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## Assignment 2: Generation of a Displacement Map

# Part 1 - An overview of the study area, where you describe the chosen site and the geohazard you are investigating. Explain why this particular site is relevant for analysis.

The study area for this assignment is **La Palma**, an island in the Canary Islands, Spain, which experienced a significant **volcanic eruption** from **September 19 to December 13, 2021**. The eruption occurred in the southern part of the island and was the most destructive in the recorded history of La Palma. It produced in total about 45 million m<sup>3</sup> of pyroclastic products and gave way to heavy lava flows, remolding the outline by burying 1,237 hectares of farming land and forming two new lava deltas on the shoreline. During the eruption process, much destruction occurred; infrastructure was partially ruined or seriously damaged - more than 3,000 houses were destroyed, a part of highways for over 70 kilometers, and extensive farm fields.

This site is relevant to the analysis for both of its dual impacts on the geohazard: geologically, in how it illustrates the dynamical nature of the activity that a volcano goes through within an oceanic island; socially, it highlights the vulnerability in dense populations, where close to 8,000 residents had to be evacuated, while large losses were recorded in essential sectors such as agriculture and tourism. Understanding the pattern of displacement and risks in this context is important for improving hazard mitigation strategies.

<u>References:</u> Troll, Valentin R., et al. "The 2021 La Palma eruption: social dilemmas resulting from life close to an active volcano." Geology Today 40.3 (2024): 96-111.

# **Part 2** - Workflow execution by documenting each step of the process, through screenshots.

To generate the displacement map of the volcanic eruption on La Palma, two Sentinel-1 SAR images were acquired via the *ASF Data Search Vertex*. The pre-event is represented by the Sentinel-1 SLC product from **September 14, 2021** and the post-event from **December 19, 2021**.

# 1. Data Preparation

## 1.1 S1-TOPS Split

#### Process:

In order to separate the Sentinel-1 SLC images into the area of interest, a sub-swath of IW2 and the bursts from 7 to 9 were selected. This split reduces the size of the dataset and enhances the speed of further processing steps. At the same time, VV polarization was selected.

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S-1 TOPS Split	S-1 TOPS Split
File Help	File Help
I/O Parameters Processing Parameters	I/O Parameters Processing Parameters
Source Product	Subswath: IW2
source:	Polarisations: VH
	W
Target Product	Bursts: 7 to 9 (max number of bursts: 10)
Name:	
S1A_20210914T_split  S1A_20210914T_split  Save as: BEAM-DIMAP  Directory:  C:\Users\annab\Documents\Master CDE\1.Semester\Remote Sensing\Assignment_Radar	
✓ Open in SNAP 11	
Run     Close       Image: S-1 TOPS Split     X       File     Help       I/O Parameters     Processing Parameters	Run Close
Source Product	
[8] S1A_IW_SLC_1SDV_20211219T191349_20211219T191419_041082_04E179_123E         v	
Target Product	
Name:	
Statuse as:       BEAM-DIMAP         Ø Save as:       BEAM-DIMAP         Directory:       C:\Users\annab\Documents\Master CDE\1.Semester\Remote Sensing\Assignment_Radar         C\Users\annab\Documents\Master CDE\1.Semester\Remote Sensing\Assignment_Radar	
Run Close	

Figure 1. S-1 TOPS Split processing.

Results:



Figure 2. Separated Sentinel-1 SLC images (intensity) from the pre-event (*left*) and post-event (*right*).

## **1.2 Apply Orbit File**

Process:

The Apply Orbit File has been applied to correct satellite positioning errors.

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Apply Orbit File X	💽 Apply Orbit File
le Help	File Help
I/O Parameters Processing Parameters	I/O Parameters Processing Parameters
Source:	Orbit State Vectors: Sentinel Precise (Auto Download)
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	De est feil if env sekt fils is est feund
Target Product	V Do not fail if new orbit file is not round
SIA 20211219 split Orb	
Save as: BEAM-DIMAP	
Directory:	
ents\Master CDE\1.Semester\Remote Sensing\Assignment_Radar	
Open in SNAP 11      Run Close	
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Open in SNAP 11      Run Close     Apply Orbit File      Help      I/O Parameters Processing Parameters  Source Broduct	Run Close
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Open in SNAP 11      Run Close     Apply Orbit File      Apply Orbit File      VO Parameters     Processing Parameters Source Product source:     [4] S1A_20210914_split      []	Run Close
Open in SNAP 11      Run Close      Apply Orbit File      Apply Orbit File      VO Parameters      Processing Parameters  Source Product source: [4] S1A_20210914_split    Lacet Packboxt	Run Close
Open in SNAP 11      Run Close      Apply Orbit File      Apply Orbit File      YO Parameters      Processing Parameters      Source Product      Source:     [4] S1A_20210914_split    Target Product Name:	Run Close
Open in SNAP 11      Run Close     Apply Orbit File ×      Help      VO Parameters Processing Parameters Source Product source:     [4] S1A_20210914_split	Run Close
Open in SNAP 11      Run Close     Apply Orbit File      Apply Orbit File      VO Parameters     Processing Parameters Source Product source: [4] S1A_20210914_split	Run Close
Open in SNAP 11      Run Close      Apply Orbit File      Apply Orbit File      X      Help      VO Parameters Processing Parameters Source Product source: [4] S1A_20210914_split   Target Product Name: S1A_20210914_split_Orb     Save as: BEAM-DIMAP      Directory:     Ints\Master CDE\1.Semester\Remote Sensing\Assignment_Radar	Run Close

