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Sentinel-1 Toolbox

Synergetic use of radar and optical data

Combination of Sentinel-1 and Sentinel-2 and application of analysis tools

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About this Tutorial

The goal of this tutorial is to provide a workflow for the combination of radar imagery from Sentinel-1 and multispectral imagery from Sentinel-2 to demonstrate their synergetic use and complementary information content for landcover analysis.

It furthermore highlights potential error sources and challenges and demonstrates the use of analysis tools to be applied on the merged product.

Background and Preparation

Why merge radar and optical data?

Sentinel-1 is a radar satellite launched by the European Space Agency (ESA) operating at C-band (5.7 cm, Figure 1 red). It measures the intensity of the returned signal which was actively sent to the earth's surface. This allows to map physical characteristics, such as roughness, moisture and structure of the surfaces. Furthermore, radar images can also be acquired through cloud cover and independently of daylight. This makes them a valuable source of information for all regular monitoring activities.

Sentinel-2 is a multispectral satellite operating in the visible and infra-red spectrum (nanometer scale, Figure 1 green). It is a passive sensor which measures the energy emitted from the earth's surface in 13 separate bands at three different resolutions (more information).

Fusion techniques exist which combine information of different sensors to exploit their complementary information content, mostly at the pixel level (Ghassemian 2016, Pandit & Bhiwani 2015). In an ideal case, the images of both sensors are acquired at the same time. At least, the time between both image products should be minimized to grant that the information of each pixel refers to the same condition of the earth's surface. In this tutorial, images of both Sentinel-1 and Sentinel-2 were acquired on 18.08.2019.
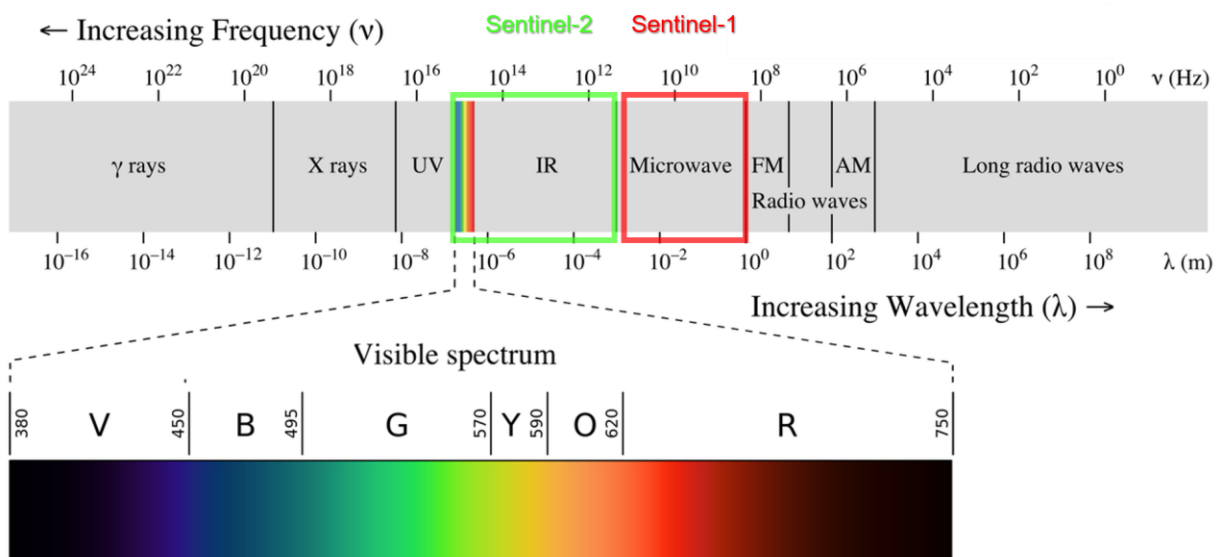

Figure 1: Electromagnetic spectrum and S1 / S2 satellites (Ronan 2013, CC BY SA 3.0)

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 for the two product IDs and download them:
SAR: S1B_IW_GRDH_1SDV_20190818T170708_20190818T170733_017643_02130B_9E0C
optical: S2A_MSIL2A_20190818T103031_N0213_R108_T32UNV_20190818T135455

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. In this tutorial, the data is stored under `C:\Temp\S1S2\`.

Location of the Data

The data used in this tutorial lies in eastern Turkey and includes the city of Erzincan and its surrounding landscapes. Figure 2 shows the extent of the Sentinel-1 data (red) and of the subset used in this tutorial (blue).
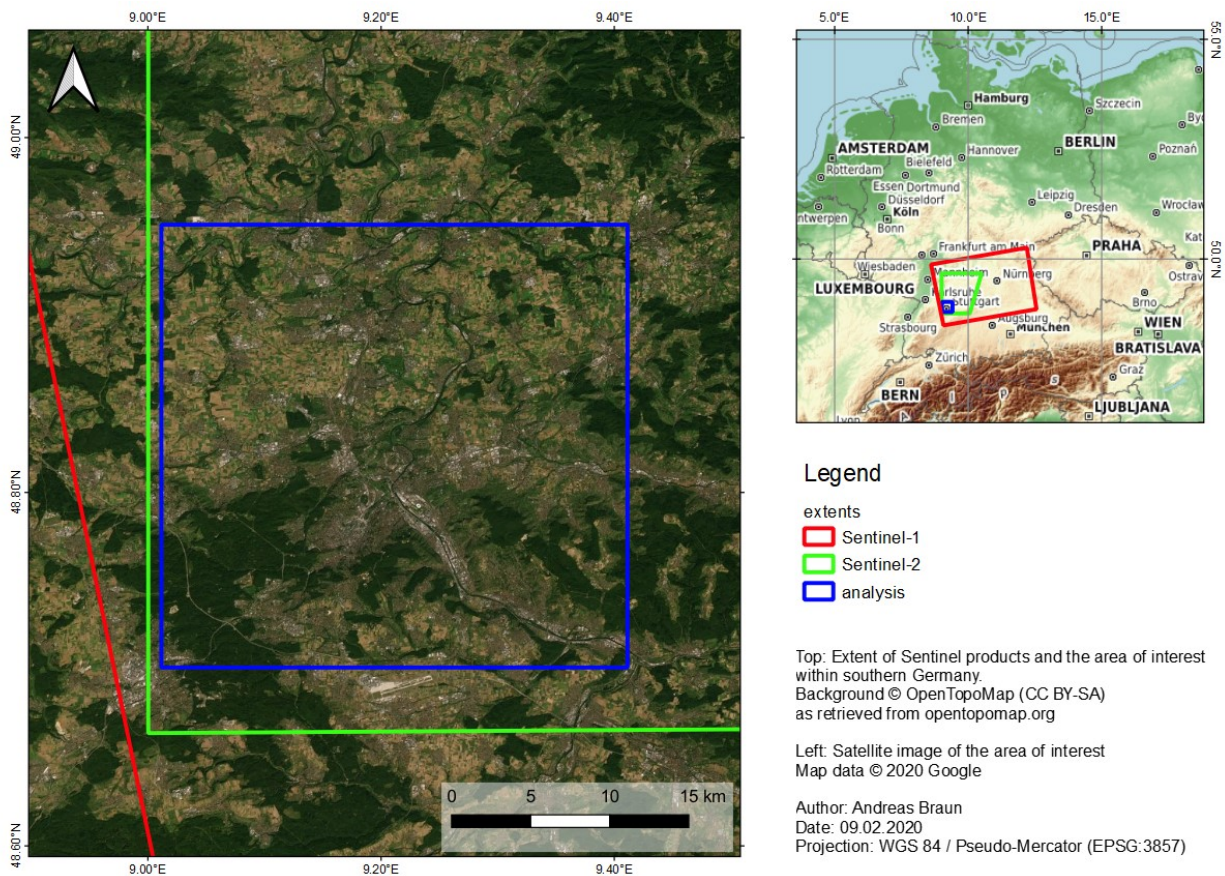

Figure 2: Extent and location of the data

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Workflow chart

Figure 3 summarizes the steps to merge images products of Sentinel-1 with Sentinel-2 (or any other combination of radar and optical data) as presented in this tutorial.
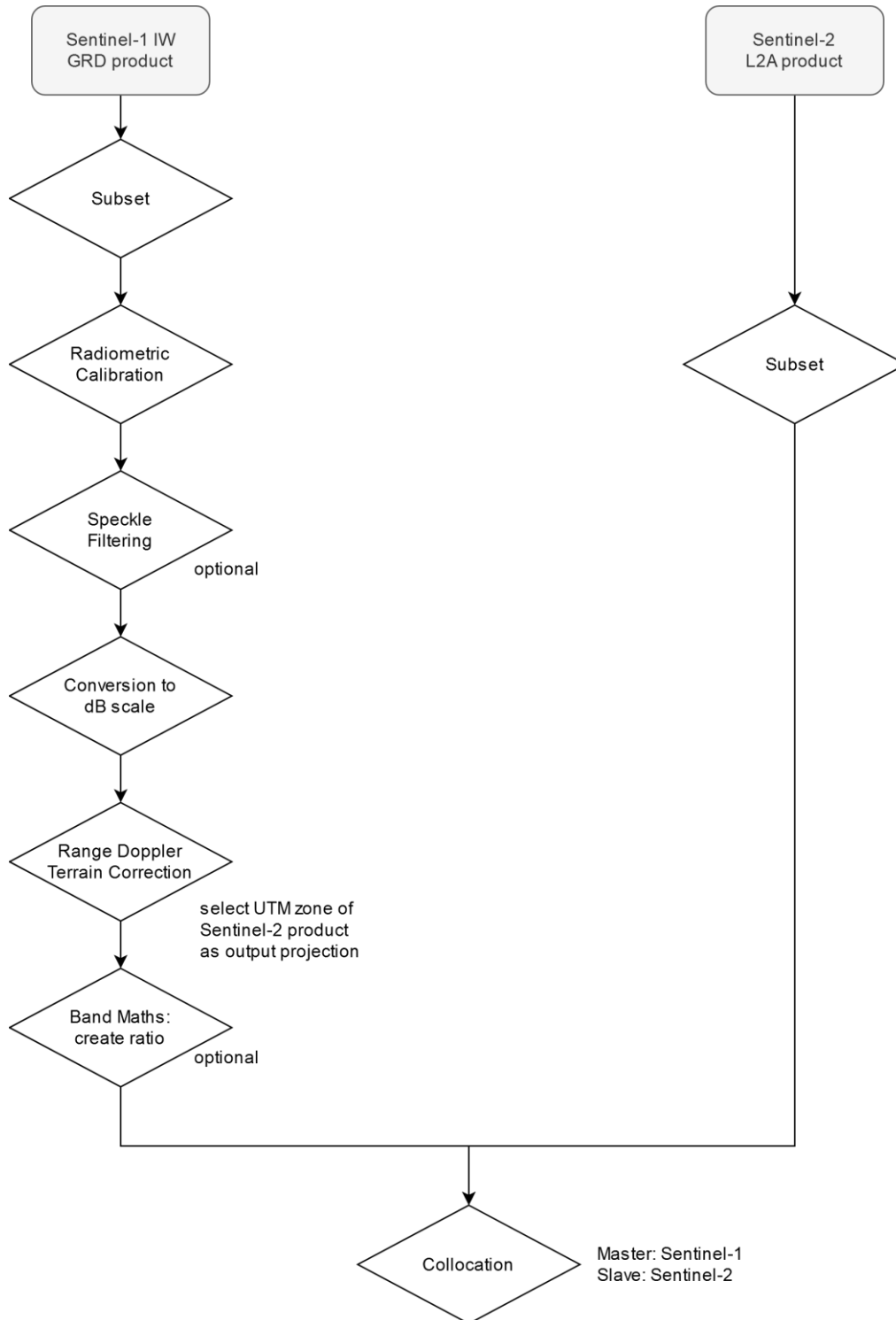

Figure 3: Systematic workflow for the merge of Sentinel-1 and Sentinel-2 images

Preprocessing by a Graph

Users with less experience are recommended to follow the steps outlined in the subsequent chapters (*Preprocessing of Sentinel-1*, *Preprocessing of Sentinel-2*, and *Merge the Products*) and skip the preprocessing by a graph.

Advanced users can use the Graph Builder of SNAP to preprocess the data. It automates the merge of both Sentinel-1 and Sentinel-2 by a predefined XML script. However, all settings (especially the subset by WKT coordinates) have to be adjusted carefully. Also, finding the reasons for failed processing in graphs can be hard.

The graph can be found in the Graph Builder ⚹ under:
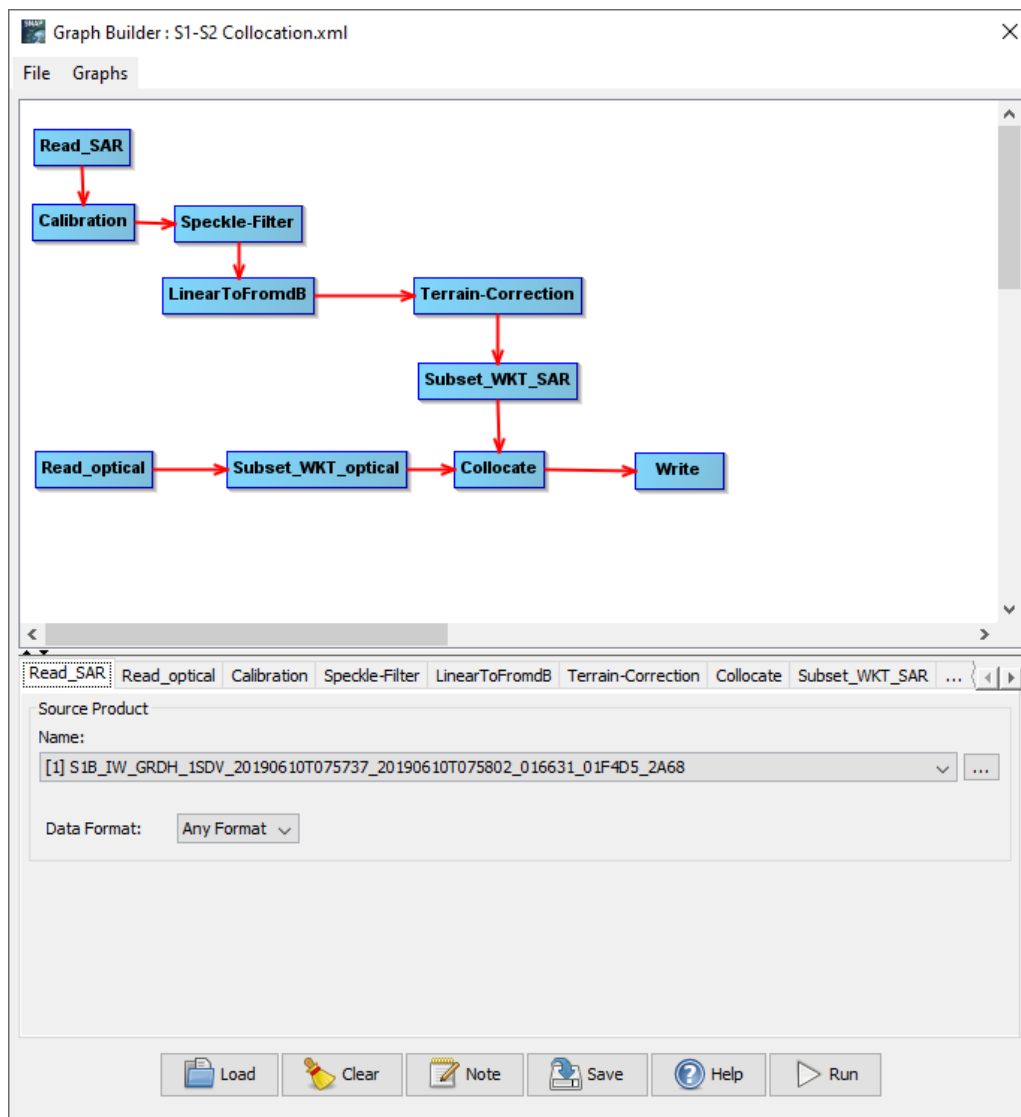   *Graphs > Radar > SAR Optical Graphs > S1-S2-Collocation*

Figure 4: Graph to collocate Sentinel-1 and Sentinel-2 data in SNAP

Open the Products

Use the *Open Product* button in the top toolbar and browse for the location of the downloaded data. Select the two downloaded zip files and press **Open Product**.

