Copernicus Sentinel-3 Surface Topography Mission - Cyclic Performance Report

SRAL

S3A	S3B
Cycle No. 109	Cycle No. 90
Start date: 08/02/2024	Start date: 18/02/2024
End date: 06/03/2024	End date: 16/03/2024

Reference: S3MPC-STM_CPR_0005-109-090

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CHRONOLOGY ISSUES

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Function	ESA Technical Officer	MPC Service Manager

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1 Introduction

The purpose of this document is to report on the performance and data quality of the Copernicus Sentinel-3 Surface Topography Mission (STM) LAND products. The constellation currently includes Sentinel-3A and Sentinel-3B altimetry satellites. This document is associated with data dissemination on a cyclic basis and is generated a few days after the end of Sentinel-3B cycle.

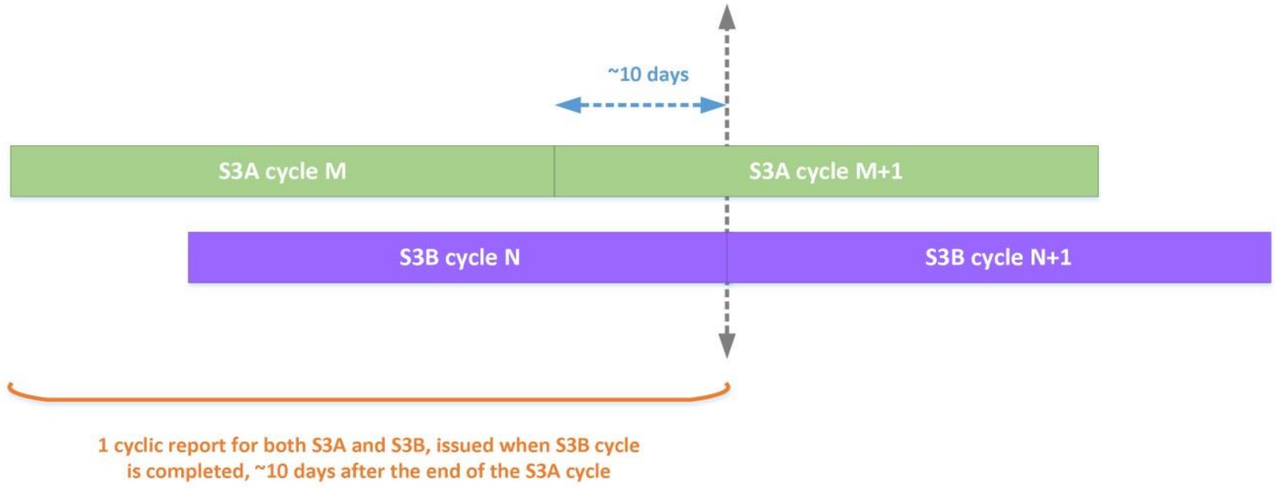


Figure 1: S3A and S3B cycles chronology

The main objectives of this document are:

- To provide an assessment and monitoring of the SRAL in-flight calibrations (section 4)
- To provide an assessment and monitoring of the SRAL absolute calibrations performed with transponders (section 5)
- To report on any changes likely to impact data quality at any level, from instrument status to software configuration.
- To present the major useful results for S3A cycle 109, from 08/02/2024 to 06/03/2024.
- To present the major useful results for S3B cycle 90, from 18/02/2024 to 16/03/2024.

Most of the assessments related to the SRAL in-flight calibrations are made with the level-1 Calibration products as input data. These products are generated by the ESA Sentinel-3 LAND Processing Centre with a Near Real Time (NRT) timeliness. Input data for the assessments related to transponder calibrations are specified in section 5.

2 SRAL performance overview

2.1 SRAL Cycle Performance

The SRAL behaviour in this cycle is nominal for the two Sentinel-3 missions. The absolute values and the local trends are as expected for the assessed calibration parameters. These parameters are related to the calibration modes CAL1, CAL2, AutoCal, and from the USO files and thermal data. From what we observe in the figures and the cycle status summary in 4.1, the performances are in line with previous cycles.

2.2 SRAL Mission Performance

The long-term behaviour of the SRAL instruments of both Sentinel-3 missions is nominal, compliant with the missions' requirements. No warning is raised currently. The power decay at the beginning of the S3A mission (-1 dB/year) is now under control (smaller than -0.3 dB/year) after a slow stabilization. A detailed summary of the health of the altimeters instruments is done in 4.2, together with explanations of different events along the missions.

2.3 SRAL anomalies and events

No anomalies to report in the cycle.

3 Processing baseline

Table 1 details the versions of the Processing Baseline (PB), and Level-1 and Level-2 Instrument Processing Facility software used for the products assessed. This is part of the Baseline Collection (BC) 005.

Cycle		Processing Baseline	IPF SM2 version	IPF SR1 version	IPF MW1 version
Sentinel-3A	109	3.25	07.07	07.07	06.15
Sentinel-3B	90	3.25			

Table 1: Processing baseline and IPF details

The evolutions of the Sentinel-3 STM Processing Baseline are summarized in the SentiWiki website: https://sentiwiki.copernicus.eu/web/altimetry-processing.

4 SRAL monitoring report

The SRAL instrumental calibration is assessed during the mission. Several parameters are monitored and analysed in detail in order to characterise the altimeter performance along the mission lifetime.

Two main groups of calibration parameters are monitored.

The first is derived from the Point Target Response (PTR) calibration in CAL1 mode. The PTR signal follows the same circuitry path as the science waveforms within the calibration loop. The delay caused by the travel through the calibration path can be measured and afterwards compensated in the total range computation. The power figure of the PTR signal when traveling through the instrument also needs to be monitored and the science waveforms need to be compensated for this power level, which can drift along a mission. Moreover, there are a collection of other parameters to be checked, such as the PTR width and the secondary lobes features. These CAL1 parameters are produced separately for LRM and SAR modes, as they follow different instrumental paths, and also they are duplicated for Ku-band and C-band. Moreover, there are different options for characterising the delay (maximum position or CoG position) and power (maximum power or total power) of the closed loop signal.

The second is related to the Instrument Transfer Function, measured by the CAL2 mode. The science waveforms spectra is distorted by the on-board instrumental hardware sections. Therefore, in order to retrieve the original echo shape, we need to compensate for this effect. Several parameters are derived from the analysis of the CAL2 waveforms for characterizing it and dissect any feature along the mission lifetime. The CAL2 waveform is the same for both modes LRM and SAR, but there is a distinction between bands Ku and C.

Additionally, the two intra-burst corrections are monitored: they are the power and phase progressions within a burst. Science pulses within a burst are to be corrected for these expected burst variations. Some characteristics are computed for describing and following up their behaviour along the S3 missions.

The Autocal parameters monitor the actual attenuation values for each on-board ATT step. They are to be used in the L1B processing for considering the real attenuation value, instead of the commanded one on-board.

It is also of major importance the monitoring of the on-board clock (USO). The altimeter clock counter, responsible for computing the echo travel time, has a multiplicative impact in the range determination. The platform clock is responsible for the overall platform instruments datation. Their stability and performance are to be supervised along the mission.

Finally, the data coming from the thermistors located in the different sections of the on-board HW (HKTM products) is to be analysed to check the relation of any calibration parameters anomaly with the thermal behaviour and find solutions for modelling the instrument characterisation (for instance orbital oscillations) if needed.

An important remark is to be made: although we can see a certain drift of a specific calibration parameter along the mission, this is not to be considered as a warning for the quality of the science data, as long as the instrumental calibration is correctly applied during the science data processing. A warning shall be raised in the scenario of a calibration parameter value approaching the mission requirement bounds.

4.1 Cycle SRAL Performance

In this chapter, the monitoring of all calibration modes main parameters for the S3A and S3B missions is depicted in figures (only Ku band). A brief analysis of the cycle results is exposed at the end of this chapter.

4.1.1 CAL1 SAR

Geolocation of the CAL1 measurements for SAR mode.

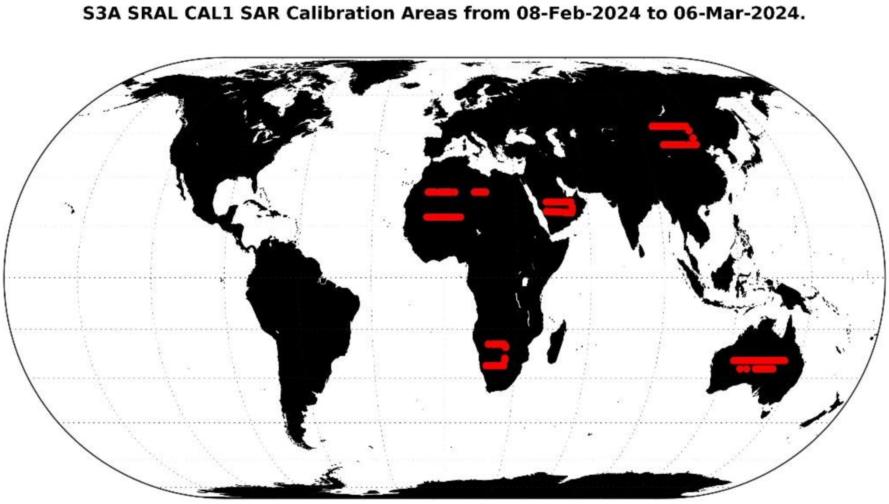


Figure 4-1. S3A Location of the CAL1 SAR measurements.

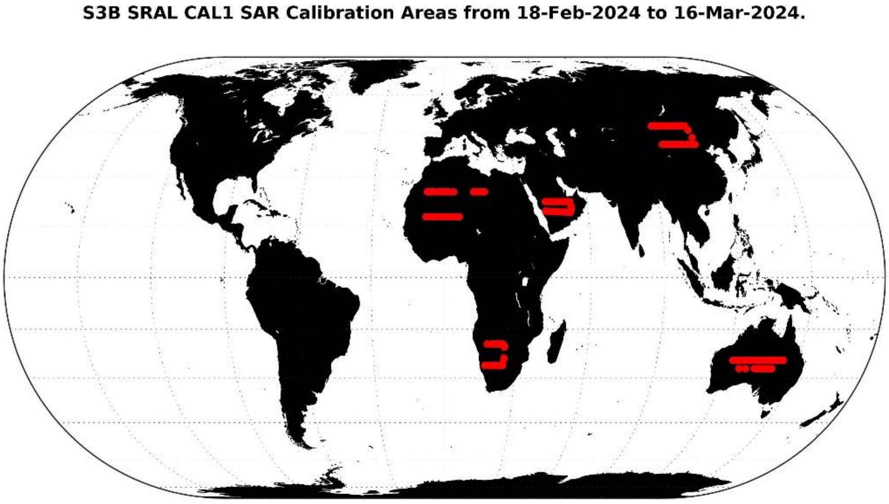


Figure 4-2. S3B Location of the CAL1 SAR measurements.

Period trend of CAL1 PTR Delay for SAR mode.

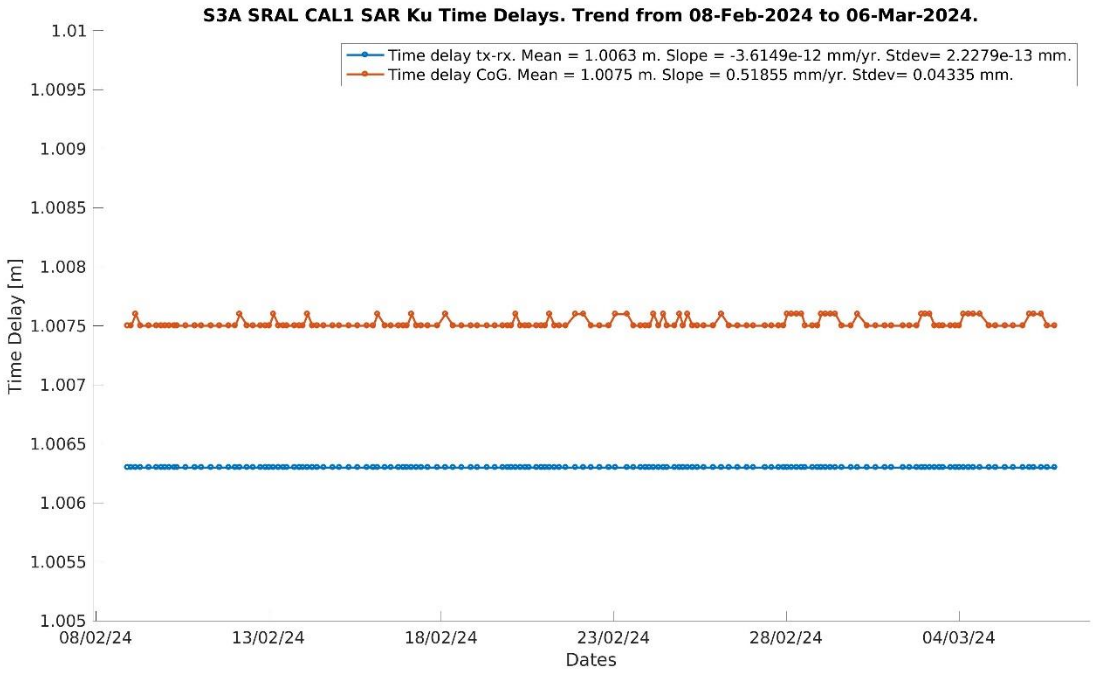


Figure 4-3. S3A CAL1 SAR Ku Time Delay trend.

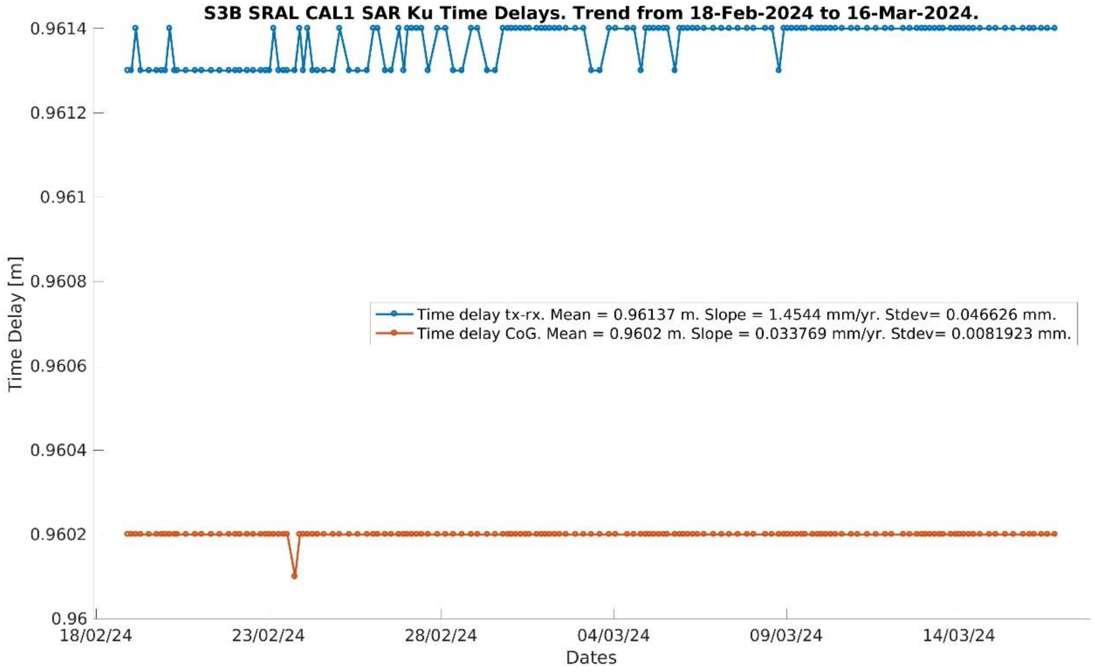


Figure 4-4. S3B CAL1 SAR Ku Time Delay trend.

Period trend of the PTR Total and Maximum Power for SAR mode.

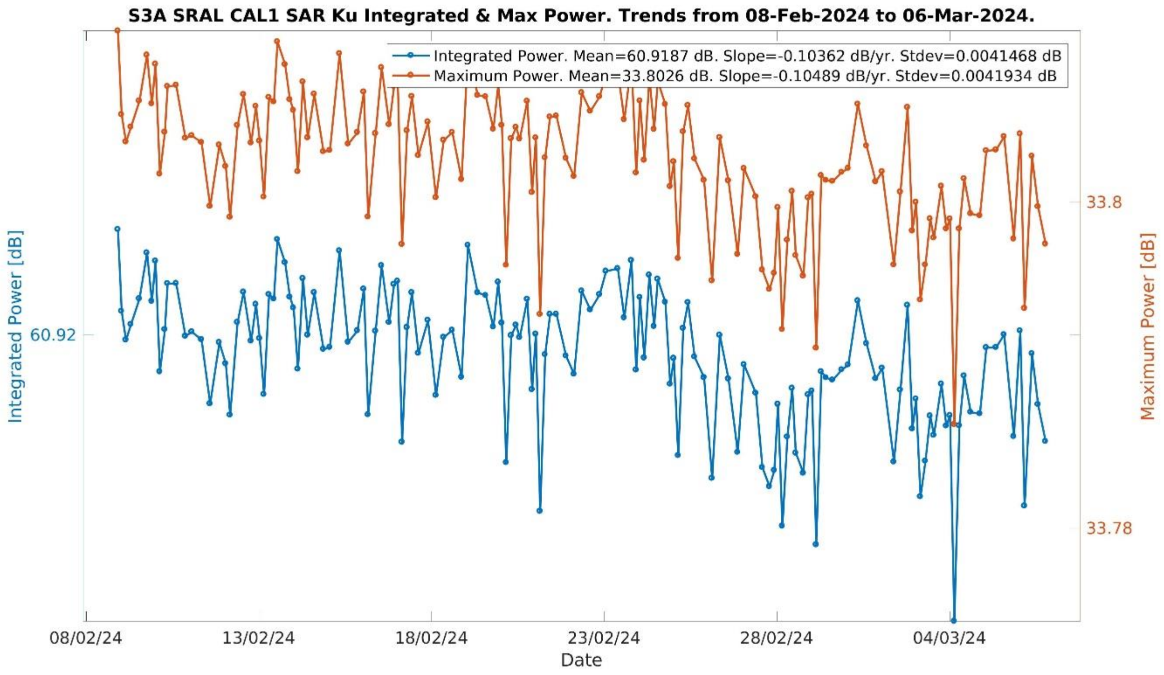


Figure 4-5. S3A CAL1 SAR Ku Power Trend.

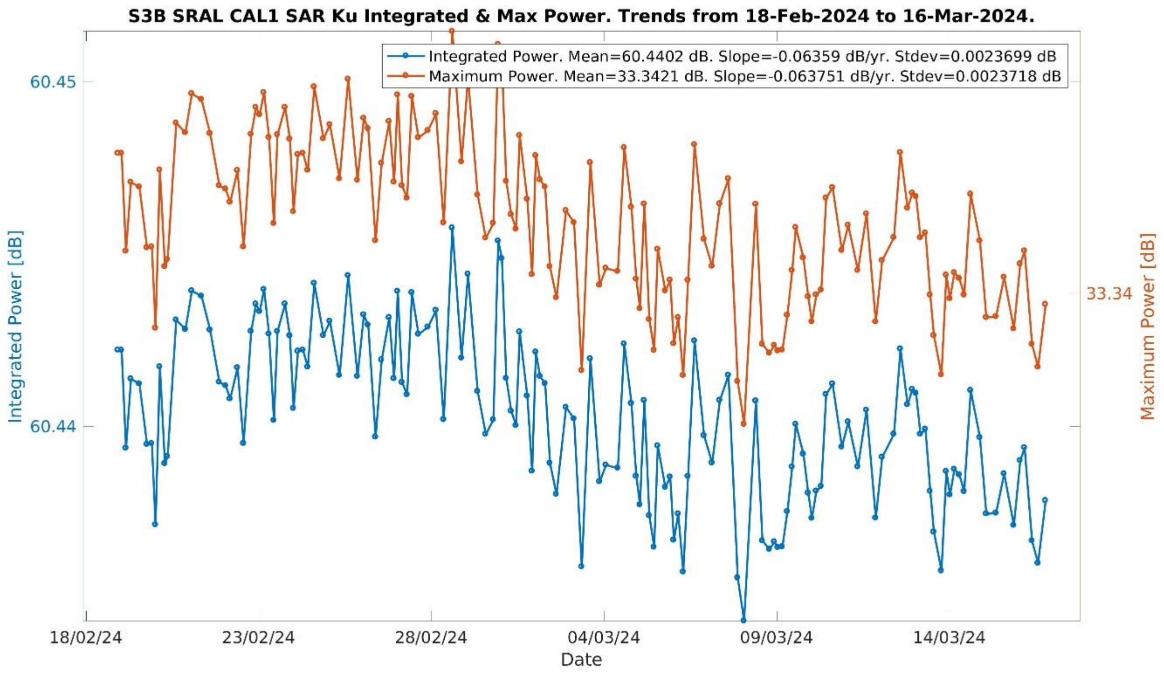


Figure 4-6. S3B CAL1 SAR Ku Power Trend.

Period trend of the CAL1 PTR width for SAR mode.