Figure 3. Apply Orbit File.

Results:



Figure 4. Corrected Sentinel-1 SLC images (intensity) from the pre-event (*right*) and post-event (*left*).

## 2. Generation of Topographic Interferogram

## 2.1 Co-registration (Back Geocoding)

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To align the images from the pre- and post-event, the *Co-registration* tool was used. In this context, the **SRTM 1Sec HGT** was used as the DEM for the *Co-registration*.

C S-1 Back Geocoding				×	S-1 Back Geocoding		×
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ProductSet-Reader Back-Geocoding V File Name Type S1A_20210914_split_Orb Derived from I S1A_20211219_split_Orb Derived from I	Virite Acquisition SLC) 145ep2021 SLC) 19Dec2021	Track 60 60	Orbit 39682 41082	+             	ProductSet-Reader Back-Geocod Digital Elevation Model: DBM Resampling Method: Resampling Type:	ing Write SRTM ISec HGT (Auto Download) BILINEAR_INTERPOLATION BILINEAR_INTERPOLATION	
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Name: S1A_20210914_split_Orb_Stack Save as: EEAM-DIMAP Directory: C:\Users\annab\Documents\Master CDE\	I.Semester\Remote Sensinç	g\Assignment_Rac	lər				
<b>.</b>	Save 🕜 Help	Run					

Figure 5. S-1 Back Geocoding for co-registration.

Results:



Figure 6. Co-registered Sentinel-1 SLC images (intensity) of the pre-event (*left*) and post-event (*right*).

## 2.2 Enhanced Spectral Diversity

#### Process:

The Enhanced Spectral Diversity tool is an optional step which removes ionospheric errors.

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ource: [9] S1A_202	ct 0914_split_Orb_9	Stack		~	
arget Produ ame:	t				
S1A_202109	4_split_Orb_Stac	:k_esd			
Save as:	BEAM-DIMAP	~			
Directory					
Open in S	NAP 11	ter\Kemote :	ensing\Assi	gnment_Kadar	

Figure 7. S-1 Enhanced Spectral Diversity tool.

Results:



**Figure 8.** Sentinel-1 SLC images (intensity) of the pre-event (*left*) and post-event (*right*) after the application of the Enhanced Spectral Diversity tool.

## 2.3 Interferogram Generation

#### Process:

The *interferogram generation* tool creates a topographic interferogram which emphasizes the phase differences caused by terrain elevation. It corresponds to both topography and the displacement.

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Conterferogram Formation X	Conterferogram Formation
File Help	File Help
I/O Parameters Processing Parameters	I/O Parameters Processing Parameters
Source Product Source product: [10] S1A_20210914_split_Orb_Stack_esd v	Flat Earth Phase       Subtract Flat-Earth Phase       Degree of "Flat Earth" polynomial       5
Target Product Name:	Number of "Flat Earth" estimation points     501       Orbit interpolation degree     3       Output Flat Earth Phase
STA_2021_split_Orb_stack_esd_ing  Save as: BEAM-DIMAP  Directory:  bDocuments: Macter CDE11 Semested Permet Sension Arrianment Padas	Topographic Phase Subtract Topographic Phase Digital Elevation Model: SRTM 3Sec (Auto Download)
✓ Open in SNAP 11	Tile Extension [%]     100       Output Topographic Phase       Output Elevation       Output Concertified Lat/Lon
	Coherence         ✓ Output Coherence         ✓ Square Pixel         Independent Window Sizes         Coherence Range Window Size         20         Coherence Azimuth Window Size         6
Run Close	Run Close

Figure 9. Interferogram Formation tool.

Results:



Figure 10. Topographic interferogram produced with the Sentinel-1 SLC images of the pre- and post-event.

