



Sentinel-1 InSAR Phase Unwrapping using S1TBX and SNAPHU

Source: Adapted from the European Space Agency's [STEP](#) community platform tutorials

Document Contents:

A) Background	2
B) System Requirements	2
C) Materials List	3
D) Pre-Unwrapping Steps	3
Step 1: Open Your Interferogram in S1TBX	4
Step 2: Create a Subset (Optional)	4
Step 3: Export to SNAPHU	6
E) Using a Virtual Machine	7
F) Unwrap Interferogram with SNAPHU	7
Install SNAPHU	7
Extract the SNAPHU Command from the Configuration File	8
Run the SNAPHU Command.....	9
Make Output Files Available to S1TBX Processing Environment	9
OPTIONAL: Defect Warning and Work-Around	10
G) Post-Unwrapping Steps.....	11
Step 4: SNAPHU Import.....	11
Step 5: Geocoding	12
Step 6: Export Data	14
Interferogram Interpretation	15
H) Sample Images.....	16
I) Extended Reading List	17

A) Background

This data recipe is a continuation from ASF's [Sentinel-1 InSAR Processing](#) recipe. It provides instructions for “unwrapping” the interferogram generated in that recipe. Once an interferogram is unwrapped, height values can be derived from the product for use in further processing, such as generating deformation maps or DEMs.

Phase unwrapping is the most complicated stage of interferometric data processing. In this recipe, we will use SNAPHU, which is a two-dimensional phase unwrapping algorithm developed by Chen and Zebker (see [Section H](#)). The software is publicly available, and should run on most Unix/Linux platforms.

The interferometric phase is ambiguous and only known within 2π . In order to be able to relate the interferometric phase to the topographic height, the phase must first be unwrapped. The altitude of ambiguity h_a is defined as the altitude difference that generates an interferometric phase change of 2π after interferogram flattening.

Phase unwrapping solves this ambiguity by integrating phase difference between neighboring pixels. After deleting any integer number of altitudes of ambiguity (equivalent to an integer number of 2π phase cycles), the phase variation between two points on the flattened interferogram provides a measurement of the actual altitude variation.

B) System Requirements

- Linux/Unix computing system, or access to a Virtual Linux environment (see [Section C](#))
- At least 16 GB memory RAM

Many of the steps take a very long time to process. Consider closing other applications and avoid using the computer while products are processing.

Note: A Solid State Drive will perform significantly faster than a Hard Disk Drive and when processing large files, this will be very advantageous.

If you encounter an error in the middle of a processing step, it may be because your disk is full. If you are using a Virtual machine, be sure to partition enough space for the virtual installation.

C) Materials List

1. Linux or Unix

Windows users have several options to access a Linux machine:

- Establish a virtual machine (VM), install a Linux operating system on the VM, and use it to run the SNAPHU processing portion of the recipe.
 - i. Options for VM software include <https://www.virtualbox.org/> or <https://www.vmware.com/>
 - ii. An option for a Linux operating system is <https://www.linuxmint.com>
 - [Launching an Amazon EC2 Linux instance through Amazon Web Services \(AWS\)](#)
- ### 2. [Sentinel-1 Toolbox](#) (S1TBX).
- ### 3. SNAPHU Algorithm for Phase Unwrapping (See Step 3 for installation instructions)
- ### 4. InSAR Data (continuation from [InSAR data recipe](#)). Note that the interferogram **must include the coherence band** in order to be unwrapped.

D) Pre-Unwrapping Steps

This data recipe assumes that you have already generated your interferogram using the Sentinel-1 Toolbox as shown in Figure 1 below and would like to follow the unwrapping process. Note that the last step should be Phase Filtering; the product should not be Geocoded (Terrain Corrected) before unwrapping.

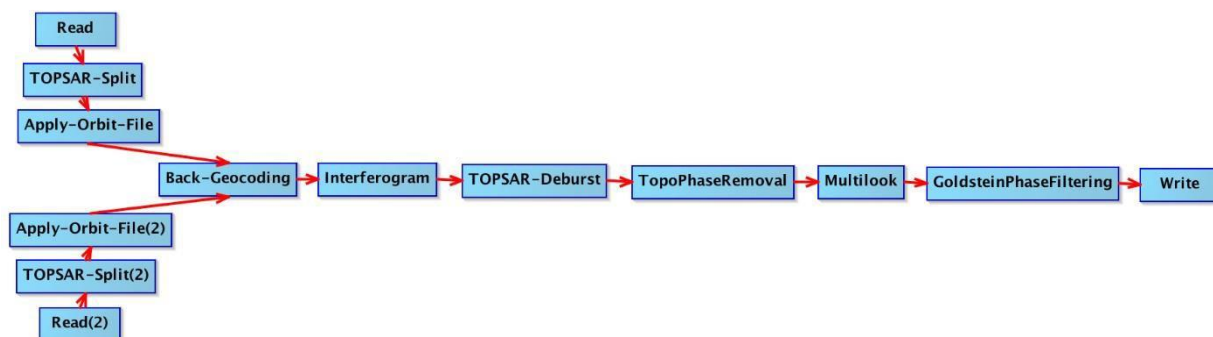


Figure 1: Interferogram Formation Process (without Geocoding/Terrain Correction).

For optimal unwrapping results it is recommended to multi-look and phase-filter the interferogram, as instructed in the [InSAR data recipe](#). **Note that when performing the multi-look process for data that will be used for phase unwrapping, the coherence band (coh) must be included along with the i and q bands.**

The quality and reliability of unwrapped results strongly depends on the input coherence. Reliable results can only be expected in areas with high coherence.

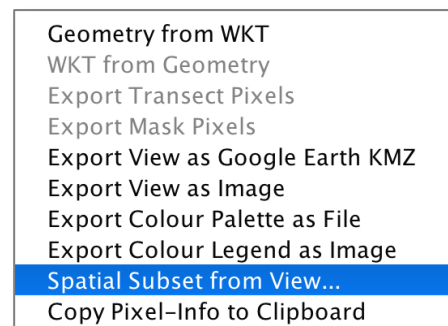
Step 1: Open Your Interferogram in S1TBX

- Open S1TBX (search for SNAP in your programs) and make sure that the Product Explorer window is open (if it is not displayed, select Tool Windows from the View menu in S1TBX and click on the Product Explorer option).
- Use the **Open Product** button and navigate to your interferogram (.dim file).
 - If you've used the default suffixes during processing, the desired product will be tagged **_Orb_Stack_ifg_deb_dinsar_MLflt.dim**
 - *If you performed Terrain Correction on the interferogram, be sure to select the product generated before that step was performed (**the product should not be tagged with _TC**).*
- Double-click on the product in the **Product Explorer** to expand the product, and double-click on the Bands folder to view the product bands.
- Double-click on the Phase band to view your interferogram
- If desired, zoom in using the mouse wheel, or using the Navigation tab in the lower left corner of the S1TBX interface (if it is not displayed, select Tool Windows from the View menu and click on the Navigation option).

Step 2: Create a Subset (Optional)

To reduce the amount of processing required, you may wish to create a subset of a smaller area within the granule, especially if you have a specific area of interest.

- Zoom in and pan to your area of interest.
- Right-click the image and select **Spatial Subset from View** from the context menu.



The subset dialog box will automatically select the area you were viewing. To adjust the extent of your subset image, you may drag the bounding box, enter the pixel coordinates, or add geo coordinates (Figure 2).

