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TRAINING KIT – HAZA05

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











Research and User Support for Sentinel Core Products

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

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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 acquired by the Copernicus Sentinel satellites constellation.

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



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

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

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

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

2 Training

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

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

2.1 Data used

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

S1B_IW_SLC__1SDV_20180423T161524_20180423T161551_010613_0135DD_33F0 S1B_IW_SLC__1SDV_20180505T161525_20180505T161552_010788_013B7D_25D2

2.2 Software in RUS environment

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

3 Register to RUS Copernicus

To repeat the exercise using a RUS Copernicus Virtual Machine (VM), you will first have to register as a RUS user. For that, go to the RUS Copernicus website (<u>www.rus-copernicus.eu</u>) 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*.

Login / Register	Cesa cds.sso
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	Score quector box and a constraint of the second se
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. Close	rigentie planitiens

Within a few minutes you will receive an e-mail with activation link. Follow the instructions in the email 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 thrid remail sent by the Copernicus service. We advise you to consult this document and this page to facilitate your registration procedure. REGISTER COPERNICUS SSO account can be advise you to consult this document and this page to facilitate your registration procedure.	CDS-SSO ID Password Max Idle Time Max Session Time	half a day Until browser close	•	0 0 0
Login		Forgot your password?		

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

The RUS Service = The RUS C	Do you want t	o subscribe for a new RUS account?		
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+ Your RUS service	Login			8
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	Where did you hear about the RUS service? Select one or more items	outreach event colleagues pewcletter	atten = Network - Francist Atten = Petiting - 5, 9 40	
		conference social media other	than - Foulonie - 26 to	27 Oct. 2018
	Institution type	Select one item	× nda	
	Phone number Italy (IT):	+39	polatingro-	
	Title	Select one item	~	

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**.

CORRUS Research and User Support	
The RUS Service * The RUS Offer * The RUS Library * The RUS Community *	Your RUS service Your profile You are here: Home > Your RUS service
Your RUS service	Your dashboard
 This section gathers pages related to your RUS services: Your profile: displays your personal information linked to your ESA SSO and RUS accounts Your dashboard: Illows you to access your private dashboard, Your training: allows you to register to a training session you have been invited to participation. 	News from RUS One year on! Copernicus Info Session – Reykjavik – 19 September 2018 SPIE Remote Sensing 2018 – Berlin (Germany) – 11-12 September 2018 SIWI World Water Week 2018 – Stockholm – 26-31
	August 2018 MedRIN Kick-off Meeting - Chania - 13 & 14 July 2018 RUS Webinar - Special edition "AskRUS - Sentinel-1" - 12 July 2018 RUS Training Session - Valencia - 22 July 2018 IGARSS 2018 - Valencia - 22-27 July 2018

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.

CORRUS General Research and User Support	an and the th	Hello, Miguel 😫
The RUS Service * The RUS Offer * The RUS Library *	The RUS Community Vour RUS service V	
	You	are here: Home > Your RUS service > Your dashboard
Your dashboard		
Request a new User Service		Chat with Support Desk
Copyright © 2017 Research and User Support	Contact Us	Terms and conditions Glossary Acronyms FAQ

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

Step 1/3 Your experience	
Please help us learn more about your background by answerin	ng a few questions. Thi
information will be stored in your User Profile.	
How many years of experience in Remote Sensing do you have?	
Choose one Item	•
Have you already downloaded Copernicus data via the Copernicus Open a	ccess hubs?
Yes	
© No	
Have you already handled/processed Copernicus data?	
W Yes	
© No	
Do you wish to practice a tutorial exercise shown in a RUS webinar? If yes, ((hold down CTRL key for multiple selections).	please select your choice
HAZA01 - Flood Mapping in Malawi	
HAZA02 - Burned Area Mapping in Portugal HYDR01 - Water Bodies Mapping over Northern Poland	
LAND01 - Crop Mapping in Seville	
LAND04 - Land Monitoring in Cyprus	-
OCEA01 - Ship Detection in Gulf of Trieste	
If you wish to request another tutorial exercise that doesn't appear in the a	bove list, please type here
its name or code. Note that you can request multiple tutorial exercises.	

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

	and shares and the second	
This is a collection of information selected	d across the USR forms.	
You can go back and edit this information	If necessary.	
General Information on your request:		
Years of experience in Remote Sensing	5-10 years	
Downloaded Copernicus data?	1	
Handled/processed Copernicus data?	1	
Webinar codes	HAZA02, LAND04	
About your RUS project:		
Thematic area	Cryosphere (ice and snow)	
Operations to perform on RUS	Algorithm development	
Preference for downloading process	Self-downloading	
Foreseen activities and support needs	Develop a land cover classification	
Project name	RUS_Project1	
Earth Observation Data information:		
Type of Earth Observation Data:		
Sentinel-1	1	
	S1-Product 1	
S1 - Product type	GRD	
S1 - Sensor mode	-	
S1 - Polarisation	-	
S1 - Orbit direction		
Sentinel-2	X	
Sentiner-3	X	
I den't know	x.	
Peolog of Interest	8	
Min Latitude	39.3303	
Max Latitude	40.5877	
Min Longitude	-4.6736	
Max Longitude	-2.7205	
Reference polygons		
Data acquisition date(s):		
None		
Additional data specifications		
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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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Your dashboard								
Request a new U	ser Servi	ce					5	Chat with Support Desk
~0								
Project Name	ID	Date of submission	Status		Actions		Virtual	Environment
	-		~	Follow my project	Get support	Close my service	Access my Virtual Machine(s)	Access my CPU monitoring dashboard
RUS_training1	231	2017-08-31	Upen		Get a webinar kit	Rate my service	Freeze my Virtual Machine(s)	Report a technical

