges for maritime surveillance has been the search for targets over relatively large areas of sea. Coastal-based surveillance systems are widely used but are limited in their coverage far away from the coast. Thus, the use of satellite sensor data is being adopted more frequently to overcome these limits. The possibility to provide ship surveillance over wide regions and under many conditions has led SAR (Synthetic Aperture Radar) to be one of the most adopted choices. SAR permits to acquire images of the area of interest both during the day or the night, and independently of cloud conditions. Different imaging modes are available and they can be selected depending on the extent of the area to monitor and the sizes of the targets of interest. This has been highlighted by extensive campaigns to detect vessels using satellite SAR imagery from RADARSAT-1 and ENVISAT-ASAR [1, 2]. On the high seas, where the area to monitor is large and the vessels are also usually big, modes with swath from 300 to 400 km² (50+ meter resolution) can be used. On the other hand, in coastal and shelf areas, where the vessels can be smaller but the areas to monitor are also smaller, modes with 100 km swath (resolution less than 25 meter) can be used. Up to now, different satellite sensors have been available for vessel surveillance. However, the availability of additional sensors is always of interest because of the revisit and coverage requirements necessary in that activity. TerraSAR-X is one of the new additional satellite sensors and this study aims to assess its performance for vessel detection. In particular, considering the need for wide area surveillance, the ScanSAR mode (100x150 km² swath and 16 m resolution) was selected.

As the specs of the TerraSAR-X ScanSAR mode [3] are better than RADARSAT/ASAR’s Standard/Image modes (increased resolution, higher Equivalent Number of Looks ENL) an increased performance was expected. This would be very welcome, because RADARSAT/ASAR’s Standard/Image modes have limitations to detect small vessels (detection rate starts to decrease markedly with vessel size for vessels smaller than the resolution) and because their target size estimates are of limited accuracy. Also the shorter synthetic aperture times of X-band imaging (at a given resolution) will lead to less azimuth smearing, which often strongly degrades ship images when a swell is present, causing big problems for target classification. Differences in performance (compared to C-band) may also be expected due to different backscattering of the target and different sea clutter characteristics. From previous data it is known that at X-band the ocean surface is more prone to the influence of atmospheric effects [4], so we may expect more wind-induced ocean features that give rise to false alarms.

The success rate of ship detection is depending on several variables, such as meteorological conditions and sea state, vessel size, type and heading, sensor orientation, incidence angle, polarisation, etc. However, the present study does not aim to quantify these dependencies because much more data would be needed for that. Rather, the present study aims to evaluate the first results. Furthermore, the present study excludes other modes of TerraSAR-X. Even if it is certainly of much interest to study high-resolution ship images as produced by TerraSAR-X, and also to see whether Along-Track Interferometry (ATI) mode would be able to obtain ship speeds, these topics are not included in the present analysis.

The approach of the study is quite straightforward. A few TerraSAR-X (TSX) images over an area where the vessel traffic is (partly) known are collected. For this reason, the North Sea off the Netherlands western coast was selected. Here it is possible to have access to data from AIS (Automatic Identification System) and VMS (Vessel Monitoring System); these systems are capable of giving vessel positions at the time of imaging – AIS for the larger merchant vessels, VMS for the larger fishing vessels. More in detail, AIS is a ship-borne transponder system via which the larger ships exchange their positions with each other and with the shore. This is used in navigation primarily for maritime safety and in particular for collision avoidance. AIS messages from ships are collected by coastal receivers. The range of coastal AIS receivers is typically 40 nm, but can be considerable longer if the receiver is installed on an elevated position, and also during particular atmospheric conditions that are favorable to VHF propagation. Among others, the AIS message contains information regarding vessel position, heading, length and width. On the other side, VMS is a satellite-communications based system which reports fishing ships’ whereabouts to the authorities at regular intervals. EU legislation mandates the use of the VMS
on fishing vessels longer than 15 meters, to monitor and control fishing vessel operations. VMS data (i.e. positions from fishing vessels) are confidential and are collected by national authorities in their Fisheries Management Centres (FMCs).

During the study, the TSX images were analysed both manually and with automatic ship detection software. For the latter, “SUMO” (Searching for Unidentified Maritime Objects) was used. SUMO is a software package for automatic detection of vessels on spaceborne SAR imagery, developed at JRC (Joint Research Centre). Based on the JAVA computer language, it can read most types of processed satellite SAR images. It has been developed on RADARSAT and ASAR imagery (C-band), and has been extensively tested for many imaging modes (resolution, incidence, and polarisation) of these sensors. This detector works with a “conventional” approach of detecting bright clusters above a local background (CFAR or Constant False Alarm Rate) [5]. SUMO is regularly used during seasonal campaigns to monitor fishing activities in national or European control operations.

2 DATA DESCRIPTION

2.1 Study Area

At the time of writing, two images were acquired over the North Sea off the Netherlands’ Western coast. The area covered by each image is represented by a green box in Fig.1.

