

# How to create a DEM from Sentinel-1 Data

Source: Adapted from the STEP Community Forum and ASF staff data recipes

# In this document you will find:

- A. Background
- B. Materials List
- C. Steps
- D. The DEM Product

# A) Background

This recipe allows the user to create a Digital Elevation Model (DEM) product from two Sentinel-1 SLC scenes. The user first creates an interferogram, and completes the appropriate phase unwrapping steps, then creates the DEM.

## Pair Selection for DEMs

ASF's <u>baseline tool</u> may be used to select a pair of Sentinel images to create the DEM. The baseline tool can be accessed as a stand-alone tool, or via a <u>Vertex search</u>. The optimum pair for DEM creation would have a large perpendicular baseline and a small temporal baseline.

## More details for pair selection

*Overlap is required.* Pairs must be of the same path number and must cover the same area. Images with different flight directions (ascending vs descending) cannot serve as pairs for interferometry.

*Coherence is key.* You need to pick a pair that has the least temporal baseline possible. This not only minimizes the coherence loss, it also minimizes any potential ground motion. The longer the time between images the higher the decorrelation.

*Baseline cannot be ignored.* Interferogram sensitivity to the perpendicular baseline is such that a large baseline improves the InSAR's sensitivity to height variations. So, from that perspective larger baselines are better than smaller. However, as the baseline increases, the coherence decreases. Image alignment is problematic if the perpendicular baseline between images is greater than about 3/4 of the critical baseline because the images will be baseline decorrelated. The critical baseline for S1A is about 5 KM.

# Tradeoffs of DEMs created with Sentinel's C-Band

On the down side, C-band doesn't penetrate vegetation. This means that DEMs derived from C-band don't actually measure the earth's surface, rather they show the top of the canopy. In contrast, an L-band radar with a long wavelength as found on ALOS, can penetrate vegetation. L-band radar receives a reflected wave from the ground and is coherent even in a forest area. C-band has lower coherence than L band because of the vegetative decorrelation. These effects make it more difficult to make accurate DEMs from Sentinel-1's C-band than from ALOS's L-Band.

On the other hand, Sentinel has excellent temporal coverage, meaning that the temporal decorrelation is lower than with previous sensors. Sentinel should be excellent for creating DEMs of barren land or urban areas. However, beware of DEMs created over vegetated areas, especially in the spring during blooming season.

# **B)** Materials List

- A. <u>Sentinel-1 Toolbox (S1TBX v6.0.0)</u>
- B. Snaphu (SNAPHU v1.4.2)
- C. ASF's Generate InSAR Processing with Sentinel-1 Toolbox data recipe
- D. ASF's InSAR Phase Unwrapping data recipe
- E. Linux
  - Windows users can:
    - a. Download a Linux virtual machine (VM) or
    - b. Use an <u>Amazon EC2 Linux Instance</u>
- F. Sample granules
  - a. <u>S1A\_IW\_SLC\_\_1SDV\_20150720T203442\_20150720T203512\_006899\_009522\_4E7A</u>
  - b. <u>S1A IW SLC 1SDV 20150801T203443 20150801T203513 007074 009A02 3CD7</u>

# C) Steps

1. Follow steps below from the "Sentinel-1 InSAR Processing using the Sentinel-1 Toolbox" Recipe

Note that Steps 7 & 8 are deliberately omitted.

- Step 1 Open the Products
- Step 2 View Products
- Step 3 View a Band
- Step 4 Co-register the images
- Step 5 Form the Interferogram
- Step 6 TOPS Deburst
- Step 9 Phase Filtering
- 2. Follow the steps below from the "Sentinel-1 InSAR Phase Unwrapping using S1TBX and SNAPHU" Recipe

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Step 1- Open your Interferogram in S1TBX

Open the wrapped interferogram file. Use the file ending Orb\_Stack\_ifg\_deb\_flt.dim.

