

Sentinel-3

Mission Performance Cluster

of Surface Topography Mission



Copernicus Sentinel-3 Surface Topography Mission - Cyclic Performance Report

SRAL

S3A

Cycle No. 100

Start date: 10/06/2023

End date: 07/07/2023

S3B

Cycle No. 81

Start date: 20/06/2023

End date: 17/07/2023

Reference: S3MPC-STM_CPR_0005-100-081

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CHRONOLOGY ISSUES

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ACCEPTANCE

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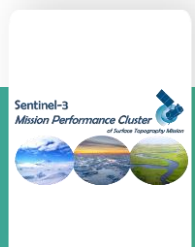
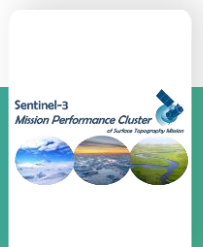


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1 Introduction

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.

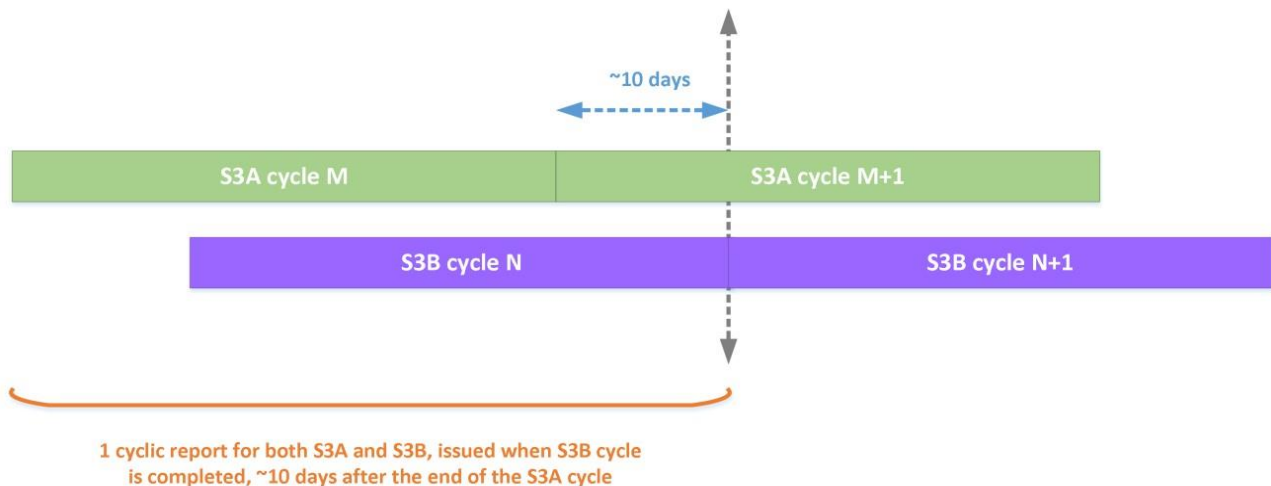


Figure 1: S3A and S3B cycles chronology

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 100, from 10/06/2023 to 07/07/2023.
- To present the major useful results for S3B cycle 81, from 20/06/2023 to 17/07/2023.

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

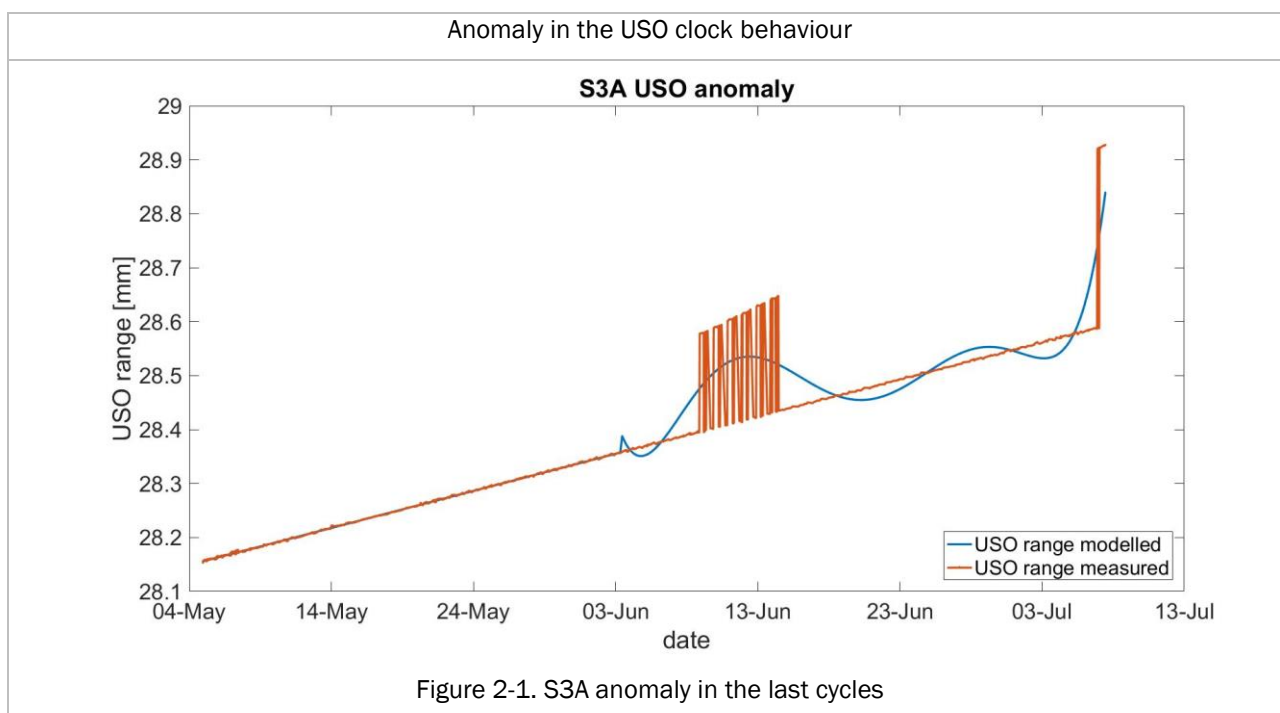
The SRAL behaviour in this cycle is nominal for the two Sentinel-3 missions. The absolute values and the local trends are as expected for the assessed calibration parameters. These parameters are related to the calibration modes CAL1, CAL2, AutoCal, and from the USO files and thermal data. From what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

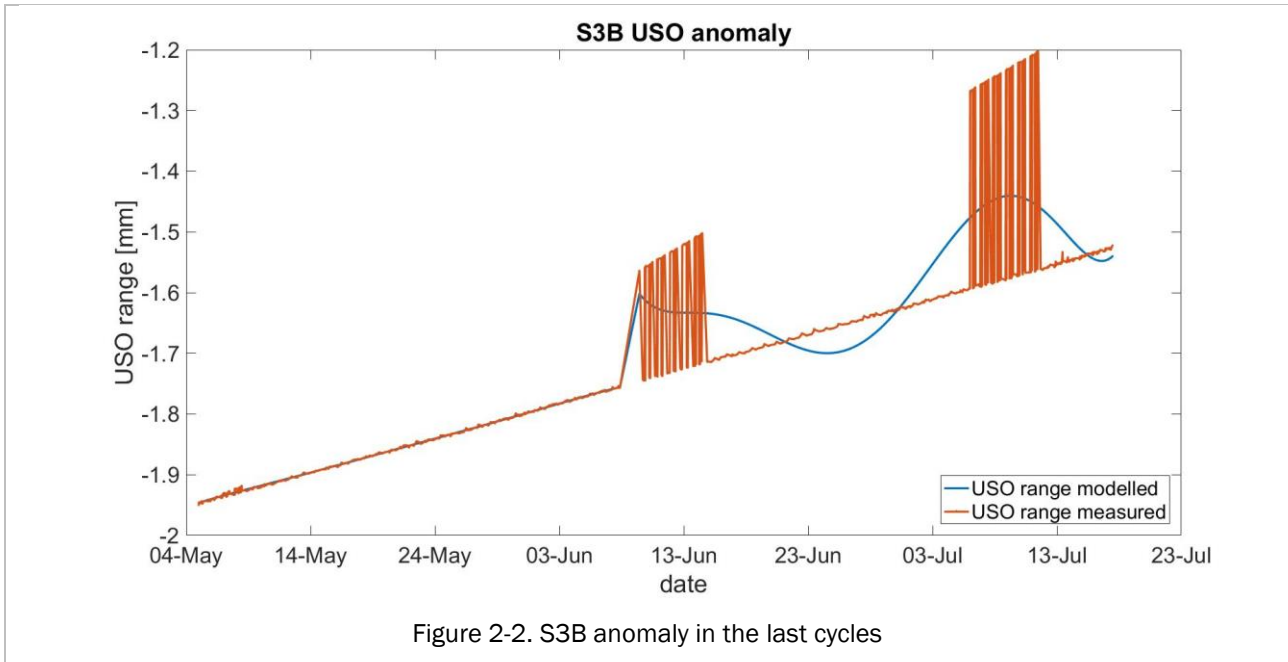
2.2 SRAL Mission Performance

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 (-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

The USO clock frequency shows an abnormal behaviour shown in Figure 2-1 and Figure 2-2 which are a zoom in the last data of the full series (Figure 4-51 and Figure 4-52) that strictly starts on May 6th (cycles S3A: 98 - S3B: 79) with a slight negligible deviation. This deviation repeats periodically escalating in intensity until the modelled USO range starts to track it. The anomaly repeats with discernible range bias of 0.2 mm from June 7th to June 14th and it can be seen again with maximum range bias of 0.3 mm from July 6th to July 11th. It happens both in S3A and S3B missions and the occurrence dates match.





This anomaly has been corrected in the subsequent USO products from July 21st, whose data is not within the temporal scope of the current report cycles 100 (S3A) and 81 (S3B).

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) 004.

| | Cycle | Processing Baseline | IPF SM2 version | IPF SR1 version | IPF MW1 version |
|-------------|-------|---------------------|-----------------|-----------------|-----------------|
| Sentinel-3A | 100 | 3.05 | 06.20 | 06.20 | 06.13 |
| Sentinel-3B | 81 | 3.05 | | | |

Table 1: Processing baseline and IPF details

The evolutions of the Sentinel-3 STM Processing Baseline since July 2016, end of commissioning phase, are summarized in the “Sentinel Online” Web pages:

<https://sentinels.copernicus.eu/web/sentinel/technical-guides/sentinel-3-altimetry/processing-baseline>

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.

S3A SRAL CAL1 SAR Calibration Areas from 10-Jun-2023 to 07-Jul-2023.

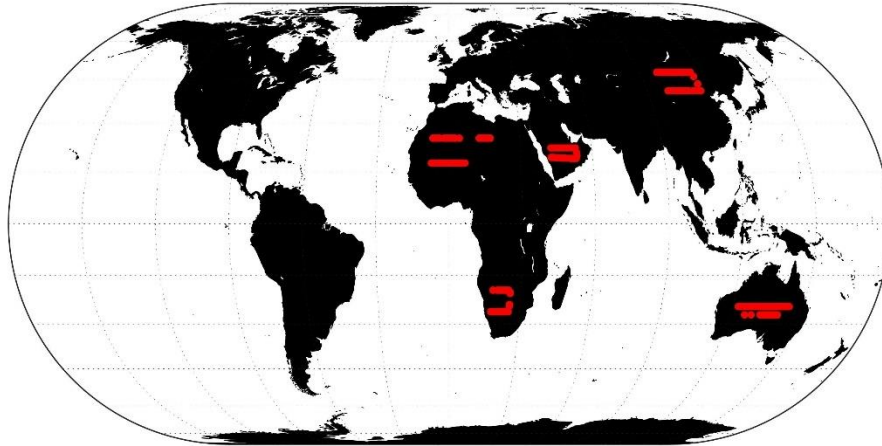


Figure 4-1. S3A Location of the CAL1 SAR measurements.

S3B SRAL CAL1 SAR Calibration Areas from 20-Jun-2023 to 17-Jul-2023.

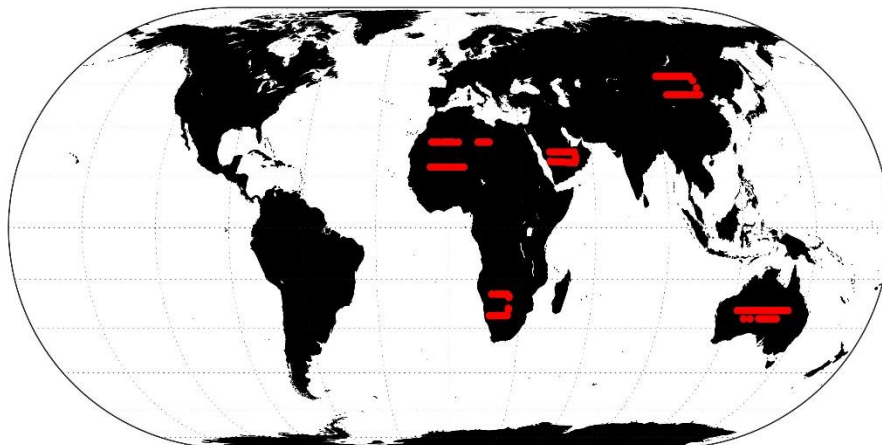


Figure 4-2. S3B Location of the CAL1 SAR measurements.

Period trend of CAL1 PTR Delay for SAR mode.

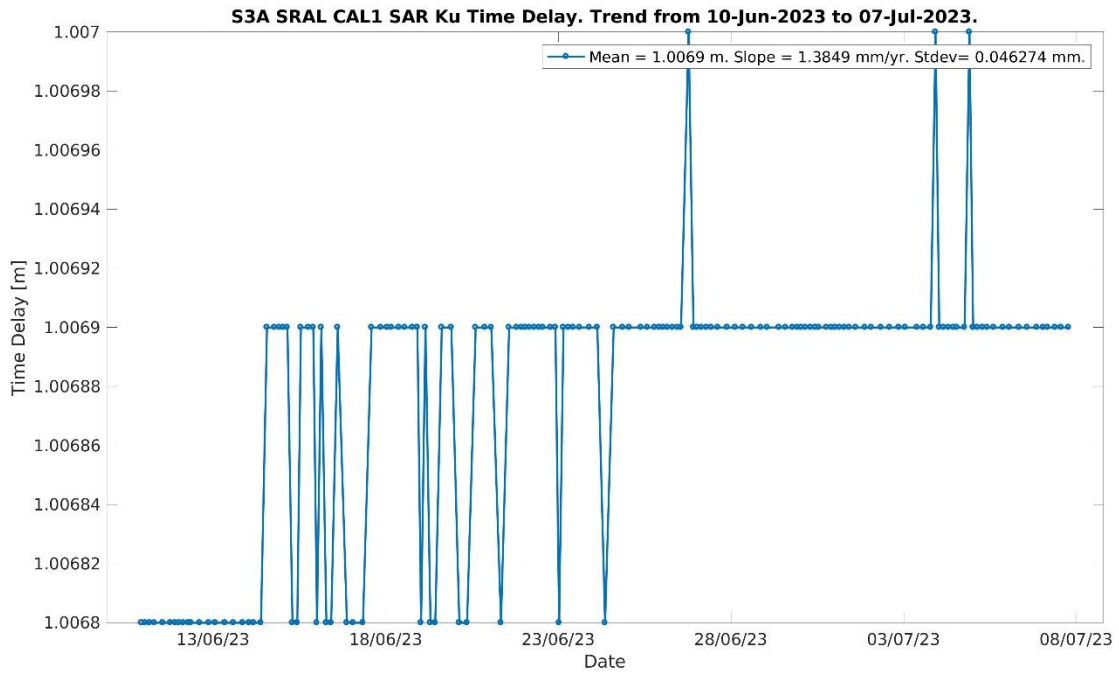


Figure 4-3. S3A CAL1 SAR Ku Time Delay trend.

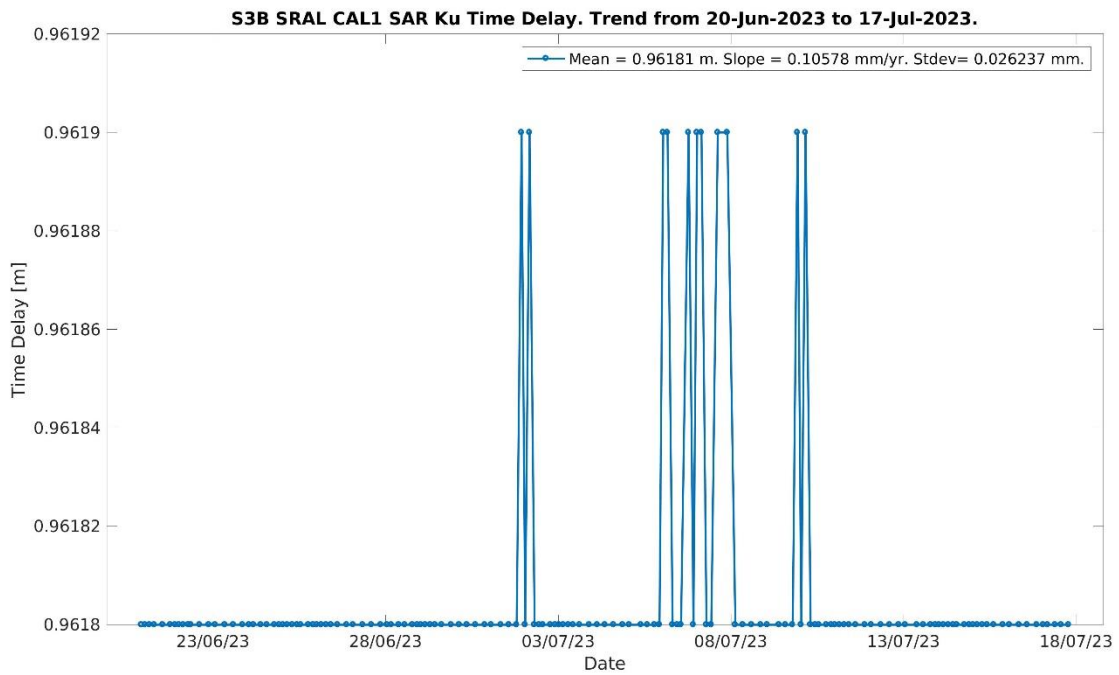


Figure 4-4. S3B CAL1 SAR Ku Time Delay trend.

