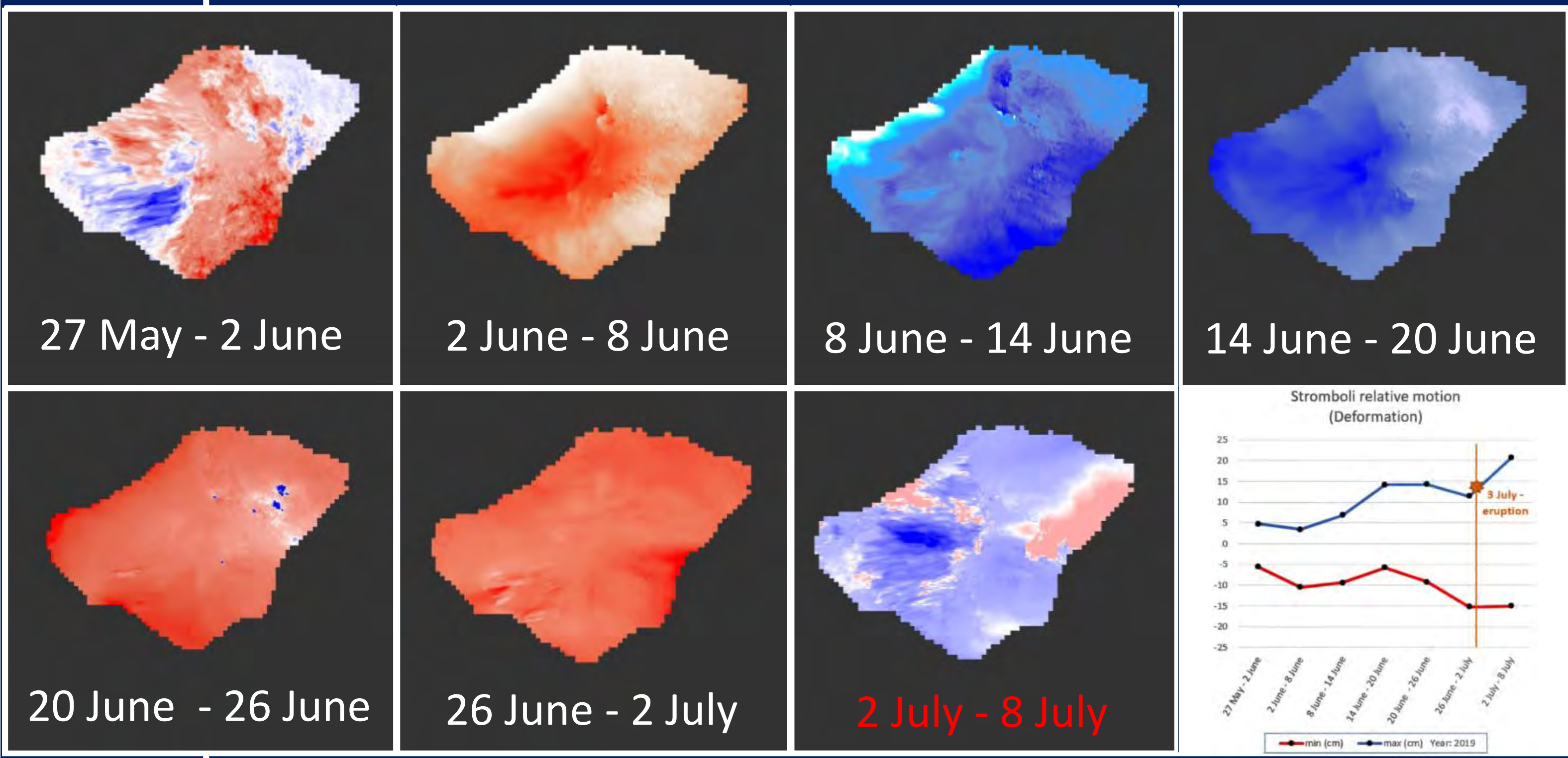

TRAINING KIT – HAZA10

VOLCANO MONITORING WITH SENTINEL-1 – 3 July 2019 (Stromboli Volcano)

Research and User Support for Sentinel Core Products

The RUS Service is funded by the European Commission, managed by the European Space Agency and operated by CSSI and its partners.

Authors would be glad to receive your feedback or suggestions and to know how this material was used. Please, contact us on training@rus-copernicus.eu

Cover images produced by RUS Copernicus

The following training material has been prepared by Serco Italia S.p.A. within the RUS Copernicus project.

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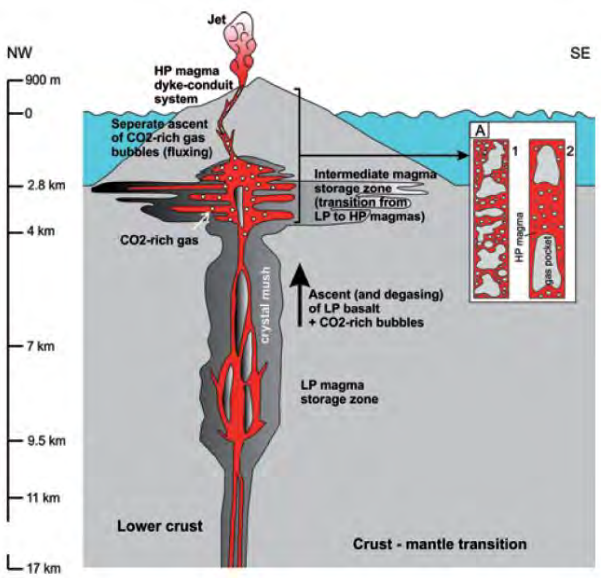
Table of Contents

1 Introduction

The Research and User Support for Sentinel core products (RUS) service provides a free and open scalable platform in a powerful computing environment, hosting a suite of open source toolboxes pre-installed on virtual machines, to handle and process data acquired by the Copernicus Sentinel satellites constellation.



Cross-section of the Stromboli plumbing system
Source: Krzysztof et al., 2016 - (after Aiuppa et al., 2010; simplified)

The Stromboli volcano is located in the Southern Tyrrhenian Sea, north of Sicily. It is one of the three active volcanoes in Italy and is the northernmost island of the main eight islands of the Aeolian Archipelago.

It is a stratovolcano of persistent eruptive activity with approximately 3 km elevation and at least the 2 km to be below the sea level. The summit is at 924 m.a.s.l. and the surface area of the island is only 12.6 km^2.

There are two settlements on the island, one in the NE and one in the SW. Due to the products of the volcanic activity, the island is enriched with very fertile soil.

The archipelago is a volcanic arc, which in present years extends for more than 140 km. The African continental plate is constantly moving towards Europe and subducts underneath the Eurasian plate. The magma generation rises to the surface and forms the volcanoes.

The relatively high pressure of the gases ejects basaltic lava and its products to hundreds of meters in the air. Volcanoes with similar mechanisms with the one we studied today, are call of “Strombolian-type” activity. Due to this behaviour, the island carries the nickname “Lighthouse of the Mediterranean”.

Many significant explosions and lava flows have been recorded during the last 50 years, with the most recent events on July 3, 2019 and on November 10 and 16, 2020. The event on July 3rd which we will focus on, was a paroxysmal eruption, meaning among others, that there were almost no warning signs for this to happen.

2 Training

Approximate duration of this training session is **two** hours.

The Training Code for this tutorial is HAZA10. If you wish to practice the exercise described below within the RUS Virtual Environment, register on the RUS portal to request a Virtual Machine. Go to Your RUS Service → Your training activities and *Request a Webinar Training*.

2.1 Data used

- Eight Sentinel-1 IW SLC images acquired from 27 May 2019 until 8 July 2019, every 6 days [downloadable at https://scihub.copernicus.eu/]

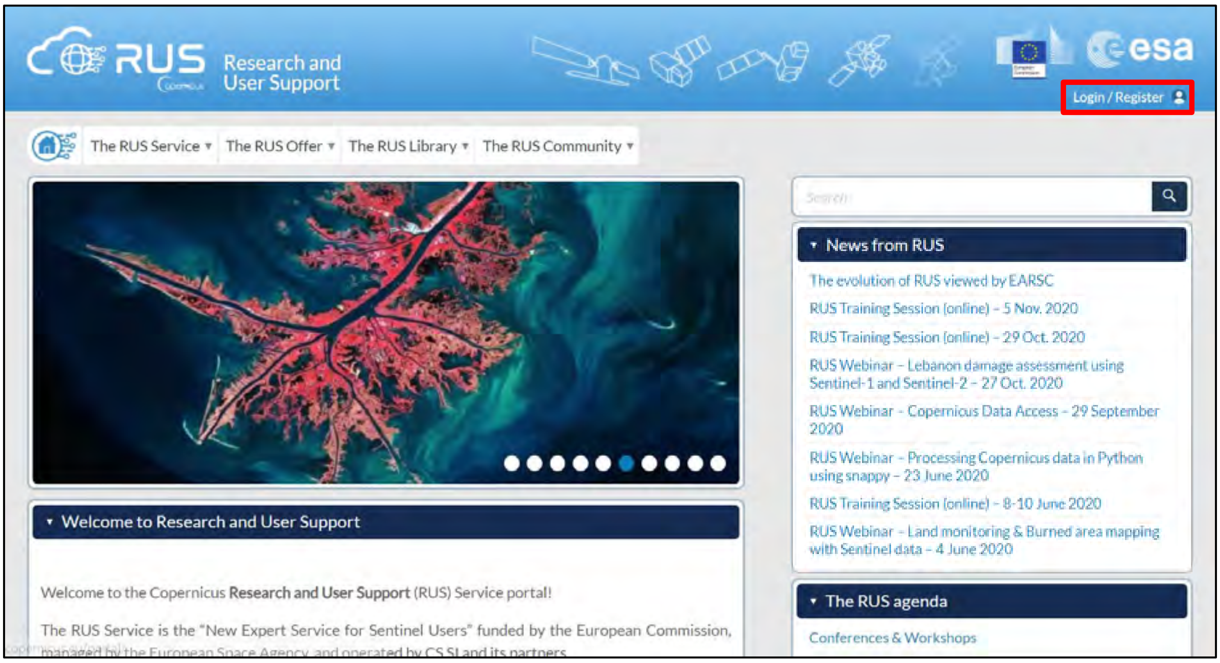
  S1A_IW_SLC__1SDV_20190527T165633_20190527T165659_027416_0317B7_C2DD.zip
  S1B_IW_SLC__1SDV_20190602T165549_20190602T165616_016520_01F187_9A86.zip
  S1A_IW_SLC__1SDV_20190608T165633_20190608T165700_027591_031D18_4A85.zip
  S1B_IW_SLC__1SDV_20190614T165550_20190614T165617_016695_01F6B7_5EB5.zip
  S1A_IW_SLC__1SDV_20190620T165634_20190620T165701_027766_032252_FE0C.zip
  S1B_IW_SLC__1SDV_20190626T165551_20190626T165618_016870_01FBE2_B18F.zip
  S1A_IW_SLC__1SDV_20190702T165635_20190702T165702_027941_03279A_BE4C.zip
  S1B_IW_SLC__1SDV_20190708T165552_20190708T165619_017045_020114_3F42.zip

2.2 Software in RUS environment

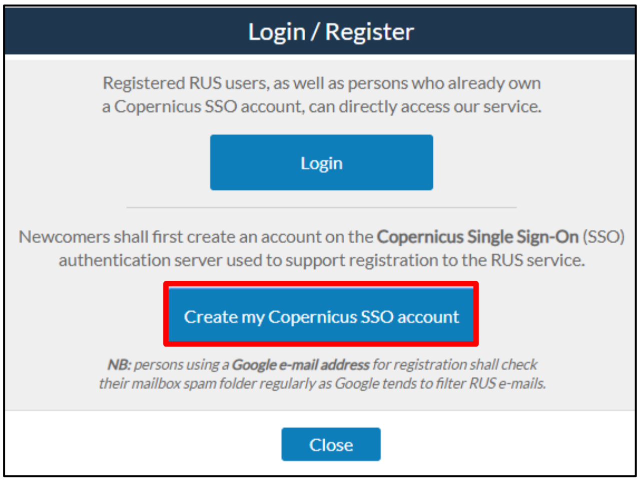
Internet browser, SNAP + Sentinel-1 Toolbox.

3 Register to RUS Copernicus

To repeat the exercise using a RUS Copernicus Virtual Machine (VM), you will first have to register as a RUS user. For that, go to the RUS Copernicus website (www.rus-copernicus.eu) and click on ***Login/Register*** in the upper right corner.

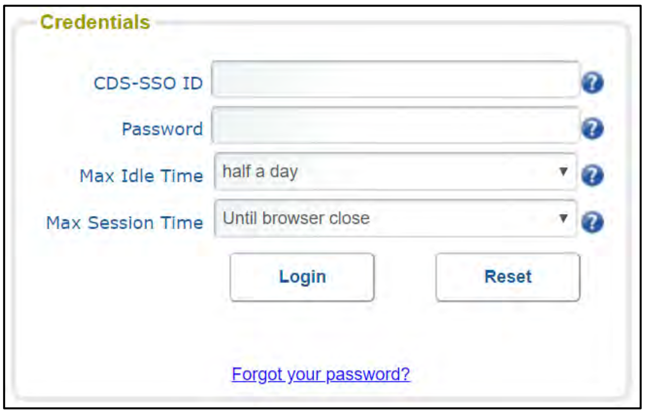


Select the option ***Create my Copernicus SSO account*** and then fill in ALL the fields on the **Copernicus Users' Single Sign On Registration**. Click ***Register***.

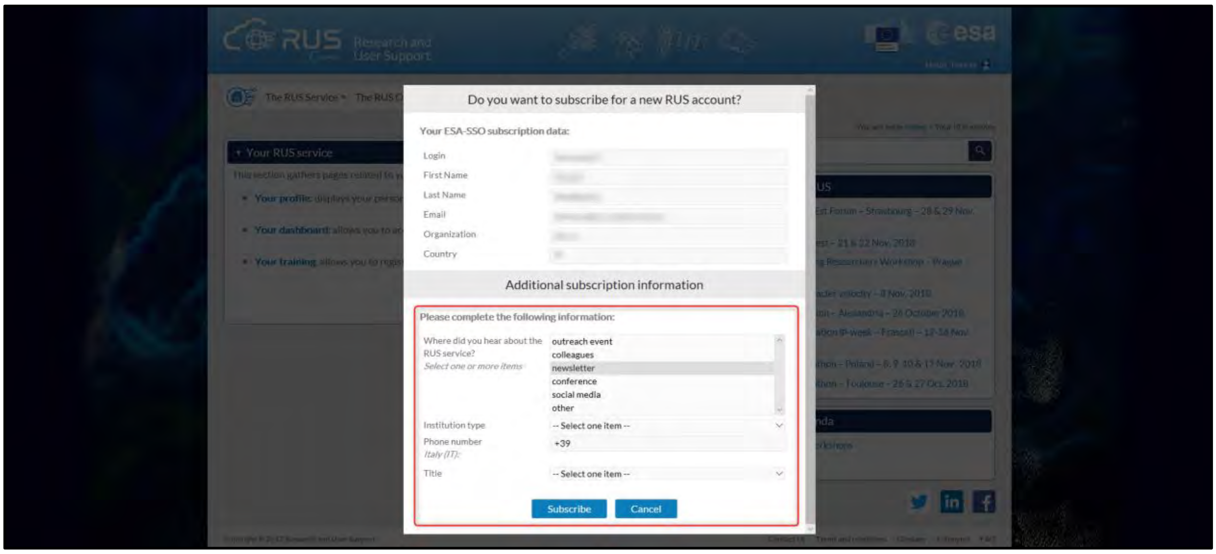


Within a few minutes you will receive an e-mail with activation link. Follow the instructions in the e-mail to activate your account.

You can now return to https://rus-copernicus.eu/, click on ***Login/Register***, choose ***Login*** and enter your chosen credentials.

