GROUP

LE SMART FUTUR
POUR UN MONDE PLUS SÛR, PLUS INTELLIGENT ET MIEUX PROTÉGÉ

A SAR radiometric correction:

Gamma Naught RTC

(DiapOTB based application)

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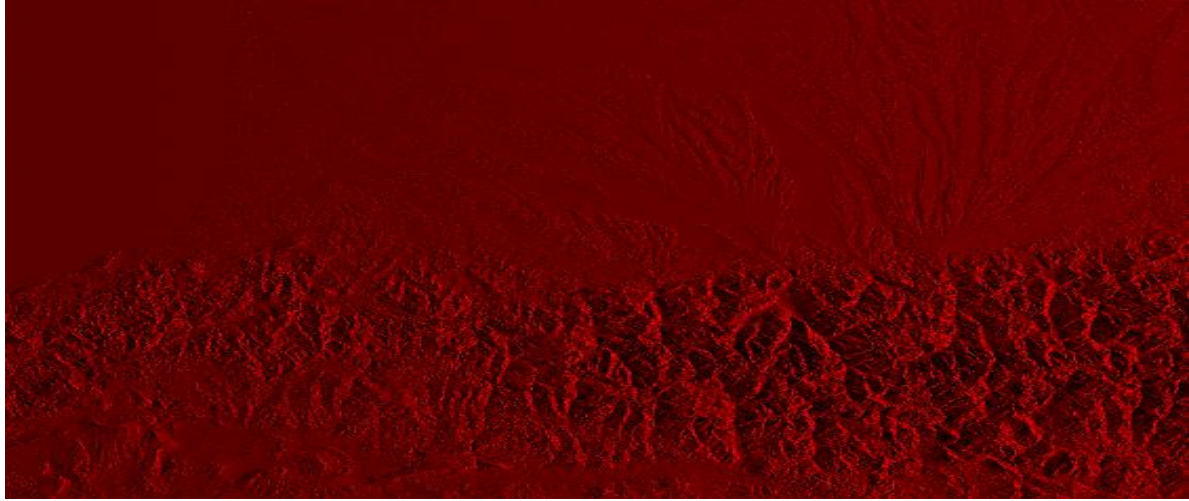
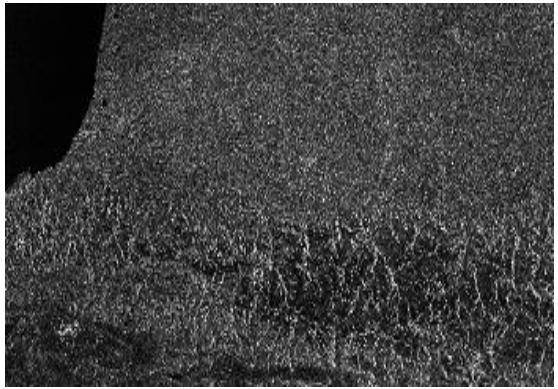
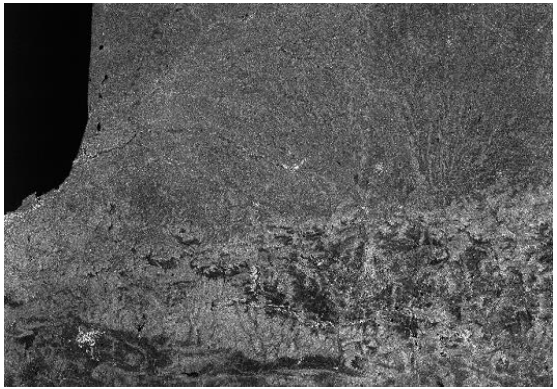


Gamma Area

Computed images:
Beta Naught
Gamma Naught RTC
XYZ
MNT projection
Gamma Area
Shadows



Beta Naught



Gamma Naught RTC

Gamma Naught RTC

01 A Radiometric correction:

Why? What is it?

02 An open source development based on DiapOTB

03 Validation

04 Conclusion and perspectives

From David Small's publication :

"Flattening Gamma: Radiometric Terrain Correction for SAR Imagery,"

in *IEEE Transactions on Geoscience and Remote Sensing*, vol. 49, no. 8, pp. 3081-3093, Aug. 2011, doi: 10.1109/TGRS.2011.2120616.

Objective:

Implement it using OTB framework (DiapOTB)

A Radiometric correction:

Why? What is it?

01

1. A RADIOMETRIC CORRECTION

Why?

- Improve native SAR Calibration Beta Naught image (backscattering estimation) in :
  - Flattening radiometric variations due to terrain slopes
  - Cancelling geometric distortions using a DEM
  - Overcoming classical incident angle corrections on high elevation zones (NORLIM)
  - Producing a Radiometrically Terrain Corrected image: Gamma Naught RTC
- Enduce improvement of post backscattering analysis and comparisons

1. A RADIOMETRIC CORRECTION

What is it?

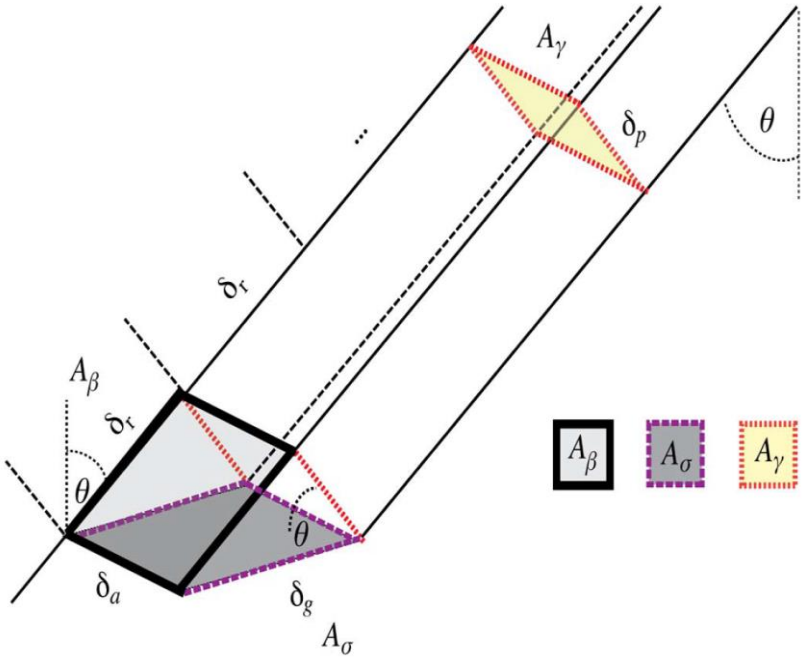
- **Normalization** of the « **Backscatter** image (β) » using a reference « **Gamma Area** image (A_γ) » from a **DEM:**

$$\gamma_0^{RTC} = \beta / A_\gamma$$

- Backscatter image (β) is deduced from Beta Naught (β_0) **native calibration** image:

$$\beta_0 = \beta / A_\beta$$

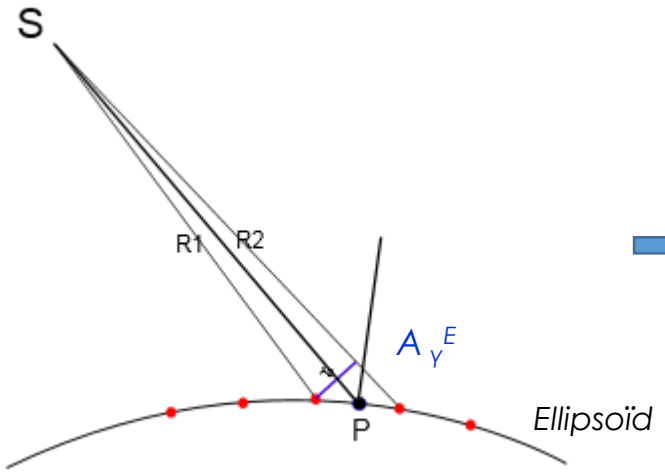
with A_β = Azimuth resolution (δ_a) x Range resolution (δ_r)

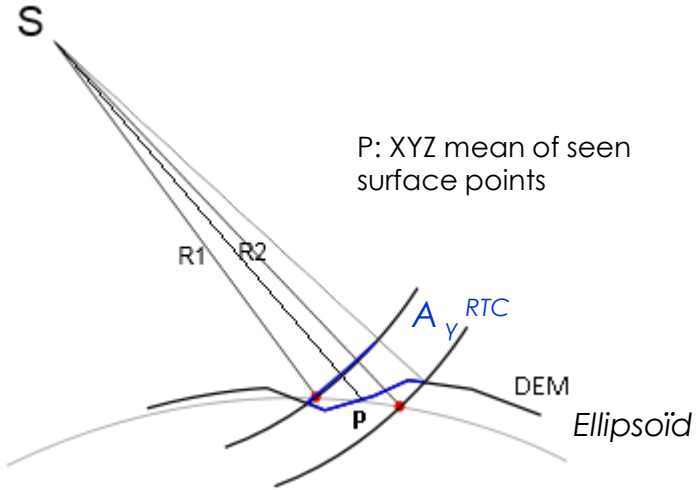


1. A RADIOMETRIC CORRECTION

What is it?