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

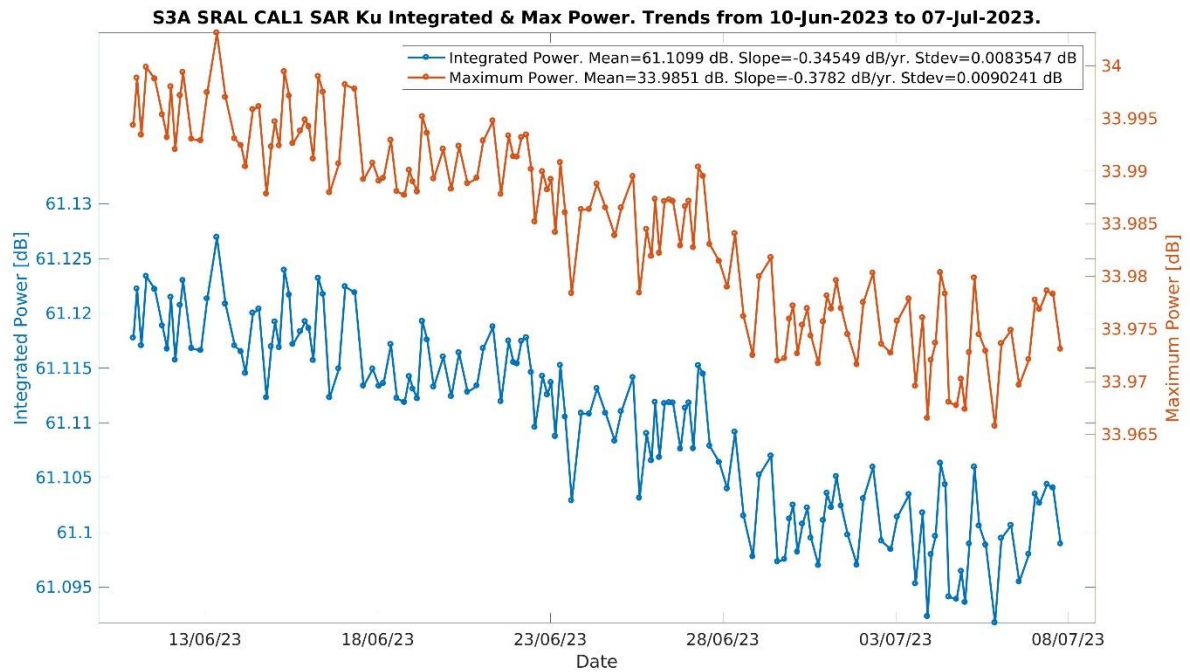


Figure 4-5. S3A CAL1 SAR Ku Power Trend.

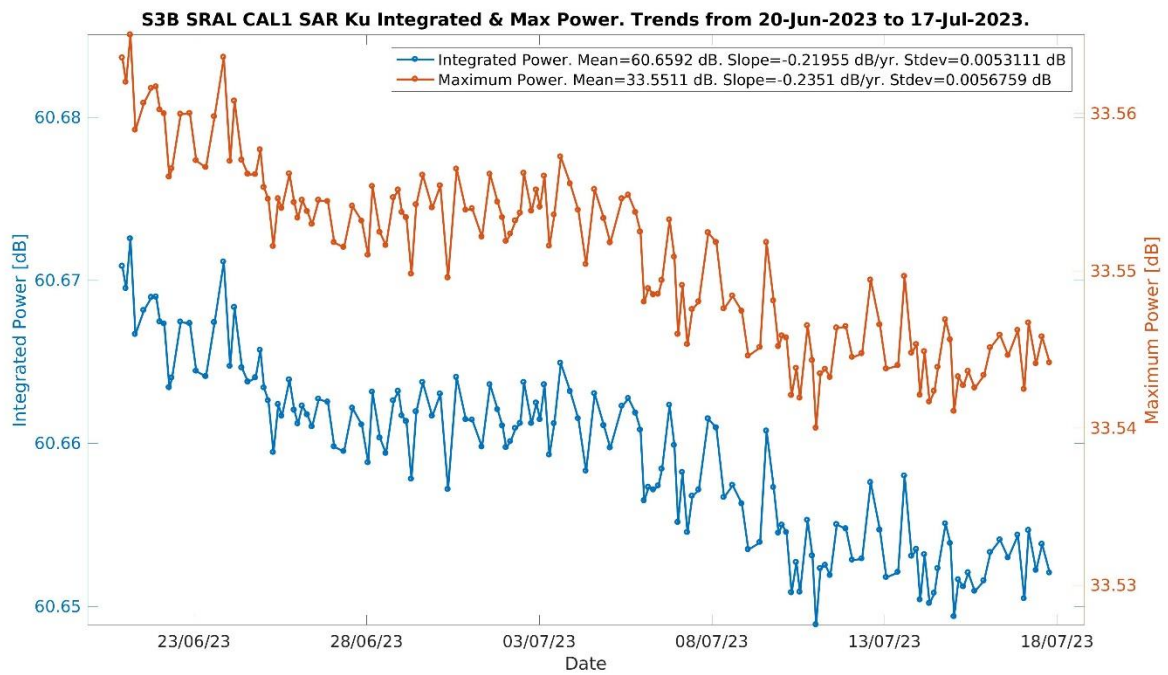


Figure 4-6. S3B CAL1 SAR Ku Power Trend.

Period trend of the CAL1 PTR width for SAR mode.

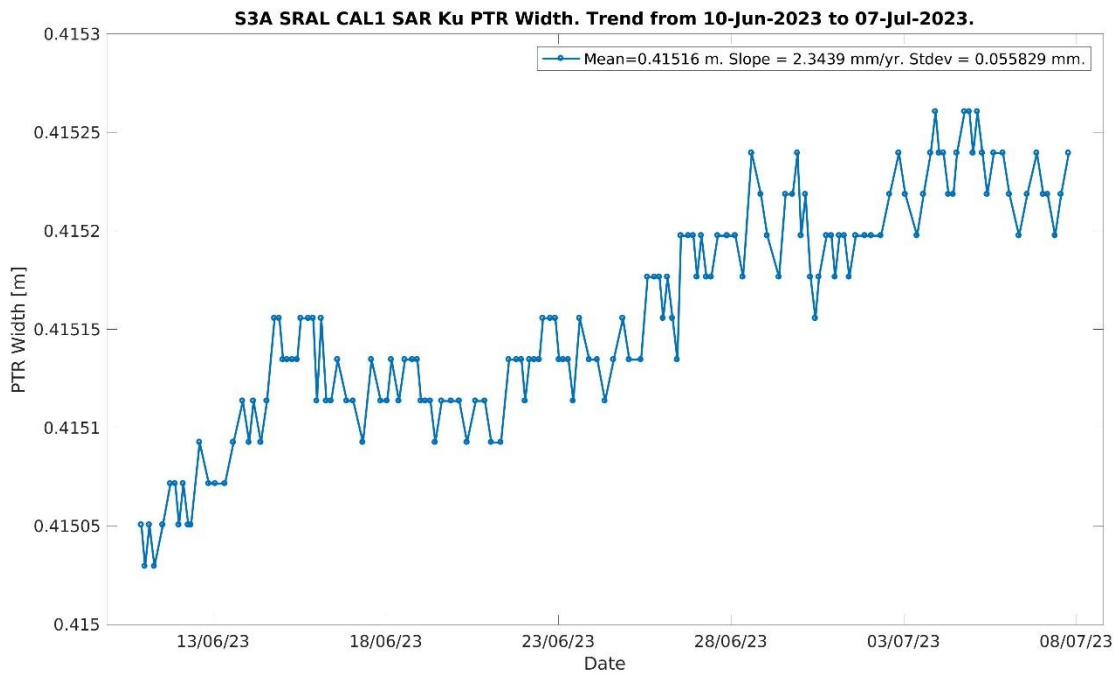


Figure 4-7. S3A CAL1 SAR Ku PTR width trend.

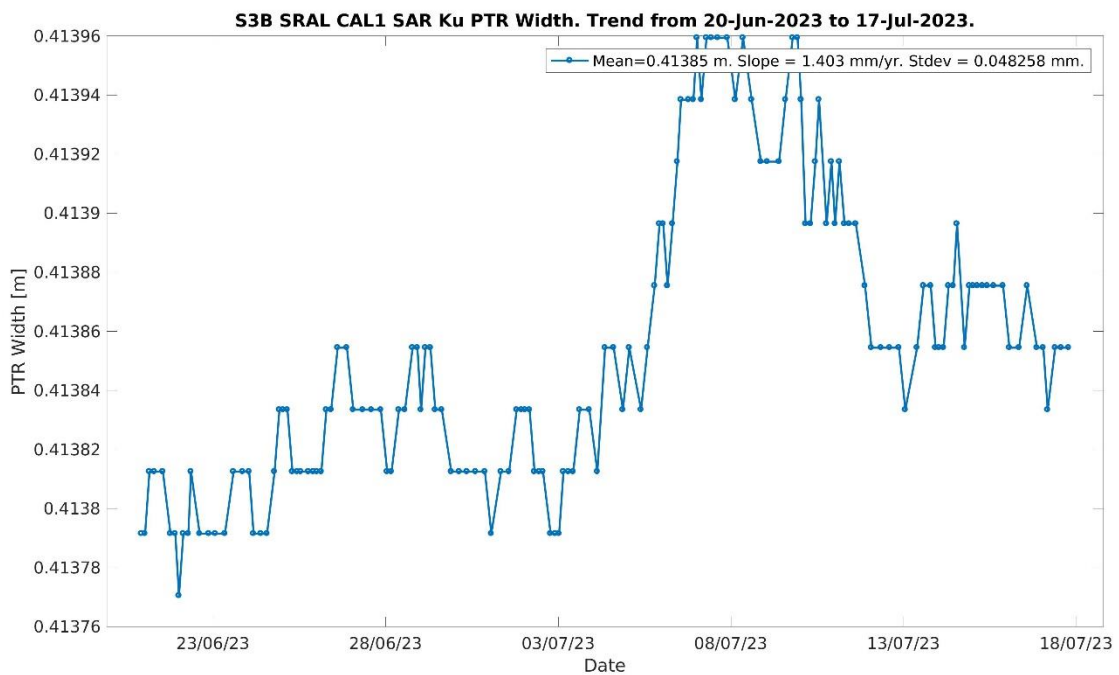


Figure 4-8. S3B CAL1 SAR Ku PTR width trend.

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

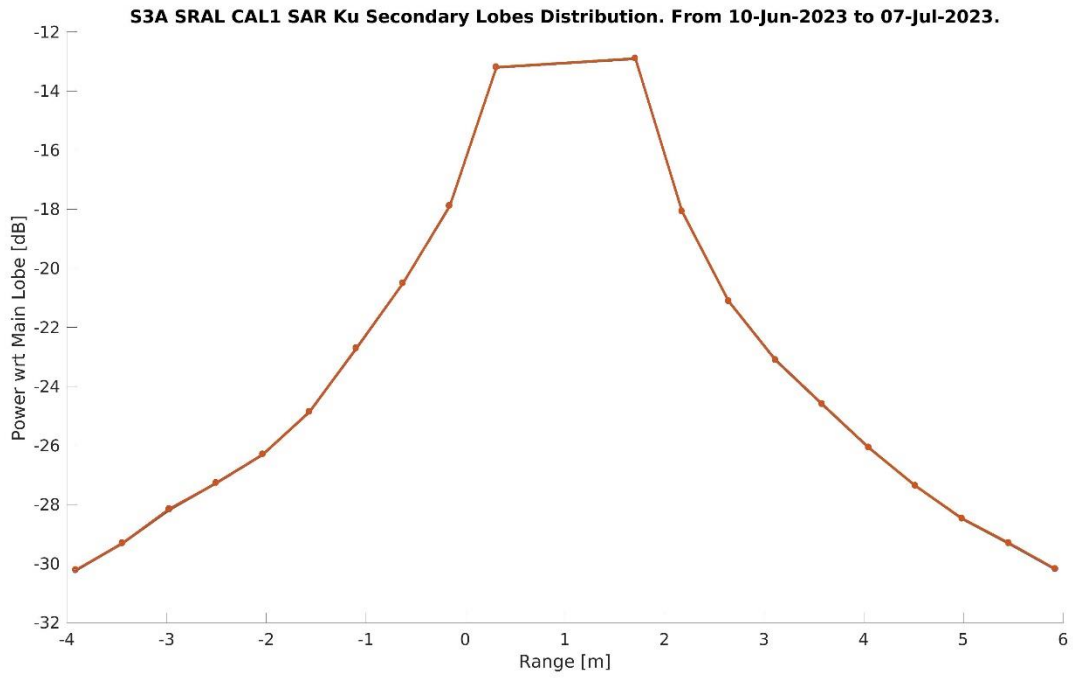


Figure 4-9. S3A CAL1 SAR Ku PTR secondary lobes Power and Position within the PTR waveform.

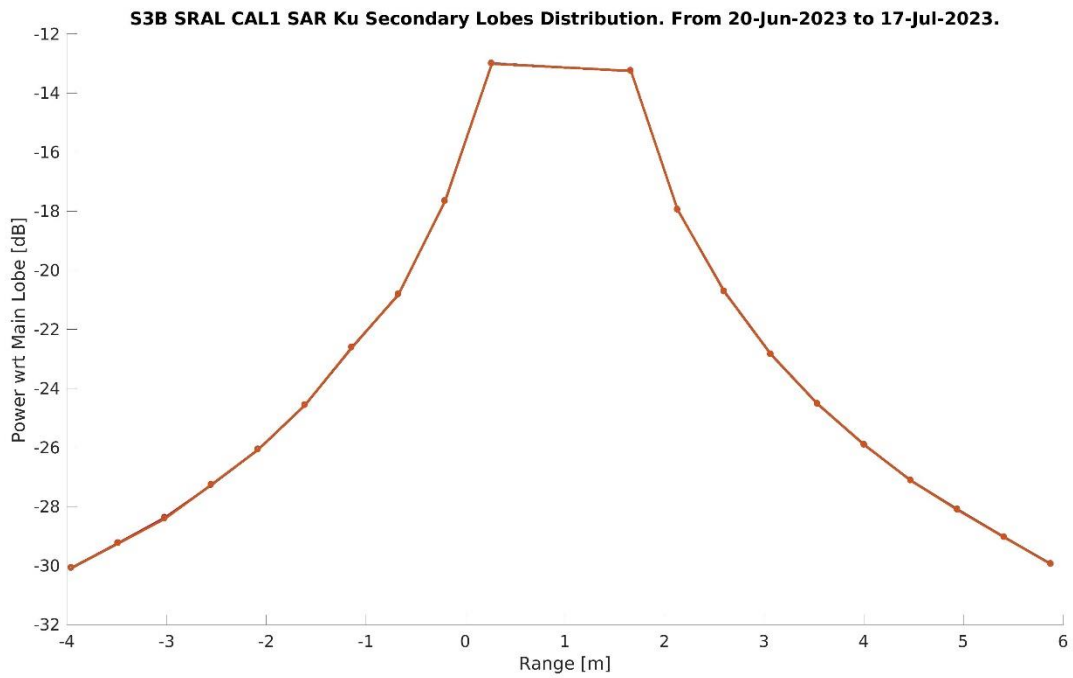


Figure 4-10. S3B CAL1 SAR Ku PTR secondary lobes Power and Position within the PTR waveform.

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

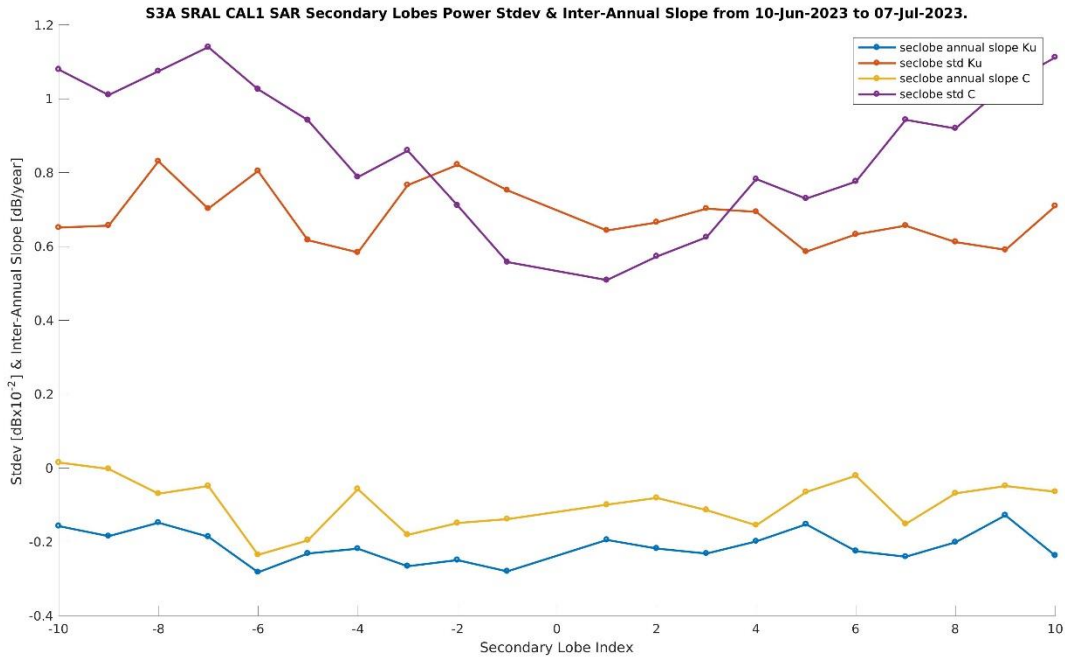


Figure 4-11. S3A CAL1 SAR Ku PTR secondary lobes characterisation. The inter-annual slope (in dB/year) and standard deviation (in $\text{dBx}10^{-2}$) of each of the secondary lobes are shown.

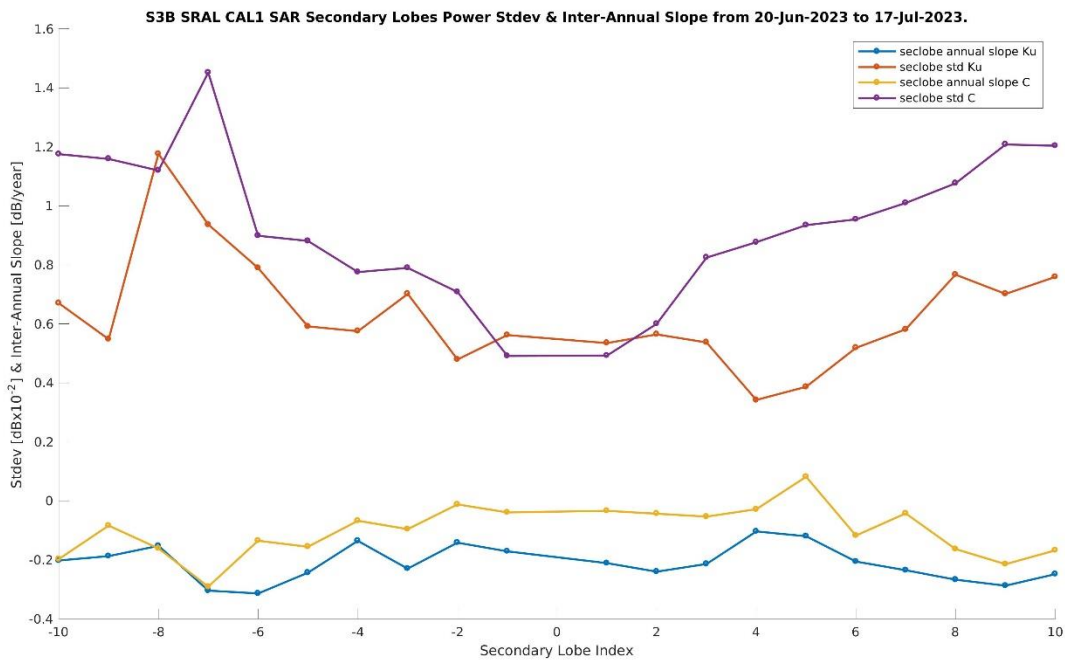


Figure 4-12. S3B CAL1 SAR Ku PTR secondary lobes characterisation. The inter-annual slope (in dB/year) and standard deviation (in $\text{dBx}10^{-2}$) of each of the secondary lobes are shown.

CAL1 Phase and Power intra-burst corrections slopes.