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.

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5 Step by step

5.1 Data download – ESA SciHUB

In this step, we will download the Sentinel-1 scenes from the Copernicus Open Access Hub using the online interface. Go to **Applications** \rightarrow **Network** \rightarrow **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.

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	Register	new account	國
	Sentinel data access is free and open to all. On completion of the registration form below you will receive an e-imal with a link to va username field access only obvercase adparaments characters pais ", ", and ", " assword fields my end to the sentence characters puis ", "ge", geo, "geo, "geo	idale your e-mail address. Following this you can start to download the data $r_{\rm c}$ and $q_{\rm c}$ are the $r_{\rm c}$ of $r_{\rm c}$	
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-	E-muk	(Cambury Bornia	
-	• Select DamAlin		_
1	• Salact Usaga		
	Select your country		
	By registering in this website you are deeme	ed to have accepted the T&C for Sentinei data use.	REGISTER

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".

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-137.5673, 13.6553		٥

Navigate to Hawaii (approximate area – green rectangle).

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

Sensing period: From 2018/04/23 to 2018/05/05

Select: Mission: Sentinel-1

Product Type: SLC

Sensor Mode: IW

Relative Orbit Number: 87 (It is important for InSAR processing since we need the products to have the same geometry).

		Copernicus Open Access Hub	10 A
🛙 👻 Insert search criteria		B 🔍 🍣	
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» Sort By:	» Order By:	Canod Oly Loniana Paris	(*
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2015/04/23	2018/05/05		
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		Walton Kawalhar	ajaulio
Mission: Sentinel-1		Beachineson	Walks
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•	tW		
Relative Orbit Number (from 1 to 175)	Collection	Pànais	
87 Mission: Sentinel-2		And	
O Masion Sentiners			
Satellite Platform	Product Type		
Relative Orbit Number (from 1 to 143)	Cloud Cover % (e.g.[0 TO 9.4])		0
Relative Orbit Number (from 1 to 143)	Cloud Cover % (e.g.[0 TO 9.4])		(

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

S1B_IW_SLC__1SDV_20180423T161524_20180423T161551_010613_0135DD_33F0 S1B_IW_SLC__1SDV_20180505T161525_20180505T161552_010788_013B7D_25D2

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Products per page: 25 Y << < page: 1 of 1 > >>>	Ħ	Parate Parate	
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			0

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

5.2 SNAP – open and explore data

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

/shared/Training/HAZA05_EarthquakeDeformation_Hawaii_TutorialKit/Original folder and open the two S-1 downloaded products (first the 20180423 and then the 20180505):

S1B_IW_SLC__1SDV_20180423T161524_20180423T161551_010613_0135DD_33F0.zip S1B_IW_SLC__1SDV_20180505T161525_20180505T161552_010788_013B7D_25D2.zip

The opened products will appear in **Product Explorer** window. Click + or **b** to expand the contents of product **[1]** from **23** April **2018**, then expand **Bands** folder and double click on *Intensity_IW1_VV* band to visualize it in the **View** window. You can go to the **World Map** tab and zoom in to see the location of the opened product on the globe (See **NOTE 1**).



Open the *Intensity_IW1_VV* band of the product [2] from 5 May 2018 as well and compare them by going to Window \rightarrow Tile Horizontally. Go to the Navigation tab and click on the two icons shown within the red rectangular below to synchronize the views and the cursor position between the views.



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

5.3 Pre-processing

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

By using the **GraphBuilder** tool, we can define the steps of the process we want to apply and at the end only the final product will be physically saved (this way we will also save disk space since the products of the intermediate steps will not be stored).

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

5.3.1 Graph Builder

Go to **Tools** \rightarrow **GraphBuilder** to build our graph.

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

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

For now, we will not define any parameters in the tabs (they will be defined in the **Batch Processing** step), we will only create the graph.

8	SNAP	1 - 6 *
Ele Edit Yiew Analysis Layer Vector Raster Optical Radar Iools Wind	Graph Builder	Q+ Securitaria
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		t Y Lat Lon Zoom Level 🧃

Every Interferometric Wide swath (IW) consists of 3 sub-swaths and each one of maximum 9 bursts. In SNAP we can process only one swath at a time until the **Deburst** step (See chapter 5.4.3). Our area of interest is located in the IW1 and is covered sufficiently by processing 2 bursts. We will use the **TOPSAR-Split** operator; this way we will reduce the total processing time (See 1 NOTE 2).

