Microwave Toolbox

Change Detection with Sentinel-1 GRD Product

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Jun Lu
Luis Veci

About this tutorial

The goal of this tutorial is to introduce three change detection operators, namely Log Ratio, REACTIV and RPCA.

The Log Ratio operator detects changes by analyzing the intensity difference between two SAR images. It is a simple and widely used method in SAR change detection.

The REACTIV operator, developed based on the REACTIV (Rapid and EAsy Change detection in radar TIme-series by Variation coefficient) algorithm proposed by Koeniguer et al. [1], identifies changes across a time series of SAR images and also serves as a visualization tool to highlight the changes.

The RPCA (Robust Principal Component Analysis) operator detects changes between two SAR images by decomposing them into a low-rank background image and a sparse target image, making it especially effective for detecting small targets such as ships.

This tutorial provides step-by-step guidance on how to apply these operators in change detection using Sentinel-1 GRD products.

[1] Elise Colin Koeniguer, Alexandre Boulch, Pauline Trouve-Peloux and Fabrice Janez, "Colored visualization of multitemporal data for change detection: issues and methods", EUSAR, 2018.

Log Ratio

Log-ratio Algorithm

The goal of a change detection algorithm is to identify and quantify difference between two SAR images acquired at different times. This is typically achieved by analyzing the intensity differences, making the generation of a difference image a crucial step.

For a given image pair I_1 and I_2, the difference image can be computed by subtraction ($I_1 - I_2$), ratio ($\frac{I_1}{I_2}$), or log ratio ($log\left(\frac{I_1}{I_2}\right)$) methods -- all of which are available in the **Log Ratio operator** in SNAP.

In this tutorial, we will use the **log ratio** method, as it converts SAR's the multiplicative noise into additive noise, which helps enhance change features and suppress background noise.

Sentinel-1 GRD Product

The Sentinel-1 SAR instrument acquires data in four exclusive modes: Stripmap (SM), Interferometric Wide swath (IW), Extra Wide swath (EW) and Wave (WV). Each mode can generate Level-1 Ground Range Detected (GRD) products. These GRD products are available at different resolution levels (full, high and medium) for different acquisition modes. For this tutorial, we will use the Sentinel-1 IW high resolution (10m meters) dual-pol GRD products.

Download the data

The data used in this tutorial can be downloaded from the Copernicus Open Access Hub at https://scihub.copernicus.eu/dhus (login required, registration is free). Search and download the following Sentinel-1 IW GRD products:

1. S1A_IW_GRDH_1SDV_20220610T175028_20220610T175053_043604_0534C1_7CFB
2. S1A_IW_GRDH_1SDV_20230629T175034_20230629T175059_049204_05EAAA_EB08

Location of the Data

The Sentinel-1 products used in this tutorial cover the central UK and were acquired one year apart. We will focus on detecting changes in Manchester, one of the UK's fastest-growing cities, between June 2022 and June 2023.

Figure 1 shows the extent of the full Sentinel-1 product (white rectangle) and the selected subset (red rectangle) which will be used for change detection.

Figure 1: Extent and location of the data

Preprocessing

The first step is to apply radiometric calibration to both images. This is essential for meaningful intensity comparison. Next, we will create a subset for our area of interest (AOI), as the full Sentinel-1 IW GRD product spans roughly 110km × 150km, which is significantly larger than our AOI. Subsetting reduces processing time and memory use.

The subset area in the image can be determined with the following steps:

1. Open one product in SNAP and display its Amplitude_VV band on screen (Figure 2).
2. Zoom in to our AOI which is Manchester (Figure 3).
3. Right-click the AOI image and select **Spatial Subset from View** to open the subset dialog window (Figure 4).
4. Take note the **Pixel Coordinates** in the dialog window:
    a. Scene start X: 2057
    b. Scene start Y: 4899
    c. Scene end X: 5589
    d. Scene end Y: 7225

    from which we can compute the subset dimension as
    a. Width: 3533
    b. Height: 2327
5. Click Cancel to close the subset dialog window.

If you could not find Manchester in the image at Step 2, you can always place your mouse cursor over the image and read the corresponding pixel geo-position (latitude and longitude) in the **Pixel Info** window. With the help of the geo-position, you should be able to find Manchester at latitude 53°28′48″ North and longitude 2°14′24″ West.

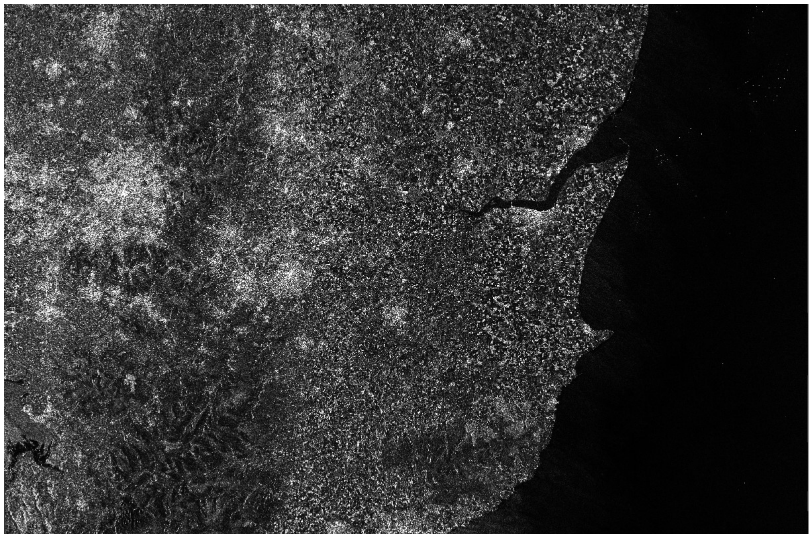

Figure 2: Amplitude_VV

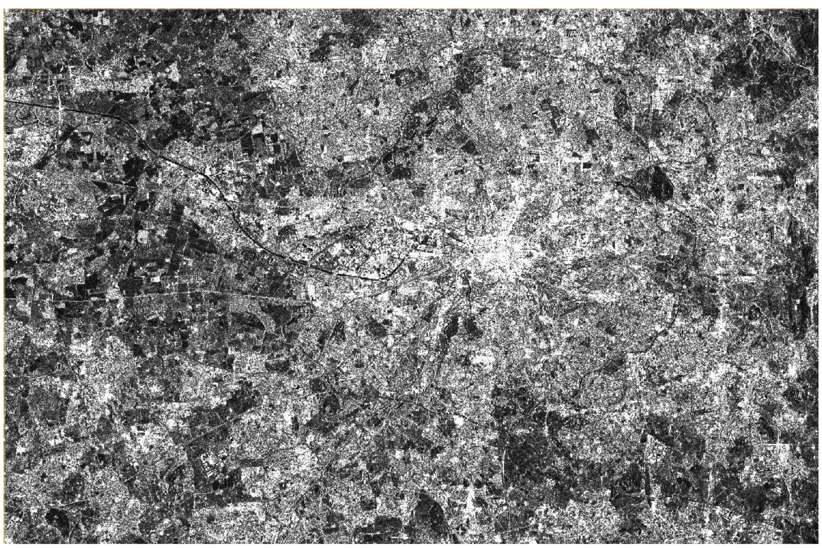

Figure 3: Subset image

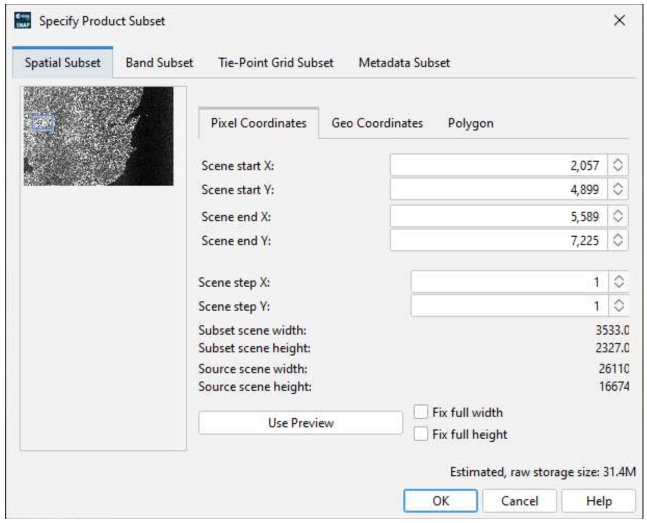

Figure 4: Subset dialog window

Now click the Graph Builder icon  to open the tool and create a graph as shown in Figure 5. The initial graph in the Graph Builder contains only the **Read** and **Writer** operators. We need to add the **Calibration** (under **Radar** > **Radiometric**) and **Subset** (under **Raster**) operators to complete the graph.

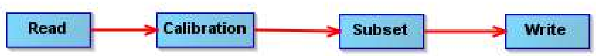

Figure 5: Pre-processing graph

In the **Read** tab, select the first Sentinel-1 GRD product. Then, in the **Calibration** tab, choose the **VV** polarization. In the **Subset** tab, enter the pixel coordinates computed earlier (Figure 6).

Click Run to process the first product.