- **Gamma Area** image (A_γ)





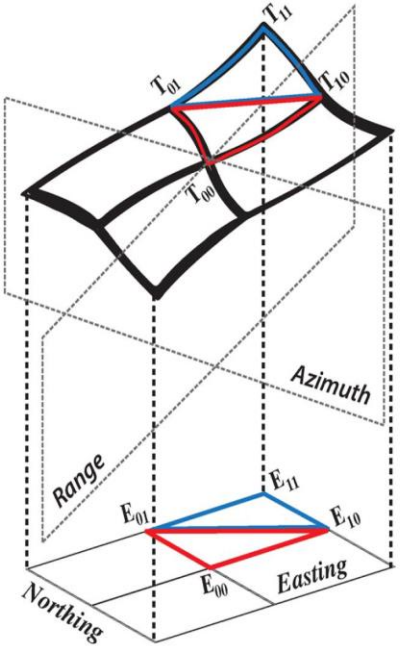
Gamma Area <u>on Ellipsoïd</u>
=> γ_0^E *Native Gamma Naught calibration*

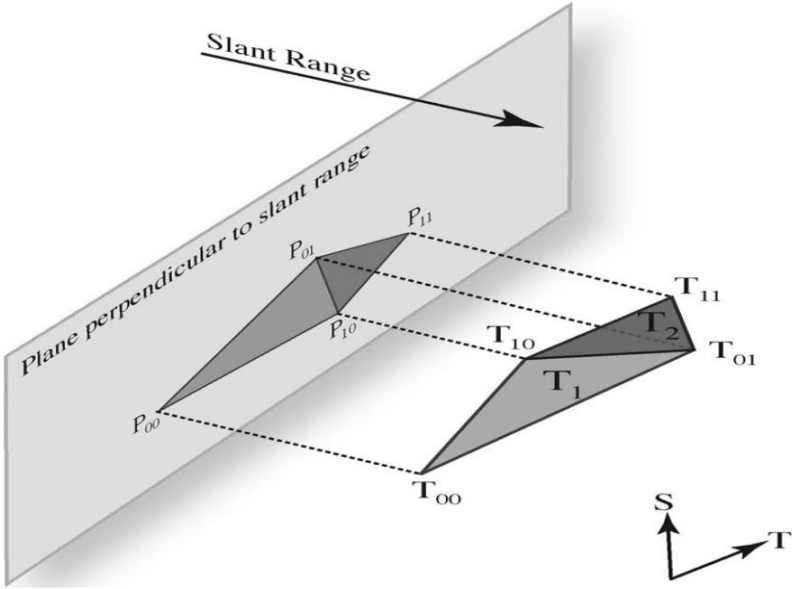
Gamma Area <u>on DEM</u>
=> γ_0^{RTC} *Gamma Naught RTC calibration*

1. A RADIOMETRIC CORRECTION

What is it?

- **Gamma Area** image (A_γ)





$$A_\gamma(\text{row,col}) = \sum_{k=0}^{Facets\ seen} A^{P00-P10-P01} + A^{P01-P10-P11}$$

An open source development based on DiapOTB

02

2. AN OPEN SOURCE DEVELOPMENT BASED ON DIAPOTB

- Started work on April 2021
  - Development : April – Sept 2021
  - Validation : Since October 2021

- DiapOTB : Differential Interferogram Application Processing
  - OTB' submodule for coregistration, interferometry, filtering
- An Orfeo-Toolbox's private project :
  - Gamma0-RTC
- Development : based on 1 product (Congo) + SRTM/Copernicus at 30m
  - S1A_IW_GRDH_1SDV_20200108T044150_20200108T044215_030704_038506_C7F5
- Objective: Make an application standalone, only OTB based, with simple execution based on a python script that can compute Gamma Naught RTC image from any S1 SAR image (GRD and SLC) and DEM and orthorectify it to S2.

2. AN OPEN SOURCE DEVELOPMENT BASED ON DIAPOTB

A pipeline of applications

- C++ applications have been developped using DiapOTB (with threading)
- Python binding to otbcli applications
- Creation of a python pipeline:
  - --from FIRST_APP_NAME and --upto LAST_APP_NAME options : to restart pipeline from any step
  - --no-APP_NAME option : to desactivate a specific step
  - --no-in-memory option : to save intermediate images on the disk
  - --streaming option : to create output images using streaming
  - --RAM option: to fix maximum RAM to be used
- User Documentation:
  - README.md
- Test example:
  - from_s1_to_GammaNaughtRTC.py

2. AN OPEN SOURCE DEVELOPMENT BASED ON DIAPOTB

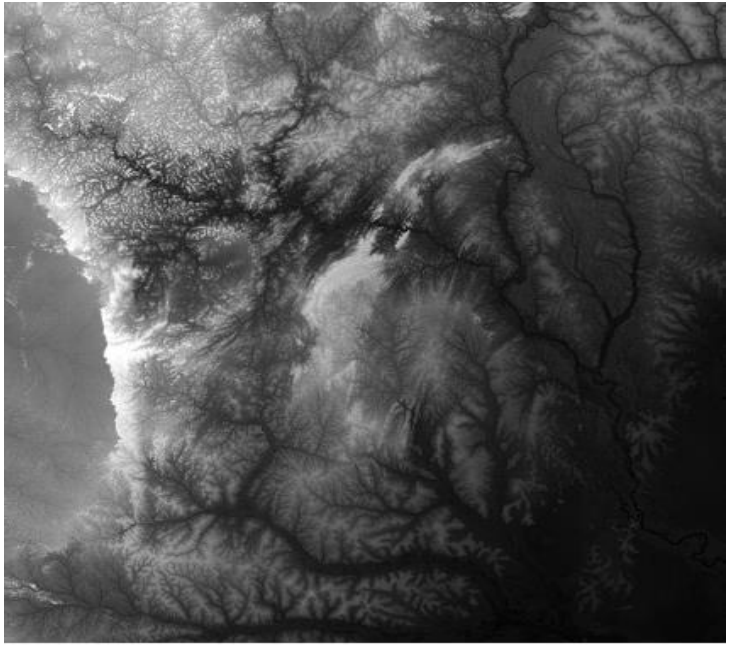
Processing flow

VRT	• Builds VRT of intersecting DEMs with **gdalbuildvrt**
RESAMPLE_DEM	• Resamples DEM geometry with **otbcli_RigidTransformResample**
DEM	• Maps SAR coordinates on DEM geometry with **otbcli_SARDEMProjectionImageEstimation**
SHADOWS	• Maps SHADOWS on SAR Geometry with **otbcli_SARShadowImageEstimation**
XYZ	• Maps XYZ on SAR Geometry with **otbcli_SARCartesianMeanEstimation**
GAMMA_AREA	• Computes GAMMA AREA maps with **otbcli_SARGammaAreaEstimation**
MULTILOOK_SAR	• Multilook SAR image with **otbcli_SARMultiLookImageEstimation**
BETA_NAUGHT	• Computes BETA NAUGHT image with **otbcli_SARCalibration**
GAMMA_AREA_TO_GAMMA_NAUGHT_RTC	• Computes GAMMA NAUGHT RTC image with **otbcli_SARGammaAreaToGammaNaughtRTCEstimation**
RESAMPLE_BETA_NAUGHT	• Resample BETA NAUGHT image to input SAR resolution (if multilooking) with **otbcli_RigidTransformResample**
RESAMPLE_GAMMA_AREA	• Resample GAMMA_AREA image to input SAR resolution (if multilooking) with **otbcli_RigidTransformResample**
RESAMPLE_GAMMA_NAUGHT-RTC	• Resample GAMMA_NAUGHT_RTC image to input SAR resolution (if multilooking) with **otbcli_RigidTransformResample**
ORT	• Orthorectify to S2 GAMMA AREA - BETA_NAUGHT - GAMMA NAUGHT RTC images with **otbcli_OrthoRectification**

2. AN OPEN SOURCE DEVELOPMENT BASED ON DIAPOTB

Implementation details

- VRT
  - Computation of S1 tile and DEM tiles intersection
  - Concatenation of the intersected DEM tiles within a single .vrt file with **gdalbuildvrt** application.



S1A_IW_GRDH_1SDV_20200108T044150_20200108T044215_030704_038506_C7F5 **(10m)**:
Generated VRT (Copernicus : GL0-30)

2. AN OPEN SOURCE DEVELOPMENT BASED ON DIAPOTB

Implementation details

- Resample_DEM

  - Upsamples the input DEM at least by a factor 2 to work on DEM's facets without loosing resolution during Gamma Area computation.

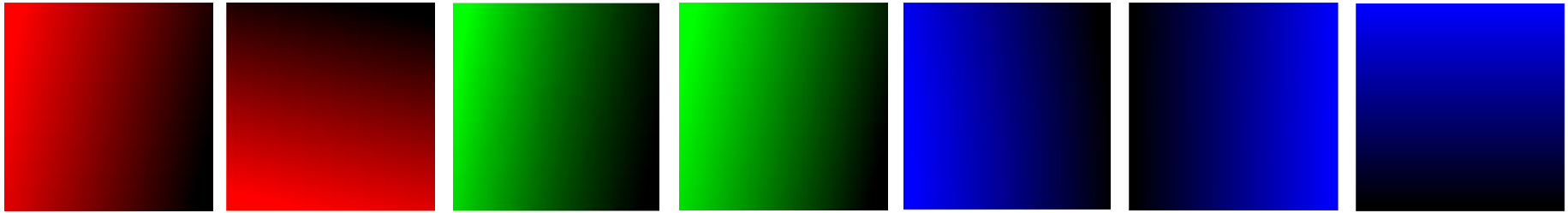
S1A_IW_GRDH_1SDV_20200108T044150_20200108T044215_030704_038506_C7F5 **(10m)**:
Generated VRT (left) / **Upsampled VRT x2** (right) **(Copernicus : GL0-30)**

2. AN OPEN SOURCE DEVELOPMENT BASED ON DIAPOTB

Implementation details

- DEM

  - Projects SAR image onto DEM geometry to get SAR <=> DEM correspondances. The output image is a vector image with C (colunm into SAR image), L (line into SAR image), Z, Y, $X_{cartesian}$, $Y_{cartesian}$, $Z_{cartesian}$. The projection is made throught the use of GCPs and RPC model estimation.



S1A_IW_GRDH_1SDV_20200108T044150_20200108T044215_030704_038506_C7F5 **(10m)**:
C / L / Z / Y / $X_{cartesian}$ / $Y_{cartesian}$ / $Z_{cartesian}$ (from left to right)

2. AN OPEN SOURCE DEVELOPMENT BASED ON DIAPOTB

Implementation details

- SHADOWS

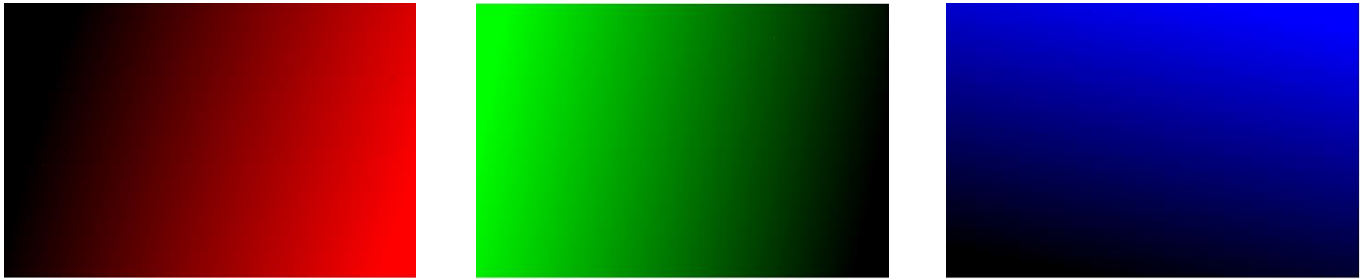
  - Pre-compute a shadow image (optional). The computation is made thanks to the correspondence between DEM and SAR image from DEM step. This shadow image is only required for the “alternate mode” during GAMMA_AREA step. Otherwise, shadow state is computed during XYZ and GAMMA_AREA steps.