The result shows the first fringes, which can be associated with surface elevation variations. At the same time, however, a lot of noise is visible, which indicates that further filtering is required. To show the real surface displacement, it is also necessary to remove the topographic phase contribution in the next steps.

#### 2.4 TOPSAR Deburst

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Process:

The *TOPSAR Deburst* ensures continuous images by removing the burst boundaries which otherwise impair the quality of the output.

😨 S-1 TOPS Deburst	×
File Help	
Processing completed in 2 seconds (804 MB/s 210 MPixel/s)	
I/O Parameters Processing Parameters	
Source Product	
source:	
[11] S1A_2021_split_Orb_Stack_esd_ifg	×
Target Product Name:	
S1A_2021_split_Orb_Stack_esd_ifg_deb	
Save as: BEAM-DIMAP	
Directory:	
nts\Master CDE\1.Semester\Remote Sensing\Assignment_Ra	adar
✓ Open in SNAP 11	
Run	Close

Figure 11. S-1 TOPS Deburst tool.

#### Results:



Figure 12. Topographic interferogram created with the Sentinel-1 SLC images of the pre-event and post-event after the deburst.

- 3. Generation of Differential Interferogram
  - 3.1 Topographic Phase Removal (Interferogram formation)

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#### Process:

The *Topographic Phase Removal* was used for the topographic correction by using a DEM, in this case the **SRTM 1Sec HGT**.

C Topographic Phase Removal X	C Topographic Phase Removal X
File Help	File Help
Processing completed in 11 seconds (243 MB/s 63 MPixel/s)         I/O Parameters       Processing Parameters         Source Product       Source product:         [12] S1A_2021_split_Orb_Stack_esd_ifg_deb          Target Product          Name:       S1A_2021_split_Orb_Stack_esd_ifg_deb_dinsar         ✓ Save as:       BEAM-DIMAP         Directory:          nents\Master CDE\1.Semester\Remote Sensing\Assignment_Radar          ✓ Open in SNAP 11	File       Help         Processing completed in 11 seconds (243 MB/s 63 MPixel/s)         I/O Parameters       Processing Parameters         Orbit Interpolation Degree:       3         Digital Elevation Model:       SRTM 1Sec HGT (Auto Download)         Tile Extension [%]       100         Image: Output topographic phase band       Output elevation band         Output orthorectified Lat/Lon bands       Output orthorectified Lat/Lon bands
Run Close	Run Close

Figure 13. Topographic Phase Removal tool.

#### Results:



Figure 14. Differential interferogram after the Topographic Phase Removal.

#### 3.2 Multilooking

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The *Multilooking* tool is used to reduce noise and create square pixels. It is used to adjust the resolution by setting the *Number of Range looks* and *Number of Azimuth looks*. In this case, the *Number of Range looks* has been set to **8** and of *Azimuth looks* to **2** to ensure an acceptable resolution.

C Multilooking	× 💽 Multilooking	×
ile Help	File Help	
I/O Parameters Processing Parameters	I/O Parameters Pro	ocessing Parameters
Source Product source: [17] S1A_2021_split_Orb_Stack_esd_ifg_deb_dinsar	Source Bands:	i_ifg_VV_14Sep2021_19Dec2021 q_ifg_VV_14Sep2021_19Dec2021 Intensity_ifg_VV_14Sep2021_19Dec2021_ifg_sr Phase_ifg_srd_VV_14Sep2021_19Dec2021
Target Product Name: S1A 2021 split Orb Stack esd ifg deb dinsar ML		topo_phase_VV_14Sep2021_19Dec2021 coh_IW2_VV_14Sep2021_19Dec2021 elevation
Save as: BEAM-DIMAP	GR Square Pixel	Independent Looks
Directory:	Number of Range Look	KS: 8
nts\Master CDE\1.Semester\Remote Sensing\Assignment_Rada	ar Number of Azimuth Lo	ooks: 2
✓ Open in SNAP 11	Mean GR Square Pixel:	28.690018
	Output Intensity	
		Note: Detection for complex data is done without resampling.
Run	Close	Run Close
Run	Close	Run Clos

Figure 15. Multilooking tool.

#### Results:



Figure 16. Differential interferogram with improved visual interpretability after using the Multilooking tool.

## **3.3 Goldstein Phase Filtering**

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The *Goldstein Phase Filtering* reduces noise and thus improves the phase quality. The *Coherence Threshold*, which ranges from 0 to 1, can be set depending on the noise level. In this case, the presetting of **0.2** was used, but due to the high noise level in this example, it would also have been possible to select a higher threshold value.