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

Read **TOPSAR-Split**

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

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

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

Then click on save the graph under window and save the graph under /shared/Training/HAZA05_EarthquakeDeformation_Hawaii_TutorialKit/Processing folder with the name Preprocess_Graph.xml.

	SNAP - Save Graph	+ = >
Save <u>i</u> n:	Processing	a 🗃 🗖 🔡 😂
Name	/ shared Training HAZA05_EarthquakeDeformation_Hawaii_TutorialK Processing	
File <u>N</u> ame	Preprocess_Graph.xml	

Close the **Graph Builder** window.

5.3.2 **Batch Processing**

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

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

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

10 Parameters TOPSAR-Split App	ly-Orbit-File	Write	1	1	-	
File Name	Туре	Acquisition	Track	Orbit	- 1 -	
1B_IW_SLC_1SDV_20180423T16152	SLC	23Apr2018	87	10613	1	Add Open
10_W_3CC_130V_20100303/10132	310	0514492010	107	10/00		
					1	
					6	Refresh
						- nenesii
					2 Products	
Target Folder						
Target Folder						
Target Folder Save as:						
Target Folder Save as:						

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

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

	Batch Proc	essing : Preprocess_Graph.xml	* = ×	
I/O Parami	ters TOPSAR-Split	Apply-Orbit-File Write		
Subswath:	IWI		-	
Polarisation	s: VH			
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Bursts:	4 to 5 (max number o	of bursts: 9)		
			0 0	– Zoom ir

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

	Batch Processing : Preprocess_Graph.xml	* = ×
File Graphs		
1/O Parameters	TOPSAR-Split Apply-Orbit-File Write	
Orbit State Vectors	Sentinel Precise (Auto Download)	-
Polynomial Degree:	3	
	🖉 Do not fail if new orbit file is not found	

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

	Batch Processing : Preprocess_Graph.xml	> = ×
File Graphs		
1/0 Parameters	TOPSAR-Split Apply-Orbit-File Write	
Target Product		
SIB_IW_SLC_ISD	V_20180423T161524_20180423T161551_010613_0135DD_33F0_Orb	
Save as, BEAM-DIN	4AP 👻	
Directory:		
/shared/Trainin	ng/HAZA05_EarthquakeDeformation_Hawaii_TutorialKit/Processing	1
	Load Graph Run Clos	ie <u>H</u> elp

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

5.4 Coregistration and Interferometric Processing

5.4.1 Data Coregistration

Image coregistration is the alignment of master and slave images; the pixels of the slave images correspond to those of the master and represent an identical area.

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

Ele Edit Yiew Analysis Layer Vector Raster Optical Radar Tools Wind/					Q.		
a 🖥 🦻 🖉 🔏 🕹 🕨 🖉 🗁	File Graphs	87 0	2 A 0	* > 7		* *	
Product Explorer X ● [1] 1518_W_SLC_150V_20180423T161554_20180423T161551_010613_010 ● [1] 1518_W_SLC_150V_20180423T161524_20180423T161551_010613_011 ● [1] Vector Data ● [1] W_LWW ● [1] W_LWV ● [1] W_LWV	Rend Hight click here to udd an operator Write	W1_V *					🔗 Product Library 🕼 Layer Manager 🔄 Man
Internaty_W4_W							sk Manager 📑 AOI Monitoring

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

Right click here to add an operator the operator write

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

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

Read Read(2)	
Source Product Name:	
[3] S1B_IW_SLC1SDV_20180423T161524_20180423T161551_010613_0135DD_33F0_Orb	
Data Format: Any Format 💌	

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

S1B_IW_SLC__1SDV_20180505T161525_20180505T161552_010788_013B7D_25D2_Orb

Read Read(2)		
Source Product		
SIB_IW_SLC_1	SDV_20180505T161525_20180505T161552_010788_013B7D_25D2_Orb	T
Data Format:	Any Format	

5.4.1.1 Back-Geocoding

Now we will coregister the two products by using their orbits and a DEM. To add the **Back-Geocoding** operator right-click and go to **Radar** \rightarrow **Coregistration** \rightarrow **S-1 TOPS Coregistration** \rightarrow **Back-Geocoding**. Connect both **Read** and **Read(2)** operators to it.

Read	
Back-Geocoding	
Read(2)	

In the Back-Geocoding tab set:

Digital Elevation Model: SRTM 1Sec HGT (Auto Download) (See 🛄 NOTE 4). DEM Resampling Method: BILINEAR_INTERPOLATION Resampling Type: BILINEAR_INTERPOLATION Select the "Output Deramp and Demod Phase" option as well (See 🛄 NOTE 5).

