Towards an improved Radiometric Accuracy for Sentinel-1 with optimized Elevation Antenna Patterns

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Abstract

The paper presents the optimization method and results for deriving new elevation antenna patterns in order to improve the radiometric accuracy of Sentinel-1 SAR systems (S1A and S1B). For this purpose, the antenna patterns have been optimized by minimizing assessment parameters derived from gamma profiles acquired over the Amazon rainforest using TOPS modes (IW and EW) with different polarization channels and acquisitions using several relative orbits (tracks). The optimization aims to reduce the (gamma) variations within sub-swathes, but also to reduce beam-to-beam gain offsets and variations within the entire swathes. The new derived antenna patterns have been used for the Sentinel-1 SAR data processing after their releases. Furthermore, the radiometric accuracy has been verified with point target measurements for the IW mode. It has been found that backscatter differences between S1A and S1B match well between both target types for IW mode with VV and VH polarizations where SAR images are acquired on a regular basis over the DLR calibration site. But higher biases have been found for HH and HV polarisations where only a few acquisitions are available.

1 Introduction

In the frame of the COPERNICUS program, the European Space Agency (ESA) has planned and realized a fleet of Sentinel-1 satellites [1]. The first one, Sentinel-1A (S1A) was launched in April 2014, followed by Sentinel-1B (S1B) in 2016. Both satellites carry a C-band SAR operated at a centre frequency of 5.405 GHz.

Well calibrated SAR data products with accurately measured radar brightness are required for a number of applications and compose the basis for the quality of higher-level products. The measured radar brightness can be exploited for various scientific applications and used to classify or even quantify the observed target area, e.g., ice areas, forests or other kinds of vegetation, soil moisture of wetland and grassland, as well as ocean currents or wind speeds.

During routine operation long-term monitoring of Sentinel-1 SAR data products is necessary to assert and ensure the product quality in particular regarding to the radiometric performance [2]. Therefore, two procedures are used:

- Estimation of **relative radiometric accuracy** with stable (distributed) targets spread over wide area, e.g. using gamma profile from uniformly distributed target like Amazon rainforest
- Estimation of **absolute radiometric accuracy** with reference point targets with well-known radar cross section like corner reflectors or transponders [3], [4], [5].

Usually, the two-way antenna patterns required for radiometric correction are predicted by an antenna model using measurements from on-ground characterization. The current work presents the method used for optimizing the excitation coefficients of TRMs in order to improve the radiometric accuracy for S1A and S1B.

2 Method

The proposed method is based on gamma profiles derived from the Amazon rainforest. From these profiles, optimization parameters are extracted which allow assessing the radiometric quality in terms of relative radiometric accuracy of SAR data products. Furthermore, within an optimization procedure, new TRM excitation coefficients are derived which improve the behaviour of selected parameters over the given profiles. The new set of excitation parameters are then used to derive new two-way elevation antenna patterns (EAP). After an official release these new derived EAPs are used for future acquisitions.

2.1 Gamma profiles derived from Amazon rainforest

SAR images are regularly acquired by S1A and S1B over the Amazon rainforest for IW and EW mode, and for dual-V (VV, VH) and dual-H (HH, HV) polarization. Furthermore, they are operated for different tracks related to different acquisition geometries corresponding to the used relative orbit (see **Table 1**).

Table 1 Relative orbit numbers (tracks) used for evaluating gamma profiles from Amazon rainforest acquisitions.

SAR systems	Mode – polarisation	Tracks
S1A, S1B	IW-DV (VV,VH)	#25, #127
S1A, S1B	IW-DH (HH,HV)	#3, #105
S1A, S1B	EW-DV (VV, VH)	#32, #76
S1A, S1B	EW-DH (HH, HV)	#32, #76

From these SAR data products gamma profiles are extracted and evaluated to monitor and assess the relative radiometric accuracy.

https://ieeexplore.ieee.org/document/9944354

Gamma profiles of not properly calibrated products may contain beam-to-beam offsets (in the order of several tenth of a dB). Gamma profiles over (uniformly) distributed targets like the rainforest canopy are supposed to be smooth or even flat with respect to incidence angle (respectively elevation angle) under the condition of observation over homogeneous areas (e.g. flat terrain). Higher spatial variations (in particular over range) are not expected.

The gamma profile from one single product is computed over large regions and averaged in the azimuth direction to compensate for semi-permanent spatial variations related e.g. to rivers, deforestation, and settlement areas.

The gamma profiles are averaged over series of successive SAR data products acquired on the same track (relative orbit), enabling to compensate for fast varying fluctuations including local variation of wind speed and rains drops. The number of products on which the averaging is performed has to be considered as an indicator of the accuracy of the performance of the profile estimation.