C Goldstein Phase Filtering X	📀 Goldstein Phase Filtering	×
File Help	File Help	
Processing completed in 0 seconds I/O Parameters Processing Parameters	I/O Parameters Processing Parameters	
Source Product	Adaptive Filter Exponent in (0,1]:	1.0
Source product:	FFT Size: 64	~
[18] S1A_2021_split_Orb_Stack_esd_ifg_deb_dinsar_ML v	Window Size: 3	~
	Use coherence mask	
Target Product	Coherence Threshold in [0,1]:	0.2
S1A_2021_split_Orb_Stack_esd_ifg_deb_dinsar_ML_flt         Save as:       BEAM-DIMAP         Directory:       1ts\Master CDE\1.Semester\Remote Sensing\Assignment_Radar         Its\Master CDE\1.Semester\Remote Sensing\Assignment_Radar          Open in SNAP 11       Run	Run	Close

Figure 17. Goldstein Phase Filtering.

#### Results:



Figure 18. Differential interferogram after the Goldstein Phase Filtering (Coherence threshold: 0.2).

## 4. Generation of displacement map

4.1 SNAPHU Export

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To generate a displacement map, it is important to unwrap the phase. This ensures continuous displacement measurements. To do this, we use a tool called *Snaphu* from ESA, which can be installed on the PC and then controlled via the console. In this context, we need to create a config file in Snap, which needs to be modified accordingly.

(a)		(b)	
C Snaphu Export	X	C Snaphu Export	
Read SnaphuExport		Kead Snaphu	txport
Source Product		et folder:	C:\Users\annab\Documents\Master CDE\1.Semester\Remote Sensing\Assignment_Radar\snaphu
Name:		stical-cost mode:	DEFO V
[19] S1A_2021_split_Orb_Stack_esd_	ifg_deb_dinsar_ML_fit v	I method:	MCF v
		iber of Tile Rows:	1
Data Format: Any Forma	t v	ber of Tile Column	s: 1
Advanced options		ber of Processors:	4
		Overlap:	0
		mn Overlan:	0
		ort Threshold	500
		Processing complet	red in 0 seconds
			Save 🕢 Help 🕞 Run
Processing completed in 0 seconds	🖹 Save 🛛 🖉 Help 🛛 🕞 Run		
<pre>(C) # CONFIG FOR SNAPHU # Created by SNAP softu # Command to call snaph # # Snaphu -f snap # # Unwrapping parameters STATCOSTMODE DEFO INITMETHOD MCF VERBOSE TRUE ####################################</pre>	<pre>vare on: 18:18:11 10/12/2024 nu: nu.conf Phase_ifg_VV_14Sep2021_19Dec2021.snaphu.img 306 ### s # ## coh_IW2_VV_14Sep2021_19Dec2021.snaphu.img Unu@bace_ifg_VV_14Sep2021_19Dec2021.snaphu.img</pre>	(d) Investigation of the second se	<pre>isd-istop MtWordd = //Documents/Mster CDE/1 Sensiter/Memote Sensing adar/snaphu/Sik_2021_split_Orb_Stack_scd_ifg_deb_sinser_M_fit naphu.conf Phase_ifg_VV_14Sep2021_19Dec2021.snaphu.img b062 -disrgagarding multiprocessor option -disrgagarding multiprocessor option -disrgagarding multiprocessor option sensitive adaption of the state of the state of the state and the sauning uniform weights lation data from file coh_Tw2_VV_14Sep2021_19Dec2021.snaphu.img e post field. Assuming uniform weights formation-mode cost parameters e cost arrays (Does three algorithm ta structures for cs2 WCF Solver Cr Solver Cr Solver near network flow optimizer on network: 25 (SS07401 to file unifore adaption to file uniforments: 26151 Adal mprovements: 26151</pre>
#LOGFILE	onwrnase_irg_vv_i4Sep2021_19Dec2021.snapnu.img snaphu.log		

**Figure 19.** Snaphu Export in SNAP (a, b); Config file with the required modifications (c); Phase unwrapping by running Snaphu on the console (d).

#### 4.2 SNAPHU Import

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C Snaphu Import X	C Snaphu Import X
1-Read-Phase 2-Read-Unwrapped-Phase 3-Snaphulmport 4-Write	1-Read-Phase 2-Read-Unwrapped-Phase 3-Snaphulmport 4-Write
Source Product	Source Product
Name	Name:
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Data Format V	Data Format V
Advanced options	Advanced options
*	
C Snaphu Import X	C Snaphu Import X
C Snaphu Import X 1-Read-Phase 2-Read-Univrapped-Phase 3-Snaphu/mport 4-Write	Snaphu Import ×      1-Read-Unorapped-Phase 3-SnaphuImport 4-Write
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Figure 20. Importing the phase which was unwrapped with Snaphu in the console into SNAP.

