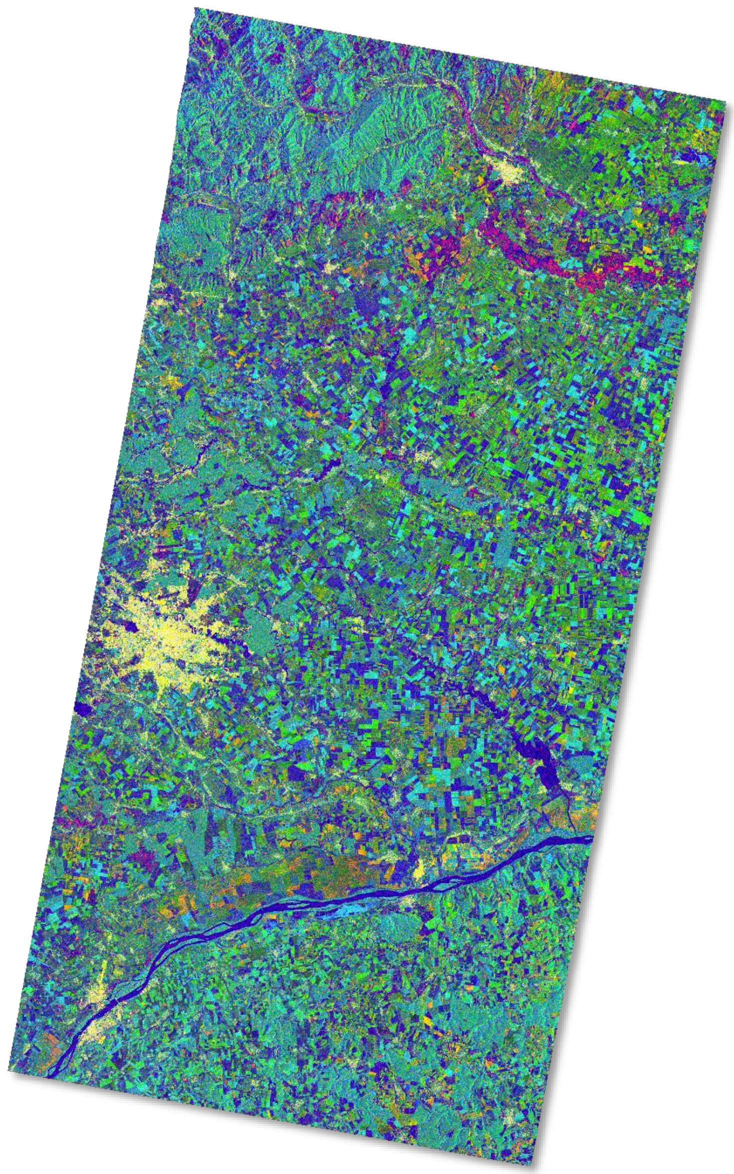
Land Cover Change Detection with S-1TBX: Create an RGB from Multi-Temporal Sentinel-1 Data

Adapted from the 2015 European Space Agency's Advanced Training course on Land Remote Sensing.

In this data recipe, you will learn how to create a coherence-based multi- temporal color composite of land coverage using the ESA Sentinel-1 Toolbox.



Contains modified Copernicus Sentinel data (2015) processed by ESA

In this document you will find

RGB – R: Coherence, **G**: Average Sigma0 & **B**: Difference Sigma0

A) System Requirements

The Sentinel-1 Toolbox is a very computer resource intensive program and some steps can take a very long time to complete. Here are some hints to help speed things up and keep the program from freezing.

- At least 16 GB memory (RAM)
- Close other applications
- Do not use the computer while a product is being processed

B) Background

The Sentinel-1 mission comprises a constellation of two polar-orbiting satellites, Sentinel-1A and Sentinel-1B, which provide all-weather, day-and-night radar imaging for land and ocean surfaces, monitoring the marine environment, vegetation mapping, and other major applications.

With multi-temporal analyses, remote sensing gives a unique perspective of how cities evolve. The key element for mapping rural to urban land use change is the ability to discriminate between rural uses (farming, pasture, forests) and urban use (residential, commercial, recreational). Remote sensing methods can be employed to classify types of land use in a practical, economical and repetitive fashion, over large areas.

A Word on Sentinel-1 Interferometric Wide Swath (IW) Data

The Interferometric Wide (IW) swath mode is the main acquisition mode over land for Sentinel-1. It acquires data with a 250km swath at 5m x 20m spatial resolution (single look). IW mode captures three sub-swaths using the Terrain Observation with Progressive Scans SAR (TOPSAR) acquisition principle.

With the TOPSAR technique, in addition to steering the beam in range as in ScanSAR, the beam is also electronically steered from backward to forward in the azimuth direction for each burst, avoiding scalloping and resulting in homogeneous image quality throughout the swath. A schematic of the TOPSAR acquisition principle is shown below in Figure 1.

The TOPSAR mode replaces the conventional ScanSAR mode, achieving the same coverage and resolution as ScanSAR, but with nearly uniform image quality (in terms of Signal-to-Noise Ratio and Distributed Target Ambiguity Ratio).

IW Single Look Complex (SLC) products contain one image per sub-swath and one per polarization channel, for a total of three (single polarization) or six (dual polarization) images in an IW product.

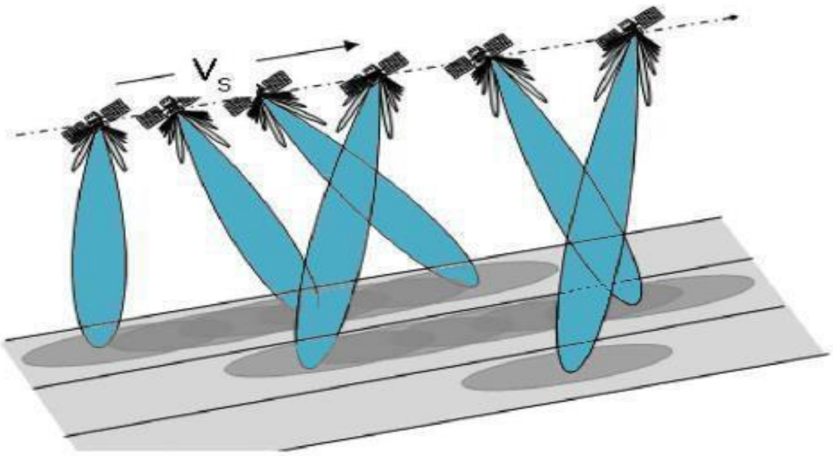


Figure 1: TOPSAR acquisition principle

Each sub-swath image consists of a series of bursts, where each burst has been processed as a separate SLC image. The individually focused complex burst images are included, in azimuth-time order, into a single sub-swath image with black-fill demarcation in between, similar to ENVISAT ASAR Wide ScanSAR SLC products.

C) Materials List

- Windows or Mac OS X
- Multi-Temporal Sentinel-1A SLC Products

  Sample Pair 1
  - S1A_IW_SLC__1SDV_20150610T042103_20150610T042131_006306_00847C_8E6C
  - S1A_IW_SLC__1SDV_20150610T042129_20150610T042156_006306_00847C_9361

  Sample Pair 2
  - S1A_IW_SLC__1SDV_20150622T042104_20150622T042131_006481_008979_946E
  - S1A_IW_SLC__1SDV_20150622T042129_20150622T042156_006481_008979_7B20
- Sentinel-1 Toolbox (Version 5.0.0)

Note: You will be prompted for your Earthdata Login username and password, or must already be logged in to Earthdata before the download will begin.

D) Steps for Generating Complex Sentinel-1 RGB Composites

Part 1: Process SLC Image Pairs

1. Download software and data
2. Open data in Sentinel-1 Toolbox (S-1TBX)
3. TOPS Slice Assembly
4. Splitting Sub-Swaths
5. Applying Precise Orbits
6. Radiometric Calibration
7. TOPS Debursting
8. Speckle Reduction
9. SAR Multilooking

Part 2: TOPS Coregistration and InSAR Coherence

10. Open assembled SLC images
11. S1 TOPS Coregistration
12. InSAR Coherence Estimation
13. TOPS Debursting
14. Multilooking

Part 3: Generate RGB Composite

15. Open Processed images, Coherence stack
16. Create Data Stack
17. 17.Create Spatial Subset over AOI
18. Range-Doppler Terrain Correction
19. Band Math Tool
20. RGB Composite Generation
21. Re-project to Geographic Coordinates
22. Export to Google Earth

Part 1: Process SLC Images – *9 Steps (x2)*

Part 1 must be completed for each pair of images. You will do Part 1 twice - once for each pair.

Part 1: Process SLC Image Pair

1. Download software and data
2. Open data in Sentinel-1 Toolbox
3. TOPS Slice Assembly
4. Splitting Sub-Swaths
5. Applying Precise Orbits
6. Radiometric Calibration
7. TOPS Debursting
8. Speckle Reduction
9. SAR Multilooking

1. Download Software and Data

Download the Materials

- Download and install the Sentinel-1 Toolbox (Select the correct version for your operating system)
- Create a working folder for the Sentinel-1 sample images and intermediary products created during processing
- Download the sample images from the Materials List and place them in the new working folder

2. Open Data in Sentinel-1 Toolbox

In order to create an RGB composite, the input products should be two or more SLC products over the same area acquired at different times, such as the sample images provided in this data recipe.

Open the products

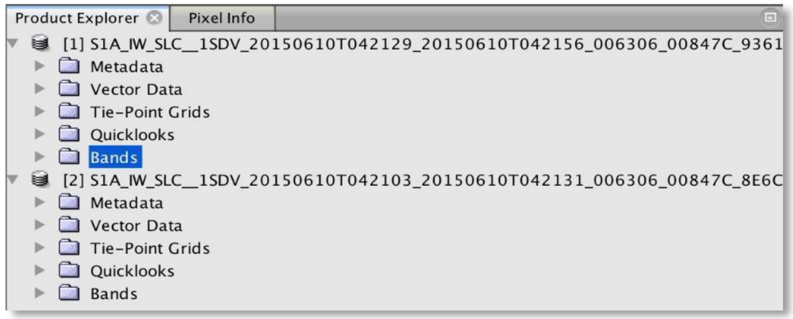
Use the **Open Product** button in the top toolbar and browse for the location of the Sentinel-1 Interferometric Wide (IW) SLC products. *To start, we will be working with both images from 6/10/2015*, as seen in the file name.

Note: *Do not unzip the downloaded files.*

Press and hold the **Ctrl** button on your keyboard and select the files. Click **Open** to load the files into the toolbox.