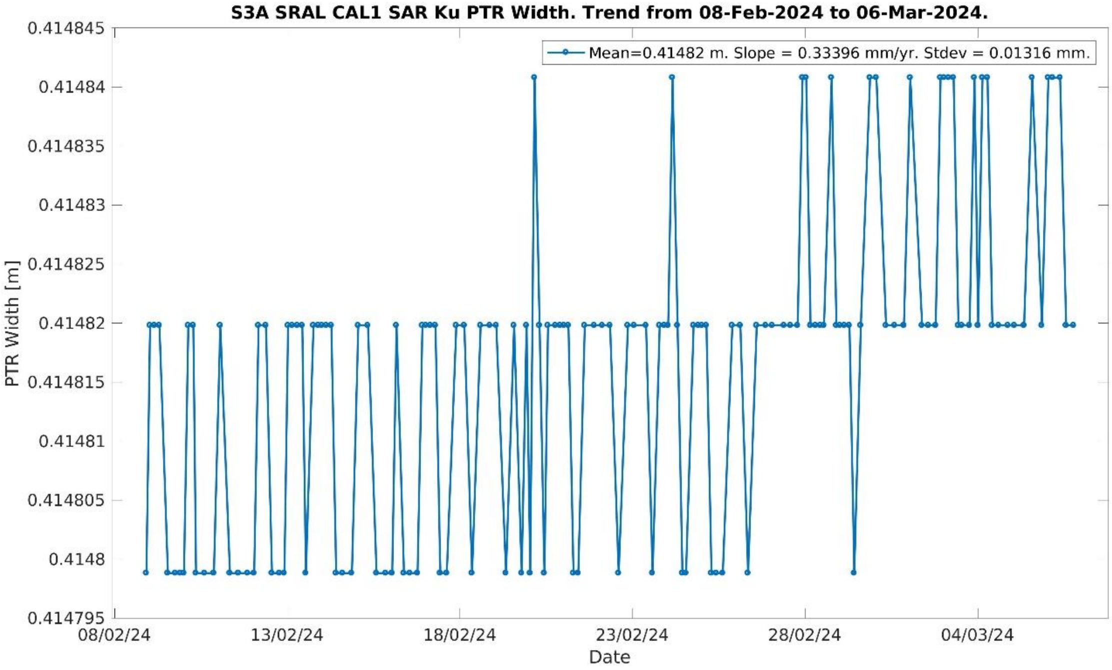


Figure 4-7. S3A CAL1 SAR Ku PTR width trend.

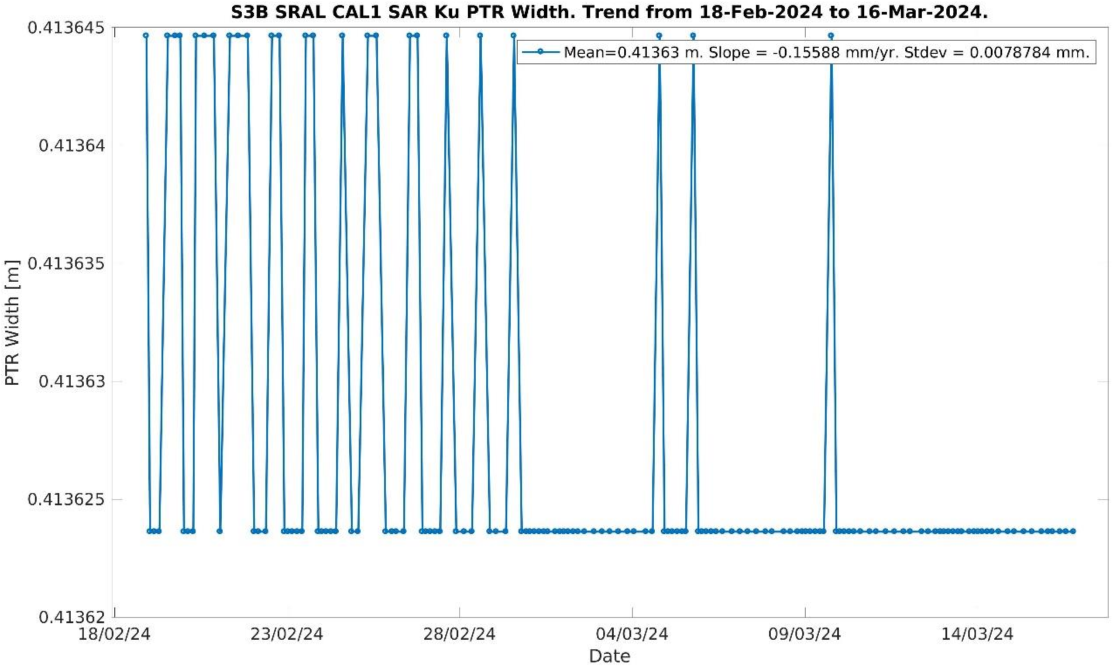


Figure 4-8. S3B CAL1 SAR Ku PTR width trend.

Distribution of the PTR secondary lobes within the CAL1 PTR waveform for SAR mode.

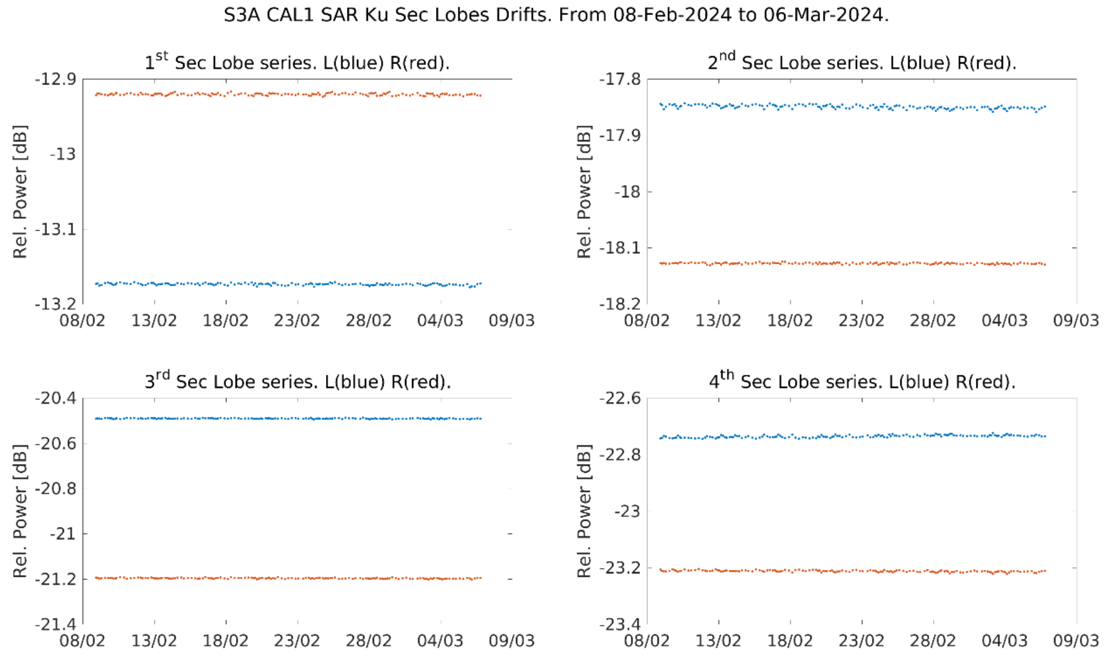


Figure 4-9. S3A CAL1 SAR Ku PTR secondary lobes Power and Position within the PTR waveform.

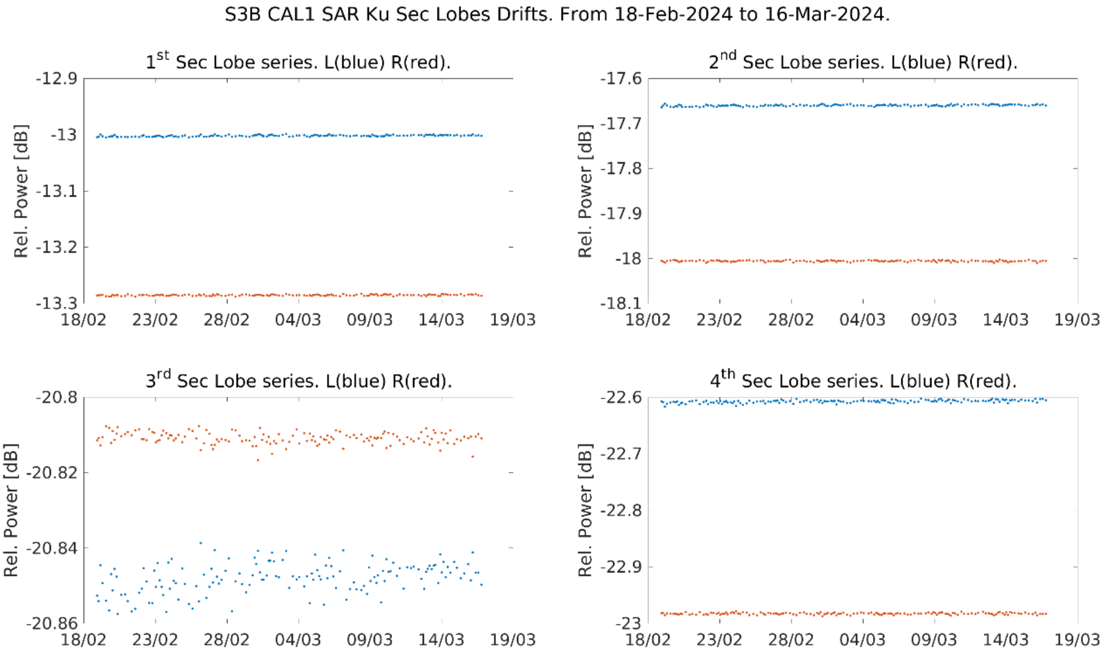


Figure 4-10. S3B CAL1 SAR Ku PTR secondary lobes Power and Position within the PTR waveform.

Slope and Standard Deviation of CAL1 SAR PTR secondary lobes power.

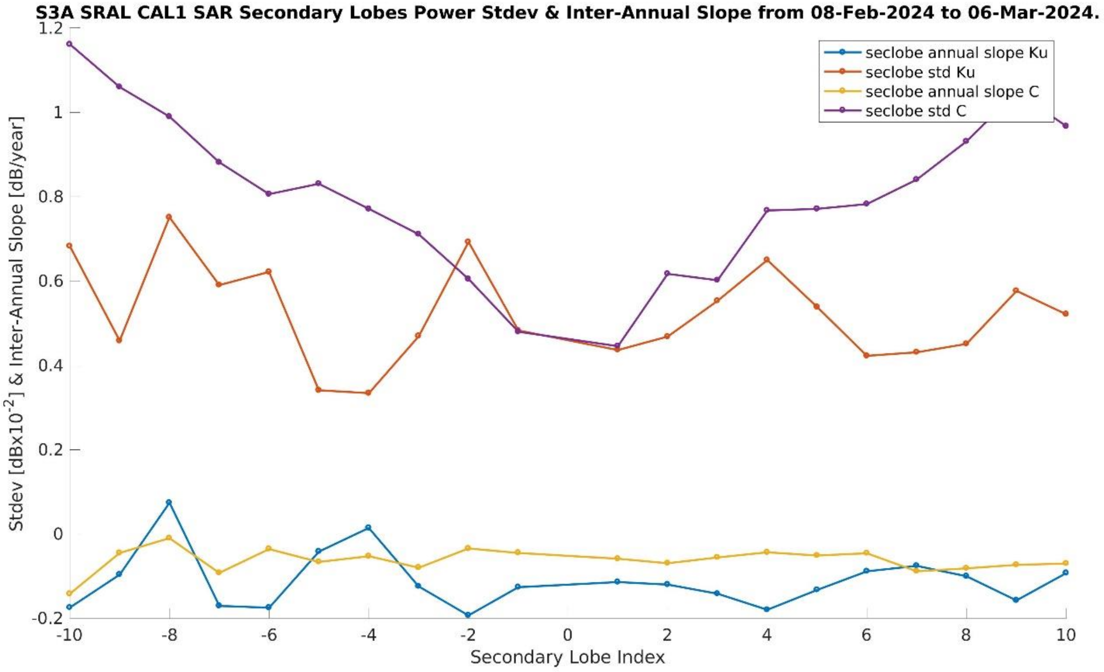


Figure 4-11. S3A CAL1 SAR Ku PTR secondary lobes characterisation. The inter-annual slope (in dB/year) and standard deviation (in dBx10^{-2}) of each of the secondary lobes are shown.

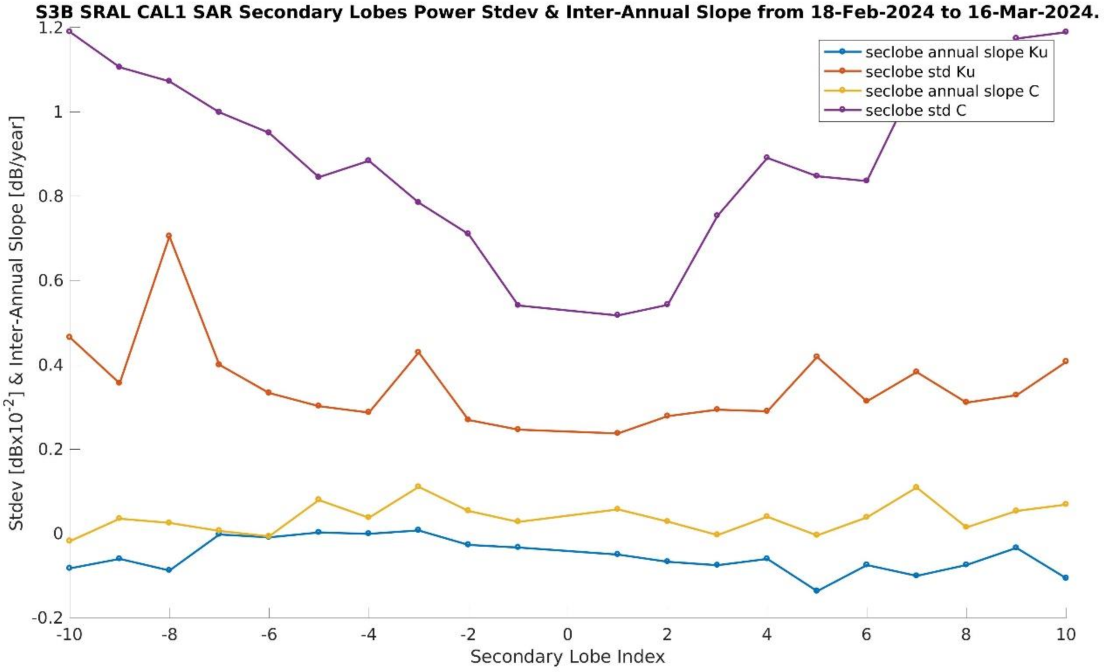


Figure 4-12. S3B CAL1 SAR Ku PTR secondary lobes characterisation. The inter-annual slope (in dB/year) and standard deviation (in dBx10^{-2}) of each of the secondary lobes are shown.

CAL1 Phase and Power intra-burst corrections slopes.

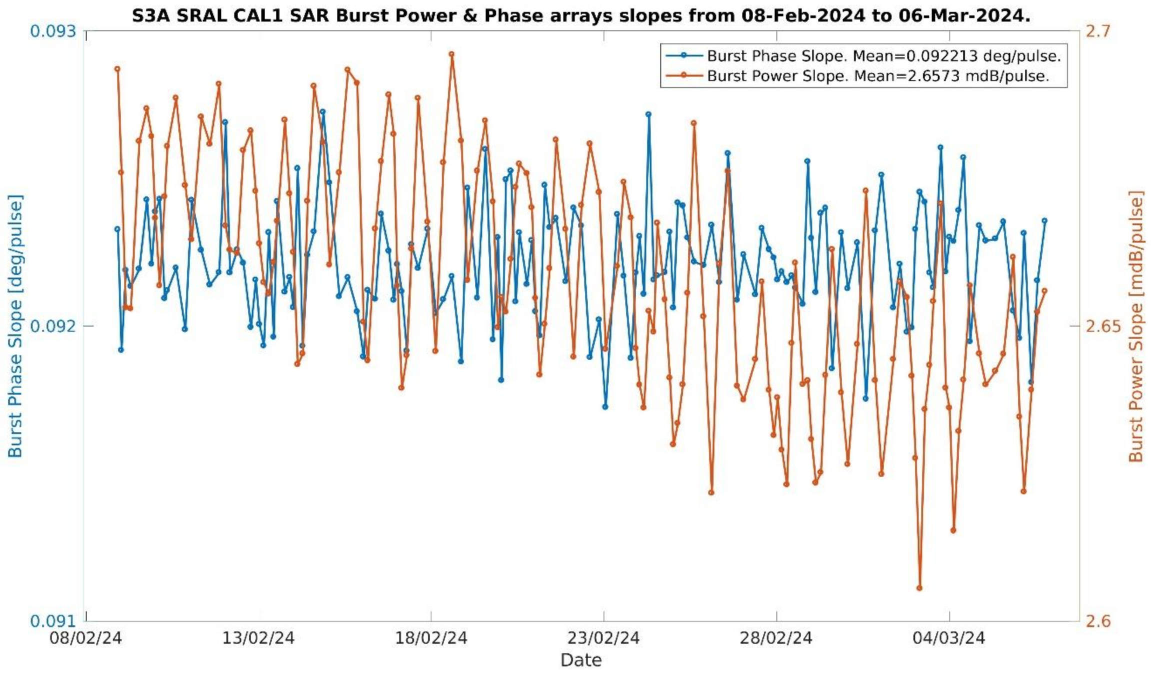


Figure 4-13. S3A CAL1 SAR Ku Phase & Power intra-burst corrections slopes over the cycle.

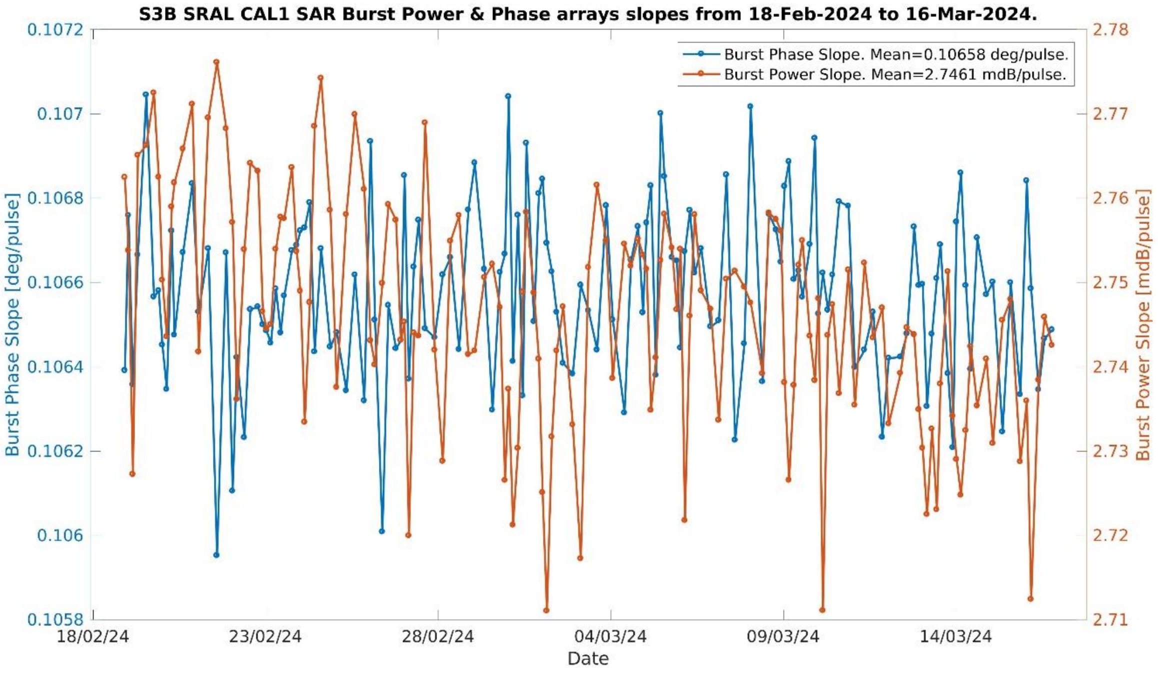


Figure 4-14. S3B CAL1 SAR Ku Phase & Power intra-burst corrections slopes over the cycle.

CAL1 Phase and Power intra-burst corrections standard deviations.

