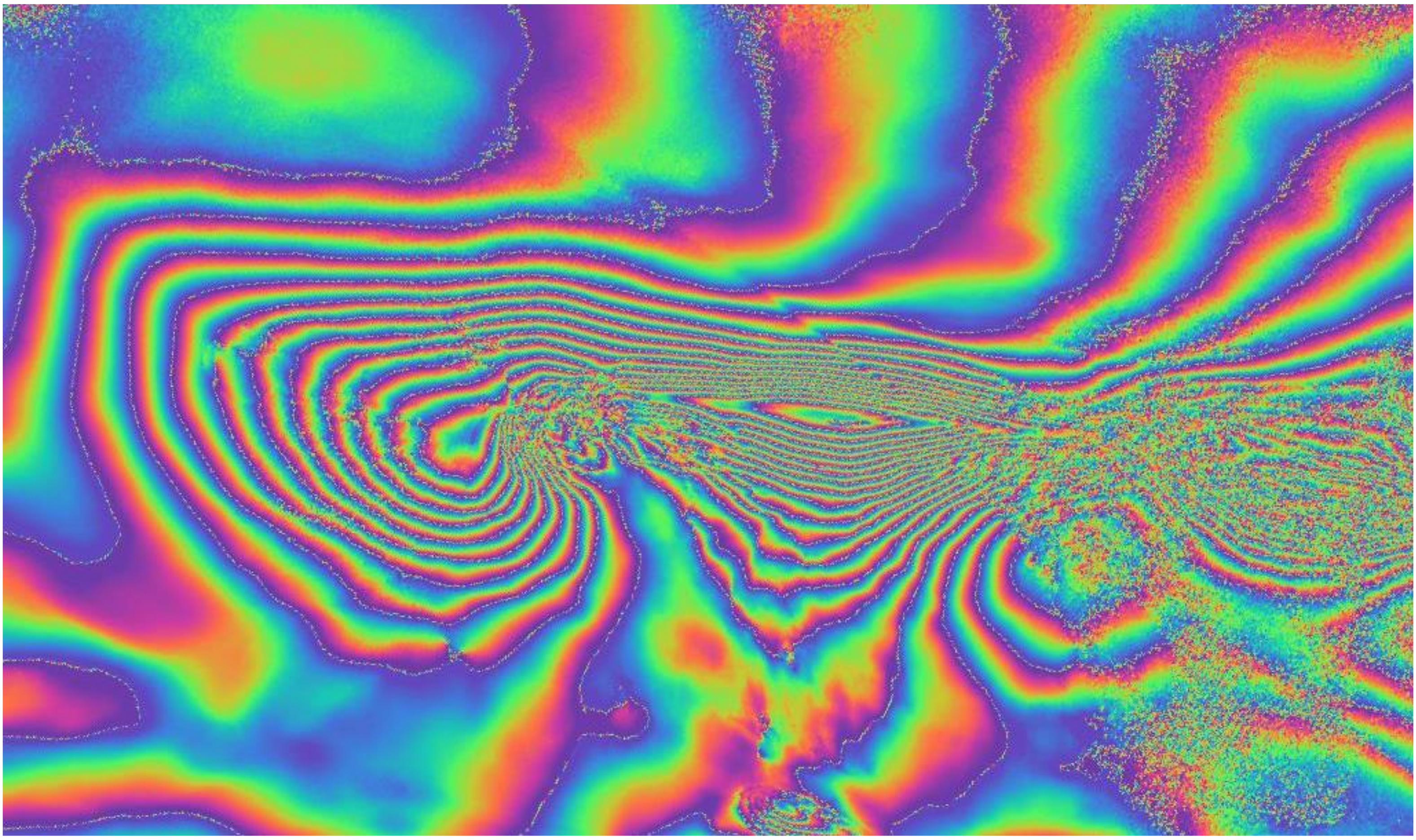

TRAINING KIT – HAZA05

EARTHQUAKE DEFORMATION USING InSAR, WITH SENTINEL-1 – MAY 2018 (HAWAII)

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-coperenicus.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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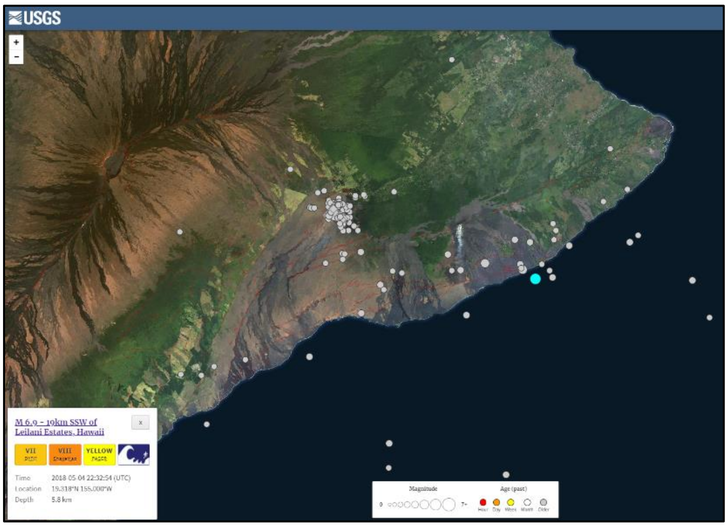
Table of Contents

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.

Earthquakes occur very often worldwide, especially in volcanic regions like Hawaii. They can be caused by tectonic faults, by the movement of magma in volcanoes (volcano tectonic earthquakes) and be related to dike intrusion.



All earthquakes recorded at the area of study from 15 March 2018 to 15 August 2018 with magnitude 3.5 – 7.0. In blue, the event of 4 May 2018. (Source: https://earthquake.usgs.gov/earthquakes/map/)

The earthquake occurred in the south-east of the Hawaii archipelago on May 4, 2018 at the Hawaii Island, was of magnitude of Mw 6.9 and produced around 5 meters of fault slip. It is the largest earthquake affecting this region after the one in 1975, where 2 people were killed and another 28 were injured.

This event was related to the new lava outbreaks at the Kilauea Volcano and the aftershock events continued until August 2018. The earthquake produced a minor tsunami that reached a maximum height of 40 cm in Kapoho, 20 cm in Hilo and 15 cm in Honuapo.

Hawaii region is known as one of around 60 hotspots that exist in the world and its islands are formed due to the continuous flow of magma towards the surface. The tectonic plate is moving to a north-west direction while the hotspot remains at the same location, creating new volcanoes. This is the reason why the youngest island is located to the south-east and why only the volcanoes in the southern half are active. Seismic activity will always take place in such regions and sometimes it can also be related to volcanic eruptions.

2 Training

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

The Training Code for this tutorial is HAZA05. If you wish to practice the exercise described below within the RUS Virtual Environment, register on the RUS portal and open a User Service request from Your RUS service → Your dashboard.

2.1 Data used

- Two Sentinel-1A IW SLC images with VH & VV polarization acquired on 23 April 2018 and 5 May 2018 [downloadable at https://scihub.copernicus.eu/]

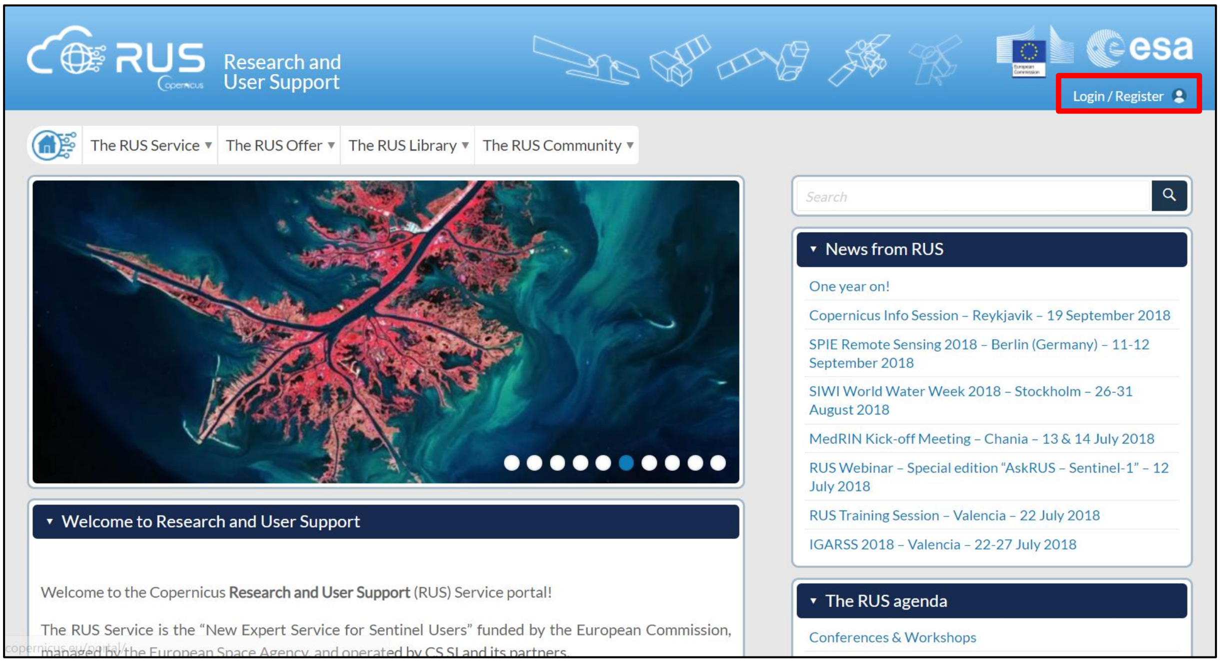
S1B_IW_SLC__1SDV_20180423T161524_20180423T161551_010613_0135DD_33F0
S1B_IW_SLC__1SDV_20180505T161525_20180505T161552_010788_013B7D_25D2

2.2 *Software in RUS environment*

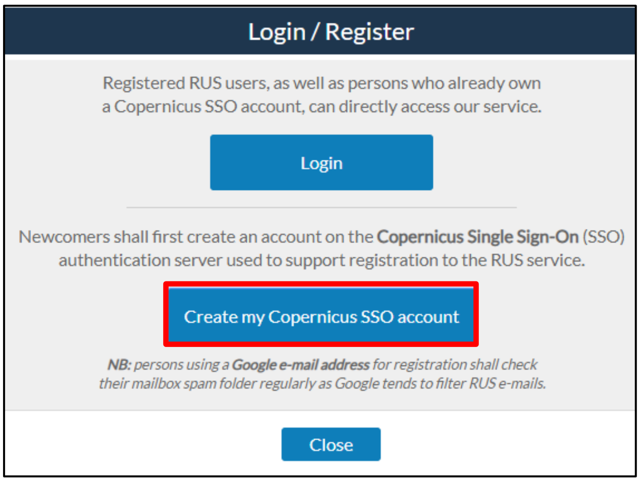
Internet browser, SNAP + Sentinel-1 Toolbox, QGIS, (Extra steps: Google Earth)

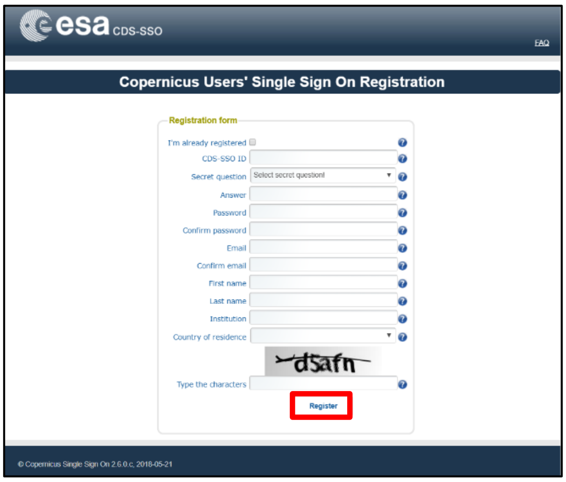
3 Register to RUS Copernicus

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.



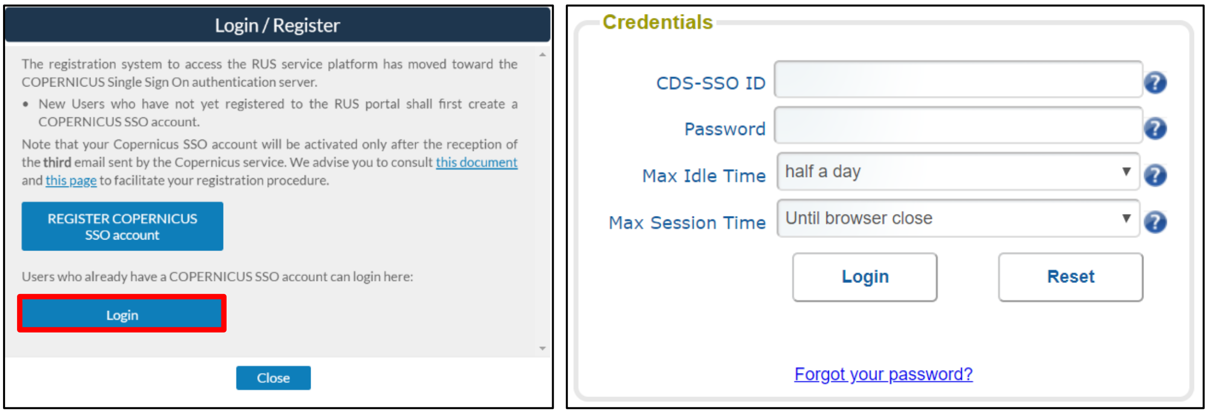
Select the option ***Create my Copernicus SSO account*** and then fill in ALL the fields on the **Copernicus Users' Single Sign On Registration**. Click ***Register***.



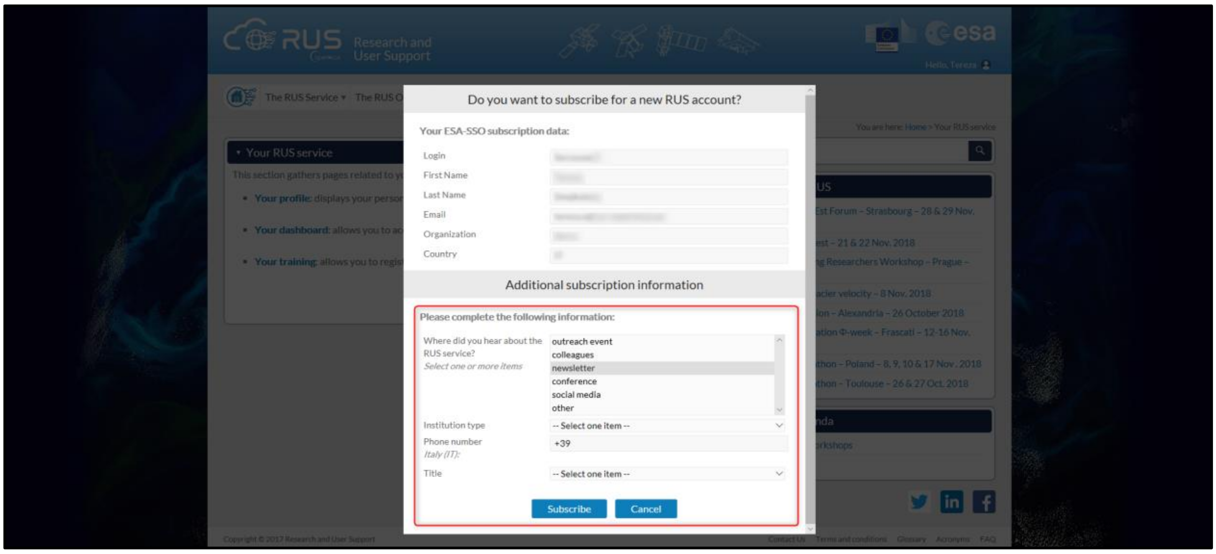


Within a few minutes you will receive an e-mail with activation link. Follow the instructions in the e-mail to activate your account.

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

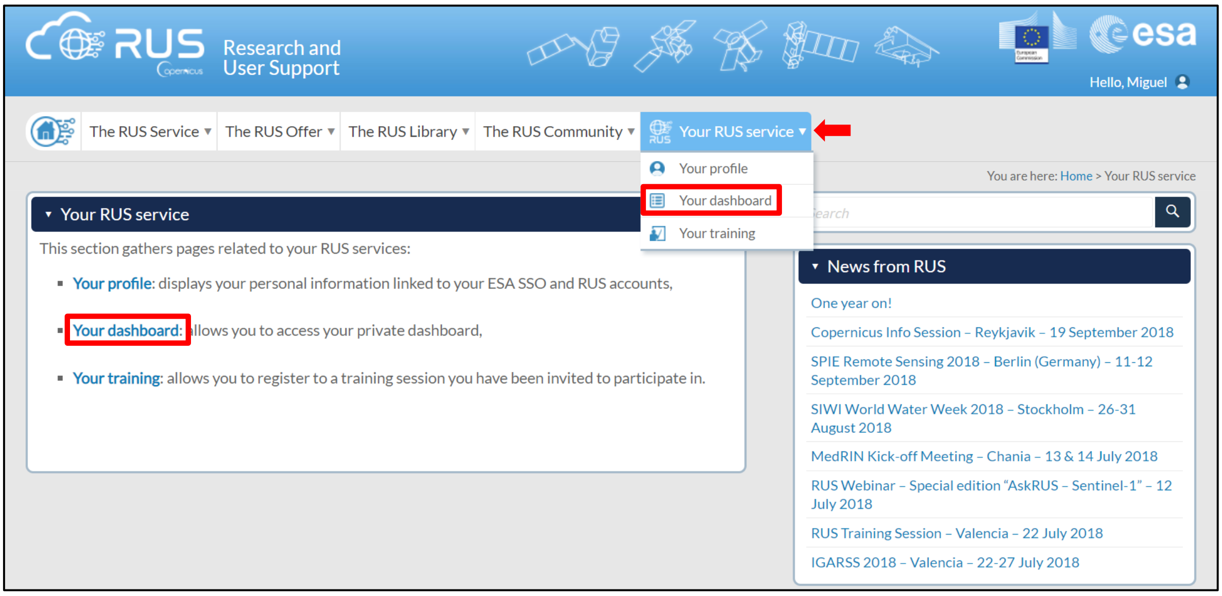


Upon your first login you will need to enter some details. You must fill all the fields.

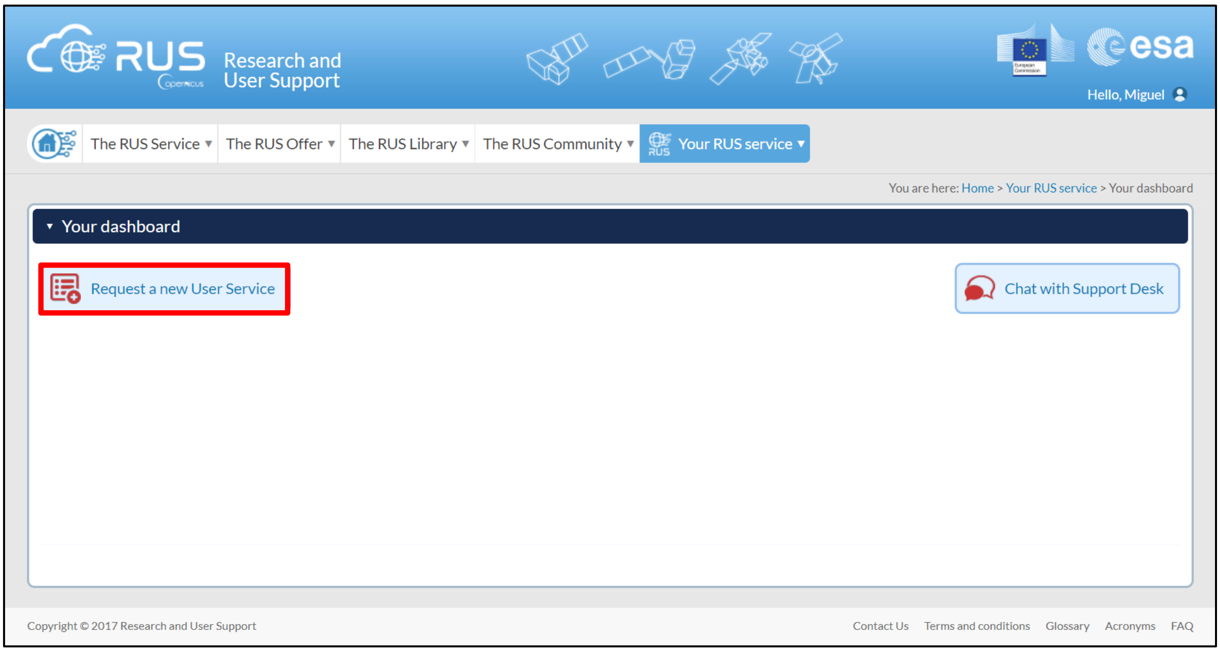


4 Request a RUS Copernicus Virtual Machine

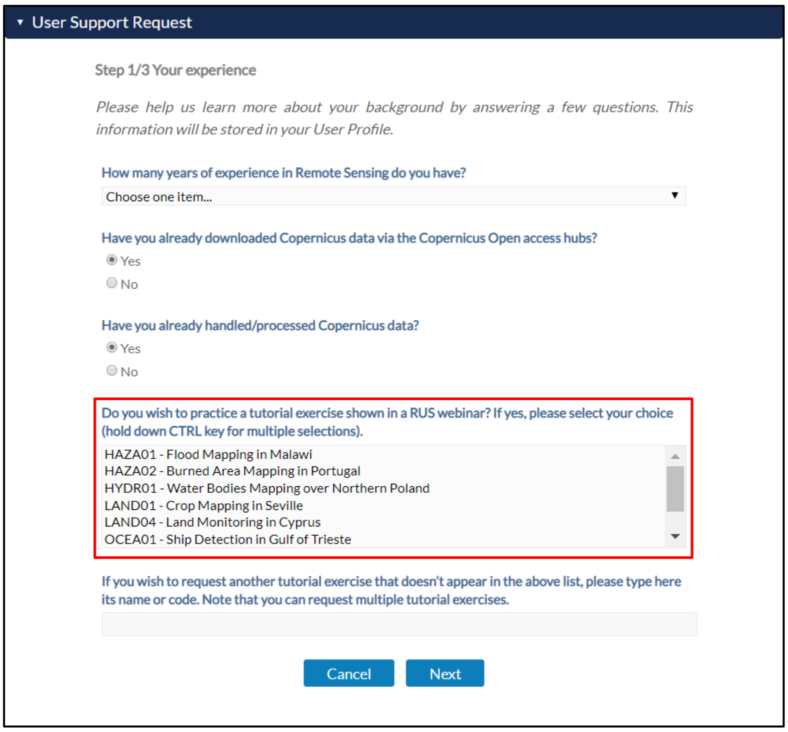
Once you are registered as a RUS user, you can request a RUS Virtual Machine to repeat this exercise or work on your own projects using Copernicus data. For that, log in and click on ***Your RUS Service → Your Dashboard***.