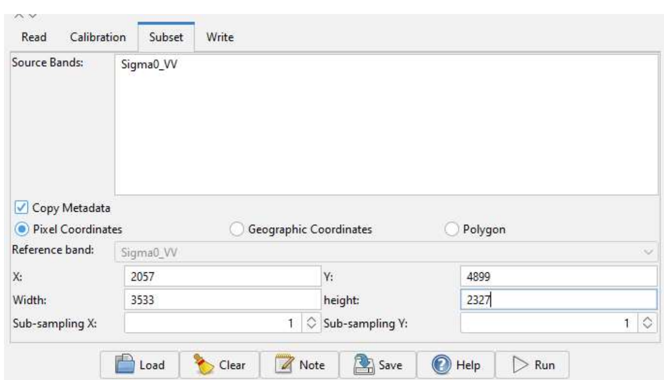

Figure 6: Subset tab

Repeat the same process for the second Sentinel-1 GRD product.

At this stage, we have two calibrated subset images covering only the city of Manchester.

Coregistration

In the previous step, we created two subset products over the Manchester area. However, there may be a slight misalignment between the two subset images. To accurately detect changes, the images must be aligned pixel to pixel using the **Coregistration** operator in SNAP.

Open the two subset products in SNAP using the **Open Product** icon and open the **Coregistration** operator under **Radar** > **Coregistration**.

Click on the **Add Opened** icon to load both subset products into the list. Ensure the 2022 product is on top of the list (Figure 7, left). If needed, adjust the ordering using the **Move Up** icon or **Move Down** icon. Here we want to sort the product list by the acquisition date.

In the **Create Stack** tab, select **Product Geolocation** as Initial Offset Method (Figure 7, right). In the **Cross-Correlation** and **Warp** tabs, we can keep the default parameters (Figure 8). In the **Write** tab, confirm the target product name and target directory. Click Run to start the coregistration process.

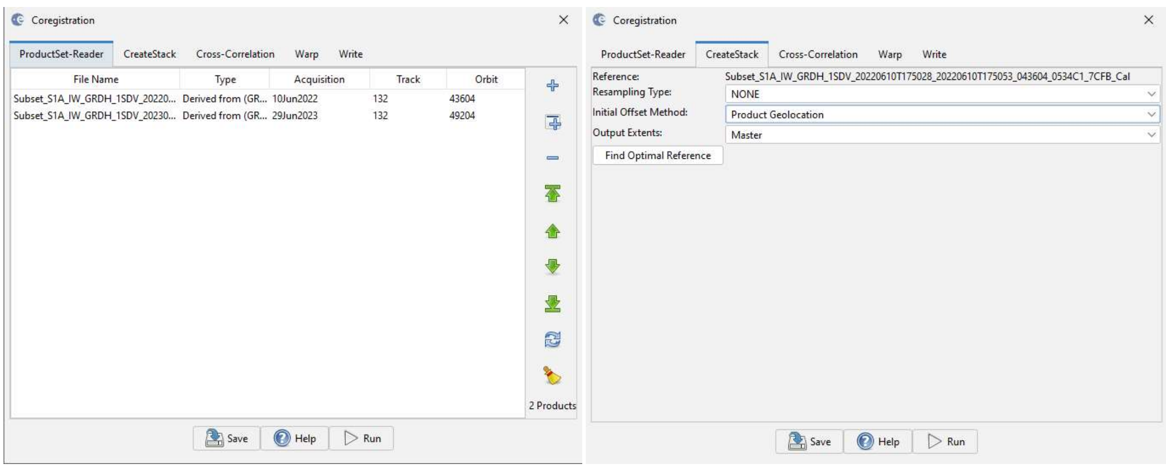

Figure 7: ProductSet-Reader (left) and Create Stack (right)

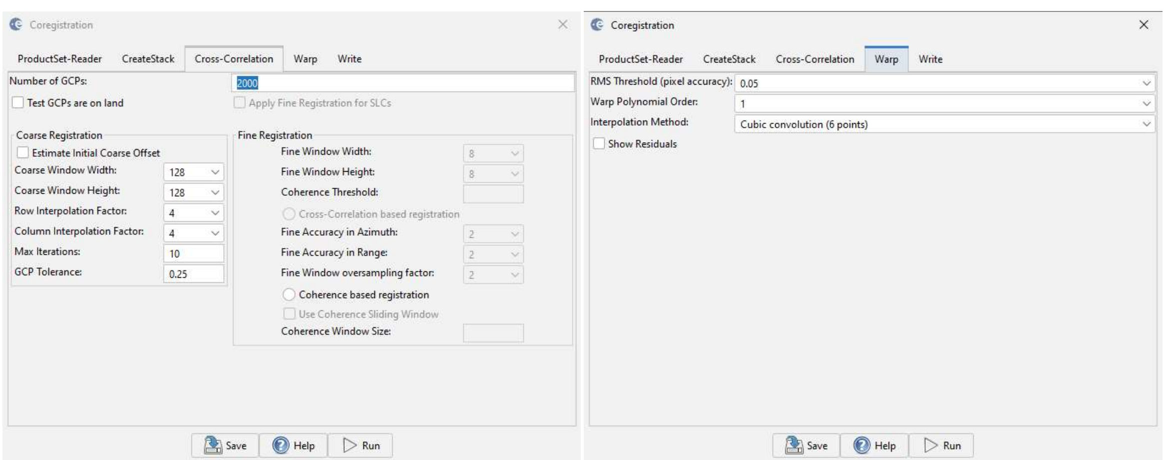

Figure 8: Cross-Correlation (left) and Warp (right)

As the result, we get a coregistered stack containing both aligned images (Figure 9).

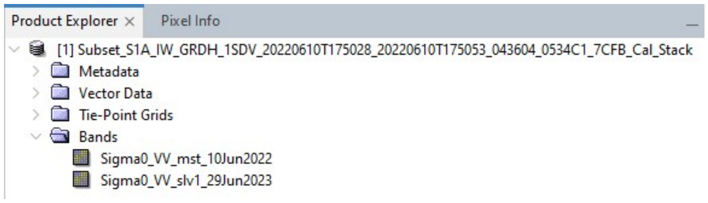

Figure 9: Coregistered stack

Performing Change Detection using Log Ratio

Now that we have the coregistered stack, we can perform the Log Ratio change detection. First open the coregistered stack in SNAP. Then open the **Log Ratio Change Detection** operator under **Raster** > **Change detection**. In the **Processing Parameters** tab, we use all the default parameters (Figure 10). Click Run to begin the processing.

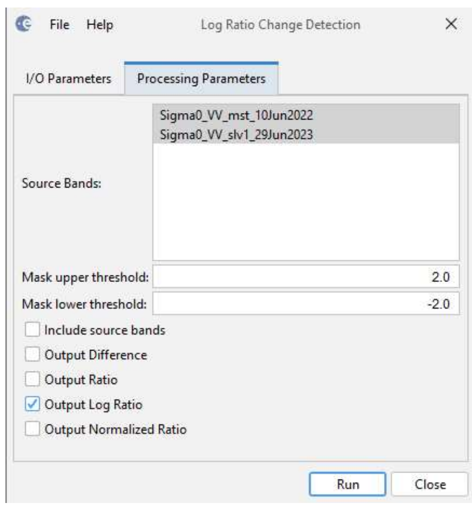

Figure 10: Log Ratio Change Detection

Figure 11 shows the output product of the Log Ratio Change Detection operator. The log_ratio band is the logarithm of the ratio of band Sigma0_VV_mst_10Jun2022 and band Sigma0_VV_slv1_29Jun2023, i.e.

$$log\left(\frac{Sigma0\_VV\_mst\_10Jun2022}{Sigma\ \ \_VV\_mst\_29Jun2023}\right).$$

The log_ratio_change is a mask created from band log_ratio using the two thresholds (2.0 and -2.0) as set in Log Ratio operator UI (Figure 10).

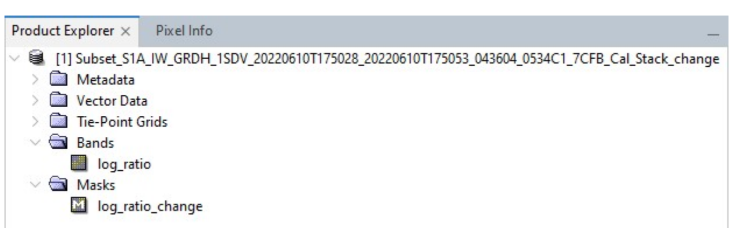

Figure 11: Output of the Log Ratio operator

Double-click the log_ratio band to display it in SNAP (Figure 12). The image is dominant by two colours: red and blue.

The red colour indicates a positive log ratio, meaning the intensity in 2022 image is stronger than in 2023 image. This suggests that targets on the ground have weakened or disappeared between 2022 and 2023.

The blue colour indicates a negative log ratio, meaning the intensity in 2022 image is weaker than in 2023 image. That implies the appearance of new targets during the time period.