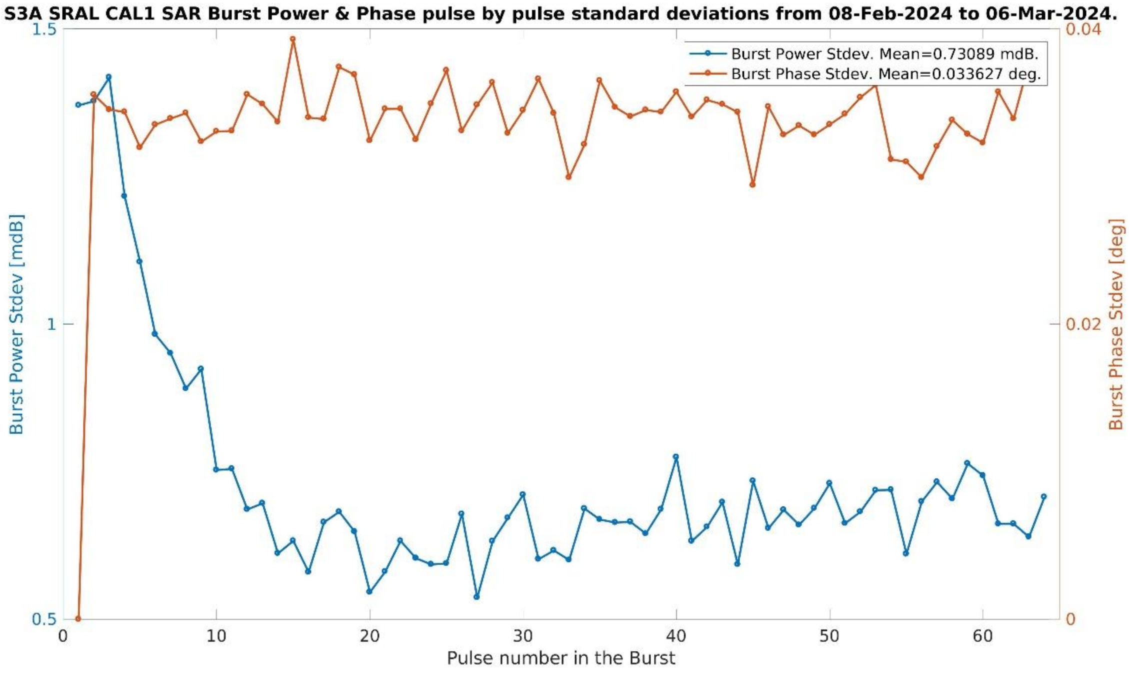


Figure 4-15. S3A Pulse by pulse standard deviations of the CAL1 SAR Ku Power and Phase intra-burst corrections.

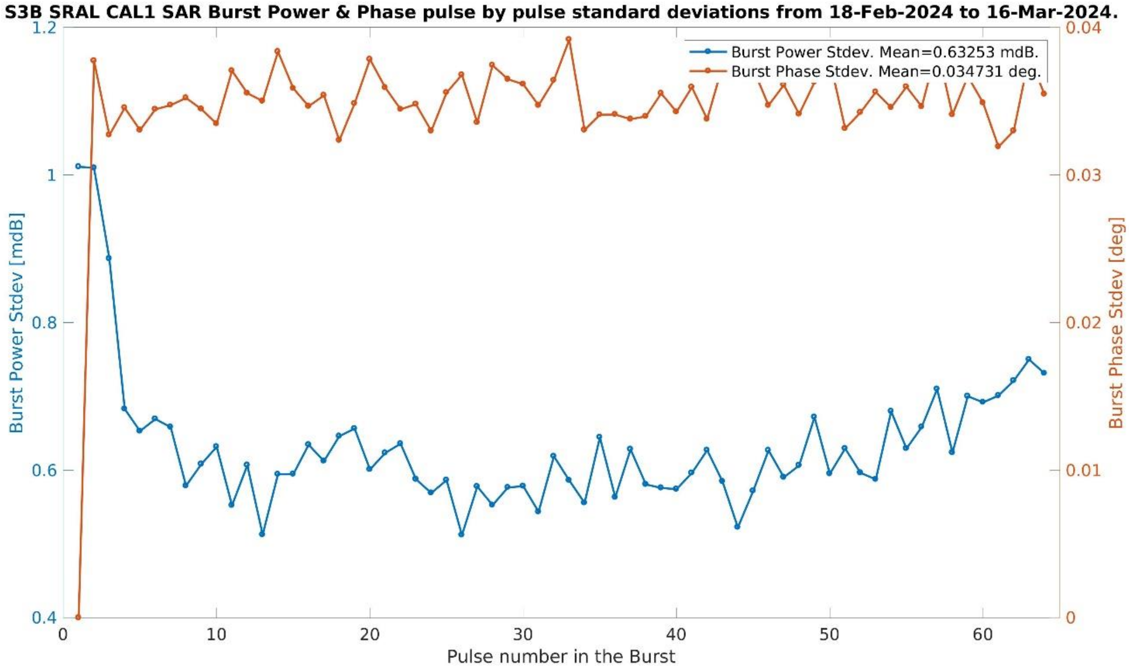


Figure 4-16. S3B Pulse by pulse standard deviations of the CAL1 SAR Ku Power and Phase intra-burst corrections.

4.1.2 CAL2

Geolocation of the CAL2 measurements for SAR mode.

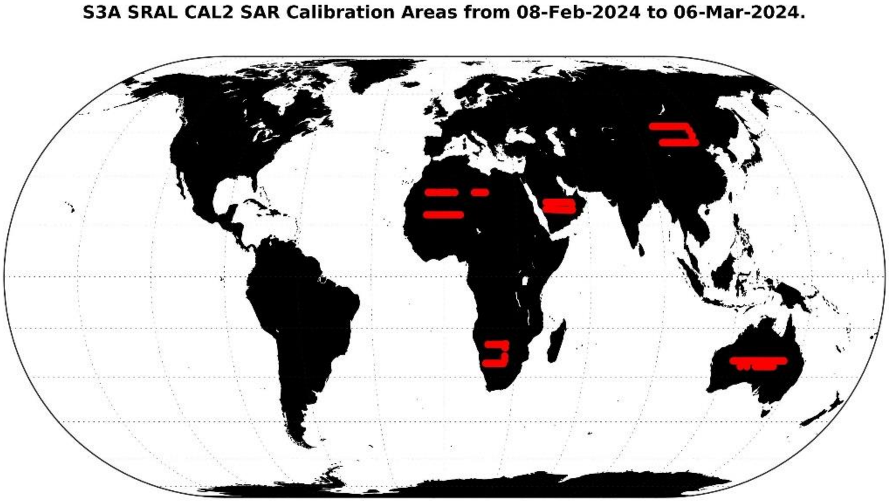


Figure 4-17. S3A Location of the CAL2 SAR measurements.

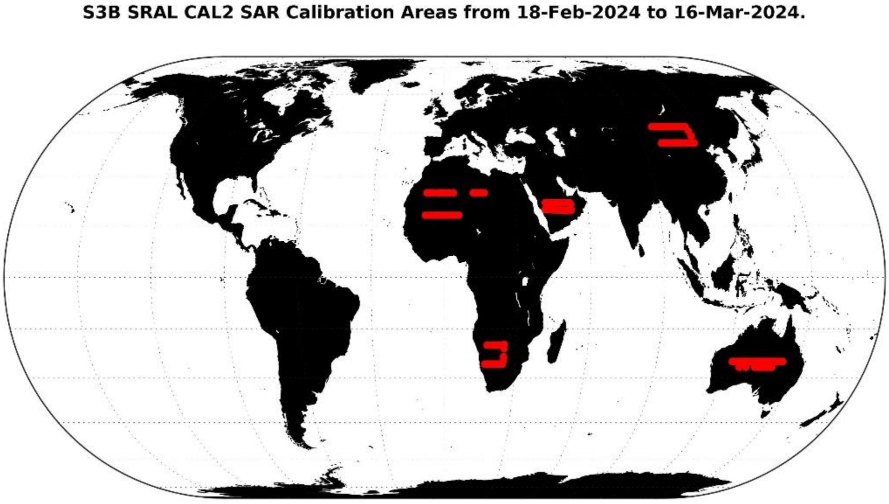


Figure 4-18. S3B Location of the CAL2 SAR measurements.

CAL2 SAR waveforms averaged over the cycle.

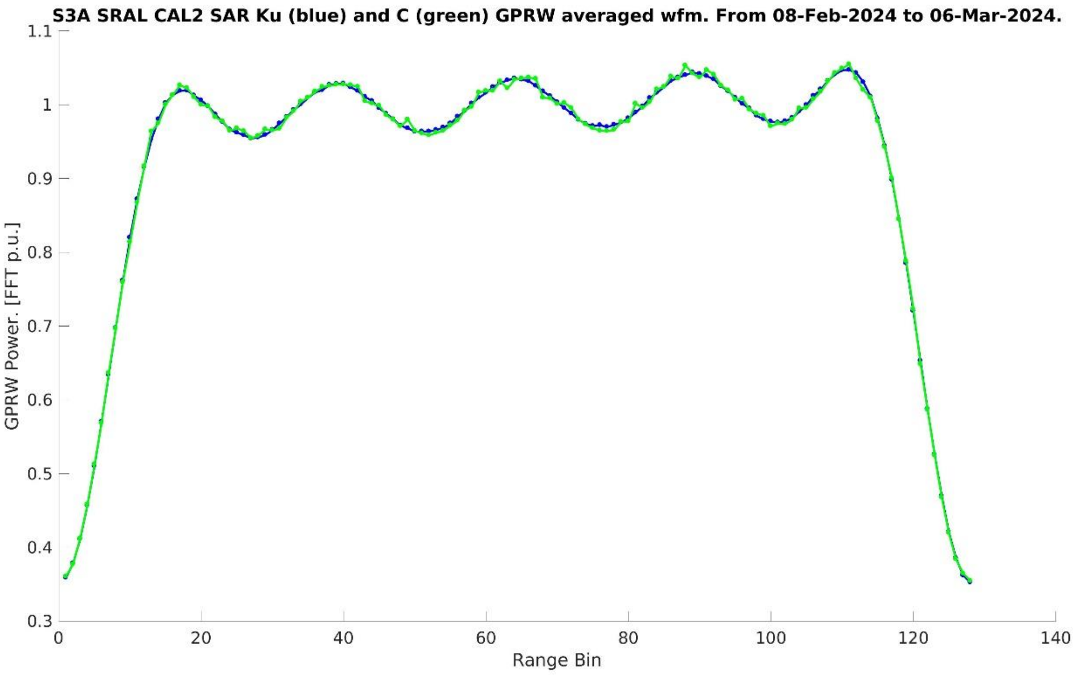


Figure 4-19. S3A Averaged CAL2 SAR Ku and C waveforms over the cycle.

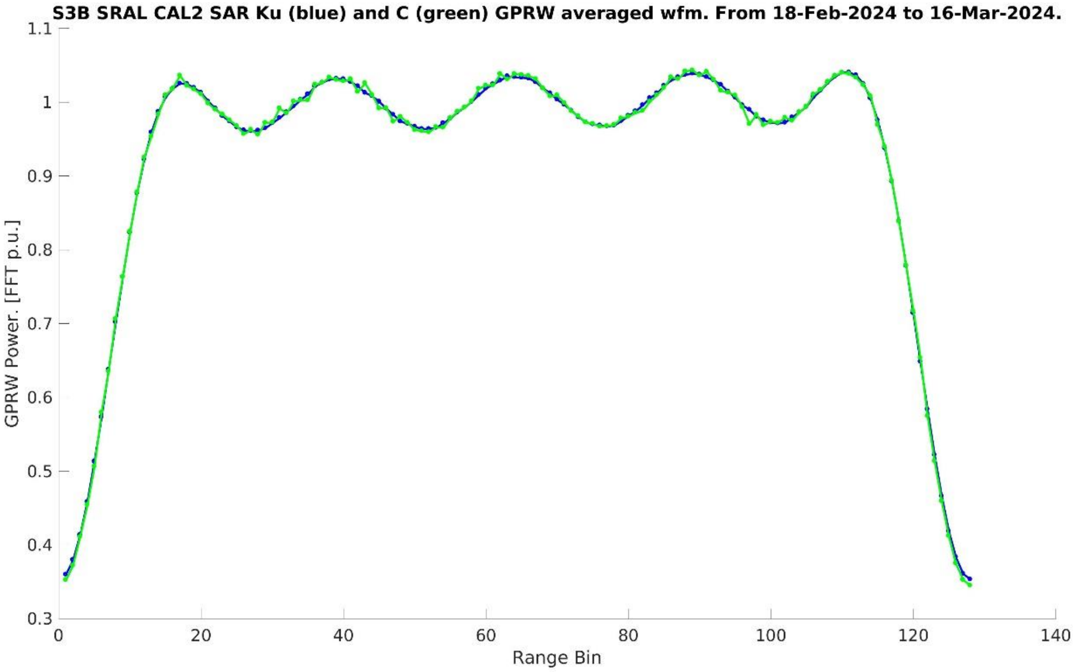


Figure 4-20. S3B Averaged CAL2 SAR Ku and C waveforms over the cycle.

Time series of CAL2 SAR waveforms right and left sides Slope.

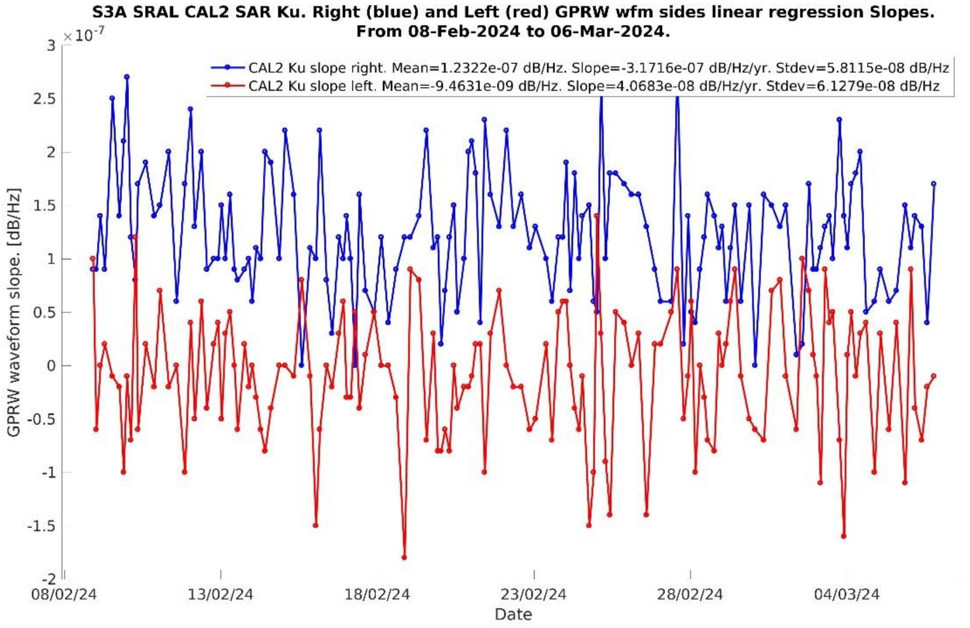


Figure 4-21. S3A CAL2 SAR Ku waveforms right (blue) and left (red) sides Slope over the period.

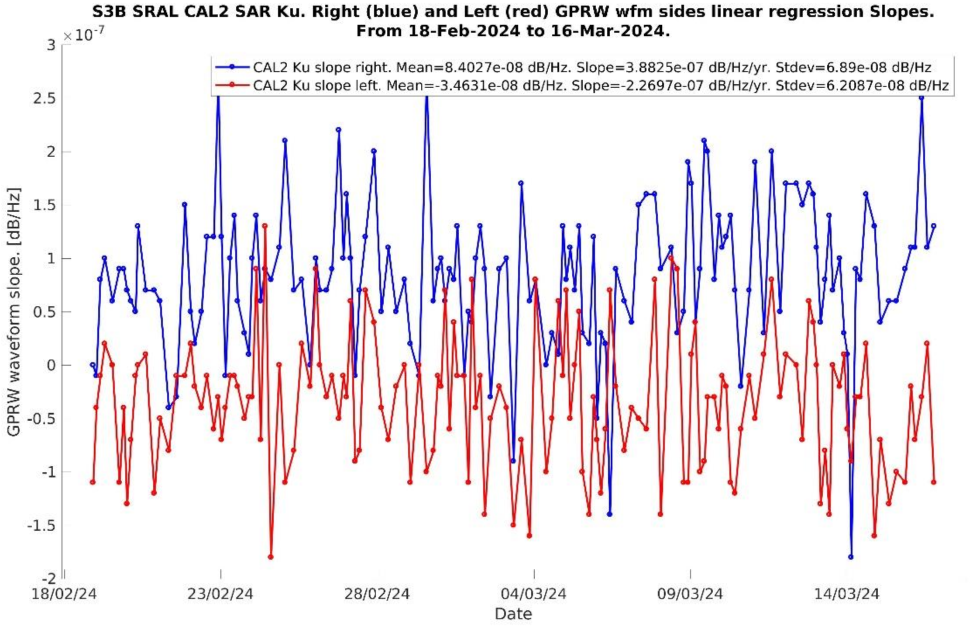


Figure 4-22. S3B CAL2 SAR Ku waveforms right (blue) and left (red) sides Slope over the period.

Time series of CAL2 SAR waveforms right and left sides Standard Deviation.

Figure 4-23. S3A CAL2 SAR Ku waveforms right (blue) and left (red) sides Standard Deviation over the period.

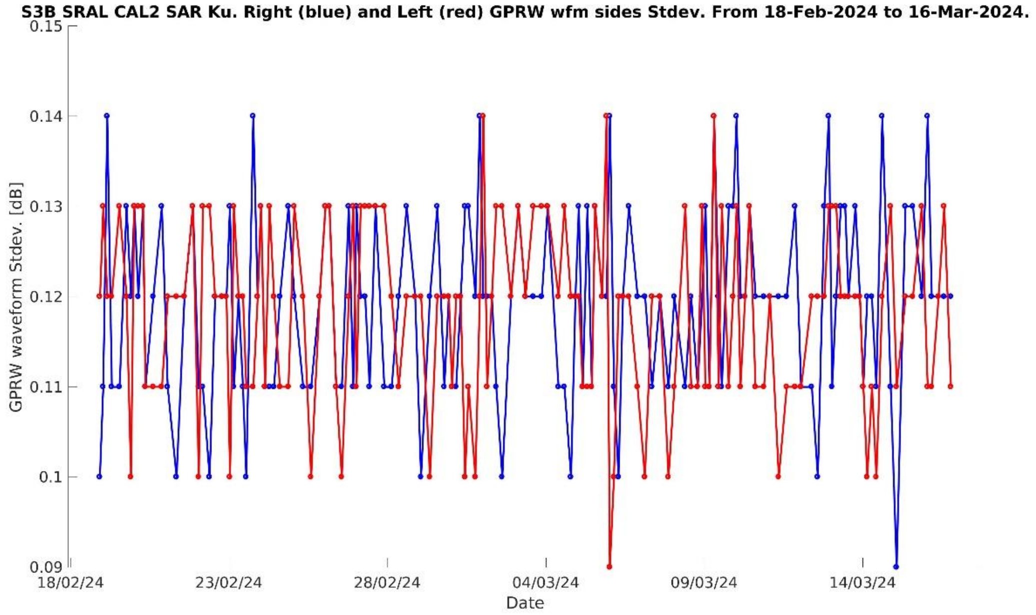
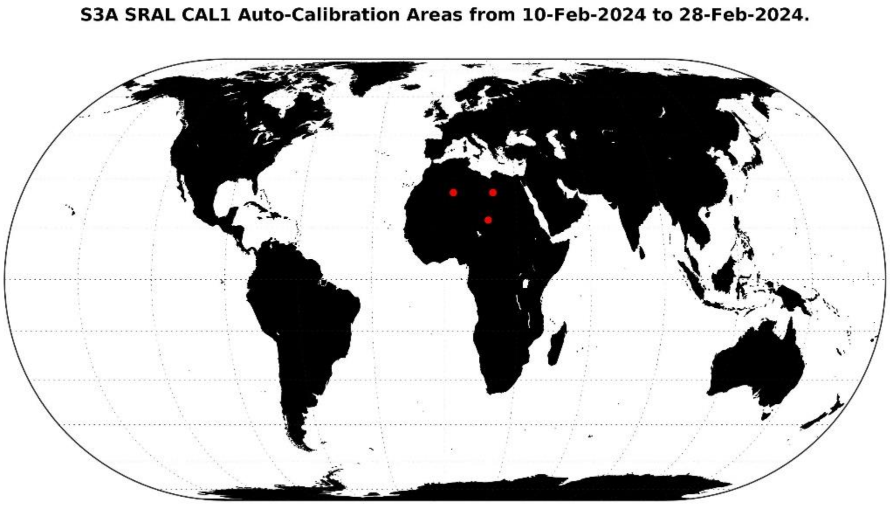
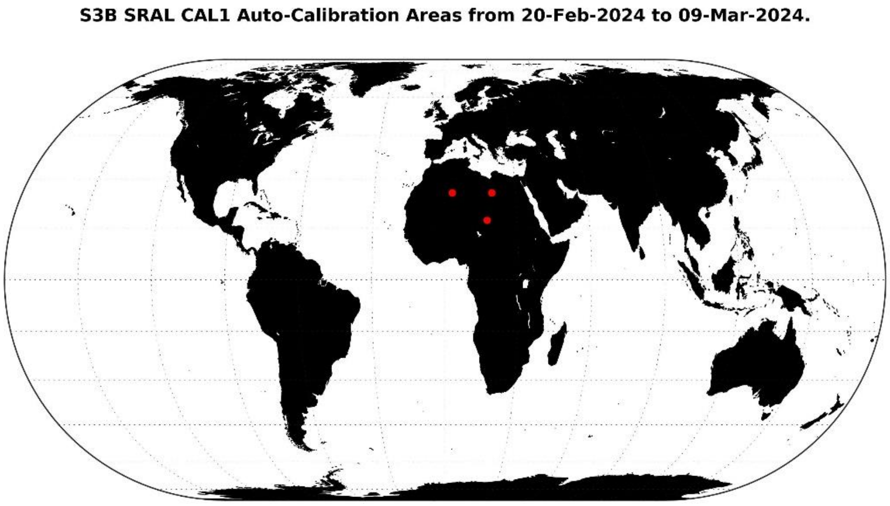


Figure 4-24. S3B CAL2 SAR Ku waveforms right (blue) and left (red) sides Standard Deviation over the period.

