

APPENDIX A

SAR Image Processing Routines

– Chapter 2 Training Module

1 GEOCODING AND RTC PROCESSING USING ASF MAPREADY

Many of the SAR data holdings in the global archives are available as so-called ground-range projected products. While these products are typically georeferenced, they usually use an ellipsoid as reference surface. Hence, geometric distortions such as foreshortening are not corrected in these products and geolocation errors occur at points that don't lie at the height of the applied reference surface.

This lab is for users who wish to geocode and generate an RTC image from ERS-2 data using MapReady. MapReady is a free software tool distributed by ASF that can be used to correct geometric distortions from SAR data and generate fully geocoded GeoTIFF products ready for use in GIS analyses. In this part of the lab, we will demonstrate the MapReady tool and use it to geocode a ERS-2 scene over Fairbanks, AK.

1.1 Starting and Exploring MapReady

MapReady is a free-and-open software tool provided by the Alaska Satellite Facility that provides some basic SAR data processing capabilities such as reading of SAR data formats, reprojection and geocoding, as well as some polarimetric data manipulations. MapReady can be downloaded from <https://www.asf.alaska.edu/data-tools/mapready/>. Installation instructions are provided in the same location. For further information about MapReady functionality, please consult the MapReady user manual (http://media.asf.alaska.edu/asfmainsite/documents/mapready_manual_3.1.22.pdf).

To start MapReady, type `mapready` in your command window. You should see the MapReady interface load (Figure 1.1).

1.2 Geocoding a ERS-2 SAR Scene over Fairbanks, AK Using MapReady

ERS-2, a C-band ($\lambda=5.66\text{cm}$) SAR operated by the European Space Agency from 1995 to 2011, has

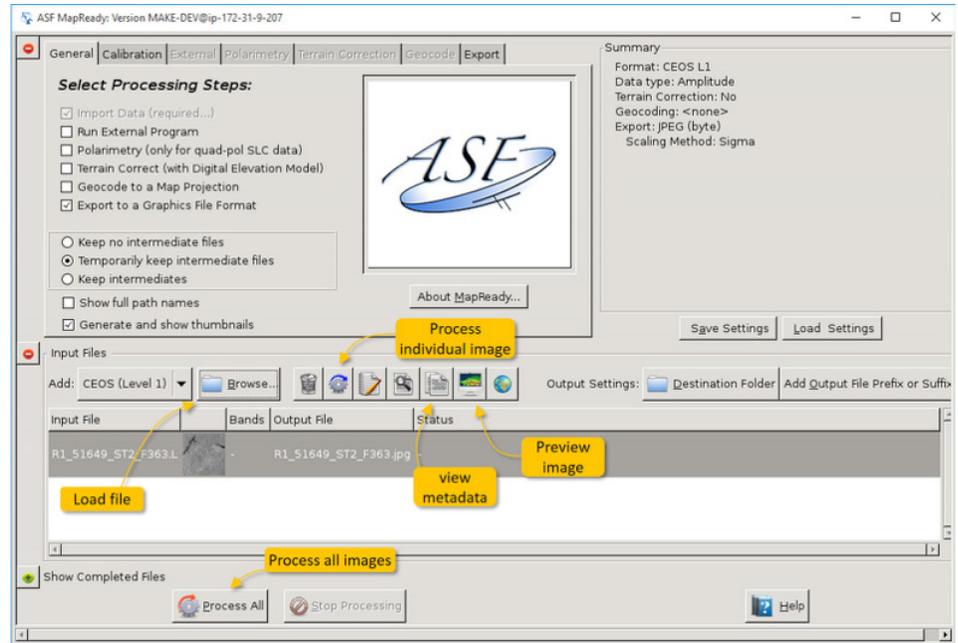


Figure 1.1 The ASF MapReady user interface

provided a wealth of Earth observation data, much of which can be accessed through the services of ASF. While the depth of the archive provides a large potential value for a range of user communities, the images of the ERS-2 archive are currently not yet available in fully geocoded formats. Hence, being able to geocode ERS-2 images will help unlock this sensor's vast potential in environmental analysis.

The data to be geocoded is ERS-2 granule E2_80464_STD_F163, which was acquired on September 10 of 2010 over the area of Fairbanks, AK.

1.3 Load the Image into MapReady and visualize the content of the Data Set

Here some instructions for loading and exploring the image:

- To load the image, click the Browse button in the Input Files section of the interface. Pick the E2_80464_STD_F163.D file within the E2_80464_STD_F163 folder and click Open.

To visualize the image, click on the icon labeled with "Preview image" as shown in Figure 1.2. A viewer will open, displaying the image as well as metadata information. Scroll around the image. Zoom in to evaluate image noise and structure. Also investigate metadata information on the left side of the viewer interface.

1.4 Geocode and Terrain Correct the Image using MapReady

Apply the following settings to geocode and terrain correct your data:

In the "General" Tab:

- To terrain correct and geocode the image, activate the Terrain Correct and Geocode to a Map Projection radio buttons in the top element of the interface. The Terrain Correction and Geocode tabs become active.

To separate input data from your processing results, change the Destination Folder settings in the Input Files section of the interface. I recommend the following folder as your destination folder: `/home/ubuntu/SARLabs/SARFocusin-gAndGeocoding/Results`

Navigate to the "Calibration" tab:

This tab allows the chosen calibration procedure to be applied to the data.

- Typically, scientists prefer data in a projection, which allows relating the brightness in an image pixel to physical quantities. Hence, I suggest picking Sigma as Radiometric projection.

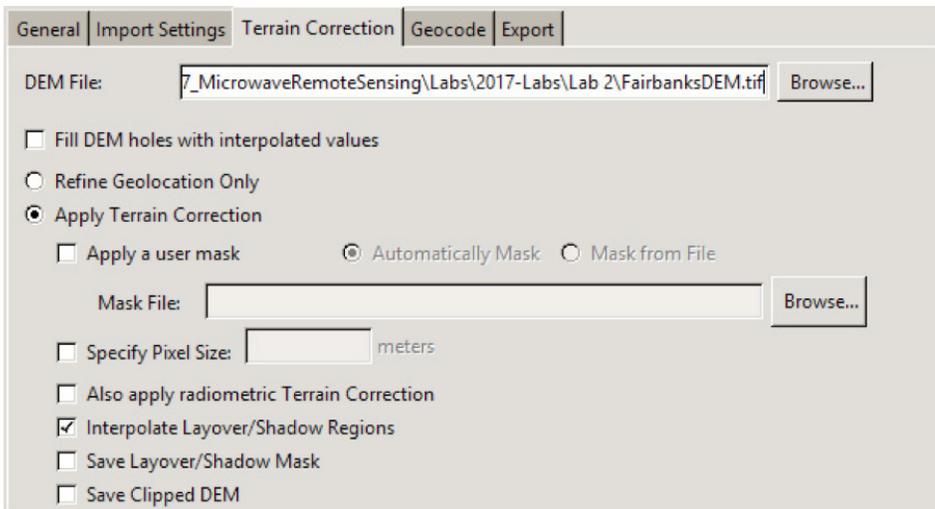


Figure 1.2 The ASF MapReady “Terrain Correction” Tab

- You can also choose whether to output your image in amplitude or decibel (dB) format. As radar data have enormous dynamic range, converting the pixel values to a dB scale is often recommended.

Navigate to the “Terrain Correction” tab:

Please create two geocoded datasets here: (1) a dataset where only geometric terrain correction was applied; and (2) an image where both geometric and radiometric terrain correction was done.

Initially, create the geometrically corrected (GTC) image:

- To Pick a DEM file for terrain correction, click on Browse and pick the file E2_80464_STD_F163_dem.tif in the Data directory.
- Explore the various options in the geocoding tab. We will discuss those options.

Ensure that the Apply Terrain Correction feature is activated (see Figure 1.2).

In a second run (after you complete the rest of the instructions), create the RTC image by:

- Selecting Also apply radiometric Terrain Correction in addition to the previous settings
- Click on Add Output File Prefix or Suffix in the “Input Files” section and add suffix “_RTC”.

Navigate to the “Geocode” tab:

In this tab, you can change geocoding parameters such as the desired projection, the pixel size, and the inter-

polation method. In our case, we will simply accept the default (UTM projection; in default mode, the pixel size is set to half the original image sampling distance).

Navigate to the “Export” tab:

This tab allows you to set output formats. Please set the Export format to GeoTIFF and activate the Output data in byte format radio button (see Figure 1.3).

Once all of these parameters are set, click on either the Process Individual Image icon (Figure 1.1) or the Process All button to start the geocoding and terrain correction process. You can monitor the progress of the procedure in your command window.

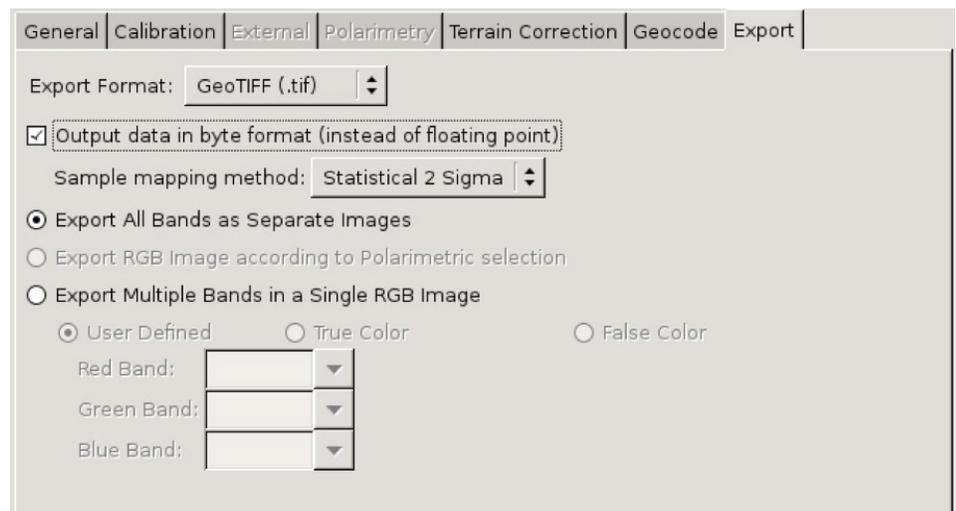


Figure 1.3 The ASF MapReady “Export” Tab

1.5 Visualize Geocoded Image in QGIS

Once the geocoding process has completed, you can visualize the product both within and outside of the MapReady tool. To compare the result with map information, we will open the file in QGIS. To do so, run the following command:

```
Qgis /home/ubuntu/SARLabs/SARFocusingAndGeocoding/Results/E2_80464_STD_F163.tif
```

2 GEOCODING AND RTC PROCESSING USING SNAP

This lab is for users who wish to generate an RTC image from Sentinel-1 data using easy-to-follow instructions in a graphical user interface (GUI). Specifically, we will use ESA’s Sentinel Application Platform (SNAP) to perform geocoding and RTC processing on Sentinel-1 images over Kathmandu, Nepal. The advantages of the SNAP tool include (1) its graphical user interface, which renders the SNAP tool straightforward to use (compared to other InSAR processing tools); (2) the easy-to-access, free-of-charge, and public domain nature of the SNAP tool; and (3) the fact that SNAP is an integrative multi-sensor toolbox and enables processing data from all Sentinel sensors within one joint processing platform. To install SNAP on your own workstation, please visit <http://step.esa.int/main/download/> for download instructions.

2.1 Sentinel-1 SAR Data Sets Used in this Exercise

The data for this exercise are two Sentinel-1 acquisitions bracketing the devastating 2015 Gorkha earthquake in Nepal, which killed nearly 9,000 people and injured nearly 22,000. It occurred at 11:56 Nepal Standard Time on 25 April, with a magnitude of 8.1Ms and a maximum Mercalli Intensity of VIII (Severe). Its epicenter was east of Gorkha District at Barpak, Gorkha, and its hypocenter was at a depth of approximately 8.2 km (5.1 mi). It was the worst natural disaster to strike Nepal since the 1934 Nepal–Bihar earthquake.

The following data sets, called Ground Range Detected (GRD) images, will be used for this exercise:

- Pre-event image acquired on April 17, 2015: S1A_IW_GRDH_1SSV_20150417T001852_20150417T001921_005516_0070C1_17AA
- Post-event image acquired on April 29, 2015: S1A_IW_GRDH_1SDV_20150429T001909_20150429T001934_005691_0074DC_B016

Please download these Sentinel-1 SAR images using ASF's Vertex search engine (<http://vertex.daac.asf.alaska.edu>).

2.2 Geocoding and RTC Processing Steps in SNAP

Start SNAP by clicking on the associated desktop icon or by typing in **snap** in your command window.

2.2.1 Open a SAR image in SNAP

In order to perform geocoding and RTC processing in SNAP, the input products should be one or more GRD or SLC products over your area of interest. While both data types can be processed to RTC images, we are using GRD images in this lab due to their smaller size.

Step 1 - open the products:

Use the Open Product button in the top toolbar of the SNAP interface and browse for the location of the Sentinel-1 GRD products (Figure 1.4).

Select the *.zip file containing the post-event image (dated 20150429) and click Open. Press and hold the Ctrl button on the keyboard should you want to select multiple products at a time.