0, ●	SNAP - Open Produc	ot
	InSAR_DEM	
Name		
\$1A_IW_SLC1SDV_20150720T203442_201507	20T203512_006899_009522_4E7A_Orb_Stack	.data
S1A_IW_SLC1SDV_20150720T203442_201507	20T203512_006899_009522_4E7A_Orb_Stack	.dim
\$1A_IW_SLC1SDV_20150720T203442_201507	20T203512_006899_009522_4E7A_Orb_Stack	_ifg.data
S1A_IW_SLC1SDV_20150720T203442_201507	20T203512_006899_009522_4E7A_Orb_Stack	_ifg.dim
\$1A_IW_SLC1SDV_20150720T203442_201507	20T203512_006899_009522_4E7A_Orb_Stack	_ifg_deb.data
S1A_IW_SLC1SDV_20150720T203442_201507	20T203512_006899_009522_4E7A_Orb_Stack	_ifg_deb.dim
\$1A_IW_SLC1SDV_20150720T203442_201507	20T203512_006899_009522_4E7A_Orb_Stack	_ifg_deb_flt.data
S1A_IW_SLC1SDV_20150720T203442_201507	20T203512_006899_009522_4E7A_Orb_Stack	_ifg_deb_flt.dim
subset_0_of_S1A_IW_SLC1SDV_20150720T2034	442_20150720T203512_006899_009522_4E7	'A_Orb_Stack_ifg_deb_flt.data
subset_0_of_S1A_IW_SLC1SDV_20150720T2034	442_20150720T203512_006899_009522_4E7	'A_Orb_Stack_ifg_deb_flt.dim
subset_0_of_S1A_IW_SLC1SDV_20150720T2034	442_20150720T203512_006899_009522_4E7	'A_UNW_Orb_Stack_ifg_deb_flt.data
subset_0_of_S1A_IW_SLC1SDV_20150720T2034	442_20150720T203512_006899_009522_4E7	A_UNW_Orb_Stack_ifg_deb_flt.dim
subset_0_of_S1A_IW_SLC1SDV_20150720T2034	442_20150720T203512_006899_009522_4E7	A_UNW_Orb_Stack_ifg_deb_flt_TC.dat
subset_0_of_S1A_IW_SLC1SDV_20150720T2034	442_20150720T203512_006899_009522_4E7	A_UNW_Orb_Stack_ifg_deb_flt_TC.dim

*Figure 1. Open the file ending Orb\_Stack\_ifg\_deb\_flt.dim.* 

Step 2 – Create a Subset (Optional)

Creating a subset can significantly speed up processing.

#### 3. Export to SNAPHU

Export your interferogram or your subset interferogram from S1TBX to SNAPHU

a. In S1TBX navigate to Radar/Interferometric/Unwrapping/Snaphu Export



Figure 2. In S1TBX, select Radar.



Figure 3. Select Interferometric/Unwrapping/Snaphu Export.

In the Snaphu Export window (Figure 4):

- b. Create a new folder for this step by entering a path and new folder name
  - i. Type the folder directory in the Target Folder box.
  - ii. This recipe will call the folder *SNAPHU\_Export*
- c. Select TOPO mode for DEM generation
- d. Select MCF
- e. Change the values of Tile Rows and Tile Columns to 20
- f. Click Run to create the <u>SNAPHU\_Export folder</u>
  - a. The folder now holds files used for phase unwrapping

Target folder:	/Users/k	jaustin/	Deskto	p/SNAP	HU_Expo	ort 🗕		
tatistical-cost mode:	ТОРО						K	
nitial method:	MCF	$\leftarrow$	$\geq$	•			K	
Number of Tile Rows:							2	0
Number of Tile Columns:						-	2	0
Number of Processors:								4
Row Overlap:								0
Column Overlap:								0
Tile Cost Threshold:							50	0
		<b>()</b>	lelp [	> Run			 	

Figure 4. Enter folder name, TOPO, MCF, and change row and column values to 20.

- 4. Install a Linux VM so you have a place to put the SNAPHU Export folder files in Step 6a. below.
- 5. Zip and move SNAPHU Export files to make them accessible to SNAPHU software on Linux
  - a. One way is to place files in Google Drive and download them to Linux
  - b. Another method is to email them to yourself and retrieve in Linux.