4.1.3 AutoCal

Geolocation of the AutoCal mode measurements.
 Figure 4-25. S3A Location of the AutoCal measurements.
 Figure 4-26. S3B Location of the AutoCal measurements.

Averaged AutoCal measurements (Corrected – Reference).

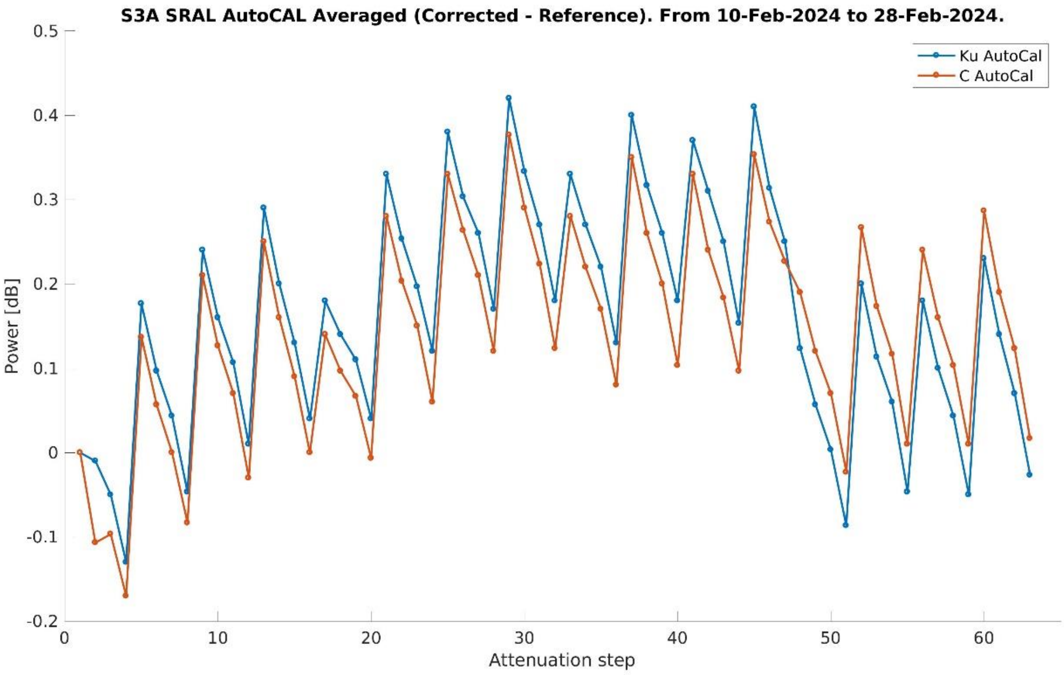


Figure 4-27. S3A AutoCal measurements: Corrected - Reference. Averaged over the cycle.

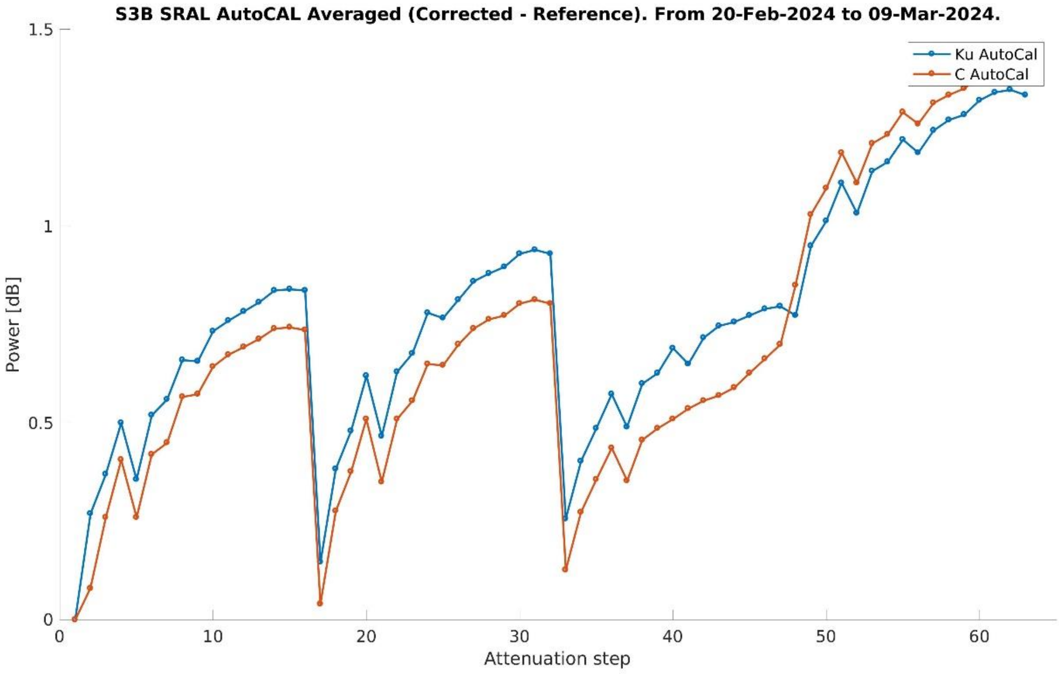


Figure 4-28. S3B AutoCal measurements: Corrected - Reference. Averaged over the cycle.

Progression of the AutoCal measurements for Ku band.

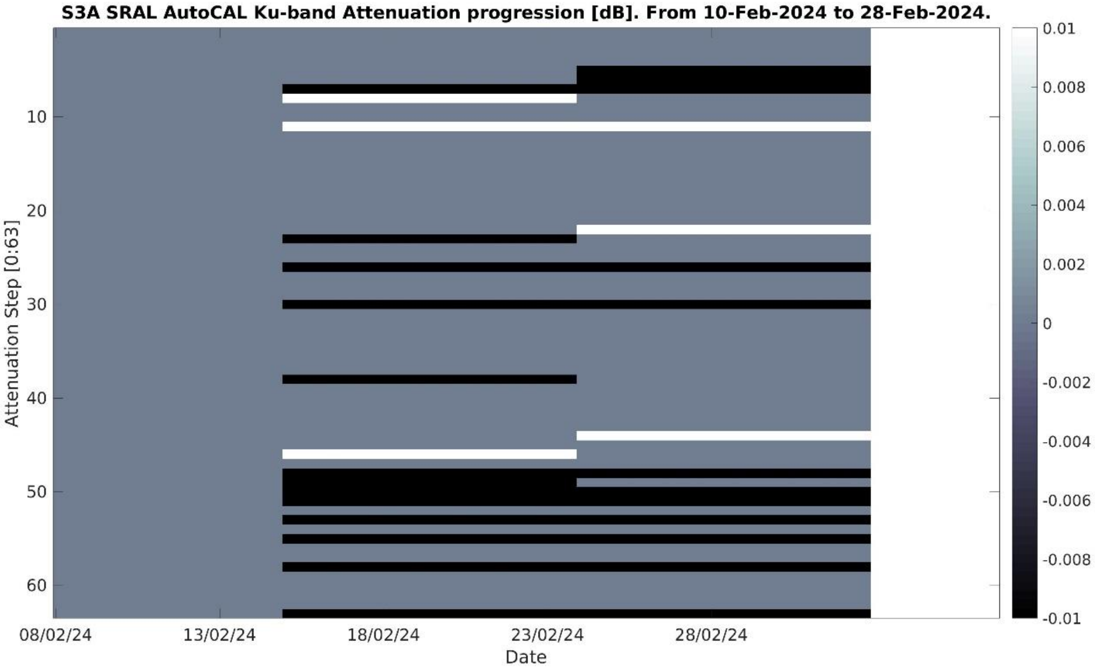


Figure 4-29. S3A Ku band Autocal Cycle Progression.

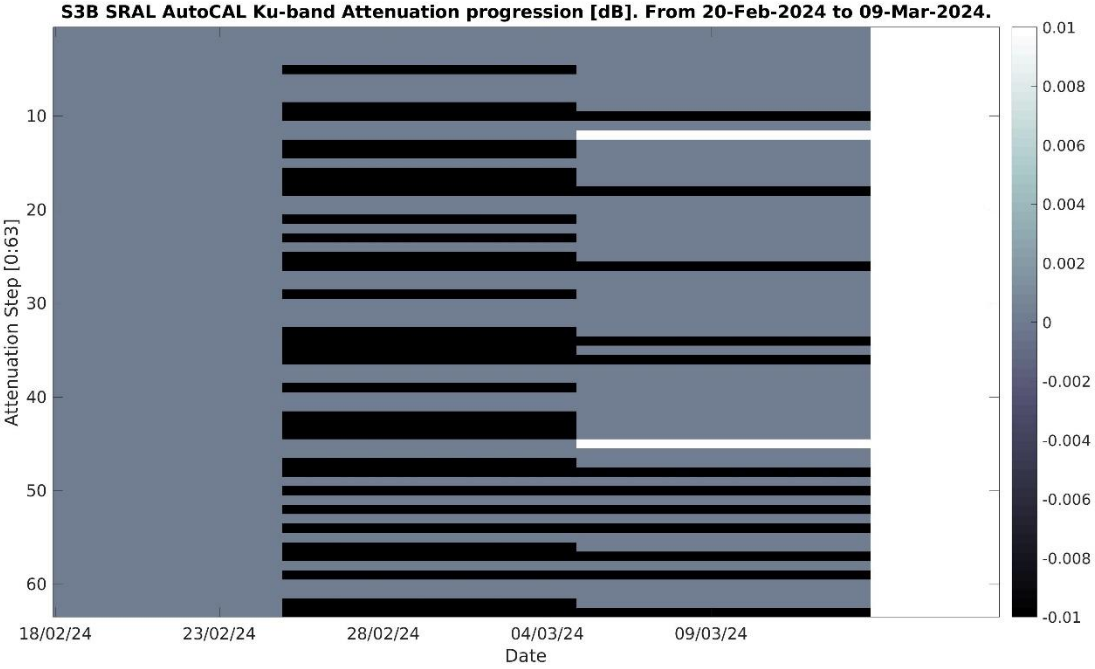


Figure 4-30. S3B Ku band Autocal Cycle Progression.

4.1.4 Thermal behaviour

The CAL1 SAR mode is assumed to be representative of the general SRAL thermal behaviour.

Time series of thermistors temperatures on CAL1 SAR mode over the cycle.

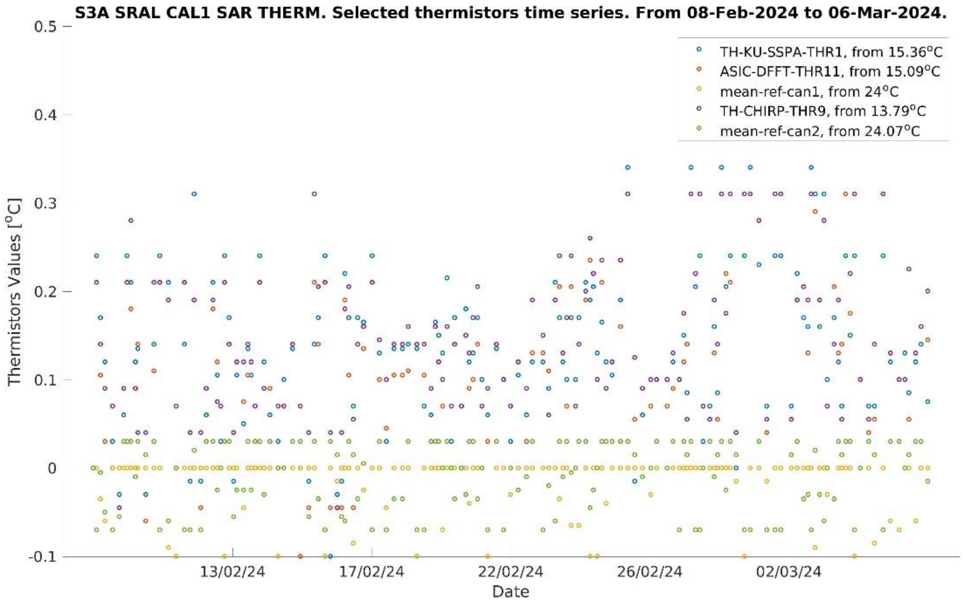


Figure 4-31. S3A Selected group of Thermistors time series on CAL1 SAR mode. The temperatures are averaged for each calibration product.

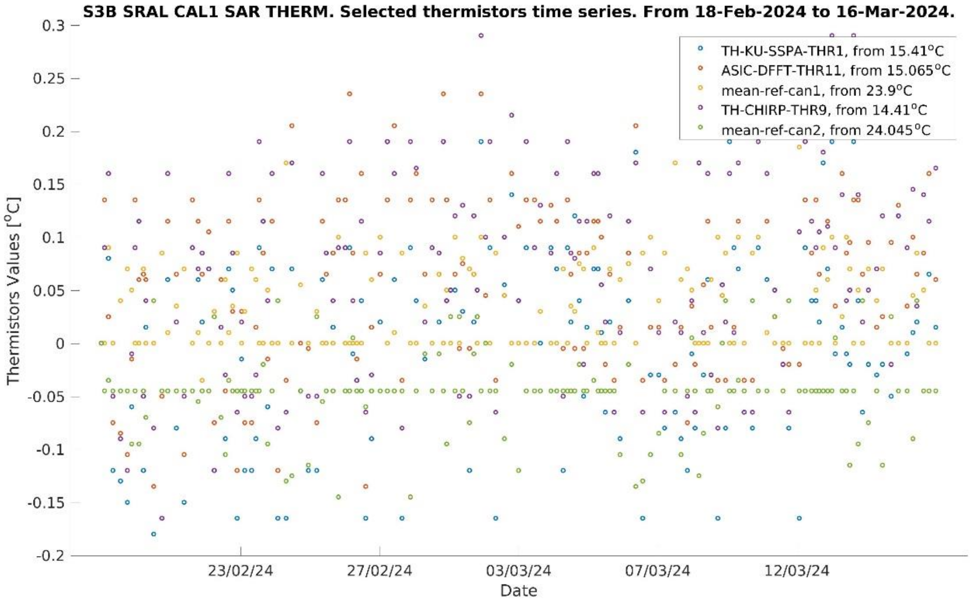


Figure 4-32. S3B Selected group of Thermistors time series on CAL1 SAR mode. The temperatures are averaged for each calibration product.

4.1.5 Cyclic Status Summary

This section is dedicated to a summary of the cyclic performances and status of the altimeter parameters exposed in sections 4.1.1 to 4.1.4. It covers both S3A and S3B missions.

The behaviour of the delay trends for both missions is nominal and stable for the period.

The S3A CAL1 power trend for Ku band is no longer close to -1 dB/year as at the first cycles of the mission. It presents a decreasing trend but much less steep than at BOM.

The power slopes are below absolute values of 1 dB/year for both modes and bands.

The CAL1 width drifts are several orders of magnitude below the nominal PTR width value.

CAL2 parameters are stable and nominal. They are similar between the two missions.

The secondary lobes present a dissymmetry that is evolving along the mission, with notable changes after a restart of the instrument. Generally, in the figures of the characterisation of the secondary lobes during the cycle, we can see differences of standard deviation between some secondary lobes. Some left-side secondary lobes tend to show higher standard deviation than the right-side ones.

AutoCal tables are nominal for both missions, and present very different attenuation steps arrays. This is not due to a fundamental difference between the S3A and S3B instruments design, but due to a different strategy for reaching the same theoretical attenuation steps values.

The thermistors values are showing generally a stable series over the analysed period.

All these observations are related to the different SRAL calibration parameters during this cycle. A whole mission monitoring is developed in section 4.2. Some of the cycle behaviours could give us the idea of a significant change of rate, but when observed within the full mission scenario, they come into scale.

4.2 Mission Status Summary

The main calibration parameters series of S3A and S3B missions are gathered and plotted in this section, in order to observe their whole mission's behaviour.

The selected calibration parameters are:

- CAL1 time delay
- CAL1 power
- PTR width
- Burst corrections (power and phase) and their slopes
- CAL2 waveform's slopes
- Autocal averaged differences and attenuation progression
- USO correction

The SAR mode thermistors series are also plotted after reading the CAL ISP TM products.

Additionally, it is represented a simulation (power model fitting) of the S3A CAL1 SAR Ku Integrated Power, in order to predict how long the SRAL Power would meet the mission requirements based in the in-flight behaviour. This need comes from the warning raised at BOM due to a high CAL1 Power drop.

The "whole mission" figures avoid a period at BOM. For the S3A mission, the considered series starts at 27/5/2016 (Cycle 4, orbit 302). For the S3B mission it starts at 12/7/2018 (Cycle 10, orbit 210). The BOM period include calibration parameters behaviours that, if included in our monitoring results, can disturb the analysis and projections made for the rest of the mission. At BOM the main parameters tend to show opposite trends with respect to the routine phase, and in the case of S3B, several operational mode changes cause jumps in the series.

The altimeter USO clock frequency has a major multiplicative impact in the determination of the altimeter range. The USO clock is the one that drives the chirp generation and controls the acquisition time (window delay or tracker range) of the returned echo signal. We depict the USO frequency impact on the altimeter range. The USO impact in the range can change around an orbit considering an elliptical orbit and the variations on the surface elevations, but these differences are far below the nominal absolute values. In addition, the temperatures on-board can make the clock suffer frequency fluctuations, but as we will see in the figures, there are no visible effects of this kind so far.

CAL1 SAR mode Ku Time Delay Whole Mission Trend.

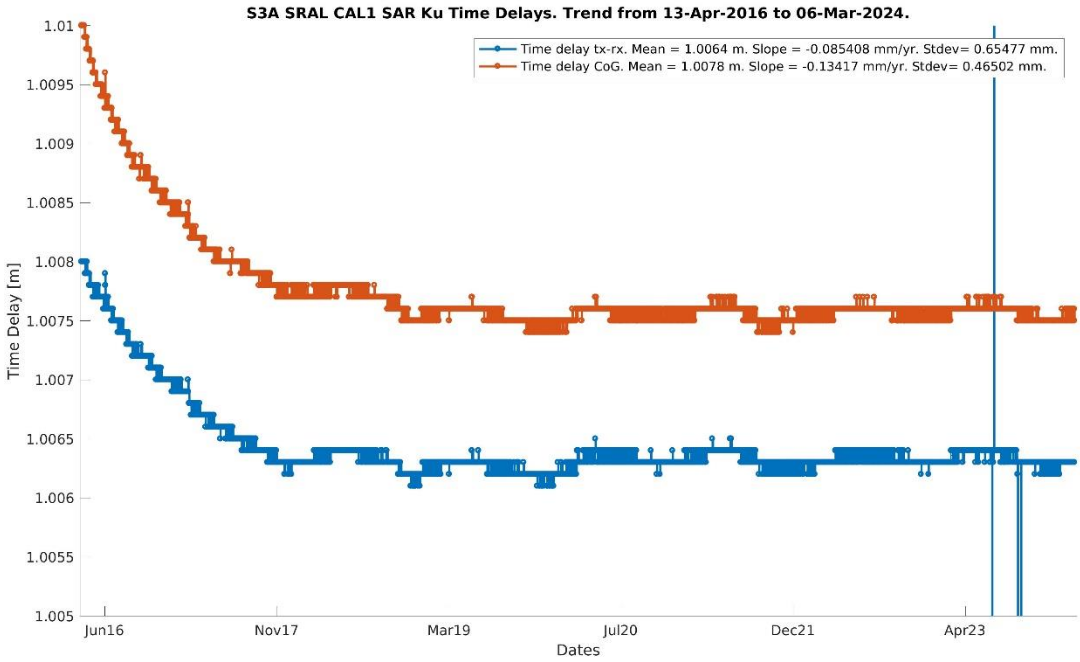


Figure 4-33. S3A CAL1 SAR Ku Time Delay Whole Mission Trend.