In the *Products View* you will see the opened products. Sentinel-1 products consist of Metadata, Vector Data, Tie-Point Grids, Quicklooks and Bands (which contains the actual raster data, represented by Amplitude and Intensity (=Amplitude²) in VV and VH polarization, as demonstrated in Figure 5).

Sentinel-2 (Level 2A) products are calibrated to Bottom of Atmosphere reflectance (BoA) and consist of Metadata, Index Codings, Vector Data, Bands, and Masks. Note: If no L2A products are available for your area, you can work with L1C as well. Just note that multi-temporal image analysis requires radiometric calibration with sen2cor to convert them to L2A (tutorial).

As both datasets are still compressed in the zip files and cover a large area, it is not advised to open the bands in their current state, because it takes a considerable time until SNAP loads the raster. If you still want to check the data before proceeding double-click on any band to view the raster data.

Another way to identify the location of your study area within the product (required for the next step), you can use the *World View* or *World Map* (to see its full extent on a base map) or open the *Quicklook* for a preview of the dataset in an RGB color representation.
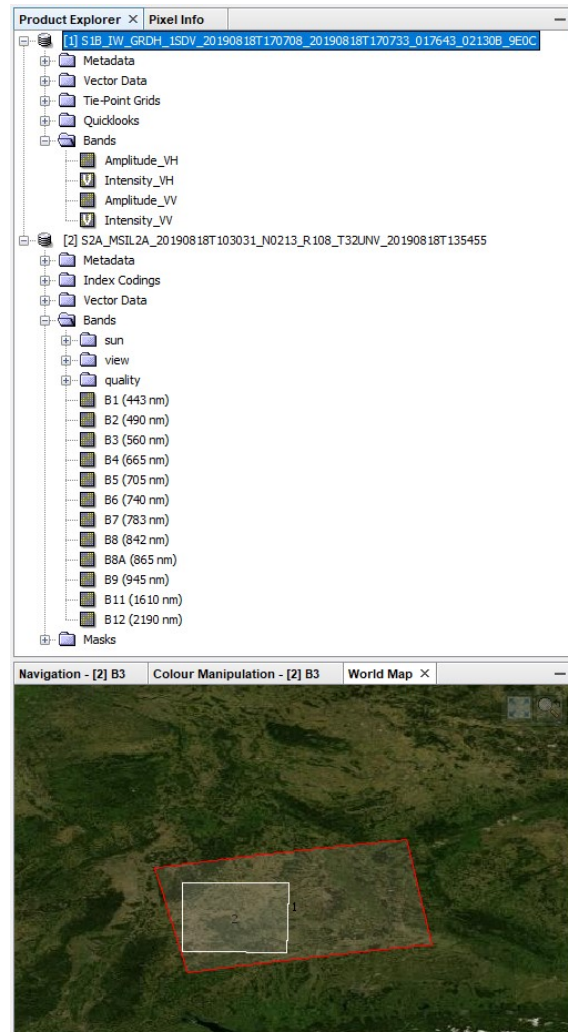

Figure 5: Product Explorer and World Map

Note: If you miss any items in your user interface you can activate them in the menu under *View* and *Tool Windows*.

A couple of steps are required before both products can be merged in one stack:

Sentinel-1: 1. Subset
2. Radiometric Calibration
3. Speckle Filtering
4. Range Doppler Terrain Correction / Projection into UTM coordinate system of Sentinel-2

Sentinel-2: 1. S2 Resampling
2. Subset

The subset is performed to clip both products on a common area and to reduce the amount of data to be processed.

In a first step, select one band of the Sentinel-2 product in the *Product Explorer* and select the **Geo-Coding** tool φ, λ from the menu bar. A new window will open (Figure 6) which shows you the coordinate reference system of the dataset.

Sentinel-2 products are stored in the corresponding UTM zone in which they are located. This projection is based on metric units (instead of degrees) and divides the earth into 60 zones with a width 6d of longitude. The UTM zone of the Sentinel-2 product in this tutorial is shown in the Geo-Coding window: Here, it is zone 32 North, as indicated in the line highlighted in Figure 6:

```
PROJCS["WGS 84 / UTM zone 32N"
```

This means, the Sentinel-1 data (currently unprojected) should be projected into the same coordinate reference system.
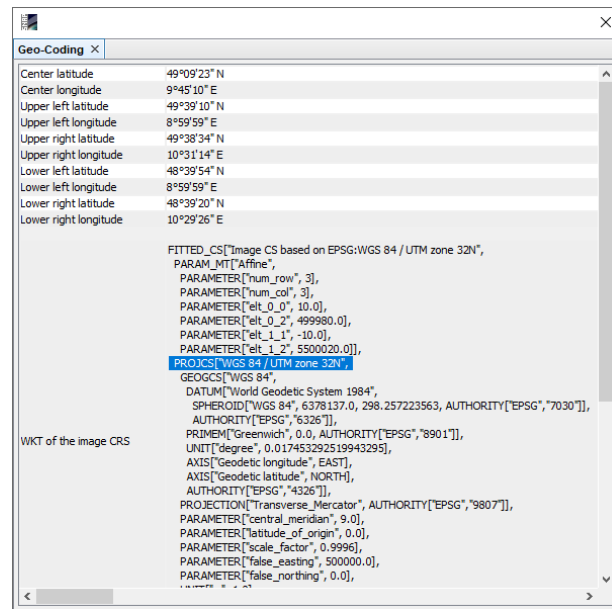
Figure 6: Geo-Coding of Sentinel-2

Preprocessing of Sentinel-1

Create a Subset

To reduce the loaded data to the area of interest, select the Sentinel-1 product in the *Product Explorer* and open the open the *Subset* operator (under *Raster*). A separate window might open ("Creating thumbnail image"), but this takes quite a long time, so it is ok to **Cancel** this window.

Switch to the Geo Coordinates tab and enter the following numbers (Figure 7):

- North latitude bound: 48.498
- West longitude bound: 9.058
- South latitude bound: 49.10
- East longitude bound: 9.50

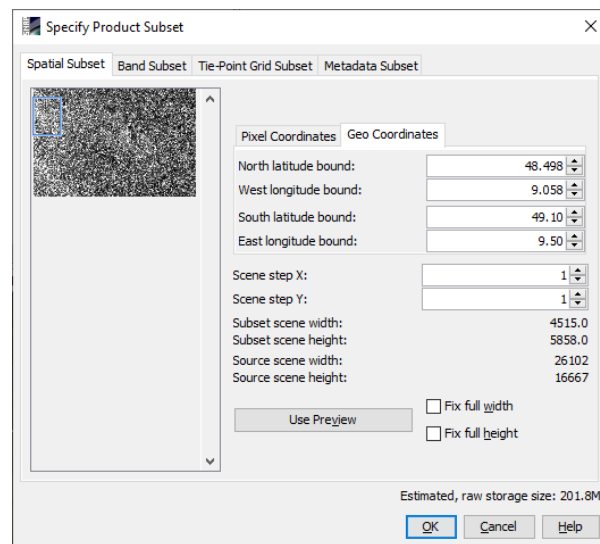Confirm with **Run** and repeat the step for the second S1 image.

Figure 7: Sentinel-1 subset

A new product is shown in the *Product Explorer*, starting with `subset_0_of_S1B`. This product is only of temporary nature and lost after SNAP is closed. Yet, it can be used as an input for the next step so that only the subset area is radiometrically calibrated.

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Radiometric calibration

Radiometric calibration converts backscatter intensity as received by the sensor to the normalized radar cross section (Sigma0) as a calibrated measure taking into account the global incidence angle of the image and other sensor-specific characteristics. This makes radar images of different dates, sensors, or imaging geometries comparable.

Open the *Calibration* operator (under *Radar > Radiometric*) and use the subset which was created in the previous step as an input.

Select a suitable output folder and enter `S1_20190818` as the output name. All other settings can be left on default. SNAP uses the image metadata to calibrate the image as described in this documentation. After completion, the output product is added to the Product Explorer.
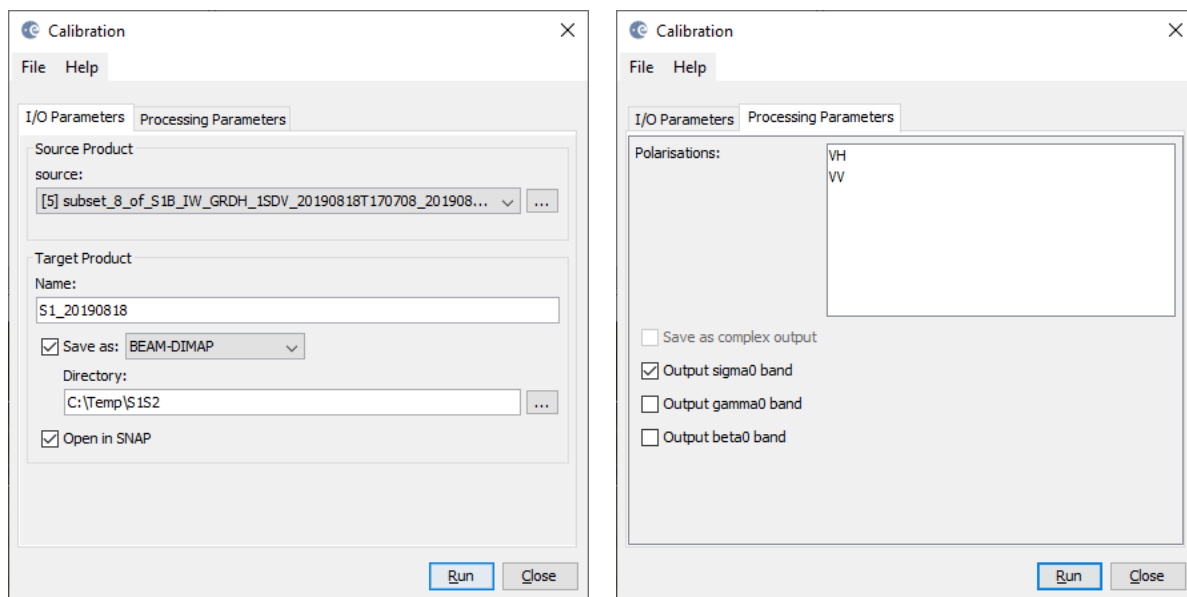
Figure 8: Radiometric Calibration

Speckle Filtering

Speckle is a systematic effect emerging from positive and negative contributions of surfaces to the measured backscattered signal. It is often described as "salt and pepper" effect which complicates the interpretation and analysis of the image. A series of speckle filters exist, all have their pros and cons and it is often a good idea to test the different filters and the effect of their parameter settings to find the configuration which is best for the application.

Extensive reviews and comparisons of speckle filters are provided by Dong et al. (2000), Touzi (2002), and Lee et al. (2009).
In this tutorial ,the Lee Sigma filter published by Lee et al. (2009), which uses two different window sizes to estimate the presence and intensity of speckle (). It minimizes speckle while maintaining sharp edges where they can be detected.

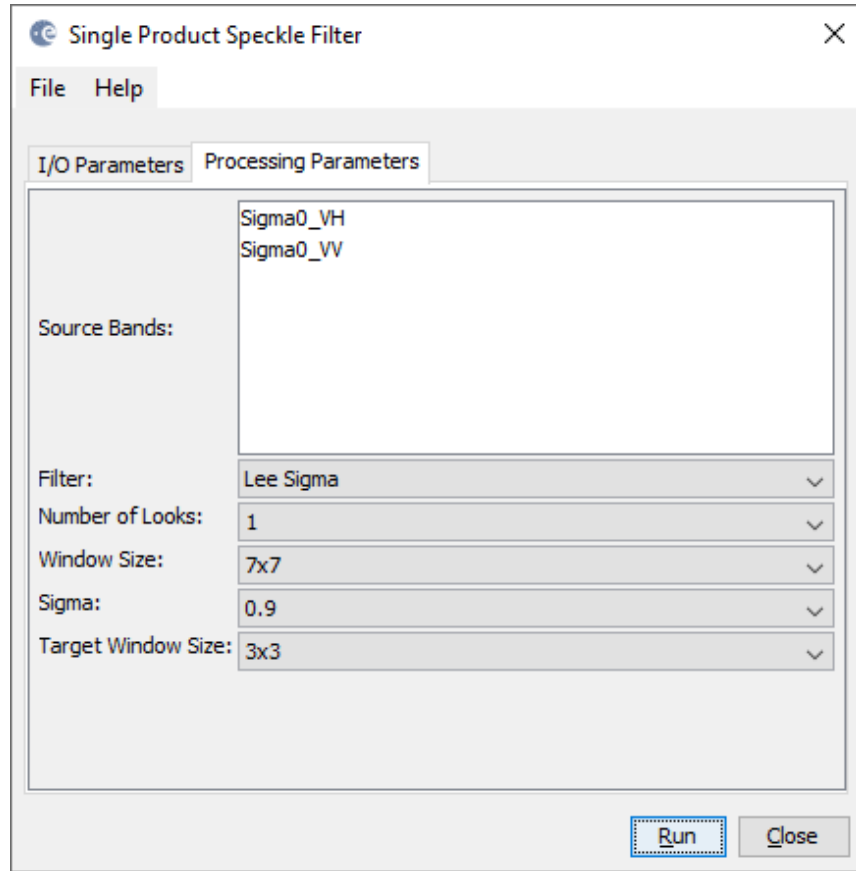The filter can be found under *Radar > Speckle Filtering > Single Product Speckle Filtering*.

