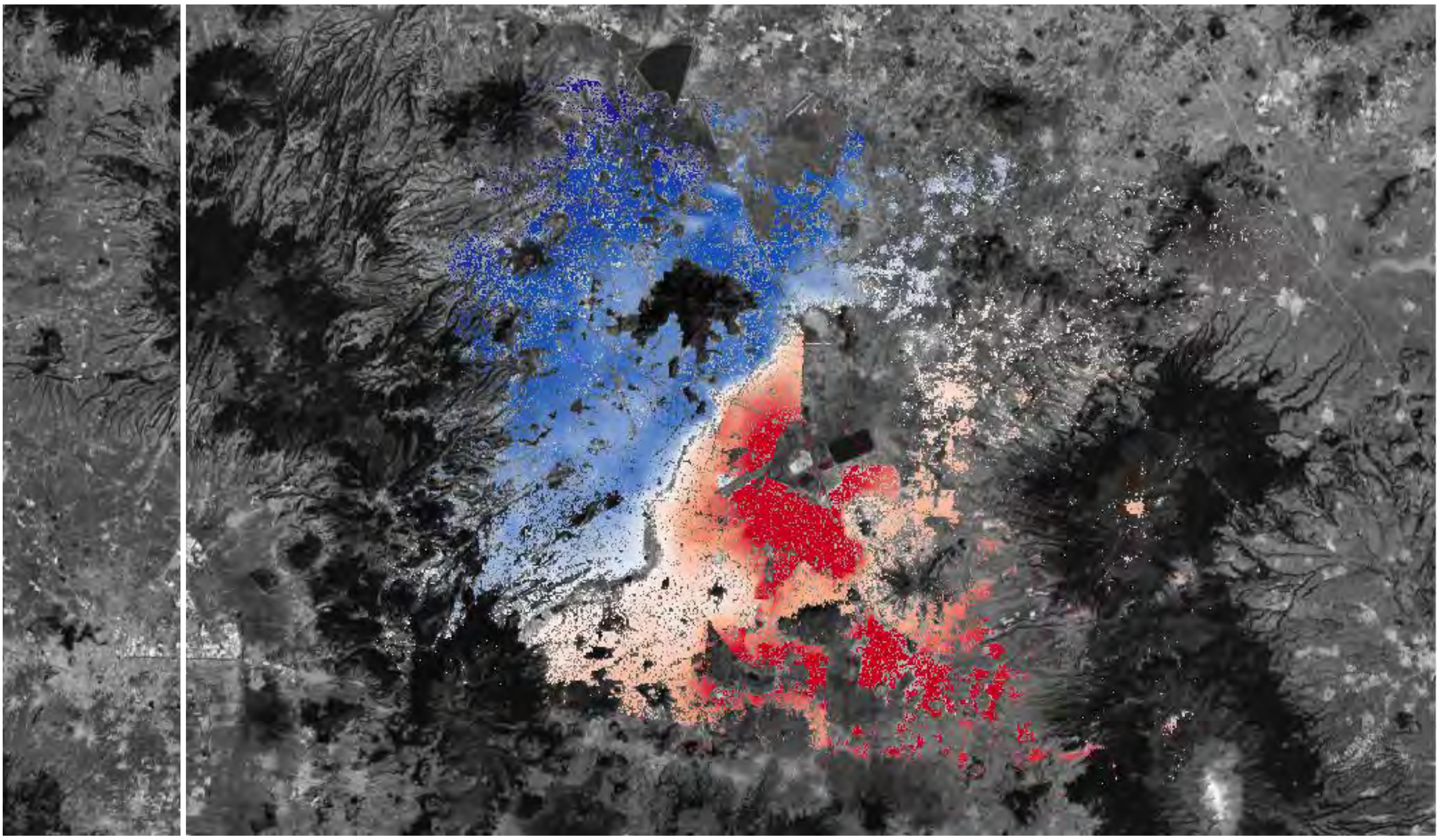

TRAINING KIT – HAZA03

LAND SUBSIDENCE WITH SENTINEL-1 using SNAP

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 derived from the Copernicus Sentinel satellites constellation. In this tutorial we will employ RUS to identify and map land subsidence in Mexico City using Sentinel-1 data.

Mexico City's buildings are seriously leaning due to land subsidence. Photo credit: JOSH HANER/THE NEW YORK TIMES (http://www.sciencemag.org)

Land subsidence in Mexico City caused by groundwater overexploitation over the last century has been more than 9 meters, resulting in damages to buildings, streets, sidewalks, sewers, storm water drains and other infrastructure [1]. Previous studies of SAR Interferometry using ERS data showed a maximum subsidence rate larger than 30 cm/year over parts of the city [2].

Due to the fact that the city is partially built on the area of a former lake (Lago Texcoco), it rests on the heavily saturated clay which is collapsing due to the over-extraction of groundwater. Current subsidence rates using Sentinel-1 SAR data approximate 2.5 cm/month [3].

2 Training

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

The Training Code for this tutorial is HAZA03. 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 images acquired on June 6, 2016 and September 10, 2016. [downloadable @ https://scihub.copernicus.eu/]

S1A_IW_SLC__1SSV_20160606T122537_20160606T122601_011590_011B5B_E555.zip
S1A_IW_SLC__1SSV_20160910T122542_20160910T122606_012990_0148FA_76D7.zip

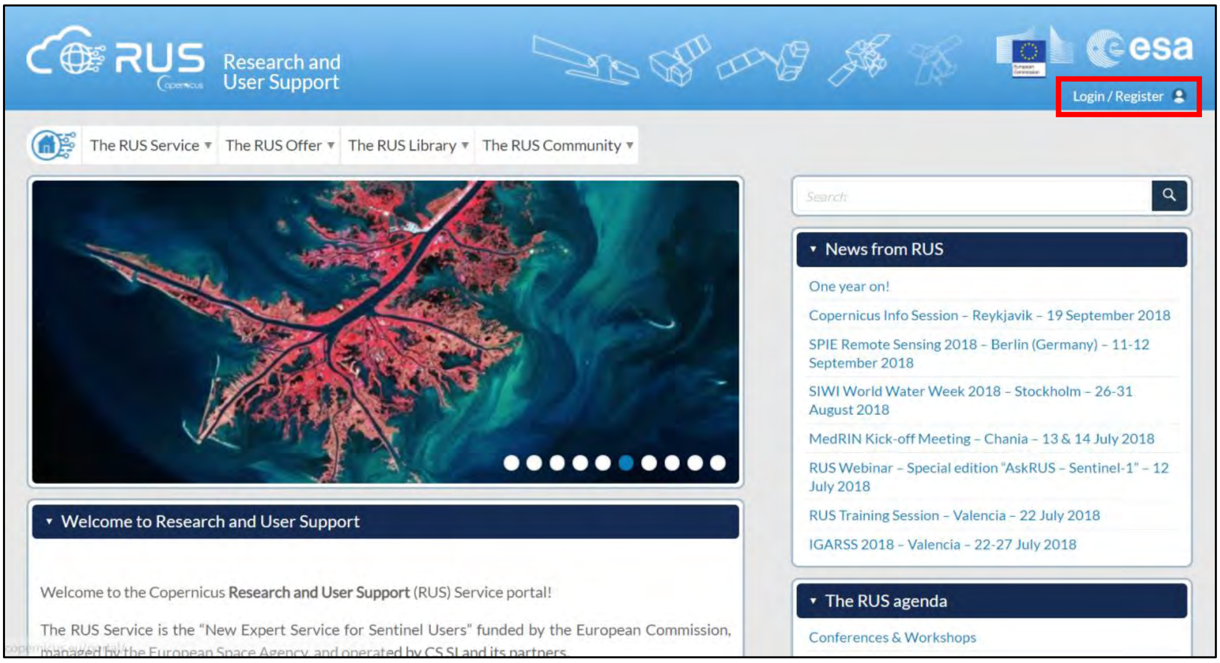
- Auxiliary data stored locally @ */shared/Training/HAZA03_LandSubsidence_MexicoCity_TutorialKit/AuxData*

2.2 Software in RUS environment

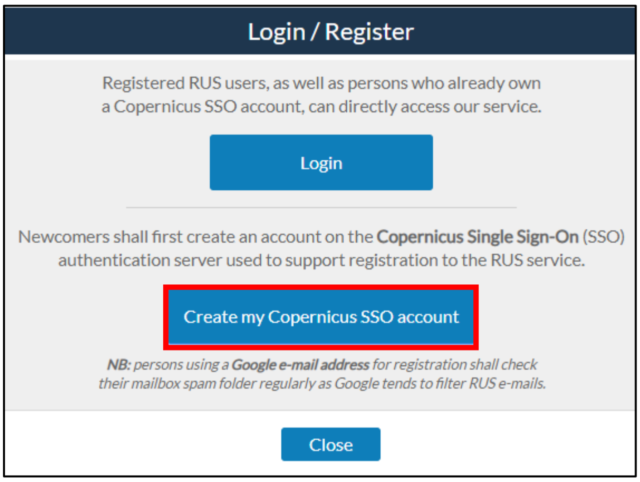
Internet browser, SNAP + Sentinel-1 Toolbox, (Extra steps: Google Earth)

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.

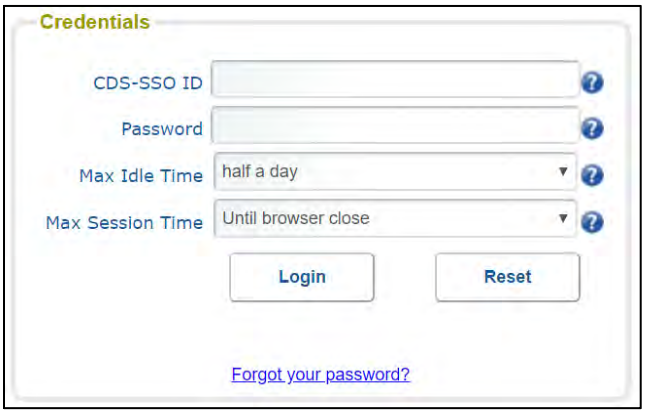


Select the option ***Create my Copernicus SSO account*** and then fill in ALL the fields on the **Copernicus Users' Single Sign On Registration**. Click ***Register***.

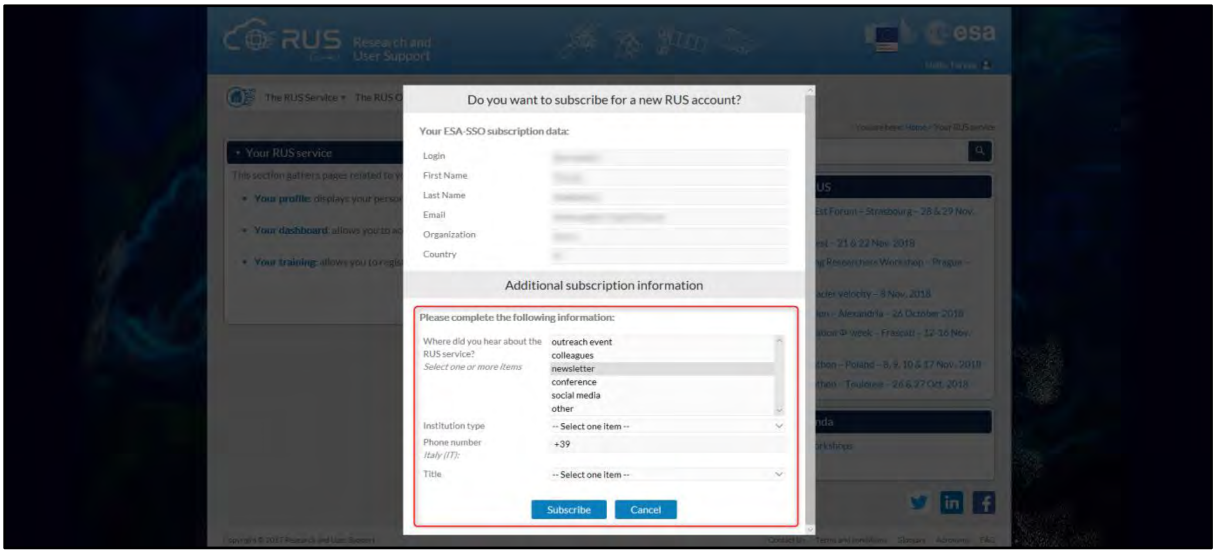


Within a few minutes you will receive an e-mail with activation link. Follow the instructions in the e-mail to activate your account.

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

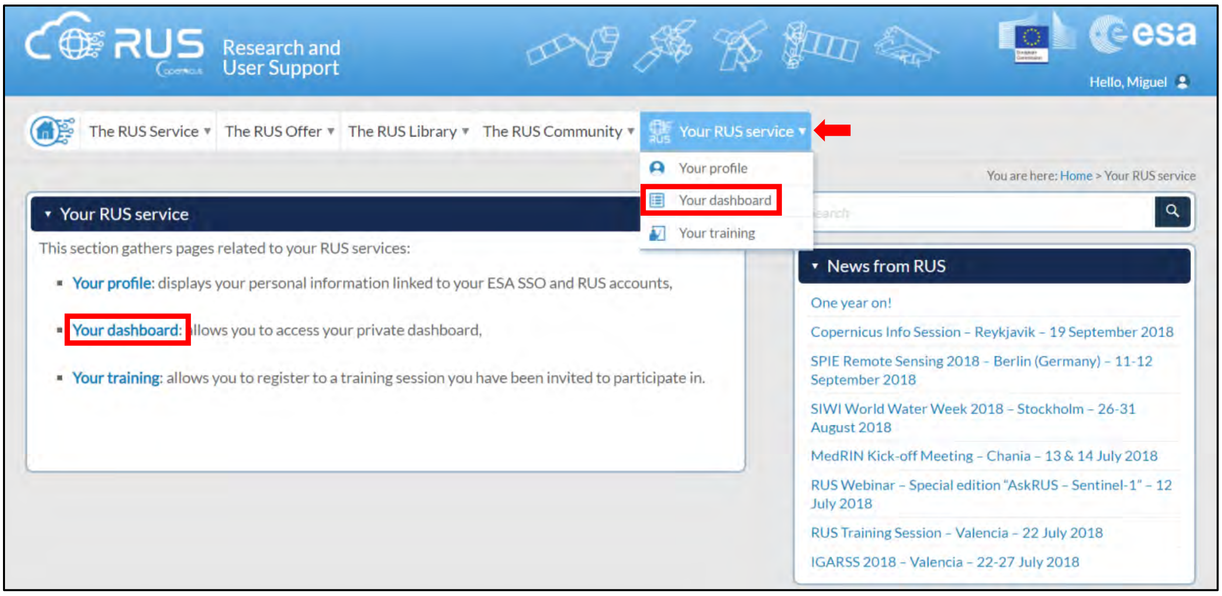


Upon your first login you will need to enter some details. You must fill all the fields.