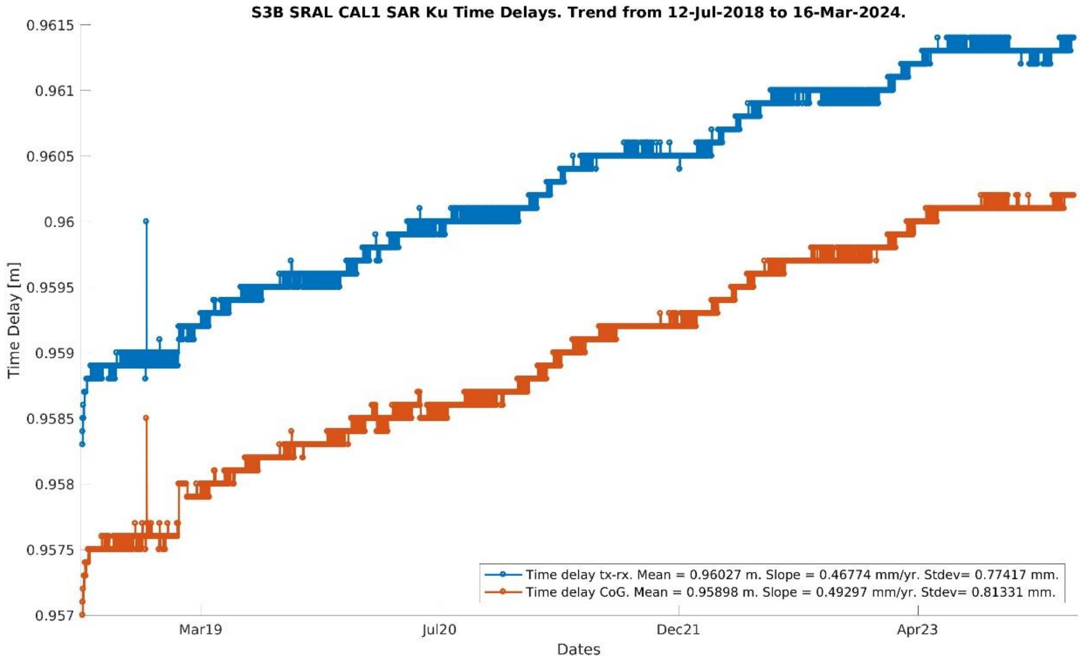


Figure 4-34. S3B CAL1 SAR Ku Time Delay Whole Mission Trend.

CAL1 SAR mode Ku Power Whole Mission Trend.

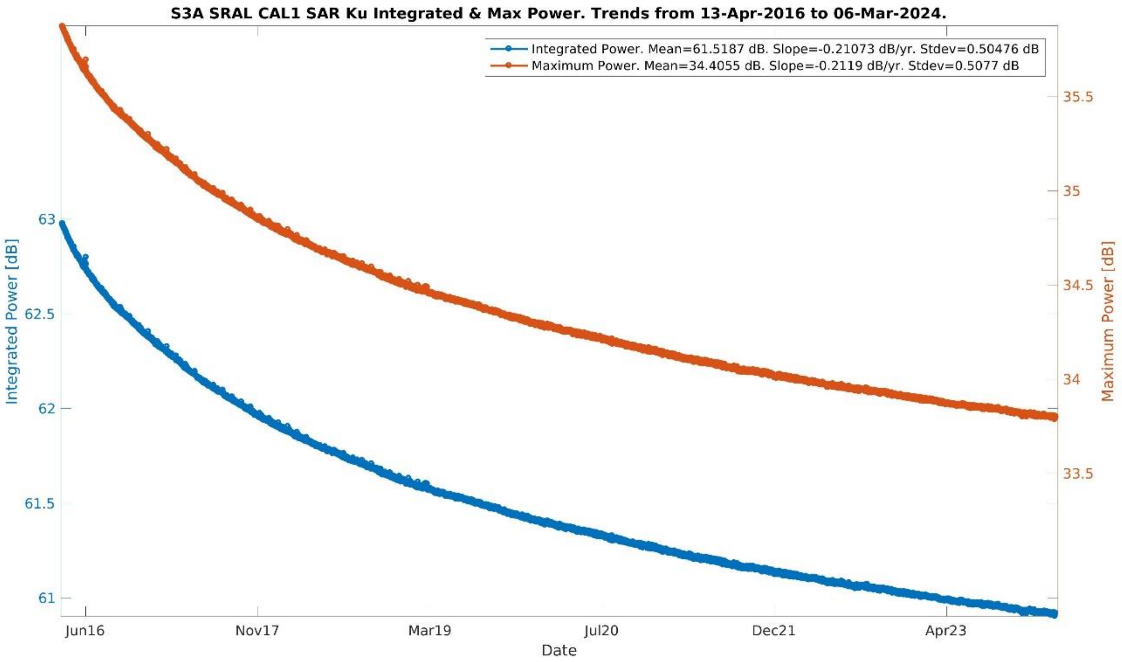


Figure 4-35. S3A CAL1 SAR Ku Power Whole Mission Trend.

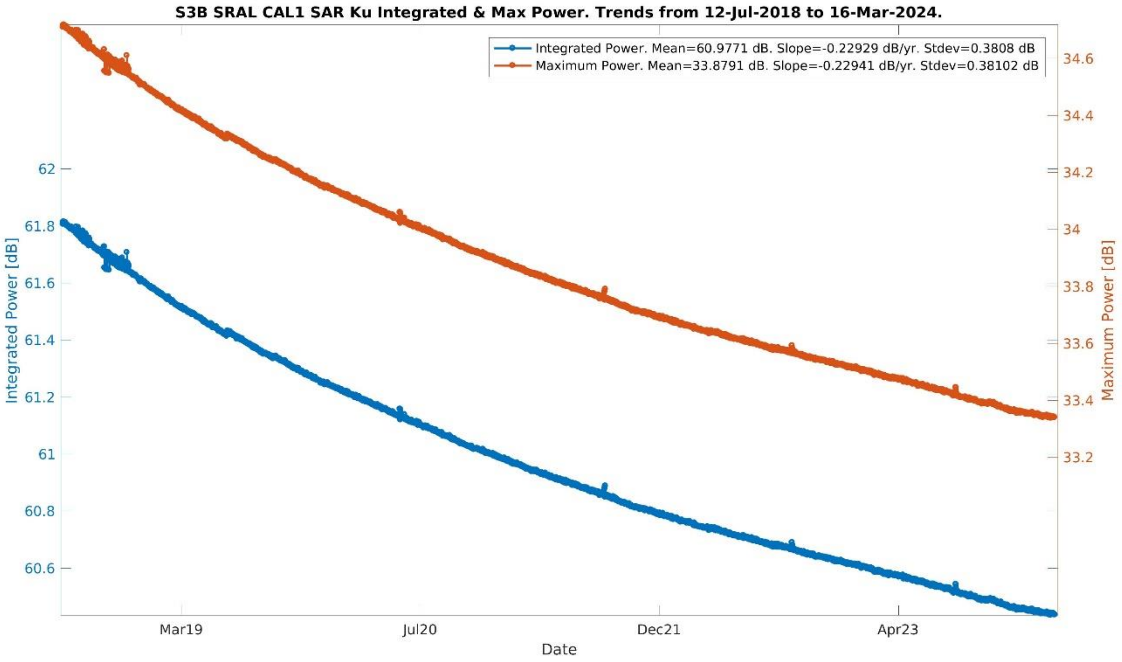


Figure 4-36. S3B CAL1 SAR Ku Power Whole Mission Trend.

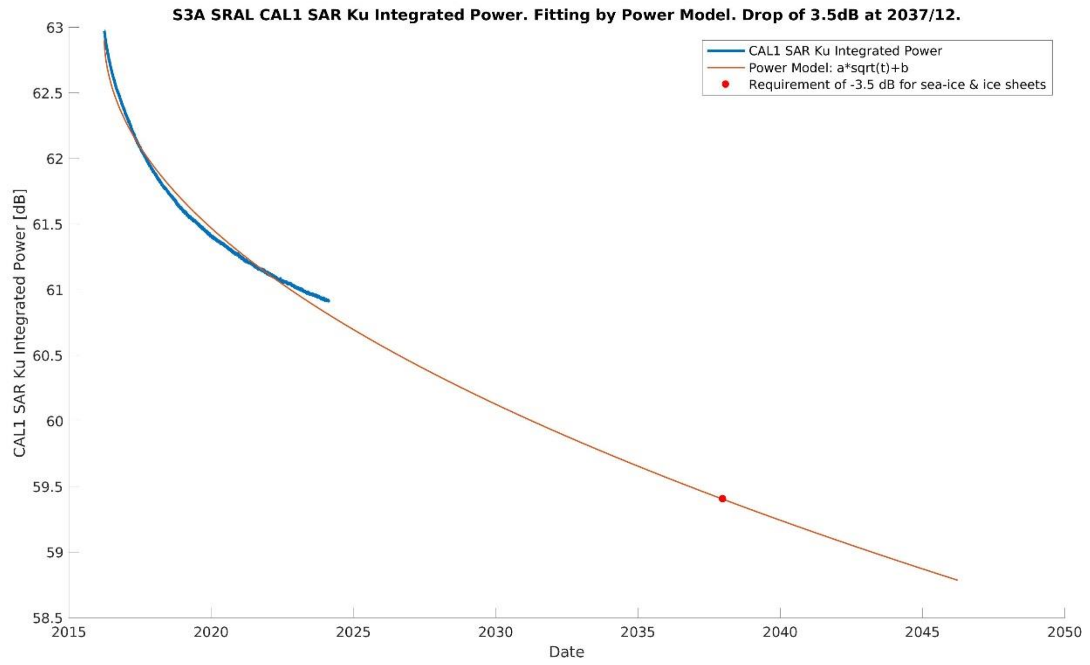


Figure 4-37. S3A CAL1 SAR Ku Power series and long-term trend prediction with power model.

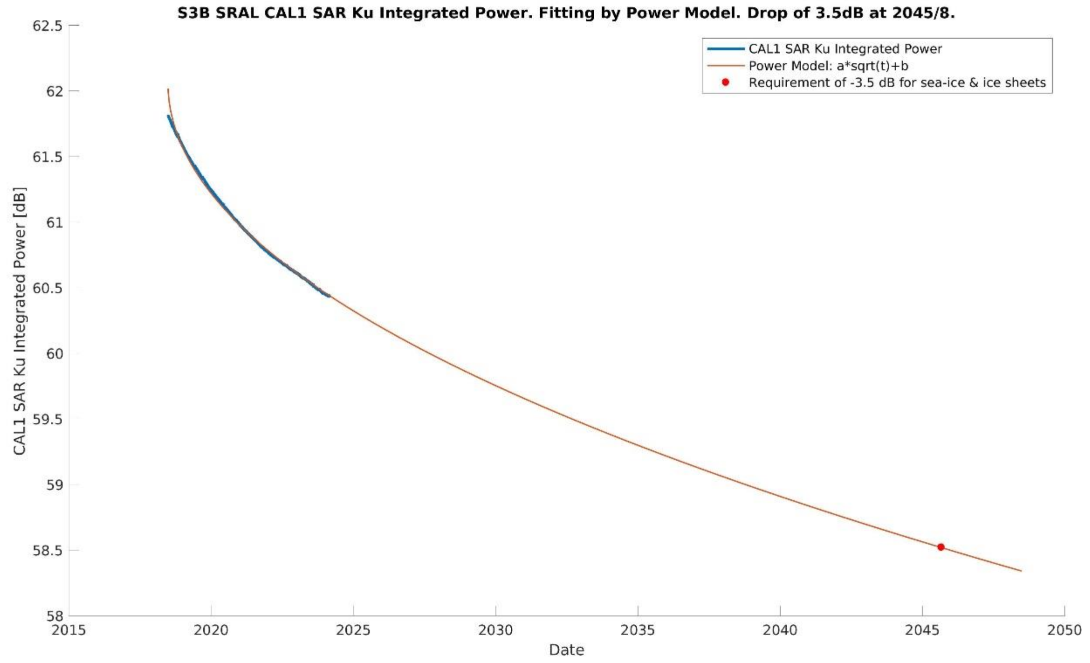


Figure 4-38. S3B CAL1 SAR Ku Power series and long-term trend prediction with power model.

CAL1 SAR mode Ku PTR Width Whole Mission Trend.

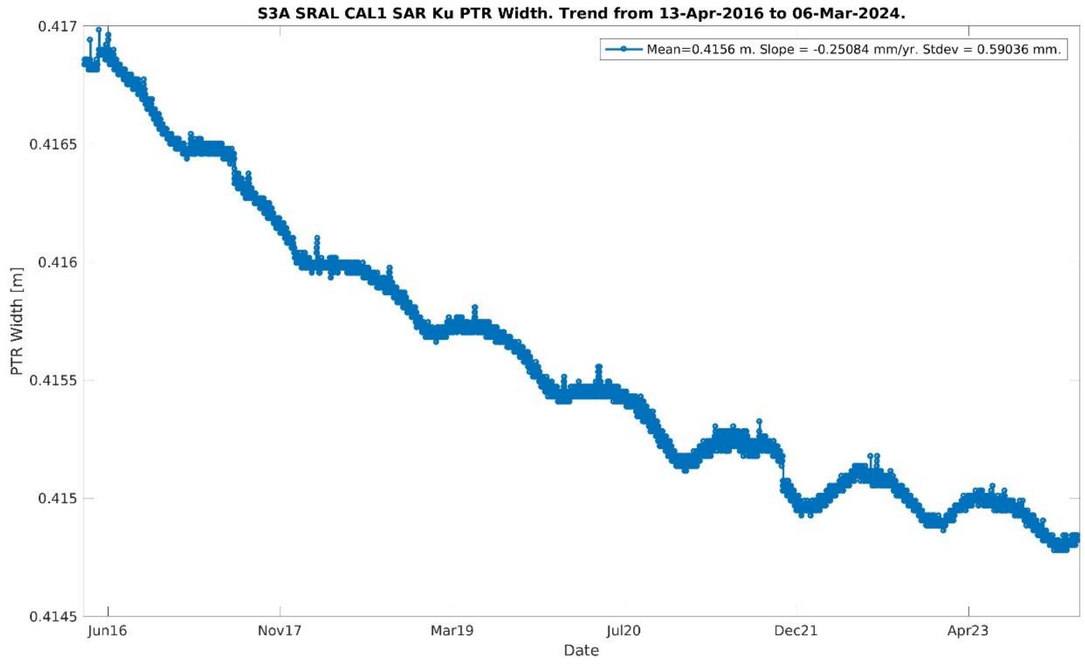


Figure 4-39. S3A CAL1 SAR Ku PTR Width Whole Mission Trend.

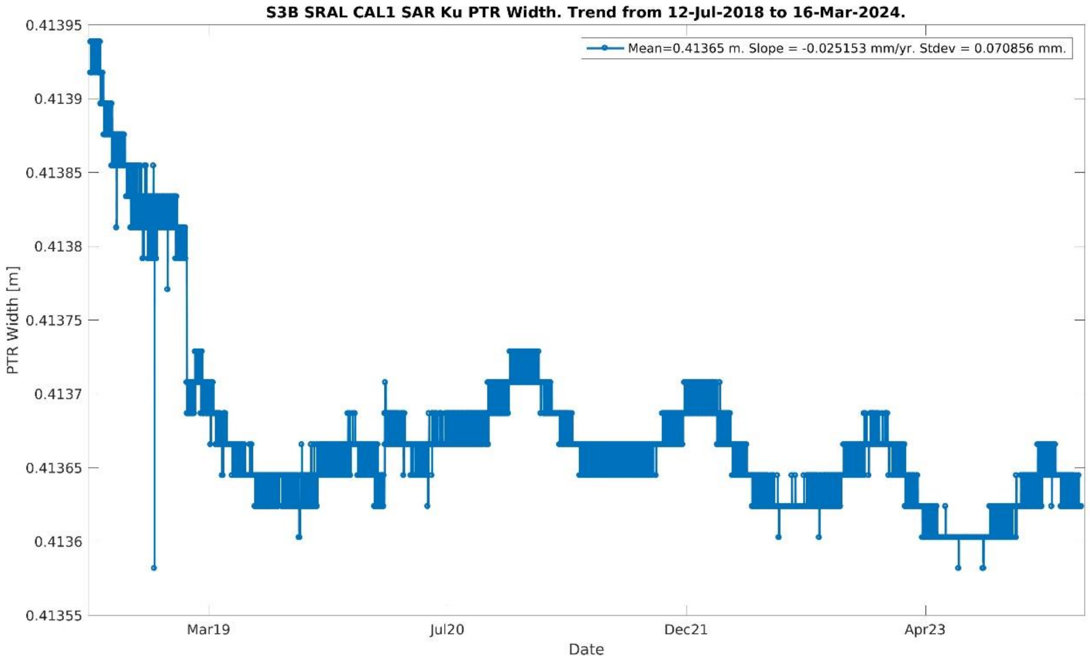


Figure 4-40. S3B CAL1 SAR Ku PTR Width Whole Mission Trend.

Whole Mission Trend of CAL1 SAR mode Ku Phase & Power intra-burst corrections slopes.

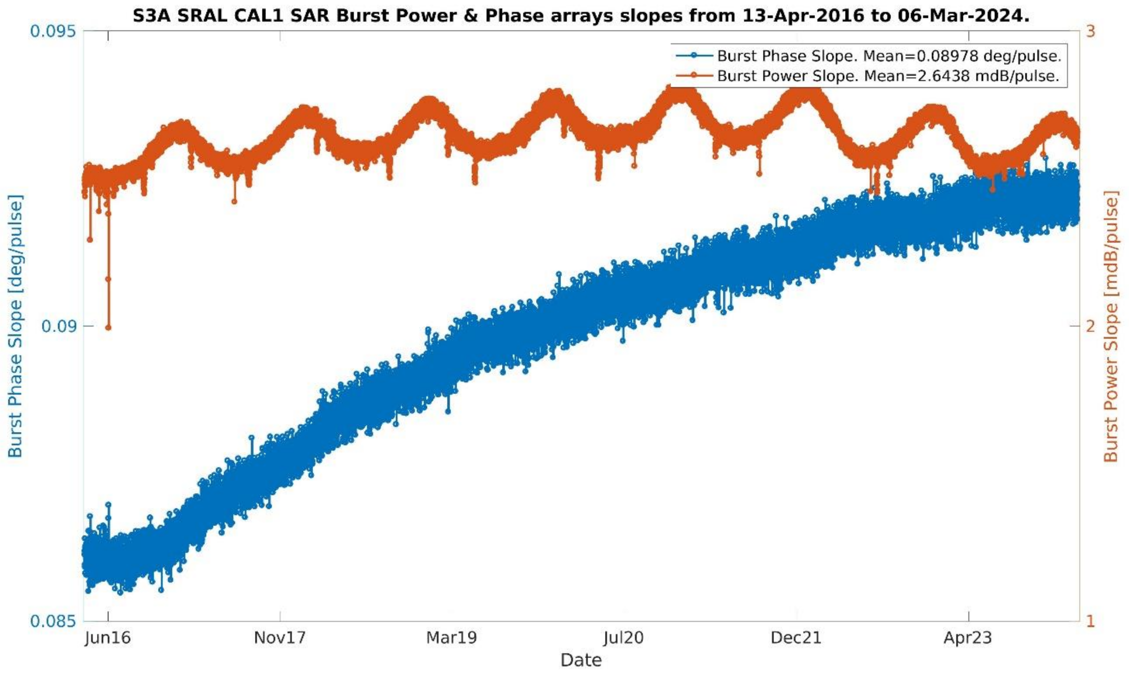


Figure 4-41. S3A CAL1 SAR Ku Phase & Power intra-burst corrections slopes along the whole mission.

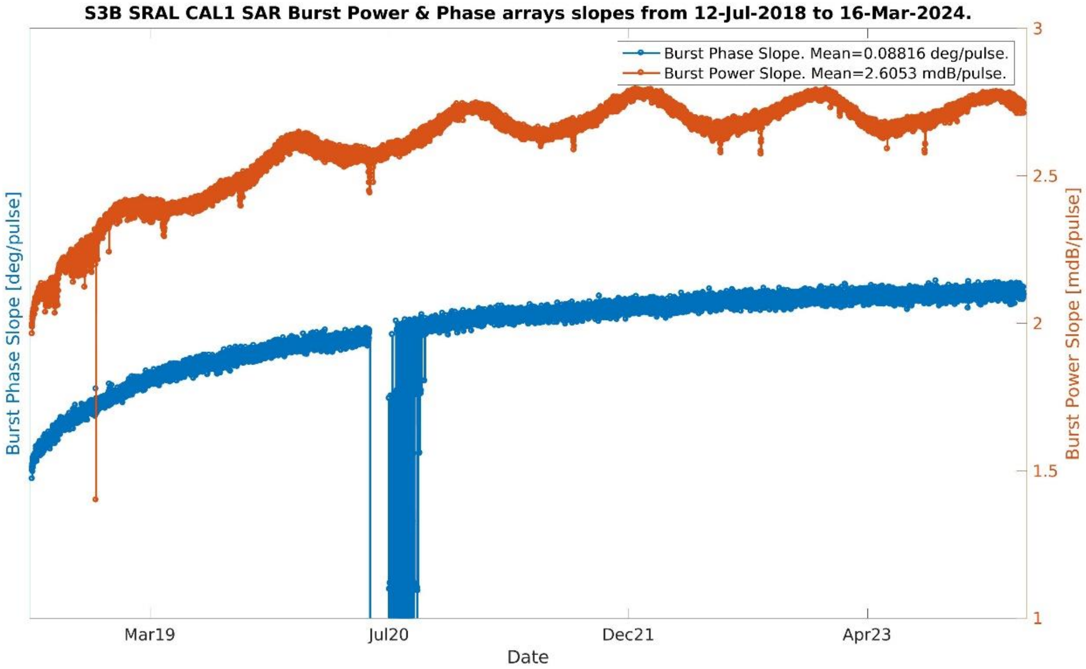


Figure 4-42. S3B CAL1 SAR Ku Phase & Power intra-burst corrections slopes along the whole mission.

Whole Mission Trend of CAL1 SAR waveform secondary lobes power.