Read Read(2) Back-Geoc	oding	
Digital Elevation Model:	SRTM 1Sec HGT (Auto Download)	•
DEM Resampling Method:	BICUBIC_INTERPOLATION	
Resampling Type:	BISINC_5_POINT_INTERPOLATION	•
Mask out areas with no eleve	ation	
🕑 Output Deramp and Demod I	Phase	

- NOTE 4: We will use the **SRTM 1Sec HGT (Auto Download)** which has **~30m resolution** instead of the default SRTM 3sec (Auto Download) which has ~90m resolution, but this will increase the processing time. In case you want to process more than 2 images simultaneously and you do not have enough RAM, you can use the SRTM 3sec (Auto Download) DEM.
- NOTE 5: The "**Output Deramp and Demod Phase**" option is necessary when Enhanced Spectral Diversity is following.

5.4.1.2 Enhanced Spectral Diversity

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

To add the **Enhanced-Spectral-Diversity** operator right-click and go to **Radar** \rightarrow **Coregistration** \rightarrow **S-1 TOPS Coregistration** \rightarrow **Enhanced-Spectral-Diversity**. Connect the **Back-Geocoding** operator to it (See \Im TIP 1).

Read Back-Geocoding Enhanced-Spectral-Diversity	
Read(2)	

Registration Window Width:	512	
Registration Window Height:	512	
Search Window Accuracy In Azimuth Direction:	16	-
Search Window Accuracy in Range Direction:	16	-
Window oversampling factor:	128	
Cross-Correlation Threshold:		0.1
Coherence Threshold for Outlier Removal:		0.15
Number of Windows Per Overlap for ESD:		10
Use user supplied shifts (please enter the	em below)	
The overall azimuth shift in pixels:		0.0
The overall range shift in pixels:		0.0

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

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

5.4.2 Interferogram Formation

Let's create the interferogram of the two images used for the stack product. To add the **Interferogram** operator right-click and go to Add \rightarrow Radar \rightarrow Interferometric \rightarrow Products \rightarrow Interferogram. Connect the **Enhanced-Spectral-Diversity** operator to it. A **phase** and a **coherence band** will be created.

Read	
Read(2)	

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

Read Read(2) Back-Geocoding	Enhanced-Spectral-Diversity Interferogram	
🖌 Subtract flat-earth phase		
Degree of "Flat Earth" polynomial	5	¥
Number of "Flat Earth" estimation points	501	-
Orbit interpolation degree	3	-
Subtract topographic phase		
Digital Elevation Model:	A Rest of Concession of Conces	-
Tile Extension (%)		-
Dutput Elevation		
Dutput Orthorectified LatiLon		
🖌 Include coherence estimation		
Square Pixel	🔲 Independent Window Sizes	
Coherence Range Window Size	18	
Coherence Azimuth Window Size	5	

5.4.3 TOPS Deburst

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

Read Back-Geocoding Enhanced-Spectral-Diversity Interferogram TOPSAR-Deburst	
Read(2)	

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

Read	Read(2)	Back-Geocoding	Enhanced-Spectral-Diversity	Interferogram	TOPSAR-Deburst	
Polarisa	tions: VV					

NOTE 6: There is overlapping information in every burst with its neighbouring ones, both in range and azimuth direction in order to provide contiguous coverage of the ground. Until now each burst has been processed as a separate SLC image We will merge the bursts (in azimuth direction) and preserve the phase information as well. For the overlapping region in range, merging is done between subswaths.

5.4.4 Write/create the product

To add the Write operator right-click and go to $Add \rightarrow Input-Output \rightarrow Write$. Connect the TOPSAR-Deburst operator to it.

Read			-		
	Back-Geocoding	Enhanced-Spectral-Div	ersity -> Interferogram	TOPSAR-Deburst	Write
Read(2)					

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

Name: S1B_IW1_20180423_Orb_stack_ifg_Deb

Directory: /shared/Training/HAZA05_EarthquakeDeformation_Hawaii_TutorialKit/Processing

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

	SNAP - Save Graph		+ = 3
Save in:	Processing	-	a 🗃 🗅 能 🗄
Name		Size	Modified
S1B_IW_S	SLC_1SDV_20180423T161524_20180423		3/6/19 1:38 PM
S1B_IW_S	SLC_1SDV_20180505T161525_20180505.		3/6/19 1:38 PM
Preproce	ss_Graph.xmi	1 KB	3/6/19 10:29 AM
File <u>N</u> ame:	Process_Graph_1.xml		
Files of <u>Type</u> :	Graph (*.xml)		
File <u>N</u> ame: Files of <u>T</u> ype:	Process_Graph_1.xml Graph (*.xml)	_	

Finally, click on the **Example to the bottom of the Graph Builder** window. *The process will be completed in 40 minutes in a 32GB RAM VM.*

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

Let's open another **GraphBuilder** window. Go to **Tools** \rightarrow **GraphBuilder**.

