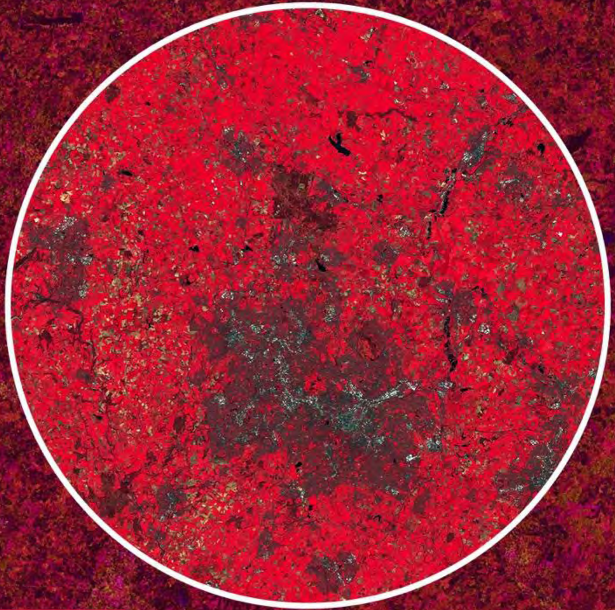
National Centre for Earth Observation
NATURAL ENVIRONMENT RESEARCH COUNCIL

UNIVERSITY OF LEICESTER

esa

→ 8th ADVANCED TRAINING COURSE ON LAND REMOTE SENSING

10–14 September 2018
University of Leicester | United Kingdom



DInSAR with Copernicus Sentinel-1 IW TOPS

Dr. Andrea Minchella (Airbus DS, Intelligence UK)

11/09/2018

Introduction

Background:

- Earthquake which took place on the 25th August 2015 in Chile
- Sentinel-1 TOPS pair acquired before (24 August) and after the event (17 September)

Objective is to show:

- Ex.#1 how coregister the pair (24 days a part) of Sentinel-1 TOPS SLC images
- Ex.#2 how to generate a wrapped DInSAR (co-seismic) interferogram from the Sentinel-1 TOPS pair providing information about the earthquake.

In particular:

- IW3 swath with VV polarisation only will be exploited
- Exercises will use GUI and Graph Builder Tool

Processing Steps: Ex.#1

0. Open Sentinel-1 SLC DV

1.a **TOPSAR-SPLIT**
Selection of IW3

1.b **Apply Precise Orbit File**
Sentinel Precise Orbit (POEORB)

1.c **Calibration** (i, q)

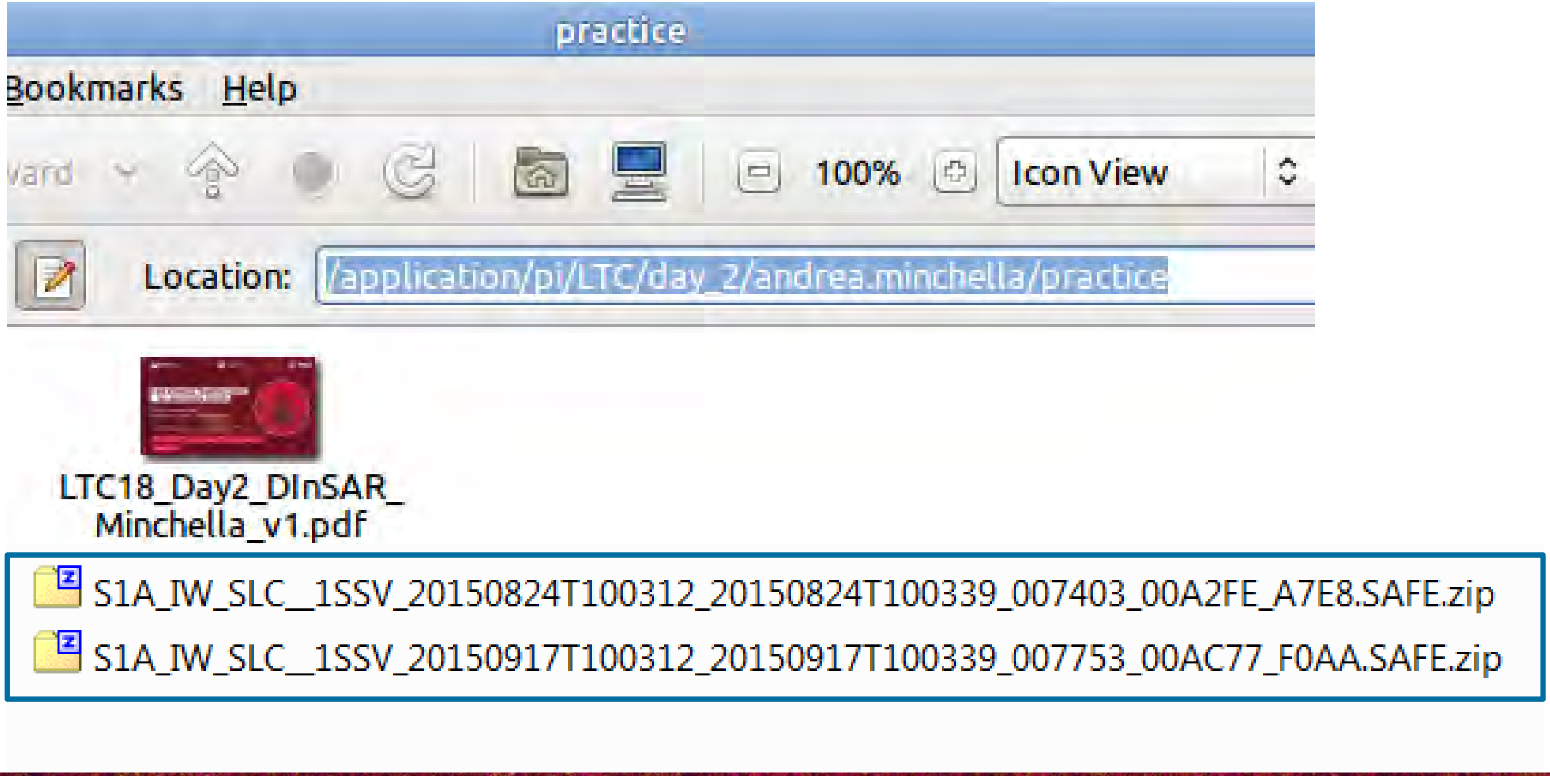
GUI

(2 X product)

2. TOPSAR Coregistration

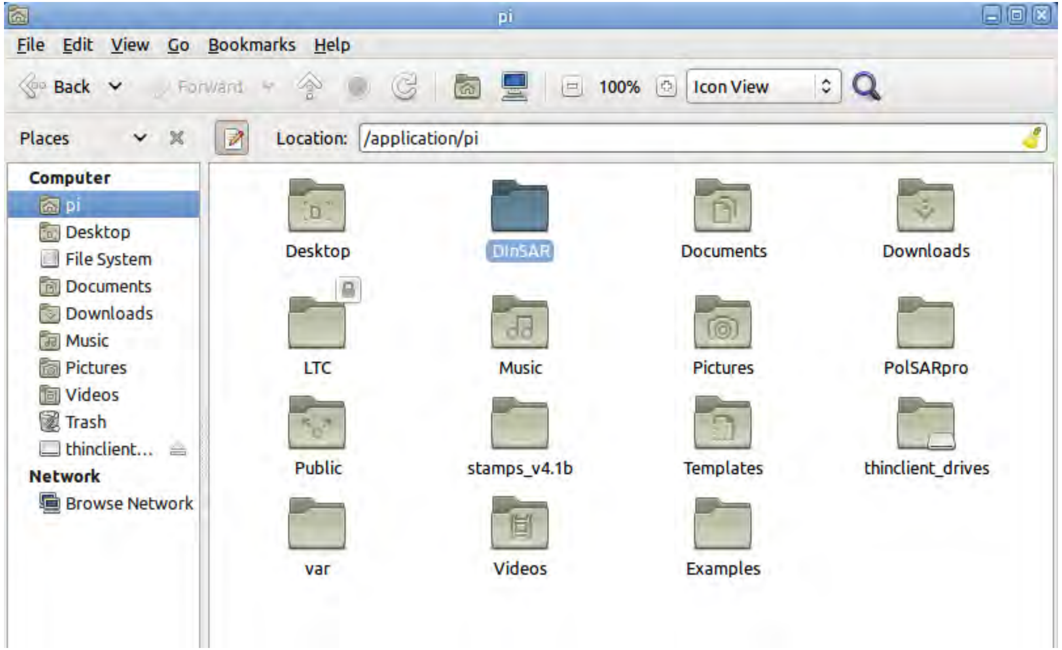
Graph Builder

Where are the data



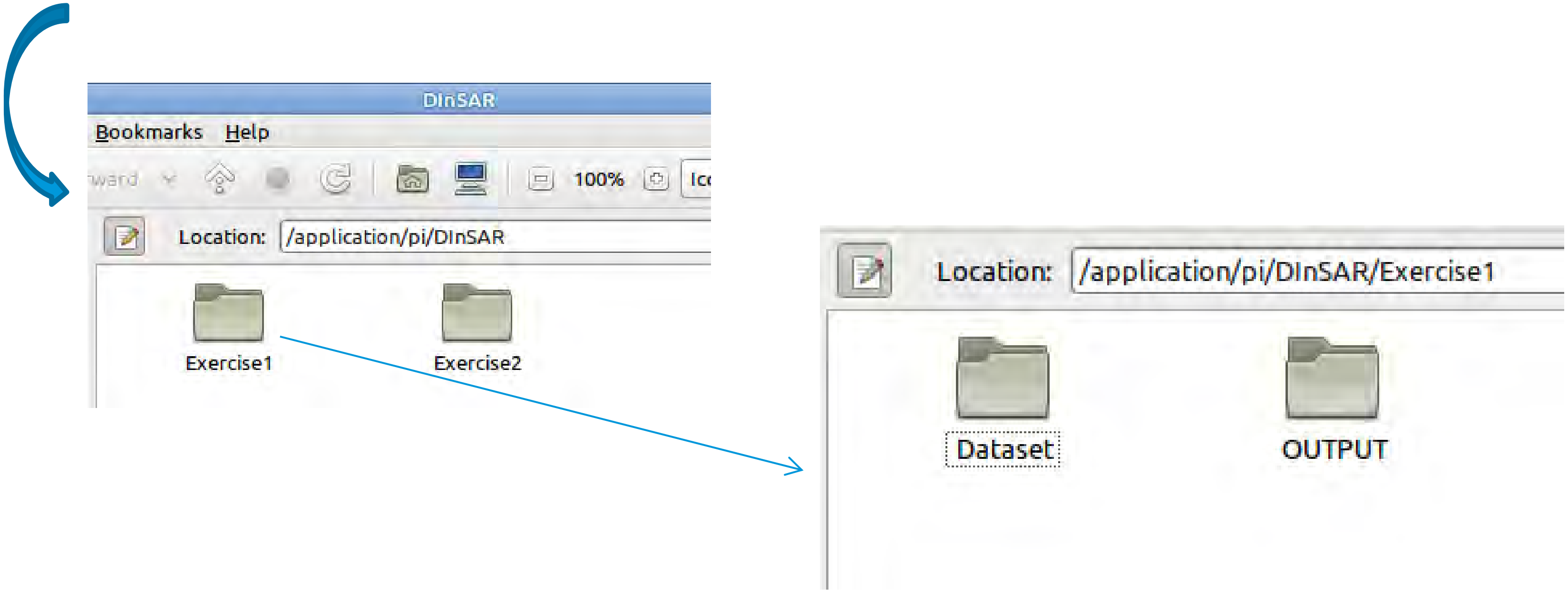
Where are the data

Creation of a new folder called “**DInSAR**” within **./application/pi**



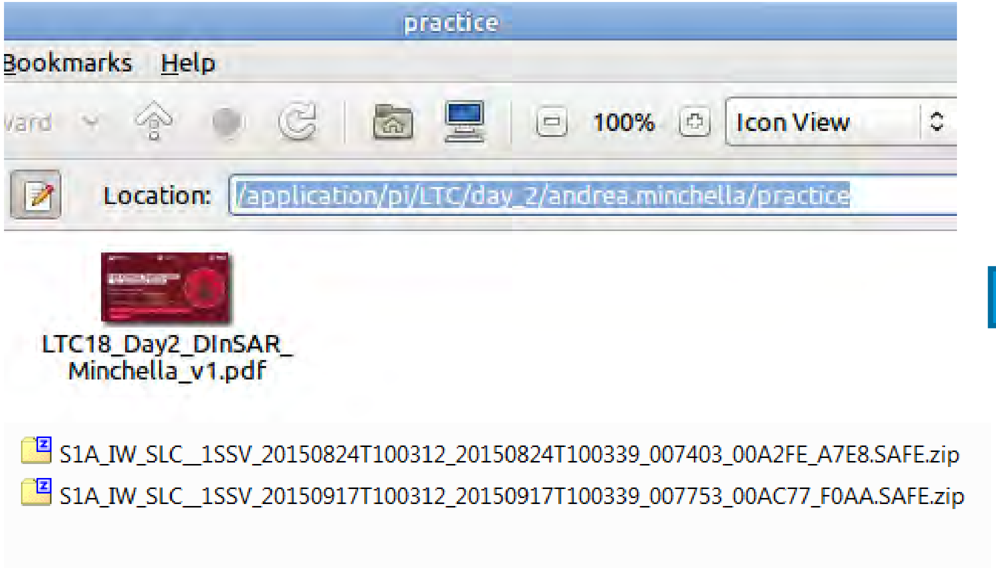
Where are the data

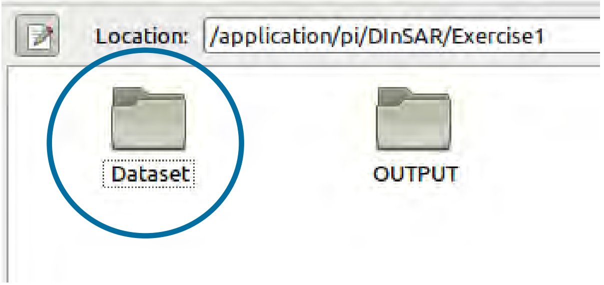
Within ./DinSAR create the following two folders



Where are the data

Copy the 2 Sentinel-1 images from

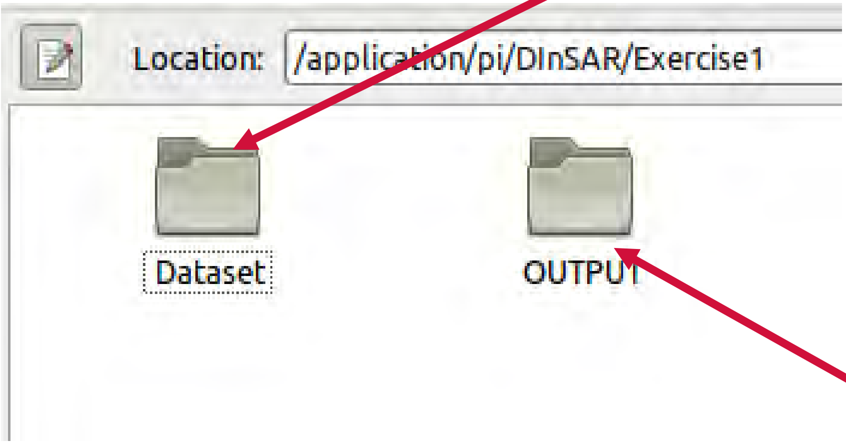




Exercise folders

./LTC2018/DInSAR/Exercise1

Dataset folder containing the input for the exercise



The OUTPUT of the exercise will be stored here

Dataset

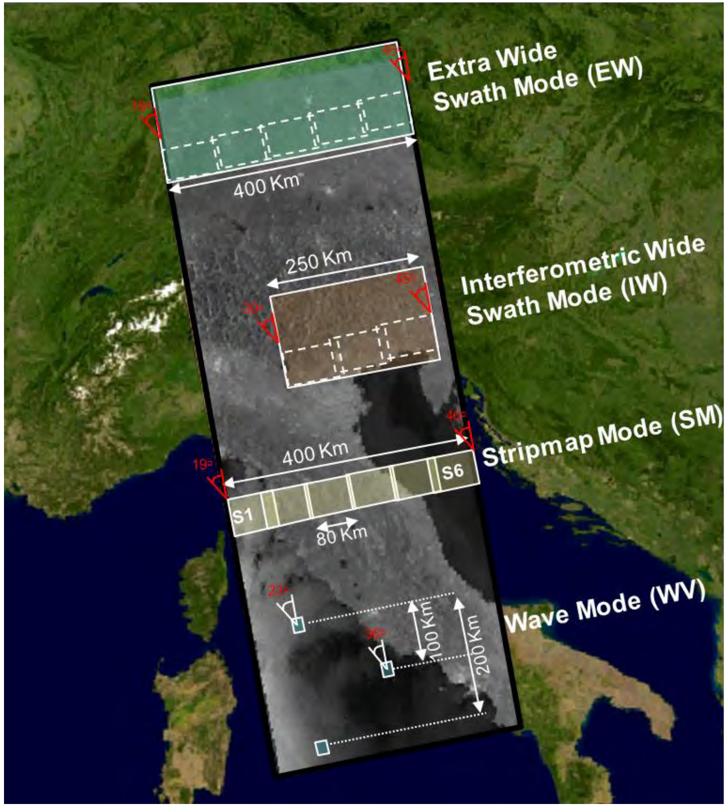
Name	Size	Date modified
S1A_IW_SLC__1SSV_20150824T100312_20150824T100339_007403_00A2FE_A7E8.SAFE.zip	2,231,889 KB	11/10/2016 15:30
S1A_IW_SLC__1SSV_20150917T100312_20150917T100339_007753_00AC77_F0AA.SAFE.zip	2,232,074 KB	11/10/2016 15:45

Product type: IW_SLC_1SSV

Acquisition mode: Interferometric wide swath
Product type: SLC
Polarisation: VV
Orbit: Ascending

Location: Chile

Sentinel-1 SAR Modes



Sentinel-1 SAR can be operated in **4 exclusive imaging modes** with different resolution and coverage:

Mode Rate	SAR Mode
High Bit Rate (HBR)	IW
	EW
	SM (S1 → S6)
Low Bit Rate (LBR)	WV

Polarisation schemes for IW, EW and SM:

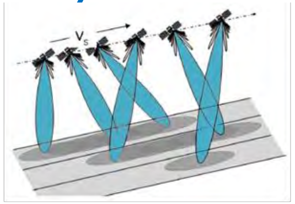
- single polarisation: HH or VV
- dual polarisation: HH+HV or VV+VH

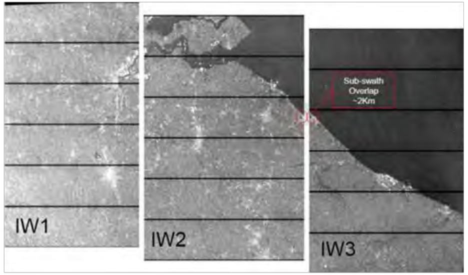
For Wave mode: HH or VV

Sentinel-1 Mission Performance

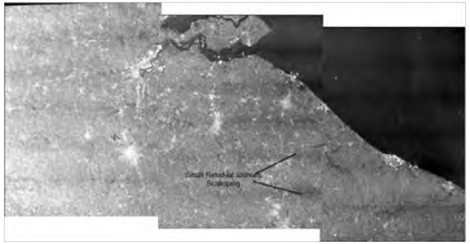
Mode	Access Angle	GR Single Look Resolution	Swath Width	Polarisation
Strip Map	20-45 deg.	Range 5 m Azimuth 5 m	> 80 km	HH or VV or HH+HV or VV+VH
Interferometric Wide Swath	> 25 deg.	Range 5 m Azimuth 20 m	> 250 km	HH or VV or HH+HV or VV+VH
Extra Wide Swath	> 20 deg.	Range 20 m Azimuth 40 m	> 400 km	HH or VV or HH+HV or VV+VH
Wave mode	23 deg. & 36.5 deg.	Range 5 m (TBC) Azimuth 5 m (TBC)	> 20 x 20 km Vignettes at 100 km intervals	HH or VV
For All Modes				
Radiometric accuracy (3 σ)				**1 dB**
Noise Equivalent Sigma Zero				**-22 dB**
Point Target Ambiguity Ratio				**-25 dB**
Distributed Target Ambiguity Ratio				**-22 dB**

Terrain Observation with Progressive Scans SAR (TOPSAR) Interferometric Wide Swath





IW Sub-Swaths with Minimal Overlap



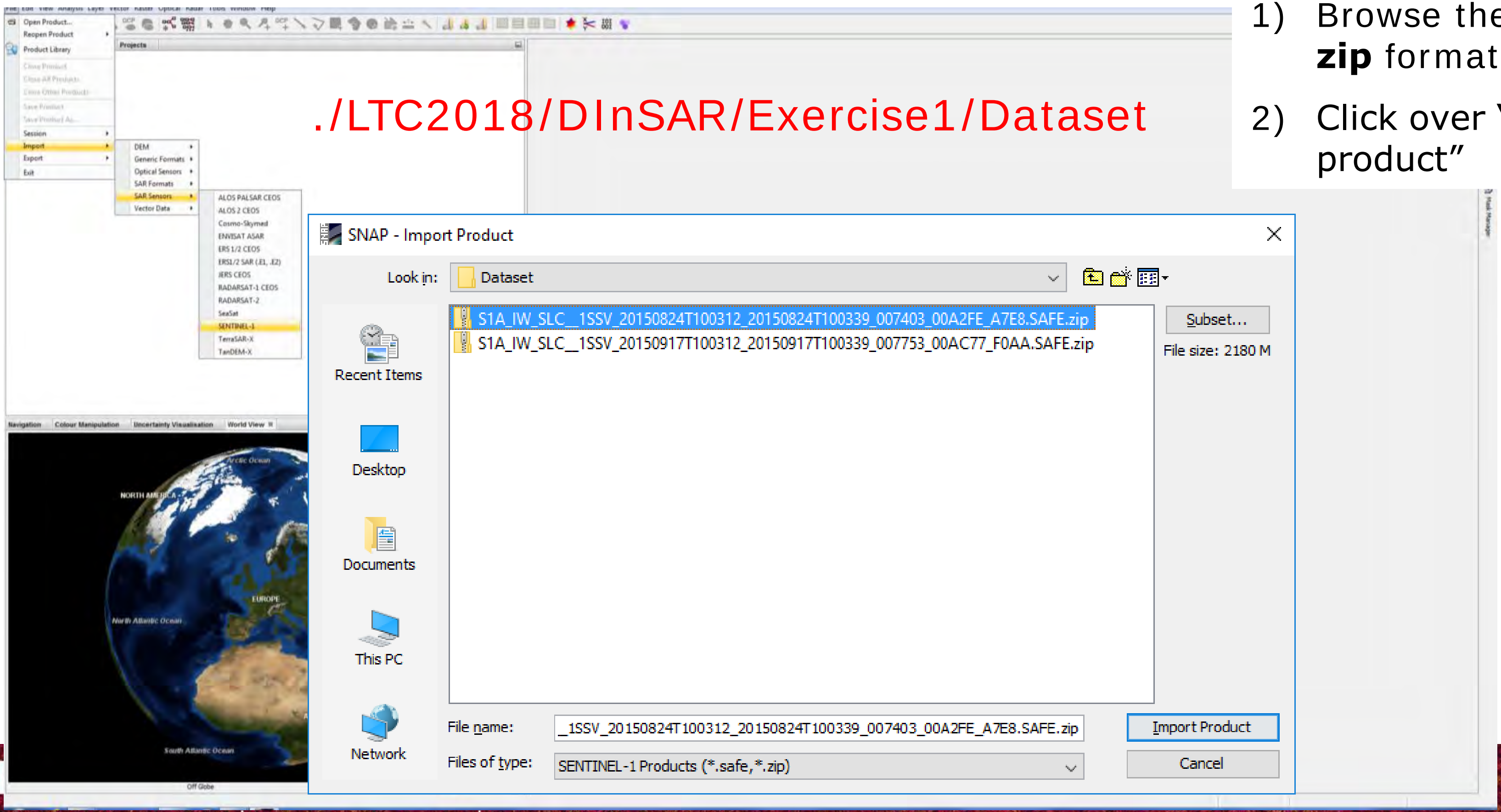
Resulting **De-Burst** and **Merged** IW Product

- The Interferometric Wide swath mode is the main acquisition mode over land.
- 250 km swath at 5 m (Range) by 20 (Azimuth) m spatial resolution (single look).
- IW mode captures three sub-swaths using TOPS mode and a IW SLC product contains one image per sub-swath (1 or 2 polarisations)
- Each sub-swath image consists of a series of bursts, where each burst has been processed as a separate SLC image.
- The individually focused complex burst images are included, in azimuth-time order, into a single sub-swath image with black-fill demarcation in between (overlap in azimuth by just enough to provide contiguous coverage of the ground)
- The images for all bursts in all sub-swaths are resampled to a common pixel spacing grid in range and azimuth while preserving the phase information (de-burst and merge)

https://sentinel.esa.int/web/sentinel/user-guides/sentinel-1-sar/acquisition-modes/interferometric-wide-swath

Step 0: Open product (24/08/2015)

