SAOCOM 1A/B Quality Assessment Summary

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AMENDMENT RECORD SHEET

The Amendment Record Sheet below records the history and issue status of this document.

ISSUE	DATE	REASON
0.1	In Progress	Initial draft
0.2	27/04/20	Added missing information in Section 2 Updated geolocation accuracy validation section results
1.0	09/07/2020	General review Added assessment of residual scalloping profiles for TopSAR data over Rain Forest Added assessment of TopSAR data quality over point target calibration sites
1.1	23/10/2020	Addressed ESA comments Added Section 3.7 with resume of data assessment results
2.0 draft	27/10/2021	Added results SAOCOM-1B data quality assessment Improved grade of Sensor Calibration & Characterisation Post-Launch filed in Mission Quality Assessment Matrix due to publication on IEEE of SAOCOM-1A Commissioning Phase results
2.0	04/11/2022	Finalization of the report with minor updates Added acronyms and reference sections

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ACRONYMS

ALE	Absolute Localization Error
ATBD	Algorithm Theoretical Baseline Document
CP	Commissioning Phase
CR	Corner Reflector
DI	Detected Image
DP	Dual Polarization
EAP	Elevation Antenna Pattern
ECEF	Earth Centred Earth Fixed
EN	Elevation Notch
GEC	Geocoded Ellipsoid Corrected
GRD	Ground Range Detected
GTC	Geocoded Terrain Corrected
IRF	Impulse Response Function
ISLR	Integrated Side Lobe Ratio
NESZ	Noise Equivalent Sigma Nought
PSLR	Peak Side Lobe Ratio
QP	Quad Polarization
RF	Rain Forest
SAR	Synthetic Aperture Radar
SLC	Single Look Complex
SM	Stripmap
TN	TopSAR Narrow
TRM	Transmit Receive Module
TW	TopSAR Wide

REFERENCES

[RD1] M. Azcueta, et alii, "External Calibration Results of the SAOCOM-1A Commissioning Phase," in *IEEE Transactions on Geoscience and Remote Sensing*

[RD2] Giudici, D.; Monti Guarnieri, A.; Cuesta Gonzalez, J.P. Pre-Flight SAOCOM-1A SAR Performance Assessment by Outdoor Campaign. Remote Sens. 2017, 9, 729.

[RD3] ASAR-Cal-Val-Team. Quality Measurements Definition for ASAR Level 1 Products. Technical report Iss. 1, ESA, Mar. 2002

[RD4] SAOCOM L-1 Products Format, January 13, 2020, on-line document, https://catalogos.conae.gov.ar/catalogo/catalogoSatSaocomDocs.html

1. EXECUTIVE SUMMARY

1.1 Mission Quality Assessment

The Argentinean SAOCOM Mission is made of two twin LEO satellites, carrying an L-band SAR payload for Earth observation.

The first satellite, SAOCOM 1-A, was launched on 7th October 2018. The Commissioning Phase was successfully concluded at the end of 2019. The twin satellite, SAOCOM-1B, was launched on 30th August 2020 and the Commissioning Phase activities, started in December 2020, will be completed before the end of 2021. The SAOCOM data is available for users on a dedicated on-line catalogue. The access requires today a registration and T&C signature process.

In the framework of the EDAP activity, we report here an assessment of the quality of the available products, following the EDAP assessment guidelines. For the time being, the assessment is only performed for L1a (SLC) products. The mission quality assessment has been performed in two steps. The first part, in early 2020, consisted in the analysis of SAOCOM-1A products after the end of the Commissioning Phase. The second part, during 2021, consisted in the analysis of SAOCOM-1B products during the final part of the Commissioning Phase.

The procedure for selecting, ordering and downloading the SAOCOM products from the on-line catalogue is straightforward and no particular issues have been encountered. The format of the products is not standard but a well detailed product format allowing to easily interpret them is available.

The ancillary information provided with the data is exhaustive and allows an easy interpretation of the data. The information is provided in xml files and quality indicators are also provided. The data uncertainties have been widely assessed during the Commissioning Phase of SAOCOM-1A [RD1]. The results of the SAOCOM-1B Commissioning Phase are not yet available.

The independently performed analyses performed allow to conclude that the data, overall, show good quality. In particular, the radiometric quality of both Stripmap and TopSAR products is quite good and the Impulse Response Function is aligned with the expected performance. The overall geolocation accuracy is within the requirements specified for the SAOCOM mission.

In conclusion the assessment of SAOCOM-1A and SAOCOM-1B products performed in the framework of the EDAP activities is positive. The availability of more documentation, in particular related to calibration and quality assessment activities, could be useful for SAOCOM data users.

1.2 Mission Quality Assessment Matrix

Product Information	Product Generation	Ancillary Information	Uncertainty Characterisation	Validation
Product Details	Sensor Calibration & Characterisation Pre-Flight	Product Flags	Uncertainty Characterisation Method	Reference Data Representativeness
Availability & Accessibility	Sensor Calibration & Characterisation Post-Launch	Ancillary Data	Uncertainty Sources Included	Reference Data Quality
Product Format	Additional Processing		Uncertainty Values Provided	Validation Method
User Documentation			Geolocation Uncertainty	Validation Results
Metrological Traceability Documentation				

Key
Not Assessed
Not Assessable
Basic
Intermediate
Good
Excellent

Information Not Public

Figure 1 - SAOCOM L1A Product Quality Evaluation Matrix.

2. MISSION ASSESSMENT OVERVIEW

2.1 Product Information

Product Details	
Product Name	*SAOCOM L1A SLC Product*
Sensor Name	*SAOCOM*
Sensor Type	*Synthetic Aperture RADAR*
Mission Type	*Constellation – 2 satellites (SAOCOM-1A and SACOM-1B)*
Mission Orbit	*Sun Synchronous*
Product Version Number	*N/A*
Product ID	*EOL1ASARSAO*
Processing level of product	*Level 1*
Measured Quantity Name	*Complex numbers:* *RADAR backscatter (sigma 0) is the squared pixel* *Angle of the pixel is proportional to the sensor-target distance (ambiguous by half of the wavelength)*
Measured Quantity Units	*m^2/m^2 (power), radians (angle)*
Stated Measurement Quality	*Radiometric accuracy not declared in the product.*
Spatial Resolution	*Stripmap DP: 10 x 5 m (ground range x azimuth)* *Stripmap QP: 10 x 6 m (ground range x azimuth)* *TopSAR Narrow DP: 10 x 30 m (ground range x azimuth)* *TopSAR Wide DP: 10 x 50 m (ground range x azimuth)* *TopSAR Narrow QP: 10 x 50 m (ground range x azimuth)* *TopSAR Wide QP: 10 x 100 m (ground range x azimuth)*
Spatial Coverage	*Stripmap DP: 50 km* *Stripmap QP: 25 km* *TopSAR Narrow DP: 160 km* *TopSAR Wide DP: 320 km* *TopSAR Narrow QP: 110 km* *TopSAR Wide QP: 220 km*
Temporal Resolution	16 days for interferometric applications (8 days for constellation)
Temporal Coverage	SAOCOM-1A: 2019 to now SAOCOM-1B: 2020 to now
Point of Contact	CONAE website: https://www.argentina.gob.ar/ciencia/conae
Product locator (DOI/URL)	https://catalogos.conae.gov.ar/catalogo/catalogoSat.html
Conditions for access and use	Terms and conditions apply. It is requested to sign in and accept a user agreement, and declare a scientific investigation proposal. It is noted that the T&C are available only in Spanish language.
Limitations on public access	Registration and acceptance of T&C required.

Product Abstract	Complex data in slant range, radiometrically calibrated with no geometric corrections. Generated from Level-0 products.

Availability & Accessibility	
Compliant with FAIR principles	*No*
Data Management Plan	*The data are easily findable on the line catalogue. The data can be retrieved according to:* • *Product ID* • *Geographical research on the Region of Interest* *The results of the geographical research can be further refined according to the following info:* • *Sensing time* • *Sensor mode* • *Polarization* • *Acquisition beam* • *Processing level* • *Processing options*
Availability Status	*The data found on the catalogue can be:* • *Ready for the download* • *If not ready, according to user needs and permissions, a dedicated re-processing can be requested*

Product Format	
Product File Format	*Product is delivered in the form of a zip file + an xml file named xemt. The zip file includes the following folders:* • *Config: folder with the configuration files used during processing. The configuration files include chirp replica and antenna patterns* • *Data: folder with the SAR measurements provided as a binary file + an xml file with the ancillary information* • *Images: folder with quick-looks and kml files for Google Earth visualization* • *Quality: folder with quality parameters including RFI and saturation masks* *The product format is fully described in the "SAOCOM L-1 Products Format" document [RD4] freely available on-line at:* *https://catalogos.conae.gov.ar/catalogo/catalogoSatSaocomDocs.html*
Metadata Conventions	*xml*
Analysis Ready Data?	*No*

User Documentation		
Document	*Reference*	*QA4ECV Compliant*

Product User Guide	*For the time being the SAOCOM user manual is available only in Spanish language at:* *https://catalogos.conae.gov.ar/catalogo/catalogoSatSaocomDocs.html*	*No*
ATBD	Not available	N/A

Metrological Traceability Documentation	
Document Reference	Not available
Traceability Chain / Uncertainty Tree Diagram Available	*No*

2.2 Product Generation

Sensor Calibration & Characterisation – Pre-Flight	
Summary	Only some information is available on line and in peer reviewed literature.
References	[RD2]

Sensor Calibration & Characterisation – Post-Launch	
Summary	SAOCOM-1A results of CP are reported in an IEEE paper. SAOCOM-1B results are not yet available since CP is not yet completed.
References	[RD1]

Additional Processing	
Projection on geographic coordinates	
Description	*The SAR data in RADAR slant coordinates (L1a) are projected into ground coordinates (L1b) or geographical coordinates on Ellipsoid (L1c) or on a Digital Elevation Model (L1d).*
Reference	*Some info can be found in the Product Format document (see previous section). ATBD document is not available.*

2.3 Ancillary Information

Product Flags	
Product Flag Documentation	*Flags related to RFI contamination, data saturation, ionosphere (quad pol only) are provided.*
Comprehensiveness of Flags	*Intermediate*

Ancillary Data	
Ancillary Data Documentation	*Ancillary data are provided as xml file associated to the RADAR measurements. The ancillary data include information about acquisition, orbit, attitude and processing*

Comprehensiveness of Data	*Good*
Uncertainty Quantified	*No*

2.4 Uncertainty Characterisation

Uncertainty Characterisation Method	
Summary	*The products uncertainties have been assessed during the Saocom-1A and Saocom-1B Commissioning Phases according to standard procedures. The procedures include:* • *Point target analysis to derive absolute radiometric calibration and geometric performance* • *Rain forest analysis to derive relative radiometric calibration* • *Very low back-scatter data to assess thermal noise level*
Reference	[RD1]

Uncertainty Sources Included	
Summary	*The information related to the main uncertainty sources is a NESZ map with the thermal noise level foreseen in the data is provided.*
Reference	*The description of the NESZ map is reported in the product format document [RD4].*

Uncertainty Values Provided	
Summary	*Not all the uncertainty values are provided in the L1 products. A NESZ map with the thermal noise level associated to the data is available. The NESZ map is derived performing a calibration of the thermal noise level over very low backscatter areas (e.g. Doldrums).*
Reference	*The NESZ map is described in the Product Format document [RD4]*
Analysis Ready Data?	*No*

Geolocation Uncertainty	
Summary	*The geolocation uncertainty is provided as a single value depending on the processing option:* • *90 m accuracy for products processed with on board GPS data* • *70 m accuracy for products processed with restituted orbit (available 2 days after data acquisition)*
Reference	*The geolocation uncertainty is declared in the SAOCOM catalogue.*

2.5 Validation

Impulse Response Function	
Independently Assessed?	Yes

Reference Data Representativeness	
Summary	*Impulse Response Function (resolution and side lobe levels) of SAOCOM-1A/B products has been assessed for Stripmap and TopSAR products. The analysed data, acquired over dedicated calibration sites, are representative of the available SAOCOM products.*
Reference	*Section 3.2*
Reference Data Quality & Suitability	
Summary	*Data used for the validation are of good quality and suitable for the performed analysis.*
Reference	*Section 3.2*
Validation Method	
Summary	*The Impulse Response Function of SAOCOM-1A/B products has been validated extracting the range and azimuth profiles from Corner Reflectors and SAOCOM transponder available in dedicated calibration sites.*
Reference	*Section 3.2*
Validation Results	
Summary	*The following parameters have benne analysed:* • *Range resolution* • *Azimuth resolution* • *Range Peak to Side Lobe Ratio (PSLR)* • *Range Integrated to Side Lobe Ratio (ISLR)* • *Azimuth Peak to Side Lobe Ratio (PSLR)* • *Azimuth Integrated to Side Lobe Ratio (ISLR)* *All the analysed parameters are in line with products specifications.*
Reference	*Section 3.2.1 for Stripmap products and Section 3.2.2 for TopSAR products*

Geolocation accuracy	
Independently Assessed?	Yes
Reference Data Representativeness	
Summary	*Geolocation accuracy (range and azimuth localisation errors) of SAOCOM-1A/B products has been assessed for Stripmap and TopSAR products. The analysed data, acquired over dedicated calibration sites, are representative of the available SAOCOM products.*
Reference	*Section 3.3*
Reference Data Quality & Suitability	
Summary	*Data used for the validation are of good quality and suitable for the performed analysis.*
Reference	*Section 3.3*
Validation Method	
Summary	*The geolocation accuracy of SAOCOM-1A/B products has been validated by comparing the measured position of reference targets in the image with their known position.*

Reference	*Section 3.3*
Validation Results	
Summary	*The following parameters have benne analysed:* • *Range Absolute Localisation Error* • *Azimuth Absolute Localisation Error* *The geolocation accuracy estimated from the data is in line with products specification.*
Reference	*Section 3.3.1 for Stripmap products 3.3.2 for TopSAR products*

Absolute Radiometric Calibration	
Independently Assessed?	Yes
Reference Data Representativeness	
Summary	*Radiometric calibration (data calibration constant) of SAOCOM-1A/B products has been assessed for Stripmap and TopSAR products. The analysed data, acquired over dedicated calibration sites, are representative of the available SAOCOM products.*
Reference	*Section 3.4*
Reference Data Quality & Suitability	
Summary	*Data used for the validation are of good quality and suitable for the performed analysis.*
Reference	*Section 3.4*
Validation Method	
Summary	*The radiometric calibration of SAOCOM-1A/B products is performed by comparing the Radar Cross Section measured from the data with the theoretical value of the acquired target (Corner Reflector or transponder)*
Reference	*Section 3.4*
Validation Results	
Summary	*The calibration constant derived from the analysed TopSAR products is in line with products specification.*
Reference	*Section 3.4.1 for Stripmap products 3.4.2 for TopSAR products*

Relative Radiometric Calibration	
Independently Assessed?	Yes
Reference Data Representativeness	
Summary	*SAOCOM acquisitions over the Rain Forest are analysed to asses SAOCOM-1A/B relative radiometric calibration*
Reference	*Section 3.5*
Reference Data Quality & Suitability	
Summary	*Data used for the validation are of good quality and suitable for the performed analysis.*

Reference	*Section 3.5*
Validation Method	
Summary	*The data acquired over Rain Forest are masked to remove non homogeneous regions (e.g. rivers) and the effect of incidence angle is compensated to obtain γ^0 profiles.*
Reference	*Section 3.5*
Validation Results	
Summary	*The γ^0 profiles measured from Rain Forest acquisitions are flat with similar levels for all the beams. The relative radiometric calibration is good.*
Reference	*Section 3.5*

Relative Radiometric Calibration: TopSAR data	
Independently Assessed?	Yes
Reference Data Representativeness	
Summary	*SAOCOM TopSAR acquisitions over the Rain Forest are analysed to asses SAOCOM-1A/B relative radiometric calibration*
Reference	*Section 3.6*
Reference Data Quality & Suitability	
Summary	*Data used for the validation are of good quality and suitable for the performed analysis.*
Reference	*Section 3.6*
Validation Method	
Summary	*The data acquired over Rain Forest are masked to remove non homogeneous regions (e.g. rivers) and the effect of incidence angle is compensated to obtain γ^0 profiles. The azimuth profiles of the data are also measured to assess de-scalloping quality.*
Reference	*Section 3.6*
Validation Results	
Summary	*The γ^0 profiles measured from Rain Forest acquisitions are flat with similar levels for all the beams. The residual scalloping profiles are flat. The relative radiometric calibration is good.*
Reference	*Section 3.6.1 for γ^0 profiles and section 3.6.2 for scalloping profiles*

3. DETAILED ASSESSMENT

3.1 SAOCOM overview

The SAOCOM mission is constellation of 2 twin satellites in a sun-synchronous orbit with 625 – 650 km altitude. The repetition cycle for the single satellite is 16 days reduced to 8 days for the constellation. The SAOCOM satellite carries on board an L-band SAR instrument with 50 MHz bandwidth. The antenna is a full-pol active array antenna (7 x 20 phase centres) allowing steering in both elevation and azimuth (for TopSAR mode implementation).

Two sets of beams have been defined for the SAOCOM mission:

- Dual Pol (DP) beams
- Quad Pol (QP) beams

The DP beams acquisition geometry is reported in **Figure 2**. 9 Stripmap DP beams have been defined ensuring 430 km maximum coverage with an access region between 20 and 50 degrees of incidence angle. The theoretical resolution of the Stripmap DP beams is 10 m (ground range) x 5 m (azimuth). The DP beams can be combined into three different TopSAR modes. The TopSAR Narrow modes exploit three beams covering about 150 km with a resolution of 30 x 10 m. The TopSAR Wide mode exploits seven beams covering about 360 km with a resolution of 50 x 10 m.

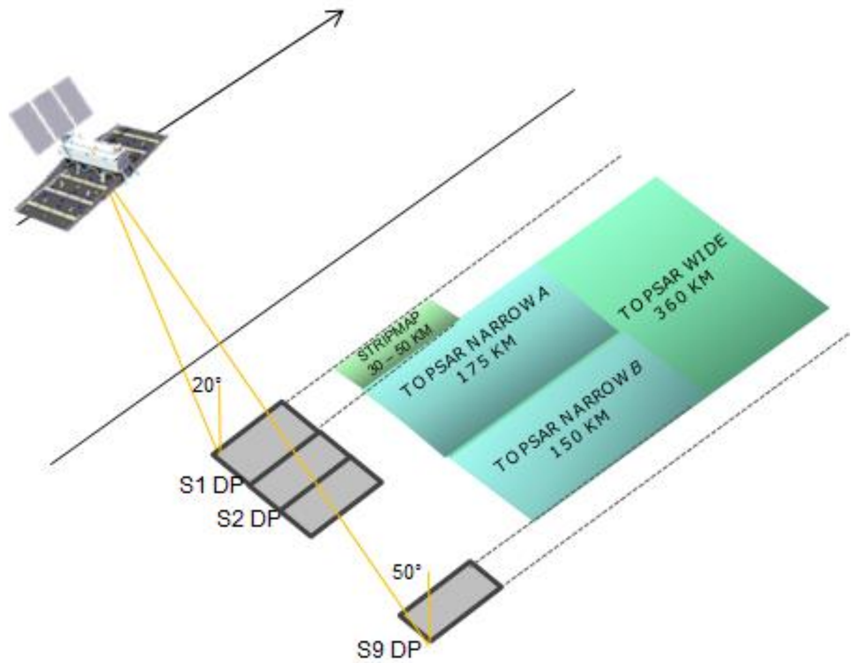

Figure 2 - SAOCOM DP beams acquisition geometry

The DP beams acquisition geometry is reported in **Figure 3**. 10 Stripmap DP beams have been defined ensuring 220 km maximum coverage with an access region between 17 and 35 degrees of incidence angle. The reduced coverage of the QP beams is related to the need of using a double PRF for the full pol acquisition. The theoretical resolution of the Stripmap QP beams is 10 m (ground range) x 6 m (azimuth). The QP beams can be combined into three different TopSAR modes. The TopSAR Narrow modes exploit five beams covering about 110 km with a resolution of 50 x 10 m. The TopSAR Wide mode exploits ten beams covering about 220 km with a resolution of 50 x 10 m.

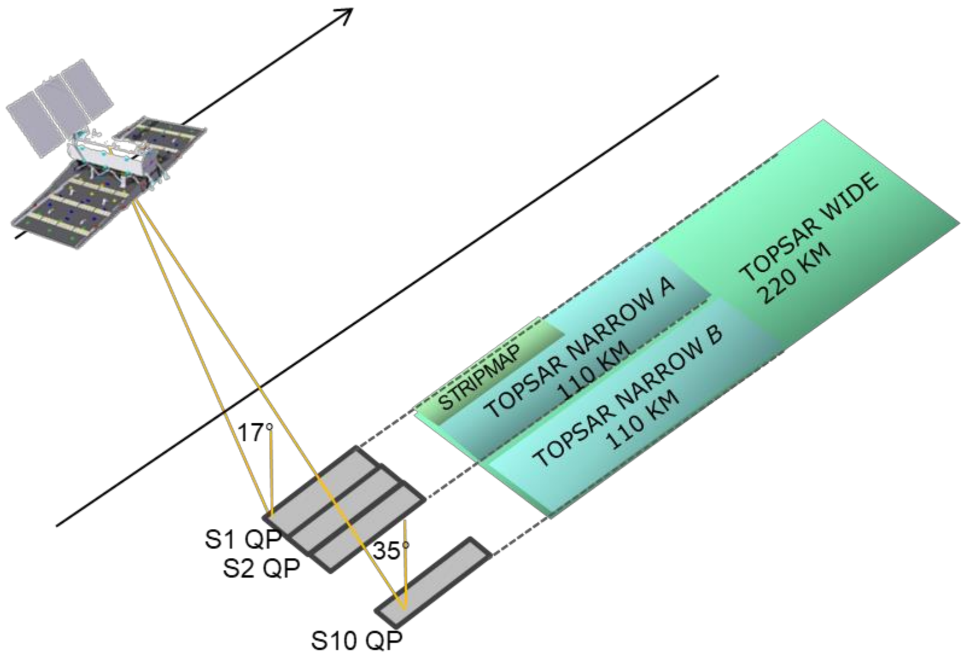

Figure 3 - SAOCOM QP beams acquisition geometry

The L1 SAOCOM products tree is reported in **Figure 4**. For each acquisition mode 5 products have been defined:

- **Single Look Complex (SLC – L1a)**: Complex data in slant range, radiometrically calibrated with no geometric corrections.
- **Detected Image (DI – L1b)**: Data projected to ground range, radiometrically calibrated and georeferenced (Medium and Low resolutions).
- **Ground Ellipsoid Corrected (GEC – L1c)**: Radiometrically calibrated, geocoded and georeferenced.
- **Ground Terrain Corrected (GTC- – L1d)**: Radiometrically calibrated, geocoded using DEM and georeferenced.