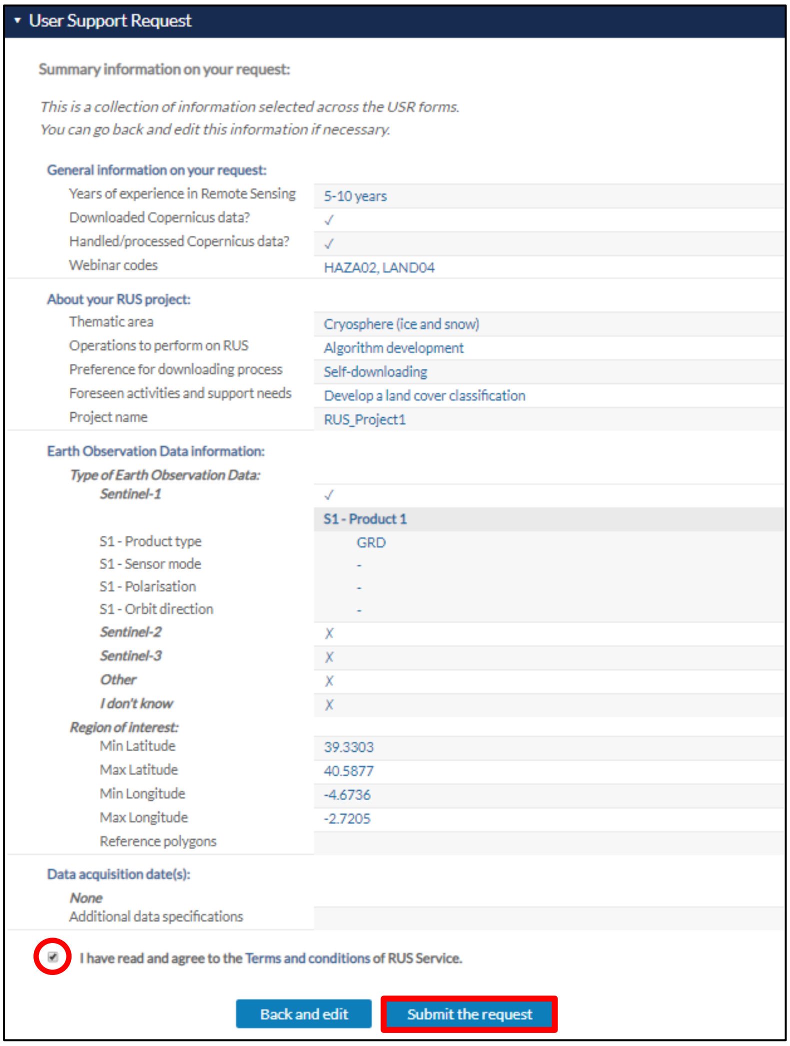
Click on ***Request a new User Service*** to request your RUS Virtual Machine. Complete the form so that the appropriate cloud environment can be assigned according to your needs.



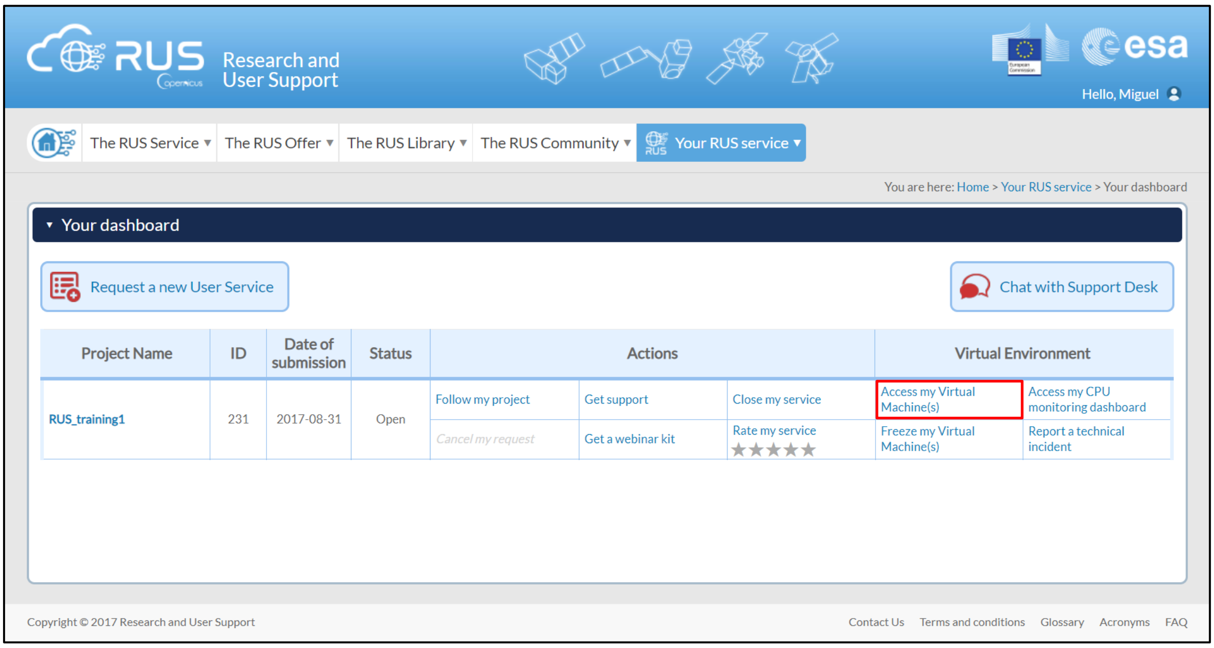
If you want to repeat this tutorial (or any previous one) select the one(s) of your interest in the appropriate field.



Complete the remaining steps, check the terms and conditions of the RUS Service and submit your request once you are finished.



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.

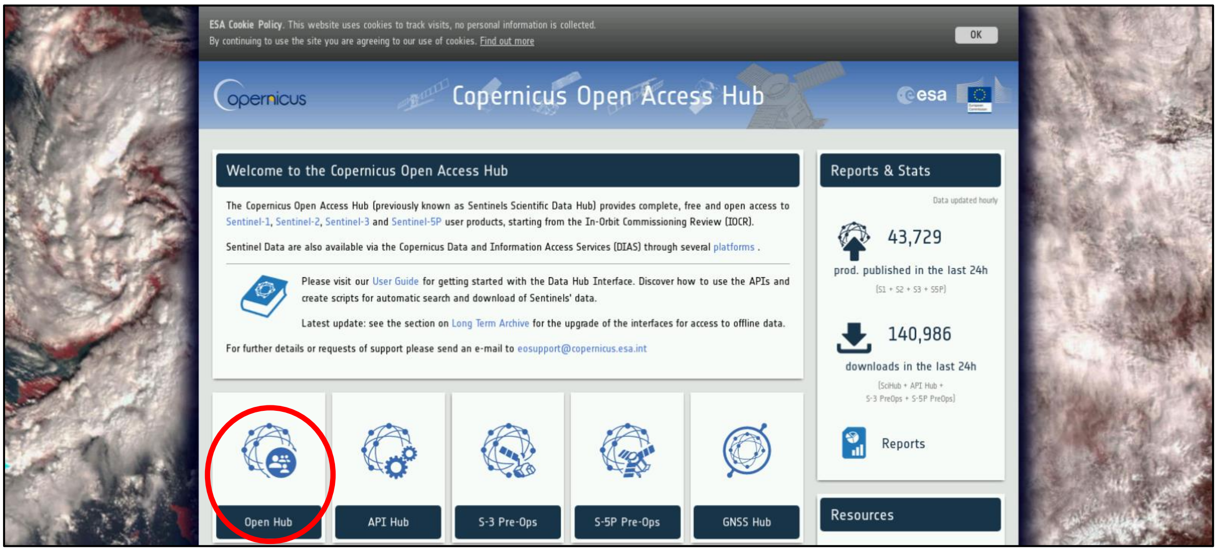
This is the remote desktop of your Virtual Machine.

5 Step by step

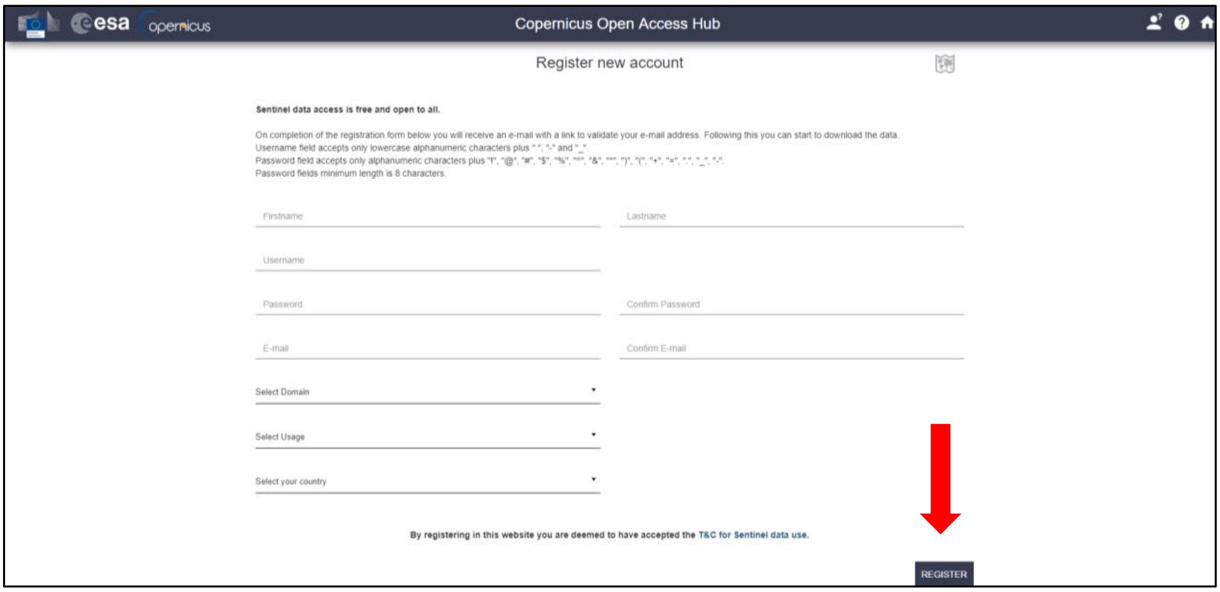
5.1 *Data download – ESA SciHUB*

In this step, we will download the Sentinel-1 scenes 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.

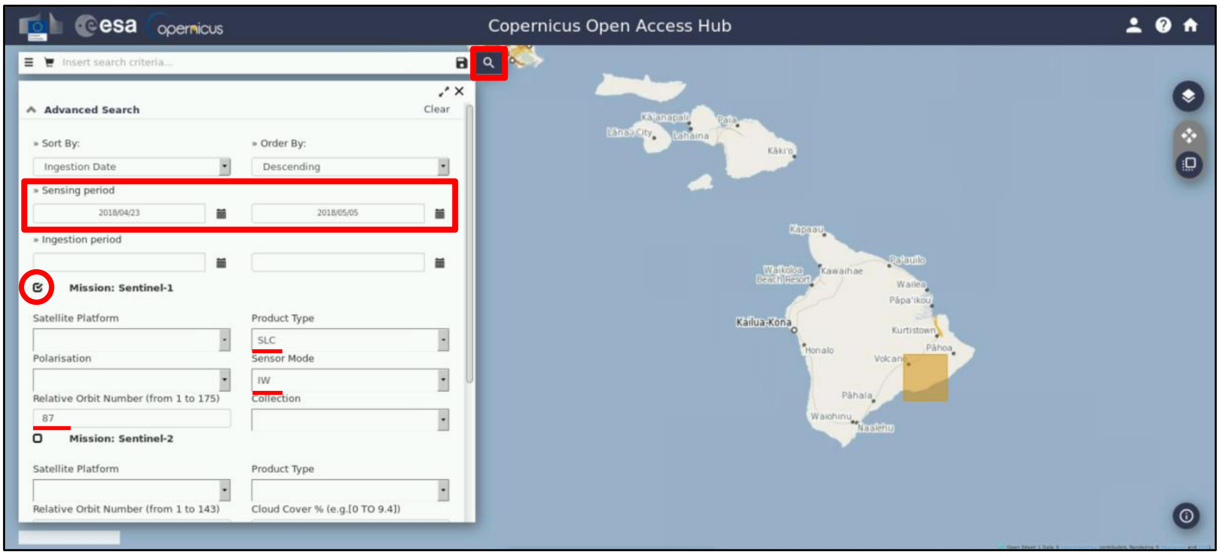


After you have filled in the registration form, you will receive an activation link by e-mail. Once your account is activated or if you already have an account, “**LOGIN**”.

Navigate to Hawaii (**approximate area – green rectangle**).

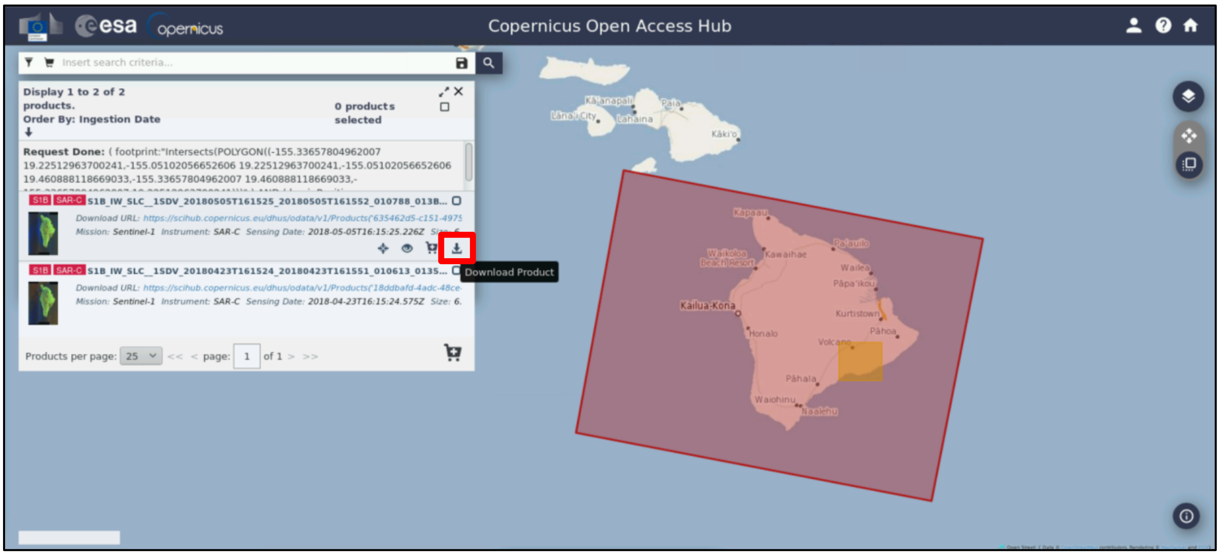
Zoom in to the south-east part of the Hawaii Island, switch to “**drawing mode**” and draw a search rectangle approximately as indicated below. Open the search menu by clicking to the left part of the search bar and specify the following parameters:

Sensing period: From 2018/04/23 to 2018/05/05
Select: Mission: Sentinel-1
Product Type: SLC
Sensor Mode: IW
Relative Orbit Number: 87 (It is important for InSAR processing since we need the products to have the same geometry).



Then click on the “**Search**” icon. In our case, the search returns 2 results for the time period we set. Download both scenes by clicking on the “**Download Product**” icon:

S1B_IW_SLC__1SDV_20180423T161524_20180423T161551_010613_0135DD_33F0
S1B_IW_SLC__1SDV_20180505T161525_20180505T161552_010788_013B7D_25D2



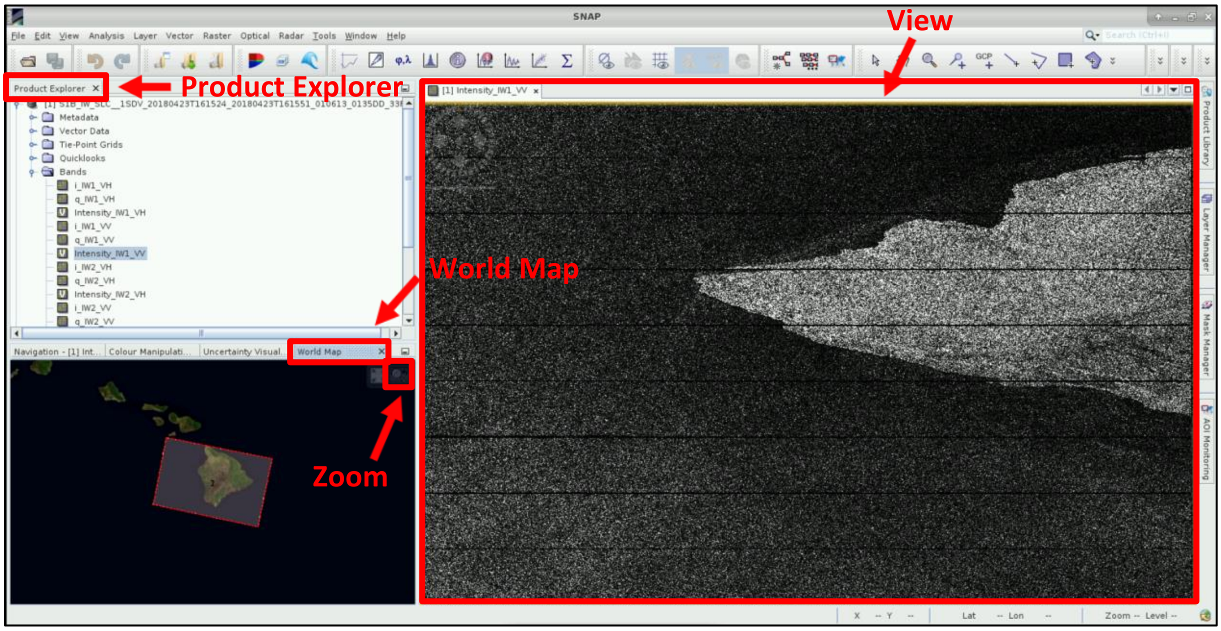
The products will be downloaded at ***/home/rus*** as zip files. Move them to: ***/shared/Training/HAZA05_EarthquakeDeformation_Hawaii_TutorialKit/Original*** folder.