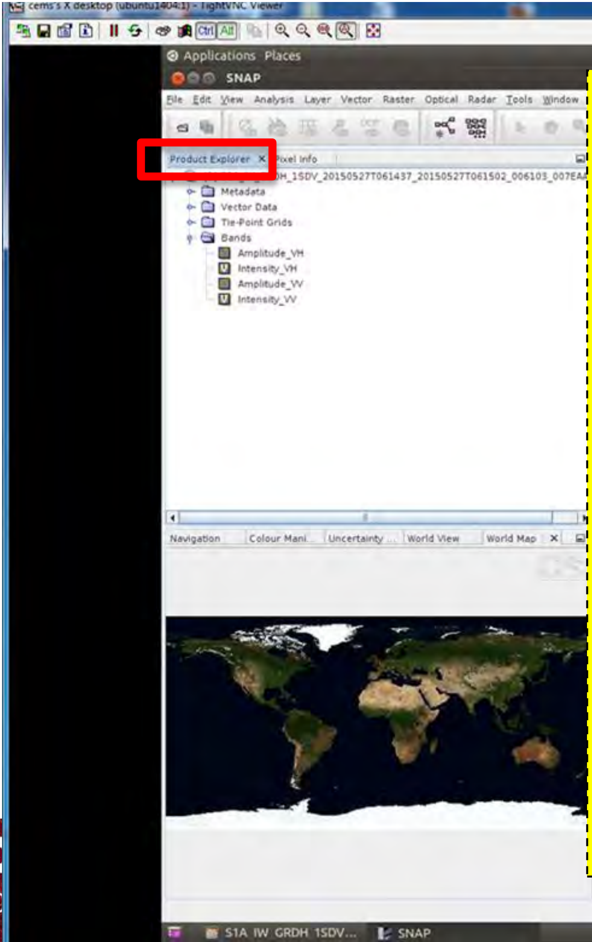
./LTC2018/DInSAR/Exercise1/Dataset



1) Browse the product in **zip** format directly

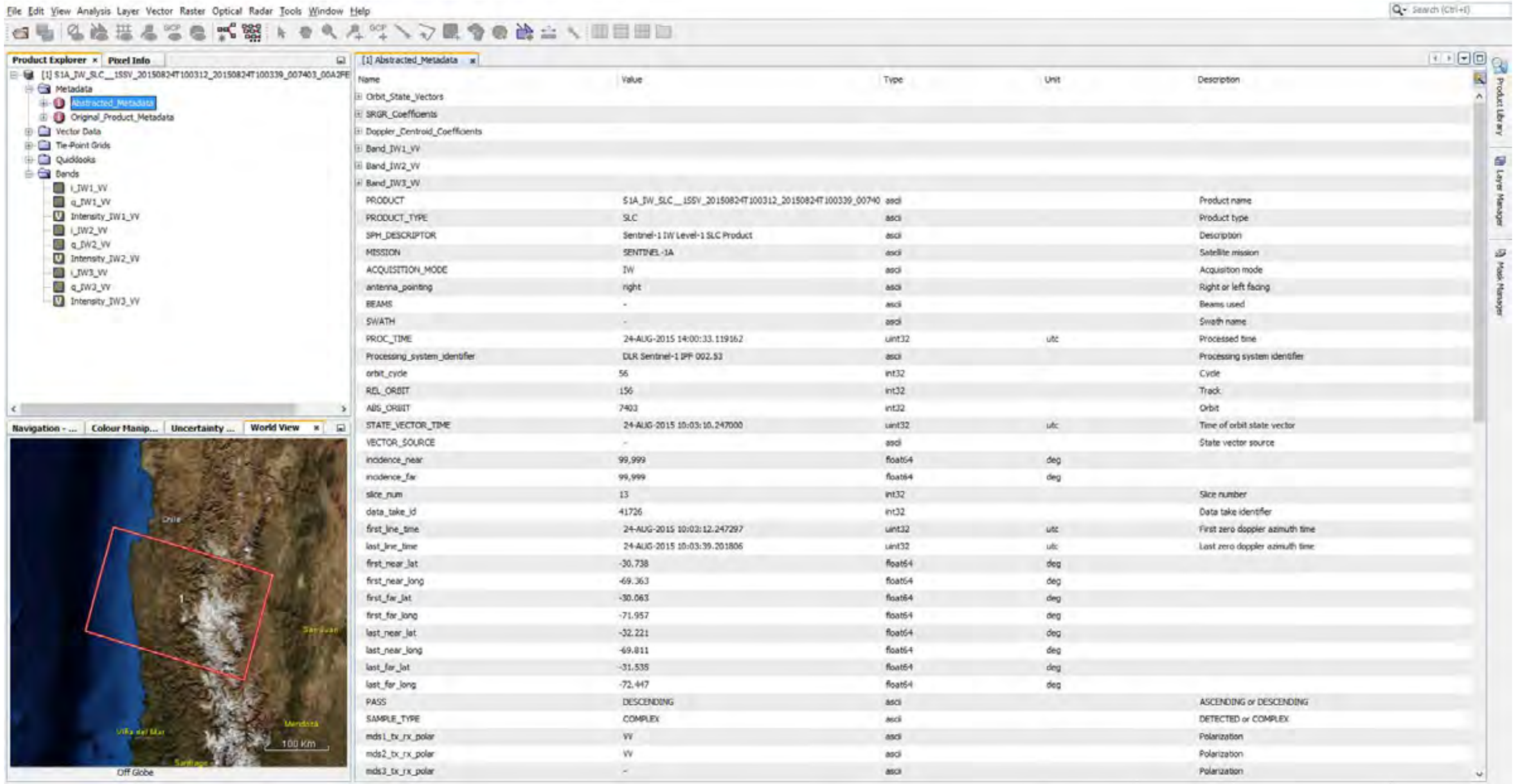
2) Click over "Import product"

Exercise 1 - Step 1: Inspect the product

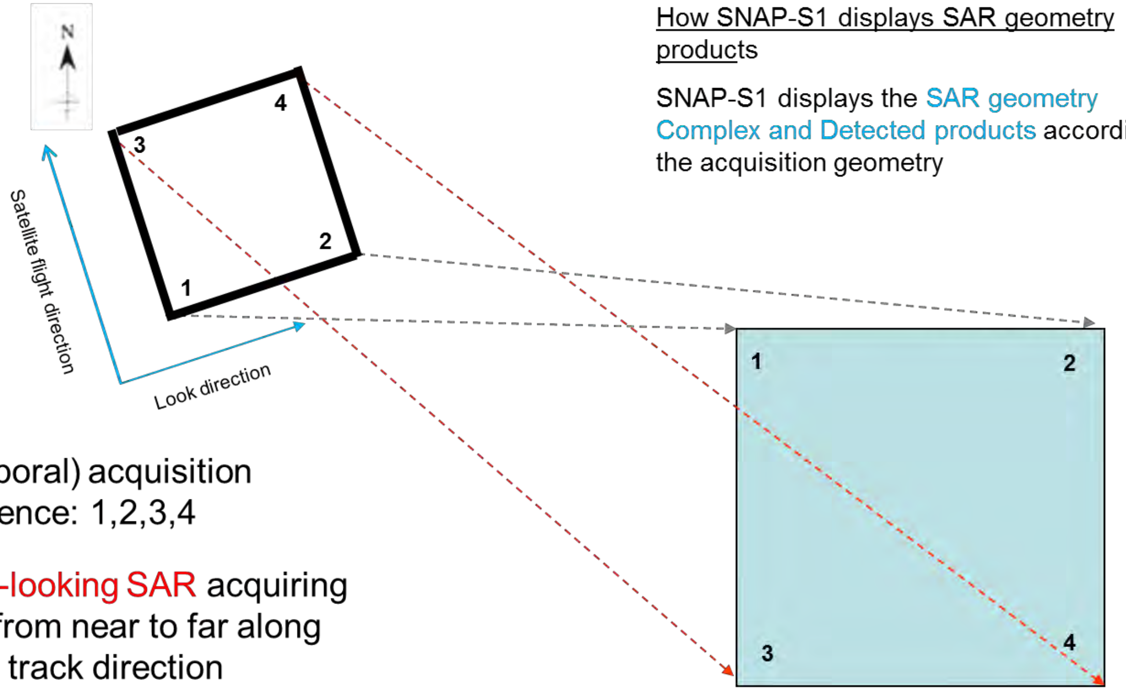


- **Metadata**: This includes all the original product metadata within the product, the Abstracted Metadata which is the important metadata fields used by the Operators in a common format and the Processing graph history recording the processing that was done
- **Vector data**: empty. It will be populated when a vector/mask is created
- **Tie-Point Grids**: Raster grids (latitude, longitude, incidence angle, elevation angle, slant range time) created from interpolation of tie-points information within the product. The interpolation is done on the fly according to the product.
- **Bands**: *The actual bands* inside the product and *virtual bands* created on the fly by SNAP from expressions. Different icons are used to distinguish these bands.

Inspecting the abstracted metadata



Ascending passage – Right looking SAR



(temporal) acquisition sequence: 1,2,3,4

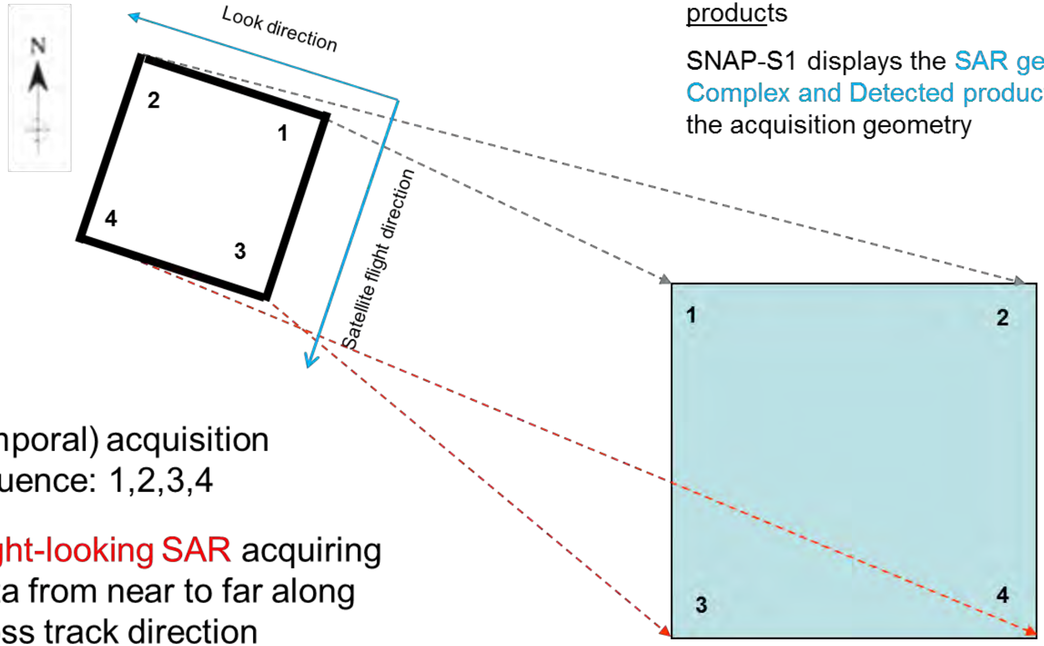
Right-looking SAR acquiring data from near to far along cross track direction

How SNAP-S1 displays SAR geometry products

SNAP-S1 displays the SAR geometry Complex and Detected products according to the acquisition geometry

To get a North orientation like the image has to be flipped vertically (1-3)

Descending passage – Right looking SAR



How SNAP-S1 displays SAR geometry products

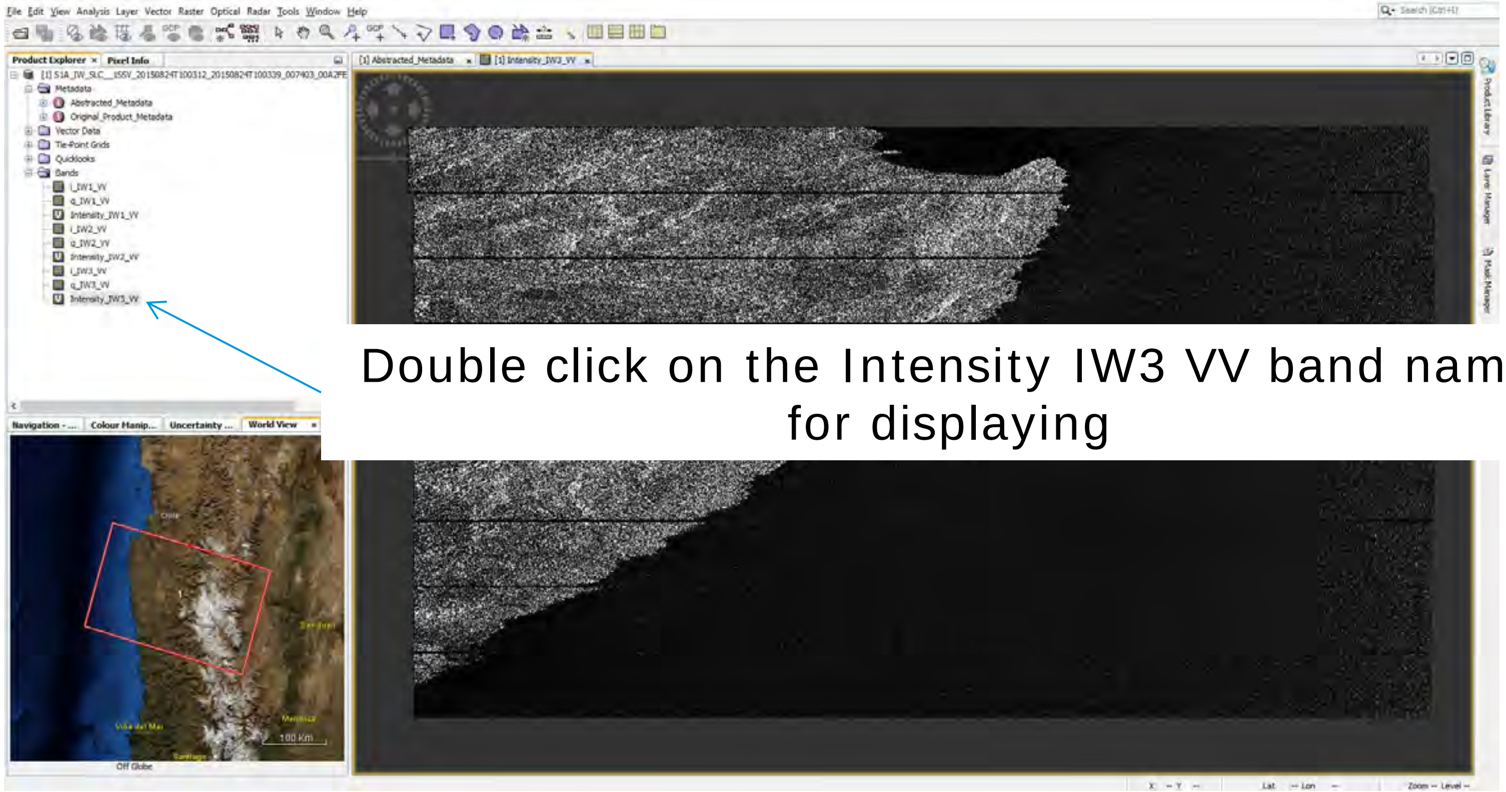
SNAP-S1 displays the SAR geometry Complex and Detected products according to the acquisition geometry

(temporal) acquisition sequence: 1,2,3,4

Right-looking SAR acquiring data from near to far along cross track direction

To get a North orientation like the image has to be flipped horizontally (1-2)

Display a band (Intensity VV)



Double click on the Intensity IW3 VV band name for displaying

Step 1 (a,b,c) with image on 24/08/2015

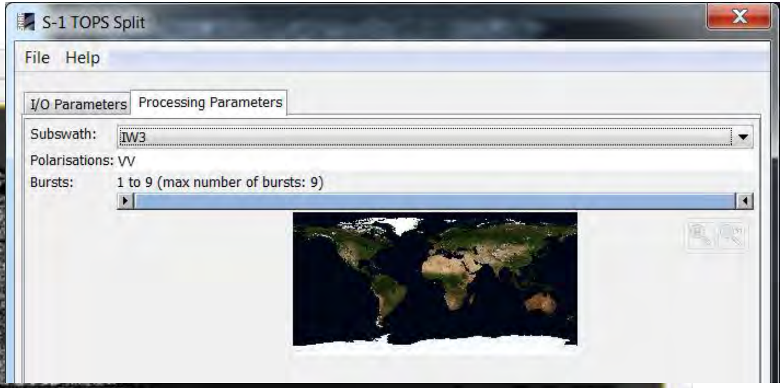
0.	Open Sentinel-1 SLC DV
1.a	**TOPSAR-SPLIT** Selection of IW3
1.b	**Apply Precise Orbit File** Sentinel Precise Orbit (POEORB)
1.c	**Calibration** (i, q)

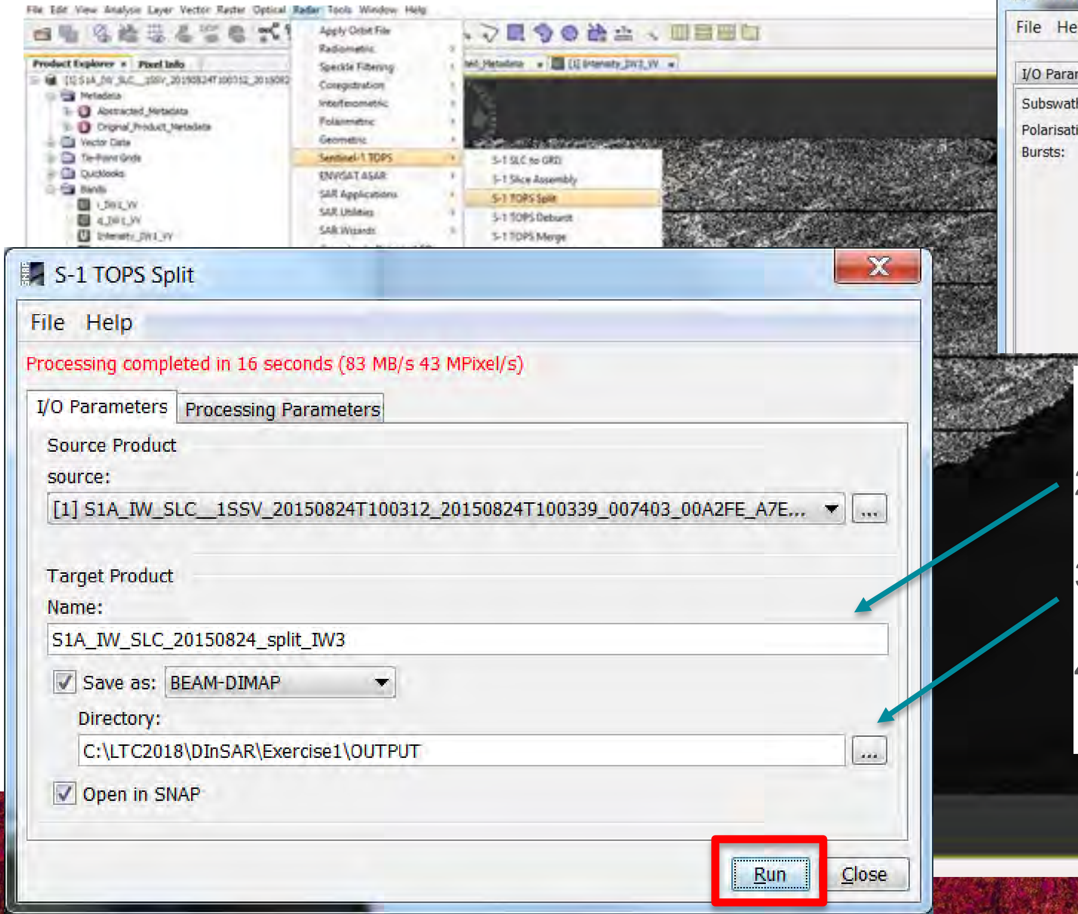
GUI

(single product)

S1A_IW_SLC__1SSV_20150824T100312_20150824T100339_007403_00A2FE_A7E8.SAFE.zip

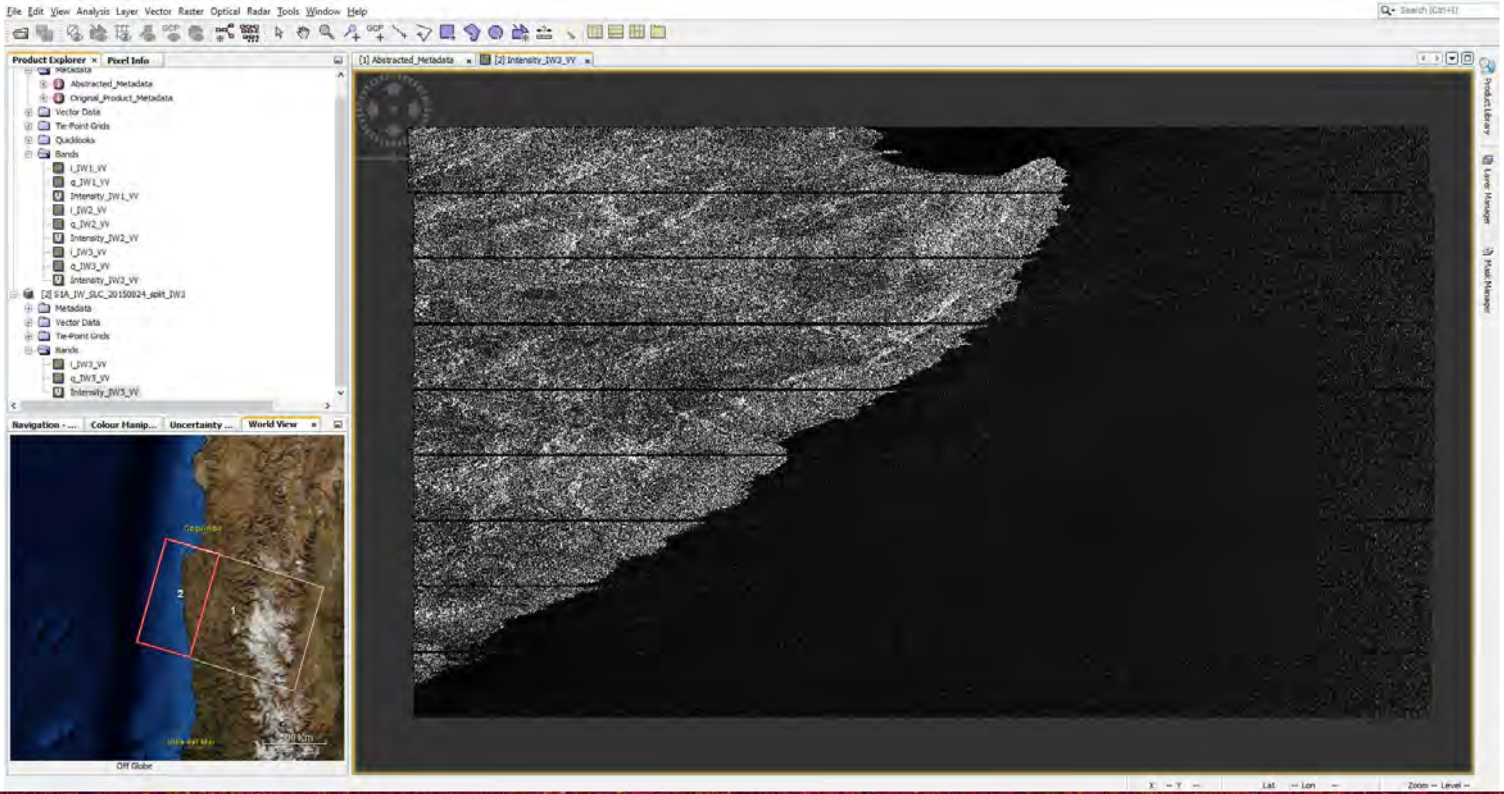
Step 1.a: TOPSAR-SPLIT



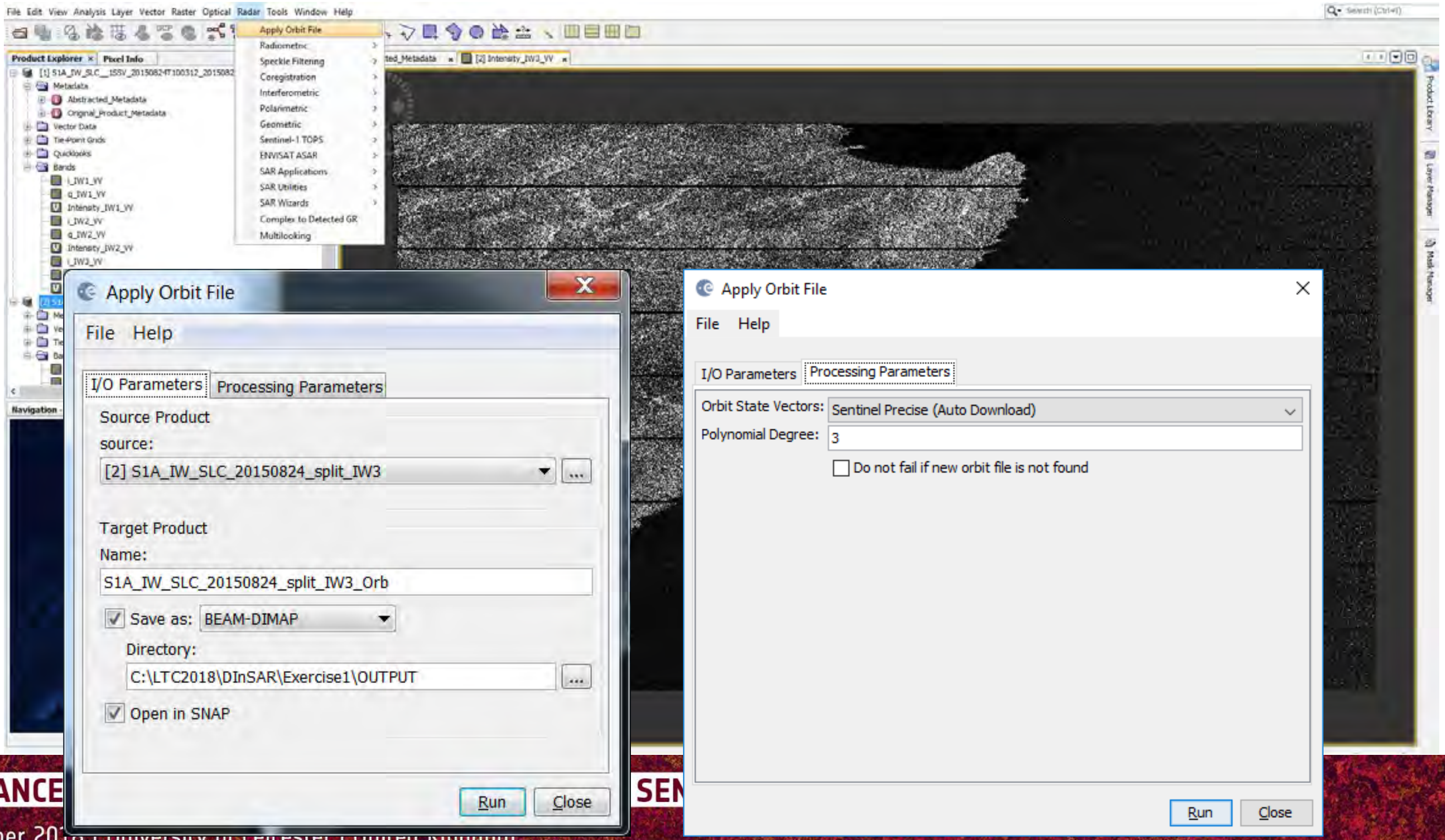


1. Processing Parameters
2. output name
3. Select the directory: ./Exercise1/OUTPUT
4. Click Run

Step 1.a: TOPSAR-SPLIT

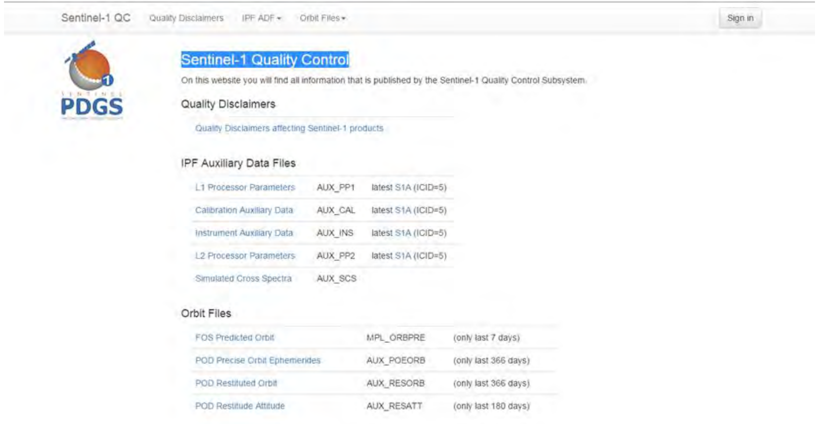


Step 1.b: Apply Precise Orbit



Sentinel-1 Quality Control

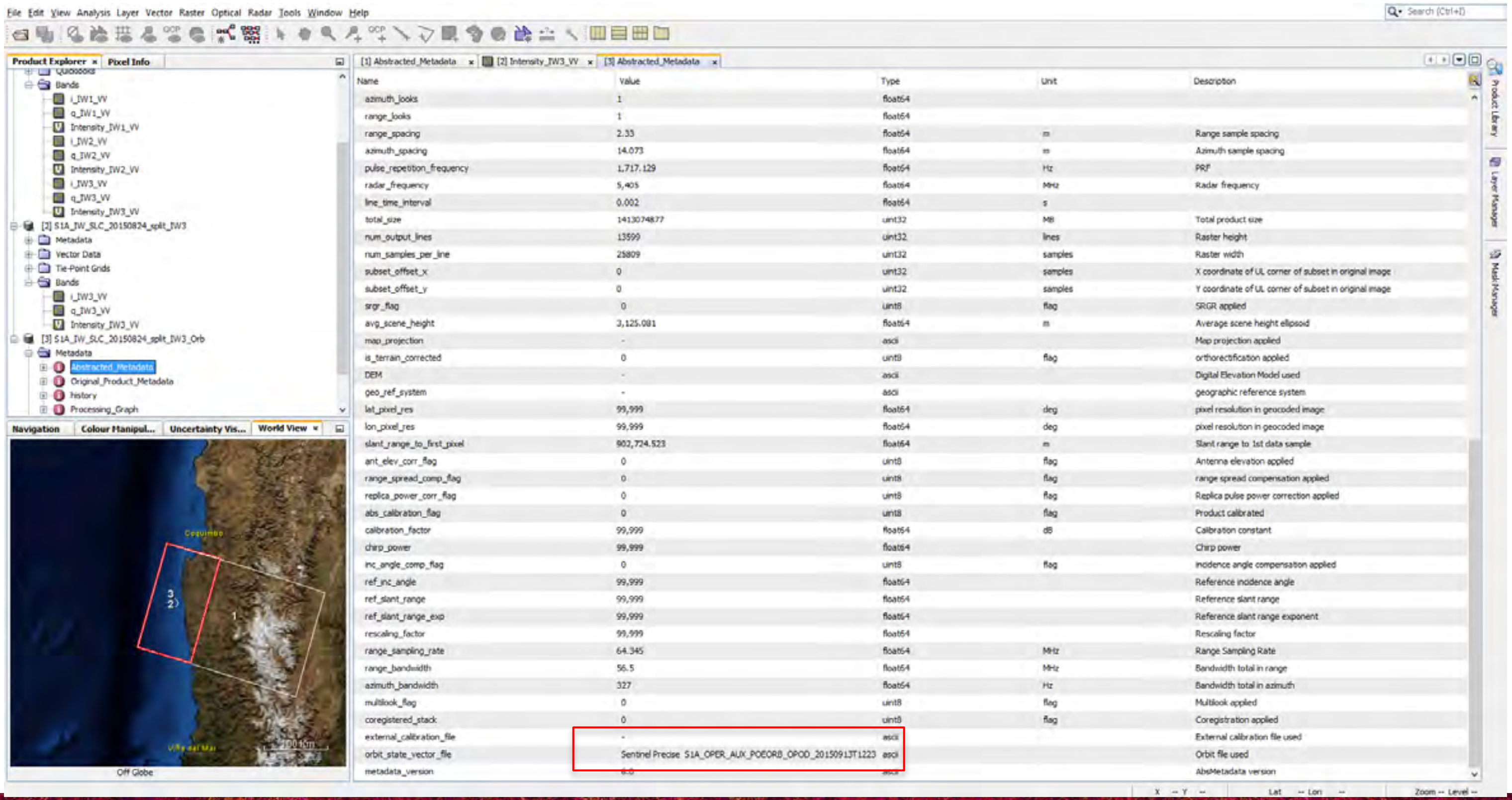
Website: https://qc.sentinel1.eo.esa.int