View the products

- In the *Product Explorer* window, you will find the products
- Double-click on each product to expand the view
- Double-click *Bands* to expand the folder

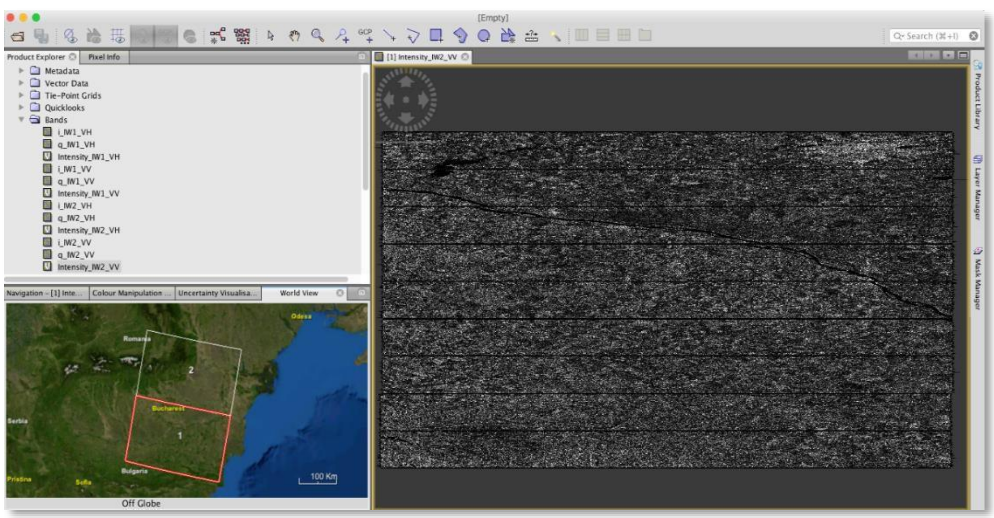


In the Bands folder, you will find bands containing the real (i) and imaginary (q) parts of the complex data. The I and q bands are the bands that are actually in the product, and represent amplitude and phase. The Virtual Intensity or V band is there to assist you in working with and visualizing the complex data.

Note that in Sentinel-1 IW SLC products, you will find three subswaths labeled IW1, IW2, and IW3. Each subswath is for an adjacent acquisition by the TOPS mode.

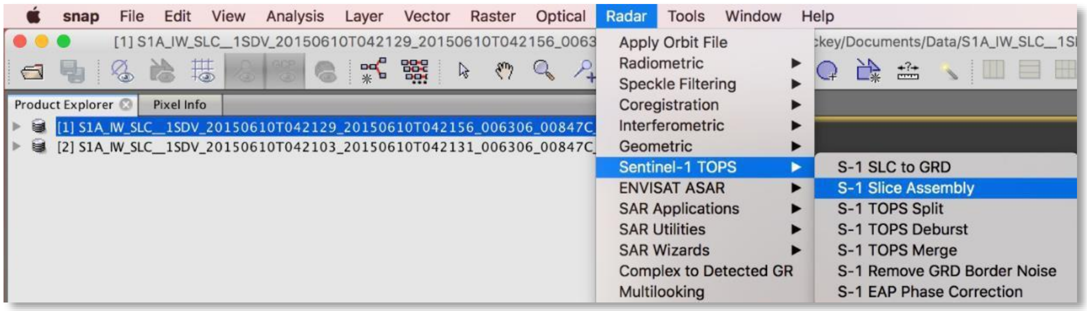
View a band

To view the data, double-click on the **Intensity_IW2_VV** band of one of the images. Zoom-in on the image and pan by using the tools in the Navigation window below the Product Explorer window.



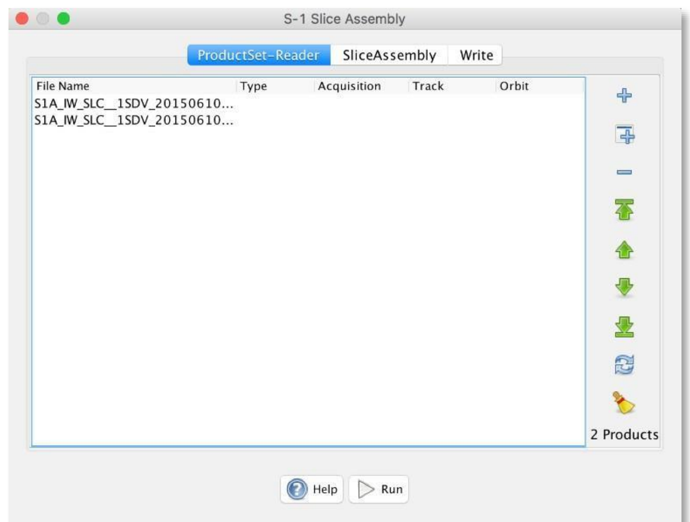
Within a subswath, TOPS data are acquired in bursts. Each burst is separated by a demarcation zone. Any ‘data’ within these demarcation zones can be considered invalid and should be zero-filled, but may also contain garbage values.

3. TOPS Slice Assembly



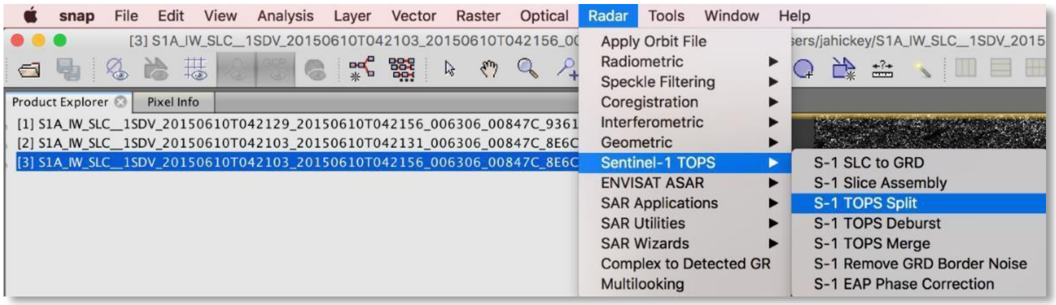
Assemble the images

- In the top menu, navigate to *Radar > Sentinel-1 TOPS > S-1 Slice Assembly*
- In the *ProductSet-Reader* tab, add both products acquired on 06-10-2015 by using the add button (+). See below
- In the *SliceAssembly* tab, select the **VV** polarization
- In the *Write* tab, save the resulting product to a folder of your choice (e.g., 20150610_assembled)

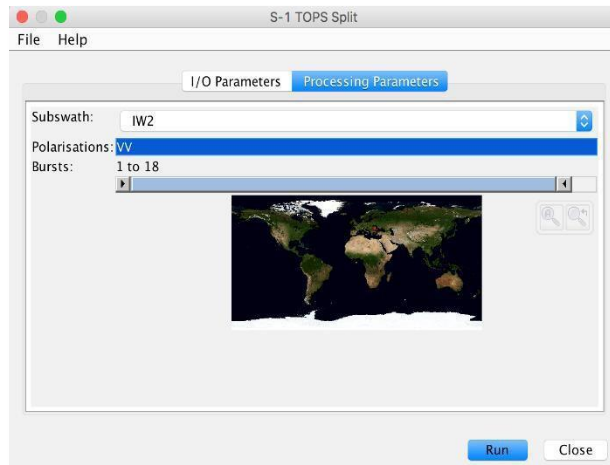


The resulting product will automatically be appended with ***_Asm*.**

4. Splitting Sub-Swaths



Split assembled sub-swath



- In the top menu, navigate to *Radar > Sentinel-1 TOPS > S-1 TOPS Split*
- In *I/O Parameters*, for *Source Product* select the product from the previous step (appended with *_Asm*)
- In *Processing Parameters*, select **IW2** as your Subswath
- For *Polarizations*, select **VV**
- Click **Run**

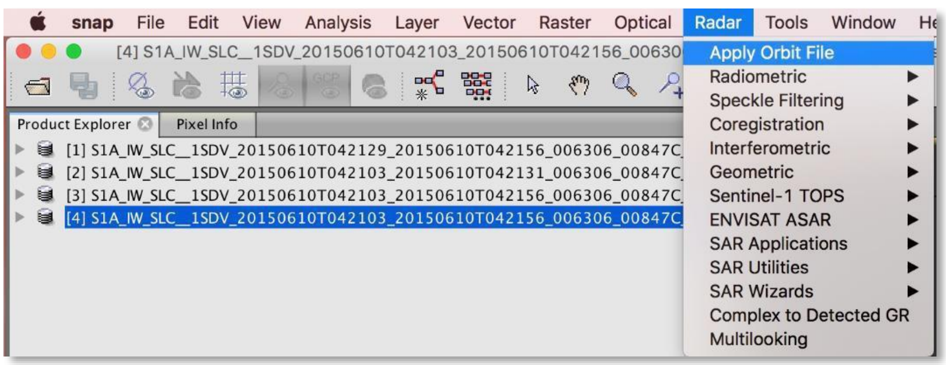
The resulting product will be appended with ***_Asm_split***

5. Applying Precise Orbits (POD)

Orbit auxiliary data contain information about the position of the satellite during the acquisition of SAR data. Orbit data are automatically downloaded by SNAP and no manual search is required by the user.

The Precise Orbit Determination (POD) service for Sentinel-1 provides Restituted orbit files and Precise Orbit Ephemerides (POE) orbit files. POE files cover approximately 28 hours and contain orbit state vectors at fixed time steps of 10-second intervals. Files are generated one file per day and are delivered within 20 days after data acquisition.

If Precise orbits are not yet available for your product, you may select the Restituted orbits, which may not be as accurate as the Precise orbits but will be better than the predicted orbits available within the product.



Apply Orbit File

- In the top menu, navigate to *Radar* > *Apply Orbit File*
- In *I/O Parameters*, for *Source Product* select the product from the previous step (appended with *_Asm_split*)
- Click **Run**

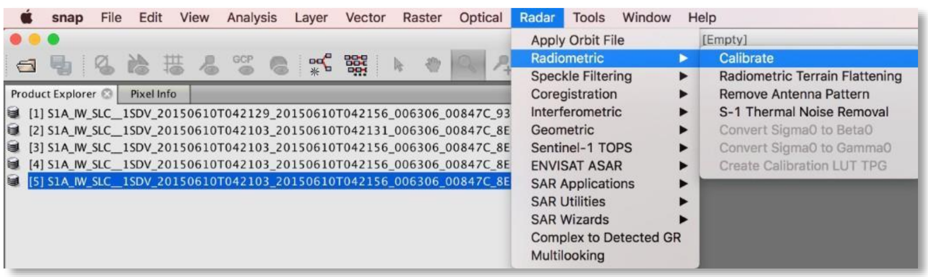
The resulting product will be appended with ***_Asm_split_Orb***

6. Radiometric Calibration

Radiometric calibration corrects a SAR image so that the pixel values truly represent the radar backscatter of the reflecting surface.

The corrections applied during calibration are mission-specific, therefore the software will automatically determine what kind of input product you have and what corrections need to be applied based on the product's metadata.

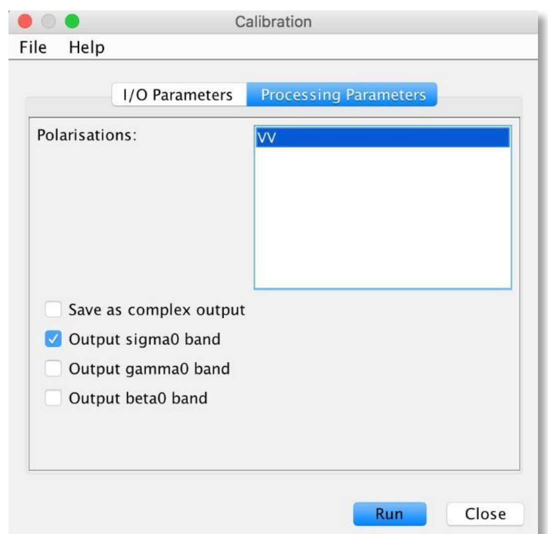
Calibration is essential for quantitative use of SAR data.



