

TRAINING KIT – HAZA09

SNAP2StaMPS: Data preparation for StaMPS PSI processing with SNAP

Case Study: Mexico City, Nov. 2019 - Nov. 2020









Research and User Support for Sentinel Core Products

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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 preinstalled 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].

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 overextraction of groundwater. Current subsidence rates using Sentinel-1 SAR data approximate 2.5 cm/month [3].

Persistent Scatterer Interferometry (PSI) is a powerful advanced DInSAR technique able to measure and monitor displacements of the Earth's surface over time with hight accuracy. Hooper et al. (2004). proposed a novel PS selection using phase characteristics, which is suitable to find low-amplitude natural targets with phase stability that cannot be identified by amplitude-based algorithms. This work originated one of the most widely used PSI software packages, StaMPS.¹

SNAP2StaMPS is a Python workflow developed by José Manuel Delgado Blasco, Michael Foumelis in collaboration with Prof. A. Hooper to automate the pre-processing of Sentinel-1 SLC data and their preparation for ingestion to StaMPS.

2 Training

Approximate time needed to complete this training session is two hours.

2.1 Data used

- 31 Sentinel-1A images acquired between November 1, 2019 and November 1, 2020.
 [downloadable @<u>ASF Data Search portal Vertex</u>]
- Auxiliary data stored locally
 @/shared/Training/HAZA09_SNAP2StaMPs_DataPrep_TutorialKit/AuxData

2.2 Software in RUS environment

Internet browser, SNAP + Sentinel-1 Toolbox, QGIS, 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 (<u>www.rus-copernicus.eu</u>) and click on *Login/Register* in the upper right corner.

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	News from RUS
The second second	The evolution of RUS viewed by EARSC
	RUS Training Session (online) – 5 Nov. 2020 RUS Training Session (online) – 29 Oct. 2020
	RUS Webinar – Lebanon damage assessment using Sentinel-1 and Sentinel-2 – 27 Oct. 2020
	RUS Webinar - Copernicus Data Access - 29 September 2020
	RUS Webinar - Processing Copernicus data in Python using snappy - 23 June 2020

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*.

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Registered RUS users, as well as persons who already own a Copernicus SSO account, can directly access our service. Login Newcomers shall first create an account on the Copernicus Single Sign-On (SSO) authentication server used to support registration to the RUS service. Create my Copernicus SSO account	Copernicus Users' Sing Registration form Tm already registered Cos 590 ID General guestion Passinical Cordinin passantit Cordinin passantit Cordinin ensai Cordinin ensai Cordini ensai Cordini ensai Fist hane List painting		EAG
NB: persons using a Google e-mail address for registration shall check their mailbox spam folder regularly as Google tends to filter RUS e-mails.	Country of residence	dSafn 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 <u>https://rus-copernicus.eu/</u>, click on *Login/Register*, choose *Login* and enter your chosen credentials.

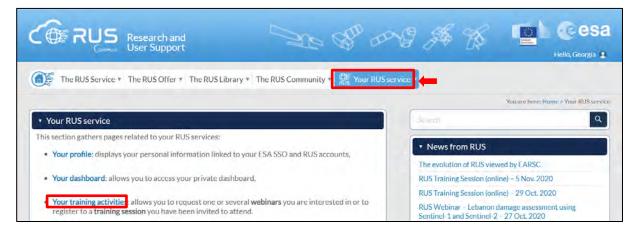
Login / Register	Credentials			
The registration system to access the RUS service platform has moved toward the COPERNICUS Single Sign On authentication server. • New Users who have not yet registered to the RUS portal shall first create a COPERNICUS SSO account. Note that your Copernicus SSO account will be activated only after the reception of the third email sent by the Copernicus service. We advise you to consult <u>this document</u> and <u>this page</u> to facilitate your registration procedure. REGISTER COPERNICUS SSO account Users who already have a COPERNICUS SSO account can login here:	CDS-SSO ID Password Max Idle Time Max Session Time	half a day Until browser close	Y	0 0 0
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Upon your first login you will need to enter some details. You must fill all the fields.

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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** \rightarrow **Your training activities**.



Select **HAZA09**, 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.

Webinar Training Request	
You wish to practice a tutorial exercise shown in a RUS webinar? • Please select your choice Select one or more items:	
HAZA05 - Earthquake deformation using InSAR with Sentinel-1 HAZA06 - Watching a Typhoon using Sentinel-1 HAZA07 - Rapid Landslide Detection with Sentinel-1	~
HAZA08 - Lebanon Damage Assessment with Sentinel-1 and Sentinel-2 HYDR01 - Water Bodies Mapping over Northern Poland HYDR02 - Freshwater Quality Monitoring with Sentinel-2 LAND01 - Crop Mapping in Seville	
Have read and agree to the Terms and conditions of RUS Service.	

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**.

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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.

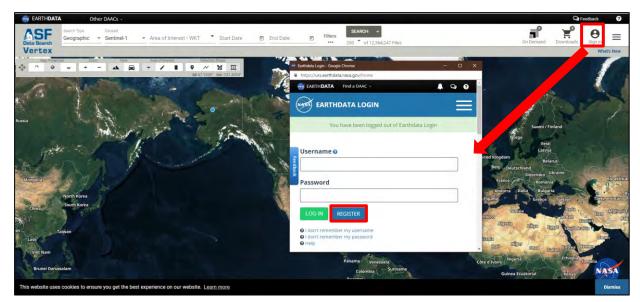


5 Data download

For this exercise we will introduce another portal for the download of Sentinel-1 SLC data. We will use the <u>Alaska Satellite Facility</u> portal which offers the full Sentinel-1 SLC archive. Many other portals (including Copernicus Open Access Hub) move data older than certain period to long term archive which makes their retrieval more time demanding.

We will work with 1 year of data from 1 November 2019 to 1 November 2020 and concentrate on acquisitions only by Sentinel-1A satellite in descending pass. In total this amounts to timeseries of 31 images in 12-day interval.

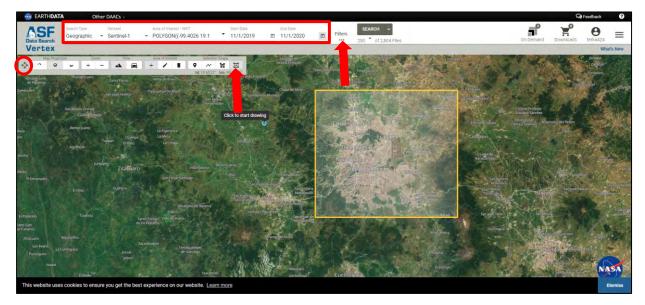
Go to the <u>ASF Data Search portal – Vertex</u>. Click on **Sign in**, a new window will appear. Click **Register** and fill your details.



Profile Information	
Jsername: •	Required field
	Username must:
Password: •	Be a Minimum of 4 characters Be a Maximum of 30 characters Use letters, numbers, periods and underscores Not contain any blank spaces
Password Confirmation: •	 Not begin, end or contain two consecutive special characters()
	Password must contain: Minimum of 8 characters
	Minimum of a Characters One Uppercase letter One Lowercase letter One Lowercase letter One Number
User Information	
First Name: •	Middle Initial:
Last Name: •	E-mail: •

Once you complete your registration and validate your e-mail address, log in. Navigate to Mexico City, select the Box drawing tool and draw a rectangle over the area of interest.

