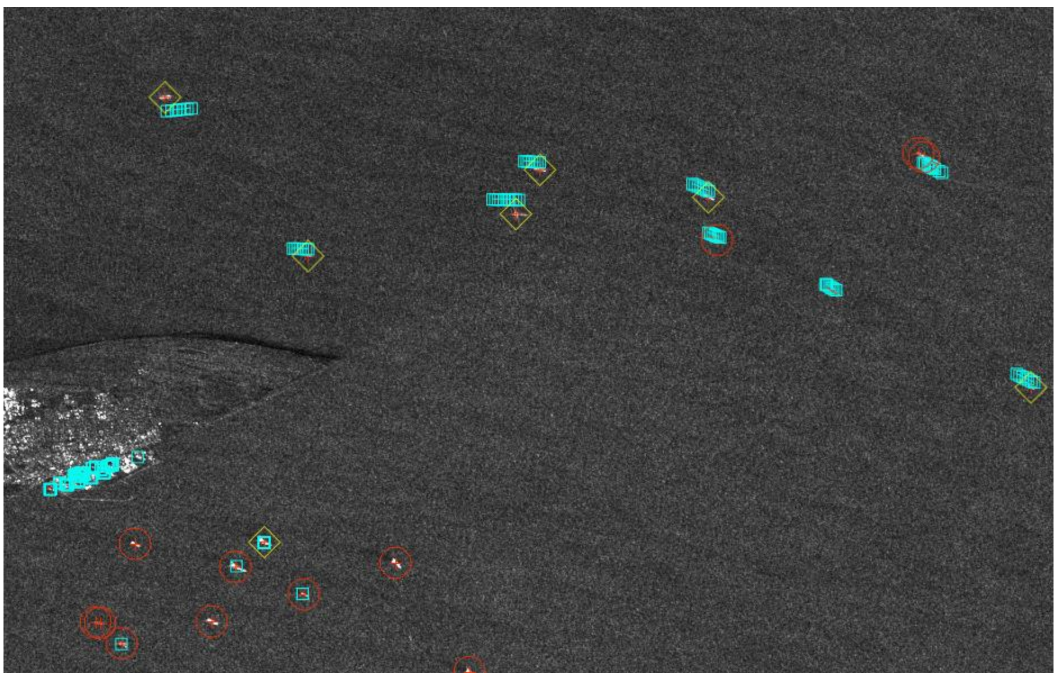
SARSCAPE TUTORIAL:
SHIP DETECTION AND AIS MATCHING



July 2026

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I. INTRODUCTION

The ship detection algorithm is based on a two-parameter Constant False Alarm Rate (CFAR) detector approach, a form of the Adaptive threshold algorithm. The goal is to identify brighter areas or "targets" of significant backscatter (from the statistical point of view), stronger than defined surrounding background. To avoid spurious effects, a guard window around the potential target (Figure 1) is discarded during this comparison (Crisp, 2004).

Figure 1. The concept of the Adaptive threshold algorithm as a base for the Ship Detection workflow

In the basic approach, all windows are moved one pixel at a time across the whole image. The algorithm requires an adaptive threshold for the target brightness in comparison to the statistics of the surrounding area. Pixels with backscatter value above the threshold are considered as significant backscatters, i.e. ships. The targets identified as having higher backscatter are exported to a new shapefile.

In case a file with information derived from Automatic Identification System (AIS) is available, the location of the SAR-detected targets can be compared with the data from the AIS messages. AIS is a mariner digital positioning system developed for identification, tracking, search and rescue operations of vessels. The requirements to the AIS are defined by the Intentional Convention for the Safety of Life at Sea (SOLAS[1]), specifically regulation V/19, of the International Maritime Organisation (IMO[2]). AIS messages are aiming at exchanging and providing information about the vessel's identity, position, speed and course, along with other relevant information.

II. SARSCAPE SHIP DETECTION WORKFLOW – OVERVIEW

The **SARscape Basic module** provides a dedicated workflow called ***Ship Detection*** which makes it possible to detect ship and other vessel over water bodies from Synthetic Aperture Radar (SAR) satellite images (Figure 2). In case marine information from AIS is available, the detected targets can

[1] https://www.imo.org/en/ourwork/safety/pages/ais.aspx
[2] https://www.imo.org/en

be matched to the ship position and voyage trajectory from the AIS messages. Alternatively, to the workflow, a set of separate tools for step-by-step processing and additional tools are also provided (Figure 3).

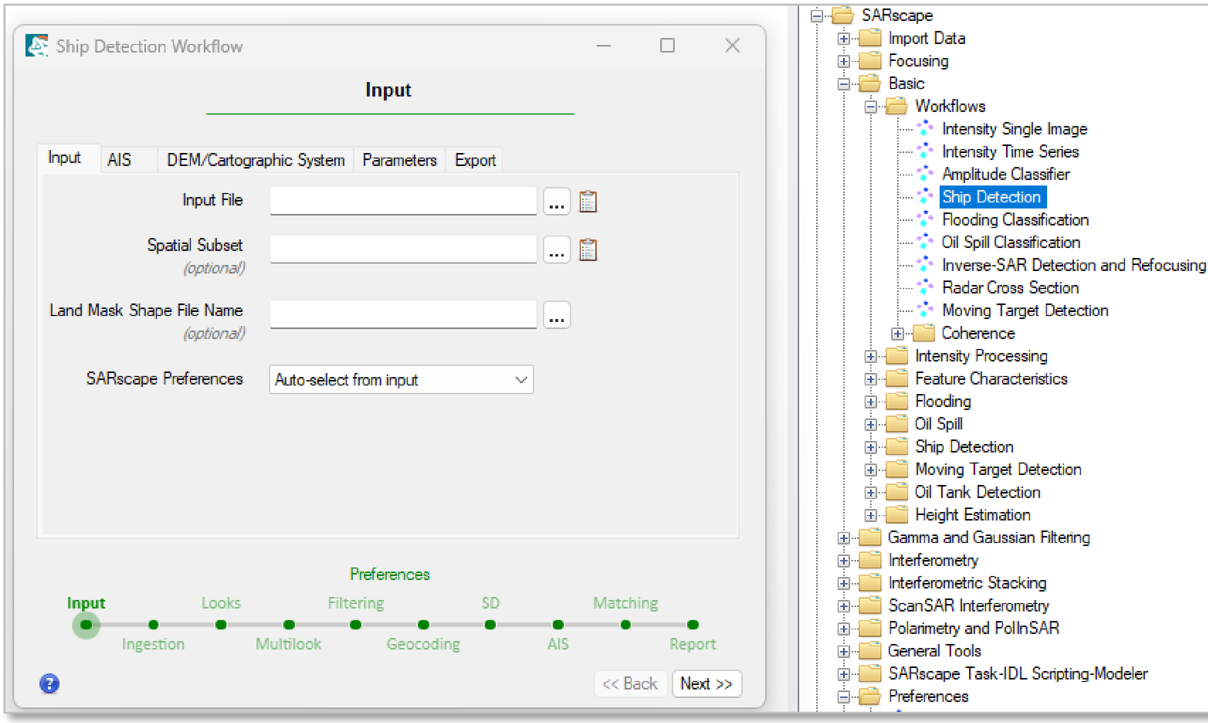


Figure 2. Ship Detection workflow within the SARscape Basic module

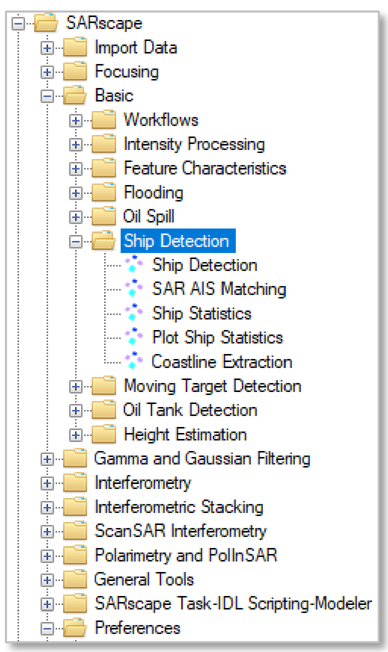


Figure 3. Ship Detection toolbox and tools within the SARscape Basic module

The Ship Detection workflow allows to execute, in a single iteration, the following processing sequence (Figure 4):

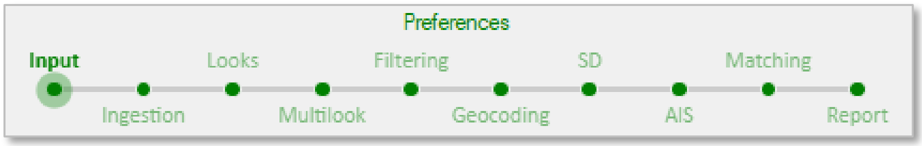


Figure 4. Ship Detection workflow steps of processing

The process can be passed to chosen step forward or backward at any time by selecting the step from the process line shown in Figure 4. Performing the actions step-by-step gives opportunity to modify the parameters. The execution can be forced to the final step by selecting "*Report*" on the processing line.

Alternatively, the full corresponding processing sequence can be accomplished by using separate SARscape tools following the table below:

<table>
<tr><th>Ship Detection workflow</th><th>Stages</th><th>SARscape set of tools for Ship Detection and AIS Matching</th></tr>
<tr><td>Input</td><td rowspan="6">SAR data preprocessing</td><td rowspan="2">Import Data Module -> SAR Spaceborne -> Import Generic SAR data</td></tr>
<tr><td>Ingestion</td></tr>
<tr><td>Looks</td><td rowspan="2">Basic Module -> Intensity Processing -> Multilooking</td></tr>
<tr><td>Multilook</td></tr>
<tr><td>Filtering</td><td>Basic Module -> Intensity Processing -> Filtering -> Single Image Filtering</td></tr>
<tr><td>Geocoding</td><td>Basic Module -> Intensity Processing -> Geocoding -> Geocoding and Radiometric Calibration</td></tr>
<tr><td>SD</td><td rowspan="4">Ship Detection and AIS Matching</td><td>Basic Module -> Ship Detection -> Ship Detection</td></tr>
<tr><td>AIS</td><td>Import Data Module –> Other Format –> AIS –> Import AIS</td></tr>
<tr><td>Matching</td><td>Basic Module -> Ship Detection -> SAR AIS Matching</td></tr>
<tr><td>Report</td><td>-</td></tr>
</table>

This tutorial guides the reader through the *SARscape Ship Detection* workflow by a step-by-step example. The reference software version used throughout the tutorial is SARscape version 6.3.1, running under ENVI 6.3 with a standard (GIS-like) interface, installed on Windows 11, 64bit.