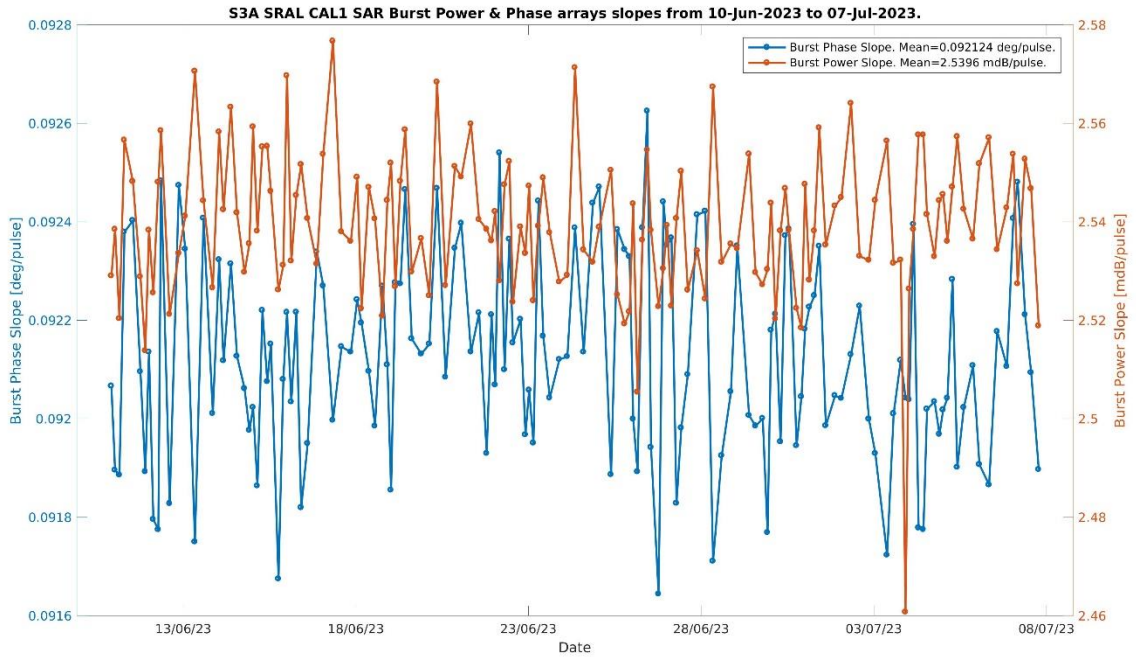


Figure 4-13. S3A CAL1 SAR Ku Phase & Power intra-burst corrections slopes over the cycle.

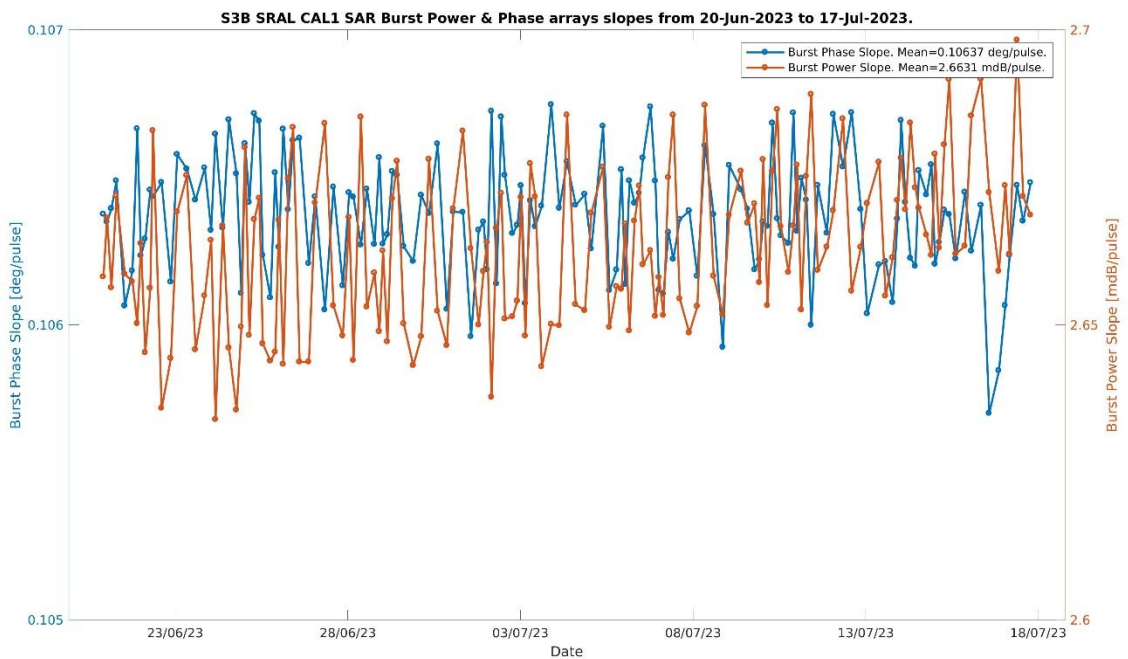


Figure 4-14. S3B CAL1 SAR Ku Phase & Power intra-burst corrections slopes over the cycle.

CAL1 Phase and Power intra-burst corrections standard deviations.

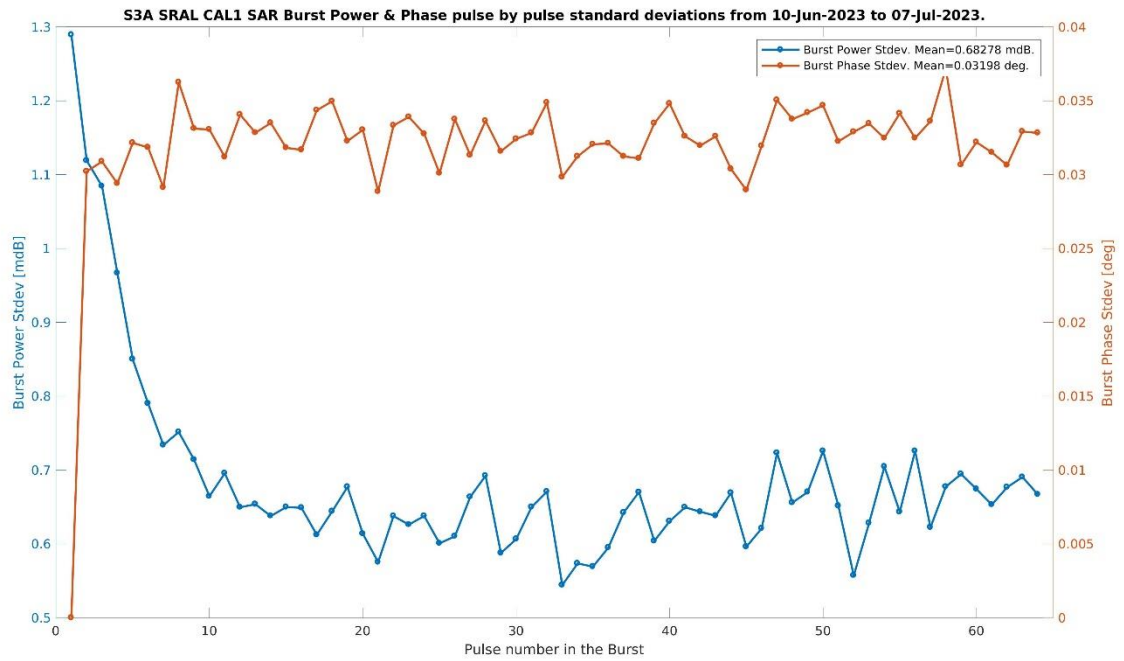


Figure 4-15. S3A Pulse by pulse standard deviations of the CAL1 SAR Ku Power and Phase intra-burst corrections.

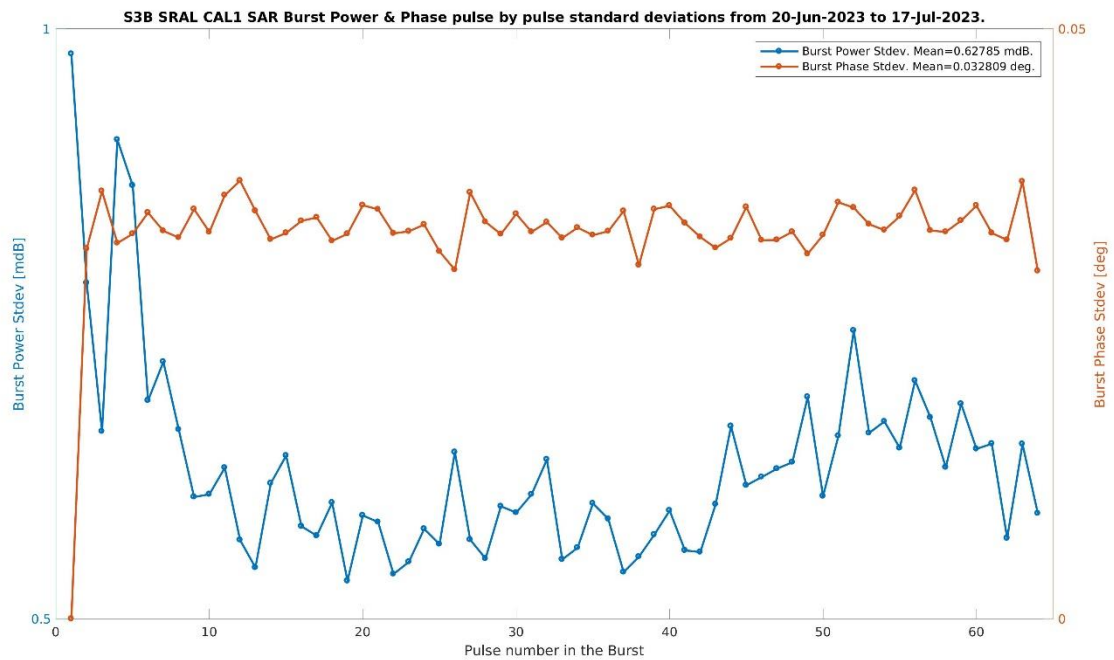


Figure 4-16. S3B Pulse by pulse standard deviations of the CAL1 SAR Ku Power and Phase intra-burst corrections.

4.1.2 CAL2

Geolocation of the CAL2 measurements for SAR mode.

S3A SRAL CAL2 SAR Calibration Areas from 10-Jun-2023 to 07-Jul-2023.

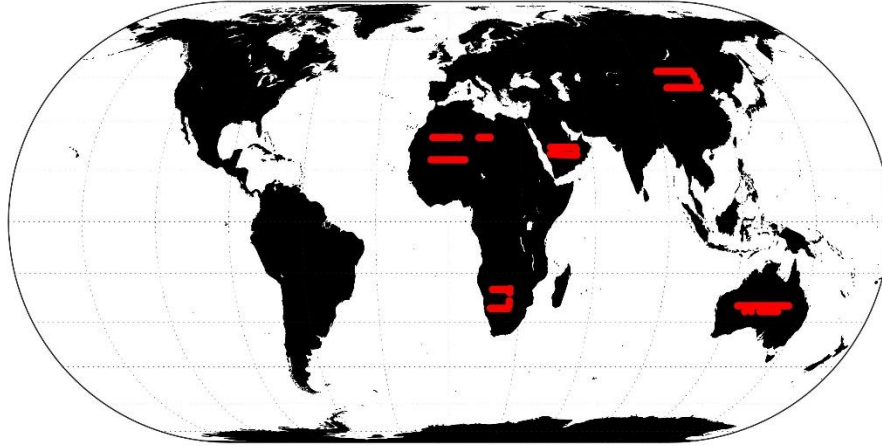


Figure 4-17. S3A Location of the CAL2 SAR measurements.

S3B SRAL CAL2 SAR Calibration Areas from 20-Jun-2023 to 17-Jul-2023.

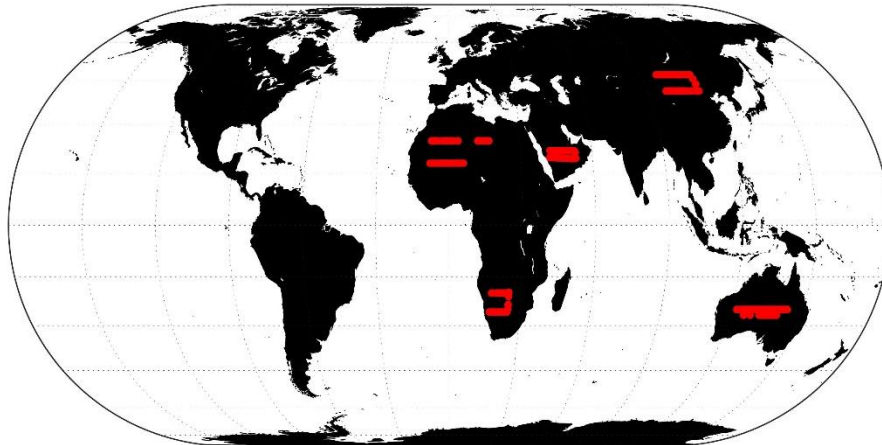


Figure 4-18. S3B Location of the CAL2 SAR measurements.

CAL2 SAR waveforms averaged over the cycle.

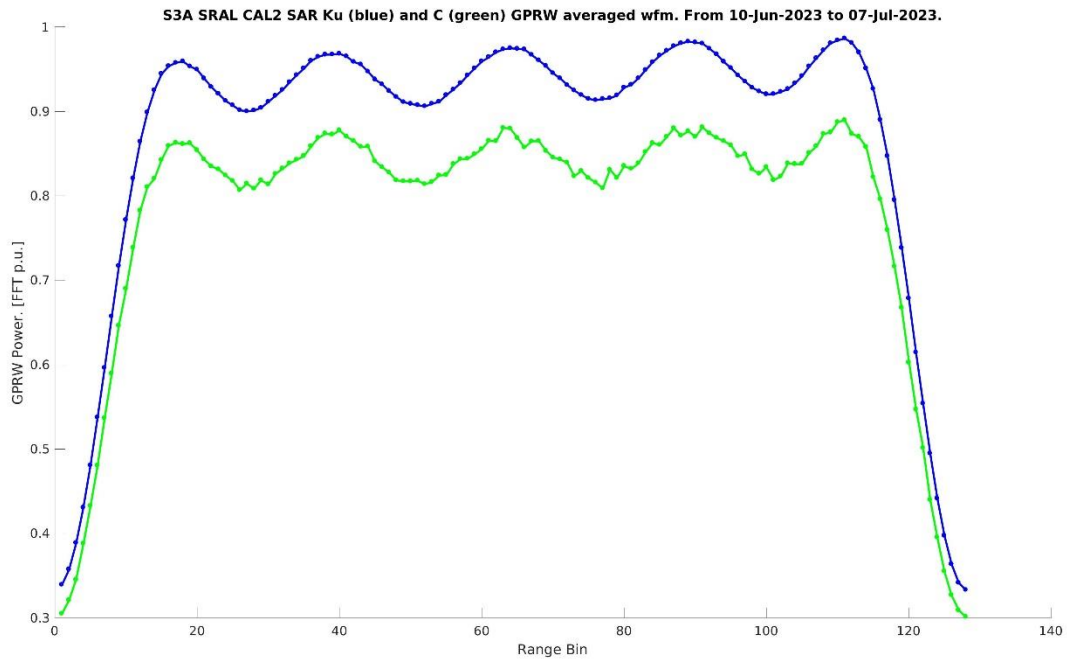


Figure 4-19. S3A Averaged CAL2 SAR Ku and C waveforms over the cycle.

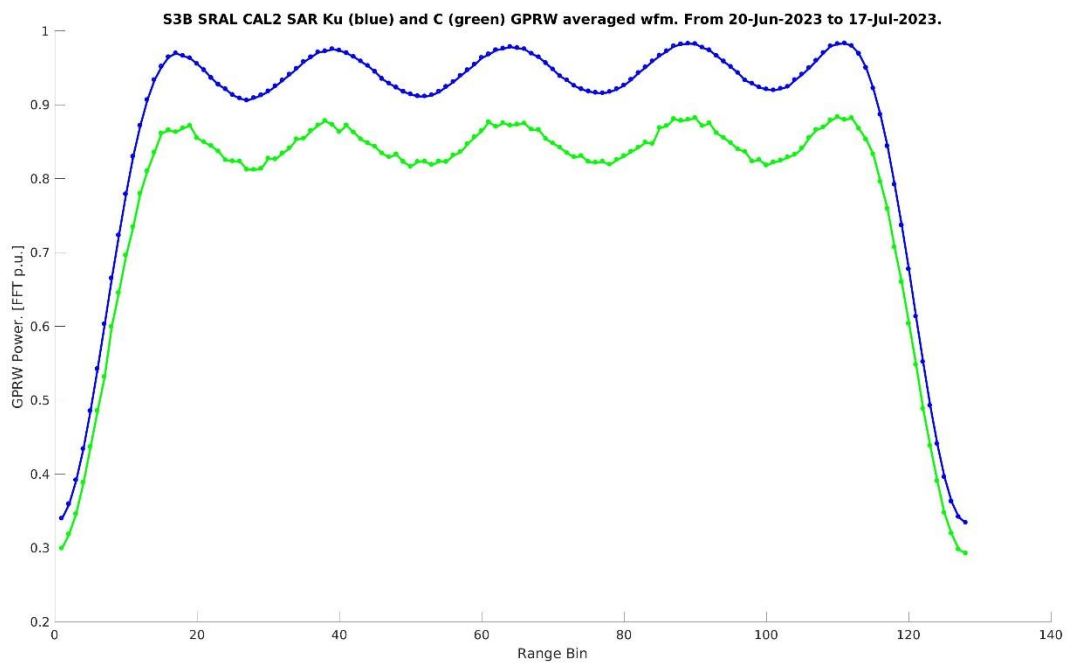


Figure 4-20. S3B Averaged CAL2 SAR Ku and C waveforms over the cycle.

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

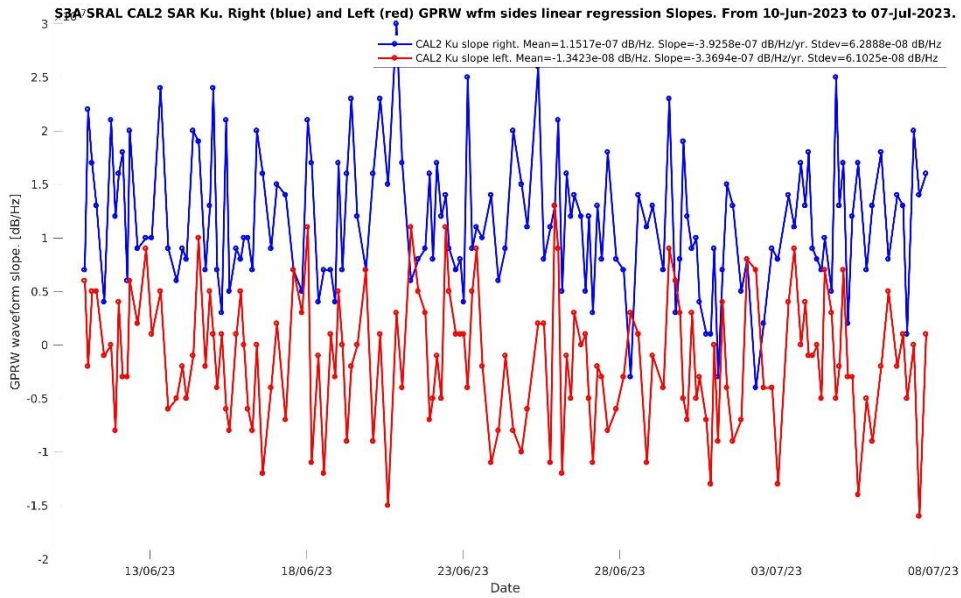


Figure 4-21. S3A CAL2 SAR Ku waveforms right (blue) and left (red) sides Slope over the period.