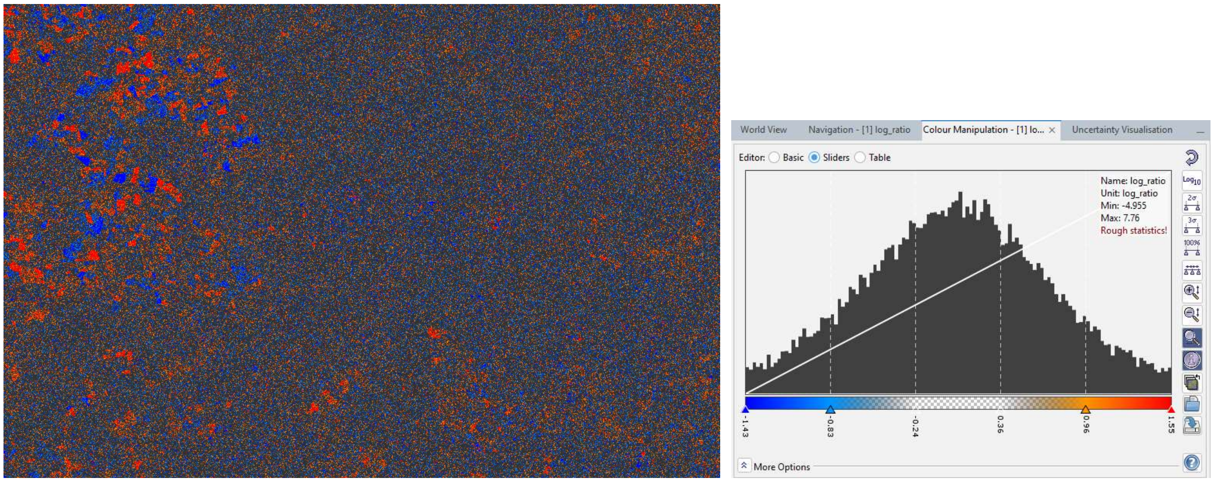

Figure 12: Band log_ratio (left) and its histogram (right)

Double-click the log_ratio_change mask to view it (Figure 13). This binary mask highlights areas with significant intensity changes between the two images.

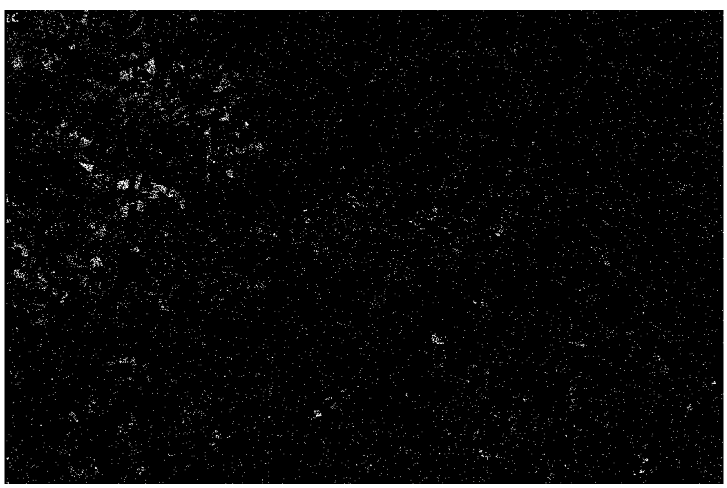

Figure 13: log_ratio_change mask

Let us zoom in to examine a specific area where changes have been detected and see what has happened in the area. First click the **Tile Horizontally** icon to display both images side by side (Figure 14). Next click the **Synchronize View** icon in the **Navigation** panel on the bottom left to link the views, allowing us to pan and zoom both images simultaneously.

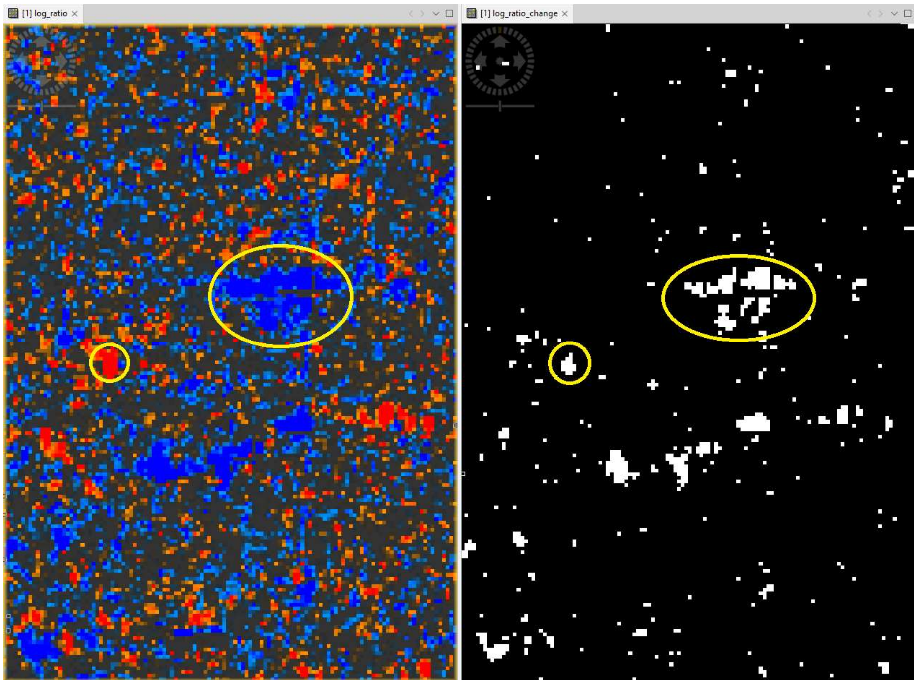

Figure 14: Log ratio band (left) and log_ratio_change mask (right)

We will focus on two areas marked with yellow circles. The large circle area is blue, indicating new targets have appeared in this area between 2022 and 2023. The small circle area is mostly red, suggesting that a target has disappeared during this period.

To verify these results, we will use the **Historical Imagery** feature in **Google Earth**. First move your mouse cursor to the center of the circle and take note the geographic coordinates in the **Pixel Info** panel:

1. Large circle area: 53°28′16″ N, 2°14′40″ W
2. Small circle area: 53°28′20″ N, 2°15′10″ W

Below are the steps to view the historical satellite imagery in Google Earth:

1. Open Google Earth on your computer.
2. Search for Manchester, UK.
3. Zoom in to the area using the coordinates above.
4. Enable the **Historical Imagery** feature under **View**. A timeline will appear at the upper-left corner.
5. Explore the satellite images from different years using the timeline.

Visual Comparison from Google Earth:

Figure 15: April 2022 -- the large circle area is mostly empty with no visible building.

Figure 16: June 2023 – the same area now has tall buildings, confirming the presence of new targets.

Figure 17: April 2022 -- the small circle area shows a building standing in the location.

Figure 18: June 2023 -- the building has disappeared and the area is now empty.

These visual confirmations validate the results from the Log Ratio change detection, demonstrating its effectiveness in identifying real-world changes on the ground.

