Microwave Toolbox

ETAD Correction of Sentinel-1 Products

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ETAD Correction Tutorial

The goal of this tutorial is to provide novice and experienced remote sensing users with step-by-step instructions on how to apply the ETAD correction to Sentinel-1 products.

Background

What is ETAD Correction?

The Sentinel-1 Extended Timing Annotation Dataset (ETAD) is a new auxiliary product developed by ESA in a joint effort with DLR. The product provides additional layers of corrections to the Sentinel-1 products which allow achieving improved geodetic accuracy in centimetric levels.

The newly developed ETAD Correction operator in the microwave toolbox performs the ETAD correction for a given Sentinel-1 product. The operator allows the users to select the range and azimuth correction layers and applies them to the Sentinel-1 product.

The ETAD corrections are applied to the Sentinel-1 product in two ways:

1. For geodetic accuracy improvement, the operator applies the range and azimuth ETAD corrections to each pixel to get the accurate range and azimuth time indices for the pixel and then resamples the ETAD corrected pixels to a regular time grid.

2. For interferometric application, the operator computes the range corrections on ETAD grid and converts them to phases. The phase layer is saved as a Tie Point Grid (TPG) of the product. The operator also computes a tropospheric-to-height gradient layer and topographic height layer. These layers are also saved as TOGs of the product. All these ETAD data will eventually be used in the correction of the interferometric phase. During the ETAD correction, no image resampling is performed.

Depending on the user’s application, different ETAD correction is used. In this tutorial, we will show both of the ETAD corrections. We will refer the demonstration for the geodetic accuracy improvement as Demo 1 and the demonstration for InSAR improvement as Demo 2 for convenience.

Sentinel-1 Products Applicable

Since the ETAD products are generated using the Sentinel-1 Interferometric Wide (IW) and Stripmap (SM) products as input, the ETAD products are available for the Sentinel-1 IW and SM products and can be applied to both the Sentinel-1 TOP SLC and SM SLC products.

Since the ETAD products are systematically produced for the Sentinel-1 IW and SM products, the ETAD products are also available for the Sentinel-1 GRD products and can be applied to the GRD products. However, the GRD is never suited for accurate geometric assessment because the ground-to-slant projection cannot revert the mosaicking of the burst data to correctly handle the burst overlaps. It is strongly advised to use SLCs only for geometric evaluation.

Preparation

Download the Data

In this tutorial, we show both the ETAD correction for the geodetic accuracy improvement (Demo 1) and the ETAD correction for InSAR improvement (Demo 2).

For Demo 1, we use the following Sentinel-1 TOPS SLC product and its corresponding ETAD product. The product is over Surat Basin in south-east Queensland, Australia (left in Figure 1).

S1A_IW_SLC__1SSH_20230722T083317_20230722T083345_049533_05F4C7_7C1C
S1A_IW_ETA__AXSH_20230722T083317_20230722T083345_049533_05F4C7_4344.SAFE

For Demo 2, the following two Sentinel-1 TOPS SLC products and their corresponding ETAD products are used. The products are acquired over the Saint-Etienne area in France (right in Figure 1).

S1A_IW_SLC__1SDV_20240812T173153_20240812T173220_055183_06B9C2_FAB2
S1A_IW_SLC__1SDV_20240824T173153_20240824T173220_055358_06C040_6841
S1A_IW_ETA__AXDV_20240812T173153_20240812T173220_055183_06B9C2_E046.SAFE
S1A_IW_ETA__AXDV_20240824T173153_20240824T173220_055358_06C040_5B80.SAFE

All the Sentinel-1 TOPS SLC products and their corresponding ETAD products above can be downloaded from the Copernicus Data Space Ecosystem at https://dataspace.copernicus.eu/ (login required, registration is free).

As some of the required steps are computationally intensive, it is good to store the data at a location which offers good reading and writing speed. If your computer has an internal SSD, processing should be done there to ensure best performance. Network drives or external storage devices are not recommended. Also, paths which include special characters should be avoided.

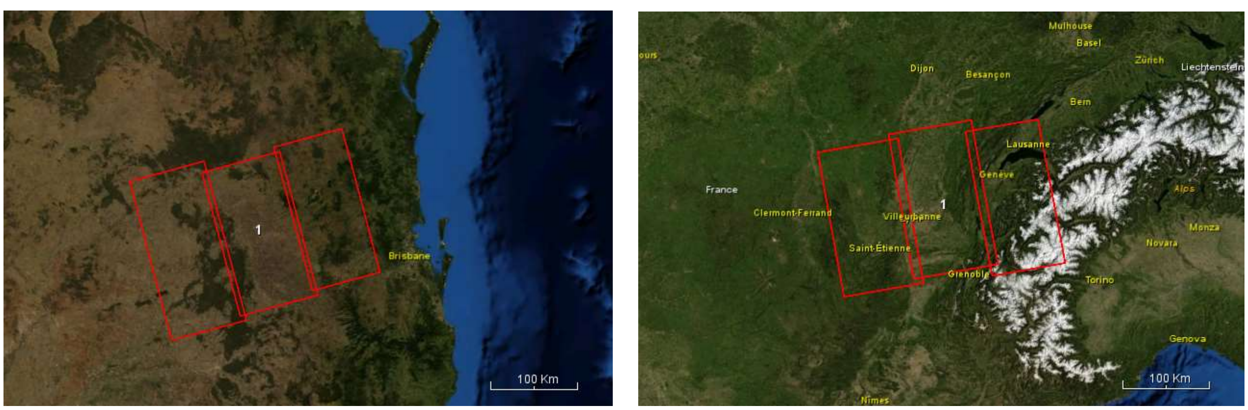

Figure 1 Data location: Surat, Australia (left) and Saint-Étienne, France (right)

ETAD Correction for Geodetic Accuracy Improvement

Prepare the Data for Demo 1

The IW products we used in this tutorial have three sub-swaths (IW1, IW2 and IW3) with different dimensions. In order to process them efficiently, we split the product into three sub-swaths and process each sub-swath individually.

To prepare the data for ETAD correction, we run the following graph for the Sentinel-1 TOPS SLC product (Figure 2):

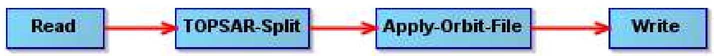

Figure 2 Graph for data preparation

For TOPSAR-Split operator, we select IW1 sub-swath and HH polarization. The Sentinel-1 TOP SLC product generally has 9 or 10 bursts in each sub-swath. If the interested area is covered by only a few bursts, for example burst 1 to 4, then you can select burst 1 to 4 to save some computations. For this tutorial, we use the default setting of the Split operator, i.e. all bursts.

For Apply-Orbit-File operator, we use the default parameters.

Then we got the following split products ready for ETAD correction:
S1A_IW_SLC__1SSH_20230722T083317_20230722T083345_049533_05F4C7_7C1C_Orb.data

Open the Split Product for Demo 1

Open the split product for Demo 1 in SNAP (Figure 3)

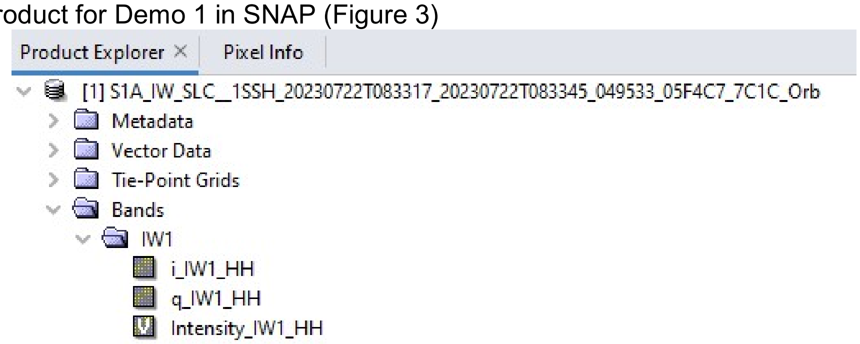

Figure 3 Split IW SLC product for Demo 1

ETAD Correction of the Split Product

Open Radar > Sentinel-1 TOPS > S-1 ETAD Correction operator and select the split product above as the Source Product (left in Figure 4).