Calibrate Sentinel-1 image

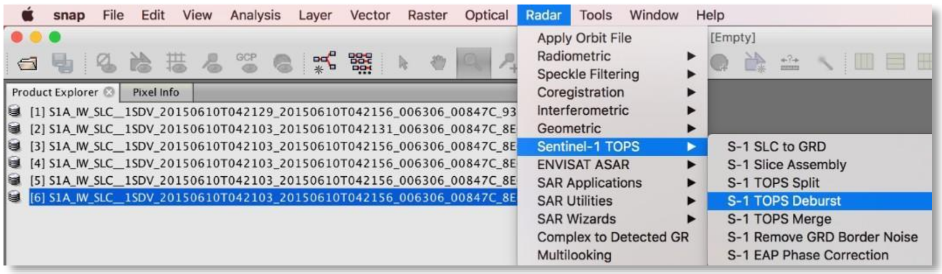
- In the top menu, navigate to *Radar > Radiometric > Calibrate*
- In *I/O Parameters*, for *Source Product* select the product from the previous step (appended with *_Asm_split_Orb*)
- In *Processing Parameters*, select **VV**
- Select *Output sigma0 band*
- Click **Run**

The resulting product will be appended with ***_Asm_split_Orb_Cal***



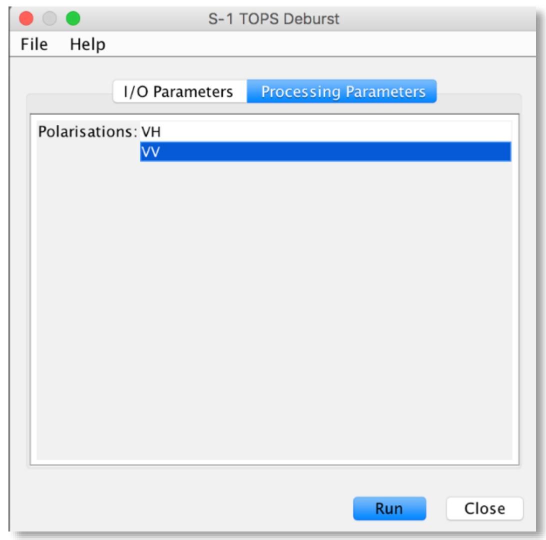
7. TOPS Debursting

To seamlessly join all burst data into a single image, apply the TOPS Deburst operator from the Sentinel-1 TOPS menu.



Deburst Image

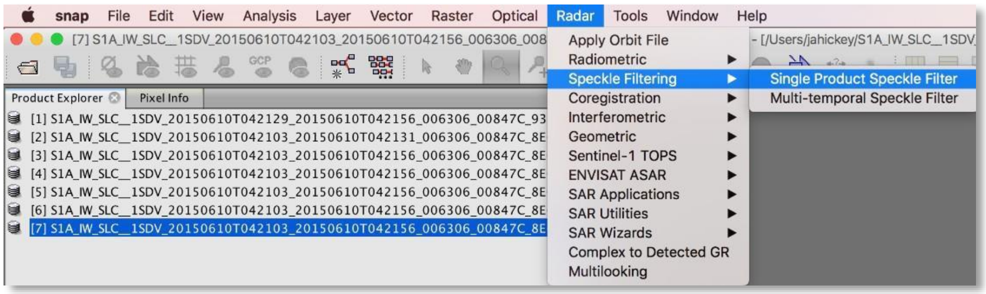
- In the top menu, navigate to *Radar > Sentinel-1 > S-1 TOPS Deburst*
- In *I/O Parameters*, for *Source Product* select the product from the previous step (appended with *_Asm_split_Orb_Cal)*
- In *Processing Parameters*, select **VV**
- Click **Run**



The resulting product will be appended with ***_Asm_split_Orb_Cal_deb***

8. Speckle Reduction

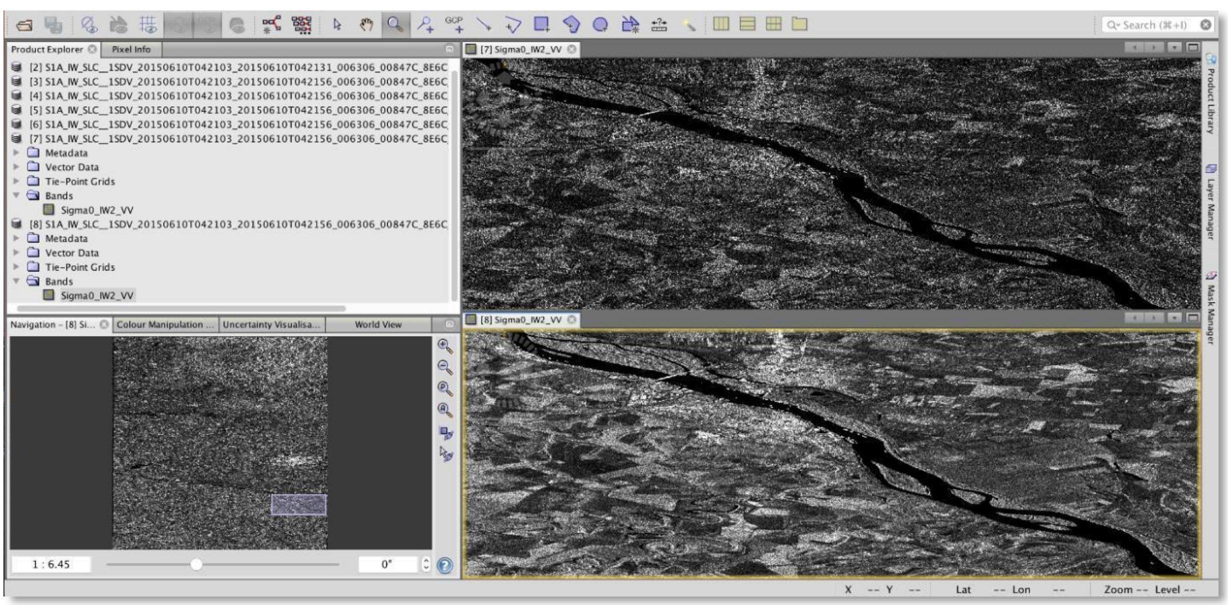
Speckle is caused by random constructive and destructive interference resulting in salt and pepper noise throughout the image. Speckle filters can be applied to the data to reduce the amount of speckle at the cost of blurred features or reduced resolution.



Speckle Filtering

- In the top menu, navigate to *Radar* > *Speckle Filtering* > *Single Product Speckle Filter*
- In *I/O Parameters*, for Source Product select the product from the previous step (appended with *_Asm_split_Orb_Cal_deb*)
- In *Processing Parameters*, set *Filter* to **Gamma Map**
- Click **Run**

The resulting product will be appended with *_Asm_split_Orb_Cal _deb_Spk*

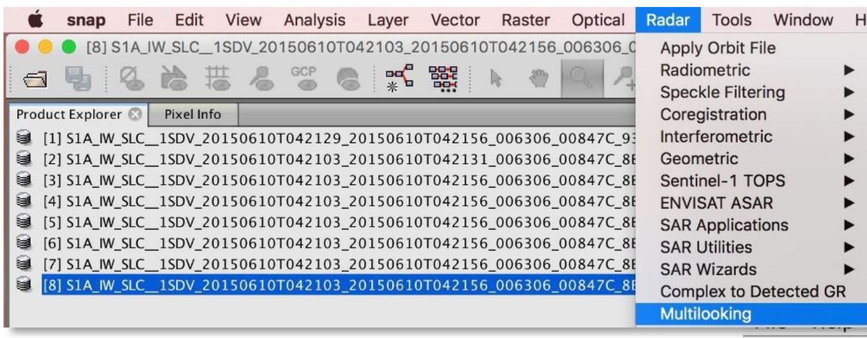


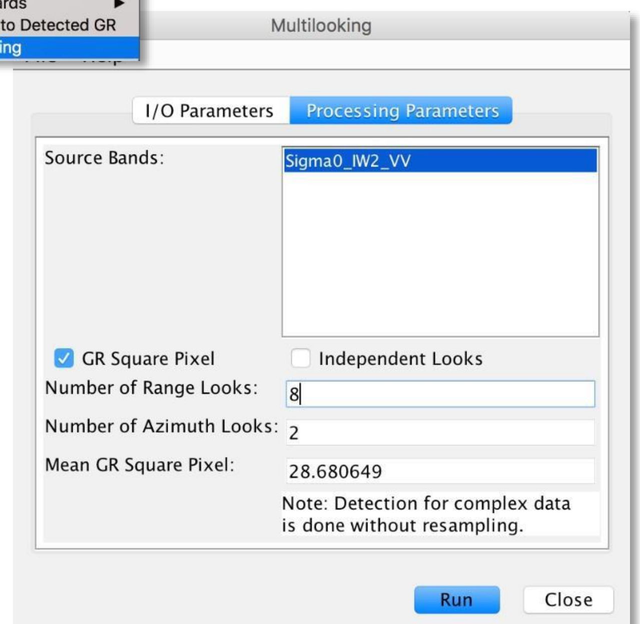
The Gamma Map filter assumes that the scene reflectivity of an image has a Gaussian distribution. Therefore, this filter uses *a priori* knowledge of the probability density function (PDF) of the scene when suppressing the speckle of the image.

9. SAR Multi-looking

Multi-look processing can be used to produce a product with nominal image pixel size.

Multiple looks may be generated by averaging over range and/or azimuth resolution cells improving radiometric resolution but degrading spatial resolution. As a result, the image will have less noise and approximate square pixel spacing after being converted from slant range to ground range.