Then in the top panel select: **Start Date:** 1 November 2019 **End Date:** 1 November 2020



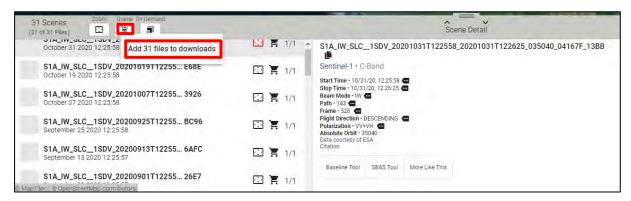
Then go to **Filters** and set:

File Type: L1 Single Look Complex Direction: Descending Subtype: SA Path Start: 143 Frame Start: 526

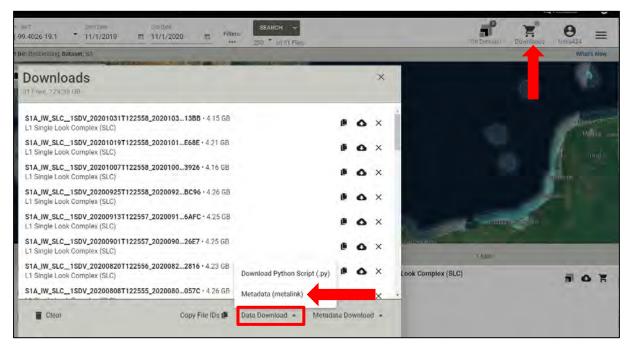
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143	国 143	526	526	Clear	Clear Search Area	
			_		250.** of 31 Files	SEARCH

Click Search. The search returns 31 products. Above the results list, click on 😤 Add all results to downloads. You need to click on Add 31 files to downloads.



Now go to the **Downloads** tab next to the account button and in the window that appears click on **Data Download**. Now you can either choose a python script or metalink to download the data. We will use **Metadata (metalink).** Click on it and a *.metalink* file will be downloaded.



Go to the **/home/rus/** folder and move the metalink to:

/shared/Training/HAZA09_SNAP2StaMPs_DataPrep_TutorialKit/Original/

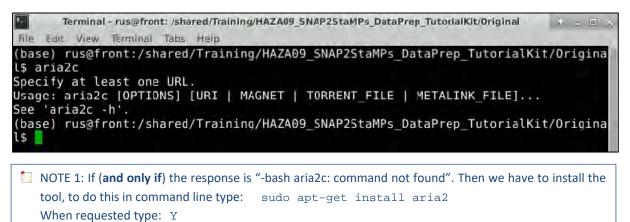
You can also rename it to: MC_desc.metalink

To download our data, we will use **aria2** tool. To do this, go to the **/Original** folder where we have placed the metalink file and right-click on the white space in the folder. Select **Open Terminal Here**. A terminal window will open.

First, let's test our aria2 installation. Type:

aria2c

The correct response should be as follows:



Then you can test your installation again.

If the response is "-bash aria2c: command not found" see NOTE 1. If you have received the correct response, then we can run the tool by typing the following commands in the command line (replace <username> and <password> with your login credentials for Copernicus Open Access Hub):

```
aria2c --http-user='<username>' --http-passwd='<password>' --check-
certificate=false -M MC_desc.metalink
```

The first line changes our directory to the target directory. The second line runs the download tool (Type the text all in a single line). All twelve products will be downloaded to the *Original* folder, automatically.

6 Step by step

6.1 SNAP2StaMPS download and installation

Persistent Scatterer Interferometry (PSI) is a powerful advanced DInSAR technique able to measure and monitor displacements of the Earth's surface over time with hight accuracy. Hooper et al. (2004). proposed a novel PS selection using phase characteristics, which is suitable to find low-amplitude natural targets with phase stability that cannot be identified by amplitude-based algorithms. This work originated one of the most widely used PSI software packages, StaMPS.¹

SNAP2StaMPS is a Python workflow developed by José Manuel Delgado Blasco, Michael Foumelis in collaboration with Prof. A. Hooper to automate the pre-processing of Sentinel-1 SLC data and their preparation for ingestion to StaMPS. The running of StaMPS SW requires MATLAB licence.

The Following part is directly taken from the SNAP2StaMPS - manual and StaMPS manual.

StaMPS is compatible with the output generated by the ESA SentiNel Application Platform (SNAP) after the version 6.0. SNAP allows the user to define a series of xml files which contain user defined processing workflow by using its Graph Builder. These files can be used to run SNAP processing in batch mode by using the GPT command (Graph Processing Tool).

snap2stamps contains a set of graphs, together with python wrappers that allow you to automatise the interferogram processing chain for single master interferograms compatible with StaMPS PSI. Information about the provided functionalities and their instructions can be found in the user manual provided within snap2stamps, which already plans newer releases increasing functionality and compatibility maintenance of SNAP-StaMPS chain. A reference to the software package (Foumelis et al., 2018) can be found in the manual.

6.2 SNAP v7 compatibility fix

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35	<pre><node id="Enhanced-Spectral-Diversity"></node></pre>	
36	<pre><operator>Enhanced-Spectral-Diversity</operator></pre>	
37	<sources></sources>	
38	<sourceproduct refid="Back-Geocoding"></sourceproduct>	
39		
40	<pre><parameters class="com.bc.ceres.binding.dom.XppDomElement"></parameters></pre>	
41	<finewinwidthstr>512</finewinwidthstr>	
42	<finewinheightstr>512</finewinheightstr>	
43	<finewinaccazimuth>16</finewinaccazimuth>	
44	<finewinaccrange>16</finewinaccrange>	
45	<finewinoversampling>128</finewinoversampling>	
46	<xcorrthreshold>0.1</xcorrthreshold>	
47	<cohthreshold>0.15</cohthreshold>	
48	<numblocksperoverlap>10</numblocksperoverlap>	
49	<usesuppliedshifts>false</usesuppliedshifts>	
50	<pre><overallazimuthshift>0.0</overallazimuthshift></pre>	
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52		
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<useSuppliedRangeShift>false</useSuppliedRangeShift> <useSuppliedAzimuthShift>false</useSuppliedAzimuthShift>

1	*coreg_ifg_computation.xml - Mousepad	
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38	<sourceproduct refid="Back-Geocoding"></sourceproduct>	
39		
40	<pre><pre><pre><pre>com.bc.ceres.binding.dom.XppDomElement"></pre></pre></pre></pre>	
41	<finewinwidthstr>512</finewinwidthstr>	
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43	<finewinaccazimuth>16</finewinaccazimuth>	
44	<finewinaccrange>16</finewinaccrange>	
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46	<xcorrthreshold>0.1</xcorrthreshold>	
47	<cohthreshold>0.15</cohthreshold>	
48	<numblocksperoverlap>10</numblocksperoverlap>	
49	<usesuppliedrangeshift>false</usesuppliedrangeshift>	
50	<pre><usesuppliedazimuthshift>false</usesuppliedazimuthshift></pre>	
51	<pre><overallazimuthshift>0.0</overallazimuthshift></pre>	
52	<overallrangeshift>0.0</overallrangeshift>	
53		
54		

coreg_ifg_computation_subset.xml - if subset
coreg_ifg_computation.xml - if no subset

6.3 Hardware requirements

There are no specific hardware requirements but note that Sentinel-1 data are quite large, and their processing requires significant resources. For example, the interferogram generation step, which is the most computationally demanding will likely require a machine with minimum of 16 GB RAM.