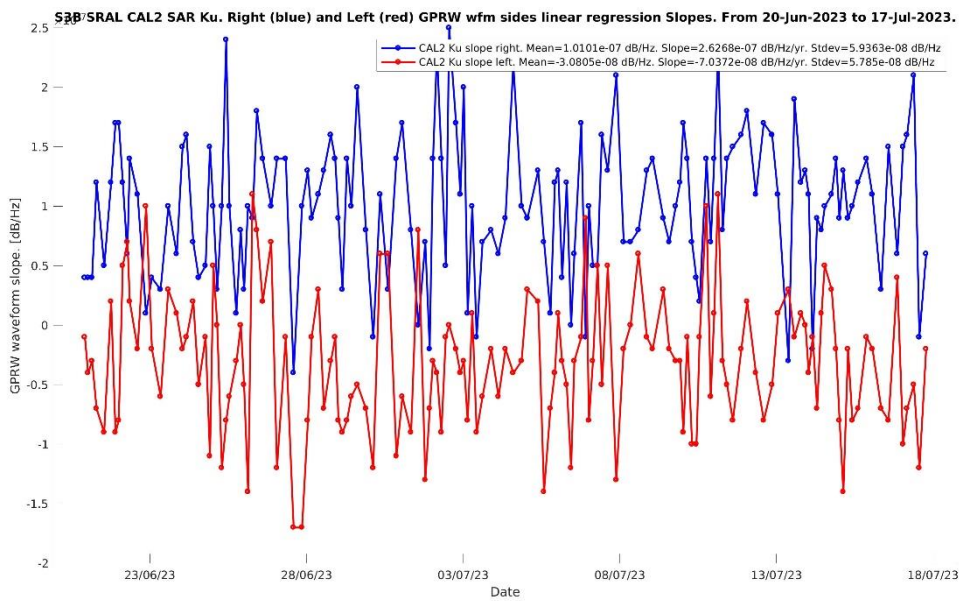


Figure 4-22. S3B CAL2 SAR Ku waveforms right (blue) and left (red) sides Slope over the period.

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

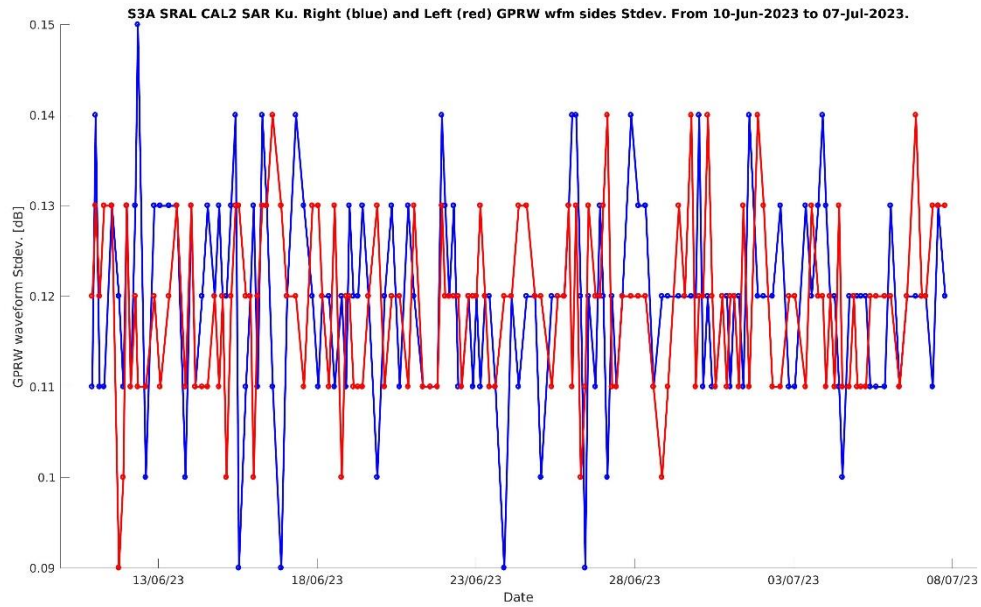


Figure 4-23. S3A CAL2 SAR Ku waveforms right (blue) and left (red) sides Standard Deviation over the period.



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.

S3A SRAL CAL1 Auto-Calibration Areas from 12-Jun-2023 to 30-Jun-2023.

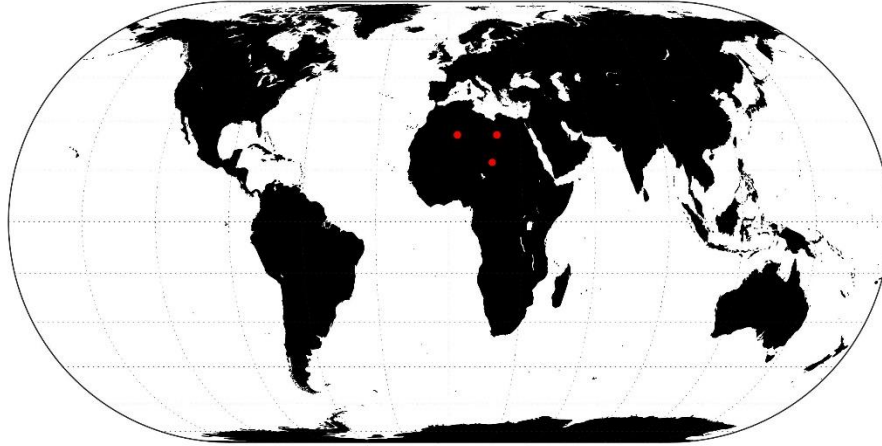


Figure 4-25. S3A Location of the AutoCal measurements.

S3B SRAL CAL1 Auto-Calibration Areas from 22-Jun-2023 to 10-Jul-2023.

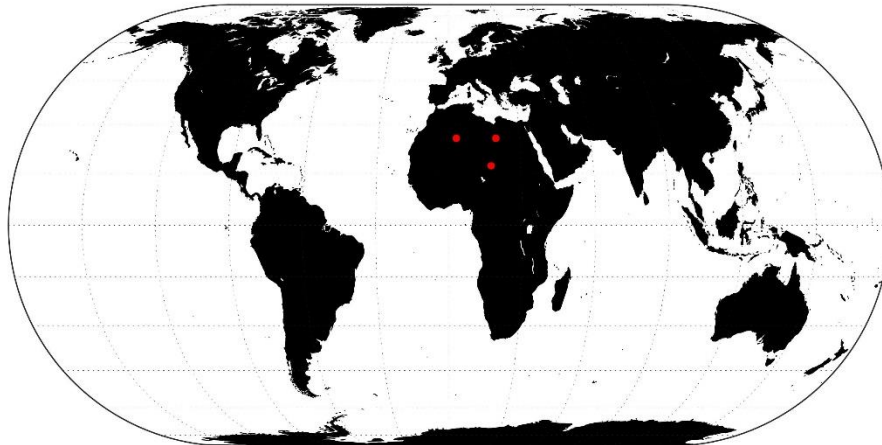


Figure 4-26. S3B Location of the AutoCal measurements.

Averaged AutoCal measurements (Corrected - Reference).

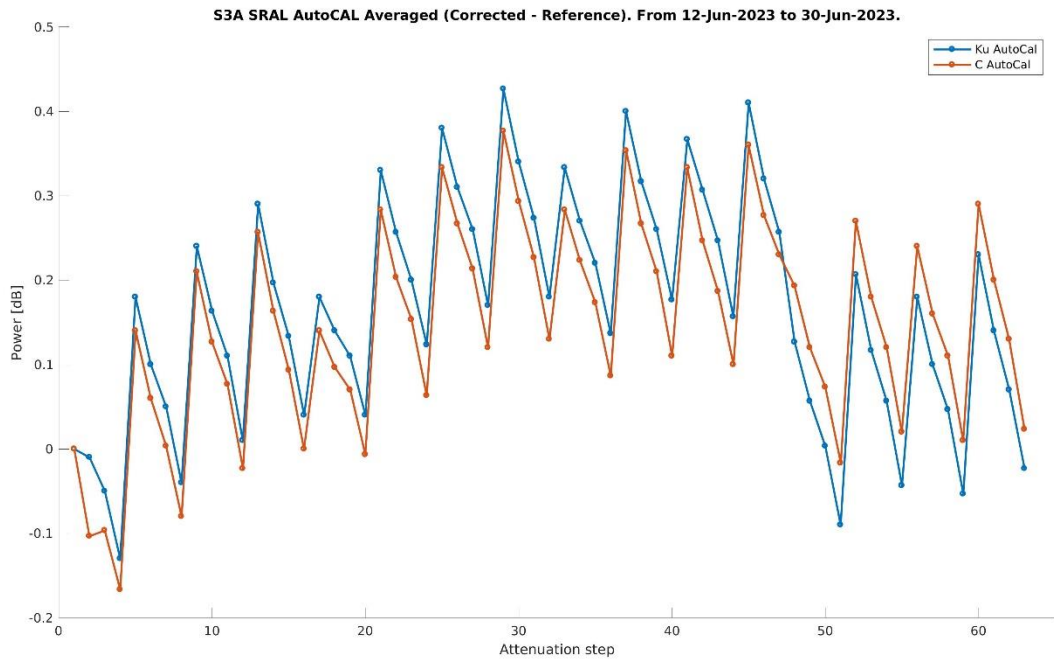


Figure 4-27. S3A AutoCal measurements: Corrected - Reference. Averaged over the cycle.

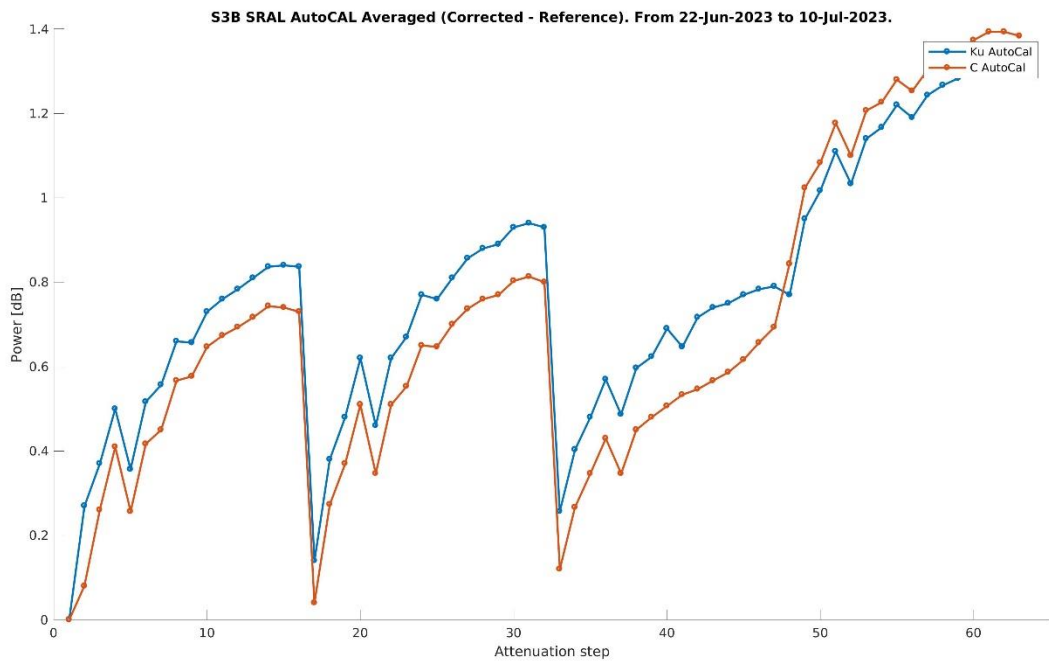


Figure 4-28. S3B AutoCal measurements: Corrected - Reference. Averaged over the cycle.

Progression of the AutoCal measurements for Ku band.

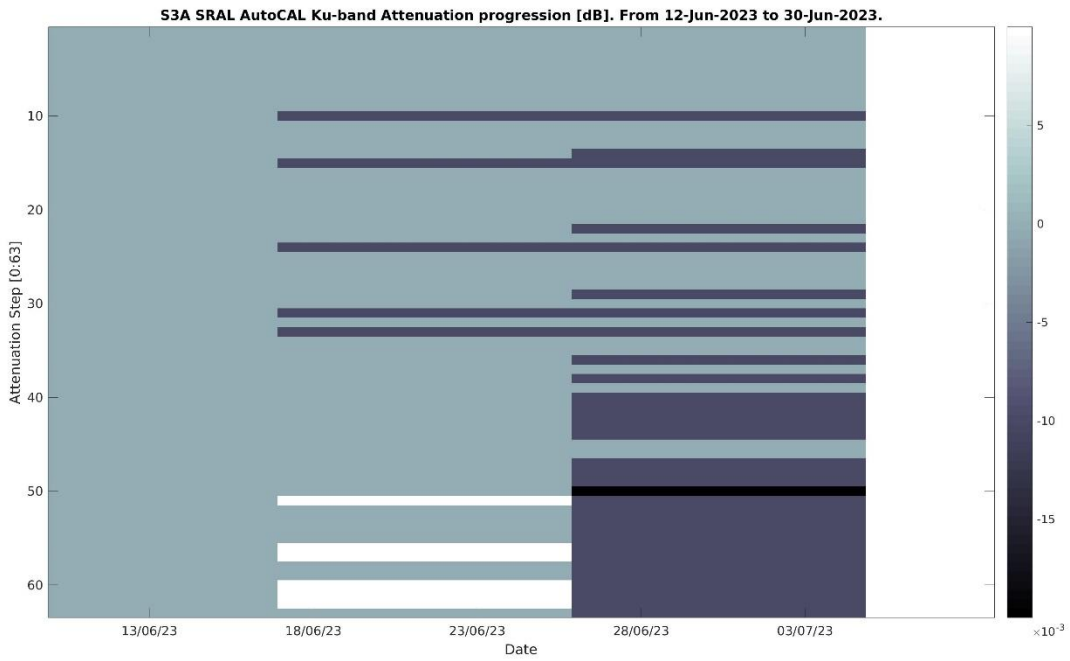


Figure 4-29. S3A Ku band Autocal Cycle Progression.

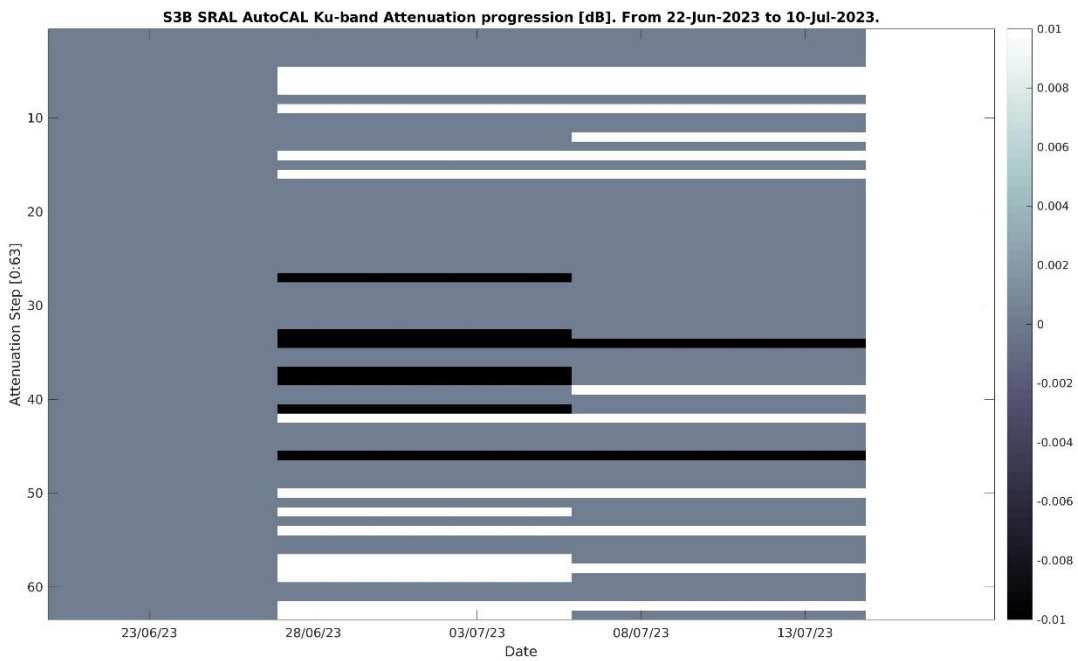


Figure 4-30. S3B Ku band Autocal Cycle Progression.

4.1.4 Thermal behaviour

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

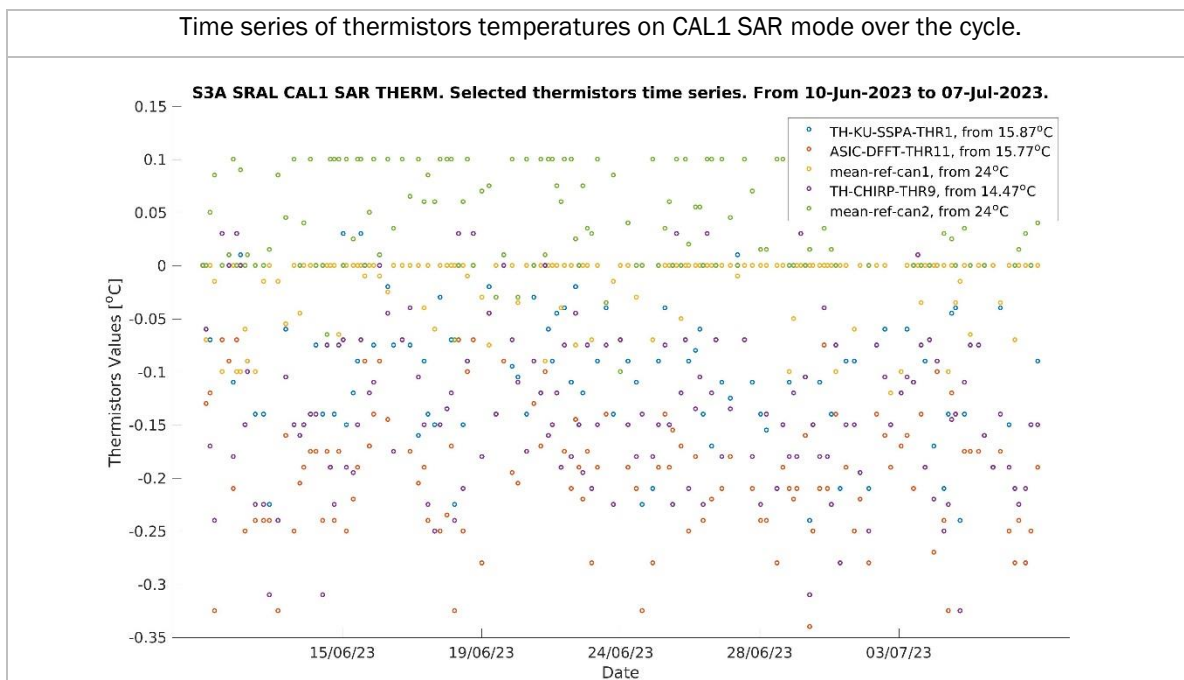


Figure 4-31. S3A Selected group of Thermistors time series on CAL1 SAR mode. The temperatures are averaged for each calibration product.