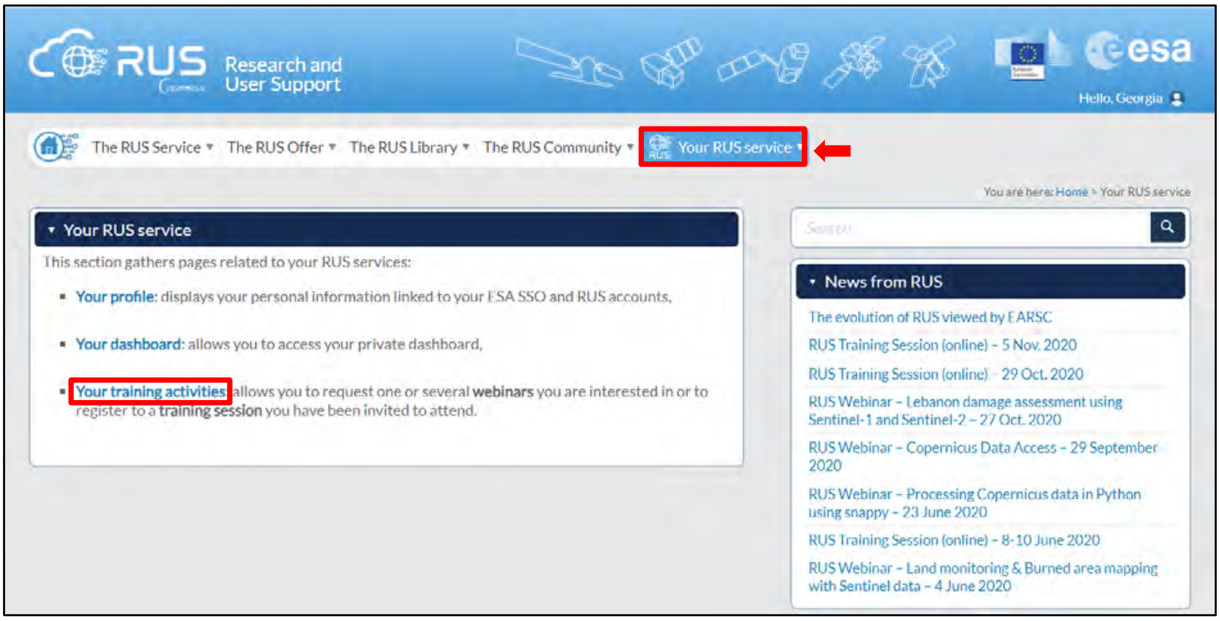


Upon your first login you will need to enter some details. You must fill all the fields.

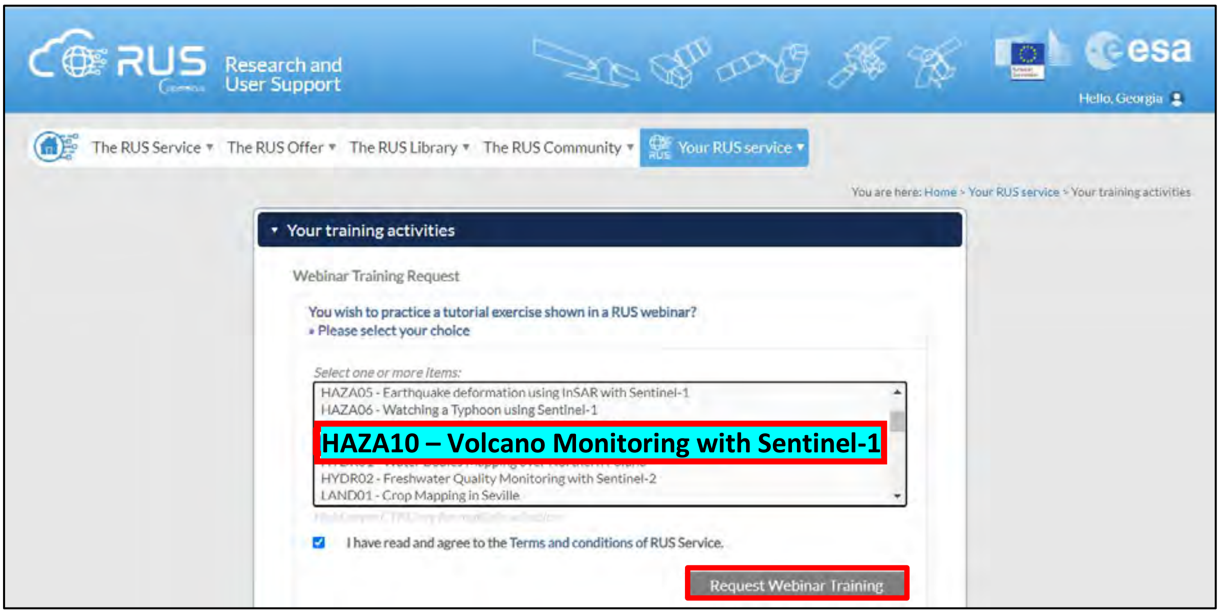


4 Request a RUS Copernicus Virtual Machine to repeat a Webinar

Once you are registered as a RUS user, you can request a RUS Virtual Machine to repeat this exercise or work on your own projects using Copernicus data. For that, log in and click on ***Your RUS Service* → *Your training activities***.

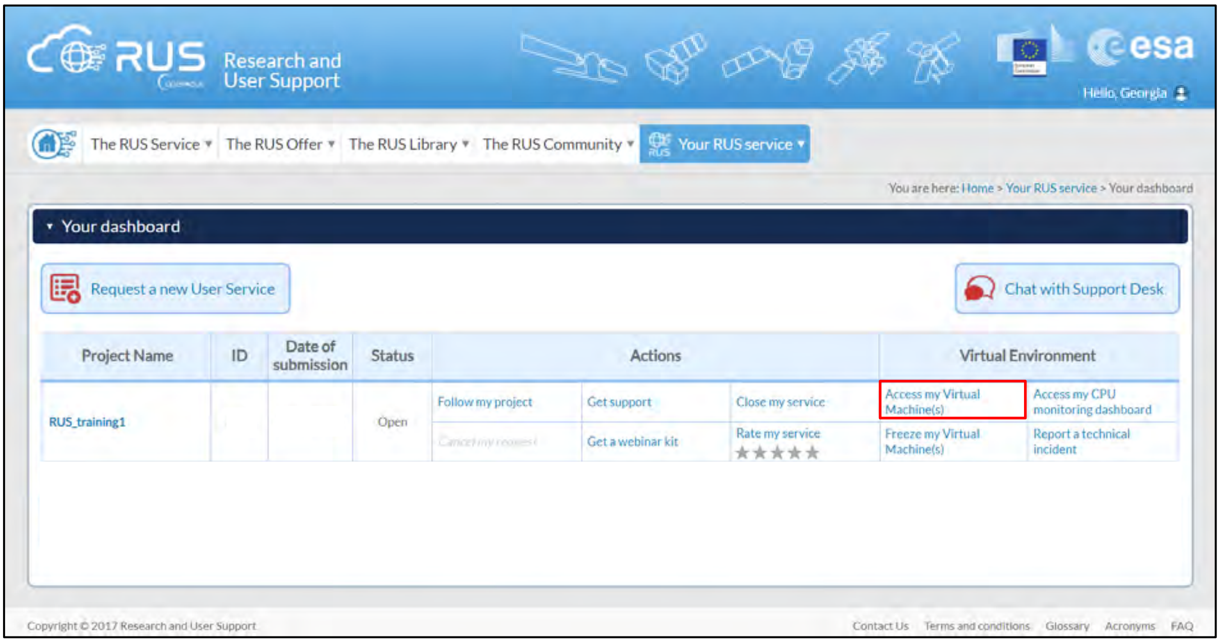


Select **HAZA10 – Volcano Monitoring with Sentinel-1**, check the field *"I have read and agree to the Terms and conditions of RUS Service"* and then click on ***Request Webinar Training*** to request your RUS Virtual Machine.



Further to the acceptance of your request by the RUS Helpdesk, you will receive a notification email with all the details about your Virtual Machine.

To access it, go to ***Your RUS Service* → *Your Dashboard*** and click on ***Access my Virtual Machine***.



Fill in the login credentials that have been provided to you by the RUS Helpdesk via email to access your RUS Copernicus Virtual Machine.

This is the remote desktop of your Virtual Machine.

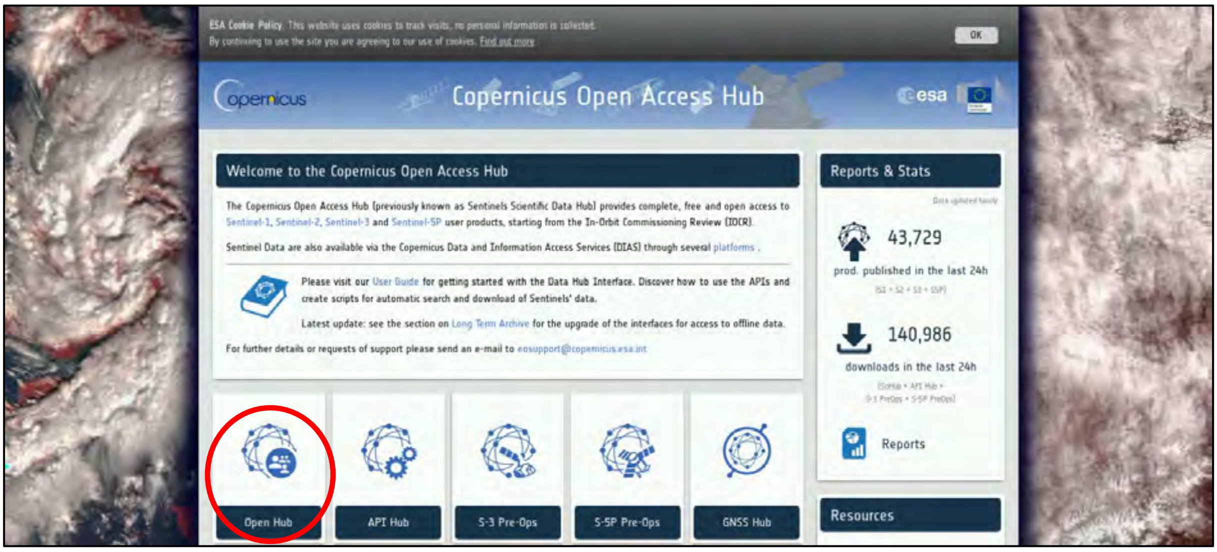
5 Step by step

5.1 *Data download – ESA SciHUB*

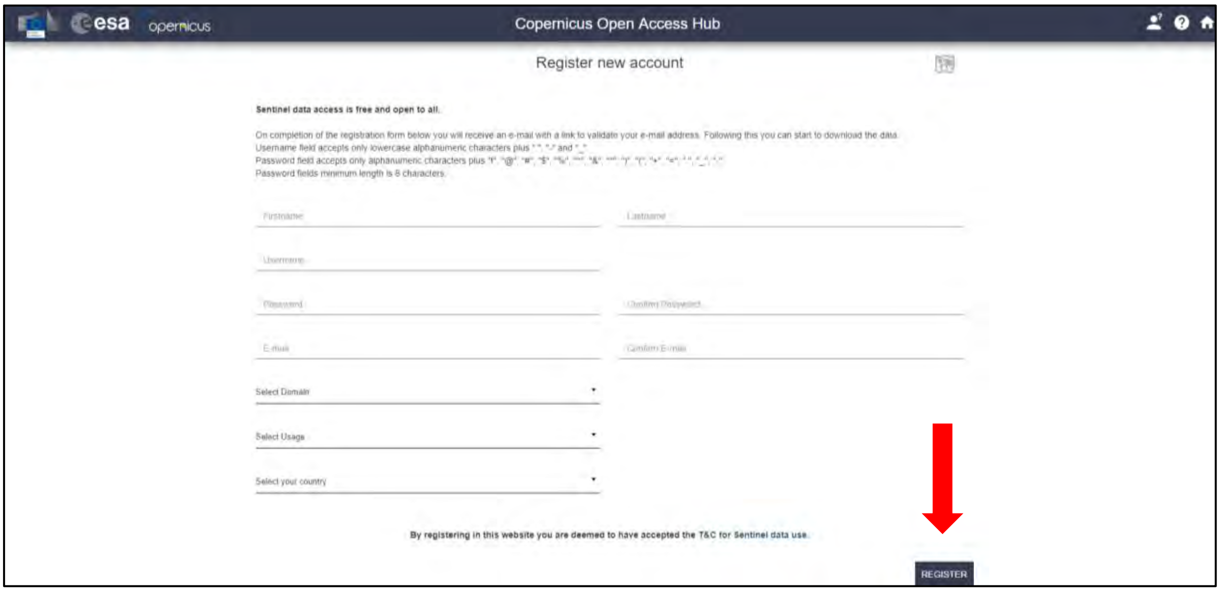
In this step, we will download the Sentinel-1 scenes we will use for the exercise, from the Copernicus Open Access Hub using the online interface.

Go to **Applications → Network → Firefox Web Browser** or click the link below.

Go to https://scihub.copernicus.eu/

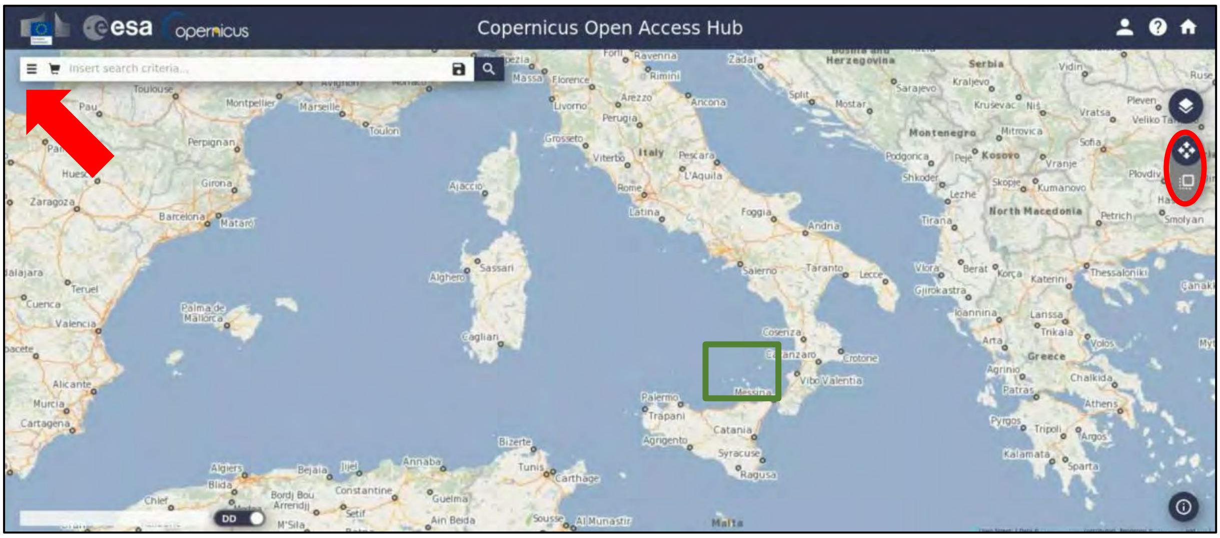


Go to "**Open HUB**", if you do not have an account please register by going to "**Sign-up**" in the LOGIN menu in the upper right corner.



After you have filled in the registration form, you will receive an activation link by e-mail. Once your account is activated or if you already have an account, "**LOGIN**".

Navigate over Stromboli island, at the Southern Tyrrhenian Sea, north of Sicily (**approximate area – green rectangle**).