5.2 SNAP – open and explore data

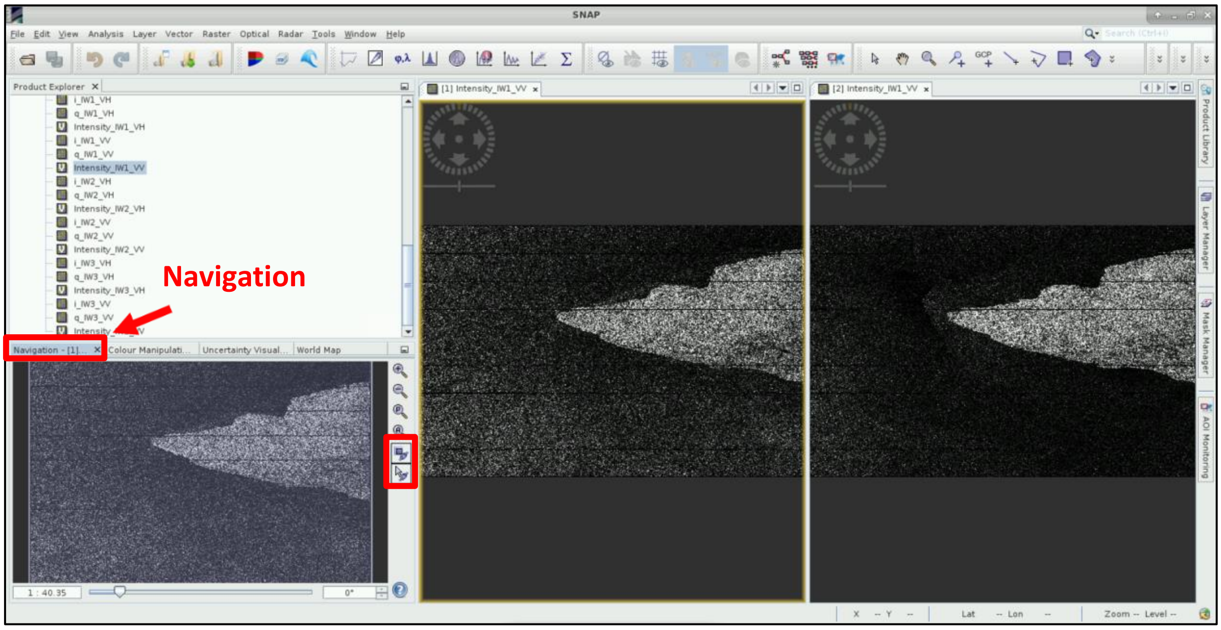
Open **SNAP** software from the icon located on the desktop or go to **Applications → Processing → SNAP Desktop**. Click the **Open Product** icon , navigate to: ***/shared/Training/HAZA05_EarthquakeDeformation_Hawaii_TutorialKit/Original*** folder and open the two S-1 downloaded products (first the **20180423** and then the **20180505**):

S1B_IW_SLC__1SDV_20180423T161524_20180423T161551_010613_0135DD_33F0.zip
S1B_IW_SLC__1SDV_20180505T161525_20180505T161552_010788_013B7D_25D2.zip

The opened products will appear in **Product Explorer** window. Click **+** or to expand the contents of product **[1]** from **23 April 2018**, 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 Map** tab and zoom in to see the location of the opened product on the globe (See NOTE 1).



Open the ***Intensity_IW1_VV*** band of the product **[2]** from **5 May 2018** as well and compare them by going to **Window → Tile Horizontally**. Go to 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.



NOTE 1: 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 **descending** pass (the satellite was moving in direction from north to south) and in this case while looking to the right it was actually looking towards the west. That is why we see that the view of the image appears as if "mirrored", because the view shows the pixels in order of the data acquisition.

5.3 *Pre-processing*

We need to apply identical pre-processing steps to both products and we will use the **GraphBuilder** and the **Batch Processing** tools.

By using the **GraphBuilder** tool, we can define the steps of the process 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).

By using the **Batch Processing** tool, we will apply all steps to both images in one go.

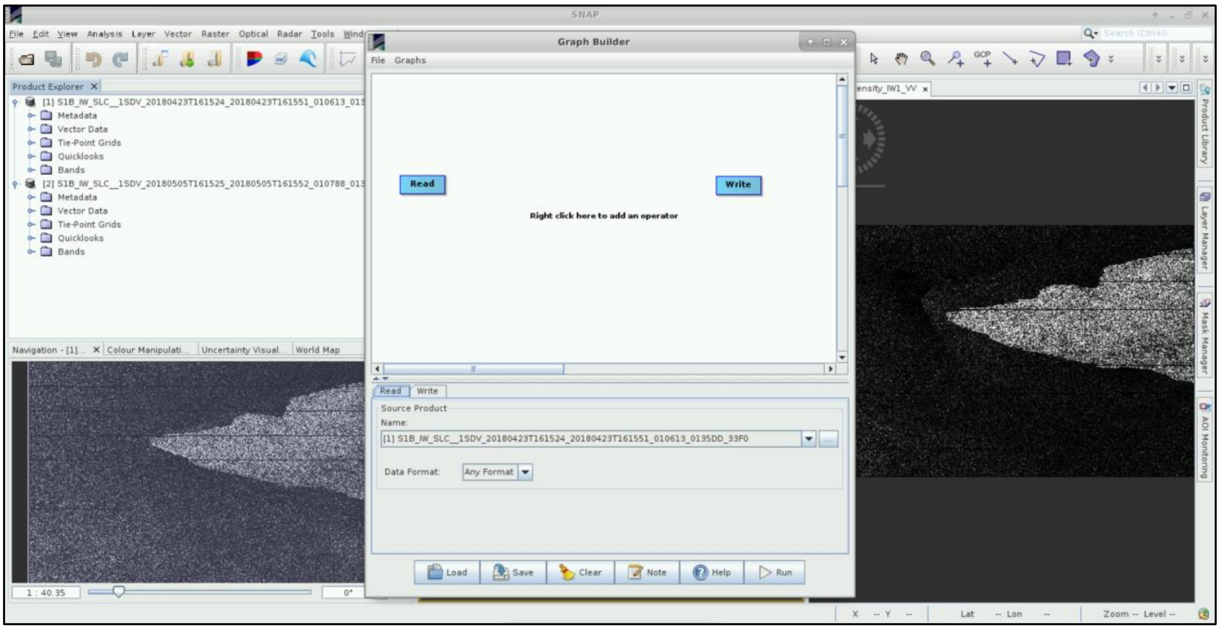
5.3.1 Graph Builder

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.

First, 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.

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.

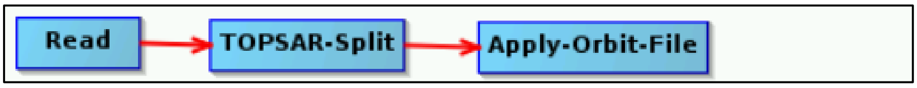


Every Interferometric Wide swath (IW) consists of 3 sub-swaths and each one of maximum 9 bursts. In SNAP we can process only one swath at a time until the **Deburst** step (See chapter 5.4.3). Our area of interest is located in the IW1 and is covered sufficiently by processing 2 bursts. We will use the **TOPSAR-Split** operator; this way we will reduce the total processing time (See NOTE 2).

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.

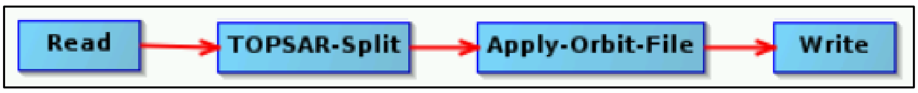
NOTE 2: In this case that we are using a pair of descending products, the IW1 is the one to the east. If we work with ascending products, the IW1 is the one to the west. Depending on our area of interest, we can process some or all bursts of a sub-swath, or even merge more sub-swaths but this will be quite time consuming and computationally heavy in the following steps.

Now we will add the **Apply-Orbit-File** operator by right-clicking and going to **Add → Radar → Apply-Orbit-File** (See NOTE 3). Connect the **TOPSAR-Split** operator to it.

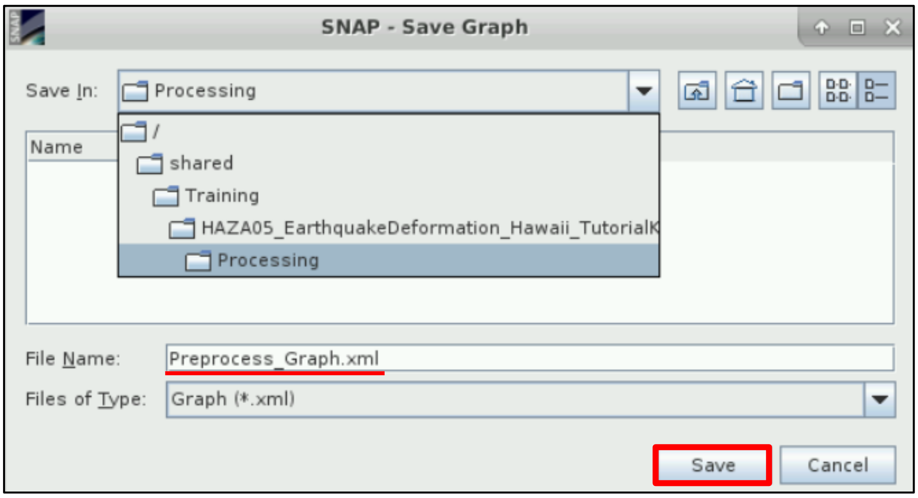


NOTE 3: The orbit state vectors provided in the metadata of a SAR product are generally not accurate and can be refined with the precise orbit files which are available days-to-weeks after the generation of the product. **The orbit file provides accurate satellite position and velocity information**. Based on this information, **the orbit state vectors in the abstract metadata of the product are updated**.

Finally, we will add the **Write** operator to write our output product. To add the operator right-click and go to **Add → Input-Output → Write**. Connect the **Apply-Orbit-File** operator to it.



Then click on  icon at the bottom of the **Graph Builder** window and save the graph under ***/shared/Training/HAZA05_EarthquakeDeformation_Hawaii_TutorialKit/Processing*** folder with the name **Preprocess_Graph.xml.**



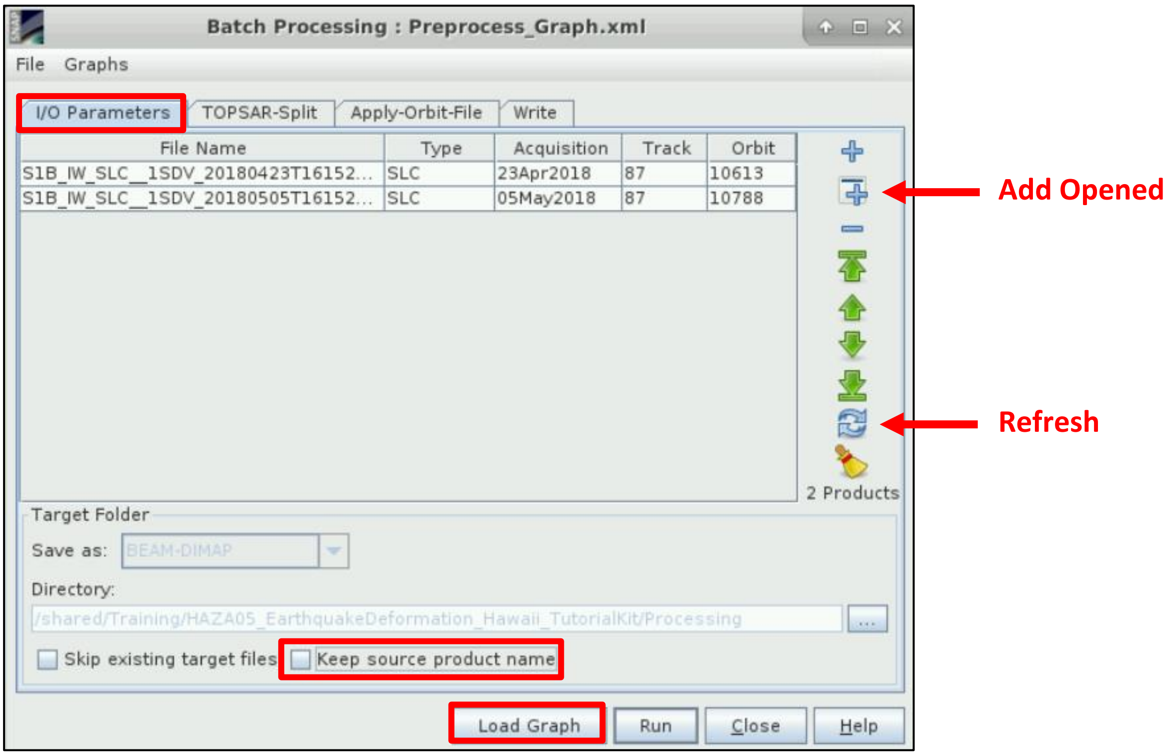
Close the **Graph Builder** window.

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**.

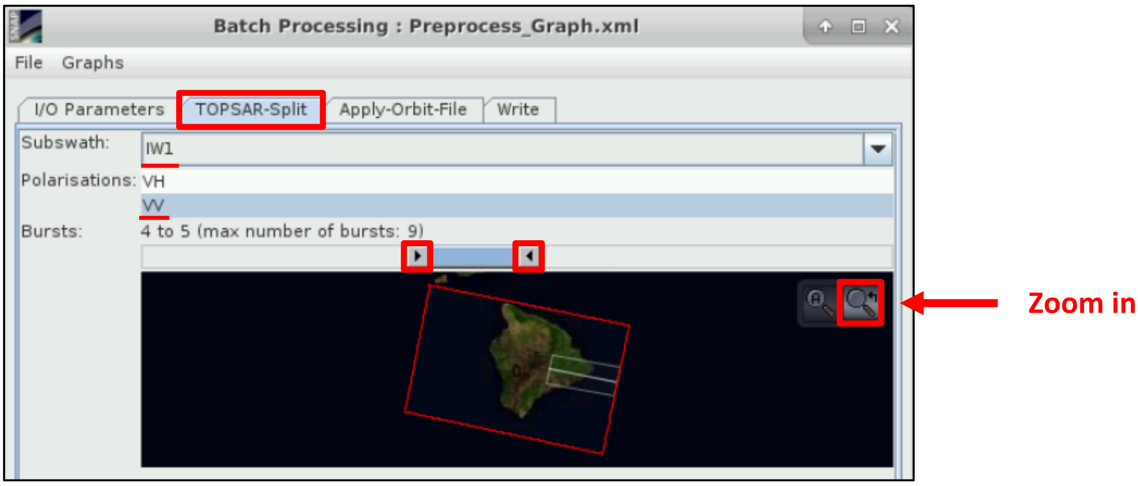
In the **I/O Parameters** tab we will add both opened products from the **Product Explorer** window by clicking **Add Opened** at the right (second icon from the top) and then click **Refresh** (second icon from the bottom). **Deselect** the "**Keep source product name**" option.

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

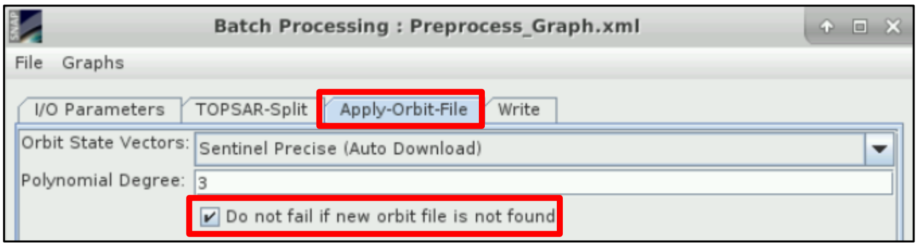


In the **TOPSAR-Split** tab **Zoom in** to the product and choose:

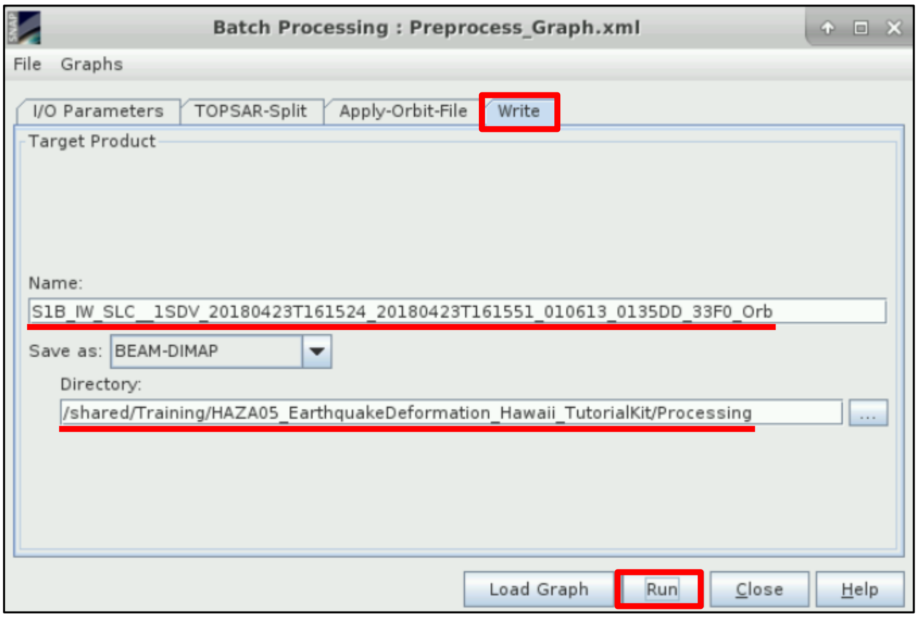
Subswath: IW1
Polarisations: VV
Bursts: 4 to 5 (drag the two sliders accordingly)



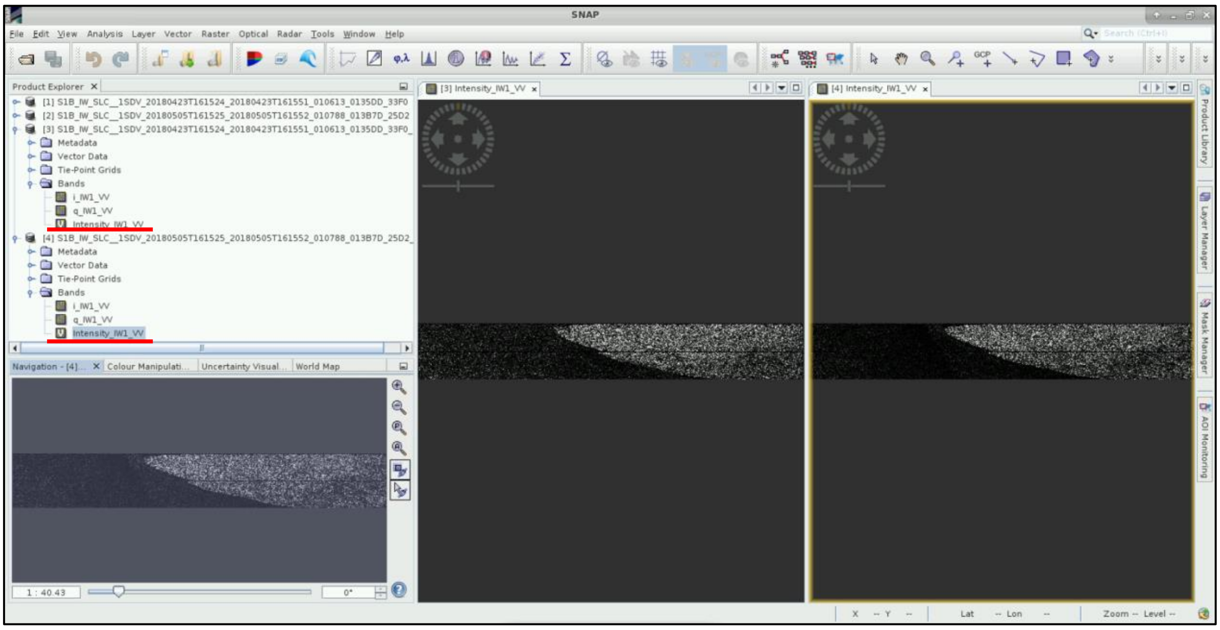
In the **Apply-Orbit-File** tab we will keep the default settings and make sure that you will **select** the "**Do not fail if new orbit file is not found**" option.



In the **Write** tab keep the "Name" that is created with the "**Orb**" suffix and under the "Directory" set the path to ***/shared/Training/HAZA05_EarthquakeDeformation_Hawaii_TutorialKit/Processing*** folder. Then click **Run**.



Now close the **Batch Processing** window, collapse the products **[1]** and **[2]** and close the opened **View** windows as well. The two new products have appeared to the **Product Explorer** window. Expand the products **[3]** and **[4]**, expand the **Bands** folder and double click on the ***Intensity_IW1_VV*** band.