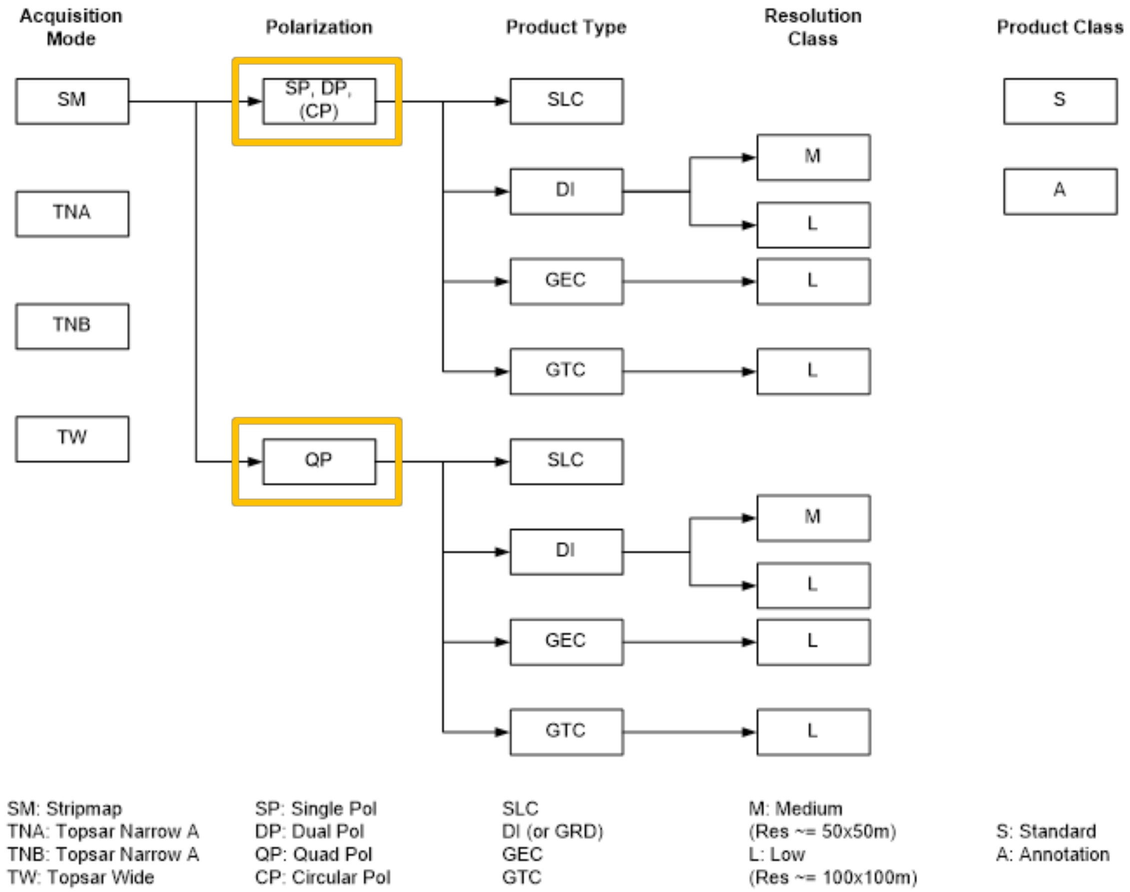

Figure 4 - SAOCOM L1 Products tree

3.2 Impulse Response Function validation

The SAOCOM IRF was characterised in terms of:

- Slant range resolution
- Ground range resolution
- Azimuth resolution
- Range Peak Side Lobe Ratio
- Azimuth Peak Side Lobe Ratio

Figure 5 provides an example of the IRF analysis performed over a SAOCOM CR for a for a DP2 DH acquisition. The point target response is first automatically detected within the data (the detection starting point is the expected target position according to the orbit information) and the 2D IRF is then oversampled to allow a better estimation of the IRF parameters. The parameters are estimated independently in the azimuth and range directions.

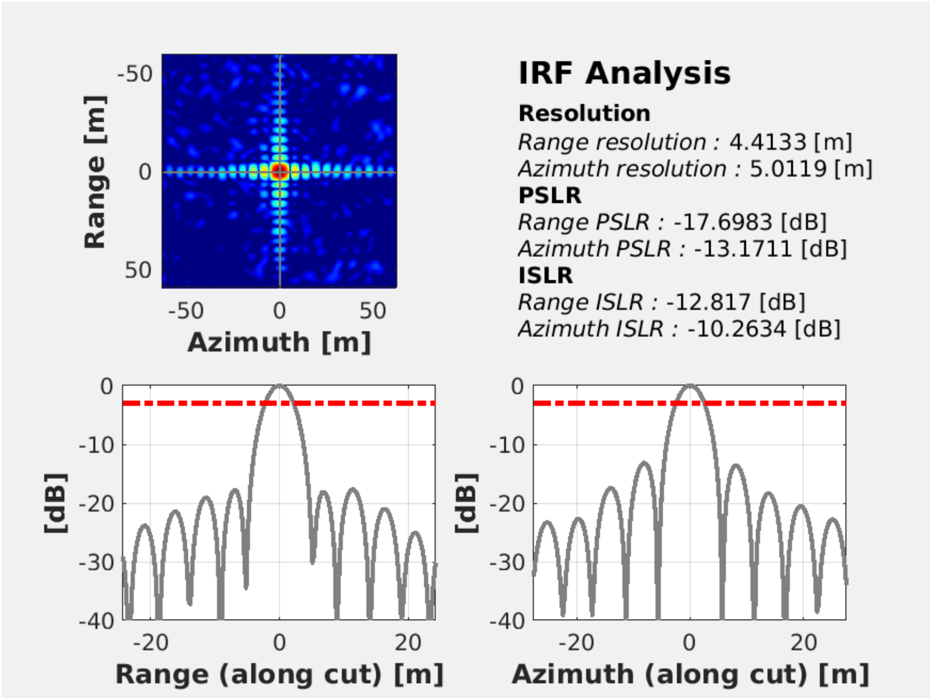

Figure 5 - Example of IRF analysis performed over a SAOCOM Corner Reflector

3.2.1 Stripmap data assessment

3.2.1.1 SAOCOM-1A results

Figure 6 and **Figure 7** show the measured slant range and azimuth resolution as a function of the incidence angle of the calibration target for DP and QP beams respectively. The black dashed lines represent the theoretical resolution. In general, there is a good agreement between the measured and the theoretical values.

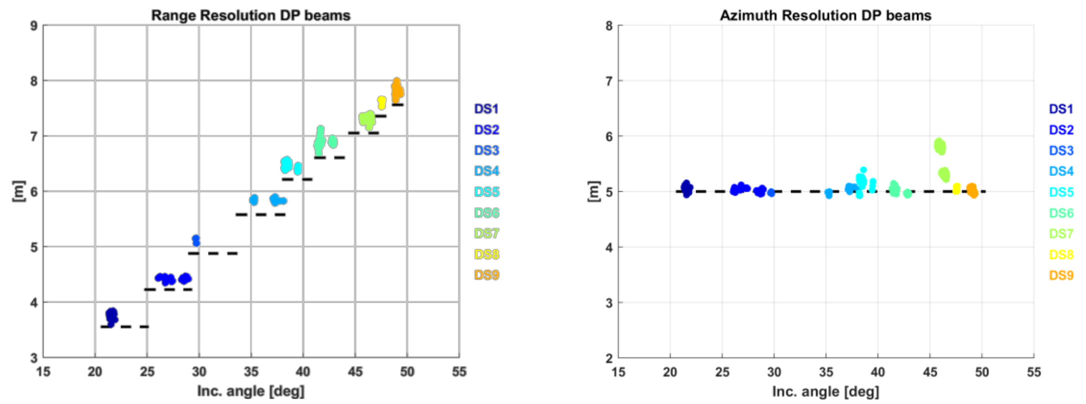

Figure 6 - SAOCOM-1A DP beams range resolution (left) and azimuth resolution (right) measured from acquisitions over CRs as a function of the incidence angle. Black dashed lines represent the theoretical resolution.

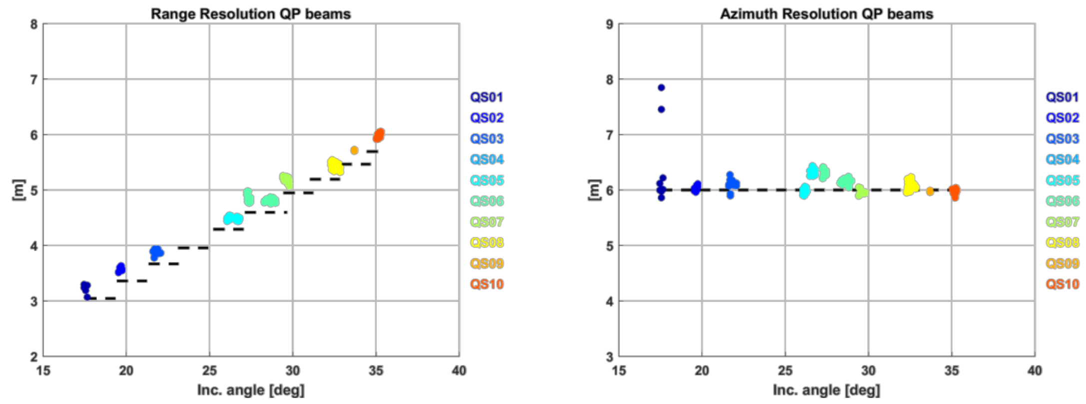

Figure 7 - SAOCOM-1A QP beams range resolution (left) and azimuth resolution (right) measured from acquisitions over CRs as a function of the incidence angle. Black dashed lines represent the theoretical resolution.

The following tables provide a resume of the resolution analysis showing the average and the standard deviation of the slant range, ground range and azimuth resolution computed for each beam separately. The reported values are in line with the mission requirements and declared products resolution:

- Ground Range: 10 m
- Azimuth (DP beam): 5 m
- Azimuth (QP beam): 6 m

Swath	Slant Range Res. [m]		Ground Range Res. [m]		Azimuth Res. [m]	
	Mean	Std.	Mean	Std.	Mean	Std.
DS1	3,758	0,061	10,217	0,177	5,039	0,043
DS2	4,424	0,030	9,584	0,362	5,028	0,041
DS3	5,106	0,051	10,301	0,114	4,974	0,014
DS4	5,842	0,027	9,749	0,222	5,031	0,043
DS5	6,459	0,055	10,365	0,153	5,150	0,111
DS6	6,875	0,058	10,297	0,121	5,017	0,044
DS7	7,315	0,041	10,137	0,064	5,516	0,250
DS8	7,618	0,048	10,322	0,065	5,044	0,042
DS9	7,797	0,057	10,326	0,078	5,024	0,038

Table 1 - Resume of IRF resolution analysis results for SAOCOM-1A DP beams

Swath	Slant Range Res. [m]		Ground Range Res. [m]		Azimuth Res. [m]	
	Mean	Std.	Mean	Std.	Mean	Std.
QS1	3,228	0,072	10,701	0,259	6,435	0,764
QS2	3,569	0,038	10,614	0,103	6,028	0,042
QS3	3,881	0,048	10,451	0,141	6,096	0,087
QS4	-	-	-	-	-	-
QS5	4,482	0,024	10,047	0,118	6,207	0,174
QS6	4,823	0,051	10,233	0,288	6,213	0,099
QS7	5,182	0,053	10,483	0,136	5,961	0,042
QS8	5,430	0,055	10,093	0,122	6,061	0,061
QS9	5,714	0,016	10,297	0,029	5,974	0,022
QS10	5,981	0,036	10,381	0,054	5,979	0,043

Table 2 - Resume of IRF resolution analysis results for SAOCOM-1A QP beams

The analysis of the side lobe levels was also performed in the framework of the IRF analyses. The side lobe levels depend on the processing parameters, in particular on the parameter of the Hamming window applied to the data spectrum. The following considerations apply for the side lobe levels:

- Range Hamming window parameter is 0.95 for all the beams resulting in a theoretical PSLR of -14.20 dB and a theoretical ISLR of -11.10 dB. The average side lobe levels measured in the range direction are reported in Table 3 and Table 4 for DP and QP beams respectively. The measured values are in line with the theoretical ones.
- Azimuth Hamming window parameters are beam dependent and for this reason the expected side lobe levels are beam dependent as well. The average side lobe levels measured in the azimuth direction are reported in Table 5 and Table 6 for DP and QP beams respectively. The theoretical side lobe levels are also reported in the tables for a quick comparison. The measured values are in line with the theoretical ones.
- Note that for some beams, the theoretical side lobe levels are so low that it is not possible to effectively measure them from the data. These values are reported in red in the tables for an easier identification.

Swath	Range PSLR [dB]		Range ISLR [dB]	
	Mean	Std.	Mean	Std.
DS1	-16,553	1,101	-12,144	1,238
DS2	-15,989	0,552	-12,328	0,445
DS3	-15,661	0,639	-12,412	0,628
DS4	-16,228	0,484	-12,709	0,206
DS5	-15,364	0,525	-11,751	0,950
DS6	-15,321	0,646	-11,999	0,649
DS7	-15,340	0,374	-12,161	0,302
DS8	-14,460	0,943	-10,704	1,215
DS9	-14,971	0,445	-11,853	0,325

Table 3 - Resume of IRF range side lobe levels analysis results for SAOCOM-1A DP beams

Swath	Range PSLR [dB]		Range ISLR [dB]	
	Mean	Std.	Mean	Std.
QS1	-15,069	1,732	-9,288	2,200
QS2	-17,057	1,357	-12,420	0,859
QS3	-16,510	1,660	-11,630	1,437
QS4	-	-	-	-
QS5	-15,599	0,689	-11,933	0,439
QS6	-15,753	0,502	-12,219	0,437
QS7	-15,522	0,989	-11,479	0,991
QS8	-15,085	0,644	-11,403	0,709
QS9	-15,033	0,437	-11,865	0,154
QS10	-15,916	0,427	-12,471	0,319

Table 4 - Resume of IRF range side lobe levels analysis results for QP beams

Swath	Azimuth PSLR [dB]			Azimuth ISLR [dB]		
	Theoretical	Mean	Std.	Theoretical	Mean	Std.
DS1	-13,26	-12,001	0,617	-10.21	-9,011	0,419
DS2	-13,26	-12,203	0,766	-10.21	-9,234	0,662
DS3	-39,59	-31,048	1,735	-37.80	-25,374	0,875
DS4	-13,26	-11,625	0,784	-10.21	-8,739	0,682
DS5	-39,59	-29,303	4,950	-37.80	-22,358	4,636
DS6	-13,26	-12,132	0,553	-10.21	-9,166	0,460
DS7	-39,59	-33,381	2,587	-37.80	-27,034	2,475
DS8	-15,09	-13,226	1,363	-11.92	-9,902	1,234
DS9	-13,26	-12,090	0,556	-10.21	-9,164	0,467

Table 5 - Resume of IRF azimuth side lobe levels analysis results for DP beams

Swath	Azimuth PSLR [dB]			Azimuth ISLR [dB]		
	Theoretical	Mean	Std.	Theoretical	Mean	Std.
QS1	-39,59	-19,131	2,989	-37,80	-12,388	2,602
QS2	-39,59	-28,467	1,553	-37,80	-20,511	0,846
QS3	-39,59	-25,235	2,690	-37,80	-19,251	2,526
QS4	-39,59	-	-	-37,80	-	-
QS5	-39,59	-29,976	2,231	-37,80	-23,959	2,003
QS6	-39,59	-30,544	2,898	-37,80	-23,464	2,847
QS7	-39,59	-28,707	3,886	-37,80	-23,321	5,195
QS8	-39,59	-27,775	4,135	-37,80	-21,205	3,803
QS9	-39,59	-29,043	0,815	-37,80	-19,361	1,201
QS10	-39,59	-31,293	2,855	-37,80	-25,641	2,834

Table 6 - Resume of IRF azimuth side lobe levels analysis results for QP beams

3.2.1.2 SAOCOM-1B results

Figure 8 and **Figure 9** show the measured slant range and azimuth resolution as functions of the incidence angle of the calibration target for DP and QP beams respectively. The black dashed lines represent the theoretical resolution. In general, there is a good agreement between the measured and the theoretical values.

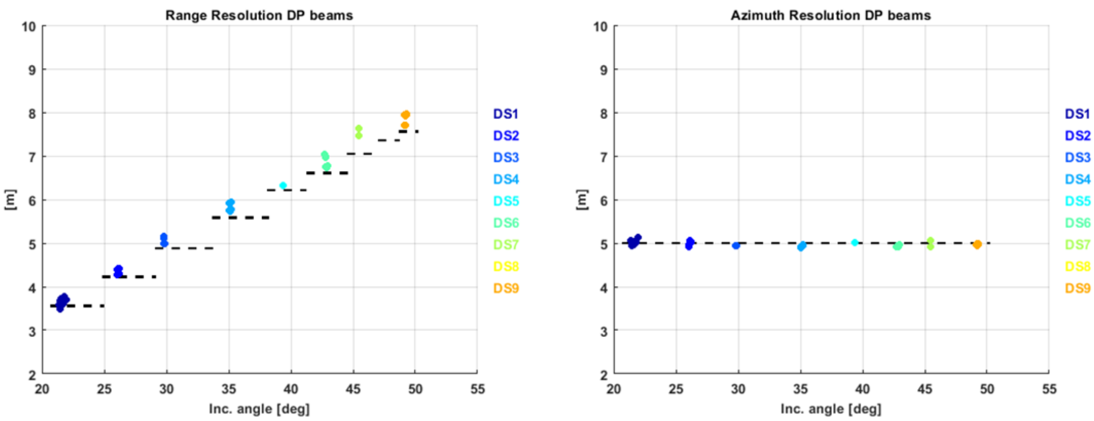

Figure 8 - SAOCOM-1B DP beams range resolution (left) and azimuth resolution (right) measured from acquisitions over PTs as a function of the incidence angle. Black dashed lines represent the theoretical resolution.

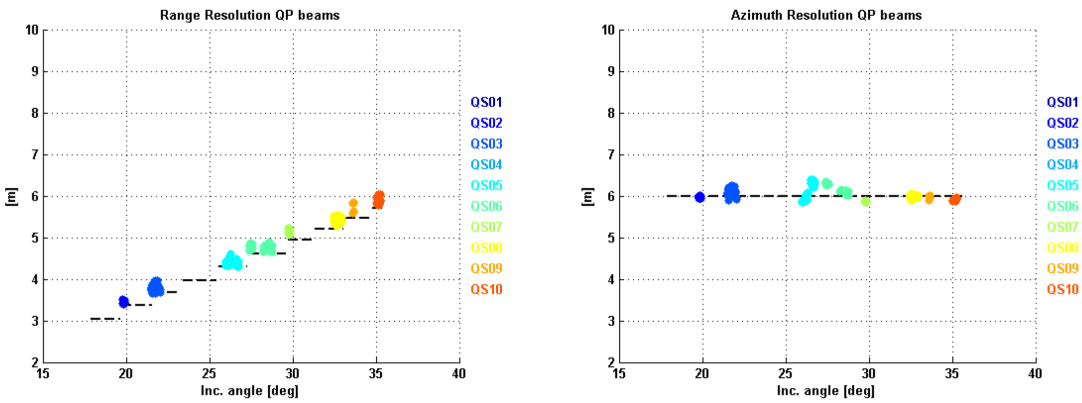

Figure 9 - SAOCOM-1B QP beams range resolution (left) and azimuth resolution (right) measured from acquisitions over PTs as a function of the incidence angle. Black dashed lines represent the theoretical resolution.