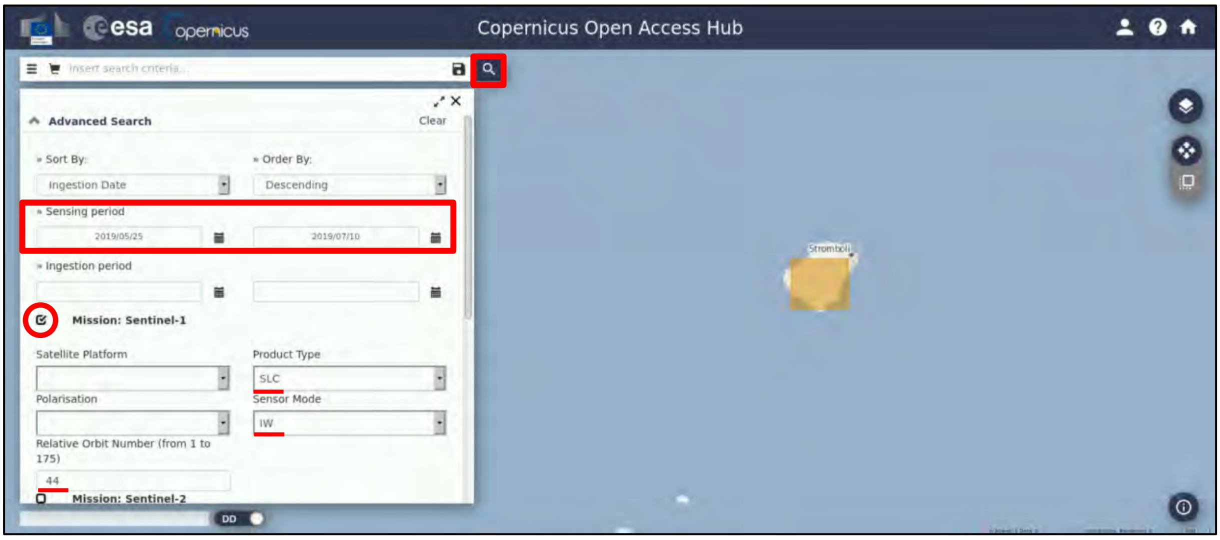


We need to download 8 Sentinel-1 images over the area of interest.

Zoom in a bit more, switch to "**drawing mode**" and draw a search rectangle approximately as indicated below. Open the search menu by clicking to the left part of the search bar. We will specify at once the parameters for all products:

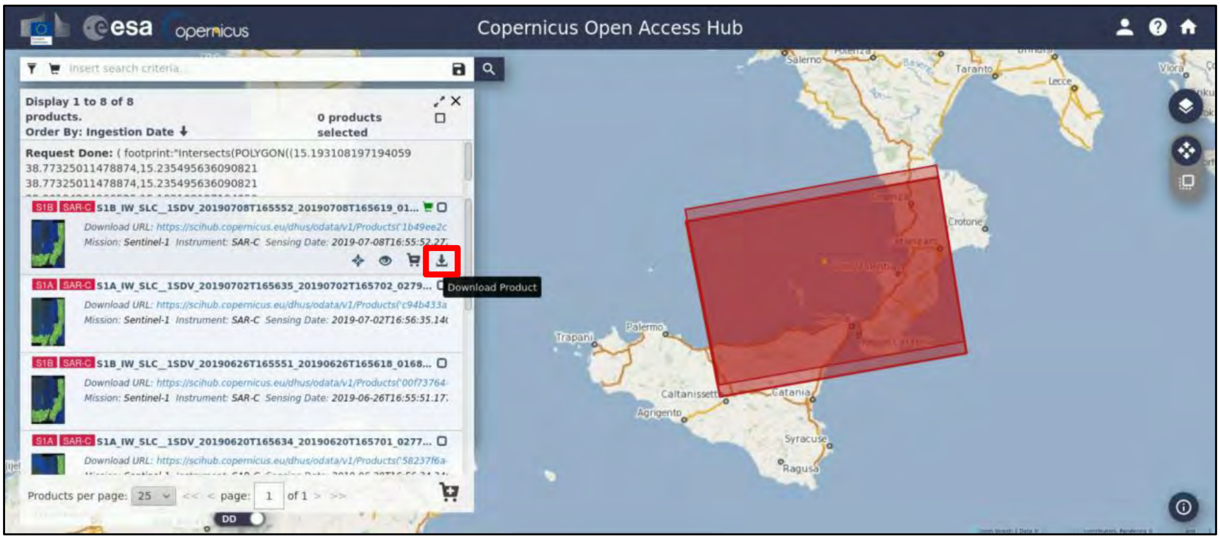
<u>For Sentinel-1:</u>

Sensing period: From 2019/05/25 to 2019/07/10
Select: Mission: Sentinel-1
Product Type: SLC
Sensor Mode: IW
Relative Orbit Number: 44



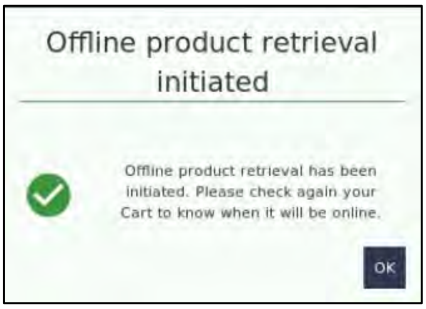
Then click on the "**Search**" icon. The search returns 8 results for the time period we set. We need to download them all, so we click on the "**Download Product**" icon of each one (See NOTE 1 and NOTE 2):

S1A_IW_SLC__1SDV_20190527T165633_20190527T165659_027416_0317B7_C2DD
S1B_IW_SLC__1SDV_20190602T165549_20190602T165616_016520_01F187_9A86
S1A_IW_SLC__1SDV_20190608T165633_20190608T165700_027591_031D18_4A85
S1B_IW_SLC__1SDV_20190614T165550_20190614T165617_016695_01F6B7_5EB5
S1A_IW_SLC__1SDV_20190620T165634_20190620T165701_027766_032252_FE0C
S1B_IW_SLC__1SDV_20190626T165551_20190626T165618_016870_01FBE2_B18F
S1A_IW_SLC__1SDV_20190702T165635_20190702T165702_027941_03279A_BE4C
S1B_IW_SLC__1SDV_20190708T165552_20190708T165619_017045_020114_3F42



NOTE 1: Please keep in mind that you cannot download more than 2 products at the same time, per account from SciHub.

If the products appear to be "Offline", once we click on the download icon, the following message will appear. Click **OK**.



The product is automatically added in the “Cart”. In case an error message appears, try again a bit later – you can request for one product per account per hour.

The product will be online within few minutes.

By the time the product turns online, it remains like that for 4 days and then it goes back to offline again. You need to frequently check your cart for the product availability.

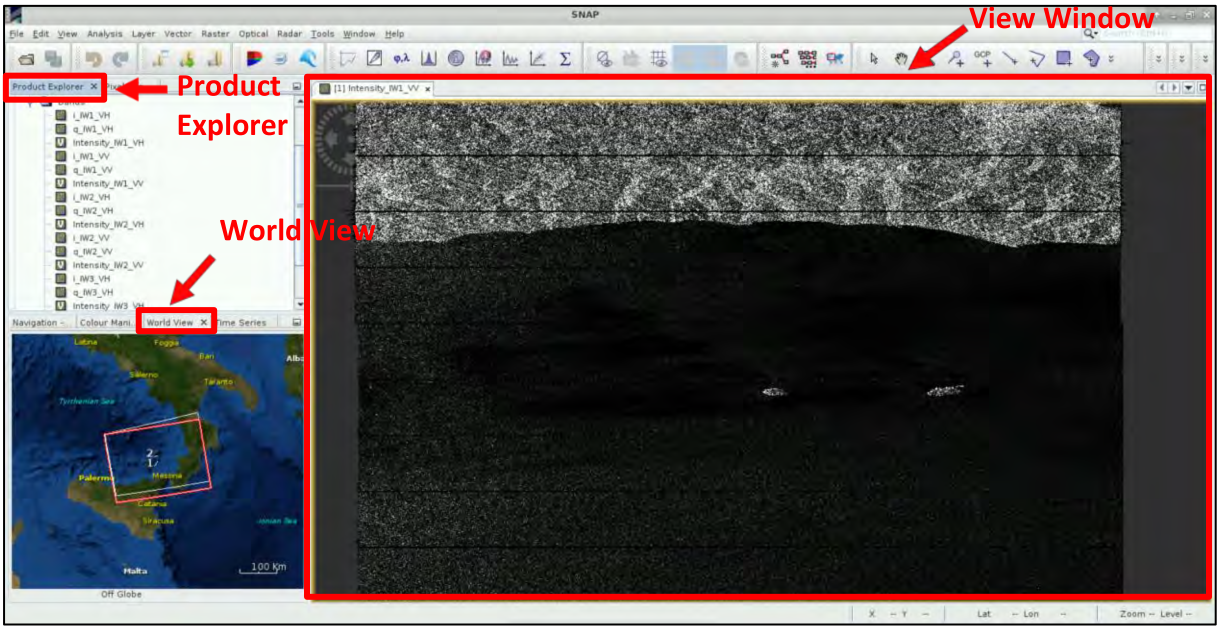
NOTE 2: You can find more information about the retrieval of offline/long term archive products here: https://scihub.copernicus.eu/twiki/do/view/SciHubUserGuide/LongTermArchive#Retrieval_of_offline_products_vi & https://scihub.copernicus.eu/userguide/LongTermArchive

The products will be downloaded at ***/home/rus*** as zip files. Move them to: ***/shared/Training/HAZA10_VolcanoMonitoring_Stromboli/Original*** folder.

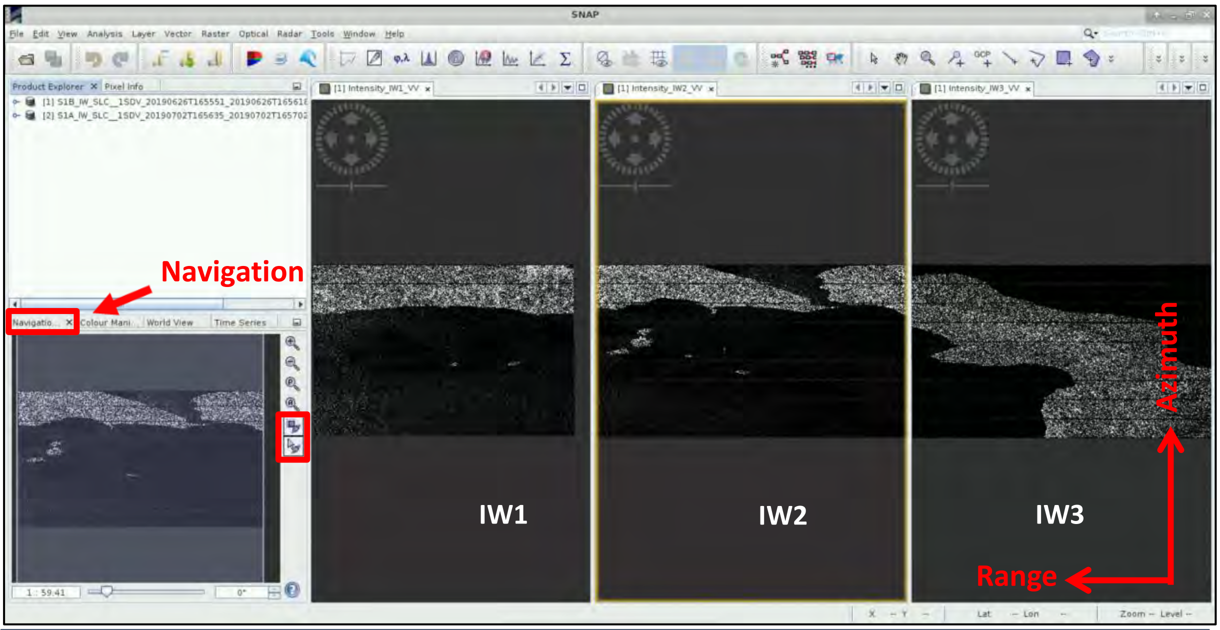
5.2 SNAP – open and explore data

Open **SNAP** software from the icon located on the desktop or go to **Applications → Processing → SNAP Desktop**. Click the **Open Product** icon , navigate to: ***/shared/Training/HAZA10_VolcanoMonitoring_Stromboli/Original*** folder and open all Sentinel-1 products (from oldest to the most recent). In this case, we will process only the pair of images acquired right before the eruption so open a folder in your VM, navigate to the path mentioned above and drag the products from the folder one by one and drop them to the **Product Explorer** Window (first the **20190626** and then the **20190702)**. The opened products will appear in **Product Explorer** window.

Click **+** or to expand the contents of product **[1]** from **26 June 2019**, then expand **Bands** folder and double click on ***Intensity_IW1_VV*** band to visualize it in the **View** window. You can go to the **World View** tab and zoom in to see the location of the opened product on the globe.



Open the ***Intensity_IW2_VV*** and ***Intensity_IW3_VV*** bands as well and go to **Window → Tile Horizontally.** In the **Navigation** tab and click on the two icons shown within the red rectangular below, to synchronize the views and the cursor position between the views. (See NOTE 3 and NOTE 4).



NOTE 3: The Interferometric Wide (IW) swath mode captures three sub-swaths using Terrain Observation with Progressive Scans SAR (TOPSAR). IW SLC products contain one image per sub-swath and one per polarisation channel, for a total of three (single polarisation) or six (dual polarisation) images in an IW product. Each sub-swath image consists of a series of bursts, where each burst has been processed as a separate SLC image. The images for all bursts in all sub-swaths are resampled to a common pixel spacing grid in range and azimuth while preserving the phase information. *(Source: https://sentinel.esa.int/web/sentinel/user-guides/sentinel-1-sar/acquisition-modes/interferometric-wide-swath)*

NOTE 4: The RADAR instrument onboard Sentinel-1 carries an antenna that is looking always to the right during its pass. These two scenes were acquired during **ascending** pass (the satellite was moving in direction from south to north). That is why we see that the view of the image appears as if "mirrored" across the horizontal dimension, because the view shows the pixels in the order of the data acquisition.

5.3 *Sentinel-1 Processing*

We will use the **GraphBuilder** tool, to create a chain with the steps of the processes we want to apply and at the end, only the final product will be physically saved (this way we will also save disk space since the products of the intermediate steps will not be stored).

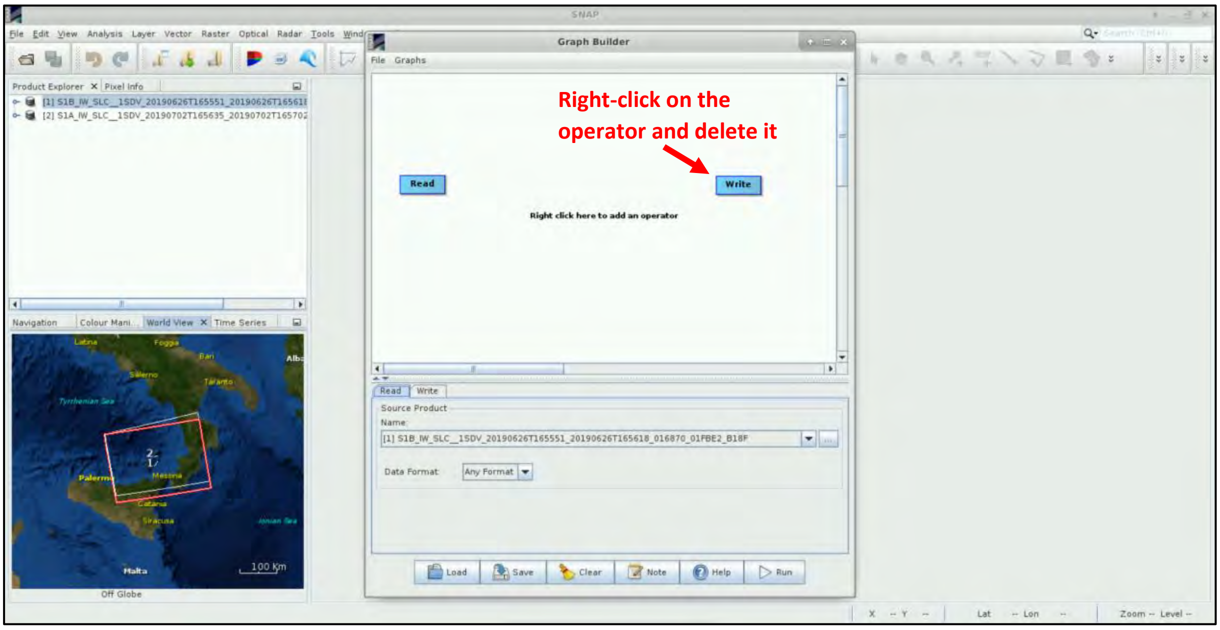
We will create in total 4 graphs for our processing steps, we will define the parameters for each operator and then you can repeat the whole methodology and apply it for the rest pairs of images we have downloaded. For now, we will not define any parameters in the tabs (they will be defined in the **Batch Processing** step), we will only create the graph.