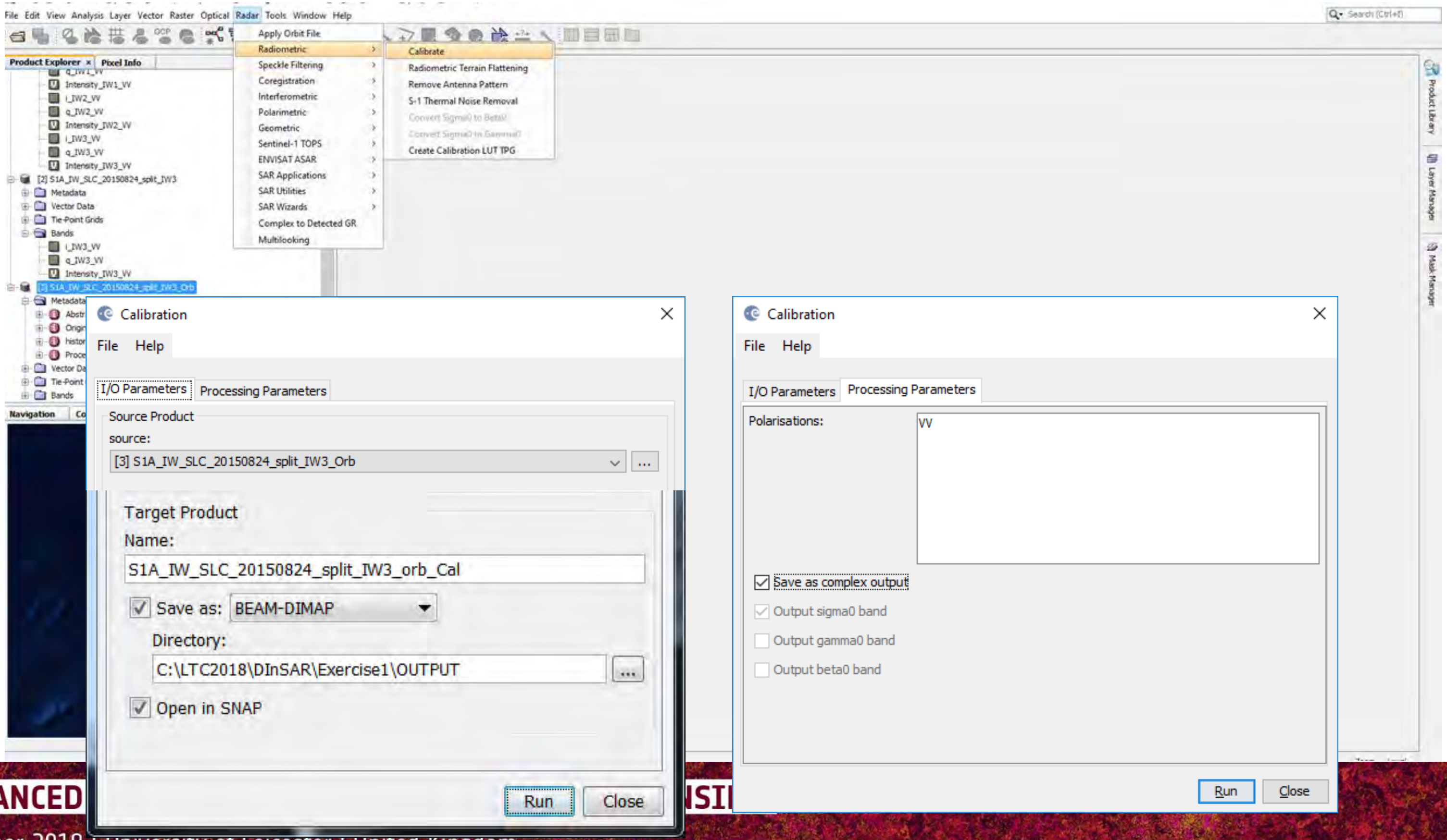
POD Restituted Orbit [AUX_RESORB]
POD Precise Orbit Ephemerides [AUX_POEORB] (most accurate)

Mission Status
https://sentinel.esa.int/web/sentinel/missions/sentinel-1/mission-status

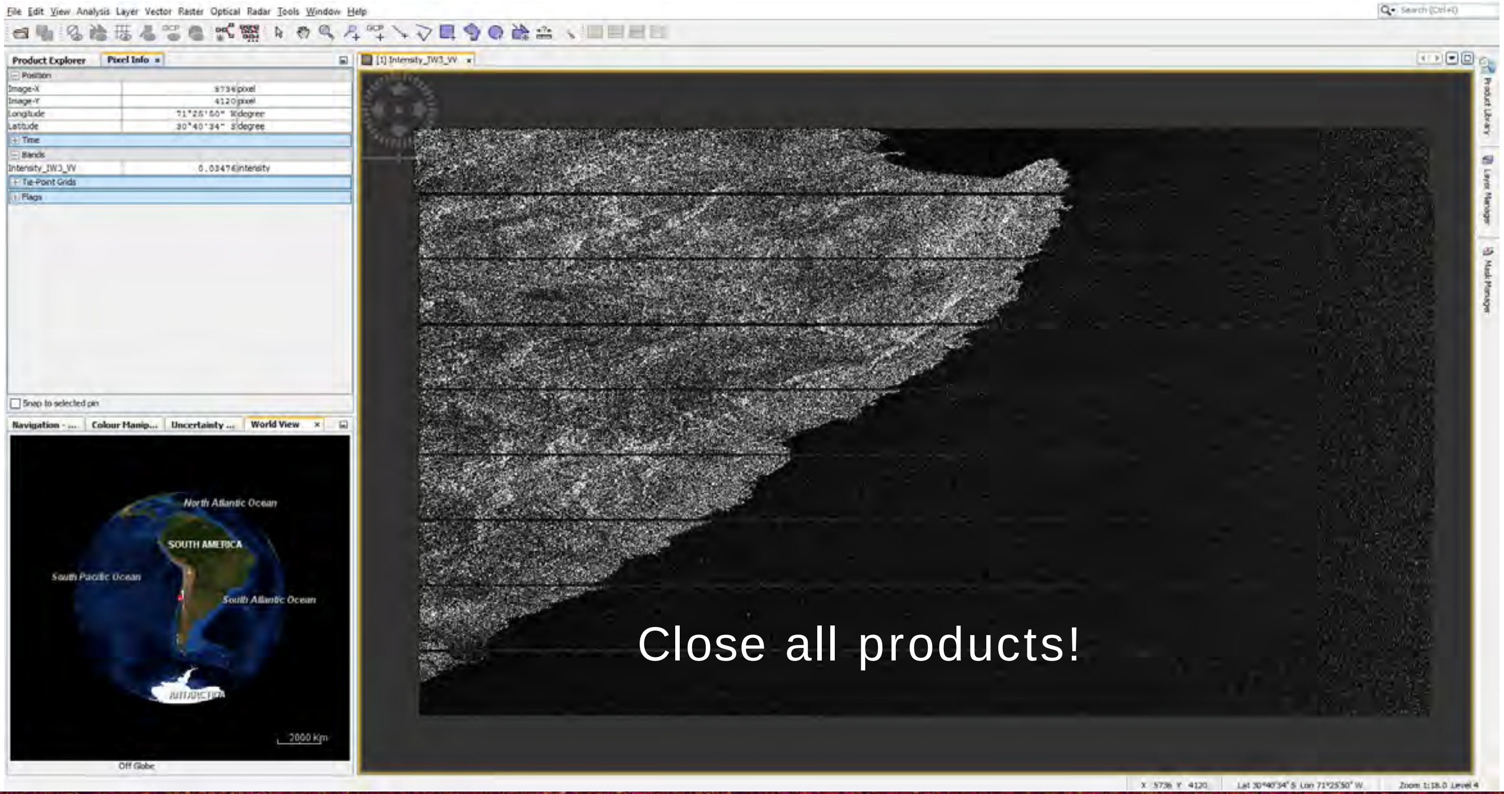
Step 1.b: Apply Precise Orbit



Step 1.c: Calibration



Step 1.c: Calibration



Close all products!

Step 1 (a,b,c) with image on 17/09/2015

0. Open Sentinel-1 SLC DV

1.a **TOPSAR-SPLIT**
Selection of IW3

1.b **Apply Precise Orbit File**
Sentinel Precise Orbit (POEORB)

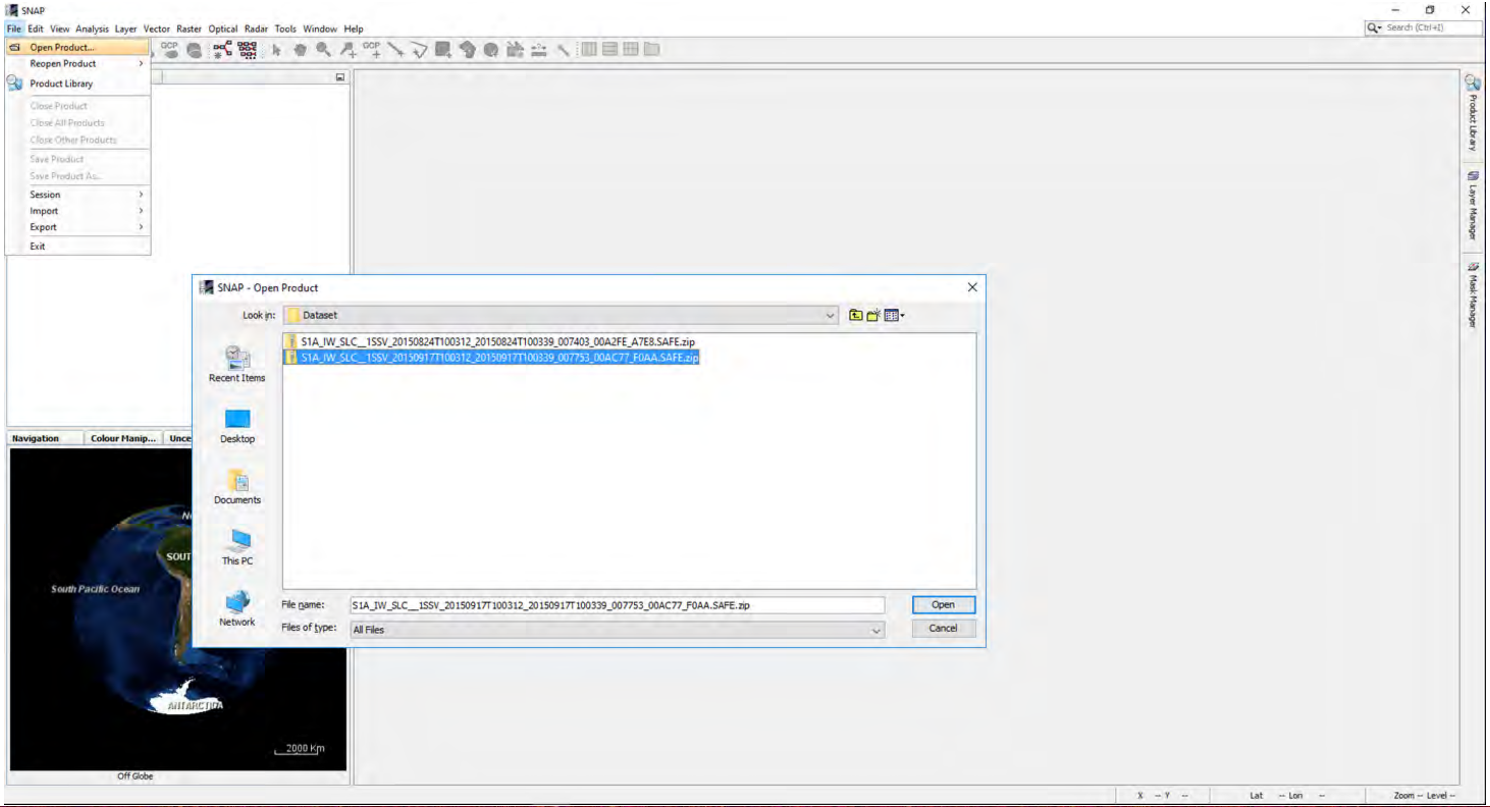
1.c **Calibration** (i, q)

GUI

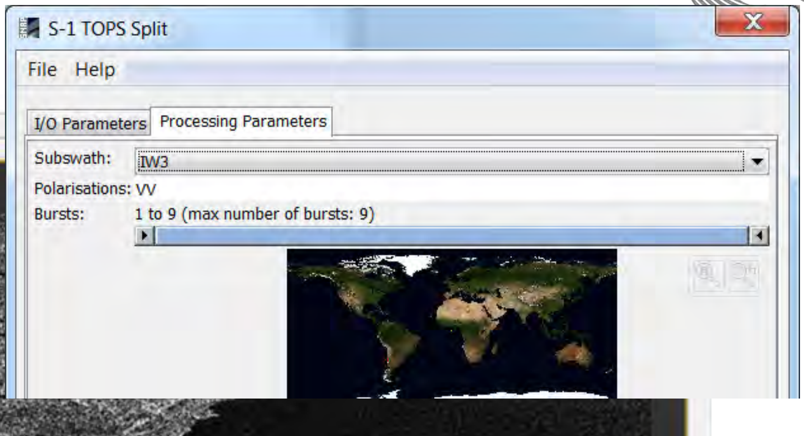
(single product)

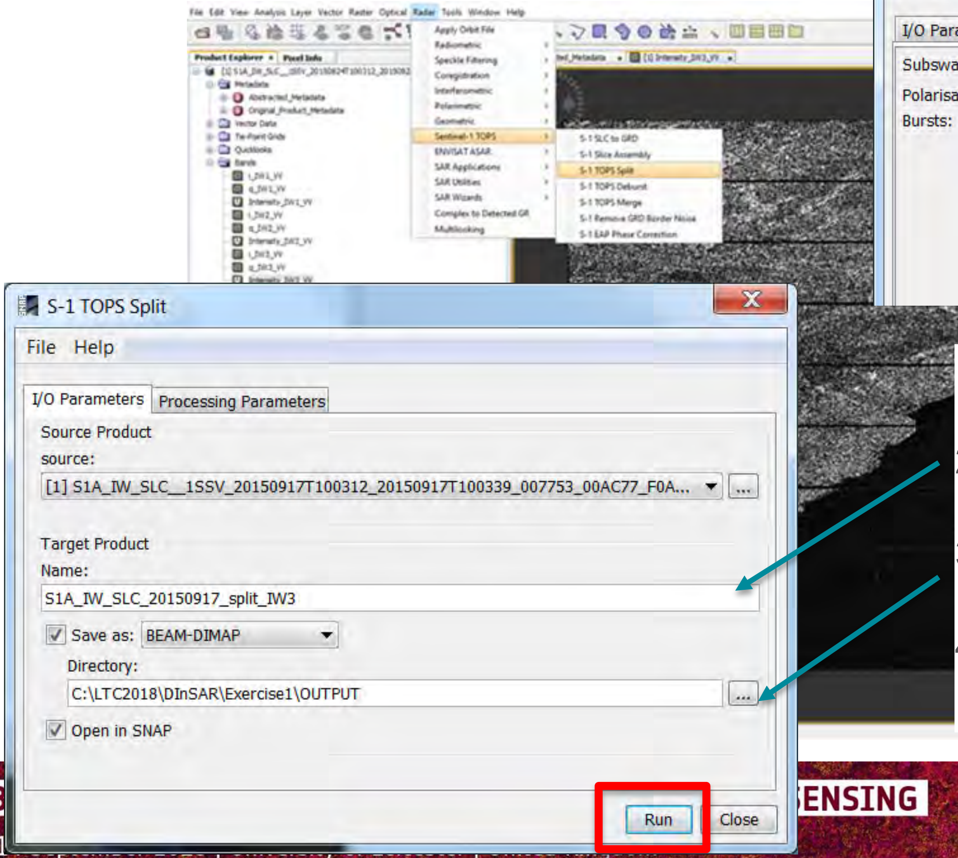
S1A_IW_SLC__1SSV_20150917T100312_20150917T100339_007753_00AC77_F0AA.SAFE.zip