Results:



Figure 21. Unwrapped Phase of the study area.

## 4.3 Phase to Displacement (Generate a Displacement Map)

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In this step, we generate displacement values from the unwrapped phase that allow us to analyze the ground movement in the study area.

e F	hase to Displa	cement				$\times$
ile	Help					
roc	essing complet	ed in 0 secor	ids			
1/0	) Parameters	Processing	Paramete	rs		
So	urce Product					
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[2	] S1A_2021_spl	it_Orb_Stack	_esd_ifg_d	eb_dinsa	r_ML_flt_unw	×
Tar	get Product					
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	Directory:					
	nts\Master C	DE\1.Semest	er\Remote	Sensing	\Assignment_R	ladar
	Open in SNAP	11				
					Run	Close

Figure 22. Phase to Displacement tool to generate a displacement map.

Results:



Figure 23. Displacement map of the study area showing displacement values.

#### 4.4 Range-Doppler Terrain Correction

#### Process:

The *Range-Doppler Terrain Correction* is used to georeference the displacement map to a coordinate system, in this case **WGS84**. We also need to the define a DEM, here **SRTM 1Sec HGT**, to remove distortions caused by the topography.

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Range Doppler Terrain Correction     X	Range Doppler Terrain Correction	
e Help	File Help	
ocessing completed in 3 seconds (49 MB/s 12 MPixel/s)	Processing completed in 1 seconds (	17 MB/s 9 MPixel/s)
I/O Parameters Processing Parameters	I/O Parameters Processing Para	imeters
Source Product source [1] SIA_2021_split_Orb_Stack_esd_ifg_deb_dinsar_ML_fit //	Source Bands:	i_ifg_VV_14Sep2021_19Dec2021 q_ifg_VV_14Sep2021_19Dec2021 Intensity_ifg_VV_14Sep2021_19Dec2021_db
Target Product Name:		Phase_ifg_W_14Sep2021_19Dec2021 topo_phase_VV_14Sep2021_19Dec2021 coh_W2_VV_14Sep2021_19Dec2021 elevation
A_2021_split_Orb_Stack_esd_ifg_deb_dinsar_ML_fit_TC  Save ac REGM-DIMAP Digital Elevation Model:	SRTM 1Sec HGT (Auto Download)	
Directory:	DEM Resampling Method:	BILINEAR INTERPOLATION
sers\annab\Documents\Master CDE\1.Semester\Remote Sensing\Assignment_Radar	Image Resampling Method:	BILINEAR INTERPOLATION
☑ Open in SNAP 11	Source GR Pixel Spacings (az x rg):	27.92098(m) x 29.45830327512722(m)
	Pixel Spacing (m): Pixel Spacing (deg): Map Projection:	29.45830327512722
		2.6462844076274937E-4
		WGS84(DD)
	Mask out areas without elevatio Output bands for:	n 🗌 Output complex data
	Selected source band Incidence angle from ellipsoid Layover Shadow Mask	DEM Latitude & Longitude Local incidence angle Projected local incidence angle
	Apply radiometric normalization	1 <u>6</u>
	Save Sigma0 band	Use projected local incidence angle from DEM
	Save Gamma0 band	Use projected local incidence angle from DEM
	Save Beta0 band	
Run Close		Run Close

Figure 24. Range Doppler Correction.

Results:



Figure 25. Georeferenced displacement map of the study area.

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The main difference between the georeferenced differential interferogram and the displacement map is that the differential interferogram shows the phase changes caused by ground displacement, while the displacement map shows displacement values in meters. The latter thus allows analyzing the ground movement. Furthermore, it ensures accurate spatial analysis and can be used for emergency response and damage control.

Part 3 - Results Analysis of the observed deformation patterns. Discuss briefly the implications of your findings.

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Figure 27. Displacement map of the study area, visualized in Google Earth Pro.

The displacement map shows significant ground deformation across La Palma, centered around the Cumbre Vieja volcano. Near the volcanic vent, the ground has lowered, likely due to the movement of magma underground. In contrast, the areas where lava flowed show an increase in elevation. Thick layers of lava built up during the eruption, creating new land and reshaping the landscape. These changes tell us how volcanic activity can dramatically alter the ground. Such information can tell us which areas need to be monitored for likely future hazards and how recovery efforts can be supported, as well as support emergency response, infrastructure planning, and further monitoring of volcanic activity.