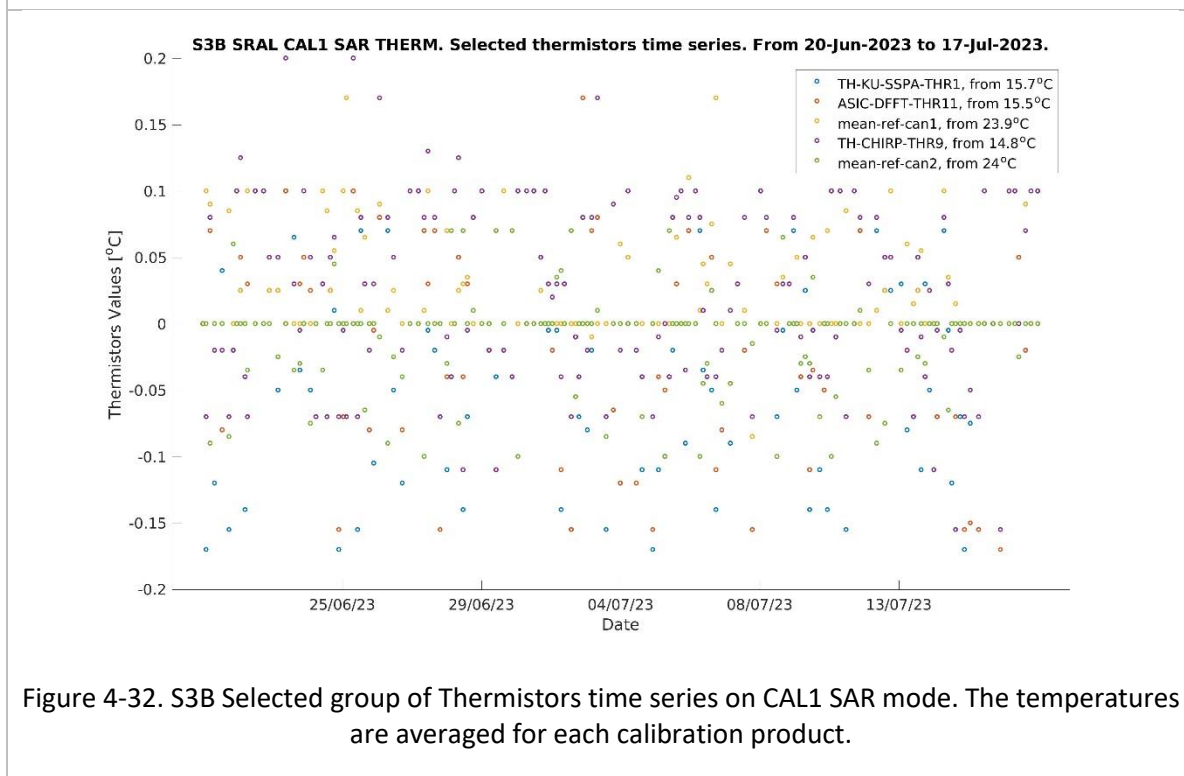


Figure 4-32. S3B Selected group of Thermistors time series on CAL1 SAR mode. The temperatures are averaged for each calibration product.

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.

All the S3A and S3B parameters collected during this cycle show a nominal behaviour.

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.

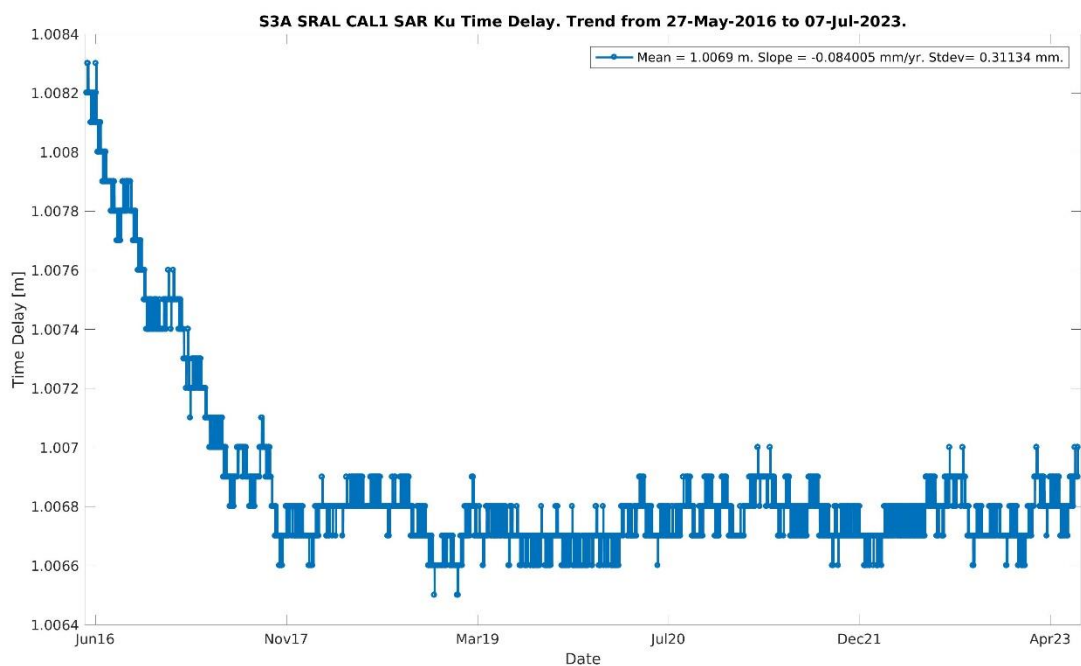


Figure 4-33. S3A CAL1 SAR Ku Time Delay Whole Mission Trend.

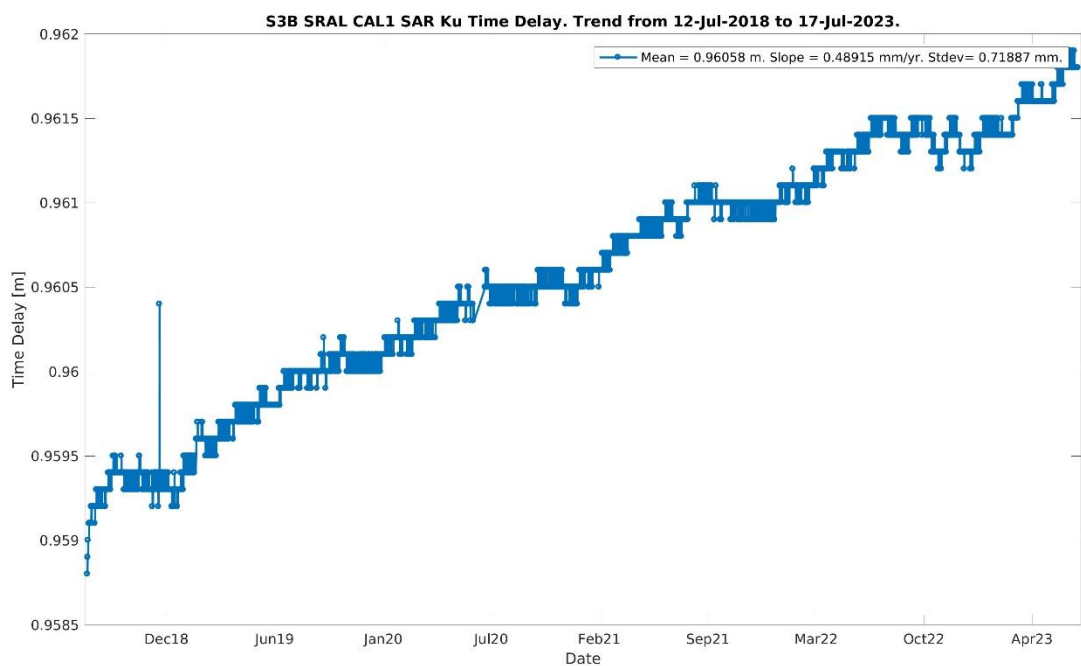


Figure 4-34. S3B CAL1 SAR Ku Time Delay Whole Mission Trend.

CAL1 SAR mode Ku Power Whole Mission Trend.

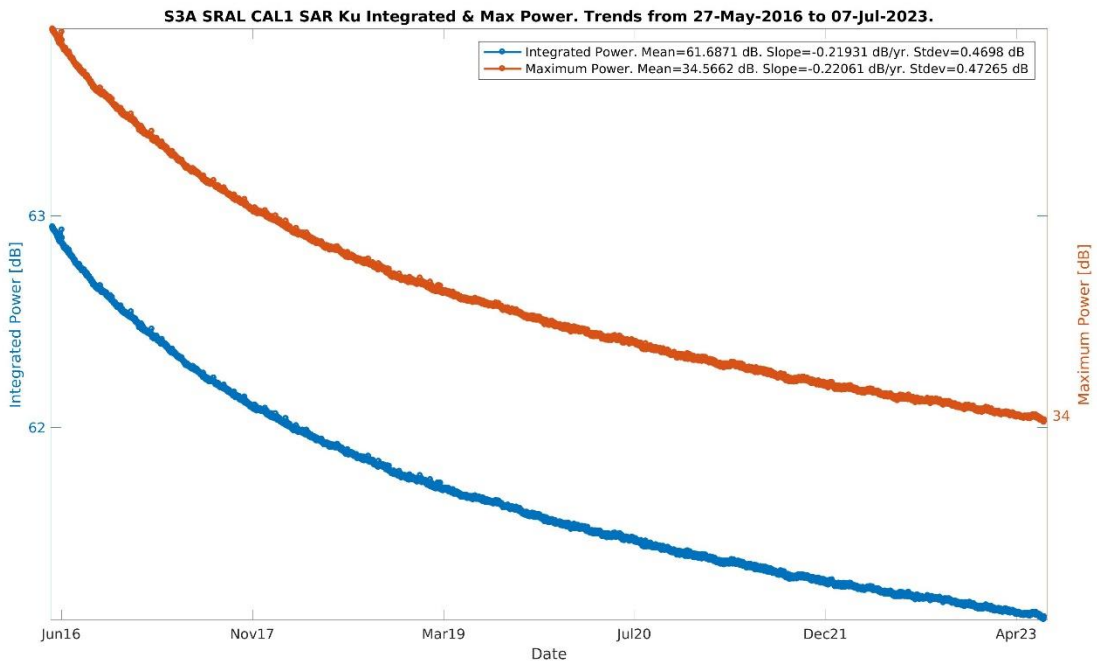


Figure 4-35. S3A CAL1 SAR Ku Power Whole Mission Trend.

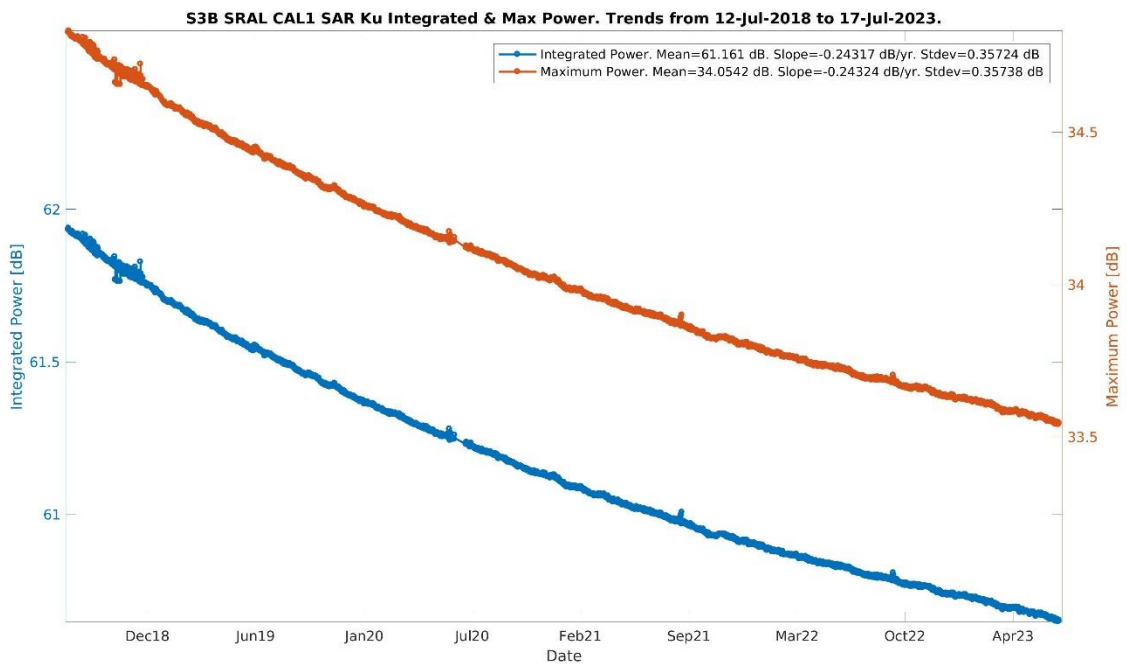


Figure 4-36. S3B CAL1 SAR Ku Power Whole Mission Trend.

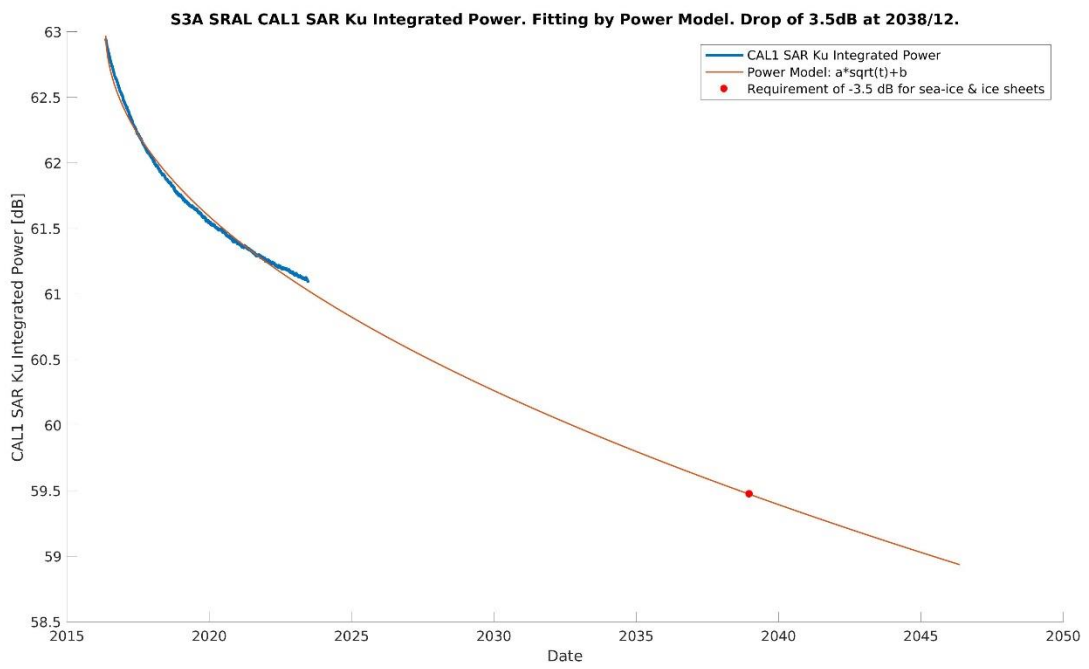


Figure 4-37. S3A CAL1 SAR Ku Power series and long-term trend prediction with power model.

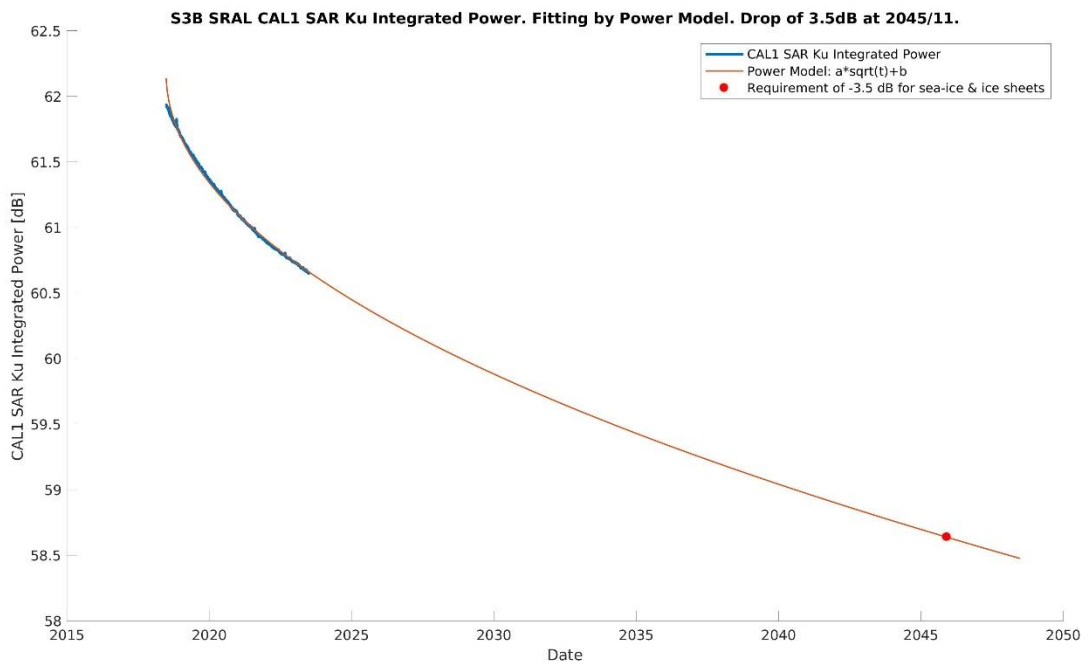


Figure 4-38. S3B CAL1 SAR Ku Power series and long-term trend prediction with power model.

CAL1 SAR mode Ku PTR Width Whole Mission Trend.

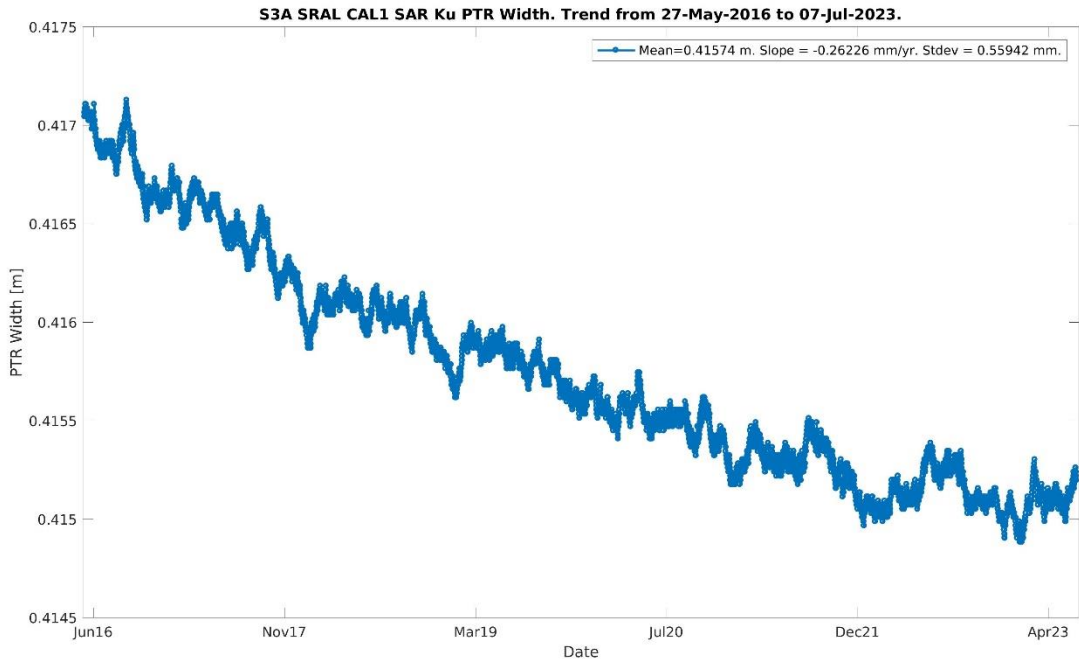


Figure 4-39. S3A CAL1 SAR Ku PTR Width Whole Mission Trend.