#### 6. Unwrap Interferogram with SNAPHU

SNAPHU is the Statistical-cost, Network-flow Algorithm for Phase Unwrapping, developed at Stanford University by Curtis Chen and Howard Zebker. http://nova.stanford.edu/sar\_group/snaphu/

SNAPHU is Linux only. The user needs to install SNAPHU on the Linux VM.

#### a. Install SNAPHU

At the Linux command line, install SNAPHU:

**\$** apt-get install snaphu

[jlaurenc@gwa	~]\$			
[jlaurenc@gwa	~]\$			
[jlaurenc@gwa	~]\$			
[jlaurenc@gwa	~]\$			
[jlaurenc@gwa	~]\$	apt-get	install	snaphu

Figure 5. At the Linux command line, install SNAPHU.

## b. Display the SNAPHU config file

Make sure you're in the same directory as the 'snaphu.conf' file

At the Linux command line, display snaphu.conf by pasting the below command

## \$ nano snaphu. conf

[jlaurenc@gwa	~]\$		
[jlaurenc@gwa	~]\$		
[jlaurenc@gwa	~]\$		
[ilaurenc@gwa	~]\$		
[jlaurenc@gwa	~]\$	nano	snaphu.conf

Figure 6. Display the SNAPHU configuration file

c. Copy the command from the config file



Figure 7. Copy the command in the red box. Ctrl + X to exit the config file.

d. Use Ctrl + X to exit the config file

#### e. Run the command you copied to unwrap your interferogram

In the same directory, paste the command at the Linux command line and Enter.

[ubuntu@ip-172-31-4-255:~\$ snaphu -f snaphu.conf Phase_ifg_VV_08Apr2016_20Apr2016] .snaphu.img 6887
<pre>snaphu v1.4.2 27 parameters input from file snaphu.conf (84 lines total) Logging run-time parameters to file snaphu.log Creating temporary directory snaphu_tiles_8349 Unwrapping tile at row 0, column 0 (pid 8351) Unwrapping tile at row 0, column 1 (pid 8352) Unwrapping tile at row 0, column 3 (pid 8354) Unwrapping tile at row 0, column 2 (pid 8353)</pre>

Figure 8. Paste the command and hit Enter.

**Note:** Execution time depends on the size of the interferogram. Unwrapping can use a lot of memory. If the unwrapping fails due to insufficient memory, you may wish to create a subset of your area of interest (see Step 2 of the InSAR Phase Unwrapping data recipe and try again).

- f. Zip and move the files from the VM to your PC or Mac, so they are accessible to S1TBX
- g. On your desktop, check your .hdr and .img filenames for a possible mismatch
  - a. A bug may cause a filename and contents mismatch between the .hdr and .img files
  - b. Mismatched filenames and contents will cause recipe failure
  - c. If this happens see the Defect Warning and Workaround section below

**Defect Warning and Workaround** 

**Workaround:** If the polarization in the .hdr filename does not match the .img filename, edit the .hdr filename and contents to match the .img filename and contents polarization.

For example:

a. Edit .hdr filename polarization to match the .img filename polarization:

UnwPhase\_ifg\_IW1\_VH\_20Jul2015\_01Aug2015.snaphu.hdr

To match .img filename

UnwPhase\_ifg\_IW1\_VV\_20Jul2015\_01Aug2015.snaphu.img

#### To get this

UnwPhase\_ifg\_IW1\_VV\_20Jul2015\_01Aug2015.snaphu.hdr

b. Edit the .hdr contents polarization to match the polarization of the .img file.

UnwPhase_ifg_IW1_VH_20Jul2015_01Aug2015.snaphu - Notepad -	×
File Edit Format View Help	
ENVI	~
<pre>description = {Unwrapped Phase from complex data - Unit: 1}</pre>	
samples = 8833	
lines = 8005	
bands = 1	
header offset = 0	
file type = ENVI Standard	
data type = 4	
interleave = bsq	
byte order = 0	
<pre>band names = { UnwPhase_ifg_IW1_VH_20Jul2015_01Aug2015 }</pre>	
data gain values = {1.0}	
data offset values = {0.0}	
	$\sim$
<	>

*Figure 9. Edit the .hdr file polarization(VH) to match the .img polarization (VV).* 

#### 7. Open the files in S1TBX

Import your wrapped and unwrapped interferograms into S1TBX

a. In S1TBX, navigate to Radar/Interferometric/Unwrapping/Snaphu Import



Figure 10. Navigate to Snaphu Import.