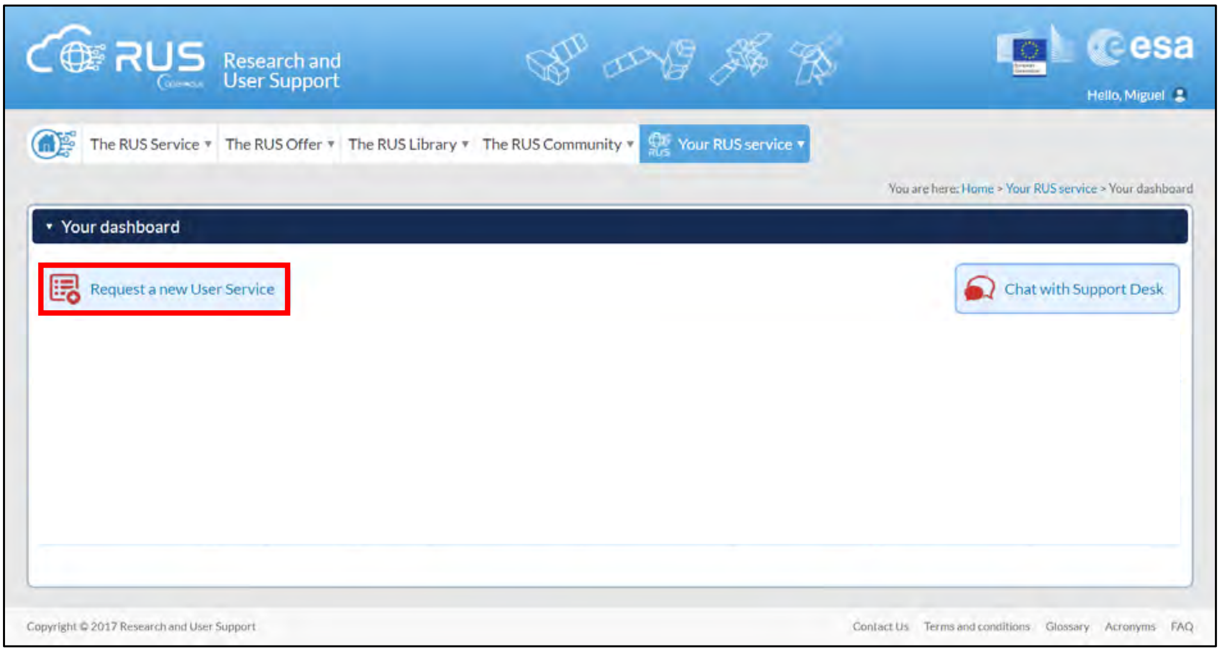


4 Request a RUS Copernicus Virtual Machine

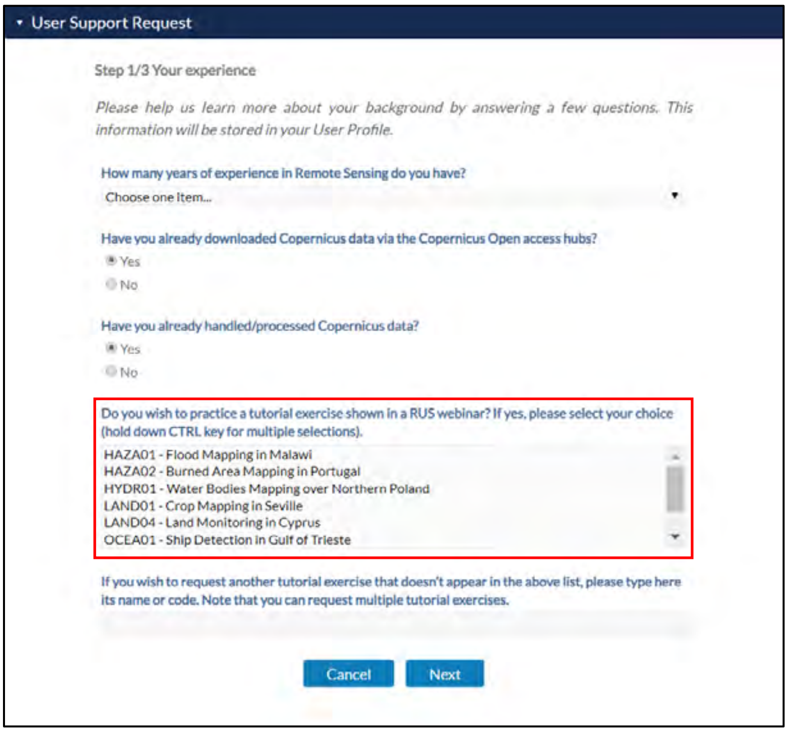
Once you are registered as a RUS user, you can request a RUS Virtual Machine to repeat this exercise or work on your own projects using Copernicus data. For that, log in and click on ***Your RUS Service → Your Dashboard***.



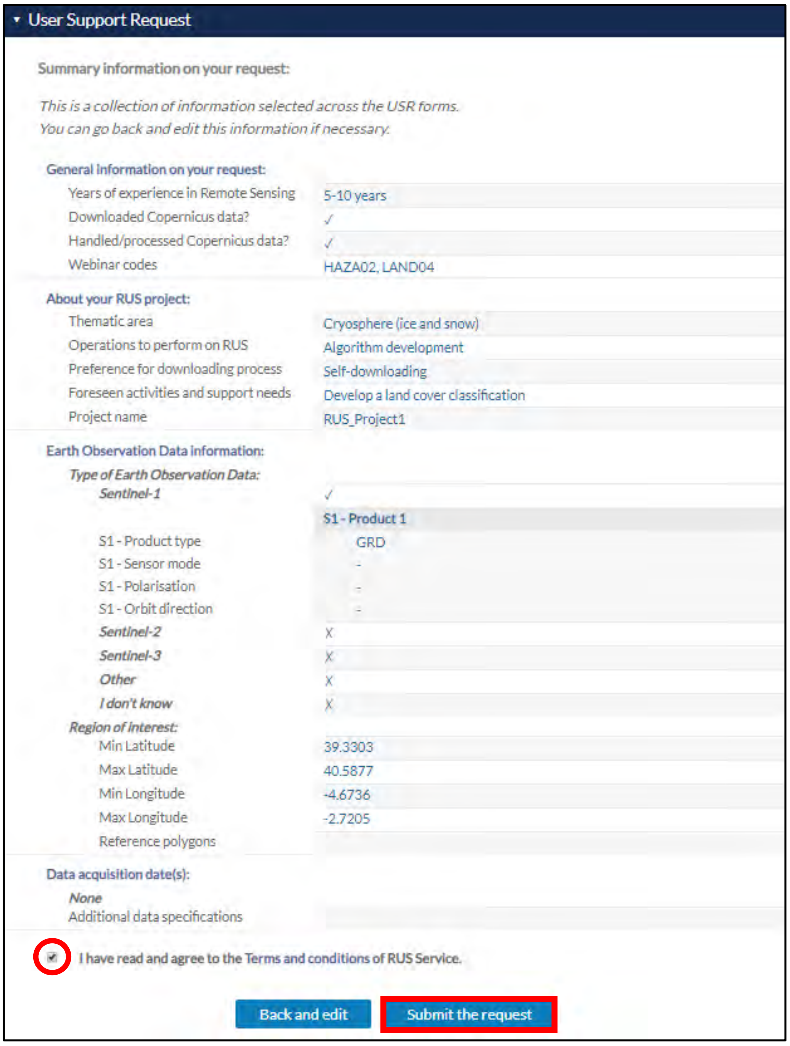
Click on ***Request a new User Service*** to request your RUS Virtual Machine. Complete the form so that the appropriate cloud environment can be assigned according to your needs.



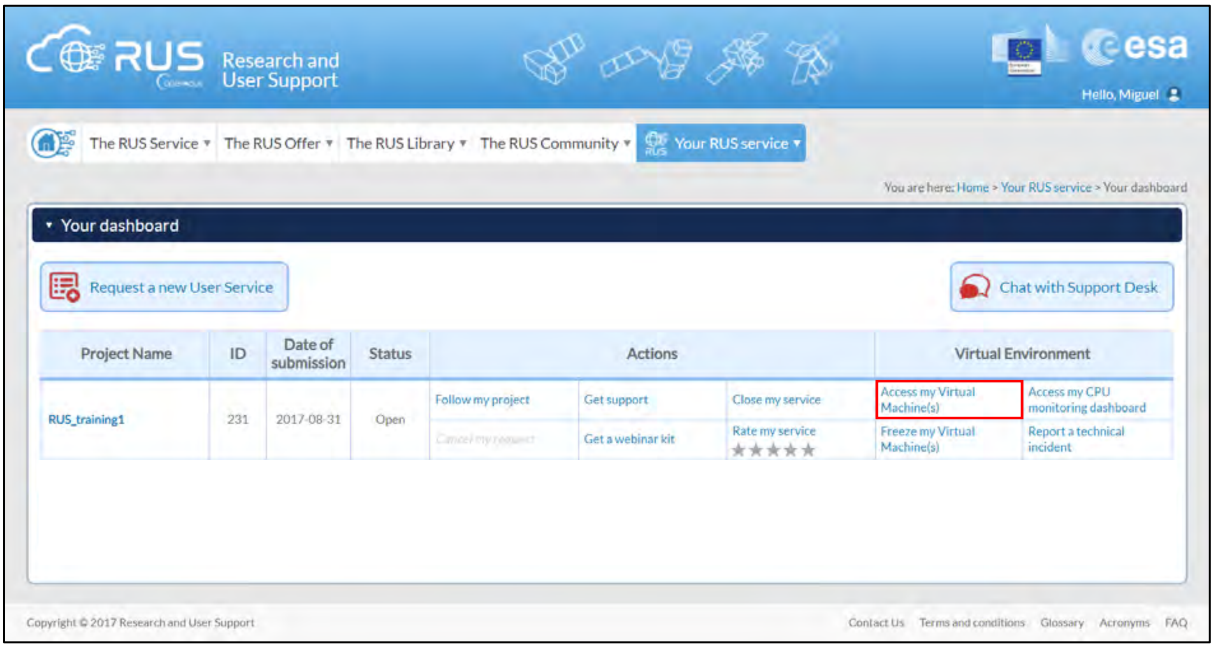
If you want to repeat this tutorial (or any previous one) select the one(s) of your interest in the appropriate field.



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.

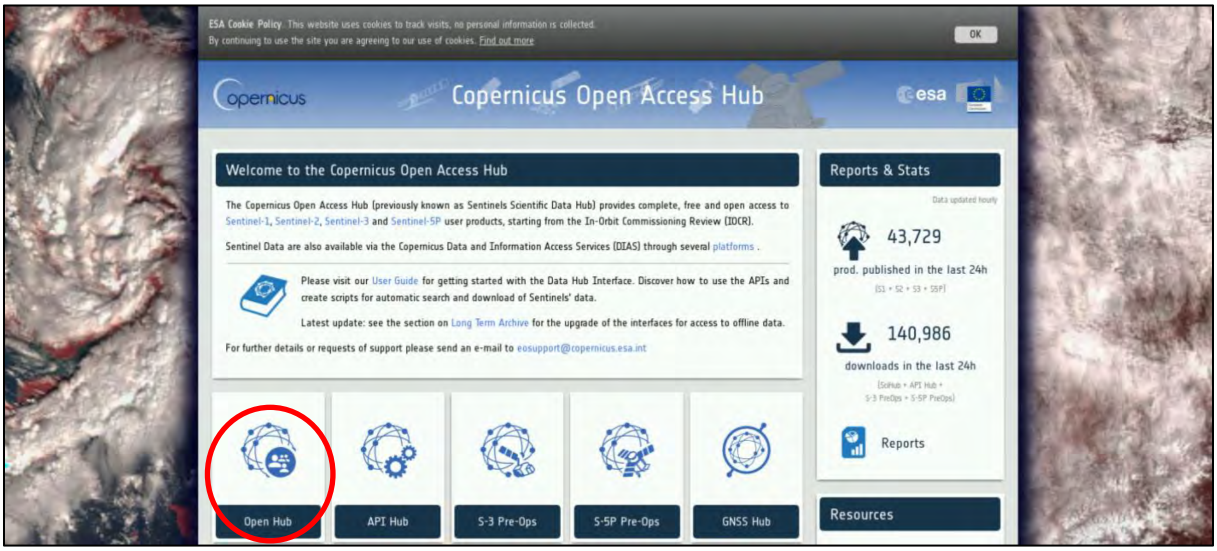
This is the remote desktop of your Virtual Machine.

5 Step by step

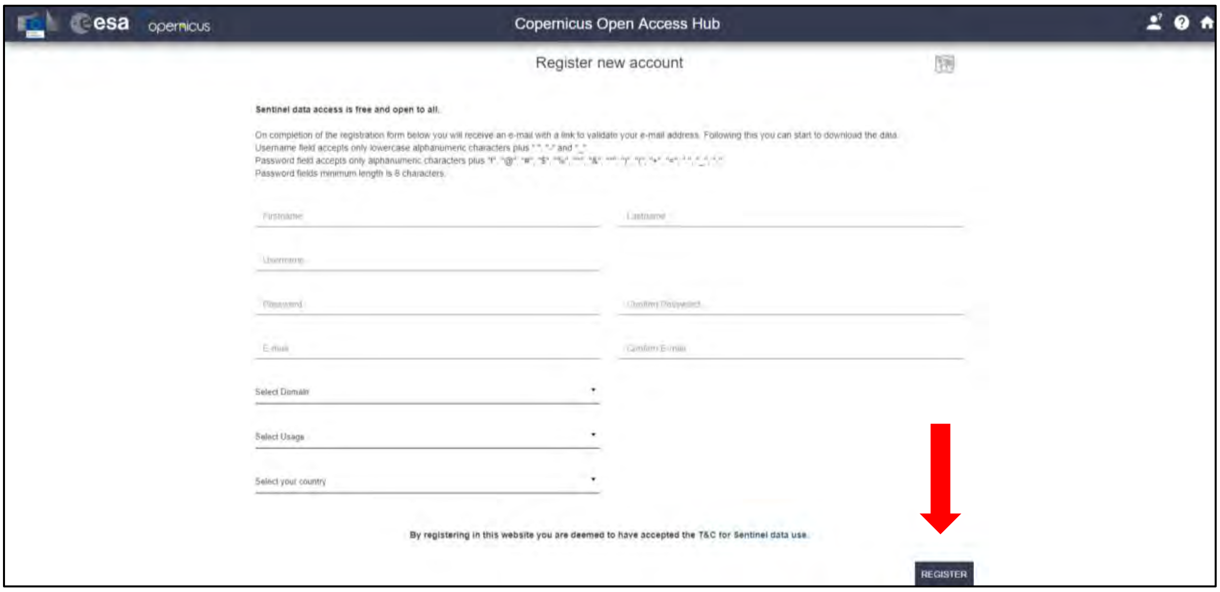
5.1 Data download – ESA SciHUB

In this step we will download two Sentinel-1 scenes from the Copernicus Open Access Hub using the online interface (**Applications → Network → Firefox Web Browser** or click the link below).