Paragraphs like this one, showing a hand on the left side, indicate a practical step that the user should perform to proceed with the tutorial.

III. DATA FOR SAR SHIP DETECTION

1. SAR DATA REQUIREMENTS

The *Ship Detection* workflow gives the possibility to open SAR images in slant or ground range coordinates (Level 1, 2 or 3), in original formats such as manifest.safe, *.h5, *.xml, *.n1, *.e1, *.e2, IMG*, *.nitf, *.ntf, and others. It also supports processing of images in the SARscape general format (e.g., *.sml files), imported from other workflows or tools, such as those produced by the tools from the *SARscape – Import Data – SAR Spaceborne* toolbox.

The SAR image used for *Ship Detection* should meet the following requirements:

- The data must be properly calibrated. Radiometric calibration aims to convert the backscatter intensity into a normalised radar cross-section. As a result, the strength of the radar signal is expressed using the conventional measure by the coefficients sigma naught or beta naught (in dB). These coefficients represent reflectivity per unit and depend on system parameters such as the antenna gain pattern and range-spreading loss. After calibration, radar data acquired by different sensors, in different acquisition modes, at different times, or generated by different processors can be directly compared and their brightness consistently analysed.
- If the input data are in slant range coordinates, the workflow automatically performs both geocoding and calibration internally.
- If the input data are geocoded, they must be already properly calibrated.

Proper calibration requires that the parameters supplied by the data provider are accurate. Therefore, the compatibility check run by the workflow includes a quality-control step to verify the correctness of the calibration parameters. These parameters are checked during the *Ingestion* process (see Section *IV. 3. Ingestion*).

2. AIS DATA AND TEMPLATE FORMATS

The Automatic Identification System (AIS) files are obtained from the mariner digital positioning system for identification and tracking of vessels. The AIS information is grouped to static, dynamic and voyage related. The AIS marine traffic information loaded to the workflow will be converted into set of shapefiles. Static messages will be stored in a point-type shapefile, while the dynamic messages (positions) belonging to the Maritime Mobile Service Identity (MMSI) code of the vessel will be merged with the corresponding static messages and stored as polylines in a second track shapefile. Another point-type shapefile will be generated for messages from stations, if present.

The AIS traffic data that can be used by the *Ship Detection* workflow at the *AIS Matching* step is an optional function. The workflow gives opportunity to load AIS data in a format among several predefined standards but also to define a custom template for the messages from the AIS (Figure 5).

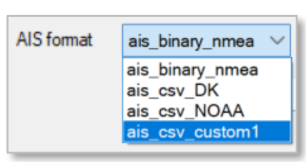


Figure 5. Available AIS format templates in the SARscape Ship Detection workflow

The predefined templates are either in binary format, or in Comma Separated Values (CSV) format, and correspond to the files distributed freely by these institutions:

- US National Marine Electronic Association (NMEA) – details for the standard NMEA data can be found here https://www.nmea.org/nmea-0183.html
- Danish Maritime Authority (http://aisdata.ais.dk/) – details about the structure of the file can be found here: http://aisdata.ais.dk/!_README_information_CSV_files.txt and
- US National Oceanic and Atmospheric Administration (NOAA) that can be found here https://coast.noaa.gov/htdata/CMSP/AISDataHandler/2024/index.html

Alternatively, a custom CSV template for AIS data can be selected via *ais_csv_custom1* (Figure 5). The structure of this template must be defined in the *CSV Fields* panel of the *SARscape Preferences common* window (Figure 6).

Note: The custom AIS format template must be pre-defined in the *SARscape Preferences common* tool before opening the *Ship Detection workflow*.

Note: The template file specifies the order of the fields in the custom AIS CSV file. Type of the data in the fields is predefined, while here only the order of the fields in the CSV file can be modified. The number associated to the field name will correspond to the consecutive record (column) in the CSV file template (values by default are given).

Note: Not all parameters are visible through the workflow and the tools (Import AIS tool, CSV Fields parameters).

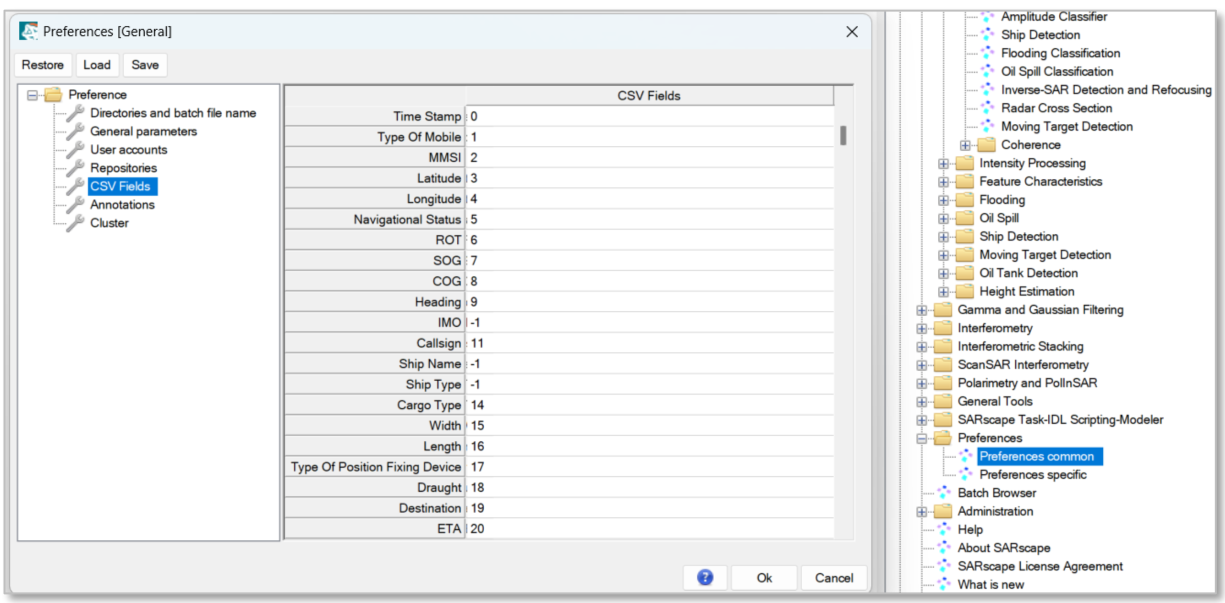


Figure 6. SARscape Preferences common tool with the panel *CSV Fields* where a custom AIS format can be defined and subsequently used in Ship Detection workflow. The numbers correspond to the sequential number of the columns in the custom CSV file template

The modified template will be saved as a new custom AIS template and will be stored in the user folder (C:\Users\XXX\.idl\sarmap\sarscape-XXX\sarmap_common_preferences_file_name.txt).

The AIS template can be later recalled from the *Ship Detection* workflow – see Section *V. 2. AIS*.

2.1. Time Stamp

The Time Stamp presents the full Coordinated Universal Time (UTC) date and time (dynamic parameter), when the position is received by the AIS and registered by the Electronic Position Fixing

System (EPFS). The date-time format is YYYY-MM-DD HH:MM:SS (ISO 8601 format) – example: 2021-12-31 23:59:59.

2.2. MMSI

This field represents static information that contains the Maritime Mobile Service Identity (MMSI) number of the vessel (nine-digit AIS identifier). The first digit of an MMSI depends on the kind of station. MMSIs starting with any number between 2 to 7 refer to ship stations. The initial digit of a ship station determines the area of origin of the vessel:

Ship station identifier in the MMSA number	Area of origin of the vessel
2	Europe
3	North America, Central America and Caribbean
4	Asia
5	Oceania
6	Africa
7	South America

The next 2 digits mark each MMSI country-specific code. As a result, the first three digits of the MMSI, known as Maritime Identification Digits (MID), correspond to the flag of the vessel.

2.3. Latitude

This is a dynamic parameter representing the geographic latitude coordinate (Coordinate system WGS84) of the vessel in decimal degrees (range from -90 to +90, North = positive, South = negative).

2.4. Longitude

This is a dynamic parameter indicating the geographic longitude coordinate (Coordinate system WGS84) of the vessel in decimal degrees (range from -180 to +180, East = positive, West = negative).

2.5. IMO

INO is a unique number of the vessel (not changeable) assigned by the International Maritime Organisation (IMO[3]). It is a 7-digit number that is a part of the static information.

2.6. Ship Name

Name of the vessel (up to 20 characters) - static information.

2.7. Ship Type

The ship type of the vessel is represented by a 2-digit numeric code and/or labelled as shown in the columns below:

Code	Label	Code	Label
1	Reserved	4	High-Speed Craft
2	Wing In Ground	5	Special Category
3	Special Category	6	Passenger

[3] https://www.imo.org/

2.8. Number of First Lines to Skip

Number of the first lines of the imported file to be skipped in case of a specific file text header. In case no description text is included, 0 must be entered.

2.9. Separator

CSV field separator – it can be selected between "(Undefined)", "," and ";".

2.10. Time Buffer in Minutes

This field identifies the total time buffer to consider during AIS import relative to the time extracted from the reference SAR image, if provided as additional input during CSV data import.

3. TUTORIAL DATA

The functionality of the tool is demonstrated with an example using data within the ***DataSetsTutorials_631*** folder:

1. **S1A_IW_SLC__1SDV_20161016T165331_20161016T165358_013518_0159FB_866C.SAFE.zip** – a Sentinel-1 image over the Skagen Odde peninsula in Denmark**.** The image is provided with courtesy of the European Space Agency (ESA) and was accessed on 30 September 2025 through the Copernicus Browser[4]. The data are distributed under the Regulation (EU) No 377/2014 and the Commission Delegated Regulation (EU) No 1159/2013, in agreement with the Copernicus Sentinel Data Policy, ESA/PB-EO(2013)30, rev. 1, and Art. 7 of the Regulation 1159/2013.

2. **aisdk_20161016_053-054.csv** – a sample of AIS file from the Danish Maritime Authority (DMA[5]) for 16 October 2016, downloaded from the DMA AIS Data[6] web site. The file is in CSV format (ais_csv_DK format).

3. **AOI_DK_SMALL.SHP** with associated files *.dbf, *.prj, *shx is a shapefile containing the polygon for the area of interest (AOI) in this exercise. The area is shown with red rectangle in Figure 7.

The Sentinel-1 image used in the tutorial has the following characteristics:

Date	Orbit	Observation direction	Azimuth resolution	Range resolution	ILOS*	ALOS*	Image format	Frequency Band
16.10.2016	ascending	right	13.842m	3.692 m	39.1˚	79.8˚	SLC	C

* ILOS – incidence angle, measured between the Line-of-Sight (LOS) and the vertical to the ellipsoid; ALOS – azimuth of the projection of the LOS directions, measured clockwise from North.

