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# Identification of SAR Detected Targets on Sea in Near Real Time Applications for Maritime Surveillance

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**KEYWORDS:** Remote sensing, Synthetic Aperture Radar (SAR), Automatic Identification System (AIS), data fusion, Maritime Surveillance, Maritime Situational Awareness.

**ABSTRACT**

*Remote sensing technologies are widely used in maritime surveillance applications. Nowadays, spaceborne Synthetic Aperture Radar (SAR) systems provide outstanding capabilities for target detection at sea for large areas independently from the weather conditions. The generated value added target detection product is composed by complementary information from the Automatic Identification System (AIS). Resulting information layers provides a more reliable picture on the maritime situation awareness. This paper describes the approach of SAR-AIS data fusion and its visualization means developed for Near Real Time (NRT) Applications for Maritime Situational Awareness by the Maritime Security Lab at the Ground Station in Neustrelitz, part DLR's German Remote Sensing Data Center (DFD). Presented implementation is based on combination of many open source geospatial libraries and frameworks (e.g., GDAL/OGR, Geoserver, PostgresSQL) and shows their effectiveness in the context of complex automated data processing in the frame of NRT requirements.*

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# 1 Introduction

The global economy is highly dependent on the shipping industry. Because of maritime transport development, nowadays ocean does not divide the world, but connects. Shipping has always been the only low-cost method of freight transport over long distances. Today, 80% of all goods are transported over the sea including oil, oil products, coal, ore, grains and others. With growing world's economy the exchange of goods utilizing maritime transport on the global scale is growing steadily, which causes an increase of ship traffic. New routes are being developed, e.g., –a North -East or North- Wert passage, opening new routing opportunities due to the global climate changes. To understand the situation and ensure maritime safety and security regarding to the shipping density as well as environmental monitoring, maritime surveillance applications are nowadays of paramount importance.

Spaceborne Synthetic Aperture Radar (SAR) systems have already proven their effectiveness on maritime surveillance. The main advantage of SAR sensors is their capability to perform observations of the Earth's surface independent from the weather conditions and time of the day. Furthermore, they can cover large areas – up to several hundreds of kilometers wide at the same time. Limitations related to the revisit time are still there, but could be reduced by involving several different missions, e.g., – TerraSAR-X, Radarsat-2, and Sentinel-1. Data acquired from these satellites demonstrated its efficiency in maritime surveillance applications, including such task as target detection at sea.

Although the SAR target (ship) detection product provides ship's position and its parameters, such as width, length and even heading (Tings, et al., 2015), this information can still not provide a complete maritime picture. Complementary information from vessel tracking systems, in particular from Automatic Identification System (AIS) can provide such parameters, like vessel type (according to international classification), speed, course over ground as well as its width and length. AIS messages are broadcasted with an update rate up to some seconds, and mandatory for all vessels larger than 300 of gross tons and all passenger ships irrespective of size.

Integration of both datasets, – SAR-derived detections and AIS data, enables to perform much more complex analysis for maritime surveillance. In particular, SAR detection would confirm vessel's physical persistence in addition to AIS reports. At the same time, vessels can be detected which due to technical reasons or malicious actions not broadcasting AIS messages.

The overall state of the NRT applications in the maritime domain at DLR's Ground Station Neustrelitz, is given in (Schwarz, et al., 2015). This paper emphases on the complete automated processing chain of deriving ship detection products with associated AIS information, which already has been integrated for operational use and being under further development.

The paper is organized as follows. Section 2 gives an overview about the whole processing chain. Section 3 explains the approach of SAR-AIS data fusion. The dissemination and visualization of resulting products are described in Section 4.

# 2 Processing, Workflow and Framework

Ground Station Neustrelitz is the main receiving and processing facility for the TerraSAR-X mission composed by the TerraSAR-X and TanDEM-X satellites. In 2015 the capabilities of the Ground Station has been extended with a Regional Ground System (RGS) to support Radarsat-2. Furthermore the collaborative ground segment to support the Copernicus Mission Sentinel-1 has been developed.

The data, received by the ground station are immediately transferred to the processing system. The whole processing is controlled by the Processing System Management (PSM) developed by DLR and Werum Software & Systems AG (Boettcher, et al., 2001). The implemented PSM control system forces rule based scheduling of different processors and call them step-by-step or in a parallel sequence. Figure 1 shows the general workflow sequence of the ship detection NRT application controlled by the PSM.