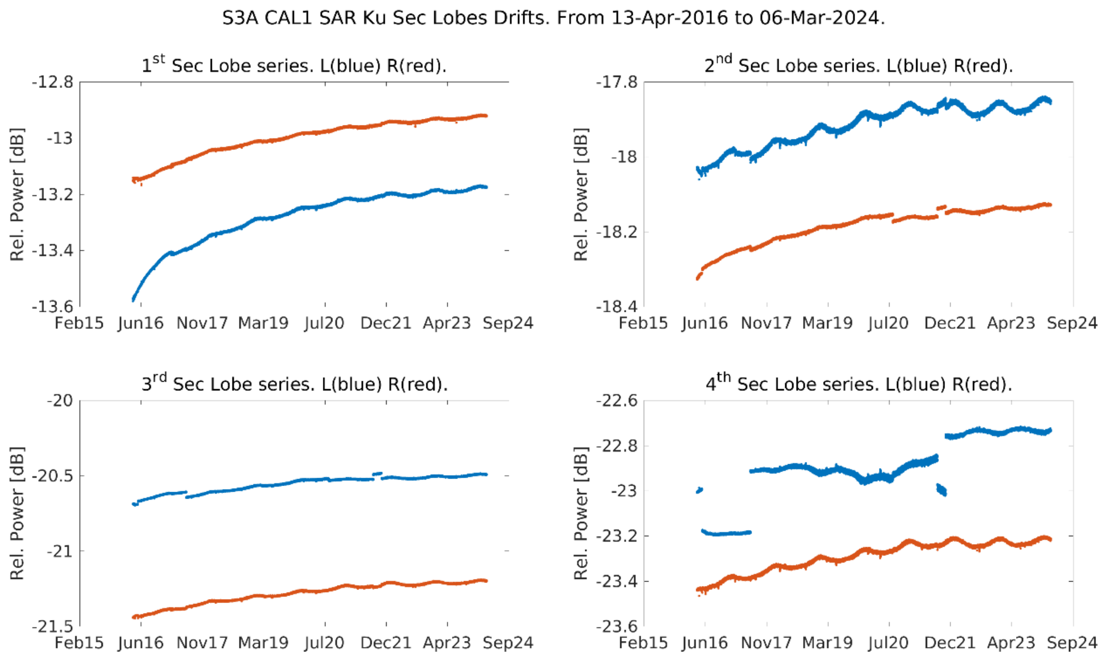


Figure 4-43. S3A CAL1 SAR waveform first four secondary lobes relative power along the mission.

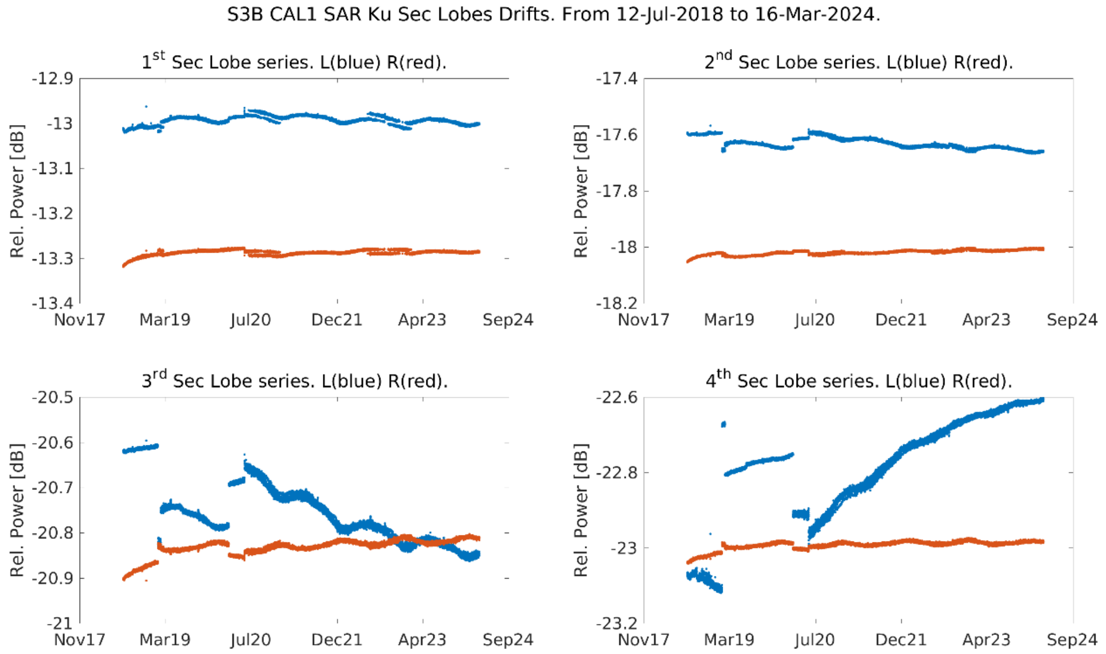


Figure 4-44. S3B CAL1 SAR waveform first four secondary lobes relative power along the mission.

Whole Mission Trend of CAL2 SAR waveform slope.

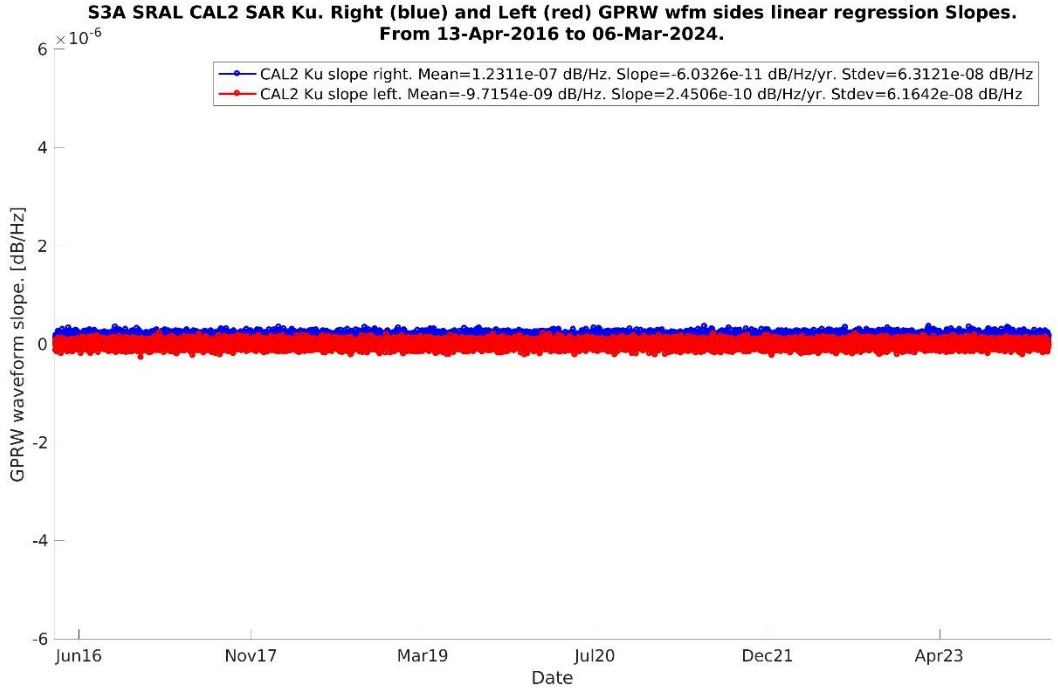


Figure 4-45. S3A Slope at each side of the CAL2 Ku waveform, averaged over the whole mission.

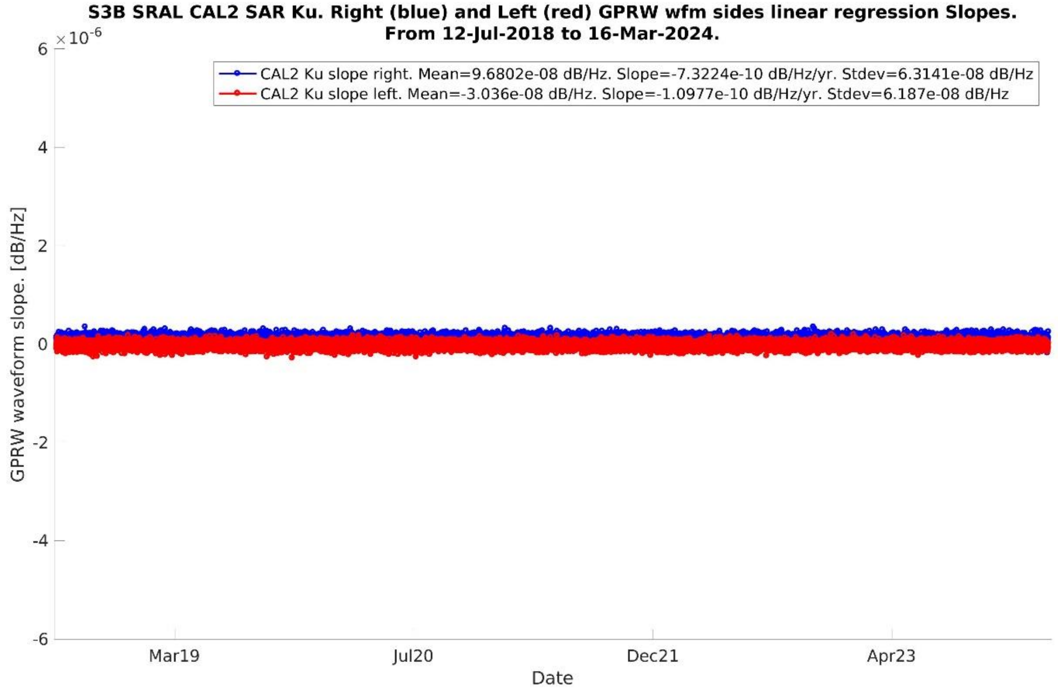


Figure 4-46. S3B Slope at each side of the CAL2 Ku waveform, averaged over the whole mission.

Whole Mission Averaged Differential AutoCal measurements.

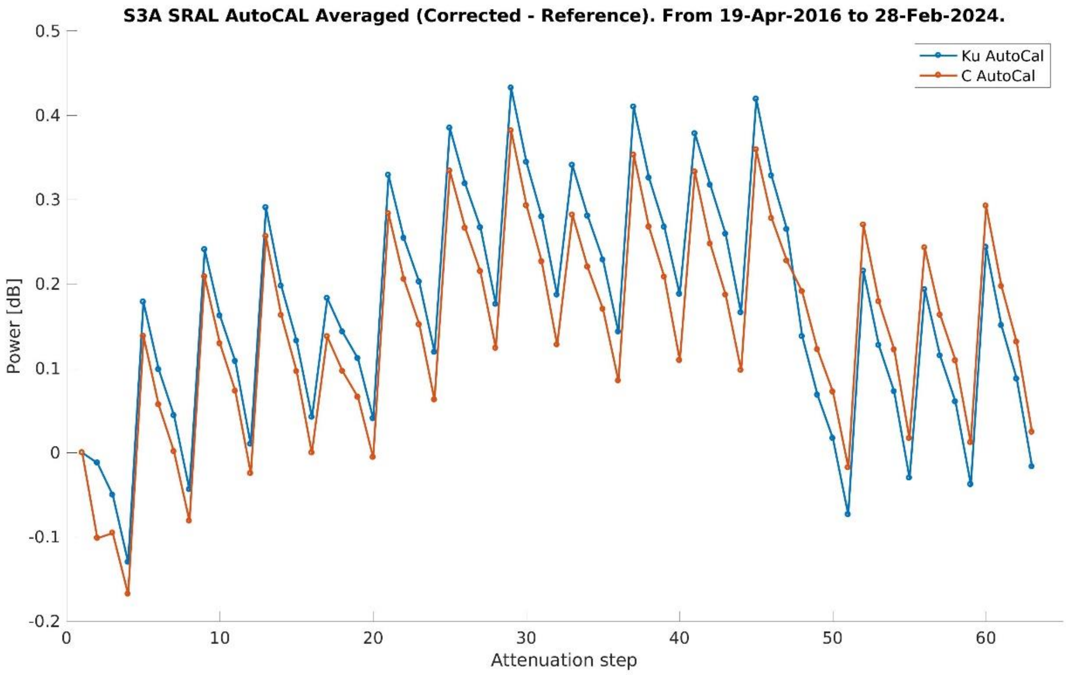


Figure 4-47. S3A Autocal measurements: Corrected - Reference. Averaged over the whole mission.

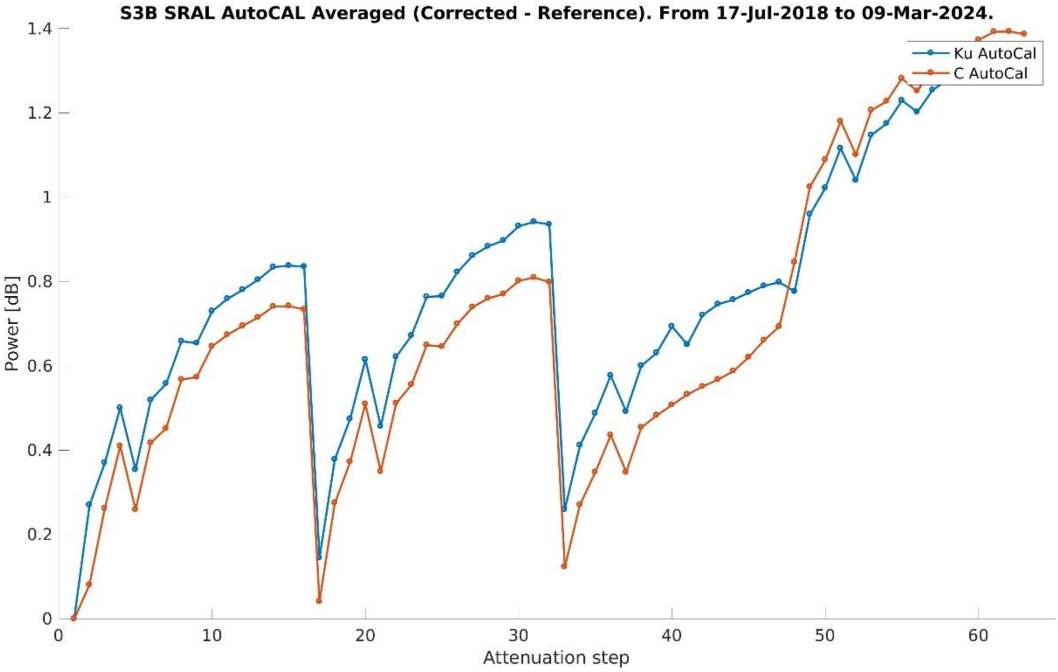


Figure 4-48. S3B Autocal measurements: Corrected - Reference. Averaged over the whole mission.

AutoCAL Ku band attenuation progression series.

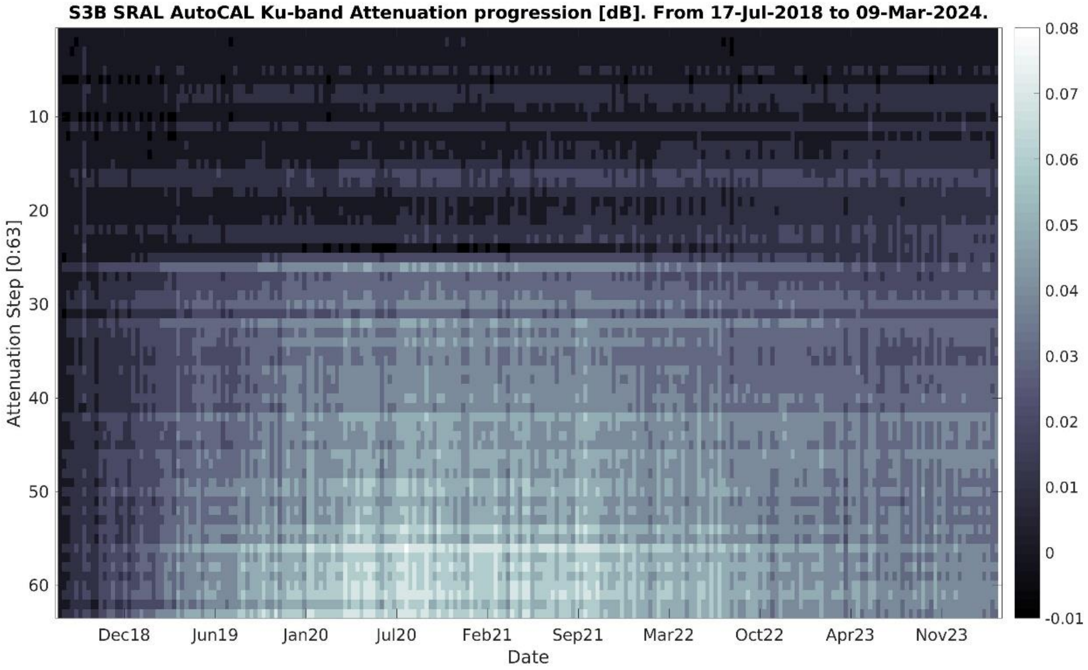


Figure 4-49. S3A AutoCAL Ku attenuation whole mission progression. Difference in dB with respect to the first attenuation value, for each attenuation step.

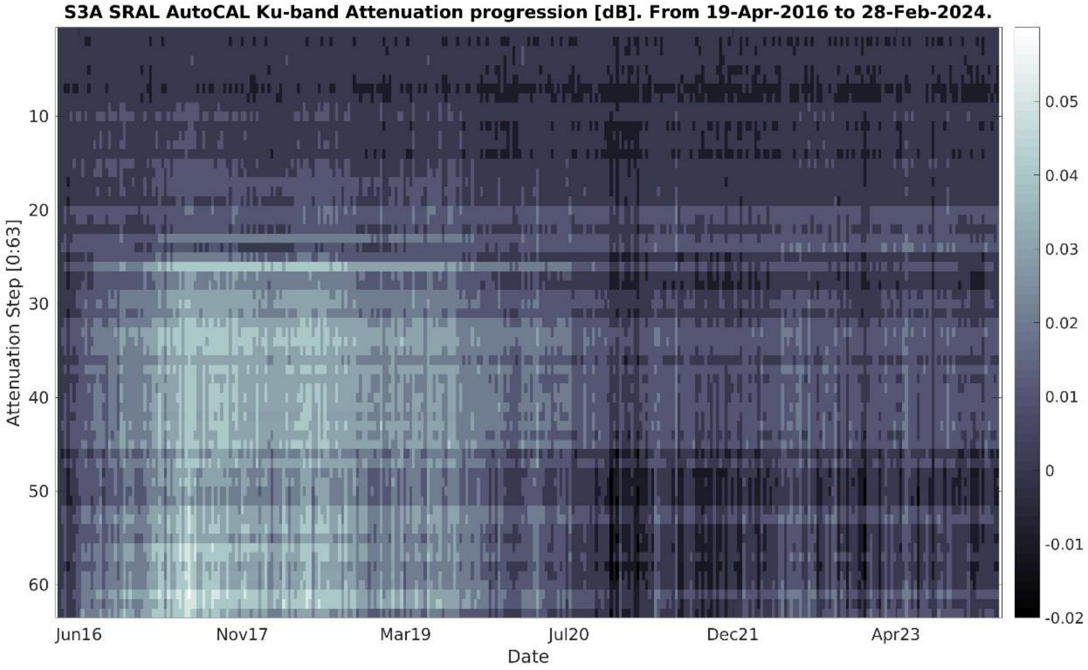


Figure 4-50. S3B AutoCAL Ku attenuation whole mission progression. Difference in dB with respect to the first attenuation value, for each attenuation step.

Time series of the USO frequency.

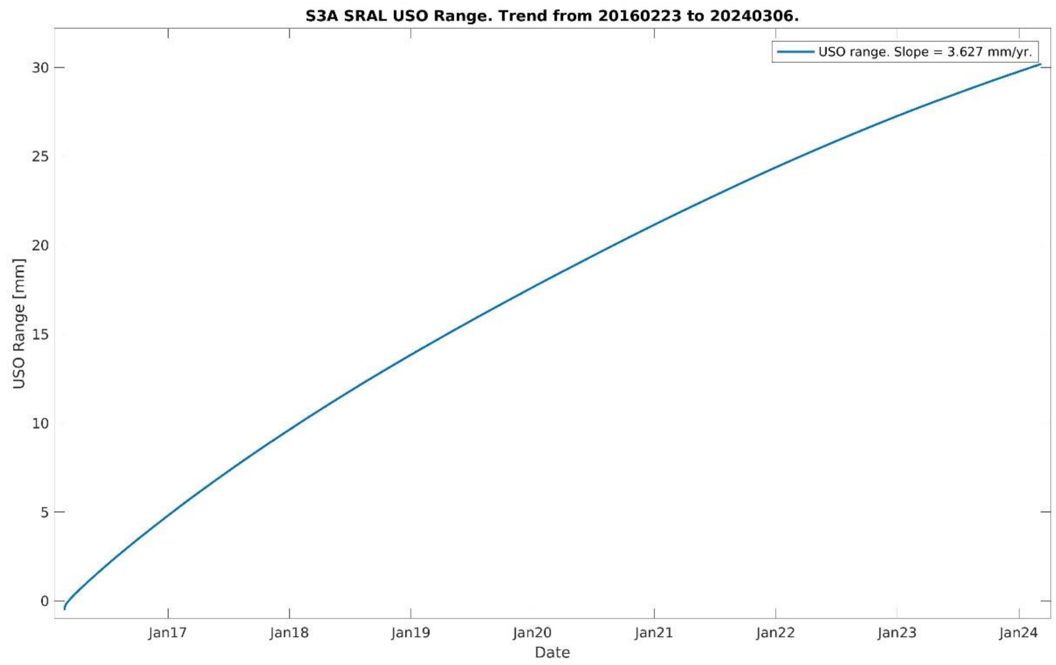


Figure 4-51. S3A USO frequency impact in the range.