2. AN OPEN SOURCE DEVELOPMENT BASED ON DIAPOTB

Implementation details

- XYZ

  - Computes the mean cartesian position on DEM for each pixel SAR. This value is useful to define the slant range direction during the surface projection on the Gamma Area plane. The intersection of a facet with a SAR line is performed. A linear interpolation is done to compute XYZ value for all pixels on the intersection. When several facets are within the same pixel, a mean between all the XYZ is computed. Some multilooking factors can be applied.



S1A_IW_GRDH_1SDV_20200108T044150_20200108T044215_030704_038506_C7F5 **(10m)**:
X_{mean} / Y_{mean} / Z_{mean} (from left to right)

2. AN OPEN SOURCE DEVELOPMENT BASED ON DIAPOTB

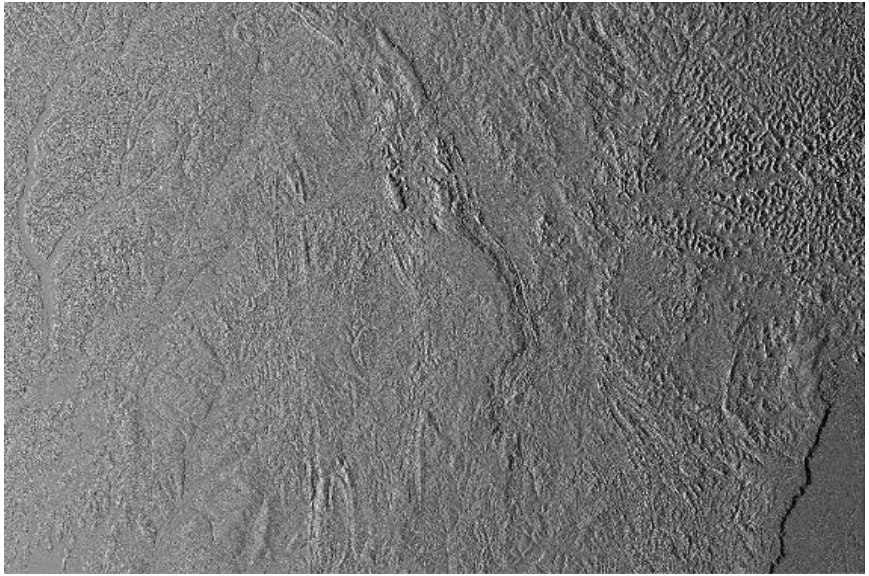
Implementation details

- GAMMA_AREA

  - Computes the Gamma Area image using the XYZ image as first slant range point and the antenna position as a second to define the Gamma Area plane.
  - The « normal mode » consists in computing the intersection between each facet and the current SAR line. All pixels in the intersection are deduced by linear interpolation. The facet is then projected on the Gamma plane for area computation. The value of a pixel area is then deduced by normalization with the facet's number of pixels in the SAR image. The distribution mode from the publication is implemented and generalized to all the pixels on the contour of the projected facet. The fractional values are equal to the shift between facet's center projection and pixel center. This allows the correction to be done even when SAR image resolution > DEM resolution.
  - The « alternate mode » consists in projecting directly the facet's center into the SAR image (only relevant when SAR image resolution =< DEM resolution).
  - An option named « distribute_area » allows the distribution of areas to the corner pixels
  - An option named « filter_by_area_center_pixel » allows to only project the facet's center point and distribute area around it (for debug only or when SAR image resolution < DEM resolution).
  - Some multilooking factors can be applied

2. AN OPEN SOURCE DEVELOPMENT BASED ON DIAPOTB

Implementation details

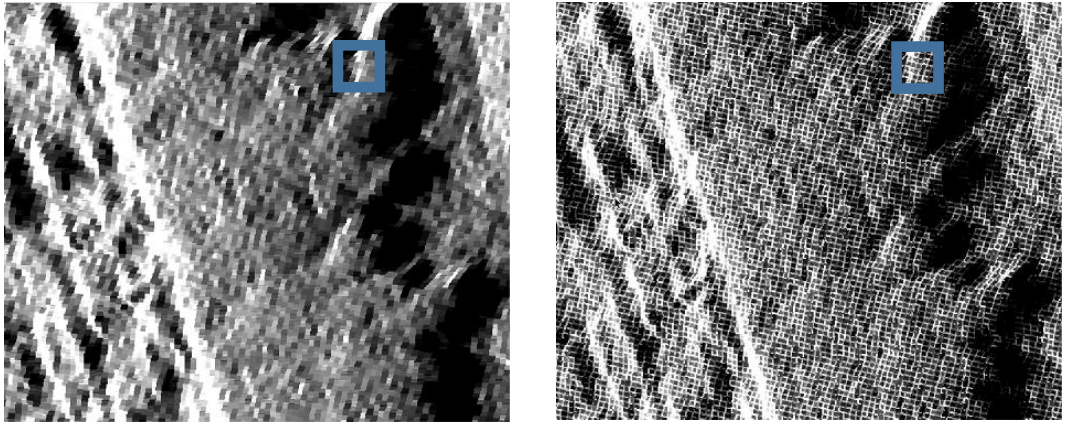


Copernicus GLO-30
S1A_IW_GRDH_1SDV_20200108T044150_20200108T044215_030704_038506_C7F5 **(10m)**:
Gamma Area image

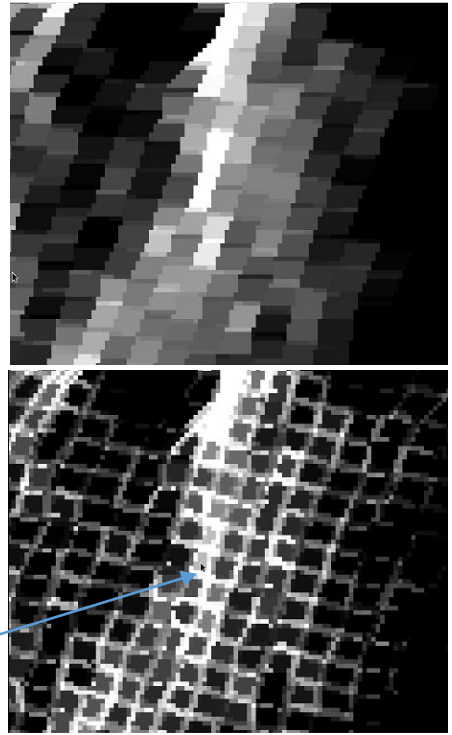
2. AN OPEN SOURCE DEVELOPMENT BASED ON DIAPOTB

Implementation details

- GAMMA_AREA
  - DEM Copernicus GLO-30 (no resampled dem)



S1A_IW_GRDH_1SDV_20200108T044150_20200108T044215_030704_038506_C7F5 **(10m)** :
Gamma Area image without/with bilinear distribution
(zoom x1.4 – on top – zoomx7.9 – on the right)

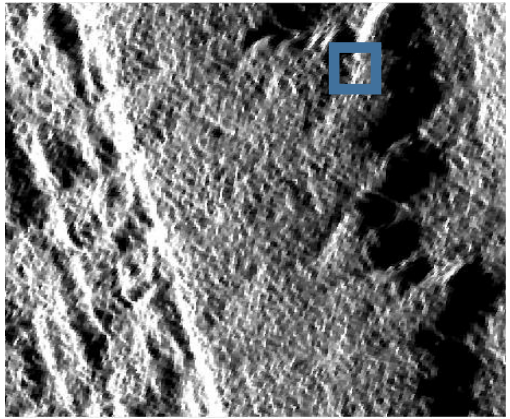


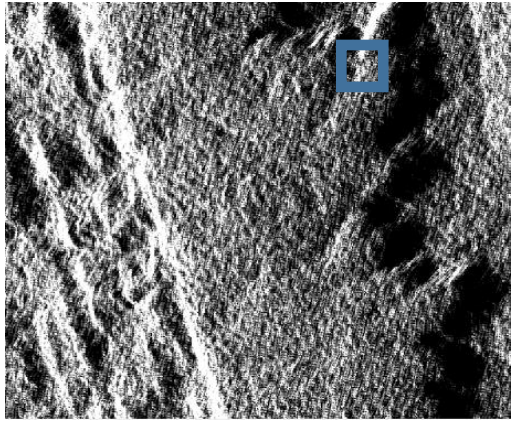
Proj	Res	Name	Effect	Column	Line	Red	Green	Blue	X	Y
Sensor	0	gamma_area_s1a-iw-grd-v...	Normal	11671	5501	128.483	128.483	128.483	11671.6	5501.32
Sensor	0	✓ gamma_area_s1a-iw-grd-v...	Normal	11671	5501	128.483	128.483	128.483	11671.6	5501.32

2. AN OPEN SOURCE DEVELOPMENT BASED ON DIAPOTB

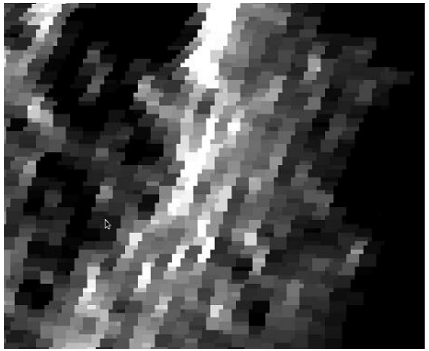
Implementation details

- GAMMA_AREA
  - DEM Copernicus GLO-30 (resampled dem x2)