Figure 15: Google Earth imagery for the large circle area in April 2022

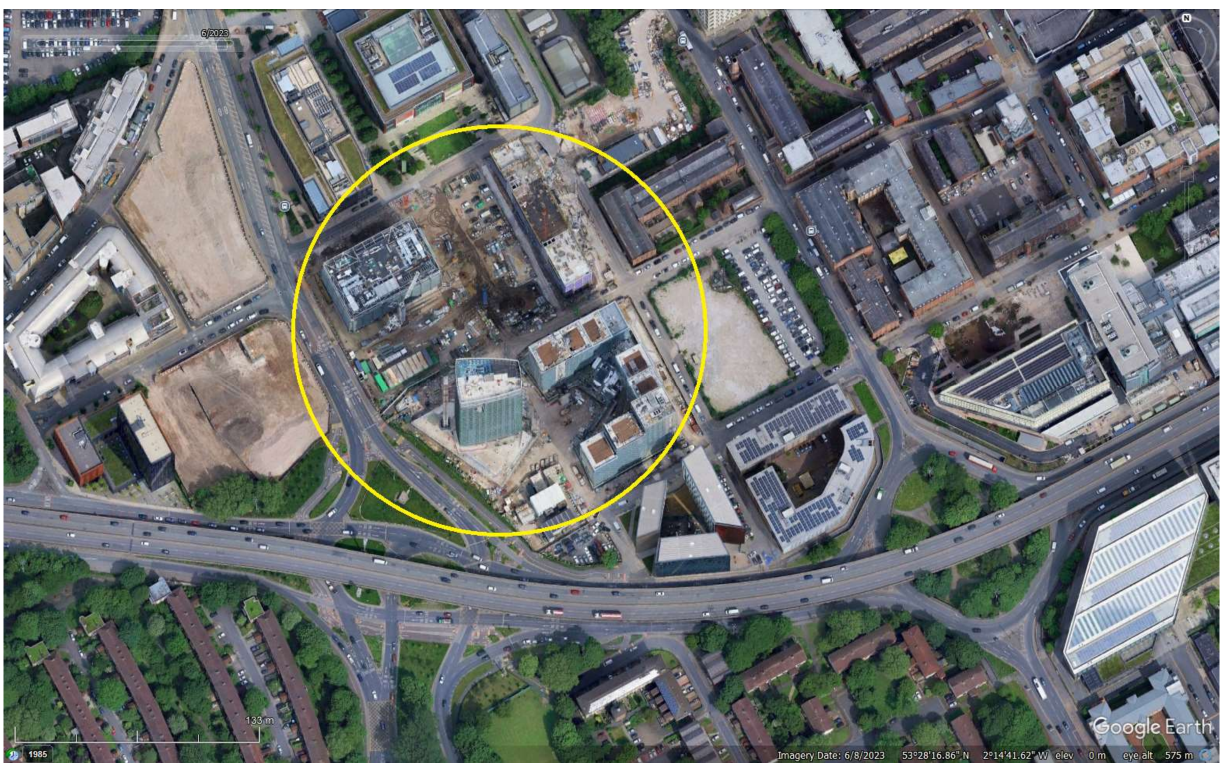

Figure 16: Google Earth imagery for the large circle area in June 2023

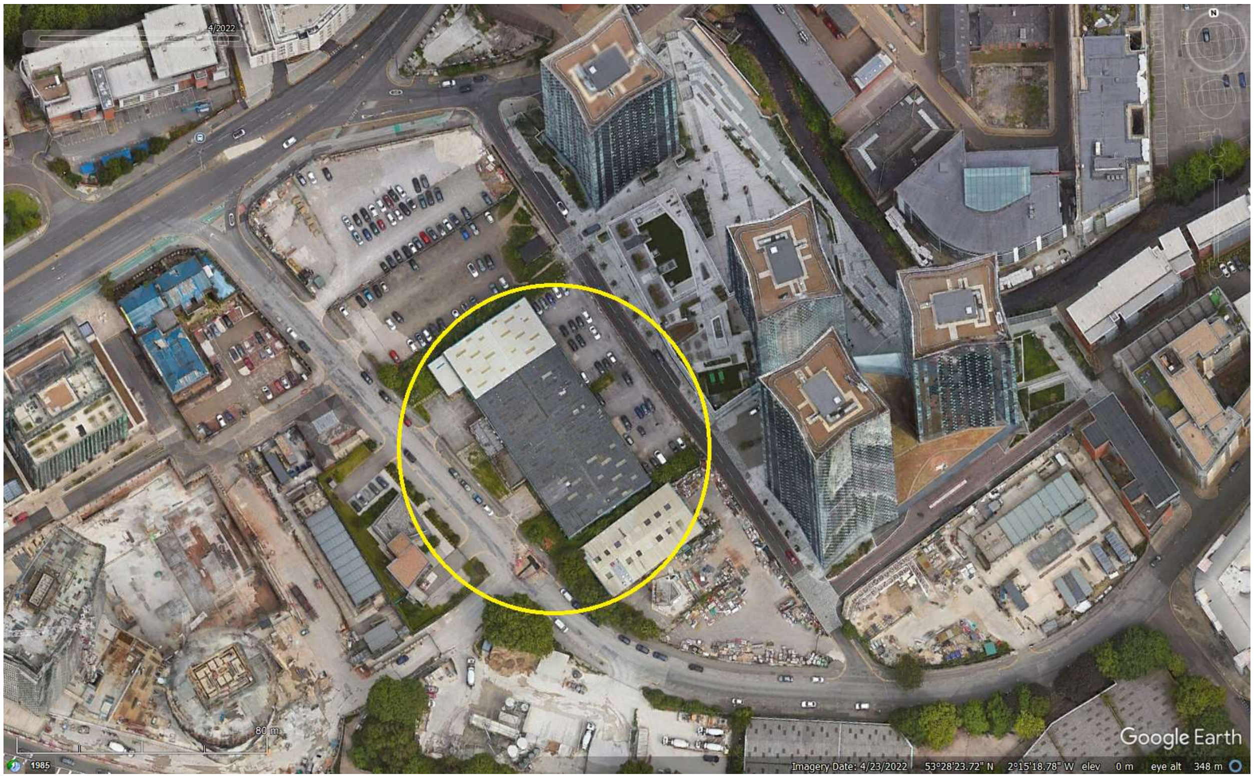

Figure 17: Google Earth imagery for the small circle area in April 2022

Figure 18: Google Earth imagery for the small circle area in June 2023

REACTIV

REACTIV Algorithm

REACTIV is a tool designed for time series analysis, with two primary objectives: first, to detect all the pixels where changes occurred between the initial and final observation dates; and second, to highlight those detected changes.

In the context of change detection within a time series of SAR images, the main questions are: where the changes are located, when they occurred and how intense they are. By leveraging the HSV colour space for visualization, the algorithm is able to present all this change-related information in a single image.

The HSV colour space is composed of three components: Hue, Saturation and Value (Figure 19).

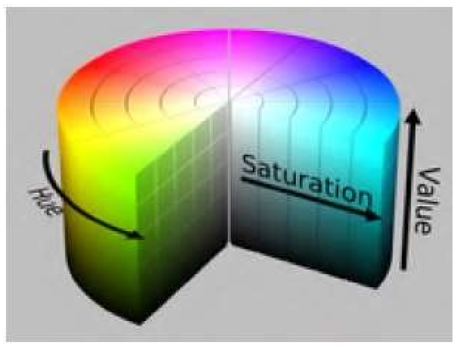

Figure 19: HSV Cylinder [1]

The Hue component encodes the temporal information of the detected change. This allows us to estimate the timing of an event within the observation period. To prevent colour similarity between the start and end of the hue spectrum, the original range of [0, 1] is reduced to [0, 0.9], creating a clear visual distinction (Figure 20). [1]

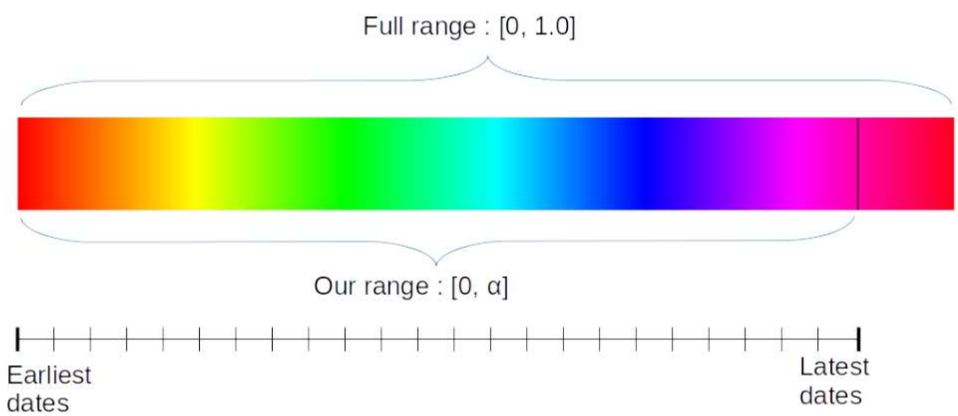

Figure 20: Custom Hue Range [1]

The Saturation component controls the intensity of the colour defined by the hue value and is directly linked to the magnitude of change. Greater changes result in more saturated colour, while areas with minimal or no change appear white on the map (Figure 21). [1]

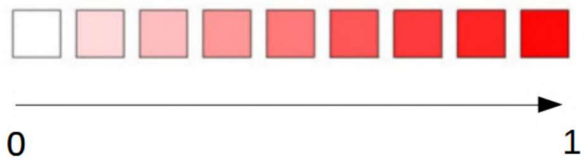

Figure 21: Colour Saturation Scale [1]

Lastly, to preserve the familiar appearance of SAR Image, the Value component -- ranging from dark to bright, depending on the hue-selected colour -- represents the maximum signal value observed across both polarizations (Figure 22). [1]

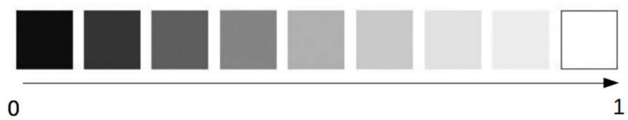

Figure 22: Colour Value Scale [1]

Download the data

Search and download the following Sentinel-1 IW GRD products from the Copernicus Open Access Hub:

1. S1A_IW_GRDH_1SDV_20230102T173332_20230102T173357_046608_0595FC_583A
2. S1A_IW_GRDH_1SDV_20230126T173331_20230126T173356_046958_05A1C5_851E
3. S1A_IW_GRDH_1SDV_20230219T173330_20230219T173355_047308_05AD87_646A
4. S1A_IW_GRDH_1SDV_20230315T173330_20230315T173355_047658_05B960_50FF
5. S1A_IW_GRDH_1SDV_20230408T173331_20230408T173356_048008_05C52D_B00A
6. S1A_IW_GRDH_1SDV_20230502T173332_20230502T173357_048358_05D0EF_19AE
7. S1A_IW_GRDH_1SDV_20230526T173333_20230526T173358_048708_05DBA1_FD1C
8. S1A_IW_GRDH_1SDV_20230619T173334_20230619T173359_049058_05E63C_4342
9. S1A_IW_GRDH_1SDV_20230713T173336_20230713T173401_049408_05F0F4_3886
10. S1A_IW_GRDH_1SDV_20230806T173337_20230806T173402_049758_05FBB4_1961
11. S1A_IW_GRDH_1SDV_20230830T173338_20230830T173403_050108_0607AE_272C
12. S1A_IW_GRDH_1SDV_20230923T173339_20230923T173404_050458_061394_DA69

As some of the required steps are computationally intensive, it is good to store the data at a location which offers good reading and writing speed. If your computer has an internal SSD, processing should be done there to ensure best performance. Network drives or external storage devices are not recommended. Also, paths which include special characters should be avoided.

Location of the Data

The data used in this tutorial covers the Scheldt River region near Antwerp, located between southwestern Netherlands and western Belgium. Figure 23 shows the full extent of the Sentinel-1 data (white) and the subset used for this tutorial (red).

Figure 23: Extent and location of the data

To demonstrate the changes in this region over the course of a year, we select 12 products spanning nine month period, from January 2023 to September 2023. The temporal interval between acquisitions is 24 days.

Preprocessing

The goal of this step is to create a subset for the Area of Interest (AOI), as shown in Figure 23, for each of the 12 products. Although subsets can be generated automatically using the **Batch Processing** function in SNAP, this method can be memory-intensive and relatively slow.