5.3.1 Graph Builder – Graph 1

Go to **Tools → GraphBuilder** to build our graph.

We can see that the graph has only two operators: **Read** (to read the input) and **Write** (to write the output). Below there also are the corresponding to the operators' tabs.

Right-click on the **Write** operator and **Delete** it. The corresponding tab will be removed as well. This is to avoid confusion to the sequence of the graph. The **Write** operator will be added again at the end.



5.3.1.1 TOPS Split

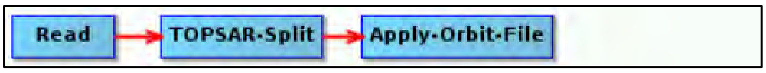
There is now only the **Read** operator. Our area of interest is located in the IW2 swath and is covered sufficiently by processing 2 bursts. We will use the **TOPSAR-Split** operator (See NOTE 5).

To add the **TOPSAR-Split** operator, right-click at the empty white space right of the **Read** operator and go to **Add → Radar → Sentinel-1 TOPS → TOPSAR-Split**. Connect the **Read** operator to it by dragging the red arrow from the right side of **Read** operator towards the **TOPSAR-Split** operator.

NOTE 5: In this case that we are using a pair of ascending products, the IW1 is the one to the west. If we work with descending products, the IW1 is the one to the east. Depending on our area of interest, we can process some or all bursts of a sub-swath, or even merge more sub-swaths but this will be quite time consuming and computationally heavy in the following steps.

5.3.1.2 Apply Orbit File

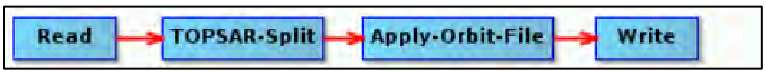
Next, we will apply the updated orbits to the products (See NOTE 6). Right-click and go to **Add → Radar → Apply-Orbit-File**. Connect the **TOPSAR-Split** operator to it.



NOTE 6: The orbit state vectors provided in the metadata of a SAR product are generally not accurate and can be refined with the precise orbit files which are available days-to-weeks after the generation of the product. **The orbit file provides accurate satellite position and velocity information**. Based on this information, **the orbit state vectors in the abstract metadata of the product are updated**.

5.3.1.3 Write – create the output

Last, we add the **Write** operator right-click and go to **Add → Input-Output → Write**. Connect the **Apply-Orbit-File** operator to it. Click on the Save icon and save the graph with the name ***Graph_1*** within the ***/shared/Training/HAZA10_VolcanoMonitoring_Stromboli/AuxData*** folder.

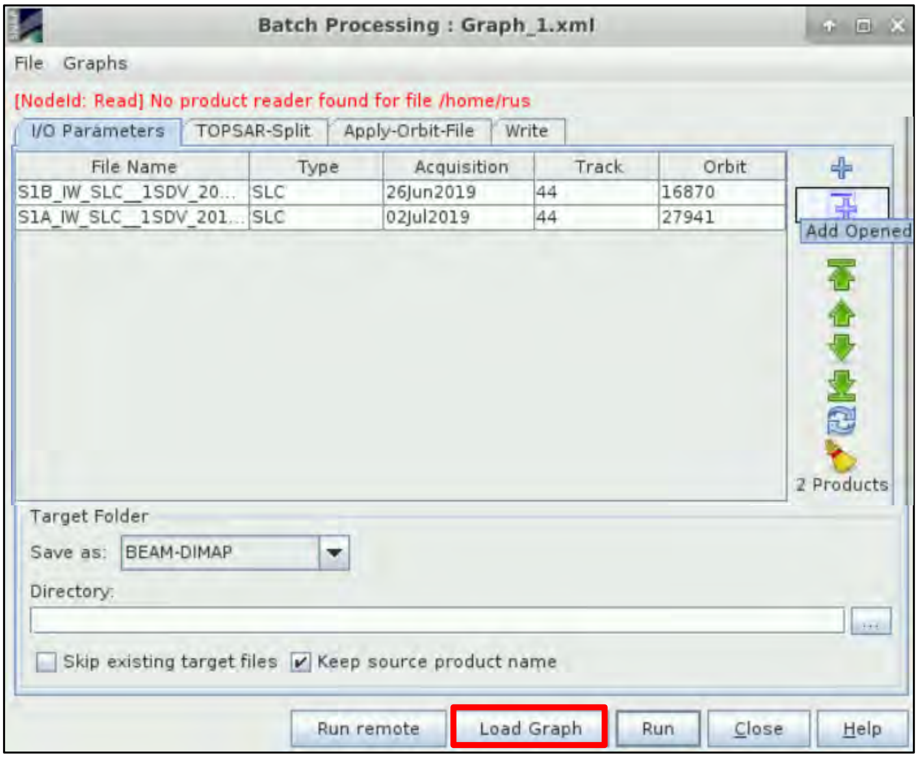


5.3.2 Batch Processing

Batch Processing is used when we want to apply identical pre-processing steps at once, to multiple images (in this case only in two). Open the **Batch Processing** tool by going to **Tools → Batch Processing**.

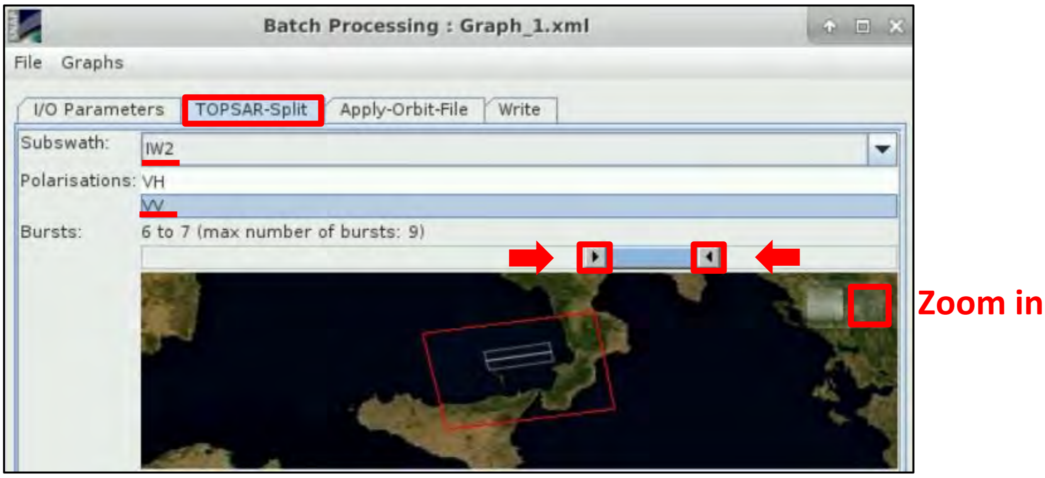
In the **I/O Parameters** tab we will add both opened products from the **Product Explorer** window by clicking **Add Opened** at the right (second icon from the top of the column at the right) and then click **Refresh** (second icon from the bottom).

Then we will click on **Load Graph** at the bottom of the window, navigate to the path of our saved graph and open it. We see that new tabs have appeared at the top of window corresponding to our operators.

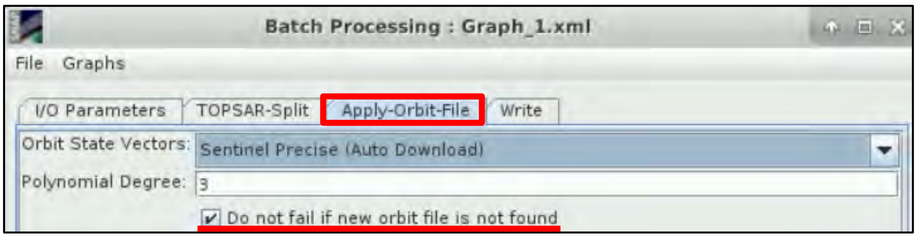


In the **TOPSAR-Split** tab **Zoom in** to the product and select:

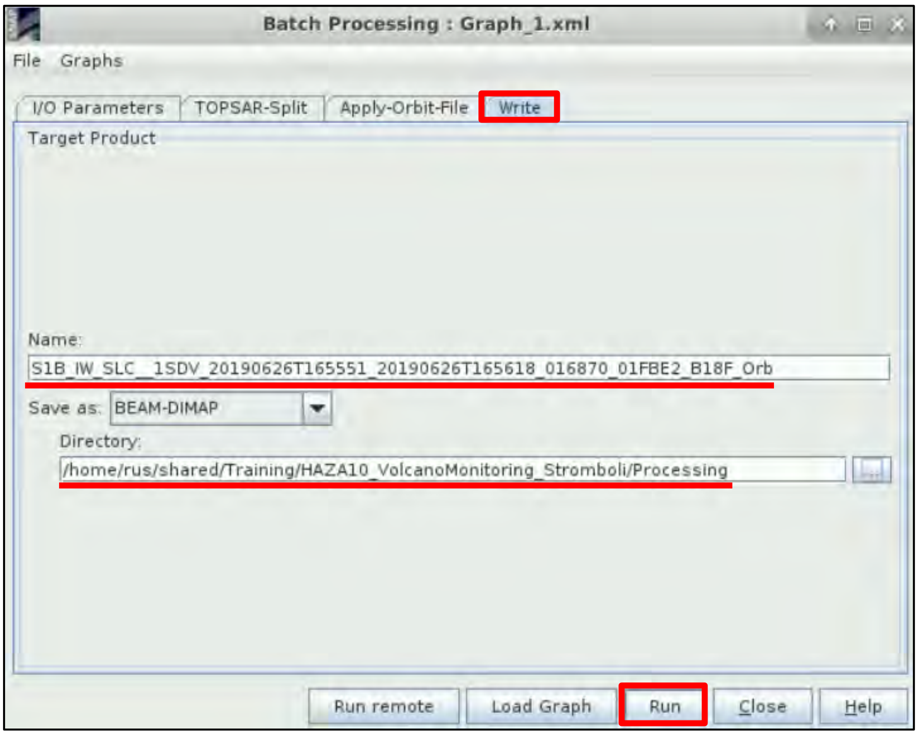
Subswath: IW2
Polarisations: VV
Bursts: 6 to 7 (drag the two sliders accordingly)



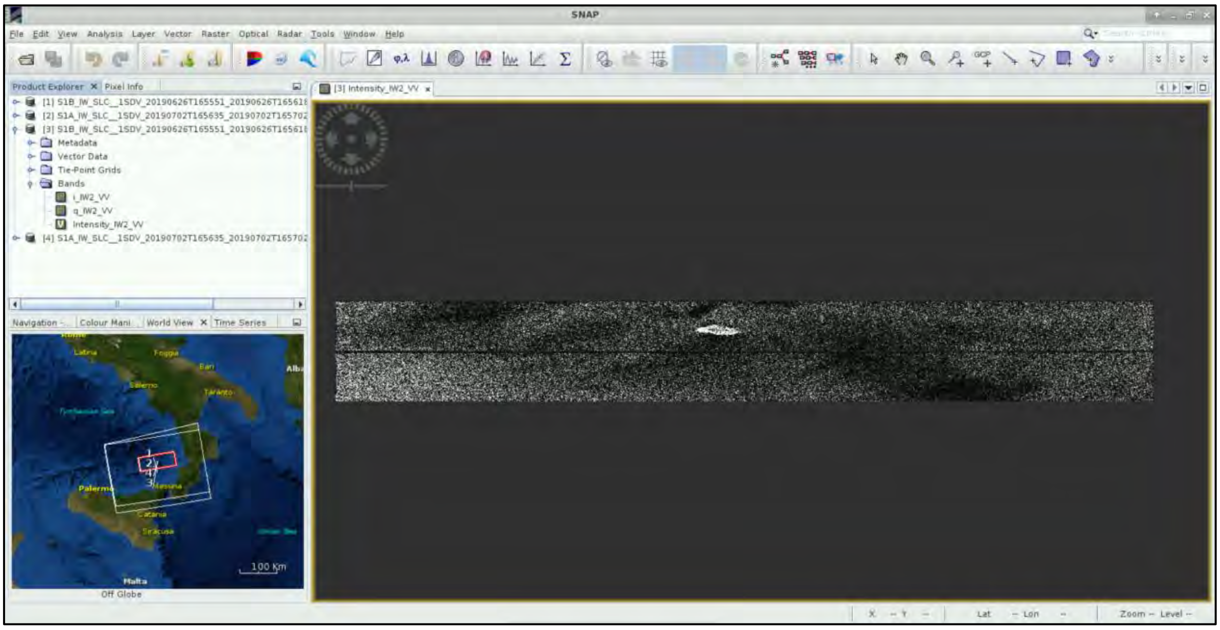
In the **Apply-Orbit-File** tab we will keep the default settings and make sure that you will **select** the "**Do not fail if new orbit file is not found**" option.



In the **Write** tab keep the "Name" that is created with the "**Orb**" suffix and under the "Directory" set the path to ***/shared/Training/HAZA10_VolcanoMonitoring_Stromboli/Processing*** folder. Click **Run**.



Both products will be created and added in the **Product Explorer** window. Expand the *Bands* folder and only the 2 bursts out of the original 9 will be included now in the product.



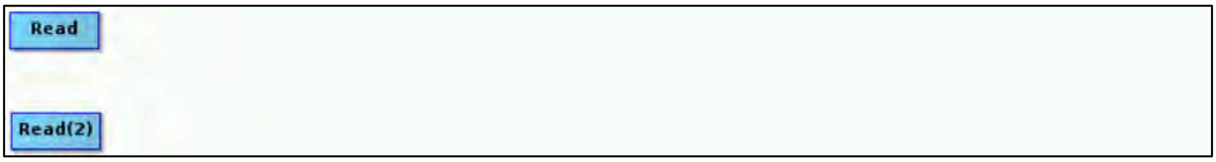
5.3.3 Graph Builder – Graph 2

Go again to **Tools → GraphBuilder**, right-click on the **Write** operator and **Delete** it. This time, we will also define in parallel the parameters in the tabs.

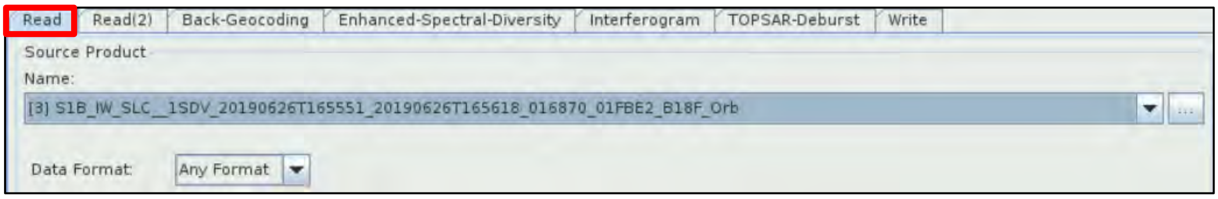
5.3.3.1 Back Geocoding

Now we will coregister the two products. Image coregistration is the alignment of master and slave images, the pixels of the slave images correspond to those of the master and represent an identical area.