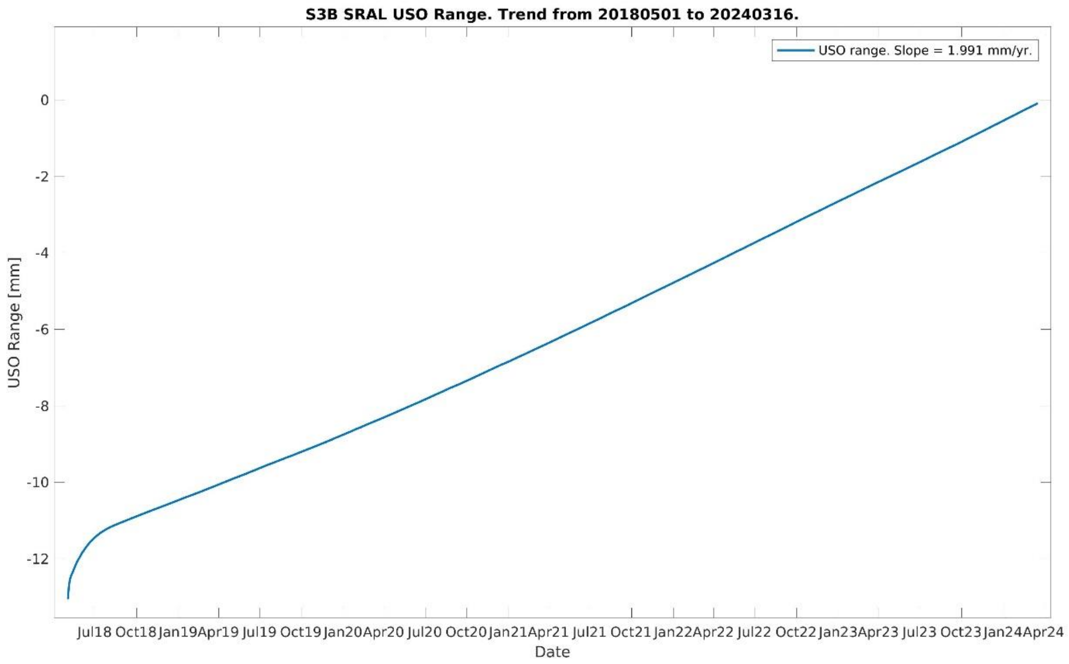


Figure 4-52. S3B USO frequency impact in the range.

CAL1 SAR thermistors series.

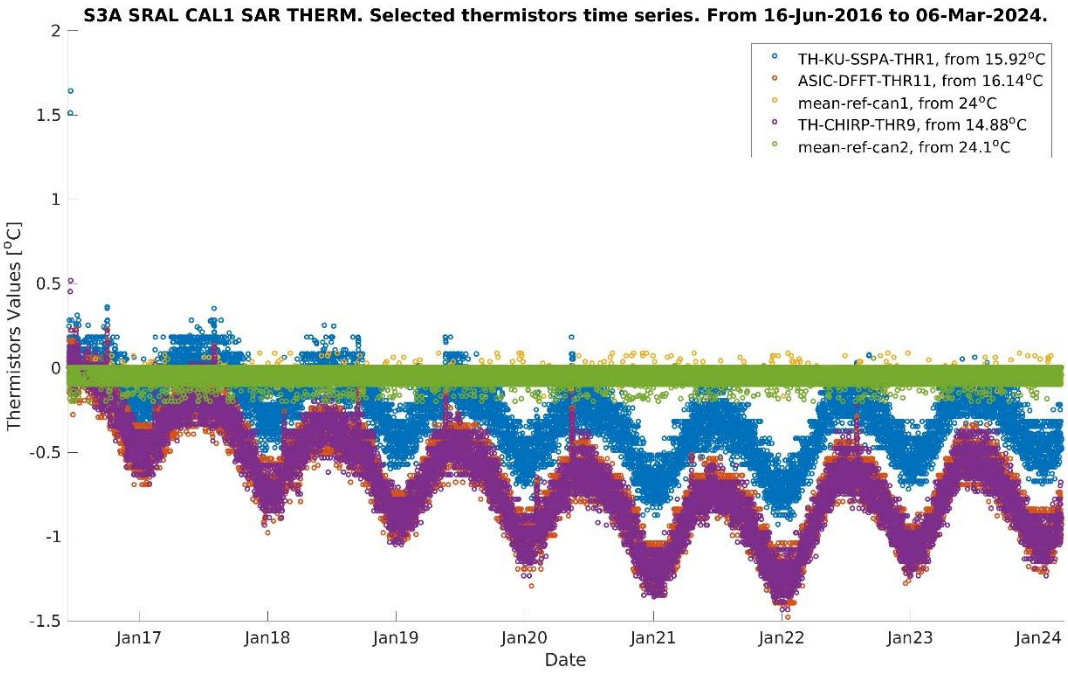


Figure 4-53. S3A Selected CAL1 SAR thermistors series along the whole mission.

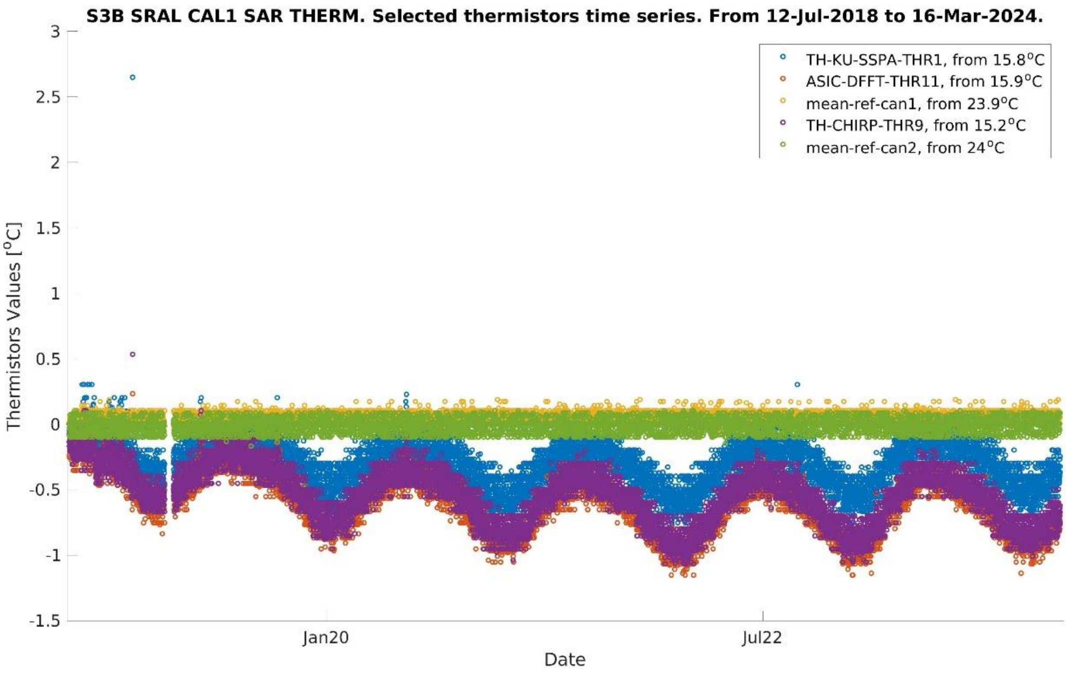


Figure 4-54. S3B Selected CAL1 SAR thermistors series along the whole mission.

We can see from the above figures a general agreement between the S3A and S3B calibration parameters absolute values.

The most important and notable drift observed in the whole mission’s series is the S3A CAL1 SAR Ku Power series, presenting a significant power decay at BOM (about -1 dB/year). Anyhow, we can see a slow stabilisation of this parameter along the mission, being below -0.3 dB/year from cycle 67.

A mission requirement of the CAL1 SAR Ku power is a maximum power drop of 3.5 dB from beginning of mission. Below that power bound, the sea-ice and ice sheets geophysical measurements are compromised by a poor SNR. A power model fitting has been computed for both S3A and S3B missions, and the assumption is to reach the limit by more than 20 years after the beginning of the mission.

For S3B, there are some spikes of CAL1 SAR Ku power of around 0.05 dB. These values coincide with products presenting a different calibration sequence, which could influence the operational point of the SRAL instrumentation, mainly SSPA/HPA. In addition, there are specific noisier periods during 2018, which are related to the existence of different operational modes (acquisition or tracking) before the calibration sequence activation, which impacts the initial conditions of the instrumental path performance. The rest of the periods are less noisy due to working in Open Loop tracking mode (where no acquisition mode is needed) except in cycle 40 where Close Loop was selected.

The S3A PTR time delay has also decreased its negative trend, being almost flat since 2018. The S3B time delay long term trend is positive, although it shows flats periods at mid-term. The new CoG method for internal delay is introduced after the 2023 reprocessing campaign. At the end of the S3A maximum position internal delay series we can see significant outliers due to wrong flagging. The impact in L1 science data range is expected to be null since the correction is performed with the CoG method.

The Ku band PTR widths trends of both missions are similar to their standard deviation, and several orders of magnitude below their absolute values. The S3A mission presents a clearer negative long-term trend, while S3B changes locally its behaviour.

The intra-burst corrections series along the missions are quite stable, except for the S3B burst phase anomaly at cycle 40: a wrap in the burst phase caused a huge jump in the series due to a code bug. The code fix for this anomaly is now implemented. The series phase wrap outliers will be corrected in the next reprocessing.

The S3A burst power slope shows a clear annual behaviour (oscillations of less than 0.2 mdB/pulse) due to sensibility to instrumental thermal changes. The annual behaviour is also noted in the S3B burst power figure, drawn over an added slope, plus a correlation with thermal events on-board (April & September 2019 and June 2020). The burst phase slope is increasing along the two missions, around 1 mdeg/pulse per year for S3A.

From the attenuation steps progression in dB we can check, for each ATT step, the delta in attenuation with respect to the first record value. The tendencies are visible for specific attenuations in each mission, with excursions (see colour code at right hand side) of less than 0.1 dB.

The CAL2 parameters behaviour is stable and nominal along the missions, with ripples of same magnitude and position in the CAL2 waveform.

The USO clock frequency impact in the range has trends around 4 mm per year for the S3A mission and around 2 mm per year for the S3B mission. The S3A mission trend is slowly becoming stabler and for S3B in the recent cycles it is slightly increasing. This behaviour is maintained in the last cycles.

The thermistors data series are showing annual oscillations, and a long-term cooling. At some dates there are increases of the thermistor's values of around 0.3ºC, returning in a short term to its precedent values, with a limited impact in the calibration series.

There is a peak in the S3B temperatures on board at date 2018/11/22 (e.g., THR1 is 3ºC up). This event affects slightly the calibration parameters (for instance the CAL1 SAR Ku Time Delay presents a jump up of 1mm). All monitored calibration parameters returned to its precedent values after the event.

In S3B, from cycle 21 - orbit 239 (2019/01/29) to cycle 22 - orbit 96 (2019/02/15), the thermistors values were not written in the TMs, and are consequently not represented in the figures. This anomaly was caused after a restart due to a SMUG event. A new command for a restart was executed and fixed the anomaly successfully.

The OLTC uploads have a limited but visible impact in some calibration parameters, mainly in the CAL1 power and the burst power. It is the case of S3A around 26/08/2021 and S3B around 19/08/2021. When an OLTC upload is carried out, the Close Loop tracking mode is activated, causing different initial conditions of the calibration sequence, depending on the operational tracking mode just before (tracking or acquisition).

The secondary lobes are monitored along the mission, representing the power distribution in the PTR, which ideally should tend to be symmetrical around the main lobe. Its behaviour suffers variations when the operational (Closed Loop on-board tracking mode) and thermal (switch-off/on) conditions are not stable, and especially after a SRAL switch off/on. This impact is limited, but not corrected for in the L1b processing (unlike the other CAL1 & CAL2 corrections).

For the two missions, the long-term drift for the SAR power variables is higher in absolute terms for the Ku band than for the C band, the Ku band ageing is faster than the one from C band, probably caused by the more stressed Ku band instrumental operations (e.g., bursts transmission & reception only in Ku band). All standard deviations in the figures are computed without detrending.

As a general observation, we can say that the behaviour of all calibration parameters is nominal.

5 Calibration with Transponder

This chapter is devoted to the analysis of the absolute calibration results from 4 different sites, 3 of them Transponders (TRP), and one Corner Reflector (CRF). In Table 5-1 we can check for each of the sites, characteristics such as the location, the mission and pass covered, and the calibrated parameters. A dedicated subchapter will cover hereafter each of the calibration sites, with their own description and assessment.

Calibration site	**Instrument type**	**Location**			**Overflight Pass**		**Parameter under analysis**		
		Lat [ºN]	**Lon [ºE]**	**Alt [m]**	**S3A**	**S3B**	**range**	**datation**	**Sigma-0**
Crete	Transponder	35.34	23.78	1048	013 Asc.	109 Desc.	✓	✓	
Leonessa	Transponder	42.61	13.04	1014	270 Asc.	307 Desc.			✓
Montsec	Corner Reflector	42.05	0.73	1613		299 Desc. 336 Asc.	✓	✓	✓
Svalbard (discontinued)	Transponder	78.23	15.39	492	233 Desc.	254 Asc.	✓	✓	

Table 5-1. Absolute calibration sites brief description

isardSAT, computing a UF-SAR analysis, has processed the Crete, Svalbard and Leonessa TRP data from a list of L1A NTC products provided on the FTP. This processing method is explained in [Garcia-Mondejar et al. 2018][2]. Passes with IPF-SR-1 Version 06.13 (cycle 3 to 23) use reprocessed L1A and L2 data provided on the s3mpc-stm-data.groupcls.com FTP server. Passes from cycle 24 increase in IPF-SR-1 Version as newer ones become available. The range, datation and RCS results are extracted from the minimisation of the RMS between theoretical and measured series. The range bias is computed as measured minus theoretical.

Also, isardSAT has processed with the FF-SAR method the passes over the CR and over the Leonessa TRP. In this case, due to fundamental differences in the processing option, no results on the Stack Alignment and Stack Range Noise are presented.

5.1 Crete transponder site

One of the transponders (TRP) used for the Sentinel-3 calibration activity is located in Crete, Greece. It was developed at the Technical University of Crete [S. Mertikas et. al. 2020][1] for the ESA's Copernicus Earth Observation programme and named as CDN1.

For S3A, the passes over Crete on cycles 13, 21, 54, 70, 80 and 81 have not been analysed because the TRP was not switched on due to extreme climate conditions and passes on cycle 48 and 50 have not been analysed due to maintenance work and cycle 80 is under investigation due the lack of the signal from the TRP. For S3B, cycles 1 to 7 and 15 to 18 have not been included as the satellite was not overflying the TRP. The Crete TRP was not switched on due to extreme climate conditions for S3B cycles 20 and 60.

During the Commissioning Phase of S6, the TRP located in Crete was rechecked, and the internal delay value was modified, with this new configuration, the range biases have been recalculated for all passes (S3A/B).

Regarding the geophysical corrections, for the Crete measurements the ionospheric, solid earth and wet/dry tropospheric corrections were extracted from the transponder auxiliary files provided by the MPC team. Then, geocentric tide and ocean loading corrections are selected from the L2 products.

Table 5-2 presents, for each mission, the range and datation processing results from the Crete TRP latest cycle, together with a whole mission average and standard deviation. The results for S3A show a negative measured range, 16.41 mm smaller than expected (elevation 16.41 mm higher than expected), and a datation bias of -115.88 microseconds. They also show a 0.54 mm stack noise. For S3B, the results show a negative measured range, 9.90 mm smaller than expected (elevation 9.90 mm higher than expected), and a datation bias of -22.03 microseconds. They also show a 0.57 mm stack noise. It is interesting to note that for S3B the results from cycle 21 show that the datation bias has been reduced from -114.60 microseconds (passes were in tandem orbit following S3A) to residual values.

Cycle – Mission	Date	Range bias [mm]	Datation bias [microseconds]	Alignment [mm/beam]	Noise [mm]	IPF-SR-1 Version
108 - S3A	2024/01/13	-18.22	-98.68	0.05	0.58	07.07
89 - S3B	2024/02/15	0.10	-18.08	0.01	0.64	07.07
Mean S3A (97 passes)		**-16.41**	**-115.88**	**0.06**	**0.54**	-
Standard Deviation S3A		**14.37**	**14.74**	**0.01**	**0.10**	-
Mean S3B (70 passes)		**-9.90**	**-22.03**	**0.02**	**0.57**	-
Standard Deviation S3B		**16.98**	**15.32**	**0.01**	**0.17**	-

Table 5-2. Results of Crete TRP passes processing

Figure 5-1 and Figure 5-2 depict the series of range and datation processing results for the two missions. Figure 5-3 and Figure 5-4 show the TRP processing results for stack alignment and stack range noise.

CDN1 Range and Datation processing results.

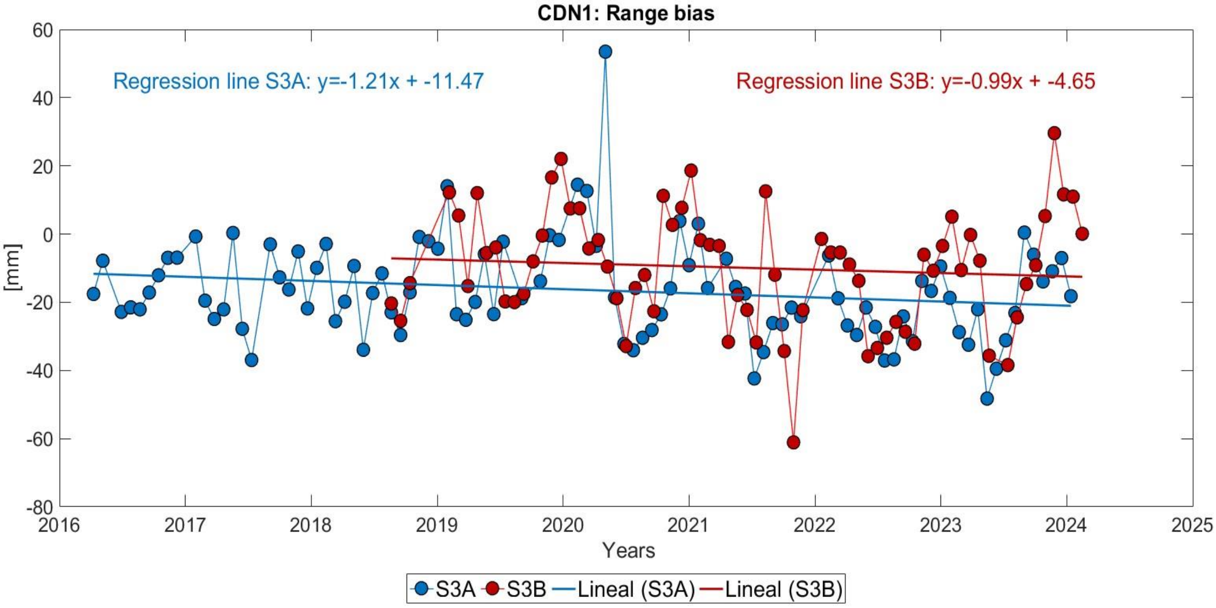


Figure 5-1. CDN1 TRP Range Results.

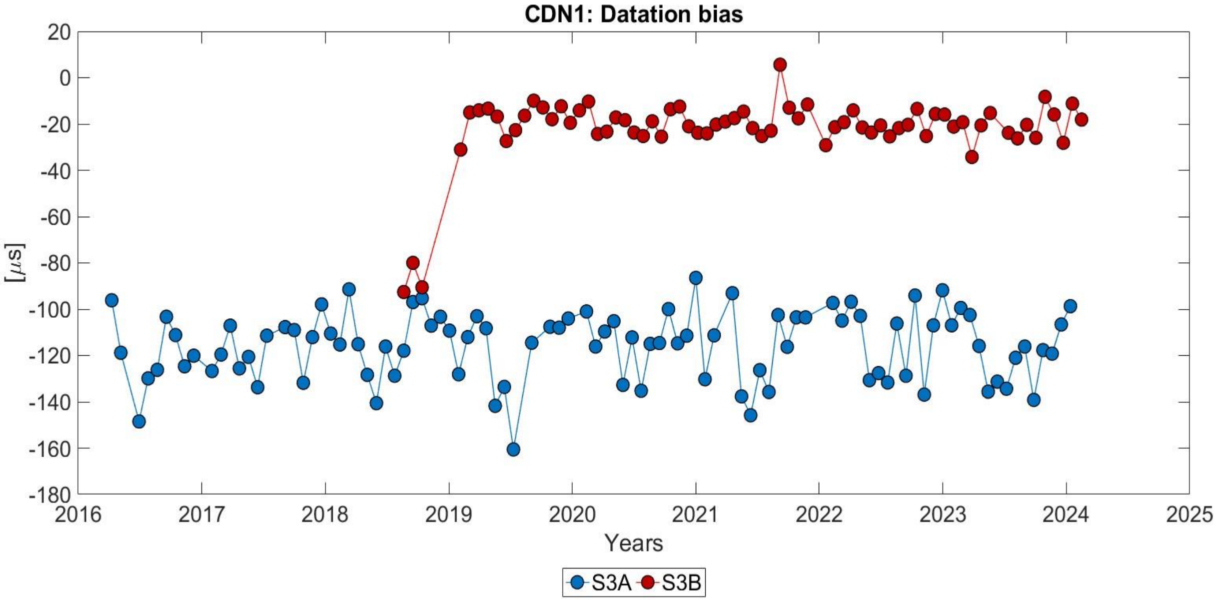


Figure 5-2. CDN1 TRP Datation Results.