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

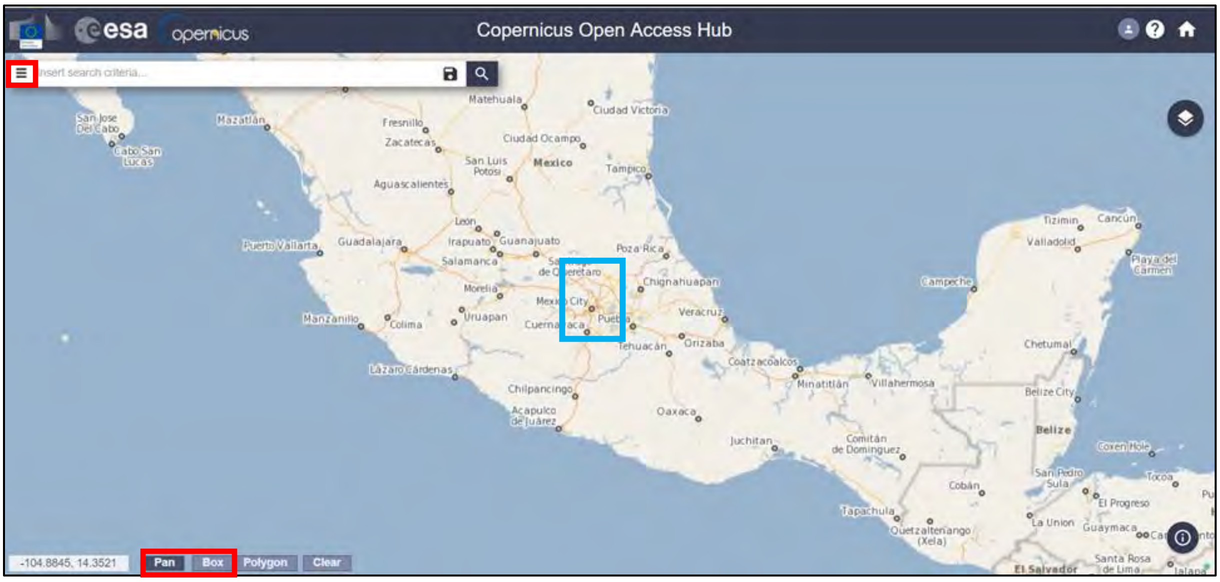


Go to “**Open HUB**”, if you do not have an account please register by going to “**Sign-up**” in the LOGIN menu in the upper right corner.



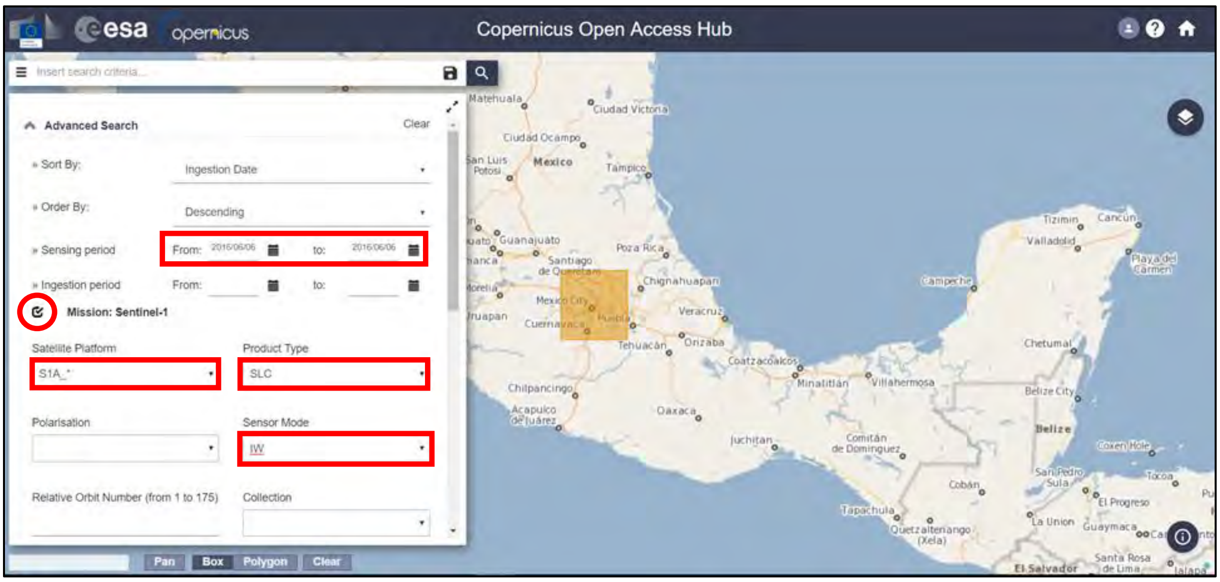
After you have filled in the registration form, you will receive an activation link by e-mail. Once your account is activated or if you already have an account, “**LOGIN**”.

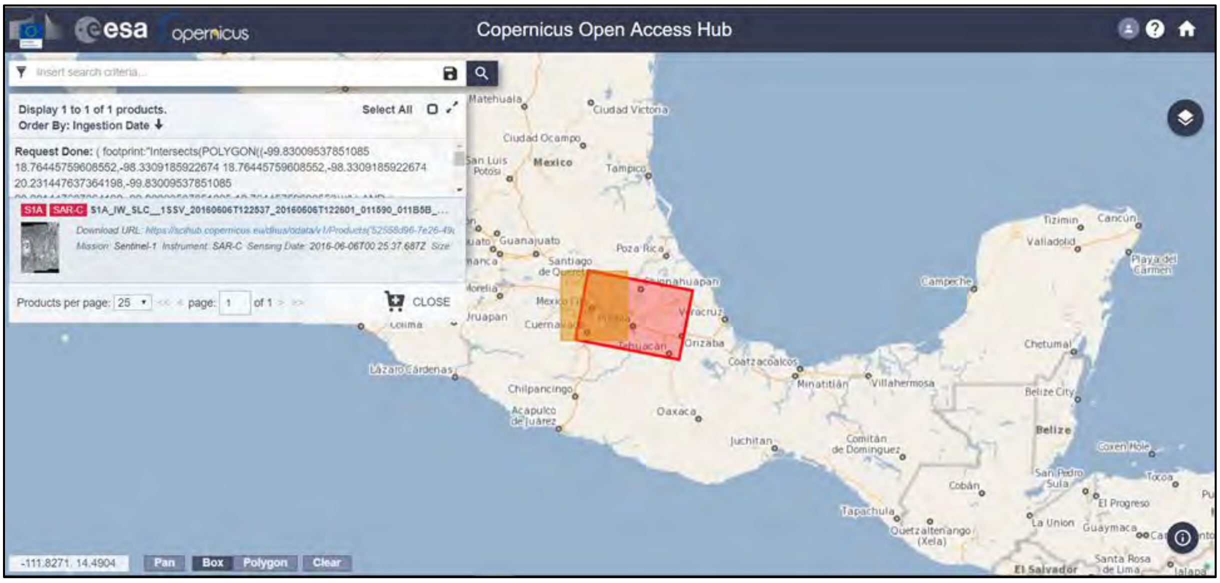
Select the “Pan” icon in the lower left corner of the map and navigate over Mexico City.



Switch to “Box” icon and draw a search rectangle approximately as indicated above (**approximate area – blue rectangle**). Open the search menu (☰) and specify the following parameters. Press the search button (🔍) after that.

Sensing period: From 2016/06/06 to 2016/06/06
Check Mission: Sentinel-1A
Satellite Platform: S1A_*
Product Type: SLC
Sensor Mode: IW





In our case the search returns 1 result depending on the exact search area defined. Download the scene:
S1A_IW_SLC__1SSV_20160606T122537_20160606T122601_011590_011B5B_E555

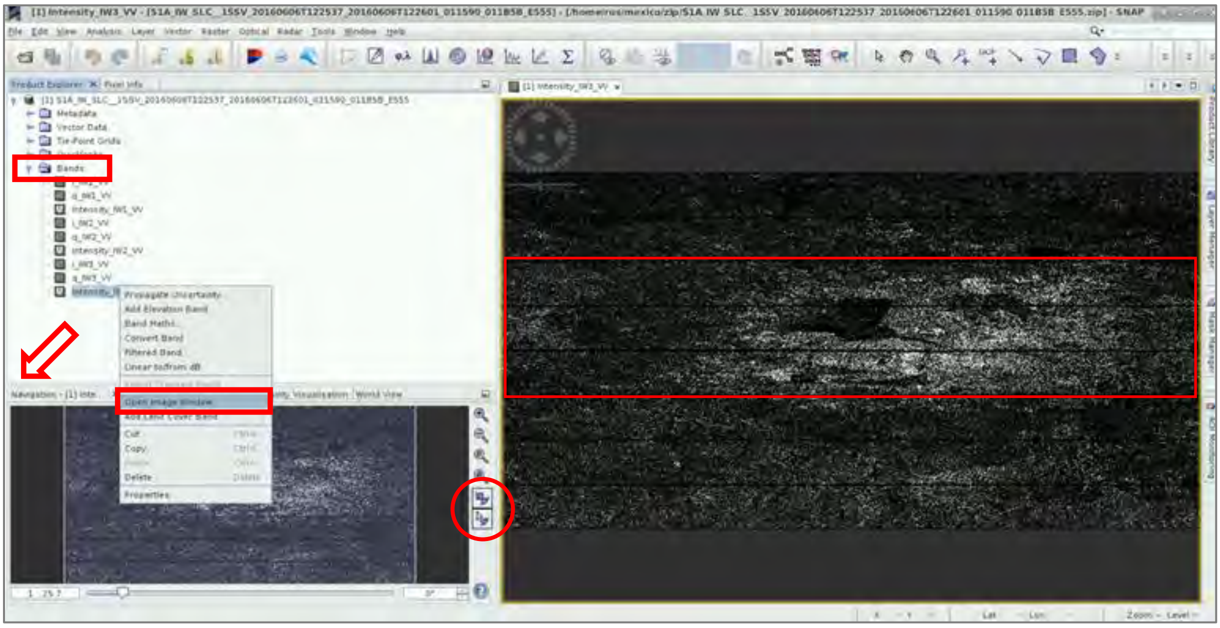
Repeat the steps for the second image September 10, 2016, by changing accordingly the sensing period range. Download the scene:
S1A_IW_SLC__1SSV_20160910T122542_20160910T122606_012990_0148FA_76D7

Data will be downloaded to */home/rus/Downloads* as zip archives. Move the archives to: ***/shared/Training/HAZA03_LandSubsidence_MexicoCity_TutorialKit/Original***.

5.2 SNAP – open and explore data

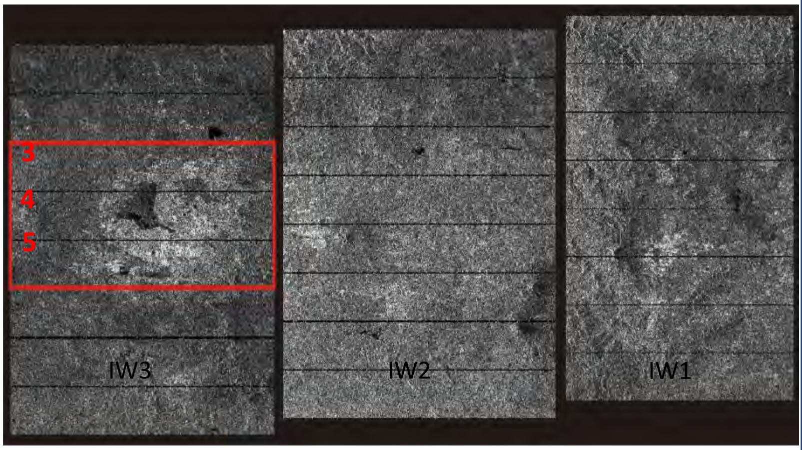
Launch SNAP (icon on desktop). When SNAP opens, click **Open product** , navigate to ***/shared/ Training/HAZA03_LandSubsidence_MexicoCity_TutorialKit/Original*** and open the *.zip files.

The opened products will appear in the **Product Explorer** window on the left. Expand the first image to the left and then expand **Bands**. Right-click on the "*Intensity_IW3_VV*" band and select **Open Image Window** to create and visualize the image of the band (or double-click on it). (See NOTE 1).



The image appears in the upper left corner of the view window. Repeat the same steps for the second product. To synchronize the views, go to **Navigation** tab in the lower left (red arrow) and make sure the cursor and the views are linked.

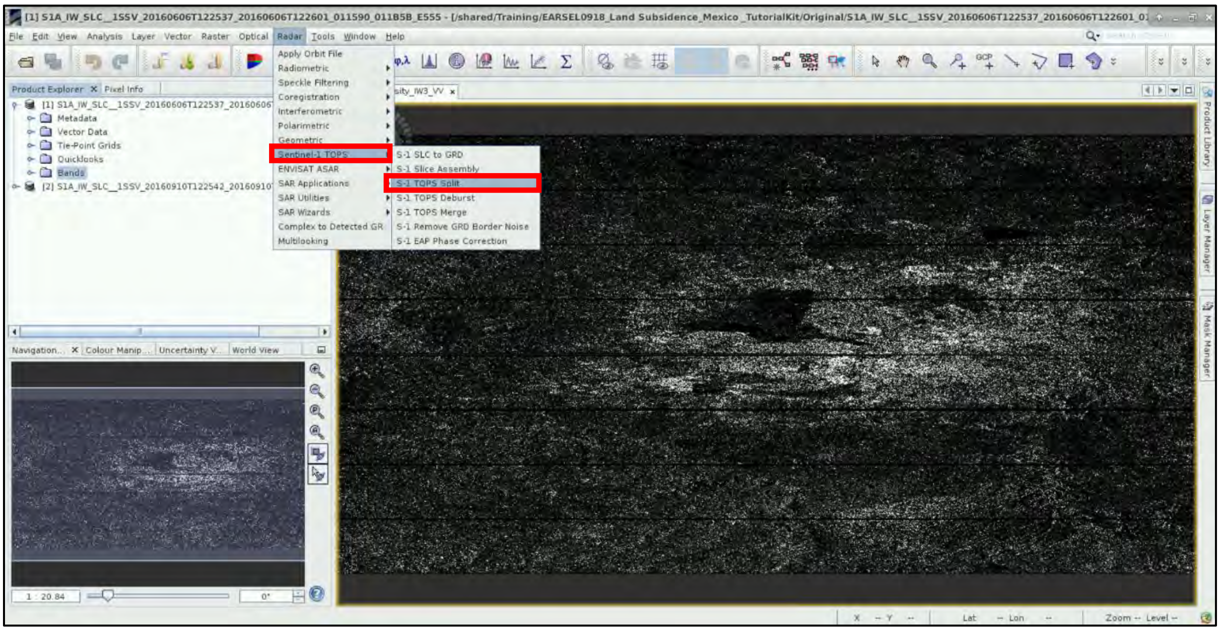
NOTE 1: The Interferometric Wide (IW) swath mode captures three sub-swaths using Terrain Observation with Progressive Scans SAR (TOPSAR). Each sub-swath image consists of a series of bursts. The input product contains 3 IW bands, and 8 bursts. Mexico City is located on the IW3 sub-swath of the Sentinel-1 images.