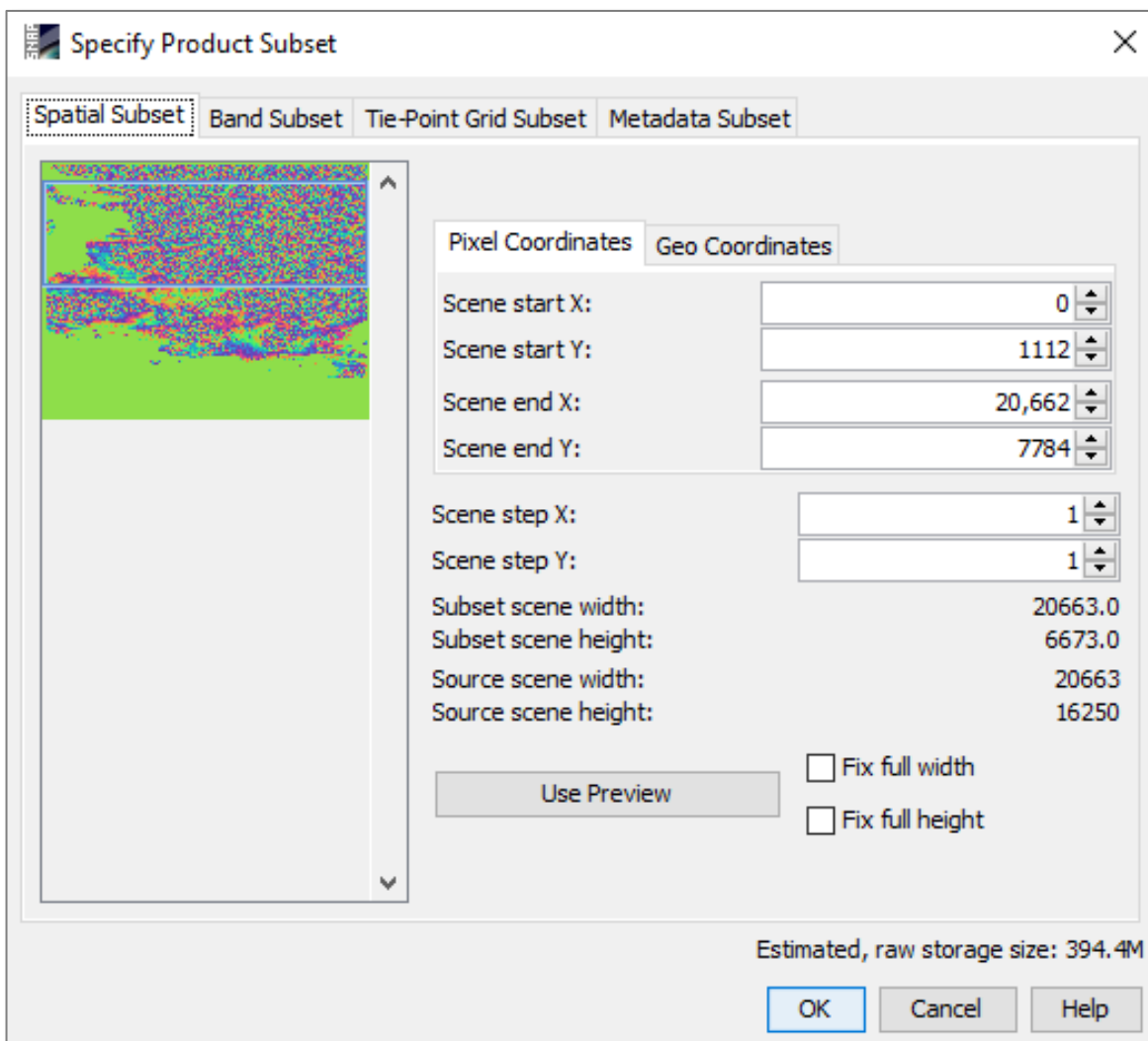


Figure 2: Specifying a Product Subset.

- Click **<OK>** to create the subset.

By default, all bands will be included in the subset output (Band Subset tab). Note that for phase unwrapping, both the **phase** and **coherence** bands must be included.

When the new subset appears in the Product Explorer window:

- Right-click on the product and select **Save Product** from the context menu
- Click the **Yes** button to convert the product to the **BEAM-DIMAP** format and save it to disk in your desired destination folder.

Step 3: Export to SNAPHU

- Select the product from the **Product Explorer** tab.
- Navigate to *Radar > Interferometric > Unwrapping > SNAPHU Export*.
- In the **SNAPHU Export** tab, navigate to or type in the path for the desired Target Folder.
 - We recommend creating a separate folder for this step (Figure 3).
- Select **DEFO** for deformation mapping.
- To speed up the unwrapping process, you may increase the number of processors (this depends on the CPU you have).
- Click **<Run>** to create the SNAPHU export product.

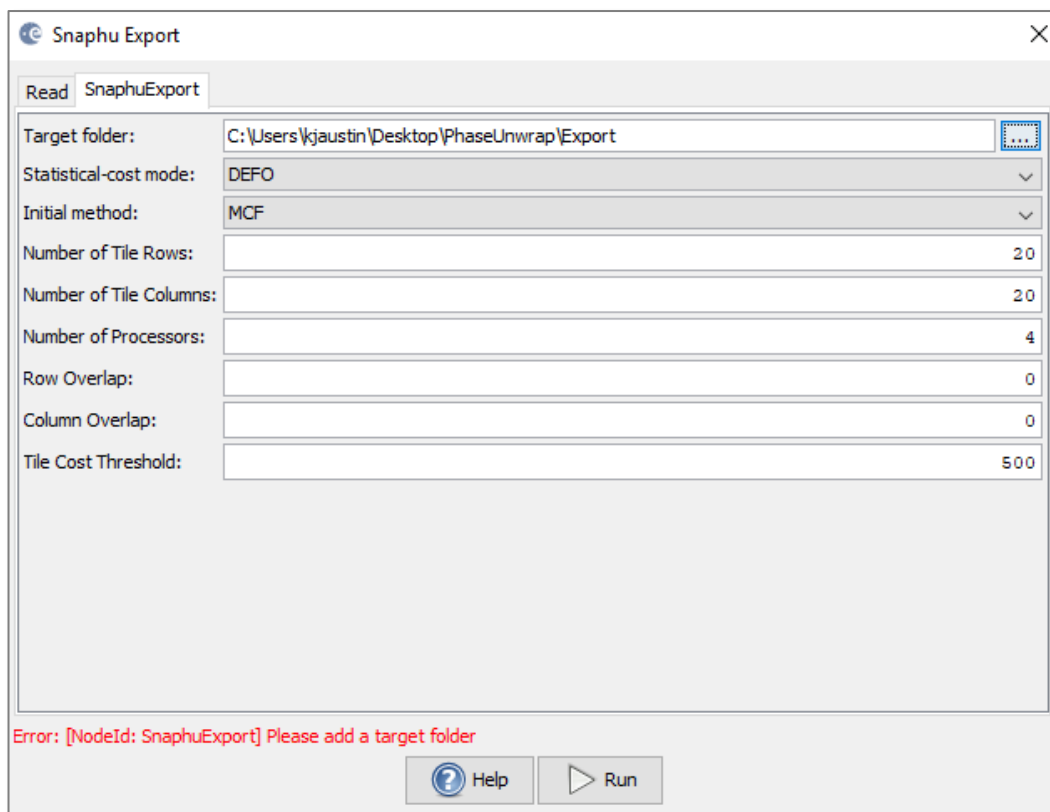
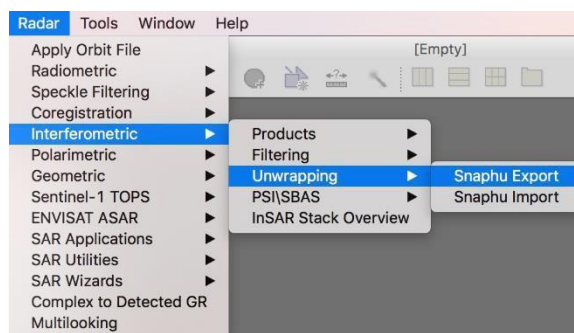


Figure 3: SNAPHU Export Dialog Box.