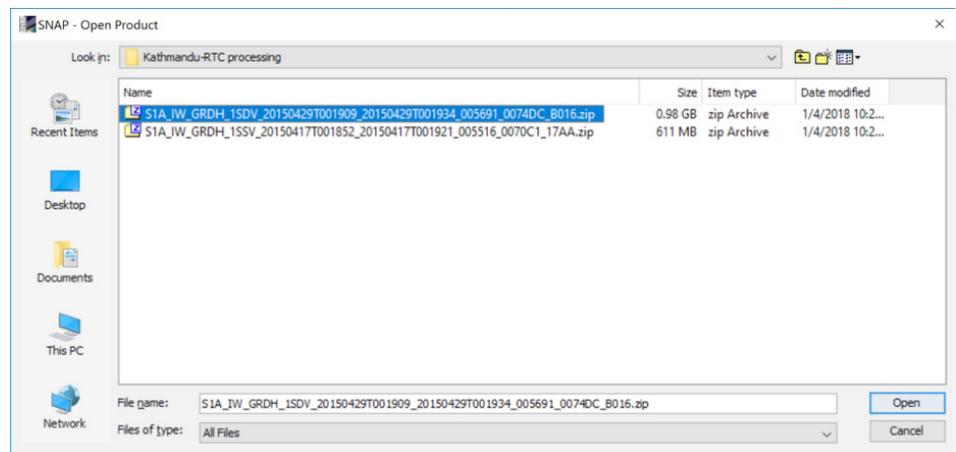


Figure 1.4 Open Product dialog in SNAP.

Step 2 - view the product:

In the Product Explorer (Figure 1.5) you will see the opened products. For GRD data, the product band folder will contain two to four layers, depending on whether the data set was acquired in single- or dual-pol (an amplitude and intensity image is provided per polarization). For SLC data, you will find two bands per polarization containing the real (i) and imaginary (q) parts of the complex data.

Note that in Sentinel-1 IW SLC products, you will find three subswaths labeled IW1, IW2, and IW3. Each subswath is for an adjacent acquisition collected by Sentinel-1's TOPS mode. For more information on this mode and on the meaning of the subswath data, please refer to the lab on Interferometric SAR processing in Section 3.

Step 3 - view a band:

To view the data, double-click on either the amplitude or intensity band for one of the polarizations (e.g., Intensity_VV). The image will appear on the right side of

the interface. Zoom in using the mouse wheel and pan by clicking and dragging the left mouse button.

2.2.2 Apply Precise Orbit File

This is an optional step that will maximize the geolocation quality that can be achieved during geocoding. Precise orbit files are issued by the European Space Agency within weeks after the acquisition of a data set. These orbits are not annotated in the image data directly but are rather provided as a separate file. SNAP is able to locate, download, and apply these precise orbit files automatically via the following step:

Step 4 – apply orbit file:

To apply precise orbits select Apply Orbit File in the Radar menu of SNAP. A new window will appear (Figure 1.6) providing some processing options. Note that the default settings for processing options should work for most applications.

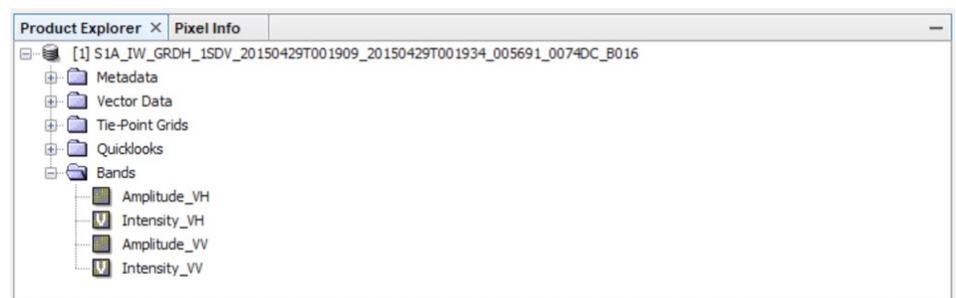


Figure 1.5 Product Explorer tab within the SNAP user interface.

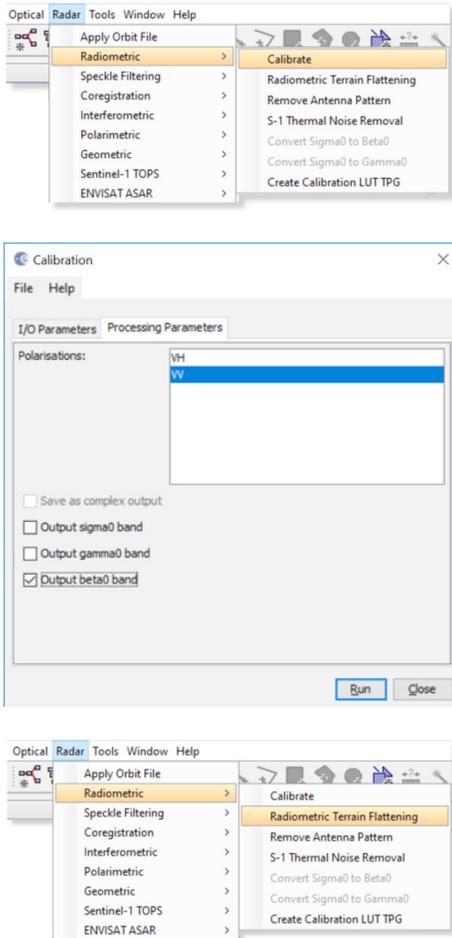


Figure 1.6 Calibration interface with relevant options selected.

The only exception to this general rule pertains to the I/OParameters tab where the output directory for the Target Products can be changed from the default to a desired storage location. Click Run to initiate the automatic download and application of files. A window will pop up showing the progress of the processing. Depending on the computing power of your machine, expect one to several minutes of processing time. Once processing is complete, the output from the previous step will appear in the Product Explorer window of the interface (filename ending in “_Orb”). Single click the file name to select it for the next processing step.

2.2.3 Apply Radiometric Calibration

Step 5 - calibration:

To correctly apply RTC corrections to the data, the image information needs to be calibrated following the β^0 definition. To calibrate to β^0 , select the Radiometric

> Calibrate option within SNAP’s Radar menu. In the box that appears, radiometrically calibrate the image to β^0 by going into the Processing Parameters tab and selecting the Output beta0 band option (Figure 1.6). If dual-pol data are available, you have the choice of processing both polarizations or selecting a subset of polarizations by clicking on the desired channels. Click Run to initiate processing. The defaults place the output into the same directory as the input.

2.2.4 Apply Radiometric Terrain Flattening (RTC Processing)

RTC processing is referred to as “Radiometric Terrain Flattening” in the SNAP tool. This step will remove most of the radiometric distortions from the data that are introduced by surface topography.

Step 6 – RTC processing:

To apply RTC processing, first select the output of the previous processing step (extension “_Orb_Cal”) in the Product Explorer window. Then, select Radiometric > Radiometric Terrain Flattening from SNAP’s Radar menu (see below). The default settings download a digital elevation model (DEM) matching the geolocation of the scene being corrected, placing the output file into the same directory as the input. Most applications will not require a modification of the default settings. Click Run (~45 minutes or longer, depending on system capability).

Note that an internet connection is necessary for this step as the DEMs necessary for processing are downloaded from an online repository.

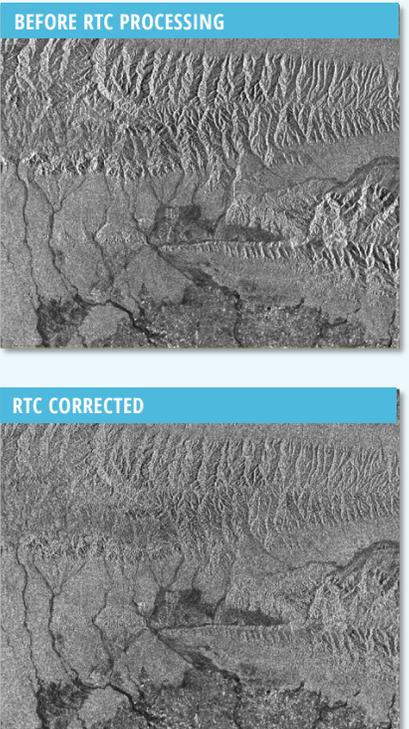
Potential necessary intermediary step – Multilooking:

Depending on the resolution of the DEM that can be found for your area of interest, the SAR data may have to be multilooked (reduced in resolution) before processing. If the DEM is of lower resolution than the SAR data, SNAP will enforce multilooking to the resolution of the DEM before RTC processing can be applied. To multilook your imagery, select the data set ending in “_Orb_Cal” in the Product Explorer window and then select Multilooking from SNAP’s Radar menu (found on the very bottom of the menu). In the emerging window, select the desired number of looks within the Processing Parameters tab and click Run. Once complete, use the output from this step (file ending in “_Orb_Cal_ML”) as the input for Step 6 – RTC Processing.

Small Data Analysis Exercise

It may be instructional to compare the SAR image data before and after RTC processing. Such a comparison will provide you with information both on the benefits and limitations of RTC correction for your area of interest.

To conduct a comparison, open both the image before (extension “_Orb_Cal_ML”) and after (extension “_Orb_Cal_ML_TF”) RTC correction in the SNAP viewer by double-clicking the image bands in the respective data sets. Click on the  symbol to synchronize views across multiple image windows and zoom into an area of interest (preferably an area with significant topography). Then toggle between images and compare content. You should see that most of the topographic shading was removed by the RTC processing step. Residual topography is mostly due to limitations in the resolution of the DEM and the small incidence angle dependence of $\sigma^0(\theta)$. An example of the performance of RTC correction is shown below. A significant (albeit not perfect) reduction of topographic shading was achieved.



2.2.5 Geocode the RTC-Corrected Data

Step 7 – Geocoding:

Unfortunately, the nomenclature that is used in SNAP for the geocoding step is a bit opaque. You will have to pick Geometric > Terrain Correction > Range-Doppler Terrain Correction from the Radar menu to apply the geocoding procedure (**Figure 1.7**). Select the output of the RTC processing step (file ending in “_Orb_Cal_ML_TF”) as input for the geocoding procedure.

The processing box pops up, and the defaults for the I/O Parameters tab place the output files in the same directory as the source file. The Processing Parameters tab enables you to specify the map projection you need, pixel spacing if you wish to change it, and options for additional output files.

For the sake of this exercise, it is recommended to use the default options for output files but select “UTM / WGS 84” as your output map projection. Click Run after your settings are applied.

2.2.6 Visualizing Processing Results

The products of this processing flow can be visualized easily both within SNAP and within a GIS system of your choosing (e.g., ArcGIS or QGIS).

To view within SNAP, double click the generated file (ending in “Orb_Cal_TF_TC”) in the Product Explorer window and explore within the SNAP interface.

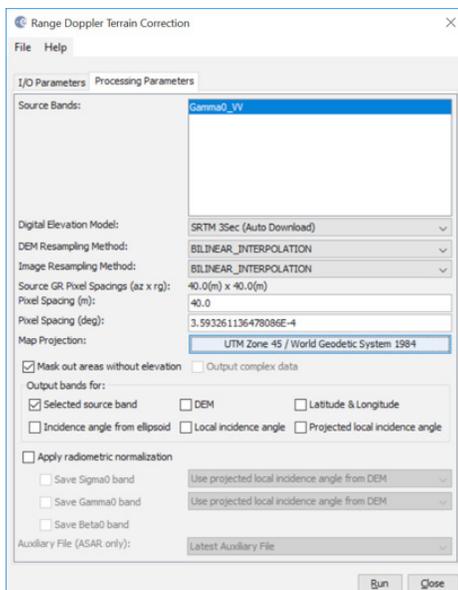


Figure 1.7 Geocoding interface in SNAP with relevant processing settings applied.

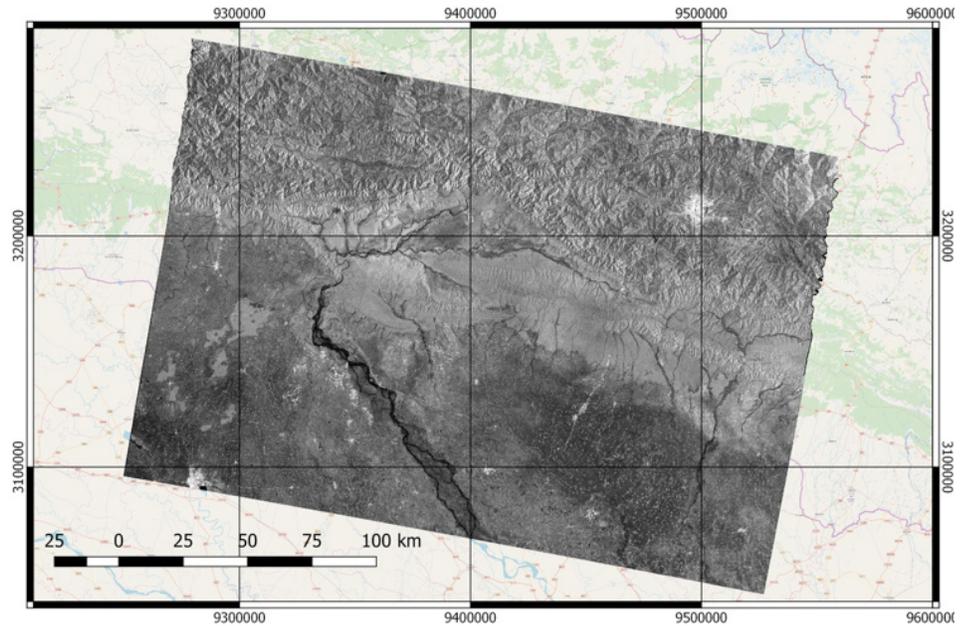


Figure 1.8 Geocoded and RTC corrected Sentinel-1 SAR image over Kathmandu, Nepal.

