Adapted transcription of the tutorial video

"ESA Echoes in Space - Hazard: Flood mapping with Sentinel-1 (ESA EO College), by Chris Stewart, 5 November 2017"

Augmented with additional illustrations and comments

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Available at https://orbi.uliege.be/handle/2268/240620

This document is an adapted transcription of the tutorial video (YouTube channel "EO College") entitled « **ESA Echoes in Space - Hazard: Flood mapping with Sentinel-1 (ESA EO College)**" from 5 November 2017 where **Dr. Chris Stewart** explains how to derive a flood map from Sentinel-1 images, using SNAP. The transcription is augmented with additional illustrations and comments.

The **video tutorial** is available here: https://www.youtube.com/watch?v=derOXkPCH80

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1. Objective (video timing: 0 min 00 sec)

- To **map flooded area with Sentinel-1** data by a simple technique: using **an image before the flood (called the "Archive image") and an image during the flood (called the "Crisis image")** to distinguish between:
  - Flooded area
  - Permanent water bodies

2. Technical description of the 2 Sentinel-1 images used

- 2 Sentinel-1 images over a part of Myanmar, with the following **technical features**:
  - **Remarque**
    - The **filename conventions** of Sentinel products are available here : https://sentinel.esa.int/web/sentinel/user-guides/sentinel-1-sar/naming-conventions
  - **Pass ascending**
    - Part of the satellite orbit trajectory going from **South to North poles**, information available in the Metadata, confer **Figure 6** page 9
  - **Mode VV**
    - Polarization mode of the SAR signal: **Vertical emitted by the sensor and Vertically received by the sensor**
  - **Sensor mode IW**
    - **Interferometric Wide acquisition mode** (**Figure 1**): confer here for more information: https://sentinel.esa.int/web/sentinel/user-guides/sentinel-1-sar/acquisition-modes
  - **Product type GRD**
    - **Ground Range Detected**
    - More information here: https://sentinel.esa.int/web/sentinel/missions/sentinel-1/data-products
    - Remarque: in GRDH (confer image filename), the H stands for the resolution class, which is High (H) in this case)

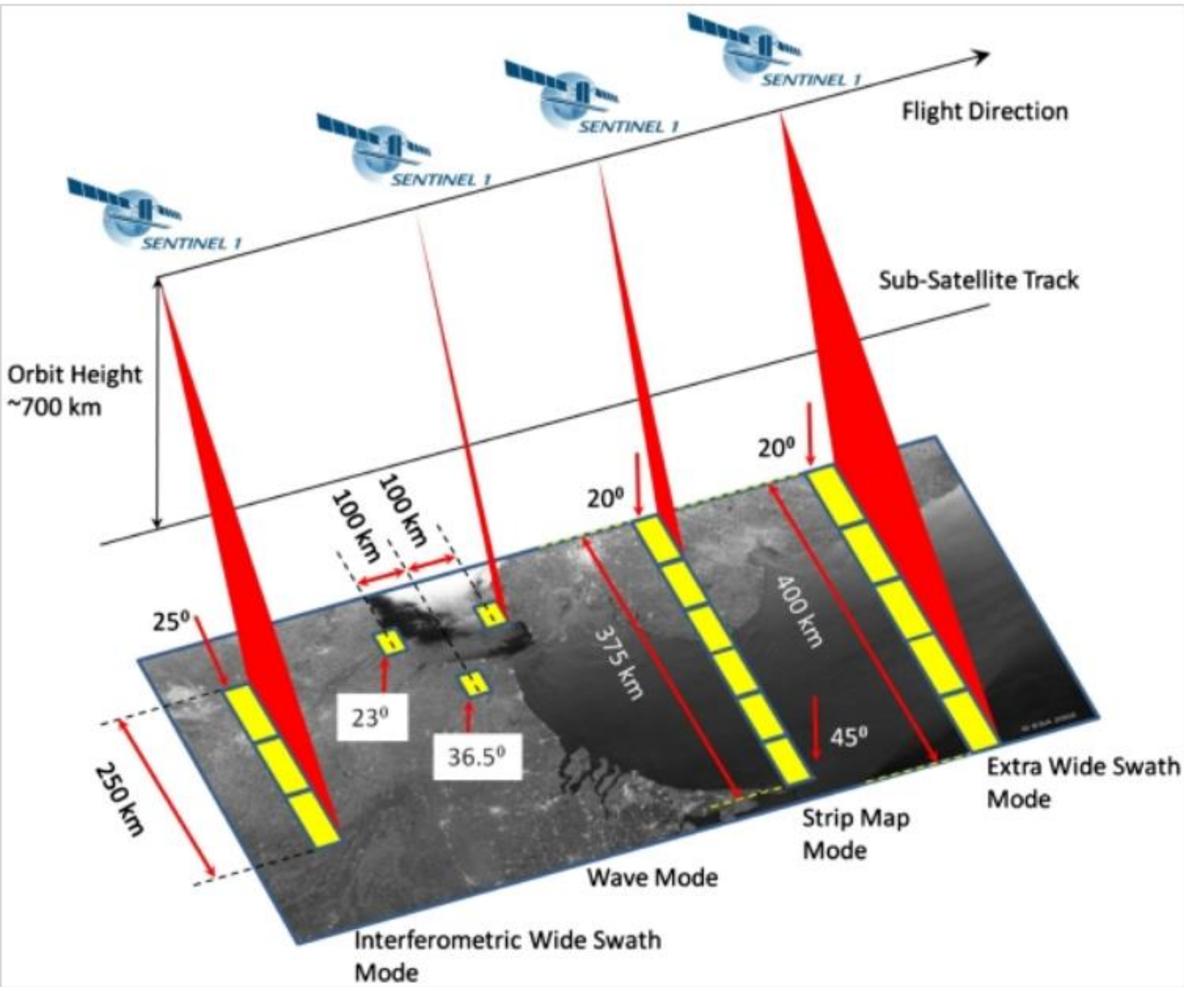


Figure 1 : Sentinel-1 Product Modes (Source : https://sentinel.esa.int/web/sentinel/user-guides/sentinel-1-sar/acquisition-modes)

3. Download of the 2 Sentinel-1 images (not in the video)

- Go to the "**Copernicus Open Access Hub**" https://scihub.copernicus.eu/dhus/#/home
- **Create an account and then log in**
- **Search and download the 2 images**
    - You can use the image name (confer below) without ".zip" extension in the search menu to easily find the images, one by one (**Figure 2**)
    - The 2 images used are (table below):

Image timing	Date	Image filename
Archive image before the flood	2015 03 20	S1A_IW_GRDH_1SSV_20150320T114745_20150320T114810_005115_0066FA_82D7.zip
Crisis image during the flood	2015 09 04	S1A_IW_GRDH_1SSV_20150904T114747_20150904T114812_007565_00A772_B9FD.zip

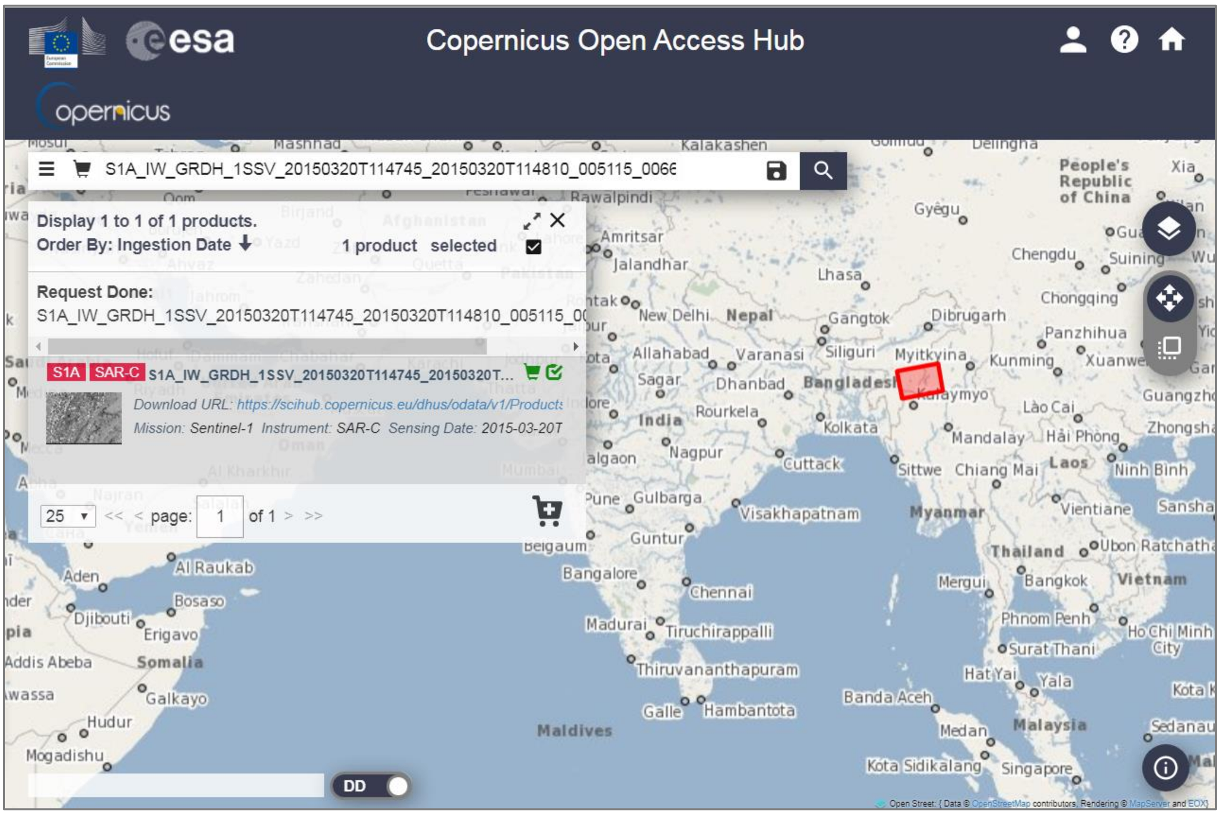


Figure 2 : Copernicus Open Access Hub with one of the 2 Sentinel-1 images identified over Myanmar