E) Using a Virtual Machine

If you do not have a Linux OS, you will need to install a Linux Virtual Machine to operate SNAPHU (See Section 0.

You will need to make the SNAPHU Export files generated in the previous section available within your Linux environment.

- Zip the SNAPHU Export files generated on your PC or Mac using S1TBX, and make the zip folder(s) accessible to SNAPHU software in the Linux environment. Approaches include:
 - Place files in Google Drive or Dropbox and download them from within Linux.
 - Email the files to yourself and retrieve them in Linux.
- Extract the SNAPHU Export file to the desired directory in your Linux environment (you may want to create a new folder for your project).

F) Unwrap Interferogram with SNAPHU

SNAPHU is a Statistical-cost, Network-flow Algorithm for Phase Unwrapping developed at Stanford University by Curtis Chen and Howard Zebker.

<https://web.stanford.edu/group/radar/softwareandlinks/sw/snaphu/>

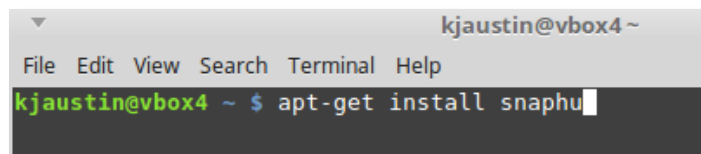
Linux users simply need to open a command line; VM users need to start their Linux VM and open the command line in that environment.

If you have already installed SNAPHU, skip to the [Extract the SNAPHU Command](#) step.

Install SNAPHU

Install the software package by typing the following in the command line followed by the Enter key.

```
apt-get install snaphu
```



If a user is not granted root access (the install snaphu command results in an Access error), use the following command, which will then prompt for the user's password for Linux (or the Linux VM) and allow the user the elevated privileges required for installing the software:

```
sudo apt-get install snaphu
```

Extract the SNAPHU Command from the Configuration File

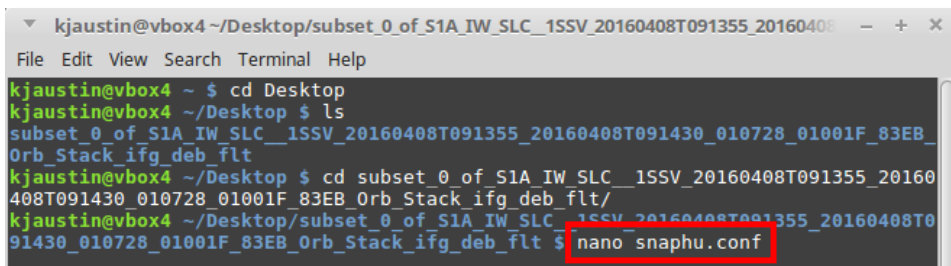
The SNAPHU product exported from S1TBX contains a configuration file with a command to call snaphu. This command can be extracted from the configuration file and pasted into the command line to run the SNAPHU process correctly for your interferogram.

- In the Command Terminal (in the Linux environment), use the **cd** command to move into the directory containing the unzipped SNAPHU Export files from S1TBX; i.e. if you put the product in a folder called SNAPHU:

```
cd ~/SNAPHU/S1A_IW_SLC__1SSV_20160408T091355_20160408T091430_010728_01001F_83EB_Orb_Stack_ifg_deb_mrg_dinsar_MLflt
```

- Use the following command or use a text-only editor of your choice to open the configuration file (snaphu.conf) located inside the export folder:

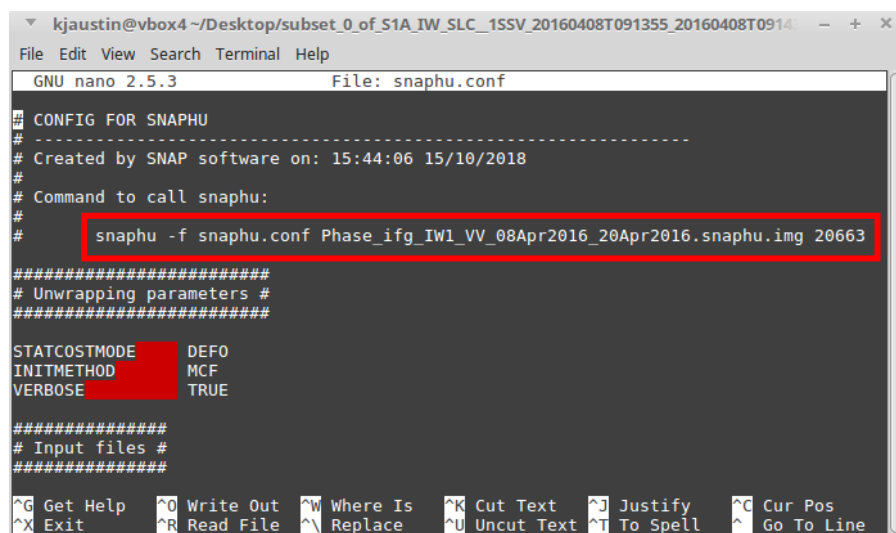
```
nano snaphu.conf
```



```
kjaustin@vbox4 ~/Desktop/subset_0_of_S1A_IW_SLC__1SSV_20160408T091355_20160408T091430_010728_01001F_83EB_Orb_Stack_ifg_deb_mrg_dinsar_MLflt
File Edit View Search Terminal Help
kjaustin@vbox4 ~ $ cd Desktop
kjaustin@vbox4 ~/Desktop $ ls
subset_0_of_S1A_IW_SLC__1SSV_20160408T091355_20160408T091430_010728_01001F_83EB_Orb_Stack_ifg_deb_mrg_dinsar_MLflt
kjaustin@vbox4 ~/Desktop $ cd subset_0_of_S1A_IW_SLC__1SSV_20160408T091355_20160408T091430_010728_01001F_83EB_Orb_Stack_ifg_deb_mrg_dinsar_MLflt/
kjaustin@vbox4 ~/Desktop/subset_0_of_S1A_IW_SLC__1SSV_20160408T091355_20160408T091430_010728_01001F_83EB_Orb_Stack_ifg_deb_mrg_dinsar_MLflt $ nano snaphu.conf
```

Figure 4: Using the Command Terminal to Open the snaphu.conf File.