The following tables provide a resume of the resolution analysis showing the average and the standard deviation of the slant range, ground range and azimuth resolution computed for each beam separately. The reported values are in line with the mission requirements and declared products resolution:

- Ground Range: 10 m
- Azimuth (DP beam): 5 m
- Azimuth (QP beam): 6 m

Swath	Slant Range Res. [m]		Ground Range Res. [m]		Azimuth Res. [m]	
	Mean	Std.	Mean	Std.	Mean	Std.
DS1	3.652	0.07	9.910	0.16	5.023	0.05
DS2	4.355	0.06	9.887	0.14	4.997	0.04
DS3	5.057	0.08	10.173	0.18	4.938	0.01
DS4	5.840	0.10	10.149	0.18	4.928	0.02
DS5	6.328	-	9.969	-	5.003	-
DS6	6.877	0.14	10.117	0.22	4.927	0.02
DS7	7.553	0.13	10.602	0.17	4.984	0.11
DS8	-	-	-	-	-	-
DS9	7.704	0.01	10.183	0.02	4.958	0.01

Table 7 - Resume of IRF resolution analysis results for SAOCOM-1B DP beams

Swath	Slant Range Res. [m]		Ground Range Res. [m]		Azimuth Res. [m]	
	Mean	Std.	Mean	Std.	Mean	Std.
QS1	-	-	-	-	-	-
QS2	3.445	0.04	10.144	0.13	6.086	0.02
QS3	3.782	0.06	10.223	0.19	6.067	0.06
QS4	-	-	-	-	-	-
QS5	4.376	0.06	9.963	0.12	5.954	0.03
QS6	4.784	0.07	9.946	0.19	6.092	0.05
QS7	5.124	0.06	10.304	0.13	5.940	0.01
QS8	5.399	0.07	10.013	0.14	5.964	0.04
QS9	5.708	0.16	10.315	0.29	5.942	0.06
QS10	5.919	0.08	10.275	0.14	5.897	0.03

Table 8 - Resume of IRF resolution analysis results for SAOCOM-1B QP beams

The analysis of the side lobe levels was also performed in the framework of the IRF analyses. The side lobe levels depend on the processing parameters, in particular on the parameter of the Hamming window applied to the data spectrum. The following considerations apply for the side lobe levels:

- Range Hamming window parameter is 0.95 for all the beams resulting in a theoretical PSLR of -14.20 dB and a theoretical ISLR of -11.10 dB. The average side lobe levels measured in the range direction are reported in Table 9 and Table 10 for DP and QP beams respectively. The measured values are in line with the theoretical ones.
- Azimuth Hamming window parameters are beam dependent and for this reason the expected side lobe levels are beam dependent as well. The average side lobe levels measured in the azimuth direction are reported in Table 11 and Table 12 for DP and QP beams respectively. The theoretical side lobe levels are also reported in the tables for a quick comparison. The measured values are in line with the theoretical ones.
- Note that for some beams the theoretical side lobe levels are so low that it is not possible to effectively measure them from the data. These values are reported in red in the tables for an easier identification.

Swath	Range PSLR [dB]		Range ISLR [dB]	
	Mean	Std.	Mean	Std.
DS1	-15.011	1.16	-10.865	1.13
DS2	-15.804	1.75	-11.570	1.27
DS3	-15.896	1.45	-12.070	1.15
DS4	-16.243	1.65	-12.547	1.00
DS5	-14.436	-	-11.099	-
DS6	-15.372	1.42	-12.225	1.07
DS7	-16.962	1.30	-11.930	0.79
DS8	-	-	-	-
DS9	-15.188	1.06	-12.233	0.96

Table 9 - Resume of IRF range side lobe levels analysis results for SAOCOM-1B DP beams

Swath	Range PSLR [dB]		Range ISLR [dB]	
	Mean	Std.	Mean	Std.
QS1	-	-	-	-
QS2	-14.708	1.56	-11.263	0.58
QS3	-15.061	1.64	-10.692	1.07
QS4	-	-	-	-
QS5	-14.864	1.19	-10.928	0.98
QS6	-15.841	1.64	-11.840	0.95
QS7	-15.227	1.06	-11.445	0.81
QS8	-15.105	1.37	-11.471	0.86
QS9	-15.800	2.79	-11.484	1.16
QS10	-15.126	1.19	-11.915	0.86

Table 10 - Resume of IRF range side lobe levels analysis results for SAOCOM-1B QP beams

Swath	Azimuth PSLR [dB]			Azimuth ISLR [dB]		
	Theoretical	Mean	Std.	Theoretical	Mean	Std.
DS1	-13,26	-12.587	0.74	-10.21	-9.365	0.62
DS2	-13,26	-12.711	0.61	-10.21	-9.901	0.50
DS3	-39,59	-31.450	1.13	-37.80	-27.738	1.45
DS4	-13,26	-12.881	0.27	-10.21	-9.872	0.24
DS5	-39,59	-39.143	-	-37.80	-32.355	-
DS6	-13,26	-12.841	0.20	-10.21	-9.774	0.28
DS7	-39,59	-22.353	0.62	-37.80	-15.724	1.38
DS8	-15,09	-	-	-11.92	-	-
DS9	-13,26	-12.895	0.21	-10.21	-9.841	0.14

Table 11 - Resume of IRF azimuth side lobe levels analysis results for SAOCOM-1B DP beams

Swath	Azimuth PSLR [dB]			Azimuth ISLR [dB]		
	Theoretical	Mean	Std.	Theoretical	Mean	Std.
QS1	-39,59	-	-	-37,80	-	-
QS2	-39,59	-29.163	2.50	-37,80	-22.249	0.99
QS3	-39,59	-24.564	2.17	-37,80	-18.783	2.55
QS4	-39,59	-	-	-37,80	-	-
QS5	-39,59	-32.347	2.77	-37,80	-26.382	1.71
QS6	-39,59	-31.834	4.67	-37,80	-23.567	4.50
QS7	-39,59	-27.010	2.92	-37,80	-23.891	2.23
QS8	-39,59	-29.133	2.57	-37,80	-23.685	1.32
QS9	-39,59	-26.512	2.21	-37,80	-19.584	1.16
QS10	-39,59	-34.092	1.11	-37,80	-28.231	0.84

Table 12 - Resume of IRF azimuth side lobe levels analysis results for SAOCOM-1B QP beams

3.2.2 TopSAR data assessment

3.2.2.1 SAOCOM-1A results

Figure 10 shows the measured slant range (top line) and azimuth (bottom line) resolution as a function of the incidence angle of the calibration targets for the analysed TopSAR beams (reported in the legend on the right). The black dashed lines represent the theoretical resolution. In general, there is a good agreement between the measured and the theoretical values. It is possible to observe an increase of the spread of the measures for low resolution TopSAR beams due to the impact of clutter on the resolution estimation process.

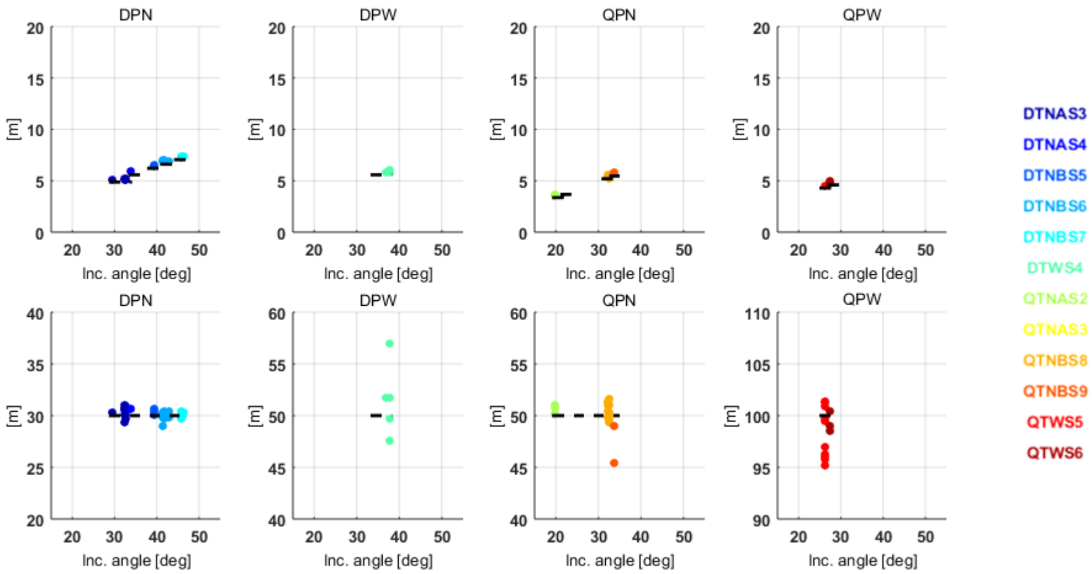

Figure 10 - Range resolution (top) and azimuth resolution (bottom) measured from SAOCOM-1A TopSAR acquisitions over CRs as a function of the incidence angle. A plot for each TopSAR mode is reported. Black dashed lines represent the theoretical resolution.

Table 13 provides a resume of the resolution analysis showing the average and the standard deviation of the slant range, ground range and azimuth resolution computed for each TopSAR beam separately. The reported values are in line with the mission requirements and declared products resolution:

- Ground Range: 10 m
- Azimuth (TNDP beams): 30 m
- Azimuth (TWDP and TNQP beams): 50 m
- Azimuth (TWQP beams): 100 m

The analysis of the side lobe levels was also performed in the framework of the IRF analyses. The side lobe levels depend on the processing parameters, in particular on the parameter of the Hamming window applied to the data spectrum. The following considerations apply for the side lobe levels:

- Range Hamming window parameter is 0.95 for all the beams resulting in a theoretical PSLR of -14.20 dB and a theoretical ISLR of -11.10 dB. The average side lobe levels measured in the range direction are reported in **Table 14**. The measured values are in line with the theoretical ones.
- Azimuth Hamming window parameters are beam dependent and for this reason the expected side lobe levels are beam dependent as well. Furthermore, the low resolution of TopSAR beams makes the estimation of the side lobe levels quite inaccurate due to clutter interference. For this reason, no table with the results of the side lobe levels estimation results is provided. Nevertheless, it was possible to assess the side lobe levels for some acquisitions over SAOCOM transponder. **Figure 11** shows an example of the IRF analysis for the beam DTNBS5. The Hamming parameter for this beam is α = 0.99 resulting in a theoretical PSLR of -13.44 dB and a theoretical ISLR of -10.38 dB. The measures are in good agreement with the theoretical values.

Swath	Slant Range Res. [m]		Ground Range Res. [m]		Azimuth Res. [m]	
	Mean	Std.	Mean	Std.	Mean	Std.
DTNAS3	5,13	0,06	9,57	0,23	30,44	0,45
DTNAS4	5,92	-	10,64	-	30,69	-
DTNBS5	6,48	0,02	10,18	0,03	30,40	0,24
DTNBS6	6,93	0,07	10,37	0,19	29,99	0,40
DTNBS7	7,34	0,06	10,20	0,07	30,05	0,26
DTWS4	5,93	0,08	9,72	0,11	51,22	3,20
QTNAS2	3,61	0,11	10,67	0,33	50,68	0,34
QTNBS8	5,39	0,09	10,04	0,18	50,41	0,73
QTNBS9	5,75	0,01	10,38	0,02	47,22	2,51
QTWS5	4,49	0,03	10,17	0,07	98,01	2,42
QTWS6	4,80	0,11	10,44	0,25	99,31	0,96

Table 13 - Resume of IRF resolution analysis results for SAOCOM-1A TopSAR beams

Swath	Range PSLR [dB]		Range ISLR [dB]	
	Mean	Std.	Mean	Std.
DTNAS3	-15,12	1,46	-10,77	0,77
DTNAS4	-15,44	-	-9,82	-
DTNBS5	-15,39	0,35	-12,01	0,61
DTNBS6	-15,01	0,92	-11,42	0,83
DTNBS7	-14,93	0,47	-11,70	0,37
DTWS4	-16,73	1,06	-12,17	0,43
QTNAS2	-14,63	1,22	-9,53	0,26
QTNBS8	-14,50	1,22	-9,20	1,02
QTNBS9	-12,87	1,66	-5,14	3,22
QTWS5	-15,25	0,59	-11,09	0,73
QTWS6	-14,29	1,82	-9,24	0,99

Table 14 - Resume of IRF range side lobe levels analysis results for SAOCOM-1A TopSAR beams

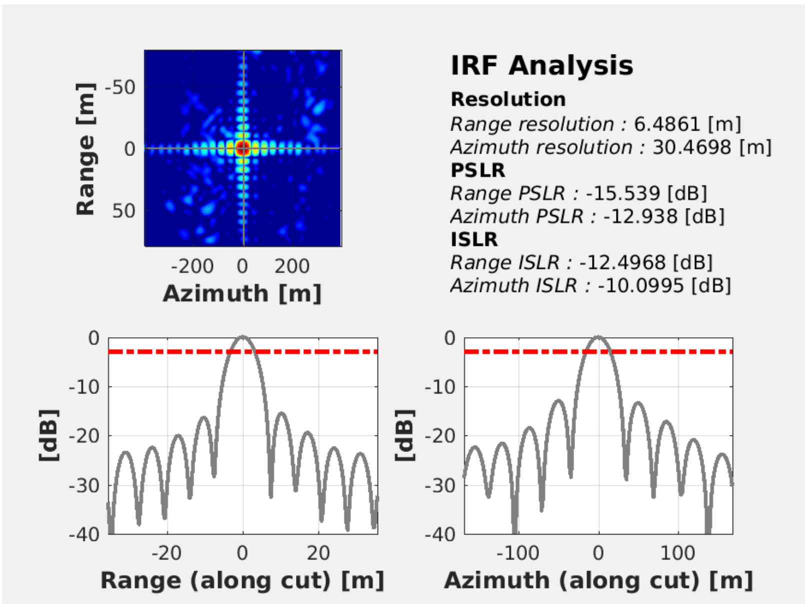

Figure 11 - Example of IRF analysis for SAOCOM-1A TopSAR beam DTNBS5 acquired over SAOCOM transponder

3.2.2.2 SAOCOM-1B results

Due to the reduced number of TopSAR acquisitions over point target calibration sites, complete results, instead of per beam statistics, are reported.

Table 15 reports the measured range and azimuth resolution for TopSAR acquisitions. It is recalled that the expected values for ground range and azimuth resolution are dependent on the implemented TopSAR mode:

- 10x30 m for DTNAS, DTNBS beams
- 10x50 m for DTWS, QTNAS, QTNBS beams

- 10x100 m for QTWS beams

In general, there is a good agreement between the measured and the theoretical values. The few results which show some significant bias w.r.t. the expected values mainly relate to products acquired over corner reflectors which for TopSAR mode, due to the low resolution in particular for QTWS beams, are less reliable than transponder.

Prod. ID	Swath	Pol.	Target ID	Sl. Range Res. [m]	Gr. Range Res. [m]	Azimuth Res. [m]
340681	DTNAS4	V/V	TR_CET_001	5.6971	9.4964	29.6306
340682	DTNBS7	V/V	TR_CET_001	7.1755	10.0711	30.2683
351845	DTNBS7	V/V	TR_CET_001	7.1473	10.0323	30.0622
356895	DTNBS7	H/H	TR_CET_001	7.4673	10.4979	30.0865
357634	DTWS8	H/H	TR_CET_001	7.8113	10.5841	50.0624
335616	QTNAS05	V/V	TR_CET_001	4.3647	9.8374	50.5962
340684	QTNAS05	V/V	TR_CET_001	4.3725	9.8785	48.8304
351847	QTNAS05	V/V	TR_CET_001	4.4009	9.9578	51.337
340680	QTNBS06	H/H	TR_CET_001	4.8565	9.9007	50.0343
340680	QTNBS06	V/V	TR_CET_001	4.7037	9.5891	49.9335
341967	QTNBS06	H/H	TR_CET_001	4.7907	9.7586	49.0526
341967	QTNBS06	V/V	TR_CET_001	4.685	9.5434	50.2639
340680	QTNBS09	H/H	CR_MAN_032	6.1426	11.0929	59.7557
340680	QTNBS09	V/V	CR_MAN_032	5.6313	10.1696	54.7696
341967	QTNBS09	H/H	CR_MAN_032	6.231	11.245	56.7827
352674	QTWS03	H/H	CR_SOS_023	3.3379	9.1857	132.685
352674	QTWS06	H/H	TR_CET_001	4.9308	10.0182	101.5501
352674	QTWS06	V/V	TR_CET_001	4.6933	9.5356	98.3777
352674	QTWS07	V/V	TR_CET_001	5.1581	10.479	101.04
352674	QTWS09	H/H	CR_MAN_032	6.5298	11.7608	139.8232
352674	QTWS09	V/V	CR_MAN_032	5.6541	10.1835	102.6222

Table 15 - IRF resolution analysis results for TopSAR products over point target calibration sites

The analysis of the side lobe levels was also performed in the framework of the IRF analyses. Results of the PSLR measurement are reported in **Table 16**.

The side lobe levels depend on the processing parameters, in particular on the parameter of the Hamming window applied to the data spectrum. The following considerations apply for the side lobe levels:

- Range Hamming window parameter is 0.95 for all the beams resulting in a theoretical PSLR of -14.20 dB.

- Azimuth Hamming window parameters are beam dependent and for this reason the expected side lobe levels are beam dependent as well. The side lobe levels measured in the azimuth direction are reported in tables together with theoretical levels for a quick comparison. The measured values are in line with the theoretical ones. Note that in some case the theoretical side lobe levels are so low that it is not possible to effectively measure them from the data.

In general, results are in line with requirements. Again, large discrepancies from theoretical values relate to acquisitions over corner reflectors. This is expected since the low resolution of TopSAR beams makes the estimation of the side lobe levels quite inaccurate due to clutter interference. The corresponding values have been marked in red in the table.

Prod. ID	Swath	Pol.	Target ID	Range PSLR [dB]	Theoretical azimuth PSLR [dB]	Azimuth PSLR [dB]
340681	DTNAS4	V/V	TR_CET_001	-14.5682	-34.31	-30.9218
340682	DTNBS7	V/V	TR_CET_001	-14.081	-19.10	-19.0615
351845	DTNBS7	V/V	TR_CET_001	-14.0411	-19.10	-18.7252
356895	DTNBS7	H/H	TR_CET_001	-16.323	-19.10	-19.2833
357634	DTWS8	H/H	TR_CET_001	-16.3498	-13.44	-12.8689
335616	QTNAS05	V/V	TR_CET_001	-13.5699	-13.44	-12.6926
340684	QTNAS05	V/V	TR_CET_001	-14.3735	-13.44	-13.4031
351847	QTNAS05	V/V	TR_CET_001	-14.3335	-13.44	-13.0079
340680	QTNBS06	H/H	TR_CET_001	-17.137	-14.00	-13.7288
340680	QTNBS06	V/V	TR_CET_001	-14.4764	-14.00	-13.8352
341967	QTNBS06	H/H	TR_CET_001	-16.0747	-14.00	-13.0417
341967	QTNBS06	V/V	TR_CET_001	-14.3895	-14.00	-13.9701
340680	QTNBS09	H/H	CR_MAN_032	-14.2392	-17.11	-13.2693
340680	QTNBS09	V/V	CR_MAN_032	-13.3781	-17.11	-13.817
341967	QTNBS09	H/H	CR_MAN_032	-13.3408	-17.11	-10.9713
352674	QTWS03	H/H	CR_SOS_023	-9.9166	-19.10	-15.2525
352674	QTWS06	H/H	TR_CET_001	-16.6072	-31.60	-21.4587
352674	QTWS06	V/V	TR_CET_001	-14.3445	-31.60	-22.6507
352674	QTWS07	V/V	TR_CET_001	-14.8818	-17.46	-17.5833

Table 16 - IRF Peak-to-Side Lobe Ratio analysis results for TopSAR products over point target calibration sites

3.3 Geolocation accuracy validation

The geolocation accuracy assessment is performed by comparing the measured against the expected point target position. The point target position in SAR coordinates is measured from the data estimating the position of the maximum of the target IRF. The expected point target position in SAR coordinates is obtained preforming an inverse geocoding over the sensor orbit annotated in the product, starting from the known target position in ECEF reference system. All the analysed products were processed with fast off-line (2-days latency) orbit information with 70 m accuracy. The Absolute Localisation Error (ALE) in azimuth and range direction is then computed as the difference between the measured and the expected position:

$$ALE_{az/rg} = \mathrm{P}_{meas,az/rg} - \mathrm{P}_{exp,az/rg} \quad (1)$$

No further corrections (e.g. ionospheric or tropospheric delay, Earth tides, …) are applied to the obtained ALE values for SAOCOM-1A. On the other hand, for SAOCOM-1B products, the compensation of tropospheric and ionospheric delays from external sources was performed. This allowed to further improve the final geolocation accuracy for the SAOCOM-1B products.

3.3.1 Stripmap data assessment

3.3.1.1 SAOCOM-1A results

The results of the geolocation accuracy assessment are reported in **Figure 12** and **Figure 13** for DS and QS beams respectively. The measured geolocation errors have been plotted separately for each beam. The colour of the triangles represents the calibration site. The direction of the triangle represents the sensor pass (upward for ascending and downward for descending).

The range ALE varies mostly in the range from -5 to 10 m with a few outliers related to beams DS1 and QS3. The azimuth error is much smaller with variations in the range of ±5 m. In some cases, it is possible to observe a clustering of the measured errors according to the calibration sites, resulting in a small increase of the standard deviation of the measures for some beams for which acquisitions over more than one calibration site have been analysed.

The resume of the results of the SAOCOM geolocation accuracy assessment analyses are reported in **Table 17** and **Table 18**. The mean and the standard deviation of the measured range and azimuth ALEs are reported. The overall geolocation performance is in line with the products specifications.