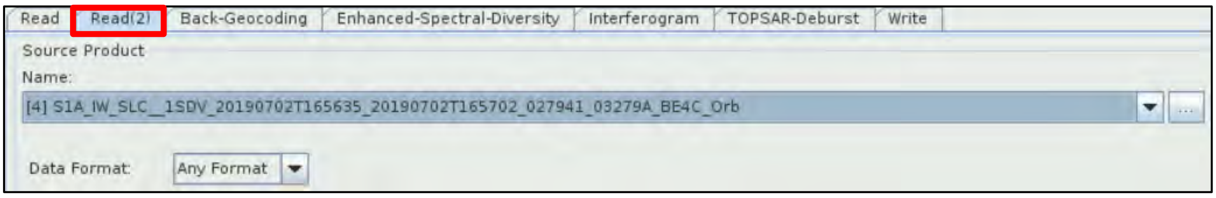
Add one more **Read** operator. Right click and go to **Add → Input-Output → Read**. The inputs will be the products we want to coregister.



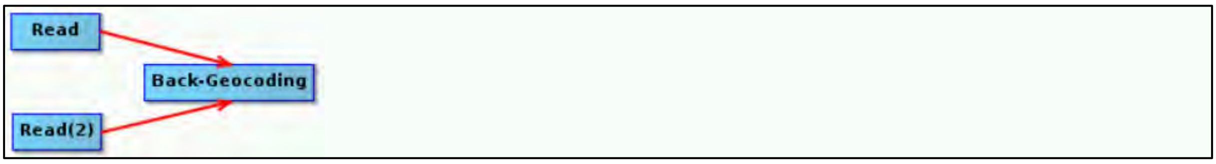
In the **Read** tab select the product [3] that contains only the 2 bursts of IW2 swath with updated orbits: **S1B_IW_SLC__1SDV_20190626T165551_20190626T165618_016870_01FBE2_B18F_Orb**



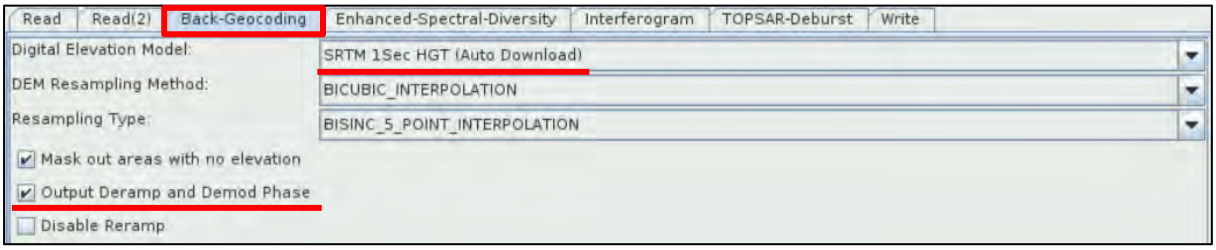
In the **Read(2)** tab select the product [4] that contains only the 2 bursts of IW2 swath with updated orbits: **S1A_IW_SLC__1SDV_20190702T165635_20190702T165702_027941_03279A_BE4C_Orb**



To add the **Back-Geocoding** operator right-click and go to **Radar → Coregistration → S-1 TOPS Coregistration → Back-Geocoding**. Connect both **Read** and **Read(2)** operators to it.



In the **Back-Geocoding** tab set: **Digital Elevation Model:** SRTM 1Sec HGT (Auto Download), **select** the "**Output Deramp and Demod Phase**" option as well and leave the rest parameters as by default.



5.3.3.2 *Enhanced Spectral Diversity*

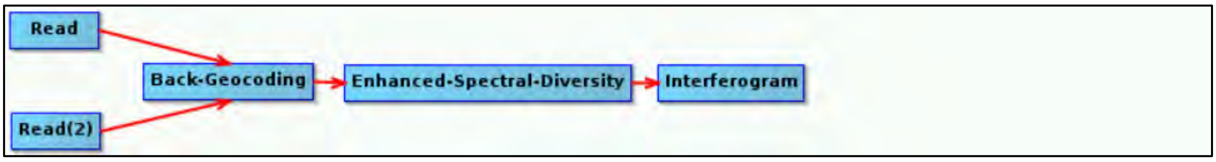
This operator follows the **Back-Geocoding** operator, it first estimates a constant range offset for each burst using a small block of data in the center of the burst and then it estimates a constant azimuth offset. Finally, the estimates from all bursts are averaged to get the final constant range and azimuth offset for the whole image.

To add the **Enhanced-Spectral-Diversity** operator right-click and go to **Radar → Coregistration → S-1 TOPS Coregistration → Enhanced-Spectral-Diversity**. Connect the **Back-Geocoding** operator to it.

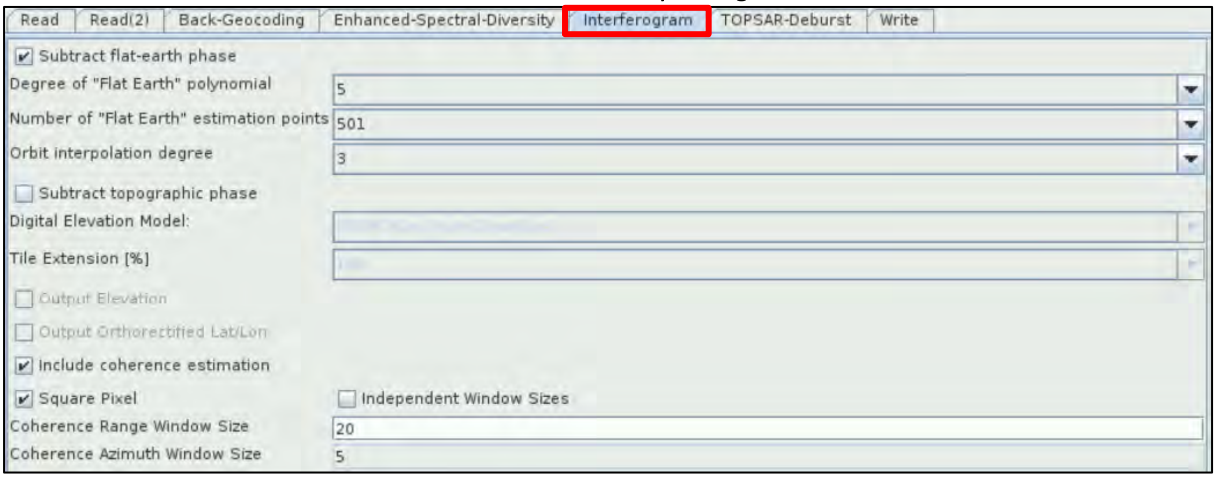
In the **Enhanced-Spectral-Diversity** tab keep all the default parameters.

5.3.3.3 *Interferogram formation*

We will create an interferogram from the two images. To add the **Interferogram** operator right-click and go to **Add → Radar → Interferometric → Products → Interferogram**. Connect the **Enhanced-Spectral-Diversity** operator to it. A **phase** and a **coherence band** will be created.

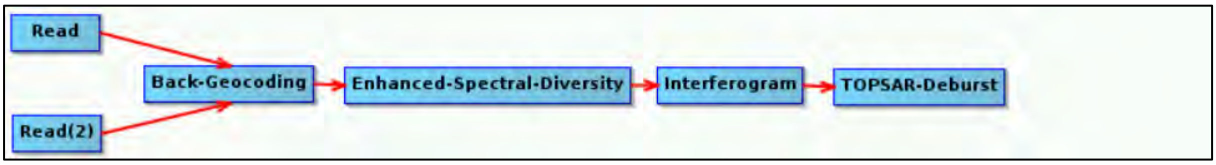


In the **Interferogram** tab, keep the default parameters and set as **Coherence Range Window Size**: 20. The **Coherence Azimuth Window Size** will automatically change to 5.



5.3.3.4 *TOPS Deburst*

Now we will remove the "black space" between the two bursts (See NOTE 7). To add the **TOPSAR-Deburst** operator right-click and go to **Add → Radar → Sentinel-1 TOPS → TOPSAR-Deburst**. Connect the **Interferogram** operator to it.

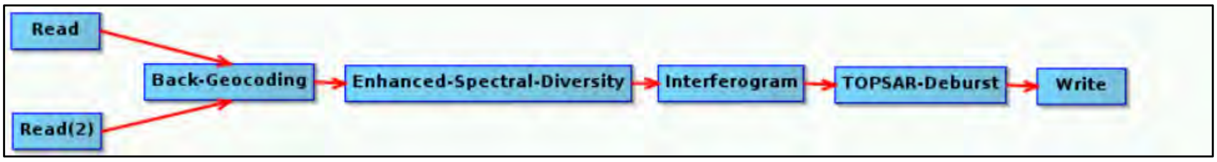


In the **TOPSAR-Deburst** tab keep the default settings (Polarizations: **VV**).

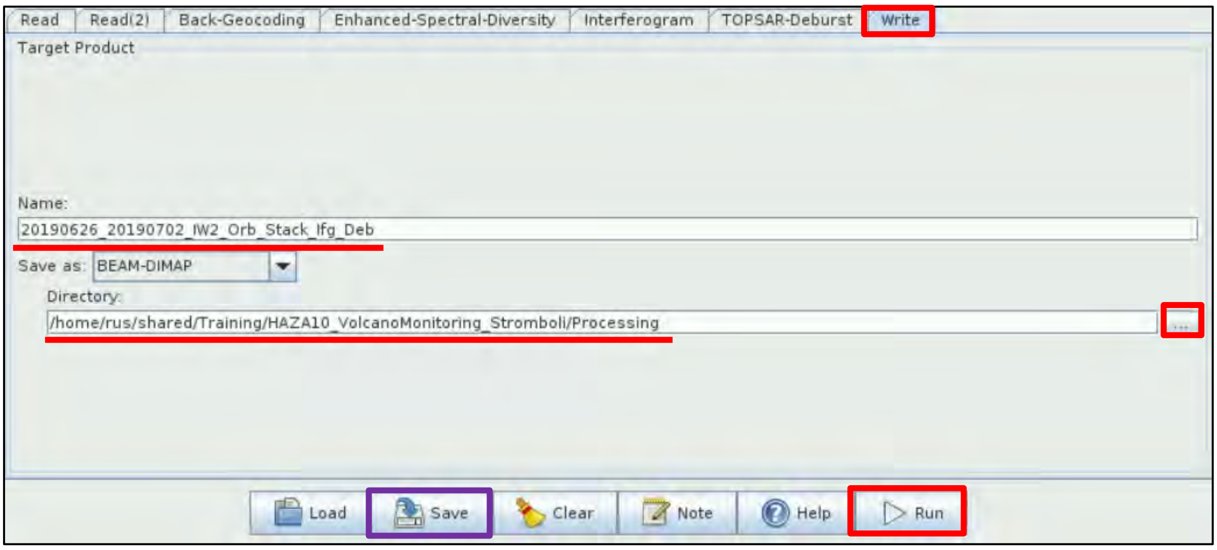
NOTE 7: There is overlapping information in every burst with its neighbouring ones, both in range and azimuth direction in order to provide contiguous coverage of the ground. Until now each burst has been processed as a separate SLC image We will merge the bursts (in azimuth direction) and preserve the phase information as well. For the overlapping region in range, merging is done between subswaths.

5.3.3.5 *Write – create the output*

To add the **Write** operator right-click and go to **Add → Input-Output → Write**. Connect the **TOPSAR-Deburst** operator to it.



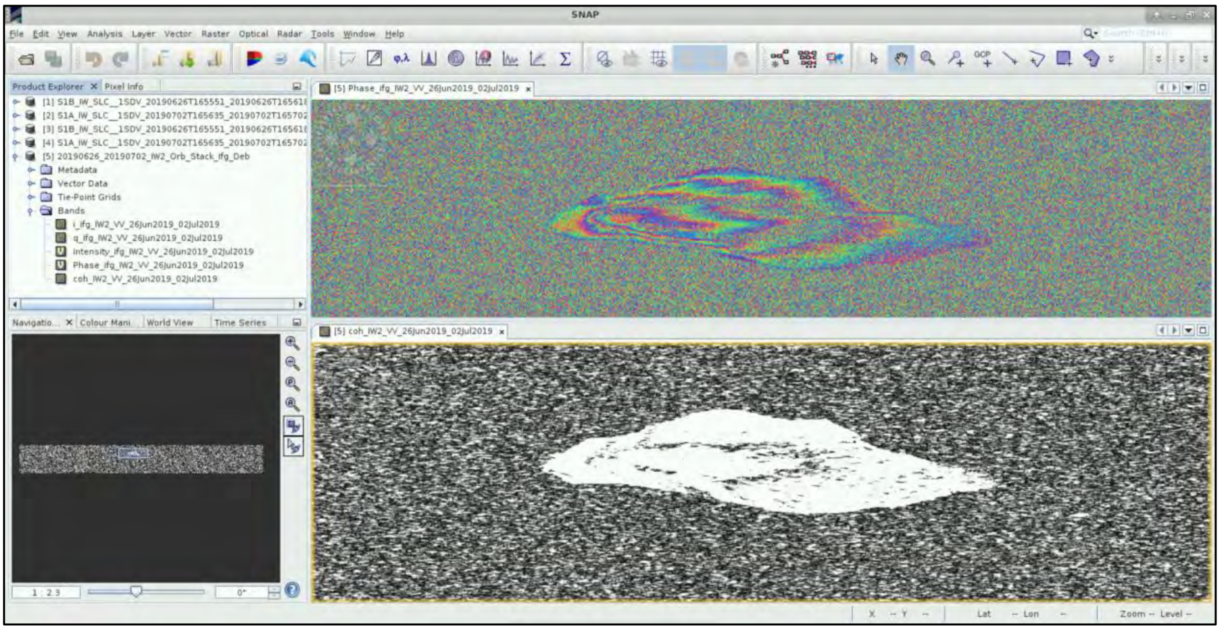
In the **Write** tab set as "*Name*"**: 20190626_20190702_IW2_Orb_Stack_Ifg_Deb** and as "*Directory*"**:** ***/shared/Training/HAZA10_VolcanoMonitoring_Stromboli/Processing*** (Click on the icon to set the appropriate path).



Click on the Save icon to save the graph for future use under the: ***/shared/Training/HAZA10_VolcanoMonitoring_Stromboli/AuxData*** folder and save it with the name: **Graph_2**.

Then click **Run**.

Once the processing is completed, the product will appear at the **Product Explorer** Window.You can open the **Phase** and the **Coherence** bands and see how the volcano looks like. (Go to **Window → Tile Vertically)**.



5.3.4 Graph Builder – Graph 3

Go once more to **Tools → GraphBuilder**, right-click on the **Write** operator and **Delete** it.

In the **Read** tab select the product [5] that contains the product with the Interferogram: **20190626_20190702_IW2_Orb_Stack_Ifg_Deb**

5.3.4.1 Topographic Phase Removal

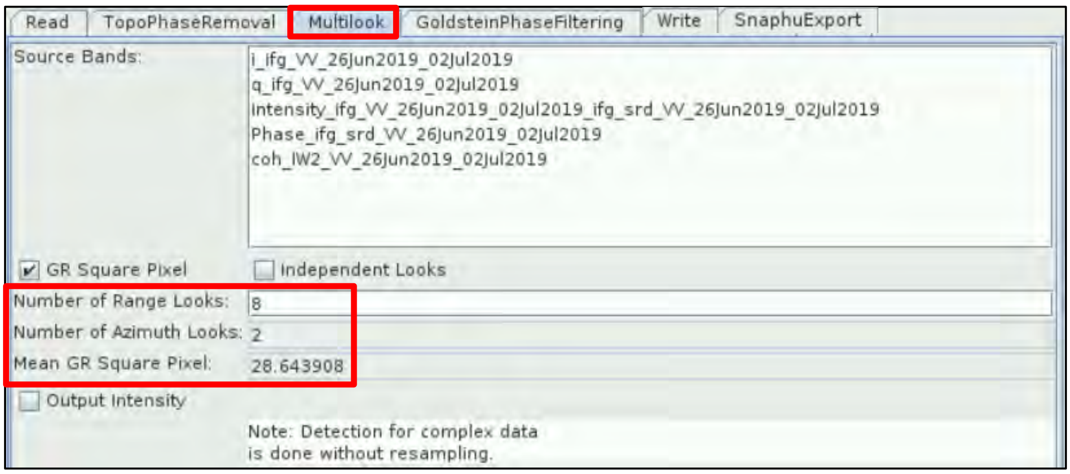
This is to estimate and subtract the topographic phase from the deburst interferogram. To add the **TopoPhaseRemoval** operator right-click and go to **Add → Radar → Interferometric → Products → TopoPhaseRemoval**. Connect the **Read** operator to it.