- Copy the command from the config file
 - You might need to use the right-click option for copying rather than Ctrl-C



```
kjaustin@vbox4 ~/Desktop/subset_0_of_S1A_IW_SLC__1SSV_20160408T091355_20160408T091430_010728_01001F_83EB_Orb_Stack_ifg_deb_mrg_dinsar_MLflt
File Edit View Search Terminal Help
GNU nano 2.5.3 File: snaphu.conf
# CONFIG FOR SNAPHU
# -----
# Created by SNAP software on: 15:44:06 15/10/2018
#
# Command to call snaphu:
#
# snaphu -f snaphu.conf Phase_ifg_IW1_VV_08Apr2016_20Apr2016.snaphu.img 20663
#####
# Unwrapping parameters #
#####
STATCOSTMODE DEFO
INITMETHOD MCF
VERBOSE TRUE
#####
# Input files #
#####
^G Get Help ^O Write Out ^W Where Is ^K Cut Text ^J Justify ^C Cur Pos
^X Exit ^R Read File ^N Replace ^U Uncut Text ^T To Spell ^_ Go To Line
```

Figure 5: Copying the "Command to call snaphu" text from the configuration file.

- The text of interest is in the following format:
`snaphu -f snaphu.conf YOUR_PHASE_BAND.snaphu.img XXXX`
- Exit the config file by typing Ctrl+X

Run the SNAPHU Command

- Paste the copied text into the command line and hit Enter
 - You might need to use the right-click option for pasting rather than Ctrl-V

```

kjaustin@vbox4 ~/Desktop/subset_0_of_S1A_IW_SLC__1SSV_20160408T091355_20160408T091430_010728_01001F_83EB_Orb_Stack_ifg_debflt
File Edit View Search Terminal Help
kjaustin@vbox4 ~ $ cd Desktop
kjaustin@vbox4 ~/Desktop $ ls
subset_0_of_S1A_IW_SLC__1SSV_20160408T091355_20160408T091430_010728_01001F_83EB_Orb_Stack_ifg_debflt
kjaustin@vbox4 ~/Desktop $ cd subset_0_of_S1A_IW_SLC__1SSV_20160408T091355_20160408T091430_010728_01001F_83EB_Orb_Stack_ifg_debflt/
kjaustin@vbox4 ~/Desktop/subset_0_of_S1A_IW_SLC__1SSV_20160408T091355_20160408T091430_010728_01001F_83EB_Orb_Stack_ifg_debflt $ nano snaphu.conf
kjaustin@vbox4 ~/Desktop/subset_0_of_S1A_IW_SLC__1SSV_20160408T091355_20160408T091430_010728_01001F_83EB_Orb_Stack_ifg_debflt $ snaphu -f snaphu.conf Phase_ifg_IW1_VV_08Apr2016_20Apr2016.snaphu.img 20663

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 2509
Unwrapping tile at row 0, column 0 (pid 2510)
Unwrapping tile at row 0, column 1 (pid 2511)
Unwrapping tile at row 0, column 2 (pid 2512)
Unwrapping tile at row 0, column 3 (pid 2513)

```

Figure 6: Running the SNAPHU Command to Unwrap the Interferogram.

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](#)) and try it again. You may also be able to increase the size of your Virtual Machine.

Make Output Files Available to S1TBX Processing Environment

Files are output to the same folder containing the input files (and snaphu.conf), and are prefixed with UnwPhase. There is a header file (.hdr) and an image file (.img).

Zip the UnwPhase hdr and img output files. If using a VM, make the zipped folders accessible to your PC or Mac (Google Drive, Dropbox, email, etc.), and download them to a location accessible by S1TBX. Extract the files from the zipped folder.

- Check the .hdr and .img filenames for a possible mismatch:
 - A bug can result in a mismatch between the filename and the contents of the .hdr and .img files, specifically in the polarization (VV vs. VH).
 - Mismatched filenames and contents will cause processing failures.
 - If this error is present, see the Defect Warning and Work-Around section below.

OPTIONAL: Defect Warning and Work-Around

Work around: 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. Example below:

- **Edit the .hdr filename polarization:**

UnwPhase_ifg_IW1_VH_20Jul2015_01Aug2015.snaphu.hdr

- **To match the polarization in the .img file name:**

UnwPhase_ifg_IW1_VV_20Jul2015_01Aug2015.snaphu.img

- Edited .hdr filename:

UnwPhase_ifg_IW1_VV_20Jul2015_01Aug2015.snaphu.hdr

- **Use a text editor to open the .hdr file and edit the .hdr contents polarization to match the polarization of the .img file**

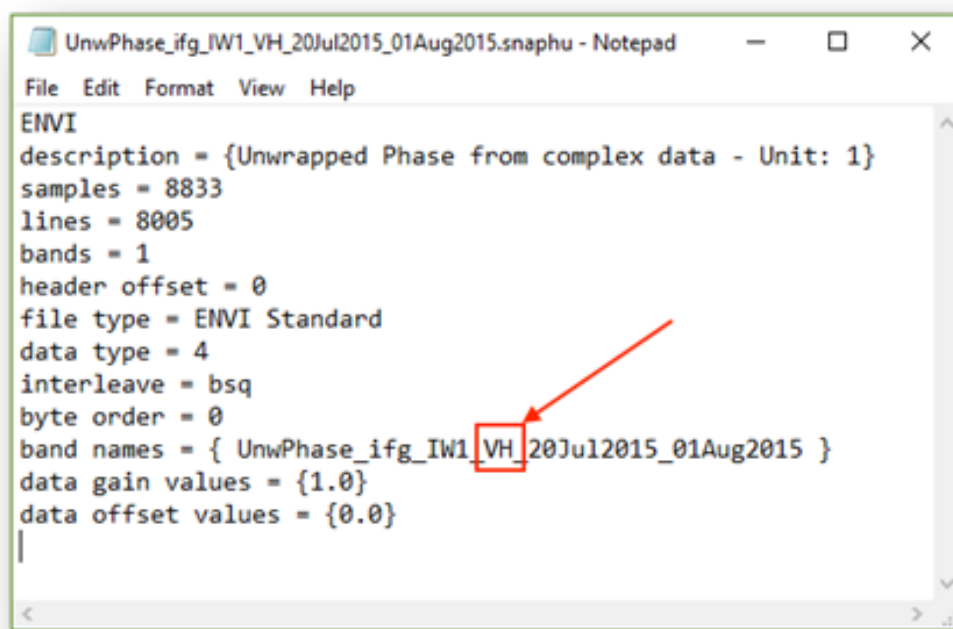


Figure 7: Edit the .hdr file polarization (VH) to match the .img polarization (VV).

G) Post-Unwrapping Steps

This section assumes you have your interferogram from [Section D, Step 3](#) still open in S1TBX. If you do not, open this product in S1TBX before proceeding.

Step 4: SNAPHU Import

- Navigate to *Radar > Interferometric > Unwrapping > Snaphu Import*.
- In the **SNAPHU Import** window (Figure 8):
 - In the **Read Phase** tab, select the interferogram product.
 - In the **Read Unwrapped Phase** tab, navigate to your SNAPHU export folder and select the UnwPhase_XXX.hdr file.
 - Note that the exported products must be extracted if they were transferred in a zip file.
 - If you want to generate an unwrapped product without including any of the other bands from the source interferogram, check the **Do NOT save Wrapped interferogram in the target product option** in the **SNAPHU Import** tab. The default is to keep all the source bands in the output.
 - In the **Write** tab, enter the desired output filename.