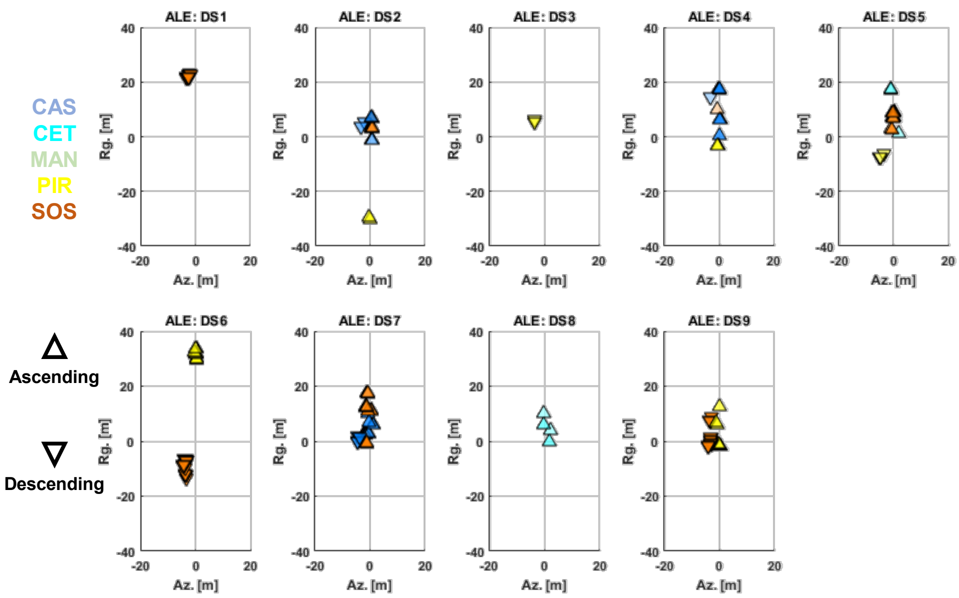

Figure 12 - Measured Absolute Localisation Error for the SAOCOM-1A Stripmap DS beams

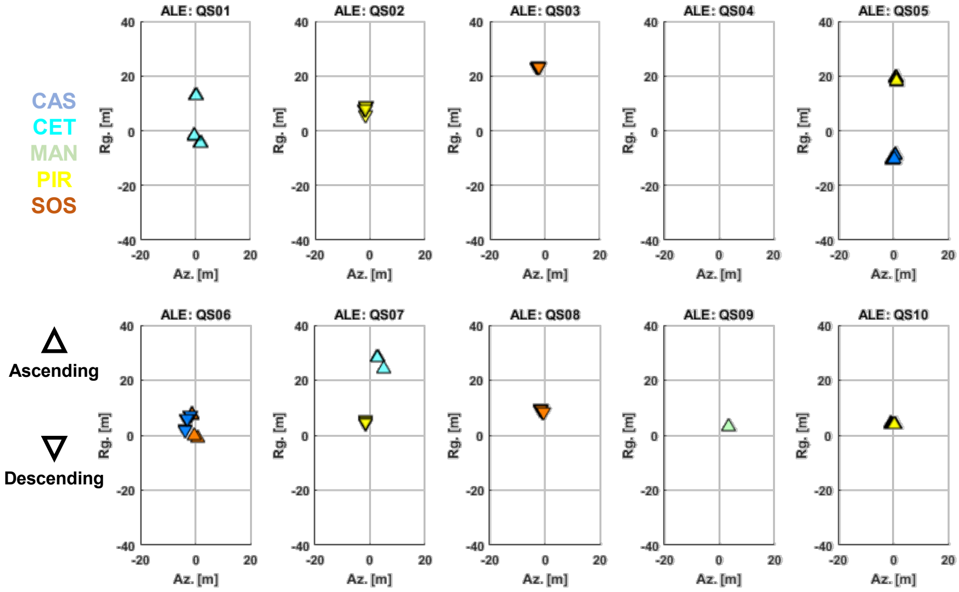

Figure 13 - Measured Absolute Localisation Error for the SAOCOM-1A Stripmap QS beams

Swath	Range ALE [m]		Azimuth ALE [m]	
	Mean	Std.	Mean	Std.
DS1	22,409	0,586	-2,398	0,428
DS2	-2,763	14,514	0,080	1,278
DS3	5,822	0,582	-3,450	0,057
DS4	6,979	8,326	-0,120	0,704
DS5	4,824	6,360	-0,864	1,606
DS6	1,395	17,333	-2,684	1,650
DS7	5,575	5,461	-1,415	1,399
DS8	4,315	4,112	0,839	1,247
DS9	2,801	4,558	-2,566	1,344

Table 17 - Resume of SAOCOM-1A geolocation accuracy assessment results for DP beams

Swath	Range ALE [m]		Azimuth ALE [m]	
	Mean	Std.	Mean	Std.
QS1	2,250	8,411	0,479	1,041
QS2	7,915	1,388	-1,590	0,189
QS3	23,366	0,102	-2,364	0,132
QS4	-	-	-	-
QS5	0,295	13,994	0,383	0,609
QS6	3,315	3,582	-1,381	1,568
QS7	11,990	10,500	0,262	2,709
QS8	8,936	0,608	-0,975	0,453
QS9	2,861	0,047	3,258	0,008
QS10	3,964	0,150	-0,272	0,467

Table 18 - Resume of SAOCOM-1A geolocation accuracy assessment results for QP beams

3.3.1.2 SAOCOM-1B results

The resume of the results of the SAOCOM-1B geolocation accuracy assessment for Stripmap beams is reported in **Figure 14**. The results from all the analysed products have been plotted on the same chart along with the nominal product accuracy (light blue circle). The colour of the triangles represents the calibration site where the measure has been performed. The direction of the triangle represents the sensor pass (upward for ascending and downward for descending).

The range ALE varies mostly in the range from -20 to 10 m for all the beams. The azimuth error is smaller with variations in the range from -10 to 5 m. From the plot, it is possible to observe a certain clustering of the measured errors according to the calibration site (e.g., CET acquisitions are mostly visible on the left). This can result in a small increase of the standard deviation of the measures for beam (e.g., QS5) for which acquisitions over more than one calibration site have been analysed.

Table 19 and **Table 20** provide the mean and the standard deviation of the measured range and azimuth ALEs for DP and QP beams respectively. The overall geolocation performance is well within the products specifications. A small negative bias can be observed for all the beams. The compensation of the small bias could further improve the overall geolocation performance.

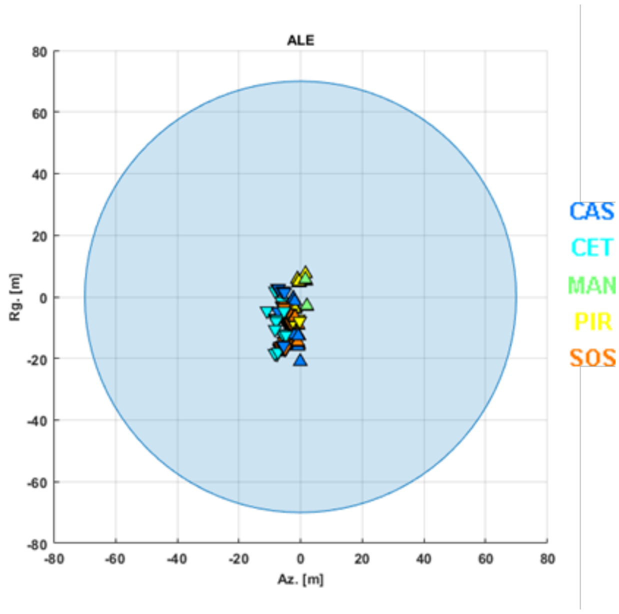

Figure 14 - Synthetic plot of the measured Absolute Localisation Error for the SAOCOM-1B Stripmap acquisitions

Swath	Range ALE [m]		Azimuth ALE [m]	
	Mean	Std.	Mean	Std.
DS1	-18.249	0.16	-2.814	0.68
DS2	-	-	-0.154	0.63
DS3	-14.769	0.30	-4.239	0.22
DS4	-12.924	5.60	-3.865	3.01
DS5	-3.497	0.11	-1.718	0.07
DS6	-14.221	7.25	-5.120	2.34
DS7	-7.052	6.88	-3.113	2.43
DS8	-	-	-	-
DS9	-4.900	3.82	-4.845	1.10

Table 19 - Resume of geolocation accuracy assessment results for SAOCOM-1B Stripmap DP beams

Swath	Range ALE [m]		Azimuth ALE [m]	
	Mean	Std.	Mean	Std.
QS01	-	-	-	-
QS02	-7.733	0.35	-0.859	0.61
QS03	-8.753	0.48	-3.434	0.35
QS04	-	-	-	-
QS05	-7.923	9.47	-1.689	2.06
QS06	-5.305	3.36	-4.285	1.51
QS07	-8.166	0.21	-2.069	0.32
QS08	-7.843	3.99	-4.157	0.80
QS09	2.620	4.36	1.785	0.22
QS10	-3.943	0.29	-2.931	0.72

Table 20 - Resume of geolocation accuracy assessment results for SAOCOM-1B Stripmap QP beams

3.3.2 TopSAR data assessment

3.3.2.1 SAOCOM-1A results

The results of the geolocation accuracy assessment are reported in **Figure 15** for the analysed TopSAR beams. The measured geolocation errors have been plotted separately for each beam: the top line of the plot shows the results for DP beams while the bottom line of the plot shows the results for QP beams. The colour of the triangles represents the calibration site. The direction of the triangle represents the sensor pass (upward for ascending and downward for descending).

The range ALE varies mostly in the range from -20 to 20 m for all the beams with the exception of QTWS5 beam. The azimuth error is smaller with variations in the range of ±10 m even if it is possible to observe some larger observation. In some cases, it is possible to observe a clustering of the measured errors according to the calibration sites, resulting in a small increase of the standard deviation of the measures for some beams for which acquisitions over more than one calibration site have been analysed.

The resume of the results of the SAOCOM geolocation accuracy assessment for TopSAR beams is reported in **Table 21**. The mean and the standard deviation of the measured range and azimuth ALEs are reported. The overall geolocation performance is in line with the products specifications.

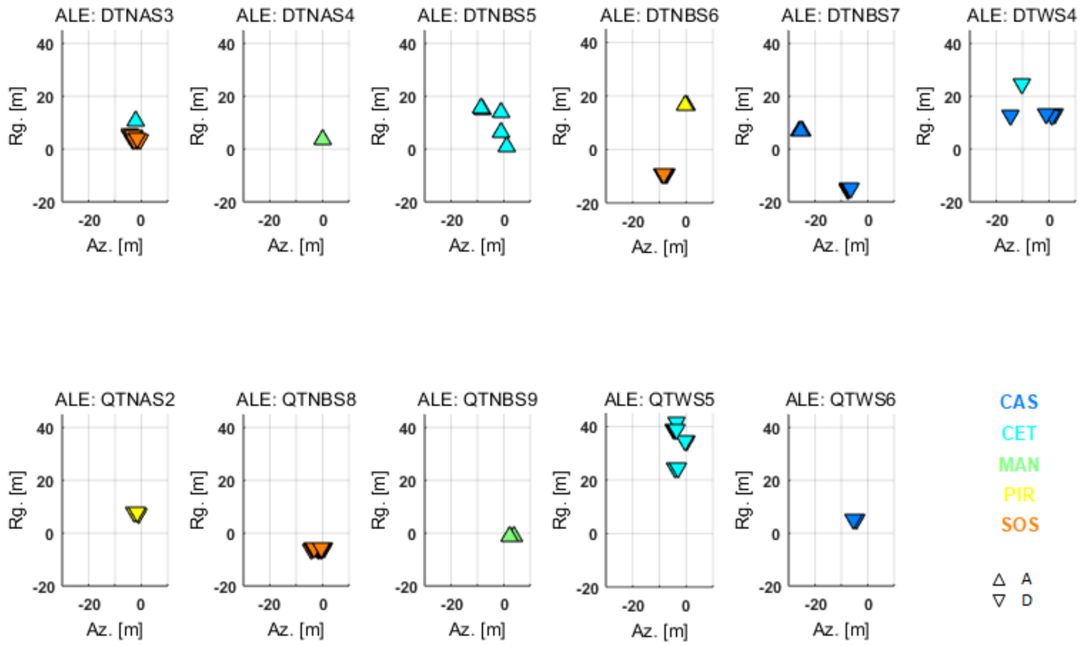

Figure 15 - Measured Absolute Localisation Error for the SAOCOM-1A TopSAR beams

Swath	Range ALE [m]		Azimuth ALE [m]	
	Mean	Std.	Mean	Std.
DTNAS3	4,86	1,66	-2,73	0,96
DTNAS4	3,84		0,12	
DTNBS5	10,23	6,29	-3,55	4,46
DTNBS6	-2,08	12,03	-5,99	3,85
DTNBS7	-4,23	11,56	-16,13	9,67
DTWS4	15,06	4,79	-3,55	7,01
QTNAS2	7,63	0,07	-1,59	0,81
QTNBS8	-5,76	0,10	-1,60	1,37
QTNBS9	-1,37	0,10	2,92	1,18
QTWS5	36,05	5,43	-2,76	1,89
QTWS6	5,37	0,10	-5,06	0,63

Table 21 - Resume of SAOCOM-1A geolocation accuracy assessment results for TopSAR beams

3.3.2.2 SAOCOM-1B results

The results of the geolocation accuracy assessment are reported in **Table 22** for the analysed TopSAR products. The range ALE varies in the range from -10 to 25 m, while the azimuth error is slightly smaller with variations in the range of -20 to 10. It is worth to note that the accuracy in the measurement of the targets' location is reduced for TopSAR products due to the lower resolution (in particular in azimuth) w.r.t. Stripmap products. Furthermore, most of the measures have been performed over an active transponder which can further reduce the measurement accuracy due to the internal electronic. The overall geolocation calibration is in any case close to the Stripmap accuracy and within the products specification.

Prod. ID	Swath	Pol.	Target ID	Range ALE [m]	Azimuth ALE [m]
340681	DTNAS4	V/V	TR_CET_001	-3.9179	-1.9397
340682	DTNBS7	V/V	TR_CET_001	-3.4389	-13.539
351845	DTNBS7	V/V	TR_CET_001	8.7208	-15.2458
356895	DTNBS7	H/H	TR_CET_001	-6.5117	-10.6828
357634	DTWS8	H/H	TR_CET_001	10.2355	-5.1755
335616	QTNAS5	V/V	TR_CET_001	6.2049	-3.1665
340684	QTNAS5	V/V	TR_CET_001	-2.5598	-0.41617
351847	QTNAS5	V/V	TR_CET_001	3.3643	-1.784
340680	QTNBS6	H/H	TR_CET_001	6.8176	3.494
340680	QTNBS6	V/V	TR_CET_001	7.0137	3.7304
341967	QTNBS6	H/H	TR_CET_001	-0.76718	2.2175
341967	QTNBS6	V/V	TR_CET_001	-0.52925	1.7207
340680	QTNBS9	H/H	CR_MAN_032	-6.6243	4.7042
340680	QTNBS9	V/V	CR_MAN_032	-6.4499	6.144
341967	QTNBS9	H/H	CR_MAN_032	-4.6631	5.817
352674	QTWS3	H/H	CR_SOS_023	-8.1806	-17.4827
352674	QTWS6	H/H	TR_CET_001	5.4664	-0.6001
352674	QTWS6	V/V	TR_CET_001	5.5726	0.16473
352674	QTWS7	V/V	TR_CET_001	25.8724	3.8684
352674	QTWS9	H/H	CR_MAN_032	-1.0713	-2.4997
352674	QTWS9	V/V	CR_MAN_032	-1.3672	9.0979

Table 22 - Geolocation accuracy assessment results for SAOCOM-1B TopSAR products over point target calibrations sites

3.4 Absolute radiometric calibration assessment

The absolute radiometric calibration of the SAOCOM products is assessed by comparing the measured Radar Cross Section against the theoretical one. In order to perform the estimation of the RCS of a point target in the SLC image, it is necessary to remove the background backscattering contribution from the image under analysis. Making reference to the image segmentation reported in **Figure 16** [RD3] the following steps are necessary:

- Conversion of pixel values to intensity.
- Derivation of the background intensity by summing the pixel intensities over four square areas of M pixels (e.g. M = 15) positioned around the target in such a way that they include only clutter intensity.
- Subtraction of the mean background intensity from the image.
- Estimation of the RCS o the point target by integrating (summing) the intensity over the pixels belonging to the main lobe of the IRF (red square **Figure 16**).
- Normalization of the RCS according to the ground range pixel area and incidence angle.

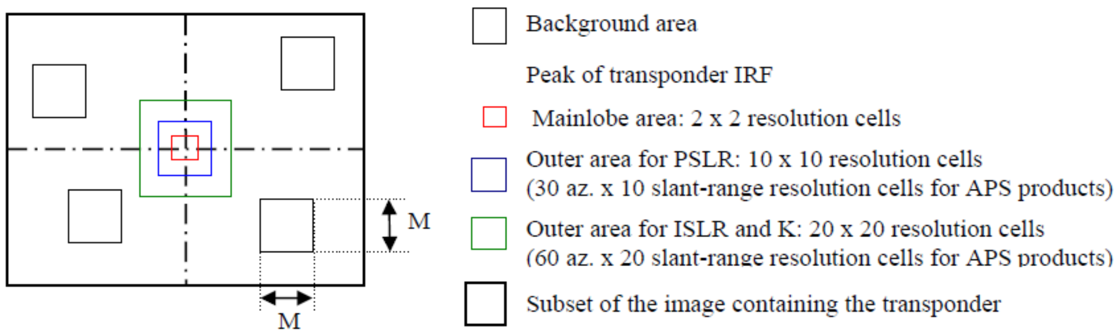

Figure 16 - SLC image segmentation for target Radar Cross Section estimation

The theoretical CR RCS is derived from the following model as a function of the target observation geometry:

$$\boldsymbol{RCS_{model}} = \frac{4\pi}{\lambda^2} a^4 \left(c_1 c_2 c_3 - \frac{2}{c_1 c_2 c_3}\right)^2 \qquad (2)$$

where λ is the sensor wavelength, a is the CR leg (3 m for SAOCOM targets) and the model parameters are: $c_1 = \sin\psi$, $c_2 = \cos\psi \sin\varphi$ and $c_3 = \cos\psi \cos\varphi$. The angle ψ is the elevation angle w.r.t. to the ground plate (directivity peak at 35.26 degrees) and the angle φ is the azimuth angle w.r.t. the closest of the vertical plates of the CR (directivity peak at 45 degrees). **Figure 17** shows an example of the considered RCS model evaluated for SAOCOM calibration.

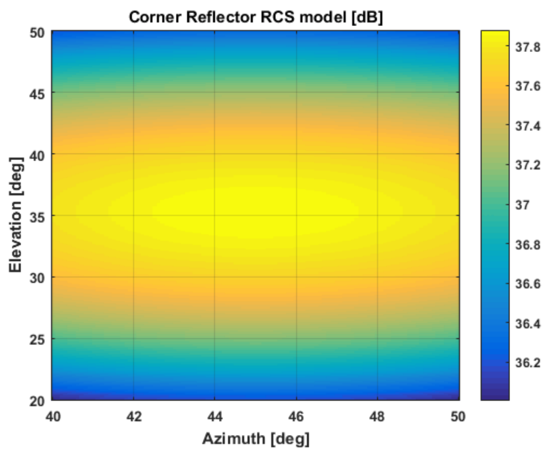

Figure 17 - Model for SAOCOM Corner Reflector RCS as a function of azimuth and elevation angles.

Finally, for each analysed calibration target the calibration constant is obtained as:

$$\boldsymbol{K} = \frac{\boldsymbol{RCS_{meas}}}{\boldsymbol{RCS_{model}}} \qquad (3)$$

3.4.1 Stripmap data assessment

3.4.1.1 SAOCOM-1A results

The results of the absolute radiometric calibration assessment are reported in **Figure 18** for DP (plot on the left) and QP beams (plot on the right). The calibration constant derived for each acquisition over a CR is plotted as a function of the incidence angle. The colour represents the calibration site to which each measure is referred. The points represented with a square refer to H/H polarization whereas the circles refer to V/V. Outliers outside the ±3 dB range have been discarded.

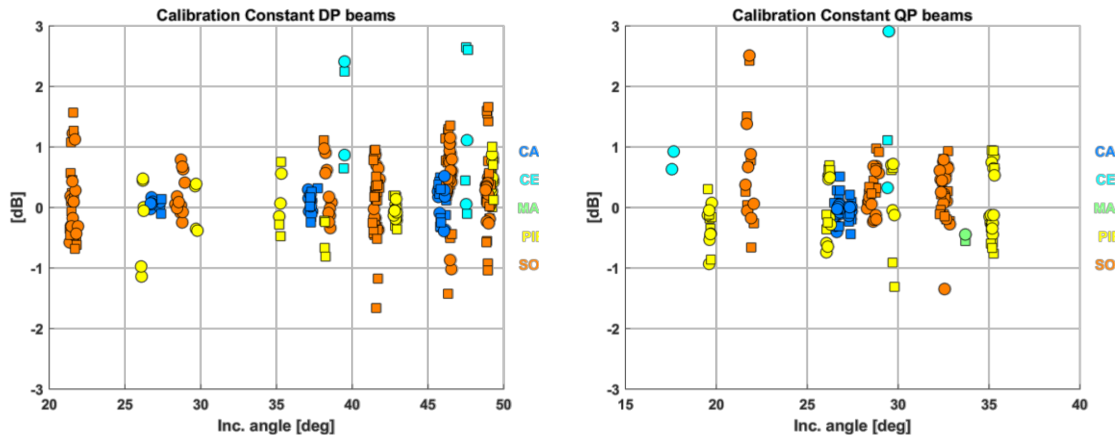

Figure 18 - Calibration constant from calibration targets as a function of the incidence angle for SAOCOM-1A DP (on the left) and QP beams (on the right).

Overall, the SAOCOM-1A beams appear to be well calibrated. The following tables report the average and the standard deviation of the calibration constants derived for each beam and polarization independently. All the beams fall in the range of ±0.5 dB. The beams falling outside this range (DS8 H/H and V/V, QS03 H/H and V/V, QS07 H/H and V/V and QS09 H/H) show a high standard deviation of the estimates suggesting that the performed analysis is not accurate enough.