![Figure 1: Selected area for acquisition A (April 5, 2008) and B (April 19, 2008).](image)
2.2 Satellite Sensor Data:

In Table 1 the details of both acquisitions are reported. Two TerraSAR-X images in ScanSAR mode were acquired on two different days, one image early in the morning and one in the evening. The ScanSAR mode permits to cover an area of 100x150 Km². The selected polarization was HH since is less sensitive to water roughness than VV polarization and, thus, better suitable for the purpose of ship detection [6]. During both days the weather and the sea conditions were quite calm. Fig. 2 shows the overviews of the two acquisitions.

<table>
<thead>
<tr>
<th>Acquisition</th>
<th>Acquisition A</th>
<th>Acquisition B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acquisition date</td>
<td>April 5, 2008</td>
<td>April 19, 2008</td>
</tr>
<tr>
<td>Acquisition time</td>
<td>05:59 UTC</td>
<td>17:26 UTC</td>
</tr>
<tr>
<td>Polarization</td>
<td>HH</td>
<td>HH</td>
</tr>
<tr>
<td>Sensor mode</td>
<td>ScanSAR</td>
<td>ScanSAR</td>
</tr>
<tr>
<td>Product type</td>
<td>Multi-Look Ground Range Detected</td>
<td>Multi-Look Ground Range Detected</td>
</tr>
<tr>
<td>Orbit Precision</td>
<td>Rapid</td>
<td>Rapid</td>
</tr>
<tr>
<td>Pass direction</td>
<td>Descending pass</td>
<td>Descending pass</td>
</tr>
<tr>
<td>Looking direction</td>
<td>Right looking</td>
<td>Right looking</td>
</tr>
<tr>
<td>Range resolution</td>
<td>16.8</td>
<td>16.8</td>
</tr>
<tr>
<td>Azimuth resolution</td>
<td>17.7</td>
<td>17.7</td>
</tr>
<tr>
<td>Incidence angle minimum</td>
<td>36.12</td>
<td>34.06</td>
</tr>
<tr>
<td>Incidence angle maximum</td>
<td>43.89</td>
<td>42.19</td>
</tr>
<tr>
<td>Daily wind average speed</td>
<td>3.9 m/s</td>
<td>6.3 m/s</td>
</tr>
<tr>
<td>Daily wind average direction</td>
<td>321 deg</td>
<td>83 deg</td>
</tr>
</tbody>
</table>

*Table 1: Details of the acquisitions.*
2.3 GROUND DATA

The collection of AIS (Automatic Identification System) and VMS (Vessel Monitoring System) data permitted to have concurrent information on vessel positions during acquisitions. Moreover, using that information it was also possible to locate and discriminate platforms and windmills in the study area.

AIS data were provided by TNO Defence, Security and Safety (both acquisitions) and by the commercial supplier AISLive Ltd (first acquisition only).

VMS data were collected by the Netherlands fisheries control authorities for both the acquisitions.

3 METHODS

The TerraSAR-X images were inspected manually and then analyzed with the SUMO automatic ship detection software. The manual analysis consisted in carefully inspecting the acquisitions in order to highlight general characteristics of the images as produced by the ScanSAR imaging mode of TerraSAR-X. In particular, the presence of natural features which could cause problems for the detection of vessels or false alarms and the overall quality of the images were inspected. Additionally, image geolocation was tested by comparing the location of different objects in the images with the location of the same objects on Google Earth.

The use of SUMO, on the other hand, aims to assess the suitability of this kind of sensor to be used for vessel detection in an automatic way. For each image, the vessels automatically detected were manually inspected to evaluate the quality of the detection and to identify possible false detections. After that, a comparison between detected vessels and information extracted from AIS and VMS helped to assess the detection performance.
At first sight it is possible to clearly identify in both the images many ships and also platforms and windmills. A manual inspection was done to identify natural features and to highlight problems in the quality of the images. Concerning natural features on the sea surface the images showed the following: “cloud”-like wind in-homogeneities; sharp and more diffuse sea water fronts; shoals, banks and possibly some sea bottom topography; small-scale striations perpendicular to the coast; and waves breaking on the shore (Fig. 3). On the other hand, concerning image quality, a further critical evaluation showed: striping parallel to the range direction with a period of about 2.5 km, and additionally as 1-pixel wide lines (Fig. 3); azimuth ambiguities of strong targets at around 5 km offset (Fig. 4 and 5); in one image, also range ambiguities at about 57 km offset; and km-long sidelobes in range and azimuth (Fig. 6) from a few very bright ships or artificial structures on land. The measured ENL was around 5-6 except in some bands parallel to the azimuth direction where it reached 9-10. The image geolocation was assessed by comparing data in the main image tiff file to GCPs (Ground Control Points) in Google Earth. This analysis showed inaccuracies of about 70 meters in the centre of the image, going up to 750 m with GCPs selected at the top of the image and to 650 m at the bottom. In particular, both the images presented a shift toward left in the top and a shift toward right in the bottom compared to GCPs in Google Earth.