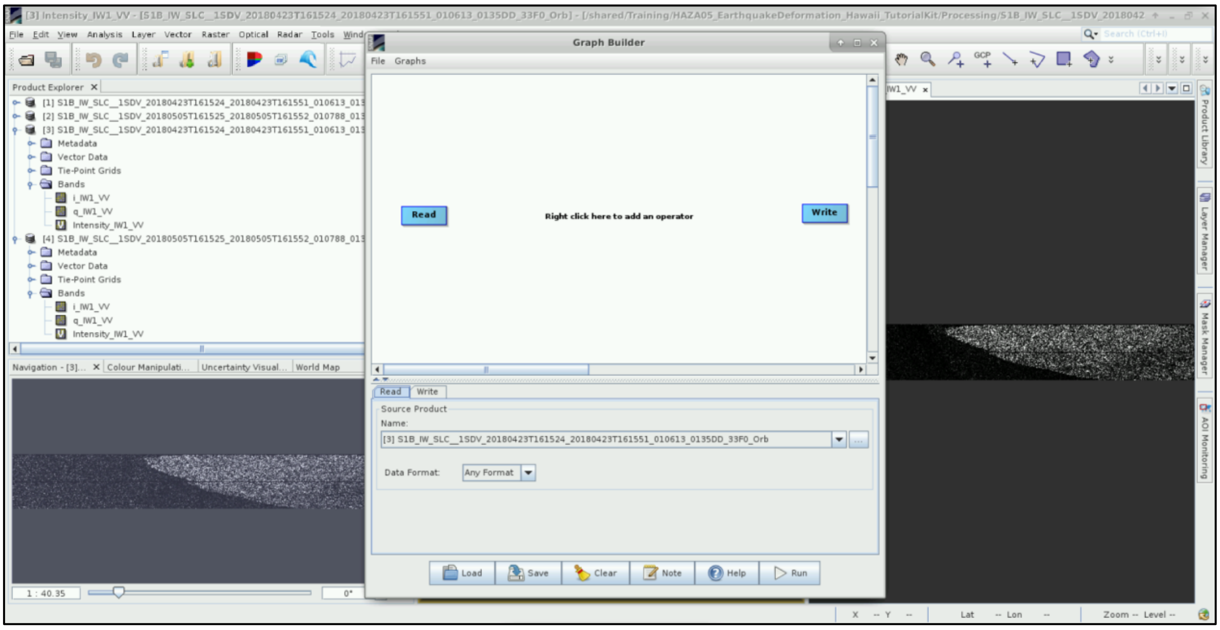


5.4 Coregistration and Interferometric Processing

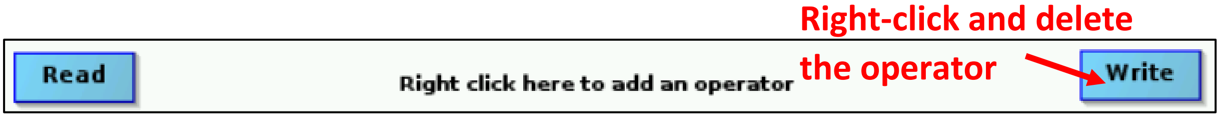
5.4.1 Data Coregistration

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.

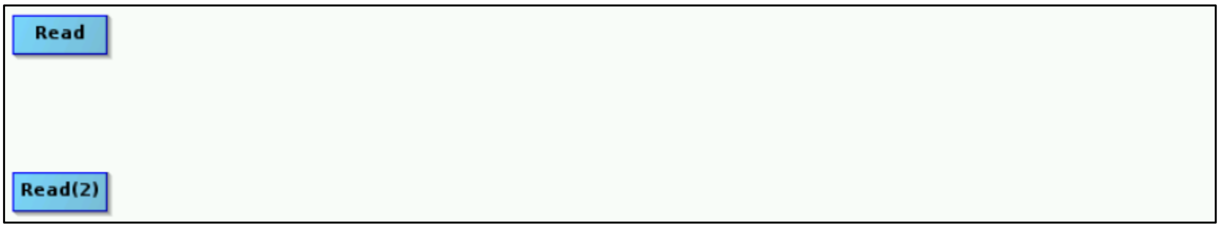
Let's open again a **GraphBuilder** window. Go to **Tools → GraphBuilder**. We can see that the graph has only two operators: **Read** and **Write** and below there also are the corresponding to the operators' tabs.



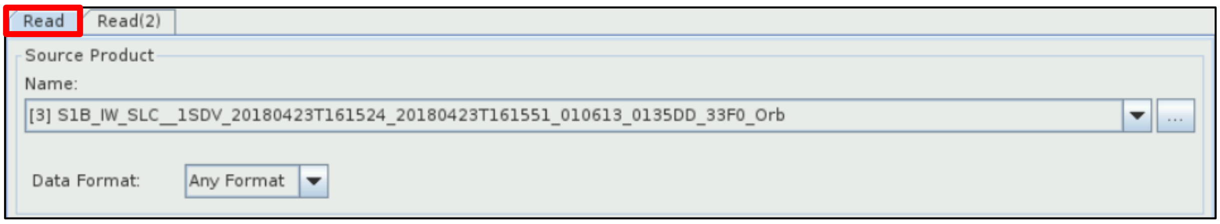
First, right-click on the **Write** operator and **Delete** it. This time, we will also define in parallel the parameters in the tabs.



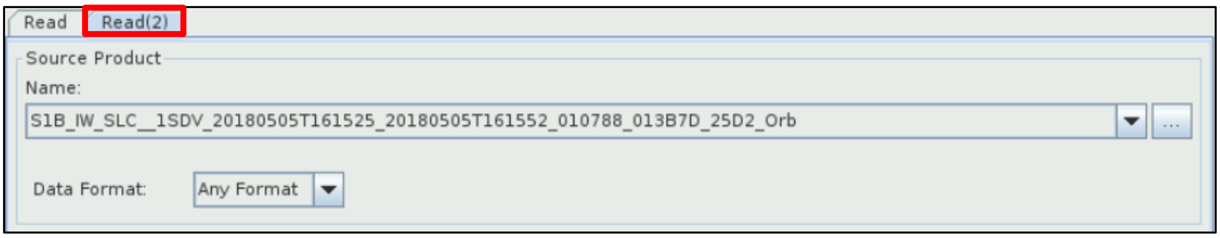
Now, add one more **Read** operator. Right click and go to **Add → Input-Output → Read**. The inputs will be the products we want to coregister.



In the **Read** tab choose the product **[3]** that contains only the 2 bursts of IW1 swath with updated orbits: **S1B_IW_SLC__1SDV_20180423T161524_20180423T161551_010613_0135DD_33F0_Orb**

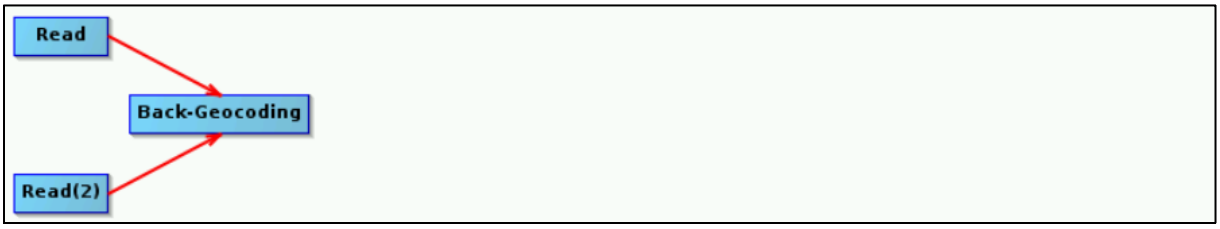


In the **Read(2)** tab choose the second product **[4]** as well that contains only the 2 bursts of IW1 swath with updated orbits:
S1B_IW_SLC__1SDV_20180505T161525_20180505T161552_010788_013B7D_25D2_Orb



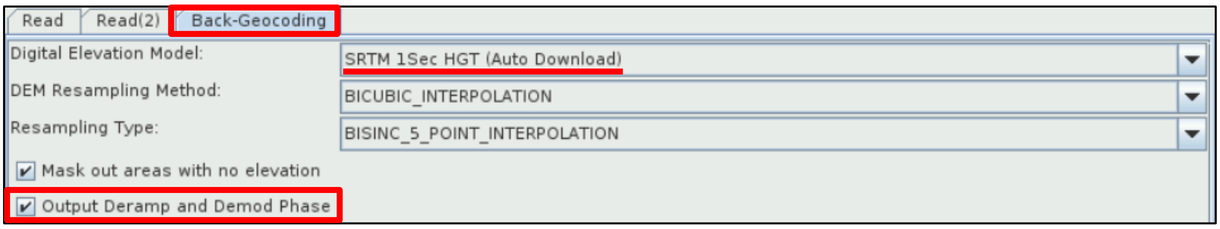
5.4.1.1 Back-Geocoding

Now we will coregister the two products by using their orbits and a DEM. 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) (See NOTE 4).
DEM Resampling Method: BILINEAR_INTERPOLATION
Resampling Type: BILINEAR_INTERPOLATION
Select the "**Output Deramp and Demod Phase**" option as well (See NOTE 5).



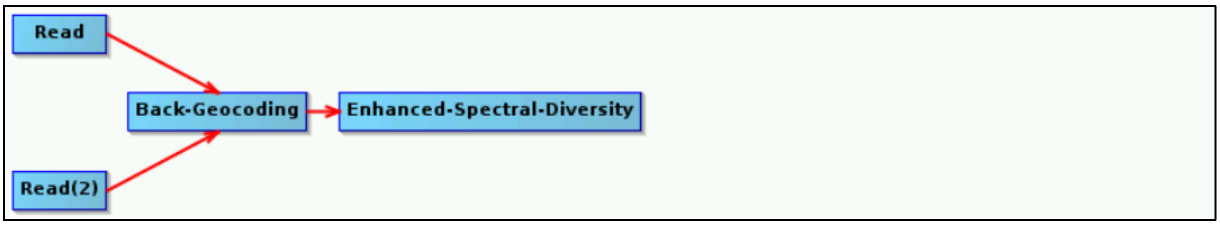
NOTE 4: We will use the **SRTM 1Sec HGT (Auto Download)** which has **~30m resolution** instead of the default SRTM 3sec (Auto Download) which has ~90m resolution, but this will increase the processing time. In case you want to process more than 2 images simultaneously and you do not have enough RAM, you can use the SRTM 3sec (Auto Download) DEM.

NOTE 5: The "**Output Deramp and Demod Phase**" option is necessary when Enhanced Spectral Diversity is following.

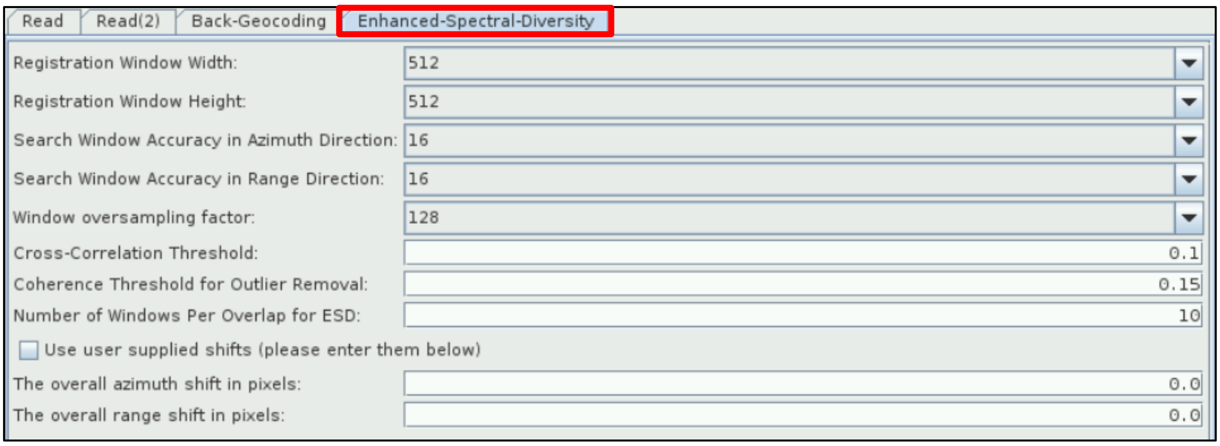
5.4.1.2 Enhanced Spectral Diversity

This **Enhanced Spectral Diversity** 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 (See TIP 1).



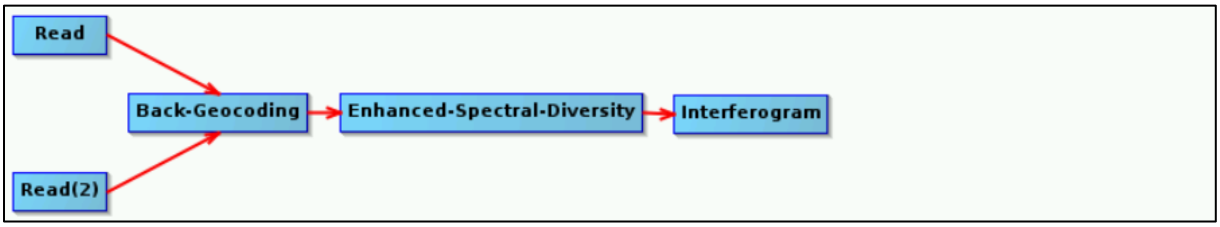
In the **Enhanced-Spectral-Diversity** tab keep all the default parameters.



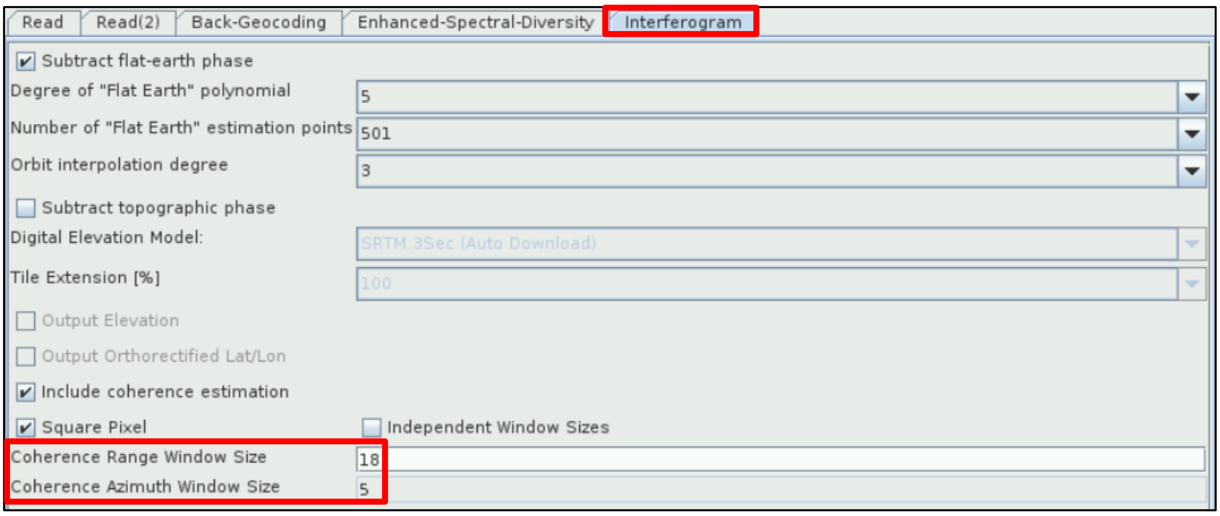
TIP 1: If you want to coregister only two Sentinel-1 images and save the stack product created, you can replace all steps of chapters 5.3 until 5.4.1.2 by going to: **Radar → Coregistration → S1 TOPS Coregistration → S-1 TOPS Coregistration with ESD**.

5.4.2 Interferogram Formation

Let's create the interferogram of the two images used for the stack product. 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.

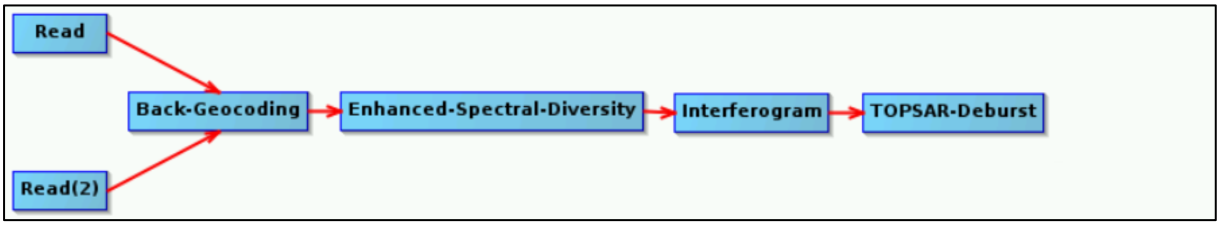


In the **Interferogram** tab keep the default parameters and set as **Coherence Range Window Size**: 18. The **Coherence Azimuth Window Size** will automatically change to 5.

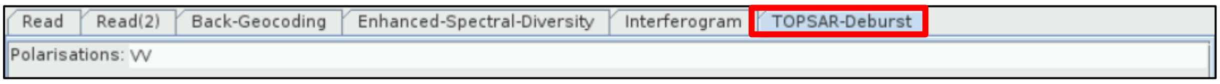


5.4.3 TOPS Deburst

Now we will remove the "black space" between the two bursts (See NOTE 6). To add the **TOPSAR-Deburst** operator right-click and go to **Add → Radar → Sentinel-1 TOPS → TOPSAR-Deburst**. Connect the **Interferogram** operator to it.



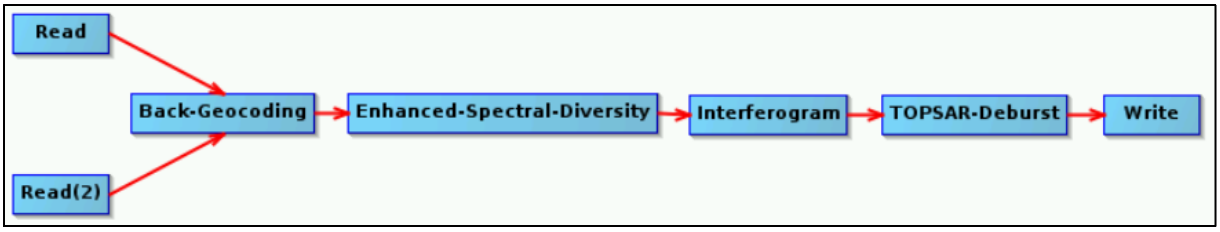
In the **TOPSAR-Deburst** tab keep the default settings (Polarizations: **VV**).



NOTE 6: 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.

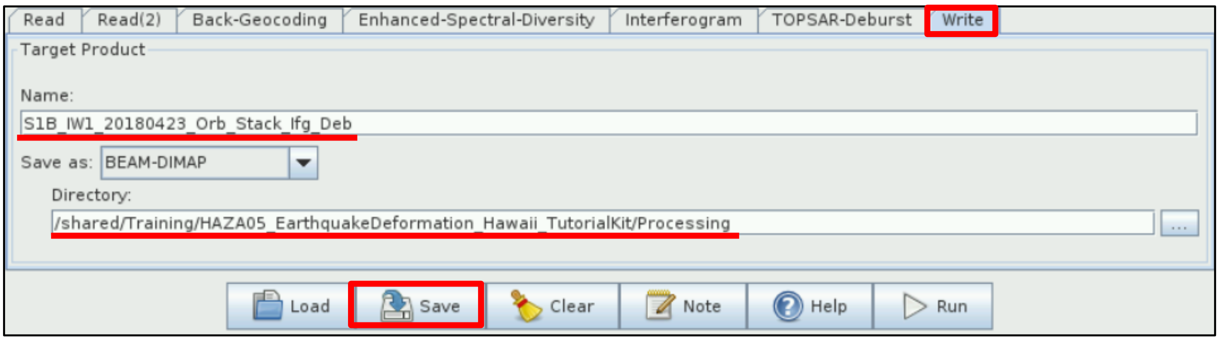
5.4.4 Write/create the product

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



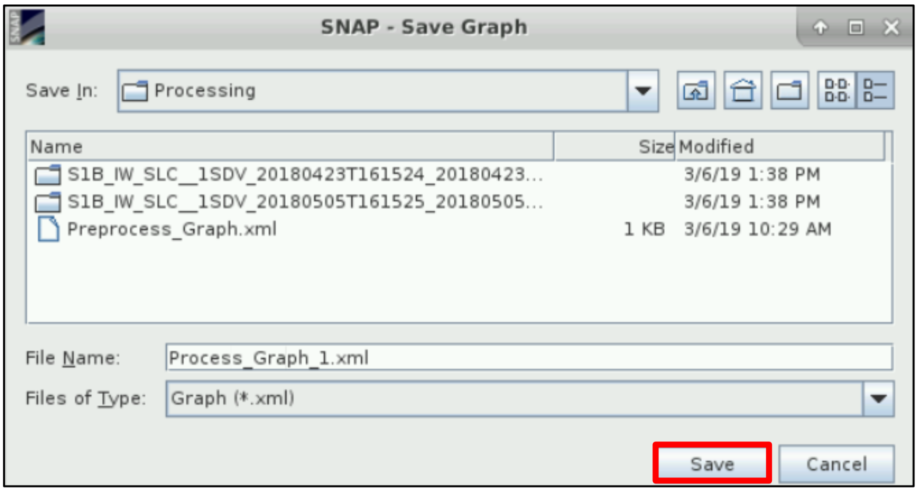
In the **Write** tab set the following:

Name: S1B_IW1_20180423_Orb_stack_ifg_Deb
Directory: ***/shared/Training/HAZA05_EarthquakeDeformation_Hawaii_TutorialKit/Processing***



Then click on 

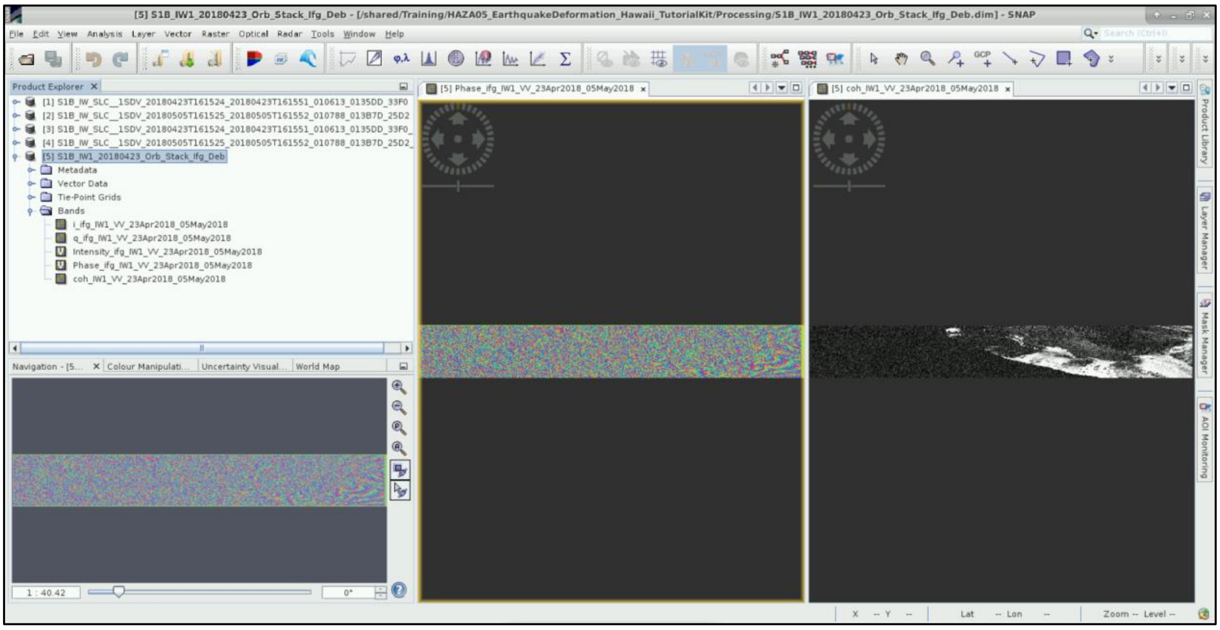
icon at the bottom of the **Graph Builder** window and save the graph under ***/shared/Training/HAZA05_EarthquakeDeformation_Hawaii_TutorialKit/Processing*** folder with the name **Process_Graph_1.xml.**



Finally, click on the 

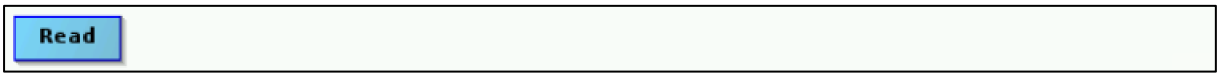
icon at the bottom of the **Graph Builder** window. *The process will be completed in 40 minutes in a 32GB RAM VM.*

Now close the **Graph Builder** window, collapse the products **[3]** and **[4]** and close the opened **View** windows as well. The new product has appeared to the **Product Explorer** window. Expand the product **[5]**, expand the **Bands** folder and double click on the ***Phase_ifg_IW1_VV_23Apr2018_05May2018*** and the ***coh_IW1_VV_23Apr2018_05May2018*** bands.