Step 1 (a,b,c) with image on 17/09/2015



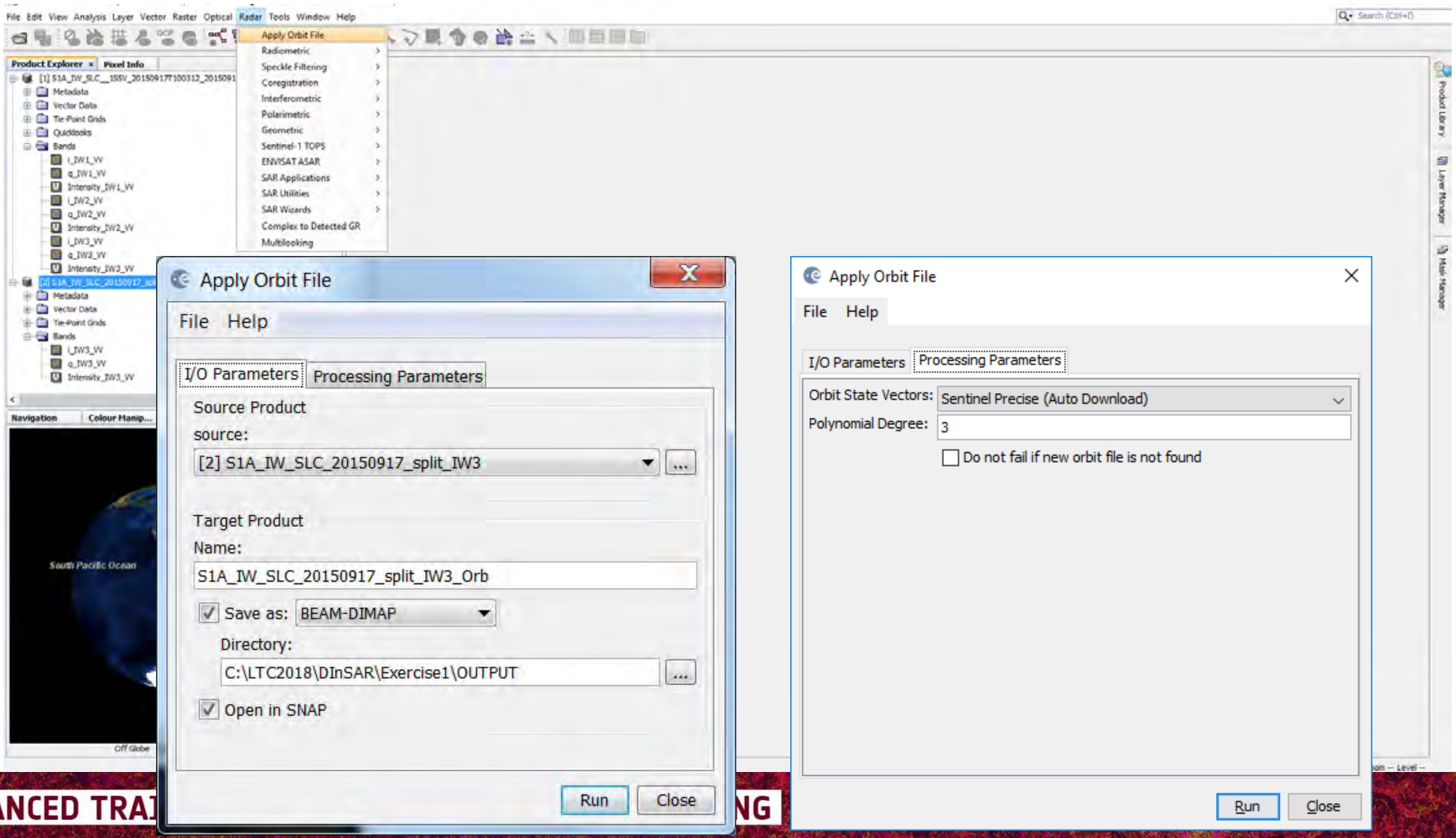
Step 1.a: TOPSAR-SPLIT



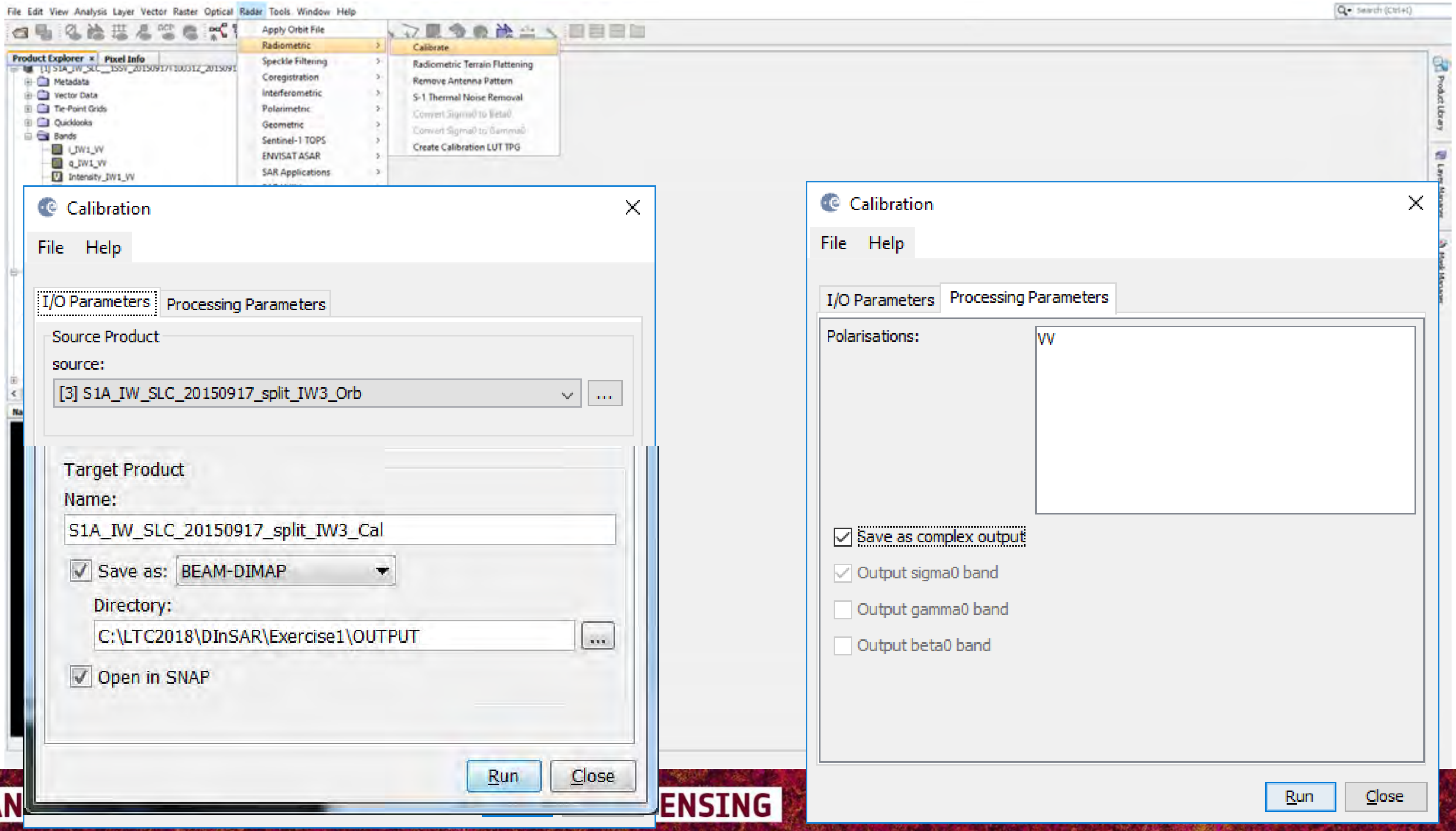


1. Processing Parameters
2. output name
3. Select the directory: ./Exercise1/OUTPUT
4. Click Run

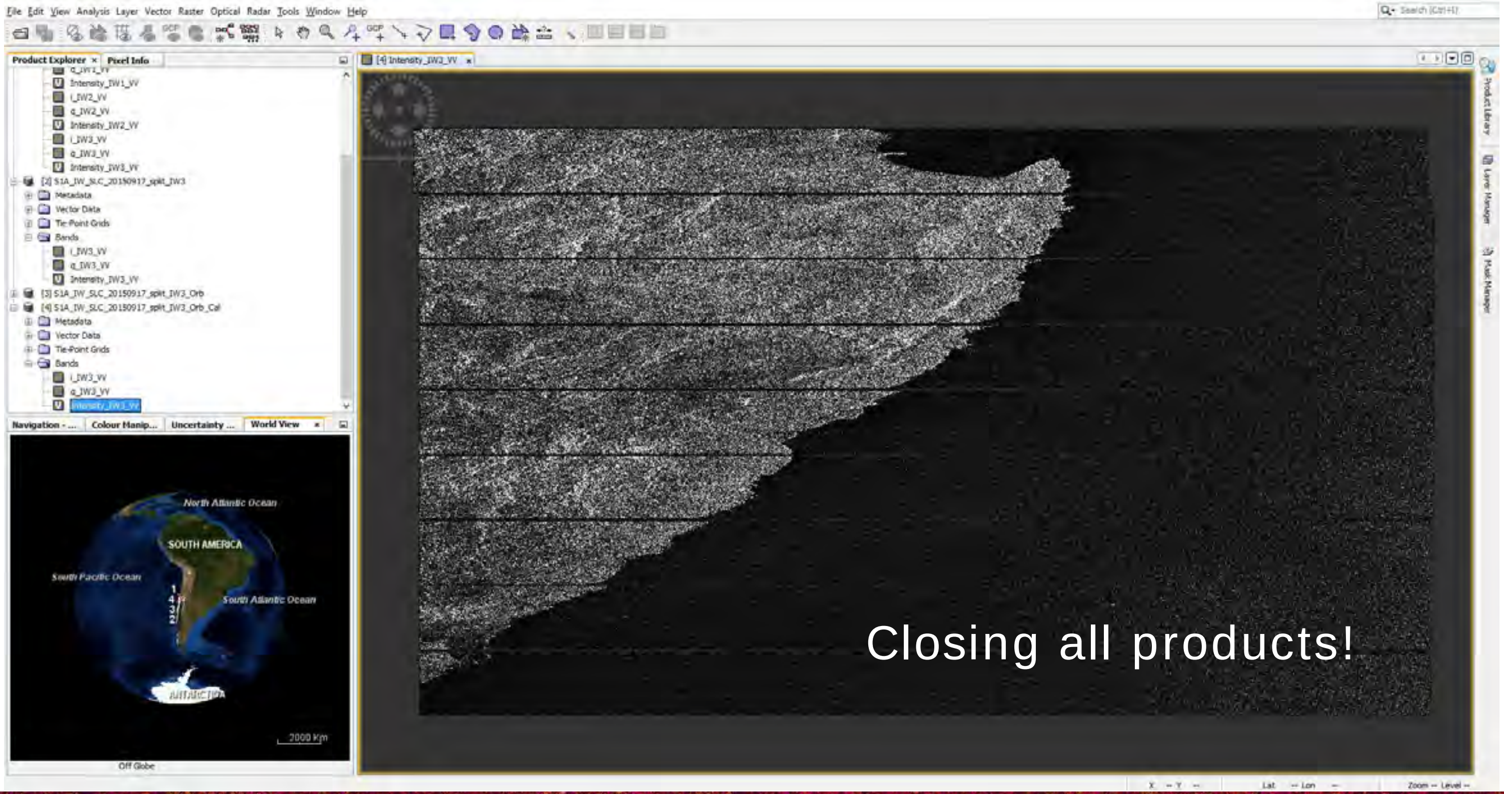
Step 1.b: Apply Precise Orbit



Step 1.c: Calibration



Step 1.c: Calibration



Step 2: TOPSAR Coregistration

0. Open Sentinel-1 SLC DV

1.a **TOPSAR-SPLIT**
Selection of IW3

1.b **Apply Precise Orbit File**
Sentinel Precise Orbit (POEORB)

1.c **Calibration** (i, q)

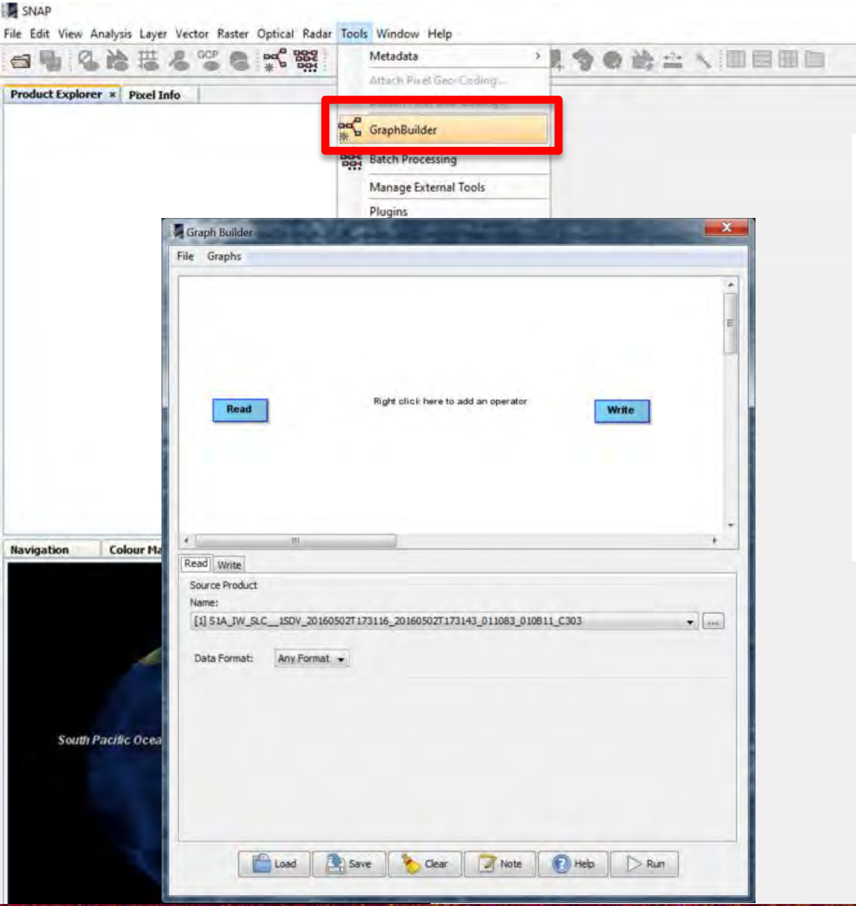
GUI

(2 X product)

2. TOPSAR Coregistration

Graph Builder

The GRAPH BUILDER



- Create your own processing chains
- Visual Graph Processing Framework interface
- Executed from command line or from GUI
- Allows for *batch processing* on stack of images

Step 2: TOPSAR Coregistration

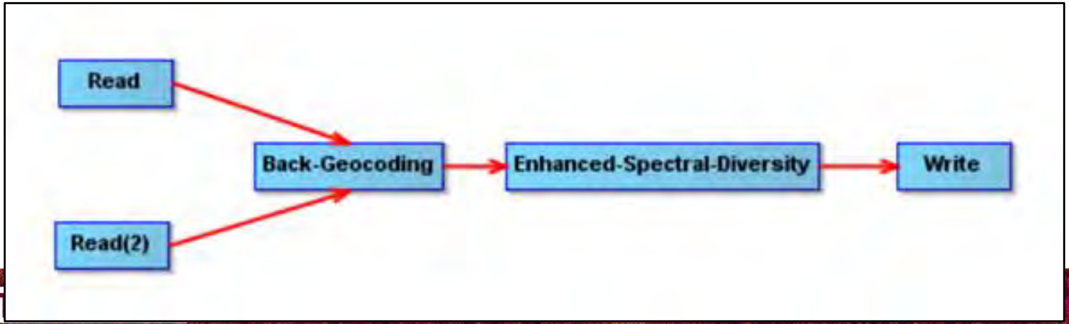
MASTER

- TOPSAR-SPLIT
  Subswath selection
- Apply Precise Orbit File
- Calibration

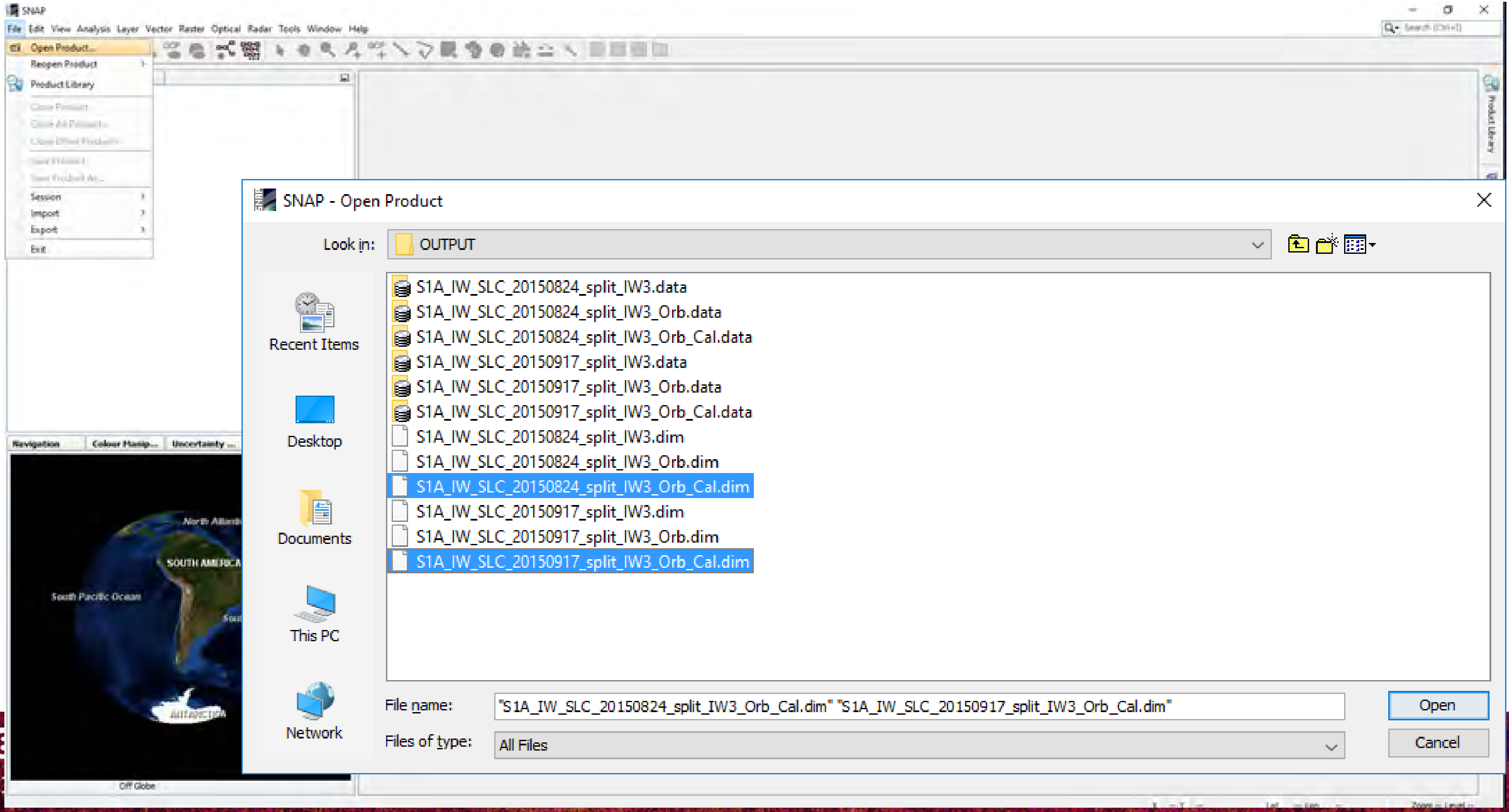
SLAVE

- TOPSAR-SPLIT
  Subswath selection
- Apply Precise Orbit File
- Calibration

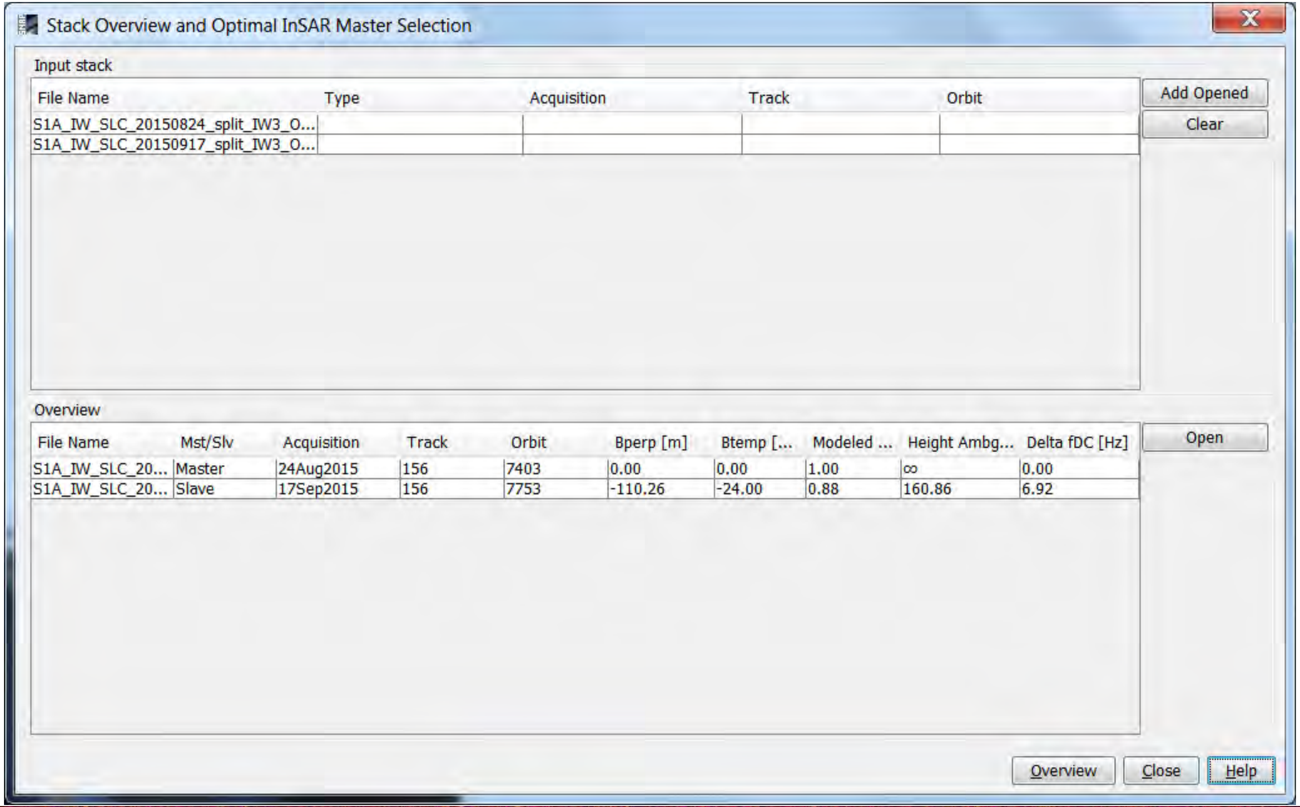
BACK GEOCODING → Enhanced Spectral Diversity → Coregistered Images



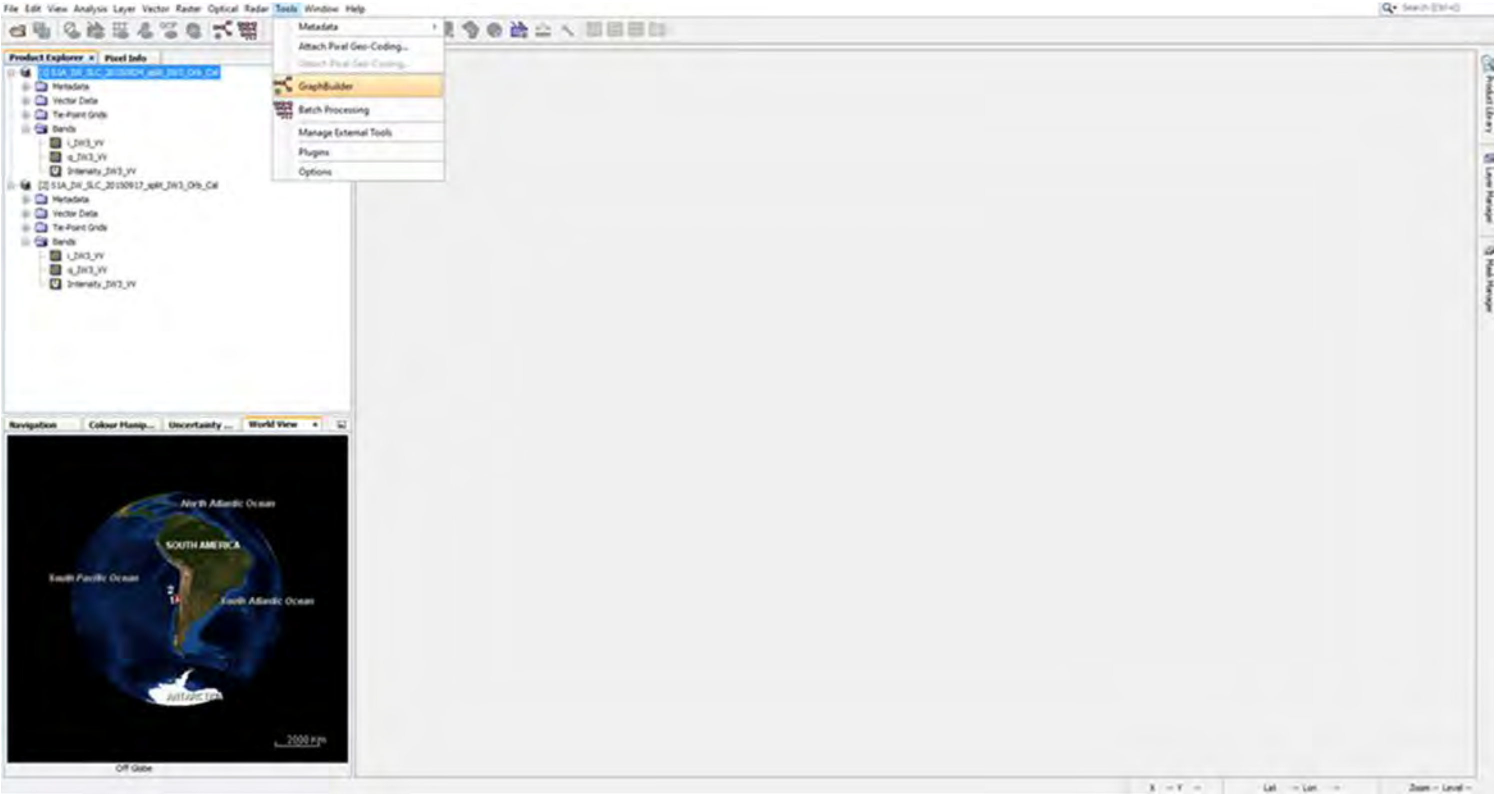
Open both pre-processed products



Baseline computation



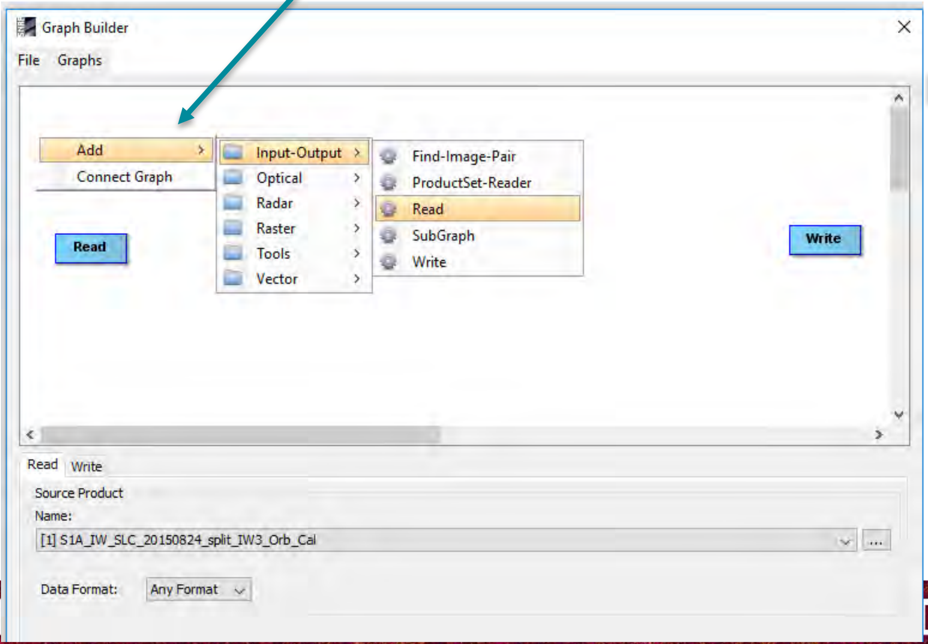
Step2 - TOPSAR Coregistration via GB

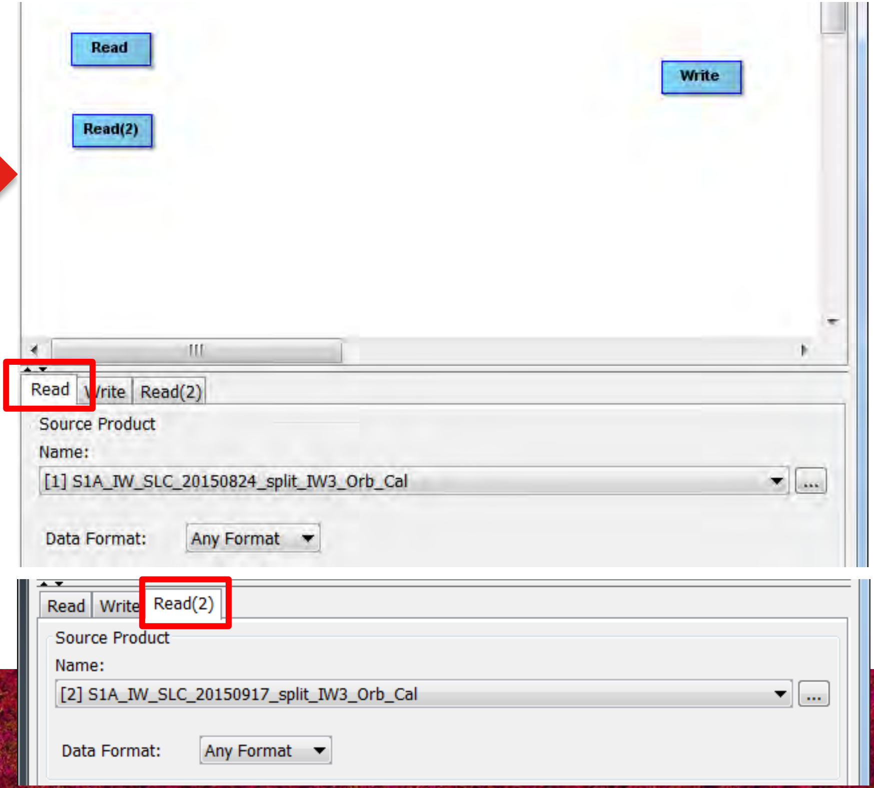


Step2 - TOPSAR Coregistration via GB

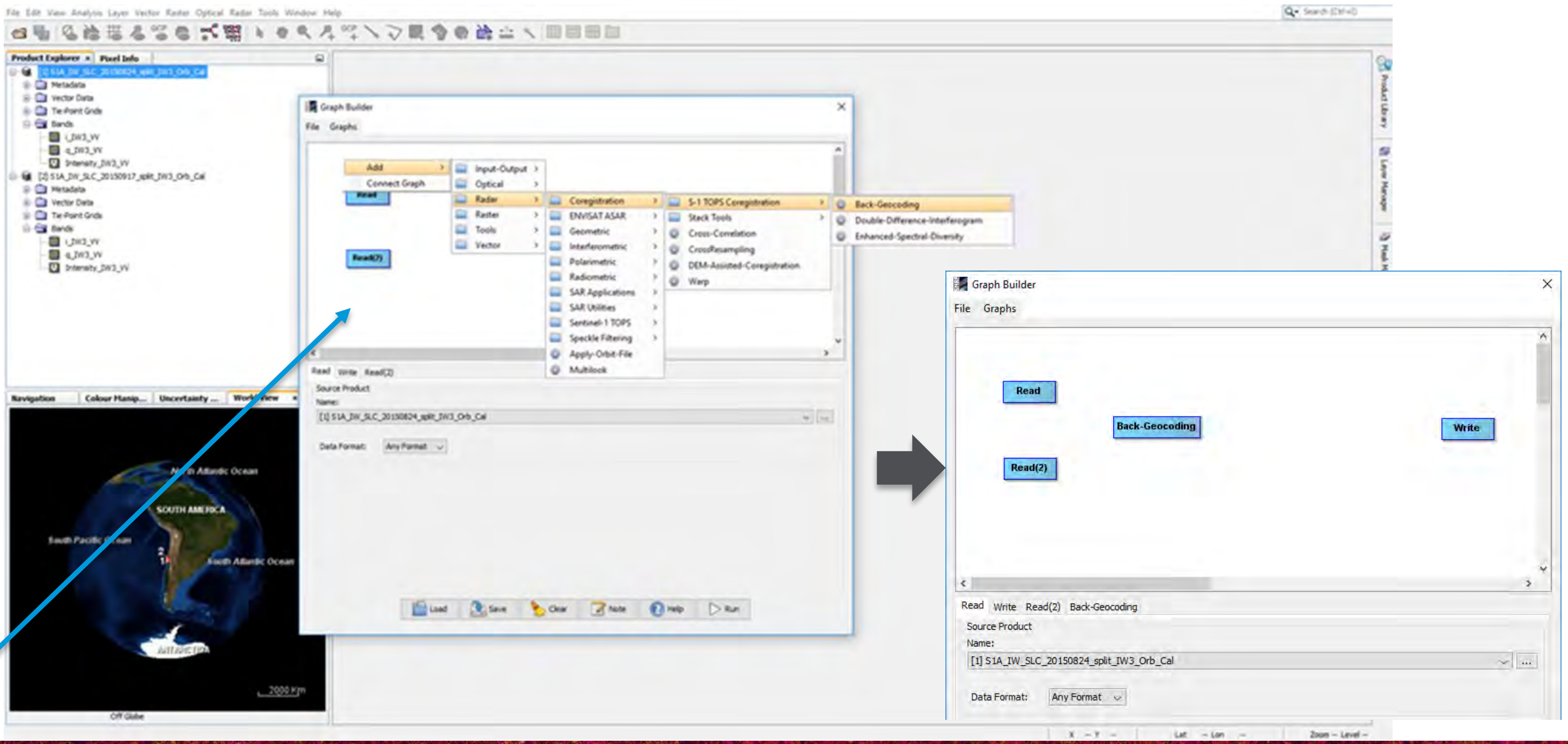
Having the mouse on the white space, click on mouse right button to access the MENU of operators