To view your RTC image within a GIS, follow these steps: (1) open ArcGIS or QGIS; (2) Select Add Data (ArcGIS) or Add Raster Layer (QGIS); (3) Navigate to the directory that contains the output from Step 7; (4) Within this folder, click on the sub-folder ending in “_TC.data”; (5) Load the .img file(s) contained within.

Figure 1.8 shows the geocoded and RTC corrected image in QGIS.

2.2.7 Visualizing Processing Results

A summary of the geocoding and RTC processing steps is provided in **Figure 1.9**. The following links may be useful in case you want to dive deeper into the topic of geocoding and RTC processing:

a) To learn a bit more about the theory behind geocoding and RTC processing, please visit Lecture 9 of UAF’s [Online Class on Microwave Remote Sensing](#). You can find Lecture 9 in Class Module 2 “[Imaging Radar Systems](#)”. To go directly to the slide deck, [click here](#).

b) To learn how to Radiometrically Terrain Correct (RTC) Sentinel-1 Data Using SNAP Scripting Languages, please visit ASF’s [SAR data recipe](#) on this topic.

c) For instructions on how to do geocoding and RTC processing using the GAMMA RS software, [please go here](#).

d) For instructions on how to geocode (no RTC) Sentinel-1 data using GDAL, [go here](#).

e) For information on how to effectively view RTC data in a GIS Environment, [go here](#).

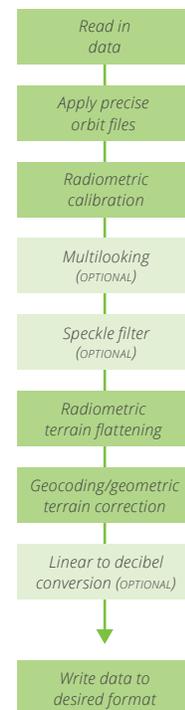


Figure 1.9 General workflow of geocoding and RTC processing.

Small Data Analysis Exercise

As an additional exercise, geocode and RTC process the second data set (pre-earthquake image). After both data sets are available in geocoded and RTC corrected form, visually compare the images and see if you can identify changes in Kathmandu that might indicate earthquake damage.

Pre-event image acquired on April 17, 2015:

- S1A_IW_GRDH_1SSV_20150417T001852_20150417T001921_005516_0070C1_17AA

Post-event image acquired on April 29, 2015:

- S1A_IW_GRDH_1SDV_20150429T001909_20150429T001934_005691_0074DC_B016

3 INSAR PROCESSING USING SNAP

3.1 Introduction

In this lab, we will analyze a pair of Sentinel-1 images that bracket the devastating 2015 Gorkha earthquake near Kathmandu, Nepal, whose 7.8 magnitude main shock on April 25 together with several aftershocks (6.9M on April 26; 7.3M on May 12) triggered an avalanche on Mount Everest. 21 people were killed, making April 25, 2015 the deadliest day on the mountain in history. Another huge avalanche was caused in the Langtang valley, where 250 people were reported missing. Hundreds of thousands of people were made homeless with entire villages flattened, across many districts of the country. Centuries-old buildings were destroyed at UNESCO World Heritage Sites in the Kathmandu Valley, including some at the Kathmandu Durbar Square, the Patan Durbar Square, the Bhaktapur Durbar Square, the Changu Narayan Temple, the Boudhanath stupa, and the Swayambhunath Stupa.

Figure 1.10 shows the USGS ShakeMap associated with the 7.8 magnitude main shock, showing both the violence of the event and the location of the largest devastation.

We will use ESA's Sentinel Application Platform (SNAP) to perform InSAR processing on these Sentinel-1 images. The advantages of the SNAP tool include (1) its graphical user interface, which renders the SNAP tool straightforward to use (compared to other InSAR processing tools); (2) the easy-to-access, free-of-charge, and public domain nature of the SNAP tool; and (3) the fact that SNAP is an integrative multi-sensor toolbox and enables processing data from all Sentinel sensors within one joint processing platform.

Should you be interested in using SNAP on your own work station, please visit <http://step.esa.int/main/download/> for download instructions.

3.2 Sentinel-1 and the 2015 Gorkha Earthquake

We will use a pair of repeated Sentinel-1A images for this lab that were acquired on April 17 and April 29, 2015, bracketing the main- and first aftershock of the Gorkha earthquake event. Hence, the phase difference between these image acquisitions capture the cumulative co-seismic deformation caused by both of these seismic events. The footprint of the Sentinel-1 images (**Figure 1.11**) shows good correspondence with the areas affected by the earthquake (**Figure 1.10**). Hence, Sentinel-1 data are a good basis for studying earthquake-related surface deformation.

SAR data for this exercise can be retrieved via the [ASF Vertex SAR data search client](#).

- Pre-event image:
S1A_IW_SLC_1SSV_20150417T001852_20150417T001922_005516_0070C1_460B
- Post-event image:
S1A_IW_SLC_1SDV_20150429T001907_20150429T001935_005691_0074DC_7332

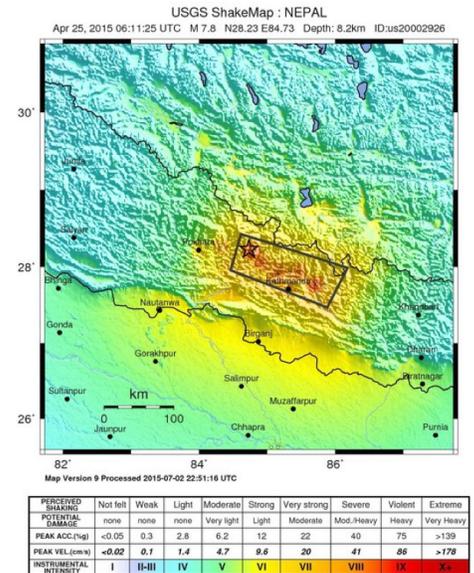


Figure 1.10 USGS ShakeMap associated with the 7.8 magnitude main shock of the 2015 Gorkha Earthquake northwest of Kathmandu, Nepal.

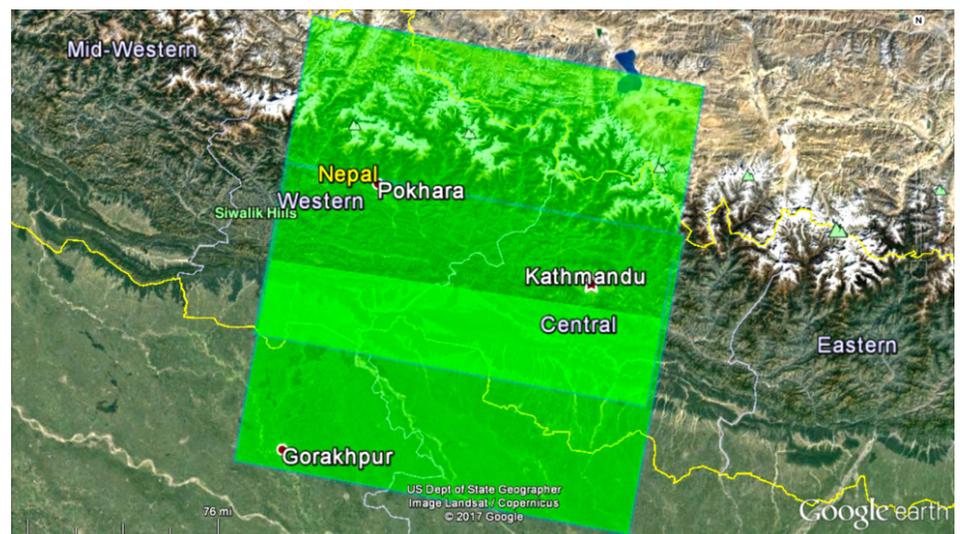


Figure 1.11 Footprint of the Sentinel-1A SAR data used in this study.

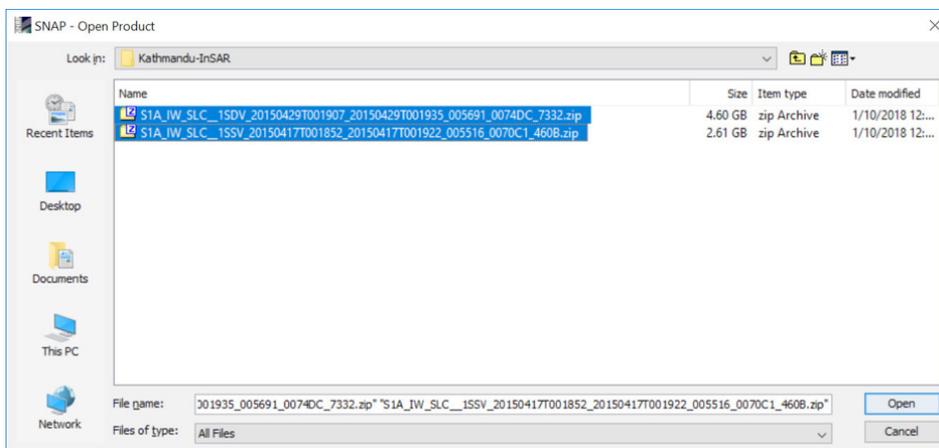


Figure 1.12 Open Product dialog in SNAP.

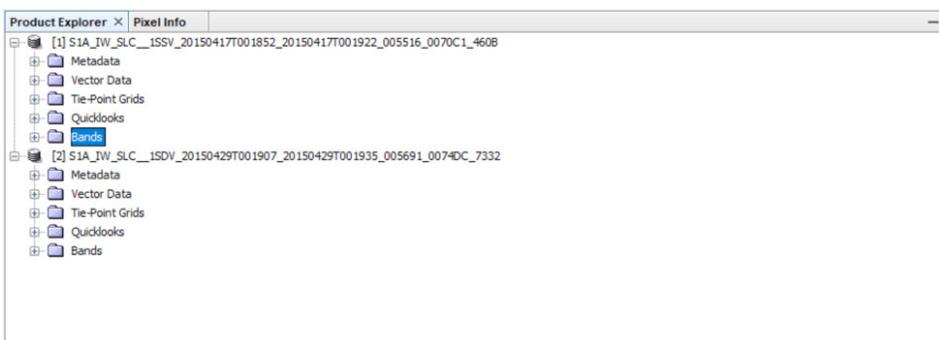


Figure 1.13 Product Explorer tab within the SNAP user interface.

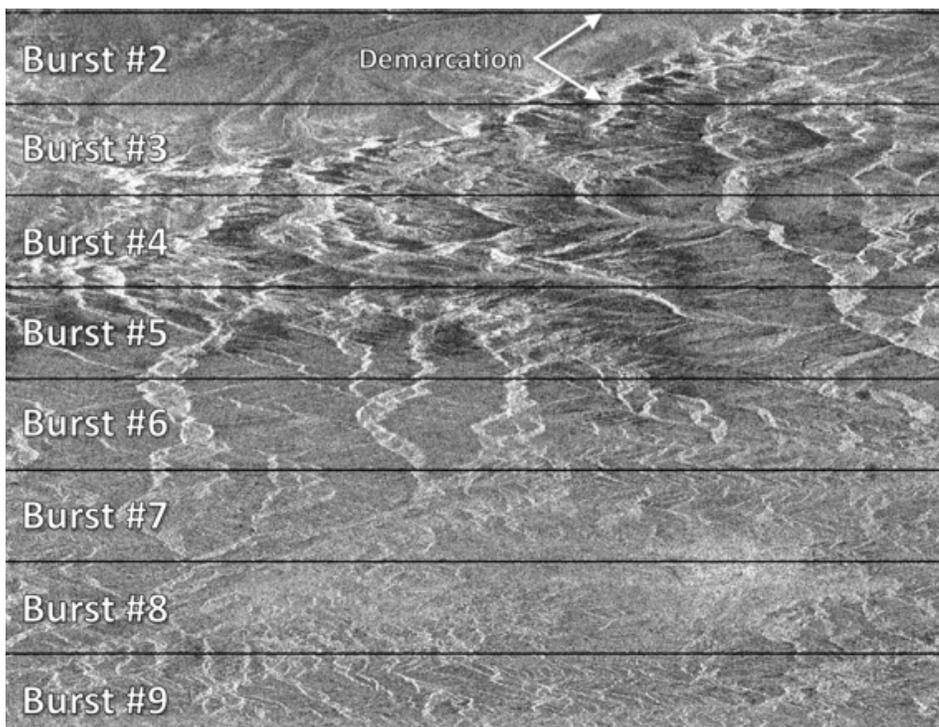


Figure 1.14 Intensity image of IW1 swath with bursts and demarcation areas identified.

3.3 InSAR Processing using the SNAP Tool

Start the SNAP on your computer by either double-clicking on the related icon or by typing **snap** in your command window.

3.3.1 Opening a Pair of SLC Products

In order to perform interferometric processing, the input products should be two or more SLC products over the same area acquired at different times.

Step 1 - open the products:

Use the Open Product button in the top toolbar of the SNAP interface and browse for the location of the Sentinel-1 Interferometric Wide (IW) swath products (Figure 1.12).

Select the *.zip files containing the respective Sentinel-1 products that will be used in this lab and press Open Product. Press and hold the Ctrl button on the keyboard to select multiple products at a time.