Swath	Cal. Constant H/H [dB]		Cal. Constant V/V [dB]	
	Mean	Std.	Mean	Std.
DS1	0,15	0,70	0,04	0,53
DS2	0,02	0,17	0,07	0,42
DS3	-	-	0,00	0,43
DS4	0,14	0,43	0,08	0,20
DS5	0,16	1,14	0,45	0,75
DS6	0,05	0,50	0,07	0,35
DS7	0,28	0,56	0,40	0,47
DS8	1,40	1,44	0,58	0,75
DS9	0,34	0,59	0,30	0,27

Table 23 - Resume of SAOCOM-1A radiometric calibration assessment results for DP beams

Swath	Cal. Constant H/H [dB]		Cal. Constant V/V [dB]	
	Mean	Std.	Mean	Std.
QS1	-	-	-	-
QS2	-0,23	0,35	-0,32	0,33
QS3	0,59	1,00	0,71	0,90
QS4	-	-	-	-
QS5	0,12	0,34	-0,09	0,32
QS6	0,20	0,37	0,09	0,30
QS7	0,61	1,70	0,75	1,12
QS8	0,24	0,37	0,24	0,53
QS9	-0,55	N/A	-0,45	N/A
QS10	-0,01	0,67	0,07	0,47

Table 24 - Resume of SAOCOM-1A radiometric calibration assessment results for QP beams

3.4.1.2 SAOCOM 1-B results

The results of the absolute radiometric calibration assessment for Stripmap beams are reported in **Figure 23** for DP (plots on the left) and QP beams (plots on the right). The plots in the top line refer to measures over CRs while the plots on the bottom line refer to measures over SAOCOM transponder. The calibration constant derived for each target is plotted as a function of the incidence angle. The colour represents the calibration site to which each measure is referred. The points represented with a square refer to H/H polarization whereas the circles refer to V/V.

Overall, the beams appear to be well calibrated both for those characterised over corner reflectors and over transponder. Table 25 and **Table 26** report, for DP and QP beams respectively, the average and the standard deviation of the calibration constants derived for each beam and polarization independently. Most of the beams fall in the range of ±0.5 dB. Only DS1 significantly falls outside this range (the reason should be further investigated but could be related to the particular acquisition analysed). The results from the available transponder acquisitions are also good.

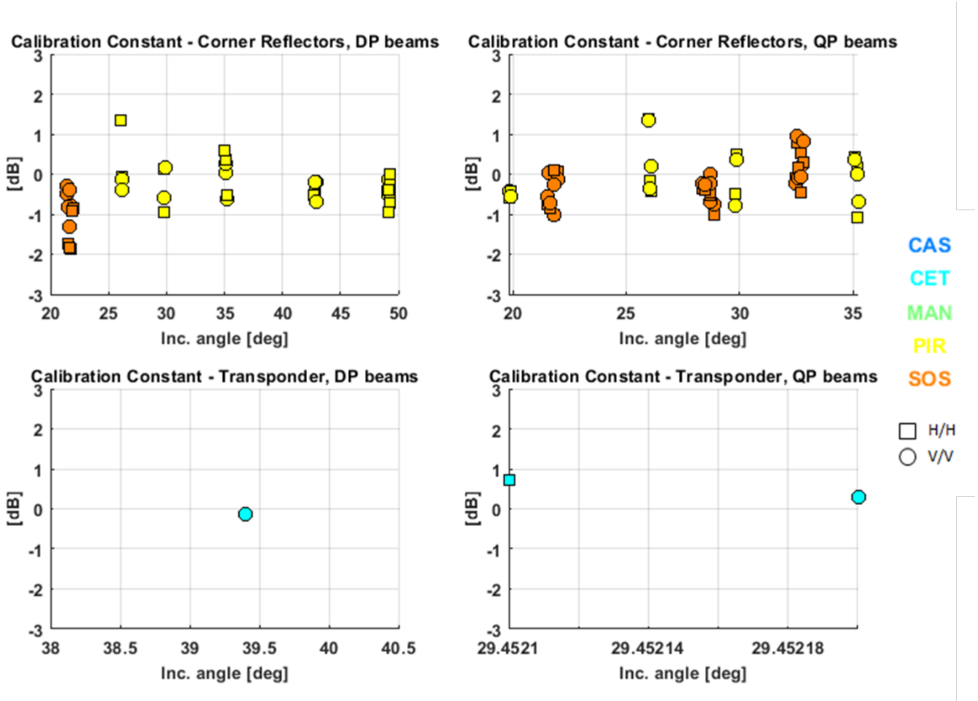

Figure 19 - Calibration constant from calibration targets as a function of the incidence angle for SAOCOM-1B Stripmap DP (on the left) and QP beams (on the right).

Swath	Cal. Constant H/H [dB]		Cal. Constant V/V [dB]	
	Mean	Std.	Mean	Std.
DS1	-1.45	0.50	-0.68	0.37
DS2	0.39	0.81	-0.25	0.18
DS3	-0.41	0.77	-0.21	0.53
DS4	0.14	0.59	-0.11	0.46
DS5	-	-	-0.14	-
DS6	-0.52	0.08	-0.35	0.28
DS7	-	-	-	-
DS8	-	-	-	-
DS9	-0.47	0.36	-0.34	0.20

Table 25 - Resume of radiometric calibration assessment results for SAOCOM-1B Stripmap DP beams

Swath	Cal. Constant H/H [dB]		Cal. Constant V/V [dB]	
	Mean	Std.	Mean	Std.
QS1	-	-	-	-
QS2	-0.52	0.12	-0.49	0.09
QS3	-0.53	0.48	-0.44	0.39
QS4	-	-	-	-
QS5	0.26	0.97	0.39	0.87
QS6	-0.38	0.53	-0.27	0.36
QS7	0.00	0.71	-0.22	0.80
QS8	0.20	0.44	0.26	0.49
QS9	-	-	-	-
QS10	-0.16	0.80	-0.11	0.53

Table 26 - Resume of radiometric calibration assessment results for SAOCOM-1B Stripmap QP beams

3.4.2 TopSAR data assessment

3.4.2.1 SAOCOM-1A results

The results of the absolute radiometric calibration assessment for TopSAR beams are reported in **Figure 20** for DP (plots on the left) and QP beams (plots on the right). The plots in the top line refer to measures over CRs while the plots on the bottom line refer to measures over SAOCOM transponder. The calibration constant derived for each target is plotted as a function of the incidence angle. The colour represents the calibration site to which each measure is referred. The points represented with a square refer to H/H polarization whereas the circles refer to V/V. Outliers outside the ±3 dB range have been discarded.

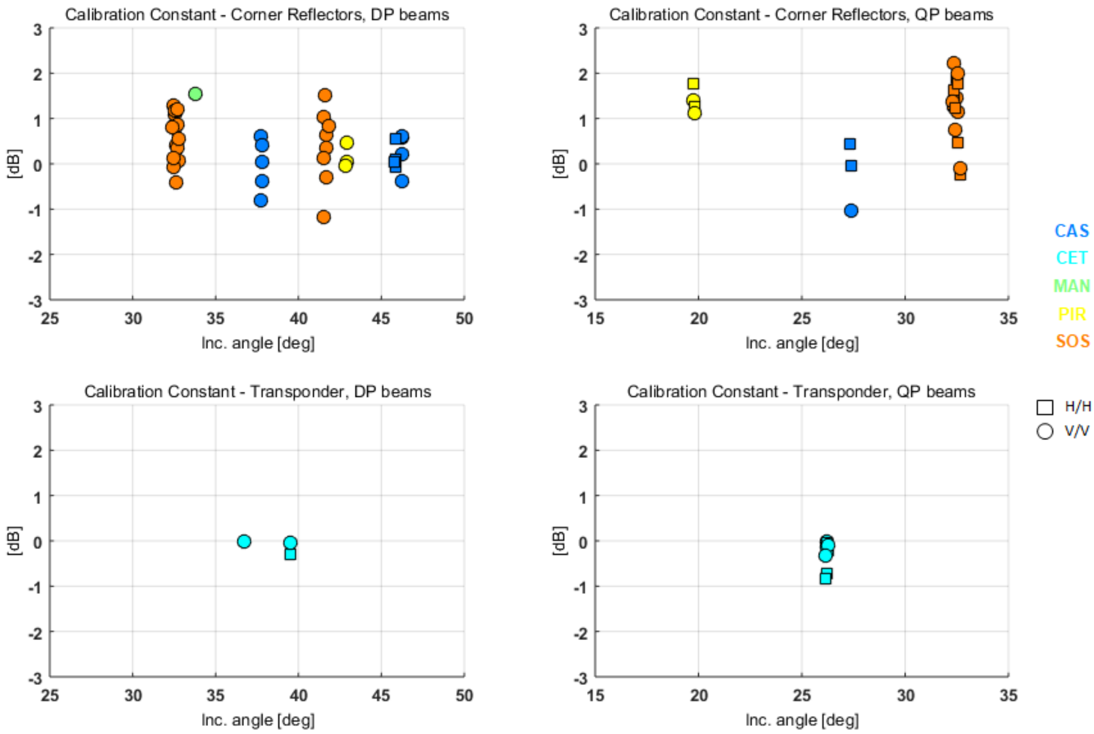

Figure 20 - Calibration constant from calibration targets as a function of the incidence angle for SAOCOM-1A TopSAR beams acquired over CRs (top line) and over transponder (bottom line).

Overall, the SAOCOM-1A beams appear to be well calibrated in particular for those characterised over transponder. The results over Corner Reflectors could be biased by the low resolution of TopSAR beams, resulting in an overestimation of the measured RCS due to clutter. The following tables report the average and the standard deviation of the calibration constants derived for each beam and polarization independently over Corner Reflectors and transponder respectively. Most of the beams fall in the range of ±0.5 dB. Some beams falling outside this range (QTNAS2 and QTNBS9 in particular) could be more affected by clutter contamination. The results from the available transponder acquisitions are very good.

Swath	Cal. Constant H/H [dB]		Cal. Constant V/V [dB]	
	Mean	Std.	Mean	Std.
DTNAS3	-	-	0,64	0,52
DTNBS6	-	-	0,32	0,72
DTNBS7	0,16	0,26	0,26	0,46
DTWS4	-	-	-0,03	0,58
QTNAS2	1,52	0,37	1,25	0,21
QTNBS9	1,19	0,72	1,26	0,71
DTNAS3	0,20	0,35	-	-

Table 27 - Resume of SAOCOM-1A radiometric calibration assessment results for acquisitions over Corner Reflectors

Swath	Cal. Constant H/H [dB]		Cal. Constant V/V [dB]	
	Mean	Std.	Mean	Std.
DTNBS5	-0,30	-	-0,04	0,00
QTWS5	-0,47	0,36	-0,17	0,14

Table 28 - Resume of SAOCOM-1A radiometric calibration assessment results for acquisitions over transponder

3.4.2.2 SAOCOM-1B results

Table 29 reports the result of the radiometric calibration assessment over the analysed SAOCOM-1B TopSAR products. Only the acquisitions performed over the active transponder have been considered. Results show that, overall, the SAOCOM-1B beams appear to be well calibrated. Most of the beams fall in the range of ±1 dB. A few outliers can be observed that are most likely due to non-proper working of the transponder.

Acq. ID	Swath	CR ID	Cal. Constant [dB]
340681	DTNAS4 V/V	TR_CET_001	0.0437
340682	DTNBS7 V/V	TR_CET_001	-0.6564
351845	DTNBS7 V/V	TR_CET_001	-0.5821
356895	DTNBS7 H/H	TR_CET_001	0.3251
357634	DTWS8 H/H	TR_CET_001	0.6008
335616	QTNAS05 H/H	TR_CET_001	5.2619
335616	QTNAS05 V/V	TR_CET_001	0.3176
340684	QTNAS05 H/H	TR_CET_001	3.8839
340684	QTNAS05 V/V	TR_CET_001	0.0110
351847	QTNAS05 H/H	TR_CET_001	3.1079
351847	QTNAS05 V/V	TR_CET_001	-0.0656
340680	QTNBS06 H/H	TR_CET_001	0.0985
340680	QTNBS06 V/V	TR_CET_001	-0.6147
341967	QTNBS06 H/H	TR_CET_001	0.5152
341967	QTNBS06 V/V	TR_CET_001	-0.7645
352674	QTWS06 H/H	TR_CET_001	0.7150
352674	QTWS06 V/V	TR_CET_001	0.2699
352674	QTWS07 V/V	TR_CET_001	-1.2002
352674	QTWS07 H/H	TR_CET_001	0.5088

Table 29 - Calibration constant measured for TopSAR SAOCOM-1B acquisitions over transponder

3.5 Relative calibration assessment: Stripmap data

Rain Forest (RF) is a natural calibration site for SAR missions due to the homogeneity of the scene. Two different RF areas have been selected for the SAOCOM radiometric calibration assessment:

- Amazon area (CEOS area)
- Congo area

The RF data are exploited to perform an assessment of the SAOCOM radiometric calibration. In particular, under the assumption that the γ^0 is independent from the incidence angle, it is possible to verify:

- the relative calibration of the SAOCOM beams by measuring the average γ^0 level.
- the agreement between the SAOCOM patterns exploited for data compensation and the actual patterns by assessing the flatness of the γ^0 profiles.

The SLC products of RF acquisitions are processed according to the steps illustrated in the following figure. The following steps are performed:

1. **Noise removal**: thermal level is removed from the RF products. This step is not deemed mandatory since SAOCOM NESZ level is well below average RF σ^0;
2. **Data masking**: SLC data intensity is analysed from a statistical point of view to discard any outlier related to non-homogeneity of the imaged scene (e.g. rivers or bright areas);
3. **Geometric calibration**: the σ^0 values are converted into γ^0 values;
4. **Profiles filtering**: the obtained γ^0 values are averaged in the azimuth direction to get a single elevation profile per each beam and polarization of the analysed product. The obtained profiles are further filtered to remove remaining outliers.

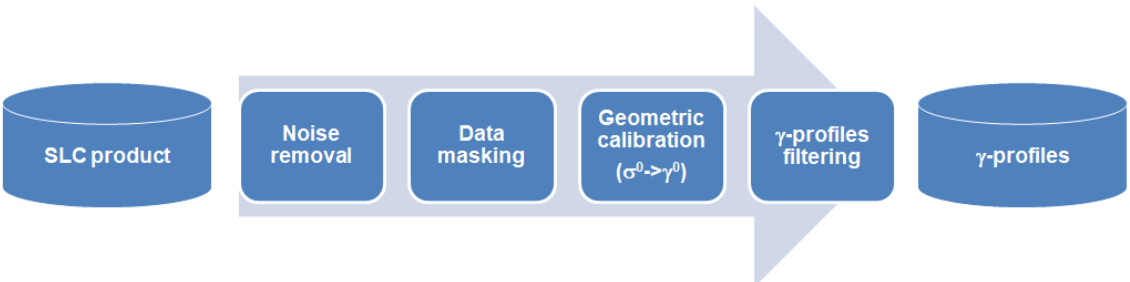

Figure 21 - Processing of Rain Forest data for γ^0 profiles derivation

The γ^0 profiles obtained according to the described processing refer to the corrections performed by the SAOCOM processor. Residual corrections can be applied to the obtained profiles to compensate for effects not accounted by the processor. These effects include:

- Errors in the annotated attitude: the annotated roll angle is different from the roll angle estimated with EN analysis.
- Topography effects: the correction applied by the processor refer to the Ellipsoid.

After such corrections the γ^0 profiles can be exploited to assess SAOCOM radiometric calibration. **Figure 22** shows a detail of a quick-look generated by the SAOCOM processor for a D6 DH acquisition over Congo Ran Forest. **Figure 23** shows the results of the γ^0 profiles estimation from the same product. The colour represents the number of points falling in a certain bin (off-boresight angle vs radiometric level). The dashed black line is the estimated average γ^0 profile. The obtained profile is very flat showing a nice agreement between predicted and actual Elevation Antenna Patterns.

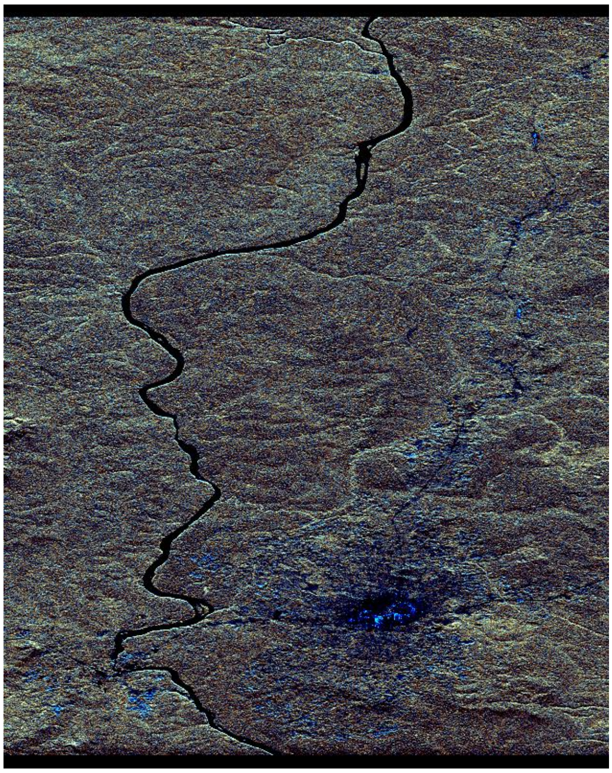

Figure 22 - Detail of a quick-look of a SAOCOM-1A D6 DH acquisition over Congo Ran Forest

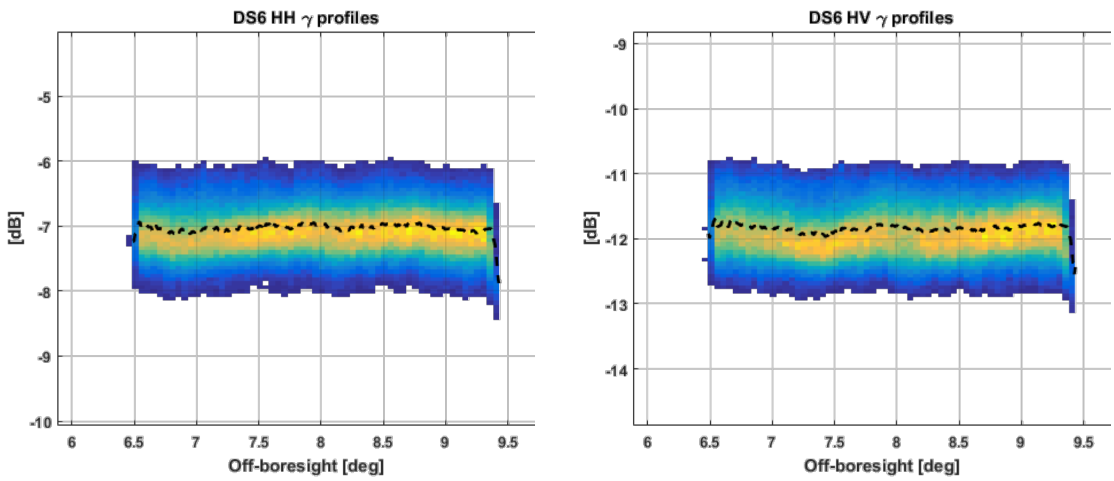

Figure 23 - Results of γ^0 profiles extraction from a SAOCOM-1A D6 DH acquisition over Congo Ran Forest. The colour represents the number of points falling in a certain bin. The dashed black line is the estimated average γ^0 profile.

3.5.1.1 SAOCOM-1A results

About 150 SAOCOM-1A products acquired over the Rain Forest have been analysed. In particular the analyses were performed over the following L1A SLC products:

- 54 QP products
- 43 DP-DH products

- 53 DP-DV products

Figure 24 and **Figure 25** show the γ^0 profiles estimated from all the analysed products for DP and QP beams respectively. The profiles are plotted as a function of the off-boresight angle with regard to the antenna pointing. Top plots of each image refer to HH and HV beams while bottom plots refer to VV and VH beams. The names of the beams are reported on the right of the image with the corresponding colour. Overall, the γ^0 profiles are quite flat meaning that patterns used for processing correspond nicely to the actual patterns. The level of the different beams is also quite well aligned.