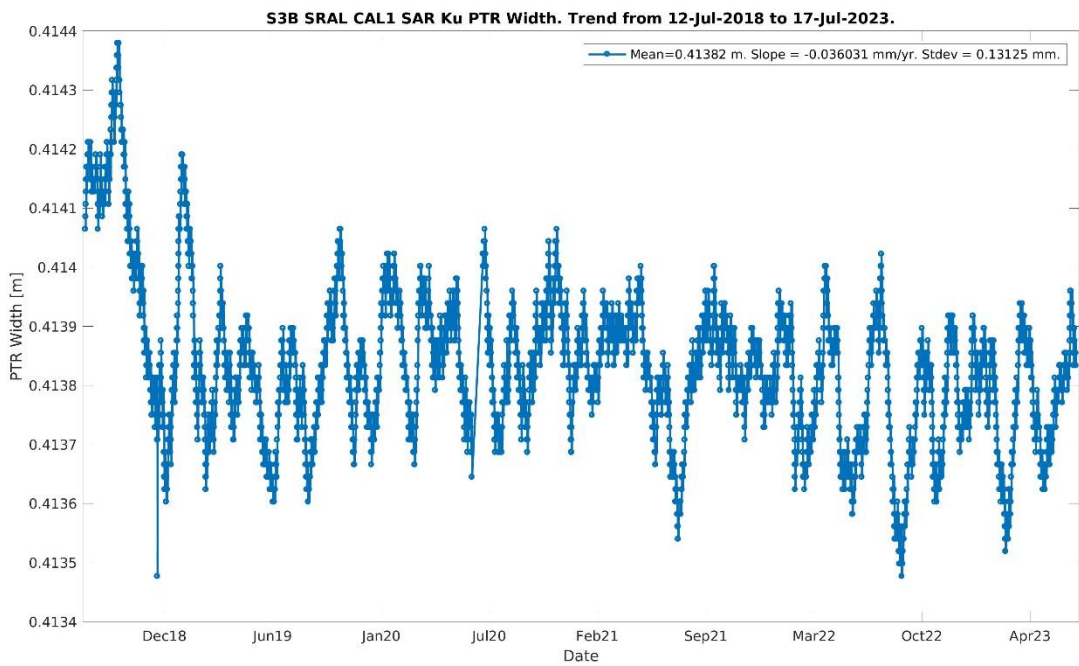


Figure 4-40. S3B CAL1 SAR Ku PTR Width Whole Mission Trend.

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

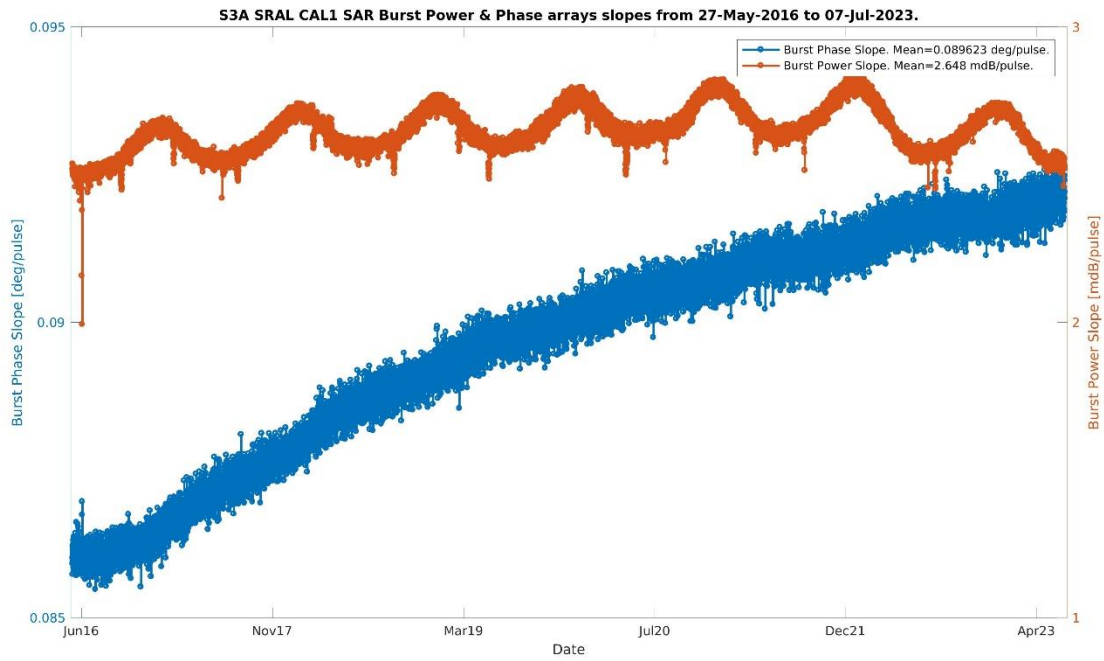


Figure 4-41. S3A CAL1 SAR Ku Phase & Power intra-burst corrections slopes along the whole mission.

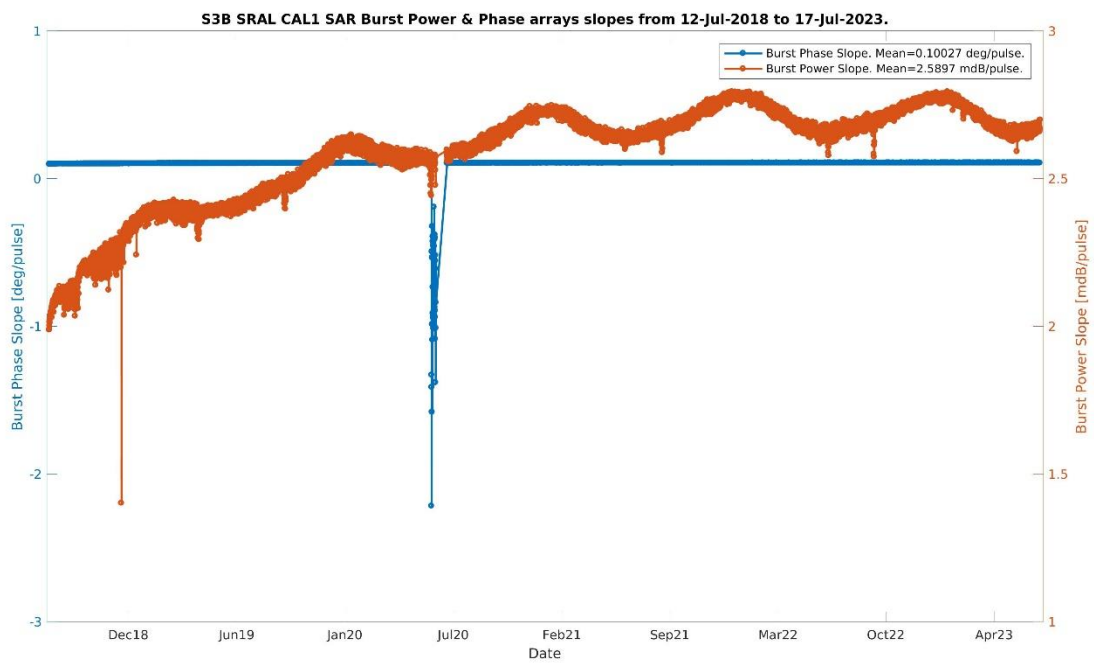


Figure 4-42. S3B CAL1 SAR Ku Phase & Power intra-burst corrections slopes along the whole mission.

Whole Mission Trend of CAL1 SAR waveform secondary lobes power.

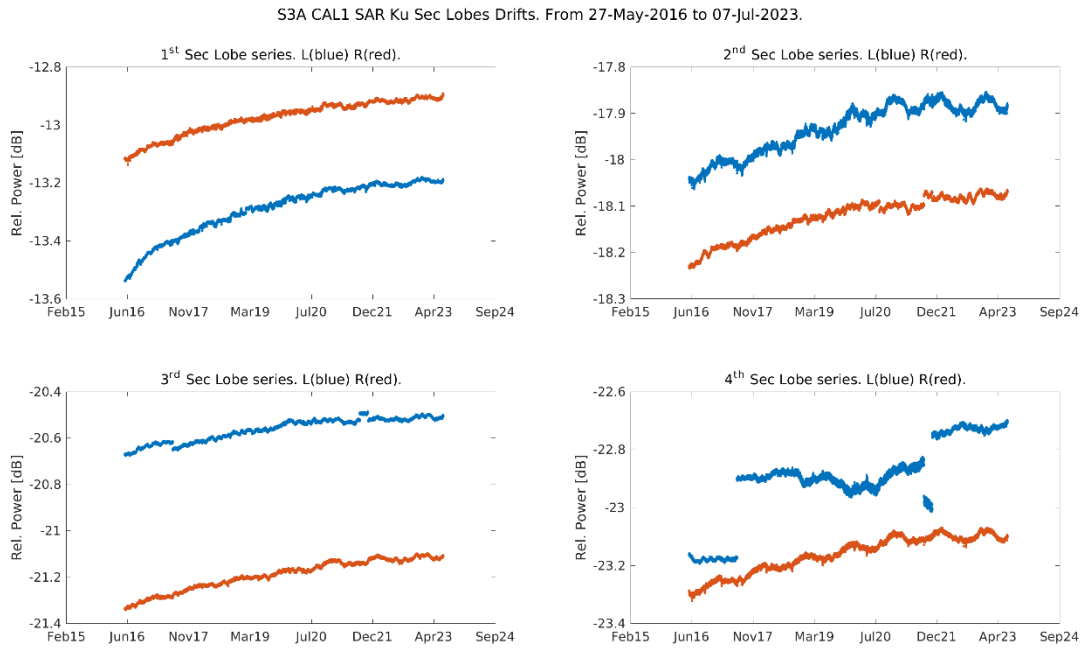


Figure 4-43. S3A CAL1 SAR waveform first four secondary lobes relative power along the mission.

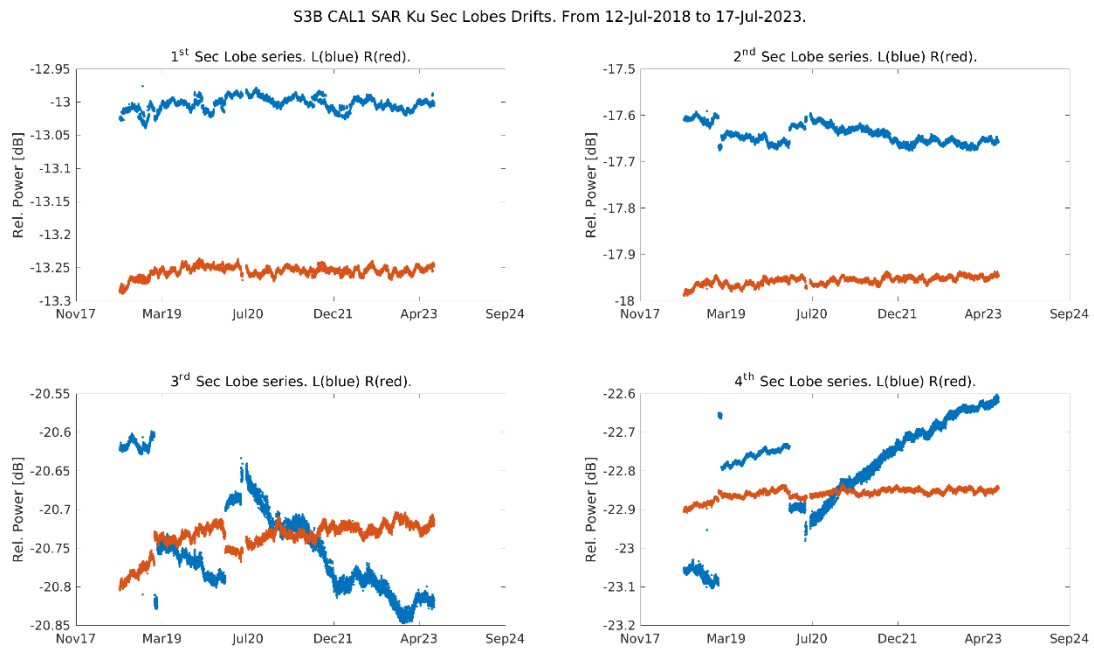


Figure 4-44. S3B CAL1 SAR waveform first four secondary lobes relative power along the mission.

Whole Mission Trend of CAL2 SAR waveform slope.

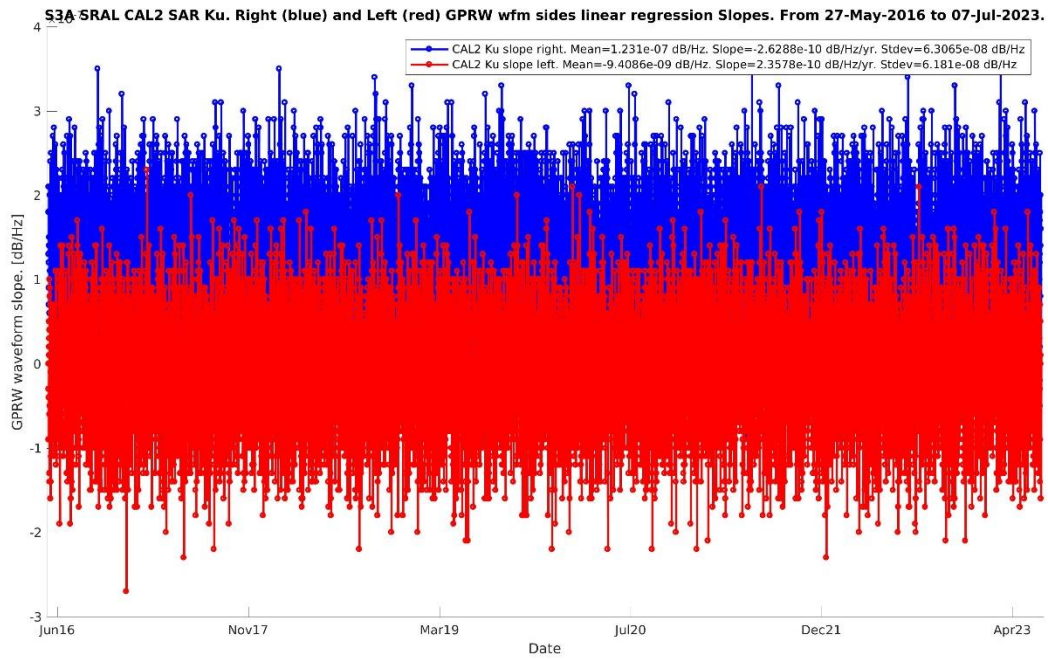


Figure 4-45. S3A Slope at each side of the CAL2 Ku waveform, averaged over the whole mission.

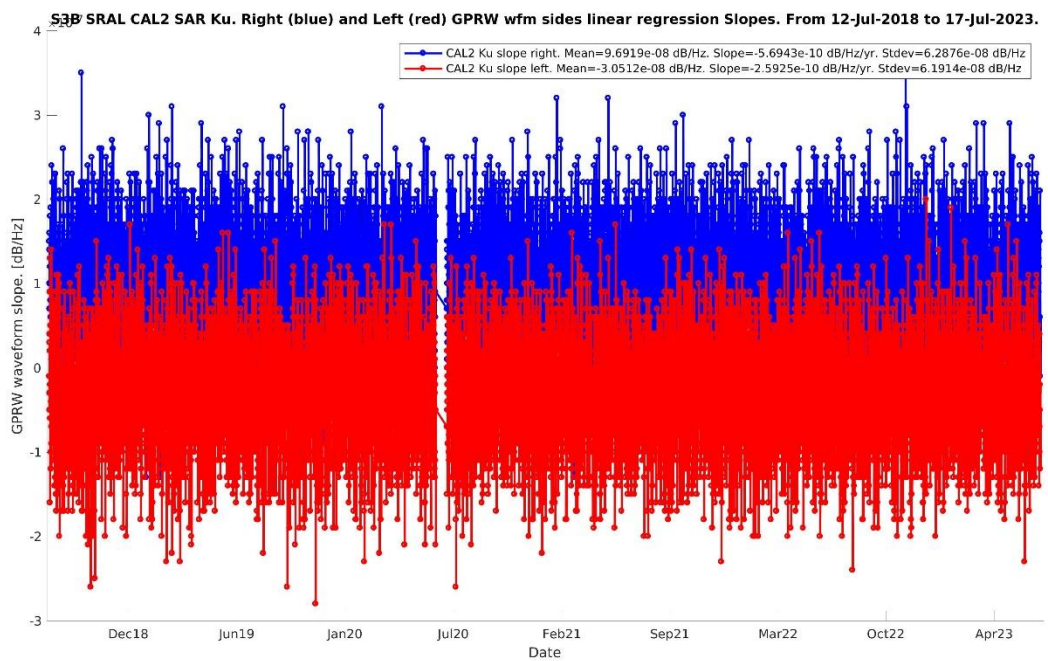


Figure 4-46. S3B Slope at each side of the CAL2 Ku waveform, averaged over the whole mission.

Whole Mission Averaged Differential AutoCal measurements.

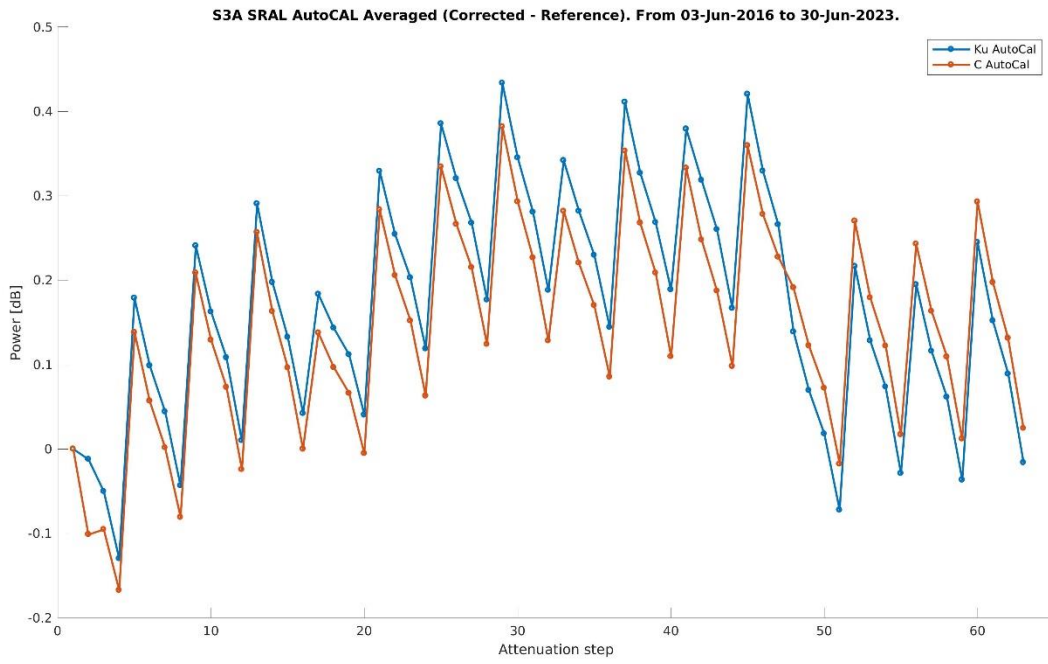


Figure 4-47. S3A Autocal measurements: Corrected - Reference. Averaged over the whole mission.