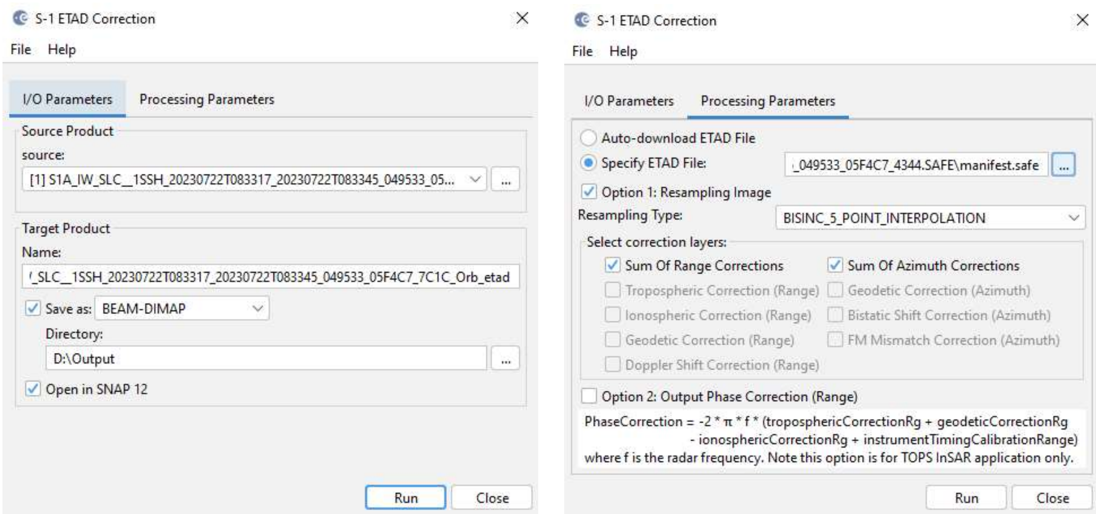

Figure 4 S-1 ETAD Corrector UI

For ETAD product selection, users have two options: “Auto-downloaded ETAD File” and “Specify ETAD File”. If “Auto-downloaded ETAD File” is selected, then the operator will find the corresponding ETAD product for the source product and download it automatically. However, the ETAD product is not always available in the Copernicus Data Space Ecosystem for its corresponding S-1 product. In that case users can select “Specify ETAD file” and use their ETAD product obtained from other sources for the correction. Here we select “Specify ETAD file” since we have already downloaded the ETAD product. To specify the ETAD file, we can either select zipped ETAD product or select the “manifest.safe” file in the unzipped product.

For the selection of the ETAD correction layers, users also have two options:

- Option 1 (Resampling Image) is for the geodetic accuracy improvement which is what we are going to do now. So select Option 1.
- Option 2 (Output Phase Correction) is for InSAR improvement. We will do it later in the second half of this tutorial.

In Option 1, users can select their desired correction layers. On the left are the range corrections while the azimuth corrections are on the right. For each column, users can select individual correction layers or select the “sum” layer which is the total summation of the individual layers. Here we select the “sum” layers for both range and azimuth corrections. Click on Run to start the ETAD correction.

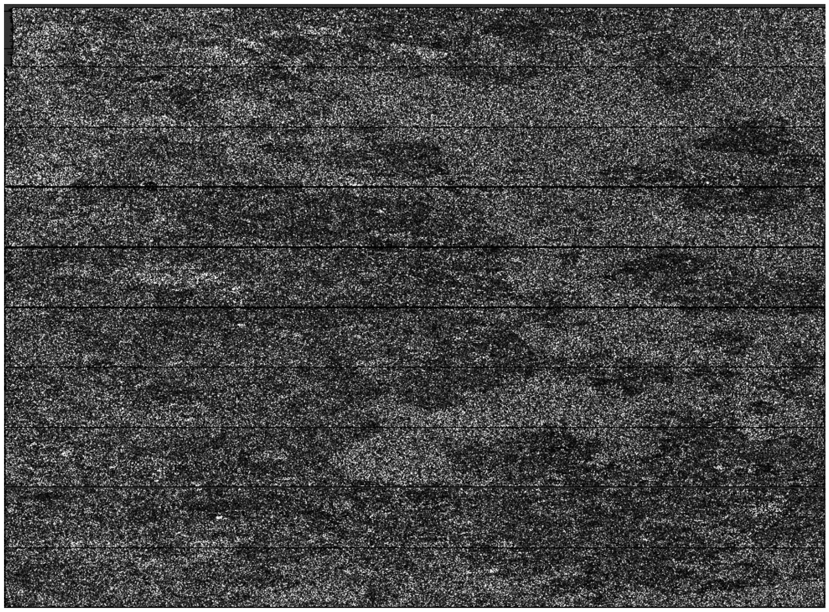

Figure 5 Intensity image of the ETAD corrected Sentinel-1 IW product

Figure 5 shows the ETAD correction result for the split S-1 product over Surat, Australia. Surat is one of the corner reflector test sites in Australia. In this test site, there are more than forty corner reflectors installed which are used for the deformation studies and the calibration of SAR sensors. If we zoom in the image, we can see the corner reflectors as point targets (Figure 6). Users can also do the point target analysis on the Sentinel-1 product before and after the ETAD correction.

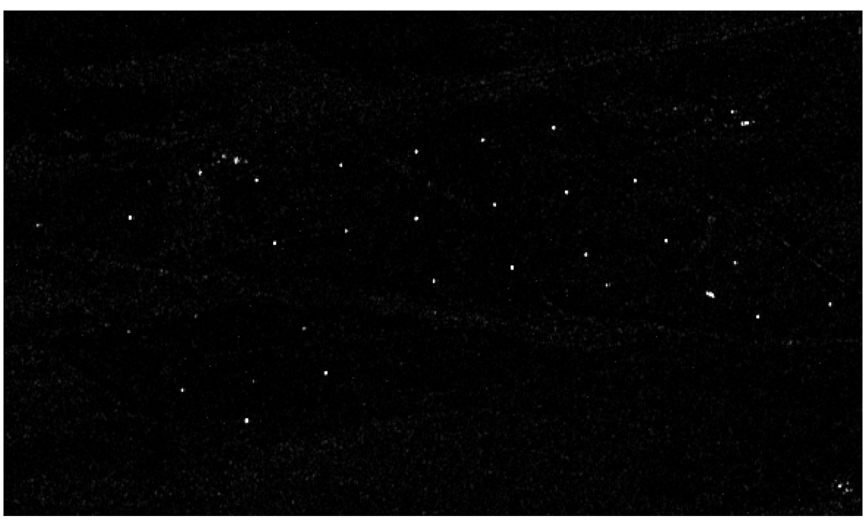

Figure 6 Corner reflectors of Surat site in the intensity image

We have measured the absolute location error (ALE) for all 40 corner reflectors at this test site using the sar-calibraion-tool (https://github.com/aresys-srl/sar-calibration-tool). Table 1 shows the statistics of the ALEs measured before and after ETAD correction. Here we can see the accuracy improvement for the corner reflectors due to the ETAD correction.