In the **TopoPhaseRemoval** tab set as **Digital Elevation Model**: SRTM 1Sec HGT (Auto Download).

5.3.4.2 *Multilooking*

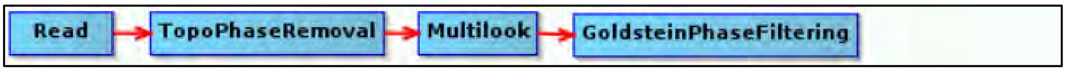
By applying this operator, we will reduce the inherent speckle noise that originally appears to the SAR images and we will obtain square pixels. To add the **Multilook** operator right-click and go to **Add → Radar → SAR Utilities → Multilook**. Connect the **TopoPhaseRemoval** operator to it.

In the **Multilook** tab keep the "**GR Square Pixel**" option selected and set **Number of Range Looks**: 8. The **Number of Azimuth Looks** will automatically change to 2 and the **Mean GR Square Pixel** to 28.643908.



5.3.4.3 *Phase Filtering*

Phase filtering reduces the phase noise (See NOTE 8). To add the **GoldsteinPhaseFiltering** operator right-click and go to **Add → Radar → Interferometric → Filtering → GoldsteinPhaseFiltering.** Connect the **Multilook** operator to it.

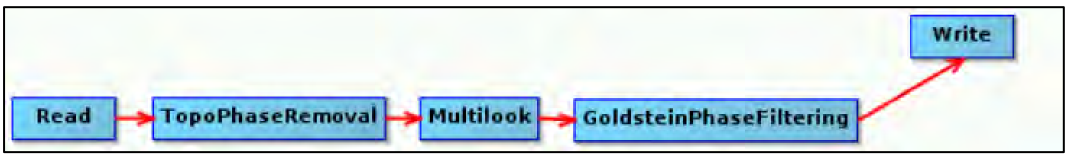


In the **GoldsteinPhaseFiltering** tab set the **FFT Size** to 32 and keep the rest parameters as by default.

NOTE 8: It is necessary step since it will enhance the phase unwrapping accuracy for the upcoming step.

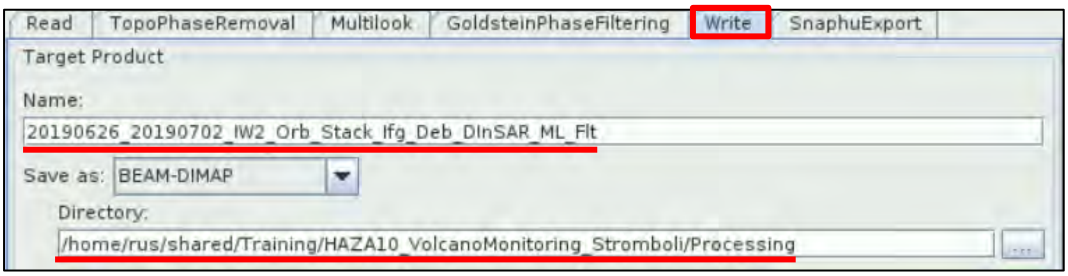
5.3.4.4 *Write – create the output*

Finally we will save the product and we will also export it for SNAPHU. To add the **Write** operator right-click and go to **Add → Input-Output → Write.** Connect the **GoldsteinPhaseFiltering** operator to it.

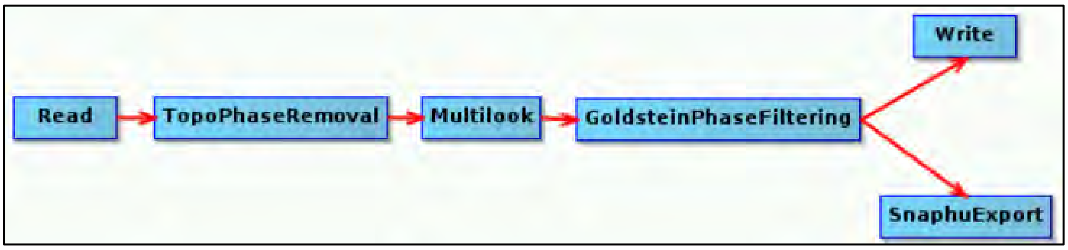


In the **Write** tab set the following:

Name: 20190626_20190702_IW2_Orb_Stack_Ifg_Deb_DInSAR_ML_Flt
Directory: ***/shared/Training/HAZA10_VolcanoMonitoring_Stromboli/Processing***



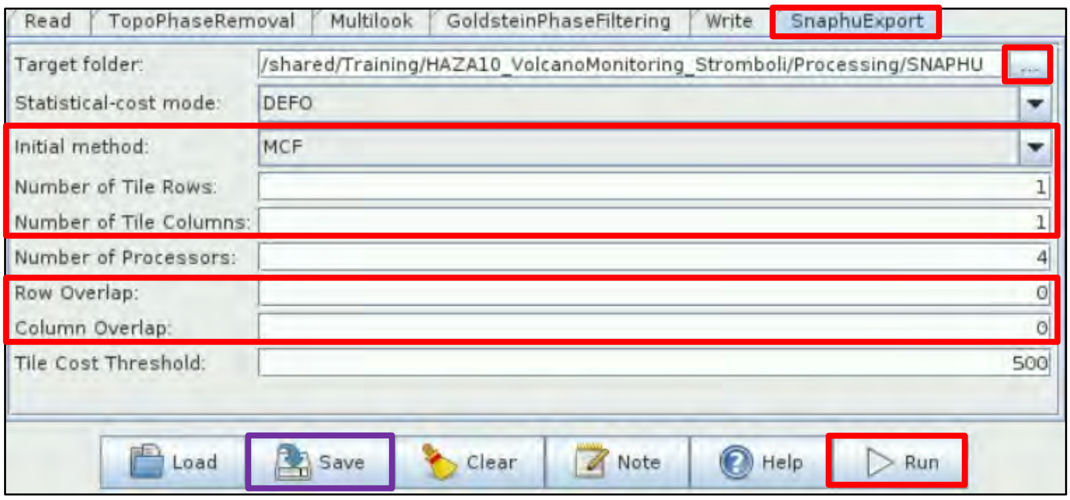
To add the **SnaphuExport** operator right-click and go to **Add → Radar → Interferometric → Unwrapping → SnaphuExport**. Connect the **GoldsteinPhaseFiltering** operator to it as well.

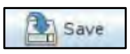


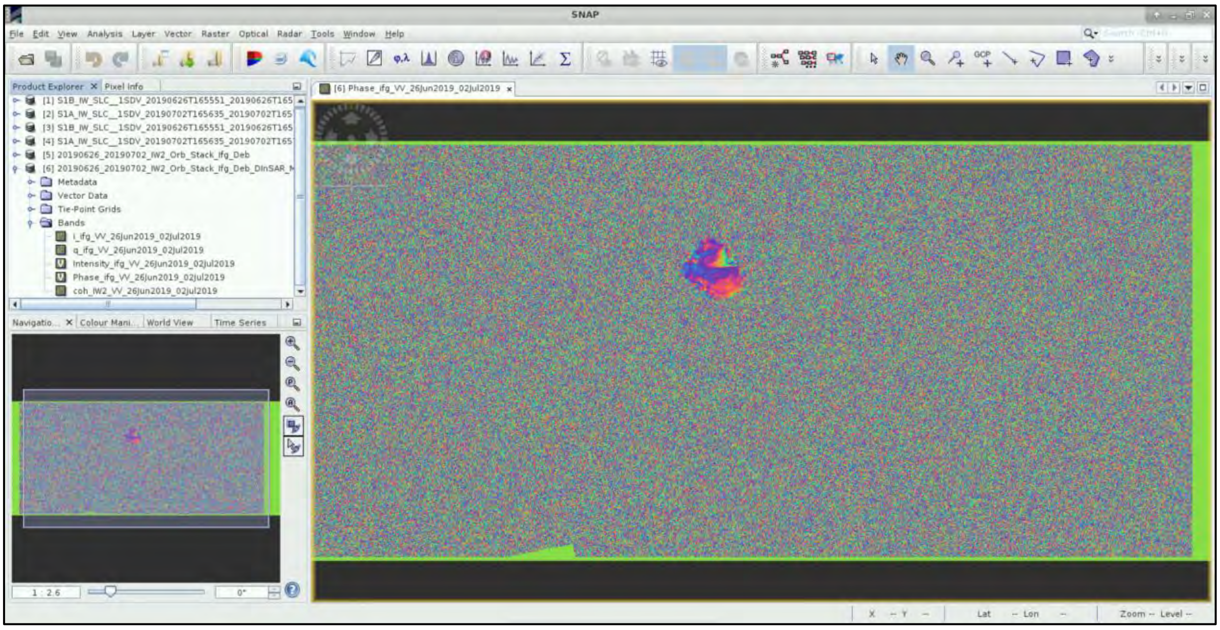
In the **SnaphuExport** tab click on  icon to set the **Target folder**. Navigate to the following path: ***/shared/Training/HAZA10_VolcanoMonitoring_Stromboli/Processing*** and write at the **File Name**: SNAPHU. Click **Select**.

Then define the following parameters in the **SnaphuExport** tab:

Initial method: MCF
Number of Tile Rows: 1
Number of Tile Columns: 1
Row Overlap: 0
Column Overlap: 0

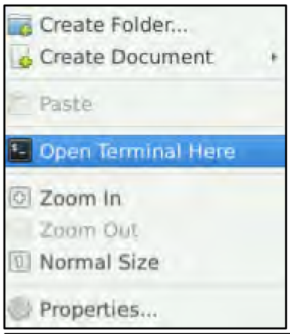


Click on  icon and save the graph under ***/shared/Training/HAZA10_VolcanoMonitoring_Stromboli/AuxData*** folder with the name **Graph_3**. Then click **Run**. This is the result.



5.3.4.5 Phase Unwrapping

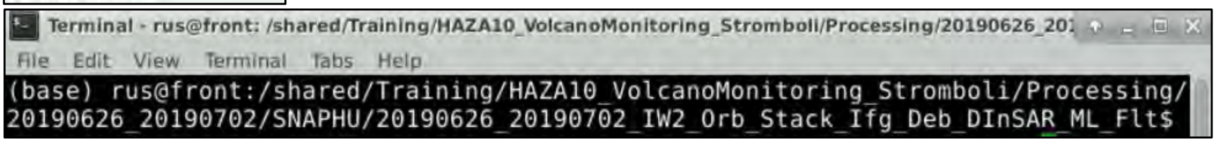
Phase unwrapping is prerequisite to convert phase units to length units (See NOTE 9). Open the:



/shared/Training/HAZA10_VolcanoMonitoring_Stromboli/Processing/ SNAPHU/20190626_20190702_IW2_Orb_Stack_Ifg_Deb_DInSAR_ML_Flt folder and right-click in the empty space.

Select "**Open Terminal Here**".

The following terminal will appear.



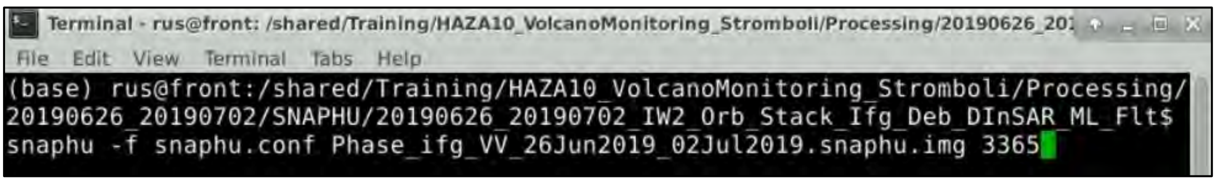
NOTE 9: Two-dimensional phase unwrapping is the process of recovering unambiguous phase data from a 2-D array of phase values known only modulo 2pi rad.

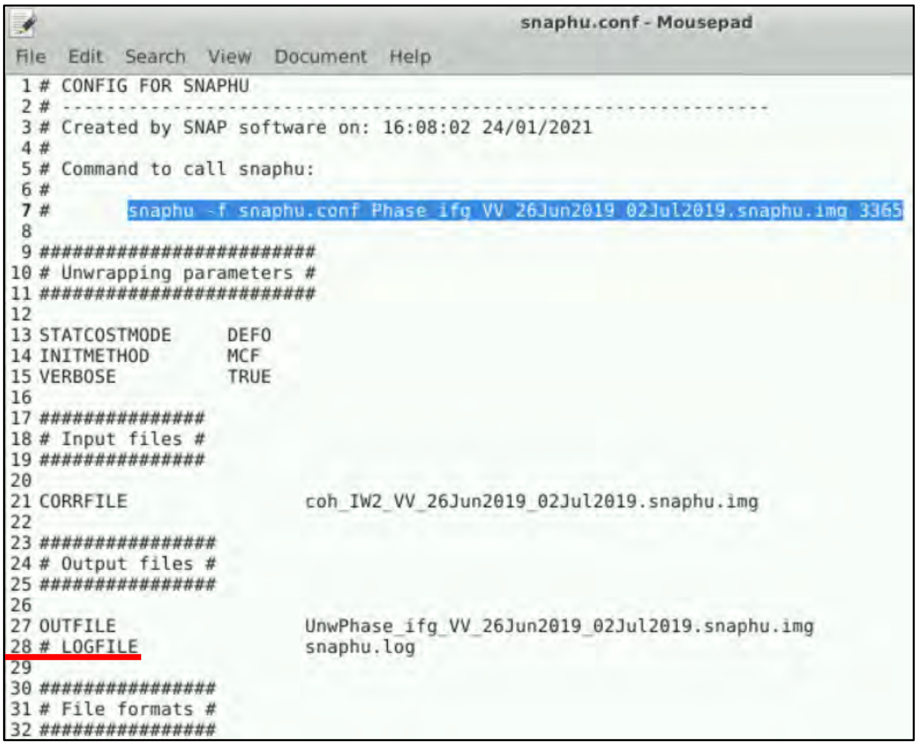
In the same folder, open the **snaphu.conf** file.

In **line 28** (go to **View → Line Numbers**), **add** the **#** symbol and leave a space before **LOGFILE**. Go to **File → Save** and save the changes. Then go to **line 7** and copy the command shown in the picture below in blue, to call snaphu:

snaphu -f snaphu.conf Phase_ifg_VV_26Jun2019_02Jul2019.snaphu.img 3365

Paste it in the Terminal and press **Enter** to run it.

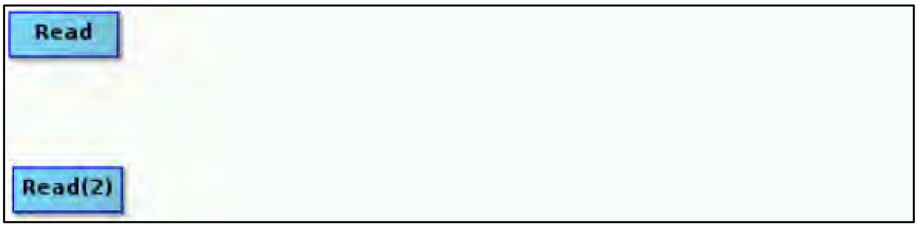




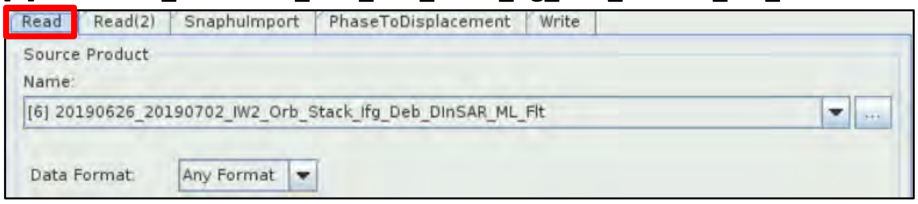
5.3.5 Graph Builder – Graph 4

Now we will create the last graph of the processing, and for this we go to **Tools → GraphBuilder** and we right-click on the **Write** operator to **Delete** it.