Multi-look the Image

- In the top menu, navigate to *Radar > Multilooking*
- In *I/O Parameters*, for *Source Product* select the product from the previous step (appended with *_Asm_split_Orb_Cal_deb_Spk*)
- In the *Processing Parameters* tab, change *Number of Range Looks* to **8**. Notice that the *Number of Azimuth Looks* automatically changes to 2.
- Click **Run**

The resulting product will be appended with *_Asm_split_Orb_Cal _deb_Spk_ML*

Note: *You must now repeat the steps in* ***Part 1*** *for the second pair of images acquired on 06-22-2015.*

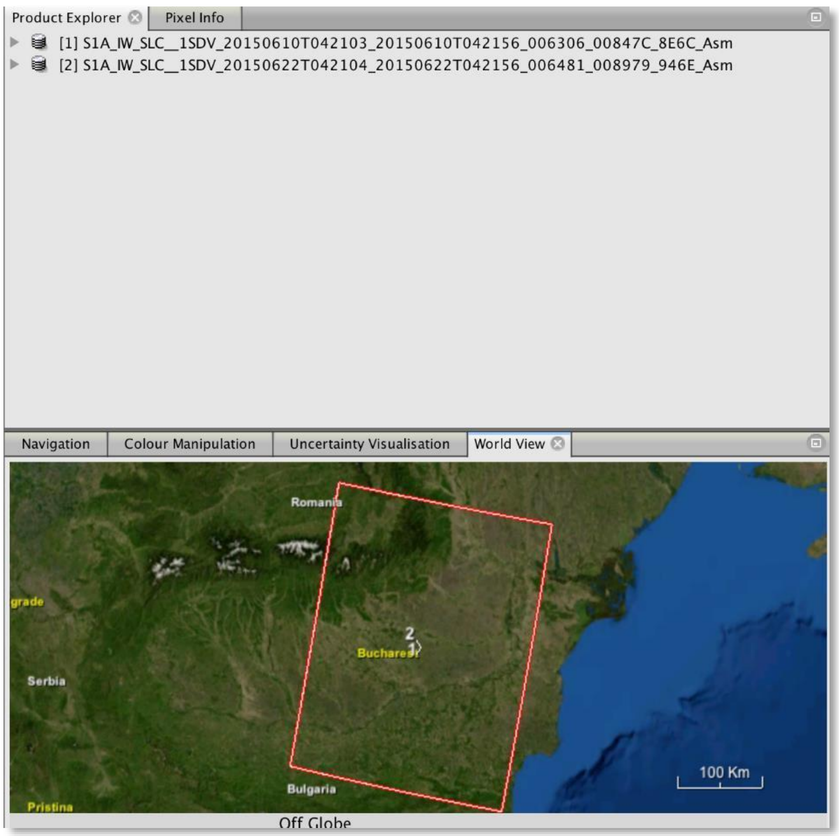
Remove all products from the Product Explorer window by selecting the products, then right-click and choose *Close All Products*.

Part 2: TOPS Coregistration and InSAR Coherence – *5 Steps*

10. Open Assembled SLC Images
11. S1 TOPS Coregistration
12. InSAR Coherence Estimation
13. TOPS Debursting
14. Multi-looking

10. Open Assembled SLC Images

In order to create the bands necessary for the RGB composite image, you will have to co-register the images created in Step 3 of Part 1 (S-1 Slice Assembly). These assembled SLC products will allow you to estimate the coherence between the two images.



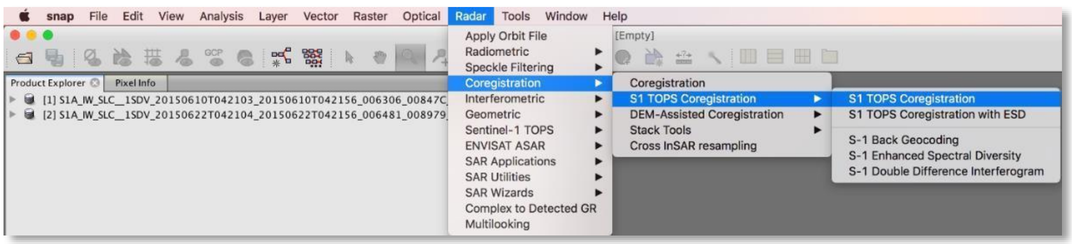
Open the products

Use the Open Product button in the top toolbar and browse to the location of the assembled SLC products. These images will have the suffix _*asm.dim* (if you did not choose to create a custom file name).

11. S-1 TOPS Coregistration

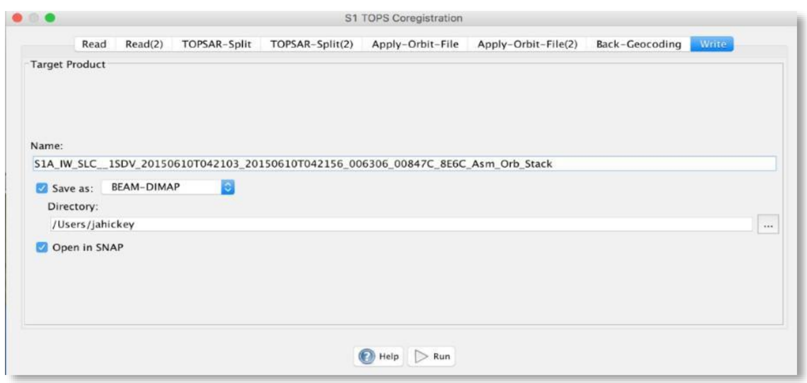
For interferometric processing (coherence estimation), two or more images must be co-registered into a stack. One image is selected as the master and the other images are the ‘slaves’. The pixels in ‘slave’ images will be moved to align with the master image to sub-pixel accuracy.

Coregistration ensures that each ground target contributes to the same (range, azimuth) pixel in both the master and the ‘slave’ image. For TOPSAR InSAR, S-1 TOPS Coregistration is used.



Co-register the images

Navigate to *Radar > Coregistration > S1 TOPS Coregistration > S1 TOPS Coregistration*



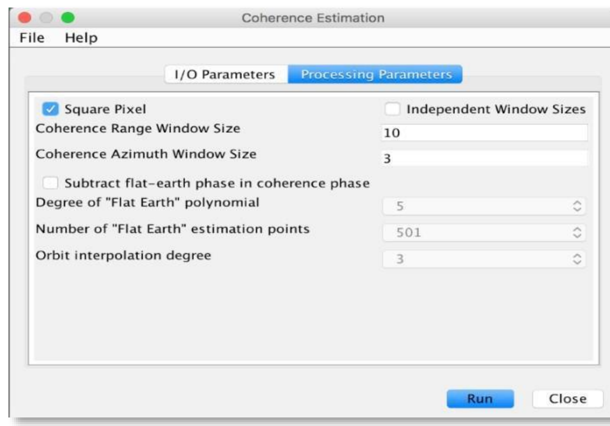
- In the **Read** tab, select the first product -this will be your master image
- In the **Read(2)** tab select the other product -this will be your ‘slave’ image
- In the **TOPSAR-Split** tabs, select the IW2 subswath for each of the products
- In the **Apply-Orbit-File** tabs select the Sentinel Precise Orbit State Vectors
- In the **Back-Geocoding** tab leave all parameters to default
- In the **Write** tab, set the Directory path to your working directory
- Click **Run** to begin co-registering the data

The resulting coregistered stack product will appear in the *Product Explorer* window with the suffix ***_Asm_Orb_Stack***

12. InSAR Coherence Estimation

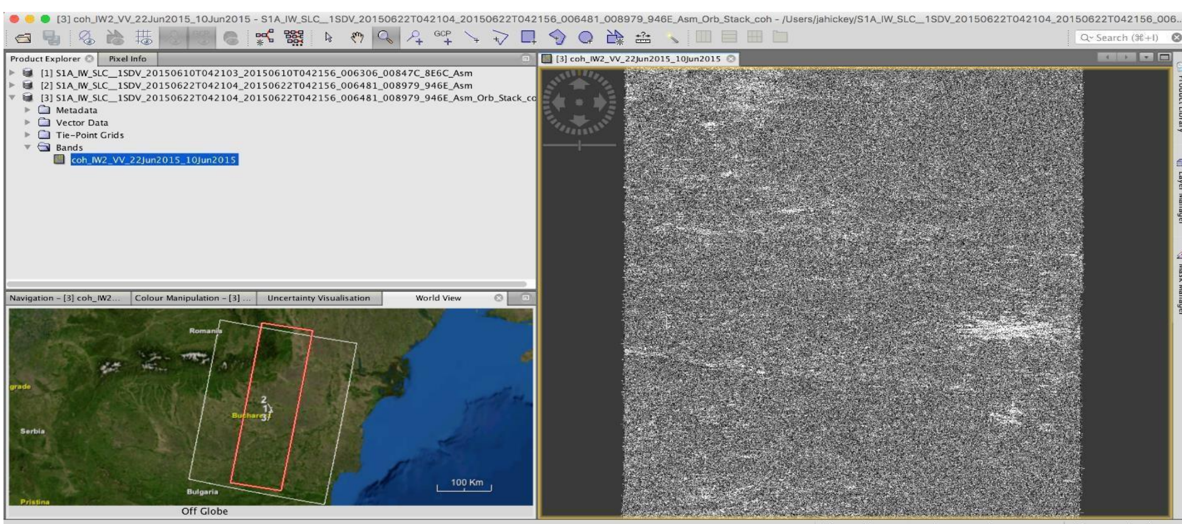
The coherence band shows how similar each pixel is between the slave and master images in a scale from 0 to 1. Areas of high coherence will appear bright. Areas with poor coherence will be dark.

Coherence Estimation

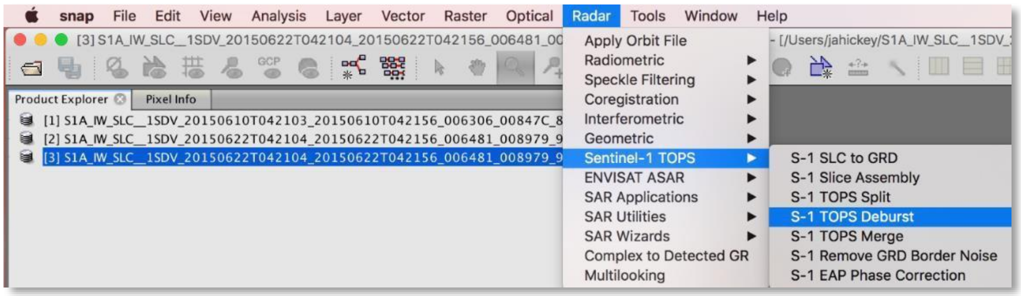


- In the top menu, navigate to *Radar > Interferometric > Products > Coherence Estimation*
- In *I/O Parameters*, for *Source Product* select the product from the previous step (appended with *_Asm_Orb_Stack*)
- Click **Run**