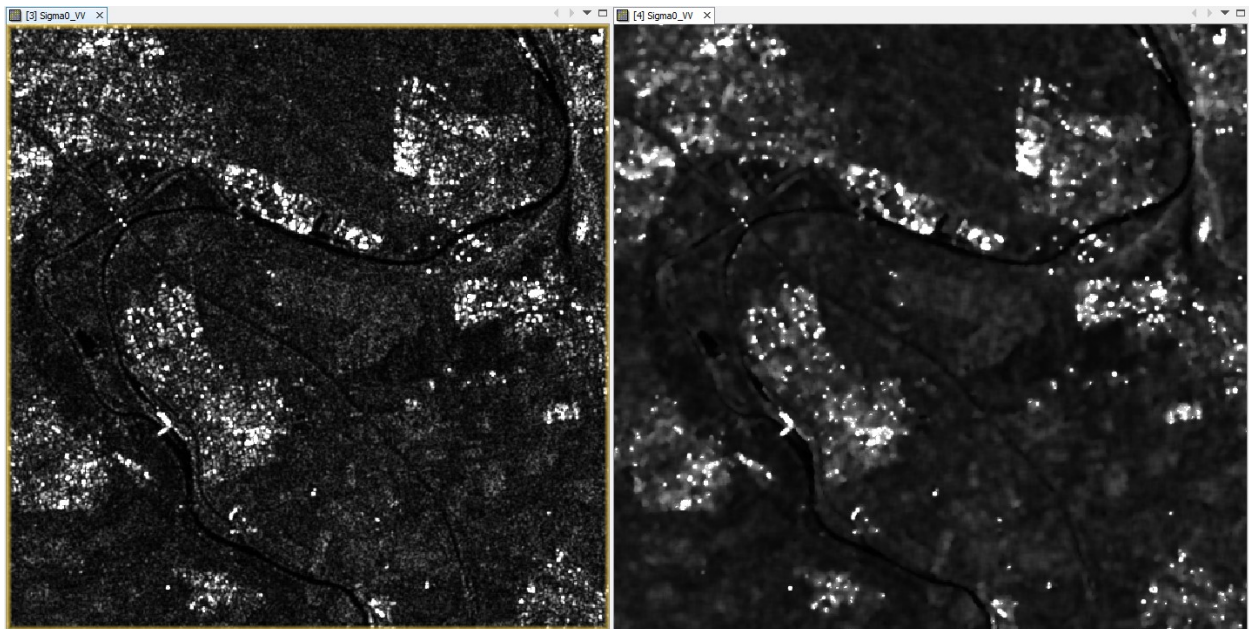**Figure 9: Lee Sigma speckle filter**

Figure 10: Sentinel-1 image before (left) and after (right) speckle filtering

Conversion to dB scale

As highlighted by the statistics tool Σ , the values of Sigma0_VV roughly range between 0 and 2380, with a mean of 0.219 (Figure 11, top). This means that a very small proportion of very bright pixels distorts the actual value distribution. This is not ideal in a statistical sense and makes the image very dark, because values of smaller than 1 have similar grey values.

To achieve a more normal distribution of values, the log function is applied to the radar image. It translates the pixel values into a logarithmic scale and yields in higher contrasts, because the bright values are shifted towards the mean while dark values become stretched over a wider color range (Figure 11, bottom).

The value range of calibrated dB data is -35 to +10 dB.
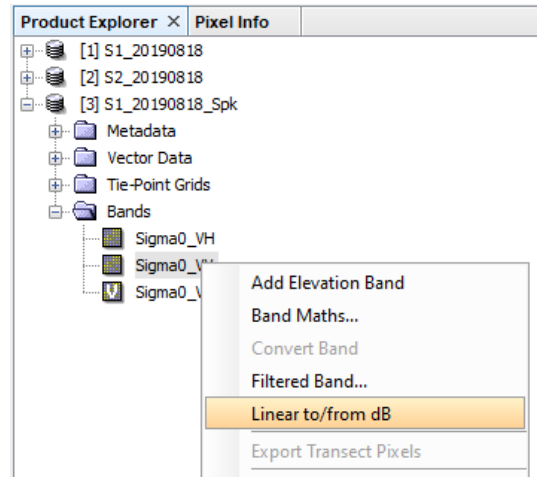
Sigma0_VV

#Pixels total:	25822863
Minimum:	0.0048
Maximum:	2378.4426
Mean:	0.2193
Sigma:	2.3987
Median:	11.9003
Coef Variation:	10.9373
ENL:	0.0084
P75 threshold:	0.0048
P80 threshold:	0.0048
P85 threshold:	0.0048
P90 threshold:	0.0048
Max error:	23.7844
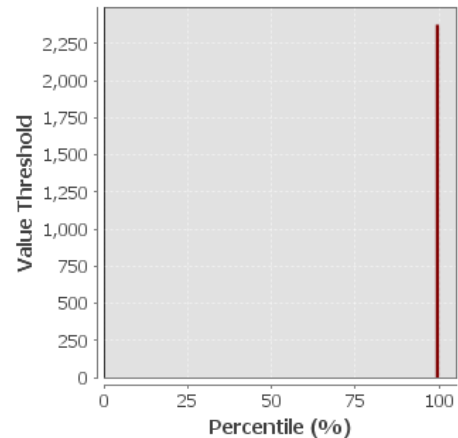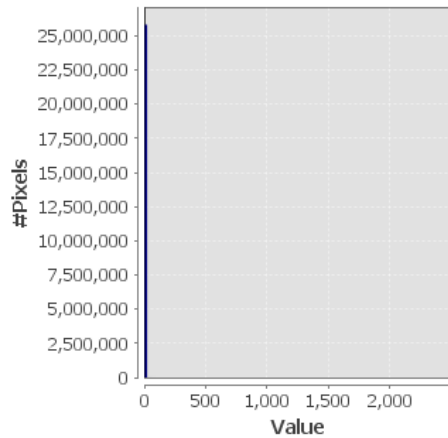
Sigma0_VV_db

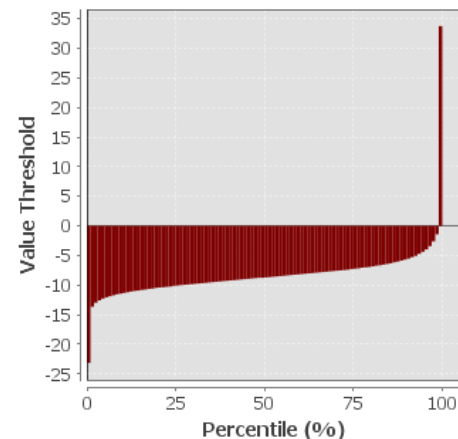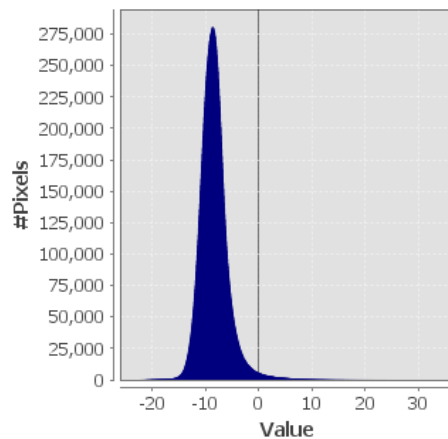| #Pixels total:	25822863
Minimum:	-23.1752
Maximum:	33.7629
Mean:	-8.4173
Sigma:	2.7375
Median:	-8.6641
Coef Variation:	-0.3252
ENL:	9.4546
P75 threshold:	-7.2325
P80 threshold:	-6.8339
P85 threshold:	-6.3215
P90 threshold:	-5.5244
Max error:	0.0569

Figure 11: Image statistics of power (top) and logarithmic (bottom) scale

10

To convert VV polarization into dB scale right-click on the filtered bands and select Linear to/from dB. This creates a new virtual band for with the extension _db. Repeat this for the VH polarization and compare the products (Figure 12).

This step is not ultimately required, and it does not change the information content of the image, but it is advisable when image contrasts matter.
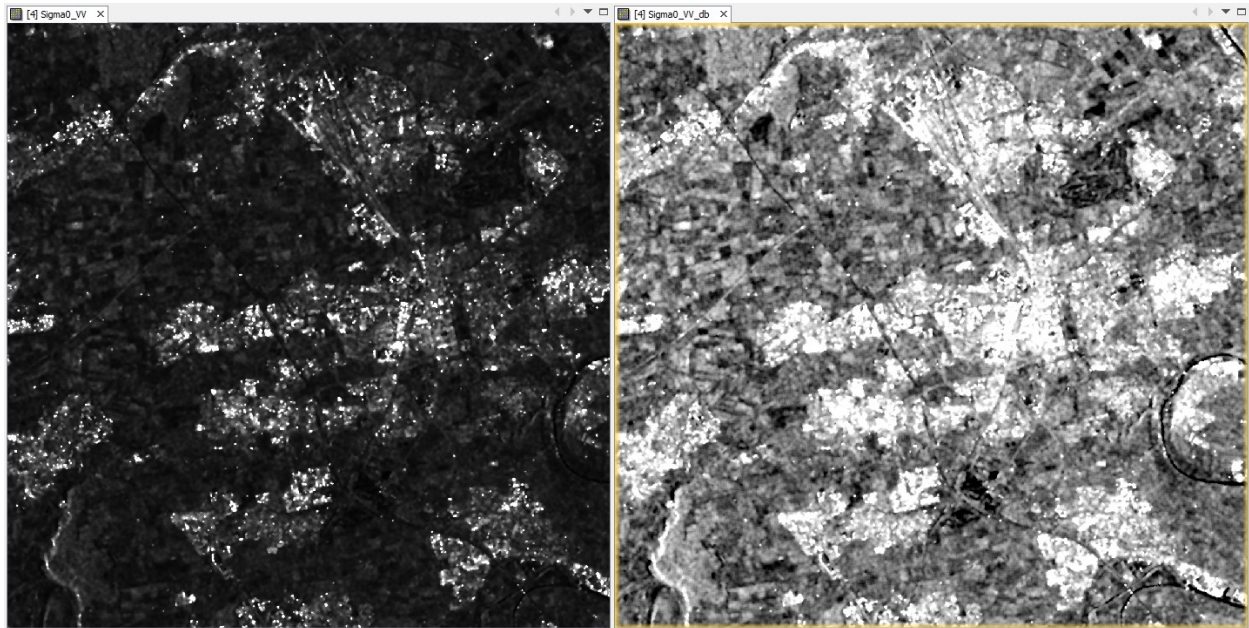

Figure 12: Sentinel-1 Sigma VV before (left) and after (right) conversion to dB scale

Terrain Correction

Terrain Correction will geocode the image by correcting SAR geometric distortions using a digital elevation model (DEM) and producing a map projected product.

Geocoding converts an image from slant range or ground range geometry into a map coordinate system. Terrain geocoding involves using a Digital Elevation Model (DEM) to correct for inherent geometric distortions, such as foreshortening, layover and shadow (Figure 13). More information on these effects is given in the ESA radar course materials.
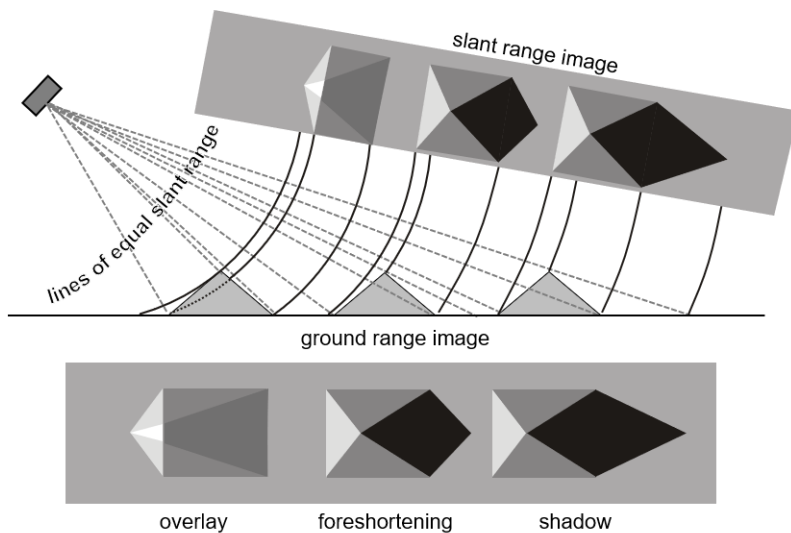

Figure 13: Geometric distortions in radar images (Braun 2019)

Open the *Range Doppler Terrain Correction* operator (under *Radar > Geometric > Terrain Correction*) and select the filtered product as input product. In the Processing Parameters tab chose the two dB products as Source Bands and select **SRTM 1Sec HGT (AutoDownload)** as input DEM.

As we terrain correct the data in dB scale, bilinear resampling of logarithmic data will lead to false backscatter values. Therefore, we select **NEAREST_NEIGHBOUR** as Image Resampling Method. Alternatively, the conversion to dB could be done after terrain correction.

Select **UTM zone 32N** as the Map Projection and click on **Run** to start the terrain correction. SNAP now establishes a connection to an external elevation database to download all SRTM tiles required to fully cover the input dataset. The output is a terrain corrected and geocoded Sentinel-1 product in dB scale.
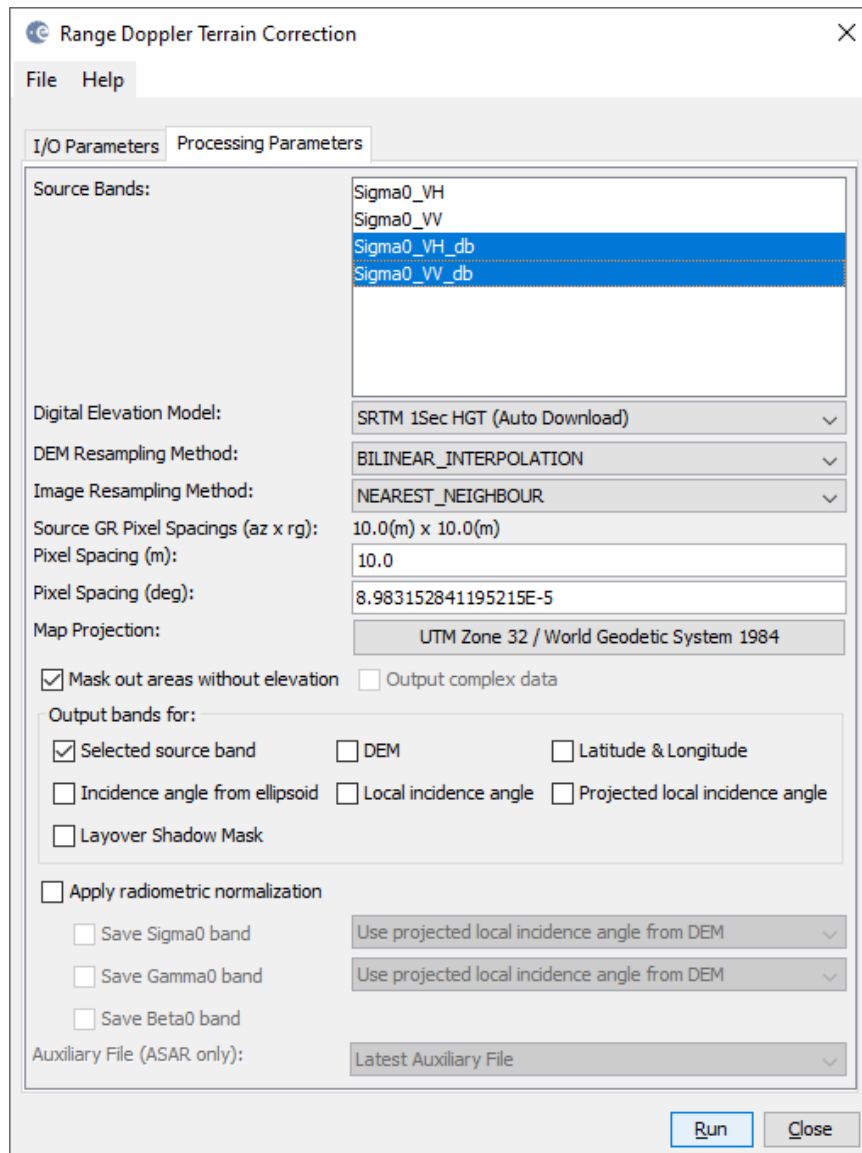

Figure 14: Range Doppler Terrain Correction

Create ratio band (optional)