CDN1 Stack analysis.

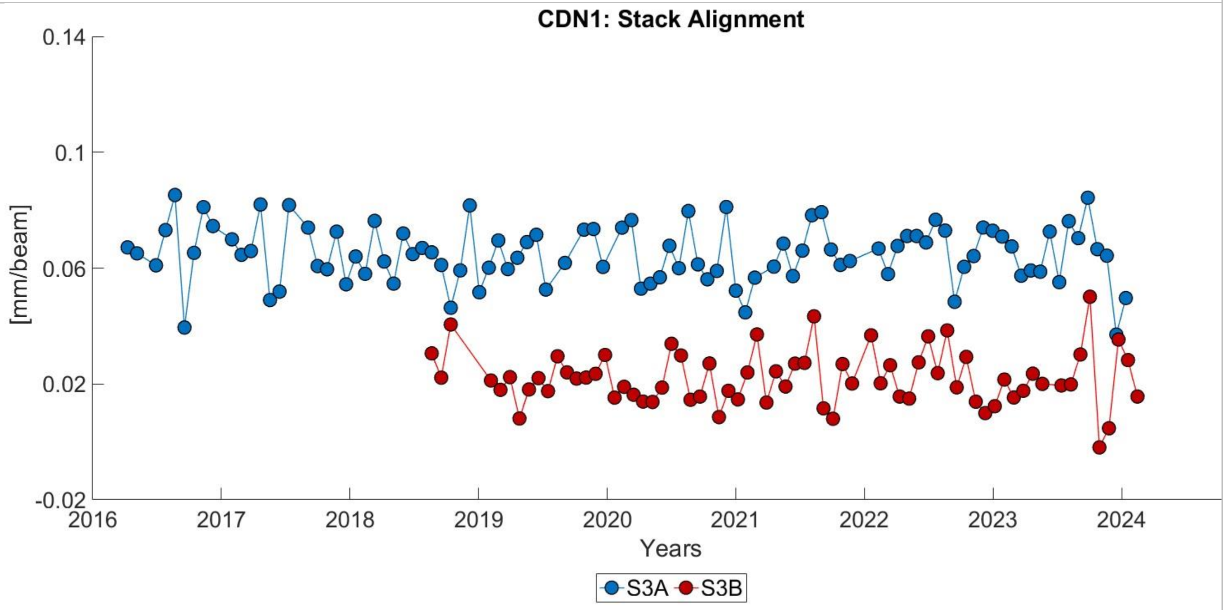


Figure 5-3. CDN1 TRP Stack Alignment Results.

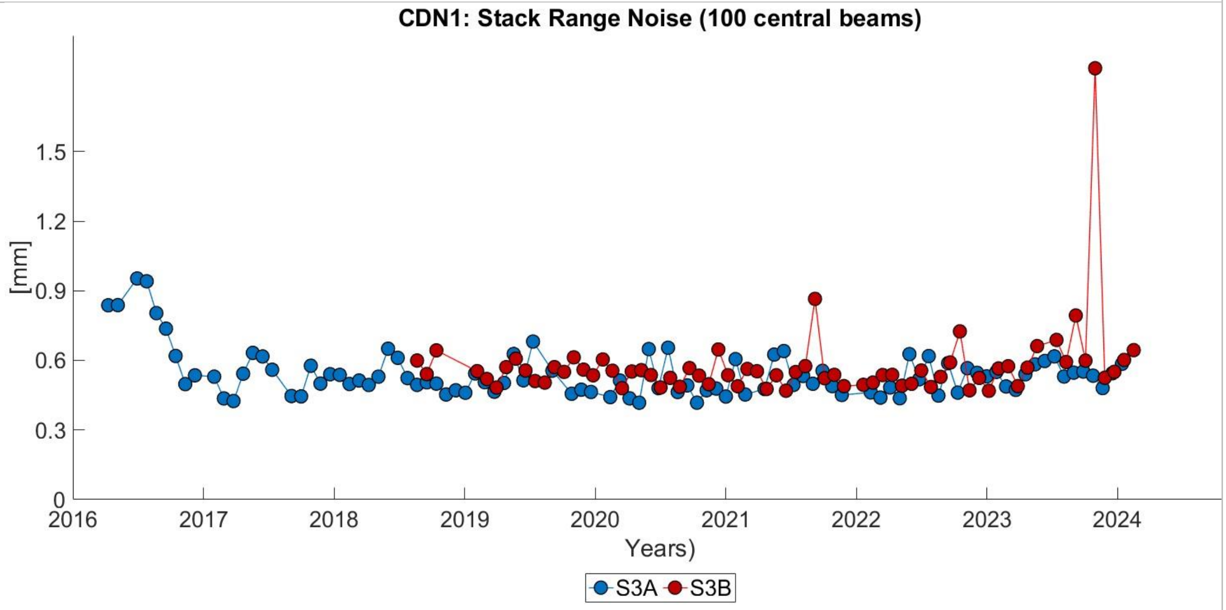


Figure 5-4. CDN1 TRP Stack Range Noise Results.

5.2 Montsec transponder site

Since February 2023, the Montsec Corner Reflector [F. Gibert et. al. 2023][3] (CRF) has been incorporated to the list of Sentinel-3 absolute calibration sites. The site has coverage of two different S3B relative orbits: #336 at 3km and #299 at 12 km. The #336 pass is the baseline one and the #299 a complementary solution. .

Within this report, we study the performance from both overflights using the FF-SAR processing, providing results of the Radar Cross Section (RCS) in addition to range and datation.

For the Montsec CRF the geophysical corrections are selected from the L2 products.

Table 5-3 presents the range, datation and sigma-0 processing results for the Montsec CRF S3B passes. For S3B #336, the results show a positive measured range, 29.24 mm larger than expected (elevation 29.24 mm smaller than expected), and a datation bias of 4.31 microseconds. They also show an RCS bias of -1.78 dB. The results for S3B #299 show a positive bias range, 22.62 mm larger range than expected (elevation 22.62 mm smaller than expected), and a datation bias of 27.58 microseconds. They also show an RCS bias of -6.53 dB.

Cycle – Mission	Date	Range bias [mm]	Datation bias [microseconds]	RCS bias [dB]	IPF-SR-1 Version
89 - S3B - 336	2024/02/15	37.60	3.25	-2.15	07.07
89 - S3B -299	2024/02/12	28.83	31.38	-6.48	07.07
Mean S3B #336 (15 passes)		**29.24**	**4.31**	**-1.78**	-
Standard Deviation S3B #336		**7.40**	**2.36**	**0.33**	-
Mean S3B #299 (7 passes)		**22.62**	**27.58**	**-6.53**	-
Standard Deviation S3B #299		**7.10**	**3.16**	**0.23**	-

Table 5-3. Results of Montsec CRF passes processing

Figure 5-5 and Figure 5-6 represent the series of CRF range and datation processing results for the two passes. Figure 5-7 represents the series related to RCS bias retrieved from the CRF processing.

CRF Range and Datation processing results.

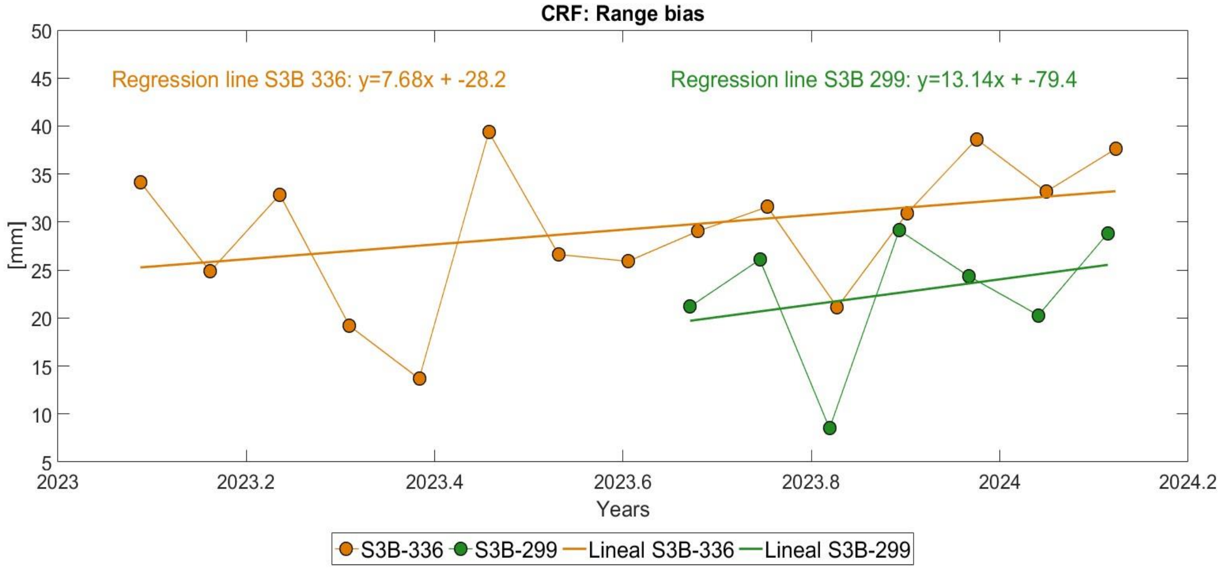


Figure 5-5. Montsec CRF Range Bias Results.

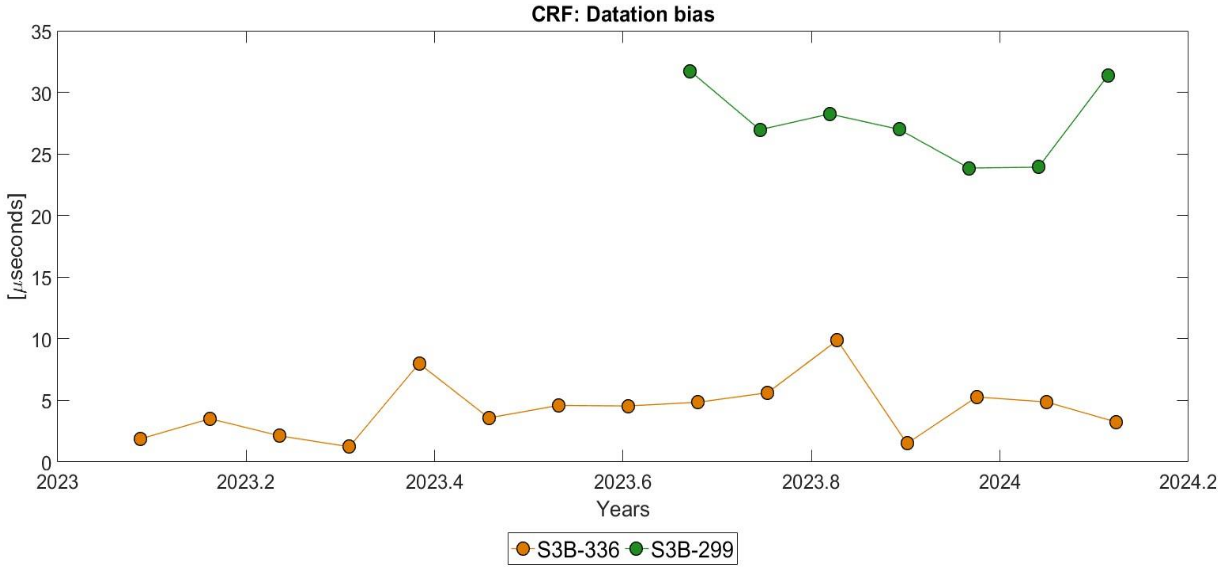


Figure 5-6. Montsec CRF Datation Bias Results.

CRF processing. RCS analysis.

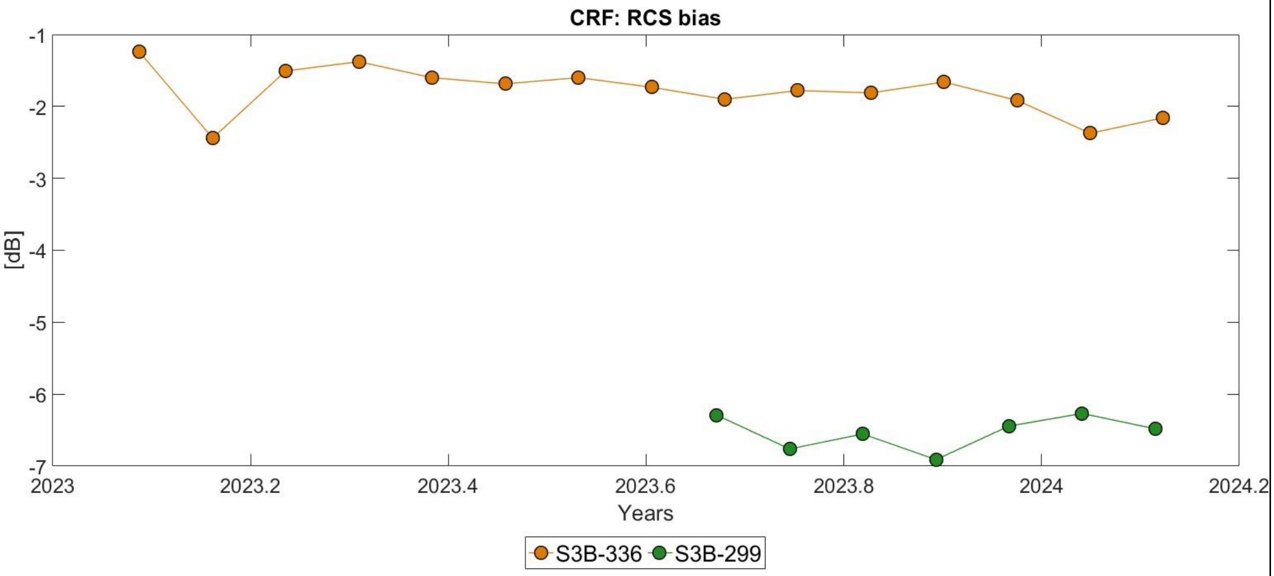


Figure 5-7. Montsec CRF RCS Bias Results.

5.3 Leonessa transponder site

The Leonessa transponder has been added as a Sentinel-3 absolute calibration since January 2023, with the aim of calibrating sigma0 for both S3 missions. The site has coverage of two different relative orbits: S3A #270 at 2.5km and S3B#307 at 0.5 km. Within this report, we study the performance from both overflights using the UF-SAR and FF-SAR processing.

For the Leonessa transponder the atmospheric attenuation is selected from the L2 products.

Table 5-4 presents the sigma0 bias results for the Leonessa transponder using both processing methods. For S3A #270, the results, using the UF-SAR processing, show a negative value of 3.42 dB lower than expected, In the case of FF-SAR processing, the results show a negative value of 3.42 dB lower than expected.

The results for S3B #307, using he UF-SAR processing, show a negative value of 0.08 dB lower than expected, In the case of FF-SAR processing, the results show a positive value of 0.01 dB higher than expected.

Cycle – Mission	Date	DDP	FF	IPF-SR-1 Version
108 – S3A – 270	2024/02/15	-3.55	-3.65	07.07
89 – S3B -307	2024/02/12	-0.35	-0.05	07.07
Mean S3A (14 passes)		**-3.42**	**-3.42**	-
Standard Deviation S3B #270		**0.67**	**0.49**	-
Mean S3B (14 passes)		**-0.08**	**0.01**	-
Standard Deviation S3B #307		**0.81**	**0.35**	-

Table 5-4. Results of Leonessa TRP passes processing

Transponder Leonessa Sigma0 processing results.

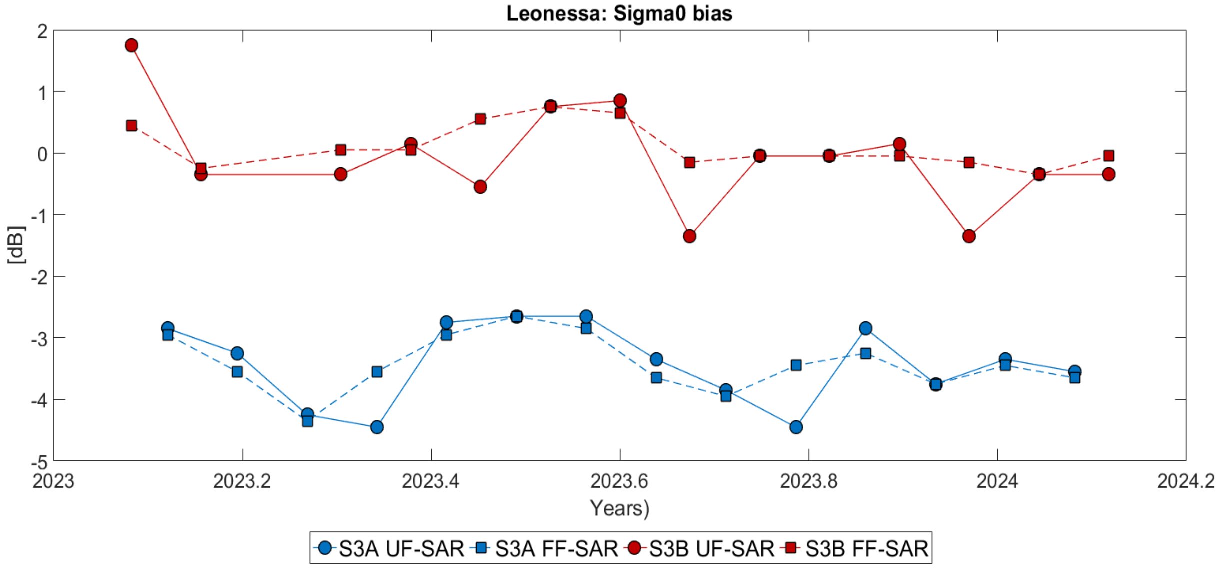


Figure 5-8. Leonessa TRP Sigma0 Bias Results.

5.4 Svalbard transponder site

Since the month of June 2019 until May 2023, the Svalbard transponder was used to calibrate the Sentinel-3 satellites. From end of 2022 to May 2023, both S3A and S3B presented strong interferences, making it very difficult to retrieve a clear signal from the TRP, causing this station to be discarded from that date onwards. The ionospheric and wet/dry tropospheric, the solid earth, geocentric tide and ocean loading corrections were selected from the ESA Sentinel-3 Land level-2 products, Non Time Critical (NTC) timeliness. A summary table with the Svalbard TRP historical results is shown in Table 5-5. Results of Svalbard TRP passes processing

Mission	Range bias [mm]	Datation bias [microseconds]	Alignment [mm/beam]	Noise [mm]
S3A Mean (51 passes)	**-69.04**	**-40.91**	**0.04**	**17.05**
S3A Standard Deviation	**37.31**	**75.36**	**0.05**	**9.96**
S3B Mean (53 passes)	**-56.92**	**-29.89**	**0.02**	**9.93**
S3B Standard Deviation	**32.24**	**57.40**	**0.04**	**8.80**

Table 5-5. Results of Svalbard TRP passes processing

Appendix A – Useful links

For more information related to Sentinel-3 Surface Topography Mission, please visit the SentiWiki website:
https://sentiwiki.copernicus.eu/web/s3-altimetry-instruments

A User Handbook provides dedicated information to the Sentinel-3 STM Thematic Products.

Appendix B – Reference

1 Mertikas, S., Tripolitsiotis, A., Donlon, C., Mavrocordatos, C., Féménias, P., Borde, F., Frantzis, X., Kokolakis, C., Guinle, T., Vergos, G., Tziavos, I., & Cullen, R. (2020). The ESA Permanent Facility for Altimetry Calibration: Monitoring Performance of Radar Altimeters for Sentinel-3A, Sentinel-3B and Jason-3 Using Transponder and Sea-Surface Calibrations with FRM Standards. Remote Sensing, 12(16), 2642. https://doi.org/10.3390/rs12162642.

2 Garcia-Mondéjar, Albert, et al. "CryoSat-2 range, datation and interferometer calibration with Svalbard transponder." Advances in Space Research 62.6 (2018): 1589-1609.

3 F. Gibert et al., “A Trihedral Corner Reflector for Radar Altimeter Calibration”, in IEEE Transactions on Geoscience and Remote Sensing, vol. 61, pp. 1-8, 2023, Art no. 5101408, doi: 10.1109/TGRS.2023.3239988.

Appendix C – Changes Log

Date	Section	Approved by
28/10/2022	Chapter 4 Chapter 5	Discard LRM section. Use of NTC products.
08/03/2023	Chapter 4.2	Updated with additional secondary lobes monitoring figure.