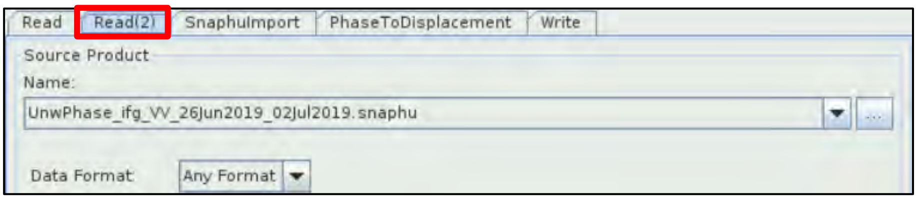
First, add one more **Read** operator. Right click and go to **Add → Input-Output → Read**.



In the **Read** tab select the product that was created from the last **Write** operator:
[6] 20190626_20190702_IW2_Orb_Stack_Ifg_Deb_DInSAR_ML_Flt

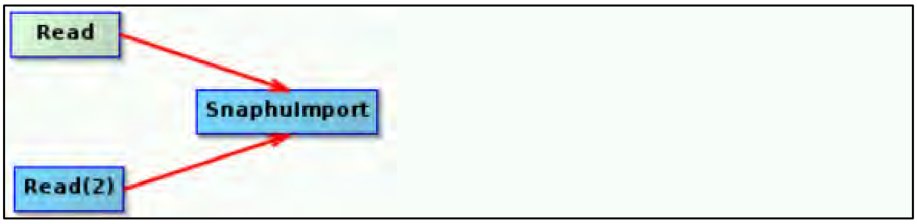


In the **Read(2)** tab click on [...] icon to select the product that contains the unwrapped phase: **UnwPhase_ifg_VV_26Jun2019_02Jul2019.snaphu.hdr** from the following path: ***/shared/Training/HAZA10_VolcanoMonitoring_Stromboli/Processing/SNAPHU/20190626_20190702_IW2_Orb_Stack_Ifg_Deb_DInSAR_ML_Flt***
Under the **Name** it will be written as: UnwPhase_ifg_VV_26Jun2019_02Jul2019.snaphu

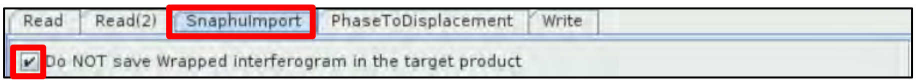


5.3.5.1 SNAPHU Import

We will import the results from SNAPHU processing. **Add → Radar → Interferometric → Unwrapping → SnaphuImport**. Connect both **Read** and **Read(2)** operators to it.

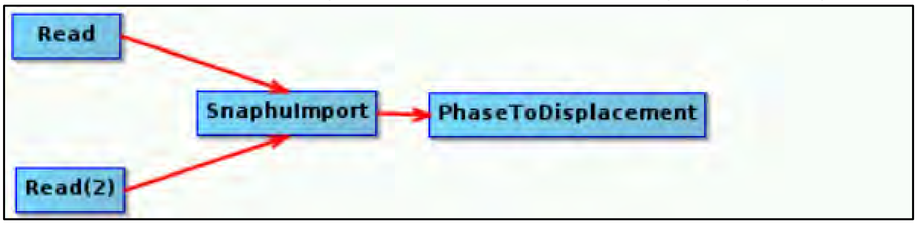


In the **SnaphuImport** tab, **select** the "**Do NOT save Wrapped Interferogram in the target product**".

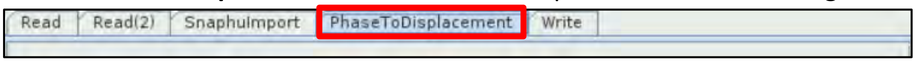


5.3.5.2 Displacement

In order to convert the phase information into displacement, go to **Add → Radar → Interferometric → Products → PhaseToDisplacement**. Connect the **SnaphuImport** operator to it.

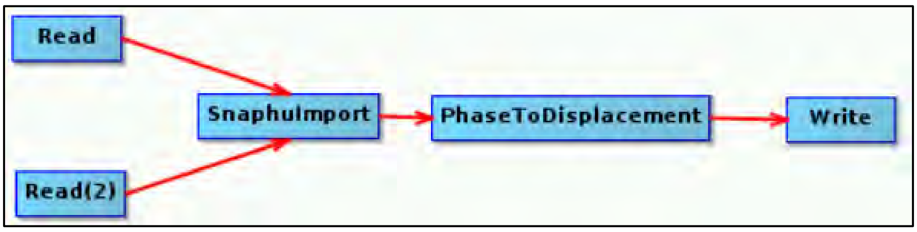


In the **PhaseToDisplacement** tab there are no parameters to be changed.



5.3.5.3 Write – create the output

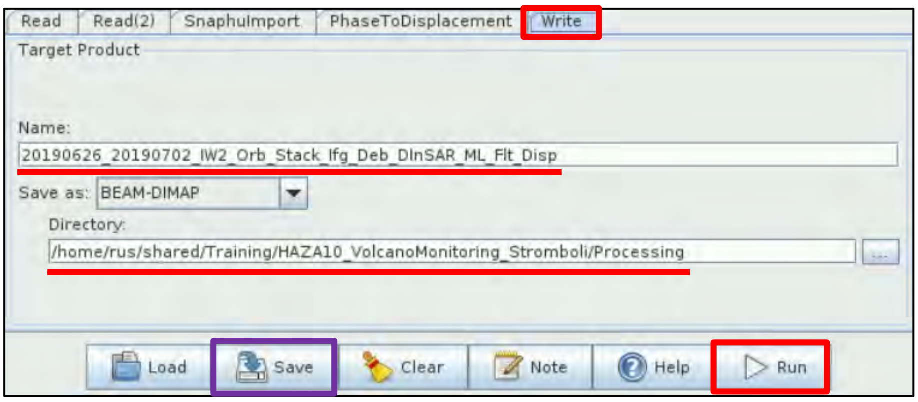
As last step, we will save the product that will contain the displacement band. Go to **Add → Input-Output → Write.** Connect the **PhaseToDisplacement** operator to it.

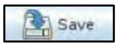


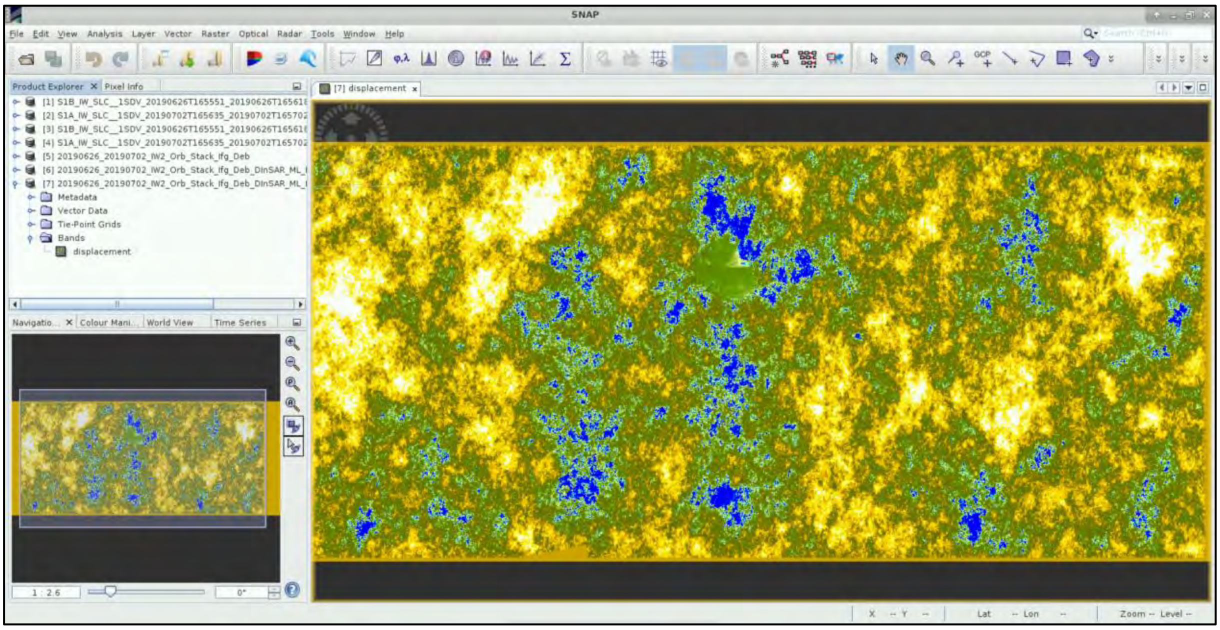
In the **Write** tab set the following:

Name: 20190626_20190702_IW2_Orb_Stack_Ifg_Deb_DInSAR_ML_Flt_Disp

Directory: ***/shared/Training/HAZA10_VolcanoMonitoring_Stromboli/Processing***



Click on  icon and save the graph under ***/shared/Training/HAZA10_VolcanoMonitoring _Stromboli/AuxData*** folder with the name **Graph_4**. Then click **Run**.



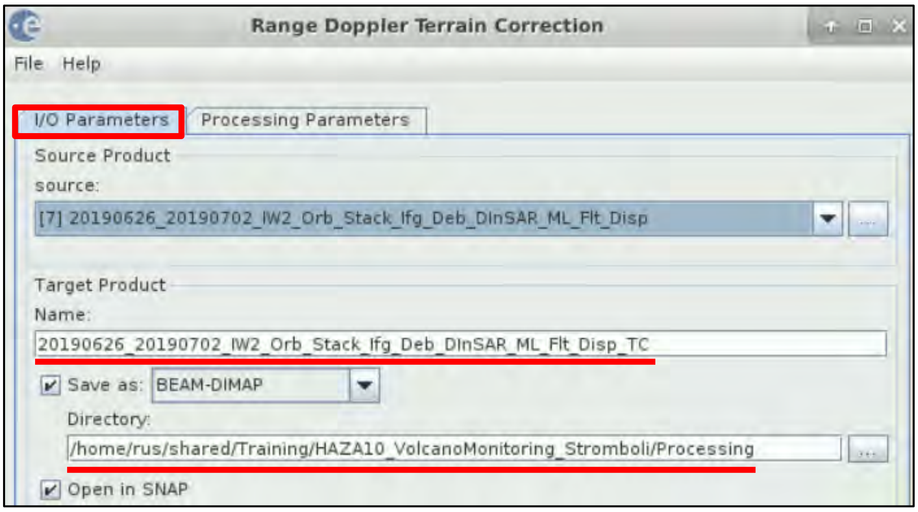
We see that we cannot understand clearly the output and for this reason we will proceed to the last step, the Geocoding, in order to convert the RADAR coordinates into geographic and remove the displacement that refers to the sea surface. We will only keep the information about the volcano.

5.3.6 Geocoding – Terrain Correction

Go to the menu **Radar → Geometric → Terrain Correction → Range Doppler Terrain Correction**.

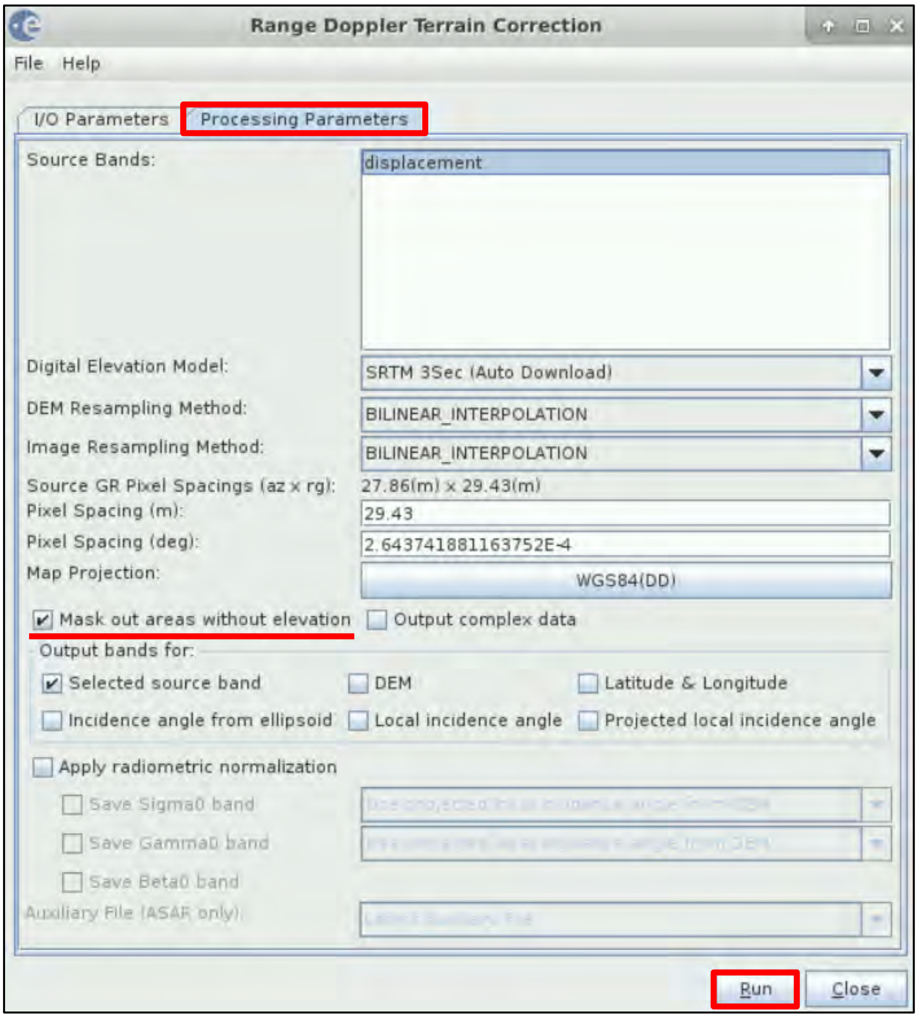
in the **I/O Parameters** tab, set the following:

Source: 20190626_20190702_IW2_Orb_Stack_Ifg_Deb_DInSAR_ML_Flt_Disp
Name: 20190626_20190702_IW2_Orb_Stack_Ifg_Deb_DInSAR_ML_Flt_Disp_TC
Directory: */shared/Training/HAZA10_VolcanoMonitoring_Stromboli/Processing*

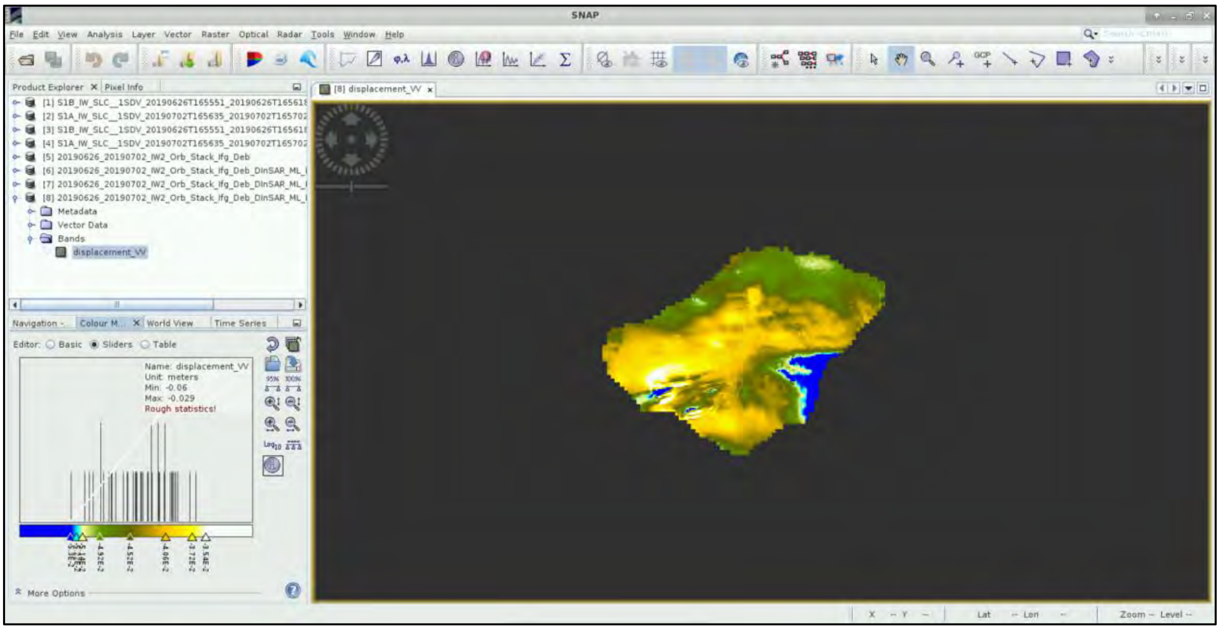


In the **Processing Parameters** tab keep the default parameters (we need SRTM3Sec as DEM.