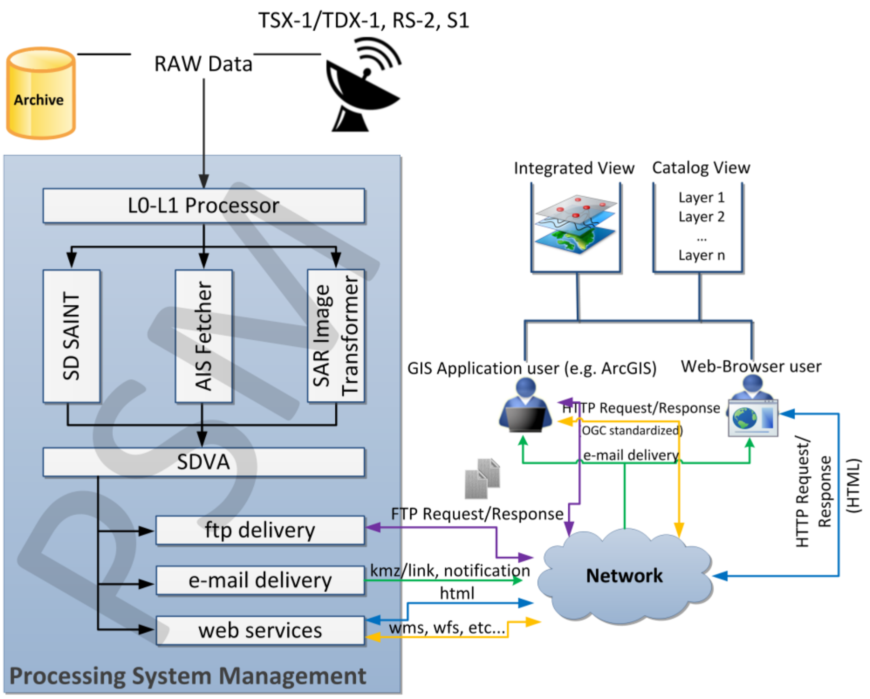



Figure 1: NRT ship detection processing workflow

The first value adding processor requires satellite sensor specific processing up to level 1b (L1b). At this point, RAW sensor data being processed to the image form with applied radiometric calibrations and extracting geolocation information. For TerraSAR-X and TanDEM-X satellites - the TerraSAR Multi Mode SAR Processor (TMSP) takes care on this task (Breit, et al., 2008).

The next three processing steps, SD SAINT; AIS Fetcher and SAR Image Transformer are scheduled in parallel as they are independent from each other. All three processor modules using the same L1b input product, and they are common for all available SAR sensors.

For the SAR target detection task the SAR AIS Integrated Toolbox (SAINT), developed in the Maritime Safety and Security Lab in Bremen, is used. The detection algorithm based on constant false alarm rate (CFAR) detector. Then, the derived binary mask, showing positions of ships on the image, is used for the parameter estimation of every detected vessel. More detailed information about the algorithms and methods used in SAINT are described in (Tings, et al., 2015) and (Brusch, et al., 2010). The output of the SAINT is a point data layer showing vessel positions in projected geographical coordinates with estimated attributive values like vessel's length, width and heading.

AIS Fetcher performs collection of the AIS data for required time extent (imagery time) and coordinates (geographical bounding box of the input L1b image). The processor has been developed in the Maritime Security Lab Neustrelitz, part of the DFD. It queries the AIS data from local database (DB) in case of historical requests or collects them from external sources like AIS providers. The software is also capable to decode RAW AIS sensor data in several formats and push them into the local DB for future use. The output of AIS Fetcher is a point data set with dynamic and static AIS attributes. Every sequence of AIS messages for specified request is processed through the embedded AIS Plausibility Processor (Heymann, et al., 2013), developed in the Institute of Communications and Navigation, part of DLR. The Processor checks certain values of the AIS message data in the context of the plausibility of the vessel behavior, in particular how fast the vessel moves, how it changes the course, etc. The processor extends every AIS message with additional fields showing possible errors in certain attributes.

The image processing software SAR Image Transformer is called to apply automatically geolocation information provided with L1b image, adjust the histogram and generates several outputs: The full resolution L1b geotiff image in UTM and in EPSG:4326 projections. Currently the processor supports data processing from the satellites TerraSAR-X, Radarsat-2 and Sentinel-1. Furthermore, quicklook products in .png and .kmz format (for visualization in Google Earth) are generated.