Step 2 - view the products:

In the Product Explorer (Figure 1.13) you will see the opened products. Within the product bands, you will find two bands containing the real (i) and imaginary (q) parts of the complex data. The i and q bands are the bands that are actually in the product. The virtual Intensity band is there to assist you in working with and visualization of the complex data.

Note that in Sentinel-1 IW SLC products, you will find three subswaths labeled IW1, IW2, and IW3. Each subswath is for an adjacent acquisition by the TOPS mode.

Step 3 - view a band:

To view the data, double-click on the Intensity_IW1_VV band of one of the two images. Zoom in using the mouse wheel and pan by clicking and dragging the left mouse button. Within a subswath, TOPS data is acquired in bursts. Each burst is separated by demarcation zones (Figure 1.14). Any 'data' within the demarcation zones can be considered invalid and should be zero-filled but may contain garbage values.

3.3.2 Coregistering the Data

For interferometric processing, two or more images must be co-registered into a stack. One image

is selected as the master and the other images are the slaves. The pixels in slave images will be moved to align with the master image to sub-pixel accuracy.

Coregistration ensures that each ground target contributes to the same (range, azimuth) pixel in both the master and the slave image. For TOPSAR InSAR, Sentinel-1 TOPS Coregistration should be used.

Step 4 - Coregister the images into a stack:

Select S-1 TOPS Coregistration in the Radar menu. TOPS Coregistration consists of a series of steps including the reading of the two data products, the selection of a single subswath with TOPSAR-Split, the application of a precise orbit correction with Apply-Orbit-File and the conduction of a DEM-assisted Back-Geocoding co-registration. All of these steps occur automatically once the process is kicked off via mouse click (inset at right).

A window will appear allowing you to set a few parameters for the co-registration process (Figure 1.15). In the first Read operator, select the first product [1]. This will be your master image. In Read (2) select the other product. This will be your slave image.

In the TOPSAR-Split tab, select the IW1 subswath for each of the products. In the Apply-Orbit-File tab, select Sentinel Precise Orbits. Orbit auxiliary data contain information about the position of the satellite during the acquisition of SAR data. Orbit data are automatically downloaded by SNAP and no manual search is required by the user.

The Precise Orbit Determination (POD) service for SENTINEL-1 provides Restituted orbit files and Precise Orbit Ephemerides (POE) orbit files. POE files cover approximately 28 hours and contain orbit state vectors at fixed time steps of 10 seconds intervals. Files are generated one file per day and are delivered within 20 days after data acquisition.

If Precise orbits are not yet available for your product, you may select the Restituted orbits, which may not be as accurate as the Precise orbits but will be better than the predicted orbits available within the product.

In the Back-Geocoding tab, select the Digital Elevation Model (DEM) to use and the interpolation methods. Areas that are not covered by the DEM or are located in the ocean may be optionally masked

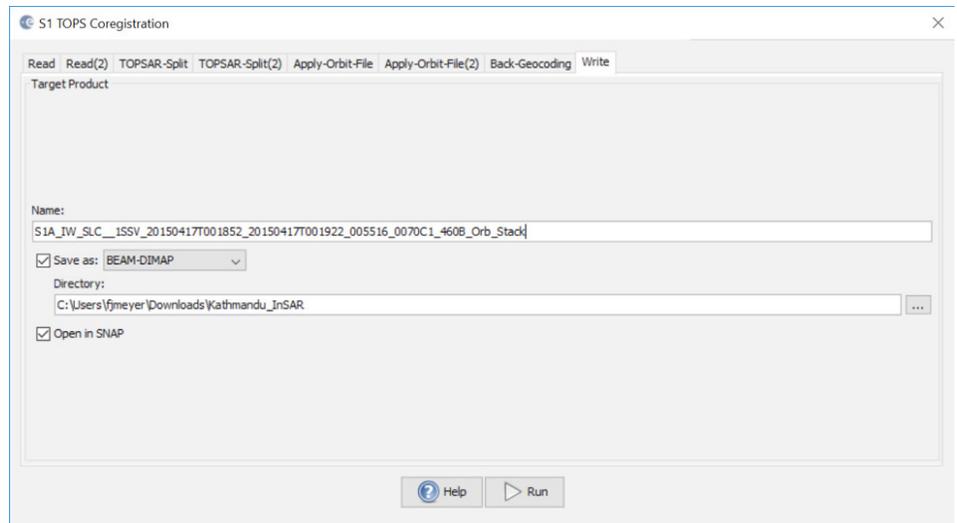
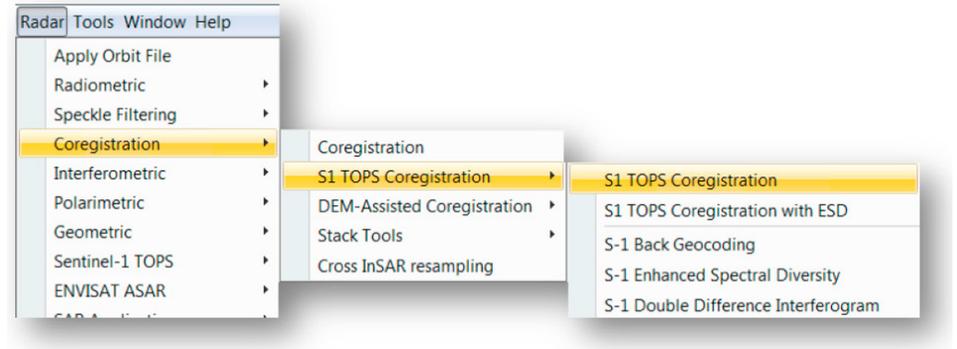


Figure 1.15 SNAP co-registration interface.



out. Select to output the Deramp and Demod phase if you require Enhanced Spectral Diversity to improve the coregistration.

Finally, in Write, change the Directory path to a preferred location.

Press Process to begin co-registering the data. The resulting coregistered stack product will appear in the Product Explorer tab.

3.3.3 Interferogram Formation and Coherence Estimation

The interferogram is formed by cross-multiplying the master image with the complex conjugate of the slave. The amplitude of both images is multiplied while their respective phases are differenced to form the interferogram.

The phase difference map, i.e., interferometric phase at each SAR image pixel depends only on the difference in the travel paths from each of the two SARs to the considered resolution cell.

Step 5 - Form the Interferogram:

Select the stack ([3] in Product Explorer) and select Interferogram Formation from the Radar/Interferometric/Products menu (see inset A at right). The information contained in the interferometric phase measurement is discussed in Lectures 12 - 14 referenced at the end of chapter 2. Please refer to the Supplemental Material on InSAR and associated lecture notes for further information.

Through the interferometric processing flow we will try to eliminate other sources of error to be left with only the contributor of interest, which is typically the surface deformation related to an event.

The flat-Earth phase removal is done automatically during Interferogram Formation step (Figure 1.16). The flat-Earth phase is the phase present in the interferometric signal due to the curvature of the reference surface. The flat-Earth phase is estimated using the orbital and metadata information and subtracted from the complex interferogram.

Once the interferogram product is created ([4] in Product Explorer), visualize the interferometric phase. You will still see the demarcation zones between bursts in this initial interferogram. This will be removed once TOPS Deburst is applied.

Interferometric fringes represent a full 2π cycle of phase change. Fringes appear on an interferogram as cycles of colors, with each cycle representing relative range difference of half a sensor's wavelength. Relative ground movement between two points can be calculated by counting the fringes and multiplying by half of the wavelength. The closer the fringes are together, the greater the strain on the ground.

Flat terrain should produce a constant or only slowly varying fringes. Any deviation from a parallel fringe pattern can be interpreted as topographic variation.

3.3.4 TOPS Deburst

To seamlessly join all bursts in a swath into a single image, we apply the TOPS Deburst operator from the Sentinel-1 TOPS menu.

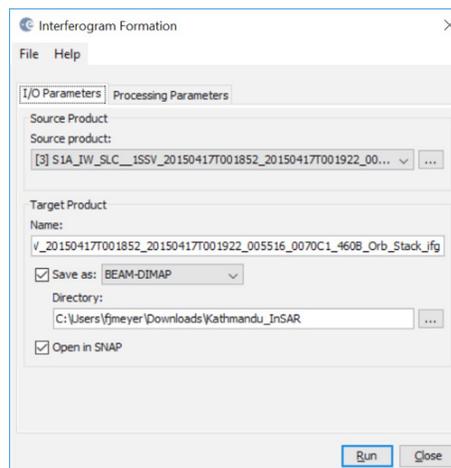
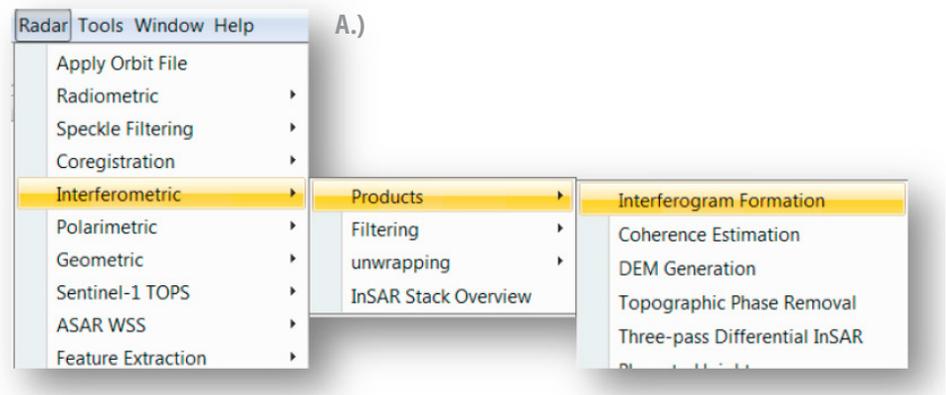
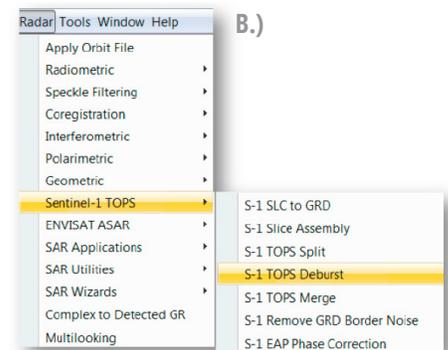


Figure 1.16 Interferogram Formation Interface.



Step 6 – TOPS Deburst:

Navigate to the the Radar/Sentinel-1 TOPS menu item and select the S-1 TOPS Deburst step (inset B).

3.3.5 Topographic Phase Removal

To emphasize phase signatures related to deformation, topographic phase contributions are typically removed using a known DEM. In SNAP, the Topographic Phase Removal operator will simulate an interferogram based on a reference DEM and subtract it from the processed interferogram.

Step 7 - Remove Topographic Phase:

Select the Radar/Interferogram/Product menu item and select the Topographic Phase Removal step (inset C, right).

SNAP will automatically find and download the DEM segment required for correcting your interferogram of interest. After topographic phase removal,

the resulting product will appear largely devoid of topographic influence. A separated band showing the topographic phase component simulated based on the DEM is also included.

3.3.6 Multi-looking and Phase Filtering

You will see that up to this stage, your interferogram looks very noisy and fringe patterns are difficult to discern. Hence, we will apply two subsequent processing steps to reduce noise and enhance the appearance of the deformation fringes.

As discussed in the previously referenced Lecture 12, interferometric phase can be corrupted by noise related to:

- Temporal decorrelation
- Geometric decorrelation
- Volume scattering
- Processing error

To be able to properly analyze the phase signa-

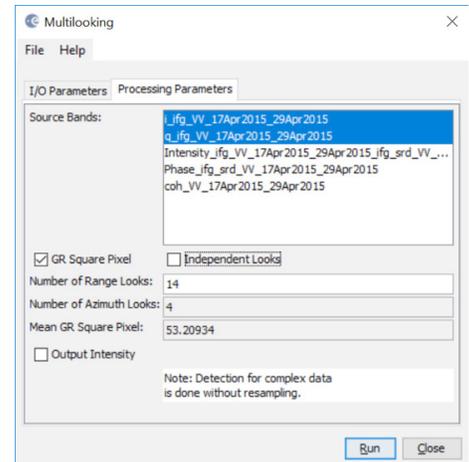
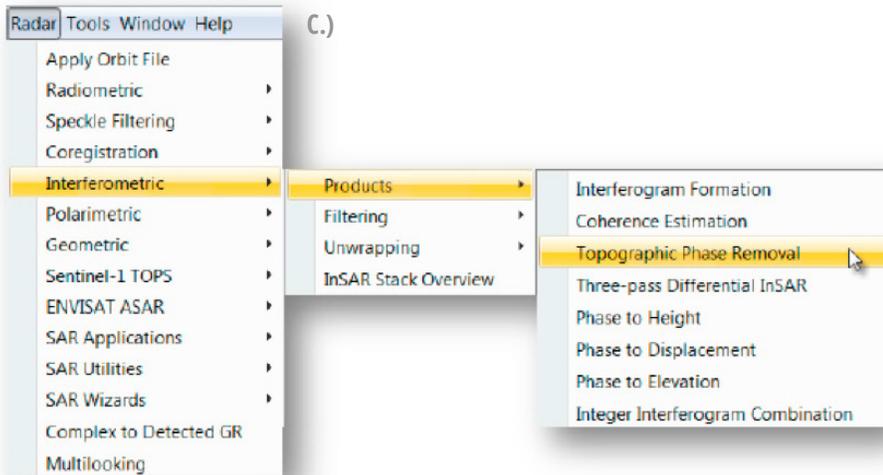


Figure 1.17 SNAP Multilooking interface.

tures in the interferogram, the signal-to-noise ratio will be increased by applying multilooking and phase filtering techniques:

Step 8 – Multi-looking:

The first step to improve phase fidelity is called multi-looking. To run this step, navigate to the Radar dropdown menu and select the Multilooking option (bottom of the menu). A new window opens. In the Processing Parameters portion of this window, pick the I and q bands as your Source Bands to be multi looked. In the Number of Range Looks field, pick 6 range looks, resulting in a pixel size of about 25m (Figure 1.17).