Credits: ESA User Guides for Sentinel-1 SAR

5.3 Pre-processing

Since the area of interest is included in 3 bursts of the Sentinel-1 image, there is no need to process the whole sub-swath with the 8 bursts (See NOTE 2). The extraction of Sentinel-1 TOPS bursts will be made per acquisition and per sub-swath. This process will reduce the processing time in the following processing steps and is recommended when the analysis is focused only over a specific area and not the complete scene. Go to **Radar → Sentinel-1 TOPS → S-1 TOPS Split.**



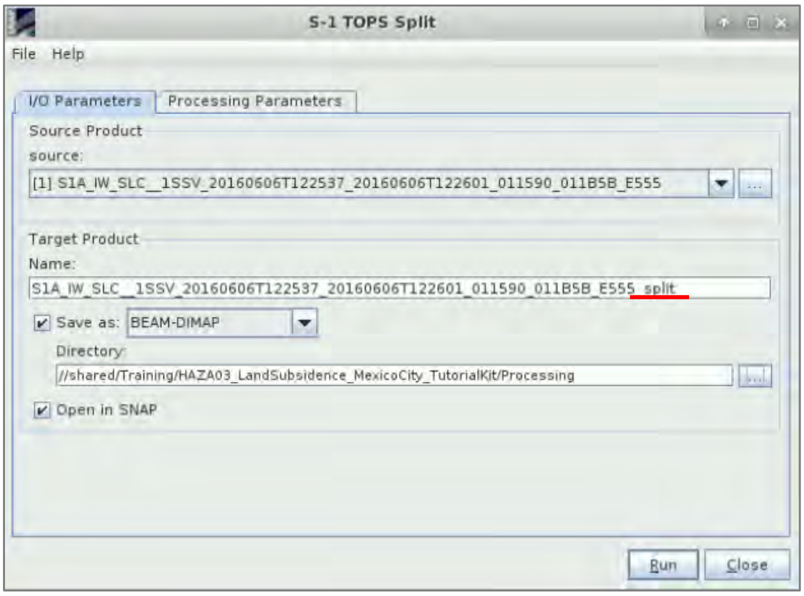
Now, let's set the parameters. In the source product select the opened image:

S1A_IW_SLC__1SSV_20160606T122537_20160606T122601_011590_011B5B_E555.zip

Then, define the output directory in:

/shared/Training/HAZA03_LandSubsidence_MexicoCity_TutorialKit/Processing.

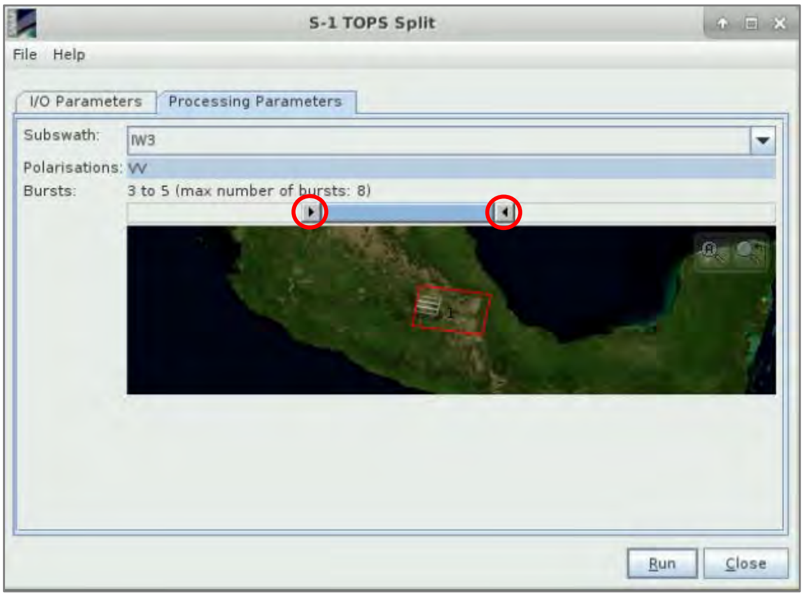
In the **I/O Parameters** tab, leave the default output name for the target product name. The system inserts automatically the suffix of the split process in order to discriminate the split product from the original data.



In the **Processing Parameters** tab, select the following parameters:

Subswath: IW3
Polarisations: VV
Bursts: 3 to 5

In **Bursts** selection click on the arrows and drag up to the specified number of bursts. Then click **RUN**.



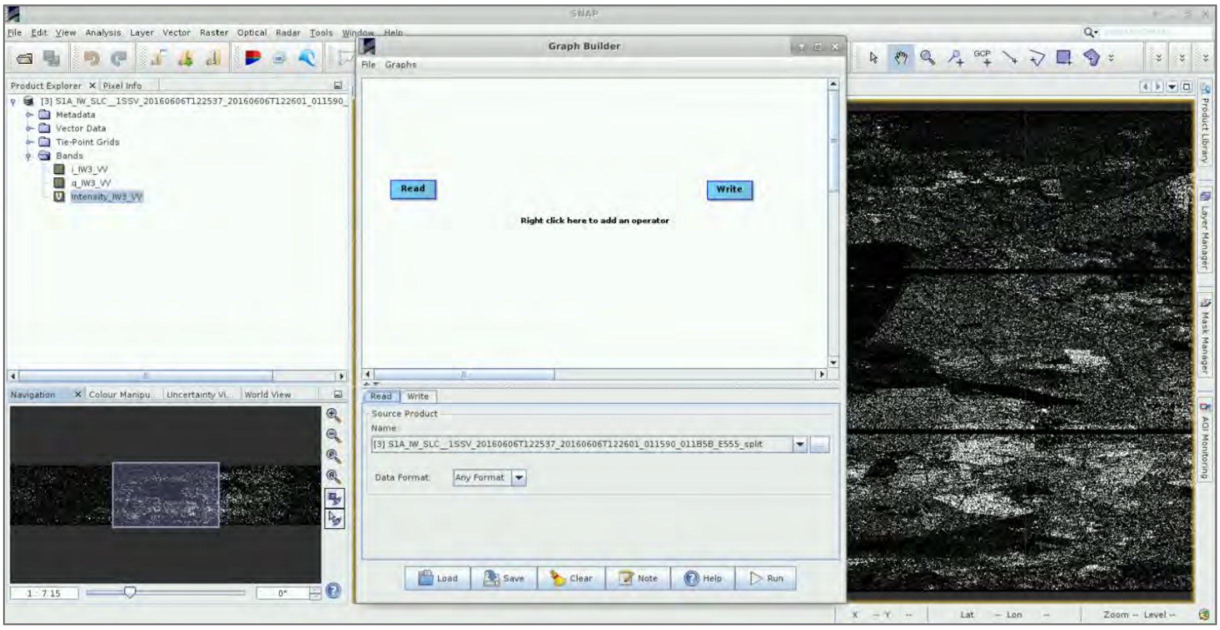
Repeat the split process for the second Sentinel-1 image using same processing parameters:

S1A_IW_SLC__1SSV_20160910T122542_20160910T122606_012990_0148FA_76D7

NOTE 2: The extraction of bursts in a sub-swath covering the area of interest may differ in Sentinel-1 images acquired on different dates.

5.4 Graph Builder

Although data processing could follow a manual step-by-step process, **Graph Builder** tool available in SNAP allows the automatic processing of the images.



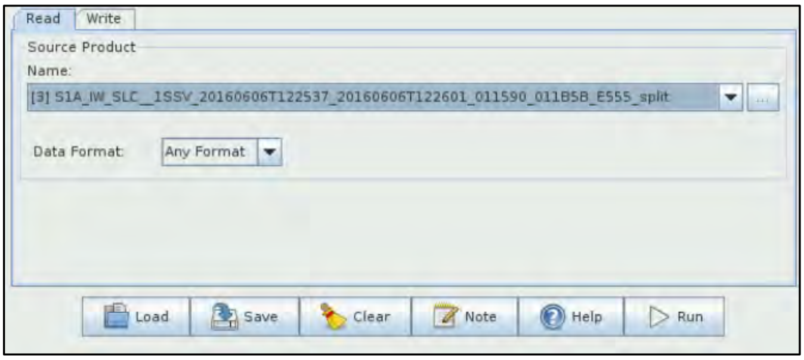
The **Graph Builder** tool allows the user to assemble graphs from a list of available operators and connect operator nodes to their sources. Therefore, the processing chain we will follow, will be represented by a graph and saved as an **XML** file.

In order to add **Graph Builder** tool, go to **Tools → GraphBuilder**.

Initially, the graph has two operators: **Read** (to read the input) and **Write** (to write the output) (See NOTE 3). With right-click on the top panel you can add an operator, while a corresponding tab is created and added on the bottom panel.

Since pre-processing split process has preceded, in the **Read** tab select the name of the split product:

***S1A_IW_SLC__1SSV_20160606T122537_20160606T122601_011590_011B5B_E555_split.dim*.**



NOTE 3: In case split process is already applied, input image in the Read tab will be the splitted product of the Sentinel-1 image.

Before adding the rest operators, **delete** the **Write** operator (right-click on it → Delete) to avoid confusion in the sequence of the graph and we will add it at the end.

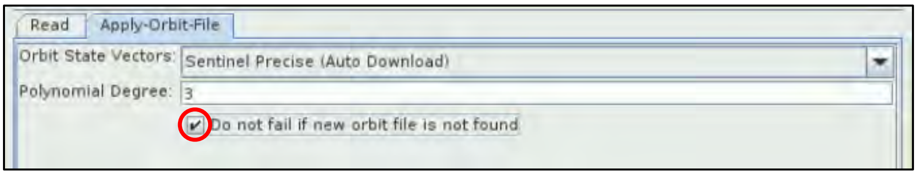
5.5 Co-registration

The first processing step is to apply the orbit files in Sentinel-1 products in order to provide accurate satellite position and velocity information. To add the operator right-click on the top panel to the right of the existing operator and go to **Add → Radar → Apply-Orbit-File**.

A new operator rectangle appears in our graph and a new tab appears below. Now connect the new **Apply-Orbit-File** operator with the **Read** operator by clicking to the right side of the **Read** operator and dragging the red arrow towards the **Apply-Orbit-File** operator.

In the **Apply-Orbit File** tab select the parameters:

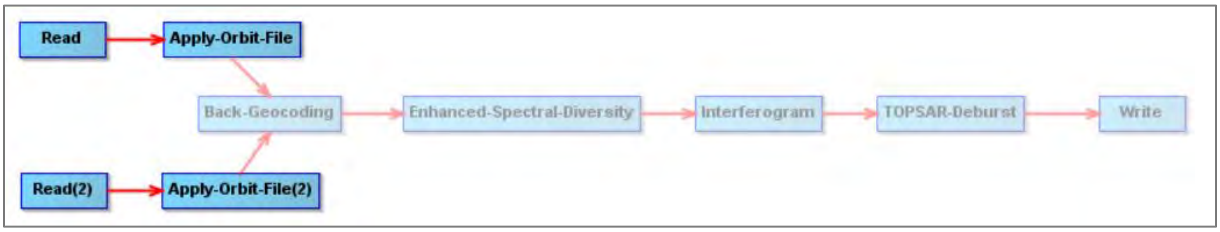
Orbit State Vectors: Sentinel Precise (Auto Download)
Check "Do not fail if new orbit file is not found"



Now, we have to repeat the same steps for the second image. First we need to add a new **Read(2)** operator**.** Right-click and go to **Add → Input-Output → Read.** In the **Read(2)** tab, select the split product**:**

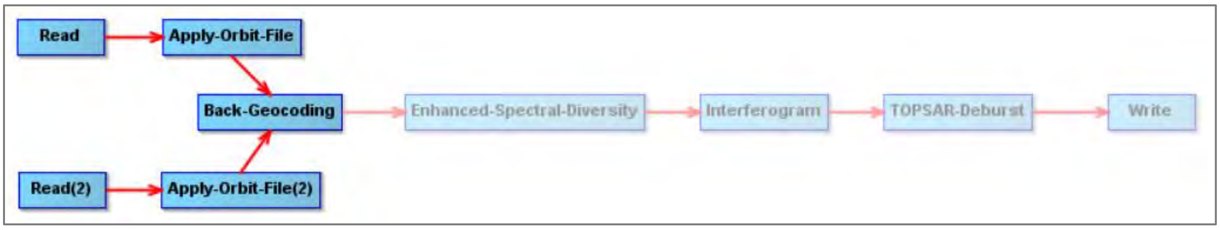
S1A_IW_SLC__1SSV_20160910T122542_20160910T122606_012990_0148FA_76D7_split.dim

Then, go to **Add → Radar → Apply-Orbit-File** and select the same parameters as in the first product and then connect the **Apply-Orbit-File(2)** to the **Read(2)** operator.



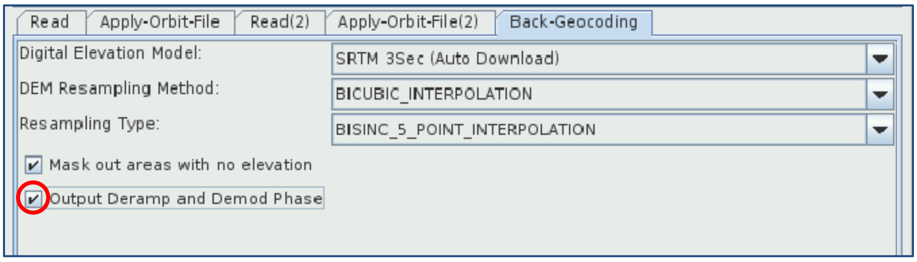
Next step will be to co-register the two Sentinel-1 images. For this reason the second image (slave) will be co-registered with respect to the first image (master). **Sentinel-1 Back Geocoding** operator co-registers two S-1 split products (master and slave) of the same sub-swath using the orbits of the two products and a Digital Elevation Model (DEM).

Rght-clicking right of the **Apply-Orbit-File** operator and go to **Add → Radar → Coregistration → S-1 TOPS Coregistration → Back-Geocoding.** Connect the **Back-Geocoding** operator with the **Apply-Orbit-File** operators.