Select a READ OP



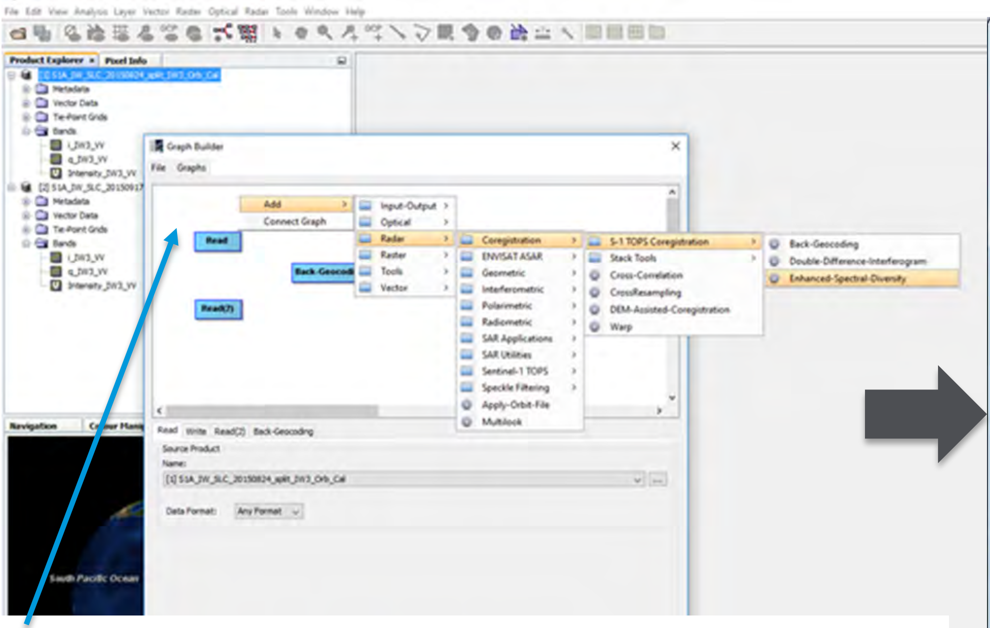


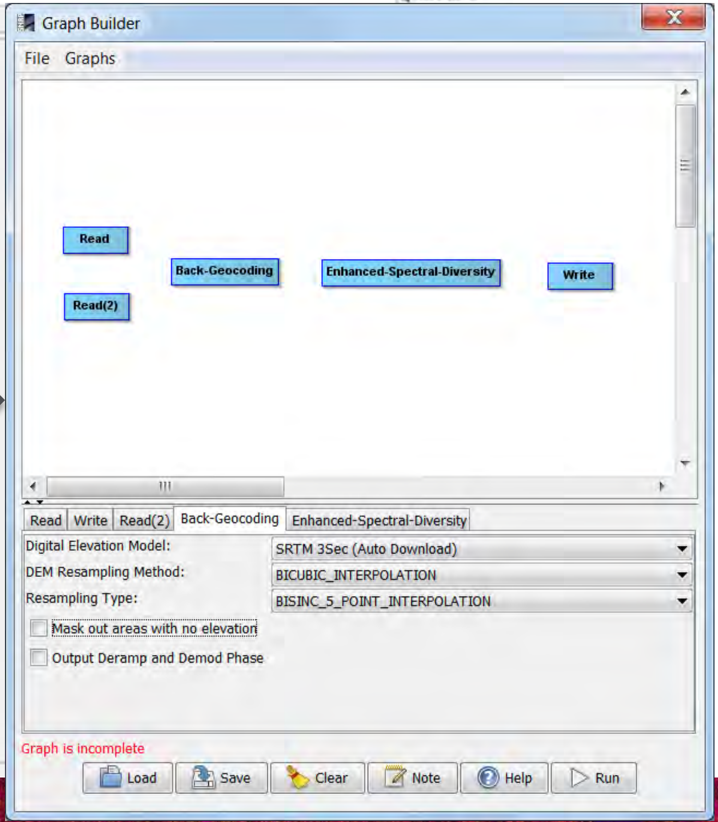
TOPSAR Coregistration via GB: Back-Geocoding OP



Having the mouse on the white space, click on mouse right button to access the MENU of operators

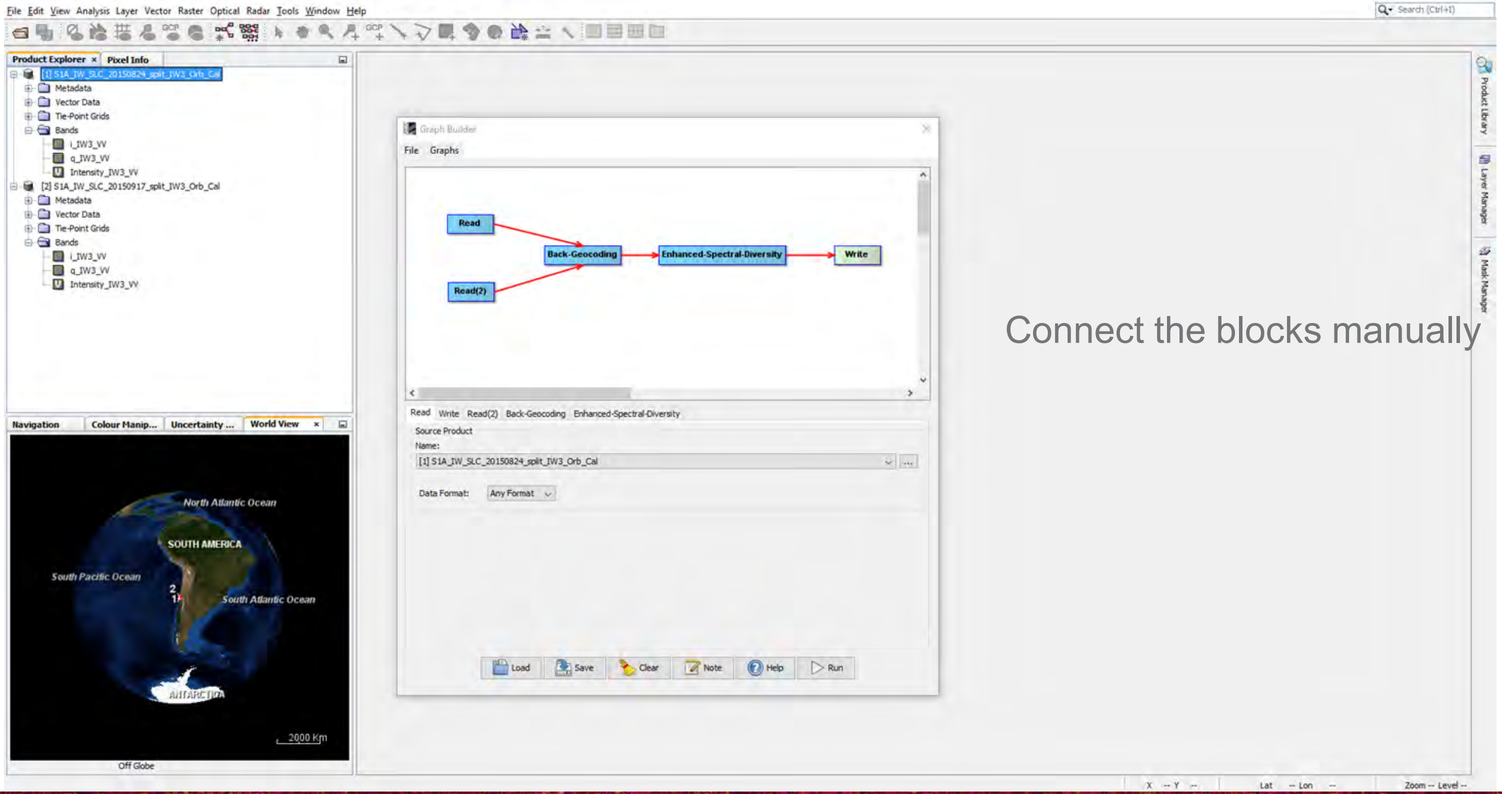
TOPSAR Coregistration via GB: Enhanced Spectral Diversity





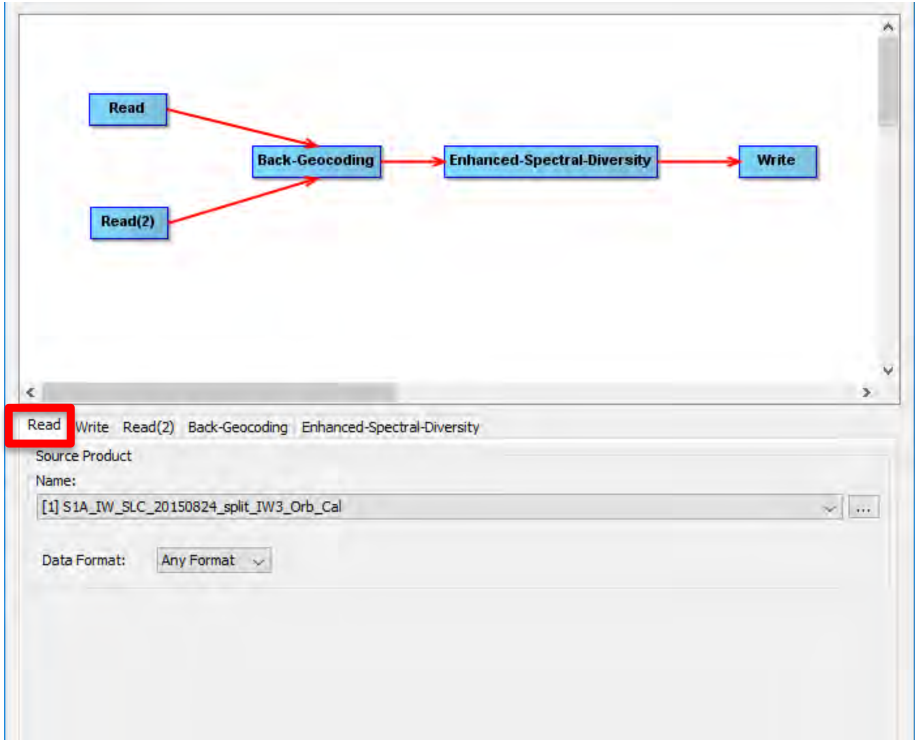
Having the mouse on the white space, click on mouse right button to access the MENU of operators

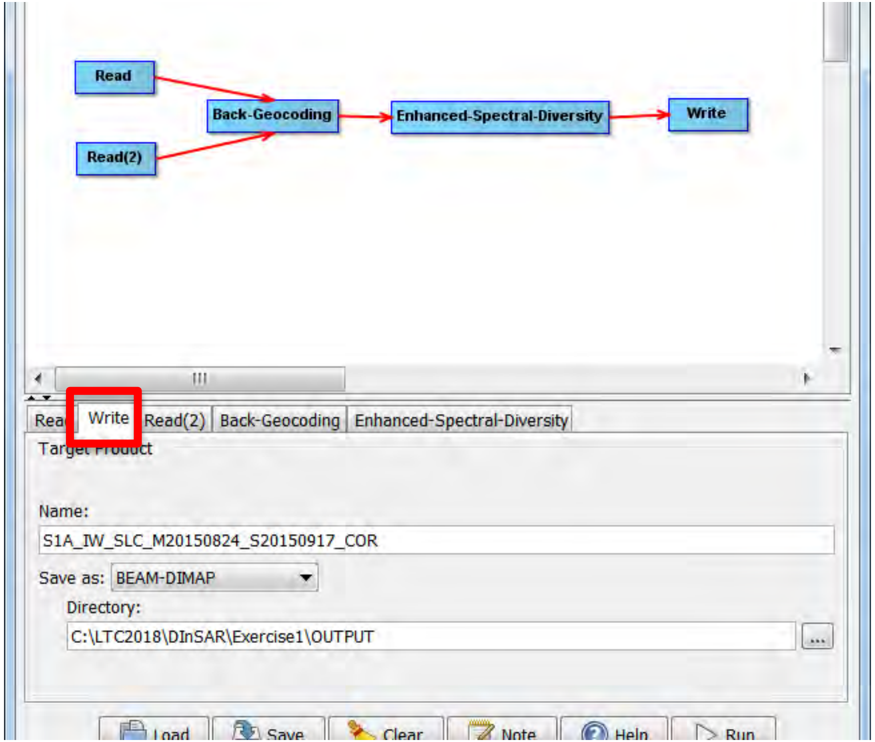
GB: Connecting the blocks



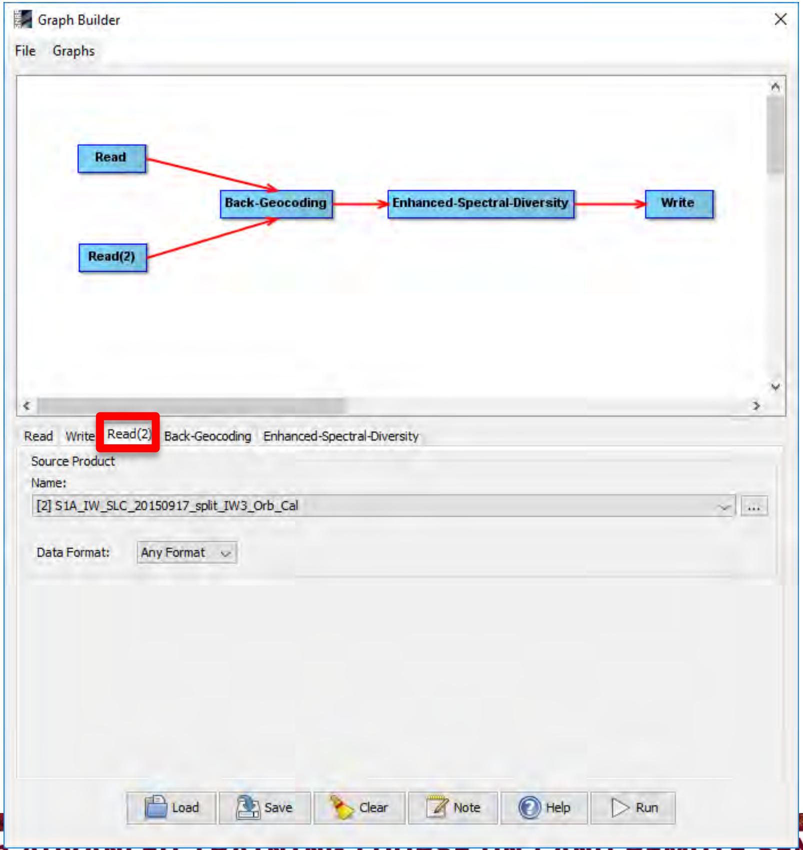
Connect the blocks manually

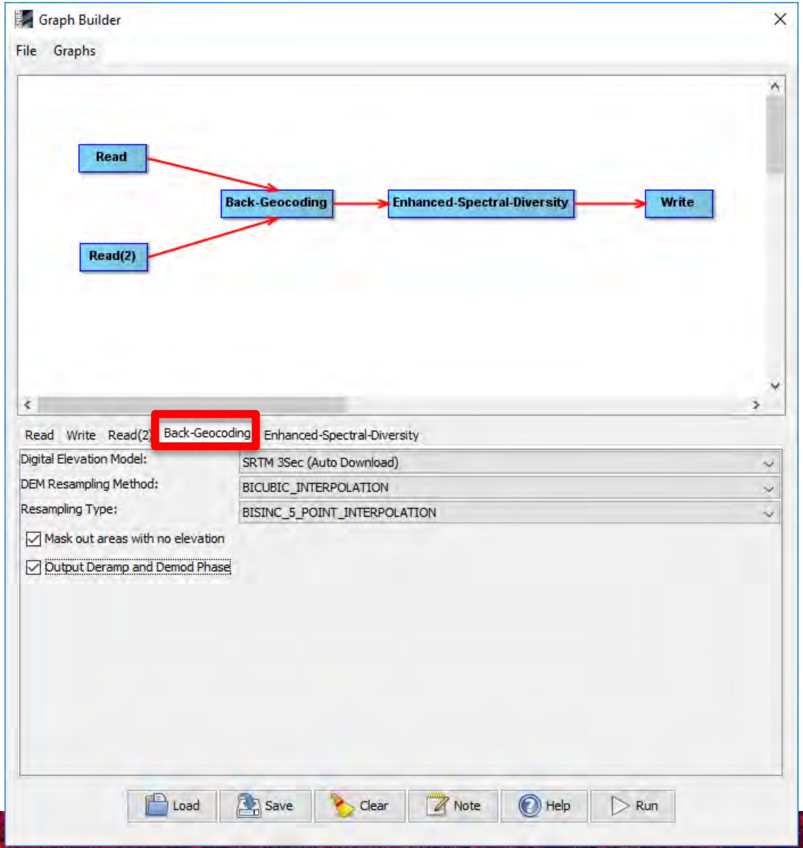
Inserting the parameters for the chain



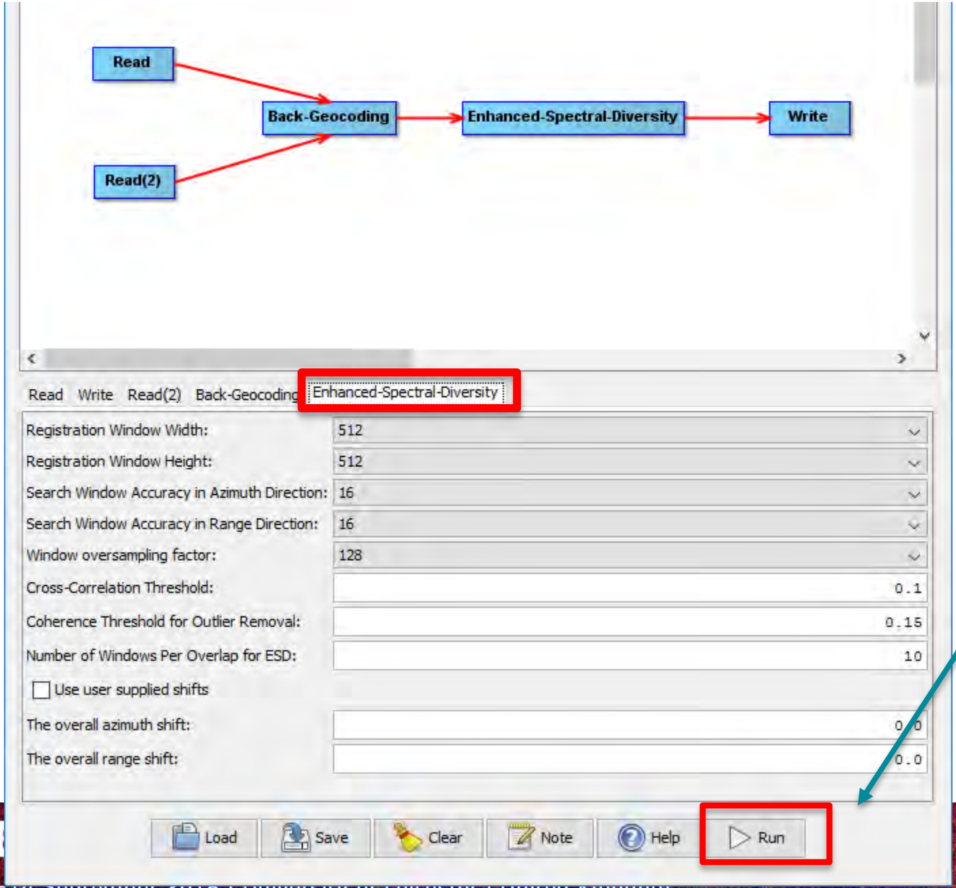


Inserting the parameters





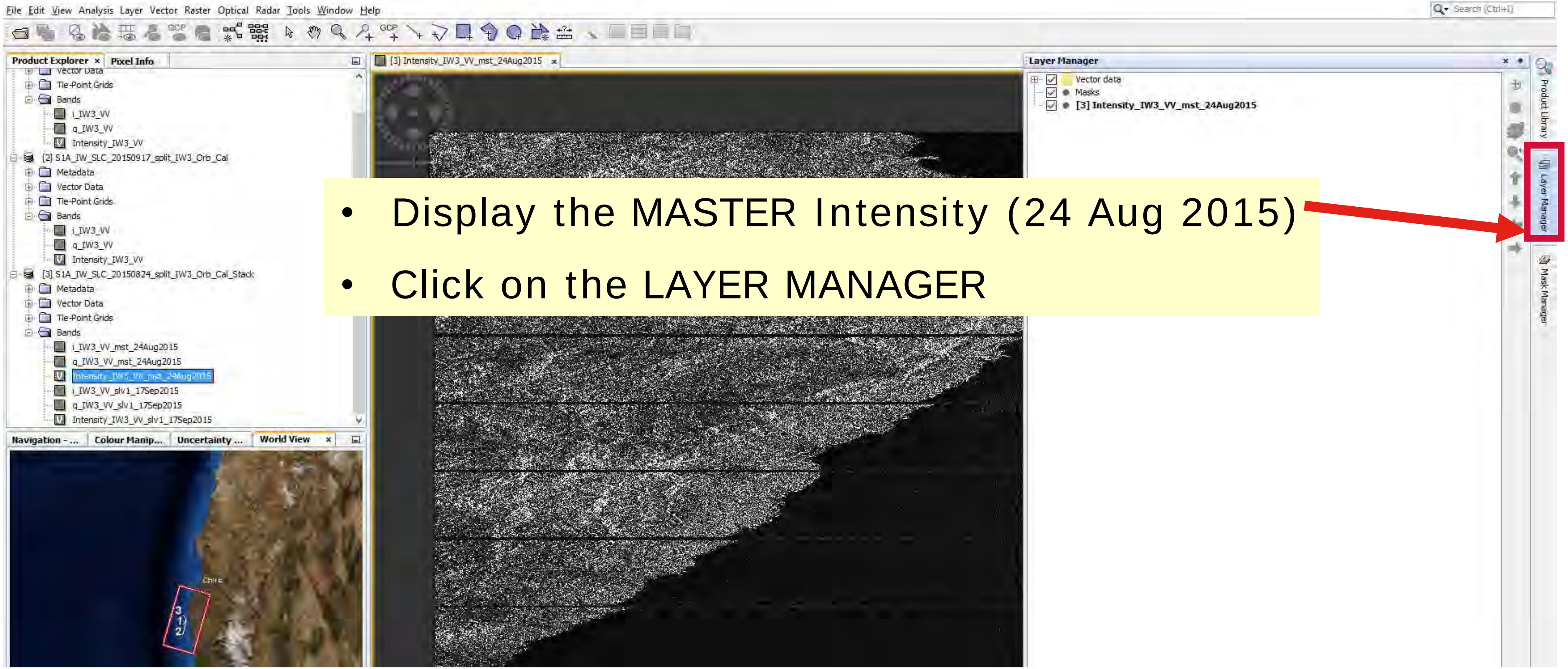
Inserting the parameters



After inserting the parameters in the operators, execute the chain

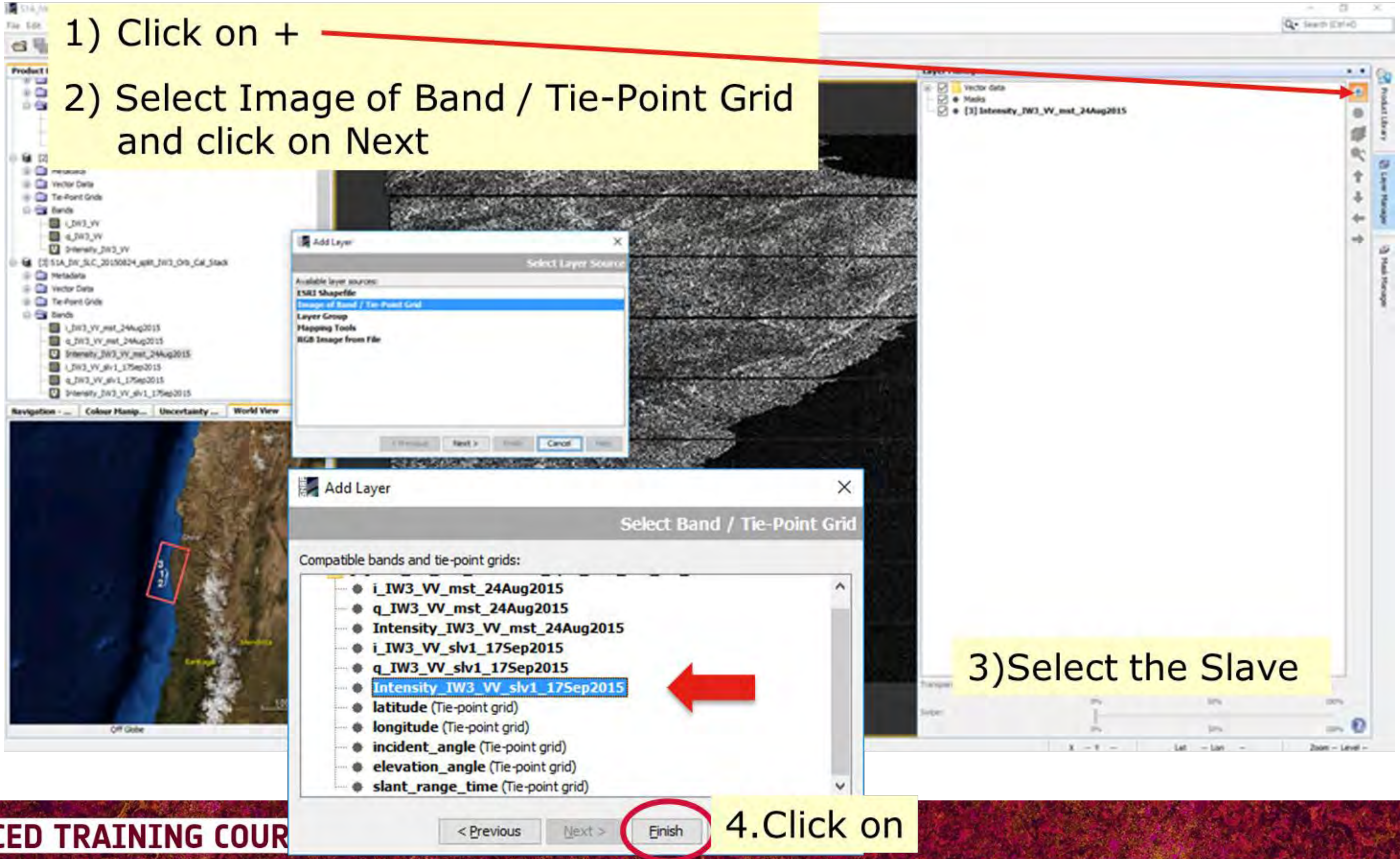
N.B.: in the backup folder Graph_TOPSAR_COR.xml