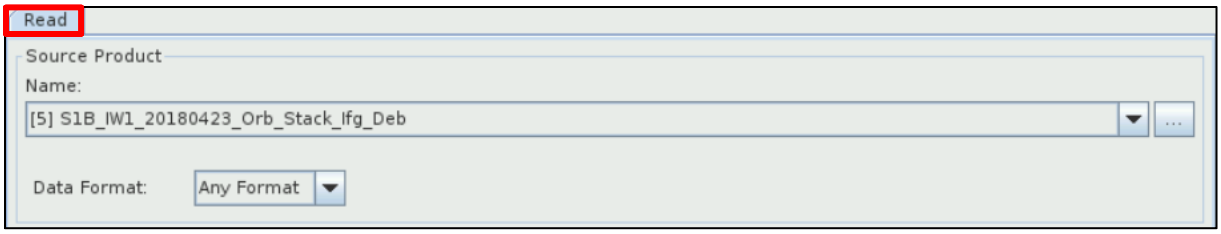


Let’s open another **GraphBuilder** window. Go to **Tools → GraphBuilder**.

Keep only the **Read** operator and delete again the **Write** operator.



In the **Read** tab choose the coregistered product **[5] S1B_IW1_20180423_Orb_stack_ifg_Deb**.



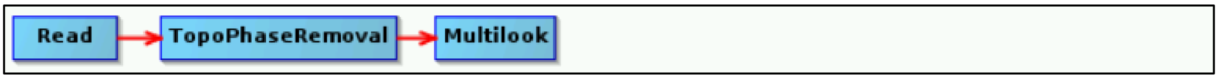
5.4.5 Topographic Phase Removal

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.

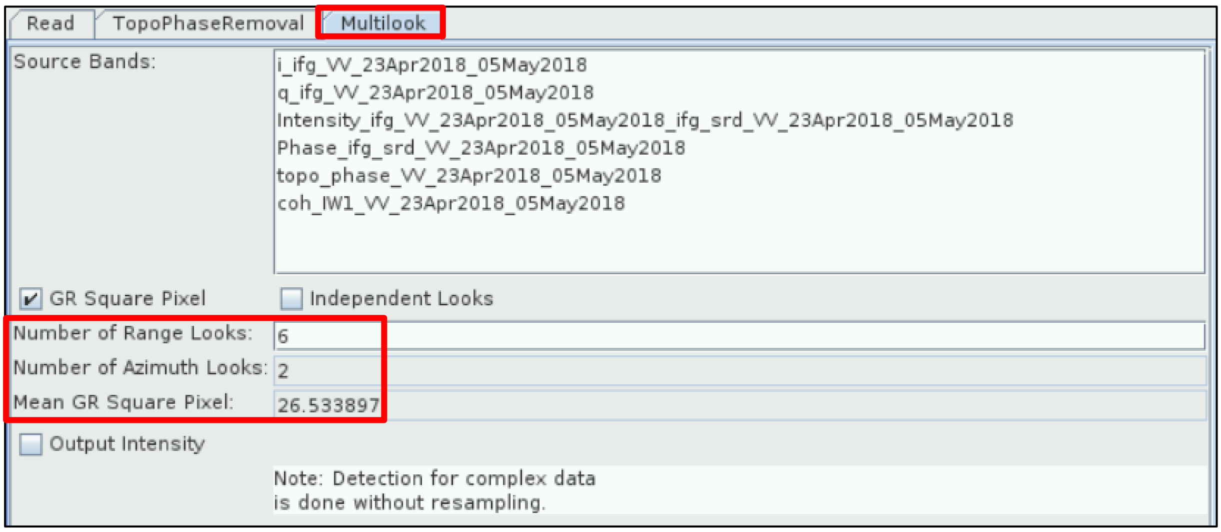
In the **TopoPhaseRemoval** tab set as **Digital Elevation Model**: SRTM 1Sec HGT (Auto Download) and **select** the “**Output topographic phase band**” option as well.

5.4.6 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 → Multilook**. Connect the **TopoPhaseRemoval** operator to it.

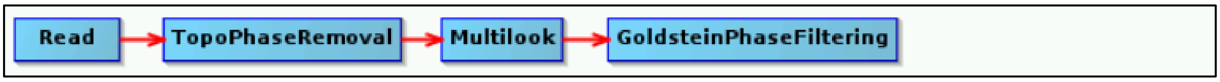


In the **Multilook** tab keep the "**GR Square Pixel**" option selected and set **Number of Range Looks**: 6. The **Number of Azimuth Looks** will automatically change to 2 and the **Mean GR Square Pixel** to 26.533897.

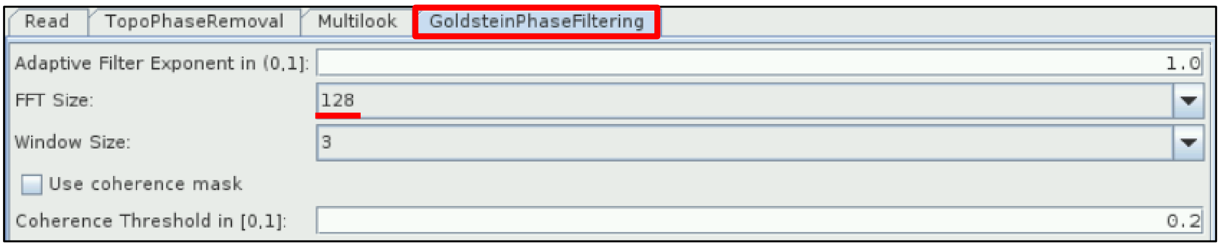


5.4.7 Phase Filtering

Phase filtering reduces the phase noise (See NOTE 7). To add the **GoldsteinPhaseFiltering** operator right-click and go to **Add → Radar → Interferometric → Filtering → GoldsteinPhaseFiltering.** Connect the **Multilook** operator to it.

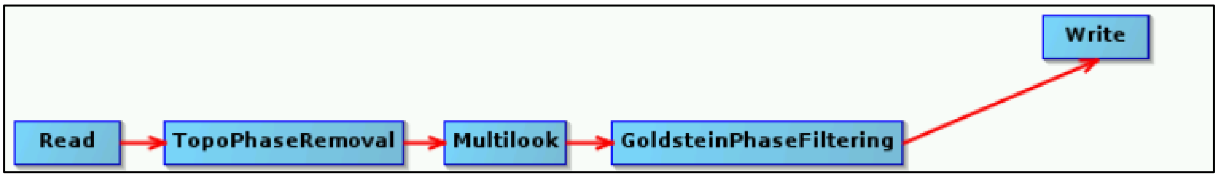


In the **GoldsteinPhaseFiltering** tab set the **FFT Size** to 128 and keep the rest parameters as by default.



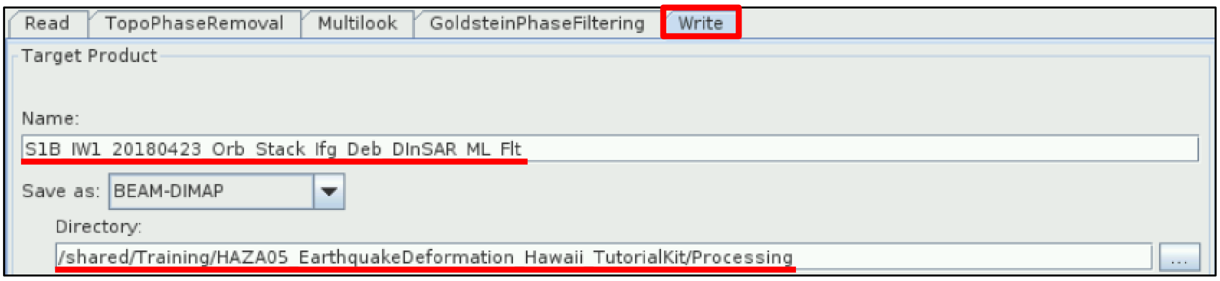
NOTE 7: It is necessary step since it will enhance the phase unwrapping accuracy for the upcoming step (See chapter 5.4.8).

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.

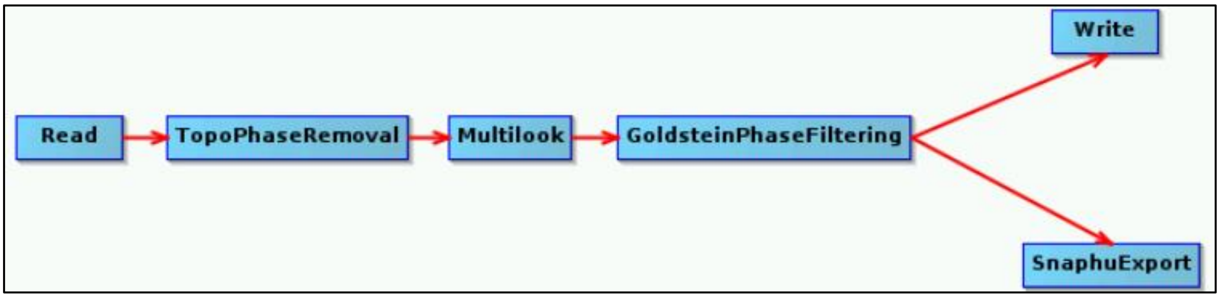


In the **Write** tab set the following:

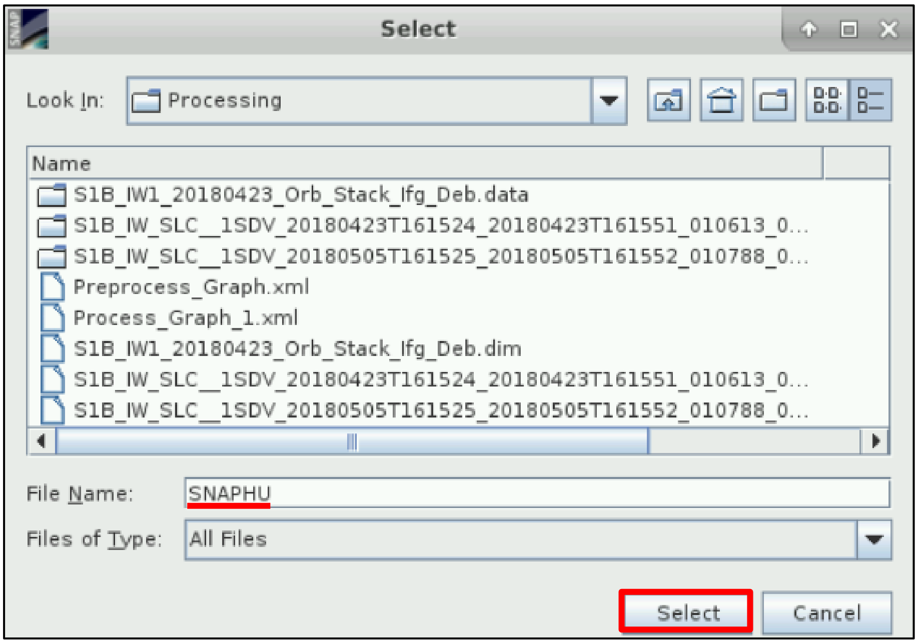
Name: S1B_IW1_20180423_Orb_stack_ifg_Deb_DInSAR_ML_Flt
Directory: ***/shared/Training/HAZA05_EarthquakeDeformation_Hawaii_TutorialKit/Processing***



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

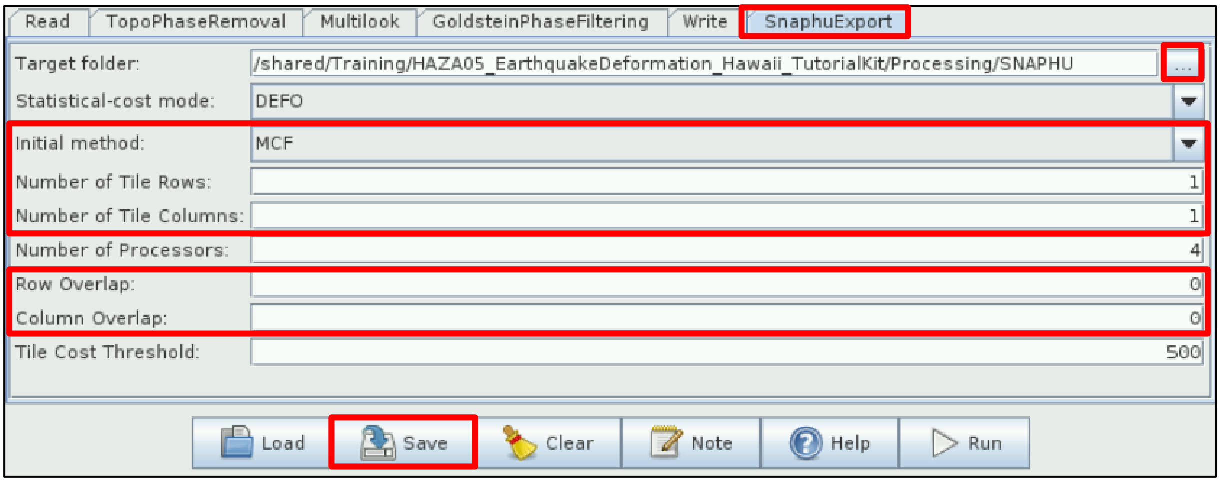


In the **SnaphuExport** tab click on  icon to set the **Target folder**. Navigate to the following path: ***/shared/Training/HAZA05_EarthquakeDeformation_Hawaii_TutorialKit/Processing*** and write at the **File Name**: SNAPHU. Click **Select**.

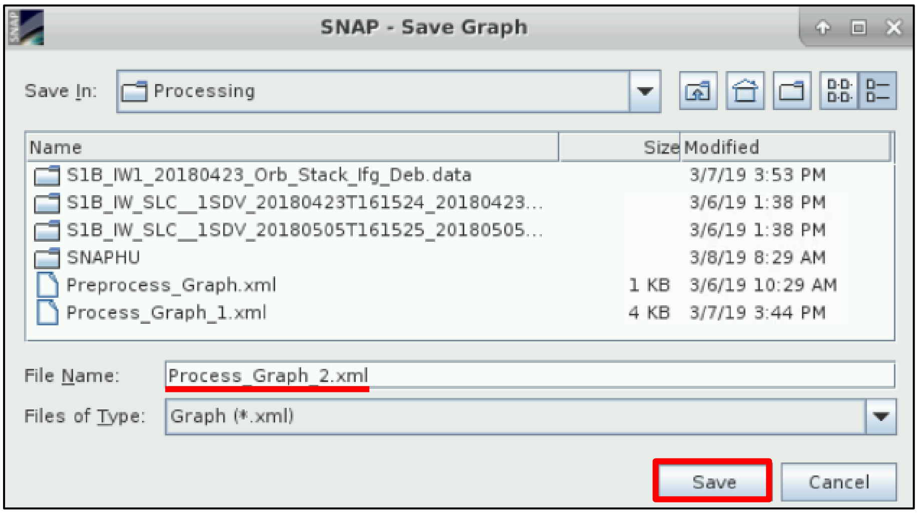


Then define the following parameters in the **SnaphuExport** tab:

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



Click on [Save] icon at the bottom of the **Graph Builder** window and save the graph under ***/shared/Training/HAZA05_EarthquakeDeformation_Hawaii_TutorialKit/Processing*** folder with the name **Process_Graph_2.xml.**

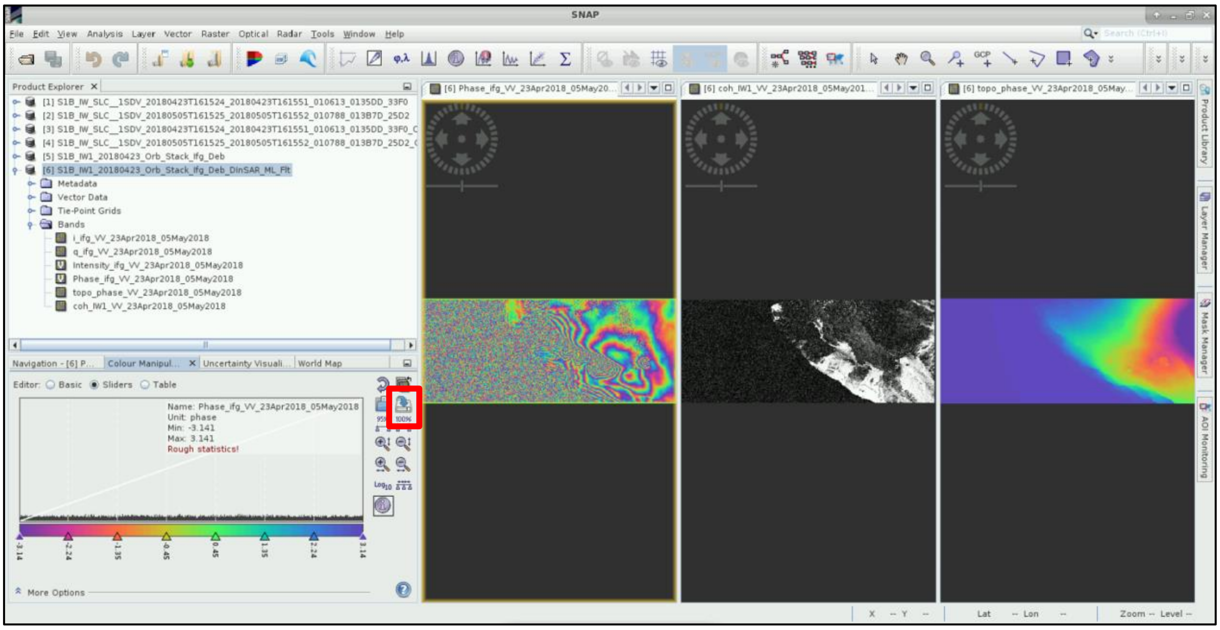


Finally, click on the [Run] icon at the bottom of the **Graph Builder** window.