In essence, multilooking performs a spatial average of a number of neighboring pixels (in our case 6x2 pixels) to suppress noise. This process comes at the expense of spatial resolution.

Step 9 - Phase Filtering:

In addition to multilooking we perform a phase filtering step using a state-of-the art filtering approach. For this purpose, navigate to Radar/Interferometric/Filtering and select Goldstein Phase Filtering (inset D).

After phase filtering, the interferometric phase is significantly improved, and the dense earthquake deformation-related fringe pattern is now clearly visible (Figure 1.18).

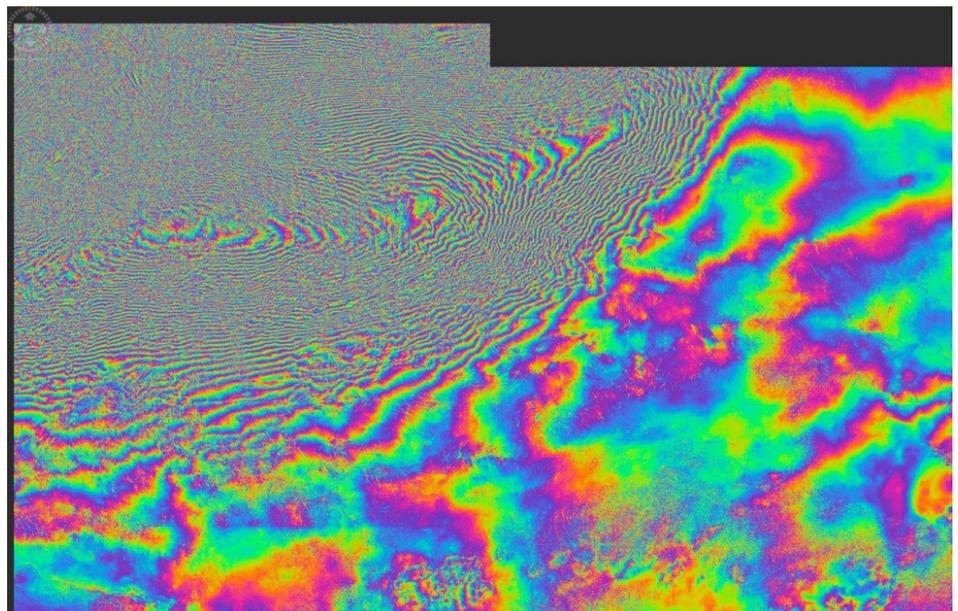
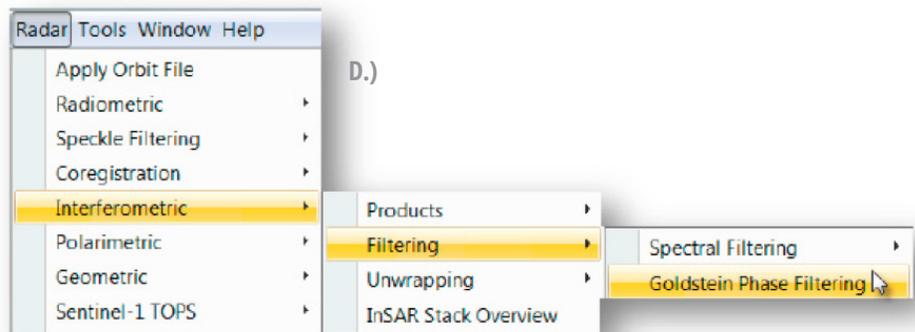
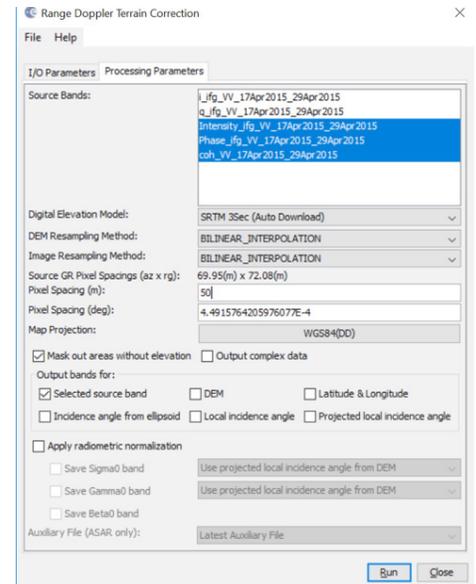
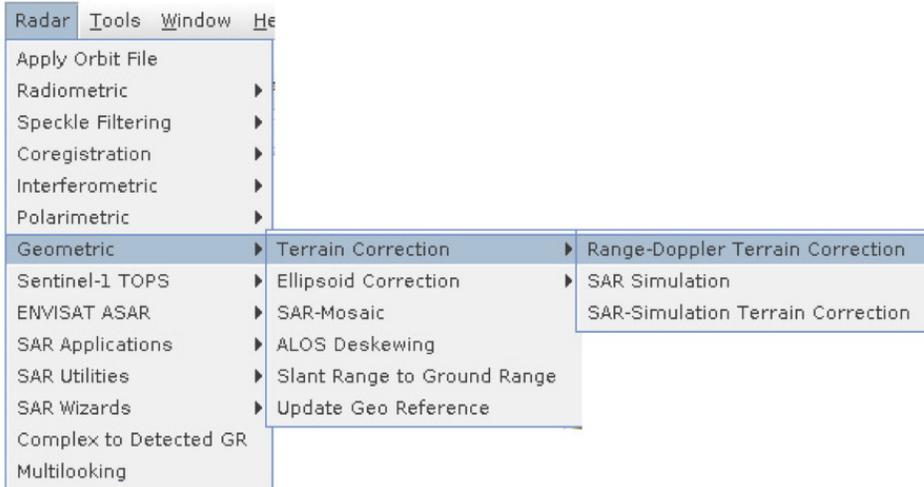


Figure 1.18 Deformation fringes related to the 2016 Kumamoto Earthquake show clearly after multilooking and phase filtering was applied.



3.3.7 Geocoding and Export in a User-Defined Format

To make the data useful to geoscientists, the interferometric phase image needs to be projected into a geographic coordinate system using a DEM-assisted geocoding step.

Step 10 - Geocoding:

To geocode the interferometric data, navigate to Radar/Geometric/Terrain Correction and select Range-Doppler Terrain Correction (inset above). In the Range-Doppler Terrain Correction window (Figure 1.19), select product [8] as source product

and pick the Intensity, Phase, and Coherence images as Source Bands to be geocoded. Adjust the pixel spacing if you want (e.g., 50m). See Figure 1.20 for the resulting geocoded interferogram of IW1.

Step 11 – Export Data:

The final geocoded data can be exported from SNAP in a variety of formats. To find the export options navigate to File/Export. In addition to GeoTIFF and HDF5 formats, also KMZs and various specialty formats are supported. In addition to the Data Export functionalities, SNAP files can also be directly

Figure 1.19 SNAP Range-Doppler Terrain Correction interface.

imported into most GIS packages such as QGIS. This is because SNAP uses the established ENVI format for its files, which breaks out each image in a binary data file accompanied by an ENVI-formatted metadata file. Figure 1.20 shows the processed Gorkha interferogram mapped on top of reference data using QGIS.

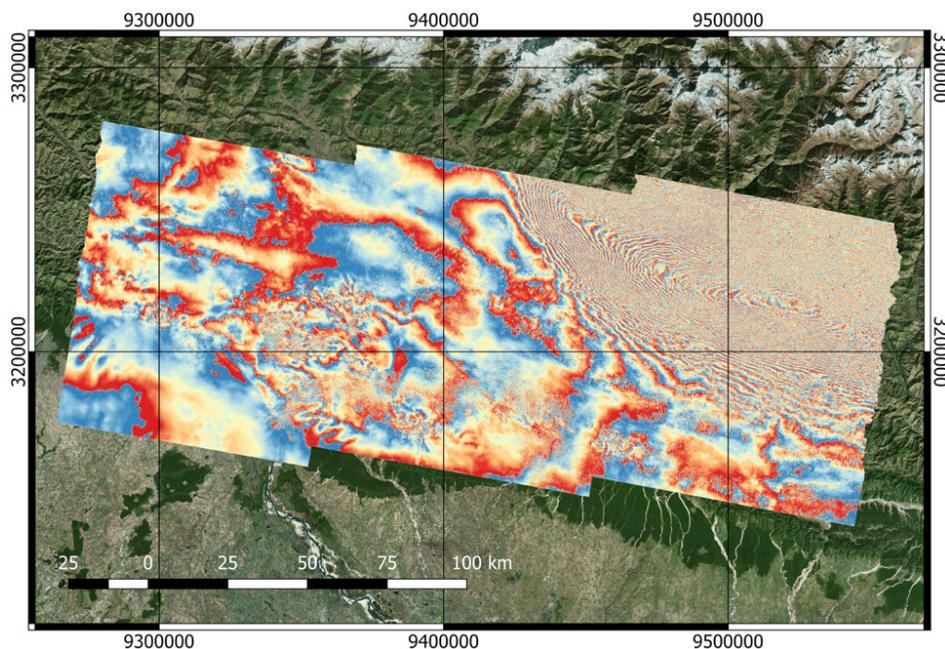


Figure 1.20 Geocoded Gorkha earthquake interferogram mapped in QGIS.

3.4 Summary of Processing Steps

A summary of the InSAR processing steps as described in this section can be found in **Figure 1.21**.

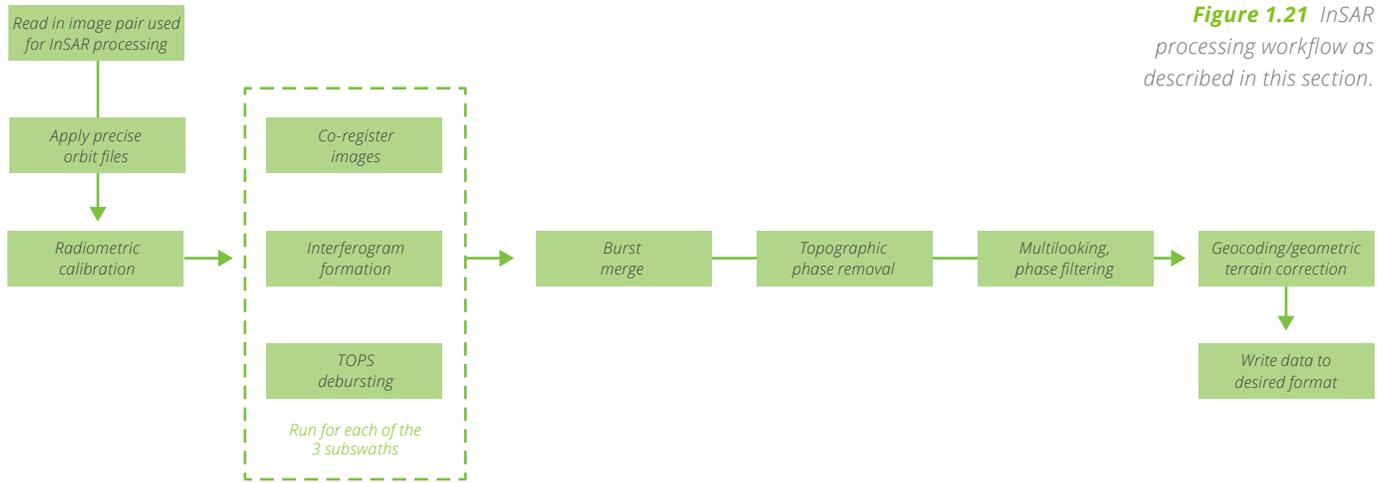


Figure 1.21 InSAR processing workflow as described in this section.

Small Data Analysis Exercise: Multi-Swath Processing

We processed sub-swath IW1 in the preceding exercise. You can extend this work by processing and merging multiple swaths. Specifically, you can create a geocoded differential interferogram by merging sub-swaths #1 and #2.

Step 1: Create a Geocoded Differential Interferogram of the Gorkha Earthquake by Merging Subswaths #1 through #3

To create this merged product, repeat the processing chain for the remaining two subswaths starting from Step 4:

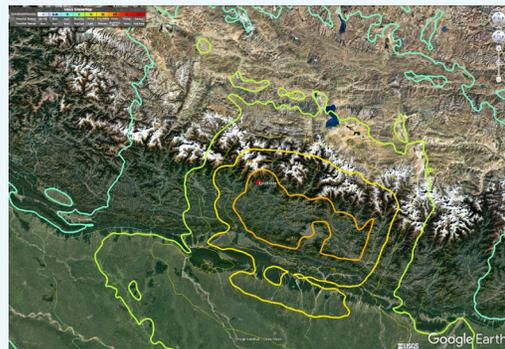
- Run “Step #4 – Coregistration” again but this time select IW2 (or IW3) in the TOPS Split operator tab → coregistered InSAR pair for sub-swath IW2 (IW3) [Note: make sure to create a new filename under the “Write” tab to no overwrite the IW1 stack result]
- Run “Step #5 – Interferogram Formation” using the new IW2 (IW3) stack as input → IW2 (IW3) interferogram
- Run “Step #6 – Debursting” for the IW2 (IW3) interferogram → debursted IW2 (IW3) interferogram
- NEW STEP: Run Burst Merge: This step is combining the previously generated “debursted IW1 interferogram” with the newly generated “debursted IW2 interferogram” and “debursted IW3 interferogram”. To run burst merge, go to Radar/Sentinel-1 TOPS menu item and select the S-1 TOPS Merge step. Select the debursted IW1, debursted IW2, and debursted IW3 interferograms as inputs.
- Run Steps #7 – #11 for this merged product.
- Produce an image of the merged differential interferogram overlaid on Google Earth or on a QGIS basemap (see **Figure 1.20**).