To reduce the imbalance of bands (2 for Sentinel-1, 13 for Sentinel-2), a ratio is calculated between the two polarizations using the Band Maths operator (Figure 15). Note: As the data was transformed into dB scale, any ratio becomes a difference according to the laws of logarithm. Enter Sigma0_ratio_db as an input name, uncheck the option "Virtual (save expression only, don't store data) and enter the following expression (optionally via **Edit Expression**):

```
Sigma0_VV_db – Sigma0_VH_db
```

A new band is created in the product S1_20190818_Spk_TC. Click *File > Save Product* to make the changes permanent. Afterwards, an RGB composite can be created from these three bands (Figure 16) to visualize the results. The radar product is now ready to be merged with other data.
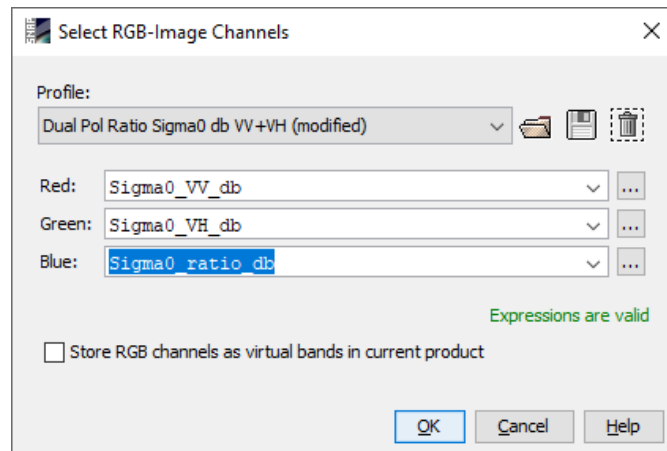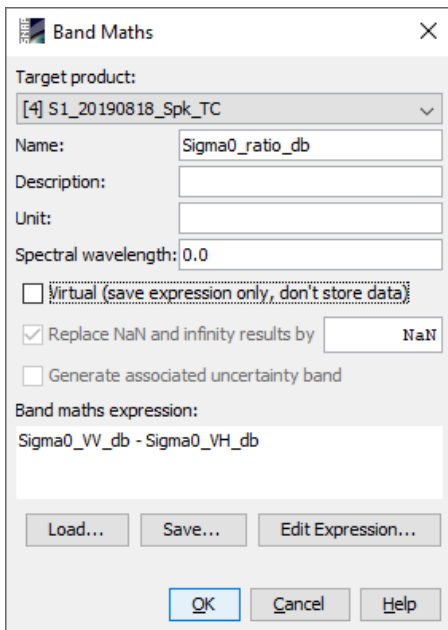

Figure 16: RGB of Sentinel-1

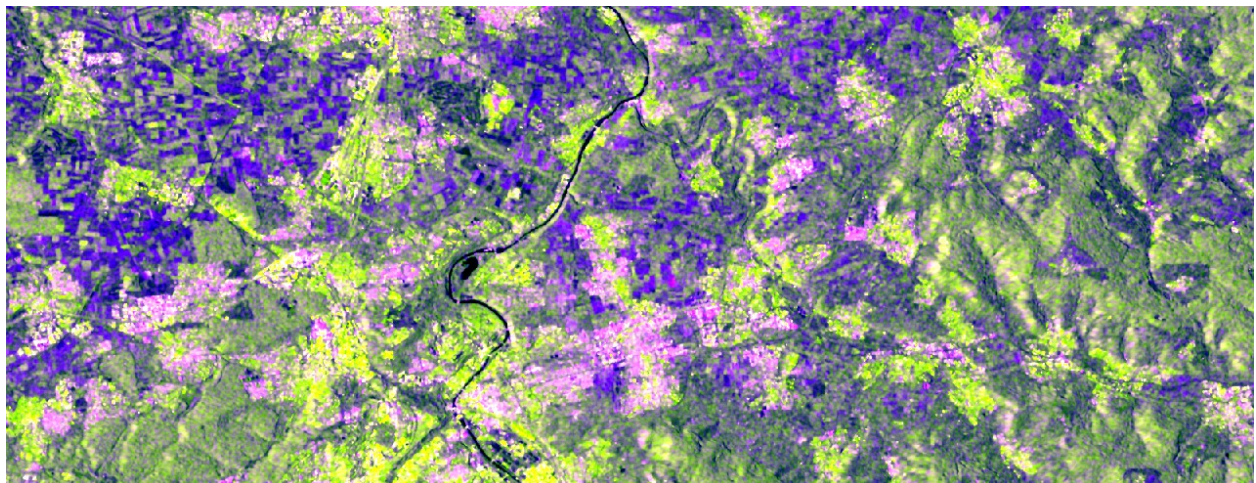**Figure 15: Sentinel-1 polarization ratio**

Figure 17: RGB composite in db scale of VV (red), VH (green) and VH-VH (blue)

Preprocessing of Sentinel-2

Import the product

Extract the file `S2A_MSIL2A_20190818T103031_N0213_R108_T32UNV_20190818T135455.zip` which was downloaded from the Copernicus hub as described earlier in this tutorial. A new folder ending with .SAFE is generated which contains the metadata file to correctly load the raster stack into SNAP.

Use *File > Import > Optical Sensors > Sentinel-2 > S2-MSI L2A* (alternatively S2-MSI *L1C* if no L2A is available), select the file `MTD_MSIL2A.xml` (Figure 18) and confirm with **Import Product**.
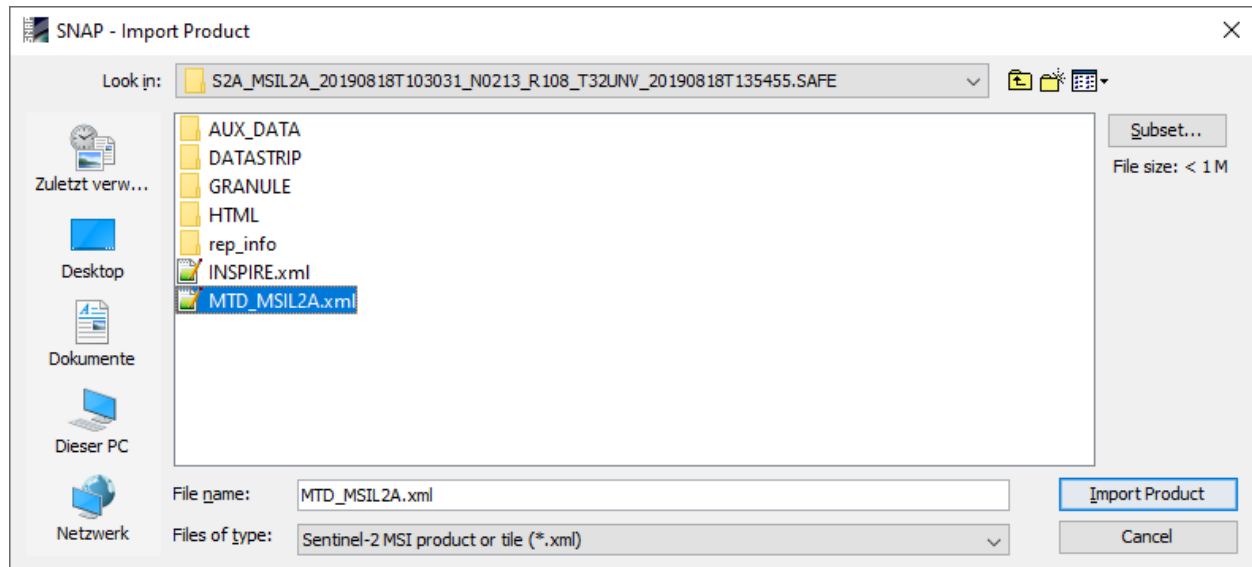
Figure 18: Import of Sentinel-2 product as subset

Create a subset

A subset allows to reduce the amount of data to be processed in the following. Select the Sentinel-2 product in the Product Explorer and navigate in the menu *Raster > Subset…*
A separate window might open ("Creating thumbnail image"), but this takes quite a long time, so it is ok to **Cancel** this window.

In the Spatial Subset tab Switch to the Geo Coordinates tab and enter the following numbers:

- North latitude bound: 48.95
- West longitude bound: 9.0
- South latitude bound: 48.70
- East longitude bound: 9.40

In the *Band Subset* tab only select the spectral bands (excluding B8A, Figure 19, right). Un-check all quality indicators and other bands which follow in the list, so they will not be part of the output product.

Note: It is easier to click **Select none** and then check the boxes for the 12 main bands.
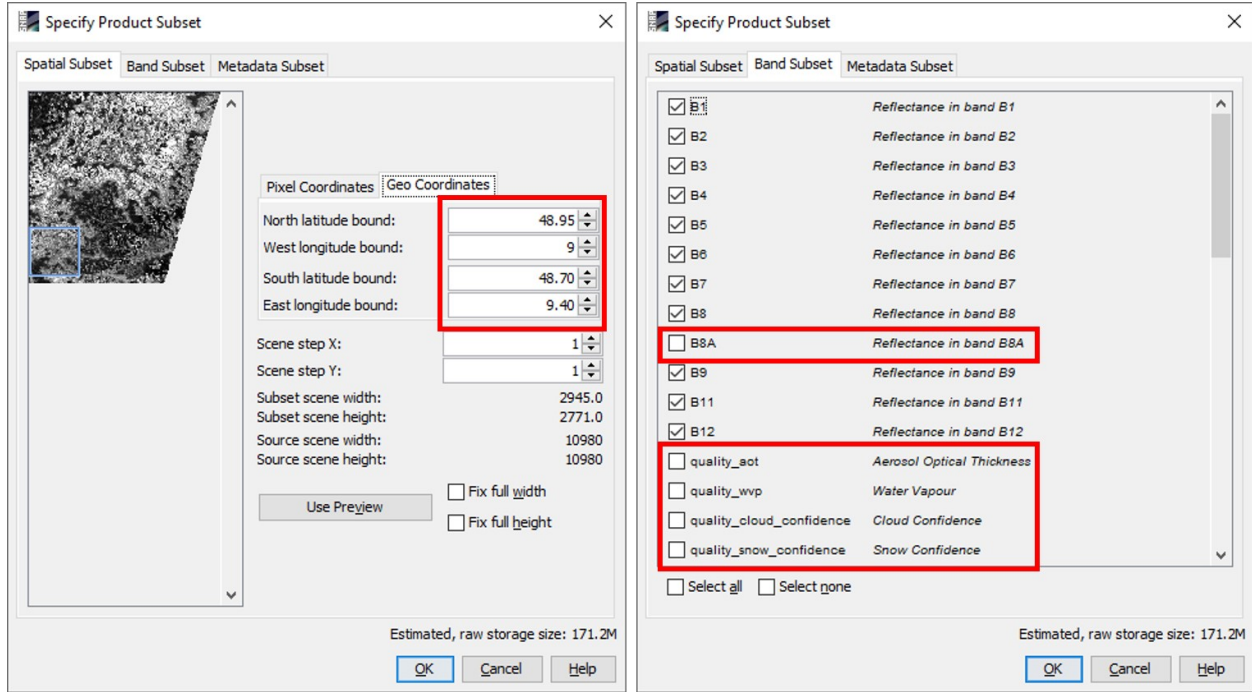
Figure 19: Sentinel-2 subset

Confirm with **OK**. A new product is shown in the *Product Explorer*, starting with `subset_S2A`. As it is only a virtual product, so now we save it with *File > Save Product as >* `S2_20190818_subset.dim`

This can now take a while because both previously defined steps (Resampling and Subset) are now finally applied to the original zipped Sentinel-2 product (Figure 20).
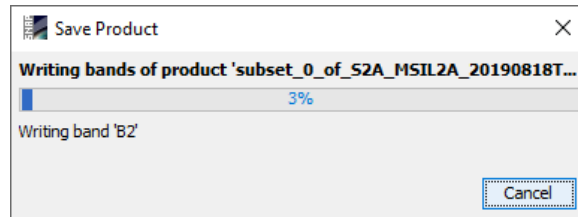

Figure 20: Saving the virtual S2 product

Merge the products

The two datasets are now prepared to be merged in a stack. They

- have the same spatial resolution (10 meters)
- have a similar spatial extent
- are projected in the same coordinate reference system (UTM zone 32 N)
- are both stored physically under the names

  - S1_20180818_Spk_TC.dim
  - S2_20180818_subset.dim

To get rid of the temporary products in the SNAP workspace and to release some memory, it is good to clear the Product Explorer at this point of the analysis with *File > Close* All Products and only open these two products again.

The workspace should now look as demonstrated in Figure 21: The Sentinel-1 product has three bands (VV, VH and ratio) in dB scale and is of slightly lager coverage (this will be resolved in the following step).

The Sentinel-2 product has 12 bands (B1-B12).

You can double-click on the raster bands to open them and check if they contain data. This should now take only a few seconds because the size of the subsets is now considerably smaller than the original product (Figure 2).

The next step is to stack these two datasets which means to bring both into one common product which can then be analyzed.

We use Sentinel-1 as the reference[1] product because its geolocation accuracy is very high after Range Doppler Terrain Correction.

Figure 21: Prepared S1 and S2 products

In this tutorial, we use the **Collocation** operator (under *Raster > Geometric Operations > Collocation*) which requires one reference product which determines the extent, pixel size and pixel registration of the output product, and one or more secondary products which will be clipped and resampled accordingly.

Open the **Collocation** operator and select the Sentinel-1 product as the reference. Use the ⊕ button to add the Sentinel-2 with **Add product(s)…** to the list of the secondary products (Figure 22). Select **Bilinear interpolation resampling** for the resampling method.