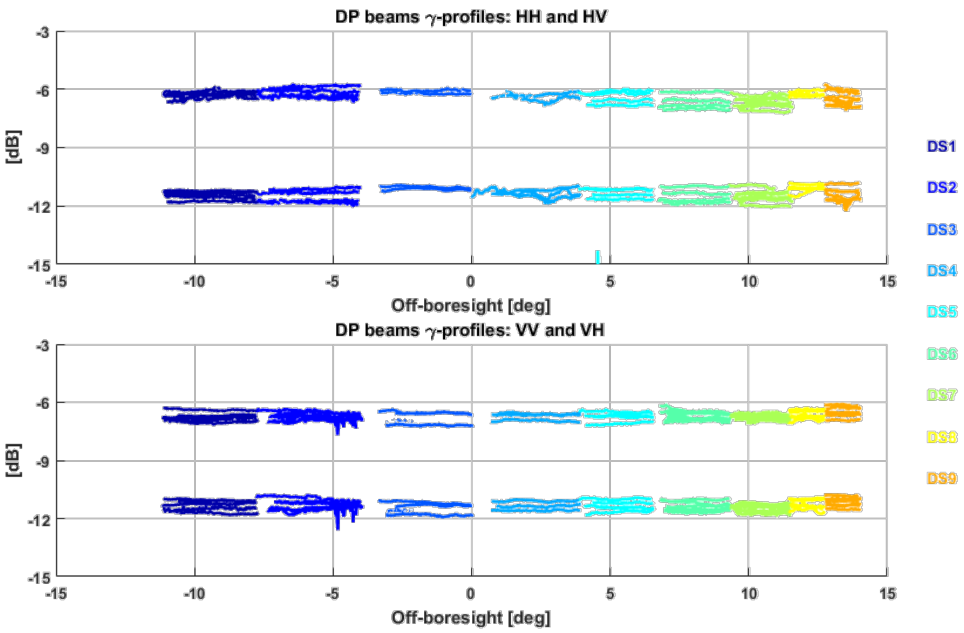

Figure 24 - SAOCOM-1A γ-profiles measured from Rain Forest acquisitions with DP beams

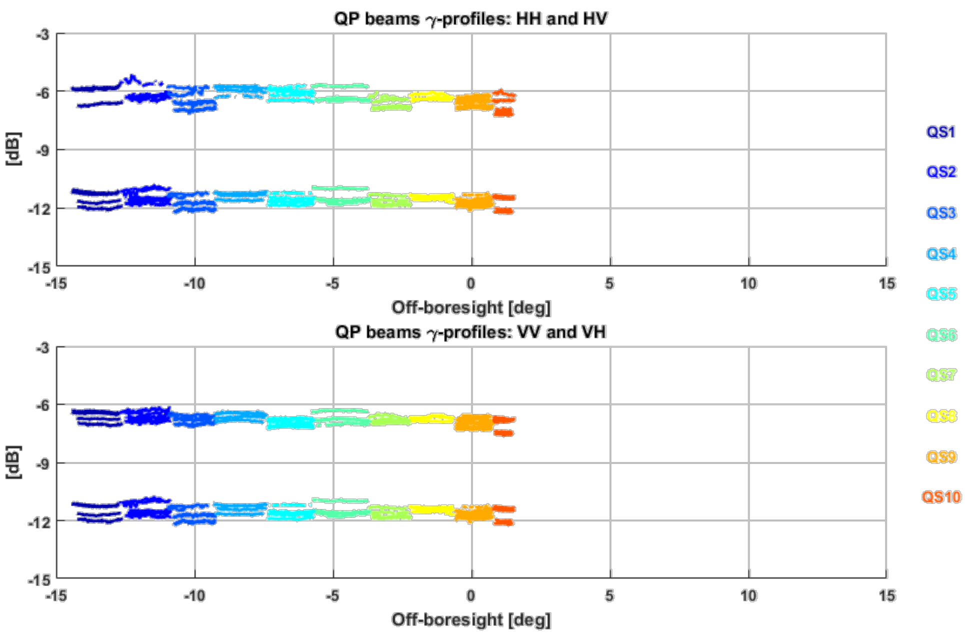

Figure 25 - SAOCOM-1A γ-profiles measured from Rain Forest acquisitions with QP beams

The following tables provide a resume of the radiometric statics for the different beams and polarizations. The mean and std. dev. values refer to the average γ^0 profiles estimated from the individual products. The different γ^0 levels appear to be very well aligned with overall level fluctuations lower than 1 dB. Such fluctuations are most likely related to the natural variability of the RF. As already assessed with the point targets data the overall SAOCOM calibration is very good.

Swath	γ^0 H/H [dB]		γ^0H/V [dB]		γ^0 V/V [dB]		γ^0 V/H [dB]	
	Mean	Std.	Mean	Std.	Mean	Std.	Mean	Std.
DS1	-6,26	0,13	-11,44	0,20	-6,76	0,24	-11,33	0,29
DS2	-6,20	0,27	-11,51	0,34	-6,73	0,16	-11,31	0,20
DS3	-6,14	0,12	-11,08	0,09	-6,81	0,31	-11,48	0,29
DS4	-5,88	0,90	-11,35	0,18	-6,87	0,33	-11,49	0,34
DS5	-6,43	0,32	-11,34	0,25	-6,74	0,23	-11,34	0,26
DS6	-6,65	0,38	-11,48	0,38	-6,71	0,21	-11,43	0,23
DS7	-6,70	0,26	-11,51	0,30	-6,77	0,13	-11,47	0,20
DS8	-6,27	0,11	-11,09	0,15	-6,61	0,23	-11,23	0,25
DS9	-6,52	0,37	-11,45	0,35	-6,53	0,25	-11,15	0,24

Table 30 - Statistics of SAOCOM-1A γ^0 measures from Rain Forest DP acquisitions

Swath	γ^0 H/H [dB]		γ^0H/V [dB]		γ^0 V/V [dB]		γ^0 V/H [dB]	
	Mean	Std.	Mean	Std.	Mean	Std.	Mean	Std.
QS1	-6,07	0,40	-11,54	0,38	-6,66	0,30	-11,54	0,38
QS2	-6,13	0,34	-11,51	0,28	-6,74	0,18	-11,51	0,29
QS3	-6,41	0,44	-11,65	0,33	-6,74	0,18	-11,63	0,33
QS4	-5,96	0,23	-11,36	0,17	-6,61	0,19	-11,38	0,21
QS5	-6,08	0,27	-11,59	0,24	-6,93	0,19	-11,60	0,25
QS6	-6,25	0,35	-11,49	0,34	-6,73	0,29	-11,48	0,34
QS7	-6,60	0,24	-11,67	0,21	-6,84	0,14	-11,66	0,21
QS8	-6,32	0,13	-11,45	0,08	-6,74	0,12	-11,41	0,10
QS9	-6,54	0,23	-11,73	0,18	-6,95	0,23	-11,70	0,18
QS10	-6,79	0,42	-11,87	0,39	-7,21	0,37	-11,81	0,39

Table 31 - Statistics of SAOCOM-1A γ^0 measures from Rain Forest QP acquisitions

3.5.1.2 SAOCOM-1B results

The assessment of the SAOCOM-1A Elevation Antenna Patterns showed a very good agreement between corresponding Stripmap and TopSAR patterns (it is recalled that unlike Sentinel-1 mission Stripmap and TopSAR modes share exactly the same EAPs). For this reason, the calibration approach for SAOCOM-1B focused more on TOPSAR products allowing to verify at the same time several EAPs. Nevertheless, 82 SAOCOM-1B Stripmap products acquired over the Rain Forest have been analysed:

- 38 QP products
- 19 DP-H products
- 25 DP-V products

Figure 26 shows the γ^0 profiles estimated from all the analysed products QP beams. The profiles are plotted as a function of the off-boresight angle with regard to the antenna pointing. Top plots of the image refer to HH and HV beams while bottom plots refer to VV and VH beams. The names of the beams are reported on the right of the image with the corresponding colour. Overall, the γ^0 profiles are quite flat meaning that patterns used for processing correspond nicely to the actual patterns. The level of the different beams is also quite well aligned (also considering the natural variability of the RF). See also the following section on TopSAR beams for more details.

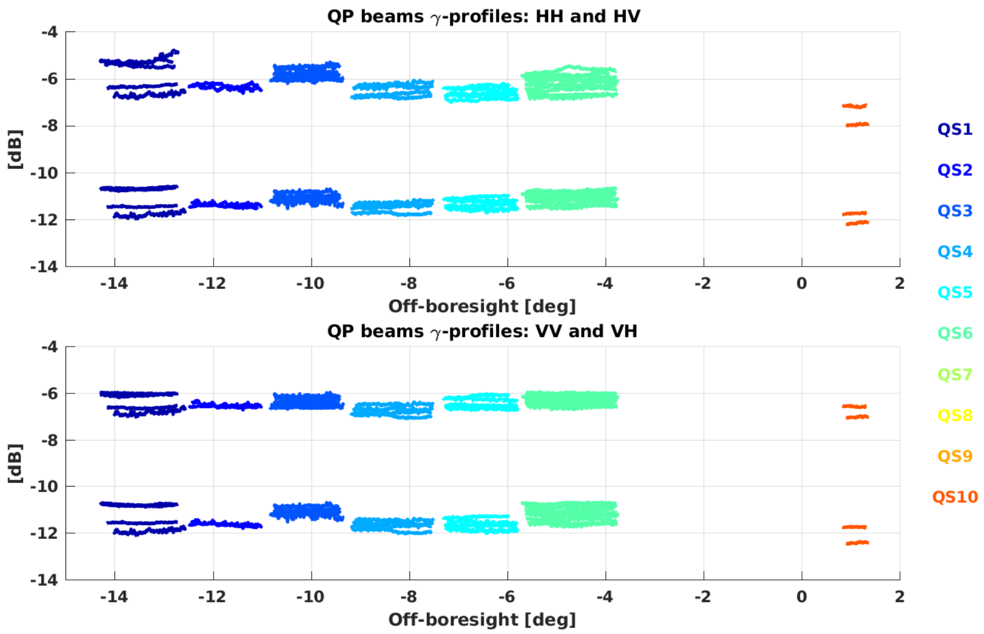

Figure 26 - γ-profiles measured from Rain Forest SAOCOM-1B acquisitions with QP beams

Table 32 and **Table 33** provide a resume of the radiometric statistics for the different beams and polarizations. The mean and standard deviation values refer to the average γ^0 profiles estimated from the individual products. The different γ^0 levels appear to be quite aligned except for QS10 beam which could be related to the particular acquisition considered.

Swath	γ^0 H/H [dB]		γ^0 H/V [dB]		γ^0 V/V [dB]		γ^0 V/H [dB]	
	Mean	Std.	Mean	Std.	Mean	Std.	Mean	Std.
DS1	-5.4986	0.2886	-10.7398	0.2905	-5.9436	0.1994	-10.7924	0.2329
DS2	-	-	-	-	-6.6166	0.3593	-11.4889	0.3185
DS3	-6.1023	0.1174	-11.3339	0.1148	-	-	-	-
DS9	-6.2403	0.2432	-11.5848	0.2818	-6.8380	0.2330	-11.6203	0.2721

Table 32 - Statistics of SAOCOM-1B γ^0 measures from Rain Forest DP acquisitions

Swath	γ^0 H/H [dB]		γ^0 H/V [dB]		γ^0 V/V [dB]		γ^0 V/H [dB]	
	Mean	Std.	Mean	Std.	Mean	Std.	Mean	Std.
QS01	-5.7751	0.6846	-11.0527	0.5328	-6.3093	0.3856	-11.1708	0.5356
QS02	-6.3271	0.0865	-11.3908	0.0802	-6.5354	0.0565	-11.6243	0.0371
QS03	-5.8080	0.2203	-11.0873	0.1352	-6.3683	0.1725	-11.0909	0.1252
QS04	-6.4889	0.2612	-11.4500	0.2030	-6.7377	0.2164	-11.6574	0.1991
QS05	-6.5902	0.2250	-11.3466	0.2274	-6.4187	0.2308	-11.6436	0.2397
QS06	-6.1749	0.3465	-11.1129	0.2321	-6.2870	0.2118	-11.1384	0.3056
QS10	-7.5494	0.5261	-11.9034	0.2791	-6.7865	0.2913	-12.0607	0.4627

Table 33 - Statistics of SAOCOM-1B γ^0 measures from Rain Forest QP acquisitions

3.6 Relative calibration assessment: TopSAR data

3.6.1 Rain Forest profiles assessment

3.6.1.1 SAOCOM-1A results

The same analyses performed for Stripmap beams have been repeated for TopSAR acquisitions. About 40 SAOCOM-1A TopSAR products acquired over the Rain Forest have been analysed. In particular the analyses were performed over the following L1A SLC products:

- 14 TopSAR QP products
- 17 TopSAR DP-DH products
- 8 TopSAR DP-DV products

The TopSAR beams γ-profiles derived from RF acquisitions are reported in the following figures. For all the figures the top plot shows HH and HV profiles and the bottom plot VV and VH profiles. **Figure 27** refers to TopSAR Narrow DP beams, **Figure 28** to TopSAR Wide DP beams **Figure 29** to TopSAR Narrow QP beams and **Figure 30** to TopSAR Wide QP beams. The beams are plotted with different colours as indicated in the legend on the right.

The overall radiometric calibration is pretty good for all the SAOCOM TopSAR beams. All the beams appear to be quite flat and no particular jumps can be observed between different sub-swaths. Please note that for some acquisition modes such TNBDP DV and TWDP DV just a single acquisition was available.

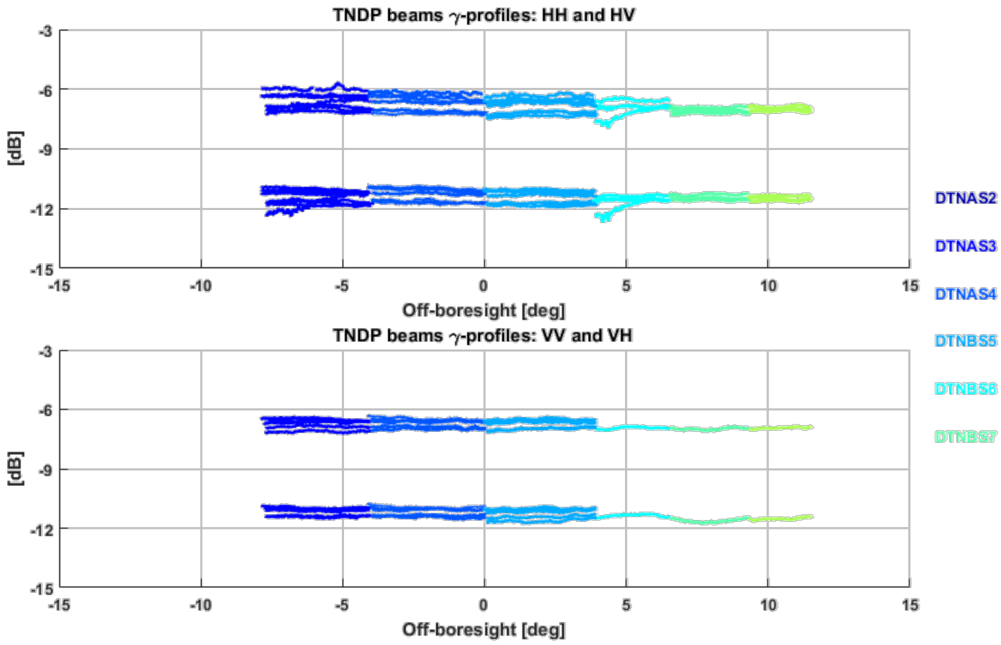

Figure 27 - SAOCOM-1A γ-profiles measured from Rain Forest acquisitions with TNDP beams

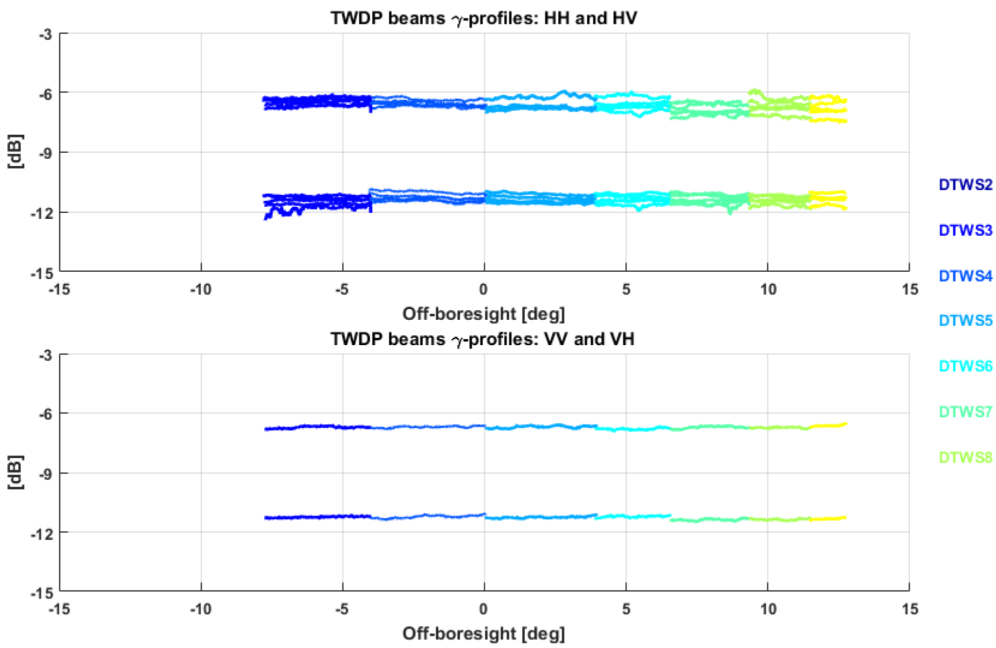

Figure 28 - SAOCOM-1A γ-profiles measured from Rain Forest acquisitions with TWDP beams

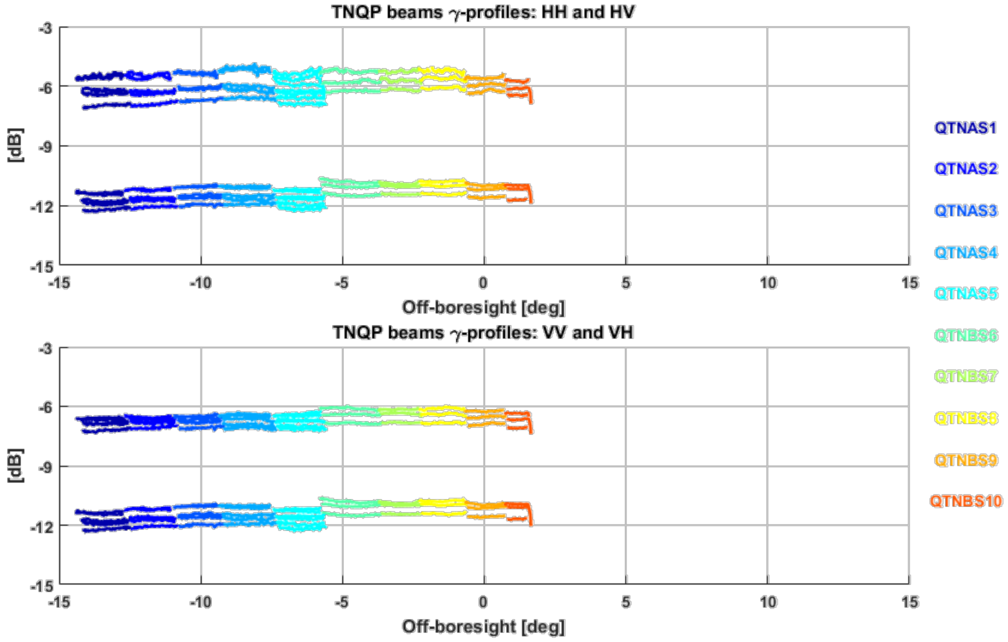

Figure 29 - SAOCOM-1A γ-profiles measured from Rain Forest acquisitions with TNQP beams

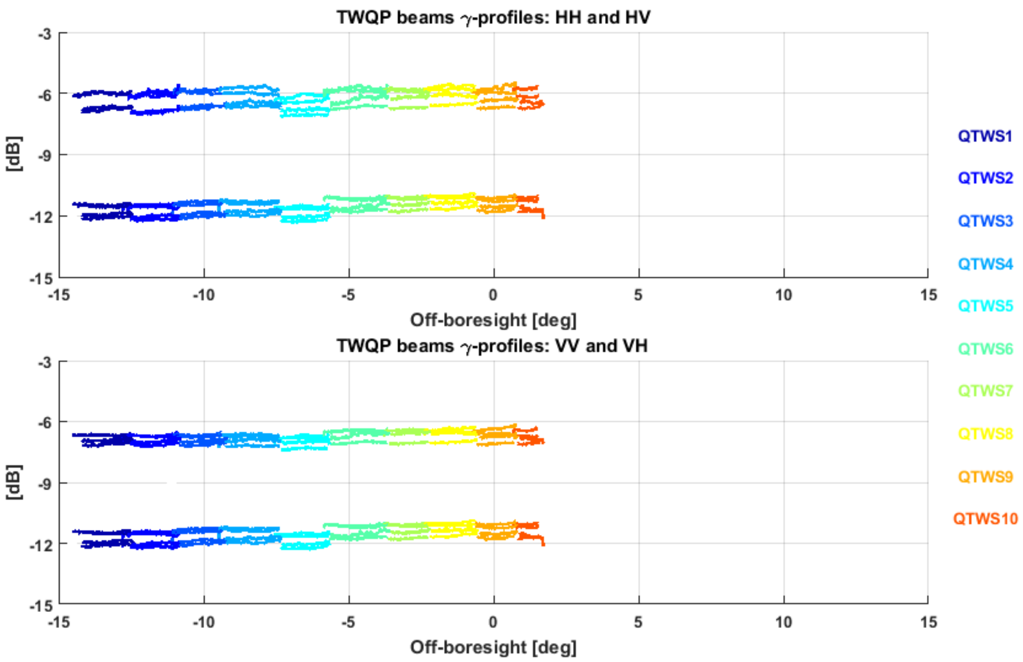

Figure 30 - SAOCOM-1A γ-profiles measured from Rain Forest acquisitions with TWQP beams

The statistics of the γ-profiles analysis results are reported in Table 34 (TNDP), Table 35 (TWDP), Table 36 (TNQP) and Table 37 (TWQP). As already observed from the plots the overall calibration is pretty good and only minor corrections seems to be needed:

- Beam DTNBS5 HH has a bias of +0.18 dB w.r.t. DTNBS6 HH beam
- Beam DTNAS4 VH has a bias of -0.08 dB w.r.t. DTNAS3 VH beam
- Beam DTWS6 HH has a bias of -0.2 dB w.r.t. DTWS5 HH and DTWS7 HH beams
- Beam DTWS2 HV has a bias of -0.18 dB w.r.t. DTWS3 HV beam
- Beams of TNAQP and TNBQP are well aligned but there seems to be an average offset between TNAQP and TNBQP beams. In order to identify if this is the natural variability of the RF (the beams are not acquired at the same time) or a calibration issue, acquisitions over calibration target sites would be needed.

Beam TWQP5 shows the lowest gain of the TWQP beams for all the polarizations. The average bias with regard to the adjacent beams is: -0.42 dB for HH, -0.37 dB for HV, -0.21 dB for VV and -0.38 dB for VH.