In the 1-Read-Phase tab, select your wrapped interferogram product.
 This is the same file you exported to SNAPHU. Filename will end in
 Orb\_Stack\_ifg\_deb\_flt.dim. If you subset, it will also start with 'subset'.



*Figure 11. Browse to your wrapped interferogram and select it. File name will end in* Orb\_Stack\_ifg\_deb\_flt.dim.

## c. In the 2-Read-Unwrapped-Phase tab

Navigate to your SNAPHU Export folder and browse to the **UnwPhase......hdr file.** See **Defect and Workaround** below in case of an error.

1-Read-Phase	2-Read-Unwrapped-Phase	3-Snaphulmport	4–Write
ource Product		_	
UnwPhase_ifg_IW1_V	V_20Jul2015_01Aug2015.snaph	u	<b></b>
Data Format: Ar	ny Format ᅌ		
	🔞 Help 🕞 Rur		

*Figure 12. Browse to your unwrapped .hdr file. Note the .hdr extension will not be displayed in this window after selection.* 

Select Source Product	
File: W_20Jul2015_01Aug2015.snaphu.	hdr
subset_0_of_S1A_IW_SLC	
Name	∧ Date Modified
Phase_ifg_IW1_VH_20Jul2015_01Aug2015.snaphu.hdr	Friday, January 2
Phase_ifg_IW1_VH_20Jul2015_01Aug2015.snaphu.img	Friday, January 2
Phase_ifg_IW1_VV_20Jul2015_01Aug2015.snaphu.hdr	Friday, January 2
Phase_ifg_IW1_VV_20Jul2015_01Aug2015.snaphu.img	Friday, January 2
snaphu.conf	Friday, January 2
snaphu.log	Friday, January 2
snaphu_tiles_2595	Friday, January 2
🗟 UnwPhase_ifg_IW1_VV_20Jul2015_01Aug2015.snaphu.hdr 🕇	Friday, January 2
UnwPhase_ifg_IW1_VV_20Jul2015_01Aug2015.snaphu.img	Friday, January 2
D ø @	Friday, January 2
File Format: All Files	0
New Folder	ancel Select

Figure 13. Select the UnwPhase...hdr file.

#### In Case of Error Message

Error messages: "No matching Envi image for header file." Or "Header file could not be read."



*Figure 14. Error message that is thrown if file names or contents are mismatched.* 

In some cases .hdr filenames and files contain the incorrect polarization. If this happens the import will fail because the .img file will not have a matching .hdr file.

Please scroll up to the Defect Warning and Workaround instructions.

#### d. In the 3-Snaphulmport tab

Running Snaphu Import will overwrite your file.

To create a new file instead, check the **Do NOT save Wrapped Interferogram in the** target product option.

1-Read-Phase 2-Read-Unwrapped-Phase 3-SnaphuImport 4-Write Do NOT save Wrapped interferogram in the target product
Do NOT save Wrapped interferogram in the target product

*Figure 15. Check the box.* 

e. In the 4-Write tab

Values will auto-fill.

Edit (add text) to create a unique file name.

We added 'UNW' to indicate unwrapped.

Click Run.

		Snaphu Impor		
1-Re	ad-Phase	2-Read-Unwrapped-Phase	3-Snaphulmport	4-Write
Target Produc	t			
		Add Text		
Name:				
20150720T2	03442_2015	50720T203512_006899_009	522_4E7A_UNW_Orb	_Stack_ifg_deb_flt
Save as:	BEAM-DIN	ИАР		
Directory:				
/Users/kj	austin/Doci	uments/InSAR_DEM/InSAR_I	DEM	
🗹 Open in S	NAP			
ocessing comp	leted in 11 s	seconds (30 MB/s 7 MPixel/	;) un	-

Figure 16. Add text to create a unique file name. Click Run.