The resulting product will be appended with ***_Asm_Orb_Stack_coh***



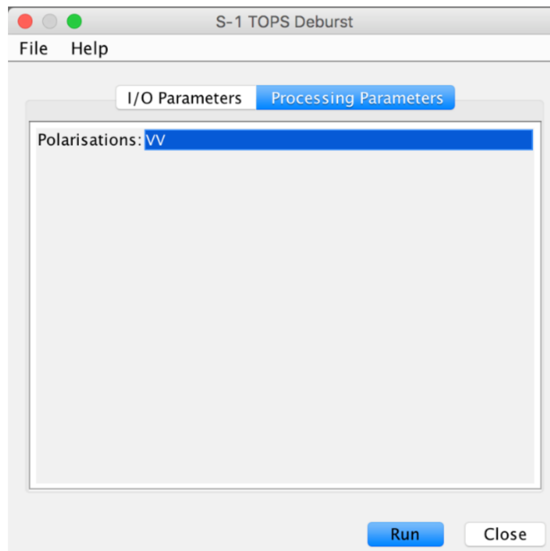
13. TOPS Debursting

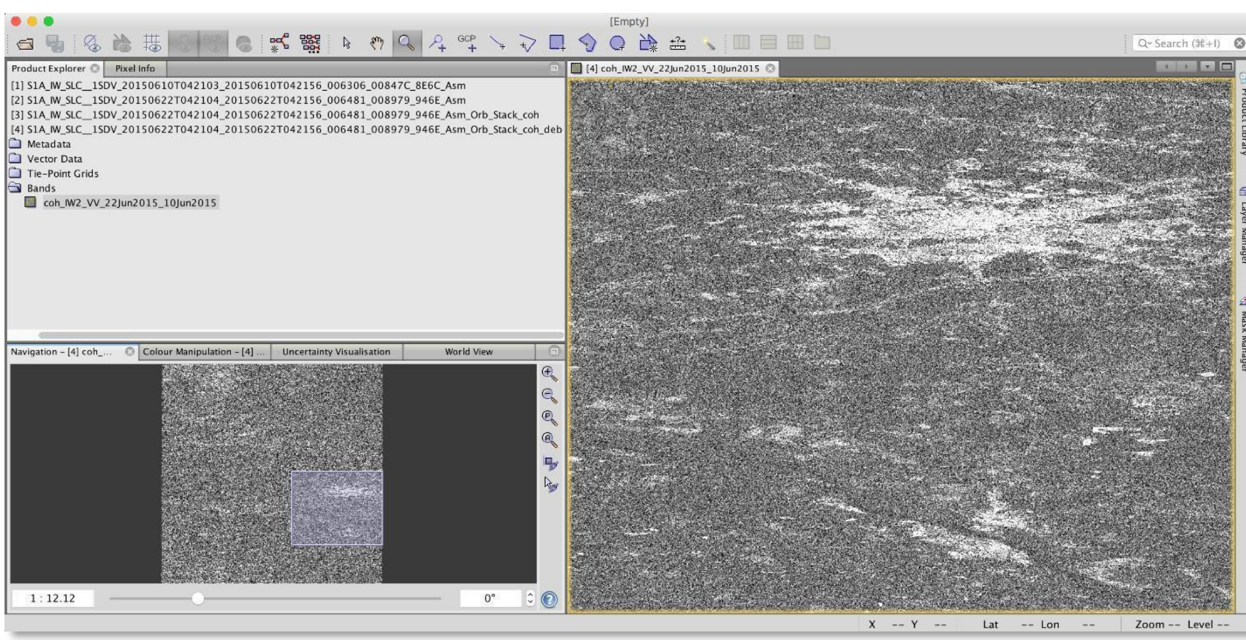


Deburst the Image

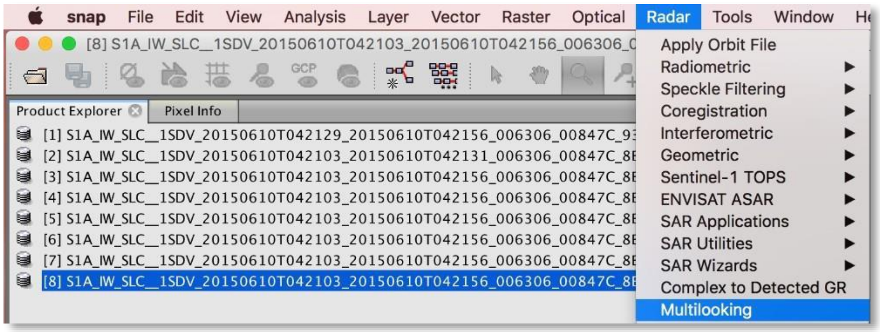
- In the top menu, navigate to *Radar > Sentinel-1 TOPS > S-1 TOPS Deburst*
- In *I/O Parameters*, for *Source Product* select the product from the previous step (appended with *_Asm_Orb_Stack_coh*)
- Click **Run**

The resulting product will be appended with ***_Asm_Orb_Stack_coh_deb***





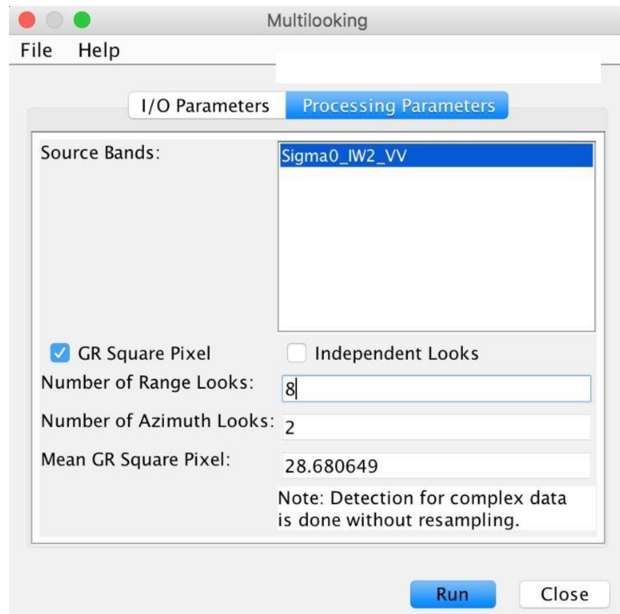
14. Multilooking



Multilook the Image

- In the top menu, navigate to *Radar > Multilooking*
- In *I/O Parameters*, for *Source Product* select the product from the previous step (appended with *_Asm_Orb_Stack_coh_deb*)
- In the *Processing Parameters* tab, change the *Number of Range Looks* to 8; the number of *Azimuth Looks* automatically changes to 2.
- Click **Run**

The resulting product will be appended with ***_Asm_Orb_Stack_coh_deb_ML***



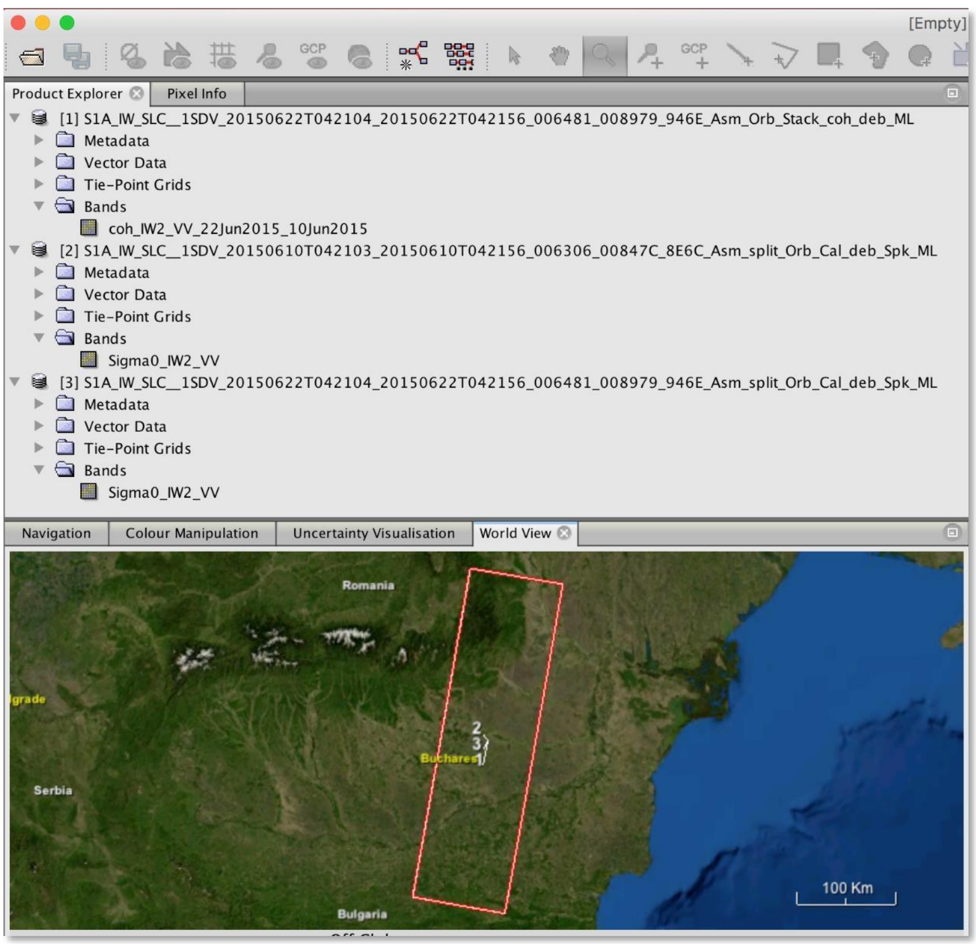
Note: Before proceeding with Part 3, remove all products from the Product Explorer window except for the final, multi-looked product (ending with *_ML*). Left-click on the *_ML* product to highlight it, then from the top menu select *File > Close Other Products*.

Part 3: Generate RGB Composite – *8 Steps*

15. Open Processed Images, Coherence Stack
16. Create Data Stack
17. Create Spatial Subset over AOI
18. Range-Doppler Terrain Correction
19. Band Math Tool
20. RGB Composite Generation
21. Reproject to Geographic Coordinates
22. Export to Google Earth

15. Open Processed Images, Coherence Stack

For this part, we will use the final two products we created in Part 1 (appended with _*ML*) and the final product in Part 2 (also appended with _*ML*) to generate our complex Sentinel-1 TOPS RGB composite.



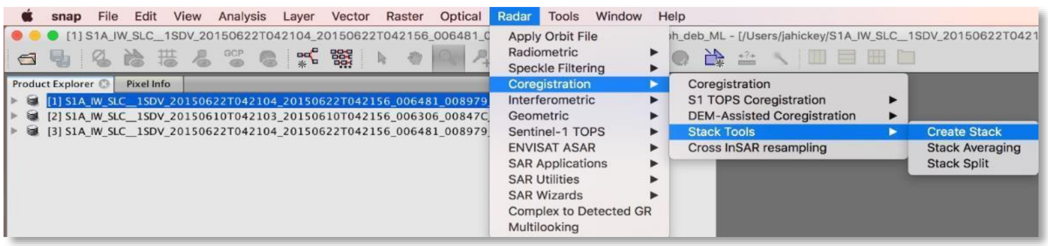
Open Final Products

Navigate to the folder you chose to store the products created in Parts 1 and 2. Open the products with the filename ending in *_ML.dim*.

- Use the *Open Product* button to add the products into the Product Explorer
- You may view the products by double clicking on each item and expand the *Bands* folder

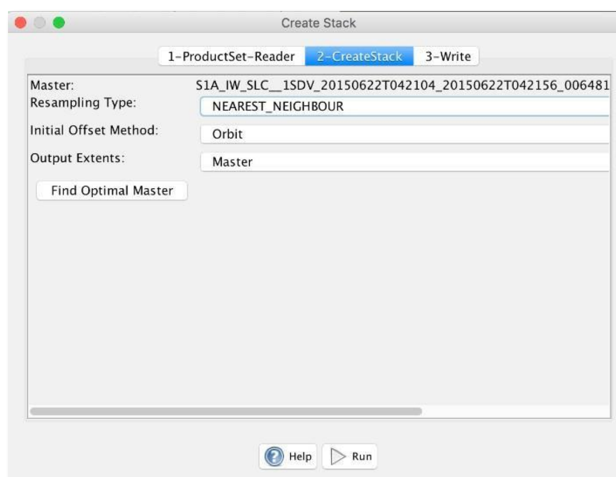
16. Create Data Stack

Creating a data stack will tie each of your final products together and create a single product with multiple bands. Each band will represent the single band present in each of your products. We will use these three bands to generate our composite image.