The next, according to this this paper most relevant, processing step is the data fusion of SAR detected ships and AIS reports. The Ship Detection Value Adder (SDVA) developed in the Maritime Security Lab Neustrelitz executes the data fusion operation. As an input the SDVA accepts the output from all the previous processing steps. Namely, SAR ship detection results (point data), AIS reports for specified area and time (point data), the quicklook image (for visualization of the results), and the L1b image metadata. The algorithm behind will be discussed in the next section. The resulting data fusion product is generated in different final formats like Google kml/ kmz, ESRI shape file, json and many others.

The last step of the NRT ship detection chain handles the product dissemination. Different delivery options are available like ftp/ sftp, via e-mail (e.g. - kmz), as well as via web mapping services, enabling customers the direct use of product results in their GIS applications over OGC interfaces (wms, wfs) or in web-browser using web-mapping client.

# 3 SAR-AIS Data Fusion

The Ship Detection Value Adder (SDVA) performs the data fusion between SAR detected targets and AIS reported information for a requested spatial and time extent. The general workflow of SDVA is shown the figure 2.

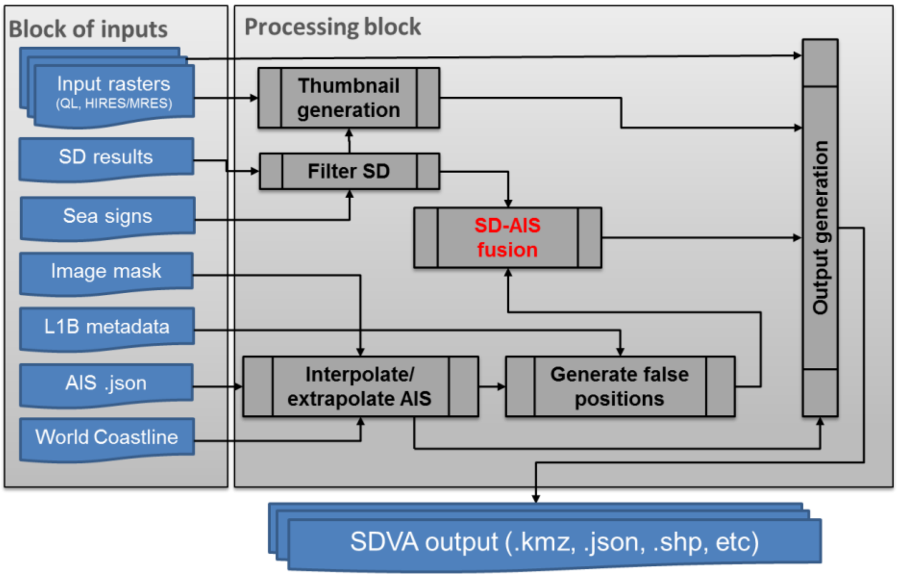



Figure 2: Ship Detection Value Adder workflow.

In order to fulfill near real time delivery requirements, most of the operations in SDVA, by analogy to all the other processors of NRT ship detection chain, are implemented in a high level of parallelization.

Nowadays, besides the ships, there are many generally known objects on the open sea. In particular, these are windfarms, oil platforms and buoys. Such objects are often detected as vessels, and looking on their estimated parameters, they are really not much different from the real detected vessels. Therefore a filtering step of ship detection results has been implemented. Filtering is done by checking if the detected object spatially intersects with objects in the database of sea signs. Once filtering is done, a thumbnail (zoomed in picture from original geotiff) will be generated for the final result. These thumbnails are embedded into the kmz product file and WMS services for the OGC feature info requests.

## 3.1 AIS Interpolation

The L1b image will be available within 10 minutes after downlink. Because of this delay, it is possible to collect some AIS data not only for the time before the image acquisition, but also up to 10 minutes afterwards. This allows reconstructing of vessel tracks in order to get an AIS ship position of highest accuracy according to the imagery time. The implemented solution enables more precise SAR-AIS data fusion based on the exact imagery time for every ship and solve the following problems:

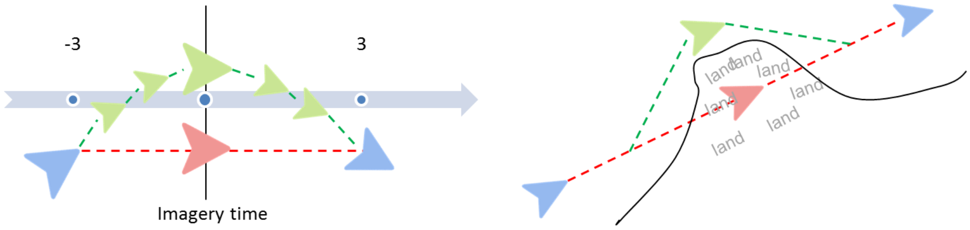
1) In the real world the AIS reports for moving vessels are being broadcasted in a different reporting interval. The transmission of updates mainly depends on the speed over ground (SOG) of the vessel. Furthermore updates occur at different intervals depending on whether a Class A or Class B transponder is used. Unfortunately, not always all of transmitted reports are being collected due to the different technical reasons. Furthermore, often

AIS providers resample the data by time. As the result, in some cases the update rate for available AIS reports could be up to a few minutes.