[4] https://browser.dataspace.copernicus.eu/
[5] https://www.dma.dk/
[6] http://aisdata.ais.dk/

Note: For details on how to download and sample Sentinel-1 data please refer to “Data Preparation” tutorial.

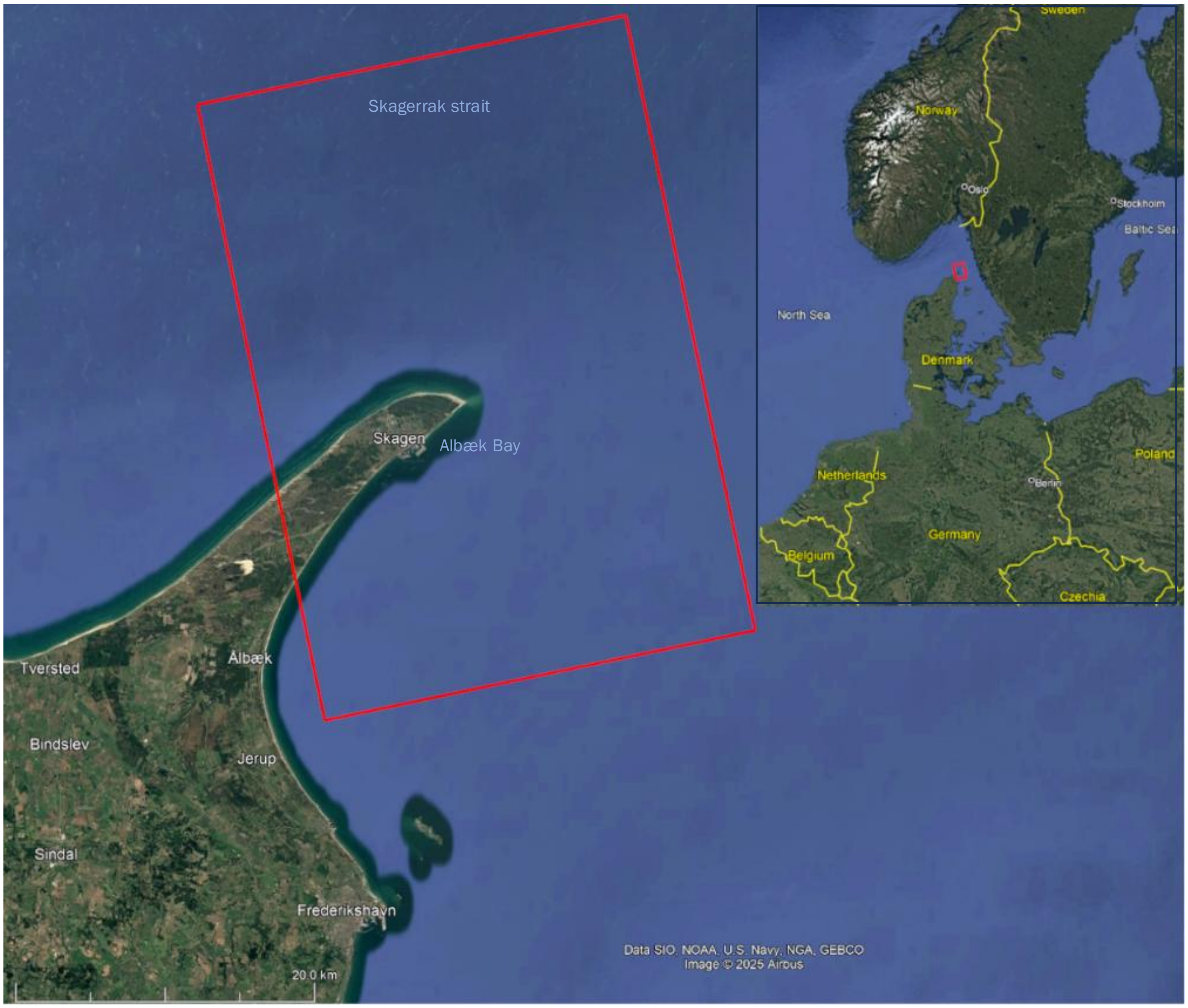


Figure 7. Footprint of the area of interest (red polygon) used in this tutorial. The AOI covers the northernmost part of Denmark – the Skagen Odde peninsula, the Skagerrak strait, the Albæk Bay and Port of Skage. The figure is displayed as an overlay in Google Earth Pro 7.3.6, *Image© 2025 Airbus from 14.12.2015*

IV. SAR DATA PREPROCESSING

1. BEFORE STARTING

Before running the *Ship Detection* processing chain, it is strongly recommended to:

- Insert the *ENVI Preferences* setting for the proper root folders (example below, Figure 8),

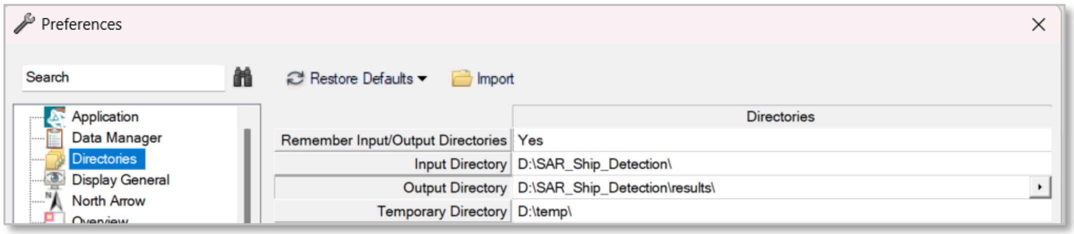


Figure 8. ENVI preferences – Directories panel

Important: It is strongly recommended to do not choose USB or external drives as Input/Output or Temporary Directory, due to the large amount of data transfer. The User must have read/write privileges for the selected location.

- Open the *SARscape Preferences common*, navigate to *Directories and batch file name* panel. Set the ***Working Directory*** and ***Batch file name***.
- Set a folder for the Sentinel-1 orbit files – ***Sentinel-1 auxiliary directory***. **Note**: this folder requires at least 17GB space.
- In *User accounts* tab of *SARscape Preferences common* add your credentials.

Important: Please, make sure that you have read/write privileges for your selected directories.

- Set the *SARscape Preferences Specific* for usage of *Sentinel TOPSAR (IW-EW)* data (Figure 9).

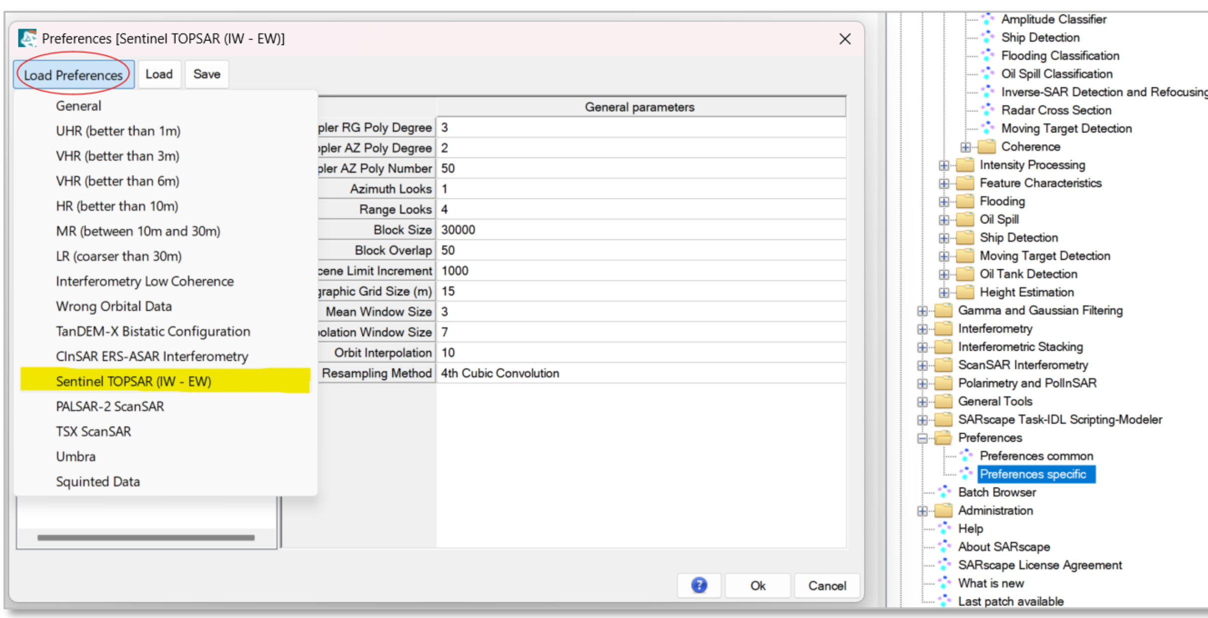


Figure 9. SARscape preferences specific – Sentinel TOPSAR setting

The *Ship Detection* workflow also provides a direct access to the *SARscape Preferences specific* (Figure 10), as well as at *Input* step through *SARscape Preferences* parameter (see Section *2.1.3*):

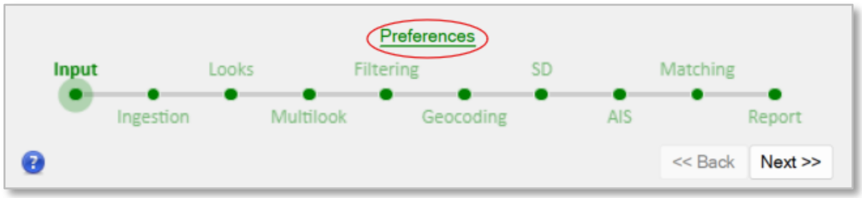


Figure 10. Access to SARscape specific preferences through Ship Detection workflow and the processing pipeline (from Input to Report)

Selecting the specific parameters for a particular SAR data set main parameters to be used by default for different processing. In the case of Ship detection processing the parameters for usage of Sentinel-1 data are set in the *Preferences -> Ship Features* (Figure 11). These values are recommended for Sentinel-1 and will be automatically loaded during the workflow execution (see Sections *V. 1. Ship Detection* and *V. 3. Matching*).