Create Stack

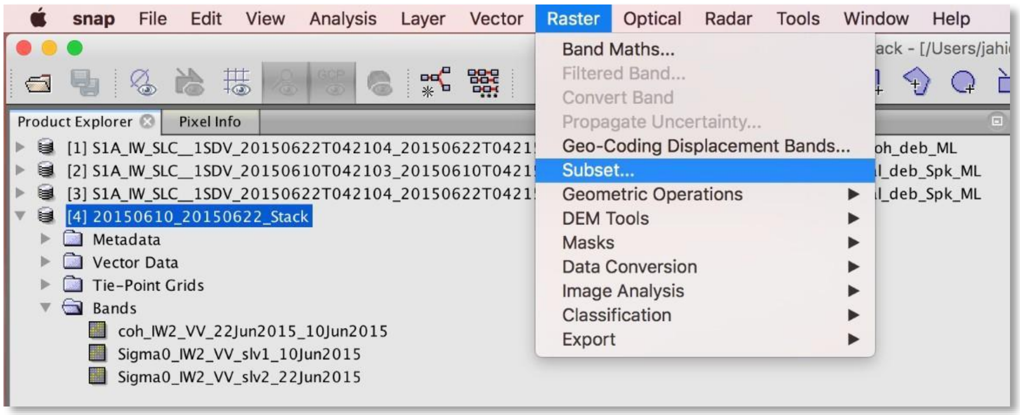
- Navigate to *Radar > Coregistration > Stack Tools > Create Stack*
- In *Create Stack*, add the three products to the *ProductSet-Reader* by clicking on the Add Opened button (the second + sign on the right)
- In the *CreateStack* tab, set the Resampling Type to *NEAREST NEIGHBOUR*
- In *Write*, set the directory to store the product
- Click **Run**



Your product will appear in the *Product Explorer* and will have all three bands.

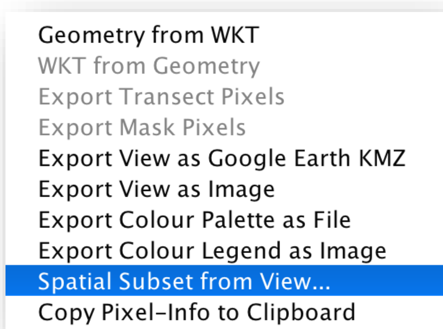
17. Create Spatial Subset over AOI

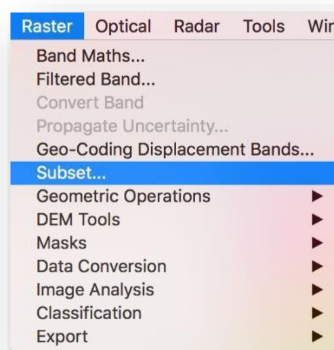
In this particular example, our area of interest will be the capital of Romania, Bucharest, and the surrounding area. This step is not necessary, but is useful if you are only interested in a particular region and desire to crop the image.



Create Subset

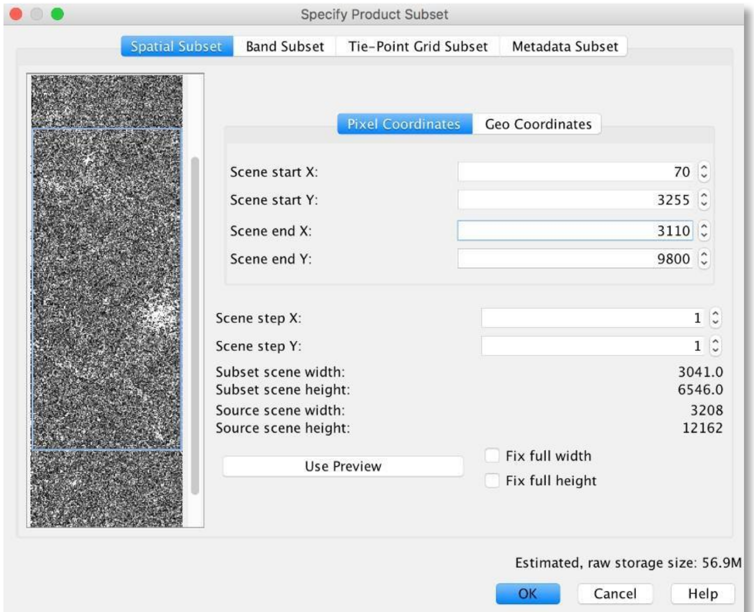
- Double-click on the opened product to view the product bands
- Double-click on any of the bands inside of the product
- Zoom in using the mouse wheel and dragging the left mouse button
- Once you have zoomed and panned to your area of interest, right click and select **Spatial Subset from View** in the context menu.





You may also access this option via the **Raster** menu by selecting **Subset…**

The subset dialog box will automatically select the area you were viewing. To adjust the extent of your subset image, you may drag the bounding box, enter the pixel coordinates, or add geo coordinates.



Click **OK** to create your subset image

When the new subset product appears in the *Product Explorer*:

- Right-click on the product
- Select Save Product in the context menu
- Select **Yes** to convert the product to the BEAM-DIMAP format

18. Range-Doppler Terrain Correction

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

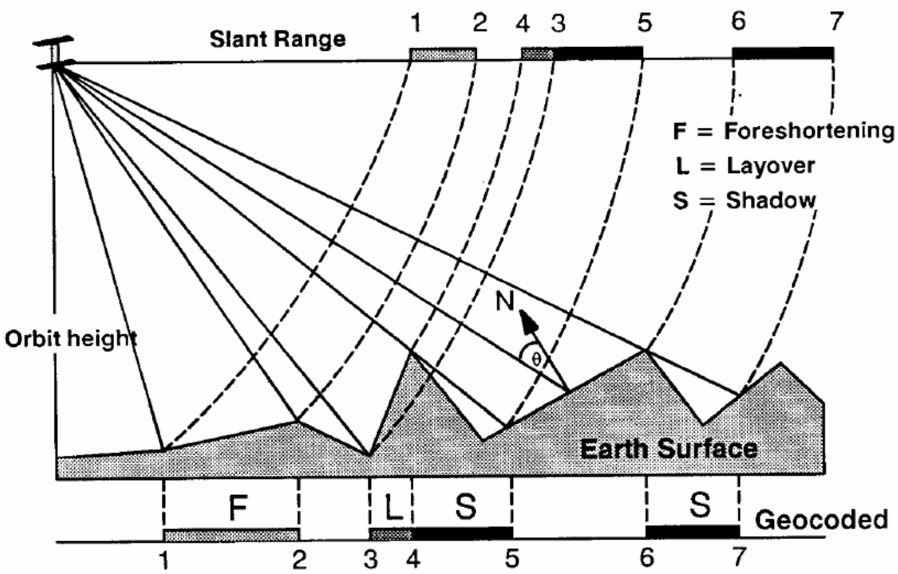


Figure 2: Slant Range geometric image distortions

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 inherent geometry effects such as *foreshortening, layover* and *shadow.*

Foreshortening

- The period of time a slope is illuminated by the transmitted pulse of the radar energy determines the length of the slope on radar imagery.
- This results in shortening of a terrain slope on radar imagery in all cases except when the local angle of incidence ( ) is equal to 90 degrees ( ).

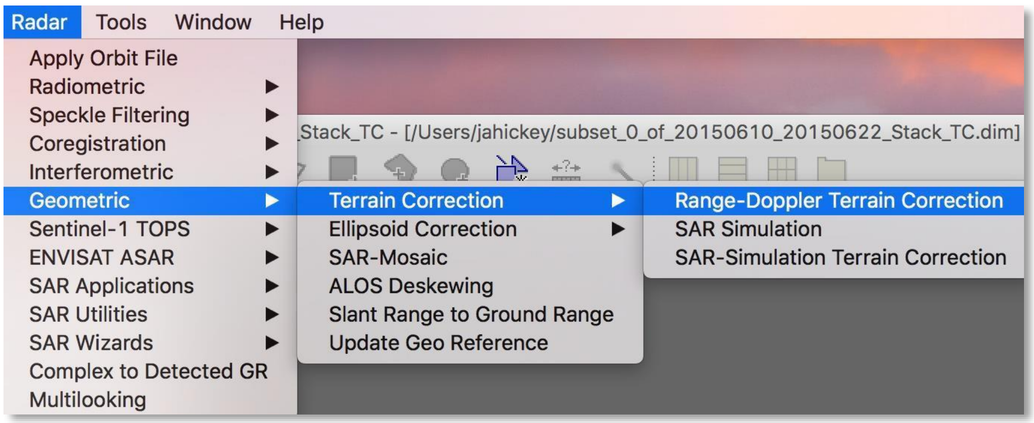
Layover

- When the top of the terrain slope is closer to the radar platform than the bottom the former will be recorded sooner than the latter.
- The sequence at which the points along the terrain are imaged produces an image that appears inverted.
- Radar layover is dependent on the difference in slant range distance between the top and bottom of the feature.

Shadow

- The back-slope is obscured from the imaging beam causing to return no area of radar shadow.

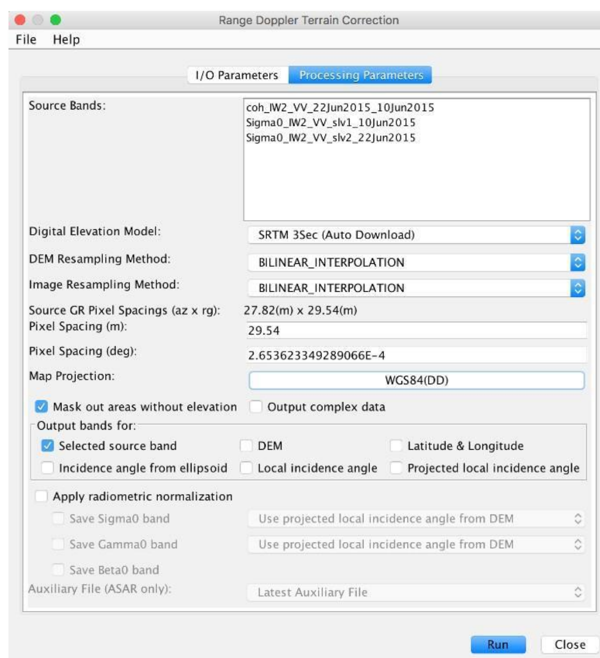
The effects of these distortions can be seen in Figure 2. The distance between 1 and 2 can appear shorter than it should and the return for 4 can occur before the return for 3 due to the elevation.



Terrain Correction

- Highlight the subset product in Product Explorer
- In the top menu, navigate to *Radar > Geometric > Terrain Correction > Range-Doppler Terrain Correction*

By default, the terrain correction will use the SRTM 3 sec DEM. The software will automatically determine the DEM tiles needed and download them from internet servers.



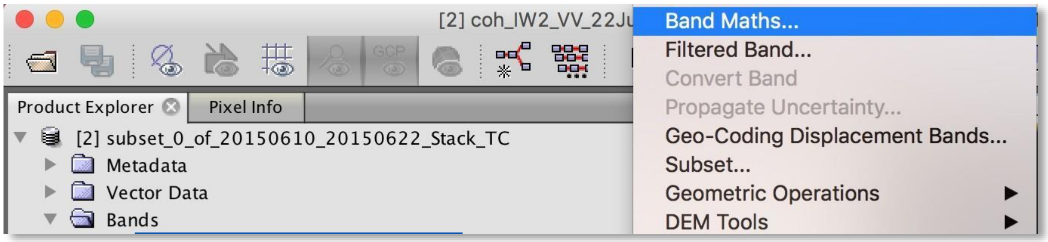
- In Processing Parameters leave all parameters as default

Note: *You may choose a projection of your liking, however, you will not be able to export to Google Earth unless you have Lat/Long coordinates.*

- Click **Run**

19. Band Math Tool

This step will allow us to create meaningful bands used in our composite RGB image. This is a three step process and will create several virtual bands.