4. SNAP software - Download and installation (not in the video)

- You can **download the free SNAP software** here:
  - https://step.esa.int/main/download/snap-download/
  - Choose the « Sentinel Toolboxes » or "All Toolboxes" in the table and the download adapted to your operating system
- **Install SNAP** on your computer and make the updates after installation

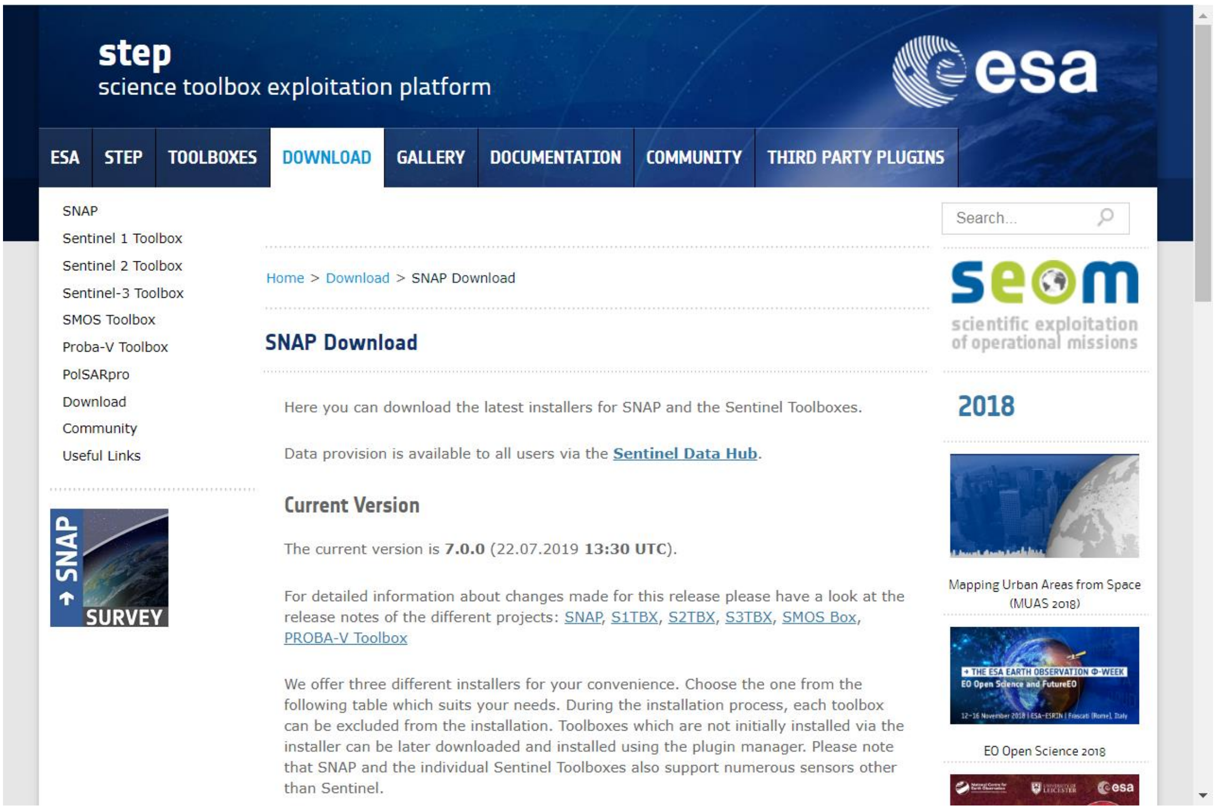


Figure 3 : Outlook of the SNAP (STEP) software download web page

5. Opening of the 2 Sentinel-1 images in SNAP (video timing: 0 min 30 sec)

- Simply **drag and drop the zip images to the "Product Explorer" tab of SNAP** (there is no need to unzip the images!)
- In the "World View" tab, you can see that the images are over a part of Myanmar
- In the "Product Explorer" tab, expand for each image the **sub-folder "Bands > Amplitude_VV" and double-clic on "Amplitude_VV"** which will open the images in the viewer
    - Open first the Archive image → in viewer 1
    - Open then the Crisis image → in viewer 2
- Remarque: notice that there are 2 bands per image, **Amplitude and Intensity**. **Definition:**
    - **Amplitude_VV image**
        - "*A SAR signal contains **amplitude and phase** information. **Amplitude** is the strength of the radar response*" (source: https://sentinel.esa.int/web/sentinel/user-guides/sentinel-1-sar/product-overview/interferometry).
        - *"Measure of the strength of a signal, and in particular the strength or **height of an electromagnetic wave** (units of voltage)."* (source: https://earth.esa.int/handbooks/asar/CNTR5-2.html)
    - **Intensity_VV image**
        - Intensity = Amplitude_VV * Amplitude_VV
- Observe the images (**Figure 5**):
    - You can zoom or move into the images by using the mouse wheel or the panning tool 
    - In the crisis image:
        - **Flooded area**: appears darker because of a low backscatter due to specular reflection over the smooth water surfaces: the signal get reflected away from the sensor.
        - **The surrounding areas**: are much rougher and look brighter.
        - **Images distortion** is visible in the mountain areas of the image due to the **layover and foreshortening effects** (**Figure 4**)

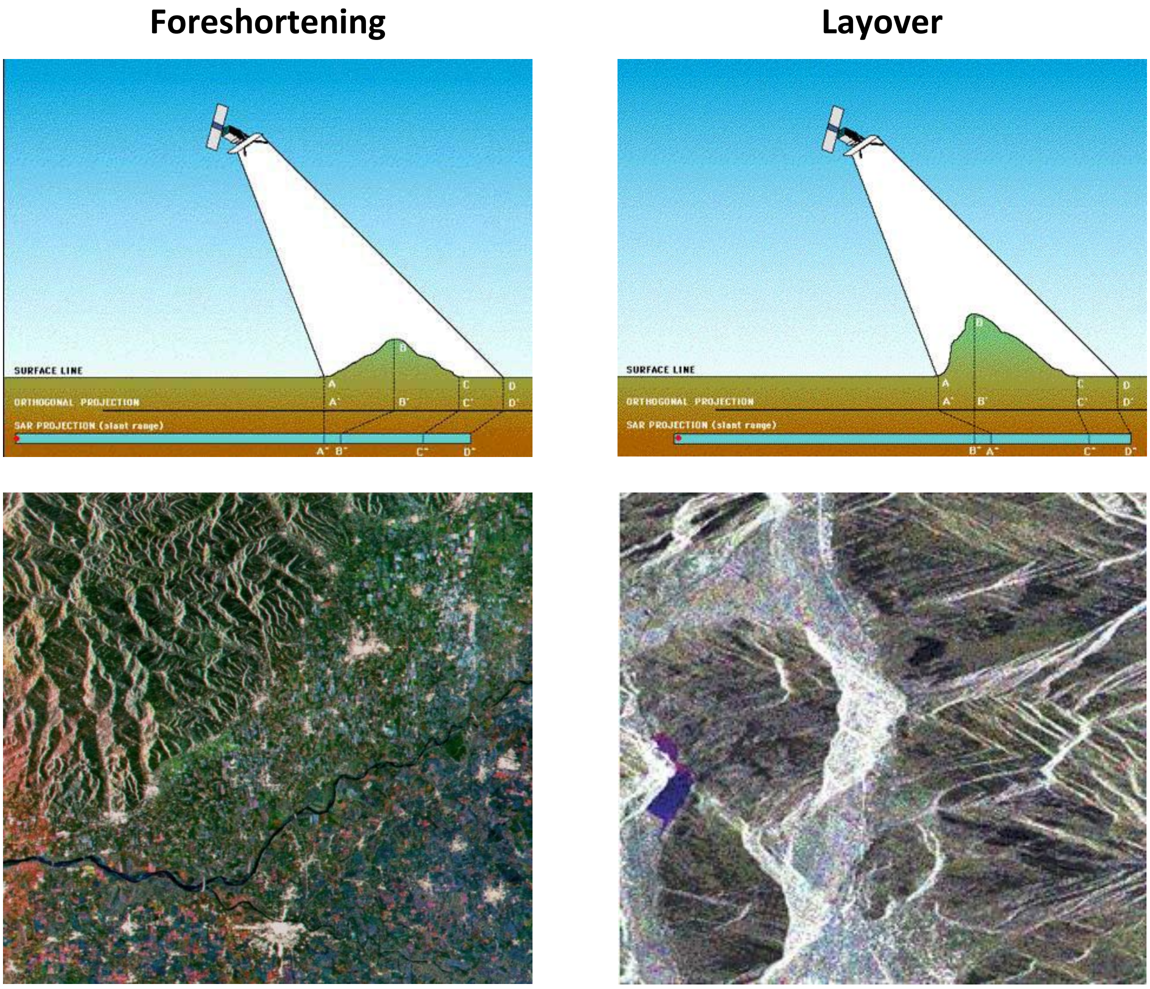


Figure 4 : Illustration of the Foreshortening and Layover effects: geometric distortions in mountainous regions (Source: https://earth.esa.int/web/guest/missions/esa-operational-eo-missions/ers/instruments/sar/applications/radar-courses/content-2/-/asset_publisher/qIBc6NYRXfnG/content/radar-course-2-slant-range-ground-range#sixteen)

6. Main steps of the workflow described in this document (video timing: 2 min 18 sec)

- Make a **spatial subset** of the images around the river over the flooded areas
- Apply a **"multilooking"** in order to reduce the speckle, and this also reduces the dimension of the images and speed up the processing time
- Apply a **calibration** which is essential to compare 2 images: to go from Digital Numbers (DN) to a physical quantity which is in this case "sigma0 backscatter"
- Apply a **terrain correction** to project the images onto a map system and also to correct for the distortions due to the terrain
- Combine the **2 images in a RGB composite** in order to distinguish between flooded areas and permanent water bodies

7. Visual analysis of the 2 images side by side (video timing: 3 min 09 sec)

- **Menu: Window > Tile evenly**
- You should **synchronize the 2 windows** (and optionally the mouse pointer) by using, in the “Navigation” tab of the bottom left panel, the 2 related tools button