# of CRs	Range ALE (mean ± std) (m)	Azimuth ALE (mean ± std) (m)	Range ALE (mean ± std) (m)	Azimuth ALE (mean ± std) (m)

	Before ETAD Correction	Before ETAD Correction	After ETAD Correction	After ETAD Correction
40	-3.212 ± 0.2522	2.475 ± 0.5092	0.053 ± 0.1231	0.525 ± 0.2587

Table 1 Mean ALEs for 40 CRs before and after ETAD correction

Since this is beyond the content of this tutorial and we will not go into the details.

In this demo, we run the ETAD Correction operator individually. Users can also run the graph below for the ETAD correction (Figure 7):

Figure 7 ETAD correction graph for geodetic accuracy improvement

ETAD for InSAR Improvement

In this application, we will generate the interferogram using the two ETAD corrected S-1 TOP SLC products.

In Demo 1, the focus is on the geodetic accuracy improvement. The operator computes the azimuth and range ETAD corrections and uses them to correct the azimuth and slant range times for all pixels. At the end the ETAD corrected pixels are resampled to a regular time grid.

For Demo 2, the focus is on the interferometric phase improvement, not on the geodetic accuracy improvement. Therefore, no image resampling is performed. For InSAR improvement, the ETAD Correction operator computes the necessary range corrections for all bursts and then converts them to phases. These phases are eventually used in the interferometric phase correction.

The InSAR processing chain with ETAD correction is as shown in the graph below (Figure 8). Users can actually run this graph to achieve the ETAD corrected interferograms. But for the purpose of demonstration, we will still run each operator separately.

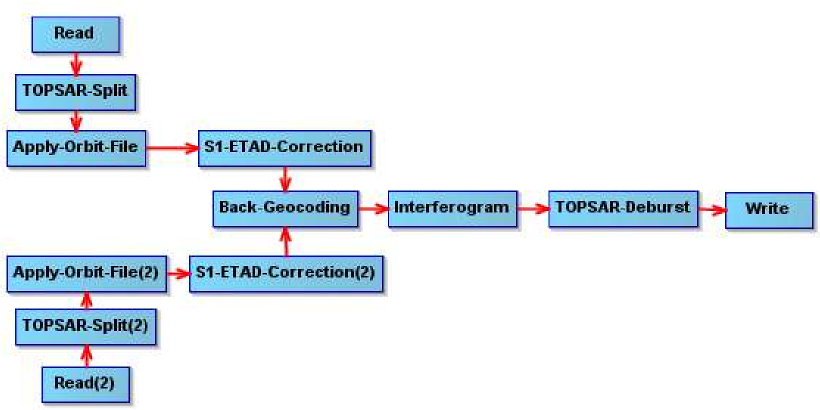

Figure 8 InSAR processing chain with ETAD correction

Prepare the Data for Demo 2

For Demo 2, the following two Snetinel-1A products are used:
S1A_IW_SLC__1SDV_20240812T173153_20240812T173220_055183_06B9C2_FAB2
S1A_IW_SLC__1SDV_20240824T173153_20240824T173220_055358_06C040_6841

To prepare the data, we need to run the graph in Figure 2 with the two products above as input. Again we select IW1 sub-swath and VV polarization. The procedure is the same as given in the data preparation for Demo 1.

One thing we should pay attention to is that we need the selected bursts in both products have the same footprint. This is because we need to coregister the two products later and use them to compute the interferogram.

For the two Sentinel-1A products above, this is not two difficult because the two products already have the same footprint (see Figure 1). If you select burst 1 to burst 4 in the first product, then you just need to select the same bursts for the second product.

However, if we want to coregister a Sentinel-1A product with a Sentinel-1B product, then the burst selection is tricky. This is because the two products have overlapped but different footprints. See example as shown in Figure 9. In this case, we can only select bursts in the overlapped area. For this particular example, we select burst 1 to 3 for the Sentinel-1B product and select burst 7 to 9 for the Sentinel-1A product. The footprint of the selected area is indicated by the red rectangle in the right image in Figure 9. At the end of this tutorial, we will show an example of the interferogram computed using Sentinel-1A and Sentinel-1B products.

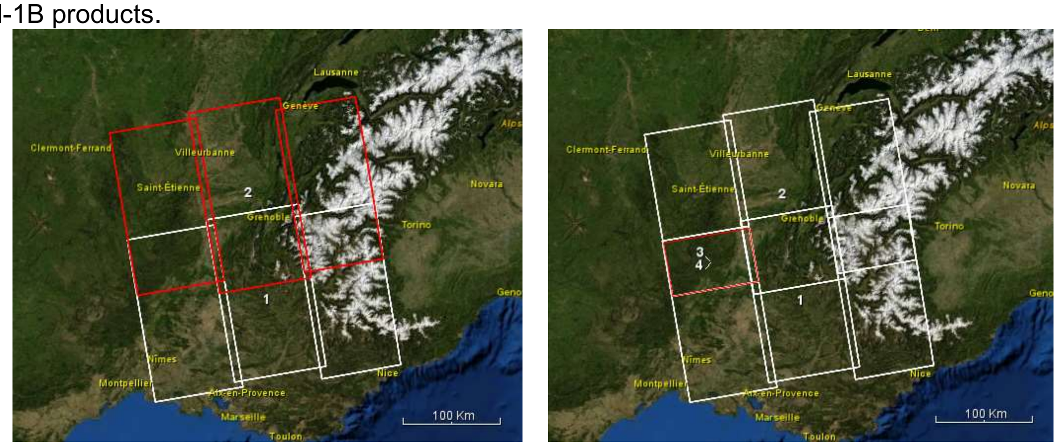

Figure 9 Footprints of one S-1A and one S-1B (left) and the selected area (right)

Back to Demo 2, here we select all bursts in both Sentinel-1A products. Below are the split products:
S1A_IW_SLC__1SDV_20240812T173153_20240812T173220_055183_06B9C2_FAB2_Orb.data
S1A_IW_SLC__1SDV_20240824T173153_20240824T173220_055358_06C040_6841_Orb.data

Open the Split Products

Open the two slit products generated in data preparation (Figure 10).

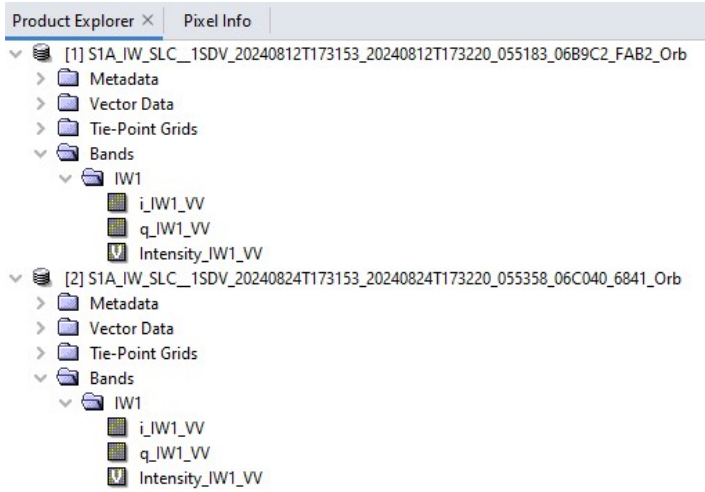

Figure 10 Split IW SLC products

Perform ETAD Correction to both Split Products

Open Radar > Sentinel-1 TOPS > S-1 ETAD Correction operator and use the first split product above as the Source Product.

