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Sentinel-1A/B SAR Calibration and Performance Status

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Abstract :

Sentinel-1 (S-1) is the European flagship SAR mission initiated by European Space Agency and the European Commission. It is a constellation of two C-band twins satellite providing backscatter globally. The calibration and overall SAR performance of the mission is continuously assessed by the S-1 Mission Performance Center being a joint venture of European experts in their domain under ESA's supervision. This paper addresses the Copernicus Sentinel-1A/B mission's SAR calibration and overall performance indicators after 8 years cumulated operation having in sight S-1A approaching its expected lifetime of 7 years. Sentinel-1 uses predefined observation scenario to provide a high revisit frequency and systematic global SAR image coverage. This is mainly based upon the operational use of the TOPS (Terrain Observation with Progressive Scans in azimuth) SAR imaging mode allowing to achieve a wide swath with a relatively high resolution. In particular, we present results of the SAR system performance analysis focusing on the instrument stability, the radiometric, geolocation accuracy, the Noise Equivalent Sigma Zero (NESZ) and all interferometric performance indicators. In addition, we discuss the Sentinel-1A/B SAR cross-calibration and the evolution of the system in the near future.

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1 Introduction

The Copernicus Sentinel-1 mission is a constellation of twins C-band (5.405 GHz) SAR satellites comprising the current A and B units, which will be eventually replaced by the planned C and D units, to provide routinely SAR data for the European Commission‘s (EC) operational Copernicus and national services.

The Sentinel-1 mission has been specifically designed to acquire systematically and provide routinely data and information products for the operational Copernicus Ocean, Land, Climate Change and Emergency services, as well as to national services [1].

Sentinel-1A was successfully launched on April 3rd, 2014 followed by the successful launch of Sentinel-1B on April 25th, 2016. Both satellites fly in a near polar, sun-synchronized (dawn-dusk) orbit at 693 km altitude, in the same orbital plane with *180 deg.* phased positions with 12 day repeat cycle or 6-days for areas both covered by S-1A&B [2].

The Sentinel-1 SAR instrument with its active phased array antenna supports four exclusive imaging modes providing different resolution and coverage: Interferometric Wide Swath (IW), Extra Wide Swath (EW), Stripmap (SM), and Wave (WV). All modes, except the WV mode can be operated in dual polarization.
Both the IW and EW mode use the TOPS technique [2] to provide large swath width of 250 km at ground resolution of 5m x 20m and 400 km at ground resolution of 20m x 40m, respectively with enhanced image performance as compared to the conventional ScanSAR mode.

Following the successful completion of the commissioning phases Sentinel-1A&B in 2014 and 2016, respectively, the SAR and InSAR performance for both satellites is constantly monitored. In particular, the radiometric and geolocation accuracy has been further improved.

In this paper, we discuss key SAR instrument performance parameters, such as gain and phase stability, radiometric and geolocation accuracy, and the achievable Noise Equivalent Sigma Zero (NESZ). Regarding the InSAR performance for the IW TOPS mode, we analyse the burst synchronization, SAR antenna pointing and across-track orbital baseline.

2 SAR instrument performance

2.1 Instrument stability

The Sentinel-1 SAR interleaves internal calibration signal during the imaging sequence [3] to measure short-term variations of the instrument gain and phase resulting from temperature variations. The monitoring of the internal calibration allows to assess long-term changes due to seasonal variations and ageing effects of the hardware, such as the degradation of thermal surfaces.

Figure 1 shows the evolution of the PG product (transmit power x receiver gain) for S-1A&B since the 2017. The discontinuity visible in S-1A is related to a major antenna maintenance aiming at recovering power from the failure that took place in mid-June 2016.