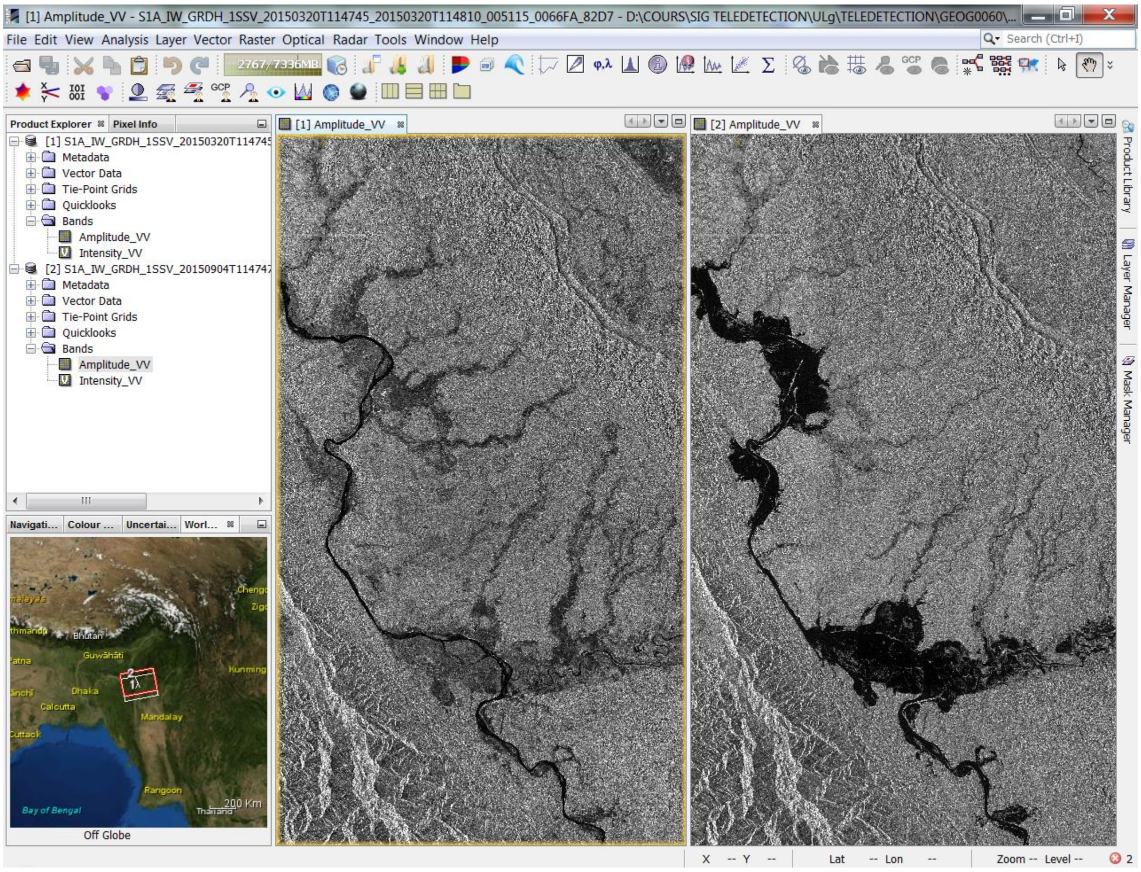


Figure 5 : The archive/normal situation (left) and crisis/flood (right) Sentinel-1 images over Myanmar displayed evenly in SNAP interface

8. Analysis of images Metadata (video timing: 3 min 15 sec)

- In the “**Product Explorer**” tab, open the subfolders “**Metadata > Abstracted Metadata**” and double-click on it to open it (**Figure 6**). You can see that:
    - Both images were acquired in the **same geometry** which is essential for flood mapping:
        - PASS = **ASCENDING**: satellite ascending
        - incidence_near (30.9°) & incidence _far (46.1°): **same incidence angle**
    - PRODUCT_TYPE = **GRD**
    - ACQUISITION_MODE = **IW**
    - mds1_tx_rx_polar = **VV** (and no info for mds2…, mds3…, mds4…)
    - etc
- There is a **shift in Azimuth** (in the North-South direction, the 2 images do not perfectly cover the same area) but this is not a problem
- To know what image is open in what tab: look at the number between [] both in the “Product Explorer” tab and in the visualization windows

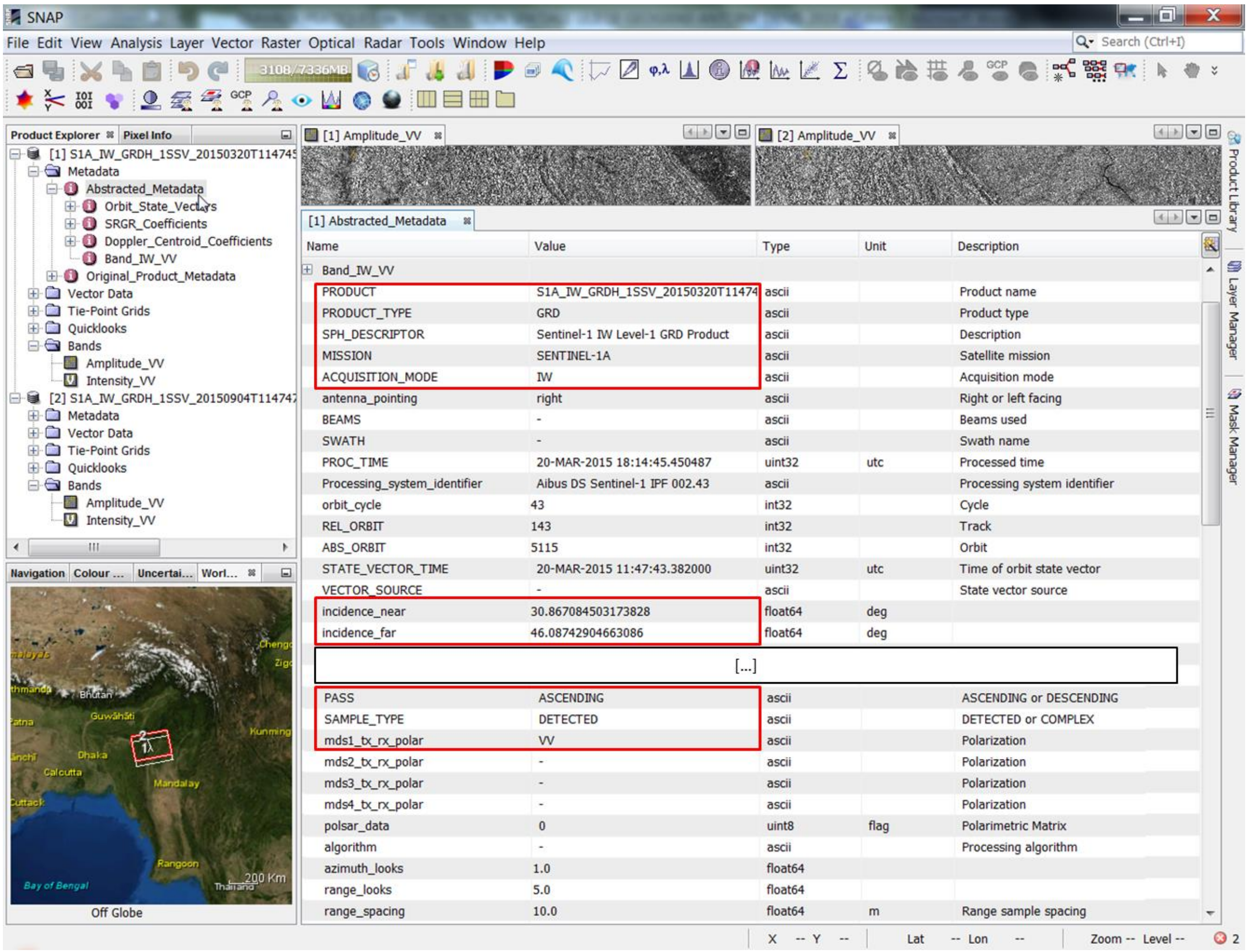


Figure 6 : Outlook of some Abstracted Metadata of one Sentinel-1 image. The […] means that some metadata are skipped from this illustration

9. Spatial subset of the images, on an area common to the 2 images, where the main floods occur (video timing: 3 min 53 sec)

- Identify in the navigation tab an **area which is common to both images**: zoom and pan in order to display that common area in the viewers (**Figure 5**)
- **Click**, in the geographical interface, on the image you want to process in order to select/active it, in order to use this image current extent for the spatial subset
- **Menu: Raster > Subset (video timing: 4 min 03 sec)**
  - The subset corresponds to the extent of the viewer. You can visually check that in the tool interface
  - Click OK
  - Repeat the operation for both images

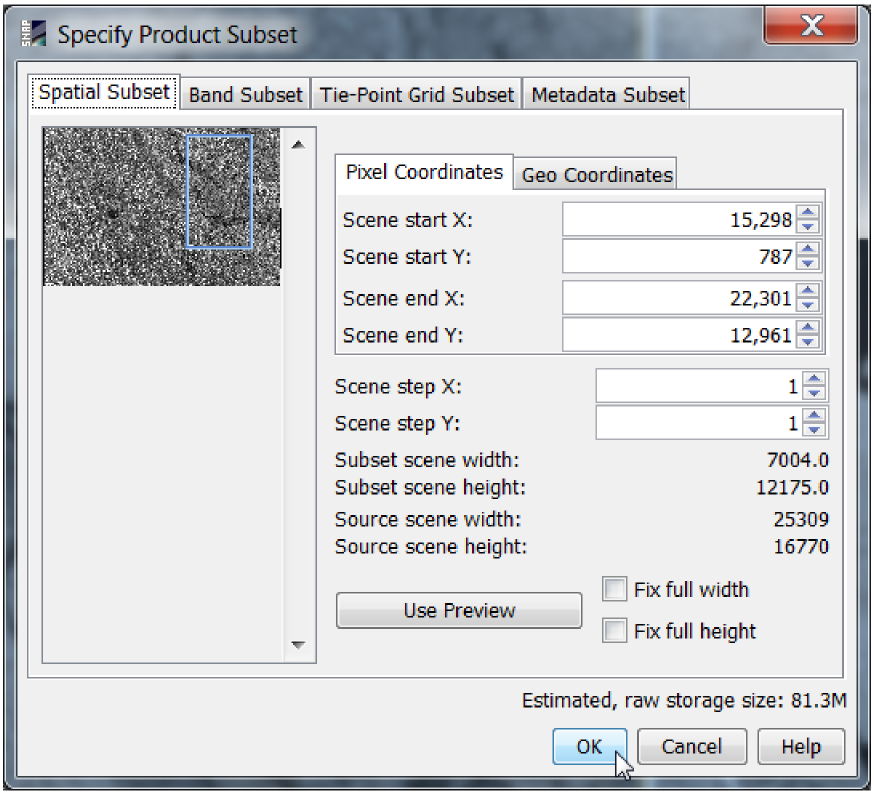
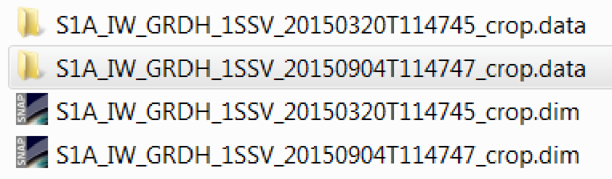


