PREPARATION AND OPERATIONS OF THE MISSION PERFORMANCE CENTRE (MPC) FOR THE COPERNICUS SENTINEL-3 MISSION

S3 SRAL Cyclic Performance Report

S3-A	S3-B
Cycle No. 050	Cycle No. 031
Start date: 29/09/2019	Start date: 09/10/2019
End date: 26/10/2019	End date: 05/11/2019

Mission Performance Centre

Ref.: S3MPC.ISR.PR.04-050-031
Issue: 1.0
Date: 13/11/2019
Contract: 4000111836/14/I-LG

Customer:	ESA	**Document Ref.:**	S3MPC.ISR.PR.04-050-031
Contract No.:	4000111836/14/I-LG	**Date:**	13/11/2019
isardSAT Doc. Ref.:	ISARD_ESA_S3_MPC_RP_842	**Issue:**	1.0

Project:	PREPARATION AND OPERATIONS OF THE MISSION PERFORMANCE CENTRE (MPC) FOR THE COPERNICUS SENTINEL-3 MISSION		
Title:	S3 SRAL Cyclic Performance Report		
Author(s):	SRAL ESL (isardSAT)		
Approved by:	G. Quartly, STM ESL Coordinator	**Authorized by**	Sylvie Labroue, STM Technical Performance Manager
Distribution:	ESA, EUMETSAT, S3MPC consortium		
Accepted by ESA	S. Dransfeld, MPC Deputy TO for OPT P. Féménias, MPC TO		
Filename	S3MPC.ISR.PR.04-050-031 - i1r0 - SRAL Cyclic Report 050-031.docx		

Disclaimer

The work performed in the frame of this contract is carried out with funding by the European Union. The views expressed herein can in no way be taken to reflect the official opinion of either the European Union or the European Space Agency.

Changes Log

Version	Date	Changes
1.0	13/11/2019	First Version

List of Changes

Version	Section	Answers to RID	Changes

Table of content

List of Figures

List of Tables

1 Introduction

1.1 Scope of the document

This document is dedicated to the cyclic monitoring report of the SRAL calibration parameters within the Sentinel-3 MPC project. This includes also a whole mission analysis.

1.2 Acronyms

ADF	Auxiliary Data File
Cal/Val	Calibration / Validation
CNES	Centre National d'Études Spatiales
DEM	Digital Elevation Model
ESA	European Space Agency
ESL	Expert Support Laboratory
ESTEC	European Space Technology Centre
HKTM	House Keeping Temperatures Monitoring
IOCR	In-Orbit Commissioning Review
LRM	Low Resolution Mode
MPC	Mission Performance Centre
PTR	Point Target Response
SAR	Synthetic Aperture Radar
SCCDB	Satellite Calibration and Characterisation Database
SCT	Satellite Commissioning Team
SRAL	Synthetic Aperture Radar Altimeter
TBD	To Be Done

1.3 Processing Baseline Version

S3A

IPF	IPF / Processing Baseline version	Date of deployment
SR1	06.14 / 2.33	CGS: 04/04/2018 10:09 UTC PAC: 04/04/2018 10:09 UTC

S3B

IPF	IPF / Processing Baseline version	Date of deployment
SR1	06.14 / 1.14	PAC: 06/12/2018 10:05 UTC

2 SRAL Internal Calibration Monitoring.

2.1 Introduction

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 attenuation suffered by the signal when traveling through the instrument also needs to be monitored and the science waveforms need to be compensated for this power variations. 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 and power of the closed loop signal, such as the PTR maximum power or PTR maximum position.

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, for SAR mode, 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 variations in the burst. Some characteristics are computed for describing and following up their behaviour along the S3 mission.

It is also of major importance the monitoring of the on-board clocks. 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), are to be analysed in order 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. The

Autocal parameters monitor the actual attenuation values for each on-board ATT step, and are to be used for updating the on-board ATT table in case of need.