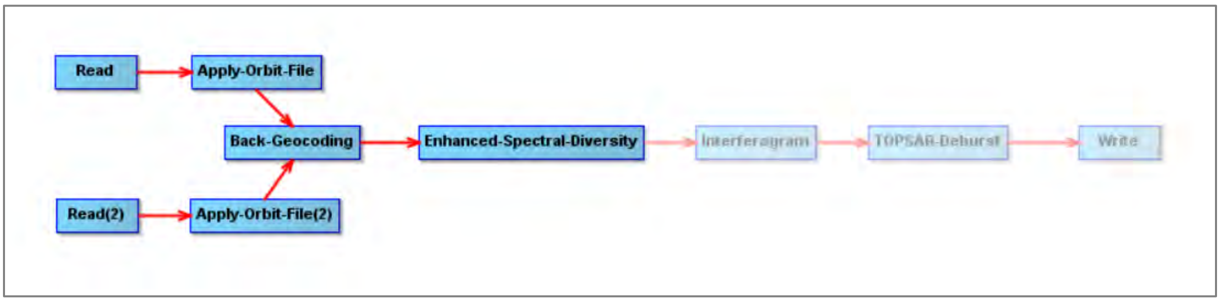


In the **Back-Geocoding** tab use default parameters, but also **check** “Output Deramp and Demod Phase” option (See NOTE 4).

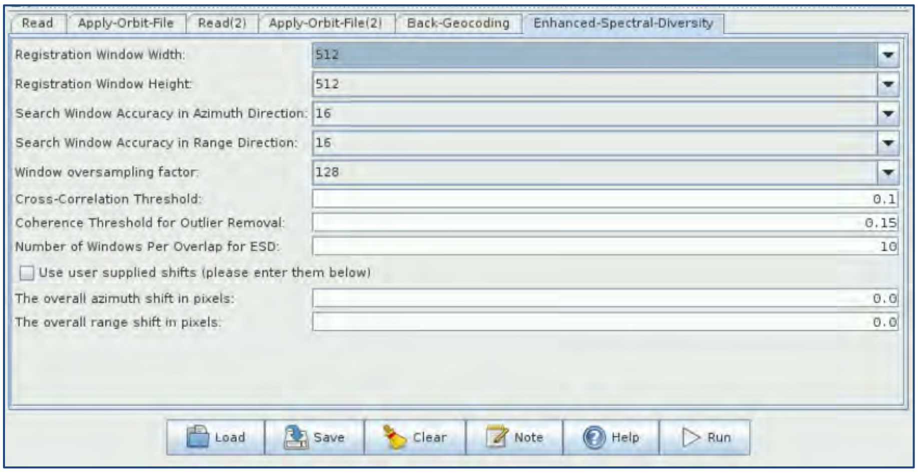
NOTE 4: Deramp and Demod Phase is required when ESD operator follows Back-Geocoding.



In this step, **Enhanced Spectral Diversity** (**ESD**) operator follows **Back-Geocoding**. The ESD approach exploits the data at the overlapped area of the adjacent bursts, and then performs range and azimuth correction for every burst. In the same manner, go to **Add → Radar → Coregistration → S-1 TOPS Coregistration → Enhanced-Spectral-Diversity** and then connect **ESD** and **Back-Geocoding** operators.

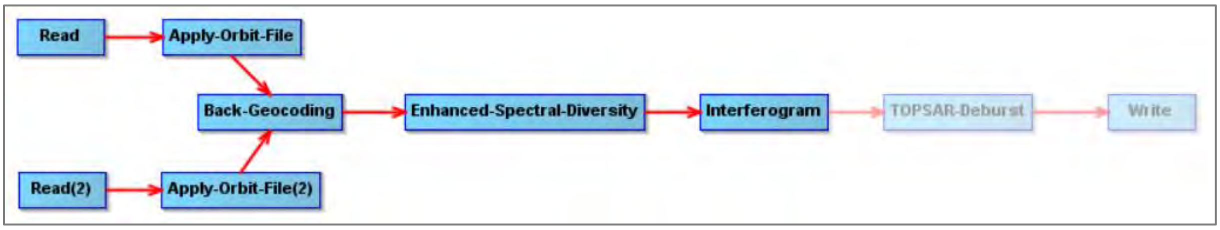


In the **Enhanced-Spectral-Diversity** tab use the default parameters.



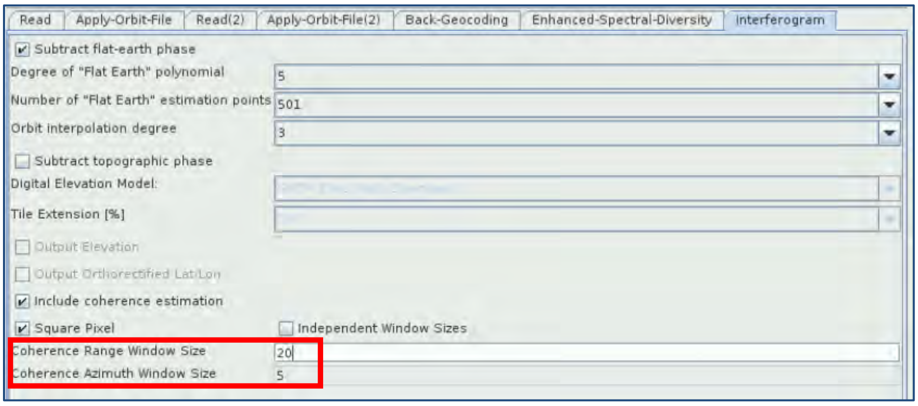
5.6 Interferometric Processing

At this stage, we will produce an Interferogram between the interferometric pair (master and slave), while a coherence image estimation from the stack of the coregistered complex images is included. To add the **Interferogram** operator go to **Add → Radar → Interferometric → Products → Interferogram** add then connect the **Interferogram operator** to **Enhanced-Spectral-Diversity** operator.



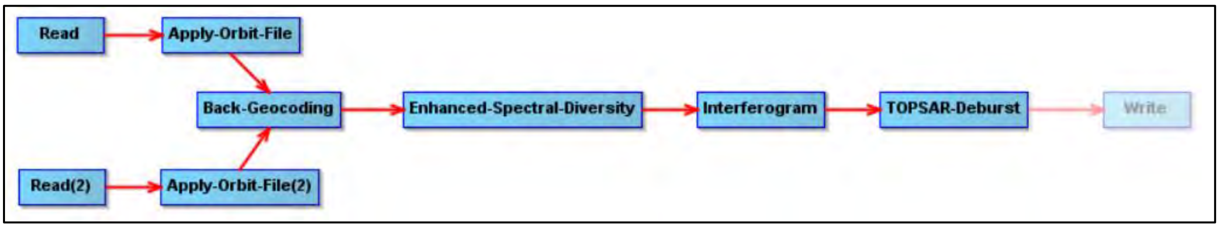
In the **Interferogram** tab set the following parameters:

Coherence Range Window Size: 20
Coherence Azimuth Window Size: 5

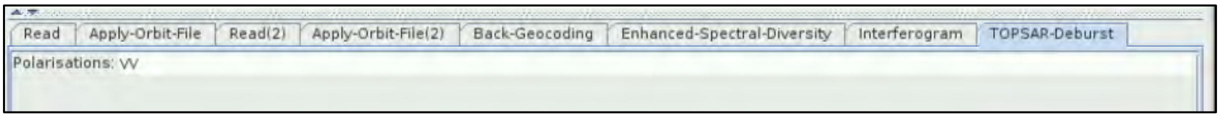


We continue the processing steps with Sentinel-1 TOPSAR Deburst. We have seen that each sub-swath image consists of a series of bursts, where each burst has been processed as a separate SLC image. The individually focused complex burst images are included, in azimuth-time order, into a single sub-swath image with black-fill demarcation in between. There is sufficient overlap between adjacent bursts and between sub-swaths to ensure the continuous coverage of the ground. 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.

To add **TOPSAR-Deburst** operator, go to **Add → Radar → Sentinel-1 TOPS → TOPSAR-Deburst**.

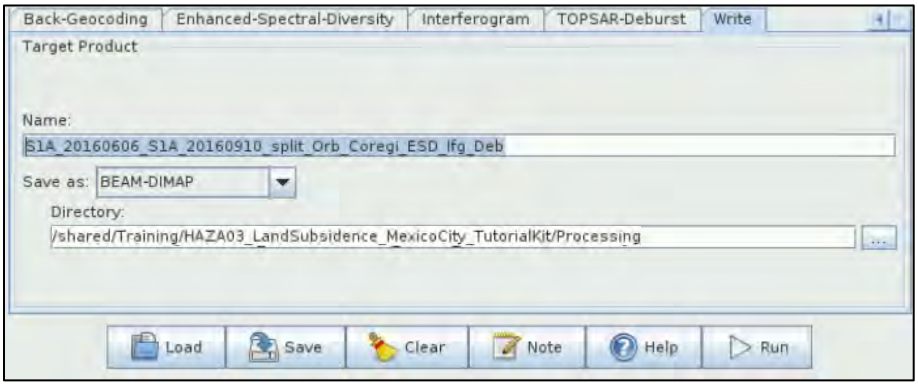


In the **TOPSAR-Deburst** tab select **Polarizations**: VV.



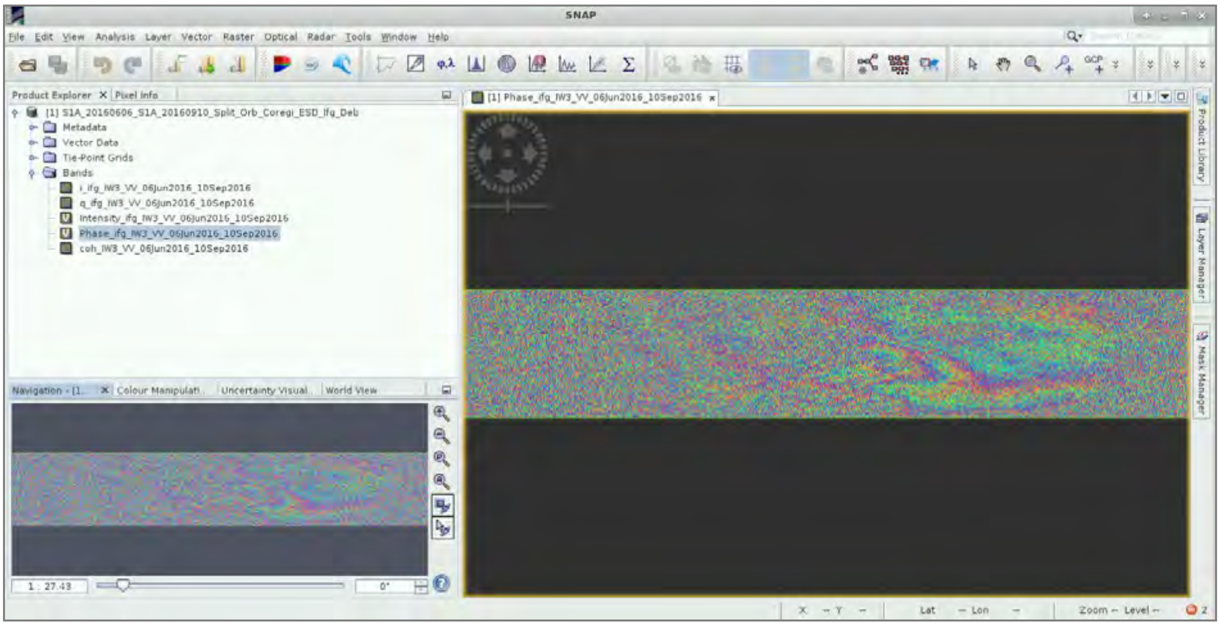
Finally add the **Write** operator, go to **Add → Input-Output → Write** and connect it with the **TOPSAR-Deburst** operator. in the **Write** tab define the output directory as:
/shared/Training/HAZA03_LandSubsidence_MexicoCity_TutorialKit/Processing

Set the name of the output product as:
S1A_20160606_S1A_20160910_Split_Orb_Coregi_ESD_Ifg_Deb



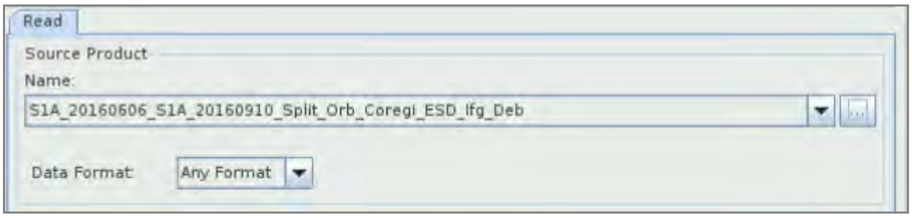
At this moment, save the graph as ***Graph_process_1.xml*** in ***/shared/Training/HAZA03_Land Subsidence_MexicoCity_TutorialKit/Processing*** by clicking **Save** at the bottom of the window.

Then click **Run.** The new product will appear in the **Product Explorer** window. *This might take approximately 40 minutes depending on your machine.*

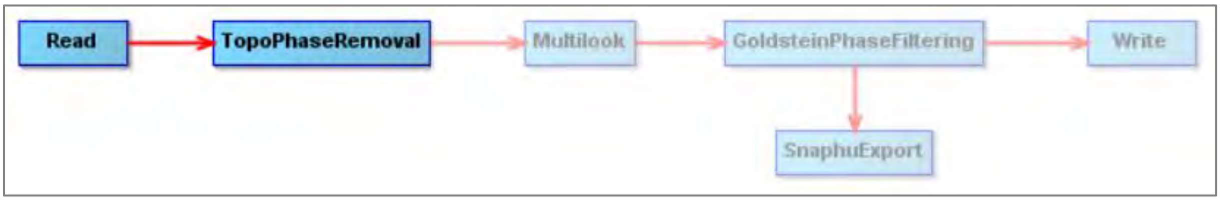


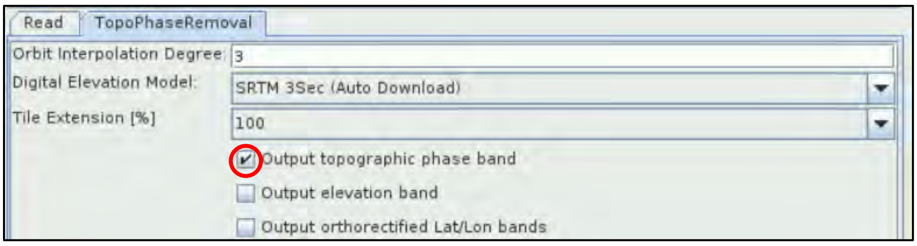
Now open a new **Graph Builder** window to create a new graph for the next processing steps. In the **Read** operator define as input name the previously produced interferogram:

S1A_20160606_S1A_20160910_Split_Orb_Coregi_ESD_Ifg_Deb

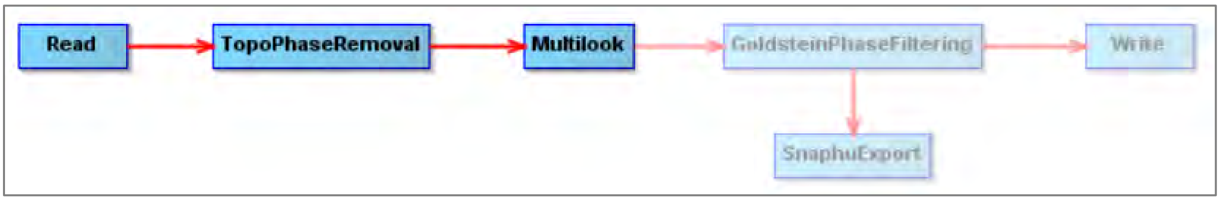


The next step is to remove the topographic induced phase from the debursted interferogram. To do so, we have to add the **TopoPhaseRemoval** operator. Go to **Add → Radar → Interferometric → Products → TopoPhaseRemoval**, keep the default parameters, and **select** the “Output topographic phase band” option.