For this tutorial, we will instead create the subsets manually by running a graph as shown in Figure 24 for each of the 12 products.

Figure 24: Graph for creating a subset

To begin, we need to identify the subset area within the SAR image:

1. Open the first product in SNAP and display the Amplitude_VH band on screen (Figure 25).
2. Zoom in the image and focus on the desired AOI (Figure 26).
3. Right click on the AOI display and select **Spatial Subset from View**. This will open the **Specify Product Subset** window (Figure 27). Take note of the **Pixel Coordinates**:
    a. Scene start X: 12404
    b. Scene start Y: 36

c. Scene end X: 16868
d. Scene end Y: 3198

from which we can compute the subset dimension as

a. Width: 4465
b. Height: 3163

4. Click Cancel to close the subset dialog window.

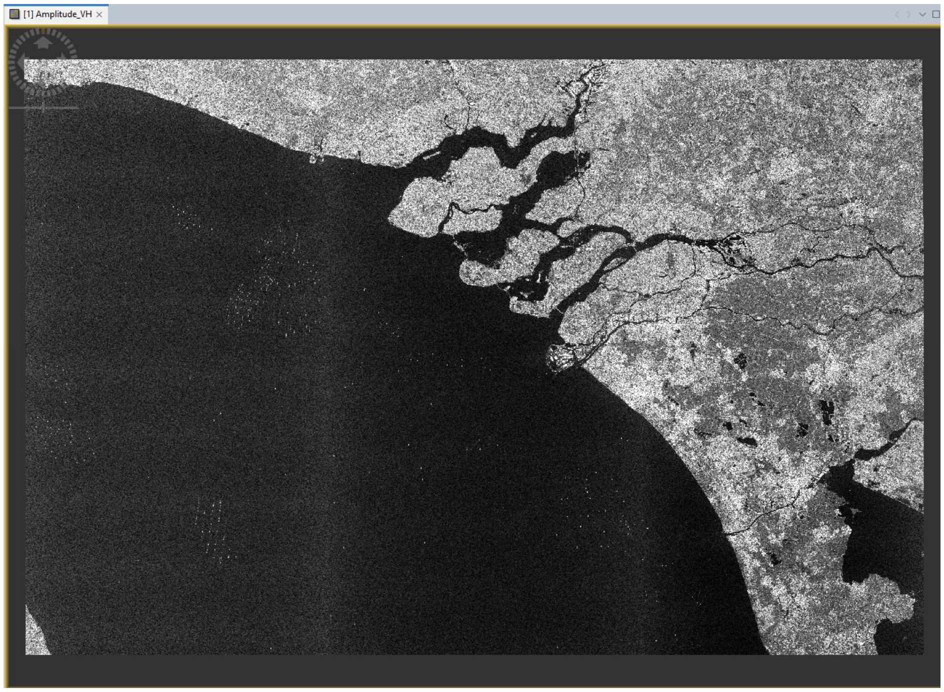

Figure 25: Amplitude_VH image of the first GRD product

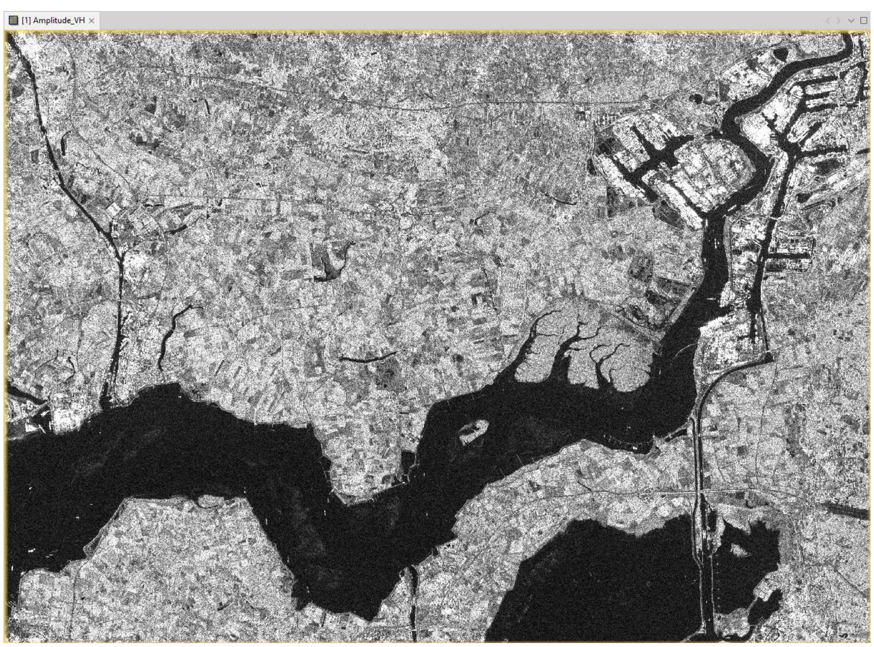

Figure 26: Image of the desired AOI

Next, create a graph as shown in Figure 24 using the Graph Builder in SNAP. In the **Subset** tab, enter the pixel coordinates obtained in the previous step, then save the graph (Figure 27). The graph can now be run individually for each of the 12 products.

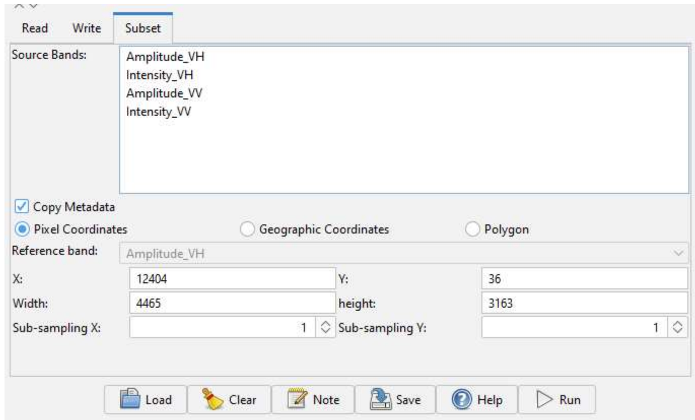

Figure 27: Subset tab

Creating coregistered multi-temporal stack

To detect changes between images, all images must be spatially aligned. This alignment is achieved using the **Coregistration** operator in SNAP.

First open all the pre-processed subset products in SNAP (Figure 28).

Figure 28: Pre-processed products

Then open the **Coregistration** operator under **Radar** > **Coregistration** and click on icon to load all the pre-processed products to the **ProductSet-Reader** in the **Coregistration** window. If the acquisition dates do not automatically appeared in the third column, click the **Refresh** button. Use the arrows on the right to sort the input products by acquisition date. In the **CreateStack** tab, set **Product Geolocation** as **Initial Offset Method** (Figure 29).

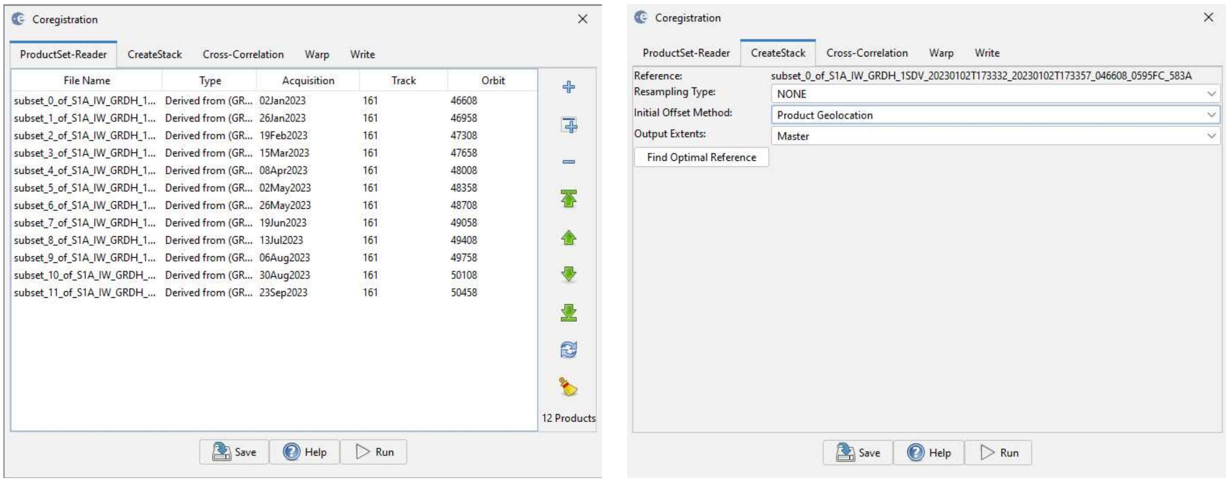

Figure 29: ProductSet-Reader (left) and CreateStack (right) in Coregistration window

In the Cross-Correlation tab, reduce the default **Number of GCPs** from 2000 to 500, as the subset images are relatively small, we set it to 500 (Figure 30). For the **Warp** tab, the default setting can be used. Finally, confirm the output name and directory in the **Write** tab, then start the coregistration by clicking on **Run**.