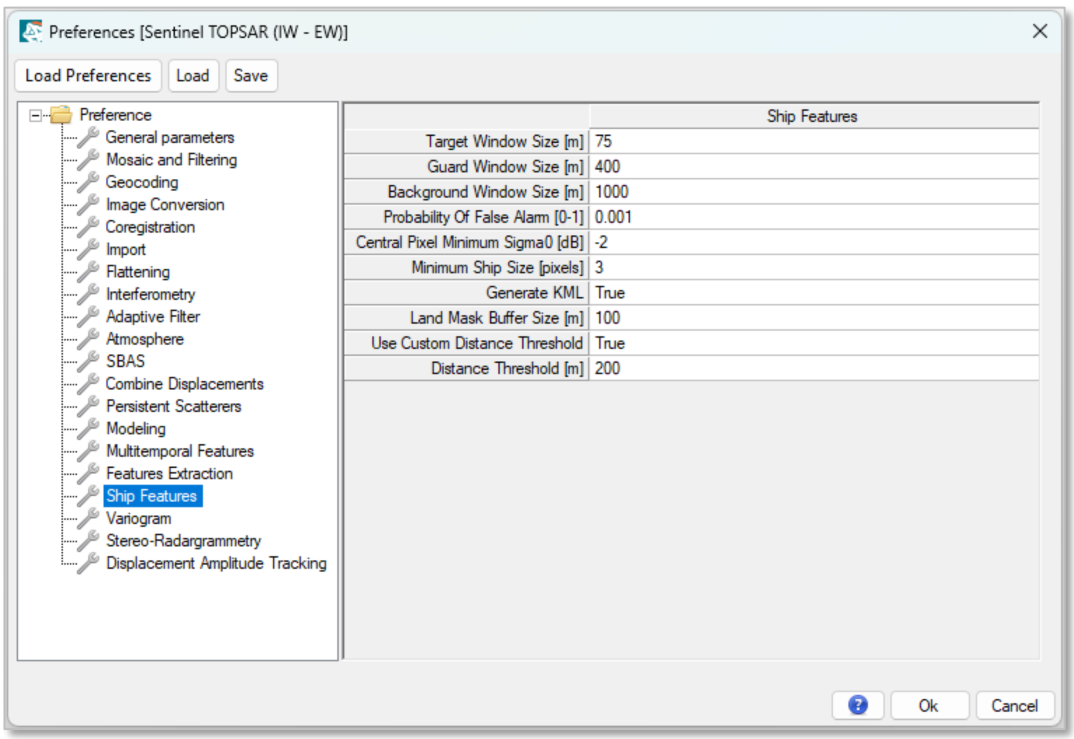


Figure 11. SARscape specific preferences – Ship Features panel

Read the *Getting Started*, *Data Preparation* and *Basic Tutorials* to become familiar with the settings and basic processing chains in SARscape.

2. INPUT DATA AND SETTINGS

The ***Ship Detection*** workflow can be found in the list of *workflows* within the *SARscape Basic Module* (Figure 2, right). The first stage of the workflow includes loading the SAR image, AIS file and setting up the main parameters of processing. Optional parameters for the exported results can be set during this step.

Open the **Ship Detection workflow** from *SARscape Basic Module –> Workflows* (Figure 2).

2.1. SAR image Input

The image *Input* operation transforms the original SAR image into the general *SARscape* format that consists of:

- a binary file without extension,
- *.sml – *SARscape* ASCII header file,
- *.hdr – *ENVI* header file.

If the image has already been imported by another SARscape process, it can be opened in this workflow step by choosing its *.sml file in the *Input File* field (Figure 12). Alternatively, it can also be loaded from the *Data Manager* if it is already open in ENVI.

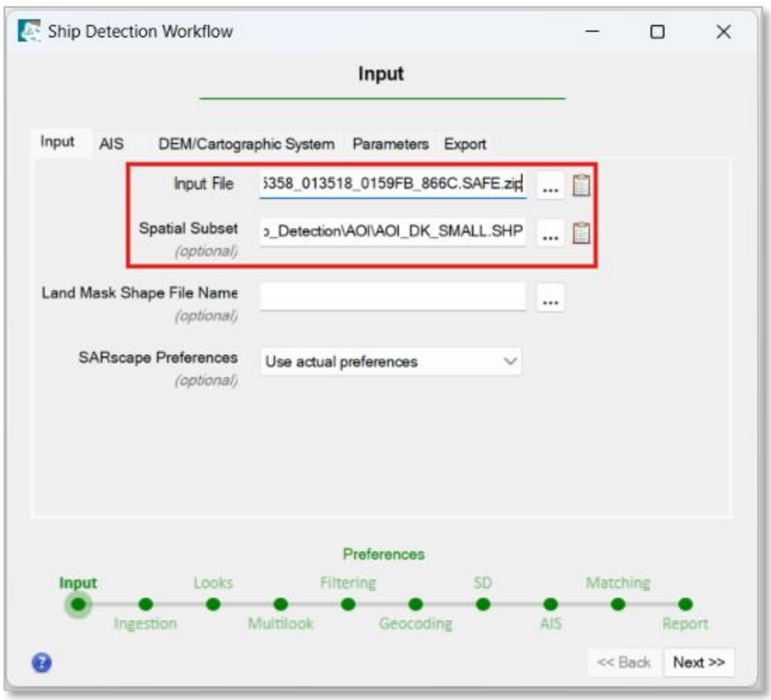


Figure 12. Input stage for setting data and processing parameters

In the *Input* panel use the **Browse...** button of the *Input File* field to navigate to the *DataSetsTutorials* folder stored on your computer. Select the abovementioned training **Sentinel-1 image over Skagen** as *Input Image* (Figure 12).

2.1.1. Spatial Subset

Optionally, the image range can be cropped to exact dimensions. For this purpose, a polygon in geographic coordinates with the Area of Interest (AOI) in vector format (*.shp, *.kml or *.kmz) can be added in the *Special Subset* field.

Use the **Browse...** button of the *Spatial Subset* field to navigate to the *DataSetsTutorials* folder stored on your computer. Select the provided *AOI* file (Figure 12).

2.1.2. Land Mask Shapefile Name

Optionally, the algorithm will avoid the areas inside the polygon(s) of the provided shapefile containing land territories.

Note: If no mask is loaded, the software will automatically apply mask from the installation folder of SARscape. This mask is derived from OpenStreetMap repository[7] (©OpenStreetMap contributors). These data are licensed under the Open Database License (ODbL). For details, see *Third-party software and libraries* document of SARscape installation package.

2.1.3. SARscape preferences

This field gives direct access to the list of predefined *SARscape preferences* (Figure 13) for chosen type of data (as an alternative to the main tool – Figure 9) or it can **Auto-select preferences from the input** data. If the option *Auto-select preferences* is chosen, the software will consider the metadata of the SAR input image and will suggest the most suitable parameters for processing. The selection of **Use actual preferences** applies to those selected in *SARscape Preferences specific* panel (Figure 9).

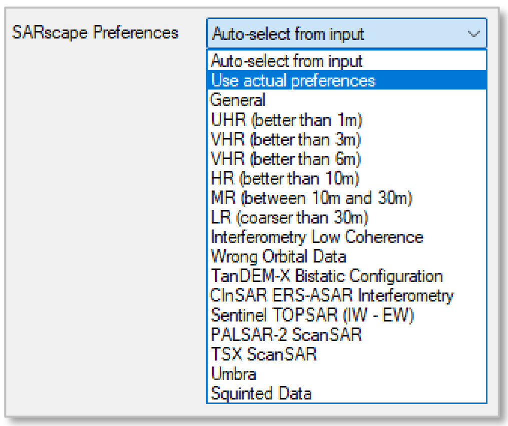


Figure 13. SARscape preferences access through Input panel of Ship Detection workflow

Select **Use actual preferences** for *SARscape Preferences* (Figure 13). Switch to next tab (AIS).

2.2. AIS Input

2.2.1. AIS format

Here a selection of the AIS format can be made among the three predefined or customized one (see Section *III. 2. AIS data and template formats*).

2.2.2. Input AIS

If a file with AIS information is loaded here, the targets detected as ship or other vessels over the water bodies within the SAR image during the ship detection step will be match with the AIS information.

Select **ais_csv_DK** in the *AIS format* field in the *AIS* panel.
Use the **Browse…** button of the *Input AIS field* to navigate to *DataSetsTutorials* folder stored on your computer. Load **aisdk_20161016_053-054.csv** file (Figure 14).
Switch to the next tab (DEM/Cartographic System).

[7] https://www.openstreetmap.org/

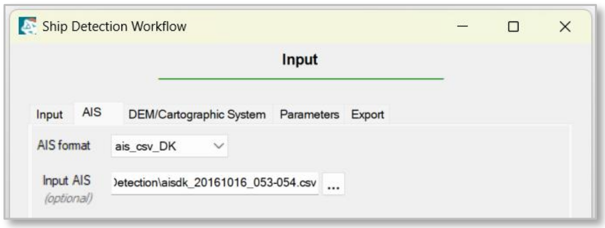


Figure 14. AIS Input data through Input panel of Ship Detection workflow

2.3. DEM/Cartographic system

2.3.1. DEM Option

An external Digital Elevation Model (DEM) is used for geocoding (transformation) of the slant-range SAR image into chosen cartographic reference system. For best results, it is important to select a DEM, that takes into consideration the acquisition time of the SAR data and its resolution (Figure 15, left). The DEM generation date should be as close as possible to the acquisition date of the SAR data. Furthermore, the resolution should be as close as possible to the native ground resolution of the SAR image.

Different predefined downloads of DEM are optional. Internet connection is needed for the download, as well as user credentials for some of them (must be set in panel *User accounts* of *SARscape Preferences common*).

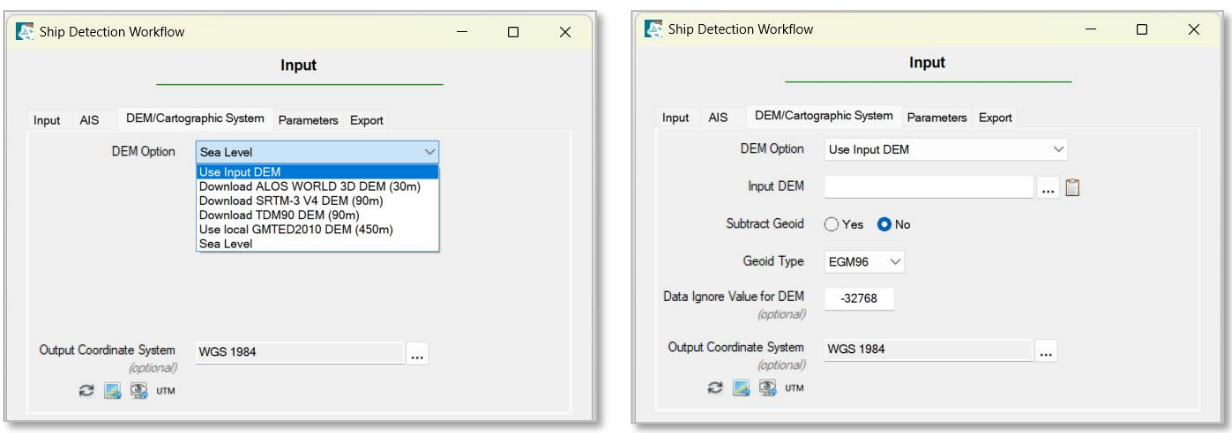


Figure 15. DEM settings through Input panel of Ship Detection workflow

In case *Input DEM* is selected (Figure 15, left) the input can be a DEM, previously imported in SARscape. In this case the fields relevant to the geoid and to the Data Ignore Value for DEM (Figure 15, right) do not need to be filled (the software will use the parameters read from the meta file .sml).