Enter `20190818_S1S2` as the target product name and confirm with **Run**. A new product is created which contains the three radar bands and 11 multispectral bands. This is the most important step for image fusion, because it allows a range of different methods to utilize the information content of both products in the following.
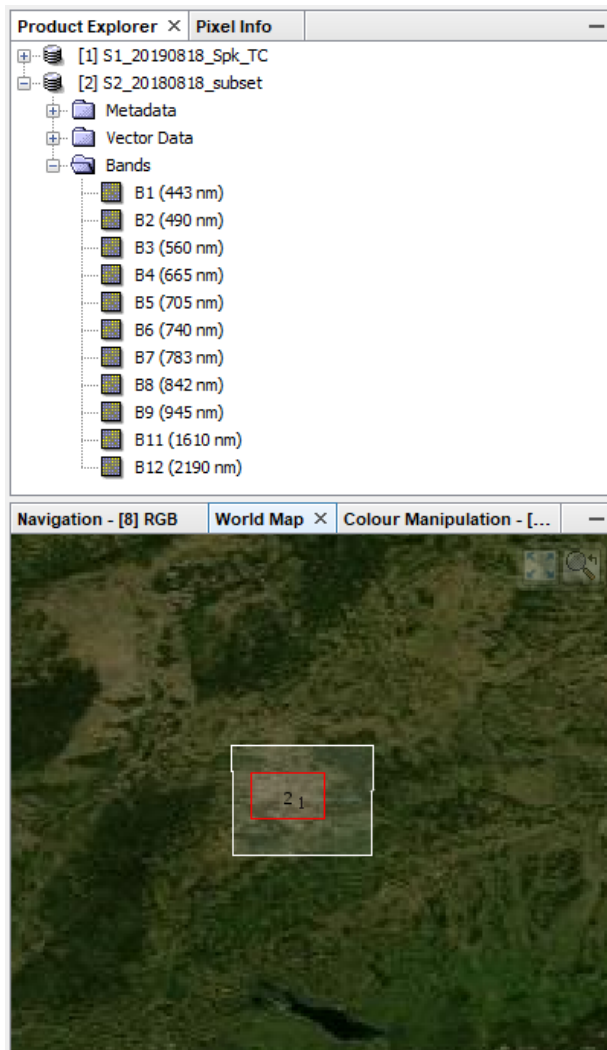
---

[1] We support the statement of the executive committees of WInSAR and COMET to exchange the inappropriate terminology in all InSAR-related fields. Accordingly, the former "master/slave" will be replaced by "reference/secondary" in future versions of SNAP.
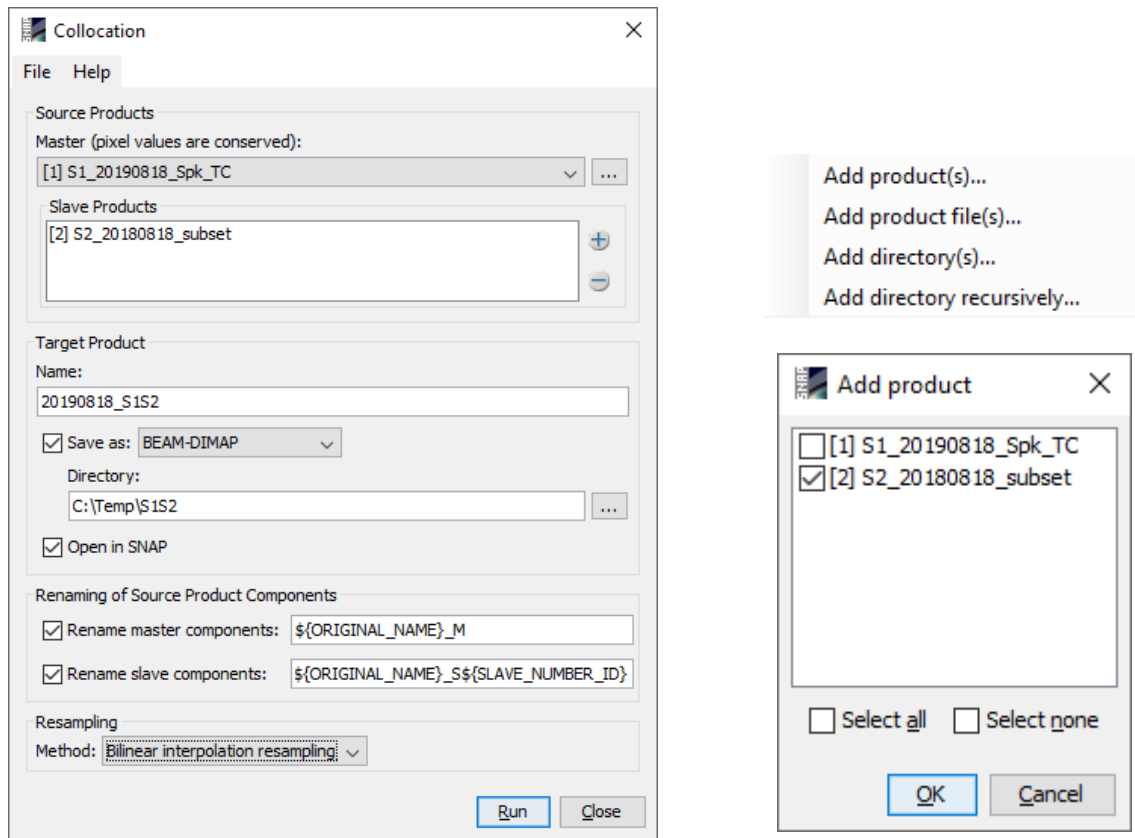
Figure 22: Collocation of Sentinel-2 (reference) and Sentinel-1 (secondary)

In the output product all optical bands are marked with _M and their corresponding wavelength (as retrieved from the metadata).

This is automatically done to avoid naming conflicts and can be modified (or completely disabled) under **Renaming of Source Product Components** of the Collocation tool (Figure 22).

The `collocationFlags` band is an indicator for the presence of the input products. The raster is 1 where both images are present. As the extent Sentinel-1 image was larger than the extent of Sentinel-2 image the common area is only a part of the output product (Figure 24).

This band is helpful for subsequent operations because it allows to limit the raster to the common area.

Note: The *Collocation* module does not support multi-resolution products as reference. If you want to have Sentinel-2 as the reference product, you must run the *S2 Resampling* Operator first.
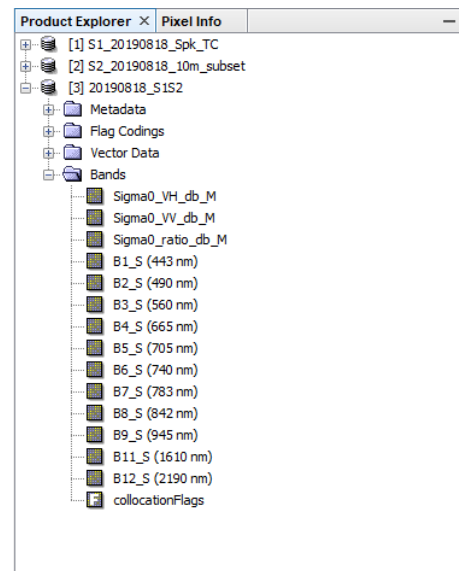
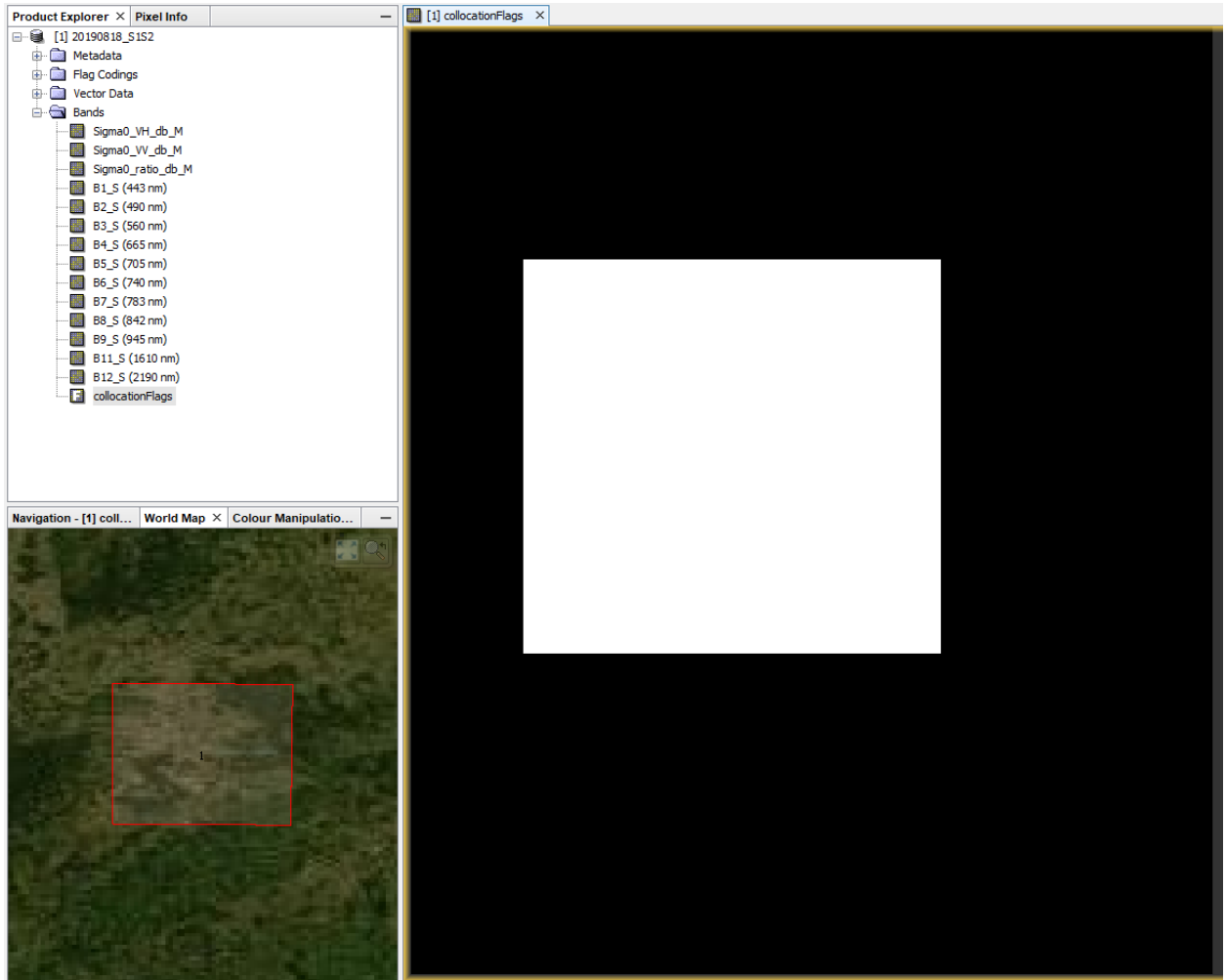**Figure 23: Merged stack of Sentinel-1 and Sentinel-2 band**

Figure 24: Collocation Flags of the merged product

Suggestions for analyses of the merged product

Visual interpretation

Figure 25 shows a true color image compared to a false color composite with red=S2-B4, green=S2-B3 and blue=S1-VV. Such combinations reveal patterns which are not visibly by optical data only.
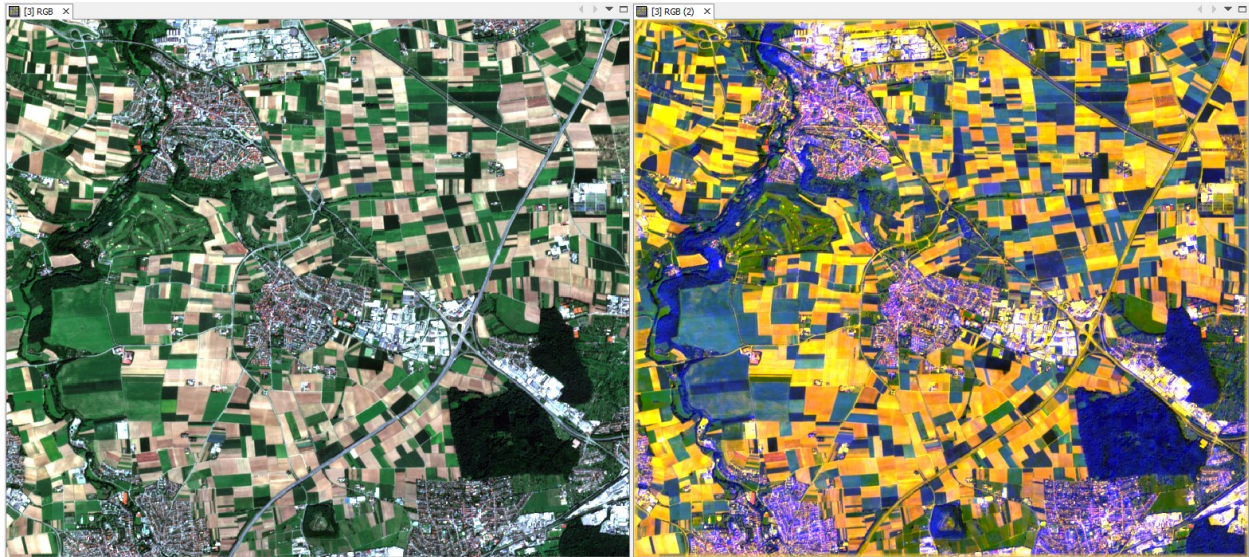

Figure 25: True color (left) and false color (right) composite

Try different combinations of the bands and also change the contrast stretch of in the *Color Manipulation* tab to enhance different structures in the image.
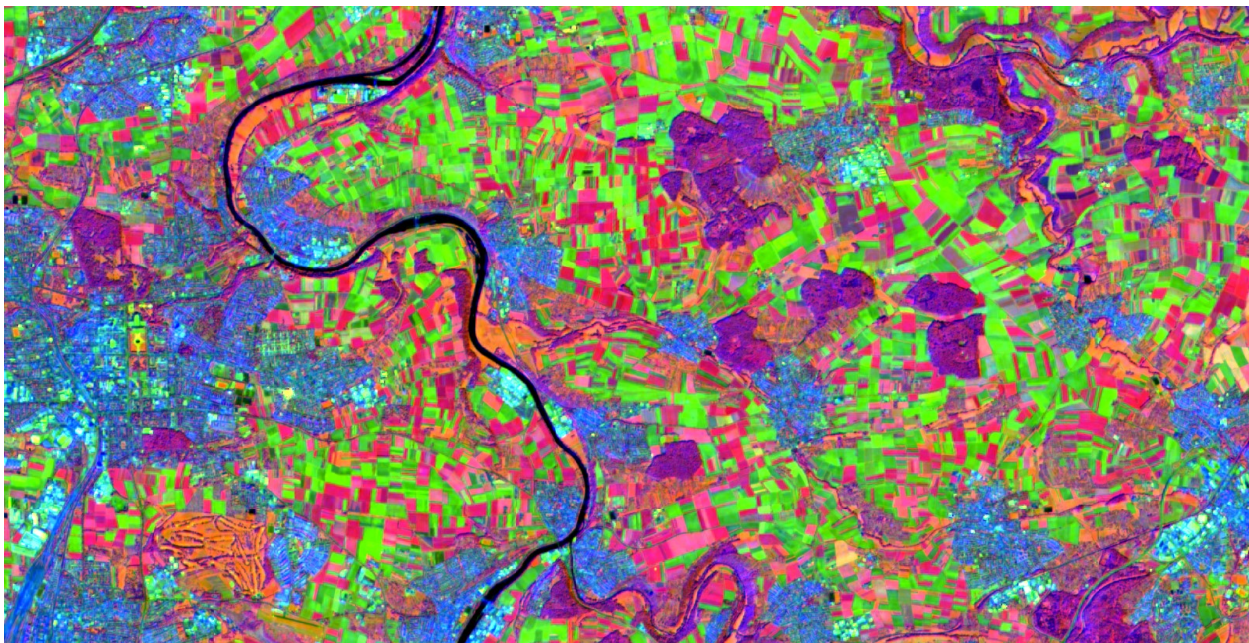
Figure 26: RGB composite of red=S2_B9, green=S2_B5, blue=S1_VH

Mask Manager (basic use)

The *Mask Manager* allows to apply logic or mathematic expressions on the pixels of an image product to see which of them fulfill certain conditions. A raster product (or RGB composite) must be opened in the current view for the tools of the Mask Manager to become active.