2.2 Cyclic In-Flight Internal Calibration.

In this chapter, the monitoring of all calibration modes main parameters for the S3A and S3B missions is depicted in figures (only Ku band). An analysis of the cycle results is developed in chapter 2.3.

2.2.1 CAL1 LRM

Geolocation of the CAL1 measurements for LRM mode.

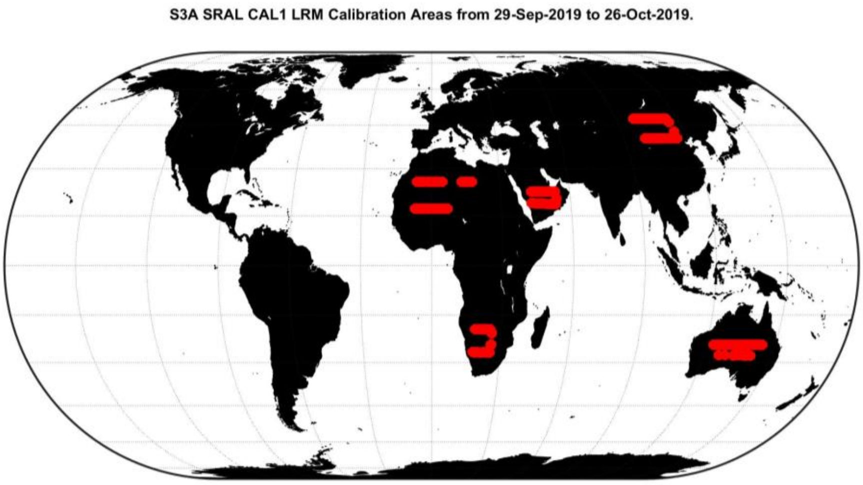


Figure 2-1. Location of the S3A CAL1 LRM measurements.

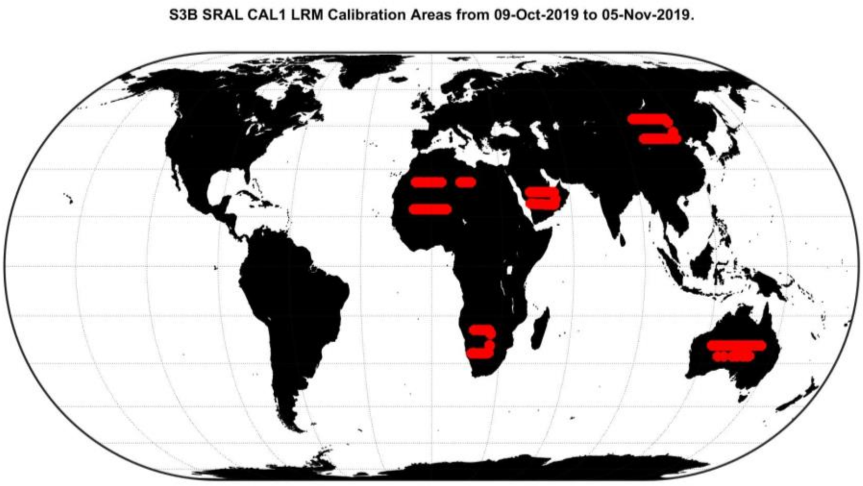


Figure 2-2. Location of the S3B CAL1 LRM measurements.

Period trend of CAL1 PTR Delay for LRM mode.