2.2 Assessment of radiometric performance

The radiometric performances of the gamma profiles derived from Amazon rainforest measurements are evaluated based on their flatness within each sub-swath, the beam-to-beam gain offset and the overall flatness over the entire profile:

P2P_fullSwath: The peak-to-peak variation over the entire profile (including all sub-swathes) from variations between the 5% and 95% percentiles over the entire profiles is computed as an indicator for the given mode (IW or EW) and polarization channel.

P2P_subSwath: The peak-to-peak variation within each sub-swath is computed considering the variations between the 5% and 95% percentiles of the values. The restriction to those percentiles aims at deriving a performance indicator that is robust to very local variation of gamma.

B2B_offsets: The beam-to-beam gain offsets are computed from variations of median values of the gamma over consecutive sub-swath. Here again, the median allows to derive a robust indicator not impacted by local outliers.

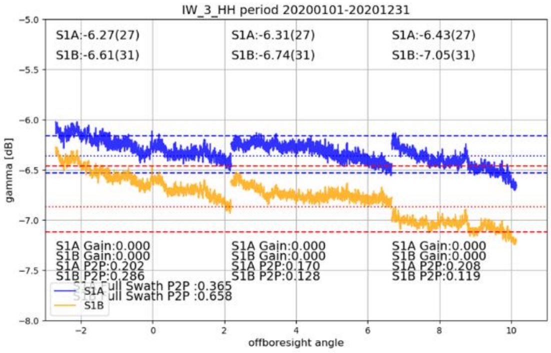

Figure 1 Example of averaged gamma profiles for a given track on IW before EAP optimisation.

Figure 1 depicts an example of original gamma profile without applying any specific optimisation for both Sentinel-1A and Sentinel-1B units. From this set of profiles, we observe strong variations within each sub-swath and strong beam-to-beam gain offsets that requires to be compensated for. Compensating only for the beam-to-beam gain offsets without optimising the flatness within each sub-swath may lead to strong variations over the entire profiles and may degrade the overall radiometric accuracy. Compensating only for the flatness within each sub-swath may lead to large beam-to-beam gain offsets and sub-optimal peak-to-peak variations within the entire swath.

This introduces the need to compensate for both: the flatness within each sub-swath and the residual beam-to-beam gain offsets by optimising the three criteria defined above.

2.3 Optimization of antenna patterns

A dedicated optimization procedure is performed in order to derive the best matching two-way elevation antenna patterns. For this purpose, the antenna model is used to derive the optimal excitation coefficients for the transmit and receive modules (TRMs) of the SAR instrument.

The optimization procedure is applied to the derived gamma profiles of the rainforest averaged over a given observation period (in the order of several months). For the optimization task, the selected assessment parameters are minimized for the given datasets, in particular the peak-to-peak variation for the given sub-swath (P2P_subswath). After this, the beam-to-beam gain offsets (B2B_offsets) are minimized (or vanished) by adding specific gain offsets for each sub-swath. The peak-to-peak variation over the entire swath (P2P_fullSwath) is derived for evaluating the quality of the given mode and polarization channel.

3 Results

3.1 Gamma profile improvement

Gamma profiles have been evaluated using the original and optimized antenna pattern configurations for the modes, polarization channels and tracks listed in **Table 1** for S1A and S1B.

The processing parameters are optimised as follows before implementation:

1- Optimisation of TRM coefficient (as exposed in section 2.3) to derive an optimized EAP
2- Compensation of original EAP from the gamma profile and computation of impact of new optimised EAP.
3- Compensation of residual beam-to-beam gain offsets using one of the sub-swathes as reference (arbitrary using the one with the larger residual peak-to-peak variations). Note, that only the larger residual offsets above 0.05 dB are compensated.
4- Adjustment of the median gamma of the entire optimised profile to match with the one of the original one

As an example, the gamma profiles for IW mode with HH polarization for track #03 are depicted in **Figure 2**. In this case only the S1B IW3 beam gain was tuned to find a mitigation between beam-to-beam gain offsets and peak-to-peak variations of the profile.

This clearly shows reduced beam-to-beam gain offsets and smaller variations within each sub-swath as well as for the entire profile. On this example, a residual beam-to-beam gain offset is visible between IW2 and IW3. The complete compensation of this offset was not considered as it would have led to a larger peak-to-peak fluctuation of the entire profile.