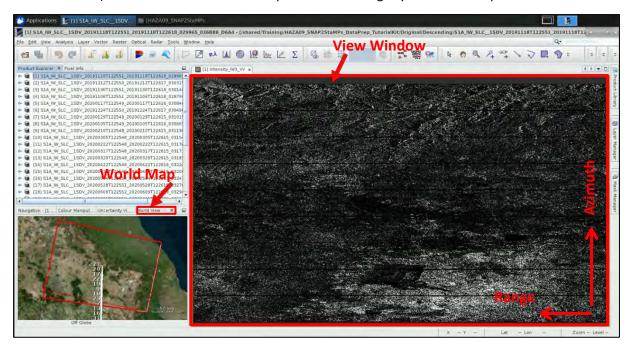
6.4 SNAP - open and explore data

Open SNAP software from the \blacksquare icon located on the desktop or go to Applications \rightarrow Processing \rightarrow SNAP Desktop. Click the Open Product icon \boxdot , navigate to:

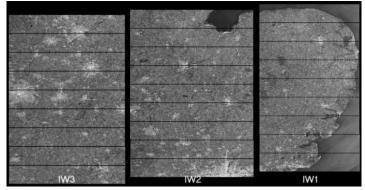
/shared/Training/HAZA09_SNAP2StaMPs_DataPrep_TutorialKit/Original/

Select all 31 downloaded products and click **Open**.

The opened products will appear in **Product Explorer** window. Click \bigcirc or to expand the contents of first product [1] in the list (it may not correspond to the first date), then expand **Bands** folder and double click on *Intensity_IW3_VV* band to visualize it in the **View** window. You can go to the **World Map** tab (**View** \rightarrow **Tool Windows** \rightarrow **World Map**) and zoom-in to see the location of the opened products (See \bigcirc NOTE 1 & 2). You can also see that some products have slightly different footprint.



- 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 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.
- NOTE 2: The Interferometric Wide (IW) swath mode captures three subswaths 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 9 bursts. Mexico City is located on the IW3 subswath of the Sentinel-1 images.



Credits: ESA User Guides for Sentinel-1 SAR

6.5 Master selection

Before we start with the pre-processing of the data, we need to select optimal master image. The master image is selected such that the distribution of the perpendicular baseline values is as low as possible as well as maximizing the (expected) stack coherence of the interferometric stack. Selection of the "optimal" master should lead to improved visual interpretation of the interferograms and assist quality assessment.

SNAP contains a tool to perform the optimal master selection for us while also providing the overview of the temporal and perpendicular baselines of all the product in respect to it.

Go to Radar \rightarrow Interferometric \rightarrow InSAR Stack Overview and click Add Opened to load all our 31 products (they will not be ordered by date, but it is not important). Then click **Overview**.