Since we have already downloaded the ETAD product, we choose "Specify ETAD File" and specify the path to the ETAD file.

For InSAR application, we select Option 2 (Output Phase Correction). With this option, the phase correction is generated using four specific range layers as shown in Figure 11. Click on Run to start the correction.

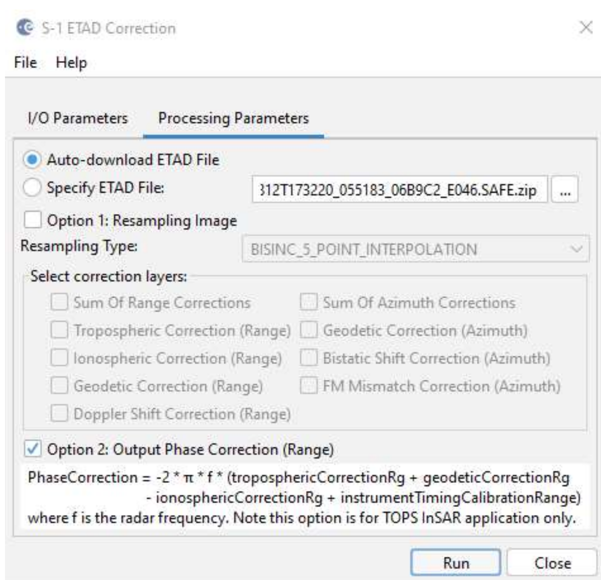

Figure 11 ETAD Correction operator UI

Repeat the procedure above for the second split S-1 SLC product.

Now we have performed ETAD correction to both the split S-1 SLC products (Figure 12).

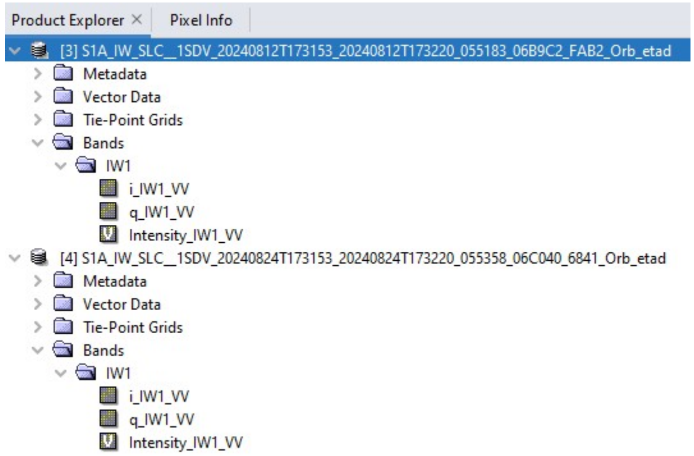

Figure 12 ETAD corrected S-1 products

The computed ETAD corrections (etadPhaseCorrection) and other ETAD data (etadHeight and etadGradient) needed for the final interferometric phase correction are saved as the Tie Point Grid (TPG) in the product (Figure 13). These data will be used in the Interferogram Formation operator for the interferometric phase correction.

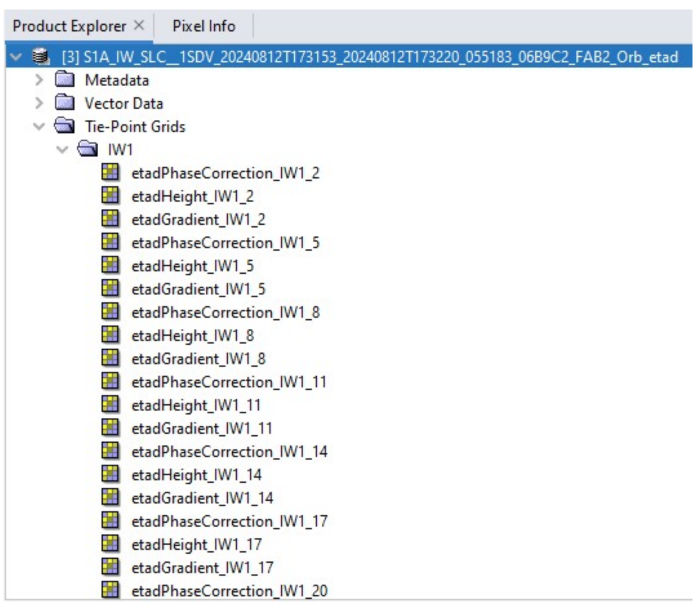

Figure 13 ETAD data saved in the TPG of the product

Next we will coregister the two ETAD corrected S-1 SLC products using Back-Geocoding operator.

Back Geocoding

The *S-1 Back Geocoding* operator (under *Radar>Coregistration>Sentinel-1 TOPS Coregistration*) coregisters the two split products based on their orbit information and a user selected Digital Elevation Model (DEM) which is downloaded automatically by SNAP during the coregistration.

Add the two ETAD corrected products to the file list in the *ProductSet-Reader* tab and select **Copernicus 30m Global DEM (Auto Download)** in the *Back-Geocoding tab* (Figure 14).

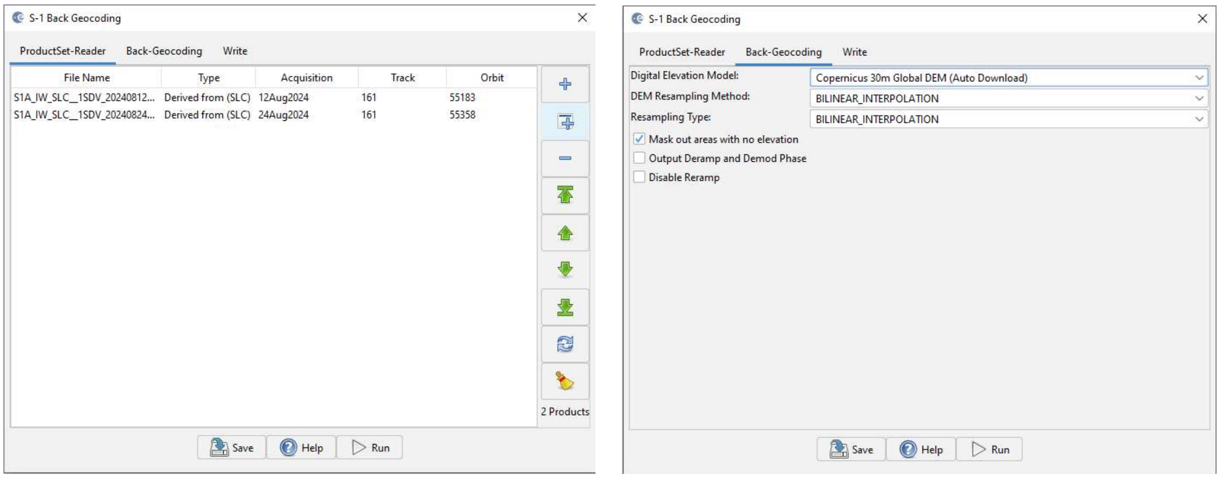

Figure 14 Back-Geocoding operator UI

Click on Run to start the coregistration. This step may take some time to finish depending on the number of selected bursts in the source product.

Figure 15 shows the coregistered SLC product in which we can see bands from both the master and the secondary products.