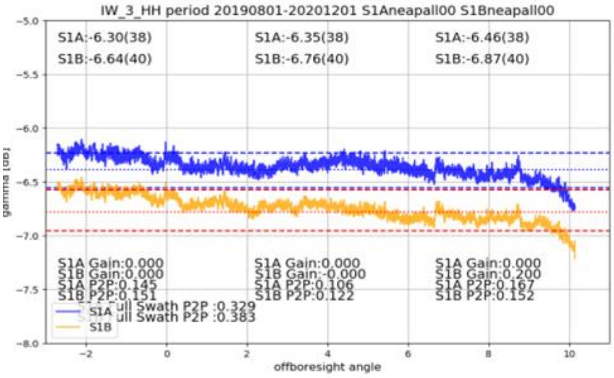

Figure 2 Gamma profiles determined from acquisitions over the Amazon rainforest with S1A (blue) and S1B (yellow) for IW mode HH polarization for track #03 after antenna pattern optimization.

3.2 Activating changes for operative processing chain

After EAP optimization the new set of parameters are used to apply for SAR data processing of future acquisitions. This includes changing the configurations used during SAR data processing covering two-way EAP updates and processing gains. This information is saved in dedicated auxiliary files (e.g. aux-cal and aux-pp1 files). The link to the related auxiliary files can be found within the Sentinel-1 SAR data products (manifest-files). Furthermore, the EAP profile (gain and phase) applied for the given sub-swath and polarization is available with the annotation section of the related SAR data product.

After an official release, the new configuration is available for future acquisitions. The release date for the operative processing chain (L1 products) with new derived optimized EAP is documented in **Table 2** for each configuration (IW or EW mode including polarization channels).

Table 2 Release date for new configurations within operating processing chain.

Mode – polarisation	**S1A**	**S1B**
IW DV (VV,VH)	27 Feb 2019	12 May 2020
IW-DH (HH,HV)	4 Jan 2021	4 Jan 2021
EW-DV (VV, VH)	31 Jul 2019	12 Dec 2020
EW-DH (HH, HV)	12 Dec 2020	12 Dec 2020

3.3 Improvement of assessment parameters

After optimization most assessment parameters has been improved. The peak-to-peak variation due to pattern optimization are analysed Within **Figure 3** this parameter is plotted for different stages:

1) Before optimization with the “old” set of EAP
2) With optimized EAP but for the same period of time as in 1)
3) Gamma profiles acquired after the new set of EAP has been activated within the processing chain.

Figure 3 contains the results for both SAR instruments: S1A (blue) and S1B (red) and for both TOPS modes: IW mode (solid lines) and EW mode (dotted lines). Furthermore, it contains acquisitions from different tracks (see **Table 1**) and all polarization channels (HH, HV, VV, VH).

The results in **Figure 3** show that the peak-to-peak variation decreases for most gamma profiles in particular for the optimization step as expected. In a number of cases the peak-to-peak variation after change is slightly higher than results achieved for the previous period of time with optimized EAP (case 2). This might be due to the fact that the optimization has been applied to this period of time.

However, in most cases the new EAP (after change) shows a better performance compared to the old EAP versions (before change) which demonstrates the benefit due to the optimized pattern used.

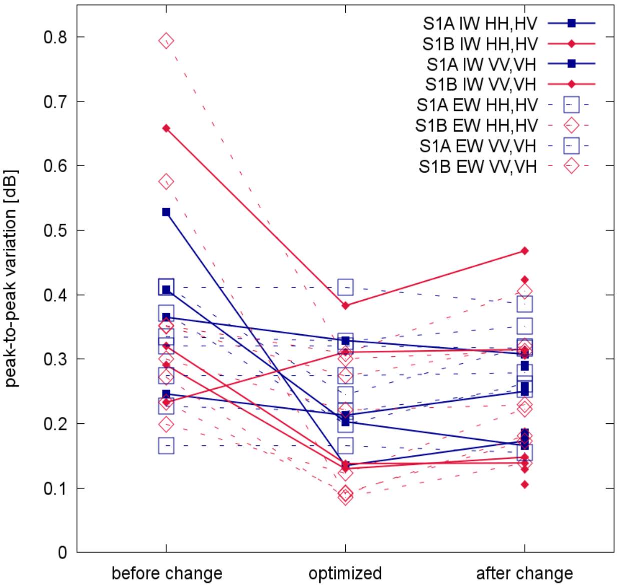

Figure 3 Peak-to-peak variations of gamma profiles derived from Amazon rainforest acquisitions with S1A (blue) and S1B (red) for IW mode (solid) and EW mode (dotted) for different EAP configurations.

3.4 Verification with DLR’s reference targets

Evaluations of gamma profiles from acquisitions over the rainforest can only be used for a relative radiometric balancing, as the absolute gamma value derived is not constant and vary over seasons and observation area. In order to verify the absolute calibration factor after, measurements against accurate reference targets are necessary. For this purpose, acquisitions over the DLR calibration site are permanently executed. In order to account for this fact, gamma profile differences between S1A and S1B are computed and verified with point target results derived in similar way and with identical antenna elevation patterns.