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input stack											
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Dierview File Name S1A W SLC 150V 20200504T122550 20200504T1225617 032415 0320E6 2880 M W SLC 150V 2019111122551 20191101122618 029965 036E88 0684 M W SLC 150V 2019112122520 20191212T122617 030315 0377A6 F08A	Mst/Slv Master Slave	04May2020 18Nov2019 12Dec2019	143 143	32415 29965	0.00 49.71	0.00	1.00 0.81	39 •314.35	0,00 2,57	-	Öpen
Die Name 514 NW SLC 150V 20200504T122550 20200504T122617 032415 03C0E6 2880 514 NW SLC 150V 201911101122551 201911101122616 029995 0360808 0688 514 NW SLC 150V 201911101122551 201911101122617 030315_0371A6 F08A 514 NW SLC 150V 201911211215252 201911301122618 030315_03735C 4804	Mst/Slv Master Slave Slave	04May2020 18Nov2019 12Dec2019 30Nov2019	143 143 143	32415 29965 30315	0.00 49.71 44.66	0.00 168.00 144.00	1.00 0.81 0.83	== -314.35 -349.90	0,00 2,57 3.33 -0.92 -4.59		Open
Diarview File Name Bla Name Bla Name Bla NW SLC 1SDV 20200504T122550 20200504T122617 032415 03C0E6 2880 Bla NW SLC 1SDV 20191110T122551 20191110T122618 029955 036B88 D684 Bla NW SLC 1SDV 20191112T122550 20191212T122617 030315 0377A6 F084 Bla NW SLC 1SDV 20191130T122551 20191130T122618 030140 03719C 4804 IA W SLC 1SDV 20191130T122551 2019110T122618 030140 03719C 4804 IA W SLC 1SDV 2019110T122551 2019110T122618 030140 03719C 1404	Mst/Slv Master Slave Slave Slave	04May2020 18Nov2019 12Dec2019 30Nov2019 06Nov2019 17Jan2020	143 143 143 143 143 143	32415 29965 30315 30140	0.00 49.71 44.66 57.57	0.00 168.00 144.00 156.00 180.00 108.00	1.00 0.81 0.83 0.82 0.82 0.82 0.87	314.35 -349.90 -271.47 -546.66 447.23	0,00 2,57 3,33 -0.92 -4,59 2,74		Open
Die Name SIA W 5LC 15DV 20200504T122550 20200504T122617 032415 030066 2880 SIA W 5LC 15DV 20191110T122550 20191110T122616 029950 036B88 6848 SIA W 5LC 15DV 20191110T122551 20191110T122616 029950 036150 777A6 F98A SIA W 5LC 15DV 20191130T122551 20191130T122618 030140 03719C 4804 SIA W 5LC 15DV 20191130T122551 20191130T122618 030140 03719C 4804 SIA W 5LC 15DV 20191130T122551 2019110T122618 030140 03719C 4804 SIA W 5LC 15DV 20191117122545 2019110T122618 030140 03719C 4804 SIA W 5LC 15DV 20191117122545 2019110T122618 030440 03719C 4804	Mst/Sly Master Slave Slave Slave Slave	04May2020 18Nov2019 12Dec2019 30Nov2019 06Nov2019 17Jan2020 24Dec2019	143 143 143 143 143 143 143 143	32415 29965 30315 30140 29790 30840 30490	0.00 49.71 44.66 57.57 24.17	0.00 168.00 144.00 156.00 180.00 108.00 132.00	1.00 0.81 0.83 0.82 0.82 0.87 0.87	-314.35 -349.90 -271.47 -546.66 447.23 -428.39	0.00 2.57 3.33 -0.92 -4.59 2.74 1.58		Öpen
Diverview File Name 514 NV 5LC 150V 20200504T122550 20200504T122617 032415 03C0E6 2880 514 NV 5LC 150V 201911101122551 201911101122618 029905 036B88 D6A4 514 NV 5LC 150V 201911101122551 201911101122618 030140 03715C 4804 514 NV 5LC 150V 201911017122551 201911017122618 030140 03715C 4804 514 NV 5LC 150V 201911017122551 201911017122616 030400 03757 11A4 514 NV 5LC 150V 201911017122551 201911017122616 038400 CC666 514 NV 5LC 150V 20201171122540 201911271122616 038400 CC666 514 NV 5LC 150V 20201171122472550 20191247112617 030490 338708 E6426	Mist/Slv Master Slave Slave Slave Slave Slave	04May2020 18Nov2019 12Dec2019 30Nov2019 06Nov2019 17jan2020 24Dec2019 29Jan2020	143 143 143 143 143 143	32415 29965 30315 30140 29790 30840 30840 30490 31015	0.00 49.71 44.66 57.57 24.17 -34.94 36.48 -19.56	0.00 168.00 144.00 156.00 180.00 108.00 132.00 96.00	1.00 0.81 0.83 0.82 0.82 0.87 0.87 0.85 0.90	-314.35 -349.90 -271.47 -546.66 447.23 -428.39 799.02	0.00 2.57 3.33 -0.92 -4.59 2.74 1.58 1.02		Öpen
Diverview File Name BIA W SLC 150V 20200504T122550 20200504T122617 032415 03C0E6 2880 SIA W SLC 150V 20191110T122551 20191110T122618 029955 036B68 0644 SIA W SLC 150V 20191212T122550 20191212T122617 030315 0377A6 F08A SIA W SLC 150V 20191310T122551 20191130T122618 030140 03719C 4804 SIA W SLC 150V 20191310T122551 2019110T122618 029790 036573 11AA SIA W SLC 150V 2020011TT122549 2020011TT122616 030440 03890E CC66 SIA W SLC 150V 2020011TT122549 2020012T122617 030490 0360573 81A2 SIA W SLC 150V 2019124T122550 2019124T122617 030490 036050 5043 SIA W SLC 150V 2019124T122550 2019124T122615 030440 036050 C665 SIA W SLC 150V 2019124T122550 2019124T122615 030490 0370B3 B432 SIA W SLC 150V 202021TT122549 2020012TT122615 030450 0370B3 D832	Mst/Slv Master Slave Slave Slave Slave Slave Slave Slave	04May2020 18Nov2019 12Dec2019 30Nov2019 06Nov2019 17jan2020 24Dec2019 29Jan2020	143 143 143 143 143 143 143 143	32415 29965 30315 30140 29790 30840 30490	0.00 49.71 44.66 57.57 24.17 -34.94 36.48	0.00 168.00 144.00 156.00 180.00 108.00 132.00	1.00 0.81 0.83 0.82 0.82 0.87 0.87	-314.35 -349.90 -271.47 -546.66 447.23 -428.39	0.00 2.57 3.33 -0.92 -4.59 2.74 1.58		Open
Diverview File Name SLA W SLC 15DV 20200504T122550 20200504T122617 032415 03C0E5 2880 SLA W SLC 15DV 201911101122551 201911101122618 029905 036B88 D6A4 SLA W SLC 15DV 201911101122551 201911101122618 029905 036B88 D6A4 SLA W SLC 15DV 201911217122550 20191126T122618 03040 0375C 4804 SLA W SLC 15DV 20191106T122551 20191106T122618 029700 036573 11A4 SLA W SLC 15DV 201911212552 20191106T122618 03040 037905 D6381 SLA W SLC 15DV 2012012T1225549 20200127T122615 030460 038905 D638 SLA W SLC 15DV 202020127T122549 20200127T122615 031065 039858 D3955 SLA W SLC 15DV 202020157T122549 20200127T122615 031065 039858 D3965 SLA W SLC 15DV 202020157T122549 202001257T122615 031065 039658 D39655 SLA W SLC 15DV 202020157T122549 202001257T122615	Mst/Slv Master Slave Slave Slave Slave Slave Slave Slave	04May2020 18Nov2019 12Dec2019 30Nov2019 06Nov2019 17jan2020 24Dec2019 29jan2020 05jan2020	143 143 143 143 143 143 143 143 143	32415 29965 30315 30140 29790 30840 30840 30490 31015	0.00 49.71 44.66 57.57 24.17 -34.94 36.48 -19.56	0.00 168.00 144.00 156.00 180.00 108.00 132.00 96.00	1.00 0.81 0.83 0.82 0.82 0.87 0.85 0.90 0.87 0.86	-314.35 -349.90 -271.47 -546.66 447.23 -428.39 799.02	0.00 2.57 3.33 -0.92 -4.59 2.74 1.58 1.02		Öpen
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Diskrivew File Name SIA W SLC 150V 20200504T122550 20200504T122617 032415 03C0E5 2880 SIA W SLC 150V 201911101122551 201911181122618 029955 036B88 D6A4 SIA W SLC 150V 201912117122550 201912181122618 029955 036B88 D6A4 SIA W SLC 150V 20191217122550 201912181122618 030140 03715C 4804 SIA W SLC 150V 201911217122550 20191201122616 03040 037108 8342 SIA W SLC 150V 20201171122549 20200127122616 03040 037108 8342 SIA W SLC 150V 20201271122549 2020127122615 031040 037108 8342 SIA W SLC 150V 2020127122549 20200127122615 031040 037108 8342 SIA W SLC 150V 20200127122549 20200127122615 031106 03680E 5956 SIA W SLC 150V 20200217122548 202002107122615 0311040 03961E 6946 SIA W SLC 150V 202000371122548 20200021712212515	Mst/Sive Master Slave Slave Slave Slave Slave Slave Slave Slave Slave Slave	04May2020 18Nov2019 12Dec2019 30Nov2019 06Nov2019 17Jan2020 24Dec2019 29Jan2020 05Jan2020 10Feb2020 05Mar2020	143 143 143 143 143 143 143 143 143 143	32415 29965 30315 30140 29790 30840 30490 31015 30665 31190	0,00 49.71 44.66 57.57 24.17 -34.94 36.48 -19.56 -26.32 74.93 11.63 30.21	0.00 168.00 144.00 156.00 180.00 108.00 132.00 96.00 120.00 84.00	1.00 0.81 0.83 0.82 0.82 0.87 0.85 0.90 0.87 0.85 0.90 0.87 0.85 0.94 0.91	89 -314.35 -349.90 -271.47 -646.66 447.23 -428.39 799.02 593.76 -208.57	0.00 2.57 3.33 -0.92 -4.59 2.74 1.58 1.02		Open
SIA. W. SLC ISDV 20220422T122549. 20200422T122616. 032240. 038ABA 5D16. Diverview File Name SIA. W. SLC ISDV 20200504T122550. 20200504T122617. 032415. 035066. 2880 SIA. W. SLC ISDV 2020151122551. 20191161122618. 039965. 036B688. D6A4 SIA. W. SLC ISDV 201911217122550. 201911217122618. 039945. 036B688. D6A4 SIA. W. SLC ISDV 201911217122550. 201911267122618. 039940. 03719C. 4804 SIA. W. SLC ISDV 201911067122551. 201911067122618. 039940. 038706. 4804 SIA. W. SLC ISDV 201911067122551. 201911067122618. 039940. 038708. C4804 SIA. W. SLC ISDV 201911107122549. 201911067122618. 039940. 038708. C4804 SIA. W. SLC ISDV 201911127122549. 20201157122618. 030140. 038718. C4804 SIA. W. SLC ISDV 2019111212554. 201911067122618. 030140. 038718. C4804 SIA. W. SLC ISDV 200201171122549. 202011571122618. 031040. 038618. C5805 SIA. W. SLC ISDV 2020201571122548. 20200157122615. 031190. 039615. 0594 SIA. W. SLC ISDV 2020201571122548. 202002107122615. 031190. 034615. 0594 SIA. W. SLC ISDV 202020157112548. 202002107122615. 031190. 034615. 0594 SIA. W. SLC ISDV 202020157112548. 2020021071122615. 031190. 03462. 431E SIA. W. SLC ISDV 202020117112548. 202003171122615. 03119	Mist/Sive Slave Slave Slave Slave Slave Slave Slave Slave Slave Slave Slave	04May2020 18Nov2019 12Dec2019 30Nov2019 06Nov2019 17Jan2020 24Dec2019 29Jan2020 05Jan2020 05Jan2020 05Mar2020 22Feb2020	143 143 143 143 143 143 143 143 143 143	32415 29965 30315 30140 29790 30840 30490 31015 30665 31190 31540	0.00 49.71 44.66 57.57 24.17 -34.94 36.48 -19.56 -26.32 74.93 11.63	0.00 158.00 144.00 156.00 180.00 108.00 132.00 96.00 120.00 84.00 60.00	1.00 0.81 0.83 0.82 0.82 0.87 0.85 0.90 0.87 0.86 0.94	30 -314.35 -349.90 -271.47 -546.66 447.23 -428.39 799.02 593.76 -208.57 -1343.87	0.00 2.57 3.33 -0.92 -4.59 2.74 1.58 1.02		Open