2) By using different acquisition modes SAR images are extended to cover very large areas, up to thousands of square kilometers. To scan such big area SAR sensor needs several seconds up to more than one minute. Even 30 seconds make big sense, e.g., a cargo vessel moves on the open sea with the speed of 20 knots which is around 10 meters per second. During the only 30 seconds, this ship will pass the distance of about 300 meters. Therefore, for prediction of the AIS position at imagery time, a specific imagery time in the proper image area should be considered. The auxiliary information for time calculation in specific places on the image is available in L1b metadata.

The first step is a reconstruction of AIS tracks with minimum specified time step. The new calculated positions are derived using "dead reckoning" concept, based on the last position, speed and course over ground as illustrated on figure 3.a.

The new positions are always crosschecked if they are not intersecting the coast line. If the new position falls on the land area, it is iteratively corrected as shown on Figure 3.b.




a) b)

7

Figure 3: AIS track reconstruction

The new attribute values for speed and course over ground are calculated by local weighted interpolation from known surrounding points

$$a_i = a_{i-1}w_{i-1} + a_{i+1}w_{i+1} \quad (1)$$

where $a_i$ is the attribute value for a new point to be calculated, $a_{i-1}$ and $a_{i+1}$ are the attribute values from neighboring points, $w_{i-1}$ and $w_{i+1}$ are corresponding weights for the known attributes and based on their distance from predicted point:

$$w_{i-1} = 1 - \frac{d_{i-1}}{d_{i-1}+d_{i+1}} \quad \text{and} \quad w_{i+1} = 1 - \frac{d_{i+1}}{d_{i-1}+d_{i+1}} \quad (2)$$

where $d_{i-1}$ is the distance from "left" known point to predict, and $d_{i+1}$is the distance from predicted point to the "right" known point.

If the predicted point is outside of the known track, namely has only one known neighbor, then the last known attribute is taken as the new point.

AIS positions at imagery time are derived in the following way. The reference time for the whole image must be defined. The optimal choice is to take a middle time point between image start and stop times. Then, it is necessary to find the closest AIS reports in time, relative to the reference time. In the next step, AIS geographical coordinates that reported closest to the reference time are used to determine on which part of the image they would appear. Normally, for every L1b SAR image the metadata provides means for computation the imaging time for every pixel. Furthermore, the time deviation in range (dimension x) direction is not significant; the most important is the time according to the azimuth (dimension y) direction. This can be calculated in different ways: out of provided georeferenced grid or by simple linear interpolation between imaging start and stop times.

## 3.2 Project Displaced Positions

Dealing with SAR images it is known that moving targets can be displaced on the image from their actual position. This effect caused by additional Doppler shift introduced by moving objects. If the object is moving in the flight direction (along-track) with the satellite, then it will be just blurred. When the object motion trajectory is crossing the sensor (across-track), the object's position will be shifted in the azimuth direction. Depending on the object's velocity, such displacement can reach up to several hundred meters. Therefore, prior the fusion of SAR detected targets and AIS reports, this effect has to be considered. More detailed explanation of theory of moving objects in SAR images can be found in (Meyer, et al., 2007). Some examples of azimuth displacement are shown on Figure 4.