In a first step, we create a mask for the common area of both input products using this button *f(x)*
In the expression dialogue, enter the expression (make sure you activate **Show bands** and **Show single flags**):
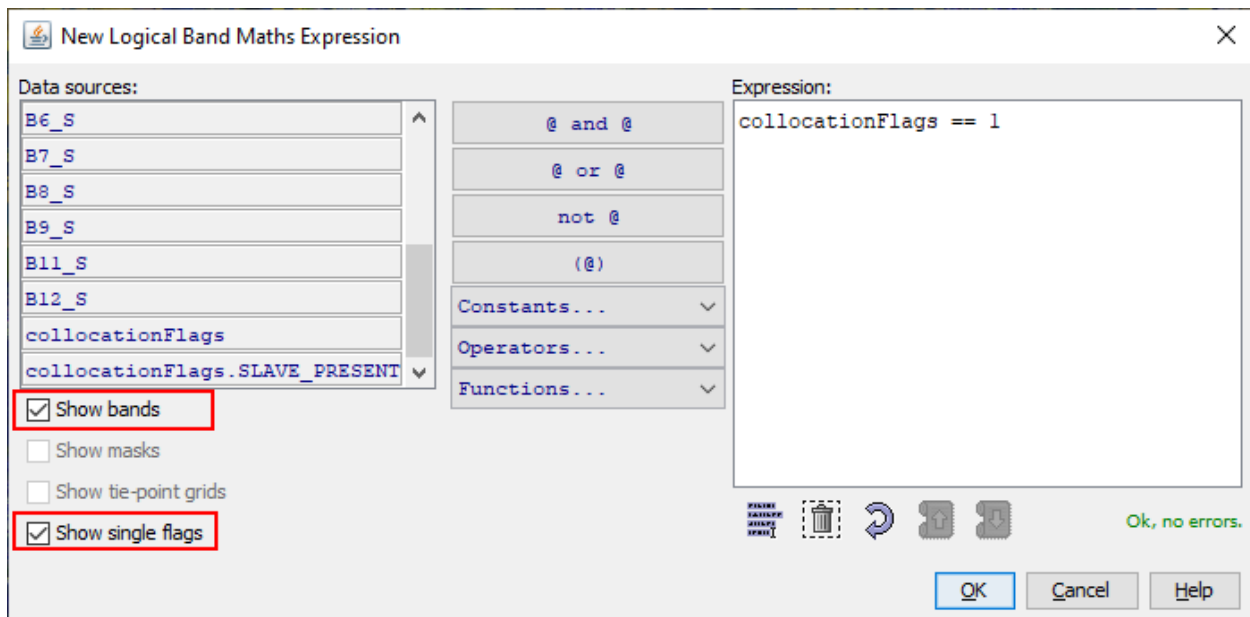
```
collocationFlags == 1
```

Figure 27: Definition of a term to create a mask in the Mask Manager

This creates a mask which is true for the common area and false for the area outside the Sentinel-2 extent. It will appear as red transparent area in the currently opened raster. Name and color can be changed in the list of masks (Figure 28). Let's call this mask "analysis" because it defines the pixels of interest, as they contain both radar and optical information.

Note: To change the expression of a mask, double-click on **Maths** and the Expression editor opens again. Changes in the **Description** field have no consequences.
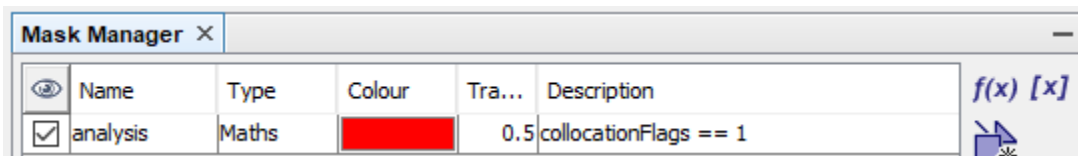
Figure 28: List of masks in the Mask Manager

Once you created a mask, select the product and make the changes permanent with *File > Save product.*

Principal component analysis

To illustrate the increased information content of the newly generated stack, a principal component analysis (PCA) can be performed on the product. It is a technique which identifies redundancies and differences in a stack of bands and transforms them into new uncorrelated bands (principal components) with have a maximized information content. Accordingly, the first principal component (PC1) represents the maximum proportion of variance from the original dataset. The remaining variation is expressed by PC2, PC3 and so on. More information can be found here.

Open the Principal Component Analysis operator (under *Raster > Image Analysis*). Select the image bands (all except for the collocationFlags) as **Source bands** and use the mask "analysis" which was created in the previous step as **ROI mask name**. Also check **Remove non-ROI-pixels** to exclude all pixels which are only covered by the Sentinel-1 image.

To reduce the processing time, set the **Maximum component count** to 5 (the standard setting -1 means that 13 components are calculated for 14 input bands). Start the processing with **Run**.

Note that a PCA can take a considerable amount of time, especially for large raster images and a high number of components.

Figure 29 shows an example of how a PCA can contain both radar and optical information. The red object shows the bright stadium roof which has high radar backscatter.
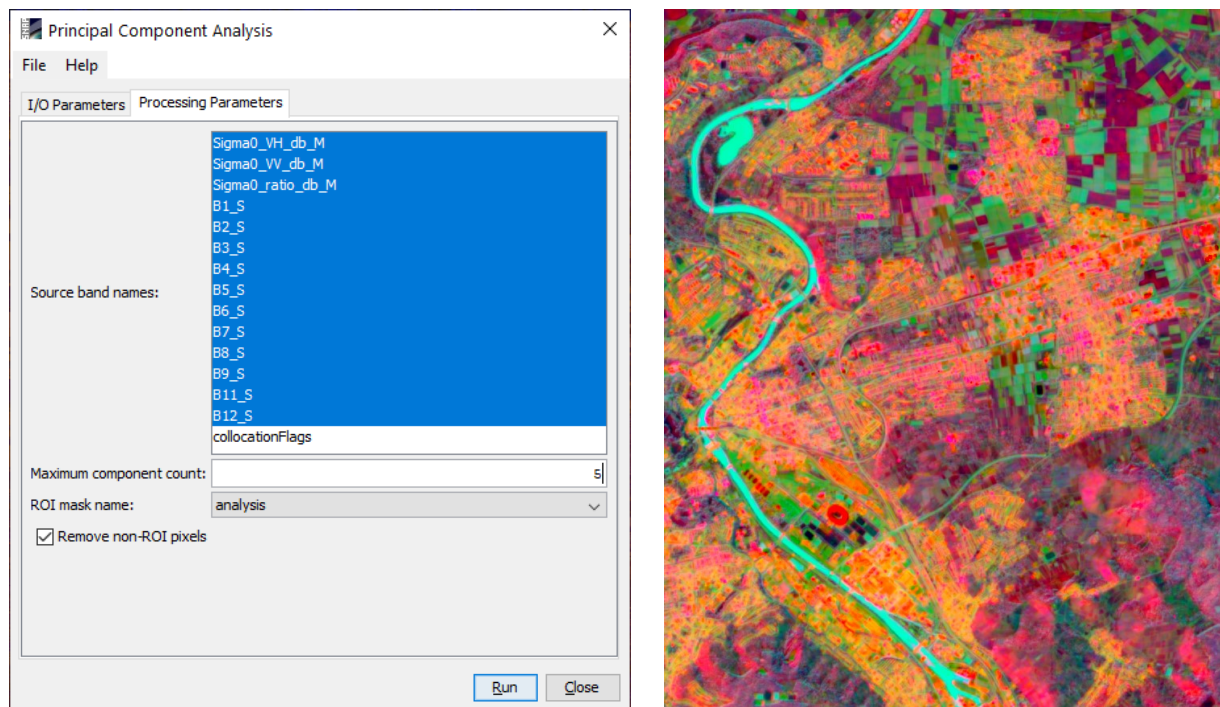

Figure 29: Principal Component Analysis of red=PC1, green=PC3, blue=PC5

Working with Vectors

Create a new vector container called "forest_AOI" using **New Vector Data Container** . It will appear in the *Layer Manager* (currently not filled with a geometry, but already defined, Figure 30).
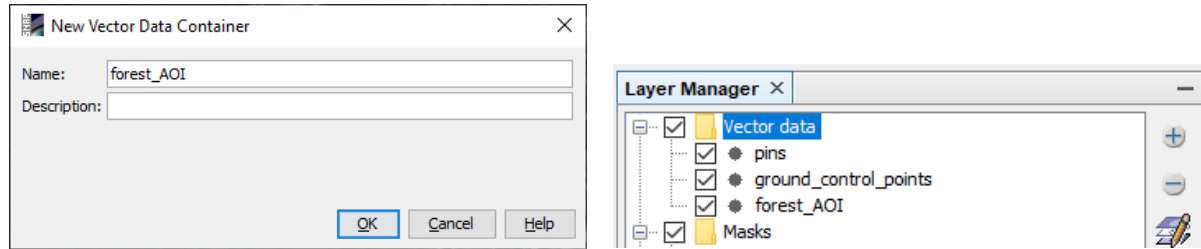

Figure 30: Creation of new vector containers

If you want to digitize geometries of multiple classes, it is important that you first define them as vector data containers as previously explained and then select the folder "Vector data" in the Layer manager, as displayed in Figure 30.

Once you select the **Polygon Drawing Tool** and click in the map, you will be asked which of the vector containers you want to edit or fill with geometries (Figure 31). This allows to digitize multiple polygons which belong to the same class (container) and to effectively manage vectors of multiple classes.
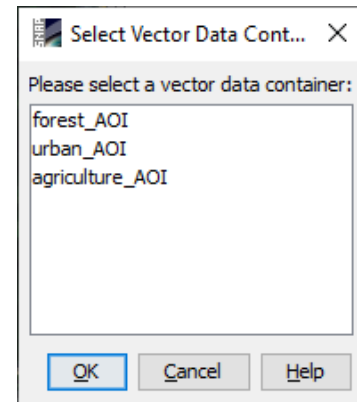
Select a container and proceed with OK. You can then digitize polygons and finish with a double-click. You can modify or delete existing polygons using the Selection tool (Figure 32). In this tutorial, a polygon is created covering a homogenous forest area.
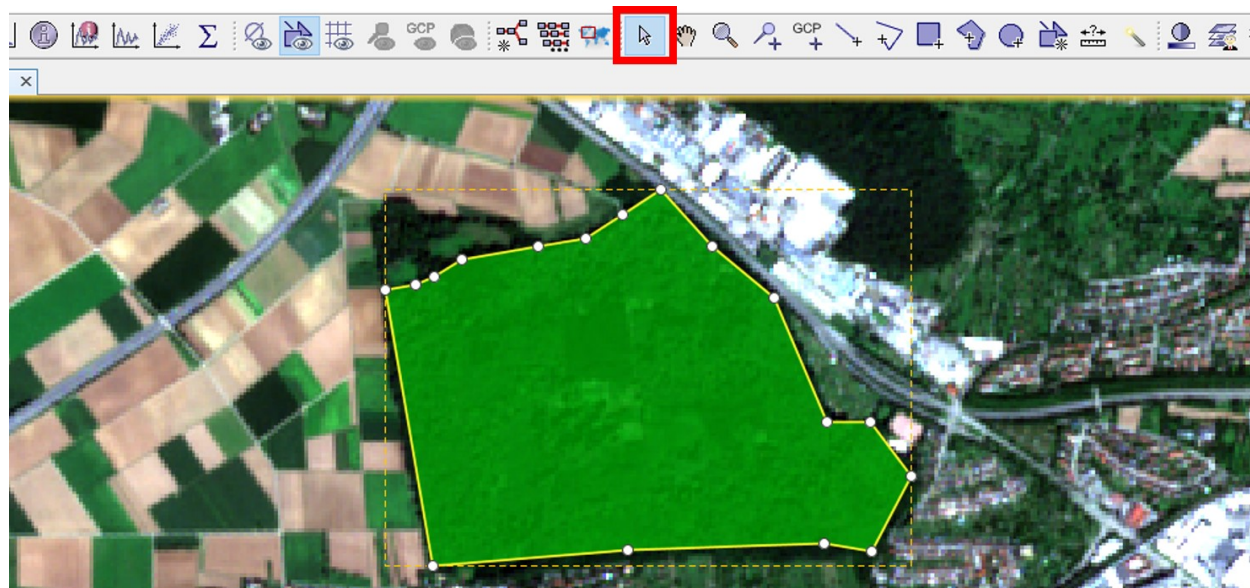

Figure 31: Selection of a vector data container for digitization

Figure 32: Editing existing vectors

Histogram and Statistics

The histogram gives information about the value distribution of a raster. It is a tool to understand the spectral characteristics (SAR backscatter or calibrated reflectance) of a surface, instead of simply extracting values at a single pixel.

To get a histogram of the forest area, which was previously digitized, select one raster band in the *Product Explorer* and click **Histogram** . A new window opens with an empty plot. Check the option **Select ROI mask**, select the polygon "forest_AOI" from the drop down menu and confirm with **Refresh View** to load the histogram (Figure 33).
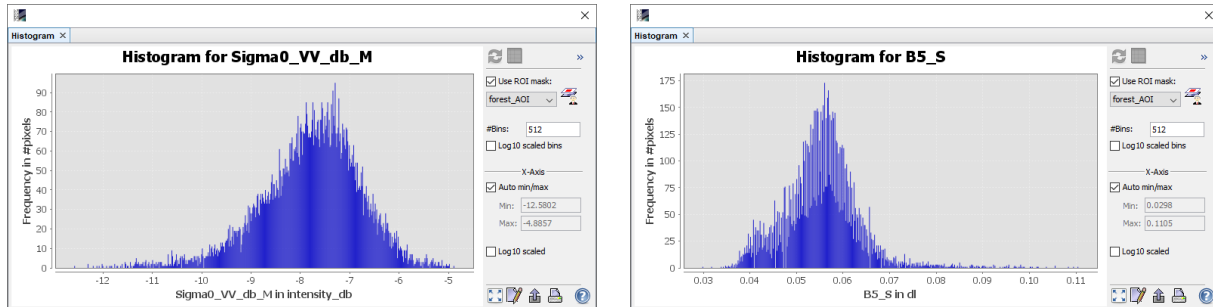
Figure 33: Histogram of digitized polygons for Sentinel-1 VV (left) and Sentinel-2 B5 (right)

The histogram shows that the forest values largely range between -10 and -5 in the *S1 VV db* band and between 0.035 and 0.07 in the *S2 B5* band. This helps to understand the interaction of specific surfaces in selected wavelengths and polarizations. *Note*: if you can't reload the histogram with the **Refresh View** button, slightly change the **#Bins** parameter to allow SNAP to recompute the image statistics.

To get a more quantitative understanding of these relationships the **Statistics** tool can be used. It lists descriptive statistics of a band or a selected region. Check **Use ROI mask(s)** and select "forest_AOI" from the list to limit the analysis to the digitized polygon (Figure 34).
Sigma is the standard variation of all pixels within the polygon. The **Median** is more robust towards outliers than the arithmetic **Mean**. **P90** stands for the 90% percentile which means that 90 % of the pixels within the digitized polygon are smaller than -12.9731. This is a valuable information for image thresholding to discriminate classes. You get even more percentiles with a right-click > **Copy Data to Clipboard**.
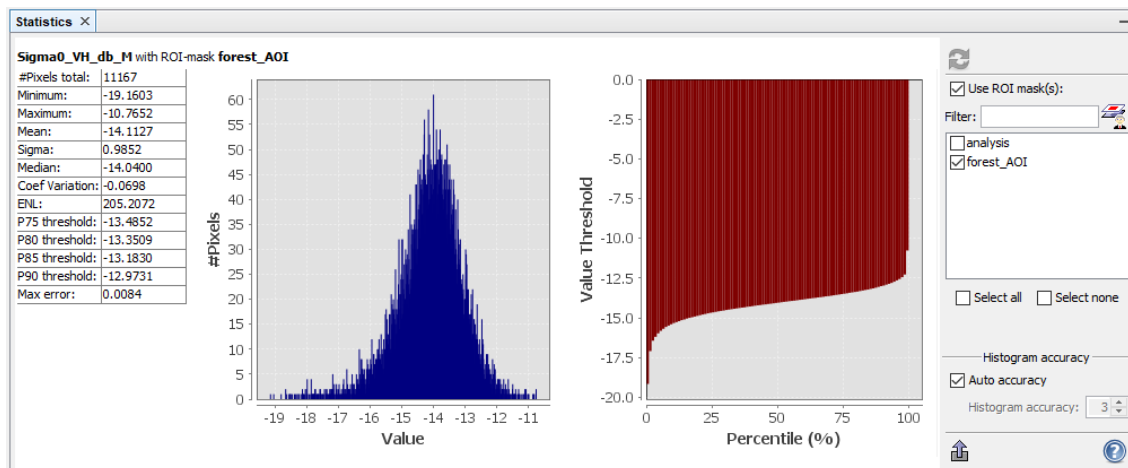

Figure 34: The Statistics tool for quantitative analysis of images or selected ROIs

Mask Manager (advanced use)

The *Mask Manager* not only serves as a mask for operators, as shown in the previous example, but also allows to systematically analyze the information one of multiple images at once, for example to determine the spectral response of certain surfaces or to find thresholds for the discrimination of defined landcover classes.