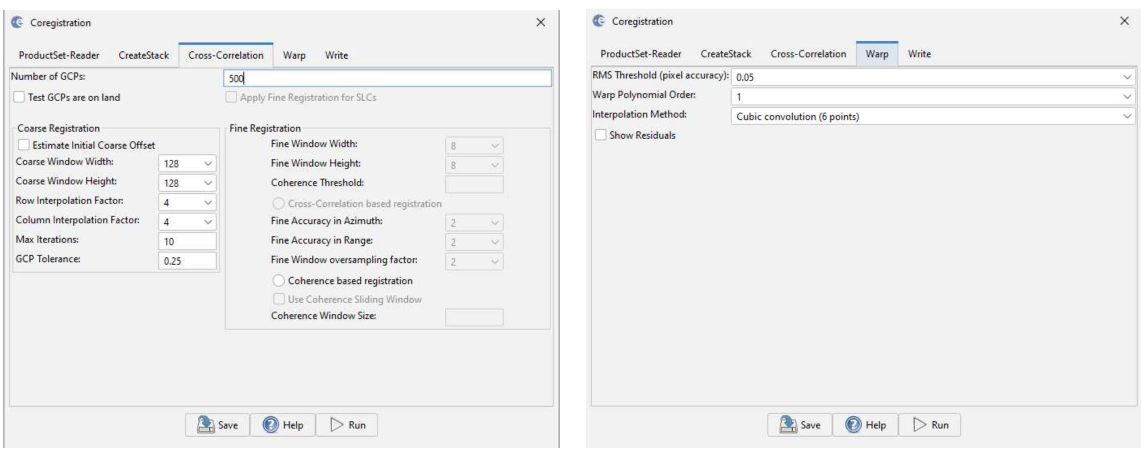

Figure 30: Cross-Correlation (left) and Warp (right) in Coregistration window

The result product will contain 24 bands, as shown in Figure 31.

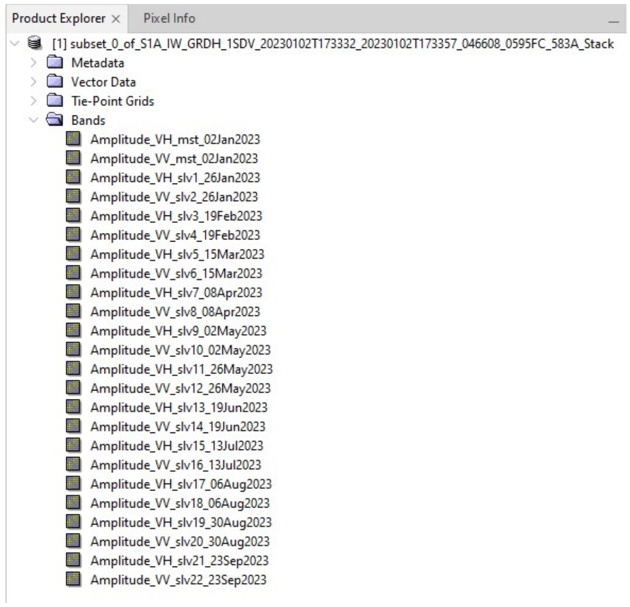

Figure 31: Coregistered multi-temporal stack

Performing Change Detection using REACTIV

We are now ready to run the REACTIV Change Detection operator. Start by opening the stack product generated during the coregistration step in SNAP. Then open the **REACTIV Change Detection** operator under **Raster** > **Change Detection** and click **Run** to begin processing (Figure 32).

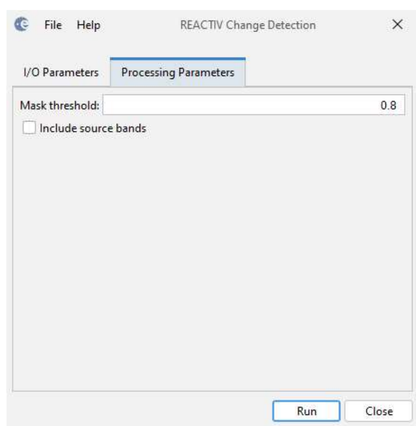

Figure 32: REACTIV Change Detection operator

The output, shown in Figure 33, includes three bands: **Hue**, **Saturation** and **Value**. The Hue band encodes the timing of changes using colours on the colour wheel. The Saturation band reflects the intensity of changes, while the Value band retains the SAR image appearance for HSV visualization.

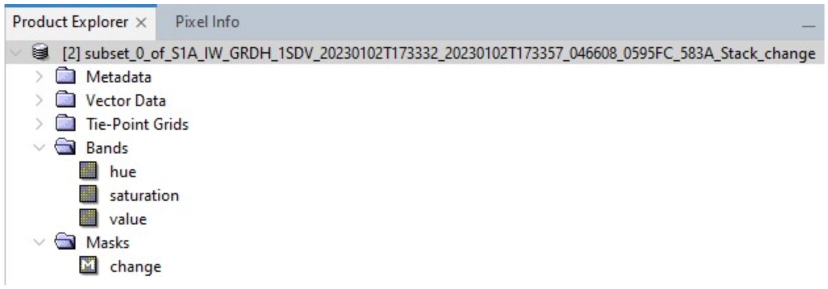

Figure 33: Output of the REACTIV operator

To view the change detection result, right-click the product and select **Open HSV Image Window**. Click OK to display the HSV image (Figure 34). Then, under **View** > **Tool Windows**, open the **Colour Manipulation** panel and click the icon for the Red, Green and Blue bands to achieve accurate colour rendering.

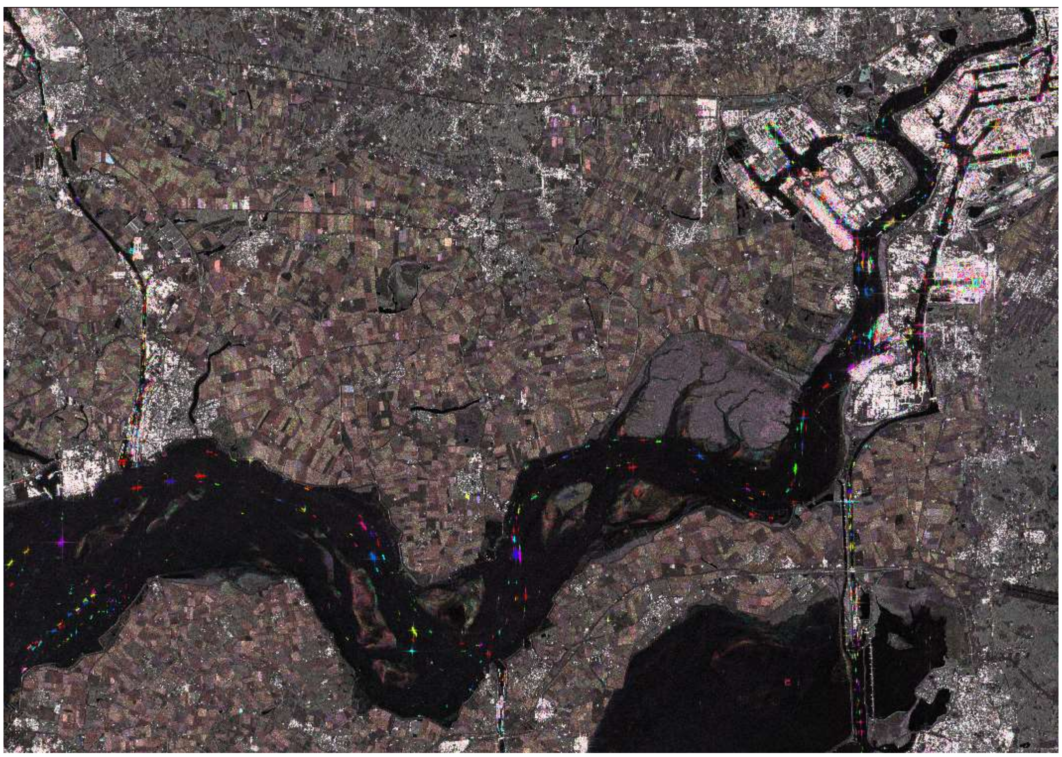

Figure 34: HSV display of the REACTIV change detection result

In REACTIV, changes are represented by hue colours that correspond to when they occurred. In Figure 34, for example, ships on the Scheldt River are displayed in varying hues. Since the observation period spans January to September 2023, ships in red likely appeared in January or February, while those in light blue appeared around May (see Figure 20 for the hue colour definition). This can be verified as follows:

1. Display the change detection result in HSV colour space as shown above.
2. Open the coregistered stack in SNAP and double-click the "Amplitude_VV_slv12_26May2023" band to open it.
3. Click the **Tile-Horizontally** icon to display both views side by side.
4. In the **Navigation** window, enable view and cursor synchronization (highlighted in Figure 35).

5. Locate a ship in the 2023-05-26 image and move the cursor over it, the synchronized cursor in the HSV image is now pointing to the same ship (Figure 36) which is light blue.