Note*:* The input DEM must be ellipsoidal for correct processing. If the DEM is referred to the geoid, make sure to subtract the geoid component or check the corresponding "Subtract Geoid" option.

Select **Download SRTM-3 V4 DEM (90m)** in the field *DEM Option* (Figure 16).

2.3.2. Output Coordinate System

As an optional parameter, the *Output Coordinate System* for the output results can be selected. By default, the World Geodetic System (WGS) 1984 is set (Figure 16). The *Browse…* button leads to a list of Predefined Coordinate Systems and tools for creating a new one.

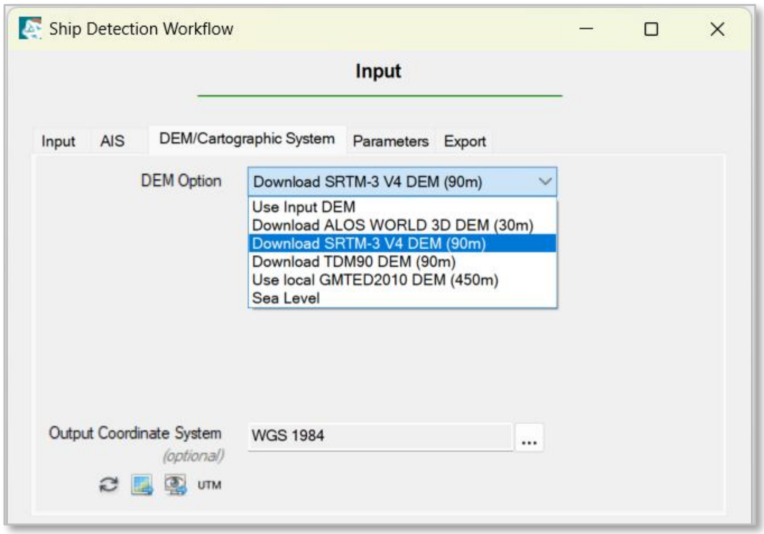


Figure 16. Selection of SRTM-3 V4 DEM (90m) in Ship Detection workflow

Leave the *Output Coordinate System* to **WGS 1984** (by default, Figure 16).
Switch to the next tab (Parameters).

2.4. Processing Parameters

The workflow gives opportunity to define the settings for the results of the processing

2.4.1. Grid Size

Defining a grid size value implies the application of a certain multilooking factor during the processing. Multiple looks Intensity images are generated by averaging over range and/or azimuth resolution cells.

The grid size value can be inserted manually or will be calculated automatically (Figure 17). In case the box is left empty, the value is automatically assigned during the processing according to the loaded preferences.

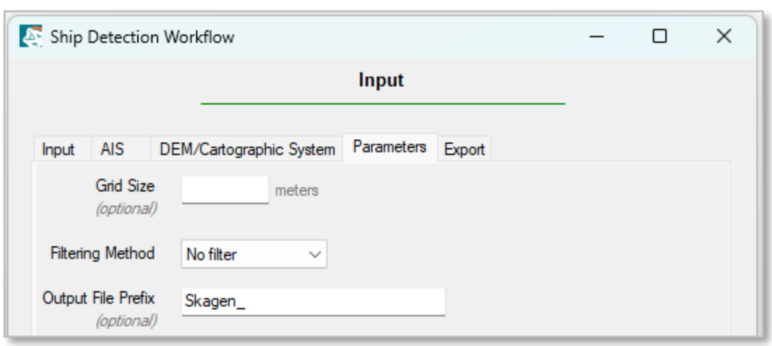


Figure 17. Ship Detection processing parameters

When the grid size is automatically calculated, the output grid size of geocoded products is approximately determined by the spatial resolution of the nominal SAR spatial resolution and the applied multilooking factor. The multilooking factor is estimated from the nominal resolutions in the range and azimuth directions to achieve squared pixels. The aim is also to preserve the maximum spatial resolution of the multilooked product.

2.4.2. Filtering Method

This function allows reducing noise in an image by applying a SAR-specific filter. It emphasizes edge and lines, or other significant details, and remove non-significant parts of the image leading to a noiseless interpretation of the image. The available options are:

- Adaptive Non-Local SAR Filter
- No filter
- Frost
- Lee
- Refined Lee
- Gamma A Posteriori Mean (APM)
- Gamma Maximum A Posteriori (MAP)
- Gamma Distribution-Entropy MAP (DE MAP)

Note: The *Filter Method* can be modified later during the step-by-step processing.

Note on Gamma Filters: Use depends on the license availability.

Note on Non Local: It is recommended to use this filter only in combination with a powerful GPU selected as the current OpenCL platform/device under the SARscape Common Preferences.

Consult the SARscape Help pages for more information for each filter.

2.4.3. Output File Prefix

A different prefix for the output files can be given here. Otherwise the prefix will be taken from the file name of the input image.

Add "**Skagen_**" as *Output File Prefix*. Keep the *Grid Size* field empty and the *Filtering Method* to **"No Filter"** (Figure 17). Switch to the next tab (Export).

2.5. Export settings

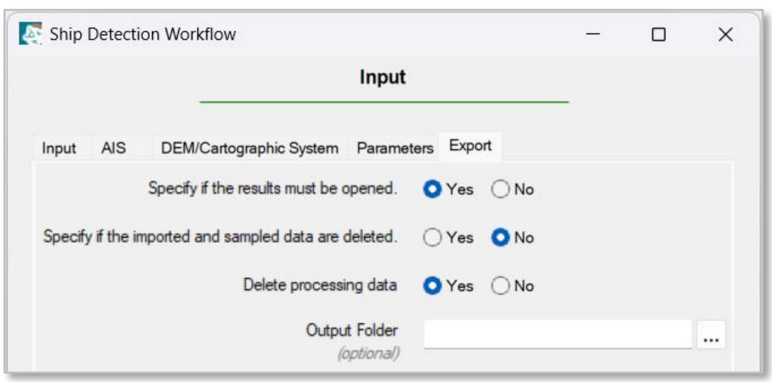


Figure 18. Export settings

2.5.1. Specify if the results must be opened

If this parameter is set to *Yes* (Figure 18), the results will be loaded in the *Layer Manager* and *ENVI View*.

2.5.2. Specify if the imported and sampled data are deleted

If this parameter is set to *Yes*, the imported and sampled data will be deleted from the drive. Alternatively, the imported and sampled data will be stored in the intermediate folder.

2.5.3. Delete processing data

If it is set to *Yes*, intermediate processing files will be deleted from the processing folder.

2.5.4. Output Folder

A chosen folder can be assigned to store the results from the workflow via the ... *Browse...* button. Otherwise, the output files will be saved in the *Output Directory* set in the *ENVI Preferences*.

The intermediate steps of the Ship detection processing can be skipped, and the processing can be passed to the final step by selecting **Report** from the processing pipeline or to pass the processing to a selected step, without stopping on the steps in between. The parameters for these intermediate steps will be taken by default, according to the selected image specific preferences or by predefined values in the *Input* panels.

To get familiar with all steps in details, go step-by-step throughout the processing following this tutorial. If a step-by-step processing is performed, some parameters may be modified during the processing. The processing may be passed forwards or backwards clicking on a chosen step from the processing pipeline (Figure 10).

Leave all the **values by default** (Figure 18).

Click **Next >>** button. The process will continue to the next step.

3. INGESTION

With the execution of this step the data will be imported and subsampled (if a *Spatial Subset* vector file is provided at the previous step). If the input file was already imported in SARscape the software recognises it and pass the processing to the next step.

3.1. Polarization

This parameter allows choosing the polarization to be imported in case the original data contains more than 1 polarization. The options are:

- Only Copolarized data (HH only, VV only)
- Only Crosspolarized data (VH or HV).

Keep **Copol Only** and click **Next >>**. Leave the flag for **Set Grid Size in selected preferences** set to **No.** The selected image will be imported in SARscape, and the process will be passed to the next step.

If the image is in an original SAR format, it will be transformed into SARscape format during the ingestion step. If the image is already in SARscape, the software will recognise it, will load it and will pass the process to the next step.

During this procedure, a compatibility check for this image is also performed. The results of the check are saved in the *Output folder*, in a newly created folder named *WF_SD_DateMonthYear_XXX*. The text file ***processing_report.txt*** contains information about the image properties and a verification report indicating whether the data meet the criteria required for this processing.

The same information will be presented on the screen at the final stage ***Report***.

4. LOOKS COMPUTATION

4.1. Grid Size

The *Grid Size parameter* (Figure 19) represents the grid size in meters for the ingested image. This value is used to tune range and azimuth looks. It can be optionally changed on this step. By default, the automatically suggested value, depending on the data type, is loaded.

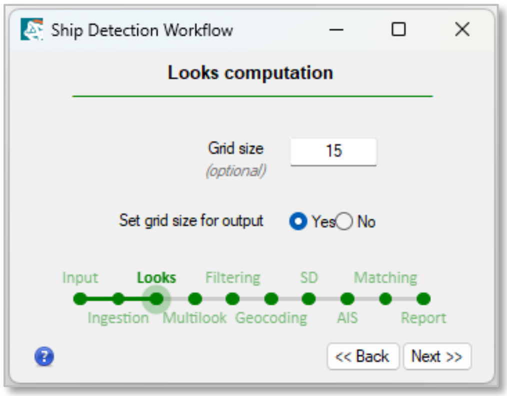


Figure 19. Looks computation step

4.2. Set grid size for output

If option *Yes* is marked, the selected parameters would be applied also to the geocoded output.

Keep the suggested value of **15 meters** for the *Grid Size* (Figure 19). Keep **Yes** for "*Set grid size for output*" and click **Next >>**. The process will be passed to the next step.

5. MULTILOOK

With the execution of this step the data are multilooked. When applied the multiple looks generate averaged resolution cells. This reduces the speckle effects and improves the radiometric resolution but also degrades the spatial resolution. The *Range and Azimuth Looks* (Figure 20) are calculated based on the *Grid Size* value (pervious *Looks computation* step). It can be optionally changed here.