Figure 7 : Spatial subset of Sentinel-1 image

- The outputs appear automatically in the "Product Explorer" as virtual files/image.
- They then have to be **saved to real file (real image)** with either
  - Select the file in the **"Product Explorer" tab, then File > Save Product >**
  - or Right click on the file in the "Product Explorer" tab, then > Save Product
- Say **Yes to BEAM-DIMAP format**
- Give a **Shorter filename** than the original long filename:
  - Keep the most important information: date product, processing level etc
  - Remove the automatically created prefix ("subset_0_of_")

  - And give also a **suffix "crop"** (or "subset") in order to easily identify the output image as the subset image
  - Select your working directory where to store the output images
  - The **output filenames** of the 2 images are, in the video:
    - S1A_IW_GRDH_1SSV_20150320T114745_crop.zip
    - S1A_IW_GRDH_1SSV_20150904T114747_crop.zip
  - Click on Save
- The **2 subseted images** are now present in you working directory



10. Intermediate steps: closing/opening images (video timing: 6 min 00 sec)

- **Close all images** in the "Product explorer" tab
  - **Right click in the left panel > Close All Products**
- **Open only the 2 subset images** in SNAP
  - **Drag and drop them to the "Product explorer"** tab from your working directory

11. Multilooking (video timing: 6 min 30 sec)

- **Purpose:** to **reduce the speckle** and **reduce the dimension** of the image **to speed up the processing time**. This will also result in a **loss of accuracy** (spatial resolution) but this is not a problem in this particular case because the flooded area is large and we are not particularly interested in having a high resolution flood map.
- **Menu: Radar > SAR Utilities > Multilooking** (this directory is a bit different than in the tutorial video due to different SNAP software versions) (Figure 8)
  - **In the "I/O Parameters" window**
    - Keep default added **suffix "ML"** in the output filename
    - Select your working directory as output directory
  - **In the "Processing Parameters" window**
    - Set the **Number of Range/Azimuth Looks to 3 by 3**
  - Click on Run
  - Repeat the process for the other image

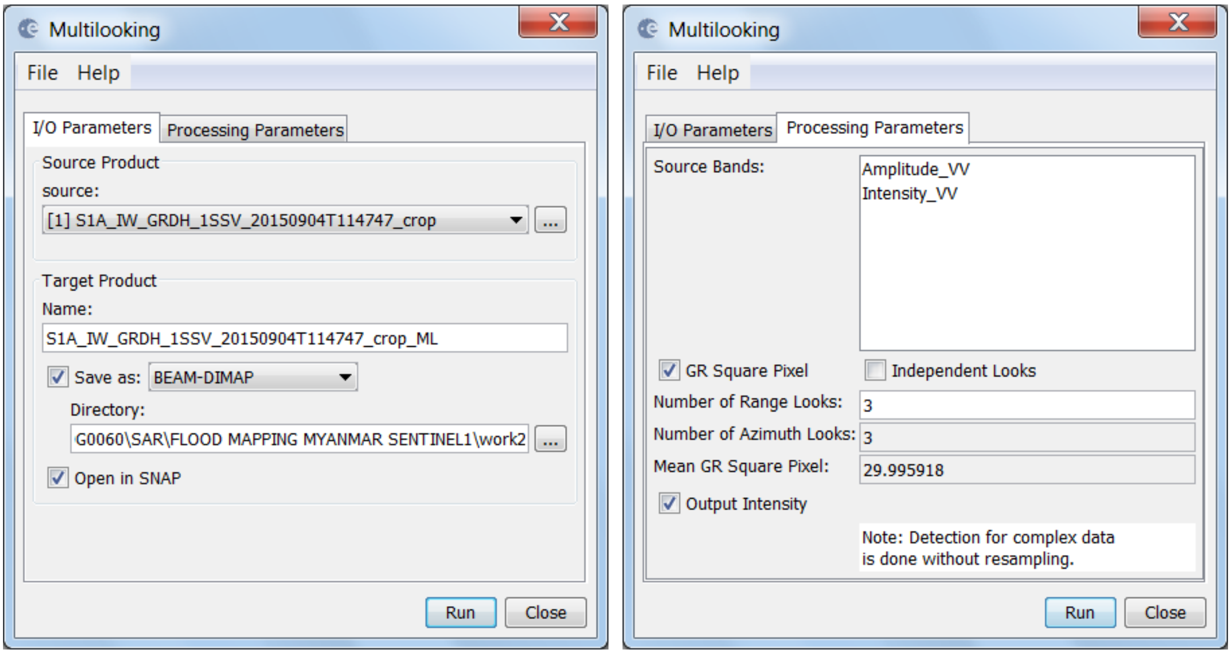


Figure 8 : Parametrization of the Multilooking tool of SNAP

- (**Remarque:** after this operation, the subseted images cannot be synchronized well with the original images because a size reduction has been applied, reason why all products were closed in the previous "intermediate steps")

12. Radiometric Calibration (video timing: 7 min 35 sec)

- Calibration is essential to enable the comparison of the 2 images
- Calibration transforms Digital Numbers (DN) to a physical quantity which is in this case **“sigma0 backscatter”**
- **Definition:**
  - *“**Backscatter**: […] The normalised measure of the radar return from a distributed target is called the **backscatter coefficient**, or **sigma nought** , and is defined as per unit area on the ground.”*
  - *“**Sigma Nought**: Scattering coefficient, or the conventional measure of the strength of radar signals reflected by a distributed scatterer, **usually expressed in dB**. It is a **normalised dimensionless number**, comparing the strength observed to that expected from an area of one square meter.”*
  - (Source: https://sentinel.esa.int/web/sentinel/user-guides/sentinel-1-sar/definitions)
- **Menu: Radar > Radiometric > Calibrate (Figure 9)**
  - **In the “I/O Parameters” window**
    - Select the “ML” images as input
    - Keep default added **suffix “Cal”** in the output filename
    - Select your working directory as output directory
  - **In the “Processing Parameters” window**
    - **Check “Output sigma0 band”** (= ratio instant/receive backscatter per unit area in ground range)
  - Click on Run
  - Repeat the process for the other image

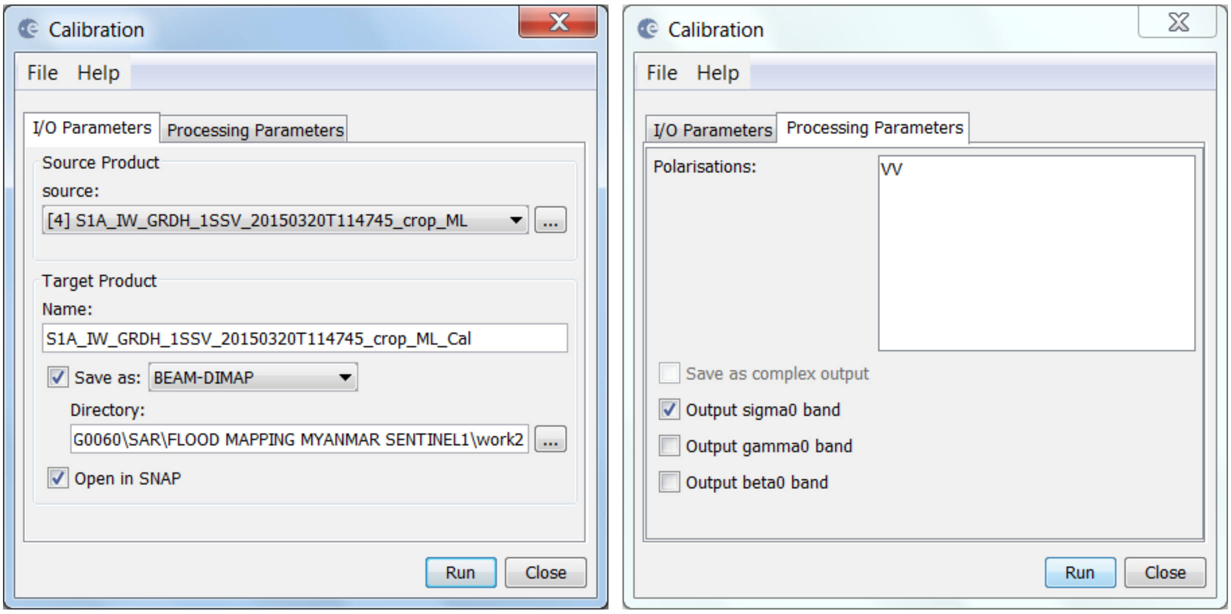


Figure 9 : Parametrization of the Radar Radiometric Calibration tool of SNAP

13. Intermediate steps: visualization (video timing: 8 min 22 sec)

- **Visualize the 2 sigma0 images** in the viewer
  - Double-click on each calibrated images in the "Product Explorer" window to open them in the SNAP viewer ("Sigma0_VV" is the name of the calibrated images)
  - **Menu: Window > Tile Evenly** to display the images side by side