Now close the **Graph Builder** window, collapse the product **[5]** and close the opened **View** windows as well. The new product has appeared to the **Product Explorer** window. Expand the product **[6]**, expand the **Bands** folder and double click on the ***Phase_ifg_IW1_VV_23Apr2018_05May2018***, ***topo_phase_VV_23Apr2018_05May2018*** and the ***coh_IW1_VV_23Apr2018_05May2018*** bands.

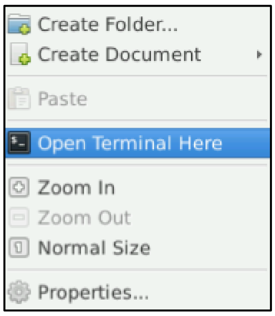
Choose the ***Phase_ifg_IW1_VV_23Apr2018_05May2018*** band in the **View** window, go to **Colour Manipulation** tab and click on the "Auto-adjust to 100% of all pixels" icon [100%]. We can see values that correspond to the fringes of the differential interferogram (-pi, pi). Repeat the same for the

coh_IW1_VV_23Apr2018_05May2018 band. Coherence values vary from 0 to 1 (1 = most coherent).



5.4.8 Phase Unwrapping

Phase unwrapping is prerequisite to convert phase units to length units (See NOTE 8). Open the:



/shared/Training/HAZA05_EarthquakeDeformation_Hawaii_TutorialKit/Processing/SNAPHU/S1B_IW1_20180423_Orb_Stack_Ifg_Deb_DInSAR_ML_Flt/ folder and right-click in the empty space.

Select "**Open Terminal Here**".

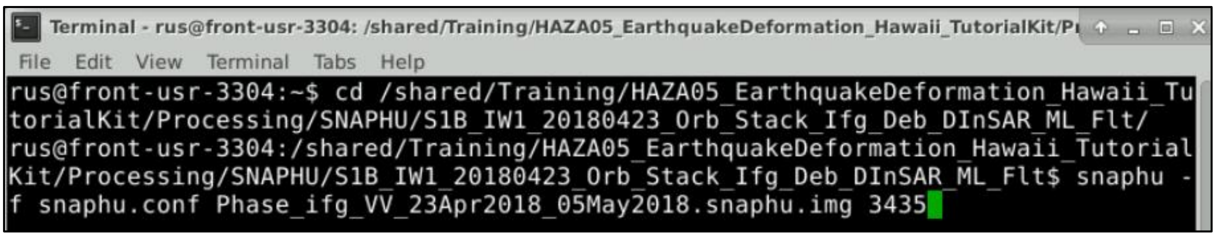
The following terminal will appear.

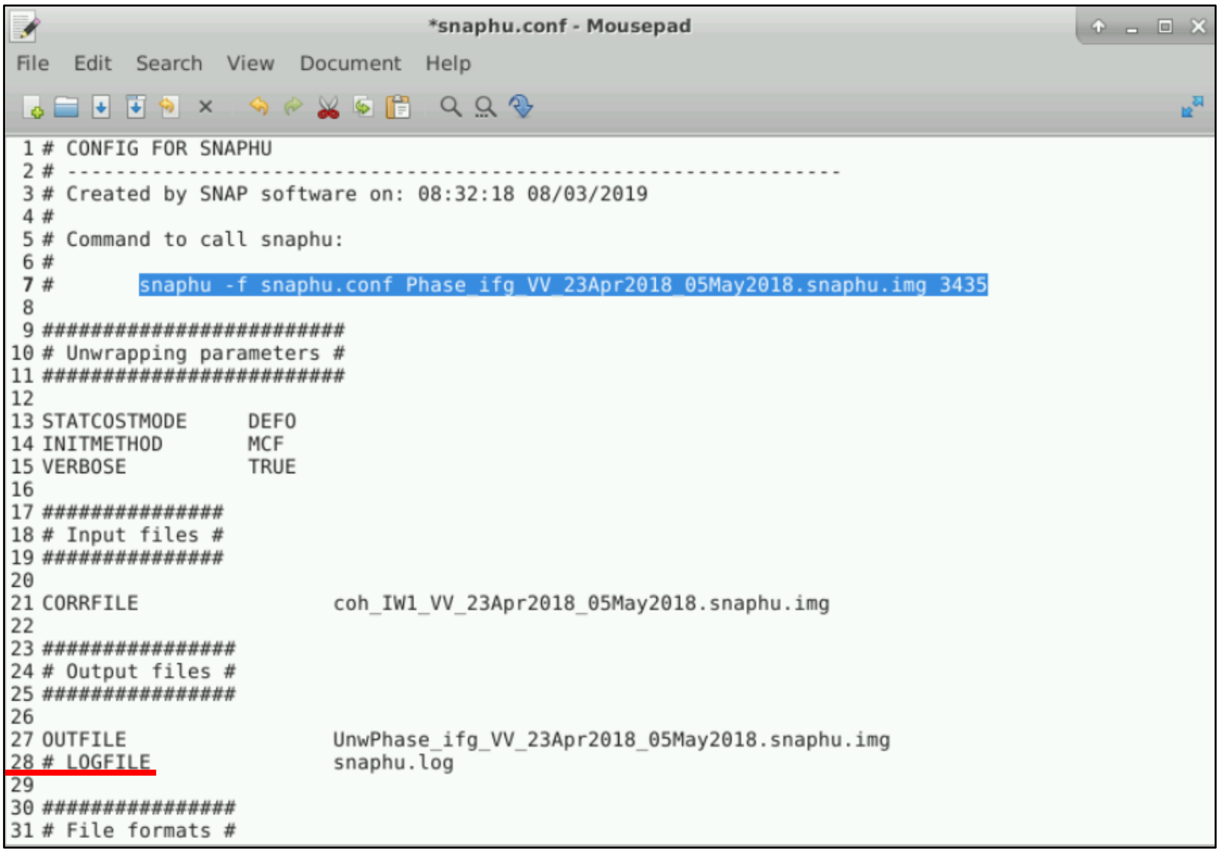
In the same folder, open the **snaphu.conf** file.

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:

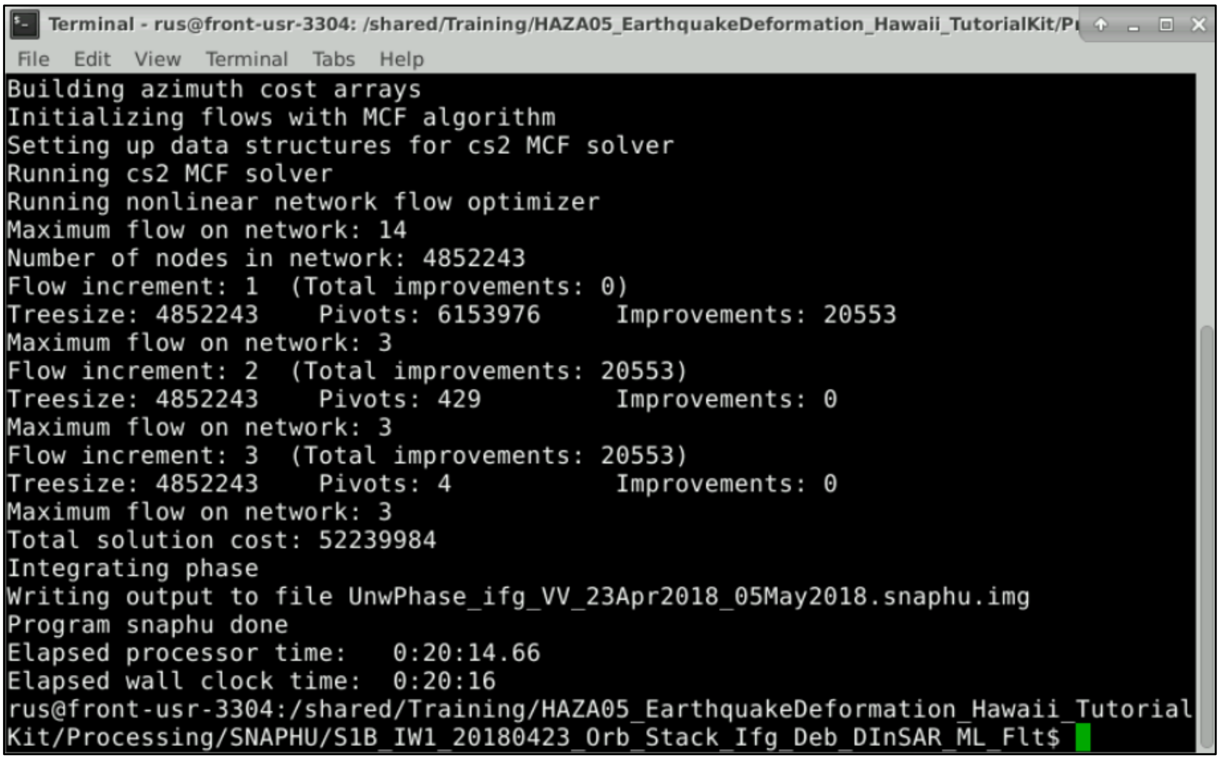
snaphu -f snaphu.conf Phase_ifg_VV_23Apr2018_05May2018.snaphu.img 3435

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





When the processing is completed, the terminal will contain all the information, as shown below.



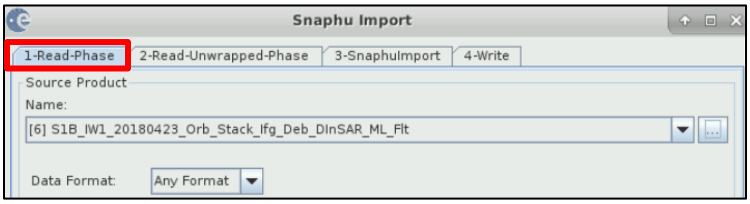
The time needed for the process to be completed depends on the characteristics of your machine. It might take up to 30 minutes. With a 32GB RAM VM it lasted 20 minutes.

> NOTE 8: 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.

5.4.8.1 SNAPHU import to SNAP

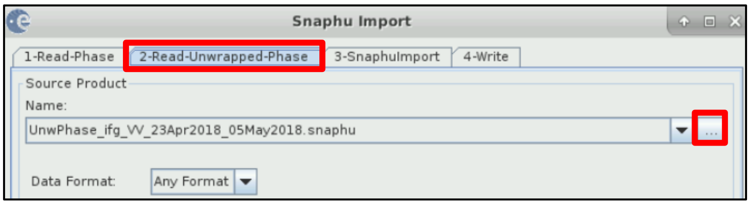
Now we will import the results from SNAPHU processing. Go to **Radar → Interferometric → Unwrapping → Snaphu Import**.

In the **1-Read-Phase** tab, select the product that was created from the **Write** operator:
[6] S1B_IW1_20180423_Orb_Stack_Ifg_Deb_DInSAR_ML_Flt



In the **2-Read-Unwrapped-Phase** tab, click on  to select the product that contains the unwrapped phase: **UnwPhase_ifg_VV_23Apr2018_05May2018.snaphu.hdr** from the following path: ***/shared/Training/HAZA05_EarthquakeDeformation_Hawaii_TutorialKit/Processing/SNAPHU/S1B_IW1_20180423_Orb_Stack_Ifg_Deb_DInSAR_ML_Flt***

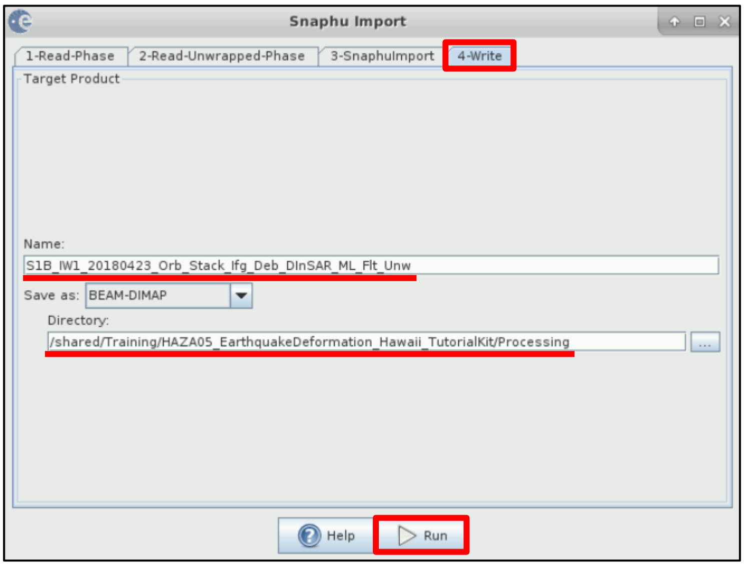
You will see that under the **Name** it is written: UnwPhase_ifg_VV_23Apr2018_05May2018.snaphu



In the **3-SnaphuImport** tab, **select** the "**Do NOT save Wrapped Interferogram in the target product**" option.

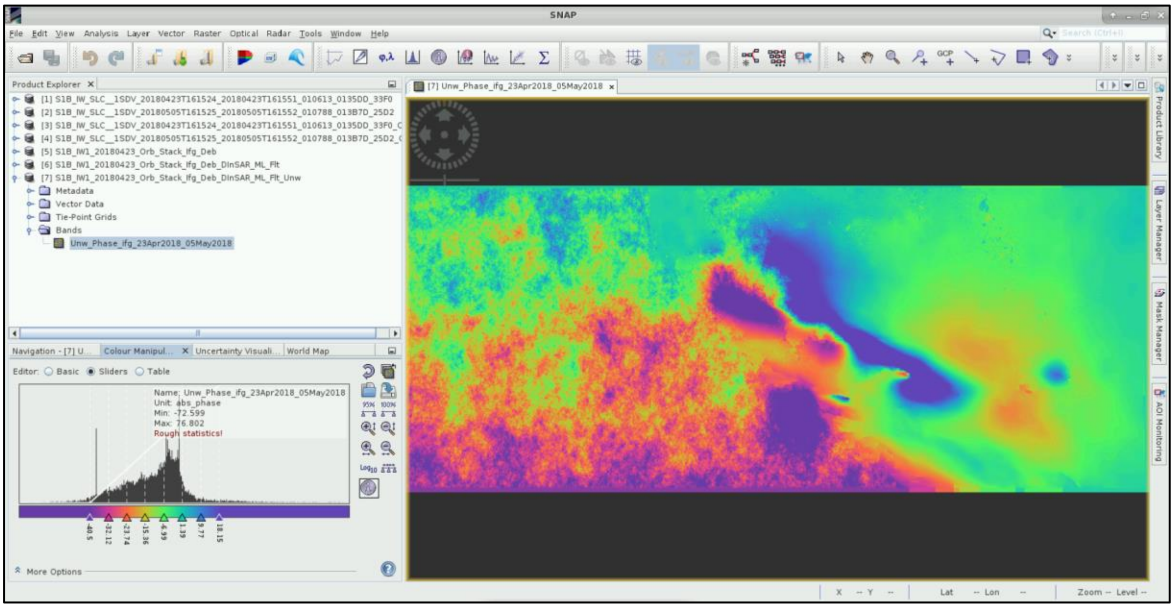
In the **Write** tab, set the following:

Name: S1B_IW1_20180423_Orb_stack_ifg_Deb_DInSAR_ML_Flt_Unw
Directory: ***/shared/Training/HAZA05_EarthquakeDeformation_Hawaii_TutorialKit/Processing***



Click **Run**.

Now close the **Snaphu Import** window, collapse the product **[6]** and close the opened **View** windows as well. The new product has appeared to the **Product Explorer** window. Expand the product **[7]**, expand the **Bands** folder and double click on the ***Unw_Phase_23Apr2018_05May2018*** band. In **Colour Manipulation** tab you can see the absolute values of the phase.

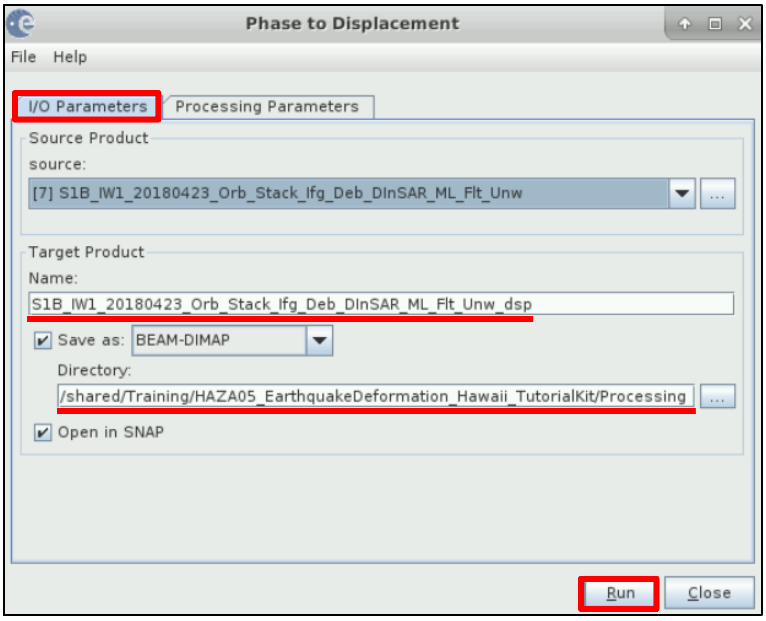


5.4.9 Displacement

It is time to convert the interferometric phase to displacement. Go to **Radar → Interferometric → Products → Phase to Displacement**.

In the **I/O Parameters** tab set the following:

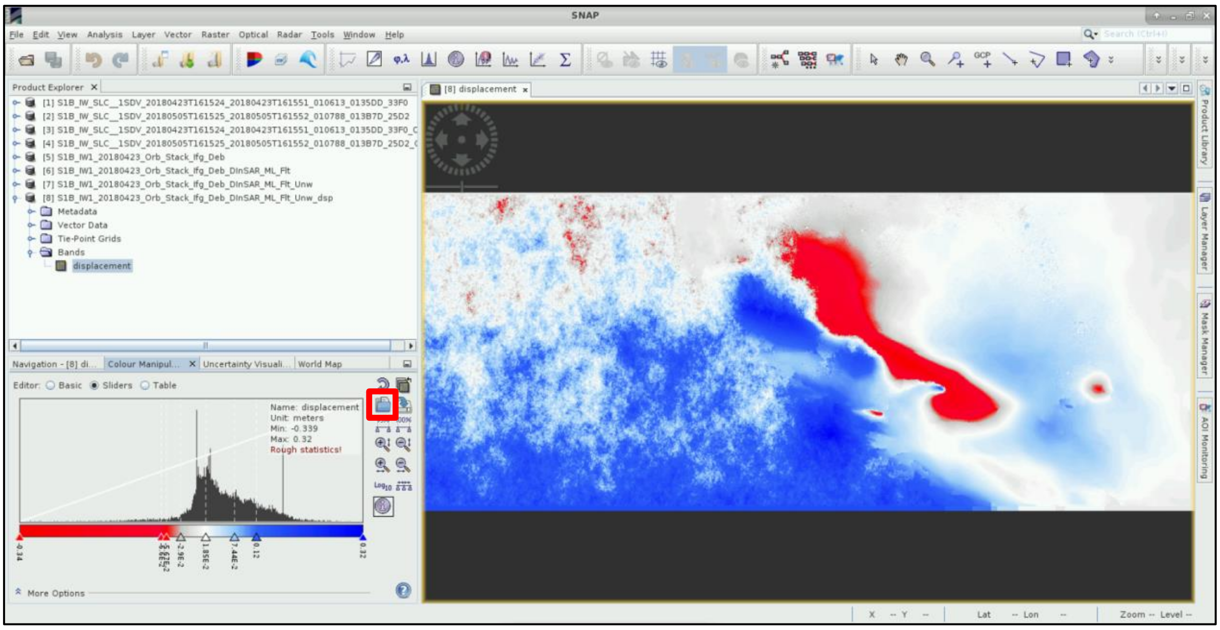
As **source (Input):** [7] S1B_IW1_20180423_Orb_stack_ifg_Deb_DInSAR_ML_Flt_Unw
As **Name (Output):** S1B_IW1_20180423_Orb_stack_ifg_Deb_DInSAR_ML_Flt_Unw_dsp
As **Directory**: ***/shared/Training/HAZA05_EarthquakeDeformation_Hawaii_TutorialKit/Processing***



Click **Run** since there are no parameters in the **Processing Parameters** tab to be changed.

Now close the **Phase to Displacement** window, collapse the product **[7]** and close the opened **View** window as well. The new product has appeared to the **Product Explorer** window. Expand the product **[8]**, expand the **Bands** folder and double click on the **displacement** band.

Click on the "Import colour palette from text file" icon, and open the **Displacement.cpd** colour palette from: ***/shared/Training/HAZA05_EarthquakeDeformation_Hawaii_TutorialKit/AuxData*** folder.