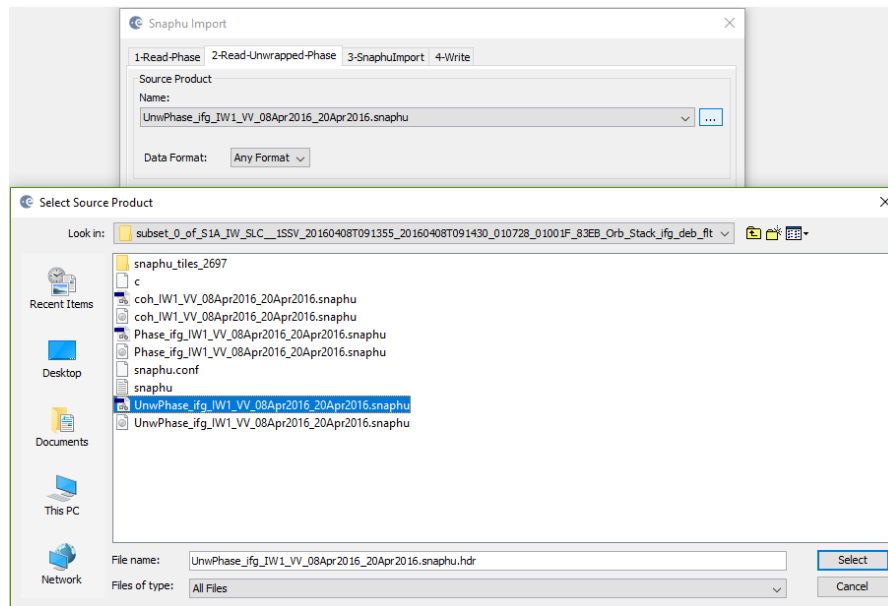
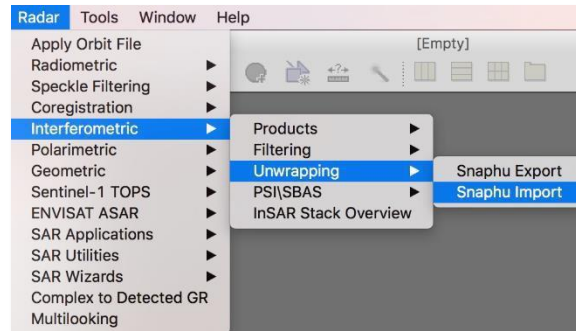


Figure 8: SNAPHU Import - Select Unwrapped Phase Product.

Step 5: Geocoding

At this point, you may view your Unwrapped Phase product (Figure 9), but you will notice that areas of no-elevation incorrectly appear as having data in the Unwrapped Phase image. To fix this, we will terrain correct and geocode the unwrapped data.

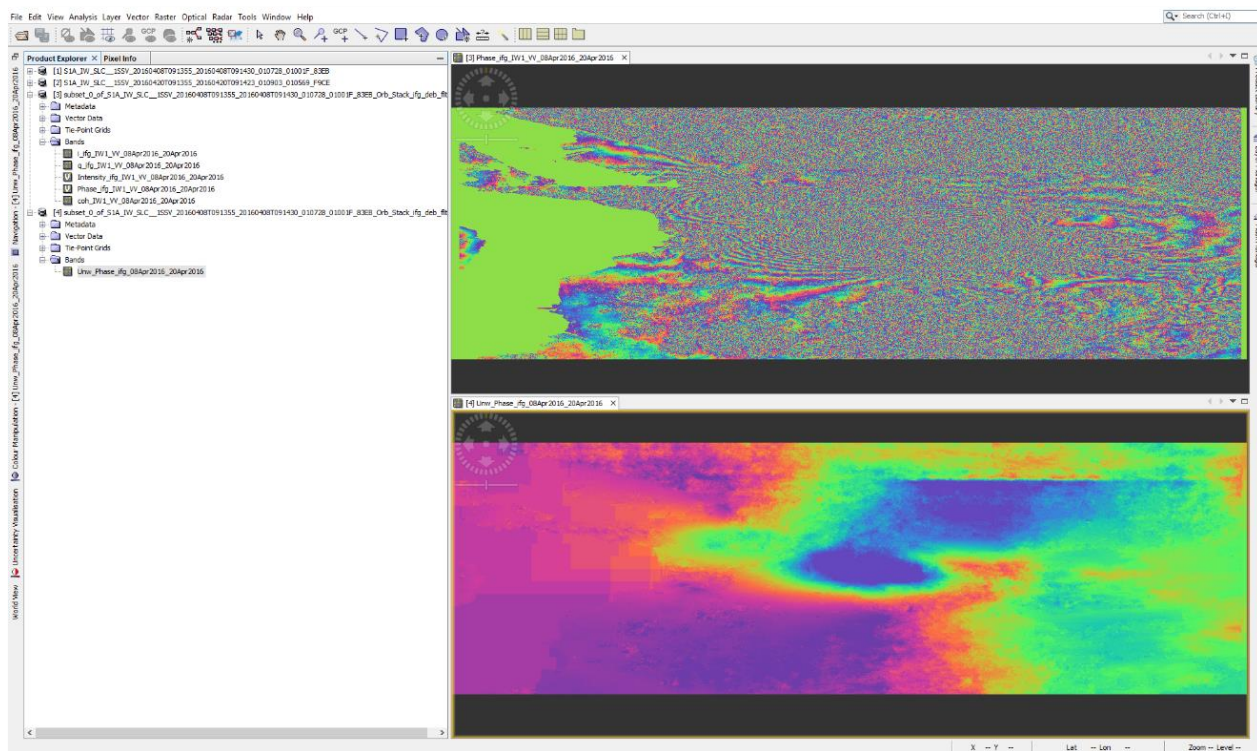


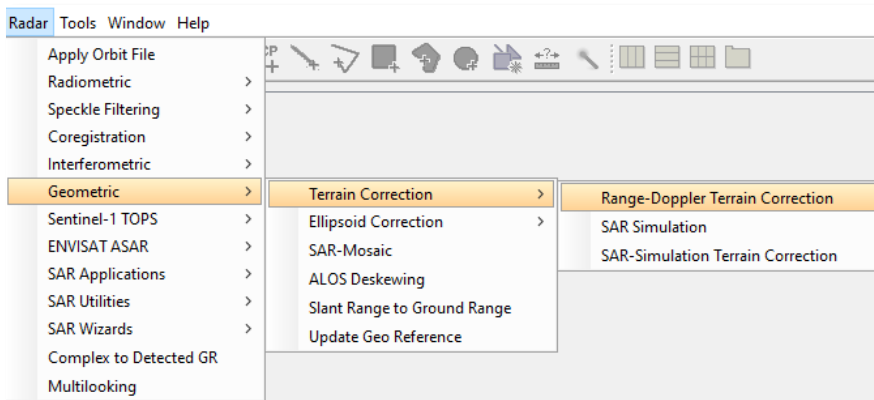
Figure 9: Unwrapped and Wrapped Phase Images.

NOTE:

This step only needs to be performed if the Unwrapped Phase product is your end product. If you will be continuing on to generate a deformation map using ASF's Deformation Recipe, you do not need to geocode your product.

If you choose to geocode your product before continuing with the Deformation Mapping recipe, make sure to use the output from Step 4 as your starting point in the Deformation recipe rather than the Geocoded/Terrain Correct product generated in this step.