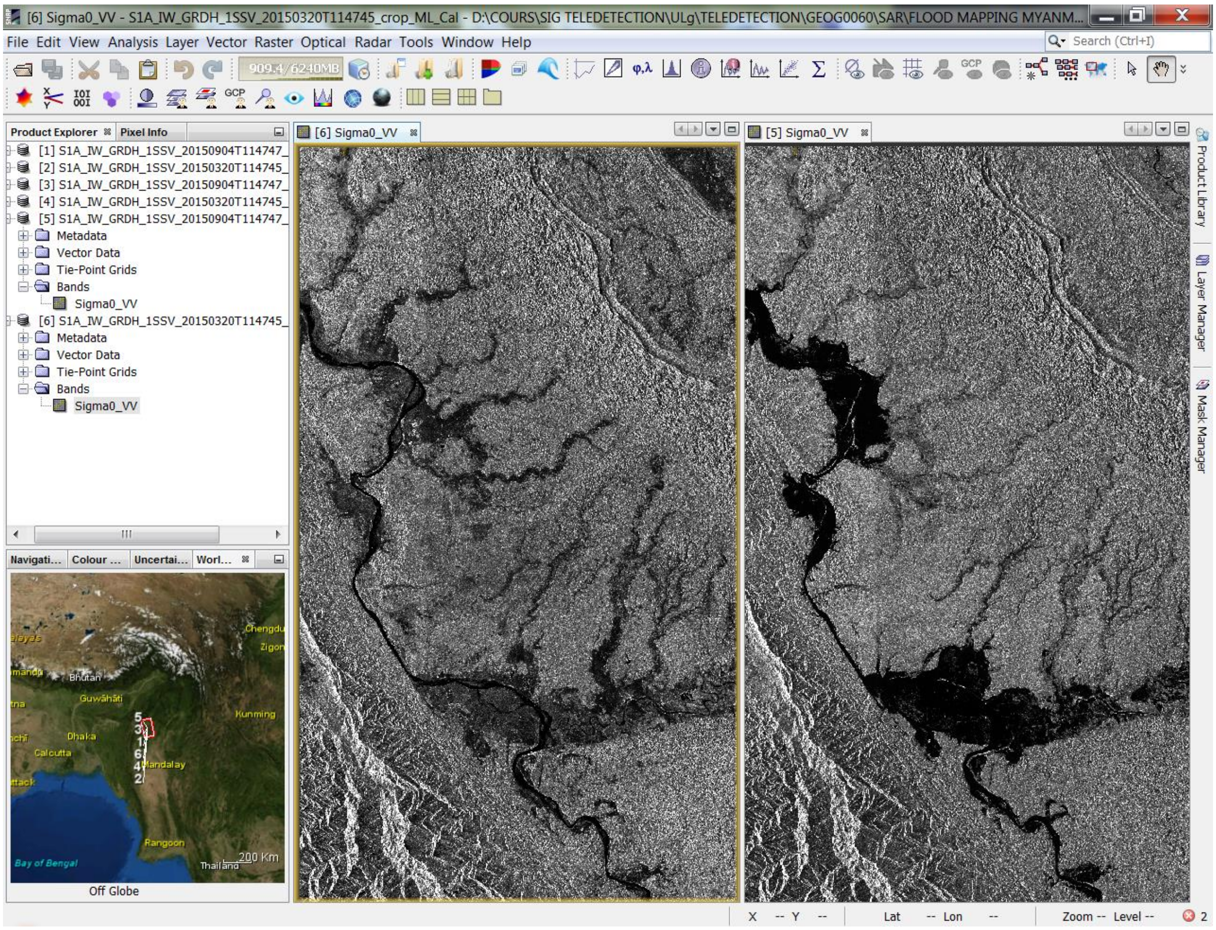


Figure 10 : Subseted, Multilooked and Radiometrically Calibrated (Sigma0_VV) Sentinel-1 images displayed side by side

- Many pixels are quite dark
- Select the flood image in the viewer
- Go to the Colour Manipulation window (bottom left panel):
  - Most of the pixels have low backscatter value
  - Few pixels have very high value
- Convert values from **linear scale to non-linear logarithmic scale decibel (dB)** to get a better visualization and an histogram easier to manipulate
  - **Right click on the band to convert (Sigma0_VV) > Linear to/from dB > Yes to create a new virtual band**
  - Repeat that for the other image
- **Open** the 2 converted images in dB by double-clicking on them

- **Menu: Window > Tile evenly** (you can rearrange the windows if you want) (**Figure 11**)
- In dB, there is a much better distinction between land and water pixels
- We can see 2 peaks in the dB images histograms:
    - 1 small low values peak for pixels over water
    - 1 big high values peak for land pixel
- Close all images from the viewer but keep the images in the "Product Explorer" tab

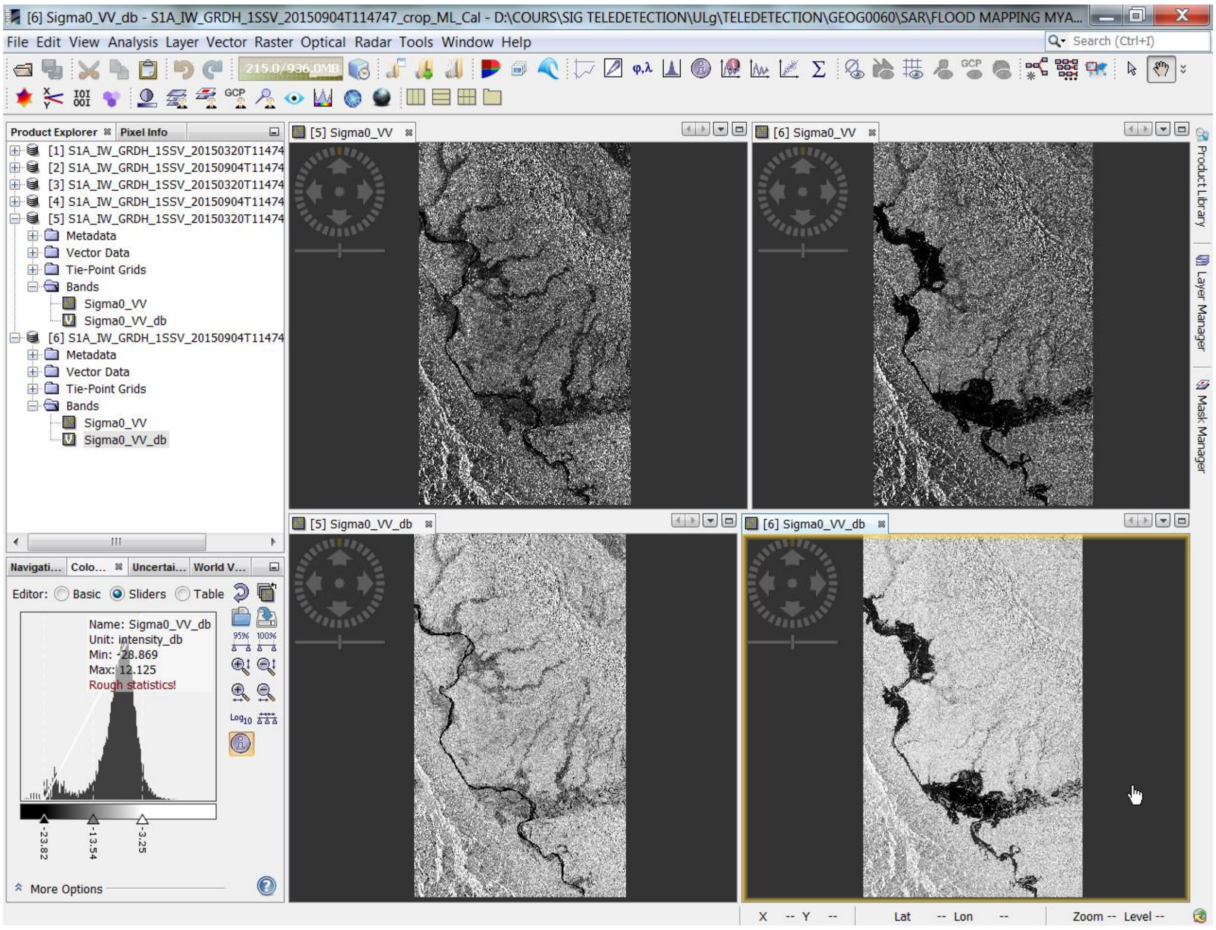


Figure 11 : Comparison of the Sigma0_VV Sentinel-1 images before (above) and after (below) the "Linear to/from dB" image histogram conversion for the archive (left) and flood (right) images

14. Terrain Correction (video timing: 10 min 22 sec)

- **Purpose:**
  - To **project the image into a coordinates system**, and
  - To **correct for distortion due to the mountainous terrain**
- **Menu: Radar > Geometric > Terrain correction > Range-Doppler Terrain Correction > all parameters by default > Run (default suffix = TC)** (Figure 12)
  - **In the "I/O Parameters" window**
    - Select the "ML_cal" images as input
    - Keep default added suffix "**TC**" in the output filename
    - Select your working directory as output directory
  - **In the "Processing Parameters" window**
    - Keep all default parameters (WGS84 map projection)
  - Click on Run
  - Repeat the process for the other image