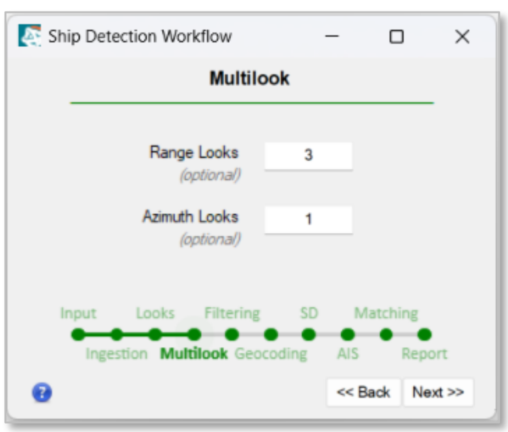


Figure 20. Multilook step

Keep the default values of **3 looks in Range** and **1 look in Azimuth** (Figure 20) and click **Next >>**.

6. FILTERING

The imported multilooked image will be loaded in the ENVI Layer Manager and visualised in the ENVI View window (Figure 21, left).

✍ Click the **Zoom to Full Extent** button in the *Toolbar*

to view the full extent of the imported Sentinel-1 image – ***_slc_list_rsp** (Figure 21, left).

The initially chosen filtering method (see *Input – Parameters*, Section *2.4.2. Filtering Method*) can be modified on this step (Figure 21, right).

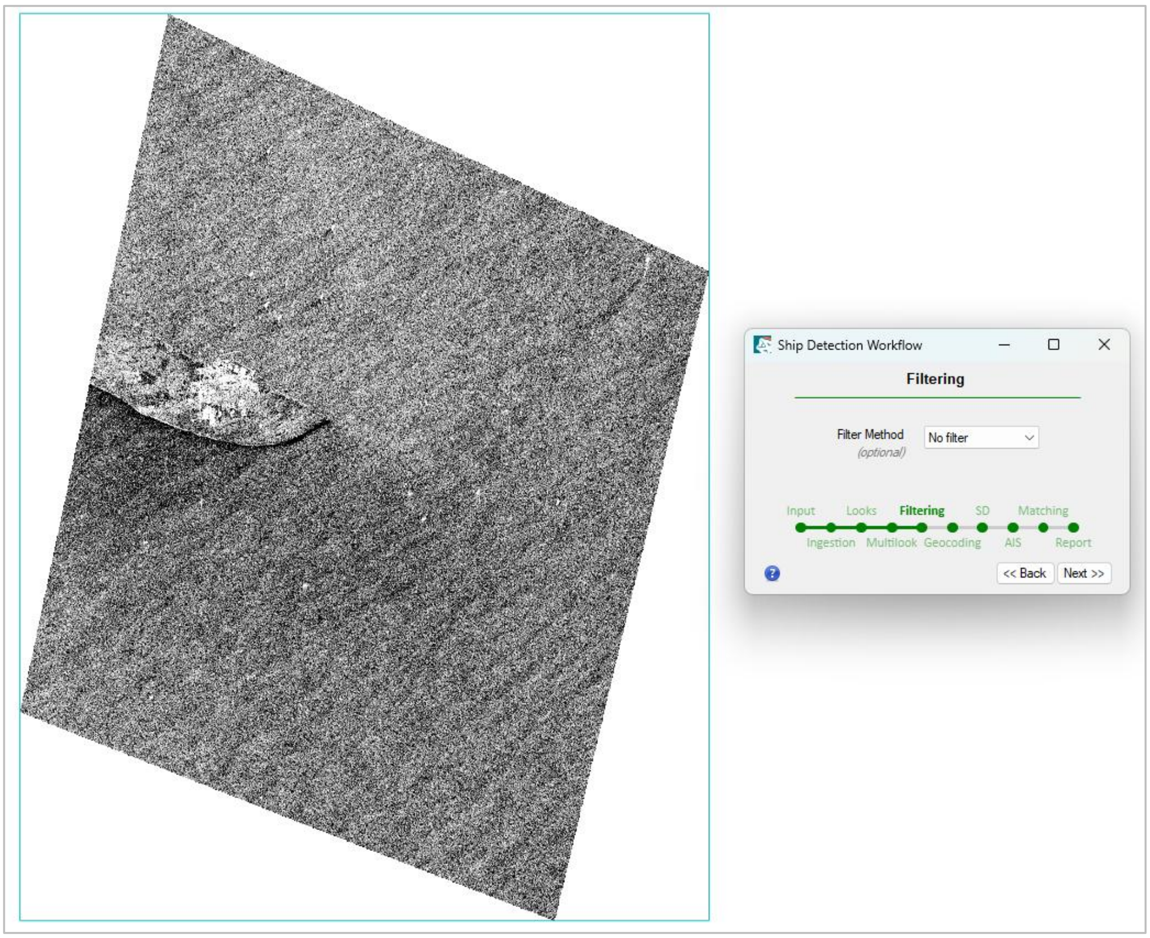


Figure 21. Imported multilooked image and Filtering step window

✍ Leave the field value by default (**No filter**, Figure 21) and click **Next >>**. The process will continue to the next step.

7. GEOCODING

At this step the image is calibrated and geocoded. To perform ship detection, the SAR data used in the processing must be calibrated. Radars measure the ratio between the power of the transmitted pulse and the power of the received echoes. This ratio is called backscatter. The calibration of the backscatter values is necessary to compare radar data acquired with different sensors, in different acquisition modes, at different times, or generated by different processors.

The geocoding process uses the selected input DEM to convert the terrain-induced distortion radar geometry to georeferenced map projection. It transforms the positions of the backscatter elements from slant range image coordinates to coordinates in the chosen cartographic reference system considering the chosen DEM and the satellite orbit data.

If the input SAR image is in slant range, the output results (both raster and shapefiles) will be geocoded. The Easting (X) and Northing (Y) grid size of the output data can be defined at this step (Figure 22), as the default unit of measure is meters.

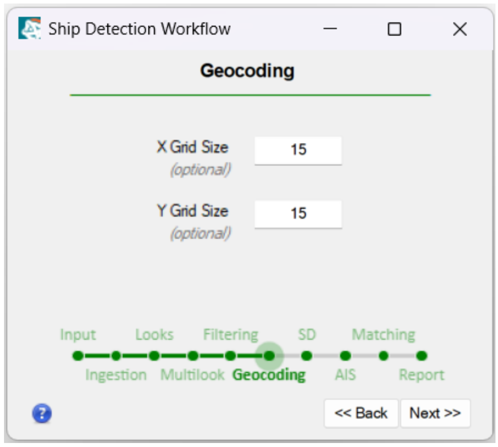


Figure 22. Geocoding step

Note: The geocoding does not preserve the full resolution of the input SAR data. The ground range pixel of the geocoded exported image is degraded following the scheme:

Actual grid size [m]	Grid size of the geocoded raster [m]
< 0.5	1.0
1	2.0
2	3.0
5	5.0

The resolution is degraded by default during geocoding. However, the needed resolution of the output data can always be set in the grid size field.

Leave the values of **15 m** (Figure 22) and click **Next >>**. The process will continue to the next step.

With the execution of this step the ingested, cut (to a defined polygon if provided), multilooked SAR image is also radiometric calibrated and geocoded. With this the preprocessing step is finished and the image is prepared to by used in the Ship Detection part of the workflow.

Click the **Zoom to Full Extent** button in the *Toolbar*

to view the full extent of the calibrated and geocoded image –> **Skagen_*_geo** (Figure 23).

Figure 23. Calibrated and geocoded testing Sentinel-1 cut image over Skagen peninsula

V. SHIP DETECTION AND AIS MATCHING

1. SHIP DETECTION

The *Ship Detection (SD)* part of the workflow contains the following stages:

- Masking out the land areas based on an optional reference shapefile;
- Identification of target areas of significant backscatters;
- Extractiing the targets of interest into a shapefile.

At this step of the workflow, the window sizes for the Adaptive threshold algorithm for ship detection from a SAR image can be set and modified, as well as the minimum average backscatter value.

Predefiened values depending on the input SAR file specifics can be loaded. The values a defined for the corresponding SAR image type in the panel *Ship Features* of the *SARscape Preferences specific*.

> Click the button **Apply Preset Values from preference**. This will load the predefined parameters most suitable for Sentinel-1 image (Figure 24, left).

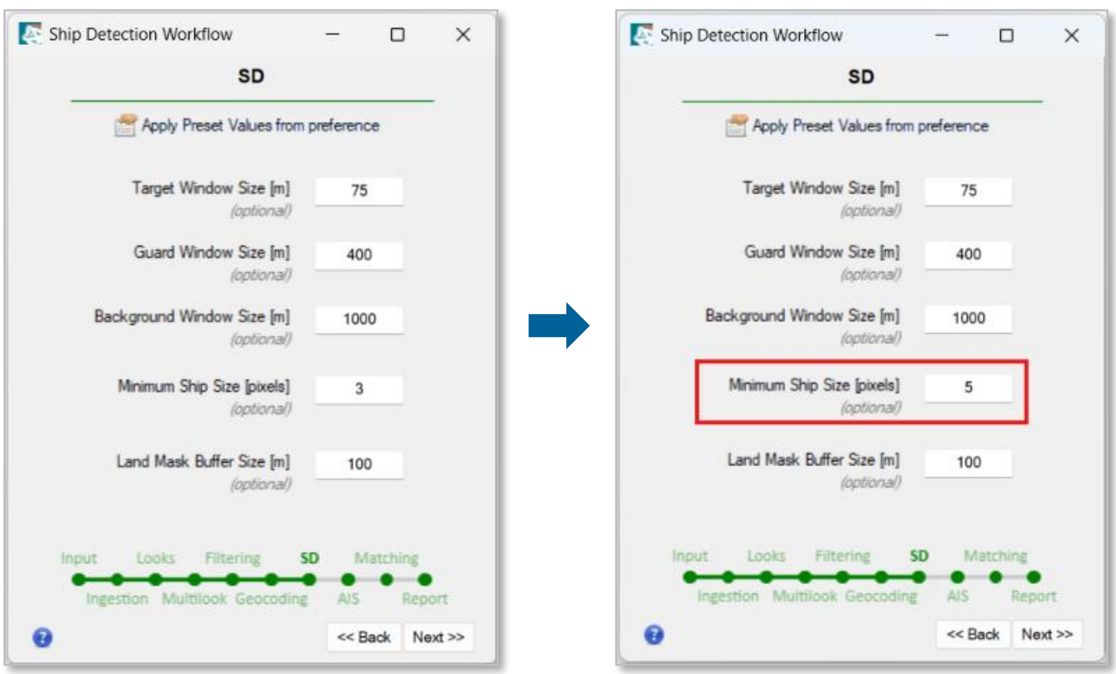


Figure 24. Window with Ship Detection parameters suitable for Sentinel-1 image

1.1. Target Window Size

The dimensions of the target(s) to be detected (Figure 1) can be defined in meters.