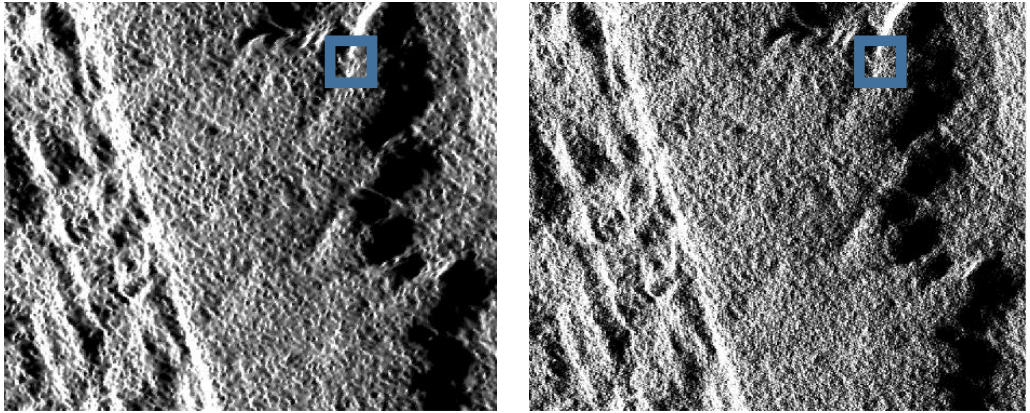
S1A_IW_GRDH_1SDV_20200108T044150_20200108T044215_030704_038506_C7F5 **(10m)** :
Gamma Area image without/with bilinear distribution
(zoom x1.4 – on top – zoomx7.9 – on the right)



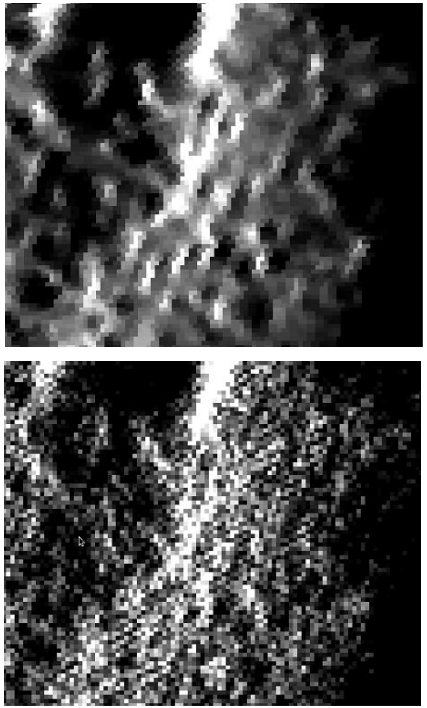
2. AN OPEN SOURCE DEVELOPMENT BASED ON DIAPOTB

Implementation details

- GAMMA_AREA
  - DEM Copernicus GLO-30 (resampled dem x4)



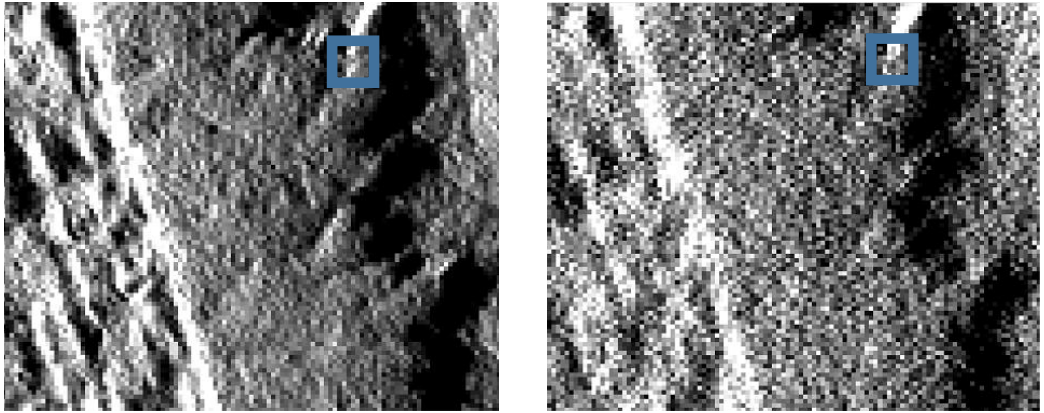
S1A_IW_GRDH_1SDV_20200108T044150_20200108T044215_030704_038506_C7F5 **(10m)** :
Gamma Area image without/with bilinear distribution
(zoom x1.4 – on top – zoomx7.9 – on the right)



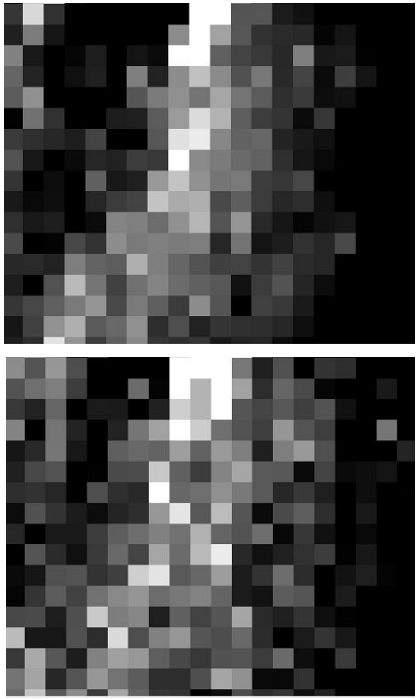
2. AN OPEN SOURCE DEVELOPMENT BASED ON DIAPOTB

Implementation details

- GAMMA_AREA
  - DEM Copernicus GLO-30 (resampled dem x4) + SAR Multilook x5



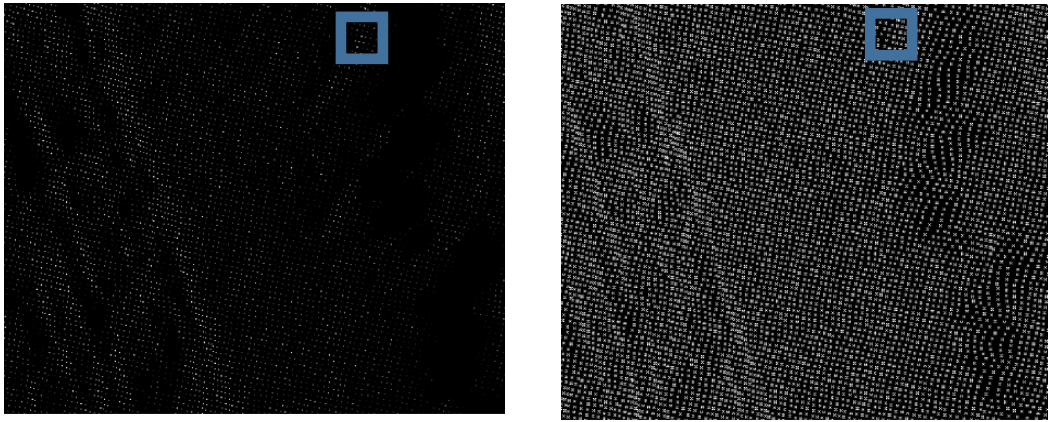
S1A_IW_GRDH_1SDV_20200108T044150_20200108T044215_030704_038506_C7F5 **(10m)** :
Gamma Area image without/with bilinear distribution
(zoom x1.4 – on top – zoomx7.9 – on the right)



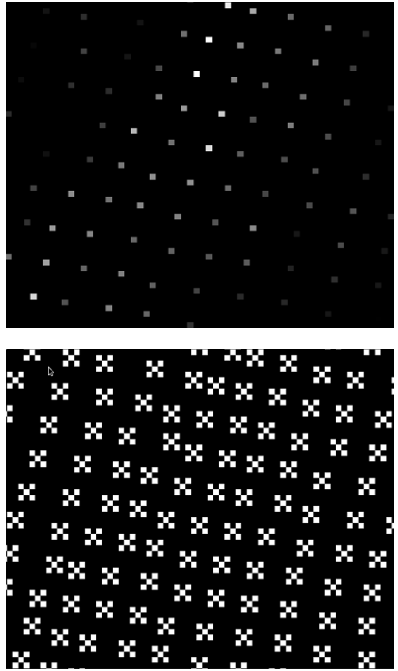
2. AN OPEN SOURCE DEVELOPMENT BASED ON DIAPOTB

Implementation details

- GAMMA_AREA
  - DEM Copernicus GLO-30 (no resampled dem)



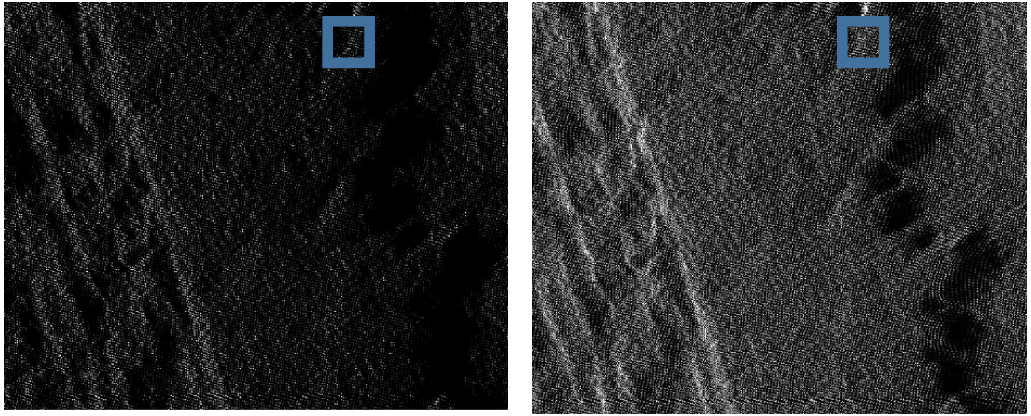
S1A_IW_GRDH_1SDV_20200108T044150_20200108T044215_030704_038506_C7F5 **(10m)** :
Gamma Area image without/with bilinear distribution (filter_by_area_center_pixel)
(zoom x1.4 – on top – zoomx11.3 – on the right)



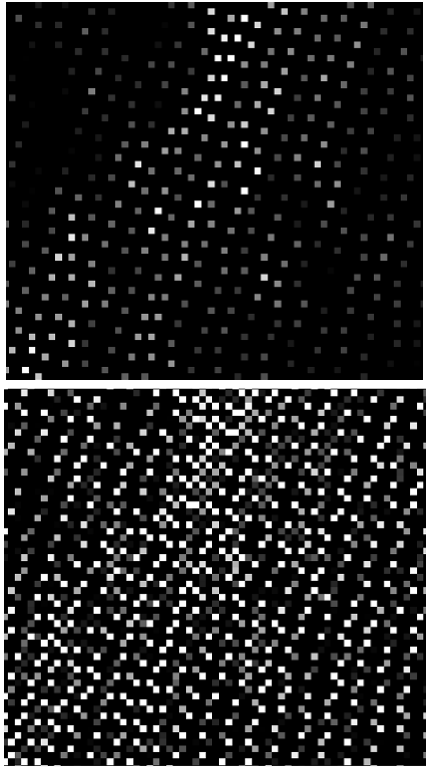
2. AN OPEN SOURCE DEVELOPMENT BASED ON DIAPOTB

Implementation details

- GAMMA_AREA
  - DEM Copernicus GLO-30 (resampled dem x2)