The analysis with SUMO evaluated the suitability of TerraSAR-X for automated vessel detection over a wide area. Both the images were analyzed and the results were compared with the positions reported by AIS and VMS. The automatically detected targets were visually inspected (Fig. 6). In particular, all the targets corresponding to false alarms, due to land or structures recognized as vessels, ambiguities (azimuth and range), platforms and windmills were removed; that operation reduced the number of detected targets from 614 to 230 in acquisition A (April 5th), and from 406 to 123 in acquisition B (April 19th). Thus, the detected targets were compared with information coming from AIS and VMS.

For acquisition A the number of distinct AIS signals was 59. Among them, 56 were exactly identified by SUMO meanwhile the remaining 3 were classified as possible vessels. For the same acquisition we had 7 VMS of which 1 detected, 3 related to vessels anchored at port, 2 corresponding to visible vessels on the image but not automatically detected and 1 linked to a not visible vessel.

For acquisition B the number of distinct AIS signals was 109. Among them, 102 were identified by SUMO, while 5 were visible but not detected and 2 not visible at all in the image. For the same acquisition we had 7 VMS of which 2 detected, 1 anchored at port, 1 visible but not detected and 3 not visible in the image.

For acquisition A it was also possible to estimate the goodness of the heading estimation made by SUMO during the detection (the AIS data of acquisition B lacked heading information). Results showed that for the 44 % of the cases the estimation presented an error of less than 20 degrees and for the 32 % of the cases the error was less than 10 degrees. In both acquisitions, the comparison of the estimated length with the real (AIS) length highlighted a good quality of the estimation for large vessels, with errors up to 10 meters. Nevertheless, the estimation of length of targets oriented in the azimuth direction was often overestimated, as well the width of vessels regardless the orientation.

Furthermore, SUMO was able to detect 171 targets in acquisition A and 24 in acquisition B which were not identified by any AIS or VMS signal. A visual inspection of those detections permitted to discriminate 12 probable noises in acquisition A and 4 in acquisition B. All the other targets, 159 in acquisition A and 20 in B, were retained to be vessels. Most of these targets detected in the SAR image but without AIS or VMS were far away from the coast, so outside of AIS coverage.
Figure 3: This image shows sand banks, waves breaking on the shore and striping present in both the study images.

Figure 4: Strong azimuth ambiguity placed at 5.2 Km above the real target. Most of the bright spots inside the ambiguity could be detected and confuse as vessels.
Figure 5: Example of azimuth ambiguity place at 5.2Km below the real vessel. That kind of ambiguity could easily lead to a false detection. The real vessel (on the left) is difficult to distinguish from the radar ambiguity (on the right).

Figure 6: Example of anchored vessels detected by SUMO. For those kinds of vessels (bigger than 100m) the estimation of the heading and of the length resulted quite precise. In the center-bottom vessel is it possible to observe an example of sidelobe effect.
5 CONCLUSIONS

The study analyzed two TerraSAR-X acquisitions made over The Netherlands’ western sea board during two different days in April 2008, in order to assess the potential of this new sensor to be used for vessel detection over wide areas. Thus, it was decided to select the ScanSAR mode for both the acquisitions. This imaging mode permits to cover a scene of 100x150 Km² and provides a resolution of 16 meters. The ships visible in the images appeared mostly with good contrast and, for the larger ones, with well-defined outlines. The geolocation of the images, assessed by comparing the position of selected targets in the images with the same in Google Earth, highlighted inaccuracies of up to 700 meters. These inaccuracies led to uncertainties during the correlation of detected vessels with their corresponding AIS or VMS signals. Moreover, the measured ENL was around 5-6 except in some bands parallel to the azimuth direction where it reached 9-10; while this shows that optimum use has been made of the available raw data, such a variation of ENL within the image is undesirable for some automatic ship detection algorithms that work with a pre-defined ENL value.

The use of the SUMO automatic ship detection software directly on the images showed its good potential in detecting both large and small boats. While this software has been used extensively on campaigns for fishing vessel detection, no tests had been done before using X-band instead of the normally used C-band. Thus, the vessel detection algorithm developed for C-band images included in SUMO was directly applied on TerraSAR-X products. SUMO demonstrated that, in case of the AIS-carrying – larger – vessels, there was mostly no difficulty in detecting them, and the length and heading estimated from the SAR image compared mostly well with the AIS values. On the other hand, for the VMS-equipped fishing vessels, 4 out of 10 vessels with a length below 20 m were not visible in the images.

Based on this limited sample, as preliminary conclusion it can be said that the TerraSAR-X ScanSAR images are well suitable for vessel detection over wide areas in calm conditions.

6 ACKNOWLEDGMENTS

The Netherlands Fisheries inspection authorities have made a crucial contribution to this study by collecting VMS data.

7 REFERENCES