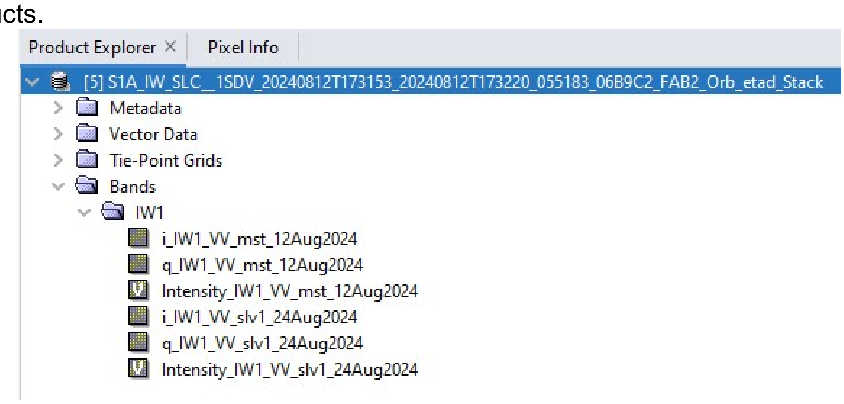

Figure 15 Coregistered product

The ETAD data that are saved as the TPGs in both the master and secondary products are also coregistered during this procedure. The coregistered ETAD data are again saved as the TPGs in the coregistered product (Figure 16).

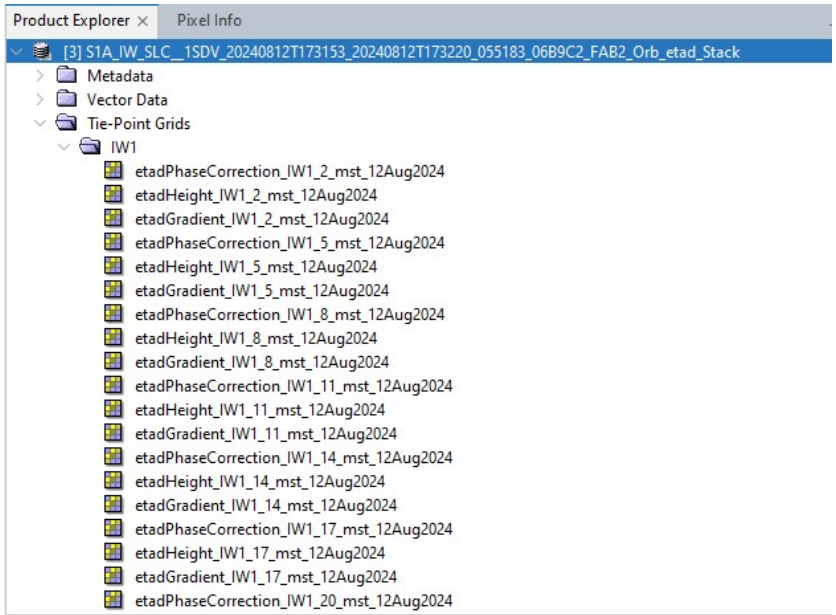

Figure 16 Coregistered ETAD data saved in the TPG of the product

Next we will generate the interferogram using the coregistered product above. In the computation of the interferogram, the ETAD data (etadPhaseCorrection, etadHeight and etadGradient) saved in the TPG will be used in computing the differential screen phase which will be finally used in the correction of the interferometric phase.

Interferogram Formation

Open the *Interferogram Formation* operator (under *Radar>Interferometric>Products*) and select the coregistered stack generated above as input. Make sure to check the following boxes (Figure 17):

- **Subtract flat-earth phase**: 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 metadata information and subtracted from the complex interferogram.
- **Include coherence estimation**: This produces a coherence band in the output calculated based on a window of 10x3 pixels in range/azimuth direction based on equation 1.13 in ESA TM-19C.

Please **do not** check "Subtract topographic phase" because this is the information we are interested in.

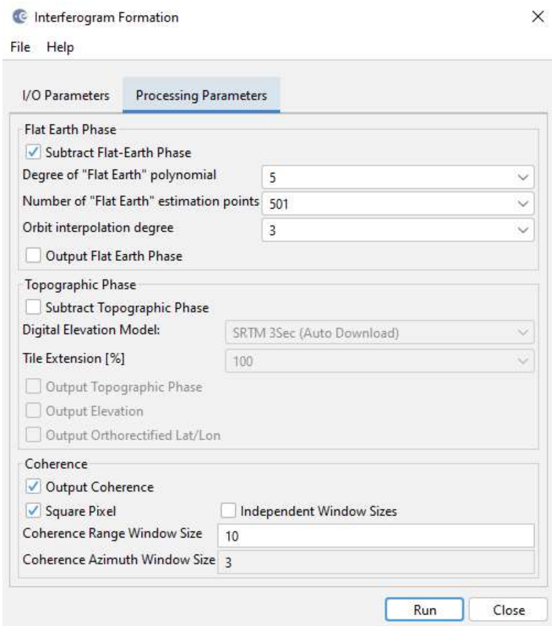

Figure 17: Interferogram Formation

Click on Run to start the processing. This step will also take some time to finish.

Figure 18 shows the ETAD corrected interferometric phase and the coherence together with the ETAD differential screen phase that has been used in the interferometric phase correction.

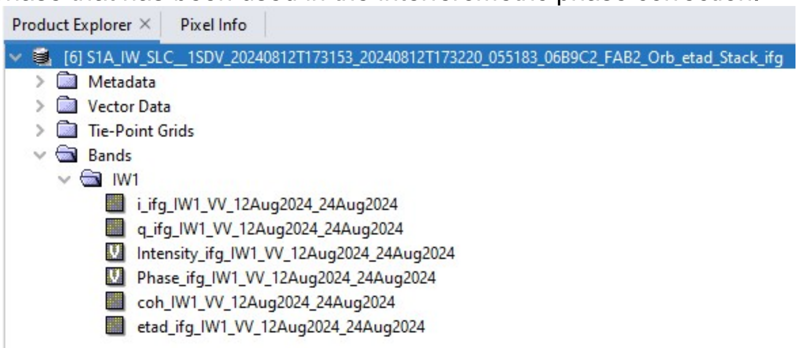

Figure 18 Interferogram and coherence

Deburst

Open the *S-1 TOPS Deburst* operator (under *Radar*>Sentinel-1 TOPS). Select the interferogram product generated above as input and select "VV" for the Polarizations (Figure 19). Click on Run to start the processing.

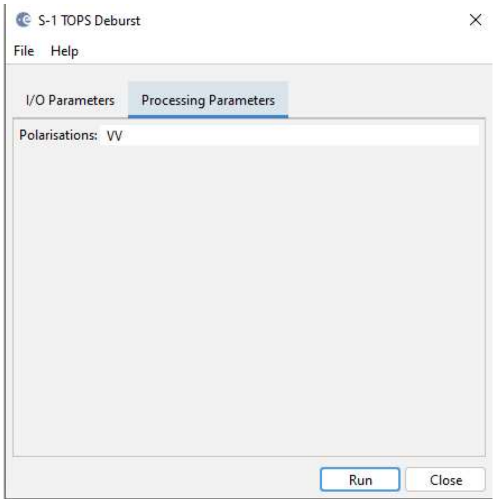

Figure 19 S-1 TOPS Deburst

Below are the deburst result: interferogram (Figure 20), coherence (Figure 21) and ETAD differential screen phase used in correcting the interferometric phase (Figure 22).