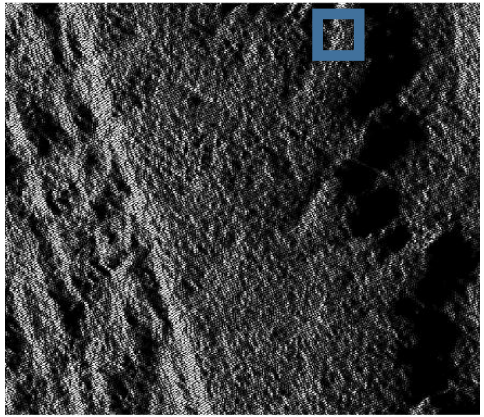
S1A_IW_GRDH_1SDV_20200108T044150_20200108T044215_030704_038506_C7F5 **(10m)** :
Gamma Area image without/with bilinear distribution (filter_by_area_center_pixel)
(zoom x1.4 – on top – zoomx11.3 – on the right)

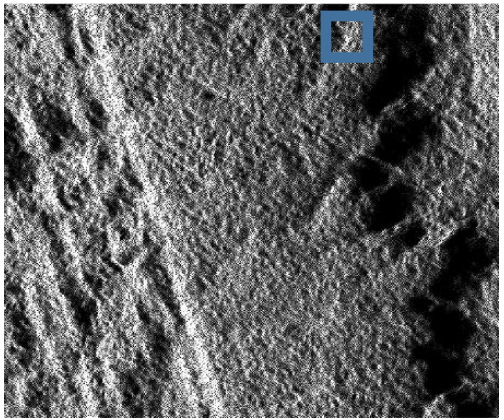


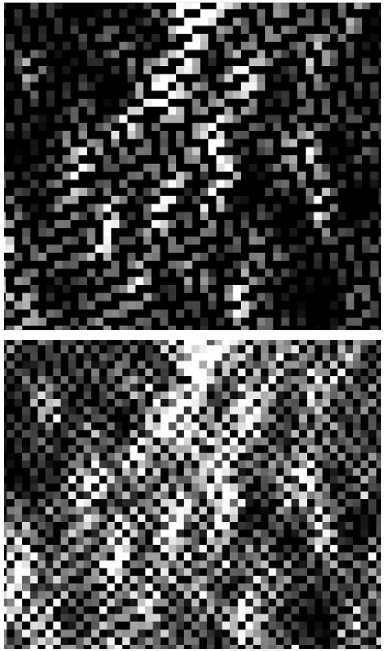
2. AN OPEN SOURCE DEVELOPMENT BASED ON DIAPOTB

Implementation details

- GAMMA_AREA
  - DEM Copernicus GLO-30 (resampled dem x4)





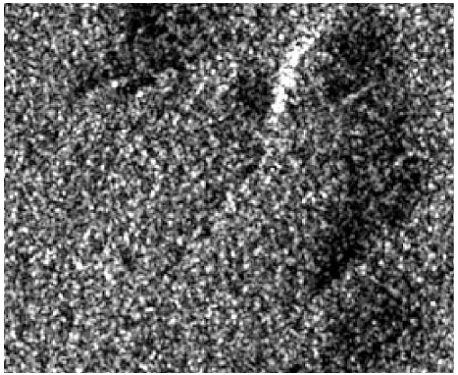


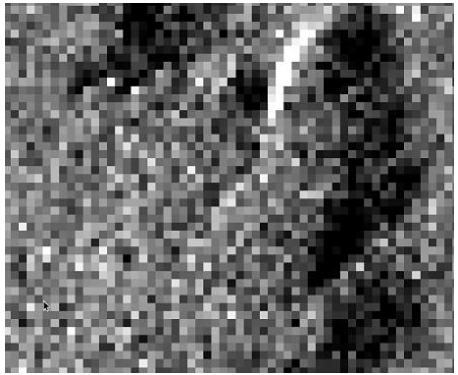
S1A_IW_GRDH_1SDV_20200108T044150_20200108T044215_030704_038506_C7F5 **(10m)** :
Gamma Area image without/with bilinear distribution (filter_by_area_center_pixel)
(zoom x1.4 – on top – zoomx11.3 – on the right)

2. AN OPEN SOURCE DEVELOPMENT BASED ON DIAPOTB

Implementation details

- MULTILOOK_SAR
  - Input SAR must be multilooked at this step if ML factors have been applied during SHADOWS, XYZ and GAMMA_AREA steps before doing native calibration (next step). After multilooking, calibration parameters in .geom file are uploaded (resampled).





S1A_IW_GRDH_1SDV_20200108T044150_20200108T044215_030704_038506_C7F5 **(10m)** :
without/with multilooking x5
(zoomx14)

2. AN OPEN SOURCE DEVELOPMENT BASED ON DIAPOTB

Implementation details

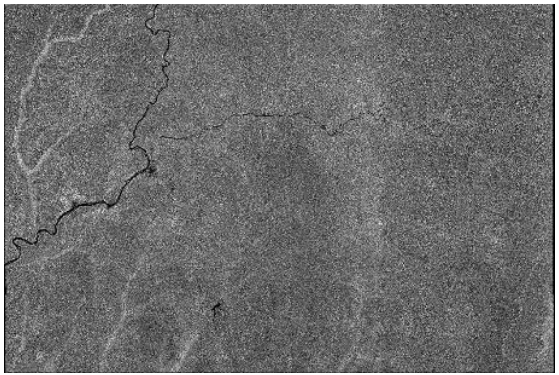
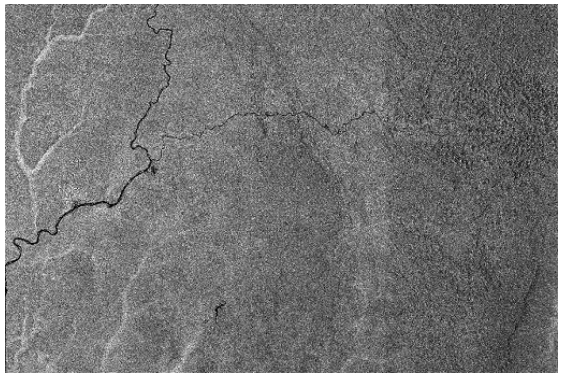
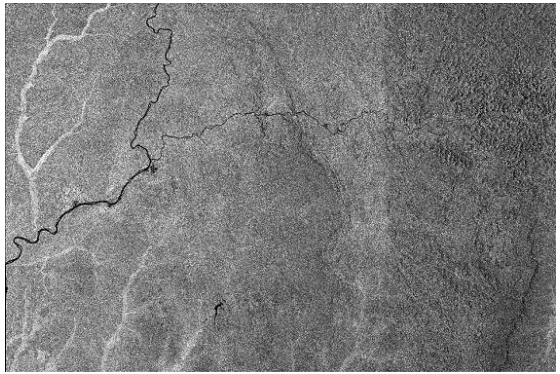
- BETA_NAUGHT
  - The native calibration produces the Beta Naught image (β_0) from which the backscatter image(β) is used for the Gamma Naught RTC image generation (next step).

S1A_IW_GRDH_1SDV_20200108T044150_20200108T044215_030704_038506_C7F5 **(10m)**

2. AN OPEN SOURCE DEVELOPMENT BASED ON DIAPOTB

Implementation details

- GAMMA_AREA_TO_GAMMA_NAUGHT_RTC
  - The Gamma Naught RTC image is computed by the normalization of the Beta Naught (β_0) image (native calibration) with the Gamma Area (A_γ) image (up to the factor). The flattening effect depends on multilooking.

S1A_IW_GRDH_1SDV_20200108T044150_20200108T044215_030704_038506_C7F5**(10m)**
Gamma Naught RTC image(x1 and x3,x5 multilooked)

2. AN OPEN SOURCE DEVELOPMENT BASED ON DIAPOTB

Implementation details

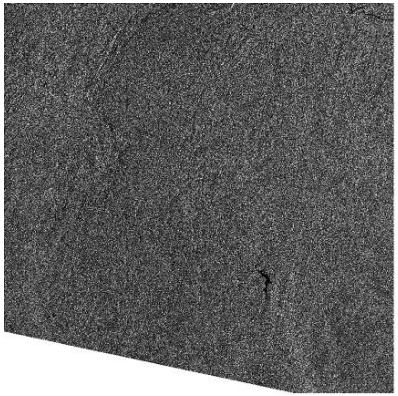
- RESAMPLE_GAMMA_AREA / BETA_NAUGHT / GAMMA_NAUGHT_RTC
  - If multilooking was used, the produced images are resampled to the input SAR resolution before potential ortho-rectification to S2.

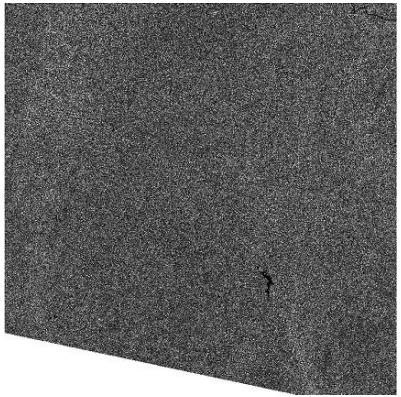
S1A_IW_GRDH_1SDV_20200108T044150_20200108T044215_030704_038506_C7F5 **(10m)**
Gamma Area / Beta Naught / Gamma Naught image resampled x5

2. AN OPEN SOURCE DEVELOPMENT BASED ON DIAPOTB

Implementation details

- ORT
  - S2 orthorectification is done at the DEM resolution in UTM indexed by the S2 tile name for generated images.