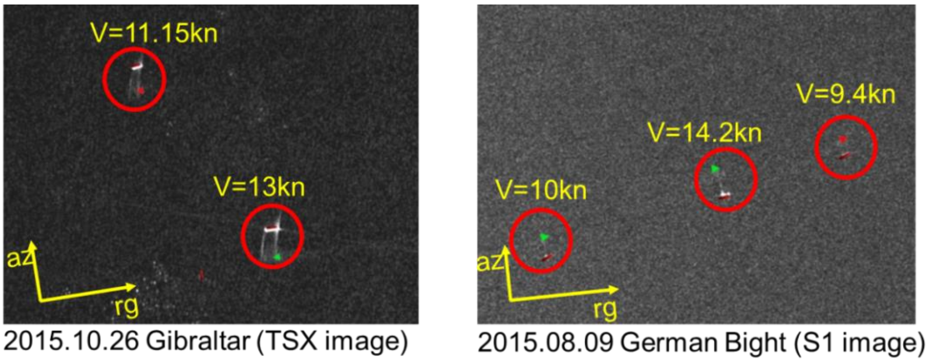



Figure 4: Azimuth displacement due to across-track movement

The azimuth shift of the moving object can be estimated following way

$$\Delta_{az} = -R\frac{V_{at}}{V_{sat}}[m]$$

where $\Delta_{az}$ is object's azimuth displacement, R is the distance between the object and the satellite, $V_{sat}$ is the satellite velocity and $V_{at}$ is the object velocity in across-track direction.

For several decades, researchers have studied object motions in SAR images. A number of methods to compensate this effect have been proposed, (e.g., Raney, 1971; Meyer, et al., 2005; Arii, 2014). In particular, with integration of a priori knowledge, such like road databases and vehicles radar signatures (Meyer, et al., 2007), or by direct velocity estimation out of image characteristics (Raney, 1971; Arii, 2014).

However, AIS reports provide the information about vessel's speed and course, which offer the possibility to calculate $V_{at}$ and $\Delta_{az}$ respectively. The reversed method was applied, where for AIS reports at imaging time a displaced position on the image is calculated. This approach is of low computational cost which is crucial for NRT services. Although the errors are possible, especially on port areas, it provides sufficient accuracy and widely used in the context of SAR-AIS data fusion, e.g., (Zhi Zhao et al., 2014; Mazzarella, et al., 2015).

## 3.3 SAR-AIS Data Fusion

After extracting AIS reports at imaging time and projecting their positions according to the Doppler shift a fusion between AIS reports and SAR-detections takes place.

SAR-AIS composition is implemented by double nearest neighbor search. First, for every AIS message with projected position on the image a nearest SAR detected target has to be associated. For different reasons, e.g., low resolution of SAR image it is possible that for a particular AIS report, there is no corresponding SAR target detection. Therefore a special, empirical threshold for the search area was specified. Once the closest SAR target has been found, the distance (Das) between AIS and SAR objects is remembered. If there was nothing found within the searching area, it is assumed there is no target for assigning.

The second step is iteration through the SAR objects and linking to the closest AIS report. This operation is similar to the AIS-SAR relation described above. The distances between SAR and AIS targets (Dsa) are saved as well.

Comparison of AIS-SAR and SAR-AIS relations is applied before finishing this process. When both relations in both directions have the same distances (Das = Dsa), it is assumed the association is valid, and attributes from AIS are linked to the corresponding SAR target.

# 4 Visualization

Providing NRT services it is very important that the end user gets the resulting products in time. Besides skilled GIS analysts, the data should be readable and comprehensible for the customer and require no special software. This concept was the determining factor in designing the products. For this purpose a number of output formats and delivery methods are implemented. As shown in Figure 1, currently three possible delivery methods are implemented:

1. Transfer files via sFTP or FTP server. This method is oriented for experienced GIS analysts, which prefer to define their own visualization and perform deeper analysis. After the processing, files are automatically transferred to either DLR delivery server or user site. The file set may include: ESRI shape files (as well as json and ASCII) containing ship detection results (point data) with assigned AIS attributes; layer with all available AIS data for the scene; quicklook or full resolution SAR image in geotiff or png format.
2. E-mail notification – a short message notifying about available results via FTP (described above) and set of files attached, with the maximum total size of 5 MByte. The e-mail could contain a set of different files based on the user requirements, e.g., an ASCII text file with detected targets, a georeferenced quicklook png image in UTM projection, as well as a kmz file. The kmz file is composed by integrated layer view of results, including the SAR ship detections, AIS reports (points and restored tracks) and quicklook overlay of SAR image. Example of kmz is shown on figure 5.
3. The web services solution enables dissemination of NRT products to the user without copying them (in the usual meaning of copy). Two ways of using web mapping services are possible: direct integration into the GIS software over the OGC services (wms, wfs), served by GeoServer, or using web-mapping client, which requires only a web browser. The web-mapping client is based on front-end components of Environmental and Crisis Information System (UKIS), developed at DFD, which is implemented by using the latest web technologies, such as AngularJS and Leaflet. The client is platform independent and supports any modern web-browser without need of any extra software or plugins. Example of product view in the UKIS client shown in Figure 6.