Step 2: Compare InSAR Data to ShakeMap Information

The Earthquake Hazards Program of the U.S. Geological Survey is providing a wealth of information about all significant earthquakes around the globe. The ShakeMap® is one of many sets of information included in this USGS feed. It was developed by the USGS to facilitate communication of earthquake information beyond just magnitude and location. By rapidly mapping out earthquake ground motions, ShakeMap portrays the distribution and severity of shaking.

To access the ShakeMap for the 2015 Nepal Gorkha earthquake event, please visit <https://earthquake.usgs.gov/earthquakes/eventpage/us20002926#executive> and download the Event KML (you will find the KML download link on the bottom of the menu on the left side of the website).

Overlay the ShakeMap onto your interferogram and analyze how well the map conforms with the interferogram. Where do the two data sets match up? Are there places where they don't match up?



4 A SIMPLE AMPLITUDE CHANGE DETECTION TECHNIQUE USING SNAP/ MAPREADY AND GIS

4.1 Introduction

Due to their 24/7 observation capabilities, SAR data are relevant for a broad range of applications in environmental monitoring and emergency response. This lab will touch on three examples of how SAR can be used to analyze various kinds of changes on the ground. Examples will include (1) repeated images over Huntsville, AL (or Fairbanks, AK), for the detection of environmental change; (2) imagery over Altamira, Brazil, a stronghold for illegal logging in the Amazon rainforest; and (3) data over Livingston Parish, LA, documenting the 2016 Louisiana flooding event.

Processing of these data will be done in QGIS, and emphasis will be put on simple, yet effective processing techniques. While this lab can be done within the cloud-based Virtual SAR Lab, which is available to you for these exercises, it might be more effective to process the data locally.

4.2 Detecting Changes in and Around Huntsville, AL / (alternatively Fairbanks, AK) from a Pair of ALOS PALAR RTC Images

The goal of this exercise to detect environmental changes around Huntsville, AL, Fairbanks, AK, or another area of interest through the observation period of the ALOS PALSAR SAR sensor system (2006 – 2011). A secondary goal is to demonstrate how quickly the ALOS PALSAR RTC products can be brought into a GIS system to aid in a geospatial analysis.

4.2.1 Identify Suitable ALOS PALSAR RTC Images for Change Detection using Vertex

To identify ALOS PALSAR RTC images suitable for change detection, go to the ASF Vertex search engine (<http://vertex.daac.asf.alaska.edu>) and draw a box centered on Huntsville (**Figure 1.22**) / Fairbanks, AK. Specify the following search settings to find suitable data:

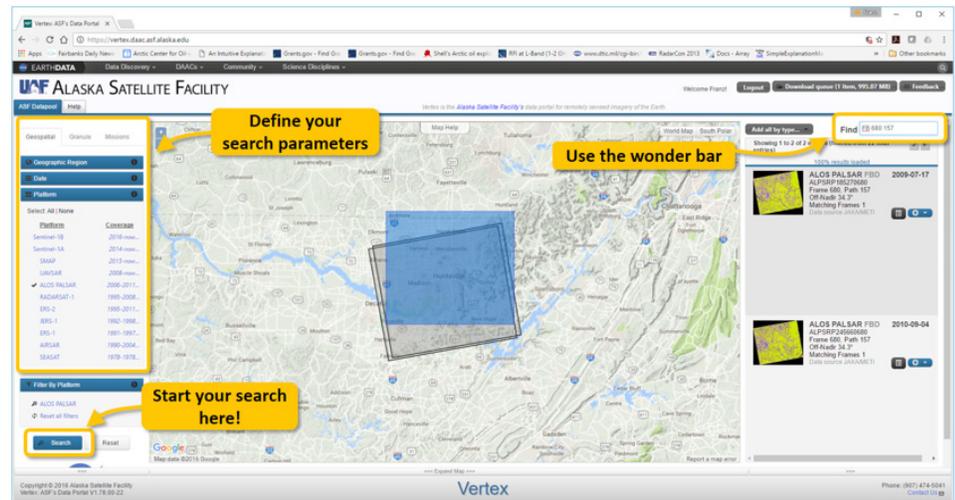


Figure 1.22 Setting up a search mask around Huntsville, AL in Vertex.

Step 1 – Set Geographic Search Region:

Draw a bounding box on the Vertex map to include your study area.

Step 2 – Set Seasonal Search Range:

Setting a seasonal search range will limit your search to images from the same season. This is important for change detection operations as it avoids seasonal changes and focuses on true environmental changes in a change detection analysis.

- In the Search Tab on the left-hand side of the Vertex interface, activate the Seasonal Search radio button and set the search range to July to September.

Also, search for the time span of the ALOS PALSAR mission by setting the year range to 2006 – 2011 (see **Figure 1.23a**).

Step 3 – Select Platform:

This is to select the sensor of interest from the list of available sensors. Deactivate Sentinel-1A and -1B and activate ALOS PALSAR in the Platform selection interface (see **Figure 1.23b**).

Step 4 – Start Search and Down select Search Results:

Start the Vertex search by clicking on the Search button. Once the search is completed, down-select your results using the wonder bar (see **Figure 1.22**).

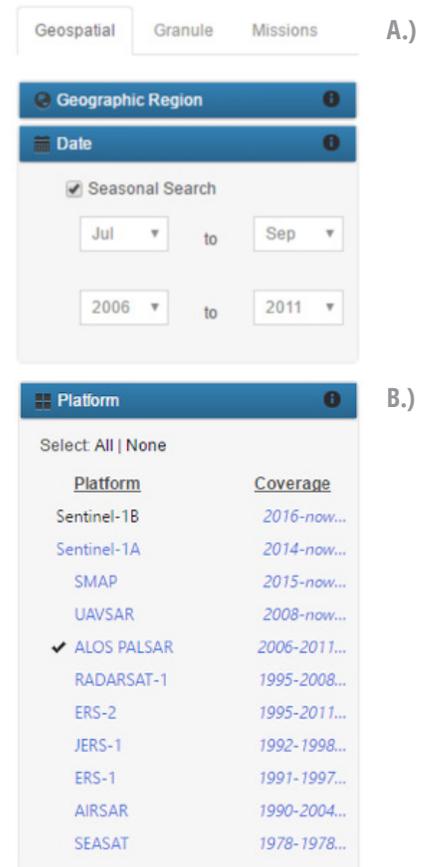


Figure 1.23 Selecting date range (a) and platform type (b) on Vertex.

Once you have identified the images you are interested in, click on their preview image to enlarge the product info tab and download the Hi-Res Terrain Corrected data set via a mouse click per image of interest (**Figure 1.24**).

Every downloaded file is encapsulated in a zip file. Expand the files into separate folders. Once that's done, we are ready for an analysis of these scenes in a GIS system (QGIS or ArcGIS).

4.2.2 Load Images into QGIS and Visualize

Load the downloaded images into QGIS (or ArcGIS) using the raster import feature (we will walk through the process in this exercise should you be unfamiliar with QGIS).

Ideally, load a background basemap image to be able to compare image features to known landmarks. I suggest loading the OpenLayers Plugin into your QGIS system via the Plugins/Manage and Install Plugins ... item in the menu bar at the top of the QGIS interface.



Visualize the images and explore the data set. To improve visualization at all spatial scales, apply a few changes to the image properties:

- Open the property editor by right clicking on an image in the image list and selecting Properties. The Layer Properties interface will appear.
- In the Style tab, change the resampling method for Zoomed in to Cubic and for Zoomed out to Average.

Analyze the data for geolocation quality, spatial resolution, and image content.

4.2.3 Perform a Simple Change Detection Procedure in QGIS

The two images in your list were acquired approximately one year apart. As the data are seasonally coordinated, differences between the images

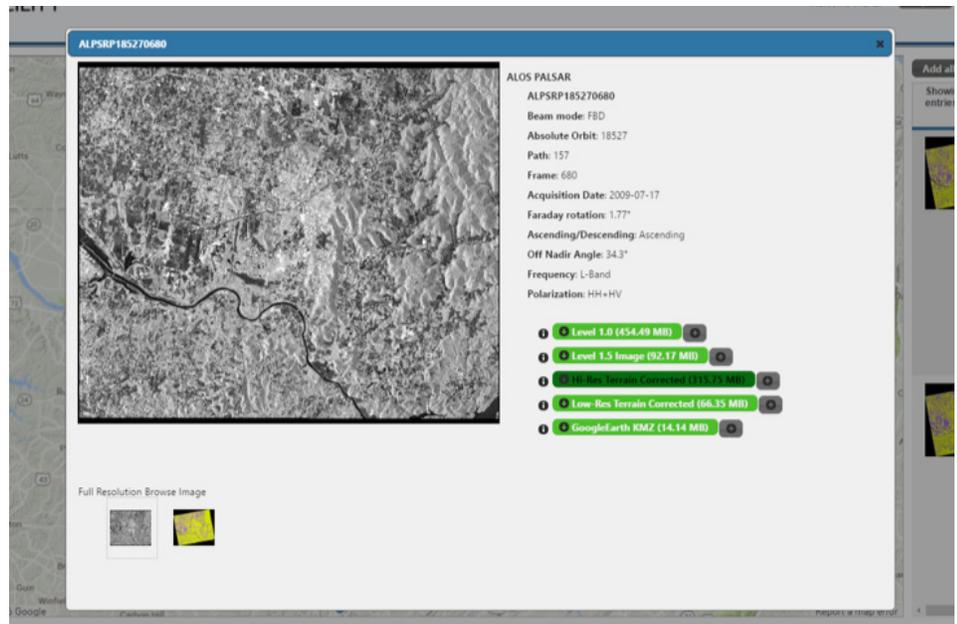


Figure 1.24 Image info view in Vertex. Download the High-res Terrain Corrected product per image of interest.

should largely be due to environmental changes between the image acquisition times, such as urban development, changes in river flow, or differences in agricultural activity.

Step 1 – Perform visual change analysis:

Flicker between the images to try to identify changes.

- Which changes can you identify?
- How difficult is it for you to identify differences between images?
- What makes the identification of change difficult?

Step 2 – Perform Log-ratio scaling, a simple change detection routine:

Identifying changes in images with complex content (e.g., the complex landforms and urban structures in these PALSAR scenes) is hard, as the image content is masking the signatures of change. Our eyes and minds are overwhelmed and distracted by the wealth of information in the data.

Hence, the main goal of image-based change detection approaches is to effectively suppress the image background information, while preserving

the main change signatures of interest. A simple and effective change detection approach is the so-called log-ratio scaling method. It is based on a differential analysis of repeated images and has been shown to be effective in background suppression and change features enhancement. The callout on the next page provides a bit more details on this change detection method.

Side-note: A Few Words on Log-Ratio Scaling

Log-ratio scaling is an effective means to suppress image background and enhance the change signatures in an image. To identify potential surface changes from SAR data using this approach, a ratio image is formed between a newly acquired image X_i and a reference data set X_R . Using ratio images in change detection was first suggested by Dekker (1998) and has since been the basis of many change detection methods (Ajadi et al., 2016; Bazi et al., 2005; Celik, 2010; Coppin et al., 2004; Meyer et al., 2015). To minimize the effects of seasonal variations as well as spurious changes of surface reflectivity on the change detection product, the reference image X_R should be selected in the same season as the newly-acquired image X_i . Before ratio image formation, all data should be geometrically and radiometrically calibrated. These steps were done by the data provider (ASF) in our case. The ratio image can be modeled as:

$$r = \frac{X_i}{X_R} = xR$$

where r is the observed intensity, x is a multiplicative speckle noise contribution, and R is the underlying true intensity ratio. The ratio image r has the disadvantage that the statistical distribution of its gray values is highly non-normal and that its multiplicative noise is difficult to remove. Therefore, a logarithmic scaling is applied to r , resulting in:

$$X_{LR} = \log_{10} \left(\frac{X_i}{X_R} \right) = y + Q$$

where $y = 10 \log(x)$, $Q = 10 \log(R)$, and X_{LR} is the log-scaled ratio data.

Related Literature:

Ajadi, O. A., Meyer, F. J., and Webley, P. W., 2016, *Change Detection in Synthetic Aperture Radar Images Using a Multiscale-Driven Approach: Remote Sensing*, v. 8, no. 6, p. 482.

Bazi, Y., Bruzzone, L., and Melgani, F., 2005, *An unsupervised approach based on the generalized Gaussian model to automatic change detection in multitemporal SAR images: IEEE Transactions on Geoscience and Remote Sensing*, v. 43, no. 4, p. 874-887.

Celik, T., 2010, *A Bayesian approach to unsupervised multiscale change detection in synthetic aperture radar images: Signal Processing*, v. 90, no. 5, p. 1471-1485.