The following product has been identified as optimal master image: *S1A_IW_SLC__1SDV_20200504T122550_20200504T122617_032415_03C0E6_2B80*

Now, close the Stack Overview window and also the SNAP window. In file explorer navigate to the original data folder:

/shared/Training/HAZA09_SNAP2StaMPs_DataPrep_TutorialKit/Original/

Move the identified optimal master product to the folder named "master":

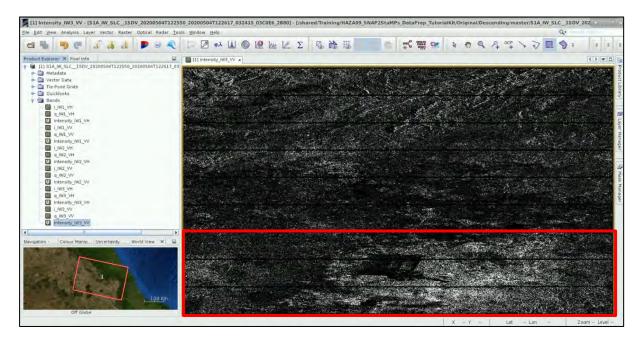
/shared/Training/HAZA09_SNAP2StaMPs_DataPrep_TutorialKit/Original/master

Move all other products to the folder named "slaves" located in the **Project** folder which will serve as our project folder:

/shared/Training/HAZA09_SNAP2StaMPs_DataPrep_TutorialKit/<u>Project</u>/slaves

Now let's relaunch SNAP again and load only the selected master product, go to the **Product Explorer** tab and open the **Intensity_IW3_VV** band in view.

The area of the city corresponds to the brighter pixels in the bottom-right part of the image and we can see that most of it is contained in the first three bursts from the bottom. Since the satellite was moving from North to South when acquiring the image these correspond to bursts with numbers 7 to 9 (See 1 & 2).

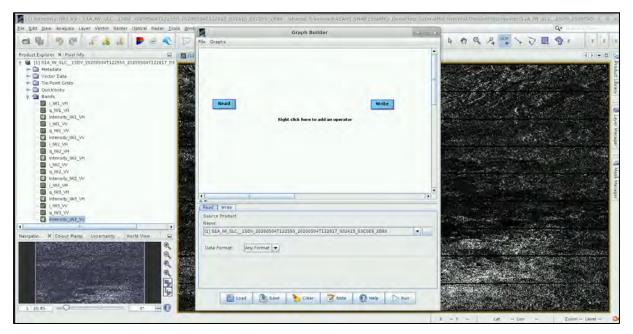


6.6 Master splitting and pre-processing

As mentioned in chapter *6.1 SNAP2StaMPS download and installation*, the snap2stamps folder contains graphs and python scripts to automate the pre-processing of the Senitnel-1 image time series for the StaMPS ingestion.

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 this step we need to perform S-1 TOPS Split and Apply orbit file steps on the master product. While there is a SNAP2StaMPS graph corresponding to this step, we will define the graph again as loading predefined graphs to the graphical interface can sometimes cause errors (See 1 NOTE 3).



In order to setup the graph go to **Tools** \rightarrow **GraphBuilder**.

	E 3: You can also attempt to open the predefined graph by clicking on <i>Load</i> in the Graph Builder u (in the bottom) then navigating to:
	rred/Training/HAZA09_SNAP2StaMPs_DataPrep_TutorialKit/Processing/snap2stamps/graphs opening: master_split_applyorbit.xml
click	ortunately, sometimes opening graphs saved in previous SNAP versions in GUI causes issues. If you on the TOPSAR-Split tab and see an error at the bottom of the window you will have to recreate the h or use the python script to run it.
Error:	[Nodeld: TOPSAR-Split] -1

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

Then, in the **Read** tab select the name of the loaded master product from 4 May 2020:

S1A_IW_SLC__1SDV_20200504T122550_20200504T122617_032415_03C0E6_2B80

Source Produ	uct	
Name:	and the second sec	
[1] SIA_IW_S	SLC1SDV_20200504T122550_20200504T122617_032415_03C0E6_2B80	👻

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 white area to the right of the existing operator and go to Add \rightarrow Radar \rightarrow 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 keep the default parameters.

	Apply-Orbit-File	
Orbit State Vector	5: Sentinel Precise (Auto Download)	*
Polynomial Degree	2	
	Do not fail if new orbit file is not found	

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 9 bursts (See NOTE 3). 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 necessary as further processing will only accept split products containing single full or partial sub-swath.

Right click the white space in the graph and go to $Add \rightarrow Radar \rightarrow Sentinel-1 TOPS \rightarrow TOPSAR-Split$.

Connect the TOPSAR-Split operator and both Apply-Orbit-File and Write operators.

Read	Apply-Orbit-File	TOPSAR-Split	Write
	shiply chart inc	Ter star spins	- Inter

In the TOPSAR Split tab, set the parameters below:

Subswath:	IW3
Polarisations:	VV
Bursts:	7 to 9

Read W	/rite Apply-Orbit-File TOPSAR-Split	
Subswath:	IW3	-
Polarisation		
Bursts:	7 to 9 (max number of bursts: 9)	
		~

Finally, in the **Write** tab, define the output directory as:

/shared/Training/HAZA09_SNAP2StaMPs_DataPrep_TutorialKit/Project/master

Set the name of the output product as:

S1A_IW_SLC__1SDV_20200504T122550_20200504T122617_032415_03C0E6_2B80_Orb_Split

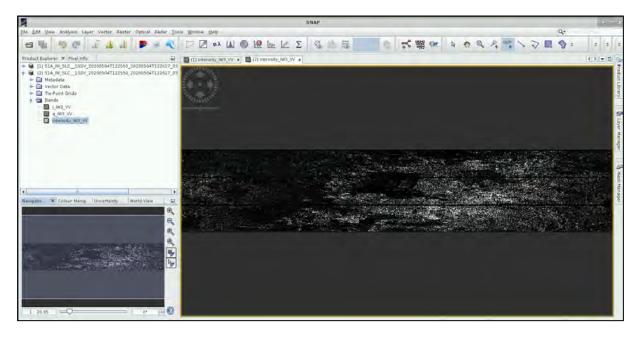
04T122617	032415_030	0E6 2B80 0	eh Calit
			rp_spin
itaMPs_Data	aPrep_Tutori	alKit/Project/r	master
5	StaMPs_Dat	StaMPs_DataPrep_Tutori	StaMPs_DataPrep_TutorialKit/Project/

At this moment, click **Save** at the bottom of the window to save the graph as *master_split_applyorbit_2.xml* in:

/shared/Training/HAZA09_SNAP2StaMPs_DataPrep_TutorialKit/Project/graphs

Click Run.