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

Read

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

Read	
Source Product	
[5] S1B_W1_20180423_Orb_Stack_lfg_Deb	×
Data Format: Any Format 💌	

5.4.5 Topographic Phase Removal

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

TopoPhaseRemoval Read

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

Read TopoPhaseRemo	val	
Orbit Interpolation Degree:	3	
Digital Elevation Model:	SRTM 1Sec HGT (Auto Download)	-
Tile Extension [%]	100	
	Output topographic phase band	
	Output elevation band	
	Output orthorectified Lat/Lon bands	

5.4.6 Multilooking

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

Read TopoPhaseRemoval Multilook

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

Read TopoPhaseRem	oval Multilook
Source Bands:	i_ifg_VV_23Apr2018_05May2018 q_ifg_VV_23Apr2018_05May2018 Intensity_ifg_VV_23Apr2018_05May2018_ifg_srd_VV_23Apr2018_05May2018 Phase_ifg_srd_VV_23Apr2018_05May2018 topo_phase_VV_23Apr2018_05May2018 coh_IW1_VV_23Apr2018_05May2018
GR Square Pixel	🔲 Independent Looks
Number of Range Looks	6
Number of Azimuth Looks:	2
Mean GR Square Pixel:	26.533897
Output Intensity	
	Note: Detection for complex data Is done without resampling.

5.4.7 Phase Filtering

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

Read TopoPhaseRemoval Multilook GoldsteinPhaseFilterin
--

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

Read TopoPhaseRemoval	Multilook GoldsteinPhaseFiltering	
Adaptive Filter Exponent in (0,1)	1	1.0
FFT Size:	128	
Window Size:	3	
🛄 Use coherence mask		
Coherence Threshold in [0,1]:		0,2

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

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

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

Name: S1B_IW1_20180423_Orb_stack_ifg_Deb_DInSAR_ML_Flt

Directory: /shared/Training/HAZA05_EarthquakeDeformation_Hawaii_TutorialKit/Processing

Read	TopoPhaseRemoval	Multilook	GoldsteinPhaseFiltering	Write	
Target	Product				
Name:					_
S1B_W	/1 20180423 Orb Stac	Ifg Deb D	nSAR ML Fit		
Save a	S: BEAM-DIMAP	-			
Dire	actory:				
/sh	ared/Training/HAZA05	Earthquaket	eformation Hawaii Tutoria	Kit/Processing	

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

Read TopoPhaseRemoval	Multilook GoldsteinPhaseFiltering
	SnaphuExport

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

N	Se	lect		• • •
Look In:	rocessing		- 62	1 C1 88 8=
Name				
SIB_IW_S SIB_IW_S Preproces SIB_IW1 SIB_IW2 SIB_IW2 SIB_IW2S	LC_1SDV_20180423T1 LC_1SDV_20180505T1 s_Graph.xml Sraph_1.xml 20180423_Orb_Stack_If LC_1SDV_20180423T1 LC_1SDV_20180505T1	g_0eb.data 61524_2018042 61525_2018050 g_Deb.dim 61524_2018042 61525_2018050	3T161551_010 5T161552_010 3T161551_010 5T161552_010	613_0 788_0 613_0 788_0
•		-	_)
File <u>N</u> ame:	SNAPHU			
Files of Type:	All Files			
			Select	Cancel

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

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

Read Topornasci	Rentoval Multiook Goldsteinringserntering write Shaphuckport	
Target folder:	/shared/Training/HAZA05_EarthquakeDeformation_Hawaii_TutorialKit/Processing/SNAPH	U perso
Statistical-cost mode:	DEFO	
Initial method:	MCF	*
Number of Tile Rows:		1
Number of Tile Colum	nns:	1
Number of Processor	rs:	4
Row Overlap:		0
Column Overlap:		0
Tile Cost Threshold:		500
T	Bud Base Sale Sur Out Nam	
	Load Save Sclear Mote W Help Skun	

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

	SNAP - Save Graph			+ = ×
Save In:	Processing	-	a 🔁 c	9 <u>80</u> 8-
Name		Size	Modified	
S1B_IW1_	20180423_Orb_Stack_Ifg_Deb.data		3/7/19 3:53	3 PM
S1B IW S	LC_1SDV_20180423T161524_20180423		3/6/19 1:38	3 PM
S1B_IW_S	LC_1SDV_20180505T161525_20180505		3/6/19 1:38	3 PM
SNAPHU			3/8/19 8:29	AM .
Preproces	ss_Graph.xml	1 KB	3/6/19 10:2	29 AM
Process_	Graph_1.xml	4 KB	3/7/19 3:44	1 PM
File <u>N</u> ame:	Process Graph 2.xml			
Files of <u>Type</u> :	Graph (*.xml)			-
		C	Save	Cancel

Finally, click on the **beau** icon at the bottom of the **Graph Builder** window.

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

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

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

5.4.8 Phase Unwrapping

Phase unwrapping is prerequisite to convert phase units to length units (See 1 NOTE 8). Open the:

/shared/Training/HAZA05_EarthquakeDeformation_Hawaii_TutorialKit/ Processing/SNAPHU/S1B_IW1_20180423_Orb_Stack_Ifg_Deb_DInSAR_ ML_Flt/ folder and right-click in the empty space.