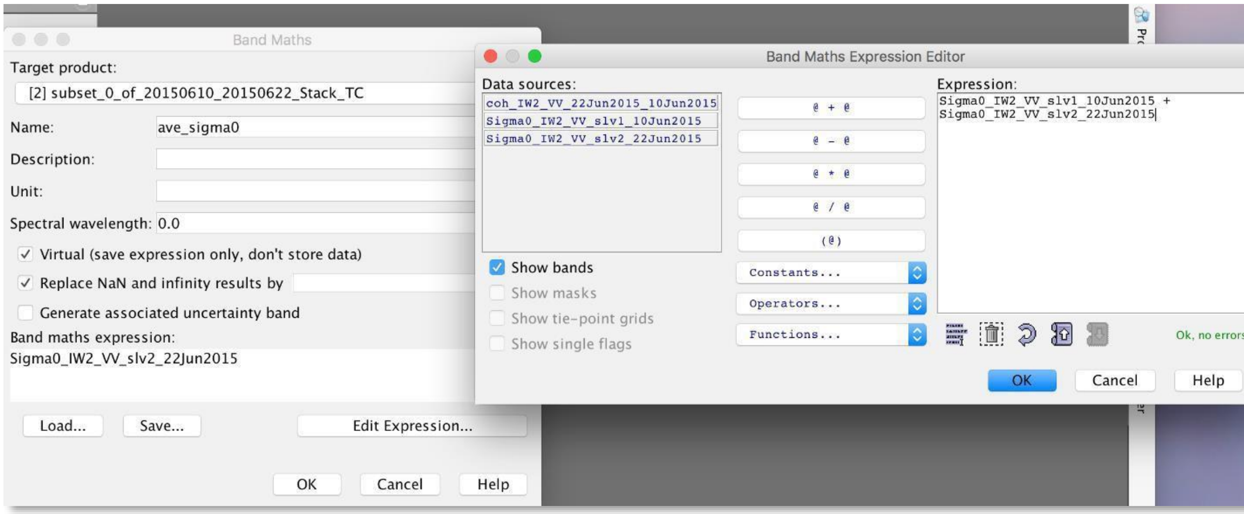


Create Average Backscatter Band

- In the top menu, navigate to *Raster* > *Band Maths*
- In the *Band Maths* window (see Figure 3):
  - Select the terrain corrected subset product (_TC)
  - Name the band **ave_sigma0**
- Click on the ***Edit Expression…*** button
  - In the Band Maths Expression Editor:
    - Click the @ **+** @ operator
    - Click on the two Sigma0 products in *Data sources* and they will be added to the expression
    - Click **OK**
- In the *Band Maths expression:* box
  - Add parenthesis around the expression and type **/ 2** (divided by 2)

The expression should look like: **(Sigma0_06-22-2015 + Sigma0_06-10-2015) / 2**

- Click **OK** to create virtual band



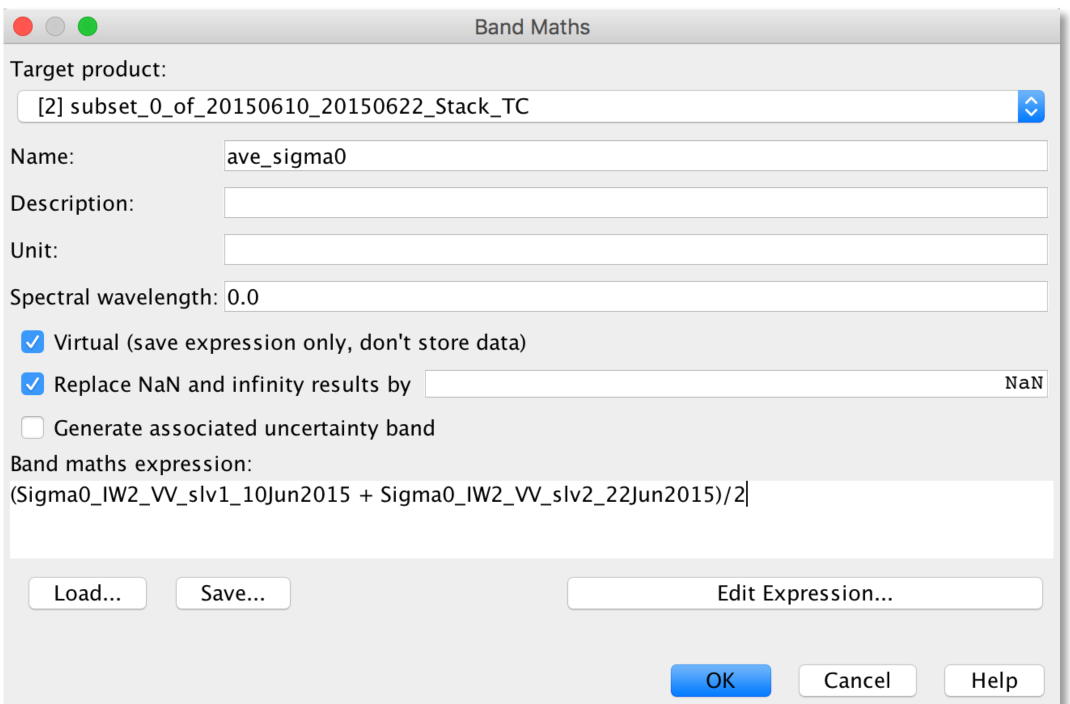


Figure 3: Band Maths dialog and Expression Editor interface

Create Backscatter Difference Band

- In the top menu, navigate to *Raster > Band Maths*
- In the *Band Maths* window
    - Select the terrain corrected subset product (*_TC*)
    - Name the band, **diff_sigma0**
- Open the *Band Maths Expression Editor* by clicking the *<Edit Expression…>* button
    - In the *Band Maths Expression Editor*
        - Delete the contents of the *Expression:* box
        - Click the @ **-** @ operator
        - Click on the two Sigma0 products in *Data sources* and they will be added to the expression
        - Click **OK**

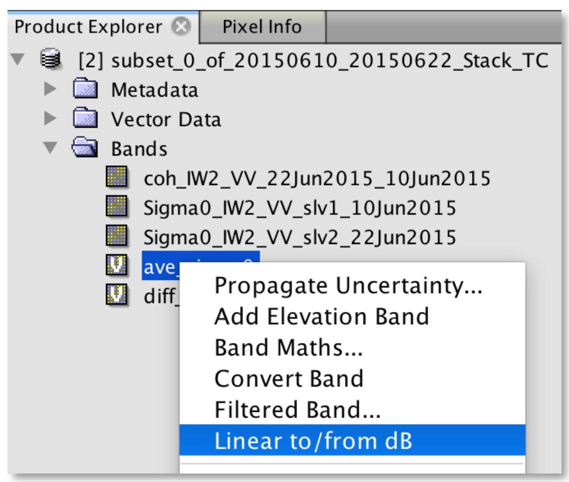
Your final expression should look like this: **older Sigma0 - newer Sigma0**

- Click **OK** to create virtual band

Linear to dB Scale Conversion

- Double-click on the terrain corrected subset product (*_TC*) in Product Explorer
- Open the bands folder
- Right-click on the band named **ave_sigma0**
- Click *Linear to/from dB*
- When prompted, click **Yes** to create a new virtual band

Note: *You may also find this function in Raster > Data Conversion > Linear to/from dB*



OPTIONAL: Save Virtual Bands

To permanently save virtual bands within your product file

- In the **Product Explorer** right-click on the newly created virtual bands (e.g., ave_sig0)
- From the context menu, select **Convert Band**

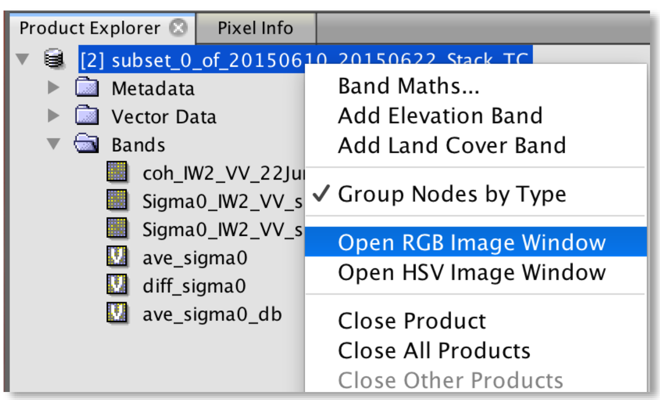
20. RGB Composite Generation

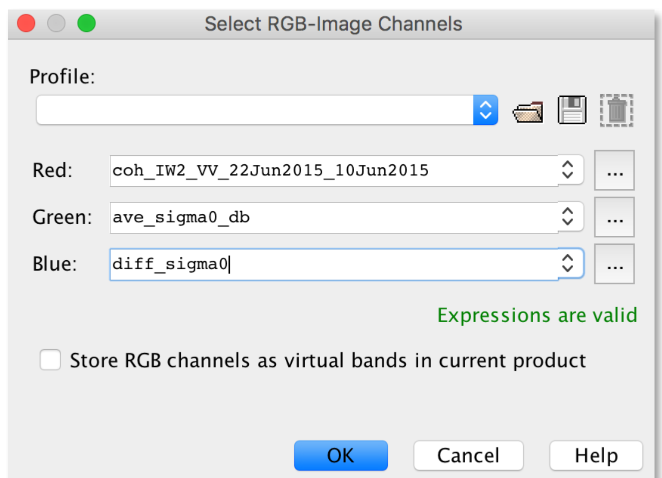
Open RGB Image

- Right-click on the terrain corrected subset product (_*TC*) in Product Explorer
- Select *Open RGB Image Window*

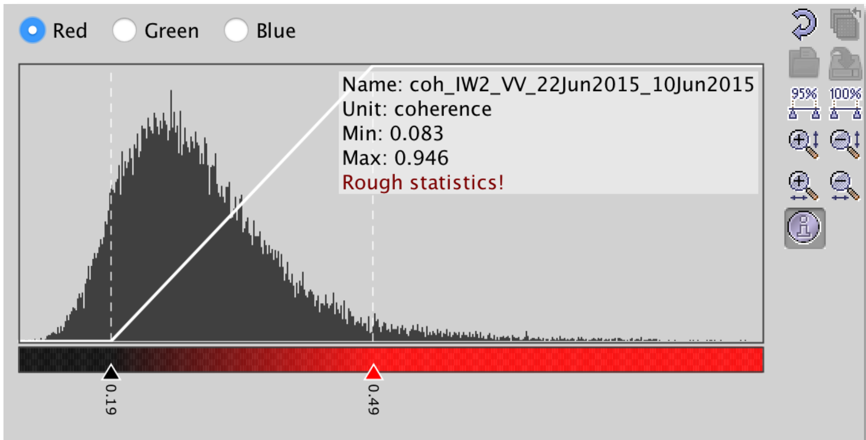
In the Select RGB-Image Channels window:

- Click on the <…> button next to **Red**
  - Delete the contents of the *Expression:* box
  - In *Edit Red Expression*, click the coherence product (coh_) in *Data sources*
  - Click **OK**
- Repeat for **Green** and select **ave_sigma0_dB**
- Repeat for **Blue** and select **diff_sigma0**
- *Optional:* Check Store RGB channels as virtual bands in current product
- Click **OK** to see results

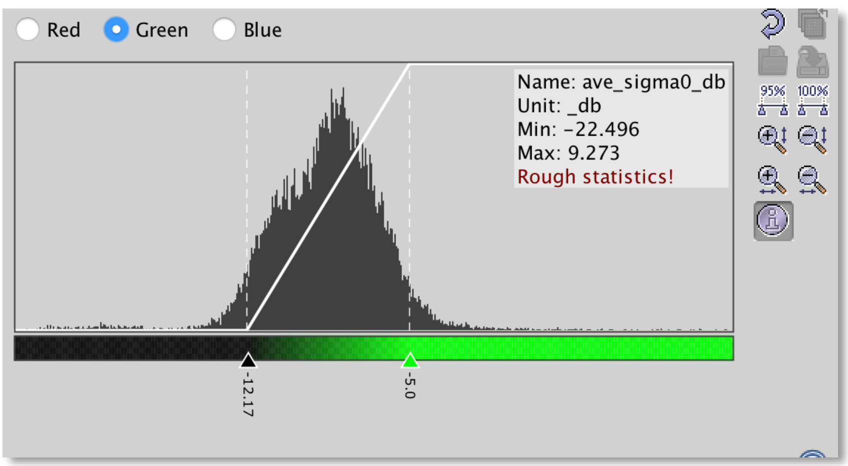




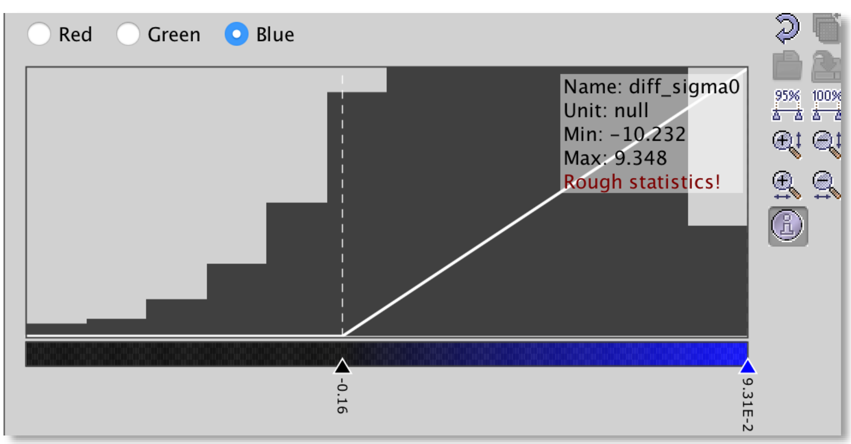
The resulting image may seem a little too light. To adjust color settings, click on the *Color Manipulation* tab below *Product Explorer*, or from the top menu, *View > Tool Windows > Color Manipulation*. The following values are suggested for each band rendering, but can be adjusted to meet your needs.



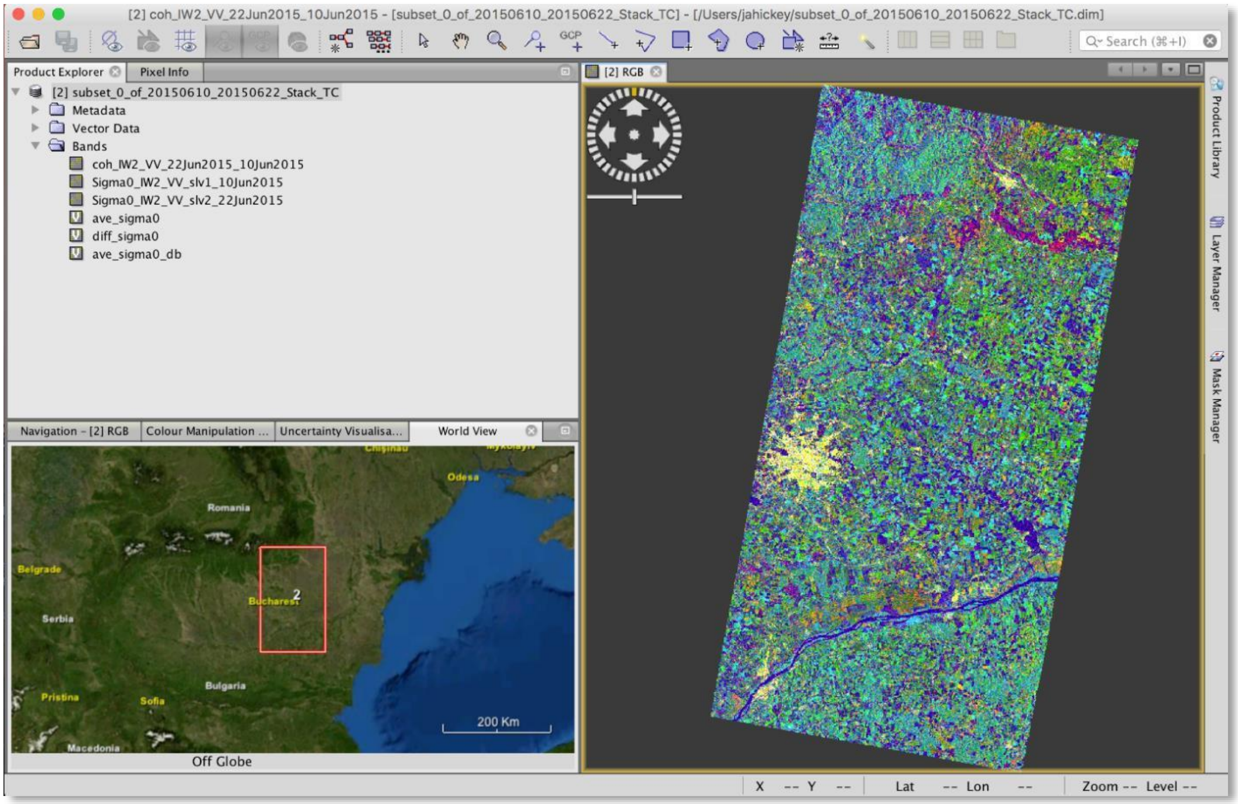
Red: 0.19 to 0.49



Green: -12.17 to -5.0



Blue: -0.16 to 9.31E-2



22. Export to Google Earth

Export Your Image

In the top menu, navigate *to File > Export > Other > View as Google Earth KMZ*

In addition to GeoTIFF and HDF5 formats, KMZ and various specialty formats are supported. Figure 5 shows a KMZ-formatted RGB composite image overlaid on Google Earth.

The resulting image also works in a GIS environment because it is geocoded.

E) Resulting Image

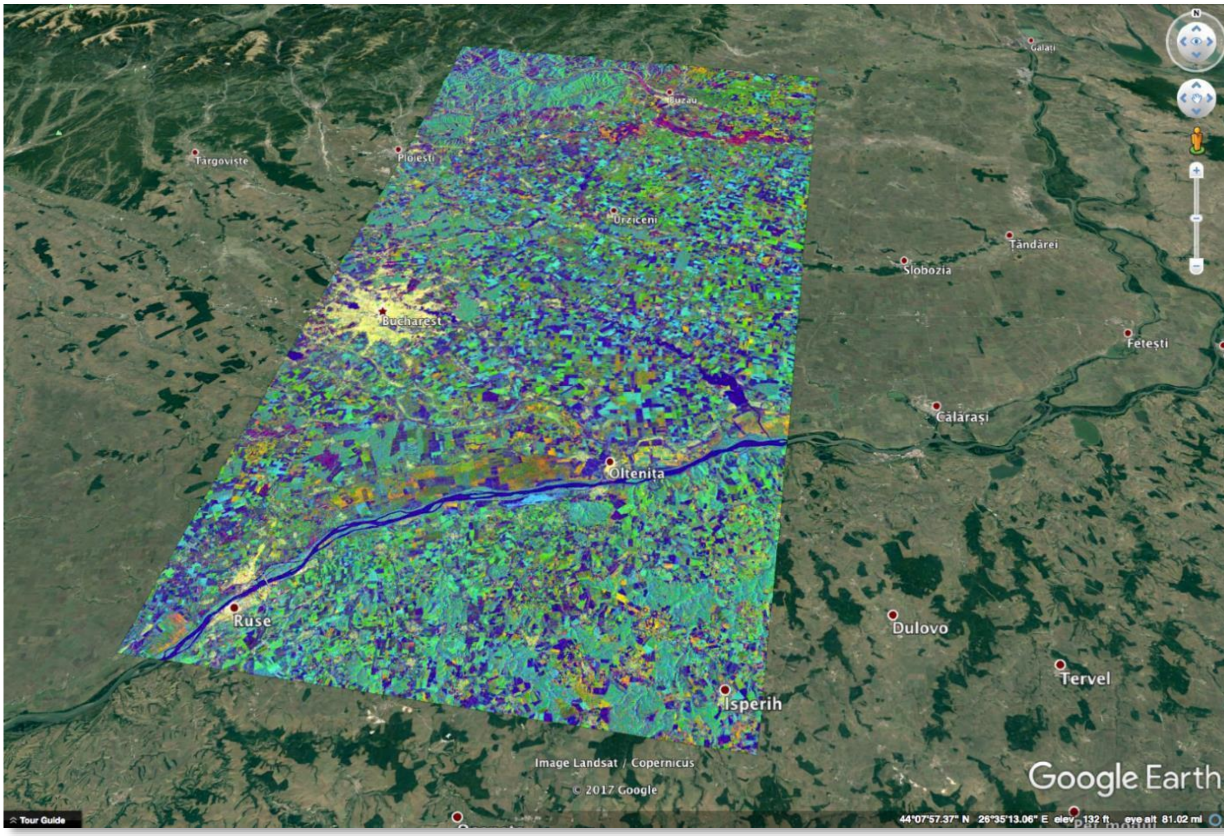


Figure 4: Geocoded RGB Composite Image of Bucharest, Romania in Google Earth. Credit: ASF DAAC 2017; Contains modified Copernicus Sentinel data [2015] processed by ESA

Multi-temporal color composite images give us an idea of an area's land cover and use. Different colors show changes that occurred over the period of coverage.

The blues across the entire image represent strong changes in bodies of water or agricultural activities such as ploughing. The yellows represent urban centers, with the capital city of Bucharest very distinct. Vegetated fields and forests appear in green. The reds and oranges represent unchanging features such as bare soil or possibly rocks that border the forests.

In this data recipe, a 12-day repeat interval is used, as we are using only Sentinel-1A data. With the launch of Sentinel-1B in early 2016, this repeat cycle is reduced to 6 days, as the satellites share the same orbit. C-band coherence is significantly lower over the image after 12 days (Sentinel-1A) as compared to 6 days, which makes it more ideal to separate agricultural areas and forest, which is ideal for temperate regions.