A newproduct will appear in you **Product Explorer** tab. We can open the **Intensity_IW3_VV** band in view again to see the burst selection and check we have chosen the correct ones. Then **Close SNAP.**

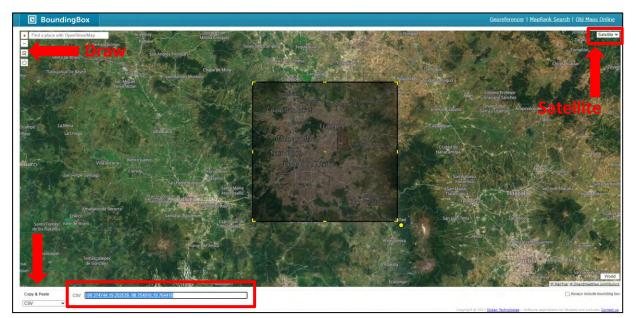


6.7 Area of interest (AOI)

To run the automated processing, we need to also define minimum and maximum latitude and longitude coordinates of the bounding box covering our area. These will be then used to further decrease the AOI size and in consequence the processing time. We can do this simply by going to an online tool such as **Bounding Box** - <u>https://boundingbox.klokantech.com/</u>

There we can simply navigate to Mexico City (easier if you change base map to satellite) click \mathbb{R} and draw a AOI as shown below.

Then at the bottom page, under the map window change the option **Copy & Paste** to **CSV.** You can then copy the bounding box coordinates in a simple format < *Min. longitude, Min. Latitude, Max. longitude, Max. Latitude >*



For polygon defined below these are: -99.374744, 19.202539, -98.754016, 19.764416

You can copy-paste them into an empty Mousepad text file or leave the page open to use the coordinates in the next step.

6.8 SNAP2StaMPS project configuration

To run the next steps in a more automated mode the snap2stamps includes *project.conf* file where all necessary user inputs are defined. Let's now set it up.

You can find the file in snap2stamps **"bin"** folder (we have copied it to the Processing folder) and have to edit it according to your data and paths:

/shared/Training/HAZA09_SNAP2StaMPs_DataPrep_TutorialKit/Project/bin

Right-click *project.conf* and select *Open in Mousepad*. At this moment all the settings are empty.

1	F	roject.conf	- Mousepad	(n = = ×
File Edit S	earch View	Document	Help	
2 ######### 3 # PROJECT 4 PROJECTFO 5 GRAPHSFOL 6 ######### 7 # PROCESS 8 IW1= 9 MASTER= 10 ##########	DER= ############# ING PARAMETE	(########### ############ ERS (#############	#####	
14 LONMAX= 15 LATMAX=	TH= ##############		####	

In the **PROJECT DEFINITION** section, we set default project folder to the **Processing** folder and set the graphs folder to the snap2stamps graph location.

PROJECTFOLDER=/shared/Training/HAZA09_SNAP2StaMPs_DataPrep_TutorialKit/Project GRAPHSFOLDER=/shared/Training/HAZA09_SNAP2StaMPs_DataPrep_TutorialKit/Project/graphs

In the **PROCESSING PARAMETERS** section, we set the same sub-swath as used when splitting the master product and point to the full path where we saved it.

IW1=**IW3**

MASTER=/shared/Training/HAZA09_SNAP2StaMPs_DataPrep_TutorialKit/Project/master

In the AOI BBOX DEFINITION we will use the coordinates retrieved in the online Bounding Box tool (6.7 Area of interest (AOI)).

LONMIN=-99.374744	LONMAX=-98.754016
LATMIN=19.202539	LATMAX=19.764416

In the SNAP GPT path, we need to point to the SNAP installation. On the RUS VM the SNAP gpt executable is located at:

GPTBIN_PATH=/usr/local/snap/bin/gpt

Finally, in the COMPUTING RESOURCES TO EMPLOY section, we can set the CPU number and Cache size to use (See 1 NOTE 4). This needs to be selected based on your VM/PC. For standard RUS VM the settings could be as follows:

CPU=4 CACHE=12G

File Edit View Terminal		al - rus@front: ~			. é. 🗉 🗶
(base) rus@front:-\$ l Architecture: CPU op-mode(s): Bute Order: CPU(s):	ALLON AND LAND				
And "free -g" to check			VB is equal t	o 1024 KB):	
File Edit View Termina		l - rus@front: ~			* - = ×
(base) rus@front:~\$ total Mem: 28 Swap: 6	used 9	free 15 0	shared 0	buff/cache 3	available 18

Now, go to **File** \rightarrow **Save** and save the changes made to the *project.conf* file. We can now start with the automated processing using the python scripts.

6.9 Slaves preparation

In the next step, we need to divide the slave images into folders with the name corresponding to the acquisition date in format *<yyyymmdd>*. This is a necessary first step enabling the automated processing. Navigate to:

/shared/Training/HAZA09_SNAP2StaMPs_DataPrep_TutorialKit/Project/bin

Then right-click on the white space in the folder and select **Open Terminal Here**. A terminal window will open with the path to the bin folder. To call the first python script paste the following command in the terminal.

```
python2 slaves_prep.py project.conf
۶__
      Terminal - rus@front: /shared/Training/HAZA09_SNAP2StaMPs_DataPrep_TutorialKit/Project/bin
                                                                                       - - - ×
File Edit View Terminal Tabs Help
(base) rus@front:/shared/Training/HAZA09_SNAP2StaMPs_DataPrep_TutorialKit/Projec
t/bin$ python2 slaves_prep.py project.conf
    1 TIP: The snap2stamps requires Python 2.7 – in RUS VM the default Python is 3.8 but 2.7 is installed as
     well - we can therefore use the command "python2" to call it. The default Python and the call for python
     2.7 might be different in you machine. You can type "python -V" and "python2 -V" commands to your
     command line to find the associated version. See chapter 6.1 for more information.
 ۶.,
                                    Terminal - rus@front: ~
                                                                                      • - • ×
  File Edit View Terminal Tabs Help
 (base) rus@front:~$ python -V
   thon 3.7.4
 (base) rus@front:~$ python2 -V
 Python 2.7.12
```

Then press ENTER to run the command. The processing will take few seconds depending on your VM.

When the processing is completed (the bin path ending with \$ will appear again). Leave the terminal window open and check the *"slaves"* folder (it should contain a folder for each slave image):

/shared/Training/HAZA09_SNAP2StaMPs_DataPrep_TutorialKit/Project/slaves

```
Terminal - rus@front: /shared/Training/HAZA09_SNAP2StaMPs_DataPrep_TutorialKit/Project/bin 

File Edit View Terminal Tabs Help

Moving /shared/Training/HAZA09_SNAP2StaMPs_DataPrep_TutorialKit/Project/slaves/S

IA_IW_SLC__1SDV_20200820T122556_20200820T122623_033990_03F1CA_2816.zip to /share

d/Training/HAZA09_SNAP2StaMPs_DataPrep_TutorialKit/Project/slaves/20200820/S1A_I

W_SLC__1SDV_20200820T122556_20200820T122623_033990_03F1CA_2816.zip

(base)_rus@front:/shared/Training/HAZA09_SNAP2StaMPs_DataPrep_TutorialKit/Project

t/bin$
```

islaves - File Manager i Edit View Go Help					
the sea class at	home/rus/Desktop/shared/Training/HAZA09_SNAP2StaMPs_DataPrep_TutorialKit/Project/slaves/	Ċ			
DEVICES	20191106 20200129 20200422 20200727 20201019				
File System	20191118 20200210 20200516 20200808 20201031				
File System	20191130 20200222 20200528 20200820				
PLACES	20191212 20200305 20200609 20200901				
rus	20191224 20200317 20200621 20200913				
	20200105 20200329 20200703 20200925				
Desktop	20200117 20200410 20200715 20201007				

6.10 Slaves splitting

Next, we need to split and update the orbit information for each of the slave images. Again, this step is run in the terminal window. It uses the following SNAP graph (predefined in the "graph" folder).