> Keep the predefined **75 m** for *Target Window Size [m]* (Figure 24, left).

1.2. Guard Window Size

A window (in meters) around the target window (Figure 1) can be defined so that these pixels will be not taken into account in the background estimation. This will eliminate eventual double targets.

> Keep the predefined **400 m** for *Guard Window Size [m]* (Figure 24, left).

1.3. Background Window Size

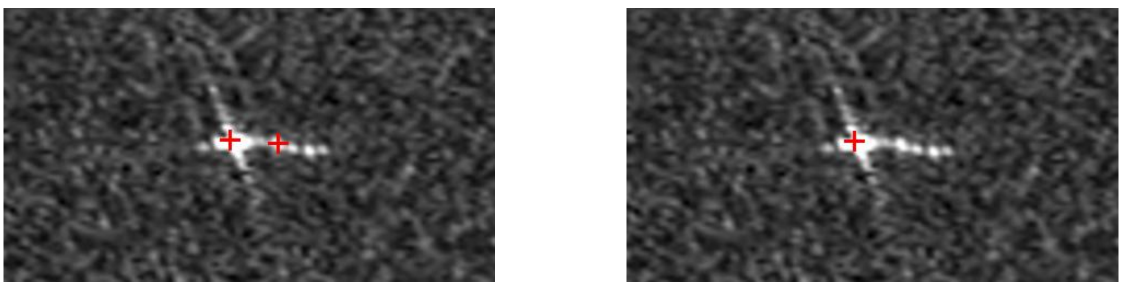
The size in meters of the window used to estimate the background value (Figure 1) can be entered here. The proper size of the window is strongly related to the density of the vessels in the AOI. This means that this parameter should be modified so that as less as possible targets are influencing the statistics of the background window. If this window size is modified, the *Guard Window Size* should be resized accordingly.

✍ Keep the predefined **1000 m** for *Background Window Size [m]* (Figure 24, left).

1.4. Minimum Ship Size

This is the threshold for the number of central pixels of the target window to be considered as a target (ship). Pixel group below this minimum threshold are not considered as ships (in pixels).

Normally, most ships exhibit consistently high backscattering across their entire surface. Other vessels exhibit inconsistent backscattering, as in the example below (Figure 25, left). This may cause the software to identify multiple points for the same ship. In the case of the Sentinel-1 image, setting a value of 3 pixels would result in multiple detections per ship as shown in the left image below. Using Minimum Ship Size of **5 pixels** addresses this issue (Figure 25, right). However, it should be kept in mind that decreasing the minimum backscatter value may result in more false positives.



Minimum Ship Size = 3 pixels   Minimum Ship Size = 5 pixels

Figure 25. Example of different Minimum Ship Size value, applied to the training Sentinel-1 image

✍ Keep **3 pixels** for *Minimum ship size [pixels]* (Figure 24, left).

1.5. Land Mask Buffer Size

An optional buffer area might be defined around the provided polygon with land mask by specifying the buffer distance in meters.

For the case of the Sentinel-1 tutorial data, the pre-set value is 100, which means that a buffer of 100 meters will be defined around the polygons, automatically downloaded as a land mask from the OpenStreetmap repository.

✍ Keep the value of **100 m** for the *Land Mask Buffer Size* (Figure 24, left).
Click **Next >>**. The process will continue to the next step of the workflow.

The *Ship Detection* will mask out the land territories, identify the target areas of significant backscatters based on the parameters set above, and extract the targets of interest into a shapefile. The shapefile with the identified targets will be loaded in the *Layer Manager* and visualised in the *ENVI View* window (Figure 26).

Click the **Zoom to Full Extent** button in the *Toolbar* to view the full extent of the detected as ships objects in ***_ship.shp** (Figure 26).

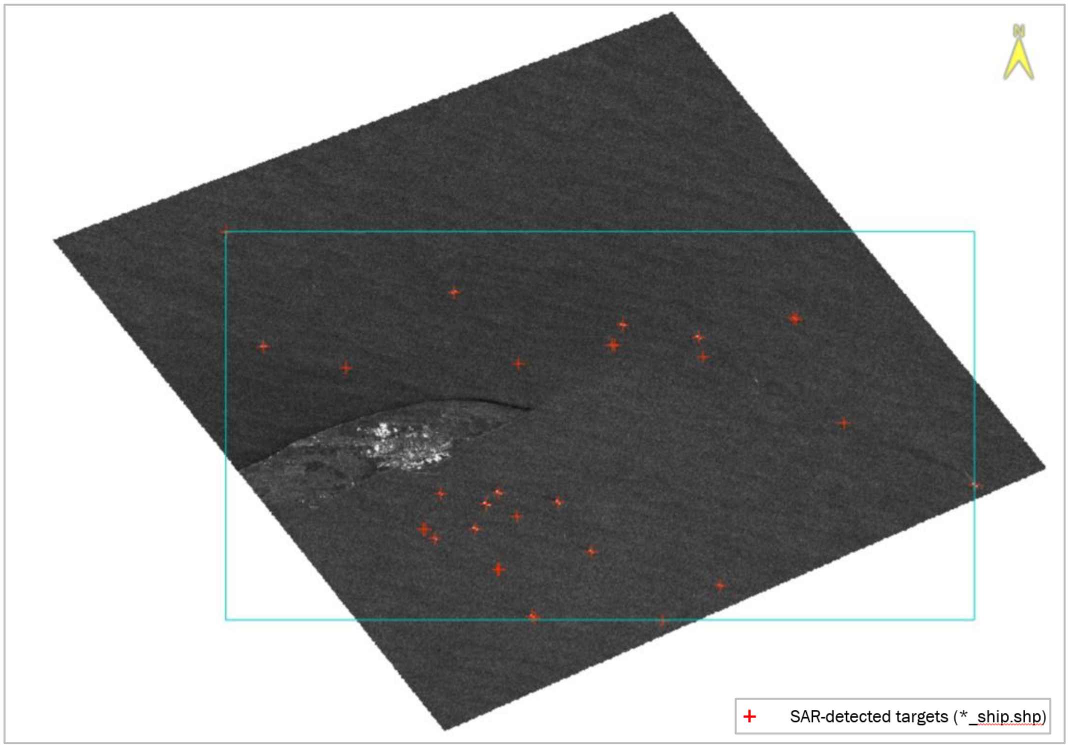


Figure 26. Visualisation of the detected as ships objects (red crosses) from the Sentinel-1 cut image over Skagen peninsula

Observe the result of the *Ship Detection* step. Effects as those shown in Figure 25 (left) can be noticed. Use the **<< Back** button to navigate to the *Ship Detection* step.

Change the *Minimum ship size [pixels]* to **5 pixels** (Figure 24, right) and re-generate the shapefile with the detected vessels to avoid identification of multiple points for the same ship (click **Next>>**).

Once a satisfying result is achieved, move to the next step of the *SAR Ship Detection* workflow – *AIS* selection and *Matching*.

2. AIS

The *Ship Detection* workflow gives an opportunity to compare and match the detected from a SAR image vessels with an available external marine information from the Automatic Identification System (AIS) for the ship position and voyage trajectory. This step is optional and can be skipped if no AIS file is loaded and passing the process to the next step of the workflow.

Otherwise, AIS information can be loaded at this stage or at the initial Input step (Section *IV. 2.2.2. Input AIS*). If a file was already loaded, at this moment it can be changed or removed.

2.1. AIS format

The format for the input AIS file can be changed to one of the options described earlier at step *Input*.

2.2. Input AIS

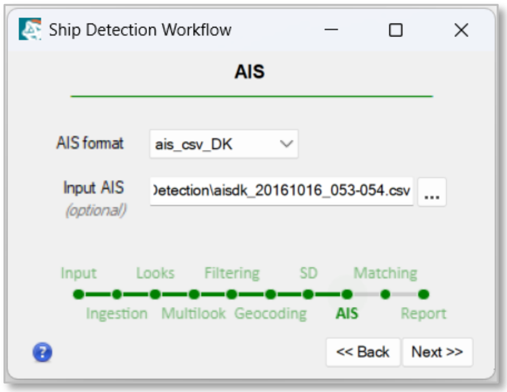


Figure 27. AIS file selection – optional functionality

Keep the format and loaded during the Input stage file (Figure 27).
Click **Next >>**. The process will continue to the next step of the workflow – Matching.

The execution of this step imports the AIS file and transforms the information from it to two shapefiles, that are loaded in the Layer Manager and ENVI View (Figure 28):

- ***_ais.shp**: point features with AIS location information about the vessels,
- ***_track.shp**: line features with AIS trajectory information about the vessels.

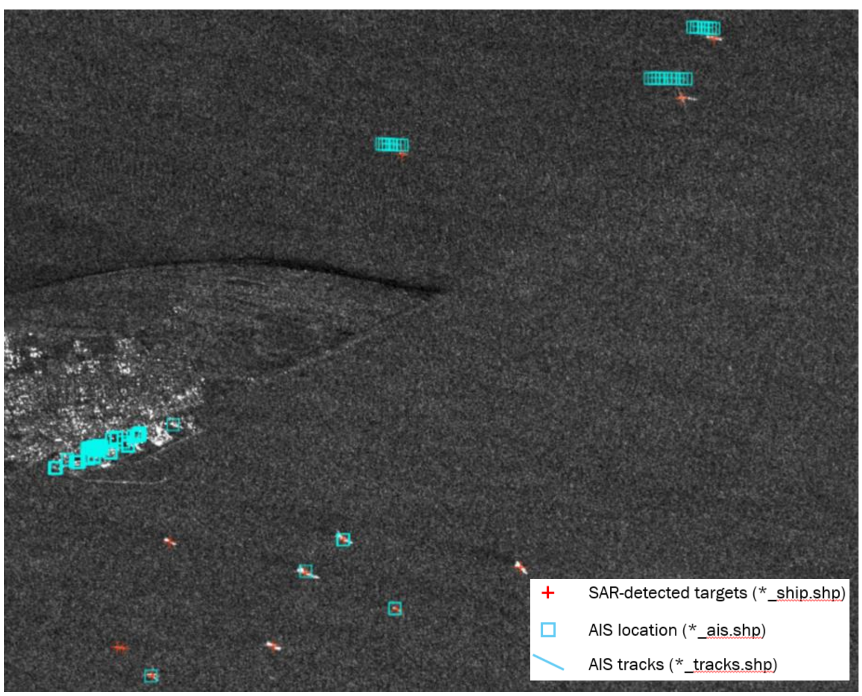


Figure 28. An example of the imported AIS information (in cyan colour) for the region of Skagen peninsula – background the calibrated Sentinel-1 image with detected targets (red crosses)

3. MATCHING

If an AIS file is loaded on the previous step, here the parameters to match this information with the detected SAR targets must be set.