Swath	γ^0 H/H [dB]		γ^0H/V [dB]		γ^0 V/V [dB]		γ^0 V/H [dB]	
	Mean	Std.	Mean	Std.	Mean	Std.	Mean	Std.
DTNAS2	-6,59	0,39	-11,44	0,32	-6,71	0,24	-11,16	0,19
DTNAS3	-6,70	0,40	-11,29	0,33	-6,69	0,21	-11,15	0,20
DTNAS4	-6,82	0,37	-11,39	0,32	-6,71	0,21	-11,23	0,25
DTNBS5	-6,89	0,29	-11,58	0,21	-6,94	N/A	-11,36	N/A
DTNBS6	-7,07	0,13	-11,46	0,12	-6,98	N/A	-11,63	N/A
DTNBS7	-6,99	0,10	-11,51	0,12	-6,94	N/A	-11,52	N/A

Table 34 - SAOCOM-1A statistics of γ^0 measures from Rain Forest TNDP acquisitions

Swath	γ^0 H/H [dB]		γ^0H/V [dB]		γ^0 V/V [dB]		γ^0 V/H [dB]	
	Mean	Std.	Mean	Std.	Mean	Std.	Mean	Std.
DTWS2	-6,47	0,18	-11,47	0,25	-6,72	N/A	-11,24	N/A
DTWS3	-6,57	0,14	-11,29	0,19	-6,71	N/A	-11,23	N/A
DTWS4	-6,68	0,25	-11,38	0,19	-6,70	N/A	-11,26	N/A
DTWS5	-6,62	0,28	-11,37	0,22	-6,81	N/A	-11,22	N/A
DTWS6	-6,86	0,27	-11,38	0,22	-6,72	N/A	-11,38	N/A
DTWS7	-6,72	0,35	-11,41	0,20	-6,74	N/A	-11,37	N/A
DTWS8	-6,81	0,43	-11,41	0,24	-6,74	N/A	-11,37	N/A

Table 35 - SAOCOM-1A statistics of γ^0 measures from Rain Forest TWDP acquisitions

Swath	γ^0 H/H [dB]		γ^0 H/V [dB]		γ^0 V/V [dB]		γ^0 V/H [dB]	
	Mean	Std.	Mean	Std.	Mean	Std.	Mean	Std.
QTNAS1	-6,10	0,51	-11,74	0,29	-6,83	0,23	-11,74	0,29
QTNAS2	-6,07	0,50	-11,56	0,30	-6,74	0,19	-11,55	0,31
QTNAS3	-5,89	0,48	-11,43	0,32	-6,73	0,21	-11,42	0,33
QTNAS4	-5,77	0,55	-11,44	0,31	-6,73	0,24	-11,43	0,32
QTNAS5	-6,13	0,55	-11,62	0,34	-6,75	0,27	-11,62	0,34
QTNBS6	-5,76	0,50	-11,10	0,34	-6,46	0,38	-11,10	0,35
QTNBS7	-5,71	0,46	-11,12	0,28	-6,45	0,34	-11,11	0,30
QTNBS8	-5,65	0,44	-11,07	0,32	-6,45	0,37	-11,05	0,33
QTNBS9	-5,93	0,34	-11,24	0,31	-6,56	0,33	-11,21	0,33
QTNBS10	-6,11	0,36	-11,30	0,38	-6,71	0,37	-11,25	0,39

Table 36 - SAOCOM-1A statistics of γ^0 measures from Rain Forest TNQP acquisitions

Swath	γ^0 H/H [dB]		γ^0 H/V [dB]		γ^0 V/V [dB]		γ^0 V/H [dB]	
	Mean	Std.	Mean	Std.	Mean	Std.	Mean	Std.
QTWS1	-6,38	0,42	-11,76	0,29	-6,85	0,20	-11,75	0,31
QTWS2	-6,48	0,47	-11,82	0,34	-6,90	0,21	-11,80	0,35
QTWS3	-6,29	0,43	-11,67	0,34	-6,88	0,21	-11,65	0,34
QTWS4	-6,22	0,41	-11,61	0,31	-6,88	0,25	-11,58	0,32
QTWS5	-6,60	0,41	-11,88	0,33	-6,98	0,26	-11,87	0,33
QTWS6	-6,15	0,42	-11,40	0,30	-6,66	0,27	-11,39	0,30
QTWS7	-6,15	0,41	-11,36	0,30	-6,64	0,29	-11,35	0,31
QTWS8	-6,03	0,39	-11,28	0,28	-6,62	0,28	-11,27	0,28
QTWS9	-6,18	0,43	-11,42	0,30	-6,69	0,30	-11,38	0,30
QTWS10	-6,27	0,40	-11,46	0,33	-6,78	0,28	-11,41	0,34

Table 37 - SAOCOM-1A statistics of γ^0 measures from Rain Forest TWQP acquisitions

3.6.1.2 SAOCOM-1B results

The assessment of SAOCOM-1B relative radiometric accuracy have been performed on 108 TopSAR products acquired over Rain Forest including:

- 41 TNA products (8 DP-H, 6 DP-V, 27 QP)
- 51 TNB products (12 DP-H, 18 DP-V, 18 QP)
- 19 TW products (1 DP-H, 6 DP-V, 12 QP)

Figure 31 to **Figure 34** show the measured γ-profiles for TopSAR Narrow DP, Narrow QP, Wide DP and Wide QP beams respectively as function of the off-boresight angle w.r.t. the antenna pointing. Plots are separated per polarization and the colour identifies the beam accordingly to the legend. The γ^0 profiles are flat and the level of the different beams is very well aligned. Please note that for TWDP DH acquisition mode just a single acquisition was available.

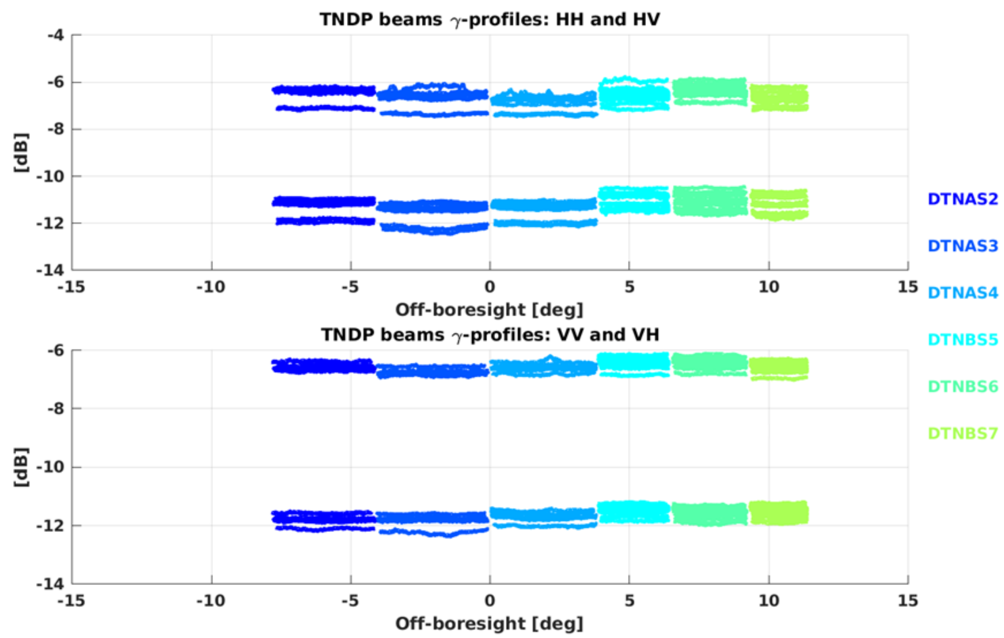

Figure 31 - SAOCOM-1B γ-profiles measured from RF TopSAR Narrow DP beams

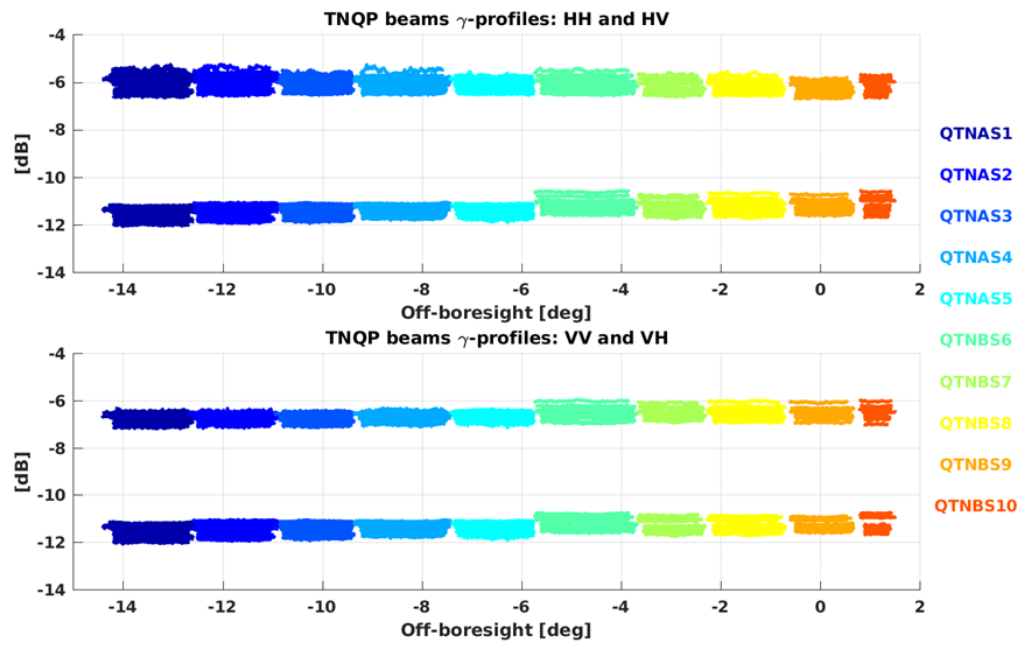

Figure 32 - SAOCOM-1B γ-profiles measured from RF TopSAR Narrow QP beams

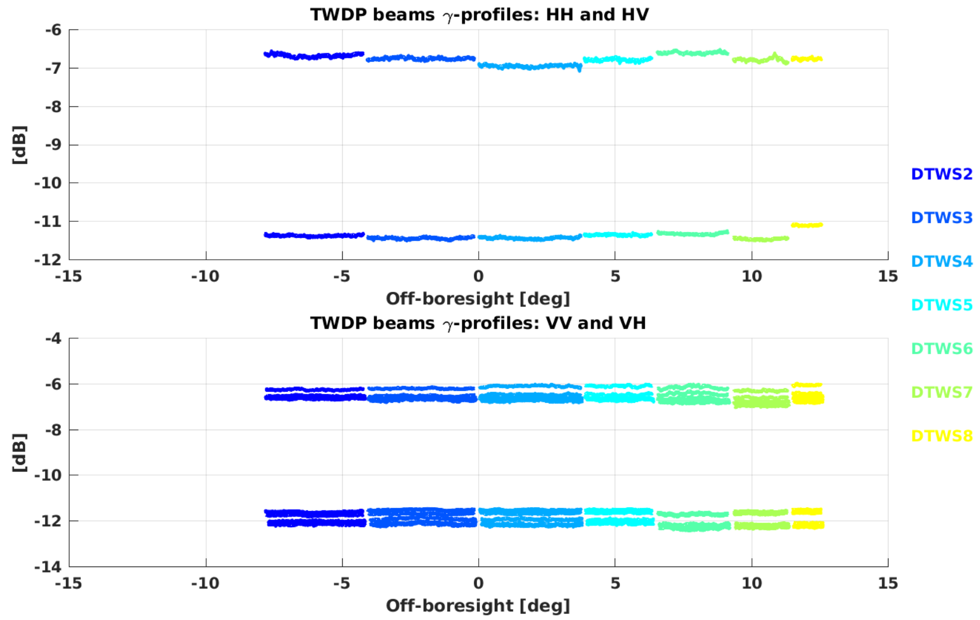

Figure 33 - SAOCOM-1B γ-profiles measured from RF TopSAR Wide DP beams

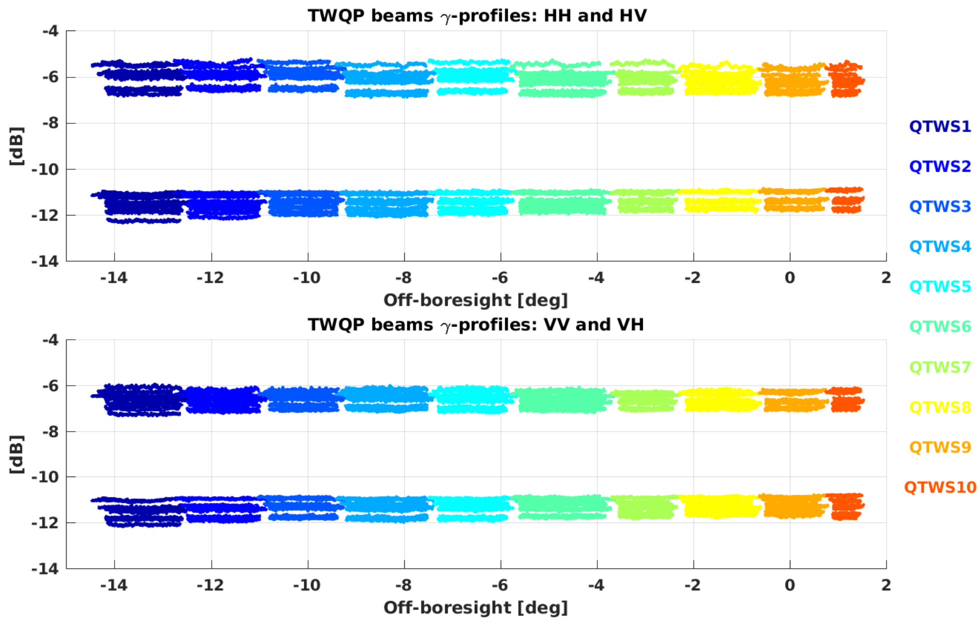

Figure 34 - SAOCOM-1B γ-profiles measured from RF TopSAR Wide QP beams

The statistics of the γ-profiles analysis results are reported in Table 38 (TNDP), Table 39 (TWDP), Table 40 (TNQP) and **Table 41** (TWQP). As already observed from the plots the overall calibration is pretty good.

Swath	γ^0 H/H [dB]	γ^0H/V [dB]	γ^0 V/V [dB]	γ^0 V/H [dB]

	Mean	Std.	Mean	Std.	Mean	Std.	Mean	Std.
DTNAS2	-6.54	0.36	-11.31	0.38	-6.58	0.12	-11.82	0.17
DTNAS3	-6.74	0.40	-11.54	0.45	-6.74	0.10	-11.84	0.21
DTNAS4	-6.89	0.32	-11.43	0.38	-6.60	0.14	-11.71	0.18
DTNBS5	-6.56	0.32	-11.08	0.33	-6.55	0.54	-11.57	0.49
DTNBS6	-6.40	0.30	-11.10	0.36	-6.55	0.53	-11.65	0.45
DTNBS7	-6.64	0.29	-11.23	0.36	-6.66	0.52	-11.60	0.44

Table 38 - SAOCOM-1B statistics of γ^0 measures from Rain Forest TNDP acquisitions

Swath	**γ^0 H/H [dB]**		**γ^0H/V [dB]**		**γ^0 V/V [dB]**		**γ^0 V/H [dB]**	
	Mean	**Std.**	**Mean**	**Std.**	**Mean**	**Std.**	**Mean**	**Std.**
DTWS2	-6.67	N/A	-11.37	N/A	-6.53	0.14	-11.86	0.24
DTWS3	-6.75	N/A	-11.44	N/A	-6.55	0.18	-11.81	0.28
DTWS4	-6.94	N/A	-11.43	N/A	-6.54	0.24	-11.83	0.30
DTWS5	-6.78	N/A	-11.35	N/A	-6.53	0.23	-11.80	0.26
DTWS6	-6.60	N/A	-11.32	N/A	-6.59	0.25	-11.98	0.31
DTWS7	-6.78	N/A	-11.46	N/A	-6.72	0.24	-11.93	0.33
DTWS8	-6.75	N/A	-11.10	N/A	-6.51	0.26	-11.89	0.34

Table 39 - SAOCOM-1B statistics of γ^0 measures from Rain Forest TWDP acquisitions

Swath	**γ^0 H/H [dB]**		**γ^0 H/V [dB]**		**γ^0 V/V [dB]**		**γ^0 V/H [dB]**	
	Mean	**Std.**	**Mean**	**Std.**	**Mean**	**Std.**	**Mean**	**Std.**
QTNAS1	-5.99	0.31	-11.51	0.23	-6.71	0.18	-11.50	0.23
QTNAS2	-5.98	0.30	-11.46	0.23	-6.71	0.17	-11.45	0.23
QTNAS3	-6.03	0.26	-11.44	0.22	-6.71	0.17	-11.43	0.22
QTNAS4	-6.06	0.26	-11.38	0.20	-6.69	0.16	-11.38	0.20
QTNAS5	-6.11	0.23	-11.41	0.19	-6.70	0.16	-11.40	0.20
QTNBS6	-6.29	0.71	-11.41	0.68	-6.76	0.71	-11.46	0.66
QTNBS7	-6.43	0.70	-11.48	0.70	-6.78	0.71	-11.53	0.68
QTNBS8	-6.39	0.71	-11.44	0.69	-6.76	0.70	-11.49	0.67
QTNBS9	-6.50	0.72	-11.46	0.69	-6.78	0.70	-11.51	0.66
QTNBS10	-6.42	0.70	-11.45	0.70	-6.78	0.72	-11.49	0.70

Table 40 - SAOCOM-1B statistics of γ^0 measures from Rain Forest TNQP acquisitions

Swath	**γ^0 H/H [dB]**	**γ^0 H/V [dB]**	**γ^0 V/V [dB]**	**γ^0 V/H [dB]**

	Mean	Std.	Mean	Std.	Mean	Std.	Mean	Std.
QTWS1	-6.06	0.43	-11.50	0.35	-6.61	0.32	-11.50	0.32
QTWS2	-6.03	0.39	-11.47	0.33	-6.62	0.28	-11.44	0.32
QTWS3	-6.05	0.39	-11.42	0.32	-6.62	0.28	-11.39	0.31
QTWS4	-6.21	0.41	-11.44	0.34	-6.61	0.31	-11.42	0.33
QTWS5	-6.10	0.43	-11.41	0.34	-6.64	0.33	-11.39	0.33
QTWS6	-6.22	0.43	-11.39	0.32	-6.65	0.31	-11.36	0.31
QTWS7	-6.19	0.39	-11.36	0.30	-6.66	0.27	-11.33	0.28
QTWS8	-6.22	0.36	-11.34	0.29	-6.64	0.28	-11.30	0.27
QTWS9	-6.26	0.39	-11.33	0.30	-6.63	0.30	-11.29	0.28
QTWS10	-6.25	0.41	-11.33	0.35	-6.61	0.32	-11.29	0.33

Table 41 - SAOCOM-1B statistics of γ^0 measures from Rain Forest TWQP acquisitions

3.6.2 De-scalloping profiles assessment

A particular analysis performed TopSAR on data is the measurement of the residual scalloping profiles. Scalloping is a characteristic of TopSAR images due to the azimuth elementary pattern of each TRM introducing an additional gain factor on the squinted beams. This gain is compensated during the processing exploiting a model of the azimuth elementary pattern. After scalloping compensation each burst is expected to be flat in the azimuth direction.

The derivation of the residual scalloping profile is performed at the same time of the γ-profile estimation and the processing is very similar. For the residual scalloping profile estimation, the average data level is removed since the overall beam gain is already accounted for in the γ-profile analysis. **Figure 35** shows the results of the residual scalloping profile estimation for beam DTNAS2 VV. The colour is proportional to the points density considering that all the bursts of the acquisition have been analysed. The dashed black line is the average residual profile. The residual scalloping profile is included in the range ±0.1 dB.

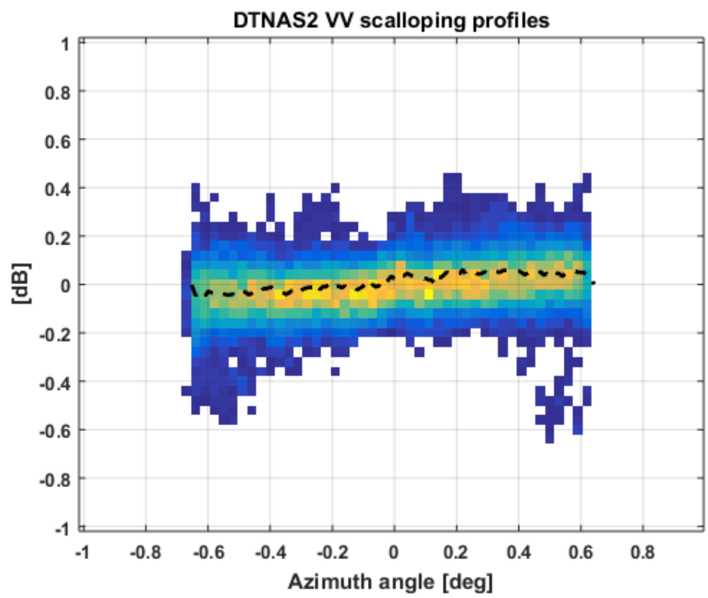

Figure 35 - Residual scalloping profile for SAOCOM-1A DTNAS2 VV beam as a function of the steering angle. The colour is proportional to the points density. The dashed black line is the average residual profile.