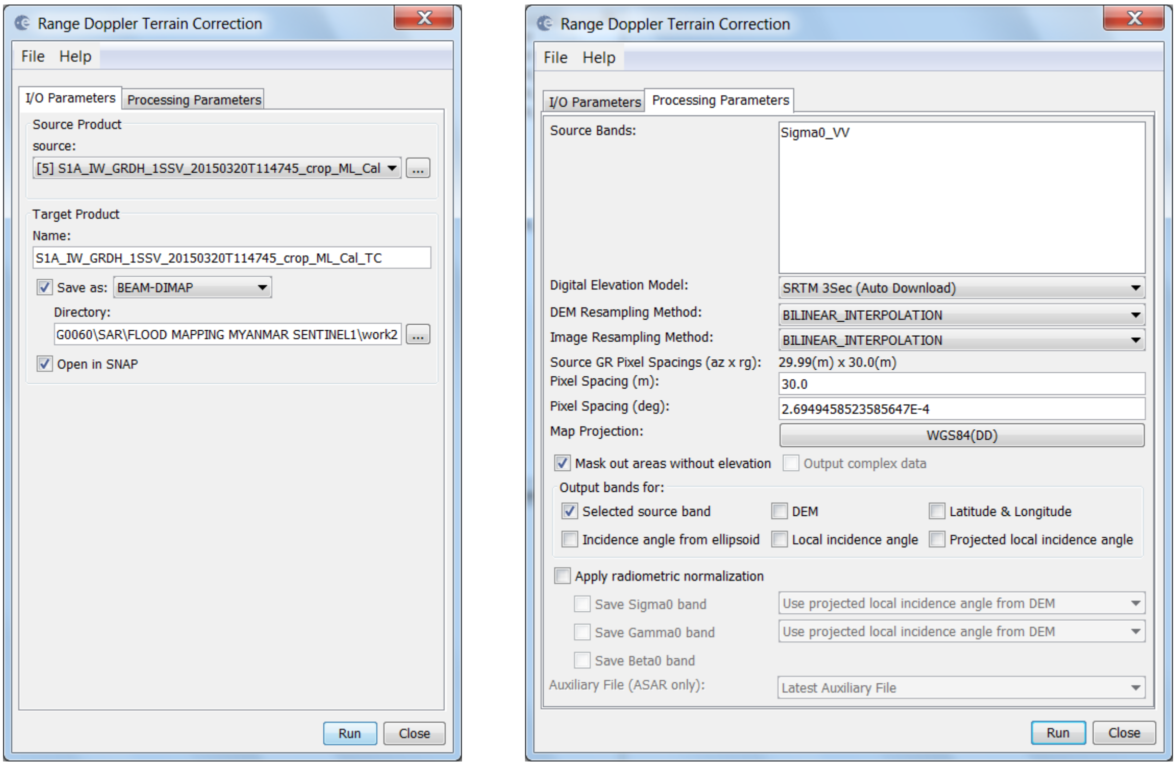


Figure 12 : Parametrization of the Range Doppler Terrain Correction tool of SNAP

15. Visualization of the terrain corrected images (video timing: 11 min 32 sec)

- **Convert the "TC" bands to dB** (confer method explained above)
- **Convert the virtual created dB bands to real file**
    - **Right click on the dB band > convert band**
- **Save to dB band to file**
    - **Select the dB band > Main menu File > Save Product**: this saves the dB band to the image
- **Visualize the dB terrain corrected bands**
    - The image has been projected into a coordinate system: the T**C image orientation has changed!** (**Figure 13**)
    - In order to be able to compare the non TC an TC images visually, you have to **unsynchronize the views** with the dedicated button in the "Navigation" tab (bottom left panel), and then **open each image** in a window that you can display side by side. You will maybe have to unzoom a lot from one of the two images to **adjust the visualization**.
    - There is **no more distortion in the mountain area** (**Figure 14**)
    - (You could also do a **contrast stretch** with the "Color Manipulation" tab (bottom left panel) to highlight only the pixels over the land)

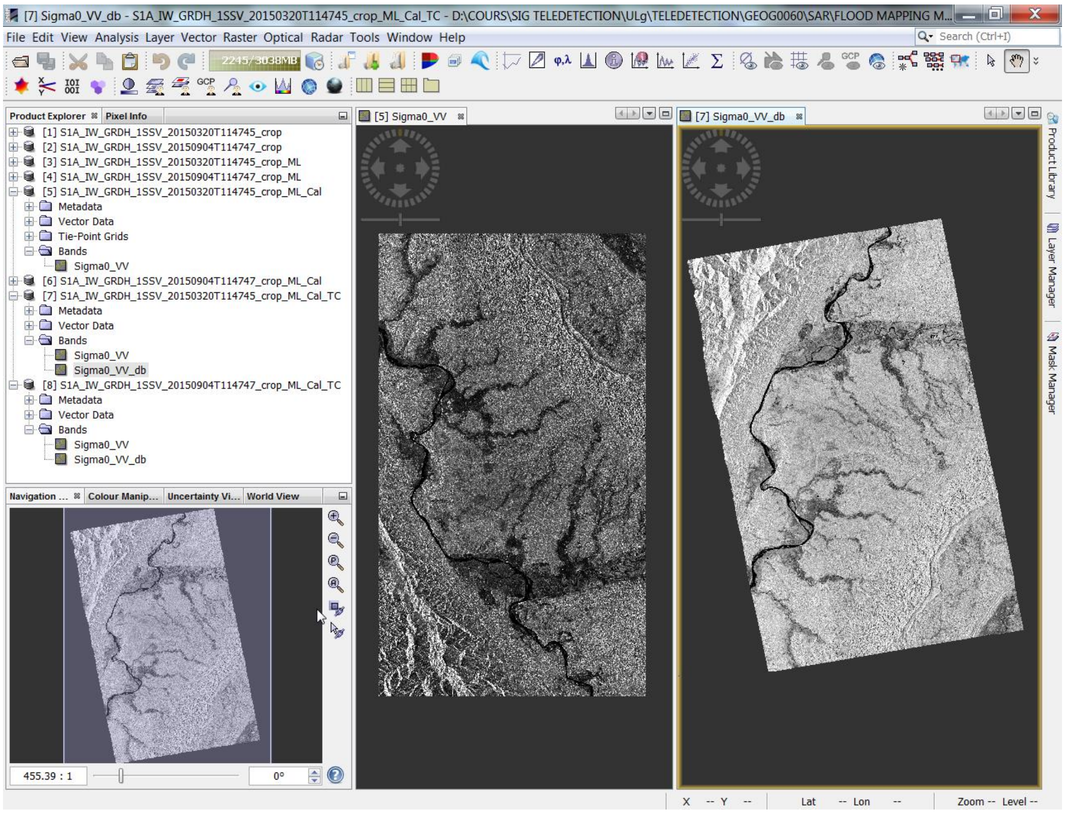


Figure 13 : Comparison of the archive Sentinel-1 images before (left) and after (right) the Terrain Correction: change of the image orientation due to the projection into a coordinate system

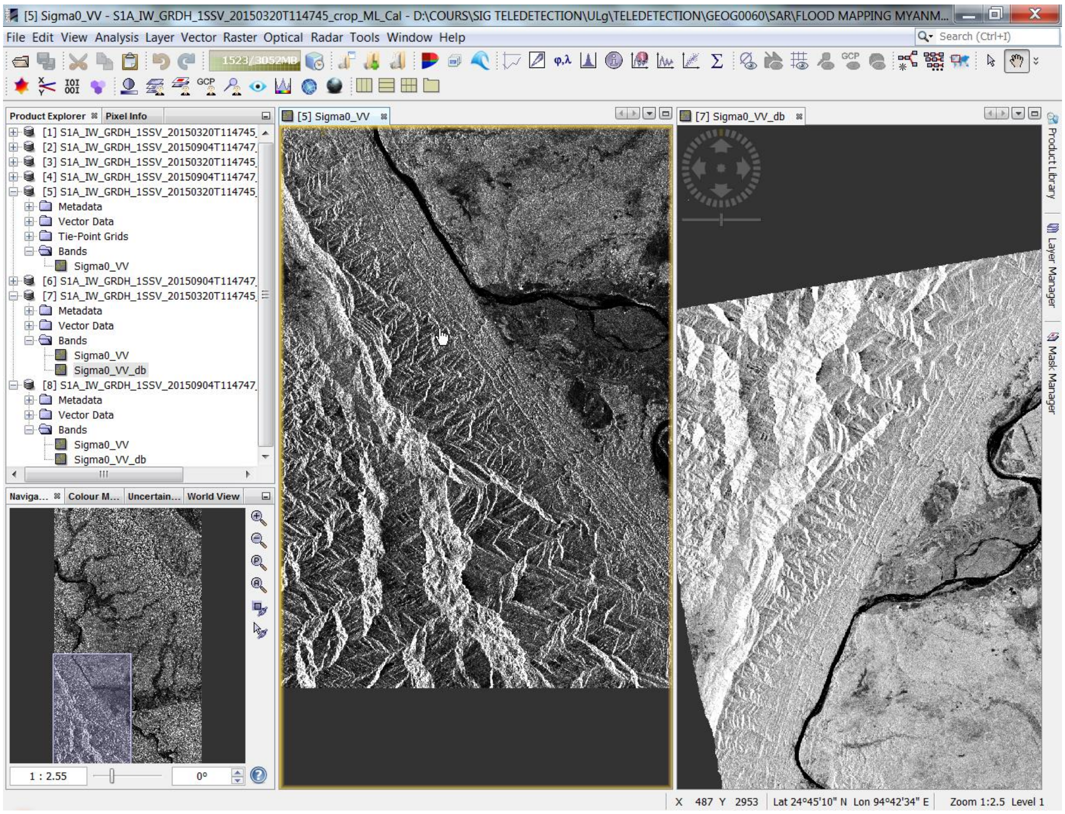
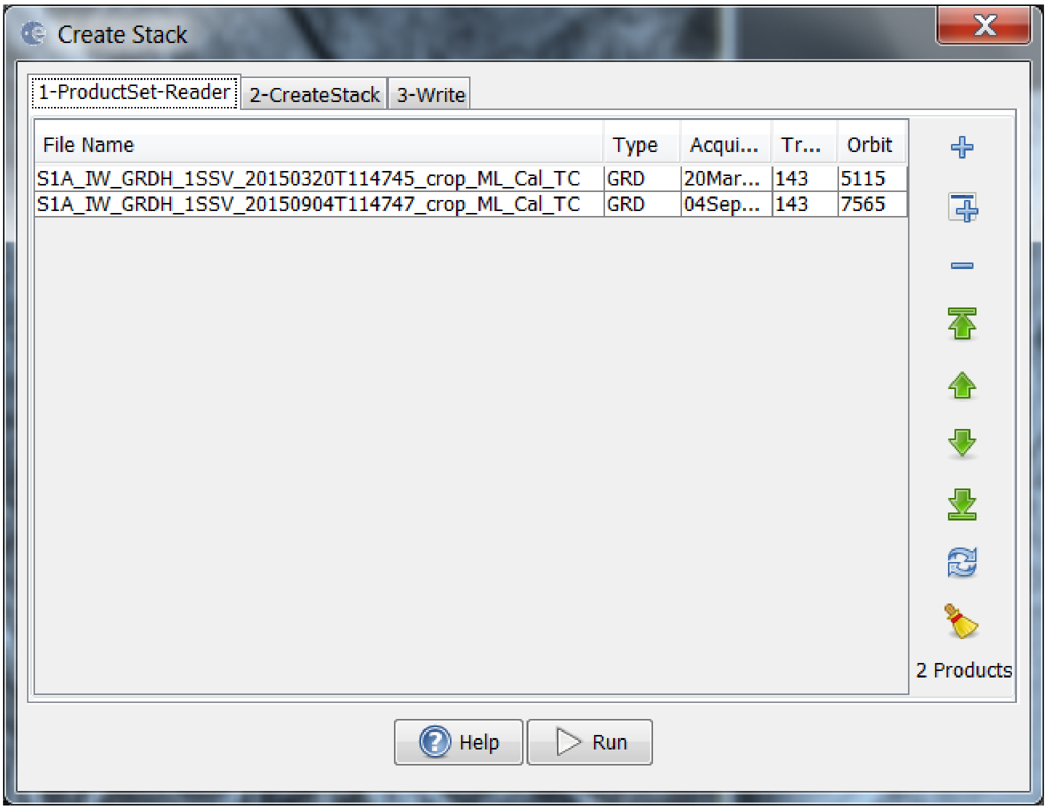