Coppin, P., Jonckheere, I., Nackaerts, K., Muys, B., and Lambin, E., 2004, *Review Article Digital change detection methods in ecosystem monitoring: a review: International Journal of Remote Sensing*, v. 25, no. 9, p. 1565-1596.

Dekker, R. J., 1998, *Speckle filtering in satellite SAR change detection imagery: International Journal of Remote Sensing*, v. 19, no. 6, p. 1133-1146.

Meyer, F. J., McAlpin, D. B., Gong, W., Ajadi, O., Arko, S., Webley, P. W., and Dehn, J., 2015, *Integrating SAR and derived products into operational volcano monitoring and decision support systems: Isprs Journal of Photogrammetry and Remote Sensing*, v. 100, no. 0, p. 106-117.

To conduct log-ratio scaling in QGIS, apply the following procedure:

- In the Raster menu, select Raster Calculator
- In the Raster Calculator window (Figure 1.25), construct the following equation: $\log_{10}((\text{newer image})/(\text{older image}))$
- Define an output layer name (e.g., HuntsvillePALSAR-Logratio.tif)
- Click Ok to calculate the log-ratio image.

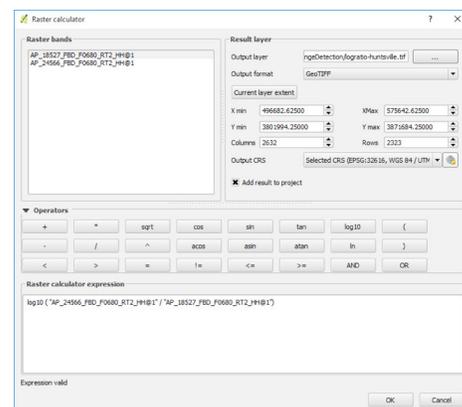


Figure 1.25 Raster Calculator Interface and entries for calculating a log-ratio image.

A screenshot of an example log-ratio image over Huntsville is shown in Figure 1.26. This image was created from a pair of images acquired on 7/17/2009 and 9/04/2010. It can be seen that most of the original image content (city of Huntsville, hills and vegetation structures near town, ...) was effectively suppressed from the image. In the log-ratio image, unchanged features have intermediate gray tones (gray value around zero) while change features are either bright white or dark black. Black features indicate areas where radar brightness decreased while in white areas, the brightness has increased.

Step 3 – Analyze the log-ratio image:

Analyze the change image that you have created. What kind of changes do you see? Compare change features to the base map (e.g., Google Maps) to explain the meaning of observed changes.

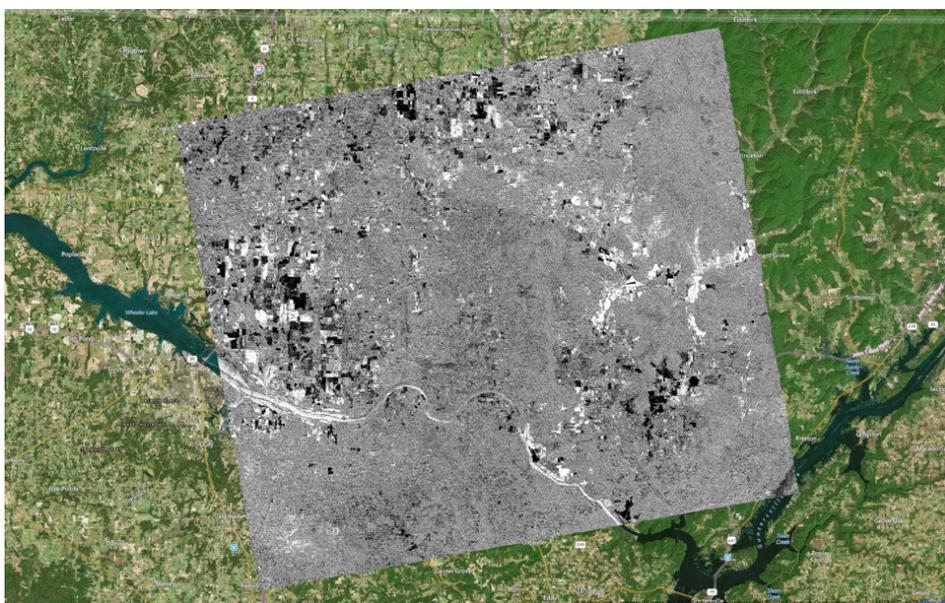


Figure 7.26 Example log-ratio image for Huntsville, AL.

4.3 Monitoring (Illegal) Logging Activities in the Amazon Rainforest

The region near Altamira, Brazil is one of the most active logging regions of the Amazon rainforest. While some of the logging activities in this area are legitimate, illegal logging operations have flourished over the last decade. Existing logging roads can be clearly identified in optical satellite images such as those used by Google Maps® (Figure 1.27). However, frequent rain and cloud cover make change detection based on optical remote sensing data impractical.

4.3.1 Retrieve Repeated ALOS PALSAR RTC Images over Logging Areas near Altamira, Brazil

Use the ASF Vertex interface to retrieve repeated images over the logging areas near the Brazilian city of Altamira. When searching for images, don't forget to target similar seasons. Due to the evergreen vegetation in this tropical area, there is no preference for which season you choose.

Once you have identified images of interest, download the High-Res Terrain Corrected images for your change detection analysis. The goal is to identify year-to-year changes in logging extent.

4.3.2 Map Logging Activities Using Log-Ratio-based Change Detection Procedures

Experiment with Log-Ratio Scaling on your repeated ALOS PALSAR RTC data.

4.4 Flood and Inundation Mapping for the 2016 Louisiana Flooding

The Louisiana flood of 2016 was touted by many as the biggest U.S. natural disaster since Hurricane Sandy in 2012. In August 2016, prolonged rainfall in southern parts of the U.S. state of Louisiana resulted in catastrophic flooding that submerged thousands of houses and businesses. Many rivers and waterways, particularly the Amite and Comite rivers, reached record levels, and rainfall exceeded 20 inches (510 mm) in multiple parishes (Figure 1.28).

4.4.1 Meteorological History

Early on August 11, a mesoscale convective system flared up in southern Louisiana around a weak area of low pressure that was situated next to an outflow

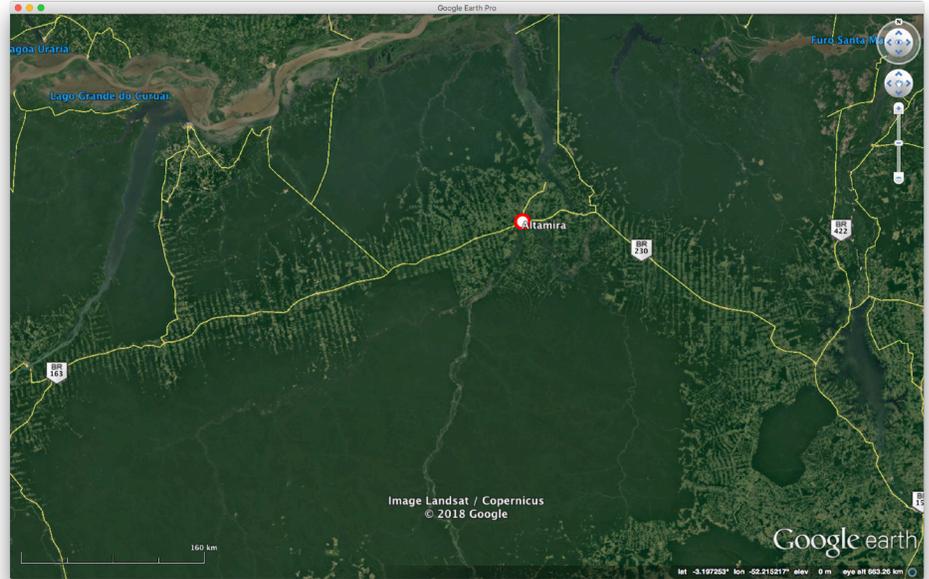


Figure 1.27 Logging roads can clearly be identified from optical satellite data around Altamira, Brazil.

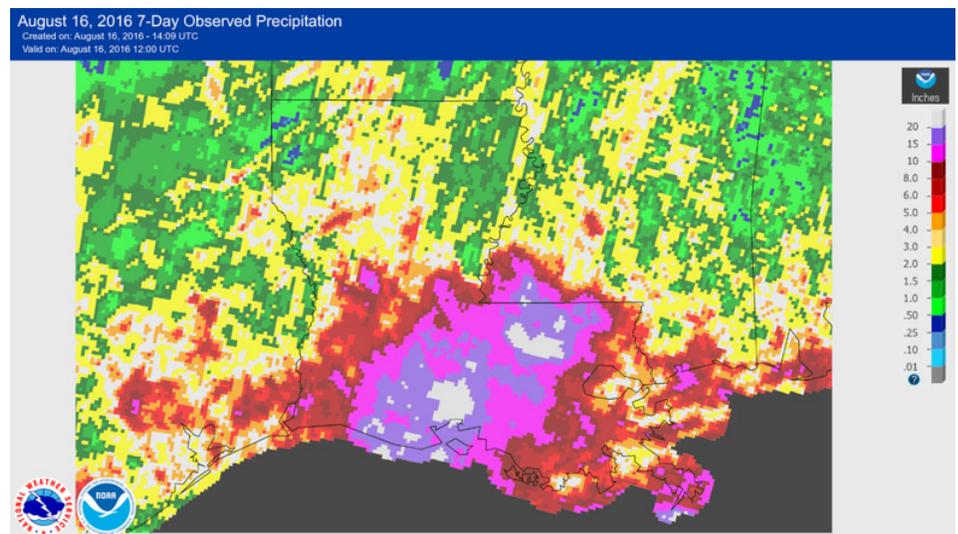


Figure 1.28 A map of radar-estimated rainfall accumulations across Louisiana between August 9 and 16, 2016; areas shaded in white indicate accumulations in excess of 20 in (510 mm).

boundary. It remained nearly stationary, and as a result, torrential downpours occurred in the areas surrounding Baton Rouge and Lafayette. Rainfall rates of up to 2–3 inches (5.1–7.6 cm) an hour were reported in the most deluged areas. Totals exceeded nearly 2 feet (61 cm) in some areas as a result of the system remaining stationary (Figure 1.28).

4.4.2 Flood History

Flooding began in earnest on August 12. On Au-

gust 13, a flash flood emergency was issued for areas along the Amite and Comite rivers. By August 15, more than ten rivers (Amite, Vermilion, Calcasieu, Comite, Mermentau, Pearl, Tangipahoa, Tchefuncte, Tickfaw, and Bogue Chitto) had reached a moderate, major, or record flood stage. Eight rivers reached record levels including the Amite and Comite rivers. The Amite River crested at nearly 5 ft (1.5 m) above the previous record in Denham Springs. Nearly one-third of all homes—approximately 15,000 structures—in

Ascension Parish were flooded after a levee along the Amite River was overtopped. Water levels began to slowly recede by August 15, though large swaths of land remained submerged. Livingston Parish was one the hardest hit areas; an official estimated that 75 percent of the homes in the parish were a “total loss”. It was thought over 146,000 homes were damaged in Louisiana. This mass flooding also damaged thousands of businesses.

4.4.3 Flood Mapping using Sentinel-1 SAR Data

In this exercise, we will look at the benefits (and limitations) of Sentinel-1 SAR data for mapping the extent of the 2016 Louisiana flood. As mentioned previously, Sentinel-1 is an operational SAR system acquiring images at a routine repeat frequency of either 12 or 24 days for all areas of the globe that were defined as hazard zones. Large parts of the western and central U.S. are part of this hazard map and, hence, are well-covered. The eastern U.S., however, is less well served by Sentinel-1 acquisitions (see **Figure 1.29**).

In addition to the coverage of hazard zones, Sentinel-1 is attempting to respond to natural disasters such as the Louisiana flood, through the scheduling of an acquisition on its next pass over this area.

For the Louisiana Flooding event, the following Sentinel-1 data are available:

Pre-event data from Aug 7, 2016:

- S1A_IW_GRDH_1SDV_20160807T000141_20160807T000210_012487_013866_11BE
- S1A_IW_GRDH_1SDV_20160807T000210_20160807T000235_012487_013866_7D4F

Post-event data from August 19, 2016:

- S1A_IW_GRDH_1SDV_20160819T000211_20160819T000236_012662_013E26_5A79
- S1A_IW_GRDH_1SDV_20160819T000142_20160819T000211_012662_013E26_8995

The footprint of these data is shown in **Figure 1.30**. The footprint matches the affected areas well. However, the post-event image on Aug 19 might come a bit late to detect the maximum extent of the event.

Sentinel-1 IW SLC coverage (Oct2014 to Aug2016)

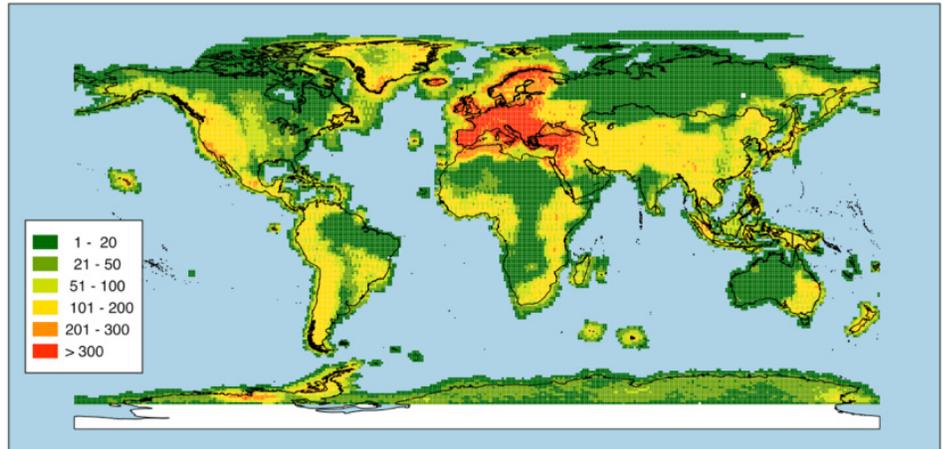


Figure 1.29 Global IW-mode coverage of Sentinel-1 between October 2014 and August 2016.