3.6.2.1 SAOCOM-1A results

The TopSAR acquisitions exploited for the residual scalloping profile assessment are the same used for the γ-profiles analysis. The results of the analysis are reported in the following figures for the different TopSAR modes. In each image the average residual scalloping profiles estimated from the analysed acquisitions have been plotted separately per polarization. The colours represent the different beams according to the legend on the right. The black dashed line represents the residual scalloping computed performing a polynomial fit of the 4th order on the measured profiles. One poly for each acquisition mode and polarization has been fitted.

Overall, the residual scalloping profiles are quite flat for all the considered beams and polarizations. For some of the TopSAR Wide beams, covering a larger angular range, it is possible to observe residual profiles varying in the range of ±0.2 dB. The observed residuals could also be related to scene features in the considered images. The resulting images are well calibrated.

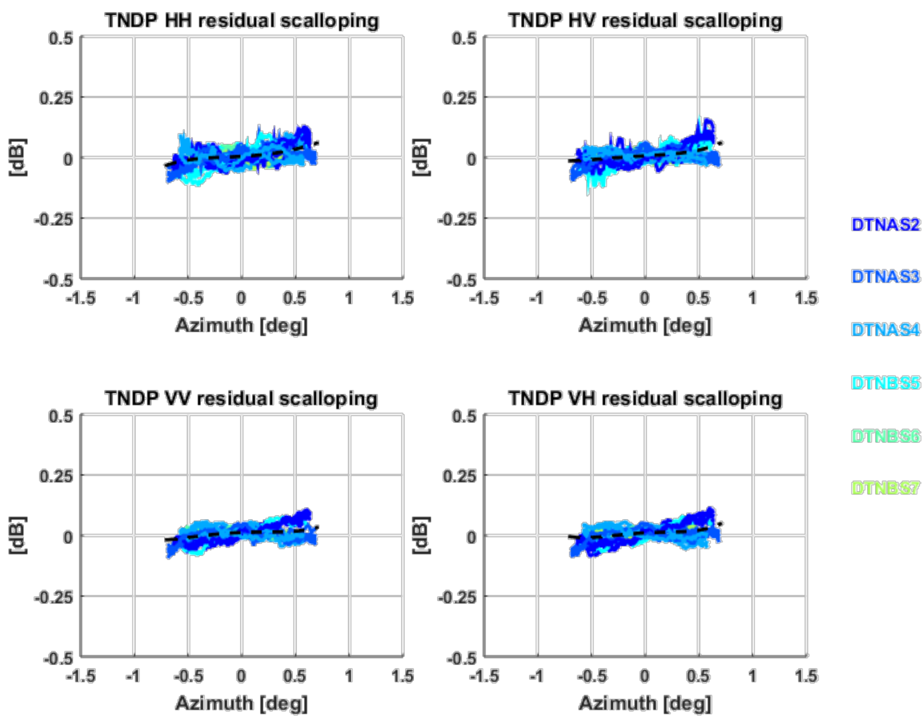

Figure 36 - Residual azimuth scalloping profiles for SAOCOM-1A TopSAR TNDP beams

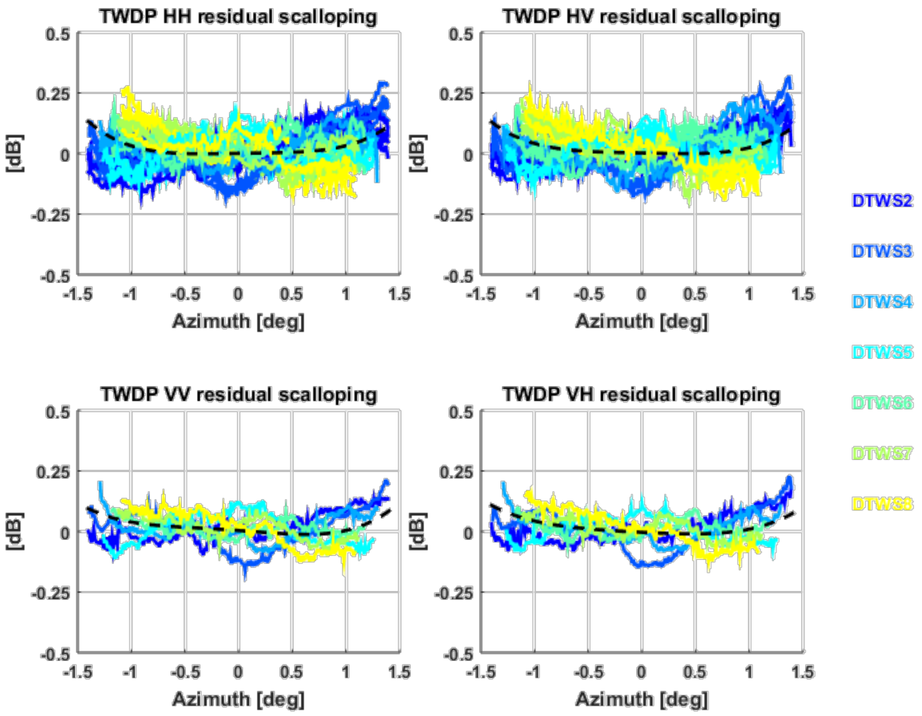

Figure 37 - Residual azimuth scalloping profiles for SAOCOM-1A TopSAR TWDP beams

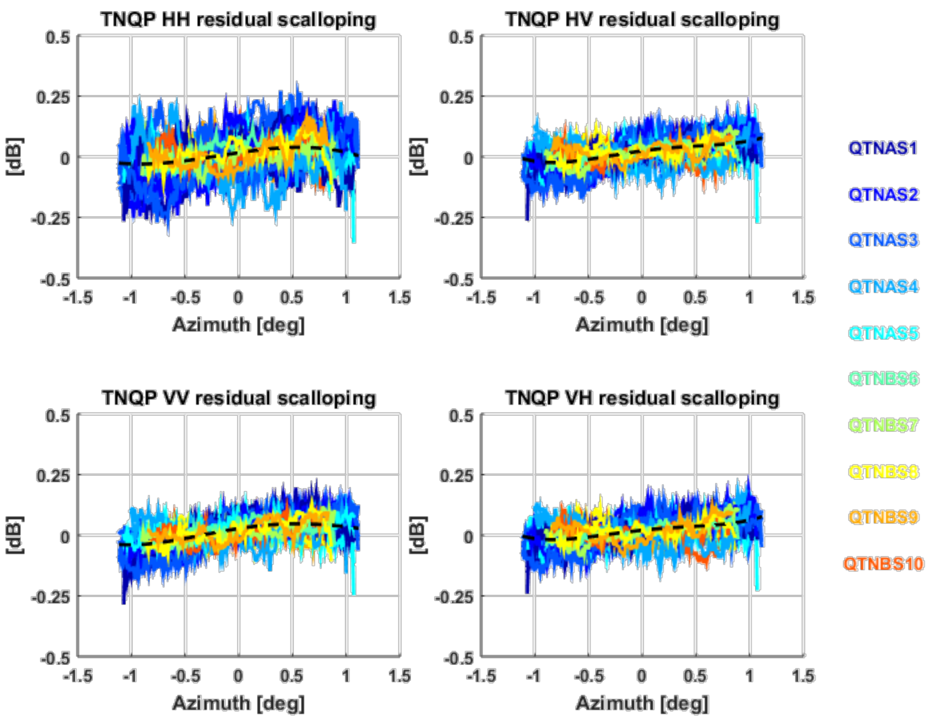

Figure 38 - Residual azimuth scalloping profiles for SAOCOM-1A TopSAR TWDP beams

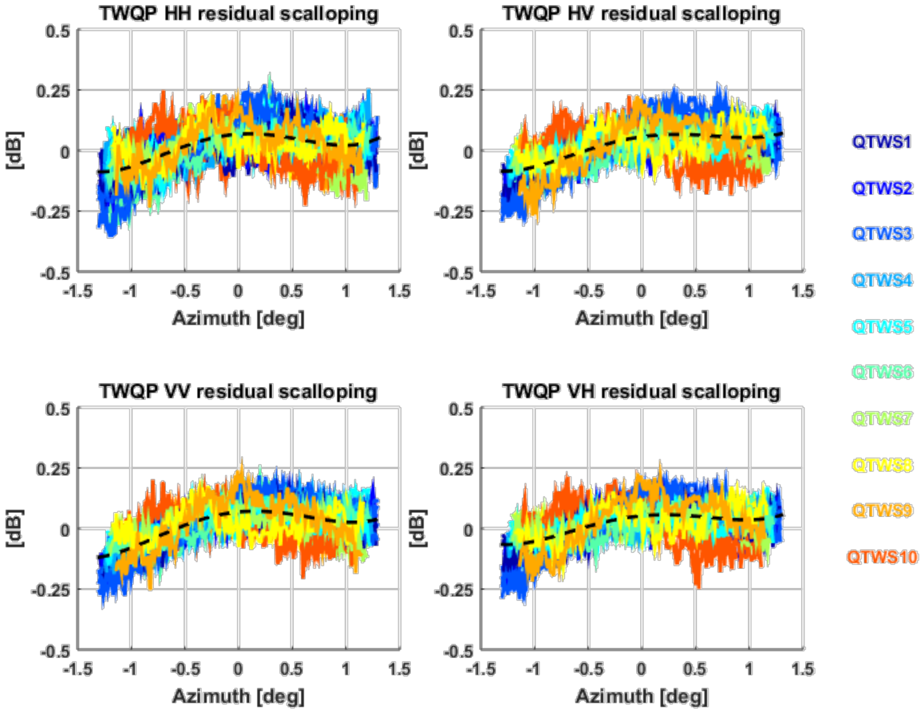

Figure 39 - Residual azimuth scalloping profiles for SAOCOM-1A TopSAR TWQP beams

3.6.2.2 SAOCOM-1B results

The same assessment was performed for SAOCOM-1B TopSAR products. The results of the analysis are reported from **Figure 40** to **Figure 43** for TopSAR Narrow DP, TopSAR Wide DP, TopSAR Narrow QP and TopSAR Wide QP acquisition mode, respectively. In each image the average residual scalloping profiles estimated from the analysed acquisitions have been plotted separated per polarization. The colours represent the different beams according to the legend on the right. For all the modes the residual scalloping profile is included in the range ±0.2 dB but not completely flat.

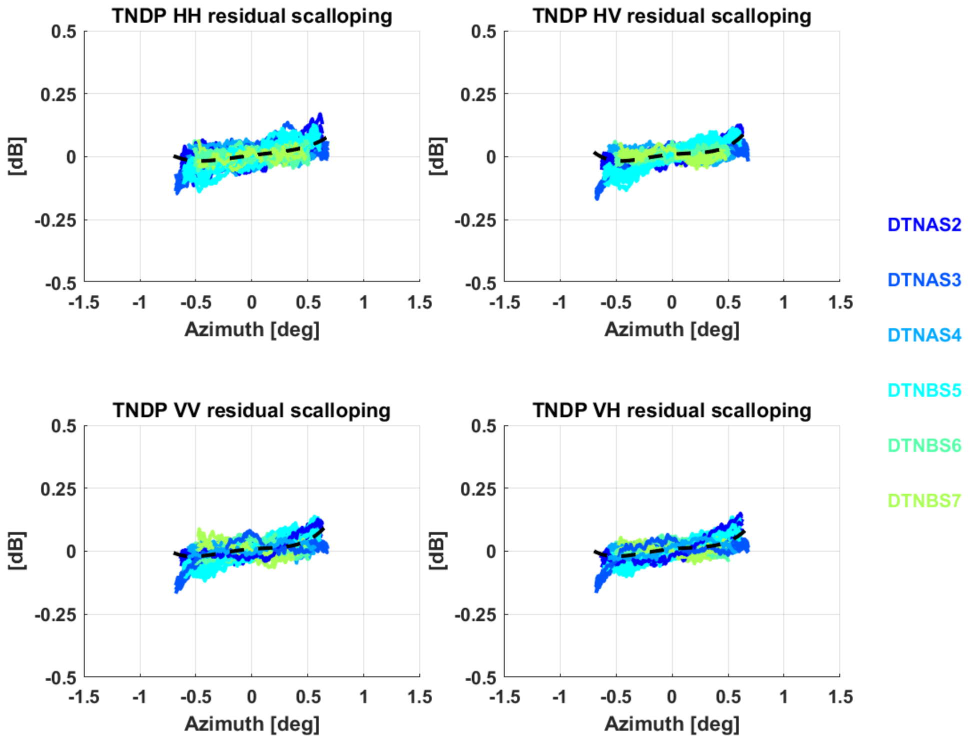

Figure 40 - Residual azimuth scalloping profiles for SAOCOM-1B TopSAR TWQP beams

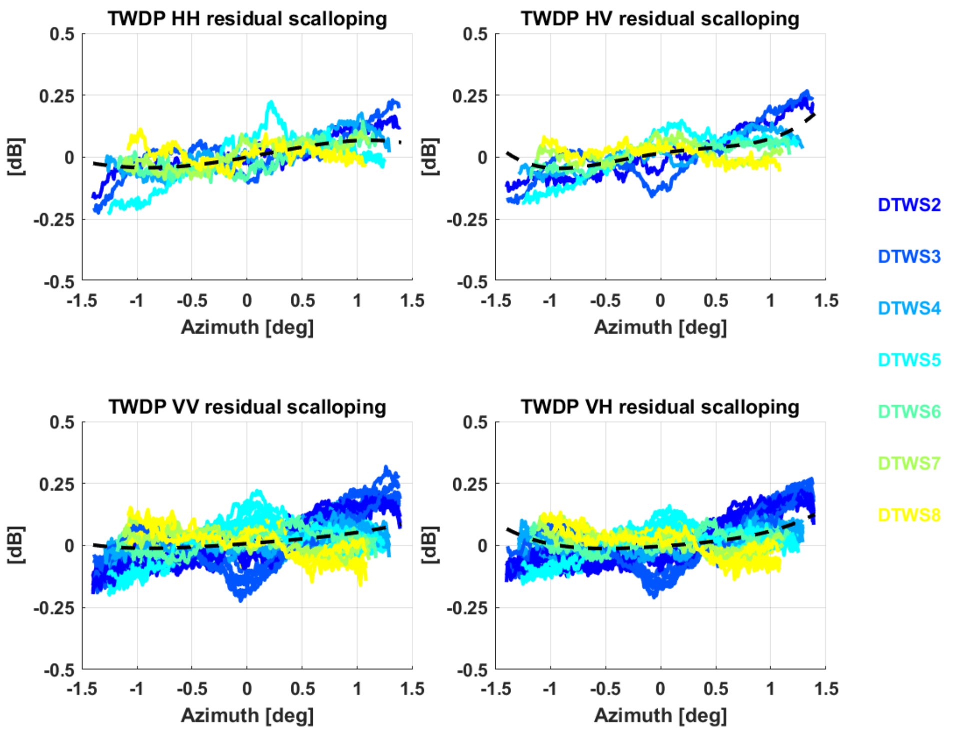

Figure 41 - Residual azimuth scalloping profiles for SAOCOM-1B TopSAR TWDP beams

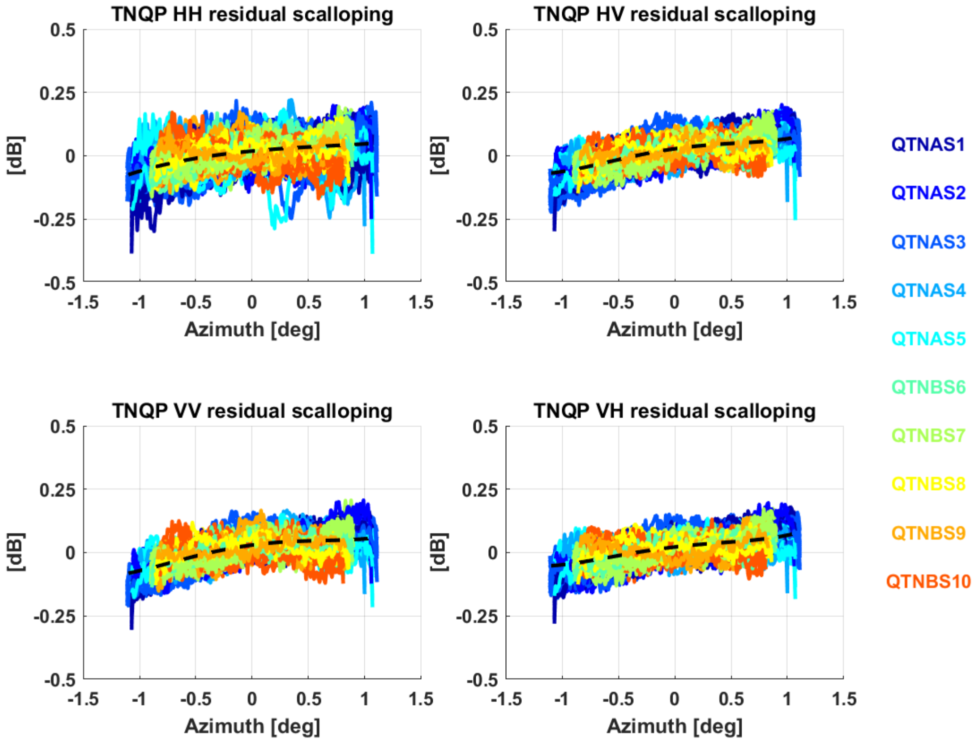

Figure 42 - Residual azimuth scalloping profiles for SAOCOM-1B TopSAR TNQP beams

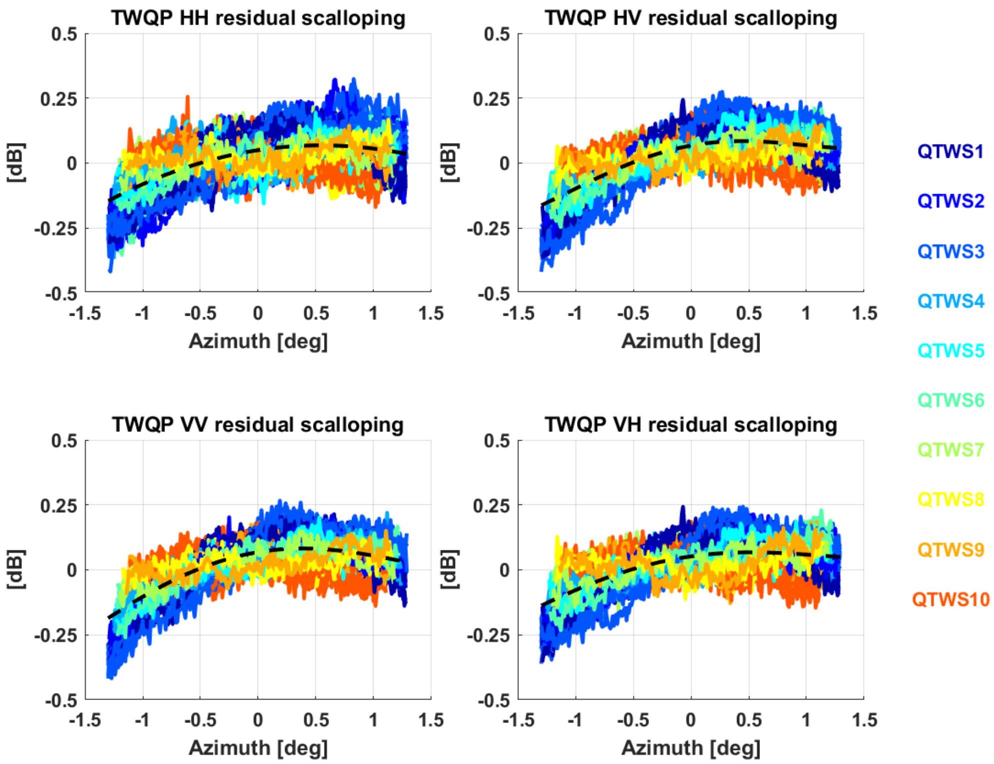

Figure 43 - Residual azimuth scalloping profiles for SAOCOM-1B TopSAR TWQP beams

3.7 Resume of detailed assessment

3.7.1 SAOCOM-1A

The results of the independent assessment of SAOCOM-1A data quality have been reported in the previous sections. The main outcomes of the assessment are resumed here below:

- The assessment of the IRF quality has shown that geometric resolution and side lobe levels are in line with the products specification. The analysis for TopSAR data should only be carried out over data including transponder due to the low resolution (in particular for QP mode).
- The assessment of the geolocation accuracy has shown that the measured geolocation accuracy is in line with the accuracy of the orbit products used for the assessment (70 m).
- The assessment of the absolute radiometric calibration has shown that all the analysed beams are well calibrated. The beams with a sufficient number of data analysed show a radiometric bias in the range ±0.5 dB (w.r.t. an ideal CR model) with a standard deviation lower than 1 dB. The few available measures over transponder show also good calibration.
- The assessment of the relative calibration over Rain Forest has shown that γ-profiles are flat and the beams are well aligned both for Stripmap and TopSAR modes. A small radiometric bias (about -0.4 dB) can be observed for beam QTWS5. The residual scalloping profiles measured for TopSAR products are mostly flat and included in the range ±0.2 dB.

3.7.2 SAOCOM-1B

The results of SAOCOM-1B assessment, shown in the previous sections, are in line with the results obtained over SAOCOM-1A data and most of the considerations reported above are valid for SAOCOM-1B as well. We report here a point-by-point comparison of the results:

- IRF quality (resolution and side lobe levels) is in line with products specification and SAOCOM-1A results.
- Geolocation accuracy is in line with products specification and SAOCOM-1A results. As additional remark a small negative bias (< 10 m) can be observed for most of the beams.
- Absolute and relative radiometric accuracy are good and in line with SAOCOM-1A results. Very small corrections of beam-to-beam offsets could further improve the overall calibration.
- Residual de-scalloping profiles observed over RF are not totally flat and quite similar to the profiles measured for SAOCOM-1A.