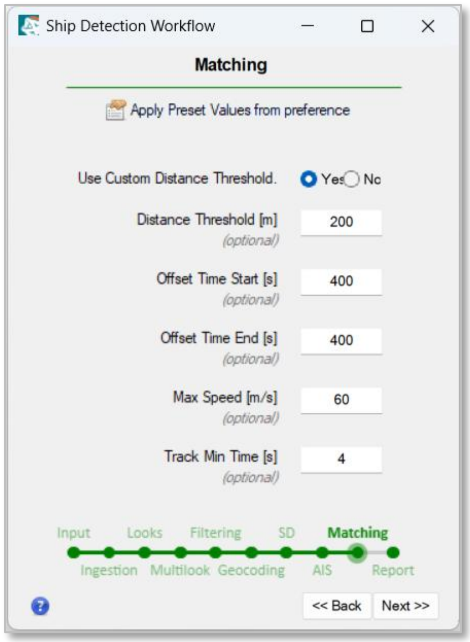


Figure 29. Parameters for verification of the matching between AIS information and SAR-detected targets

Click the button "Apply Preset Values from preference". This will load the predefined parameters most suitable for Sentinel-1 image (Figure 29).

3.1. Use Custom Distance Threshold

Setting this flag to *YES* gives the possibility to set a custom Distance Threshold.

3.2. Distance Threshold

This parameter defines the maximum acceptable distance (in meters) between a ship position and the corresponding AIS track.

3.3. Offset Time Start

Tracks records will be discarded when their starting time (in seconds) is after the image acquisition time, and the difference is more than selected value, or:

(track start time) – (SAR time) > offset_time_start

3.4. Offset Time Start

Tracks records will be discarded when their ending time (in seconds) is before the image acquisition time, and the difference is more than selected value, or:

(SAR time) - (track end time) > offset_time_start

3.5. Max Speed

This parameter marks the maximum acceptable speed (in meters per second) for a moving object. Speed is computed using consecutive AIS data, a threshold value helps preventing miscalculations caused by wrong AIS data.

3.6. Track Min Time

This value shows the minimum acceptable time (in seconds) between consecutive AIS data in each track.

Keep the suggested values (Figure 29). Click **Next >>**.
The process will continue to the final processing step of the workflow and load the *Results*.

VI. RESULTS

The final stage of the *Ship Detection* workflow contains the **Report** (Figure 30) from the Compatibility check for the imported image (see Section *IV. 3. Ingestion*). If the results generated from the processing are acceptable, the process can be finalised by the button **Finish**. Otherwise, corrections in the parameters can be done by going **<< Back** by clicking at the needed step from the processing pipeline diagram.

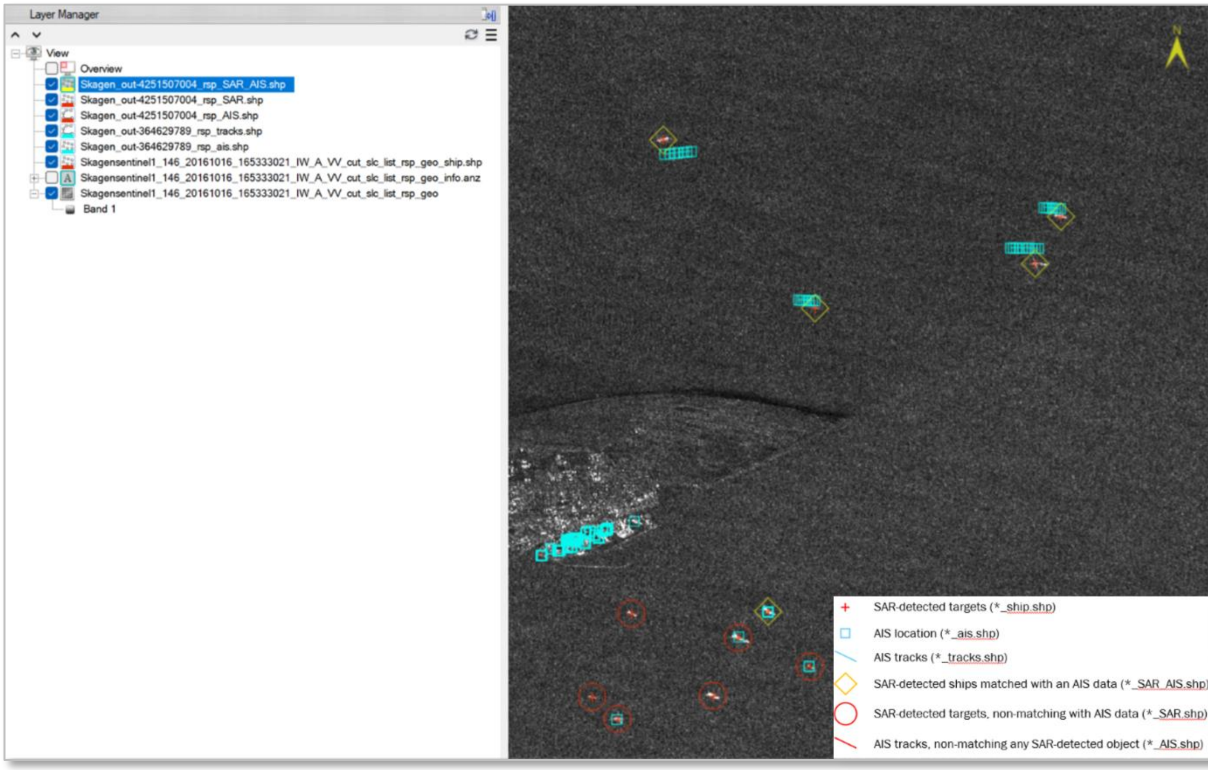


*Figure 30. Final step of the Ship Detection workflow – SAR image compatibility **Report**, visualisation of the SAR-detected targets and resulted shapefiles from AIS Matching step*

The previous *Matching* step produces and visualises three shapefiles:

- ***_AIS.shp**: AIS tracks, non-matching any SAR-detected object,
- ***_SAR.shp:** containing SAR-detected ships, non-matched with any AIS data,
- ***_SAR_AIS.shp: showing SAR-detected ships matched with an AIS track.**

1. MATCHED VESSELS

Ship locations detected from the SAR image which match AIS records are stored in a point shapefile named ***_SAR_AIS.shp.** Records are marked by default with yellow diamond symbols (Figure 31).

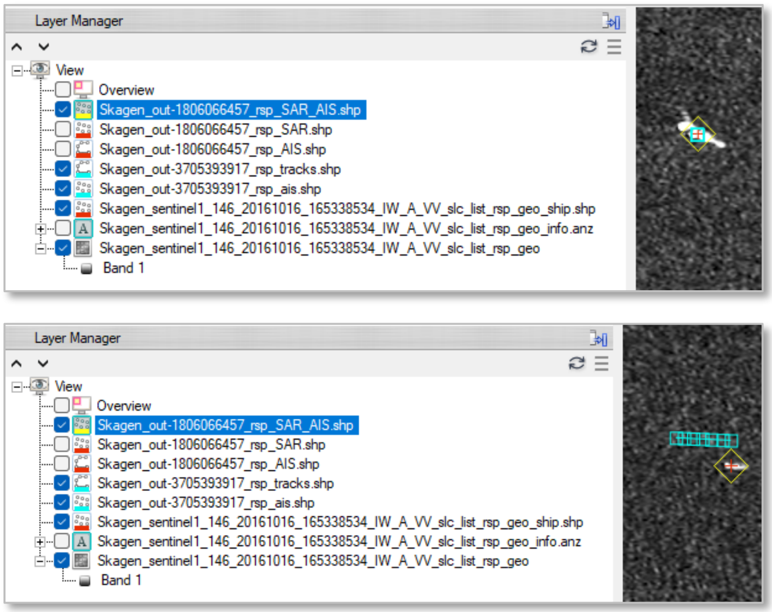


Figure 31. Examples for matched points between SAR-detected objects and AIS ship records

2. UNMATCHED POINTS

Detected ships with no matching AIS records are stored in a point shapefile named ***_SAR.shp**. In the example, these records are marked with red circle symbols (Figure 32).

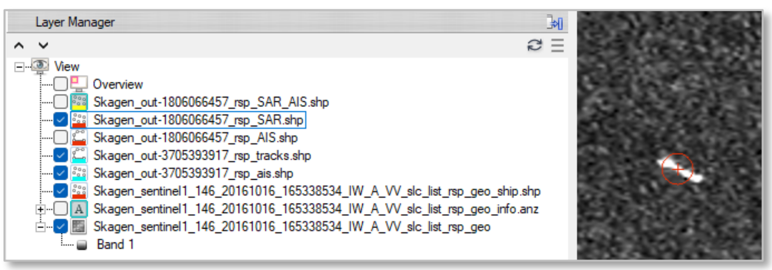


Figure 32. Example of unmatched SAR-detected objects with any AIS ship records

3. UNMATCHED TRACKS

AIS tracks that do not match any SAR-detected ships are stored in a polyline shapefile named ***_AIS.shp**. In this example they are displayed in red (Figure 33).

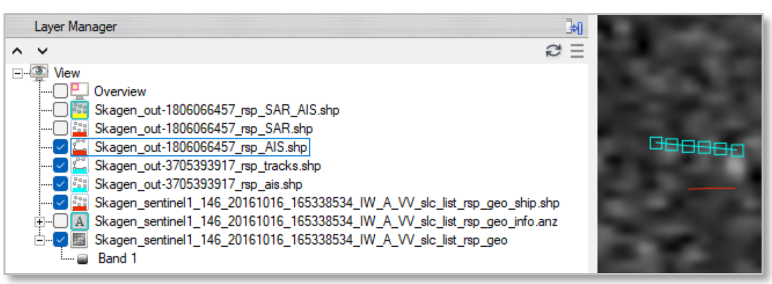


Figure 33. Example of unmatched AIS track with any SAR-detected objects

VII. RESOURCES

Crisp, D. J. (2004). The State-of-the-Art in Ship Detection in Synthetic Aperture Radar Imagery, *Australian Government, Department of Defence, Edinburgh, DSTO Information Sciences Laboratory*, DSTO-RR-0272, 1-115