Based on the information retrieved from the **Histogram** and Statistics tool, expressions can be formulated which include both criteria from the optical and microwave spectrum. Together they allow the precise delineation of specific surfaces. Make new expressions $f(x)$ as defined in Table 1 and Figure 35:

Table 1: Expressions for the definition of classes

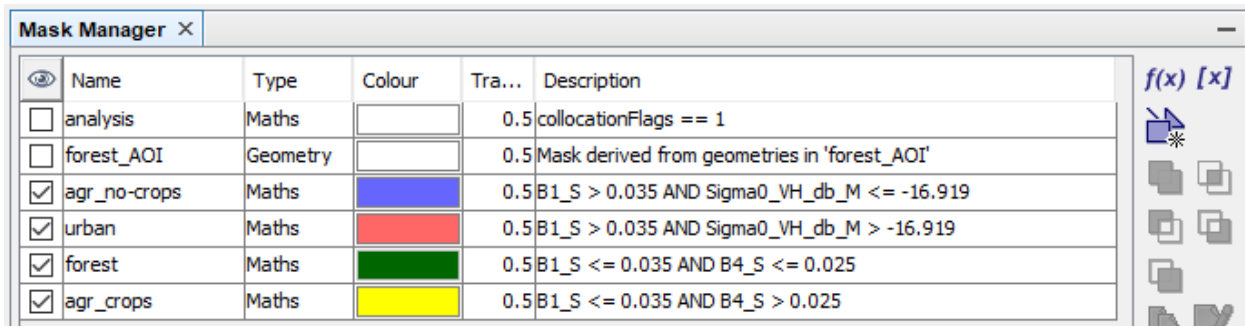| name of the mask	color	expression
agr_no-crops	blue	`B1_S > 0.035 AND Sigma0_VH_db_M <= -16.919`
urban	red	`B1_S > 0.035 AND Sigma0_VH_db_M > -16.919`
forest	green	`B1_S <= 0.035 AND B4_S <= 0.025`
agr_crops	yellow	`B1_S <= 0.035 AND B4_S > 0.025`

Figure 35: Definition of classes in the Mask Manager

It is important that the mask descriptions are not overlapping. It is however also possible to select two masks and combine them with logical expressions: Union (OR) , Intersection (AND) , difference , or complement . Figure 36 shows how the result of the mask definitions looks like.
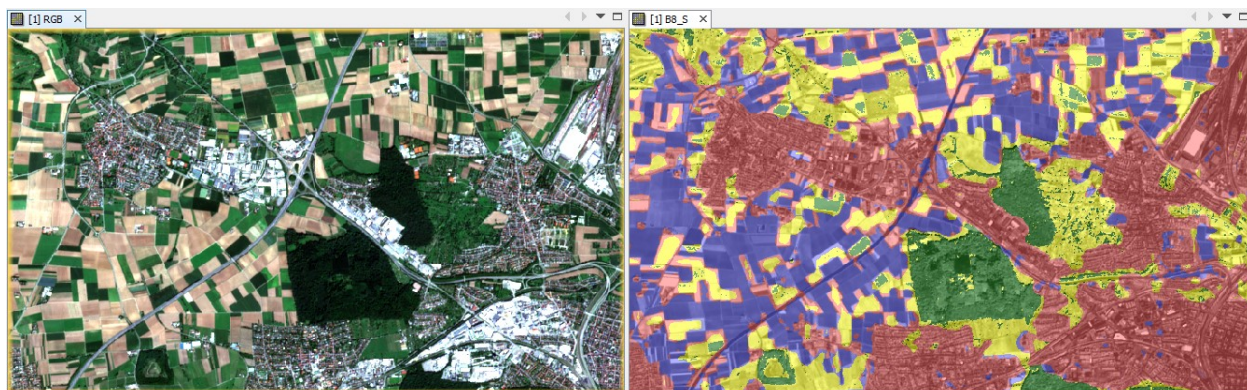

Figure 36: Masking of landcover classes with the Mask Manager

Scatter Plot

A scatter plot compares values of two datasets in a cartesian coordinate system. It is a good way to analyze how pixel values of one raster correspond to pixel values of another raster. Each point in the scatter plot represents a pair of values – one from raster 1 (x-axis) and one from raster 2 (y-axis). The relationship between both raster products is then described by the shape and extent of the created point cloud.

We want to analyze if radar information is linked to vegetation. For this reason, we compute the [Normalized Difference Vegetation Index](#) (NDVI) based on the red and infra-red band of the Sentinel-2 data. It ranges between -1 and 1, where negative values indicate water and high values are an indicator for vegetation health and vitality.

This is done with the **Band Maths** by entering the formula

`(B5_S - B4_S) / (B5_S + B4_S)`

Make sure you un-check the **Virtual** option (Figure 37) so that the NDVI band will be physically written on the hard drive. This ensures quicker access to the pixel values.
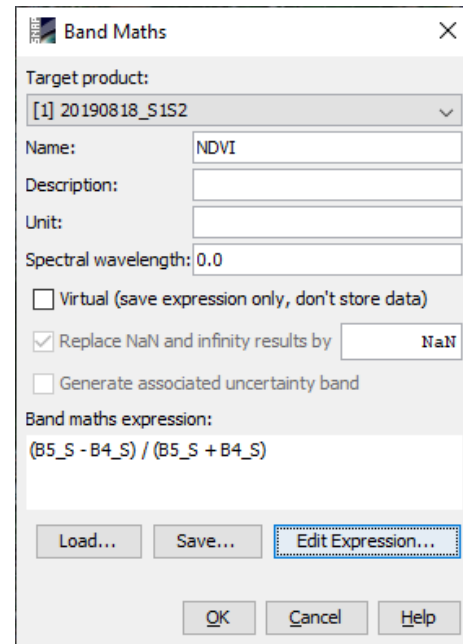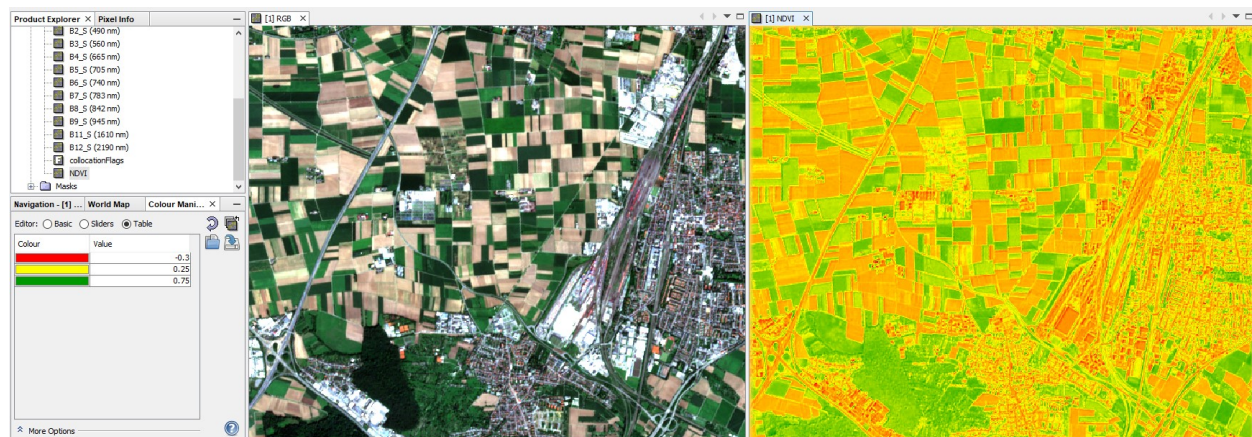
Figure 37: Calculation of the NDVI

Figure 38: NDVI of the study area

First, we compute a **Scatter Plot** ✎ for the entire image. For the x-axis select **Sigma0_VV_db_M** and for the y-axis select the newly generated **NDVI** band. Click **Refresh View** 🔄 to load the plot (Figure 39).

It is often advisable to adjust the minimum and maximum values of both axes for a better visualization of the graph. Here we selected -25 to 25 for the radar data (x-axis) and -0.5 to 1 for the NDVI (y-axis). At first glance, there is no direct relationship between both raster bands: the point cloud has no specific shape.

But there are some areas where pairs of pixel values are more frequent (yellow) than others (black).
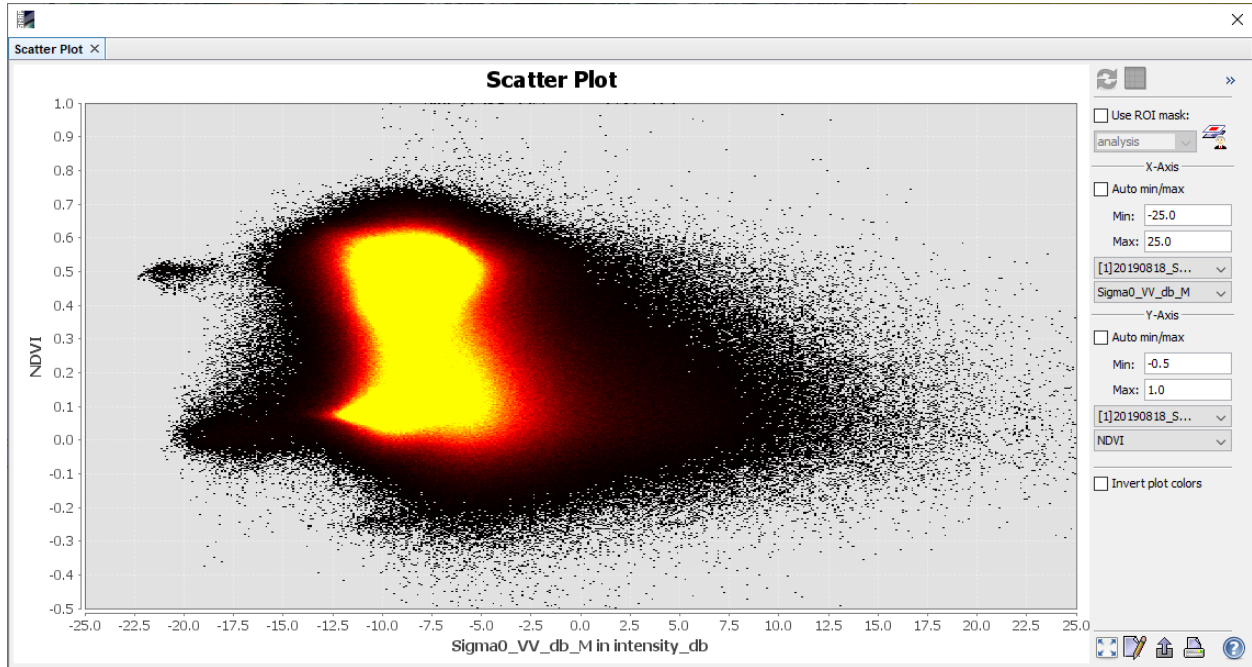
Figure 39: Scatter Plot between Sigma0 VV db (x) and NDVI (y) for the entire image

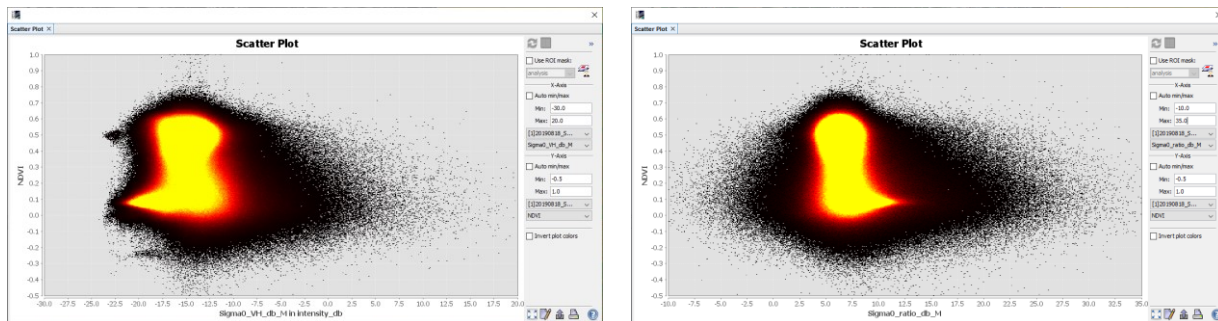The same applies for the VH-band (Figure 40, left) and the ratio image (Figure 40, right)

Figure 40: Scatter Plot between Sigma0 VH db and ratio (x) and NDVI (y) for the entire image

These patterns are not surprising, because the NDVI is only valid for vegetation areas. To restrict the scatter plot to natural areas, a mask must be created which excludes urban areas.

This can be done in the **Mask Manager** using the expression

```
NOT urban AND analysis
```

The first (`NOT urban`) part indicates that every pixel which is inside the urban mask, is not part of the new mask. The second part (`AND analysis`) applies to the mask generated at an earlier stage which includes all pixels covered by both Sentinel-1 and Sentinel-2.