Make sure that the “Mask out areas without elevation” is selected and click **Run**.

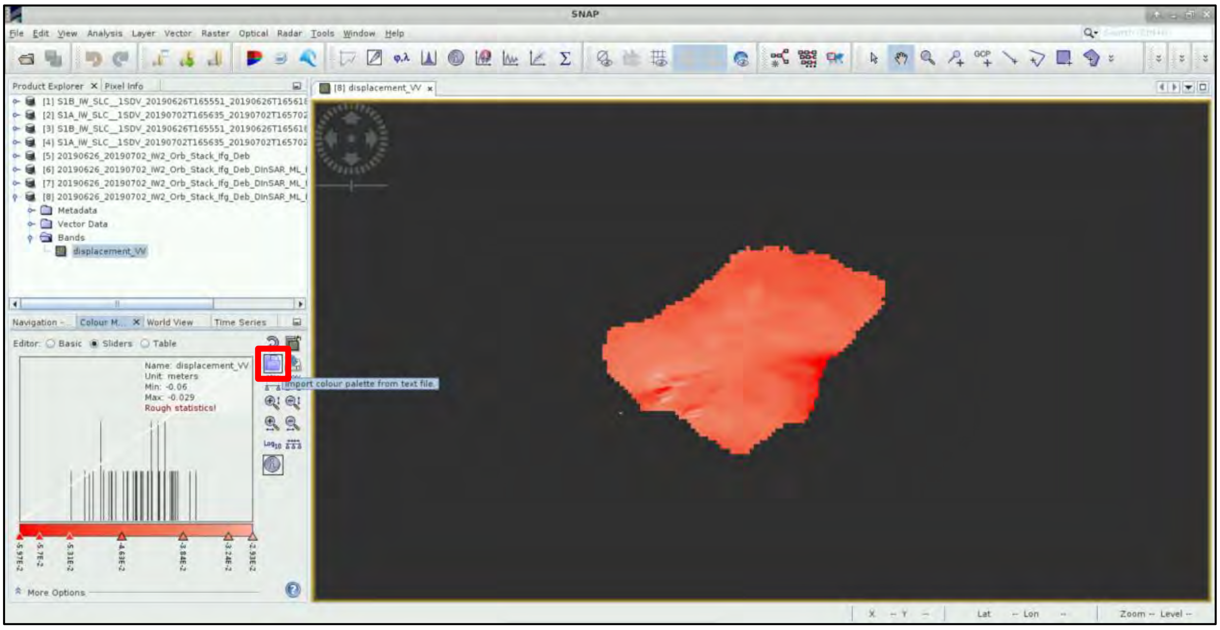


This is the final product.



In order to better visualize the deformation, we have created a colour palette where with within the scale, with red we show the areas that have been moved away relatively to the satellite, with blue the areas that have been moved closer to the satellite and with white those who remained stable. Go to the  icon - “Import colour palette from text file”.

For the dates of images we have processed, navigate to ***/shared/Training/HAZA10_VolcanoMonitoring_Stromboli/AuxData*** folder and insert the **20190626_20190702.cpd** colour palette.



5.3.7 Export products

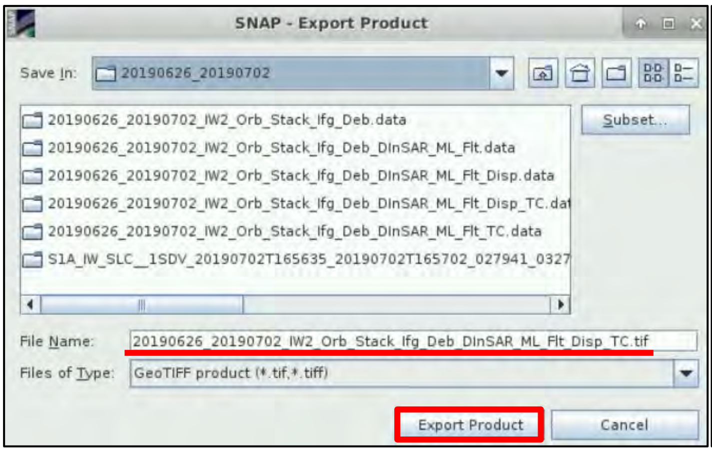
If you want to further process your outputs and combine them with any other kind of data in a GIS environment or in Google Earth, you first need to export them to the compatible format.

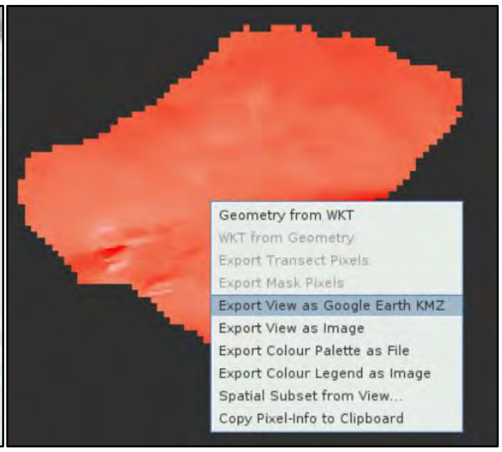
<u>For GIS processing:</u>

Select the **20190626_20190702_IW2_Orb_Stack_Ifg_Deb_DInSAR_ML_Flt_Disp_TC** product and go to **File → Export → GeoTIFF.**

Set it with the name you wish, and then set the path you want to save the **tif** file at the **Save in** field e.g. ***shared/Training/HAZA10_VolcanoMonitoring_Stromboli/Processing***. Click **Export Product**.

If you want to export it for use is **Google Earth**, first you need to have it Terrain Corrected in geographic Lat and Lon, right click on the opened band at the **View Window** and select "**Export View as Google Earth KMZ**". Then set the path to which you want to save it.



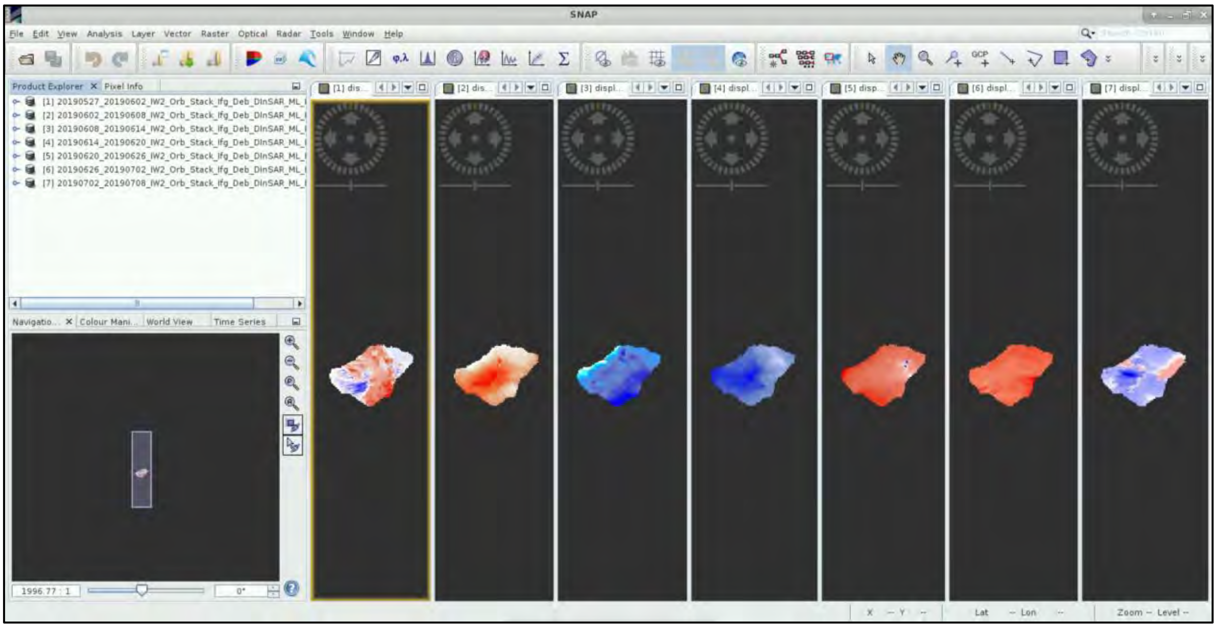


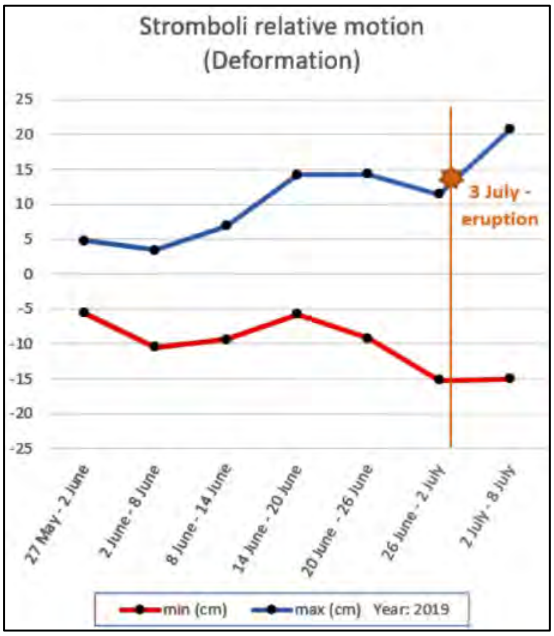
6 Data Interpretation

We have downloaded 8 images in total, but we processed only 2 of them as a pair. In order to monitor the volcano, it is suggested to process some images before the eruption and some after. In this case, the rest suggested pairs to be proceed are those of the following dates:

Pair 1: 20190527 - 20190602
Pair 2: 20190602 - 20190608
Pair 3: 20190608 - 20190614
Pair 4: 20190614 - 20190620
Pair 5: 20190620 - 20190626
Pair 6: 20190626 - 20190702 →THIS HAS BEEN PROCESSED IN THIS TUTORIAL
Pair 7: 20190702 - 20190708

If we load them all in SNAP with the corresponding to each colour palette that is available in the **AuxData** folder, we can see the following displacement over time.





In the results showing the conditions every 6 days consequently, we can see that the whole island is periodically deflating and inflating.

Stromboli is one of the most monitored volcanoes in the world with a great surveillance system and many scientists have worked all these years on its activity.

As confirmed by *F. Di Traglia et al., 2014*, inflation and deflation were recorded immediately before and after each new effusive event, like in our case. Any vent opening can cause sliding and high displacement rate is recorded.

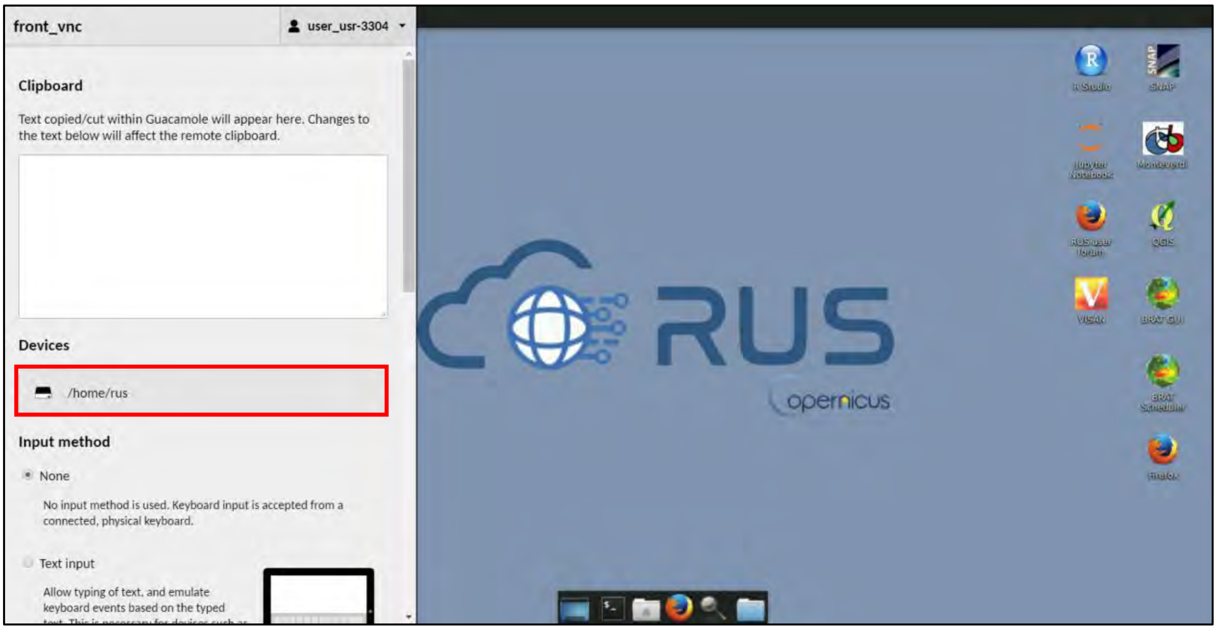
Also, the displacement rate increases during the upwelling because the magma is less dense, while the displacement rate decreases when the degassed magma column is pushed out from the pipe.

7 Extra Steps

7.1 Download files from VM

In your VM, press **Ctrl+Alt+Shift.**

A pop-up window will appear on the left side of the screen. Click on the bar below **Devices**, navigate to the folders you have saved the files you want to download and **double click** on them. The downloading process to your local computer will start automatically.



THANK YOU FOR FOLLOWING THE EXERCISE!

8 Further reading and resources

- Bevilacqua, A., Bertagnini, A., Pompilio, M., Landi, P., Del Carlo, P., Di Roberto, A., Aspinall, W., & Neri, A. (2020). Major explosions and paroxysms at Stromboli (Italy): a new historical catalog and temporal models of occurrence with uncertainty quantification. *Scientific Reports*, *10*(1). https://doi.org/10.1038/s41598-020-74301-8
- Inguaggiato, S., Vita, F., Cangemi, M., & Calderone, L. (2019). Increasing summit degassing at the stromboli volcano and relationships with volcanic activity (2016-2018). *Geosciences (Switzerland)*, *9*(4). https://doi.org/10.3390/geosciences9040176
- Beermann, O., Holtz, F., & Duesterhoeft, E. (2017). Magma storage conditions and differentiation of the mafic Lower Pollara volcanics, Salina Island, Aeolian Islands, Italy: implications for the formation conditions of shoshonites and potassic rocks. *Contributions to Mineralogy and Petrology*, *172*(5). https://doi.org/10.1007/s00410-017-1363-z
- Bąk, K., Bąk, M., & Szubert, M. (2016). Stromboli – the best place to actively learn and understand the behavior of an active volcano and its processes. *Geotourism/Geoturystyka*, *44–45*(1), 3. https://doi.org/10.7494/geotour.2016.44-45.3
- Ripepe, M., Donne, D. D., Genco, R., Maggio, G., Pistolesi, M., Marchetti, E., Lacanna, G., Ulivieri, G., & Poggi, P. (2015). Volcano seismicity and ground deformation unveil the gravity-driven magma discharge dynamics of a volcanic eruption. *Nature Communications*, *6*. https://doi.org/10.1038/ncomms7998

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