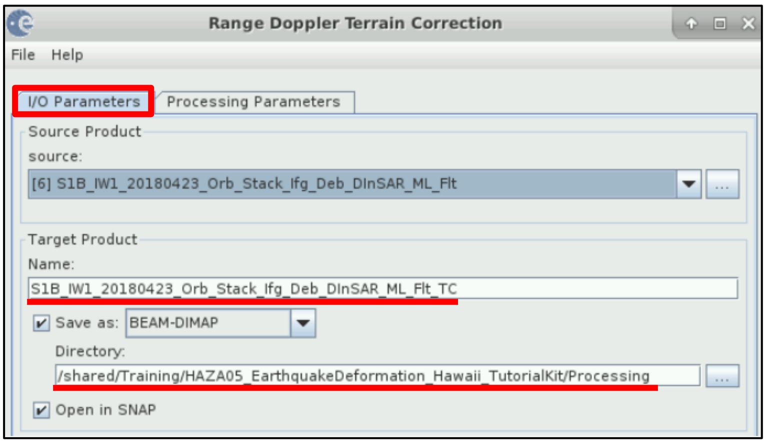
5.5 *Geocoding*

We will apply the **Terrain Correction** in the product containing the unwrapped interferogram and then to the one containing the displacement as well, to convert the RADAR coordinates into geographic.

Go to **Radar → Geometric → Terrain Correction → Range-Doppler Terrain Correction**.

In the **I/O Parameters** tab set the following:

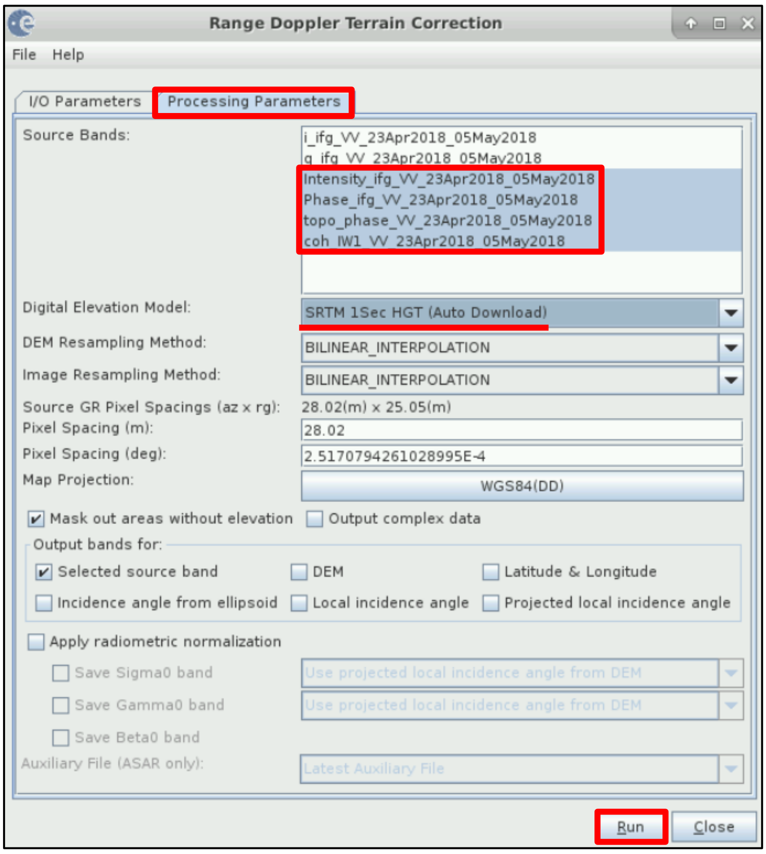
As **source (Input):** [6] S1B_IW1_20180423_Orb_stack_ifg_Deb_DInSAR_ML_Flt
As **Name (Output):** S1B_IW1_20180423_Orb_stack_ifg_Deb_DInSAR_ML_Flt_TC
As **Directory:** ***/shared/Training/HAZA05_EarthquakeDeformation_Hawaii_TutorialKit/Processing***



In the **Processing Parameters** tab set the following:

In **Source Bands select** only: Intensity_ifg_VV_23Apr2018_05May2018
Phase_ifg_VV_23Apr2018_05May2018
topo_phase_VV_23Apr2018_05May2018
coh_IW1_VV_23Apr2018_05May2018

In **Digital Elevation Model**: SRTM 1Sec HGT (Auto Download)

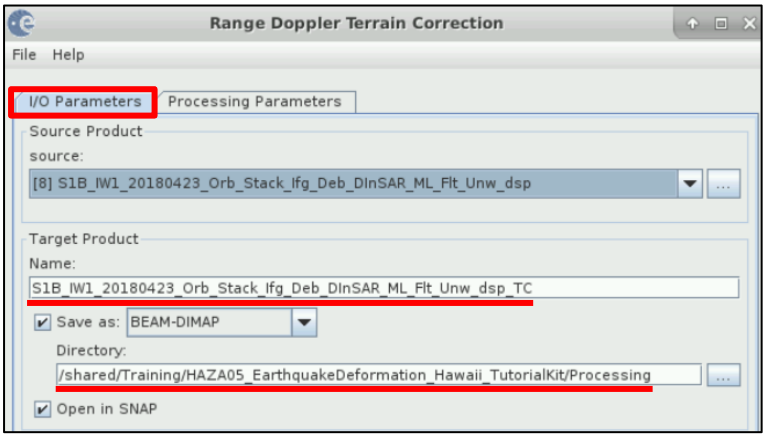


Keep the rest parameters as by default. Click **Run**.

Repeat the same for the displacement product as well.

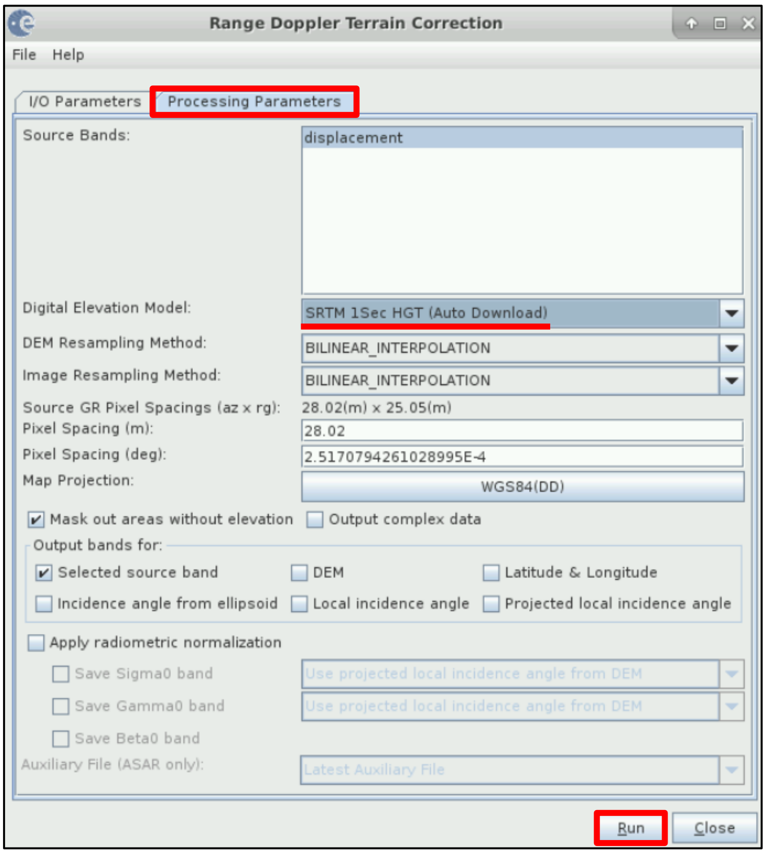
In the **I/O Parameters** tab set the following:

As **source (Input):** [8] S1B_IW1_20180423_Orb_stack_ifg_Deb_DInSAR_ML_Flt_Unw_dsp
As **Name (Output):** S1B_IW1_20180423_Orb_stack_ifg_Deb_DInSAR_ML_Flt_Unw_dsp_TC
As **Directory:** ***/shared/Training/HAZA05_EarthquakeDeformation_Hawaii_TutorialKit/Processing***



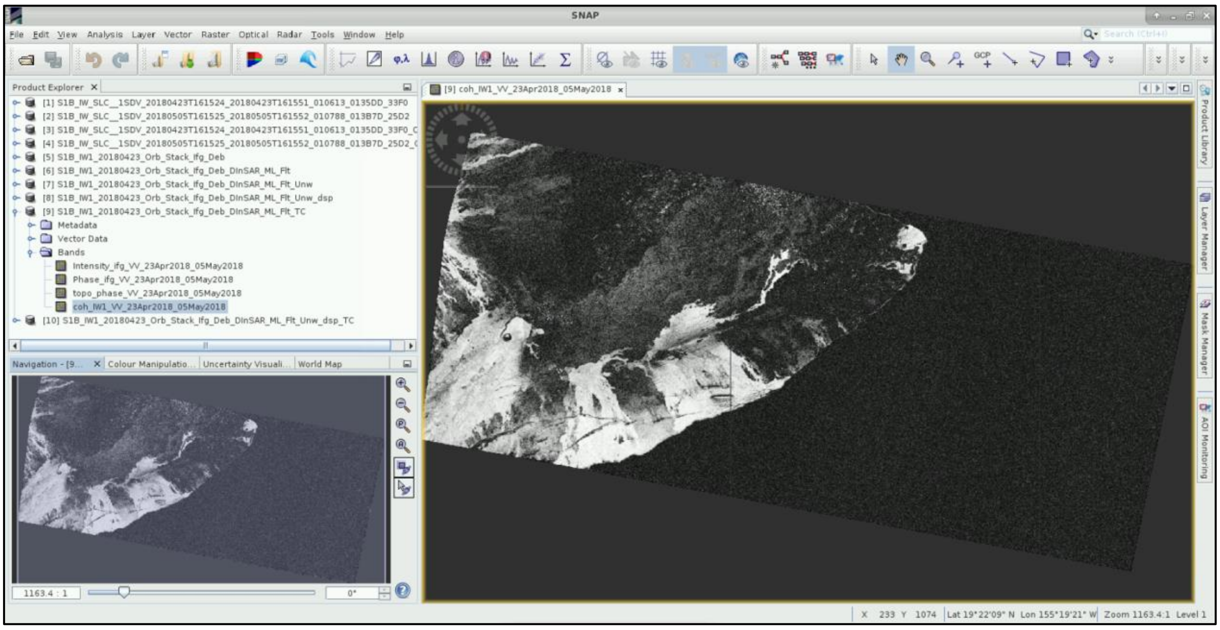
In the **Processing Parameters** tab set the following:

In **Source Bands select**: displacement
In **Digital Elevation Model**: SRTM 1Sec HGT (Auto Download)



Keep the rest parameters as by default. Click **Run**.

Now close the **Range Doppler Terrain Correction** window, collapse all products and close the opened **View** windows as well. The two new products have appeared to the **Product Explorer** window. Expand the products **[9]** and **[10]**, expand the **Bands** folder and double click on the bands you want to visualise (e.g. ***coh_IW1_VV_23Apr2018_05May2018*** band of product **[9]**).



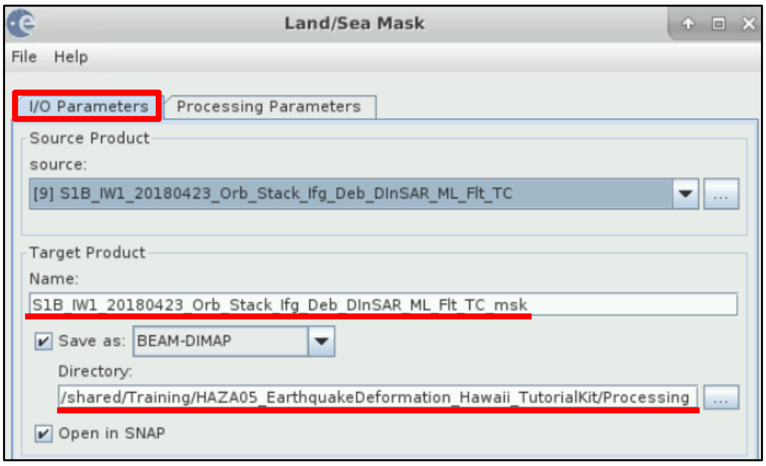
As you can see, although at the **Range Doppler Terrain Correction** step the option "**Mask out areas without elevation**" was selected, we still have pixels that correspond to sea. This is because we used SRTM 1sec DEM with 30m resolution.

5.6 Masking

To mask out the sea from both geocoded products, go to **Raster → Masks → Land/Sea Mask.**

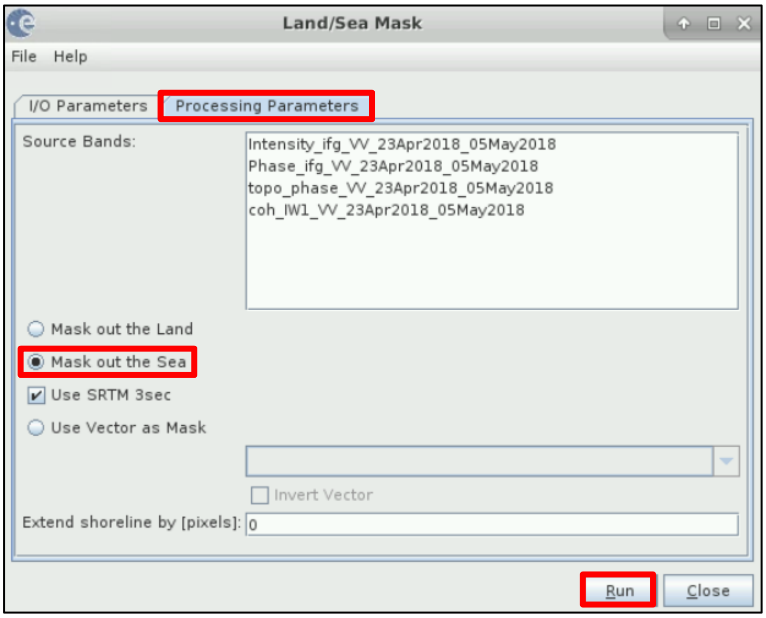
In the **I/O Parameters** tab set the following:

As **source (Input):** [9] S1B_IW1_20180423_Orb_stack_ifg_Deb_DInSAR_ML_Flt_TC
As **Name (Output):** S1B_IW1_20180423_Orb_stack_ifg_Deb_DInSAR_ML_Flt_TC_msk
As **Directory:** ***/shared/Training/HAZA05_EarthquakeDeformation_Hawaii_TutorialKit/Processing***



In the **Processing Parameters** tab **select** the "**Mask out the Sea**" option.

Click **Run**.



Repeat the same for the displacement product as well.

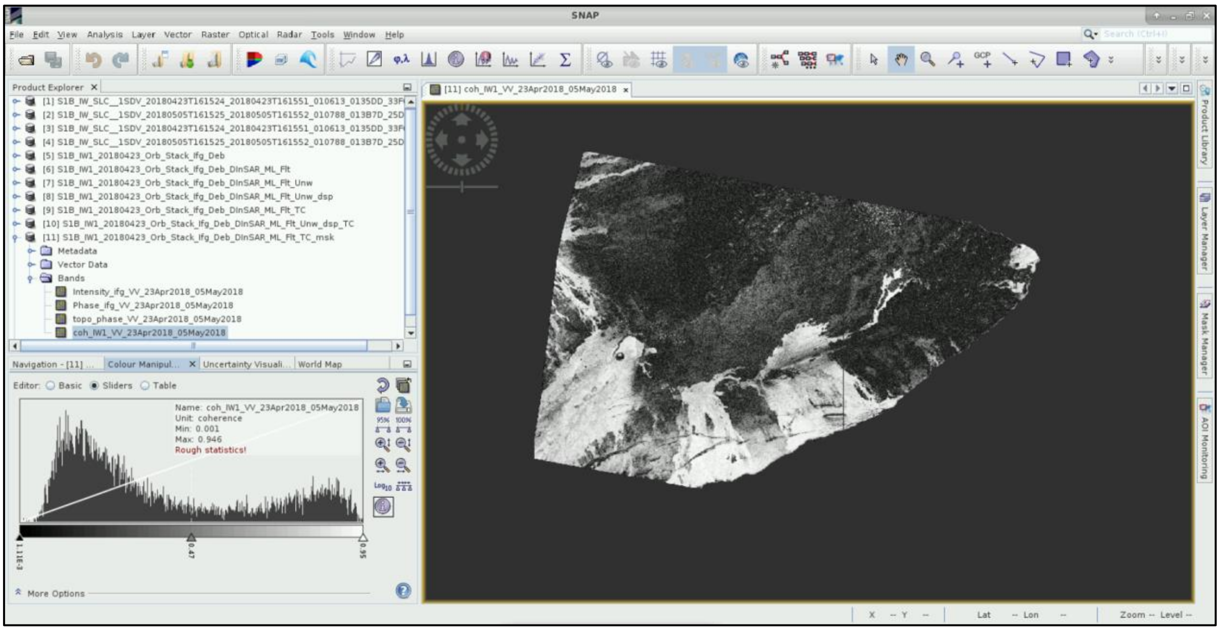
In the **I/O Parameters** tab set the following:

As **source (Input):** [10] S1B_IW1_20180423_Orb_stack_ifg_Deb_DInSAR_ML_Flt_Unw_dsp_TC

As **Name (Output):** S1B_IW1_20180423_Orb_stack_ifg_Deb_DInSAR_ML_Flt_Unw_dsp_TC_msk
As **Directory:** ***/shared/Training/HAZA05_EarthquakeDeformation_Hawaii_TutorialKit/Processing***

In the **Processing Parameters** tab **select** the "**Mask out the Sea**" option. Click **Run**.

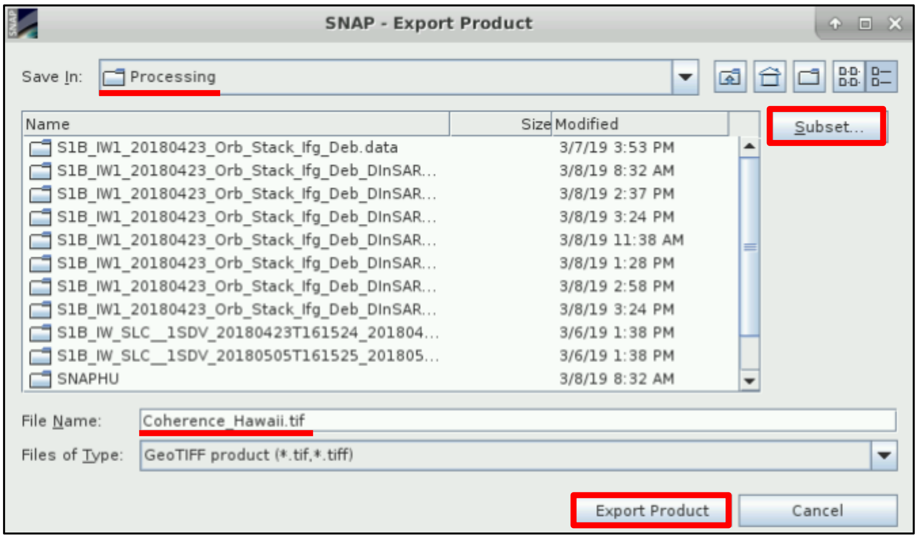
Now close the **Range Doppler Terrain Correction** window, collapse all products and close the opened **View** windows as well. The two new products have appeared to the **Product Explorer** window. Expand the products **[11]** and **[12]**, expand the **Bands** folder and double click on the bands you want to visualise (e.g. ***coh_IW1_VV_23Apr2018_05May2018*** band of product **[11]**).



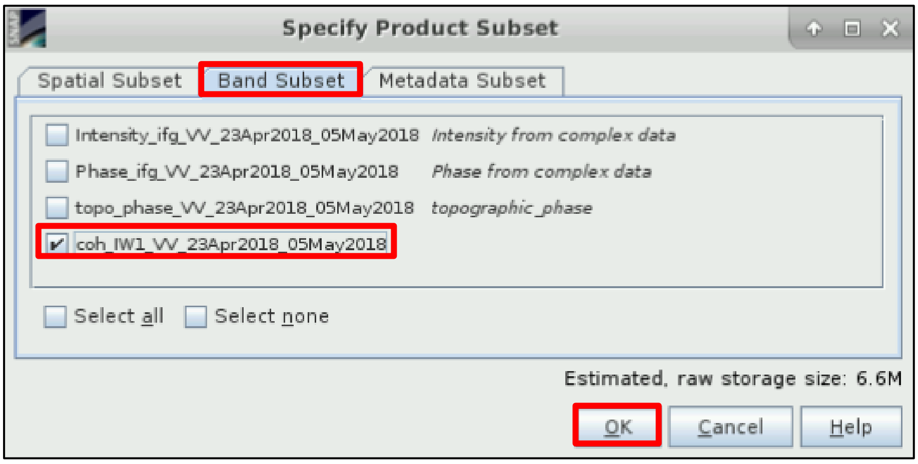
5.7 Export products

Now we will export the bands we want to visualise in **QGIS**, in ***GeoTIFF*** format. Select the appropriate band from the **Product Explorer** window. Go to **File → Export → GeoTIFF.**

Set in **Save In:** ***/shared/Training/HAZA05_EarthquakeDeformation_Hawaii_TutorialKit/Processing*** path and click on "**Subset**".