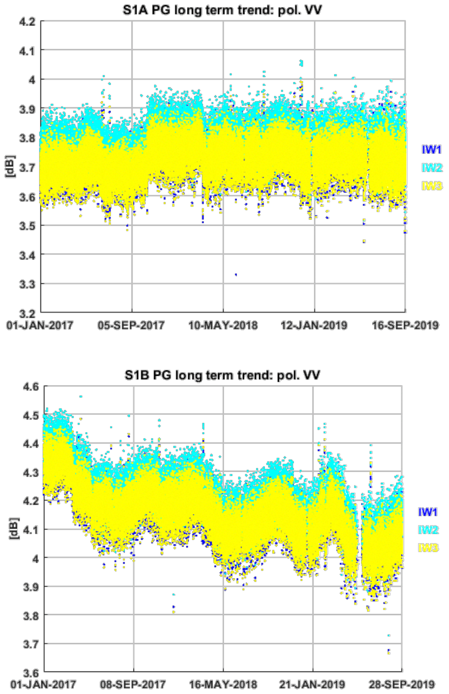

Figure 1: PG evaluation for S-1A IW (top) and S-1B (bottom) for IW VV

For S-1B there hasn't experience any major antenna failure. The decreasing trends (now stabilized) coincided with the ramping-up of in instrument usage after the commissioning phase. Seasonal variation of the instrument power is visible in both satellites. All in all, both exhibits a slight decreasing (like S-1A) of 0.2dB/y demonstrating the very high stability of the system.

The calibration pulses experiencing path and settings as the nominal pulses, they are used by the SAR ground processor to compensate the final data for variations in gain, phase and internal delay.

2.2 Antenna status

In addition to the classical interleaved calibration, S-1 features a dedicated calibration mode *RF Characterization (RFC) mode* [3] to measure health and stability of the individual TRMs, whilst all modules are operating under realistic thermal conditions and nominal power loads. Variations in the TRMs can be used as input to the Sentinel-1 Antenna Model to predict the resulting changes in the antenna patterns.

Figure 2 shows the error matrix derived from RFC product indicating the drifts and failure on the S-1A antenna. Except for the loss of half tile 11 in June 2016 there are very sparse failure not impacting the performance. The tile 11 failure had an impact on the S-1A antenna that has been compensated by updating the elevation antenna patterns.

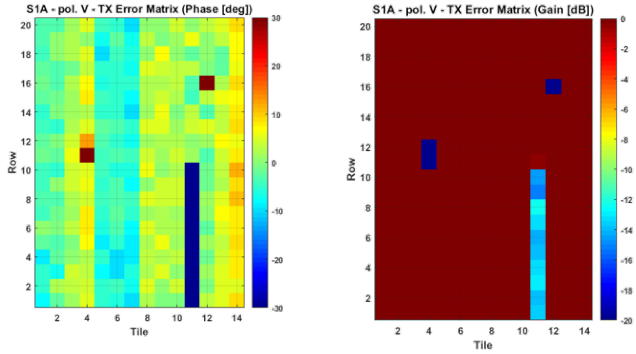

Figure 2: Error Matrix in phase (left) and gain(right) for S-1A in transmit V polarisation

In the final paper the antenna status, burst synchronisation, orbital tube and pointing will be further discussed

3 Radiometric accuracy

The radiometric accuracy of a SAR system is defined by the accuracy at which the elements of radar equation. The S-1 radar equation as defined in (1) relates the radiometric accuracy to the knowledge PG product which stability has been discussed in §2.1, the knowledge and stability of the calibration constant discussed in §3.1, the accuracy of the antenna pattern and the accuracy of the noise power.
Sentinel-1 has an unprecedented radiometric accuracy requirement of 1dB (3σ) requiring to continuously assess the system.

$$\sigma_0 = \frac{(P_{rx} - P_{noise}).2.(4\pi)^3.R^3.sin(i)}{(P_{Tx}.G_{rx}).G^2_{ant}.c.\tau.\Delta_{\phi_{azi}}.\lambda^2}.K \qquad (1)$$

3.1 Point target analysis

Since the beginning of the mission the DLR calibration site composed of transponders and corner reflectors have been used to assess the calibration constant (K) during the respective commissioning phases and to assess its variation over time in IW VV/VH. The targets used have sufficiently high RCS such that the system noise can be neglected. The measured RCS is derived independently for each sensor and compared wrt each other and to the mission requirements.