Overlay Master and Slave: the Layer Manager

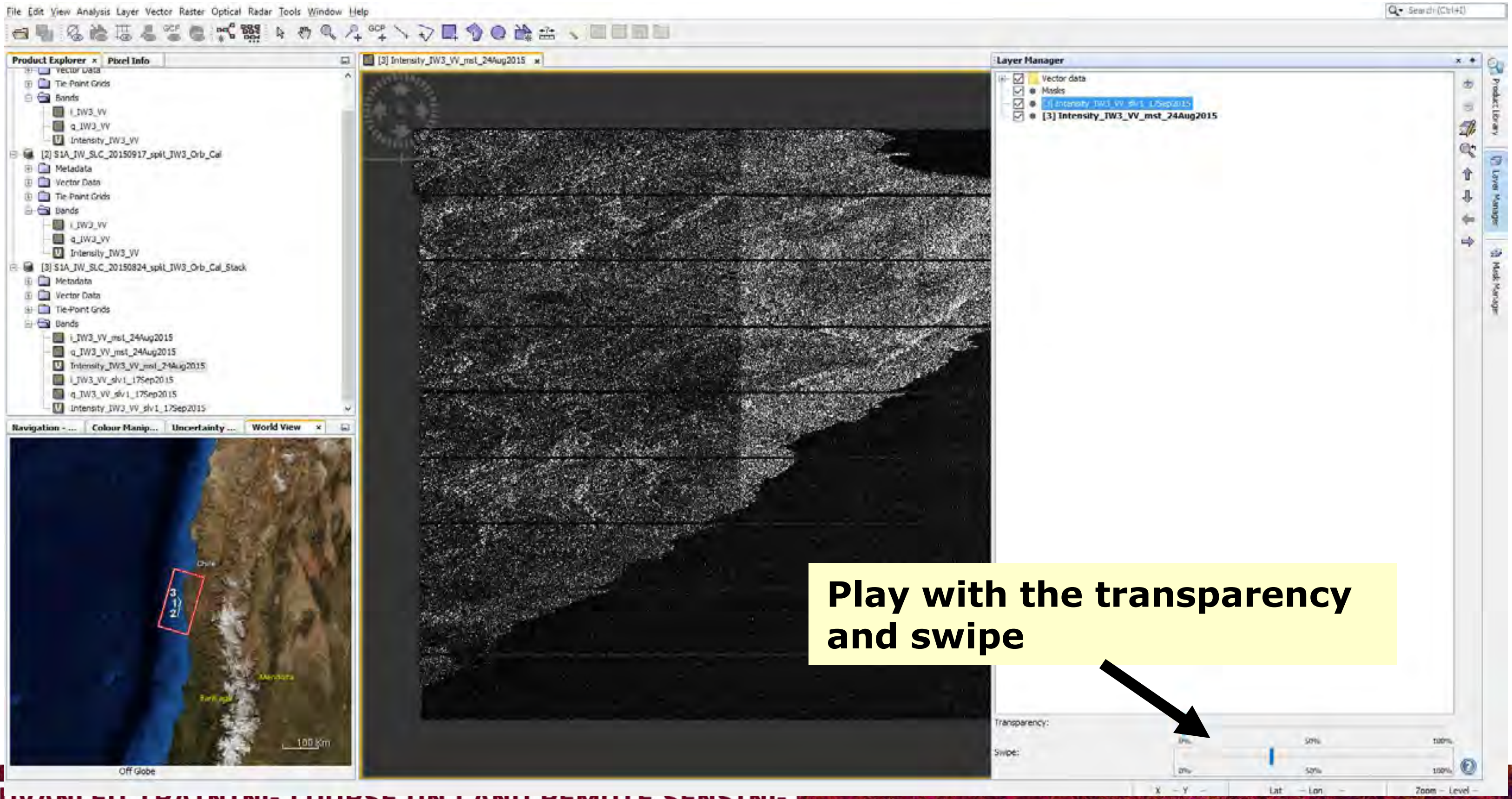


- Display the MASTER Intensity (24 Aug 2015)
- Click on the LAYER MANAGER

Overlay Master and Slave: the Layer Manager



Overlay Master and Slave: the Layer Manager



Exercise 2 – DinSAR processing

Generation of a wrapped differential (co-seismic) interferogram, employing a Sentinel-1 TOPS pair acquired before (24 August) and after the event (17 September) providing information about the earthquake which took place on the 25^{th} August 2015 in Chile

The exercise would consist in:

1. Open the Coregistered Sentinel-1 pair (output of step 2 from Exercise 1)
2. Interferogram Formation and Coherence Estimation
3. TOPS debursting
4. Comparison of interferograms and coherence
5. Interferogram with subtraction of topography
6. Goldstein phase filtering
7. Multilooking for filtered phase
8. Geocoding of ML interferogram
9. Export of results to Google Earth

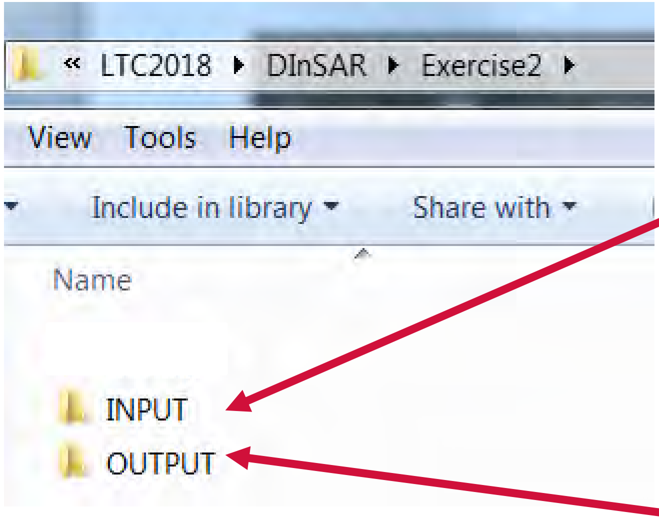
The exercise will be done using the GUI

Exercise 2 – DinSAR processing: data location

Copy the following 2 files from **./Exercise1/OUTPUT** to **./Exercise2/INPUT**

S1A_IW_SLC_M20150824_S20150917_COR.data

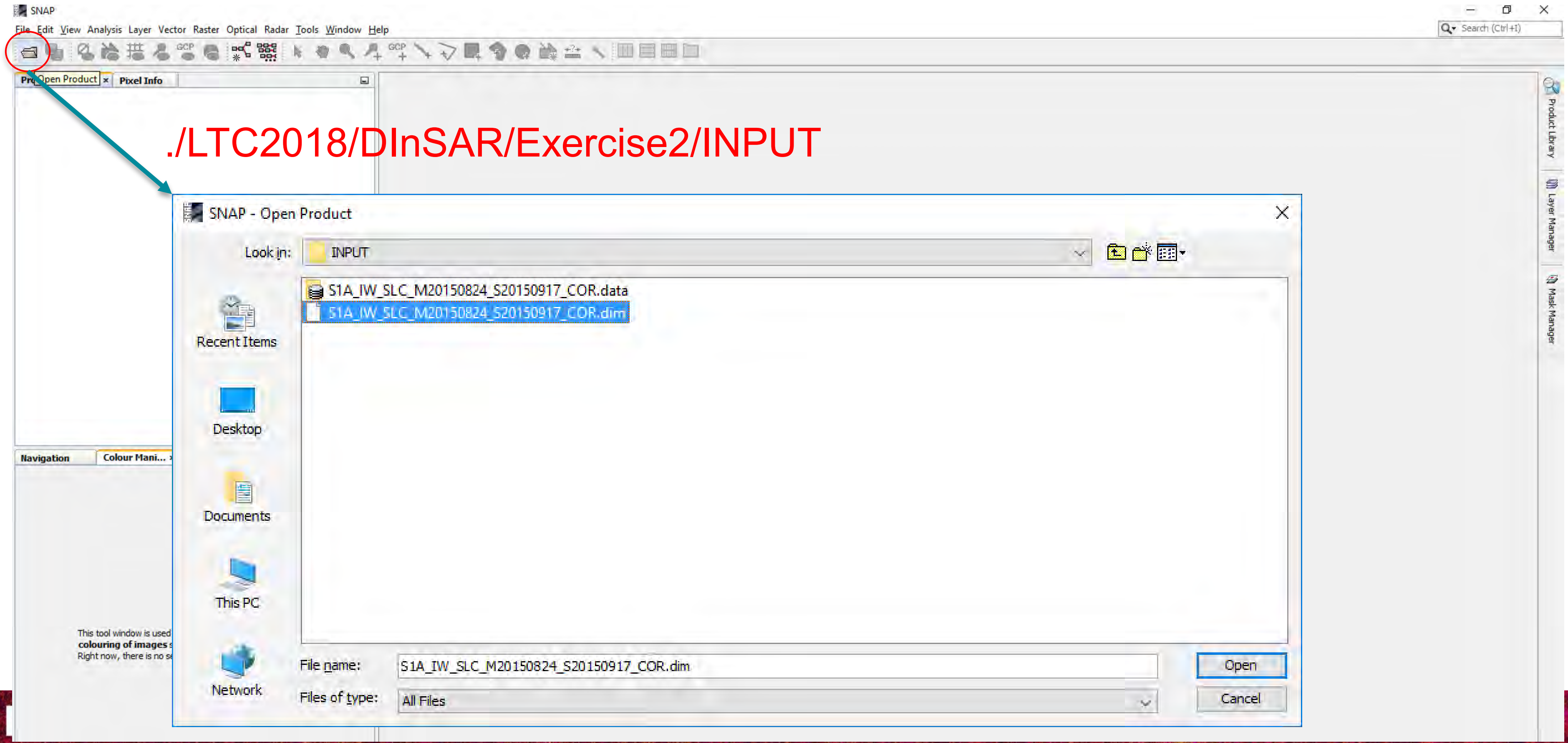
S1A_IW_SLC_M20150824_S20150917_COR.dim



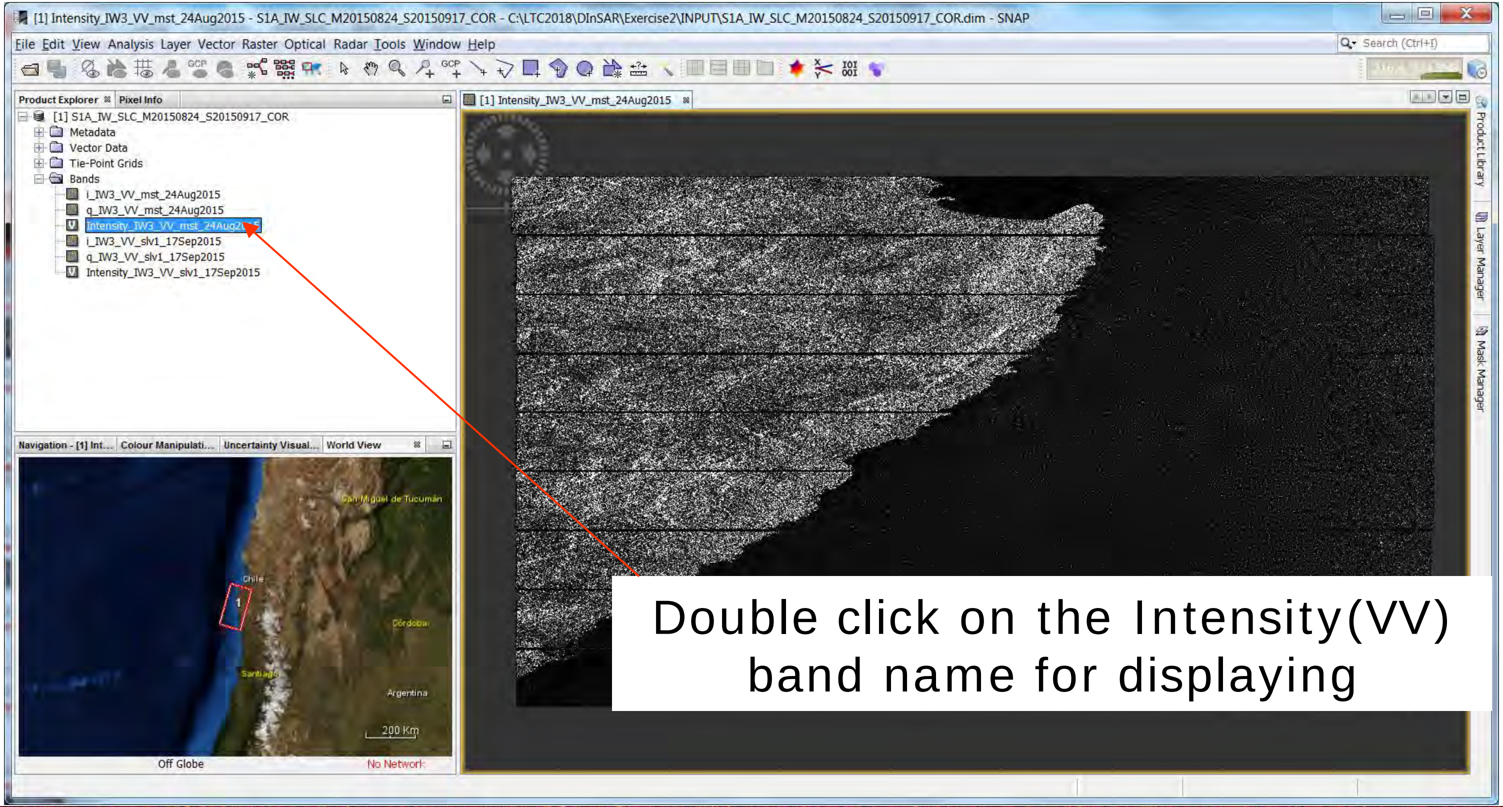
INPUT folder containing the input for the exercise

The outputs of the exercise will be stored here

Step 1: Open Coregistered product



Step 1: Open Coregistered product



Double click on the Intensity(VV) band name for displaying

Interferometric phase contribution

$$\Delta\varphi = \Delta\varphi_{flat} + \Delta\varphi_{elevation} + \Delta\varphi_{displacement} + \Delta\varphi_{atmosphere} + \Delta\varphi_{noise} + \Delta\phi_{err}$$

$$\boxed{-\frac{4\pi}{\lambda}\frac{B_n s}{R\tan\theta}} \qquad \boxed{-\frac{\Delta q}{\sin\theta}\cdot\frac{B_n}{R_0}\cdot\frac{4\pi}{\lambda}} \qquad \boxed{+\frac{4\pi}{\lambda}d}$$

- Δϕflat is called flat Earth phase which is the phase contribution due to the earth curvature.
- Δϕelevation is the topographic contribution to the interferometric phase.
- Δϕdisplacement is the surface deformation contribution to the interferometric phase.
- Δϕatmosphere is the atmospheric contribution to the interferometric phase. It is introduced due to the atmospheric humidity, temperature and pressure change between the two acquisitions.
- Δϕnoise is the phase noise introduced by temporal change of the scatterers, differentlook angle, and volume scattering.
- $\Delta\ \phi_{err}$ = orbital error, coreg. error, thermal noise, other noise

Coherence

- A quality measure for the interferometric phase
- Similar to principles of correlation, but for the complex data

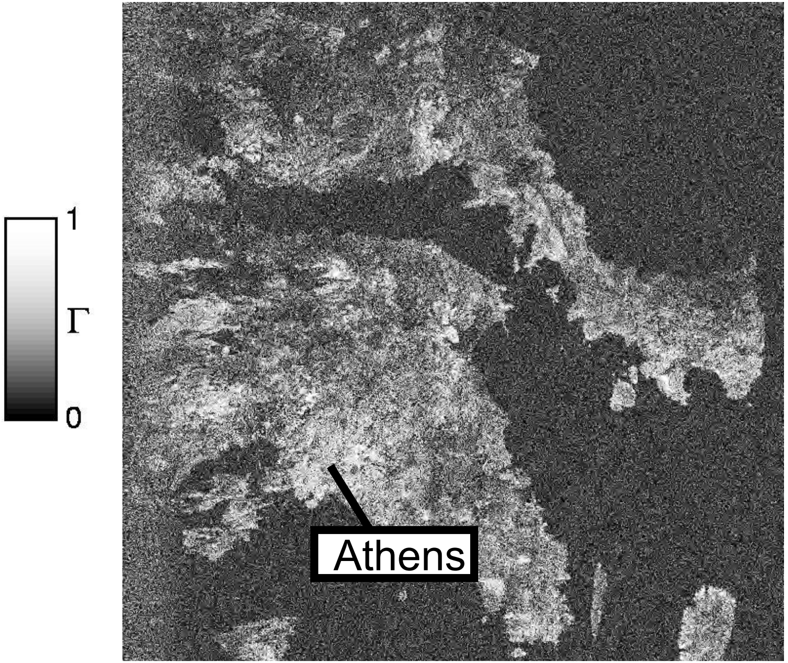
➔ Also as used in change detection monitoring

$$\gamma = \frac{E\{y_1 y_2^*\}}{\sqrt{E\{|y_1|^2\} \cdot E\{|y_2|^2\}}}$$

Estimation of (degree) coherence

$$|\hat{\gamma}| = \frac{|\sum_{n=1}^{N} y_1^{(n)} y_2^{(n)}|}{\sqrt{\sum_{n=1}^{N} |y_1^{(n)}|^2 \sum_{n=1}^{N} |y_2^{(n)}|^2}} \qquad [0,1]$$

Coherence



Coherent surface types

- Buildings (towns/cities)
- Bare Rock

- Grassland
- Agricultural fields
- Ice

Incoherent surface types

- Leafy Trees
- Water

Simplified approximation: Interferogram Formation

$$\Delta\varphi = \cancel{\Delta\varphi_{flat}} + \Delta\varphi_{elevation} + \Delta\varphi_{displacement} + \Delta\varphi_{atmosphere} + \cancel{\Delta\varphi_{noise}} + \cancel{\Delta\phi_{err}}$$

$$\boxed{-\frac{4\pi}{\lambda}\frac{B_n s}{R\tan\theta}} \qquad \boxed{-\frac{\Delta q}{\sin\theta}\cdot\frac{B_n}{R_0}\cdot\frac{4\pi}{\lambda}} \qquad \boxed{+\frac{4\pi}{\lambda}d}$$

- $\Delta\phi$flat is called flat Earth phase which is the phase contribution due to the earth curvature.
- $\Delta\phi$elevation is the topographic contribution to the interferometric phase.
- $\Delta\phi$displacement is the surface deformation contribution to the interferometric phase.
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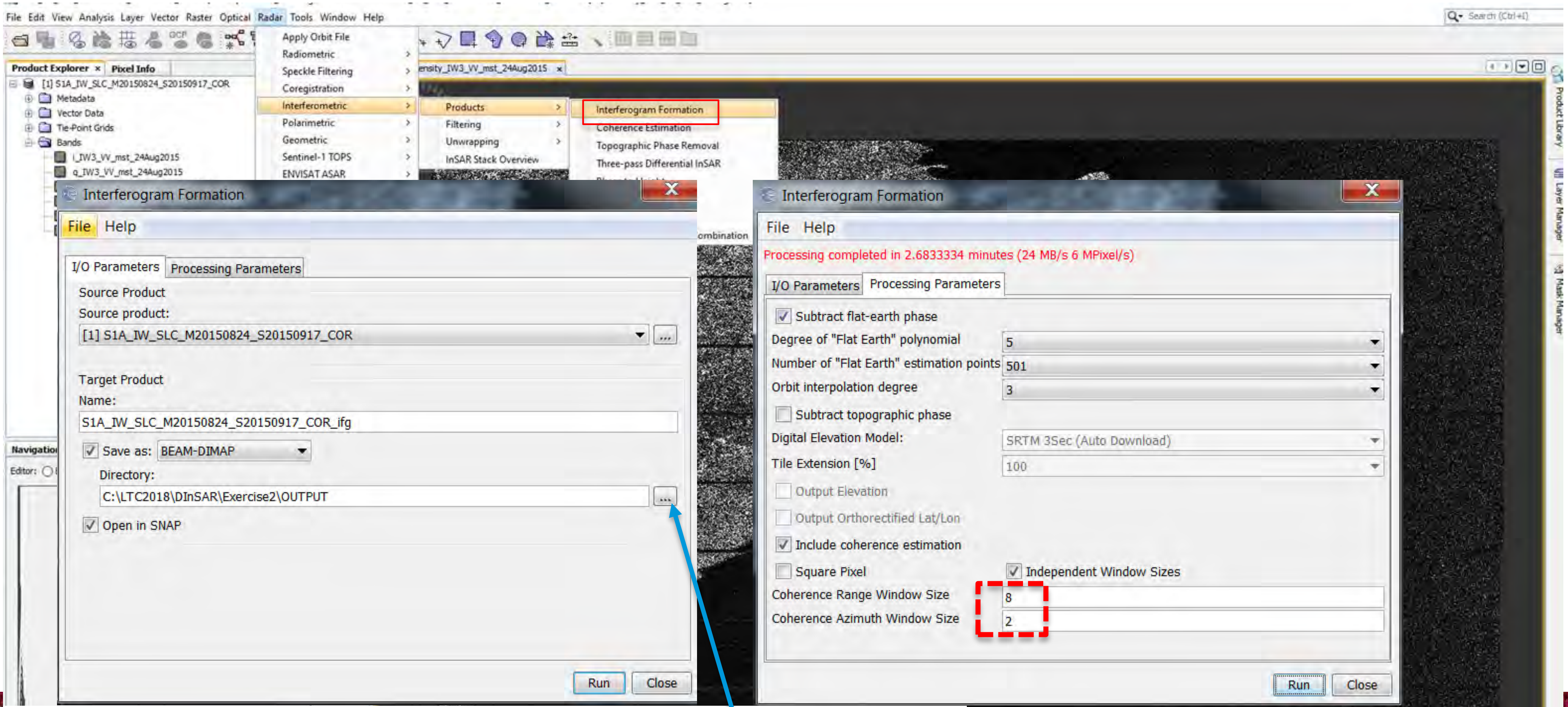
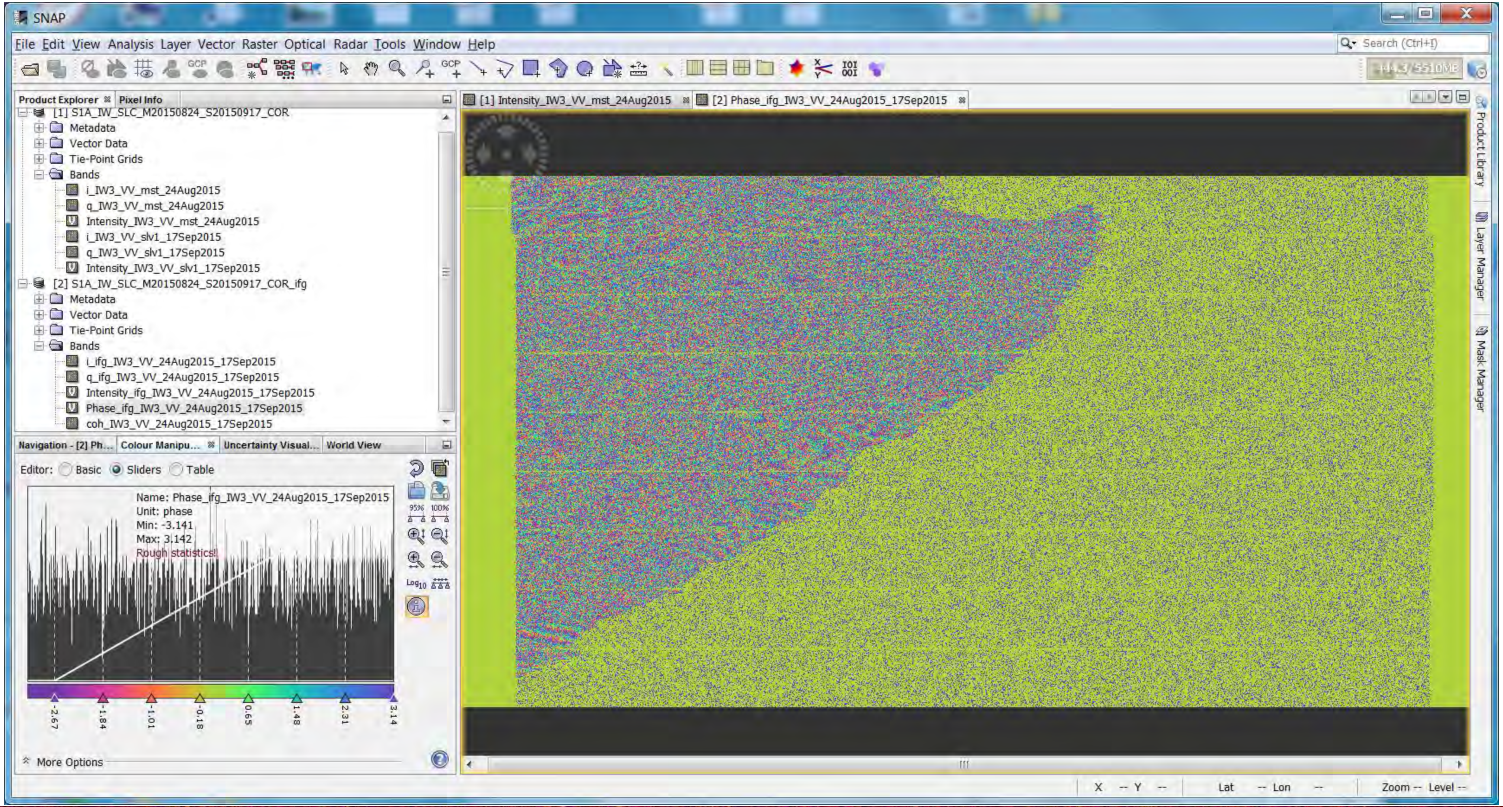
- $\Delta\phi$noise is the phase noise introduced by temporal change of the scatterers, differentlook angle, and volume scattering.
- $\Delta\,\phi_{err}$ = orbital error, coreg. error, thermal noise, other noise