Select "Open Terminal Here".

The following terminal will appear.

	Fermin a	al - rus(@front-usr	-3304:	shared/Training/HAZA05_EarthquakeDeformation_Hawaii_TutorialKit/Pi 🔹 🚊
File	Edit	View	Terminal	Tabs	Help
rus	afron	t-usi	r-3304:/	shar	ed/Training/HAZA05 EarthquakeDeformation Hawaii Tutorial
Kit	/Proc	essin	1g/SNAPH	U/S1	IW1_20180423_Orb_Stack_Ifg_Deb_DInSAR_ML_Flt\$

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

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

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

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

1	*5	naphu.conf - Mousepad	1 = E X
File Edit Search	View Document He	lp	
0 = 0 0 + ×		228	1 ⁰
1 # CONFIG FOR SN	APHU		
2 # Crostod by CN	AD coffuero oni 00	-22.19 00/02/2010	
4 #	Ar Suitware on. do	.52.10 00/03/2019	
5 # Command to ca	ll snaphu:		
6#			100 m 1 h 1
7 # snaphu	-t snaphu.cont Pha	se_irg_VV_23Apr2018_05May2018.snaphu	img 3435
9 #####################################	***		
10 # Unwrapping pa	rameters #		
11 #################	****		
12 13 STATCOSTMODE	DEED		
14 INITMETHOD	MCF		
15 VERBOSE	TRUE		
16			
1/ ####################################			
19 ####################################			
20			
21 CORRFILE	coh_IW1_V	/_23Apr2018_05May2018.snaphu.img	
22	*		
24 # Output files	¥		
25 ####################################	ŧ		
26	U.S. Disease	- 10/ 224- 2010 OFM- 2010	
27 001FILE 28 # 10GETLE	snaphu lo	1Tg_VV_23Apr2018_05May2018.snaphu.im	g
29	Shapina. co	,	
30 ################	#		
31 # File formats	#		

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

💶 Terminal - rus@front-usr-3304: /shared/Training/HAZA05 EarthquakeDeformation Hawaii TutorialKit/Pi File Edit View Terminal Tabs Help Building azimuth cost arrays Initializing flows with MCF algorithm Setting up data structures for cs2 MCF solver Running cs2 MCF solver Running nonlinear network flow optimizer Maximum flow on network: 14 Number of nodes in network: 4852243 (Total improvements: 0) Flow increment: 1 Treesize: 4852243 Pivots: 6153976 Improvements: 20553 Maximum flow on network: 3 (Total improvements: 20553) Flow increment: 2 Treesize: 4852243 Pivots: 429 Improvements: 0 Maximum flow on network: 3 Flow increment: 3 (Total improvements: 20553) Treesize: 4852243 Pivots: 4 Improvements: 0 Maximum flow on network: 3 Total solution cost: 52239984 Integrating phase Writing output to file UnwPhase_ifg_VV_23Apr2018_05May2018.snaphu.img Program snaphu done Elapsed processor time: 0:20:14.66 Elapsed wall clock time: 0:20:16 rus@front-usr-3304:/shared/Training/HAZA05_EarthquakeDeformation_Hawaii_Tutorial Kit/Processing/SNAPHU/S1B_IW1_20180423_Orb_Stack_Ifg_Deb_DInSAR_ML_Flts

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

NOTE 8: Two-dimensional phase unwrapping is the process of recovering unambiguous phase data from a 2-D array of phase values known only modulo 2pi rad.

5.4.8.1 SNAPHU import to SNAP

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

In the 1-Read-Phase tab, select the product that was created from the Write operator:

[6] S1B_IW1_20180423_Orb_Stack_Ifg_Deb_DInSAR_ML_Flt

In the **2-Read-Unwrapped-Phase** tab, click on to select the product that contains the unwrapped phase: **UnwPhase_ifg_VV_23Apr2018_05May2018.snaphu.hdr** from the following path:

/shared/Training/HAZA05_EarthquakeDeformation_Hawaii_TutorialKit/Processing/SNAPHU/S1B_ IW1_20180423_Orb_Stack_Ifg_Deb_DInSAR_ML_Flt

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

2	Sna	iphu Import	• = ×
1-Read-Phase	2-Read-Unwrapped-Phase	3-Snaphulmport 4-Write	
Source Product Name:			_
UnwPhase ifg	▼		

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

C Snaphu Import				
1-Read-Phase	2-Read-Unwrapped-Phase	3-Snaphulmport	4-Write	
Do NOT save	2-Read-Unwrapped-Phase	3-Snaphulmport	4-Write	

In the Write tab, set the following:

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

Phase 2-Read-Unwrapped-Phase 3-Snaphulmport 4-Write	ead-Phase 2-Read-Unwrapped-Phase 3-Snaphulmport 4-Write get Product I W1_20180423_Orb_Stack_Ifg_Deb_DINSAR_ML_Fit_Unw as: BEAM-DIMAP Directory: /shared/Training/HAZA05_EarthquakeDeformation_Hawaii_TutorialKit/Processing
Product	ee: I UVI_20180423_Orb_Stack_Ifg_Deb_DINSAR_ML_Fit_Unw e as: BEAM-DIMAP Directory: /shared/Training/HAZA05_EarthquakeDeformation_Hawaii_TutorialKit/Processing
1_20180423_Orb_Stack_lfg_Deb_DInSAR_ML_Flt_Unw	e as: BEAM-DIMAP Directory: /shared/Training/HAZA05_EarthquakeDeformation_Hawaii_TutorialKit/Processing

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

5.4.9 Displacement

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

In the I/O Parameters tab set the following:

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

e	Phase to Displacement	×
ile Help		
I/O Paramete	Processing Parameters	
Source Produ	t	
[7] S18_IW1	0180423_Orb_Stack_lfg_Deb_DinSAR_ML_Flt_Unw	
Name: S1B_IW1_203	10423_Orb_Stack_Ifg_Deb_DInSAR_ML_FIt_Unw_dsp	
/shared/	aining/HAZA05_EarthquakeDeformation_Hawaii_TutorialKit/Processing	1
Open in S	IAP	
	Run Clos	e

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

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

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

5.5 Geocoding

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

Go to Radar \rightarrow Geometric \rightarrow Terrain Correction \rightarrow Range-Doppler Terrain Correction.

In the I/O Parameters tab set the following:

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

	Range Doppler Terrain Correction	+ = ×
le Help		
I/O Parameters	Processing Parameters	
Source Product source:		
[6] S1B_IW1_201	80423_Orb_Stack_Ifg_Deb_DInSAR_ML_Flt	•
Target Product Name:		
S18_IW1_201804	23_Orb_Stack_lfg_Deb_DInSAR_ML_FIt_TC	
Save as: BE	am-dimap 👻	
Directory:		
	ning/HAZA05 FarthquakeDeformation Hawaii TutorialKit/Proce	ssing

In the Processing Parameters tab set the following:

In Source Bands select only:

Intensity_ifg_VV_23Apr2018_05May2018 Phase_ifg_VV_23Apr2018_05May2018 topo_phase_VV_23Apr2018_05May2018 coh_IW1_VV_23Apr2018_05May2018

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

Range Doj	opler Terrain Correction 💿 💿
ile Help	
I/O Parameters Processing Param	neters
Source Bands:	i_lfg_VV_23Apr2018_05May2018 g_ifg_VV_23Apr2018_05May2018 Intensity_ifg_VV_23Apr2018_05May2018 Phase_ifg_VV_23Apr2018_05May2018 topo_phase_VV_23Apr2018_05May2018 coh_WV_VV_23Apr2018_05May2018
Digital Elevation Model:	SRTM 1Sec HGT (Auto Download)
DEM Resampling Method:	BILINEAR INTERPOLATION
Image Resampling Method:	BILINEAR INTERPOLATION
Source GR Pixel Spacings (az x rg):	28.02(m) × 25.05(m)
Pixel Spacing (m):	28.02
Pixel Spacing (deg):	2.5170794261028995E-4
Map Projection:	WGS84(DD)
Mask out areas without elevation Output bands for:	Output complex data
Selected source band	DEM 📃 Latitude & Longitude
Incidence angle from ellipsoid	Local incidence angle 🔲 Projected local incidence angle
Apply radiometric normalization	
Save Sigma0 band	Use an exception of some sector to constrain the
🔲 Save Gammaŭ band	O an early as many throught the
Save Betaŭ band	

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

Repeat the same for the displacement product as well.

In the I/O Parameters tab set the following:

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

e	Range Doppler Terrain Correction	+ = >
ile Help		
I/O Parameters	Processing Parameters	
Source Product source:		
[8] S1B_IW1_20	180423_Orb_Stack_Ifg_Deb_DInSAR_ML_Flt_Unw_dsp	• 344
Target Product Name:		
S18_IW1_20180	423 Orb Stack Ifg Deb DINSAR ML Flt Unw dsp TC	
Save as: BE	AM-DIMAP	
Directory:		
/shared/Tra	ning/HAZA05_EarthquakeDeformation_Hawaii_TutorialK	it/Processing
Open in SNA	P	

In the Processing Parameters tab set the following:

In Source Bands select: displacement

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

I/O Parameters Processing P	arameters
Source Bands:	displacement
Digital Elevation Model:	SRTM 1Sec HGT (Auto Download)
DEM Resampling Method:	BILINEAR_INTERPOLATION
Image Resampling Method:	BILINEAR_INTERPOLATION
Source GR Pixel Spacings (az x r	g): 28.02(m) × 25.05(m)
Pixel Spacing (m):	28.02
Pixel Spacing (deg):	2.5170794261028995E-4
Map Projection:	WGS84(DD)
 Mask out areas without eleva Output bands for: Selected source band 	tion Output complex data
Incidence angle from ellipso	id 🔲 Local incidence angle 🔛 Projected local incidence angle
Apply radiometric normalizati	on
Save Sigma0 band	Use more that the maximum events from the tax
🔲 Save Gammaŭ band	Democratic model is the article
Save Betal band	

Keep the rest parameters as by default. Click Run.