S1A_IW_GRDH_1SDV_20200108T044150_20200108T044215_030704_038506_C7F5 **(10m)**
Gamma Area / Beta Naught / Gamma Naught image at 30m, 33NWB S2 tile

Validation

03

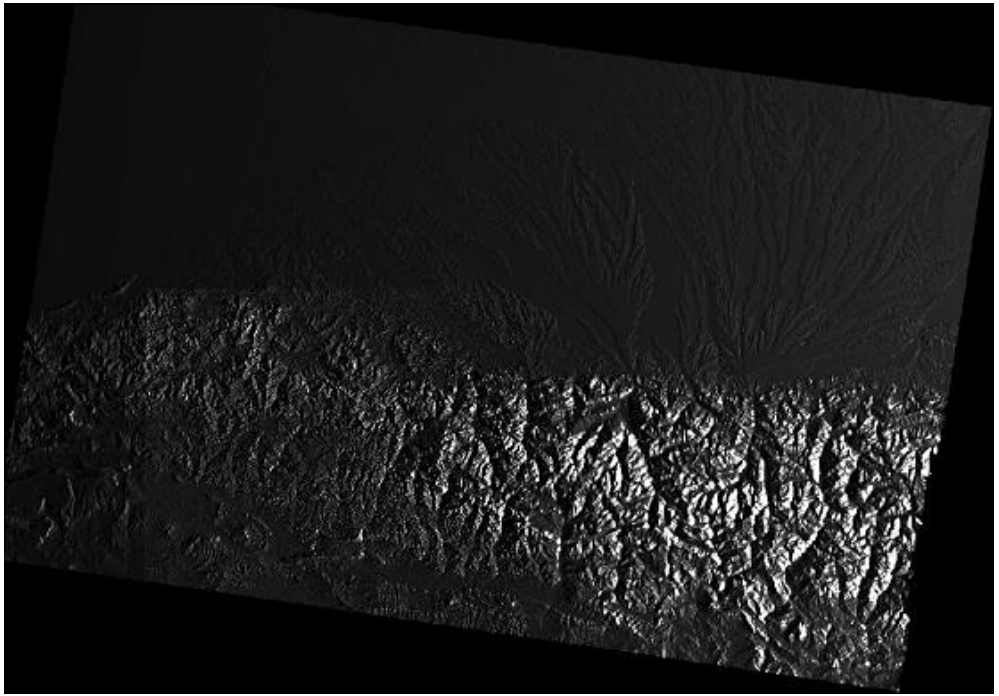
3. VALIDATION

- Started work on October 2021
- Comparison with corrections made by ASF (SNAP based) : https://search.asf.alaska.edu
- Validation based on 3 products (Toulouse, Utah, Michigan) + Coperncus/SRTM at 30m:
  - S1A_IW_GRDH_1SDV_20210923T060919_20210923T060944_039805_04B546_3C23
  - S1B_IW_GRDH_1SDV_20210801T012648_20210801T012713_028046_035872_206C
  - S1B_IW_GRDH_1SDV_20210404T233245_20210404T233310_026324_032454_AC6A
- Objective: Compare S2-orthorectified images produced vs ASF'ones.

3. VALIDATION

Gamma Area image : Toulouse

- ASF image multilooked x5
  - => ML factor = 5 in our correction
- Copernicus DEM GLO-30
- No DEM matching
- Ortho spacing at 30m
- No spacial shift

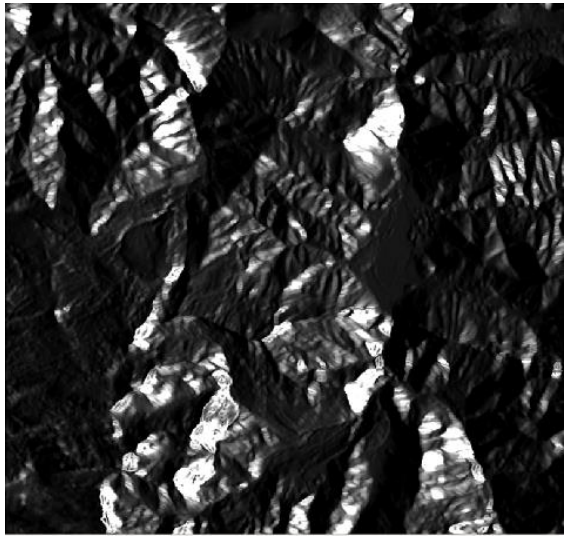


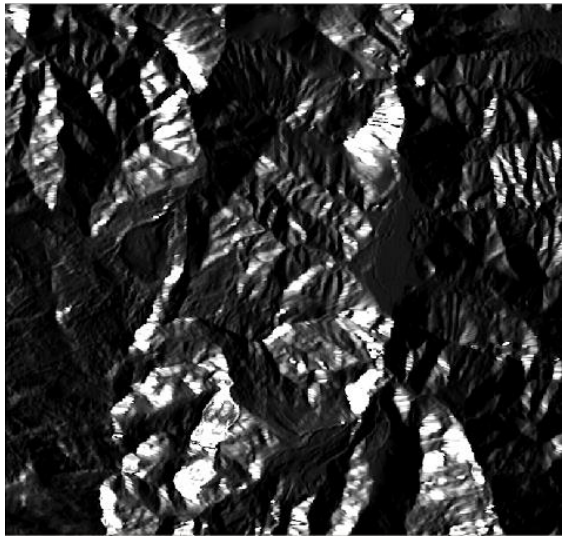
Toulouse **(30m)**
ASF 's Gamma Area / Our Gamma Area / 30TXN S2 tile

3. VALIDATION

Gamma Area image : Toulouse

- First look analysis not bad.
- Values are close on many pixels.



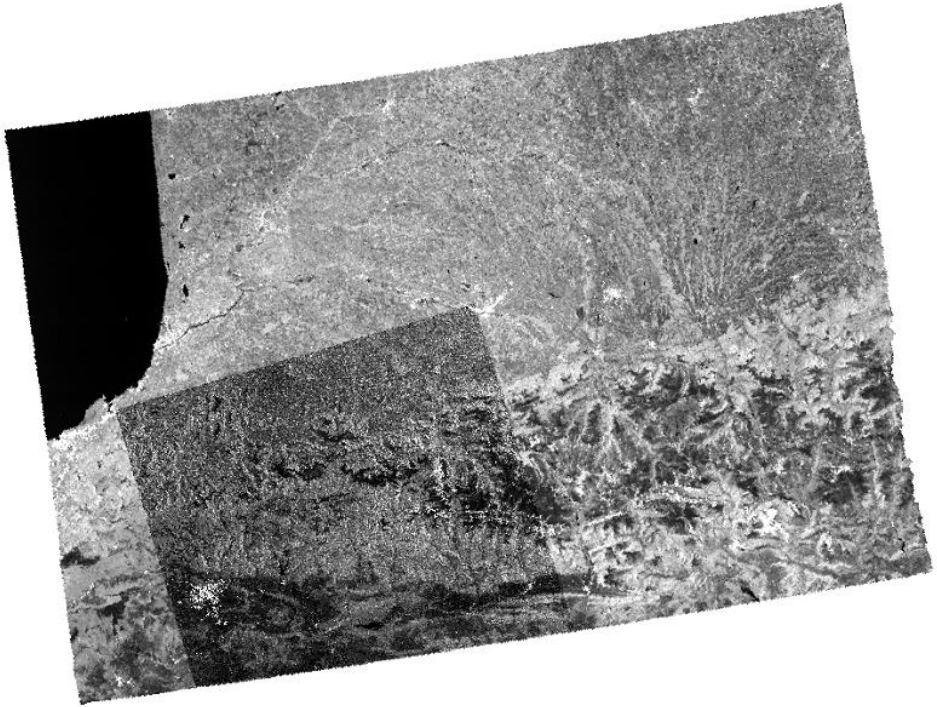


Toulouse **(30m)**
ASF 's Gamma Area / Our Gamma Area / 30TXN S2 tile

3. VALIDATION

Gamma Naught RTC image : Toulouse

- ASF image multilooked x5
  - => ML factor = 5 in our correction
- Copernicus DEM GLO-30
- No DEM matching
- Ortho spacing at 30m

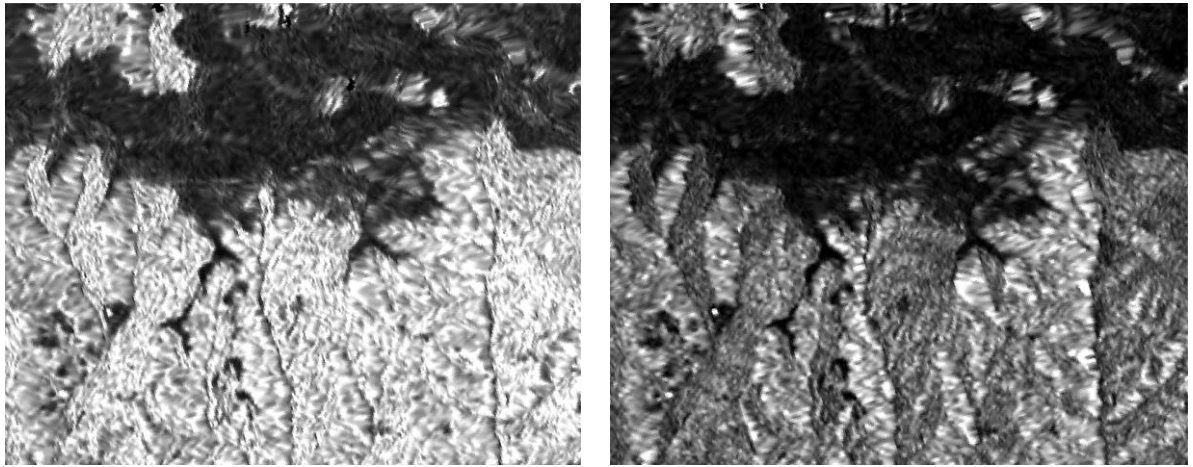


Toulouse **(30m)**
ASF 's Gamma Naught RTC / Our Gamma Naught RTC / 30TXN S2 tile

3. VALIDATION

Gamma Naught RTC image : Toulouse

- First look analysis not bad.
- Values are close on many pixels.
- A calibration factor (K_Y) may be applied by ASF.