Figure 14 : Comparison of the archive Sentinel-1 images before (left) and after (right) the Terrain Correction for a mountainous area: the geometric distortion have been corrected

16. Combination of the Archive and Crisis images to produce a RGB composite of the flooded area, preliminary step: images stack (video timing: 13 min 25 sec)

- **Purpose of the RGB composite**: to enable the distinction of permanent water bodies and flooded areas.
- **Remarque**: The RGB composite is effectively produced in the section 18 page 22.
- **Application of a stack** by simply using the products geolocation
  - **Menu: Radar > Coregistraction > Stack Tools > Crate Stack tabs**
  - **In window "1-ProductSet-Reader"**
    - Click on the "Add opened" button > and keep only the TC file by removing unwanted files or open only the 2 images of interest with the Add button
  - **In window "2-CreateStack"**
    - Choose "Product Geolocation" for "Initial offset method"
    - ([…Remarque: for interferometry, a much more precise geolocalization method should be used…])
  - **In window "3-Write"**
    - Remove part of the filename which is not common to both images: the acquisition dates
  - Select Run
  - Close window



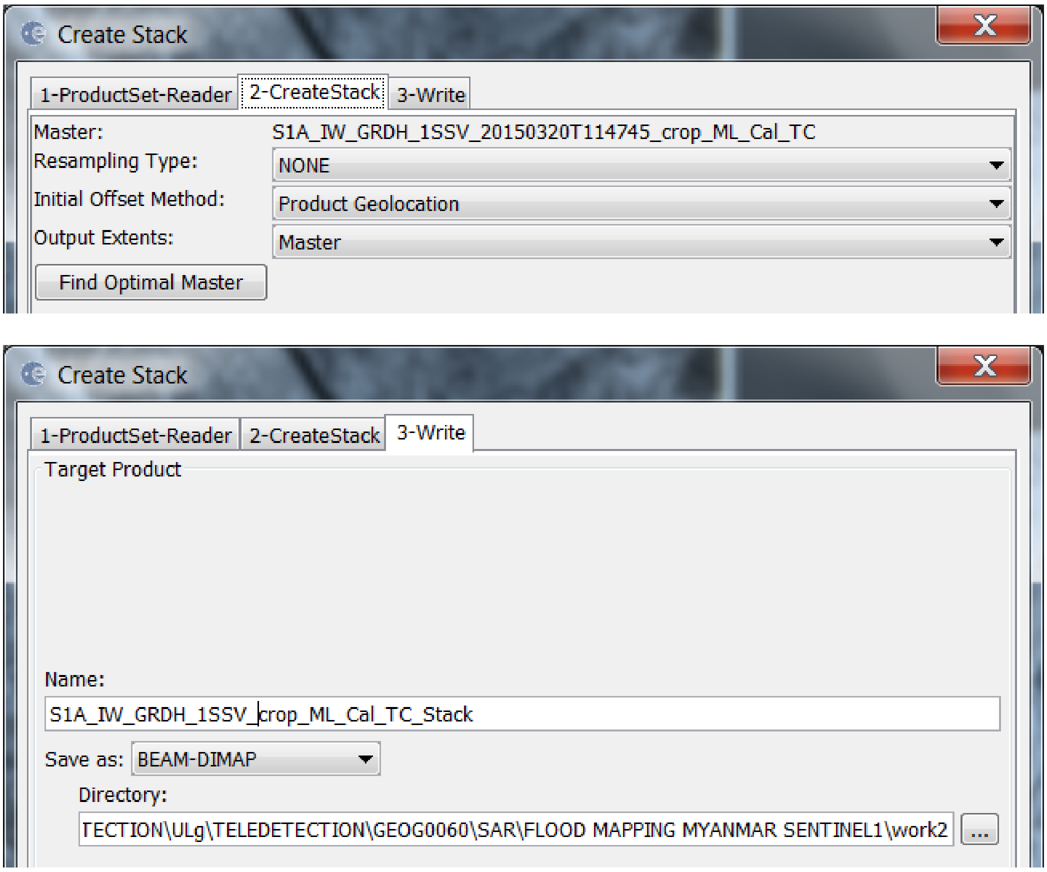


Figure 15 : Parametrization of the « Create Stack » tool of SNAP

17. Overlay of the stacked images for visual comparison of the 2 images (optional)

- **(This step is not really necessary in the general workflow) (video timing: 15 min 33 sec)**
    - We get the stack image file which is one single image file that contains **4 layers** coming from the 2 archive and crisis images in the “Bands” subfolder
    - **Open the 2 images in dB**
    - Apply a **contrast stretch** with the histogram focused on the higher pixel values peak
    - To **overlay the 2 images in the same viewer**:
        - Click on the Archive image in the viewer to select it
        - **Go to “Layer manager” (right panel) > + icon >Image of Band / Tie-point Grid > Next > overlay the 2nd image in dB (Crisis image) on the first one > Finish**
    - You can then compare both images by checking unchecking one image in the right panel “Layer manager” or by playing with the transparency slider at the bottom of the “Layer manager”

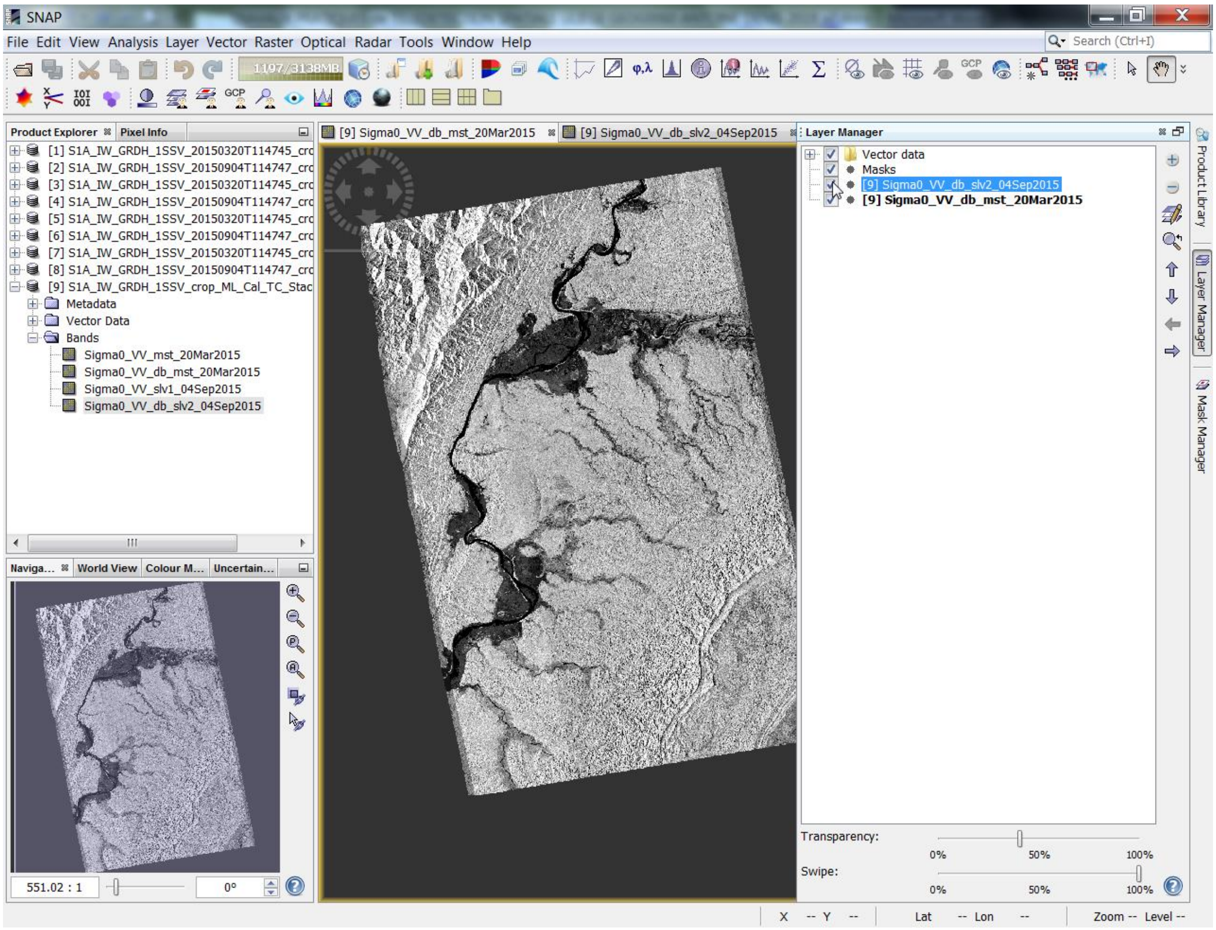
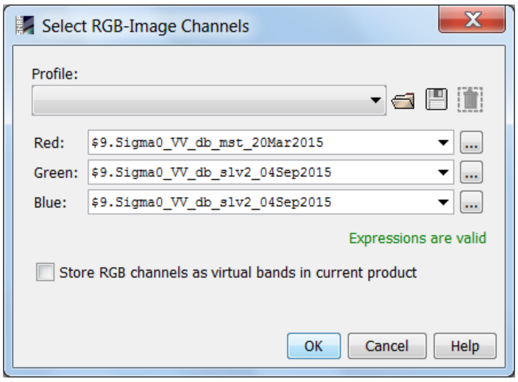