4.4.4 Data Processing

Sentinel-1 data are (currently) available as SLC and as so-called Ground-Range Detected (GRD) products. While the GRD images are georeferenced, neither of these products come fully geocoded and some pre-processing is needed before it is straightforward to work with these data in a GIS system. The images hosted on the website for this lab are pre-processed, using the steps below:

A – Extract Image Files:

Extract the .tiff file that you are interested in. In each zip file there will be a base directory that is the name of the granule followed by “.SAFE” and then a number of lower level directories. One of these is named measurement, and within this directory will be the georeferenced .tiff files. Using the Unix (or Windows) unzip utility, you can extract only the file you want with a command like this:

```
unzip <filename.zip> */
measurement/*vv*.tiff
```

This will extract just the VV polarized image from this zip package. If you know which file you want, this is usually much faster than extracting the whole zip file.

B – Project the Image Files:

Using the gdal (www.gdal.org) command line utilities you can project and export these files as more useful

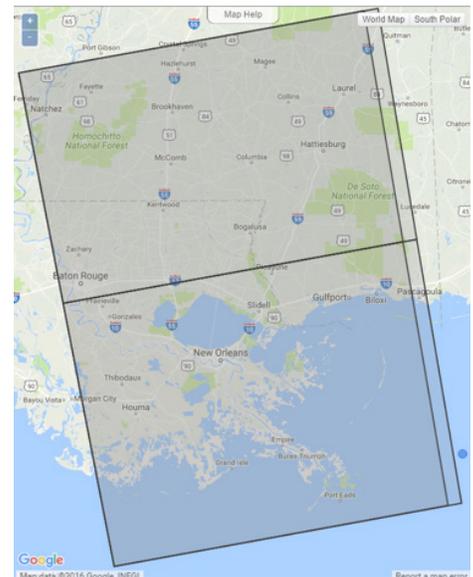


Figure 1.30 Footprint of Sentinel-1 data covering the 2016 Louisiana flooding event.

products. To begin, we want to project the files. The Sentinel-1’s GCPs are provided in GCS (lat/lon) coordinates, but can easily be reprojected into another projection. In the case of the Louisiana data, this will be UTM zone 15 (EPSG 32615). To do this, you use the gdalwarp command:

```
gdalwarp -tps -r bilinear
-tr 10 10 -t_srs
EPSG:32615 <inputfile.tiff>
<output-utm-file.tif>
```

Note that:

- t_srs specifies the output projection
- r specifies the resampling method (default is nearest neighbor)
- tr specifies the output pixel size
- tps specifies to use the thin plate spline technique when interpolating control points

Executing this command will result in a map projected geotiff file that could be read by nearly any GIS application. For Sentinel-1, the datatype will still be uint16.

C – Scale the data:

Scale to byte using `gdal_translate`. You can easily scale the data to byte if you want, which may be more useful.

```
gdal_translate -ot Byte  
-scale 0 700 0 255 <infile.  
tif> <output.tif>
```

In this case, we convert from long int to byte and scale the range 0 to 700 into the 0 to 255 byte range. Values above 700 will be set to 255 and values below 0 (though there shouldn't be any) will be set to 0.

Once these pre-processing steps are completed, the data is ready for analysis in a GIS system.

For the purpose of this training module, these steps have been fully geo-coded and pre-processed. Download the required image data from the website (radar.community.uaf.edu/lab-8-change-detection-from-sar-images/).

Load the pre-processed data 20160807.tif and 20160819.tif into your GIS system and overlay them on a map. Inspect the images and flicker between them to get a first idea of potential flood extents in the area.

We will apply two different simple yet effective water/flood masking approaches to these data: (1) Image Thresholding and (2) Log-ratio scaling.

(1) Image Thresholding:

Image thresholding can be an effective method for the detection of open water bodies in a SAR image.

Here, we use the fact that water is often much darker than the true image content, causing the image histogram to be bimodal and enabling the separation of water from the rest of the image using simple thresholding operations. To conduct image thresholding on both images, please go through the following steps for both data, starting with image 20160819.

Step 1 - Perform a log-transformation:

This step creates image histograms for the data that are more Gaussian and simplifies the thresholding operations. In QGIS, go to the Raster menu and select the Raster Calculator. Perform a log transformation by applying an equation to the image (e.g., `log10 ("20160819@1")`). Export the image as geotiff under the name 20160819-log.tif.

Step 2 – Analyze the image histogram:

Right click on the 20160819-log and select properties. Navigate to the histogram tab and zoom into the histogram to see its shape.

You should see a clearly bi-modal histogram (inset A) with water pixels appearing significantly darker than the main image data.

Step 3 – Pick a threshold:

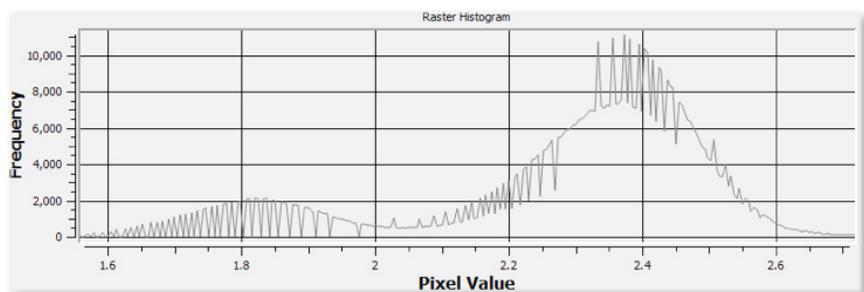
To separate water from the rest of the image, pick a threshold at (or near) the minimum between the two modes of the distribution (e.g., at 2.05)

Step 4 – Create a black/white water mask:

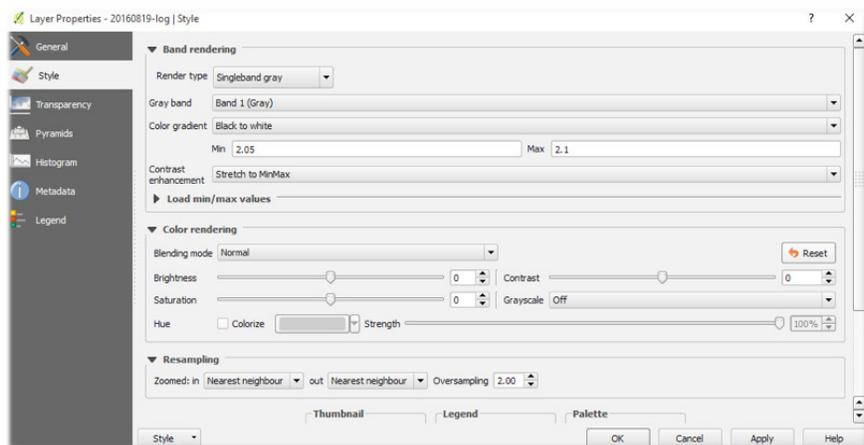
A simple approach is to navigate to the Style tab of the Layer Properties window and rest the minimum and maximum value of the image to values just below and just above the threshold. Click ok or Apply to view the result (inset B). Your image should look similar to the one in [Figure 1.31](#).

Repeat this process for image 20160807 and compare the resulting flood masks:

- Analyze the quality of the water masks
- Compare flood mapping results to a base map (e.g., Google maps)
- Think about the benefit of such a map in emergency management situations



A.)



B.)

(2) Log-Ratio Scaling:

Apply the log-ratio scaling approach from Section 4.2 to the Louisiana flood data. Use the following equation in your analysis:

$$\log_{10} \left(\frac{("20160819@1")}{("20160807@1")} \right)$$

The result of your analysis should resemble the map in **Figure 1.32**. Analyze the log-ratio map:

- Which signatures can you see?
- What may the bright areas in the log-ratio image represent?
- How does the log-ratio result compare to the water masks created via image thresholding?
- Do you think this may be a useful layer for emergency management situations?

4.4.5 Take Away Points

The goal of this last exercise was to demonstrate the potential of SAR data for flood mapping. We learned about two different simple water masking methods and compared them. You should have seen that even very simple techniques can achieve quite impressive results that can have bearing on emergency management situations.

At the same time, this lab should also showcase some of the remaining limitations that still plague SAR data in general and Sentinel-1 SAR data specifically:

- Currently, Sentinel-1 data does not come fully geocoded and some pre-processing is required to be able to manipulate it effectively in a GIS environment.
- While Sentinel-1 is an operational system, it doesn't cover all parts of the globe equally well (even though this is improving as Sentinel-1B is ramping up production).
- The temporal sampling of SAR systems is still limited. In the Louisiana flood example, we are missing the main flood pulse due to inconvenient image acquisition times. By the time of the post-event acquisition, most of the flood water has already receded.
- Freely-available SAR data are also a bit limited in their spatial sampling. In the Louisiana flood case, this may have reduced the quality of flood maps in urbanized environments.

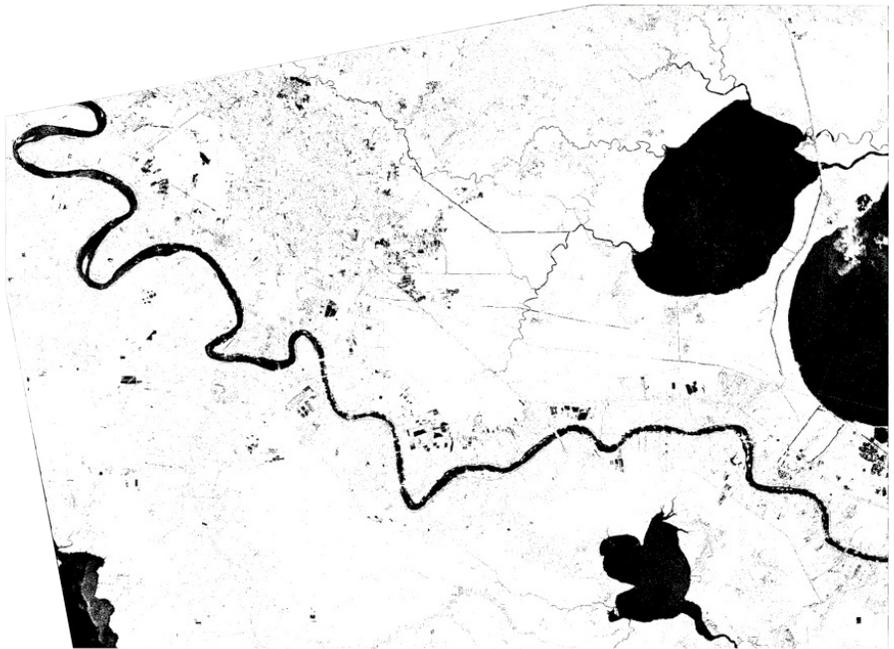


Figure 1.31 Threshold-based water mask for 20160818.

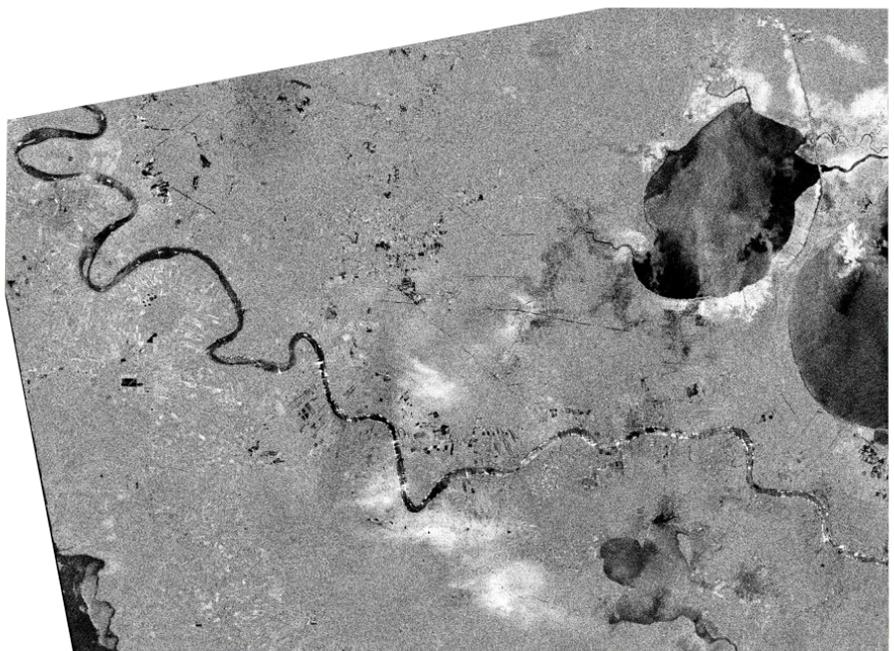


Figure 1.32 Log-ratio image for 2016 Louisiana flood