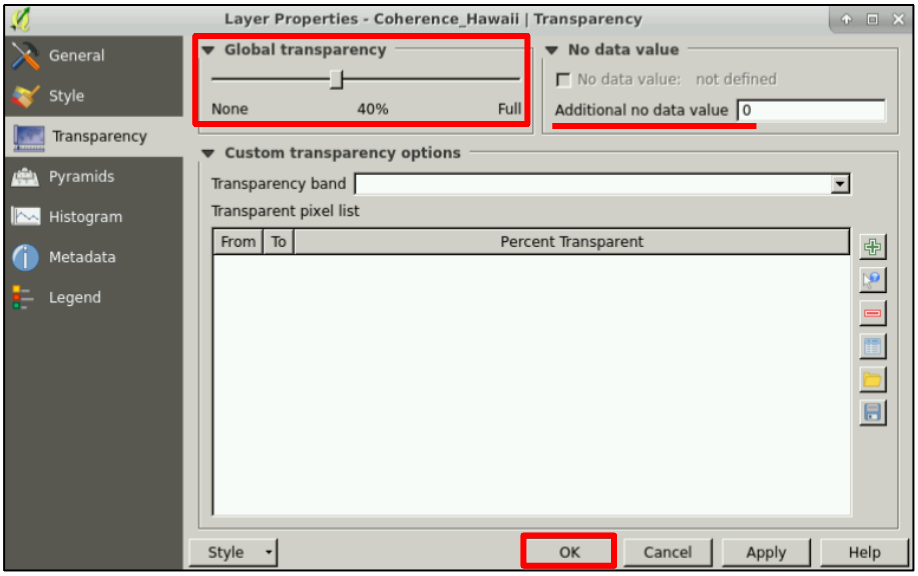
Go to **Band Subset** tab and select only the band you want to export, e.g. from **S1B_IW1_20180423_ Orb_stack_ifg_Deb_DInSAR_ML_Flt_TC** product, select the ***coh_IW1_VV_23Apr2018_05May2018*** band and click **OK**. Set as **File Name**: **Coherence_Hawaii.tif**



Repeat for any band you want to export.

6 Visualization in QGIS

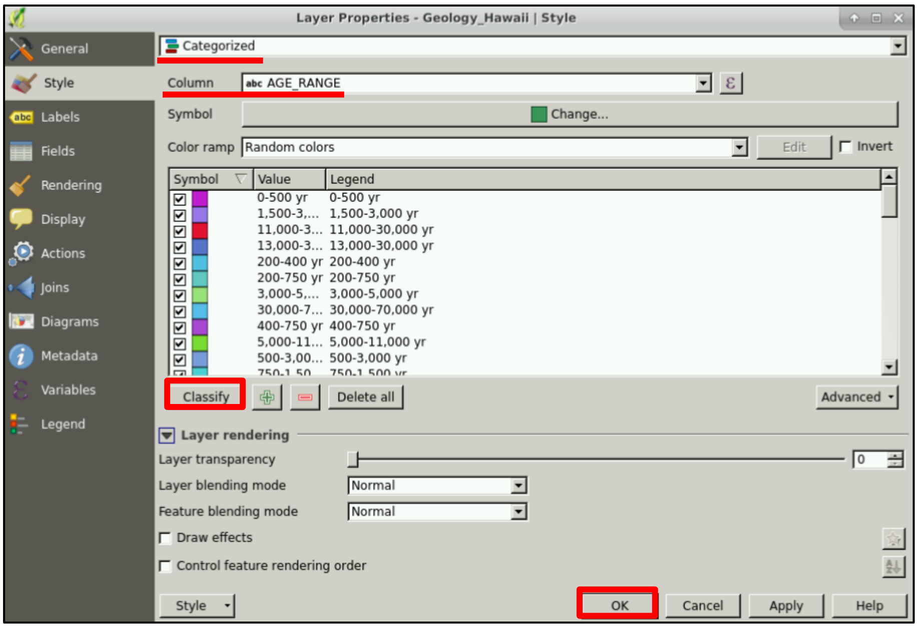
Open **QGIS Desktop** application. In the **Browser Panel**, navigate to ***/shared/Training/HAZA05_Earth quakeDeformation_Hawaii_TutorialKit/Processing*** folder and add the **Coherence_Hawaii.tif**. Right-click on it, go to **Transparency** tab, set the "**Additional no data value**" to **0** to remove the black area of the layer. In order to visualize better the results, set the *Global Transparency* to e.g. **40%** and click **OK**.

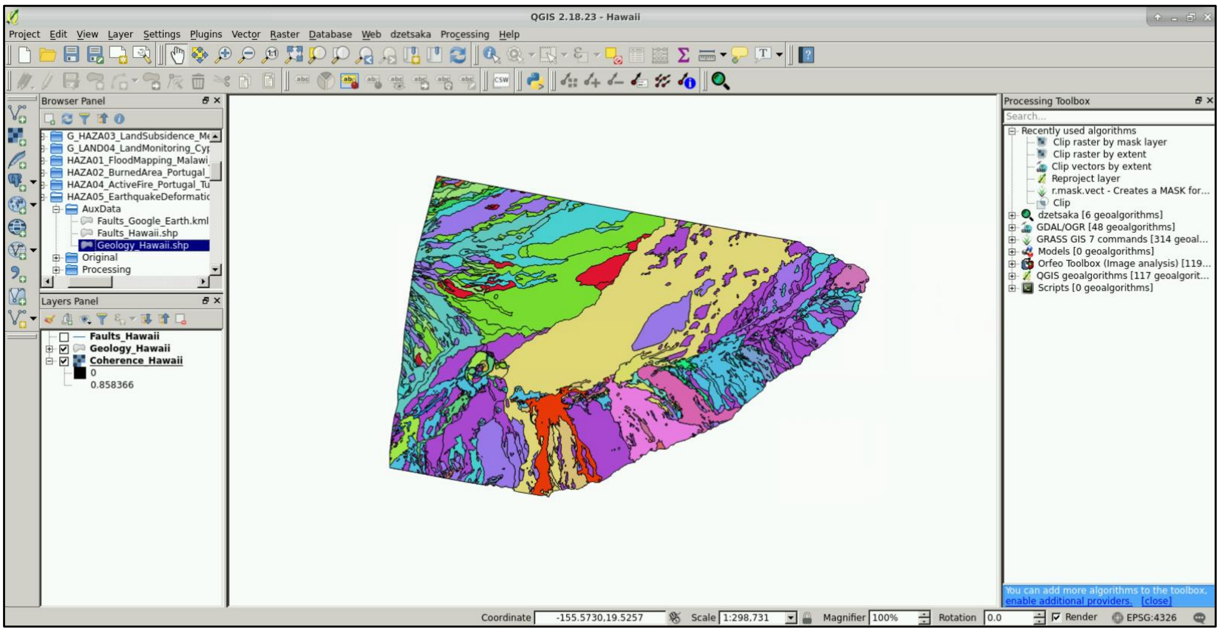


Also, go to the ***Auxdata*** folder and add the **Geology_Hawaii.shp** and **Faults_Hawaii.shp**. You can select which layers you want to be activated and arrange then in the desired order.

Activate the **Geology_Hawaii.shp**, right-click on it and go to **Properties**. In the **Style** tab select:

Categorized, in **Column**: AGE_RANGE, then click **Classify** and finally **OK**. You can also select other category in the **Column** field to classify the data or set a specific **Color ramp**.



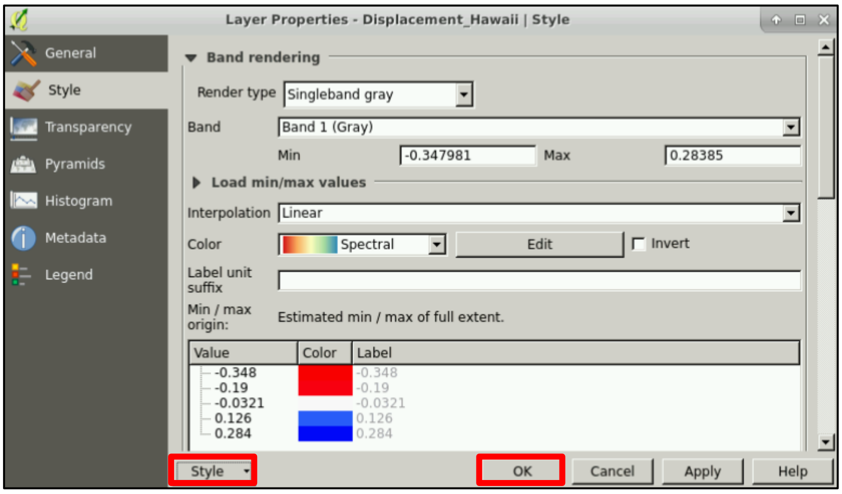


Deactivate all layers and add the **Displacement_Hawaii.tif** from the ***Processing*** folder. Right-click on it and go to **Properties**.

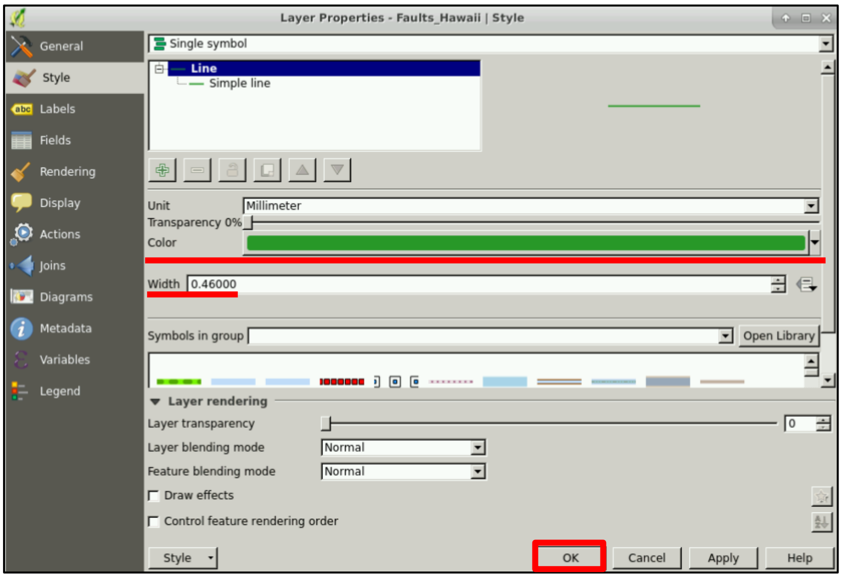
In the **Transparency** tab, set the "**Additional no data value**" to **0** to remove the black area of the layer.

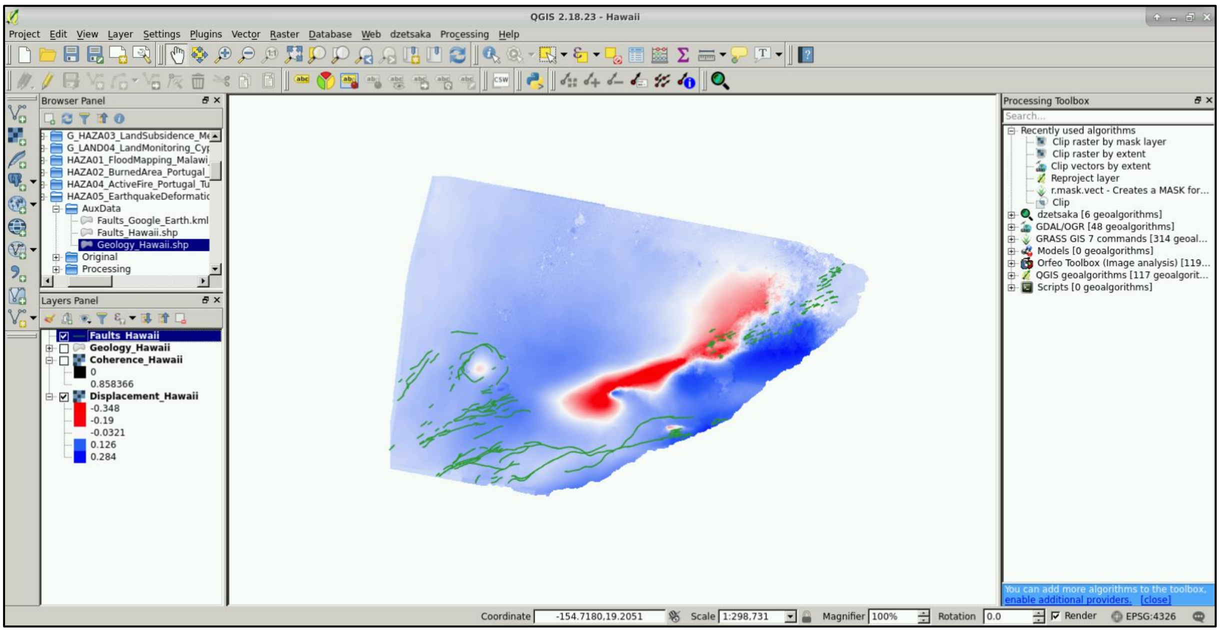
In the **Style** tab go to **Style → Load Style**, navigate to the ***Auxdata*** folder and open the predefined color palette: **Displacement_qgis.qml**.

Click **OK**.



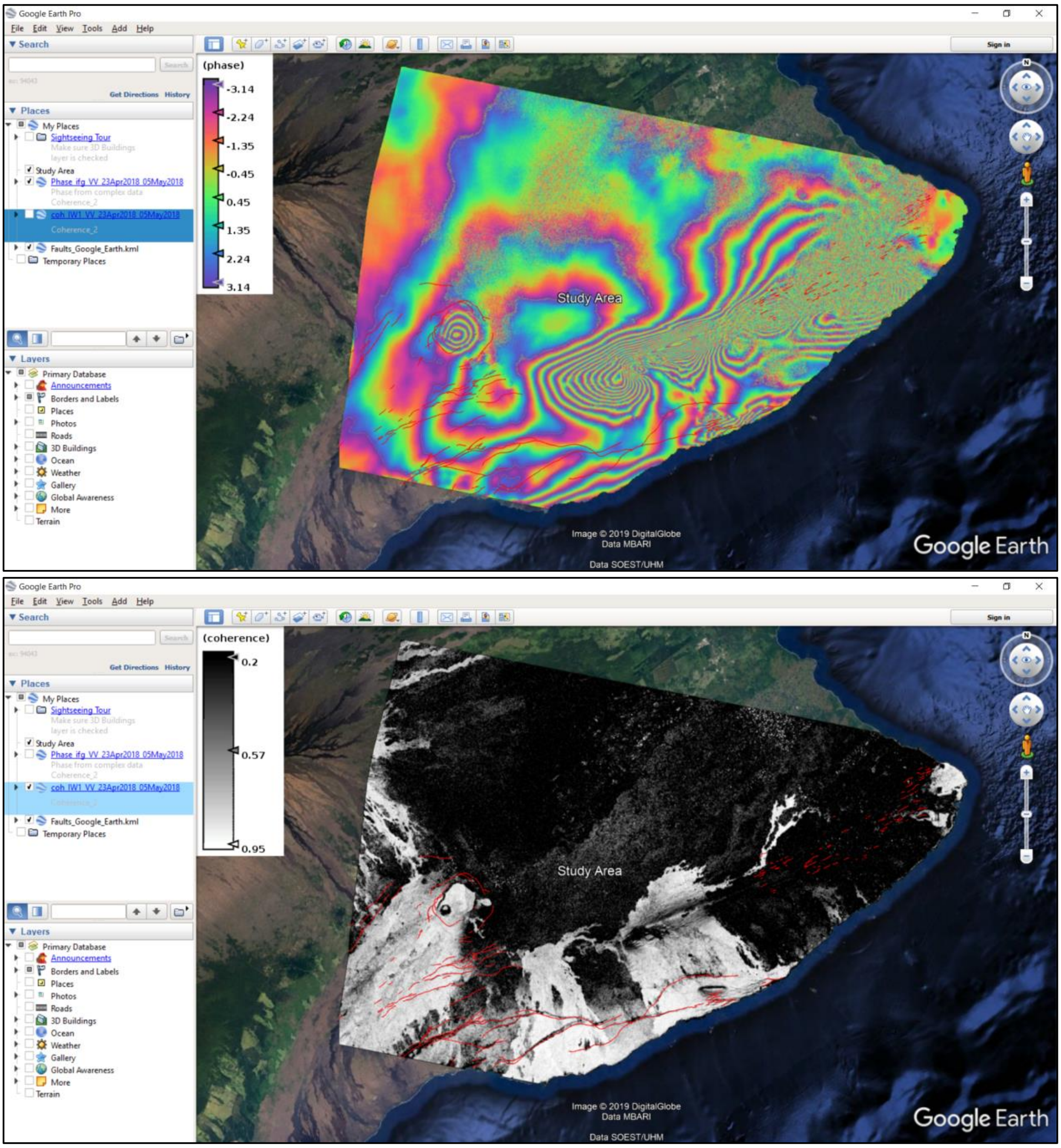
Activate the **Faults_Hawaii.shp**, right-click on it, go to **Properties** and in the **Style** tab set the **Color** to green and the **Width** to **0.46**. Select **OK**.





7 Extra Steps

Google Earth is not pre-installed in RUS VMs and if you want to visualise the results, you need to download them to your local computer. Let's export the results to **KML** format. Go to SNAP and export the bands you want from the final products (e.g. **Phase**, **Coherence**) as mentioned in the 5.7 chapter. Go to **File → Export → Other → View as Google Earth KMZ**. Also, download from the ***Auxdata*** folder the **Fault_Google_Earth.kml** file and then load them in Google Earth.

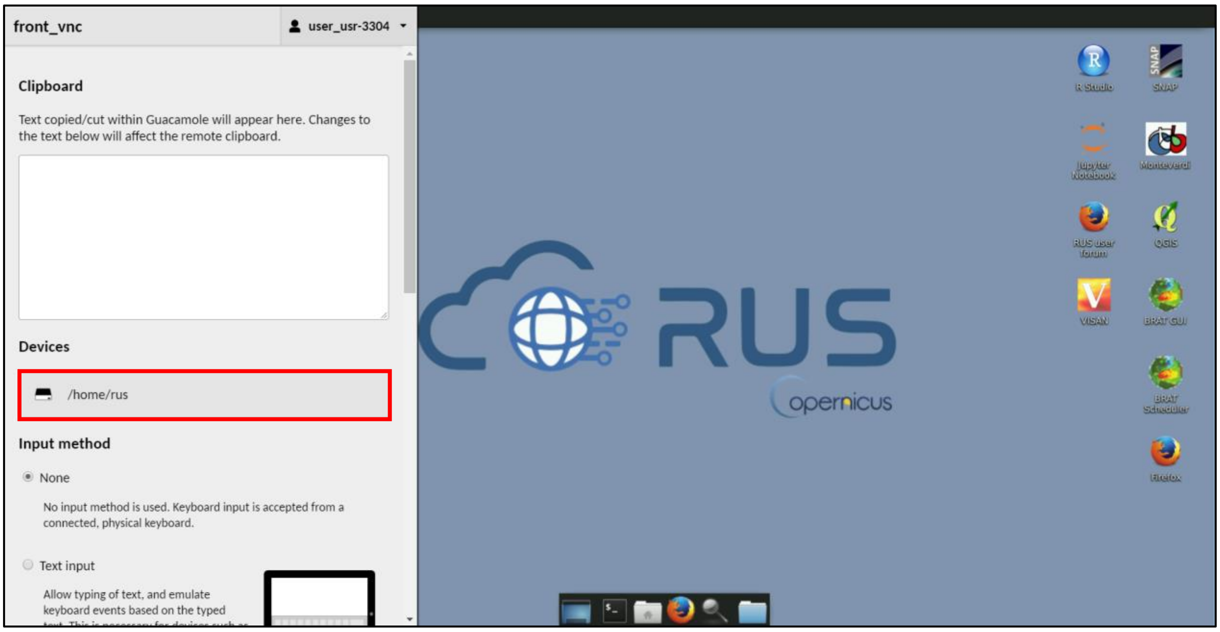


7.1 Download files from VM

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.

Once the KML files have been downloaded, you can load and visualize them in **Google Earth**.



THANK YOU FOR FOLLOWING THE EXERCISE!

8 Further reading and resources

- Richards J.A., 2009. Remote Sensing with Imaging Radar. Springer-Verlag Berlin Heidelberg. 376pp.
- Walter T.R., Amelung F., 2006. *Volcano-earthquake interaction at Mauna Loa volcano, Hawaii*. Journal of Geophysical Research, vol. 111, B05204, 2006.
- Ghiglia D.C., Pritt M.D., 1998. Two-dimensional phase unwrapping: theory, algorithms, and software. New York: Wiley. 493pp.
- http://www.esa.int/About_Us/ESA_Publications/InSAR_Principles_Guidelines_for_SAR_Interferometry_Processing_and_Interpretation_br_ESA_TM-19 - InSAR Principles
- https://sentinel.esa.int/web/sentinel/missions/sentinel-1 - Sentinel-1 Mission
- https://earthquake.usgs.gov/hazards/ - Download Hawaii shapefiles

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