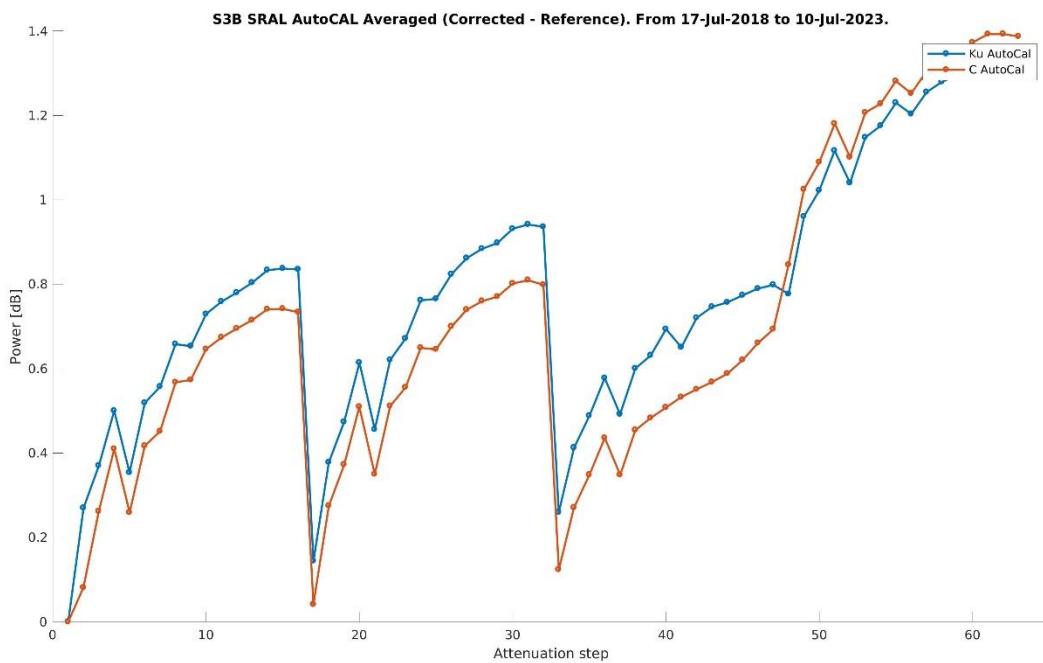


Figure 4-48. S3B Autocal measurements: Corrected - Reference. Averaged over the whole mission.

AutoCAL Ku band attenuation progression series.

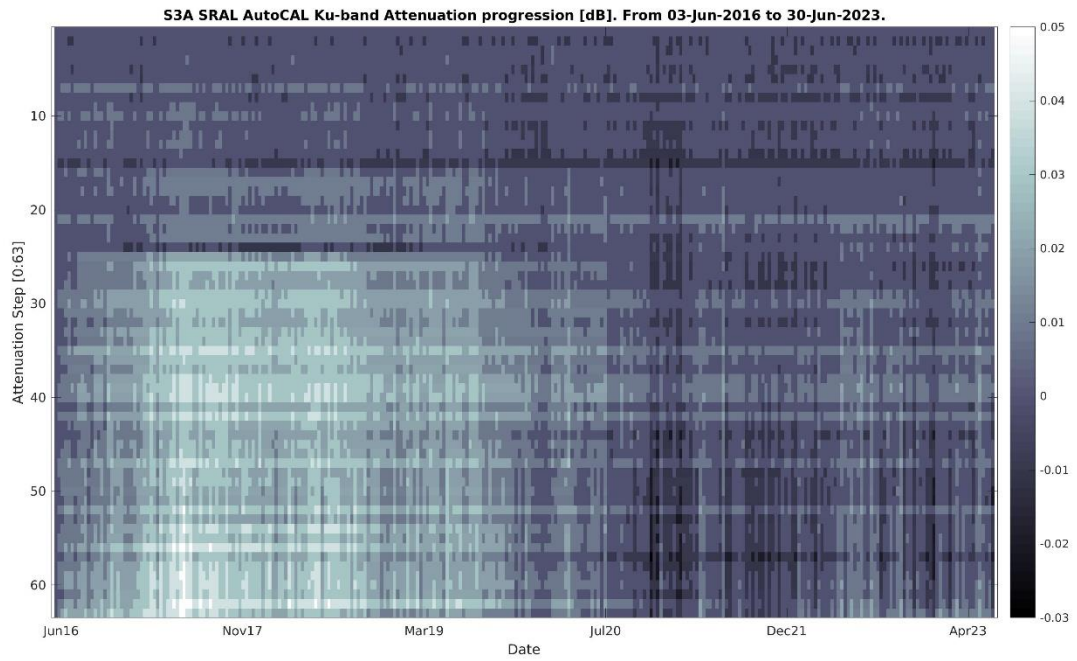


Figure 4-49. S3A AutoCAL Ku attenuation whole mission progression. Difference in dB with respect to the first attenuation value, for each attenuation step.

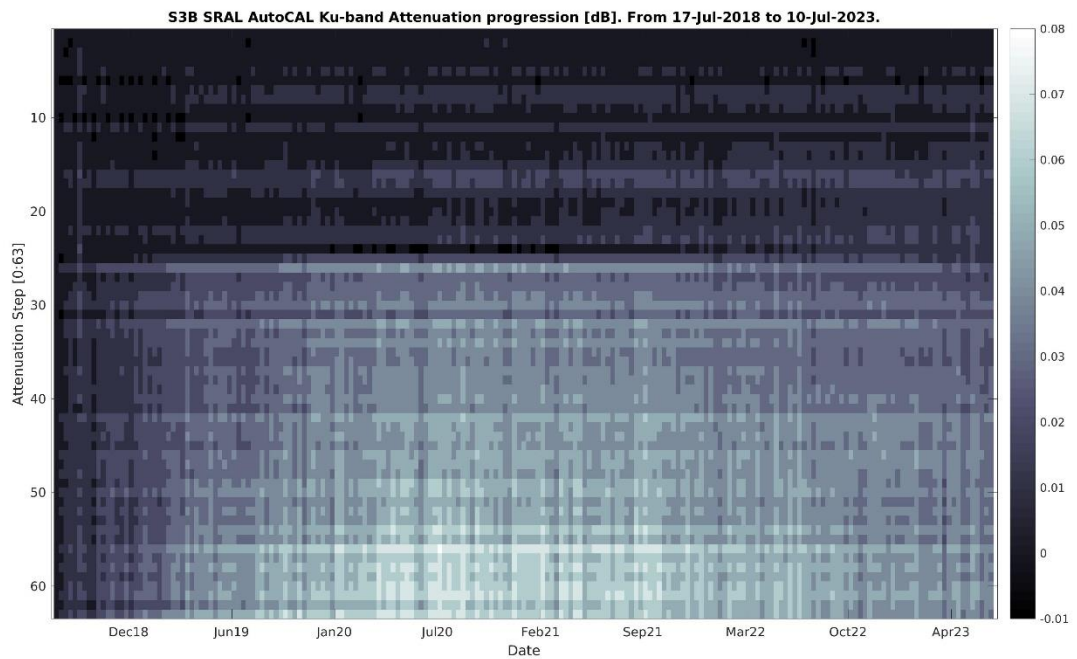


Figure 4-50. S3B AutoCAL Ku attenuation whole mission progression. Difference in dB with respect to the first attenuation value, for each attenuation step.

Time series of the USO frequency.

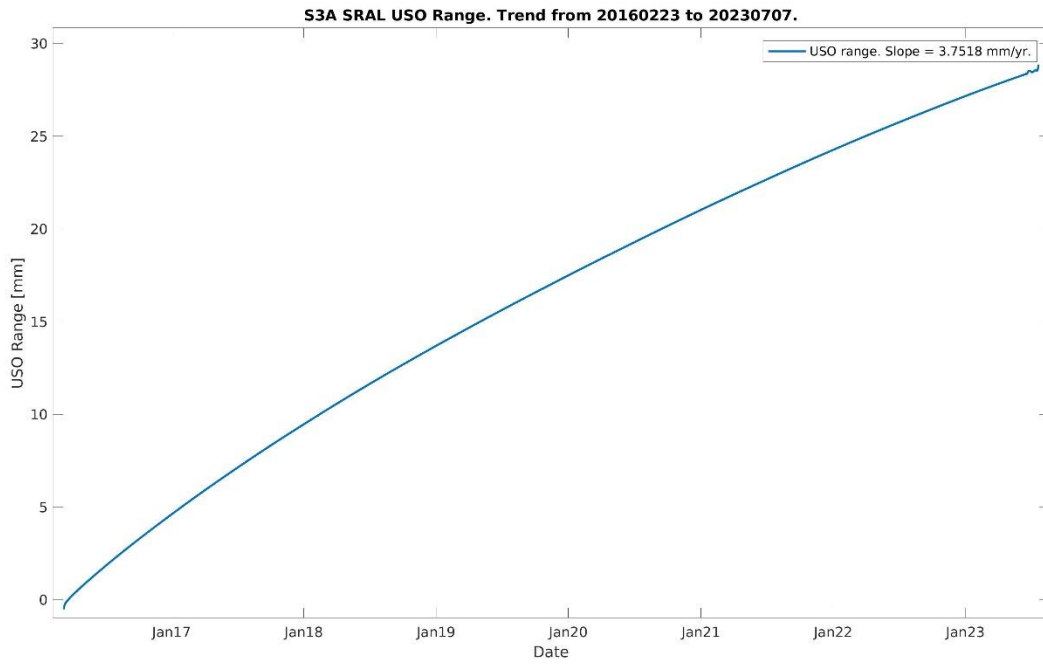


Figure 4-51. S3A USO frequency impact in the range.

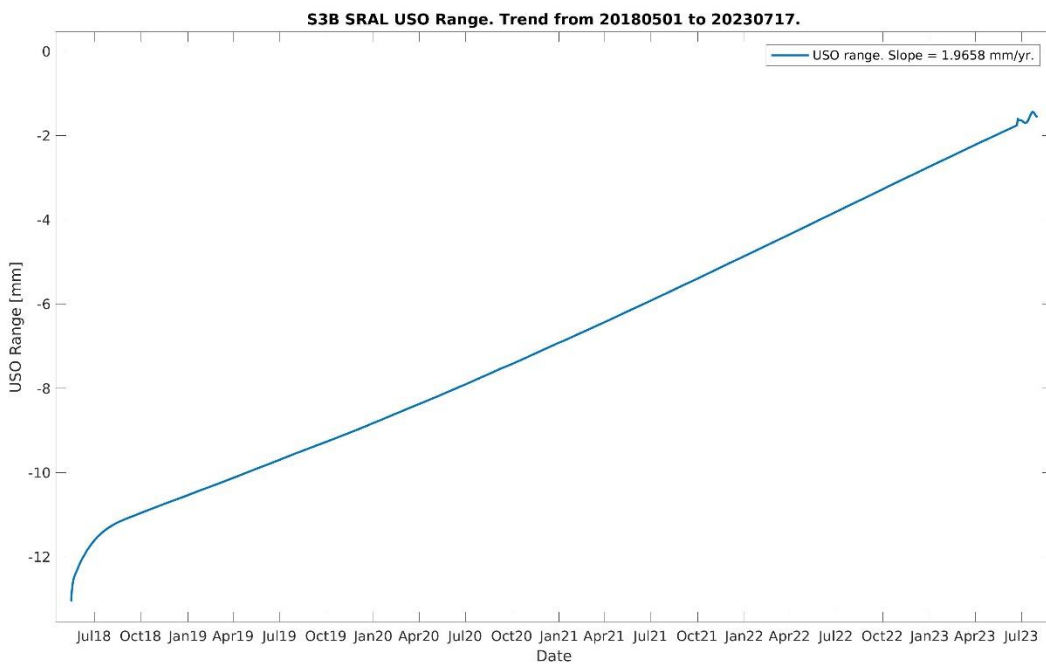


Figure 4-52. S3B USO frequency impact in the range.

CAL1 SAR thermistors series.

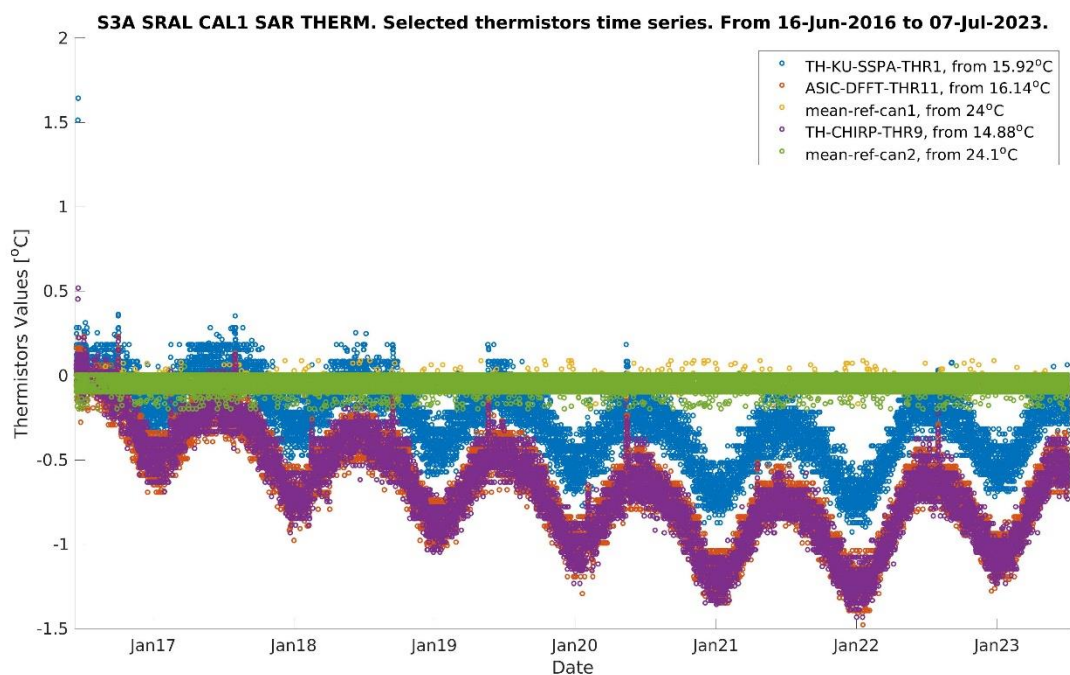


Figure 4-53. S3A Selected CAL1 SAR thermistors series along the whole mission.

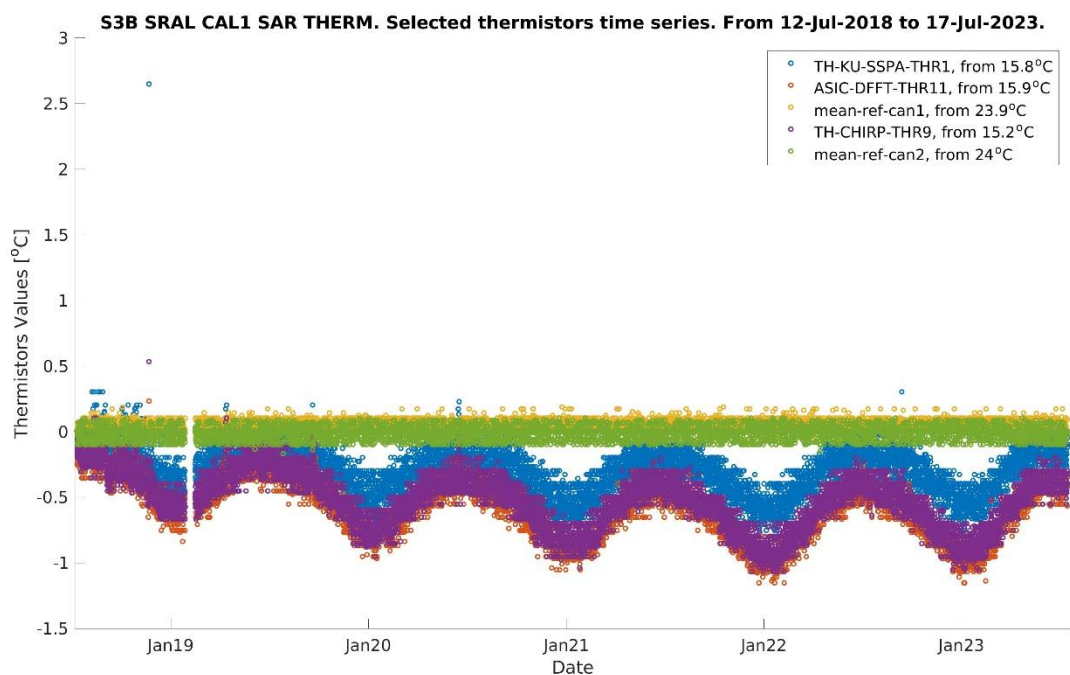


Figure 4-54. S3B Selected CAL1 SAR thermistors series along the whole mission.

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 a flat period around end of 2018.

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, and the data returned to its precedent nominal values. Anyhow this problem caused a stop of the calibration processing during the time of its correction & implementation, and a gap in the S3B series will be present until a new reprocessing is completed from a new PB.

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. From May to July 2023 in both missions there is an USO range bias anomaly with maximum value of 0.3 mm that

+causes a USO modelled oscillation to become evident. The impact of this is expected to be corrected in future USO products released.

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 0.3°C, 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 3°C 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). A numerical retracker, considering the PTR real shape, would be a good candidate to overcome this drawback.

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

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 for the ESA's Copernicus Earth Observation programme. This site has been named CDN1 Cal/Val and is located at 35.3379302808°N, 23.7795182869°E and 1048.8184 m height with respect to the WGS84 reference system.

isardSAT has processed the Crete and Svalbard TRP data from a list of L1A NTC products provided on the FTP. This processing method is explained in [Garcia-Mondejar et al. 2018]¹. 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 to 45 increase in IPF-SR-1 Version as newer ones become available.

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.

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 ESA Sentinel-3 Land level-2 products, Non Time Critical (NTC) timeliness.

Since the month of June 2019, the Svalbard transponder has also been used to calibrate the Sentinel-3 satellites. The transponder is located at 78.23052306°N, 15.39376997°E and 492.772 m of height with respect to the WGS84 reference system.

For the Svalbard transponder, the ionospheric and wet/dry tropospheric, the solid earth, geocentric tide and ocean loading corrections are selected from the ESA Sentinel-3 Land level-2 products, Non Time Critical (NTC) timeliness.

The range and datation results detailed here below are extracted from the minimisation of the RMS between theoretical and measured series. The range bias is computed as measured minus theoretical.