Interferogram Formation and Coherence Estimation

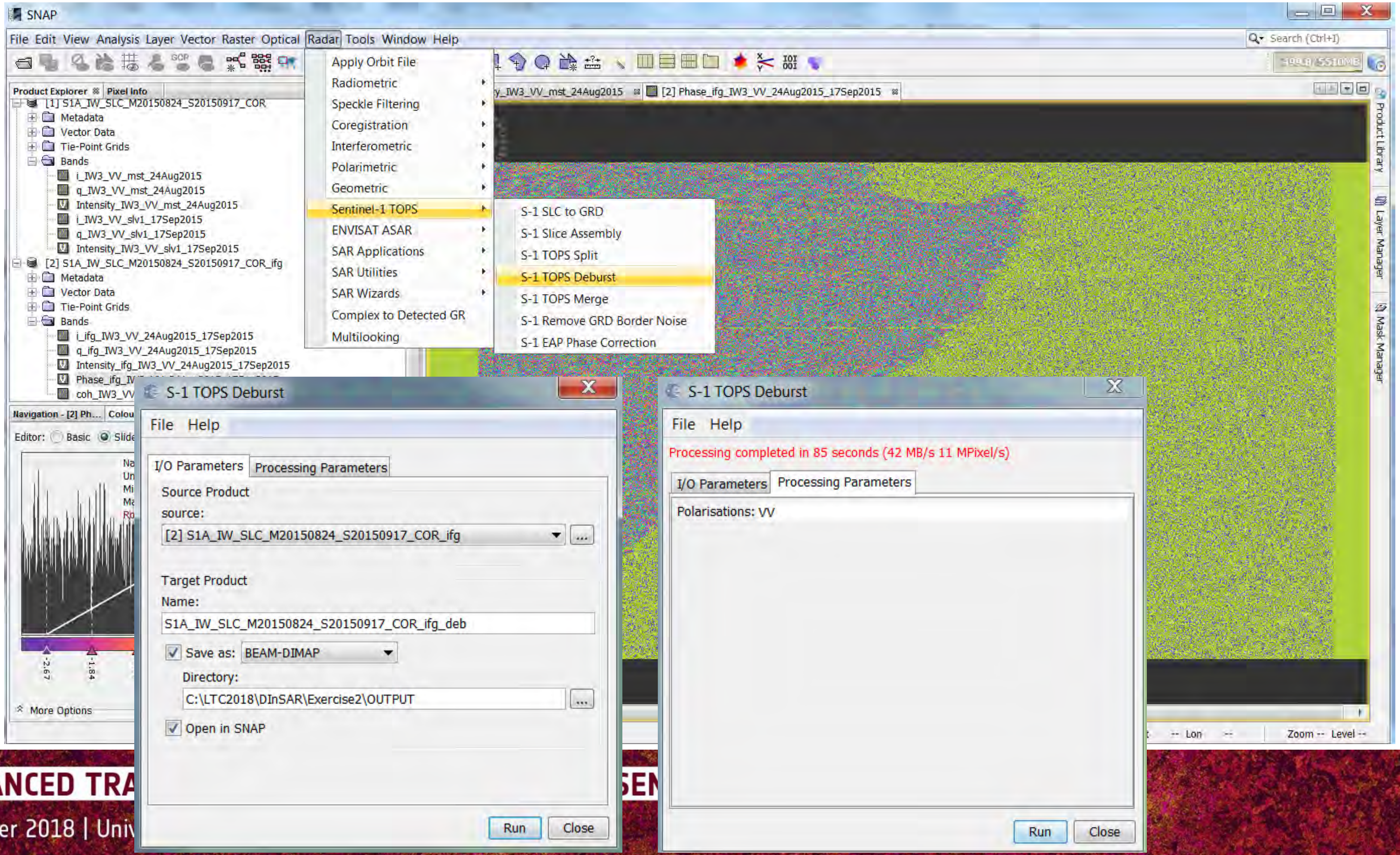


.\LTC2018\DInSAR\Exercise2\OUTPUT

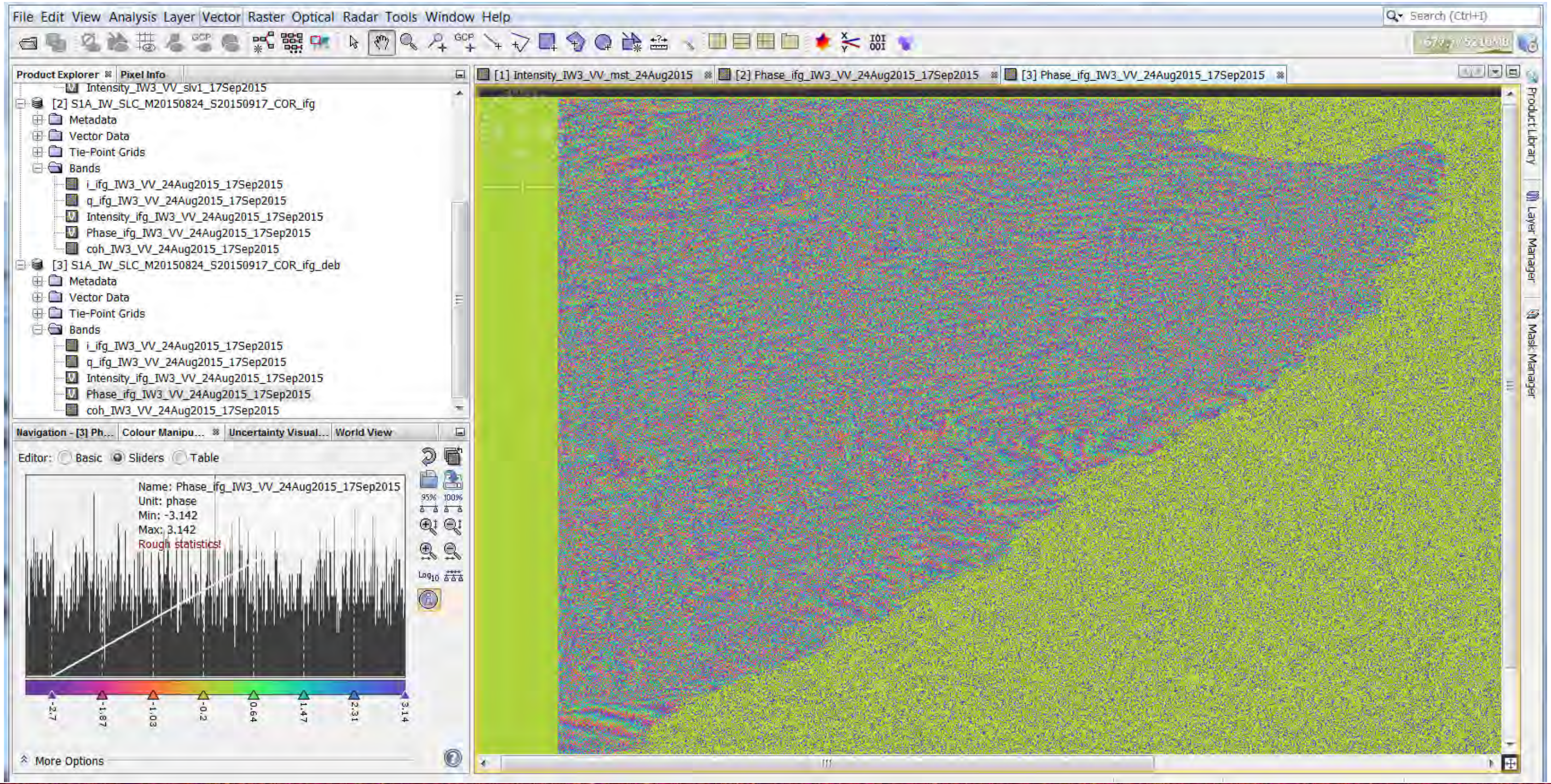
Interferogram Formation



(TOPS) debursting



Interferogram visualisation



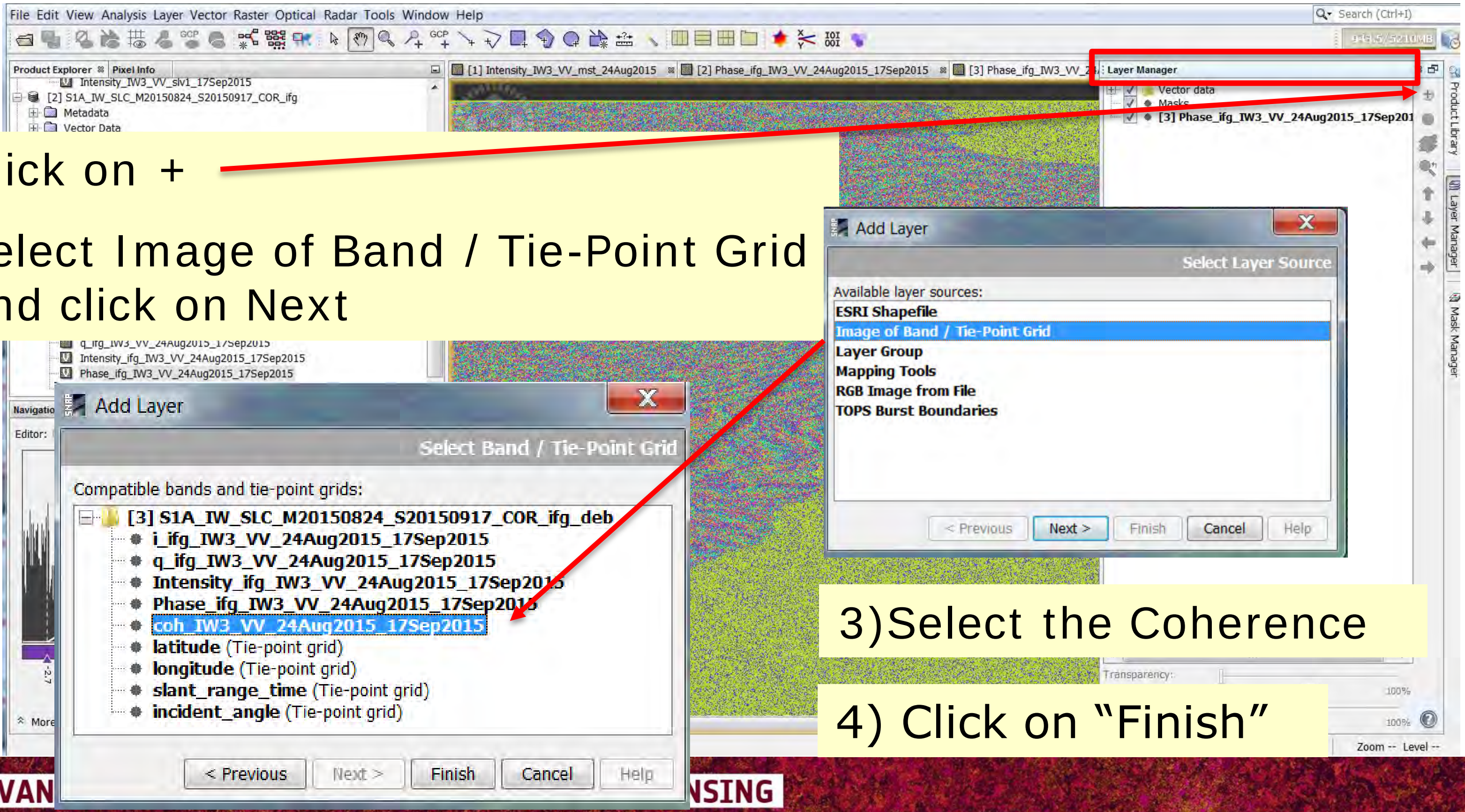
Interferogram phase vs. (degree) coherence

1) Click on +

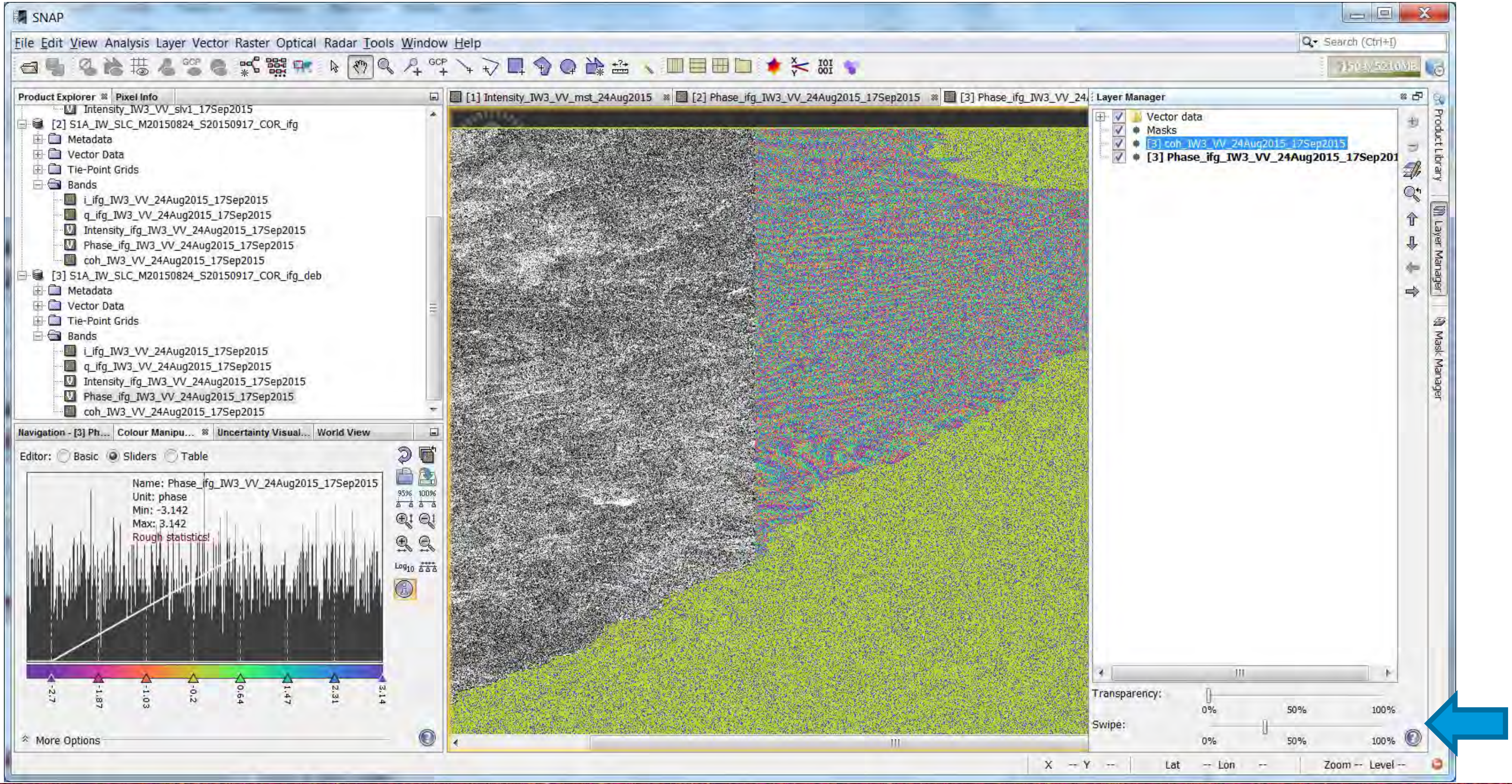
2) Select Image of Band / Tie-Point Grid and click on Next

3)Select the Coherence

4) Click on “Finish”



Interferogram phase vs. (degree) coherence



Simplified approximation: DInSAR interferogram

$$\Delta\varphi = \cancel{\Delta\varphi_{flat}} + \cancel{\Delta\varphi_{elevation}} + \Delta\varphi_{displacement} + \cancel{\Delta\varphi_{atmosphere}} + \cancel{\Delta\varphi_{noise}} + \cancel{\Delta\phi_{err}}$$

$$\boxed{-\frac{4\pi}{\lambda}\frac{B_n s}{R\tan\theta}} \qquad \boxed{-\frac{\Delta q}{\sin\theta}\cdot\frac{B_n}{R_0}\cdot\frac{4\pi}{\lambda}} \qquad \boxed{+\frac{4\pi}{\lambda}d}$$

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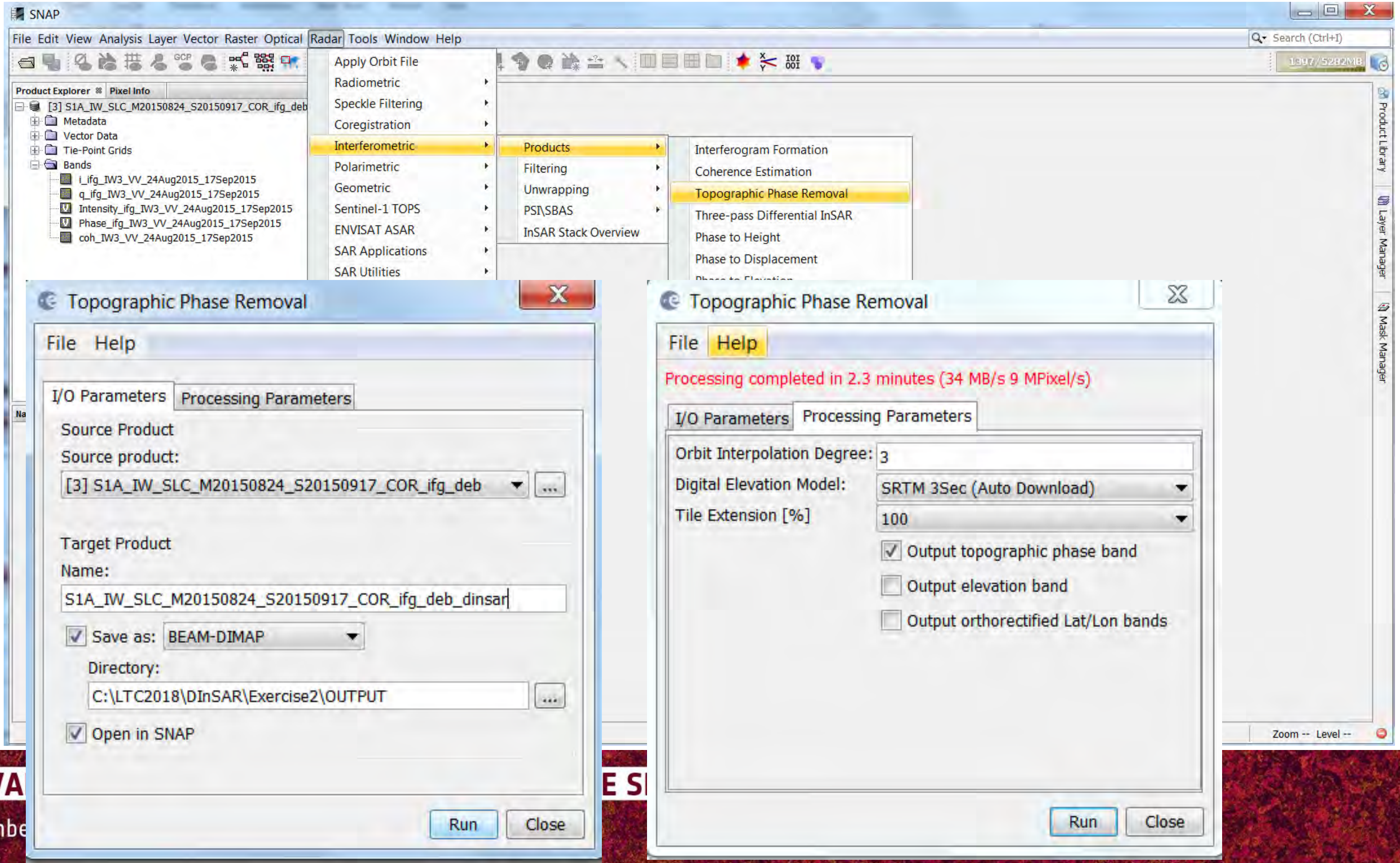
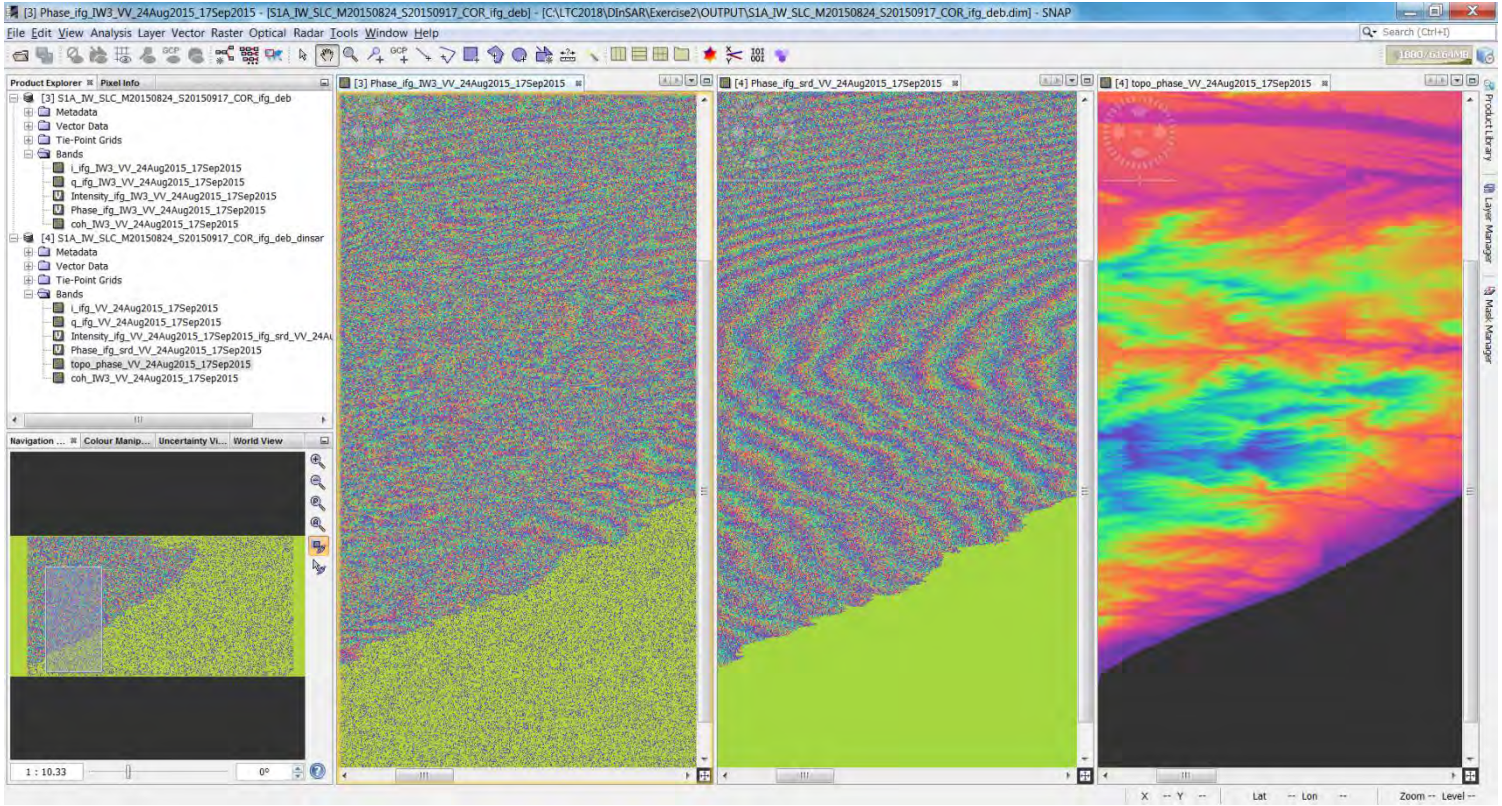
- $\Delta\,\phi_{err}$ = orbital error, coreg. error, thermal noise, other noise