This new mask is named vegetation and then used as ROI for a scatter plot as demonstrated in Figure 41. This scatter plot shows a slight positive correlation, indicating that areas with a high NDVI also have larger Sigma0 VH db values (blue dotted trend line, inserted outside SNAP).
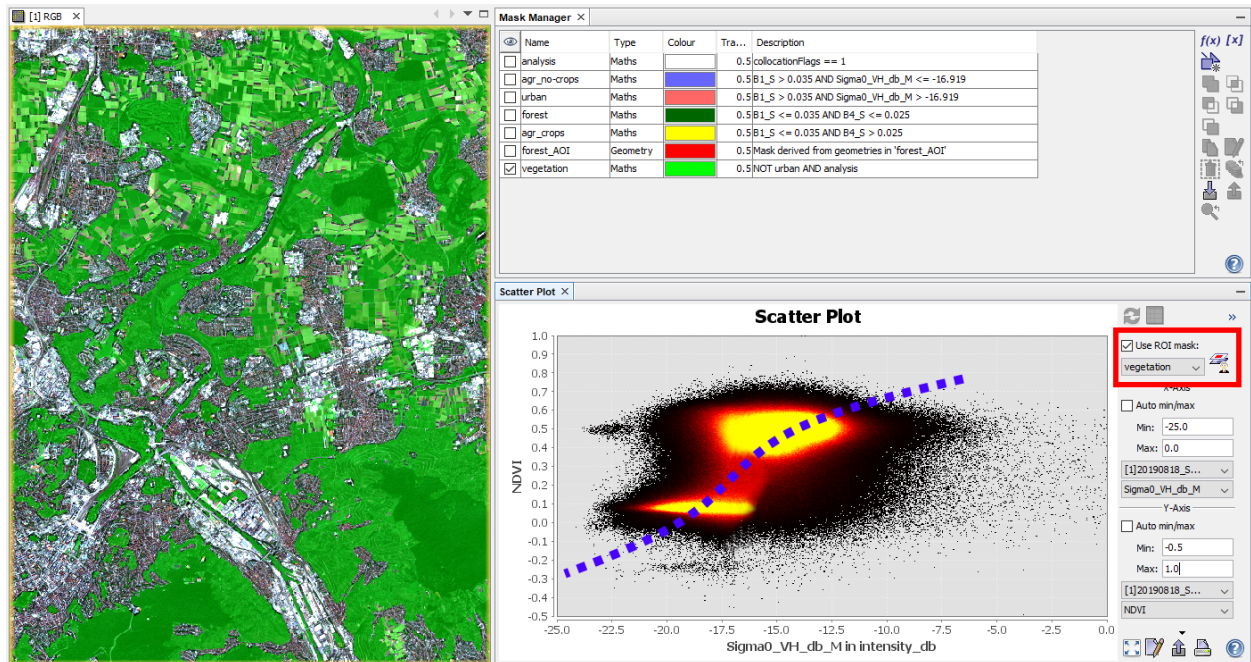

Figure 41: Sigma0 VH db (x-axis) in relation to NDVI (y-axis) for vegetated areas

Profile Plot

The Profile Plot tool [icon] allows to plot the values along a digitized line by a line graph with a defined pixel radius (box size). It helps to understand how much surfaces differ in selected bands (Figure 42). SNAP only allows to display one band at a time, but the data can be exported via right-click > **Copy Data To Clipboard**. This allows to analyze the data along the profile in external tools, such as MS Excel. This helps to identify the bands which are most important to delineate a class and also to find suitable class thresholds.
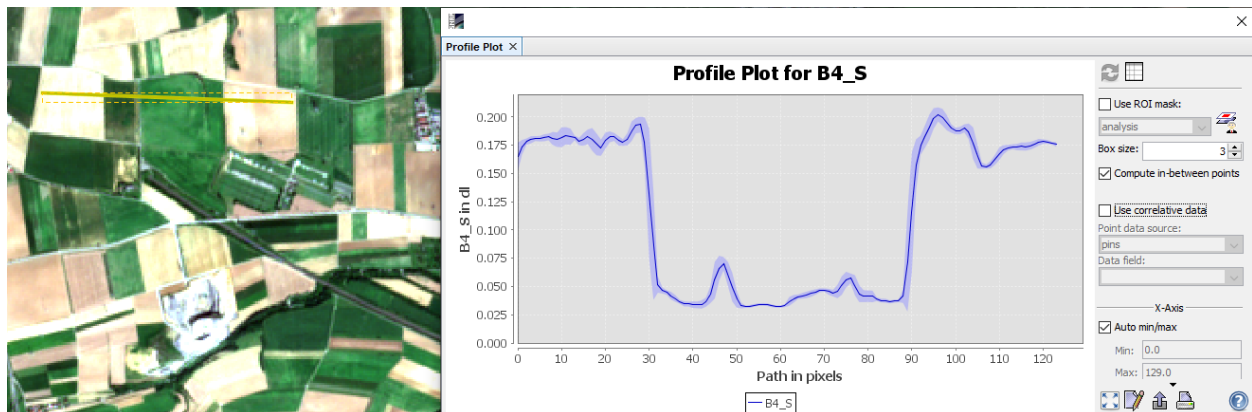

Figure 42: Profile plot across four agricultural fields for band 4 of Sentinel-2

Figure 43 shows pixel values along the digitized lines of both radar and optical raster bands. It highlights that band 4 of Sentinel-2 and VH polarization of Sentinel-1 have higher contrasts than band 1 or VV polarization. A suitable threshold to discriminate between bare and vegetated fields lies at 0.1 reflectance of band 4, or accordingly, at -18 dB backscatter intensity of VH polarization.
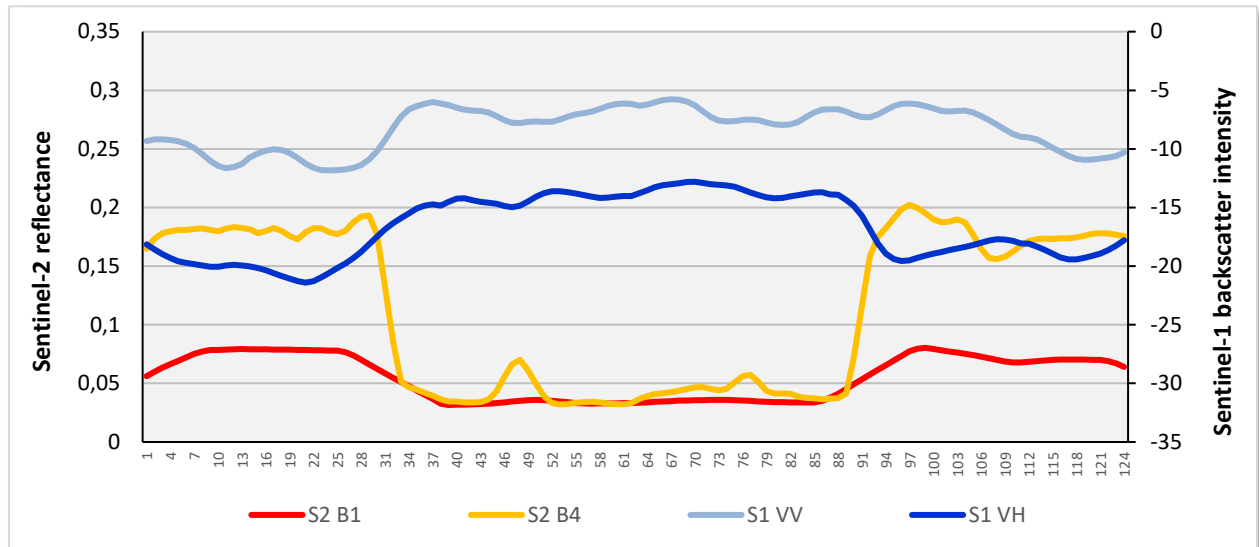

Figure 43: Profile plot across four fields for Sentinel-2 (left y axis) and Sentinel-1 (right y-axis)

Unsupervised classification

An unsupervised classification is a good way to identify and aggregate pixels with similar features.

Open the *K-Means Cluster Analysis* under *Raster > Classification > Unsupervised Classification* and select your merged product stack as input product.

In the second tab, select all bands as **source bands**, except for the "collocationFlags" because they store no information which is relevant here. Select the "analysis" mask as **ROI-mask** to limit the classification on the pixels which are covered by both Sentinel-1 and Sentinel-2 data. Confirm with **Run**.

This can take some minutes because the classifier now undertakes 30 iterations with random cluster centers of the multi-dimensional feature space to find pixels of similar properties. More information.

These clusters do not necessarily represent reasonable classes of landcover, but they are homogenous regarding their pixel characteristics.
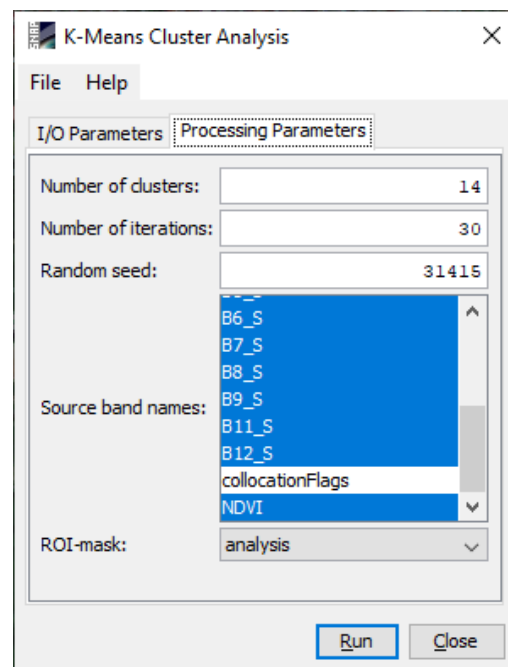
Figure 45 shows a potential result of the k-means clustering with colors assigned and cluster centers described in the *Color Manipulation* tab.
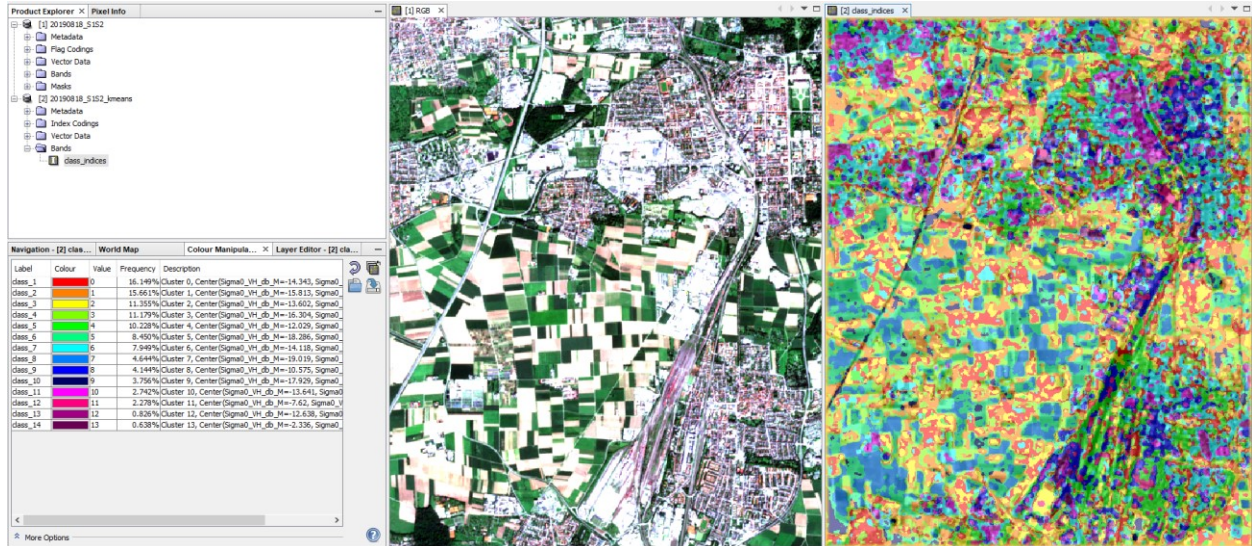

Figure 44: Unsupervised clustering of both optical and radar information

Figure 45: Result of the k-means clustering of Sentinel-1 and Sentinel-2 data

Scatter Plot with Mask Manager

Once a scatter plot is created, you can right-click in the plot area and activate **Select Mask 'scatter_plot_area'** from the menu. You can now select areas in the scatter plot by holding the left mouse button down and drawing a circle in the plot area (highlighted by the blue dotted ellipse in Figure 46).

All pixels which lie in the selected area will be highlighted red in the map. Additionally, a new mask 'scatter_plot_area' is placed in the *Mask Manger* (and can be modified there). To stop the selection of pixels in the Scatter Plot right-click and deactivate **Select Mask 'scatter_plot_area'** again.
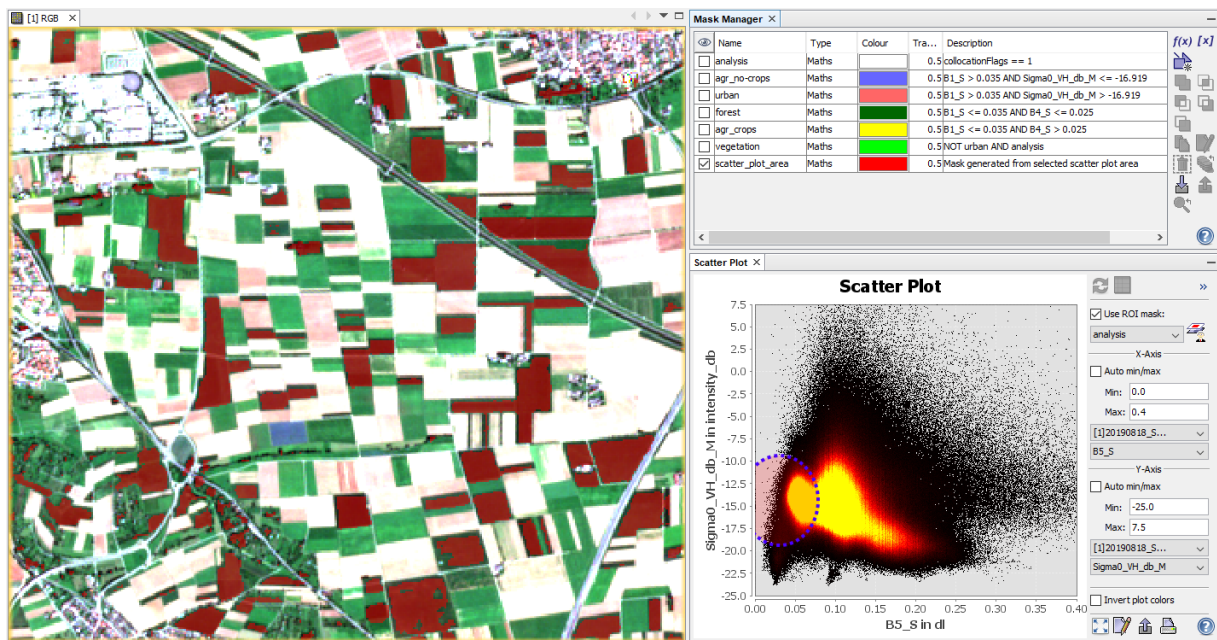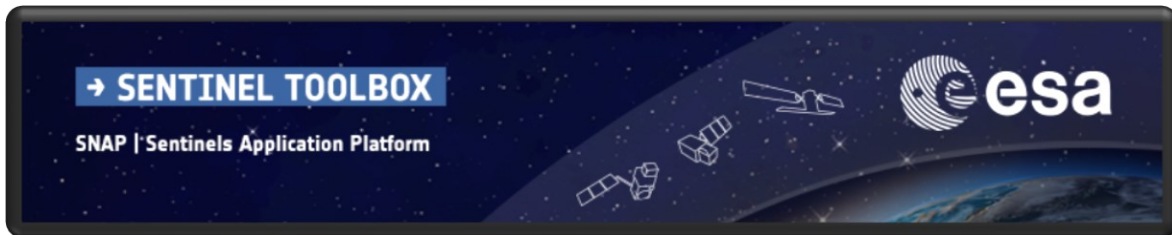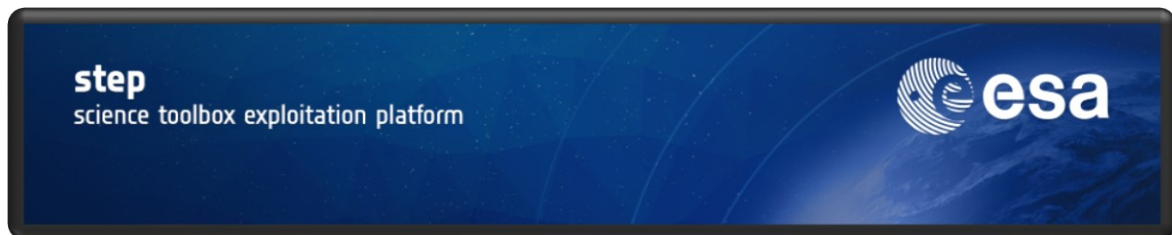

Figure 46: Selection of pixels in the Scatter Plot

For more tutorials visit the Sentinel Toolboxes website

http://step.esa.int/main/doc/tutorials/

Send comments to the SNAP Forum

http://forum.step.esa.int/