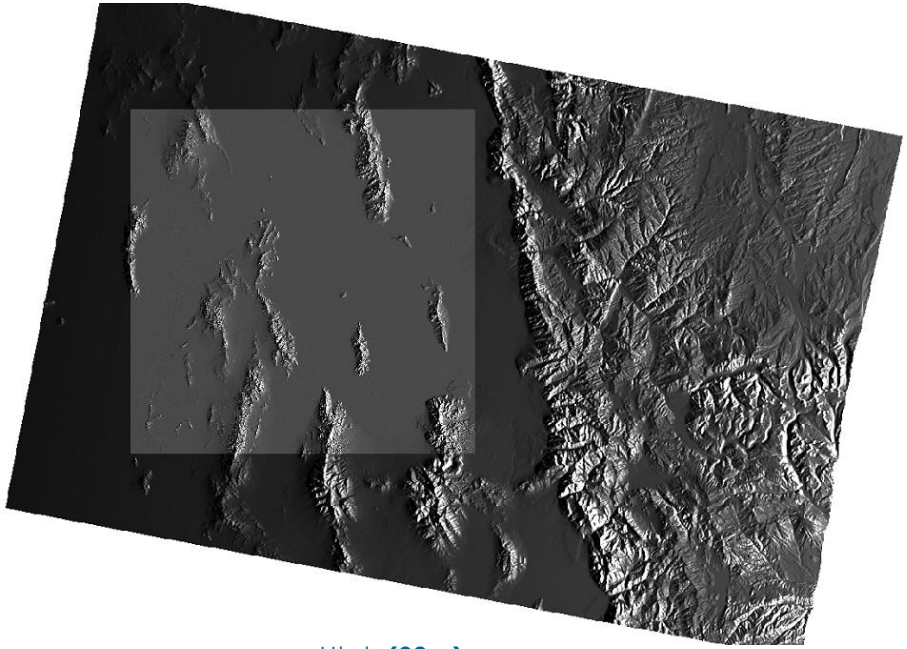


Toulouse **(30m)**
ASF 's Gamma Naught RTC / Our Gamma Naught RTC / 30TXN S2 tile

3. VALIDATION

Gamma Area image : Utah

- ASF image multilooked x5
  - => ML factor = 5 in our correction
- Copernicus DEM GLO-30
- No DEM matching
- Ortho spacing at 30m
- No spacial shift

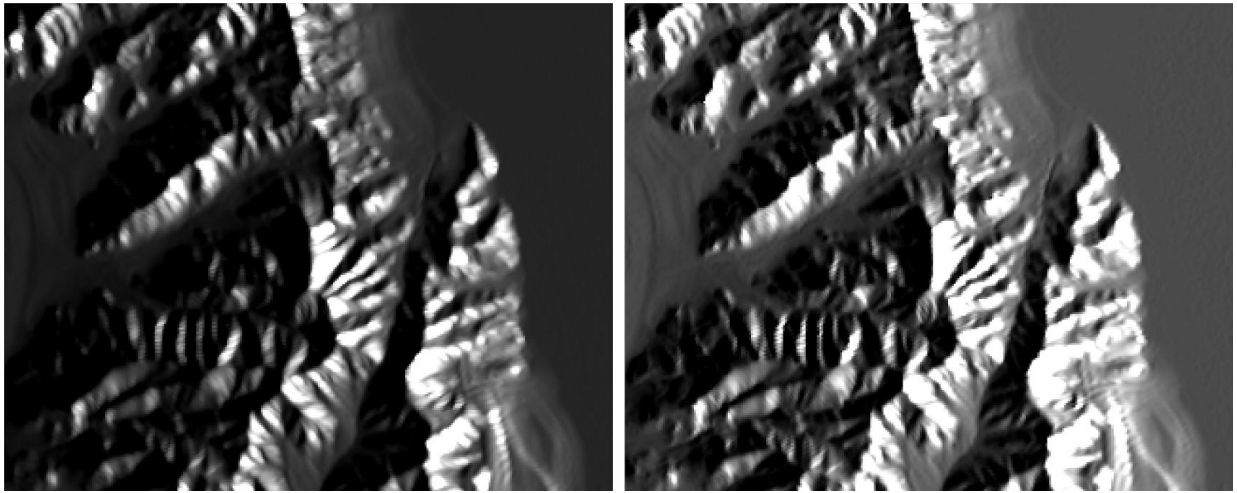


Utah **(30m)**
ASF 's Gamma Area / Our Gamma Area / 12TUL S2 tile

3. VALIDATION

Gamma Area image : Utah

- First look analysis not bad.
- Values are close on many pixels.

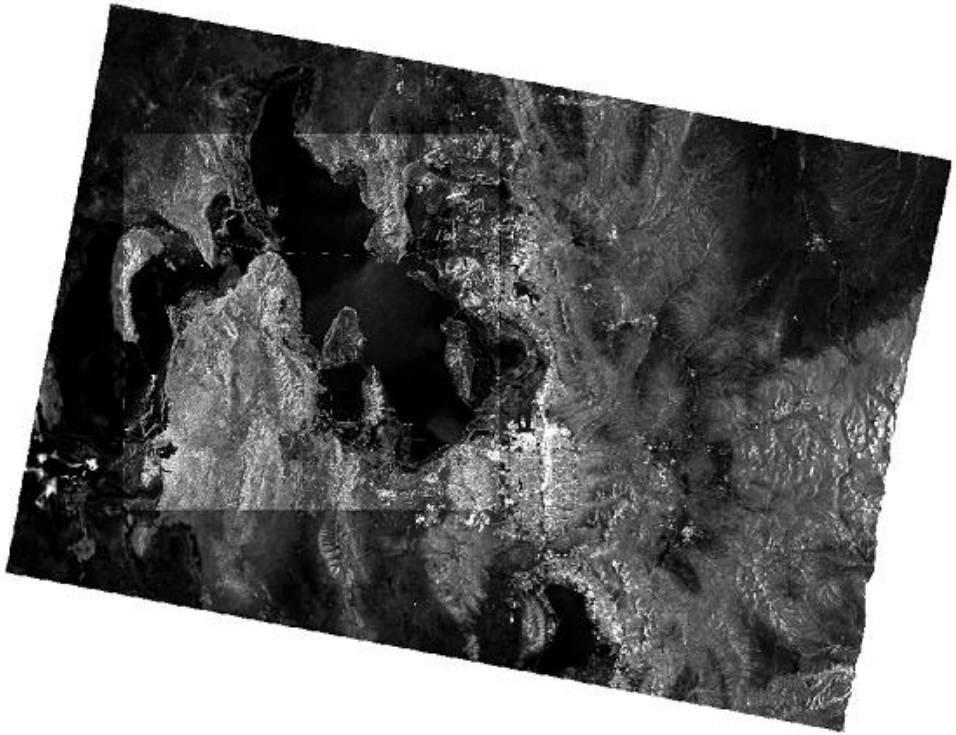


Utah **(30m)**
ASF 's Gamma Area / Our Gamma Area / 12TUL S2 tile

3. VALIDATION

Gamma Naught RTC image : Utah

- ASF image multilooked x5
  - => ML factor = 5 in our correction
- Copernicus DEM GLO-30
- No DEM matching
- Ortho spacing at 30m

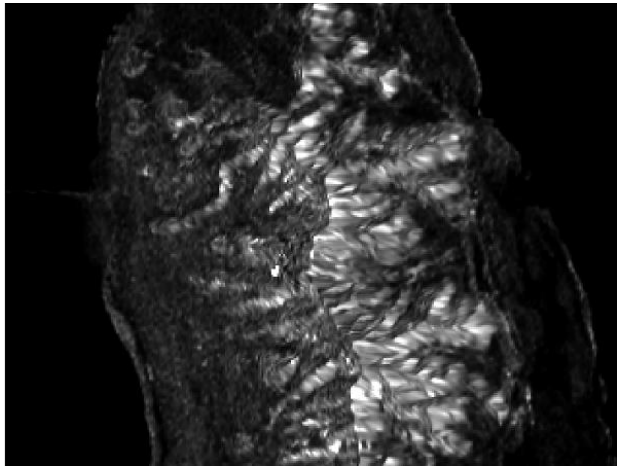


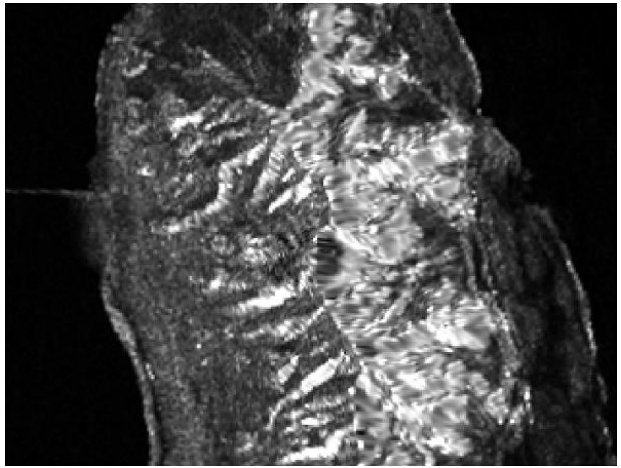
Utah **(30m)**
ASF 's Gamma Naught RTC / Our Gamma Naught RTC / 12TUL S2 tile

3. VALIDATION

Gamma Naught RTC image : Utah

- First look analysis not bad.
- Values are close on many pixels.
- A calibration factor (K_Y) may be applied by ASF.