Figure 16 : Overlay of the 2 TC dB images in 1 viewer and use of the « Layer Manager » panel allowing to check/uncheck one of the 2 overlaid layers as well as applying a transparency in order to compare the 2 images

18. RGB composite image (video timing: 16 min 50 sec)

- **Purpose:** to distinguish between flooded area and permanent water bodies
- Select the name of the stack file in the "Product Explorer" window
- **Menu: Window > Open RGB window**
    - **Red band**: select Archive image
    - **Green and Blue bands**: select Crisis image
    - Click OK
    - View the flood map (**Figure 17**)



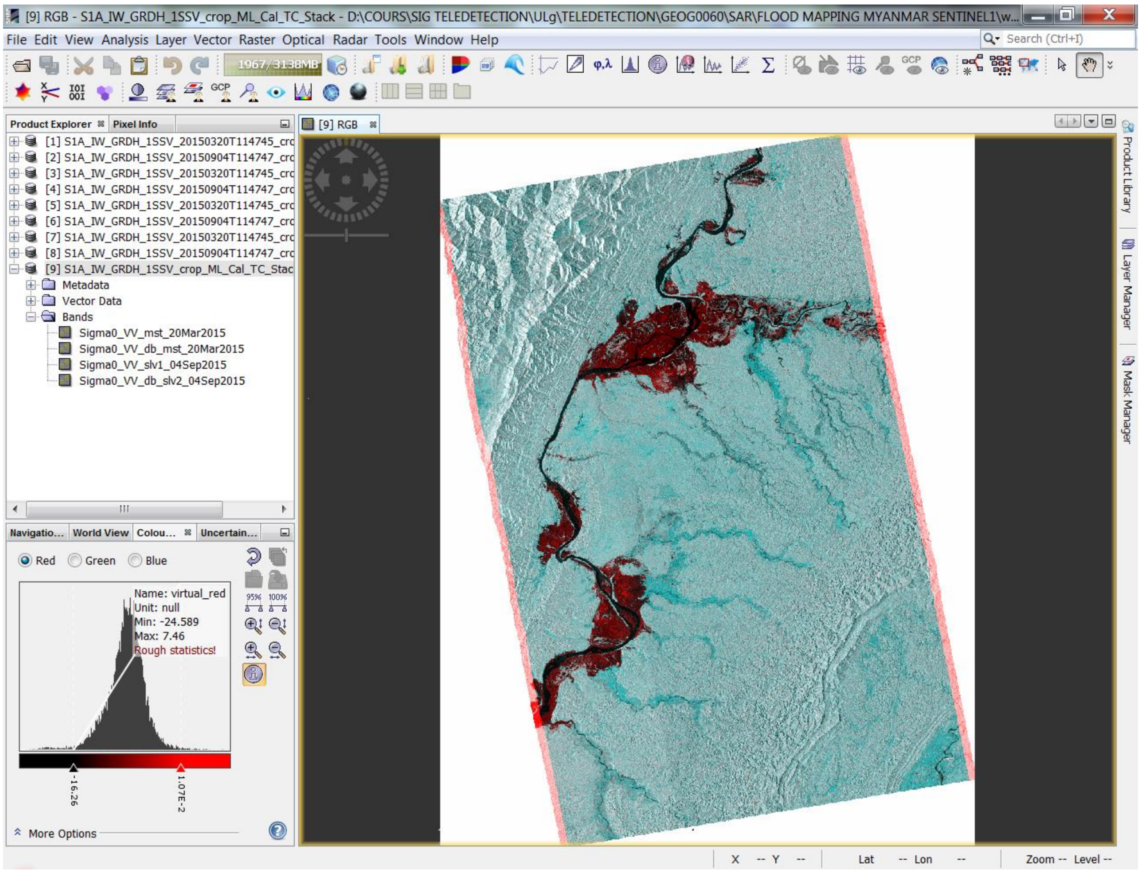


Figure 17 : RGB composite using, in the Red band, the Archive image, and in the Green and Blue bands, the Crisis image

19. Interpretation of the RGB composite (video timing: 17 min 28 sec)

- The **RGB composite image** is presented in Figure 17.
- **Flooded areas**
  - Appears **in red** because, given the selected RGB composite above, where floods occur,
    - the **Archive image** (in the red channel) has higher backscatter (no flood) than
    - the **Crisis image** (in the green and blue channel) (low backscatter for flooded areas)
  - So for flooded areas, there is a high value in the red channel and low value in the green and blue channels.
- **Non-flooded land**
  - Appears in **tones of gray** as there is approximately the same backscatter for the 2 images (no difference), and that that "same" information is associated to all 3 channels
- **Permanent water bodies**
  - Appears as **uniform dark areas** as there is a low backscatter values for both Archive and Crisis images, both associated to the 3 RGB channels
- **Some part of the land are cyan**
  - This translates a **higher response in the green and blue channels** corresponding to the crisis image, than in the Archive image. This may be due to particular ground cover which is not related to flood.

20. Exportation of the RGB composite of the flood map in another format and visualization of the result in GOOGLE EARTH PRO (video timing: 19 min 22 sec)

- (Menu: File > Export > Geotiff). This step is not done in the video. This is just an example.
- The **visualization of the RGB composite of the flood map in GOOGLE EARTH PRO** is presented in Figure 18.
- **Right click on the view > Export View as Google Earth KMZ**
  - Record the output in your working directory and call it for example "Flood"
  - Browse to you working directory where the file "**Flood.kmz**" has been saved
  - If you have **Google Earth Pro** installed on your computer, you can simply **double-click** on this file and it will automatically open in Google Earth at the right position.
  - (If you do not have Google Earth Pro installed on your computer, you can get it here for example: https://www.google.com/intl/fr_ALL/earth/versions/ (bottom of page))
  - You can then **compare the flood map with Google Earth Pro imagery** and also **check the registration** (georeferencing) of the flood map, which is good in this case (by deselecting the layer or playing with the layer transparency). In Google Earth Pro you

can also apply an **oblique view and ask for a 3D rendering of the natural relief** (that can be exaggerated: menu Tools > Options > 3D View > Relief > and set the elevation factor to 3).

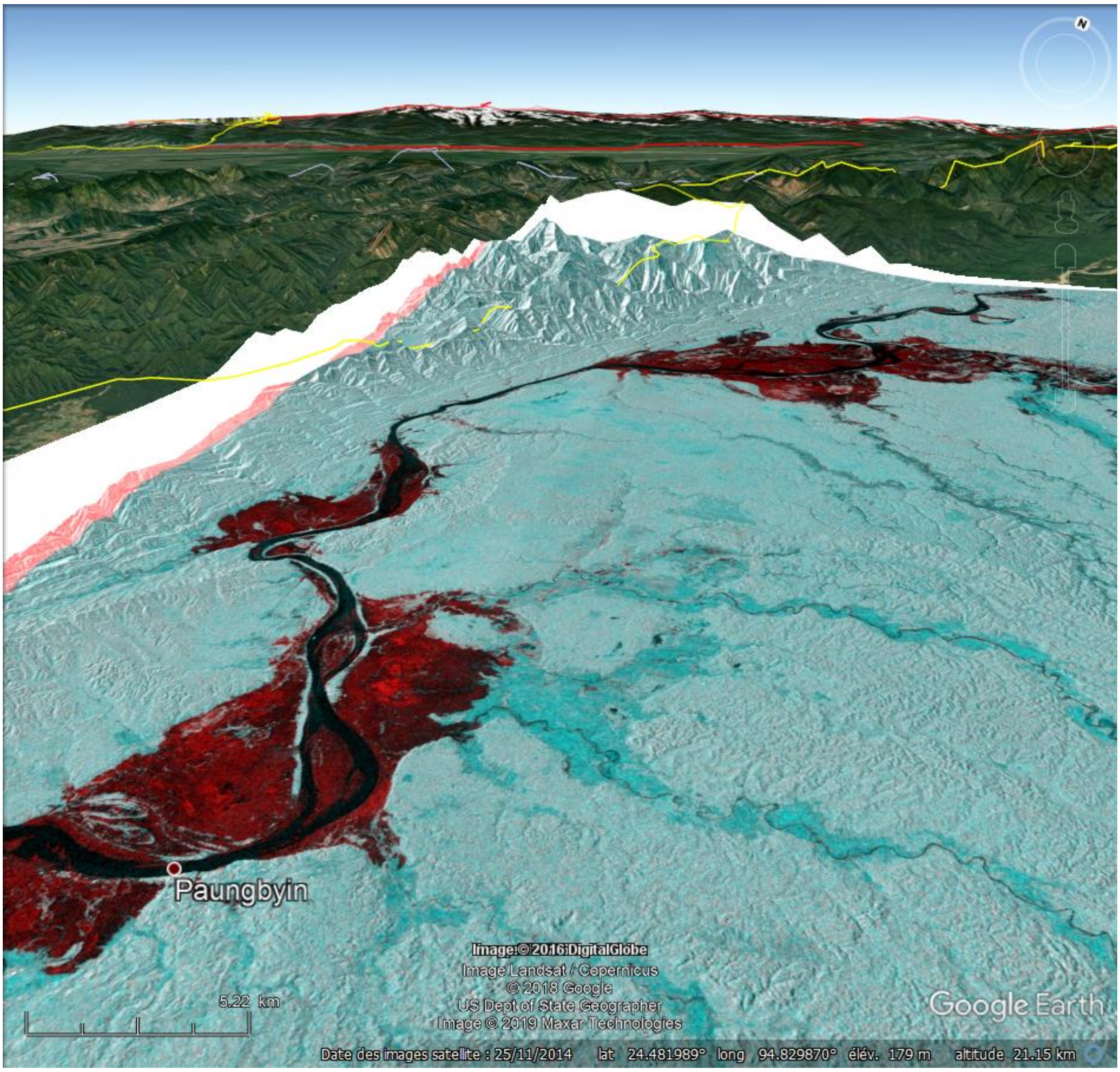


Figure 18 : Outlook of the RGB composite flood map overlaid in Google Earth Pro with an oblique 3D view