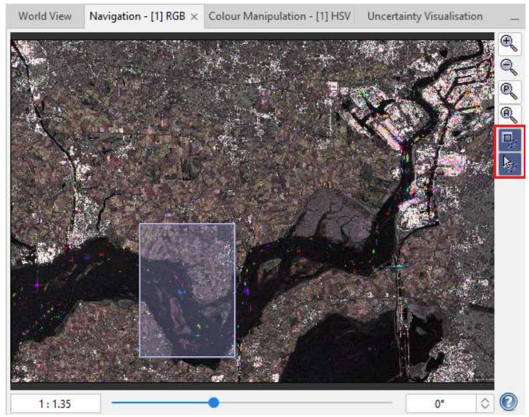

Figure 35: View and cursor synchronization icons in Navigation window

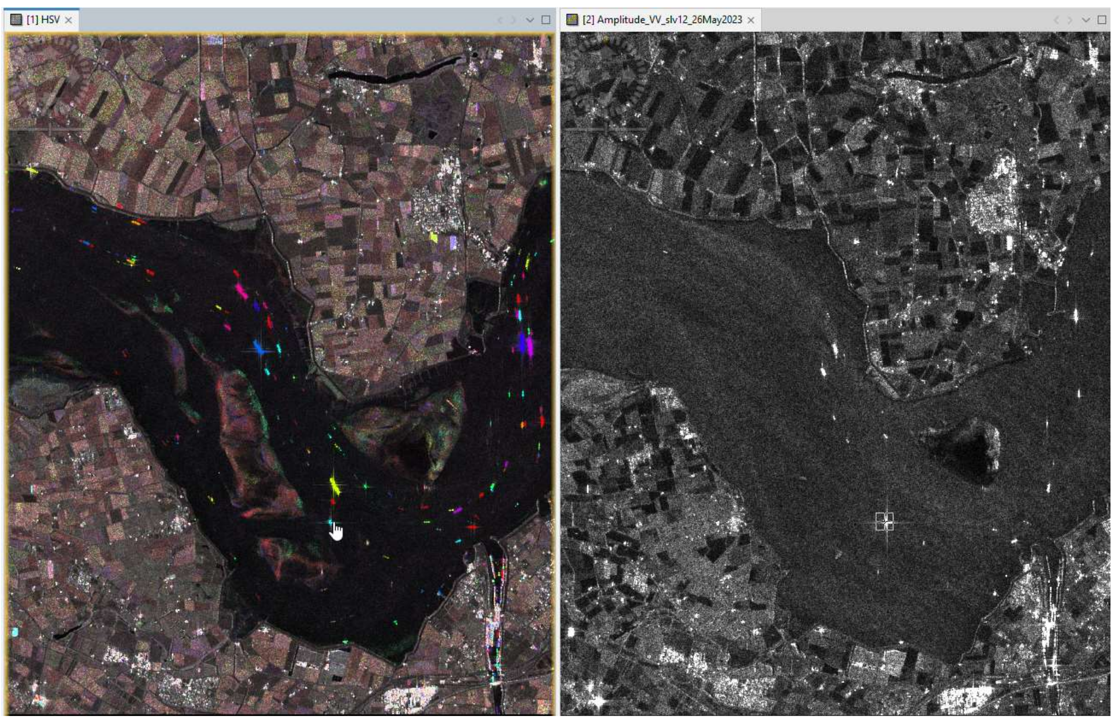

Figure 36: Ships in 2023-05-26 image are in light blue colour in HSV display

To highlight only strong changes, we can filter the Saturation band using a threshold. Since Saturation values range from 0 to 1, users can set a threshold (e.g., 0.8 as in Figure 32) to mask out low-intensity changes.

Figure 37 illustrates the Saturation band (left) and the resulting change mask (right), created using the default threshold. The change mask reveals that most changes occurred in the Scheldt River and the port of Antwerp.

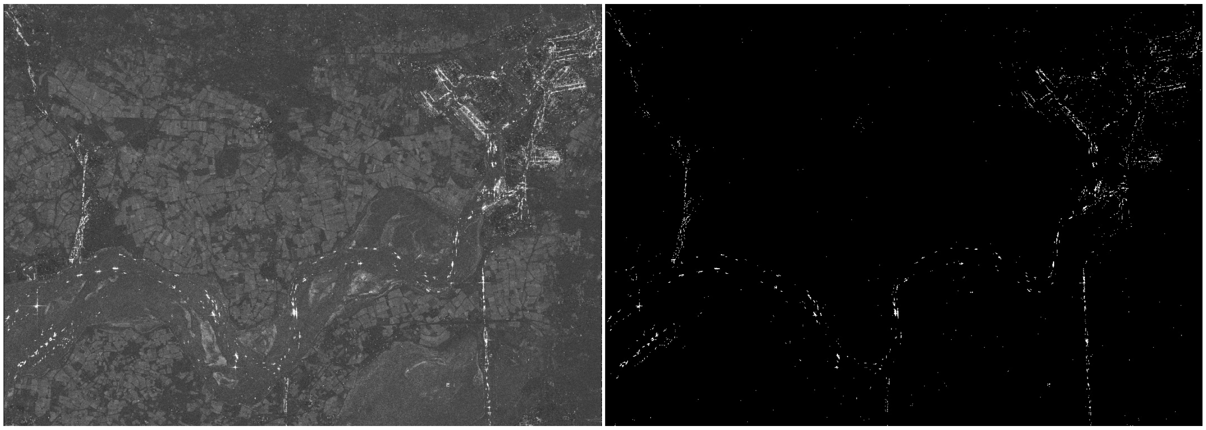

Figure 37: Saturation (left) and change mask (right)

RPCA

RPCA Algorithm

The Robust Principal Component Analysis (RPCA) is a popular data analysis tool. It is an extension of the traditional PCA algorithm. The goal of the RPCA is to decompose a given matrix ***X*** into a low-rank matrix ***L*** and a sparse matrix ***S***, i.e. ***X*** = ***L*** + ***S***. In the context of image, the low-rank part corresponds to the image background while the sparse part corresponds to outliers or small targets.

To detect changes between two images, we vectorize both images to create matrix ***X*** and decompose the matrix using the RPCA. As the result, the changes are given in matrix ***S***.

Download the data

Search and download the following Sentinel-1 IW GRD products from the Copernicus Open Access Hub:

S1A_IW_GRDH_1SDV_20240115T181831_20240115T181856_052121_064CC2_8D2C
S1A_IW_GRDH_1SDV_20240127T181831_20240127T181856_052296_0652A5_6D5A

Location of the Data

The products used for this tutorial cover the Gibraltar area and our AOI is right over the Strait of Gibraltar. Figure 38 shows the full extent of the Sentinel-1 product (white) and the subset AOI used for this tutorial (red). Small targets such as ships will be detected in this area.

Figure 38: Extent and location of the data

Preprocessing

Again we start our processing by subsetting both Sentinel-1 products. This can be achieved with the graph below (Figure 39).

Figure 39: Pre-processing graph

In the **Subset** tab, enter the following to the **Pixel Coordinates** and save the graph.

a. Scene start X: 5092
b. Scene start Y: 9180
c. Scene end X: 10254
d. Scene end Y: 12963

Now run this graph for both products individually to create the subsets.

Creating coregistered stack

Now we align both subset images using the **Coregistration** operator under **Radar** > **Coregistration**.

To start, we open both subset images in SNAP, and then open the **Coregistration** operator. In the **ProductSet-Reader** tab, click on icon to load all opened products to the list. In the **CreateStack** tab, set **Product Geolocation** as the **Initial Offset Method** (Figure 40).

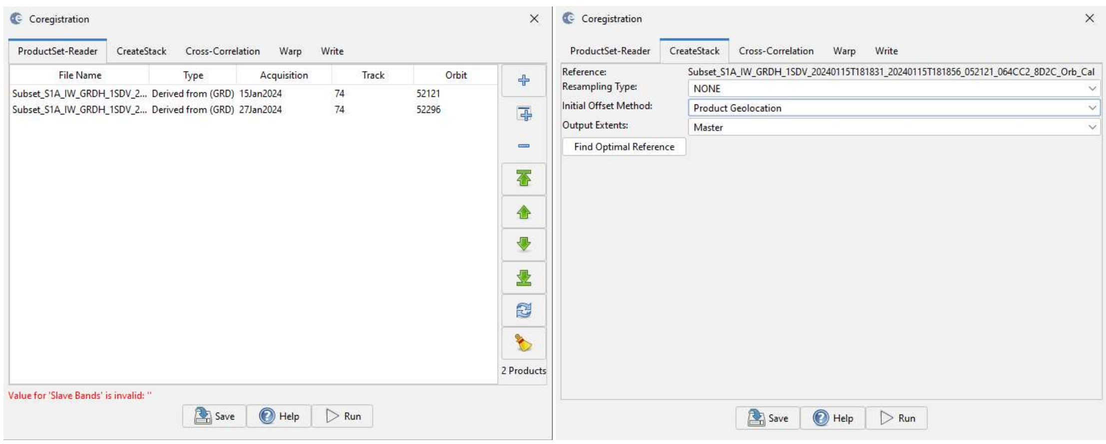

Figure 40: ProductSet-Reader (left) and CreateStack (right)

Set 500 for the **Number of GCPs** in the **Cross-Correlation** tab and keep the default setting in the **Warp** tab. Click Run to begin coregistration (Figure 41).