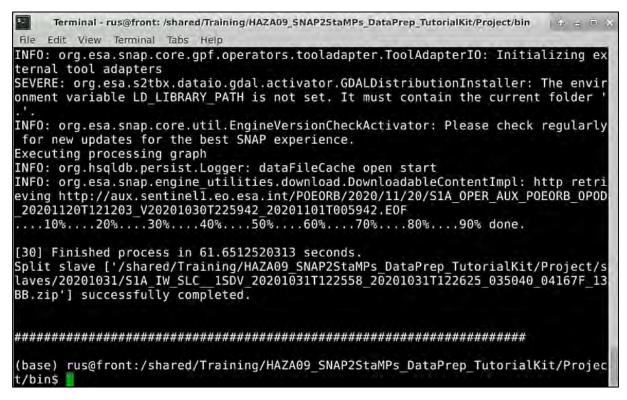
It includes the same operators as the graph we used to pre-process the master image. However, this time we do not need to open the graph. The python script will automate processing by looping over the slave images and updating the input and output accordingly and then running the graph for each slave image.

Go back to the terminal window and run the following command.

python2 splitting_slaves.py project.conf

(base) rus@front:/shared/Training/HAZA09_SNAP2StaMPs_DataPrep_TutorialKit/Projec t/bins python2 splitting_slaves.py project.conf

Then press **ENTER** to run the command. *The processing will take approximately a 1 minutes per slave image depending on your VM (30 minutes for 30 images on VM with 30GB RAM).*



When the processing is completed, a new folder *"split"* was created in the *Project* folder. It contains folder for each pre-processed slave product. Leave the terminal window open.

6.11 Master-slave coregistration and interferogram generation

In the next step we need to co-register each slave image with the master image and create an interferogram and other steps. Below you will find the description of each of the steps, you however do not need to open the graph or change any settings.

Read Back-Geocoding Enhanced-Spectral-Diversi	ly 😝 Interferogram 📥 TOPSAR-Deburst 🛶 TopoPhaseRemoval 🛶 Subset 🛶 Write
Read(2)	TOP5AR-Deburst(2) Subset(2) Write(2)

6.11.1 Back-Geocoding

This operator co-registers two S-1 SLC split products (master and slave) of the same sub-swath using the orbits of the two products and a Digital Elevation Model (DEM). (SNAP Help)

6.11.2 Enhanced-Spectral-Diversity (ESD)

This operator follows the S-1 Back Geocoding operator in the TOPS InSAR processing chain. It first estimates a constant range offset for the whole sub-swath of the split S-1 SLC image using incoherent cross-correlation. The estimation is done for each burst using a small block of data in the center of the burst. The estimates from all bursts are then averaged to get the final constant range offset for the whole sub-swath. *(SNAP Help)*

6.11.3 Interferogram

This operator computes (complex) interferogram, with subtraction of the flat-earth (reference) phase (can also be run without). The flat-earth phase is the phase present in the interferometric signal due to the curvature of the reference surface (WGS84). *(SNAP Help)*

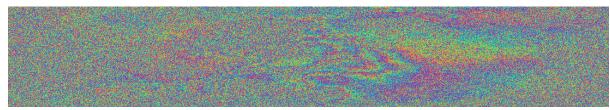
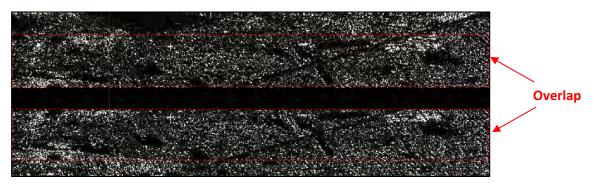


Image: Mexico City interferogram (not multilooked)

6.11.4 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, in 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. Images for all bursts in all sub-swaths of an IW SLC product are re-sampled to a common pixel spacing grid in range and azimuth. This processor merges the bursts to a continuous image based on their zero Doppler time and removes the demarcation pixels. (SNAP Help)



6.11.5 Topographic Phase Removal

This operator estimates and subtracts topographic phase from the interferogram. More specifically, this operator first "radarcodes" the Digital Elevation Model (DEM) of the area of interferogram, and then subtracts it from the complex interferogram. (SNAP Help)

This operator must be performed after the interferogram generation. It also requires an input DEM, SRTM can be used, or any other supported DEM. The DEM handling for most of elevation models, selection and download from internet of tiles covering the area of interest, interpolation, accounting for geoid undulation, etc, is performed automatically by the operator itself. (SNAP Help)

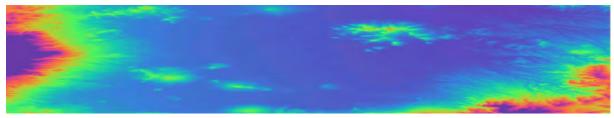


Image: Mexico City Topographic phase based on SRTM 1Sec HGT DEM (not multilooked)

6.11.6 Subset

In this step a spatial subset is applied to reduce the product extent to the study area we have set in the *"project.conf"* and defined in *6.7 Area of interest (AOI)*.

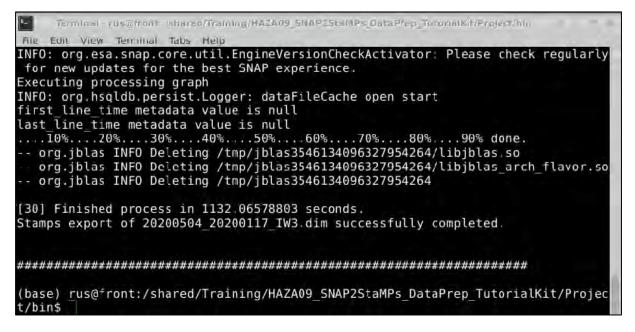
6.11.7 Run

Go back to the **terminal** window and run the following command. Note that this is the most time demanding step in the pre-processing chain.

python2 coreg_ifg_topsar.py project.conf

(base) rus@front:/shared/Training/HAZA09_SNAP2StaMPs_DataPrep_TutorialKit/Projec t/bin\$ python2 coreg_ifg_topsar.py project.conf

Then press **ENTER** to run the command. *The processing will take approximately a 15 minutes per slave image depending on your VM (<u>7 hours and 30 minutes for 30 images</u> on VM with 30GB RAM).*



When the processing is completed, two new folders "coreg" and "ifg" were created in the **Project** folder. The "coreg" folder contains coregistered and debursted product and the "ifg" folder contains the interferogram with topographic phase removed. The products in both folders are named identically as <masterDate_slaveDate_IW3>. Leave the terminal window open.

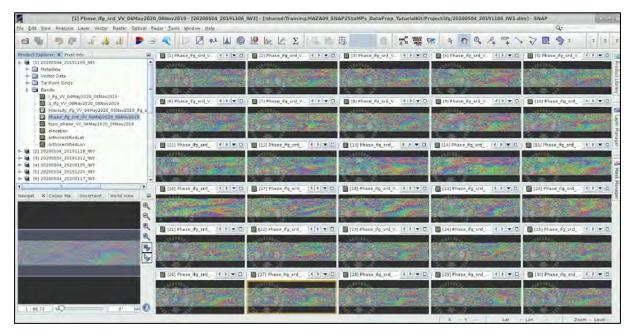
6.11.8 Check the interferograms

Now, before the export we need to test if all the interferograms have been correctly completed. Open SNAP graphical interface and load all the products in:

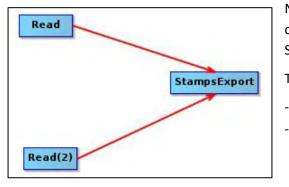
/shared/Training/HAZA09_SNAP2StaMPs_DataPrep_TutorialKit/Project/ifg/

Then open the *"Phase_ifg_*****"* band for each product. You do not need to open all at once as below, you merely need to check for empty interferograms.