## 8. Create the DEM - Convert Phase to Elevation

This step converts the interferometric phase to a digital elevation map (DEM).

**a.** In S1TBX, in the Radar tab, select Interferometric/Products/Phase to Elevation.



Figure 17. SNAP S1TBX menu. Select Radar.

Apply Orbit File	14		)	
Radiometric	>		-4	
Speckle Filtering	>			
Coregistration	>			
nterferometric	>	Products	>	Interferogram Formation
Geometric	>	Filtering	>	Coherence Estimation
Sentinel-1 TOPS	>	Unwrapping	>	Topographic Phase Removal
ENVISAT ASAR	>	PSI\SBAS	>	Three-pass Differential InSAR
AR Applications	>	InSAR Stack Overv	iew	Phase to Height
SAR Utilities	>			Phase to Displacement
AR Wizards	>		1	
Complex to Detected GR				Phase to Elevation
Aultilooking				Integer Interferogram Combination

Figure 18. Select Phase to Elevation.

- **b.** Enter the <u>unwrapped</u> interferometric product filename in Source Product, source:
  - i. Use the file you added the 'UNW' text to in Step 7e. (Figure 19)
  - ii. The Target Product Name, your DEM final product, will automatically populate
  - iii. Edit the Directory the product will appear in, if desired.

SNAPHU Export
ubset 0 of SIA IW SLC 1SDV 20150720T203442 20150720T203512 006899 009522 4E7A UNW Orb Stack ifg deb fit dem.data
ubset 0 of S1A IW SLC 1SDV 20150720T203442 20150720T203512 006899 009522 4E7A UNW Orb Stack ifg deb flt TC.data
S1A_IW_SLC_1SDV_20150720T203442_20150720T203512_006899_009522_4E7A_Orb_Stack.data
S1A_IW_SLC_1SDV_20150720T203442_20150720T203512_006899_009522_4E7A_Orb_Stack_ifg.data
SIA_IW_SLC_1SDV_20150720T203442_20150720T203512_006899_009522_4E7A_Orb_Stack_ifg_deb.data
S1A_IW_SLC_1SDV_20150720T203442_20150720T203512_006899_009522_4E7A_Orb_Stack_ifg_deb_flt.data
subset_0_of_S1A_IW_SLC1SDV_20150720T203442_20150720T203512_006899_009522_4E7A_Orb_Stack_ifg_deb_flt.data
🍯 subset_0_of_S1A_IW_SLC_1SDV_20150720T203442_20150720T203512_006899_009522_4E7A_UNW_Orb_Stack_ifg_deb_flt.data
IA_IW_SLC_1SDV_20150720T203442_20150720T203512_006899_009522_4E7A.zip
S1A_IW_SLC_1SDV_20150720T203442_20150720T203512_006899_009522_4E7A_Orb_Stack.dim
S1A_IW_SLC_1SDV_20150720T203442_20150720T203512_006899_009522_4E7A_Orb_Stack_ifg.dim
S1A_IW_SLC_1SDV_20150720T203442_20150720T203512_006899_009522_4E7A_Orb_Stack_ifg_deb.dim
S1A_IW_SLC_1SDV_20150720T203442_20150720T203512_006899_009522_4E7A_Orb_Stack_ifg_deb_flt.dim
IA_IW_SLC_1SDV_20150801T203443_20150801T203513_007074_009A02_3CD7.zip
subset_0_of_S1A_IW_SLC1SDV_20150720T203442_20150720T203512_006899_009522_4E7A_Orb_Stack_ifg_deb_flt.dim
subset_0_of_S1A_IW_SLC1SDV_20150720T203442_20150720T203512_006899_009522_4E7A_UNW_Orb_Stack_ifg_deb_flt.dim

Figure 19. Select the file you added 'UNW' to, your unwrapped interferogram.