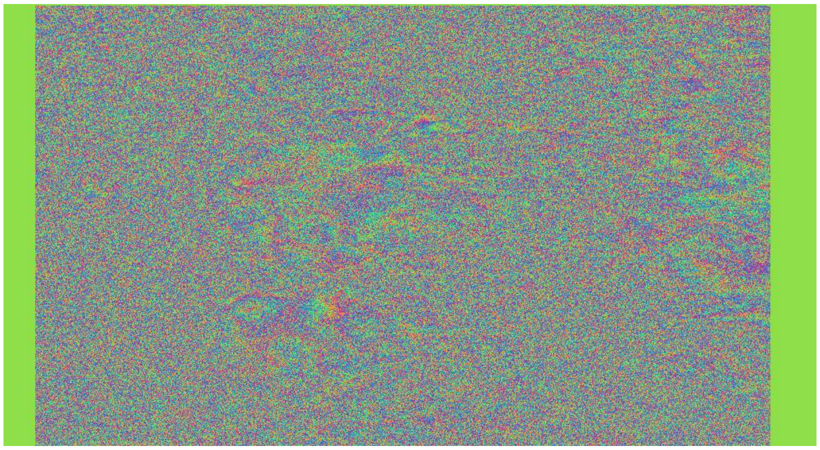

Figure 20 Interferogram in the deburst product

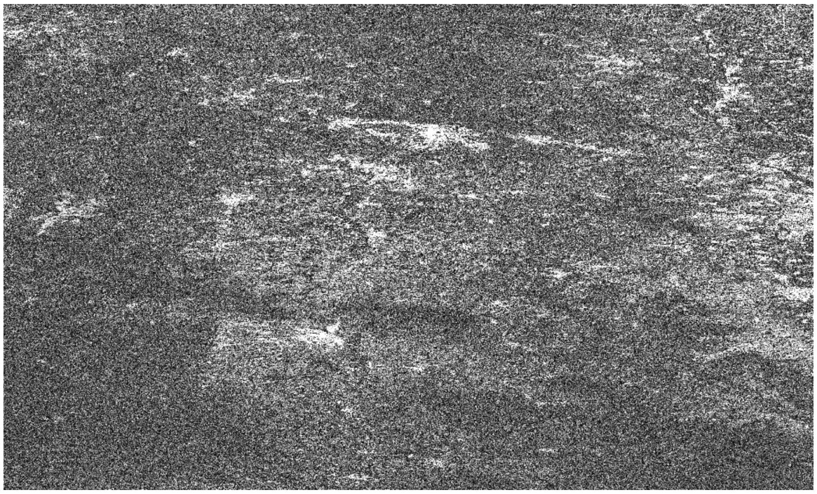

Figure 21: Coherence in the deburst product

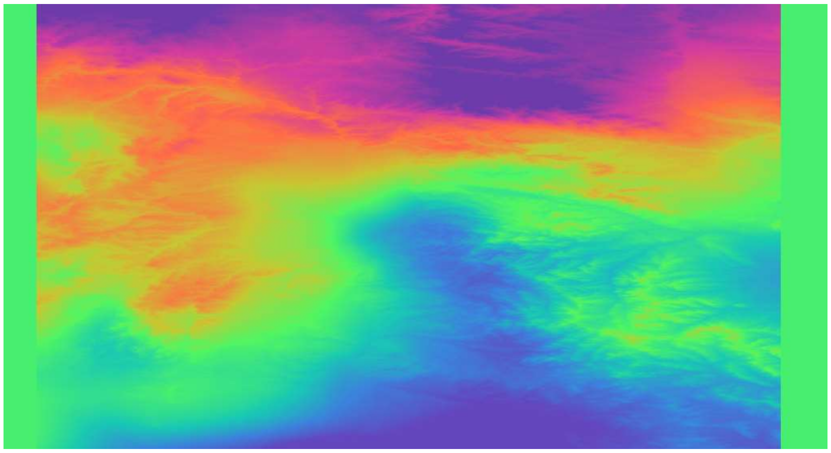

Figure 22 ETAD differential screen phase used in correction

The interferogram is a bit noisy at this moment. We can further improve the interferogram by running the Goldstein Phase Filtering operator to suppress the phase noise while still preserving the fringe edges.

Goldstein Phase Filtering

Open the Goldstein Phase Filtering operator under Radar > Interferometric > Filtering. Select the deburst product as the source product and use the default parameters (Figure 23). Then we can click on Run to start the filtering.

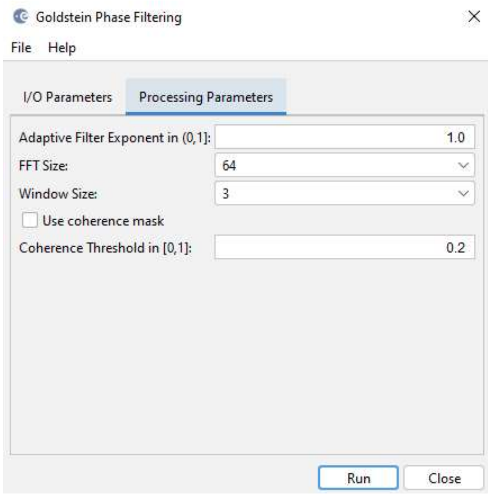

Figure 23 Goldstein Phase Filtering operator

Figure 24 shows the filtered interferogram. For comparison, we have computed the interferogram without applying the ETAD correction (Figure 25). Here we can see the differences in the fringes.

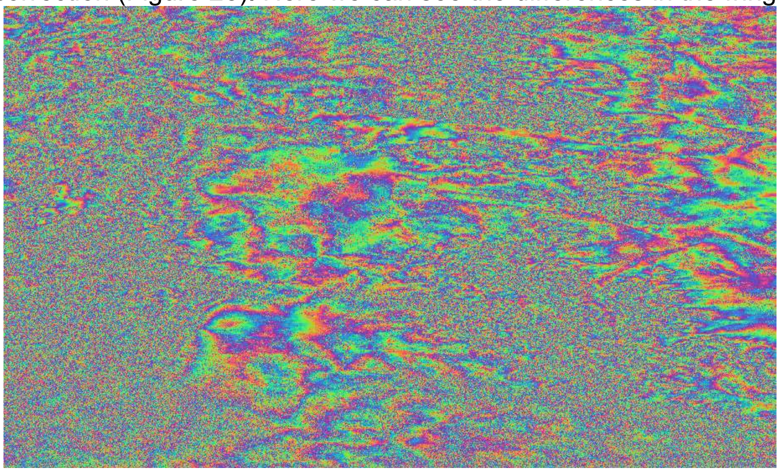

Figure 24 Interferogram with ETAD correction

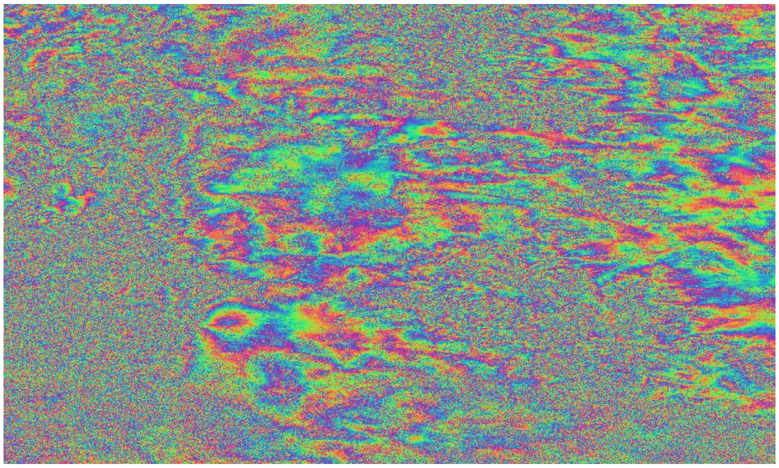

Figure 25 Interferogram without ETAD correction

Interferogram of Sentinel-1A and Sentinel-1B

In the demo above, we have computed the interferogram of two Sentinel-1A products. Now we will show an example where the interferogram is computed between Sentinel-1A and Sentinel-1B products.