Therefore, RCS derived from point targets acquired for S1A and S1B for identical antenna elevation angles are compared and plotted in **Figure 4** (VV, VH) and **Figure 5** (HH, HV) with mean values (symbols) and corresponding standard deviations (error bars). In addition, the remaining offsets (S1A – S1B) for each IW sub-swath derived from gamma profiles over the same track are plotted as lines in each subfigure.

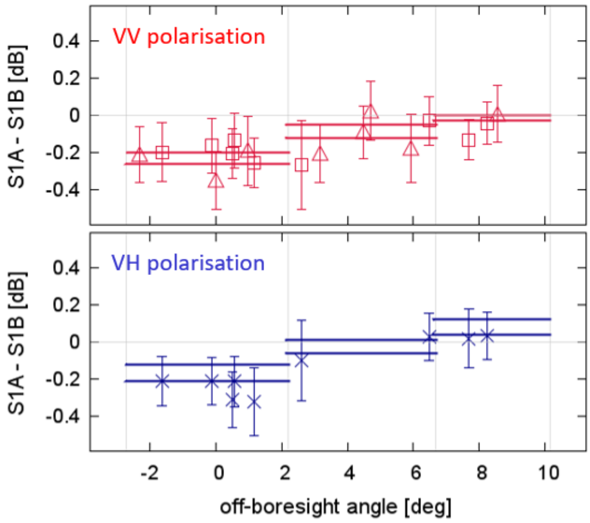

Figure 4 Differences between S1A and S1B from point target's RCS (symbols with standard deviations as error bars) and mean offset differences derived from gamma profiles (lines) for VV pol (top) and VH polarisation (bottom) for IW mode.

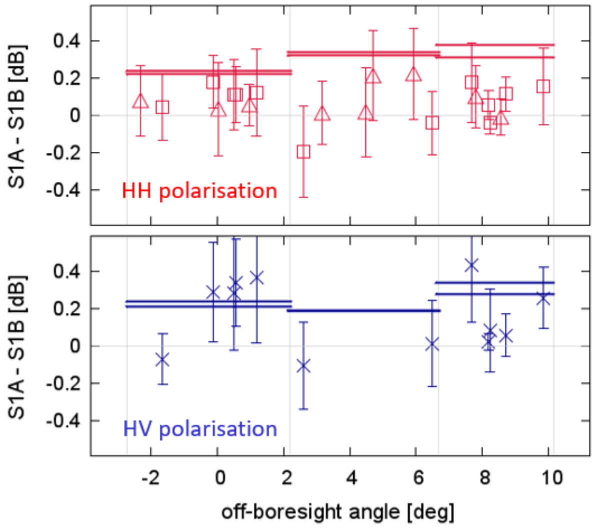

Figure 5 Differences between S1A and S1B from point target's RCS (symbols with standard deviations as error bars) and mean offset differences derived from gamma profiles (lines) for HH pol (top) and HV polarisation (bottom) for IW mode.

It has been found that the differences between S1A and S1B are well reflected for VV and VH polarization as depicted in **Figure 4**. These biases (up to 0.2 dB) can be considered in a future antenna pattern update.

Higher deviations between point target and rainforest results in the order of 0.3 dB have been in particular found for HH polarization (**Figure 5**). This might be due to the fact that only a few acquisitions could be aquired during specific campaigns over the DLR point targets for this polarization channel. This fact is also reflected by higher standard deviations compared to VV. It has to be mentioned that gamma profiles are not constant (in contrast to visualizations in Fig 4 and 5) but show variations up to 0.4 dB over the swath as reflected in **Figure 3**.

4 Conclusion

The paper presents the optimization method and results for deriving new EAPs in order to improve the radiometric accuracy for Sentinel-1 SAR instruments (S1A and S1B). Therefore, gamma profiles have been derived from rainforest acquisitions and the TRM's excitation coefficients have been optimized to reduce the variation within sub-swathes of TOPS modes (IW and EW mode). Furthermore, additional (sub-swath) offsets have been introduced to reduce beam-to-beam gain offsets and to reduce the variation over the entire swathes. The new derived EAPs are used for the Sentinel-1 SAR data processing after their releases.

The radiometric accuracy has been verified with accurate reference point target measurements. It has been found that differences between S1A and S1B derived from point target's RCS match well with gamma profile differences for IW mode with VV and VH polarizations. Higher discrepancies have been found for IW mode with HH and HV polarizations where less acquisitions over point targets are available.

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The views expressed herein can in no way be taken to reflect the official opinion of the European Space Agency or the European Union.

6 Literature

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