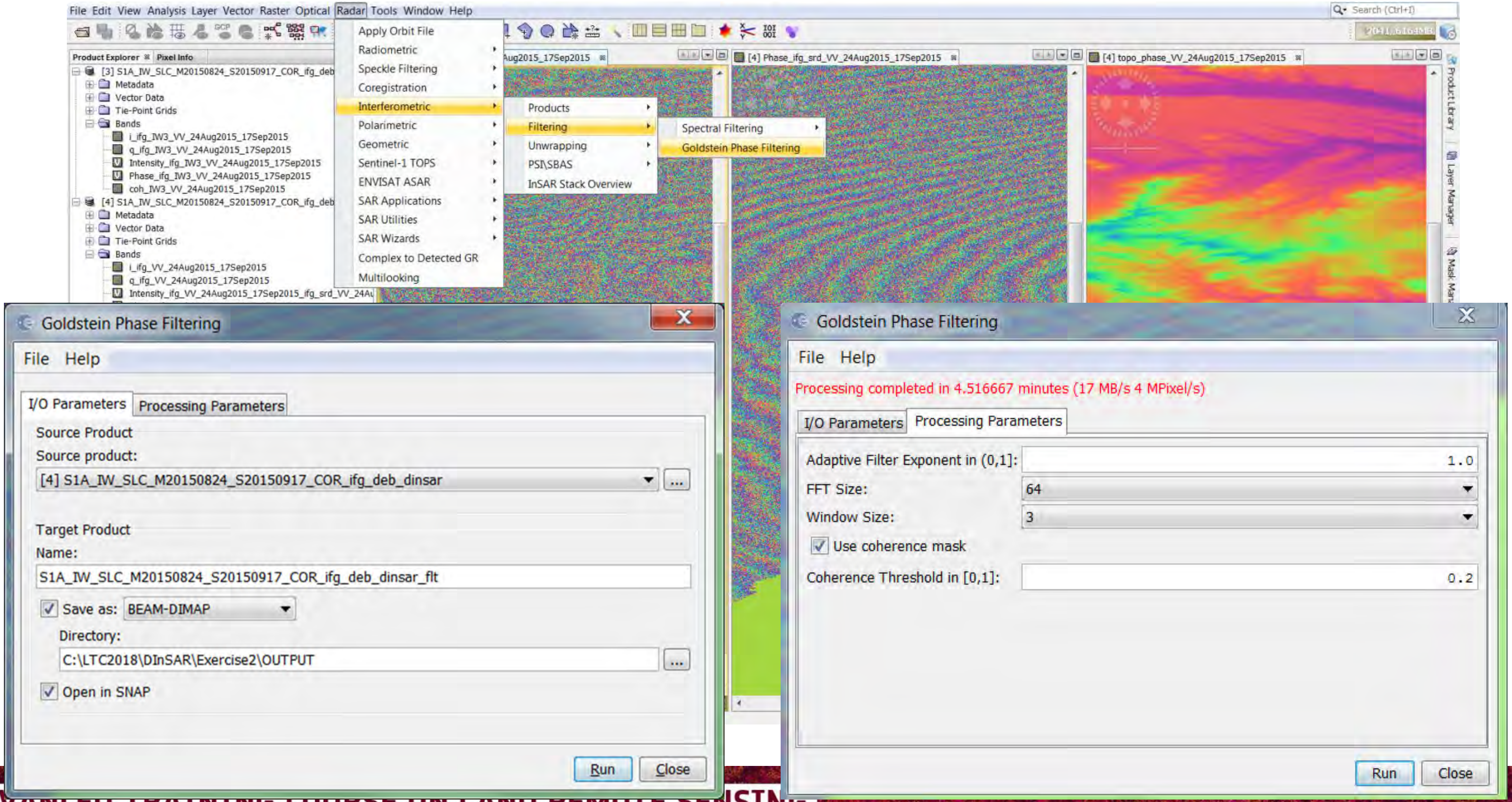
Topographic phase removal



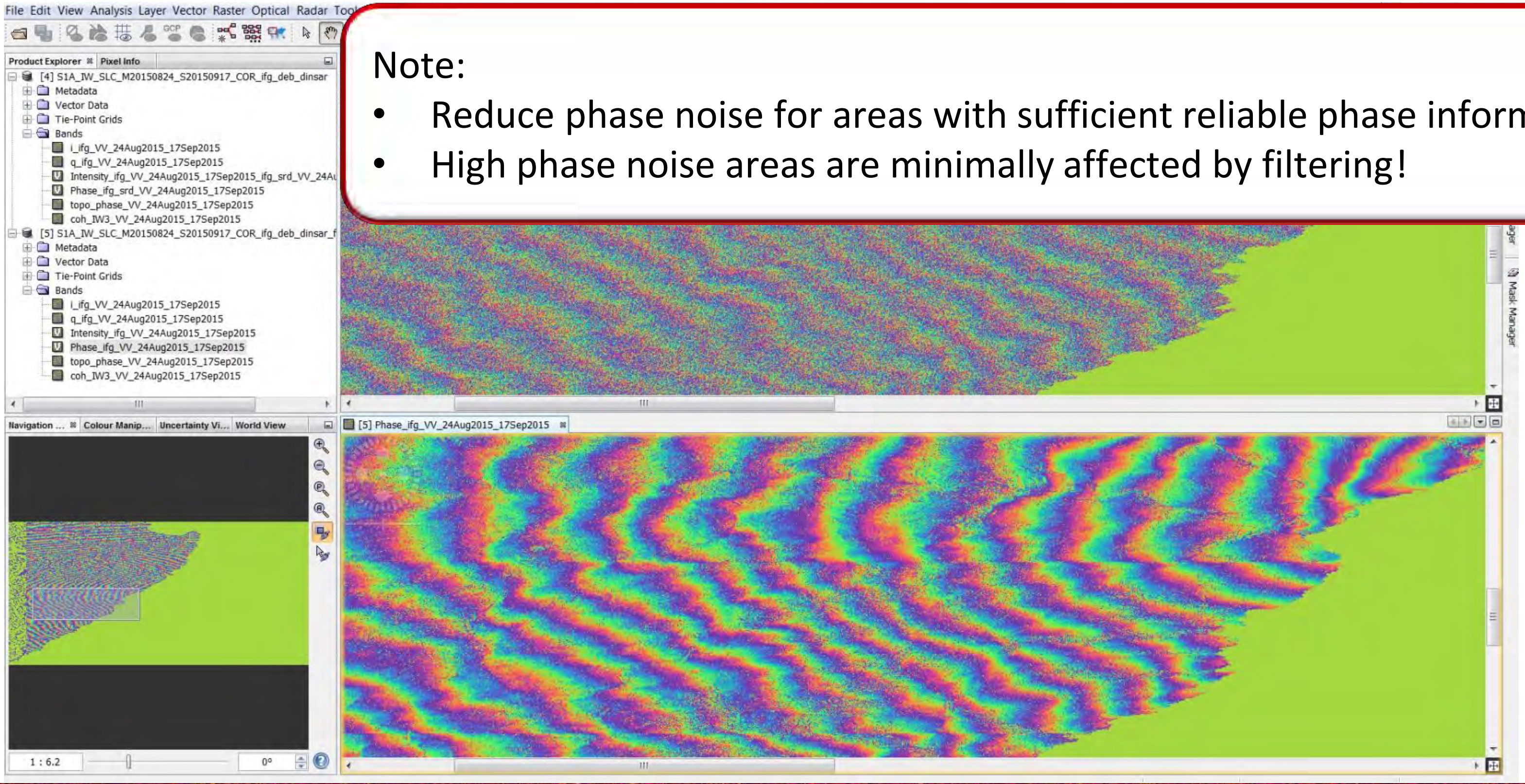
Topographic phase removal



Goldstein phase filtering



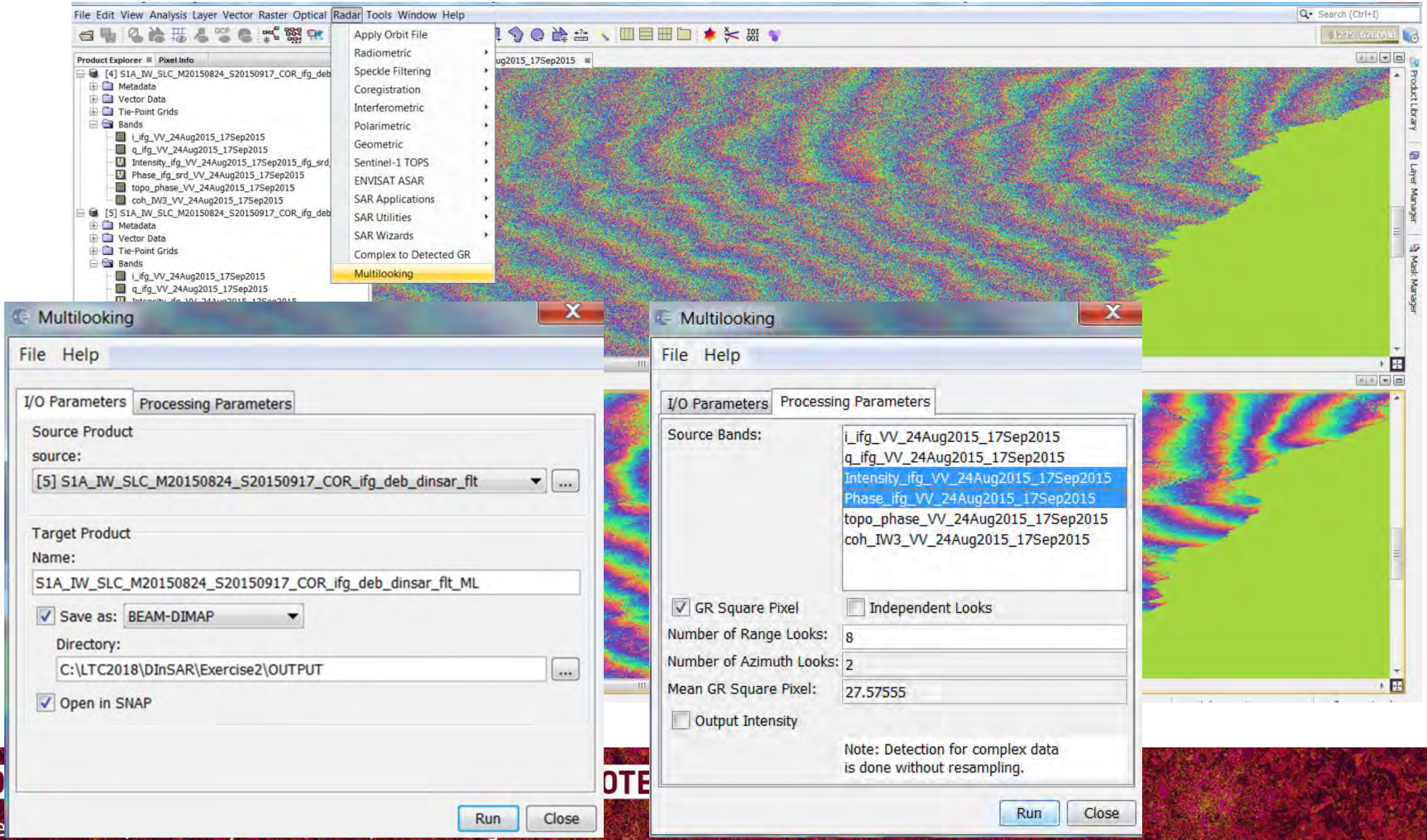
Goldstein phase filtering



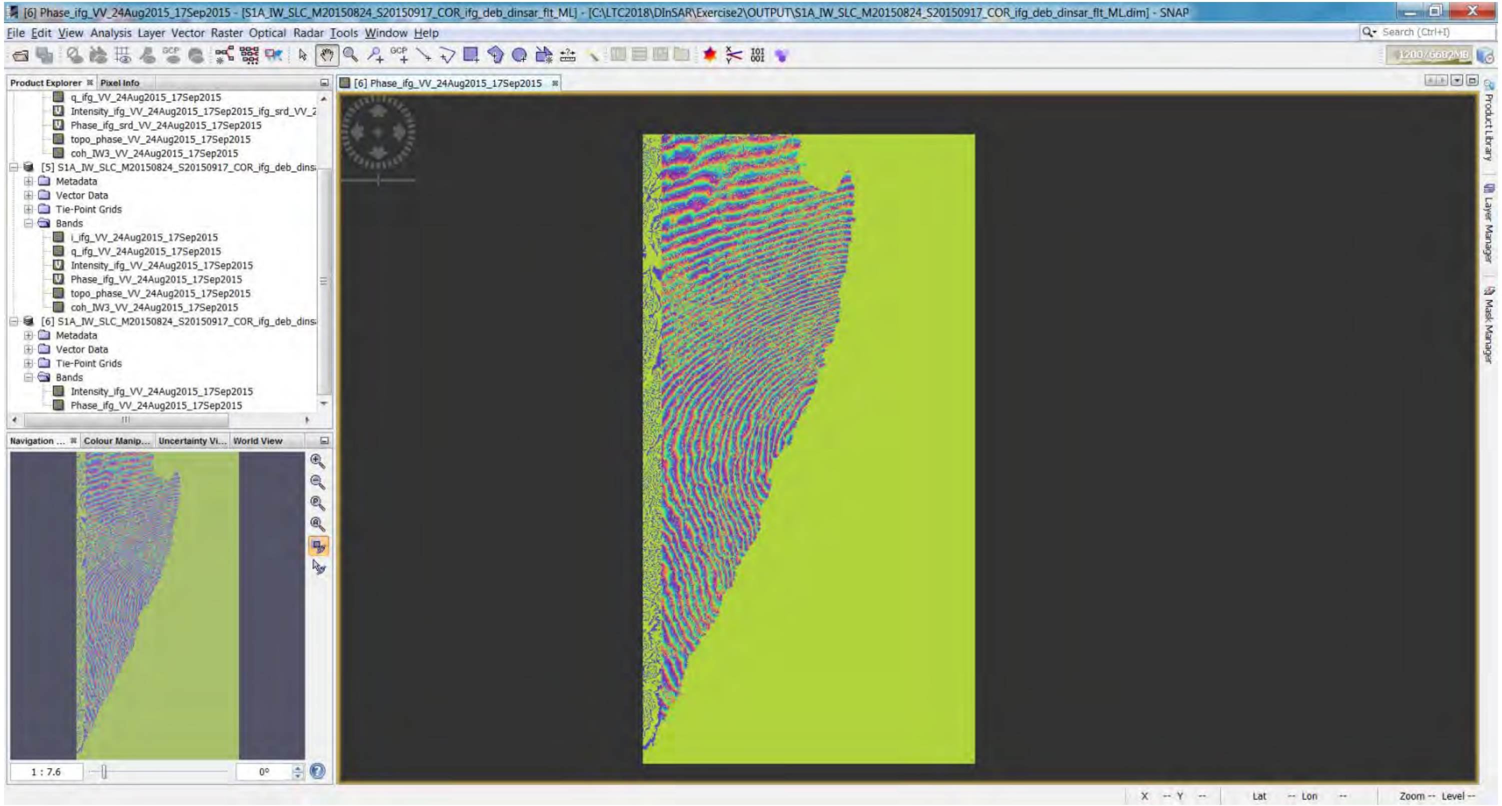
Note:

- Reduce phase noise for areas with sufficient reliable phase information!
- High phase noise areas are minimally affected by filtering!

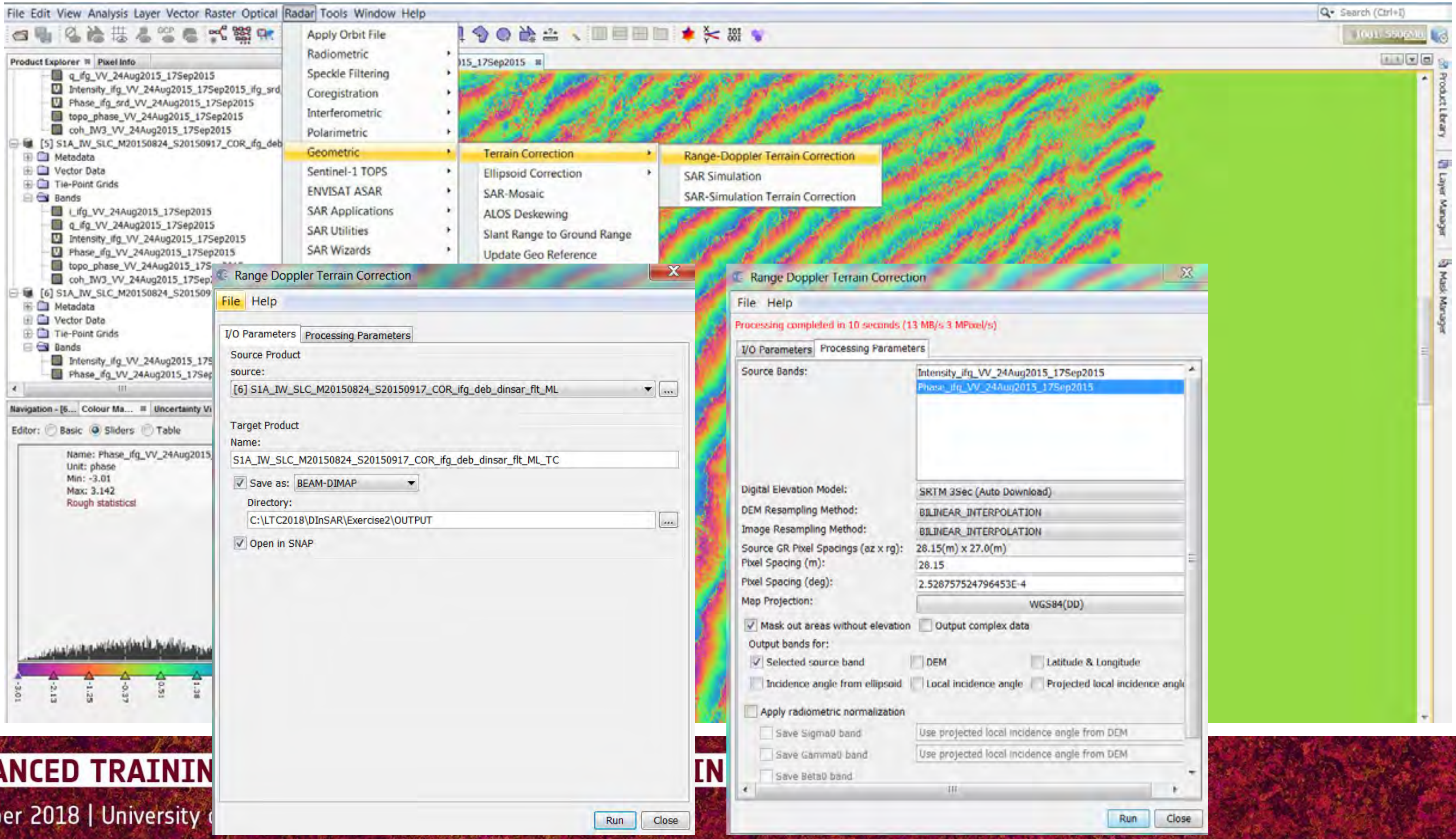
Multilooking [8 (range); 2 (Azimuth)]



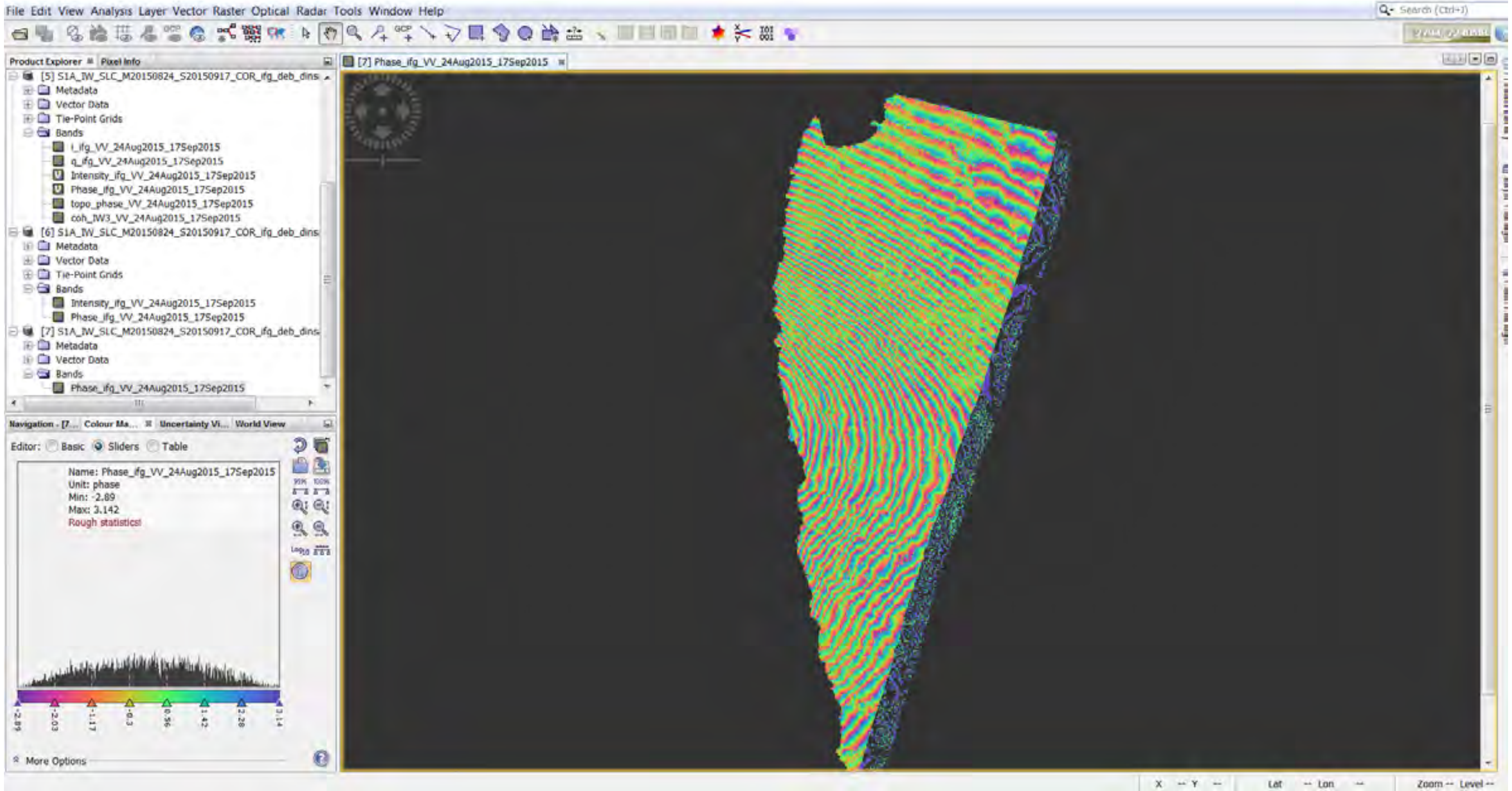
Display Multilooking [8 (range); 2 (Azimuth)]



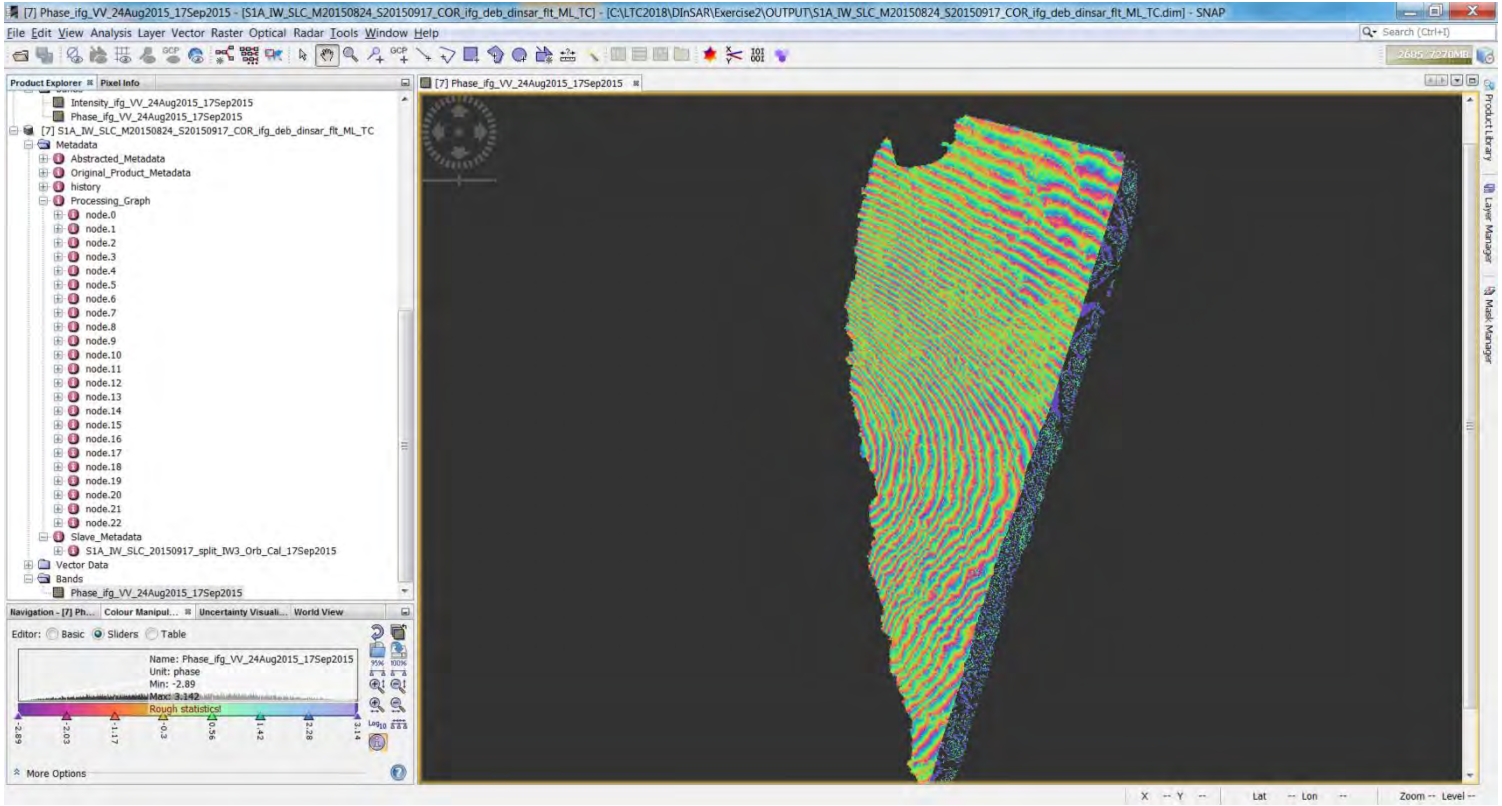
Terrain Correction of the differential wrapped interferogram



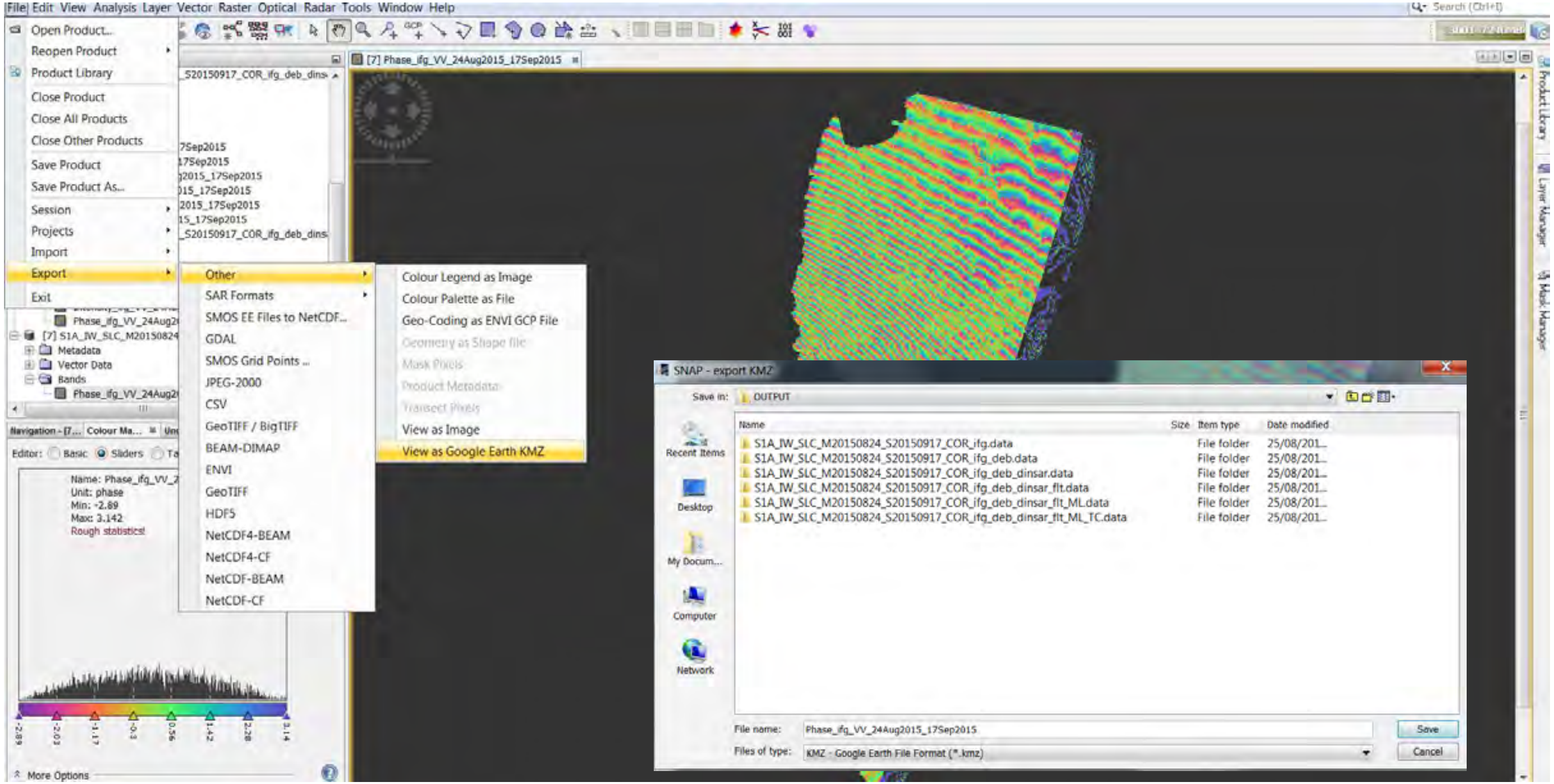
Terrain Correction of the differential wrapped interferogram



Processing Graph



Export to Google Earth



Visualisation in Google Earth

.\LTC2018\DInSAR\Exercise2\OUTPUT

Name

- S1A_IW_SLC_M20150824_S20150917_COR_ifg.data
- S1A_IW_SLC_M20150824_S20150917_COR_ifg_deb.data
- S1A_IW_SLC_M20150824_S20150917_COR_ifg_deb_dinsar.data
- S1A_IW_SLC_M20150824_S20150917_COR_ifg_deb_dinsar_flt.data
- S1A_IW_SLC_M20150824_S20150917_COR_ifg_deb_dinsar_flt_ML.data
- S1A_IW_SLC_M20150824_S20150917_COR_ifg_deb_dinsar_flt_ML_TC.da...
- Phase_ifg_VV_24Aug2015_17Sep2015.kmz
- S1A_IW_SLC_M20150824_S20150917_COR_ifg.dim
- S1A_IW_SLC_M20150824_S20150917_COR_ifg_deb.dim
- S1A_IW_SLC_M20150824_S20150917_COR_ifg_deb_dinsar.dim

Thank you for your attention!

Any Question?

andrea.minchella@airbus.com