For this example, we will use the following Sentinel-1 IW SLC products

(1) S1A_IW_SLC__1SDV_20200914T173141_20200914T173208_034358_03FEBE_DB9F.SAFE
(2) S1A_IW_SLC__1SDV_20200914T173116_20200914T173143_034358_03FEBE_116E.SAFE
(3) S1B_IW_SLC__1SDV_20200827T173049_20200827T173117_023112_02BE1A_F904.SAFE

and their corresponding ETAD products

(1) S1A_IW_ETA__AXDV_20200914T173116_20200914T173143_034358_03FEBE_B536.SAFE
(2) S1A_IW_ETA__AXDV_20200914T173141_20200914T173208_034358_03FEBE_D395.SAFE
(3) S1B_IW_ETA__AXDV_20200827T173049_20200827T173117_023112_02BE1A_9710.SAFE

which are provided by DLR.

Figure 26 shows the footprints of the three products: the footprint of Product (1) is indicated by the three white rectangles at the bottom (each rectangle represents one sub-swath), the footprint of Product (2) are given by the three rectangles at the top while the footprint of Product (3) is presented by the three red rectangles in the middle.

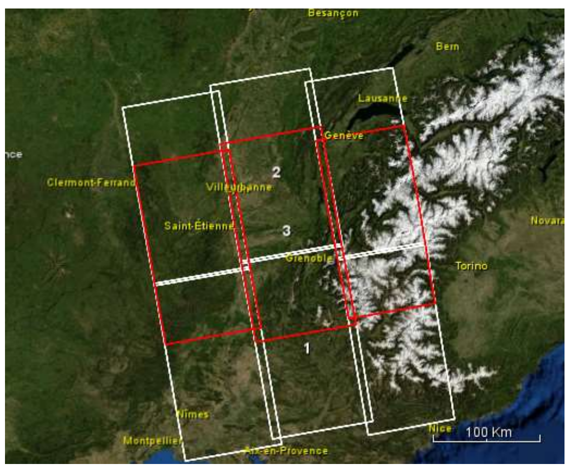

Figure 26 Footprints of the three products

For this example, interferograms should be computed between the two Sentinel-1A products and the Sentinel-1B product separately in order to get one complete interferogram. For each pair of products, the interferogram are computed for all three sub-swathes by following the steps given in the previous sections.

Since Sentinel-1A and Sentinel-1B products have different footprints, only the bursts for the overlapped region of the two products are selected for computing the interferogram. Table 2 shows the selected bursts for the overlapped areas of Product (1) and Product (3).

Products	Bursts in IW1	Bursts in IW2	Bursts in IW3
Product (1)	7, 8, 9	6, 7, 8, 9	7, 8, 9
Product (3)	1, 2, 3	1, 2, 3, 4	1, 2, 3

Table 2 Selected bursts for the overlapped area of Product (1) and Product (3)

Table 3 shows the selected bursts for the overlapped areas of Product (2) and Product (3).

Products	Bursts in IW1	Bursts in IW2	Bursts in IW3
Product (2)	1, 2, 3, 4, 5, 6	1, 2, 3, 4, 5, 6	1, 2, 3, 4, 5, 6
Product (3)	4, 5, 6, 7, 8, 9	5, 6, 7, 8, 9, 10	4, 5, 6, 7, 8, 9

Table 3 Selected bursts for the overlapped area of Product (2) and Product (3)

Figure 27 shows the final compete interferogram computed using Products (1), (2) and (3) for the three sub-swathes.

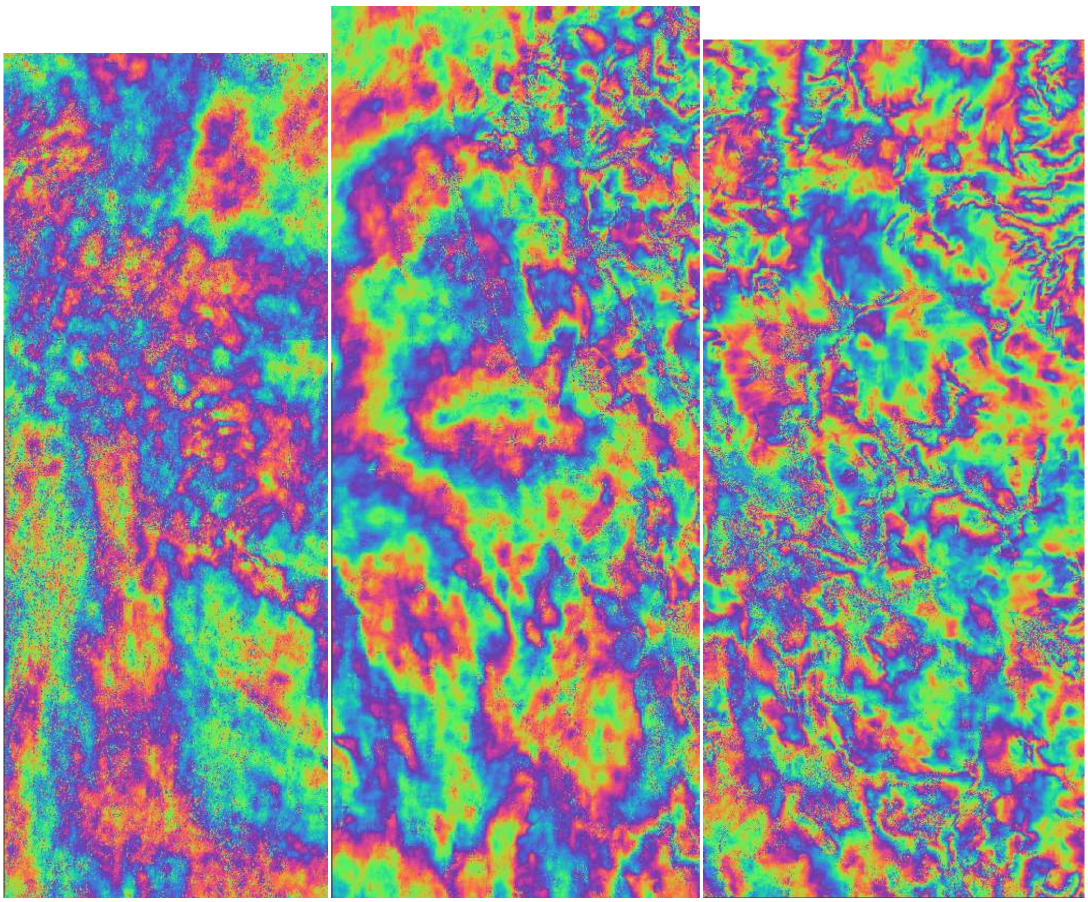

Figure 27 Interferograms with ETAD correction: IW1 (left), IW2 (middle) and IW3 (right)

Figure 28 are the ETAD screen phases for the three sub-swathes that are used in the interferometric phase correction.