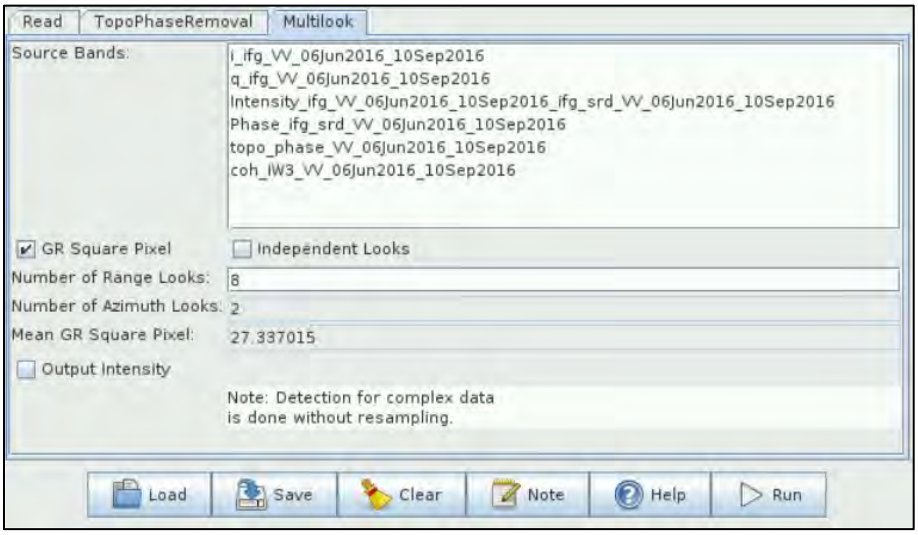


As the original SAR image contains inherent speckle noise, multilook processing is applied at this moment to reduce the speckle appearance and to improve the image interpretability. To add the **Multilook** operator go to **Add → Radar → Multilook**.

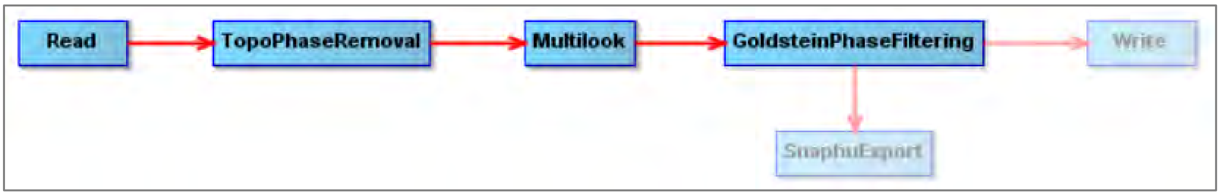


In the **Multilook** tab set the following parameters:

Number of Range Looks: 8
Number of Azimuth Looks: 2

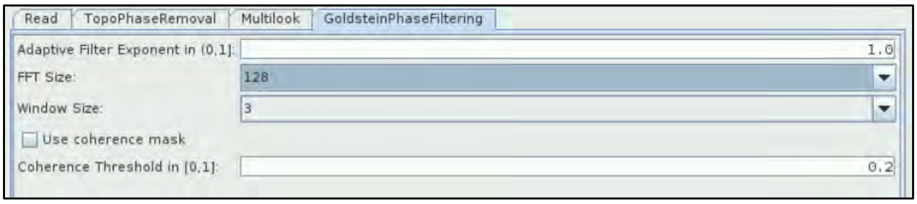


At this stage we will perform phase filtering of the interferogram in order to reduce phase noise e.g., for visualization or to aid the phase unwrapping which will be shown in the next step. The filtering method we will implement in this operator is *Goldstein method* proposed by Goldstein & Werner in 1998 [4]. To add the **GoldsteinPhaseFiltering** operator go to **Add → Radar → Interferometric → Filtering → GoldsteinPhaseFiltering.** Connect it to the **Multilook** operator.

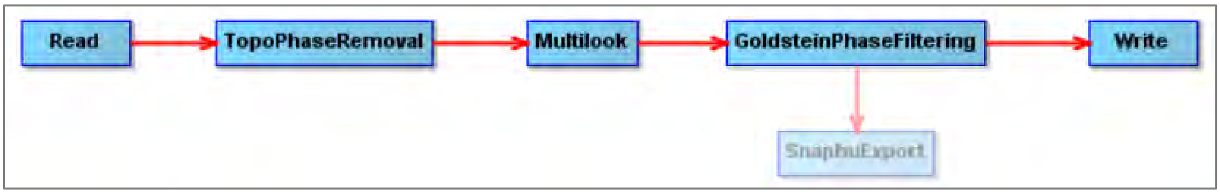


In the **GoldsteinPhaseFiltering** tab set the parameters as defined below:

Adaptive Filter Exponent in (0,1]: 1.0
FFT Size: 128



In this step we have to save the output, which is the multilooked and filtered differential interferogram. Add the **Write** operator by going to **Add → Input-Output → Write** and connect it with the **GoldsteinPhaseFiltering** operator.



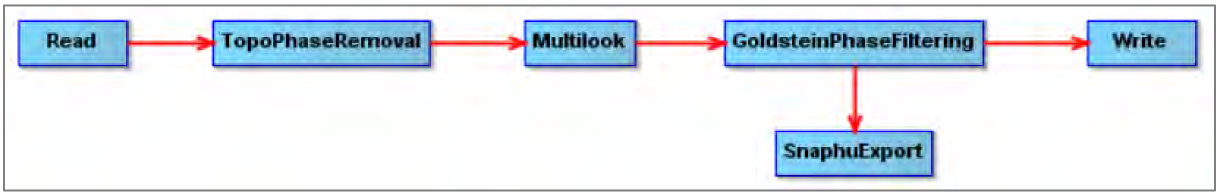
In the **Write** tab define the output directory as:

/shared/Training/HAZA03_LandSubsidence_MexicoCity_TutorialKit/Processing

Set the name of the output product as:
S1A_20160606_S1A_20160910_Split_Orb_Coregi_ESD_Ifg_Deb_DInSAR_ML_Flt (See NOTE 5)

NOTE 5: For each new operator in the GraphBuilder a corresponding suffix is added in the output product name.

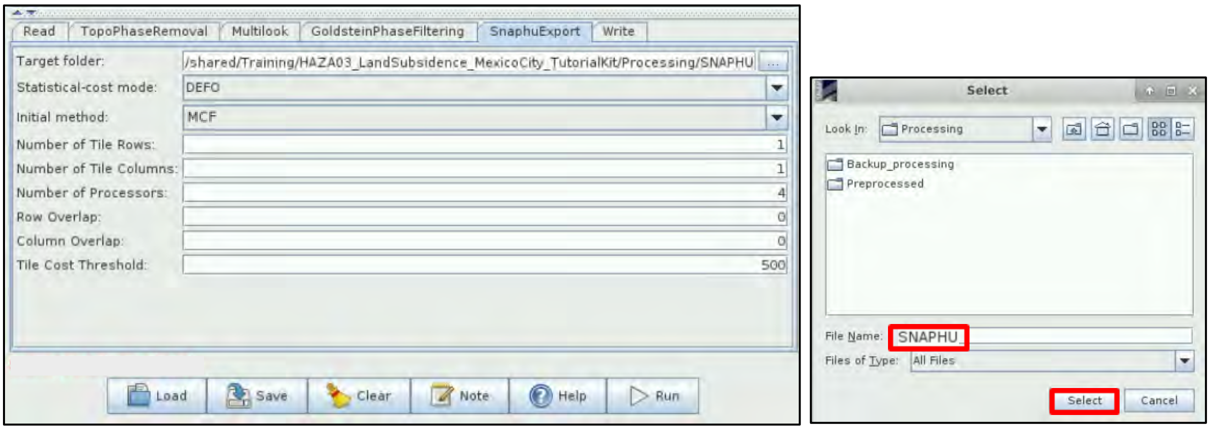
The final step in this processing part is to export the data for **SNAPHU** processing in order to apply phase unwrapping. For a general reference on phase unwrapping see Ghiglia and Pritt [5], Constantini [6]. To export data (bands) in the format compatible for SNAPHU processing, go to **Add → Radar → Interferometric → Unwrapping → SnaphuExport** and connect it with the **GoldsteinPhaseFiltering** operator as well.



In the **SnaphuExport** tab specify the full path to "Target folder" and save in ***/shared/Training/HAZA03_LandSubsidence_MexicoCity_TutorialKit/Processing/SNAPHU***. In this case, you will have to create a folder with the File name "SNAPHU" in the processing folder. Also, set the parameters as indicated below (See NOTE 6):

Statistical-cost mode: DEFO
Initial method: MCF
Number of Tile Rows: 1
Number of Tile Columns: 1
Row Overlap: 0
Column Overlap: 0

In the **Target Folder**, the following path will be created: ***/shared/Training/HAZA03_LandSubsidence _MexicoCity_TutorialKit/Processing/SNAPHU.***

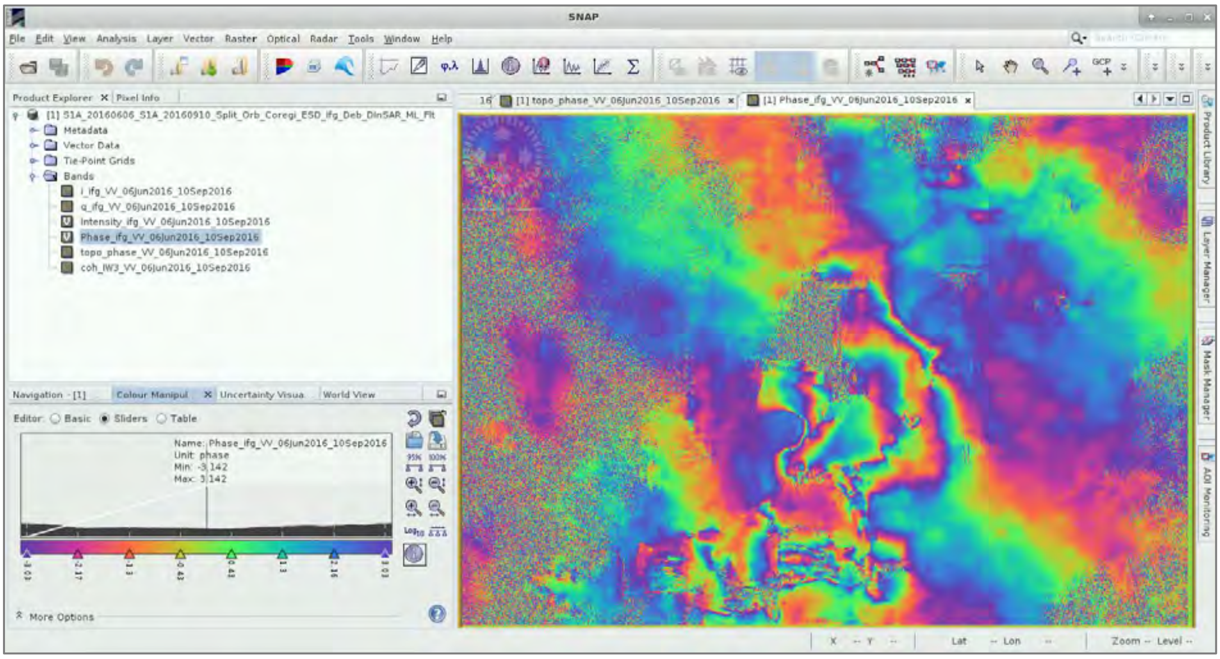


NOTE 6: Number of tiles is specified depending on the memory allocated to your machine.

At this moment, save the graph as ***Graph_process_2.xml*** in ***/shared/Training/HAZA03_Land Subsidence_MexicoCity_TutorialKit/Processing*** by clicking **Save** at the bottom of the window.

Then click **Run.** *This will take approximately 2 minutes depending on your VM.*

Now, we can close the **GraphBuilder** window. In the **Product Explorer** window, the new (multilooked) output product has been added. We can expand the **Bands** folder and select the "*Phase_ifg_VV_06Jun2016_10Sept2016"* band. In the **View** window we can see the output differential interferogram, where the phase is represented in the form of fringes (-pi, pi).