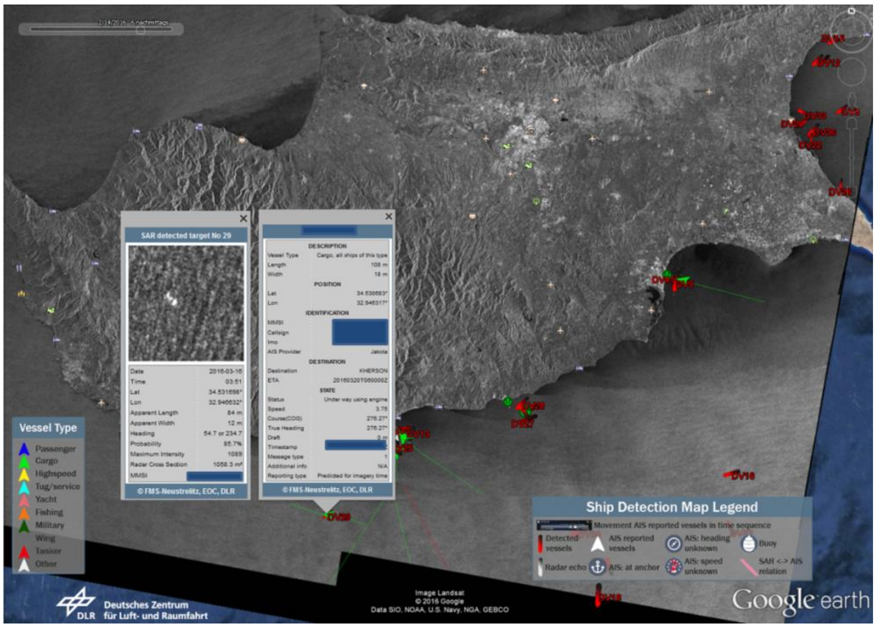



Figure 5: Example of kmz output visualized in Google Earth

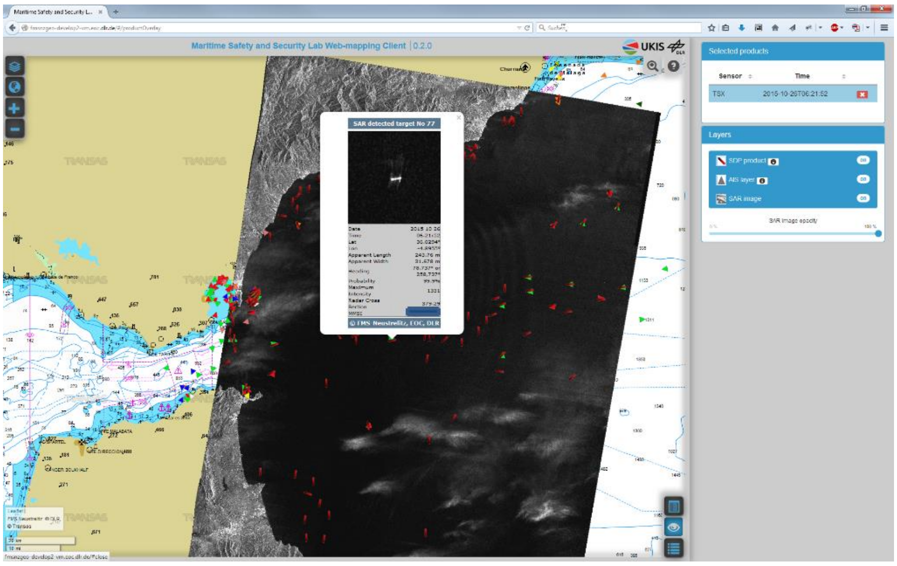



Figure 6: Product view in web-mapping client

## 5 Conclusion

This paper discusses the SAR-AIS data fusion methods, part of the automated processing chain for NRT ship detection and identification, developed at DLR. The workflow is implemented in a high level of parallelization, to ensure deriving ship detection products within 10 to15 minutes after image acquisition.

Although the presented approach showed good results according to the service performance and product accuracy, regardless there is still space for improvements. In particular, for AIS interpolation and data fusion more complex models could be applied in order to improve the accuracy, especially near the coast or port areas where the vessel routes are not linear. This can be improved, for example, by utilizing additional auxiliary information about the traffic on the sea like it was proposed by (Mazzarella, et al., 2015).

The integration of the new sensors and data streams, not only from radar, but also optical sensors, as well as satellite based AIS will increase the reliability of the service.

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