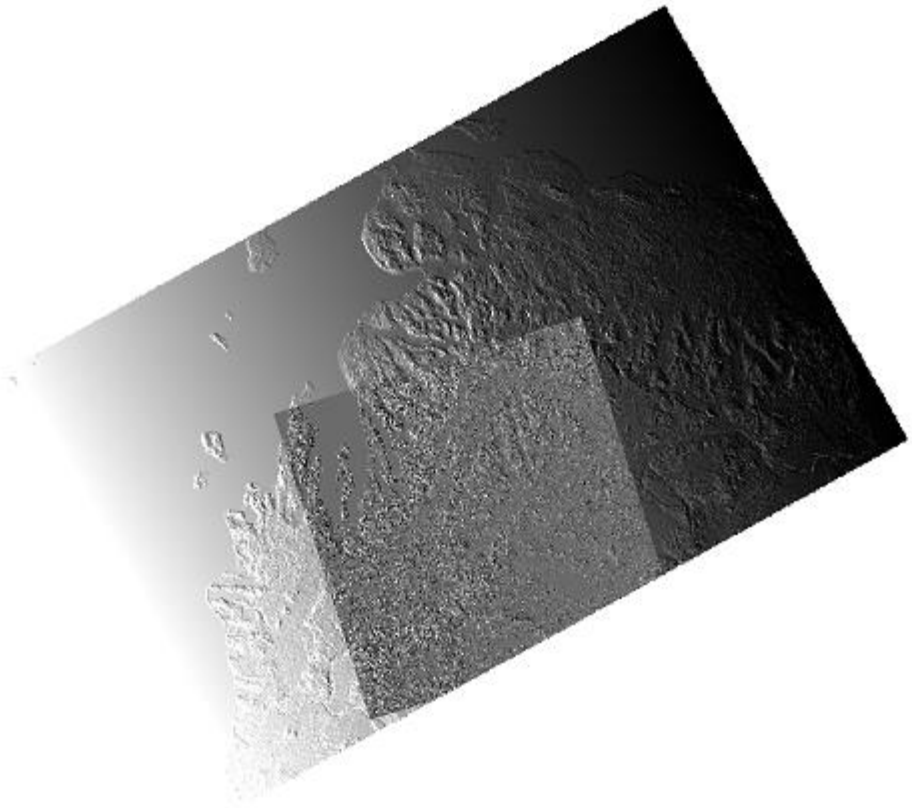


Utah **(30m)**
ASF 's Gamma Naught RTC / Our Gamma Naught RTC / 12TUL S2 tile

3. VALIDATION

Gamma Area image : Michigan

- ASF image multilooked x5
  - => ML factor = 5 in our correction
- Copernicus DEM GLO-30
- No DEM matching
- Ortho spacing at 30m
- No spacial shift

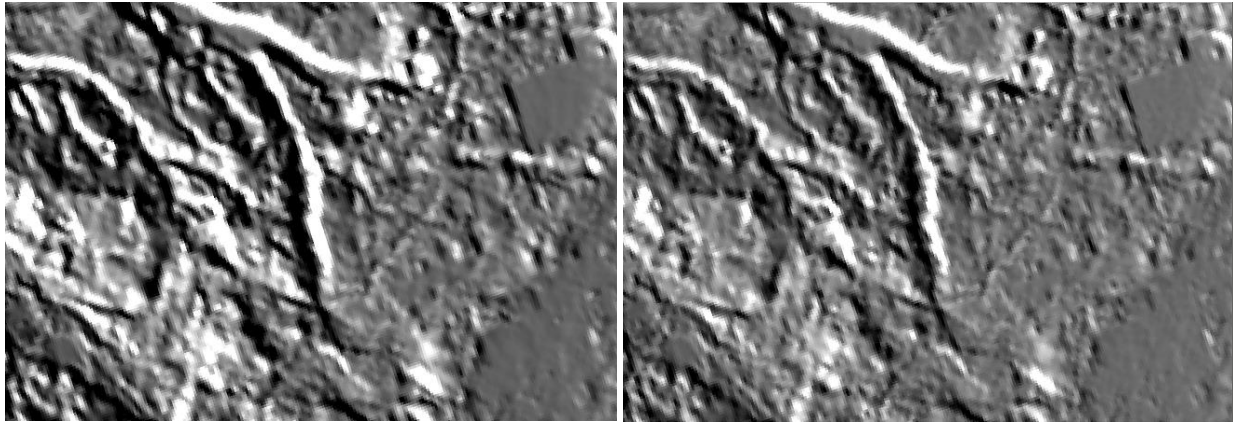


Michigan **(30m)**
ASF 's Gamma Area / Our Gamma Area / 12TFQ S2 tile

3. VALIDATION

Gamma Area image : Michigan

- First look analysis not bad.
- Values are close on many pixels.

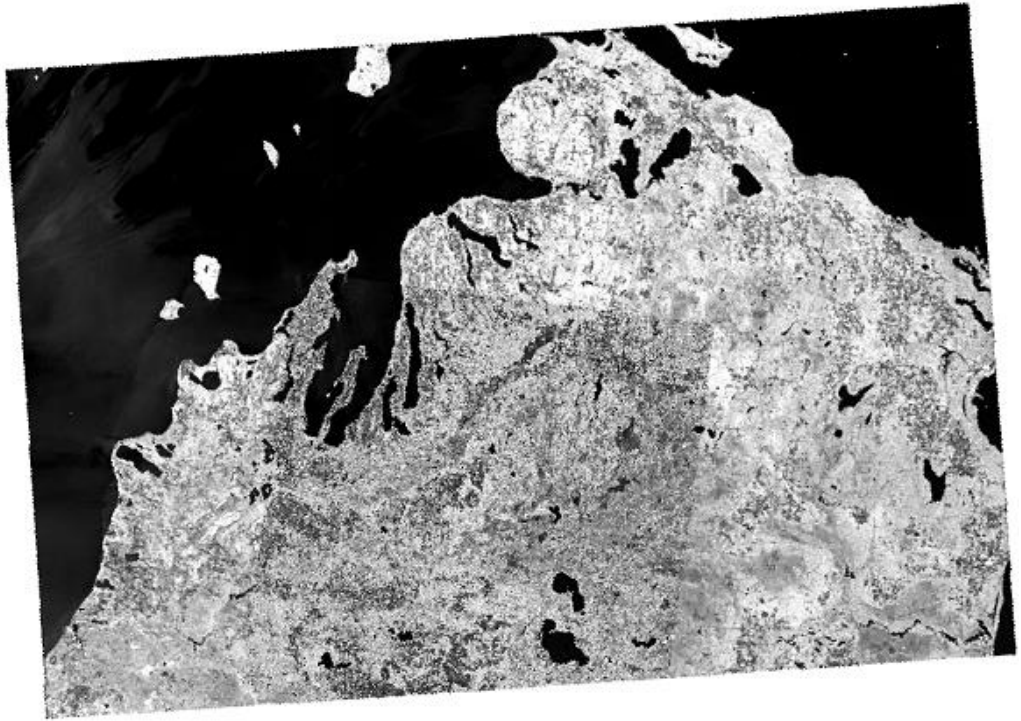


Michigan **(30m)**
ASF 's Gamma Area / Our Gamma Area / 12TFQ S2 tile

3. VALIDATION

Gamma Naught RTC image : Michigan

- ASF image multilooked x5
  - => ML factor = 5 in our correction
- Copernicus DEM GLO-30
- No DEM matching
- Ortho spacing at 30m

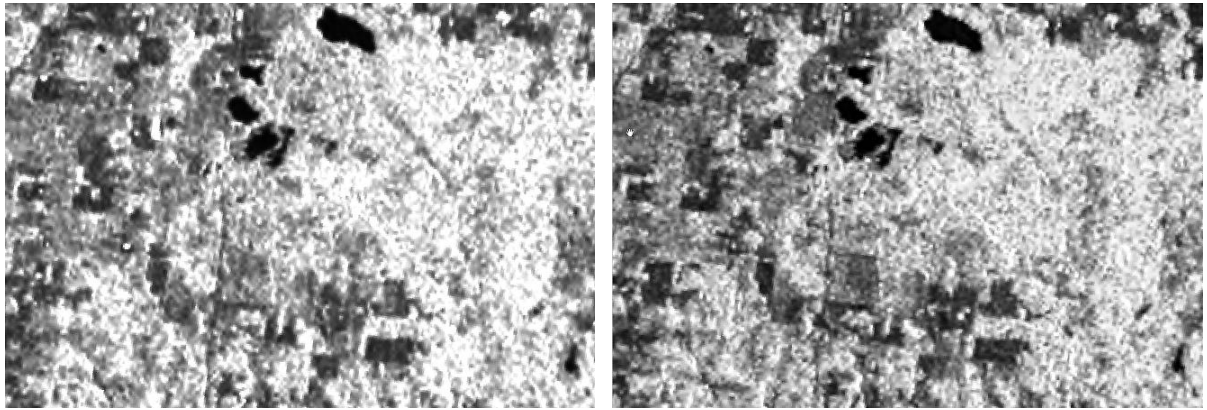


Michigan **(30m)**
ASF 's Gamma Naught RTC / Our Gamma Naught RTC / 12TFQ S2 tile

3. VALIDATION

Gamma Naught RTC image : Michigan

- First look analysis not bad.
- Values are close on some pixels.
- A calibration factor (K_γ) may be applied by ASF.



Michigan **(30m)**
ASF 's Gamma Naught RTC / Our Gamma Naught RTC / 12TFQ S2 tile

Conclusion and Perspectives

04

CONCLUSION AND PERSPECTIVES

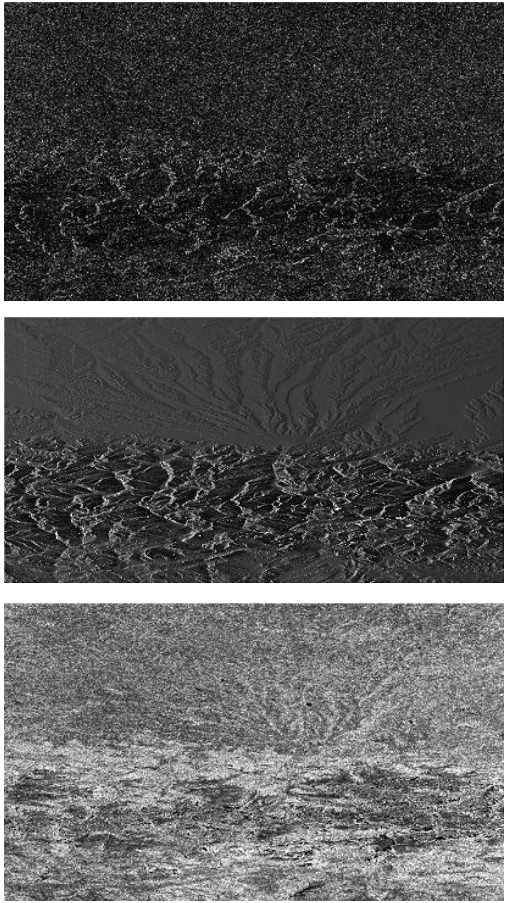
Conclusion

- Gamma Naught RTC correction implemented and does the job.
- Magnitude of the flattening effect depends on multilooking factors and gain.
- Validation up to a multilooking parameters and calibration factor (K_γ)

CONCLUSION AND PERSPECTIVES

Perspectives

- Multilooking and calibration factor effects must be investigated.
- The shadow image computation needs to be improved (work in progress) by taking into account the incidence angle.
- S2 Ortho-rectification of SLC corrections to be fixed
- The orthorectification to S2 of all the pure geometric steps (up to Gamma Area computation) prevent to do them again if a new S1 tile, analog to a previous one, has to be calibrated
- The integration into S1Tiling is then possible



Toulouse – SLC product – SRTM 30m
Top to bottom : Beta Naught / Gamma Area / Gamma Naught RTC

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