5.7 *Phase Unwrapping – Displacement Map*

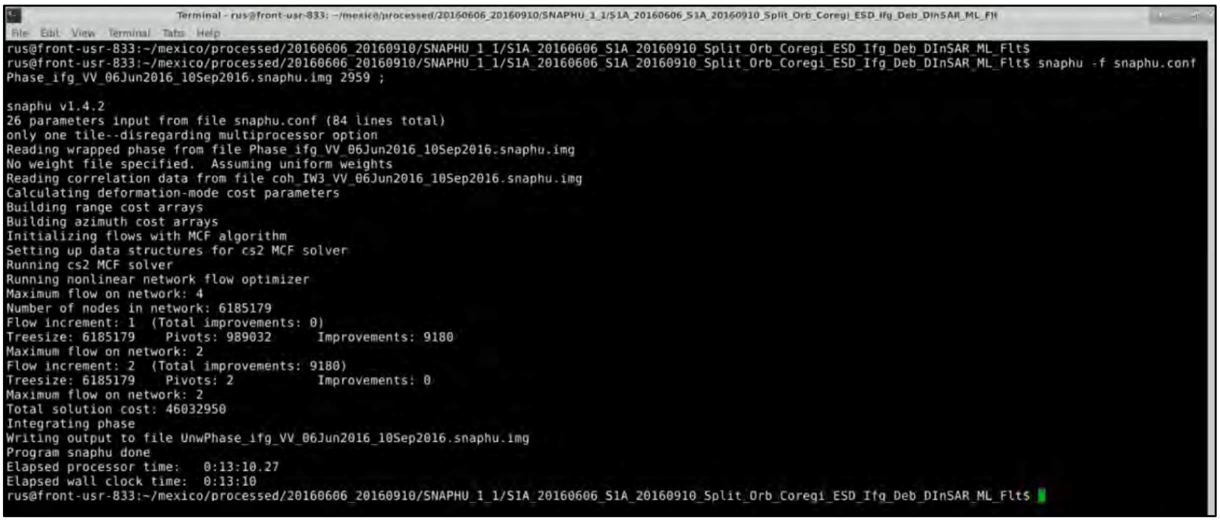
We are about to proceed with phase unwrapping via SNAPHU. Open a Linux terminal and navigate to:

```
cd /shared/Training/HAZA03_Land_Subsidence_MexicoCity_TutorialKit/Processing/SNAPHU/
S1A_20160606_S1A_20160910_Split_Orb_Coregi_ESD_Ifg_Deb_DInSAR_ML_Flt
```

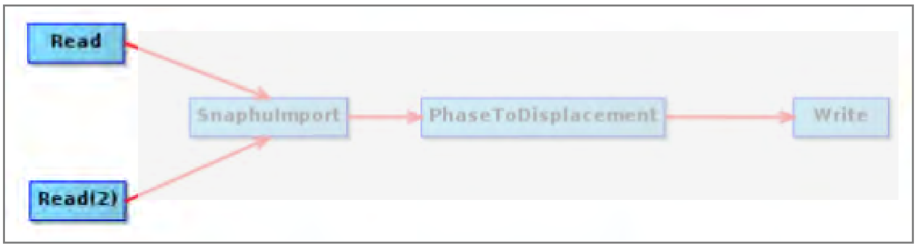
TIP: Write the first few letters of each folder name and click **Tab** to auto-complete. For example, “cd /sh” + **Tab** → “cd /shared/” → “cd /shared/Tr” + **Tab** → “cd /shared/Training” …

Now, open configuration file “**snaphu.conf**” and copy the following command to call “snaphu”:
snaphu -f snaphu.conf Phase_ifg_VV_06Jun2016_10Sept2016.snaphu.img 2959

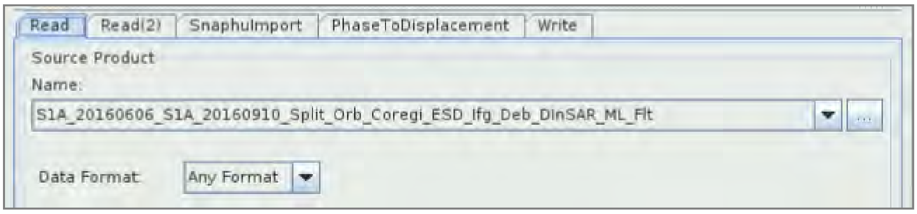
and paste it in the Terminal. Also, add the comment (**#**) before “LOGFILE”. Proceed by executing the command. The results are stored in the above-mentioned folder.



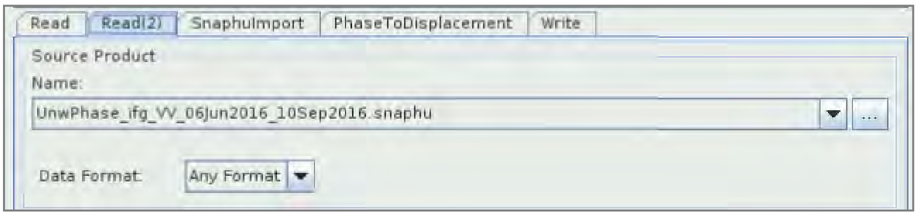
Now, open a new **Graph Builder** window to create a new graph for the next processing steps. Now, add one more **Read** operator. Right click and go to **Add → Input-Output → Read**.



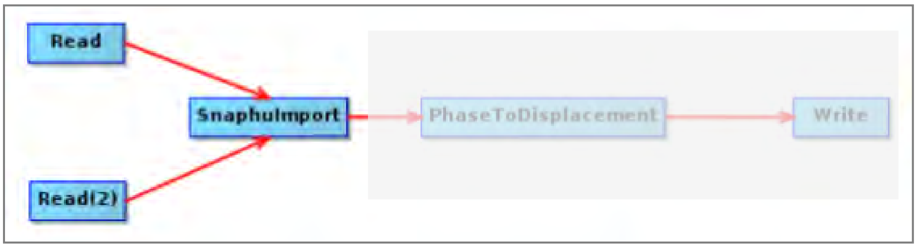
In the **Read** tab select the opened differential interferogram, saved in:
shared/Training/HAZA03_LandSubsidence_MexicoCity_TutorialKit/Processing:
S1A_20160606_S1A_20160910_Split_Orb_Coregi_ESD_Ifg_Deb_DInSAR_ML_Flt



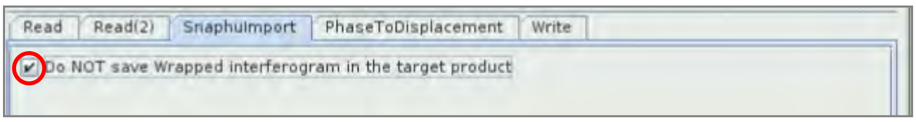
In the **Read(2)** tab select the following: ***UnwPhase_ifg_VV_06Jun2016_10Sep2016.snaphu.hdr*** from the ***/shared/Training/HAZA03_LandSubsidence_MexicoCity_TutorialKit/Processing/SNAPHU/S1A_20160606_S1A_20160910_Split_Orb_Coregi_ESD_Ifg_Deb_DInSAR_ML_Flt/*** folder.



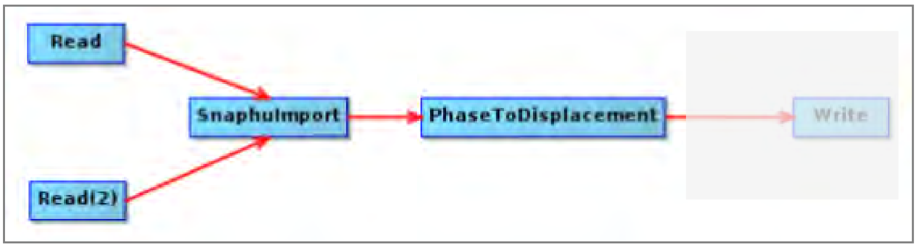
The first step is to import the results from SNAPHU processing and to construct the interferometric product that contains the unwrapped phase band, and the metadata of the source interferometric product. Go to **Add → Radar → Interferometric → Unwrapping → Snaphu Import** and connect it with the two **Read** operators.



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

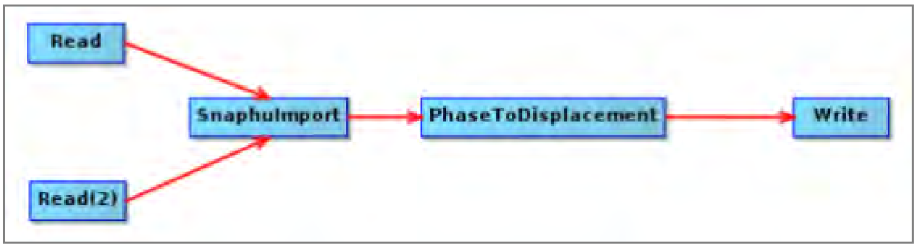


The second step is to convert the interferometric phase to displacement and to produce the displacement product. Go to **Add → Radar → Interferometric → Products → PhaseToDisplacement** and connect it with the **SnaphuImport** operator.



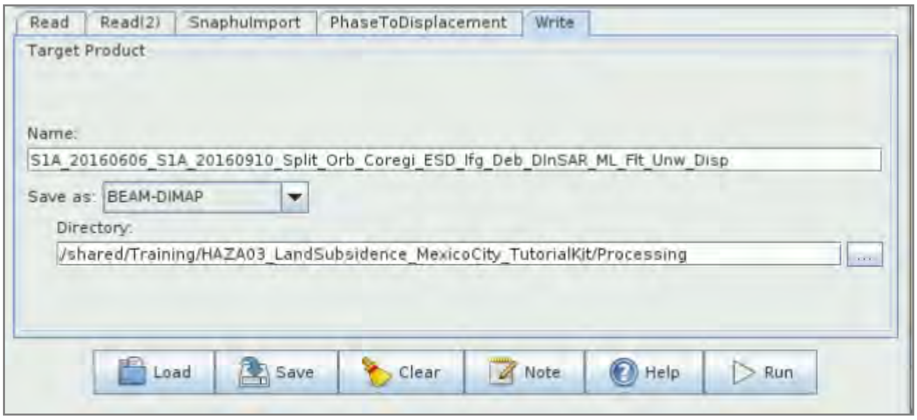
In the **PhaseToDisplacement** tab there are no parameters to specify.

Finally, add the **Write** operator by going to **Add → Input-Output → Write** and connect it with the **PhaseToDisplacement** operator.



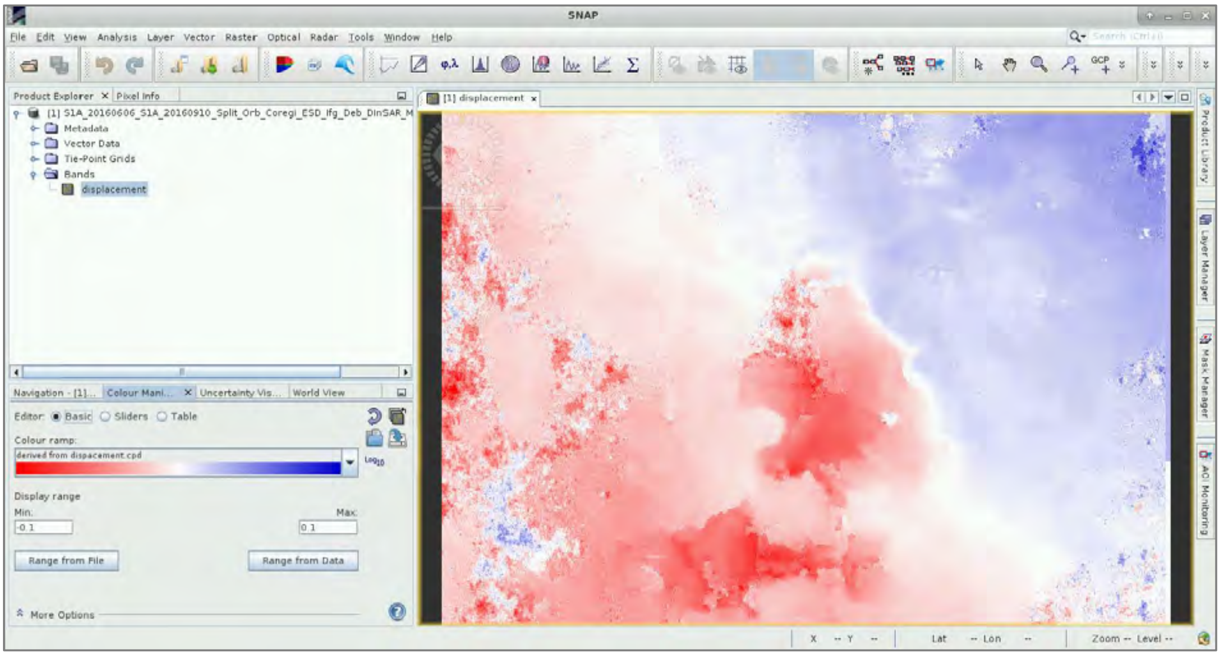
In the **Write** tab define the output unwrapped product as below:

Name: *S1A_20160606_S1A_20160910_ Split_Orb_Coregi_ESD_Ifg_Deb_DInSAR_ML_Flt_Unw_Disp*
Directory: */shared/Training/HAZA03_LandSubsidence_MexicoCity_TutorialKit/Processing*



Click **Run**.

In the **Product Explorer** window select the “displacement” band from the new opened product to open the displacement product in the view window.



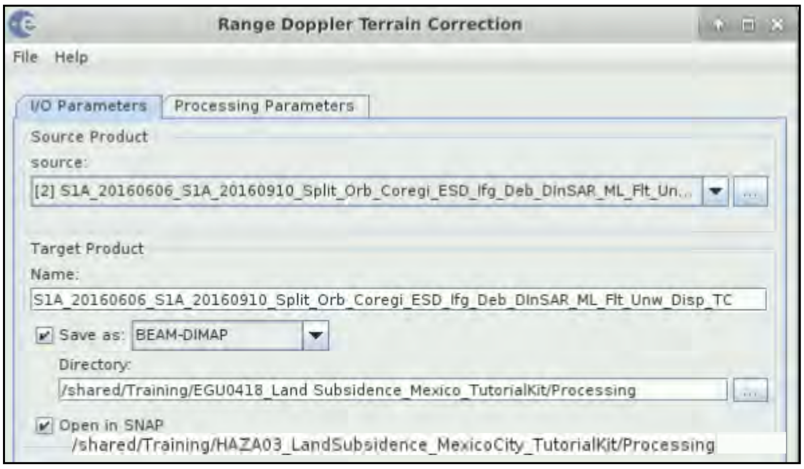
5.8 Geocoding

Due to topographical variations of a scene and the tilt of the satellite sensor, distances can be distorted in the SAR images. Terrain corrections are intended to compensate for these distortions, so that the geometric representation of the image will be as close as possible to the real world. For geocoding the Sentinel-1 products we will use the **Range Doppler Terrain Correction** operator that implements the Range Doppler orthorectification method [7].