In the image bellow you can see that all interferograms have been correctly created. If in your dataset you find an empty interferogram remove note the name and consequently remove the file from the *"coreg"* and *"ifg"* folders.



6.12 StaMPS export



Now we need to prepare the data into a StaMPS compatible format. This is done by using a SNAP tool for StaMPS export.

The inputs are:

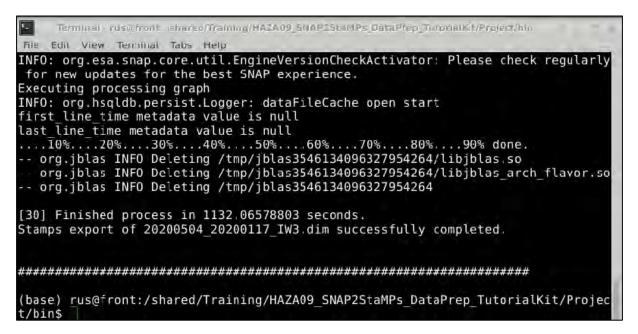
- the coregistered master-slave pair
- its corresponding interferogram with the elevation and orthorectified latitude and longitude bands

Go back to the terminal window and run the following command.

python2 stamps_export.py project.conf

(base) rus@front:/shared/Training/HAZA09_SNAP2StaMPs_DataPrep_TutorialKit/Projec t/bin\$ python2 stamps_export.py project.conf

Then press **ENTER** to run the command. *The processing will take again quite long time - approximately a 12 minutes per slave image depending on your VM (6 hours for 30 images on VM with 30GB RAM).*



When the processing is completed, a new folder named *"INSAR_20200504"* was created in the *Project* folder. It contains the final output structure - four folders: *rslc*, *diff0*, *geo* and *dem*.

6.13 Amplitude dispersion (only possible with StaMPS installed)

The final step before we can ingest the data into StaMPS for PSI processing is the estimation of the amplitude dispersion index. The D_A is a value that describes the amplitude stability, which is used to preselect pixels and therefore reduces the number of pixels for the phase analysis. It is calculated as:

$$D_A = \frac{\sigma_A}{\mu_A}$$

Where σ_A is the standard deviation and μ_A is the mean of a series of amplitude values. The recommended range for D_A is 0.40 - 0.42. The higher the threshold, more pixels will be selected for phase analysis. Note that surfaces like water and vegetation, where amplitude is instable, exhibit higher D_A values than bedrock outcroppings or man-made strucutres (i.e. most likeley PS pixels). See Ferretti et al. (2001) and Hooper et al. (2007) for further information. (*GIS-Blog - Matthias Schlögl*)

The script is included in the StaMPS installation but does not require MATLAB licence, it was provided by Andy Hooper (University of Leeds) and customised for SNAP interferograms generated.

Go back to the **terminal** window and run the following three commands.

cd .. mkdir prep cd prep

Now your terminal line should start with the path to the *prep* folder.

(base) rus@front:/shared/Training/HAZA09_SNAP2StaMPs_DataPrep_TutorialKit/Project/bin\$ cd .. (base) rus@front:/shared/Training/HAZA09_SNAP2StaMPs_DataPrep_TutorialKit/Project\$ mkdir prep (base) rus@front:/shared/Training/HAZA09_SNAP2StaMPs_DataPrep_TutorialKit/Project\$ cd prep (base) rus@front:/shared/Training/HAZA09_SNAP2StaMPs_DataPrep_TutorialKit/Project/prep\$

Then call the script without parameters: mt_prep_snap

We choose the following parameters:

da_thresh = 0.4
rg_patches = 9
az_patches = 3
rg_overlap = 50
rg_overlap = 200

mt_prep_snap 20200504
/shared/Training/HAZA09_SNAP2StaMPs_DataPrep_TutorialKit/Project 0.4 9 3 50 200

(base) rus@front:/shared/Training/HAZA09_SNAP2StaMPs_DataPrep_TutorialKit/Project/prep\$ mt_p
rep_snap 20200504 /shared/Training/HAZA09_SNAP2StaMPs_DataPrep_TutorialKit/Project/INSAR_202
00504 0.4 9 3 50 200

Then press **ENTER** to run the command. *The processing will take again quite long time - approximately* a 12 minutes per slave image depending on your VM (6 hours for 30 images on VM with 30GB RAM).

Once the calculations are finished, move the contents of the *"prep"* folder to the *"INSAR_20200504"* folder. Now your data are ready to proceed with StaMPS processing in MATLAB.

```
    TIP: Note that errors have been reported when running StaMPS on Windows – Linux is the preferred environment.
    MATLAB should be run from command line (provided that StaMPS_CONFIG.bash is included in .bashrc)
    Follow steps outlined in:

            by Matthias Schlögl in his posts on <u>GIS-Blog</u>
            in the <u>stamps</u> and <u>snap2stamps</u> manuals
            <u>StaMPS Persistent Scatterer Exercise</u> by A. Hopper (2015, v3.1)
```

THANK YOU FOR FOLLOWING THE EXERCISE!

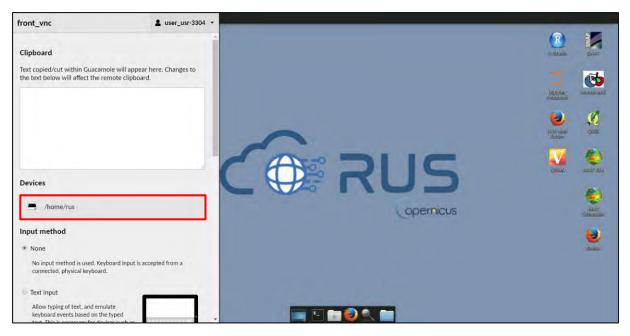
7 Extra steps

7.1 Downloading the outputs from the 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**.



8 References

8.1 Software

SNAP2StaMPS Manual and download - https://github.com/mdelgadoblasco/snap2stamps StaMPS Manual StaMPS Download

8.2 PSI resources

Crosetto, M., Monserrat, O., Cuevas-González, M., Devanthéry, N., & Crippa, B. (2016). Persistent Scatterer Interferometry: A review. *ISPRS Journal of Photogrammetry and Remote Sensing*, 115, 78–89. https://doi.org/10.1016/j.isprsjprs.2015.10.011

Delgado Blasco, J. M., Foumelis, M., Stewart, C., & Hooper, A. (2019). Measuring Urban Subsidence in the Rome Metropolitan Area (Italy) with Sentinel-1 SNAP-StaMPS Persistent Scatterer Interferometry. *Remote Sensing*, 11(2), 129. <u>https://doi.org/10.3390/rs11020129</u>

Jia, H., & Liu, L. (2016). A technical review on persistent scatterer interferometry. Journal of Modern Transportation, 24(2), 153–158. <u>https://doi.org/10.1007/s40534-016-0108-4</u>

8.3 Tutorials

GIS-Blog - Matthias Schlögl – Using StaMPS/MTI for PSI Analysis (post series) - <u>https://www.gis-blog.com/stamps-1/</u>

A. Hooper – StaMPS Persistent Scatterer Exercise (2015) – ESA Land Training Course http://seom.esa.int/landtraining2015/files/Day_4/D4P2a_LTC2015_Hooper.pdf

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