c. Click Run

	I/O Parameters Processing Parameters
ource Produ	ct
ource:	
[2] subset_	0_of_S1A_IW_SLC1SDV_20150720T2034 📀
arget Produ	ct
ame:	
0720T20351	2_006899_009522_4E7A_Orb_Stack_ifg_deb_flt_dem
<b>—</b> c	
Save as:	
Directory	
Directory	isustin (Decuments (InSAR DEM
/Users/k	Jaustin/Documents/Insak DEM
/Users/k	
/Users/k	SNAP
/Users/k	SNAP
/Users/k	SNAP

Figure 20. Click **Run** to create a DEM.

d. You now have a DEM file called *yoursourcefilename\_dem* 

#### 9. Geocode the DEM

- a. From the Radar menu, select Geometric/Terrain Correction/Range Doppler Terrain Correction.
  - i. *Note:* This correction method uses available orbit state vector information in the metadata, the radar timing annotations, the slant to ground range conversion parameters together with the reference DEM data to derive the precise geolocation information.

Edit View Analysis	Layer Vector Raster	Optical Radar	Window Help	 	
3 <b>5</b> 8 <b>6</b> 6	带 🕹 😋 🖨	*****	🖗 🔍 🖊 GCP	• • • • • • • • • • • • • • • • • • • •	
oduct Explorer × Pi	ixel Info				-

Figure 21. SNAP S1TBX menu. Select Radar.

Apply Orbit File		, 🖓 🖳 🧐 😭 🚵 🗠 🚿	
Radiometric	>		,
Speckle Filtering	>		—
Coregistration	>		
Interferometric	>		
Geometric	>	Terrain Correction >	Range-Doppler Terrain Correction
Sentinel-1 TOPS	>	Ellipsoid Correction >	SAR Simulation
ENVISAT ASAR	>	SAR-Mosaic	SAR-Simulation Terrain Correction
SAR Applications	>	ALOS Deskewing	
SAR Utilities	>	Slant Range to Ground Range	
SAR Wizards	>	Update Geo Reference	
Complex to Detected GR			J
Multilooking			

Figure 22. Select Range-Doppler Correction

b. Without changing any values, click Run.

.,	s Processing				
eleva	elevation				
SR	TM 3Sec (Auto D	ownload)	0		
BIL	BILINEAR_INTERPOLATION				
BIL	BILINEAR_INTERPOLATION		0		
az x rg): 14.07 14.0	14.07(m) x 4.22(m) 14.07 1.2639296047561668E-4				
1.26					
	WGS84(DD)				
t elevation 🗌 C	utput complex	data			
🗌 DE	М	🗌 Latitude & Longitud	de		
ellipsoid 🗌 Lo	cal incidence an	gle 📃 Projected local inci	dence angle		
malization					
Us	Use projected local incidence angle from DEM		0		
Us	Use projected local incidence angle from DEM		0		
	eleva SR BIL az x rg): 14.07 14.0 1.26 ellipsoid Loo malization Us	elevation SRTM 3Sec (Auto D BILINEAR_INTERPO BILINEAR_INTERPO az x rg): 14.07 1.263929604756160 ut elevation Output complex ellipsoid Local incidence an malization Use projected loca i Use projected loca i	elevation SRTM 3Sec (Auto Download) BILINEAR_INTERPOLATION BILINEAR_INTERPOLATION Az x rg): 14.07(m) x 4.22(m) 14.07 1.2639296047561668E-4 WCS84(DD) At elevation Output complex data U DEM Latitude & Longitud ellipsoid Local incidence angle Projected local incidence angle from DEM Use projected local incidence angle from DEM Use projected local incidence angle from DEM		

Figure 23. Click Run.

# **D)** The DEM product

- Double-click the resulting\_TC product
  - Double-click on Bands
  - Then double-click on the Unw\_Phase\_ifg\_20Jul2015\_01Aug2015\_VH file

The image of your DEM will appear.

You now have a geocoded terrain-corrected DEM called *yoursourcefilename\_TC*.

## Completed DEM



Figure 24. The complete geocoded terrain-corrected Sentinel-1 DEM