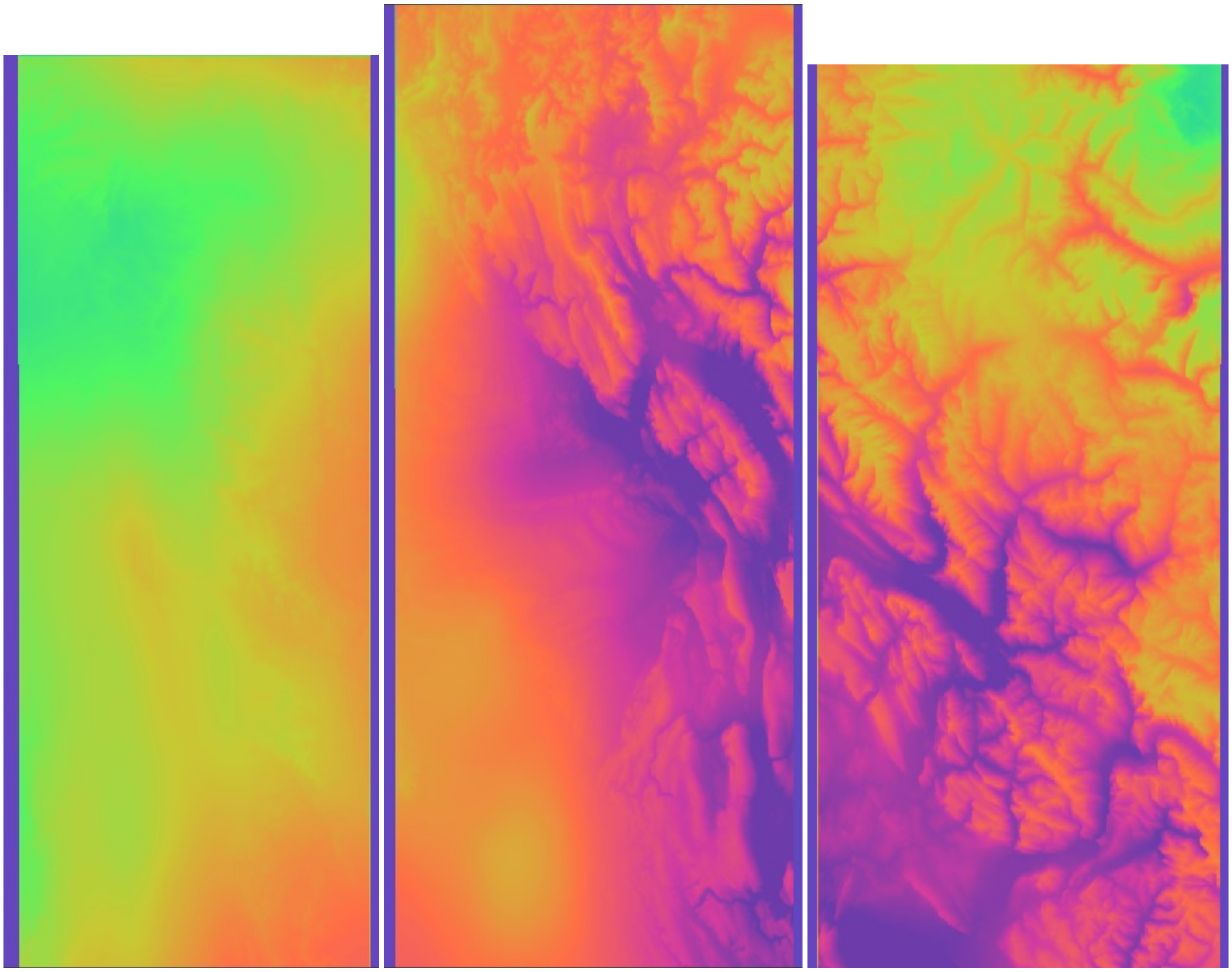

Figure 28 ETAD screen phases used in interferometric phase correction

Again, for the purpose of comparison, we also computed the interferogram without applying the ETAD correction (Figure 29). Here we can see the difference in the fringes.

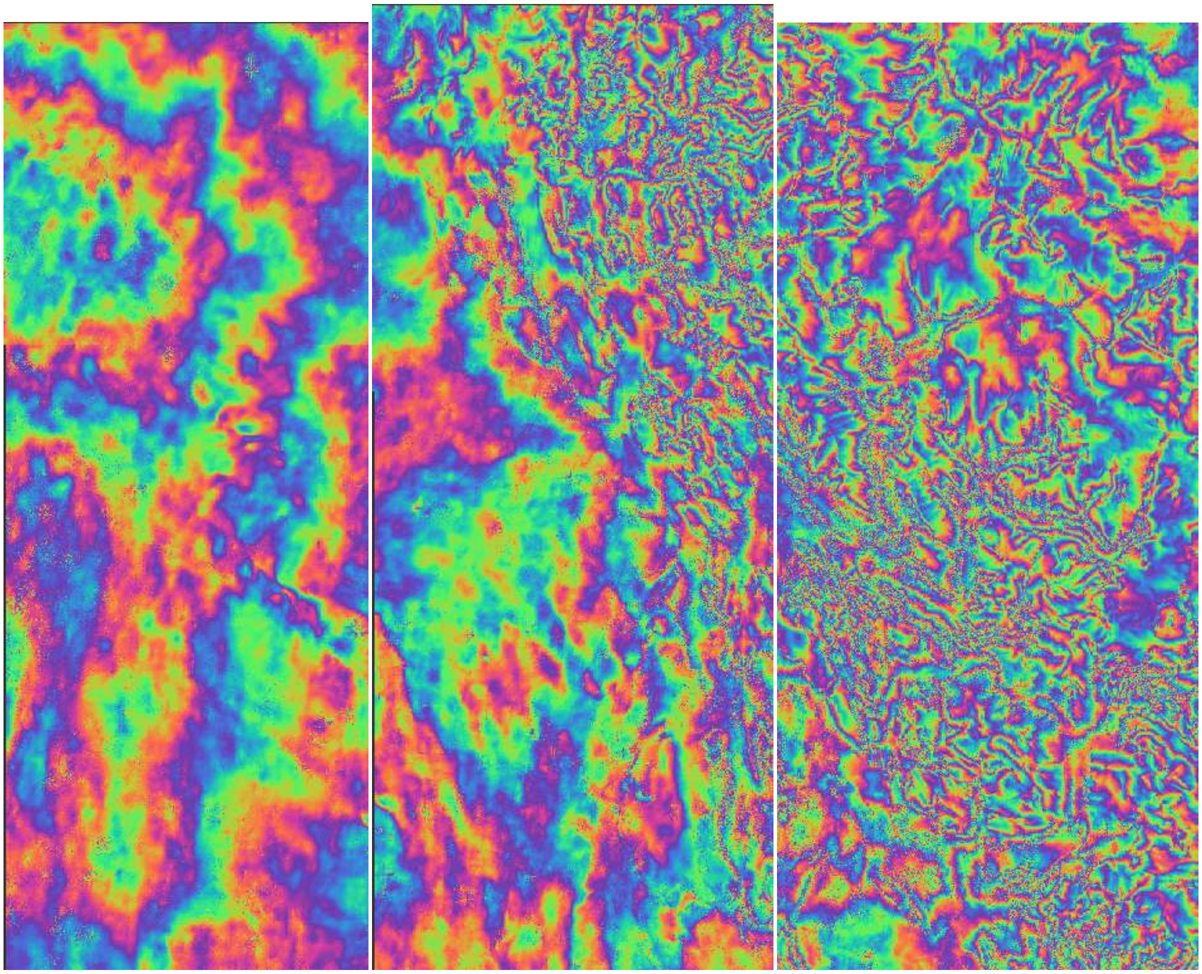

Figure 29 Interferograms without correction: IW1 (left), IW2 (middle) and IW3 (right)

The generated interferogram can be used for DEM generation or for other applications. But this is beyond the scope of this tutorial and we will not go into it.