- Navigate to *Radar > Geometric > Terrain Correction > Range-Doppler Terrain Correction*



- In the **Range Doppler Terrain Correction** window (Figure 10), select the Unwrapped Phase product you just imported from SNAPHU.

- If you did not check the option to NOT save the wrapped interferogram in the previous step, all of the bands will be present in the list of Source Bands in the Processing Parameters tab. Use Ctrl to highlight the bands you would like to terrain correct.

- In the **Processing Parameters** tab:
 - Select the option to **Mask out areas without elevation**, if desired.
 - Change **Pixel Spacing**, if desired.
 - Leave all other parameters as default settings.
 - Click **<Run>** to geocode your data.

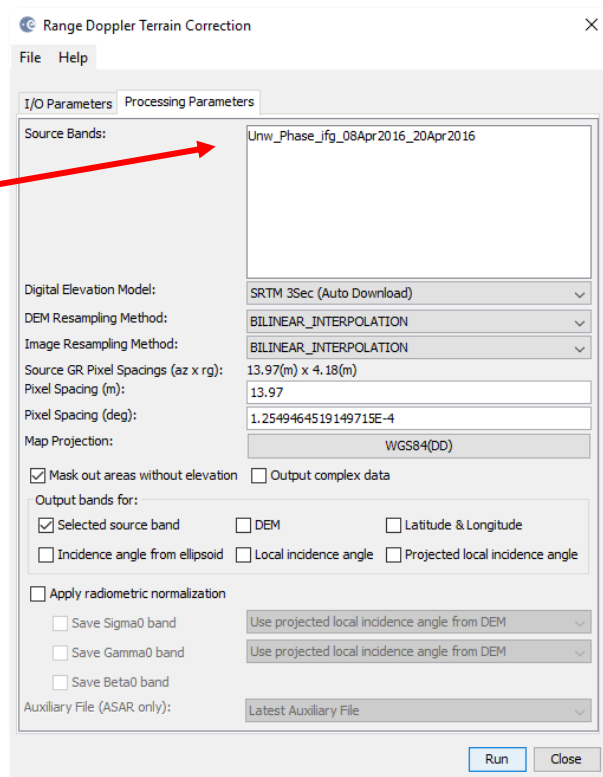


Figure 10: Range Doppler Terrain Correction window.

The resulting product name is appended with _TC. It will include all selected bands. See Figure 11 for the resulting geocoded wrapped and unwrapped interferograms.

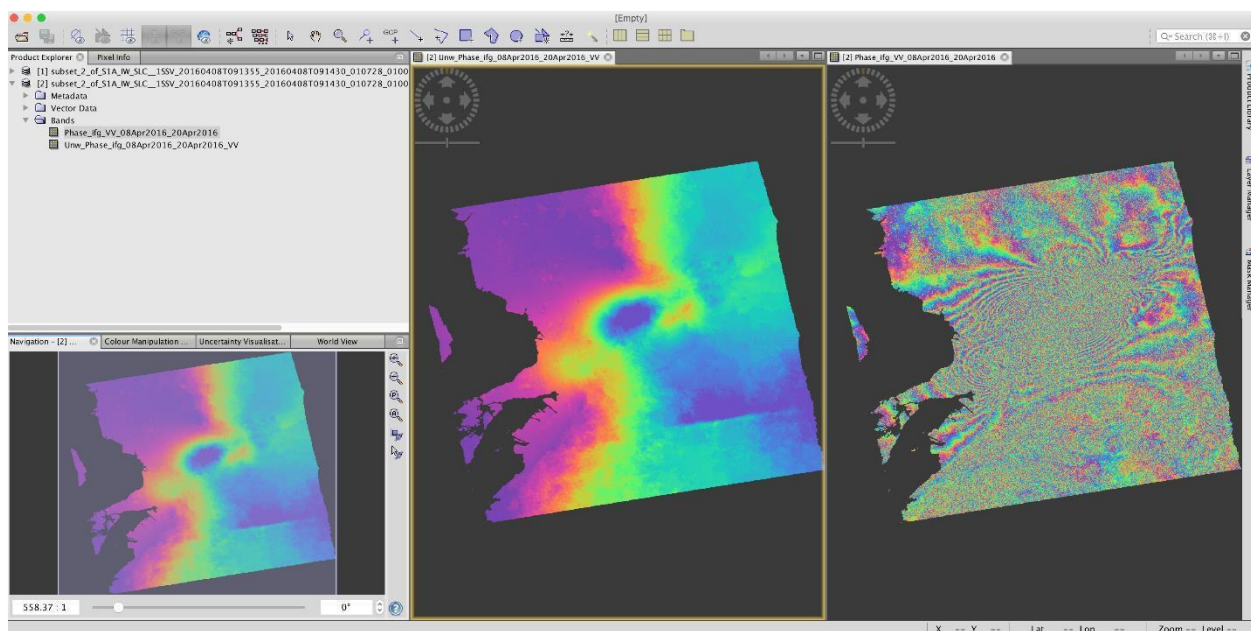


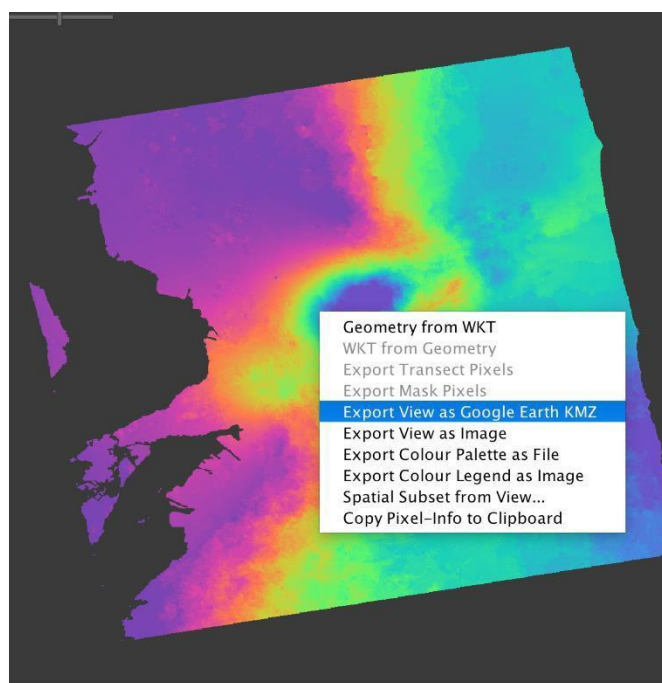
Figure 11: Geocoded Wrapped and Unwrapped Phase.

Step 6: Export Data

The final geocoded data can be exported from S1TBX in a variety of formats.

To export you may either right-click on your product in the product view or navigate to **File > Export**.

In addition to GeoTIFF and HDF5 formats, KMZ and various specialty formats are supported. Figure 12 on the next page shows a KMZ-formatted unwrapped interferogram in Google Earth.