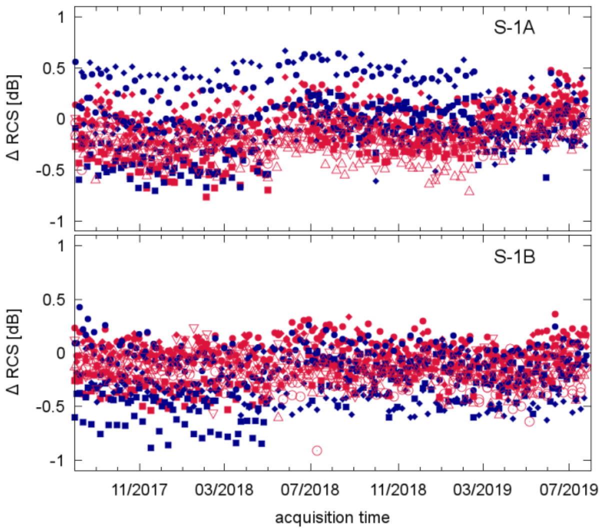

Figure 3: S-1A(top) and B (bottom) deviation around the nominal target RCS

Over the analysis period, both systems exhibit a stable radiometric performance over time with slight fluctuation mainly related to seasonal effect, antenna pattern update (03/19; S1A) or to transponder maintenance (03/18). One can note, the reduction of the spread for S-1A in march 2019 after the update of the antenna pattern. Such exercise is currently on-going for S-1B. **Table 1** provides the mean values and standard deviations

Table 1 RCS deviations derived from point targets

polarization channel	S-1A RCS [dB] (μ±σ)	S-1B RCS [dB] (μ±σ)
VV	-0.19 ± 0.21	-0.11 ± 0.17
VH	-0.03 ± 0.33	-0.24 ± 0.26

In the final paper elevation antenna pattern and geolocation accuracy will be addressed

3.2 Radiometric accuracy for low NRCS data

SAR images are impacted by thermal noise that becomes only visible when the mean signal is low. Furthermore, the noise depends on the Earth's emissivity [5] and system parameters (receiver gain, bandwidth) leading to swath dependent bias shaped by the elevation antenna pattern and in the case of TOPS also by the azimuth elementary pattern used for burst descalloping [6].

Sentinel-1 being mostly operated in dual-polarisation, the cross-polarisation channel is significantly biased by thermal noise that if not compensated impedes the accurate usage of the NRCS for unbiased retrieval of bio/geophysical variables for soil moisture or wind retrieval for example. Noise removal is possible if the all the elements contributing to the noise are well characterised. In the past years, strong effort was put on that side to properly handle the impact of the processing parameters on the noise, to accurately measure the Noise Equivalent Sigma Zero and to assess the noise power throughout the timeline using the first echoes after the beam switching in TOPS. As a result, Figure 4 shows the noise power sensed by S-1A and its dependency with the Earth's brightness temperature [7].

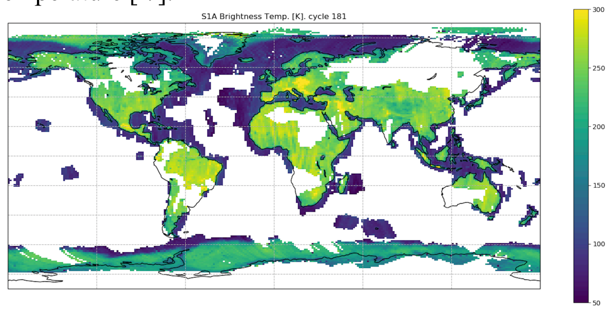

Figure 4: S-1A noise power map for the cycle 181.

As a result, the Sentinel-1 product metadata have been updated [8] to allow for more efficient denoising as shown in Figure 5 and in fine (for this application) to perform an unbiased wind speed estimate.

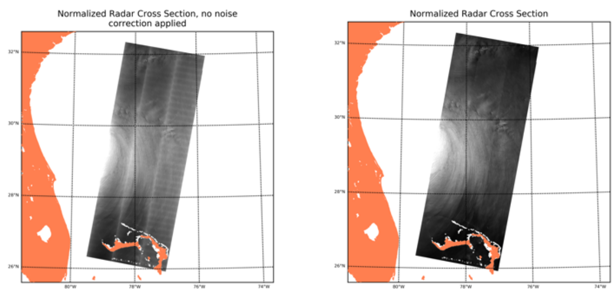

Figure 5: (left) Native S-1B IW VH product, (right) after denoising using the provided annotations

4 Literature

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