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

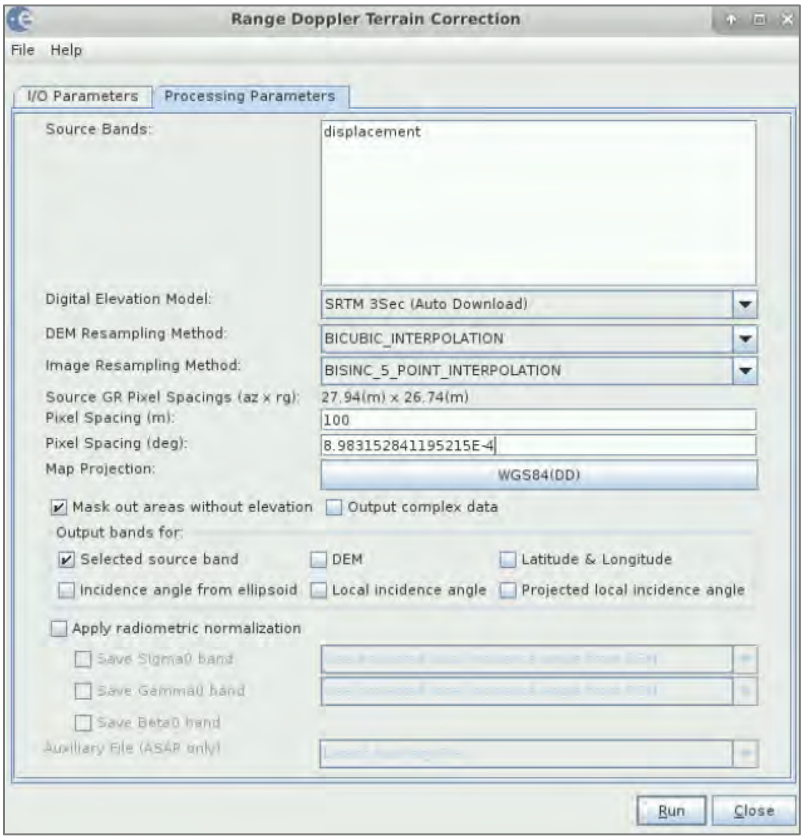
In the **I/O Parameters** tab, set the following:

Input: *S1A_20160606_S1A_20160910_ Split_Orb_Coregi_ESD_Ifg_Deb_DInSAR_ML_Flt_Unw_Disp*
Output:
S1A_20160606_S1A_20160910_Split_Orb_Coregi_ESD_Ifg_Deb_DInSAR_ML_Flt_Unw_Disp_TC
Directory: */shared/Training/HAZA03_LandSubsidence_MexicoCity_TutorialKit/Processing*



In the **Processing Parameters** tab, set the following (See NOTE 7):

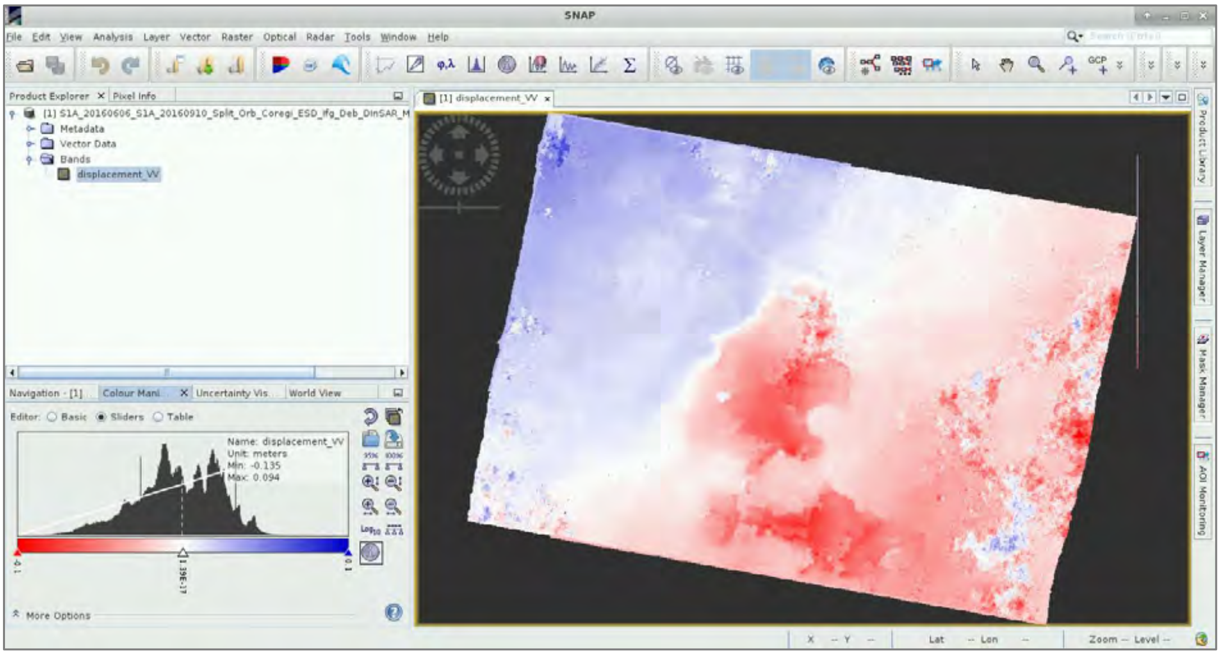
Pixel Spacing (m): 100
Map Projection: WGS84(DD)



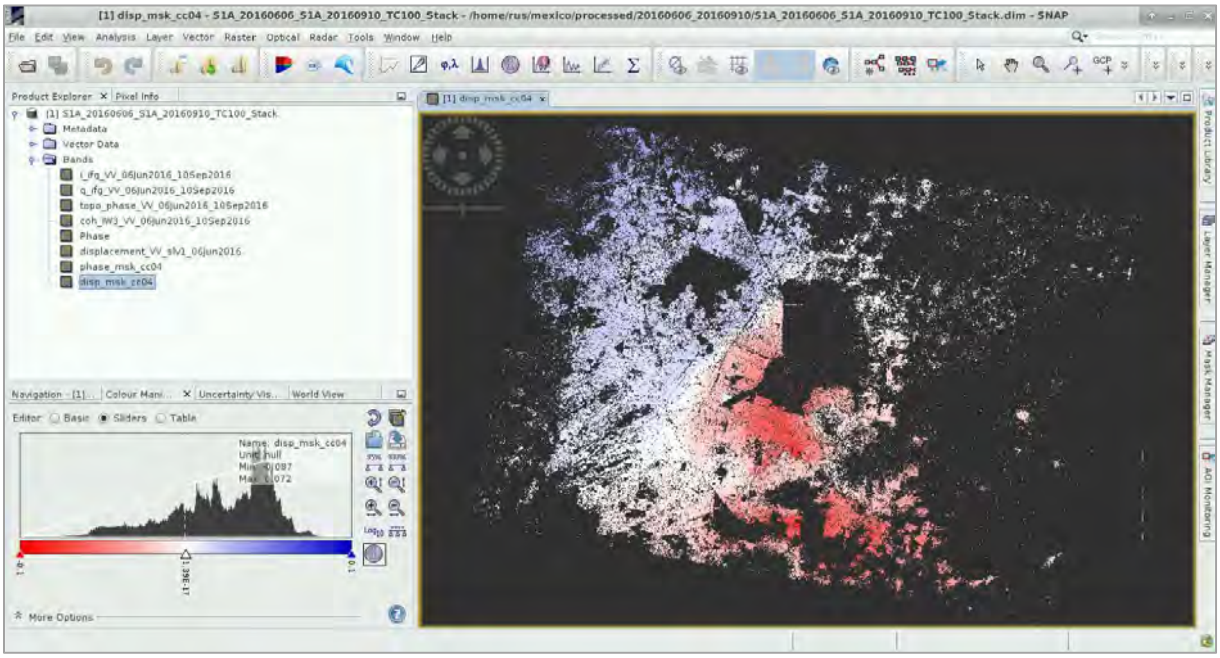
NOTE 7: The pixel spacing in meters can be specified for the orthorectified image. Alternatively, default pixel spacing computed from the source SAR image is used.

Now, click **Run**.

In the **Product Explorer** window select “displacement_VV” band to see the new geocoded product in the **View** window.



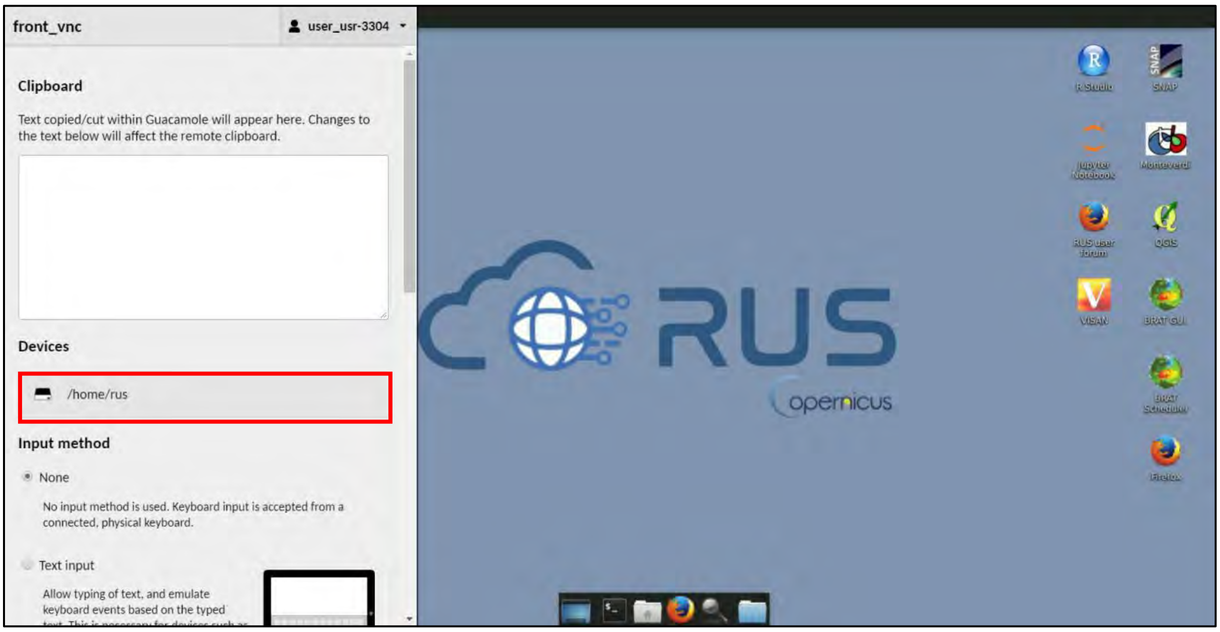
By appropriate post-processing of the displacement product, like for example the masking of the incoherent values, more accurate displacement measurements can be produced.



6 Extra steps

6.1 Downloading the outputs from VM

Press **Ctrl+Alt+Shift.** A pop-up window will appear on the left side of the screen. Click on bar below **Devices**, the folder structure of your VM will appear. Navigate to the folders you have saved the files you want to download and **double click any file you want to download.** The downloading process to your local computer will start automatically.



6.2 Export as KMZ (Google Earth)

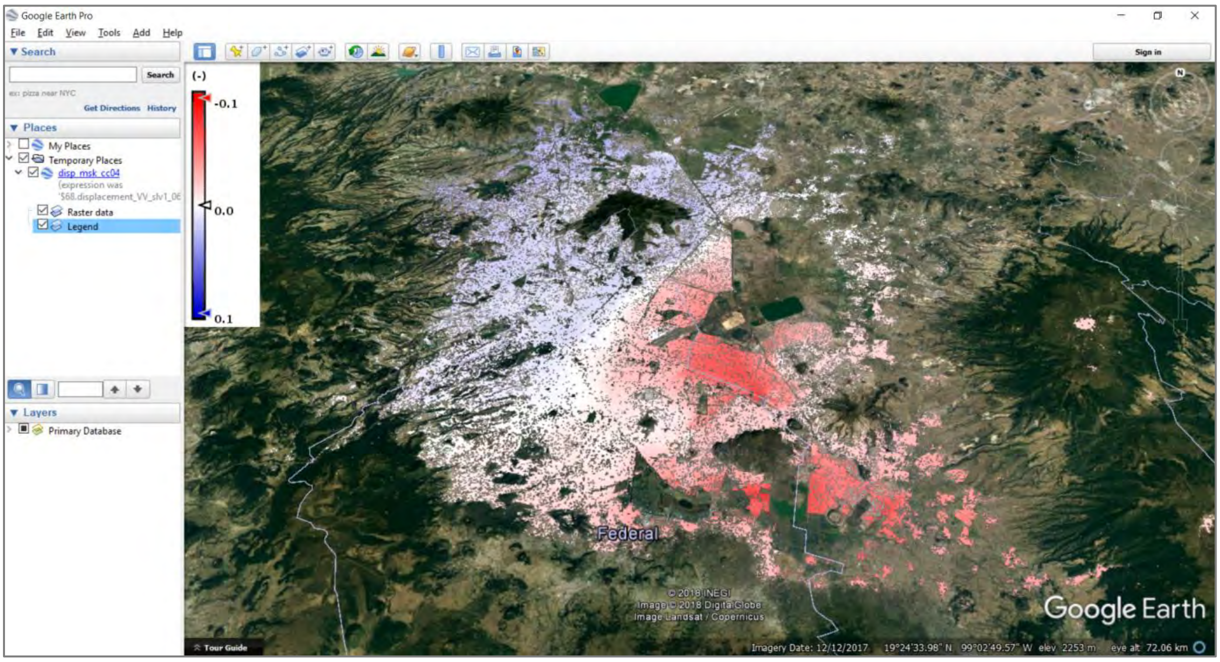
If we want to view the products in Google Earth we have to export to **KMZ** format, readable by Google Earth and then download results to our local PC for visualization, as the RUS VM does not support Google Earth installation. Readable KMZ format by Google Earth is **WGS 84 Lat/Lon coordinate system (EPSG 4326)**. If during the geocoding you have used a different coordinates system, you need to reproject the final product in SNAP accordingly by going to **Raster → Geometric Operations → Reprojection.**

Since our results are already in WGS 84, we proceed to the export of KMZ layer. In SNAP, go to **File → Export → Other → View as Google Earth KMZ** (only the active band open in the view window will be saved).

Save to the ***Processing*** folder as: ***Mexico_disp.kmz*.**

Download the KMZ files to your laptop following the instructions in section 6.1.

Open Google Earth. Go to **File → Open** and open the downloaded layer. The new layer will appear as overlay in the **Places** panel on the left (activate and deactivate layer and legend) with the name of the original band (not the saved KMZ).



THANK YOU FOR FOLLOWING THE EXERCISE!

7 Further reading and resources

SENTINEL-1 SAR User Guide Introduction – link

ESA Sentinel Online - link

Science Toolbox Exploitation Platform (STEP) – link

8 References

1. Figueroa Vega G.E., Subsidence of the City of Mexico, a Historical Review, Proc. Anaheim Symposium, IAHS Publication Nr. 121, pp. 35-38, 1976.
2. D Strozzi, T. and U. Wegmüller. Land subsidence in Mexico City mapped by ERS differential SAR interferometry, Geoscience and Remote Sensing Symposium (IGARSS) 1999 IEEE International, 1999.
3. ESA INSARAP project (http://www.esa.int/spaceinimages/Images/2014/12/Mexico_City_subsidence).
4. Goldstein R.M. and C.L. Werner, "Radar Interferogram Phase Filtering for Geophysical Applications", Geophysical Research Letters, 25, 4035-4038, 1998.
5. Ghiglia D. and M. Pritt (1998), Two-dimensional phase unwrapping: theory, algorithms, and software, 512pp.
6. Constantini M. (1998), A novel phase unwrapping method based on network programming , IEEE Tran. on Geoscience and Remote Sensing, 36, 813-821.
7. Small D. and Schubert A., Guide to ASAR Geocoding, RSL-ASAR-GC-AD, Issue 1.0, March 2008.

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