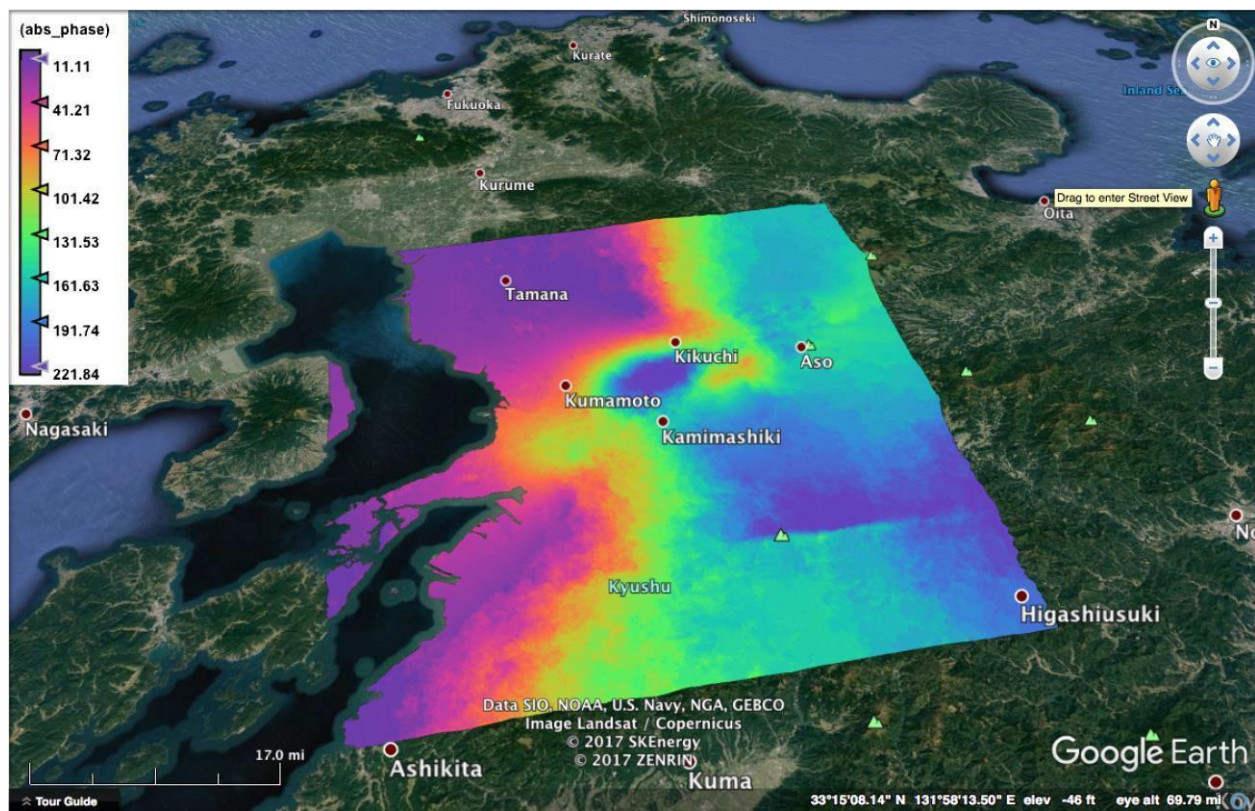


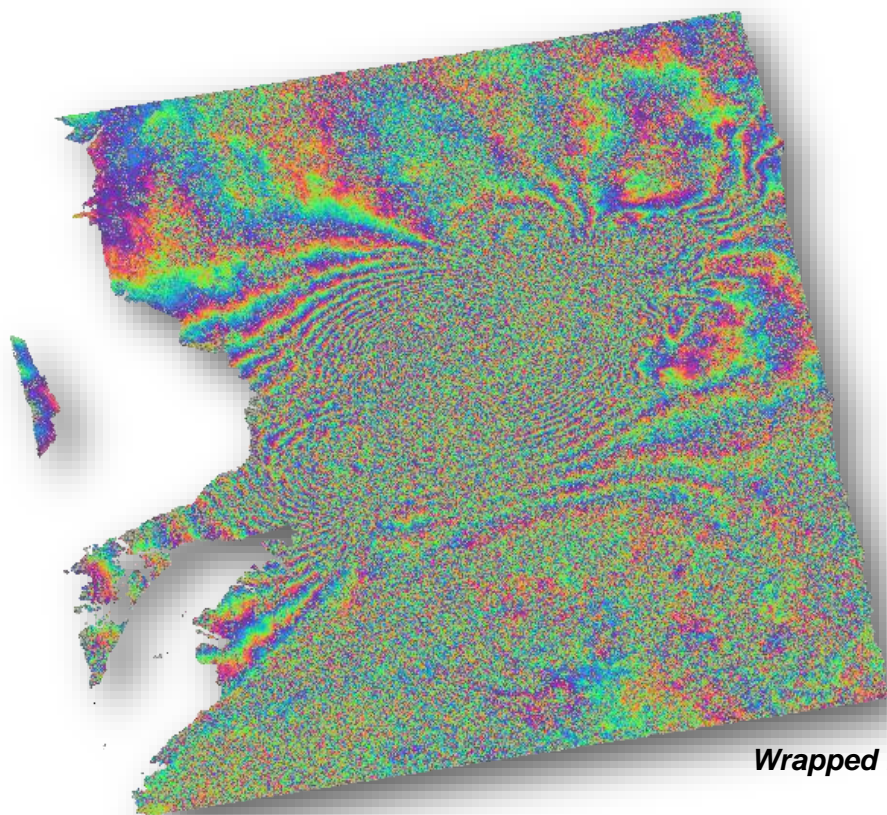
Figure 12: Geocoded Kumamoto Unwrapped Phase Projected onto Google Earth. Contains modified Copernicus Sentinel data (2016) processed by ESA.

Interferogram Interpretation

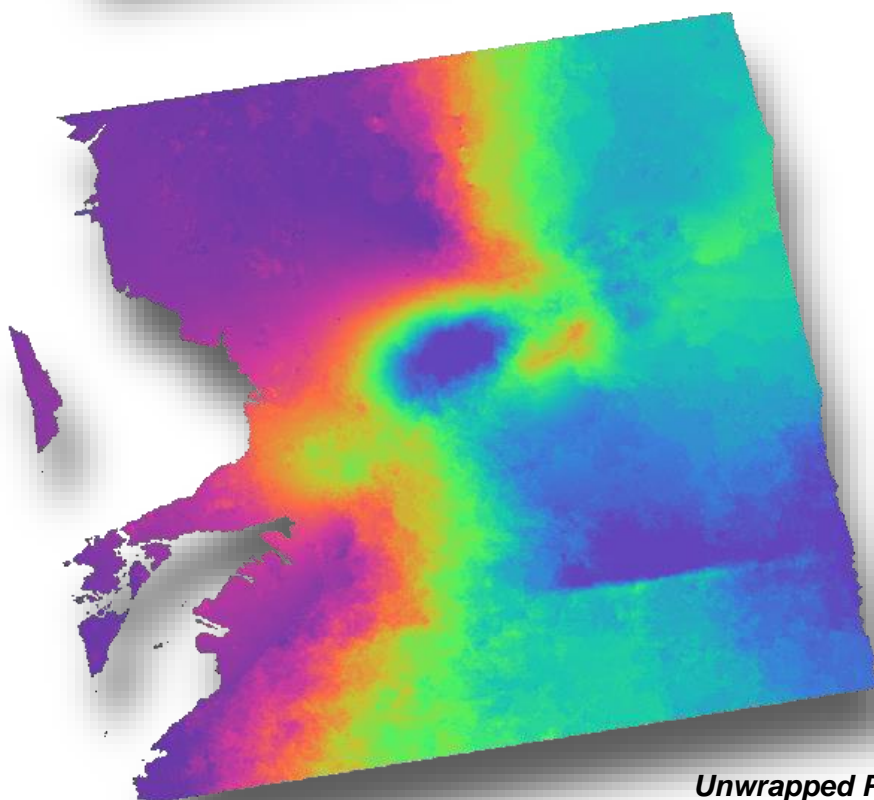
The interferometric phase carries a wealth of information about surface deformation (strength and direction of motion) and the location of the surface rupture. The phase map is also a proxy for other earthquake-related parameters such as the energy released during an event and the amount of shaking experienced across the affected area.