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

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

5.6 Masking

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

In the I/O Parameters tab set the following:

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

sing Parameters	
rb_Stack_lfg_Deb_DInSAR_ML_Fit_TC	
Stack Ifg Deb DinSAR ML Fit TC msk	
	sing Parameters rb_Stack_lfg_Deb_DInSAR_ML_FIt_TC Stack_lfg_Deb_DInSAR_ML_FIt_TC_msk

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

Click Run.

e	Land/Sea Mask	• E ×
File Help		
1/O Parameters Pro	cessing Parameters	
Source Bands:	Intensity_ifg_VV_23Apr2018_05May2018 Phase_ifg_VV_23Apr2018_05May2018 topo_phase_VV_23Apr2018_05May2018 coh_IW1_VV_23Apr2018_05May2018	
O Mask out the Land		
Mask out the Sea		
Use SRTM 3sec		
🔾 Use Vector as Mas	c 1	
	Dinvert Vector	
Extend shoreline by (pi	xels]: 0	
Extend shoreline by (pi	xels]: 0	
		<u>R</u> un <u>C</u> lose

Repeat the same for the displacement product as well.

In the I/O Parameters tab set the following:

As source (Input): [10] S1B_IW1_20180423_Orb_stack_ifg_Deb_DInSAR_ML_Flt_Unw_dsp_TC

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

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

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

5.7 Export products

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

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

Save In:	Processing	-	a a	
Name		Size Modified		Subset
518 W1	20180423 Orb Stack Ifg Deb.data	3/7/19 3:53 PM	- I.	2000 0000
S1B W1	20180423 Orb Stack Ifg Deb DInSAR	3/8/19 8:32 AM		
518_IW1_	20180423 Orb_Stack_Ifg_Deb_DInSAR	3/8/19 2:37 PM		
518_IW1_	20180423_Orb_Stack_Ifg_Deb_DInSAR	3/8/19 3:24 PM		
518_IW1	20180423 Orb_Stack_Ifg_Deb_DInSAR	3/8/19 11:38 AM	=	
S18_IW1_	20180423_Orb_Stack_Ifg_Deb_DInSAR	3/8/19 1:28 PM		
518_IW1_	20180423_Orb_Stack_Ifg_Deb_DInSAR	3/8/19 2:58 PM		
S1B_IW1_20180423_Orb_Stack_Ifg_Deb_DInSAR		3/8/19 3:24 PM		
SIB_IW_S	LC_1SDV_20180423T161524_201804	3/6/19 1:38 PM		
SIB W S	LC_1SDV_20180505T161525_201805	3/6/19 1:38 PM		
SNAPHU		3/8/19 8:32 AM	-	
ile <u>N</u> ame:	Coherence_Hawaii.tif			
iles of Type:	GeoTIFF product (* tif.* tiff)			2

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

Specify Pr	roduct Subset 🛛 🖓 🖽 🗧
Spatial Subset Band Subset M	etadata Subset
Intensity_ifg_VV_23Apr2018_05May20 Phase_ifg_VV_23Apr2018_05May2018 topo_phase_VV_23Apr2018_05May2018 coh_IW1_VV_23Apr2018_05May2018	18 Intensity from complex data Phase from complex data 18 topographic_phase
Select all Select none	
	Estimated, raw storage size: 6.6

Repeat for any band you want to export.

6 Visualization in QGIS

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

<u>X</u>	Layer Properties - Cohere	nce_Hawaii Transparency	* E X
🔀 General	▼ Global transparency	No data value No data value: not defined	
Transparency	Custom transparency opt Transparency band	Full Additional no data value 0	
Histogram	Transparent pixel list		
👔 Metadata	From To	Percent Transparent	
	Style -	OK Cancel Appl	ly Help

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

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

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

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

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

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

Click OK.

General	▼ Band rendering					
Style	Render type	Singleba	nd gray 🔹			
Transparency	Band	Band 1 (G	iray)			2
Pyramids		Min	-0.347981	Max	0.28385	_
	▶ Load mit	n/max vali	les			
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Metadata	Color		Spectral 🔹	Edit	F Invert	
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	Value	Color	Label			
	-0.348		0.348			
	0.0321	_	0.0321			
	-0.0321	Concession of the local division of the loca	10-1 D.D.			

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

1	Layer Properties - Faults_Hawali Style	· + 6 *
General	Single symbol	-
🎸 Style	Line Simple line	4
abe Labels	-	
Fields		
Rendering		
Display	Unit Millimeter	•
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	1 Condon leasure remeaning order	25
	Style - OK C	ancel Apply Help

7 Extra Steps

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

7.1 Download files from VM

In your VM, press Ctrl+Alt+Shift.

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

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

THANK YOU FOR FOLLOWING THE EXERCISE!

8 Further reading and resources

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

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