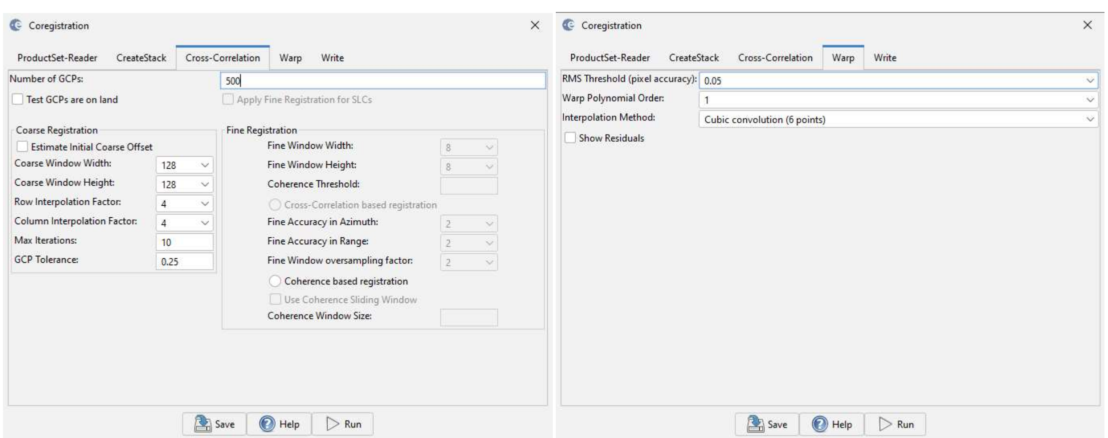

Figure 41: Cross-Correlation (left) and Warp (right)

The coregistered stack, as shown in Figure 42), contains four bands with two from each subset.

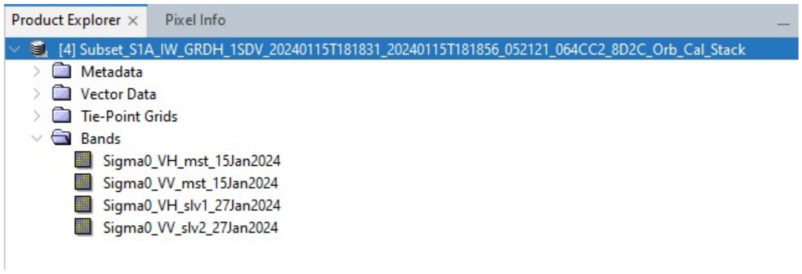

Figure 42: Coregistered stack

Performing Change Detection using RPCA

We are now ready to run the RPCA operator. Open the coregistered stack in SNAP and open the **RPCA Change Detection** operator under **Raster** > **Change Detection**. Select two bands with one from each product (Figure 43) and click Run to start the processing.

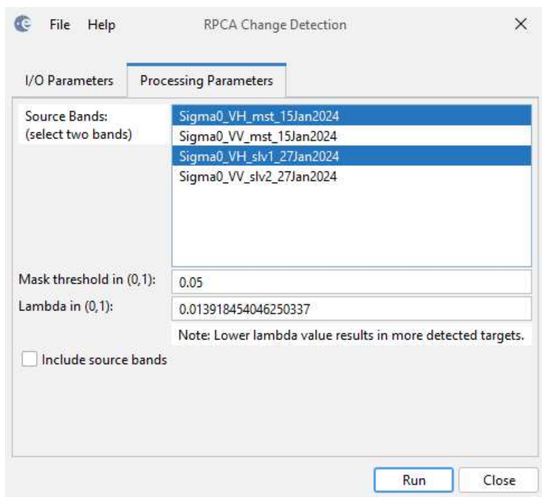

Figure 43: RPCA operator

Figure 44 shows the detection result of the RPCA operator.

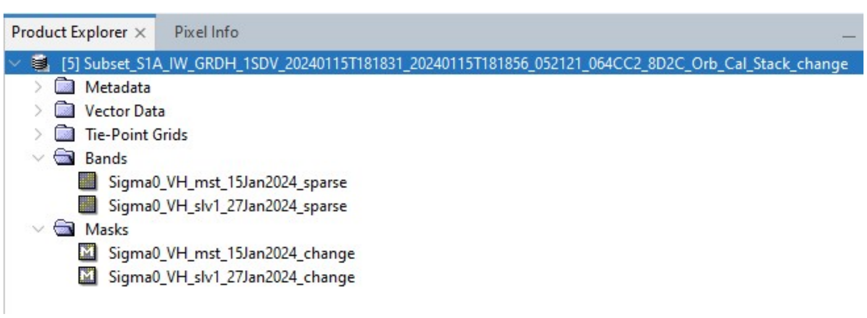

Figure 44: Output product of the RPCA operator

There are two bands in the output corresponding to the two vectors in the sparse matrix ***S***. Since we are interested in the changes during the observation period, we open the second band (Sigma0_VH_slv1_ 27Jan2024_sparse).

For comparison, we open the corresponding amplitude band (Sigma0_VH_slv1_27Jan2024) in the stack product as well. Click on icon to display both views side by side. In the Navigation window, enable both view and cursor synchronization.

Figure 45 shows the detected changes and their positions in the original amplitude image.

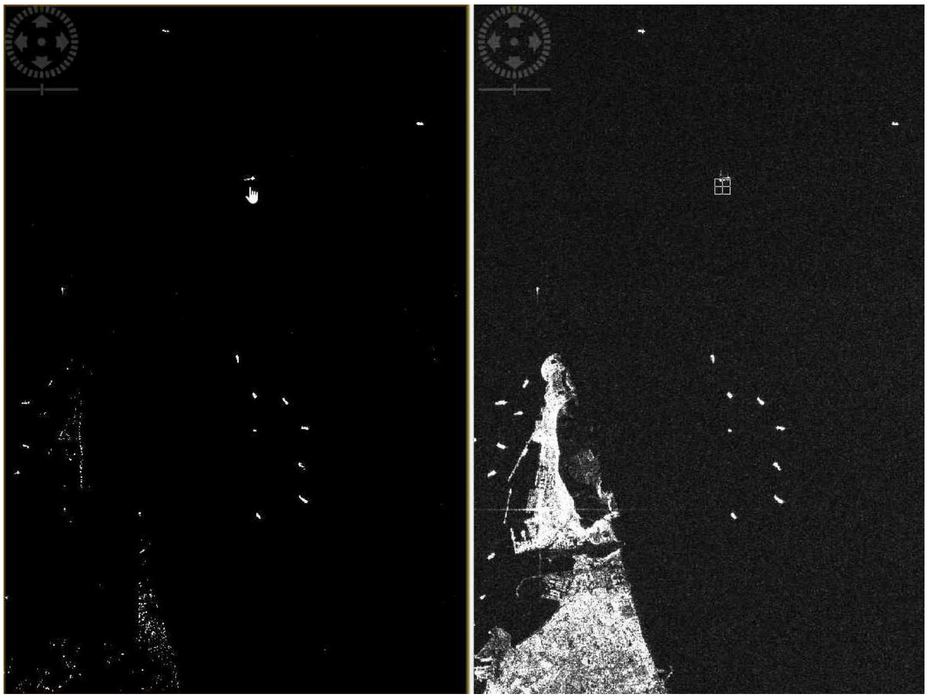

Figure 45: Detected changes (left) vs. original amplitude image (right)

The detected changes are filtered by masking out low-intensity outliers using the **Mask threshold** as shown in Figure 43. The filtered result is given as a mask (e.g. Sigma0_VH_slv1_27Jan2024_change) in the output. Figure 46 shows the change mask and the corresponding detected changes.

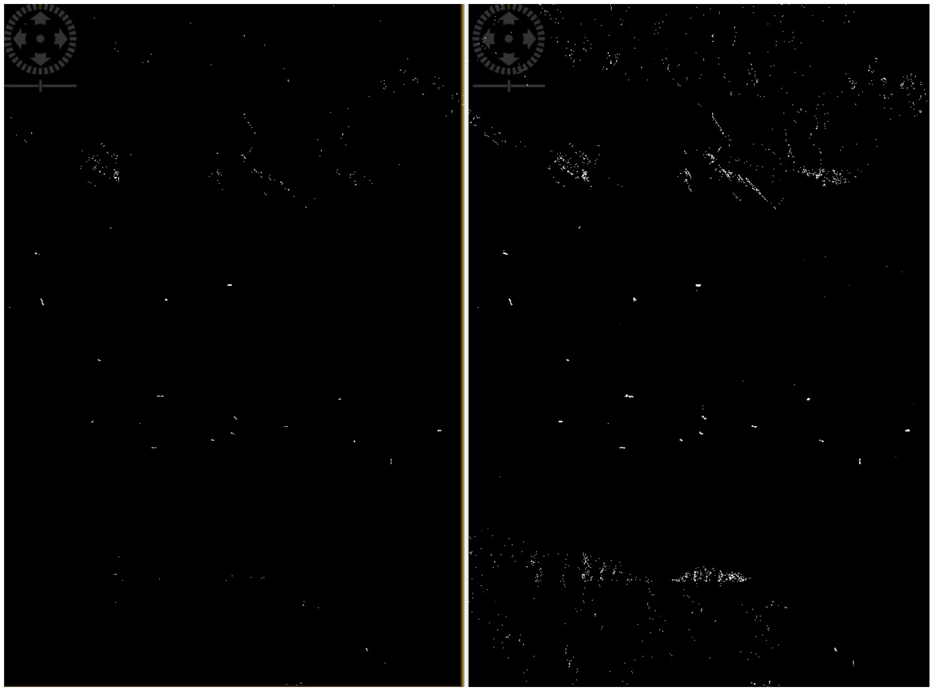

Figure 46: Change mask (left) vs. detected changes (right)

The filtered image appears much cleaner than the original change image. For further refinement, users may apply additional tools -- such as morphological tools -- to remove the outliers. However, this falls outside the scope of this tutorial and will not be covered here.

For more tutorials, please visit the Sentinel Toolboxes website at http://step.esa.int/main/doc/tutorials/.