Table 5-1 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, 14.01 mm smaller than expected (elevation 14.01 mm higher than expected), and a datation bias of -116.16 microseconds. They also show a 0.72 mm stack noise. For S3B, the results show a negative measured range, 3.21mm smaller than expected (elevation 3.21 mm higher than expected), and a datation bias of -23.13 microseconds. They also show a 0.67 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.

Table 5-2 presents the same kind of results, from the TRP passes over Svalbard. For S3A, the results show a negative measured range, 69.04 mm smaller than expected (elevation 69.04 mm higher than expected), and a datation bias of -40.91 microseconds. They also show a 17.05 mm stack noise. The results for S3B show a negative bias range, 56.92 mm smaller range than expected (elevation 56.92 mm higher than expected), and a datation bias of -29.89 microseconds. They also show a 9.90 mm stack noise (we have less than 1 mm with S3A/B over Crete and 7.4 mm with CryoSat-2 over Svalbard).

Figure 5-1 to Figure 5-4 depicts the series of TRP processing results for the two missions and the two transponders, including range, datation, stack alignment and stack range noise.

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).

On the other hand, at the last CM in November 2021, S. Dinardo (CLS) showed that the IPF was reading the USO delta frequency from the USO ASCII files overlooking the sign. This affects the S3B mission, which present negative values along the full series. This impact has been accounted for. The TRP processing results have been updated accordingly. Before applying this correction, the S3B range drift was of - 5 mm/year, while currently the regression line for S3B shows a drift of -3.34 mm/year.

The last passes over Svalbard, both S3A and S3B are having strong interferences, making it very difficult to retrieve a clear signal from the TRP. As shown in the tables and figures, the stack range noise is quite different from their usual values. For S3B, the pass on cycle 70 has no signal from the TRP

There is no signal received from the TRP for the passes over Svalbard since May 2023.

| Cycle – Mission | Date | Range bias [mm] | Datation bias [microseconds] | Alignment [mm/beam] | Noise [mm] | IPF-SR-1 Version |
|-------------------------------|------------|-----------------|------------------------------|---------------------|-------------|------------------|
| 99 - S3A | 2023/05/15 | -48.25 | -135.61 | 0.06 | 0.58 | 06.20 |
| 80 - S3B | 2023/06/17 | - | - | - | - | 06.20 |
| Mean S3A (87 passes) | | -14.01 | -116.16 | 0.06 | 0.72 | - |
| Standard Deviation S3A | | 15.26 | 18.13 | 0.01 | 0.18 | - |
| Mean S3B (61 passes) | | -3.21 | -23.13 | 0.02 | 0.67 | - |
| Standard Deviation S3B | | 16.38 | 16.81 | 0.01 | 0.15 | - |

Table 5-1. Results of Crete TRP passes processing

| Cycle – Mission | Date | Range bias [mm] | Datation bias [microseconds] | Alignment [mm/beam] | Noise [mm] | IPF-SR-1 Version |
|-------------------------------|------------|-----------------|------------------------------|---------------------|--------------|------------------|
| 99 - S3A | 2023/05/30 | - | - | - | - | 06.20 |
| 80 - S3B | 2023/06/11 | - | - | - | - | 06.20 |
| Mean S3A (51 passes) | | -69.04 | -40.91 | 0.04 | 17.05 | - |
| Standard Deviation S3A | | 37.31 | 75.36 | 0.05 | 9.96 | - |
| Mean S3B (53 passes) | | -56.92 | -29.89 | 0.02 | 9.93 | - |
| Standard Deviation S3B | | 32.24 | 57.40 | 0.04 | 8.80 | - |

Table 5-2. Results of Svalbard TRP passes processing

Transponder processing results.

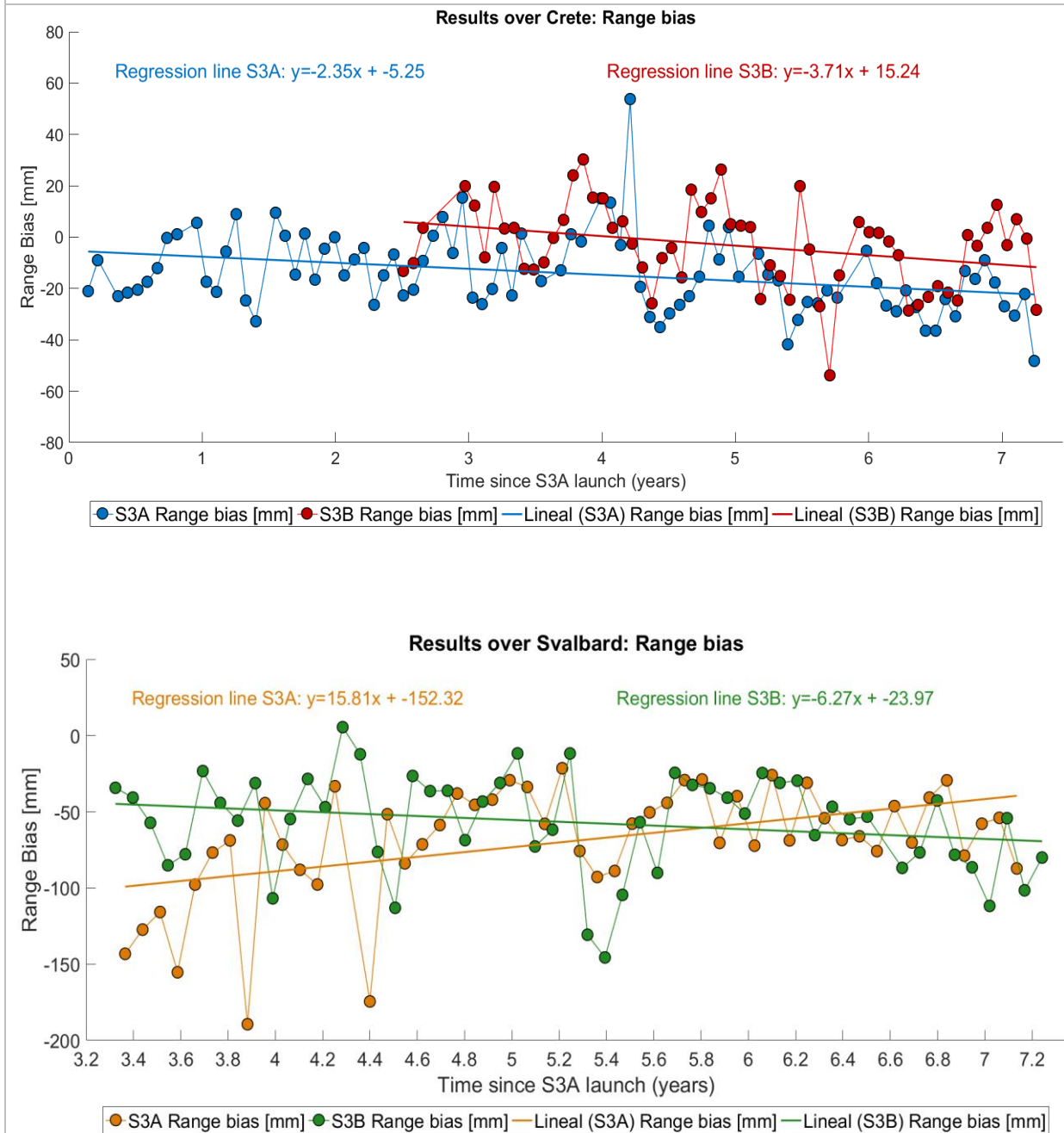
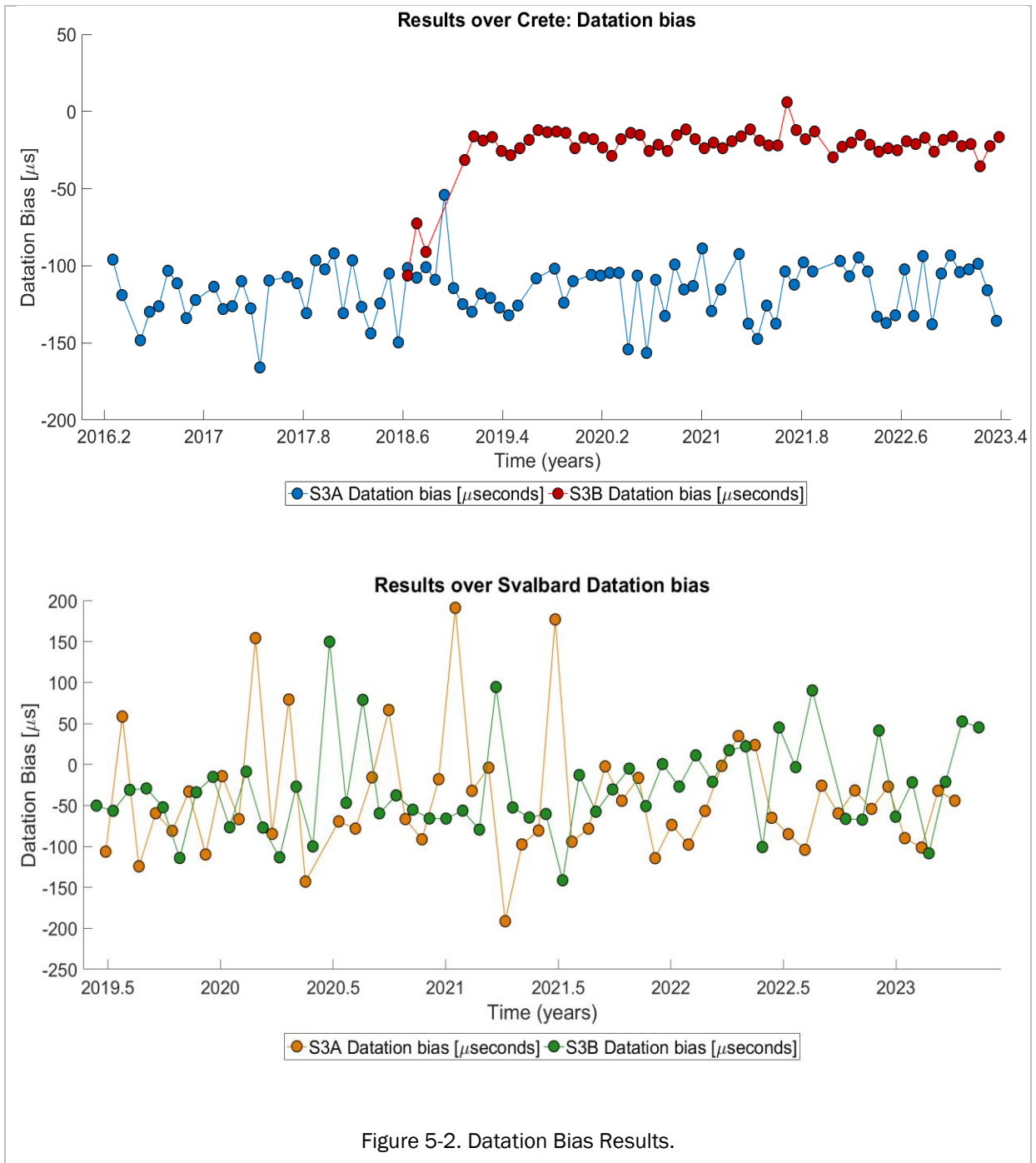


Figure 5-1. Range Bias Results.



Transponder processing. Stack analysis.

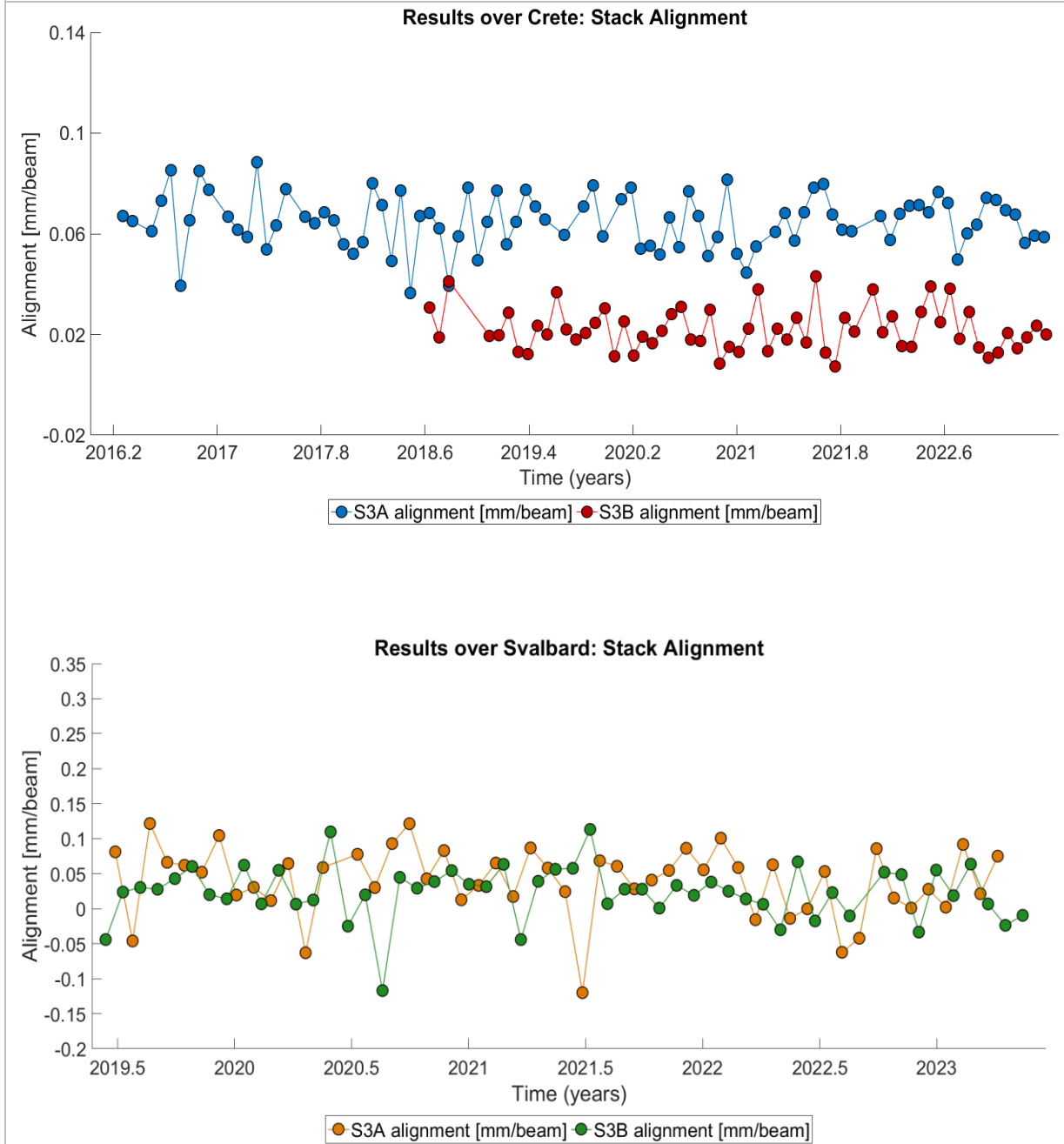
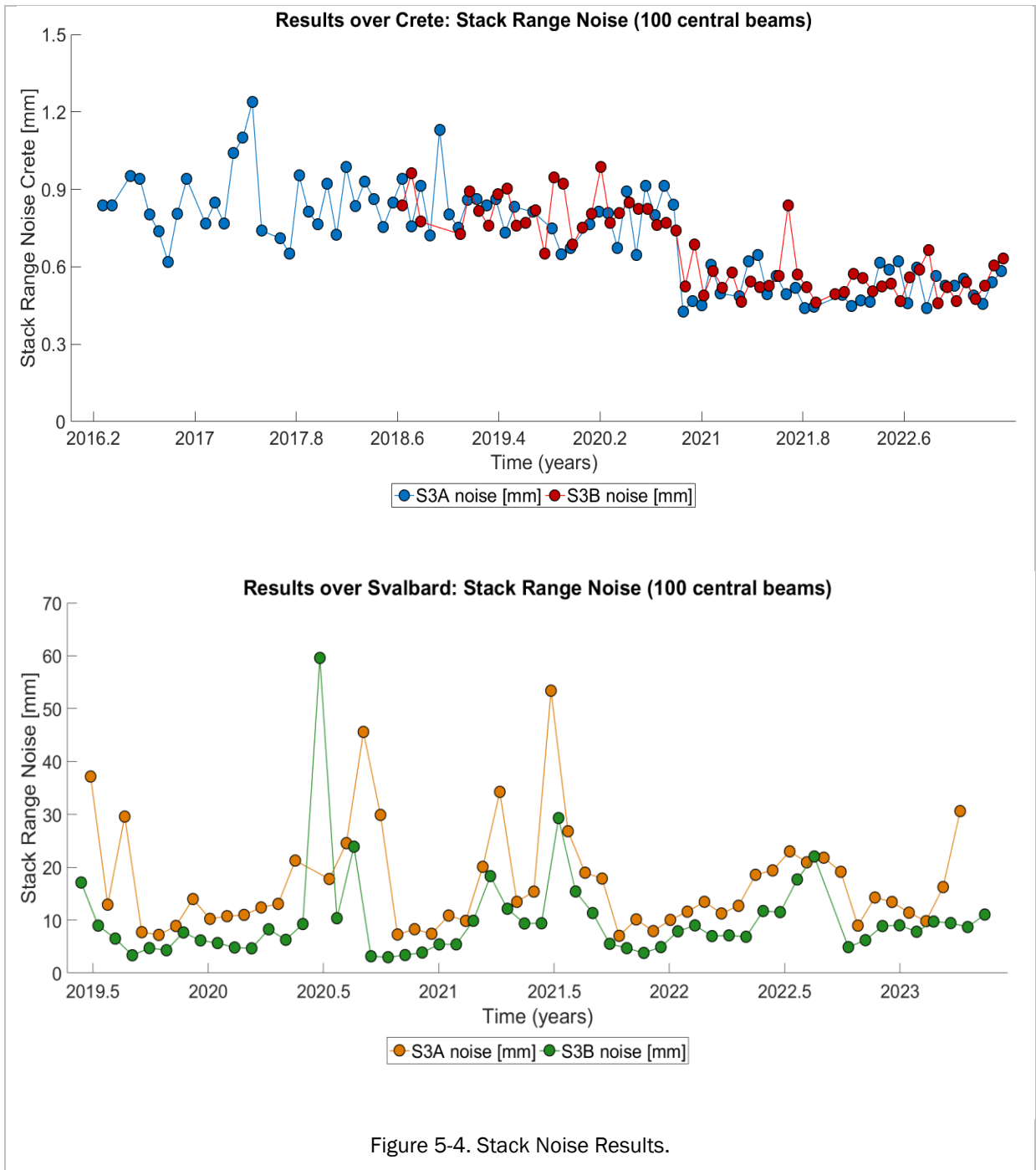


Figure 5-3. Alignment Results.



Appendix A – Useful links

The Product Format Specification applicable to the S3 STM CAL Level-1B products assessed in this report is available in Sentinel Online, version 2.13:

<https://sentinel.esa.int/documents/247904/0/Sentinel-3-Product-Data-Format-Specification-Level-1-products/2b7c773b-44ca-447e-9b86-f7ebd231261c>

Appendix B – Reference

¹ Garcia-Mondéjar, Albert, et al. "CryoSat-2 range, datation and interferometer calibration with Svalbard transponder." *Advances in Space Research* 62.6 (2018): 1589-1609.