Unwrapped results should be interpreted as a relative height/displacement between two pixels. To obtain absolute estimates, a tie point can be used in the unwrapped phase to height operation.

H) Sample Images



Wrapped Phase



Unwrapped Phase

11 July 2019 v.8.1 | 16

I) Extended Reading List

- Akerson, J. J., Yang, Y. C. E., Hara, Y., Wu, B. I. and Kong, J. A., 2000. Automatic phase unwrapping algorithms in Synthetic Aperture Radar (SAR) Interferometry. *IEEE Transactions on Electronics*, **E83C** (12):1896-1904.
- Chen, C. W. and Zebker, H. A., 2001. Two-dimensional phase unwrapping with use of statistical models for cost functions in nonlinear optimization. *Journal of the Optical Society of America A-Optics Image Science and Vision*, **18** (2):338-351.
- Chen, C. W. and Zebker, H. A., 2002. Phase unwrapping for large SAR interferograms: Statistical segmentation and generalized network models. *IEEE Transactions on Geoscience and Remote Sensing*, **40** (8):1709-1719.
- Costantini, M., Farina, A. and Zirilli, F., 1999. A fast phase unwrapping algorithm for SAR interferometry. *IEEE Transactions on Geoscience and Remote Sensing*, **37** (1):452-460.
- Davidson, G. W. and Bamler, R., 1999. Multiresolution phase unwrapping for SAR interferometry. *IEEE Transactions on Geoscience and Remote Sensing*, **37** (1):163-174.
- Egidi, N. and Maponi, P., 2004. A comparative study of two fast phase unwrapping algorithms. *Applied Mathematics and Computation*, **148** (3):599-629.
- Flynn, T. J., 1997. Two-dimensional phase unwrapping with minimum weighted discontinuity. *Journal of the Optical Society of America A-Optics Image Science and Vision*, **14** (10):2692-2701.
- Fornaro, G., Franceschetti, G., Lanari, R., Sansosti, E. and Tesauro, M., 1997. Global and local phase-unwrapping techniques: a comparison. *Journal of the Optical Society of America A-Optics Image Science and Vision*, **14** (10):2702-2708.
- Fu, S. H., Long, X. J. and Yang, X., 2010. Coherence estimation method and its application to phase unwrapping. *Journal of Applied Remote Sensing*, **4** (5).
- Gang, Li, Jia, Xu, Ying-Ning, Peng and Xiang-Gen, Xia, 2007. An efficient implementation of a robust phase-unwrapping algorithm. *IEEE Signal Processing Letters*, **14** (6):393-6.
- Gens, R., 2003. Two-dimensional phase unwrapping for radar interferometry: developments and new challenges. *International Journal of Remote Sensing*, **24** (4):703-710.

- Ghiglia, Dennis C. and Pritt, Mark D., 1998. Two-dimensional phase unwrapping: theory, algorithms, and software. *International Journal of Remote Sensing*, **24** (4):xiv, 493 p..
- Ghiglia, D. C. and Romero, L. A., 1994. Robust 2-Dimensional Weighted And Unweighted Phase Unwrapping That Uses Fast Transforms And Iterative Methods. *Journal of the Optical Society of America A-Optics Image Science and Vision*, **11** (1):107-117.
- Ghiglia, D. C. and Romero, L. A., 1996. Minimum L(p)-norm two-dimensional phase unwrapping. *Journal of the Optical Society of America A-Optics Image Science and Vision*, **13** (10):1999-2013.
- Goldstein, R. M. and Werner, C. L., 1998. Radar interferogram filtering for geophysical applications. *Geophysical Research Letters*, **25** (21):4035-4038.
- Goldstein, R. M., Zebker, H. A. and Werner, C. L., 1988. Satellite Radar Interferometry - Two-Dimensional Phase Unwrapping. *Radio Science*, **23** (4):713-720.
- Guarnieri, A. M., 2003. Using topography statistics to help phase unwrapping. *IEEE Proceedings-Radar Sonar and Navigation*, **150** (3):144-151.
- Hooper, A. and Zebker, H. A., 2007. Phase unwrapping in three dimensions with application to InSAR time series. *Journal of the Optical Society of America A-Optics Image Science and Vision*, **24** (26):2737-2747.
- Li, Z. F., Bao, Z. and Suo, Z. Y., 2007. A joint image coregistration, phase noise suppression, and phase unwrapping method based on subspace projection for multibaseline InSAR systems. *IEEE Transactions on Geoscience and Remote Sensing*, **45** (3):584-591.
- Lin, Q., Vesecky, J. F. and Zebker, H. A., 1992. New Approaches in Interferometric SAR Data Processing. *IEEE Transactions on Geoscience and Remote Sensing*, **30** (3):560-567.
- Lin, Q., Vesecky, J. F. and Zebker, H. A., 1994. Phase Unwrapping Through Fringe-Line Detection in Synthetic-Aperture Radar Interferometry. *Applied Optics*, **33** (2):201-208.
- Lyuboshenko, I. V., Maitre, H. and Maruani, A., 2002. Least-mean-squares phase unwrapping by use of an incomplete set of residue branch cuts. *Applied Optics*, **41** (11):2129-2148.
- Nico, G., Palubinskas, G. and Datcu, M., 2000. Bayesian approaches to phase unwrapping: Theoretical study. *IEEE Transactions on Signal Processing*, **48** (9):2545-2556.

- Sandwell, D. T. and Price, E. J., 1998. Phase gradient approach to stacking interferograms. *Journal of Geophysical Research-Solid Earth*, **103** (B12):30183-30204.
- Shanker, A. P. and Zebker, H., 2010. Edgelist phase unwrapping algorithm for time series InSAR analysis. *Journal of the Optical Society of America A-Optics Image Science and Vision*, **27** (3):605-612.
- Shanker, A. P. and Zebker, H. A., 2009. Sparse Two-Dimensional Phase Unwrapping Using Regular Grid Methods. *IEEE Geoscience and Remote Sensing Letters*, **6** (3):519-522.
- Spagnolini, U., 1993. 2-D Phase Unwrapping and Phase Aliasing. *Geophysics*, **58** (9):1324-1334.
- Wei, Z. Q., Xu, F. and Jin, Y. Q., 2008. Phase unwrapping for SAR interferometry based on an ant colony optimization algorithm. *International Journal of Remote Sensing*, **29** (3):711-725.
- Yang, Lei, Liu, Wei and Zhao, Yong-jun, 2007. Branch - cut strategy analyses in phase unwrapping algorithm for interferometric SAR. *Science of Surveying and Mapping*, **37** (1):75-7.
- Zakharova, L. N. and Zakharov, A. I., 2003. Comparison of some modern phase unwrapping methods in radar interferometry. *Journal of Communications Technology and Electronics*, **48** (10):1108-1112.