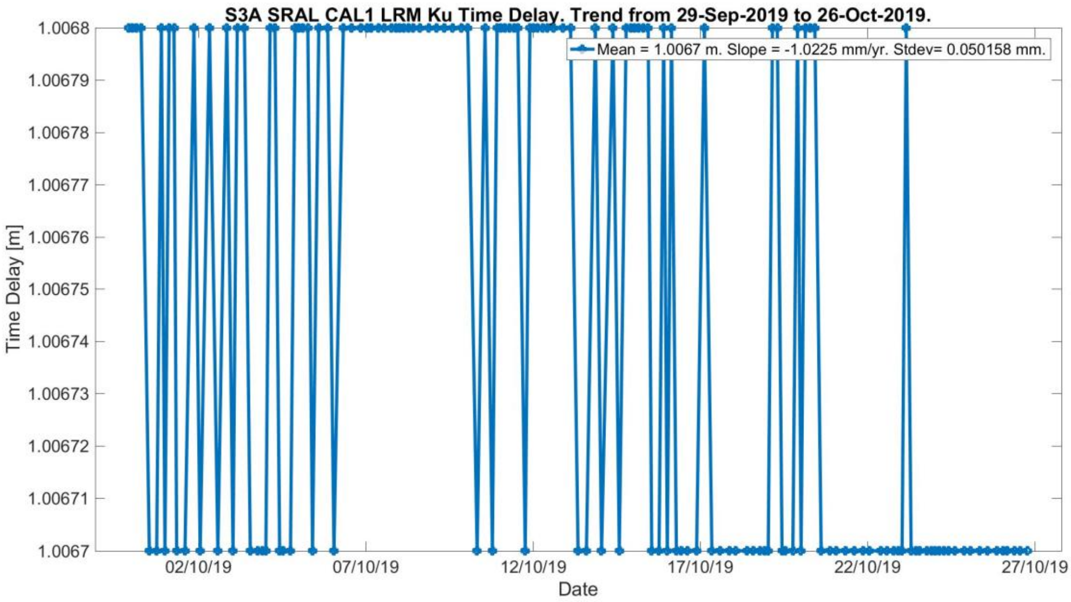


Figure 2-3. S3A CAL1 LRM Ku Time Delay trend.

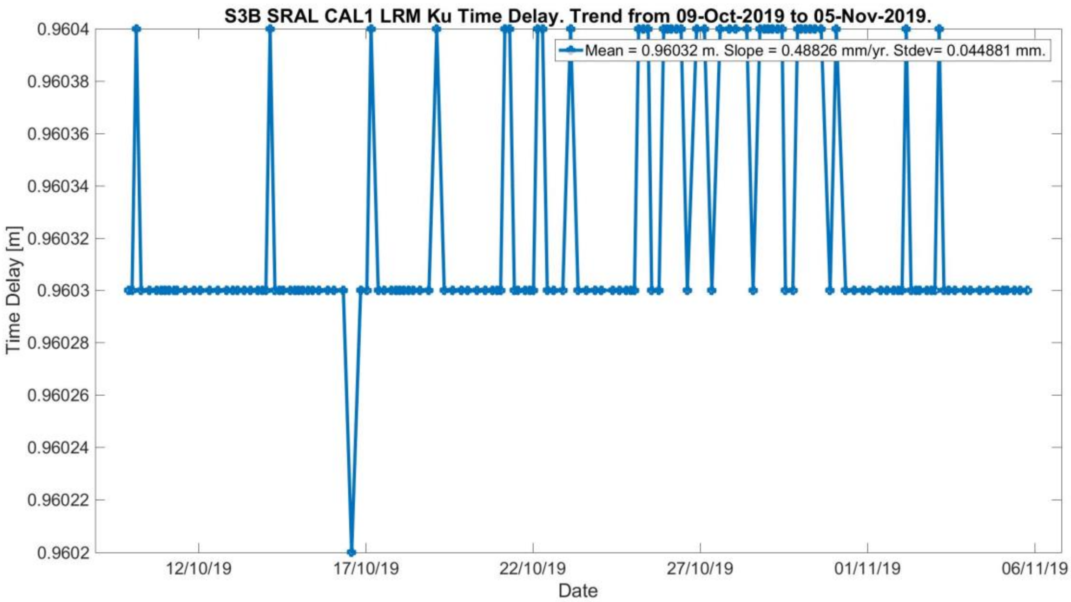


Figure 2-4. S3B CAL1 LRM Ku Time Delay trend.

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

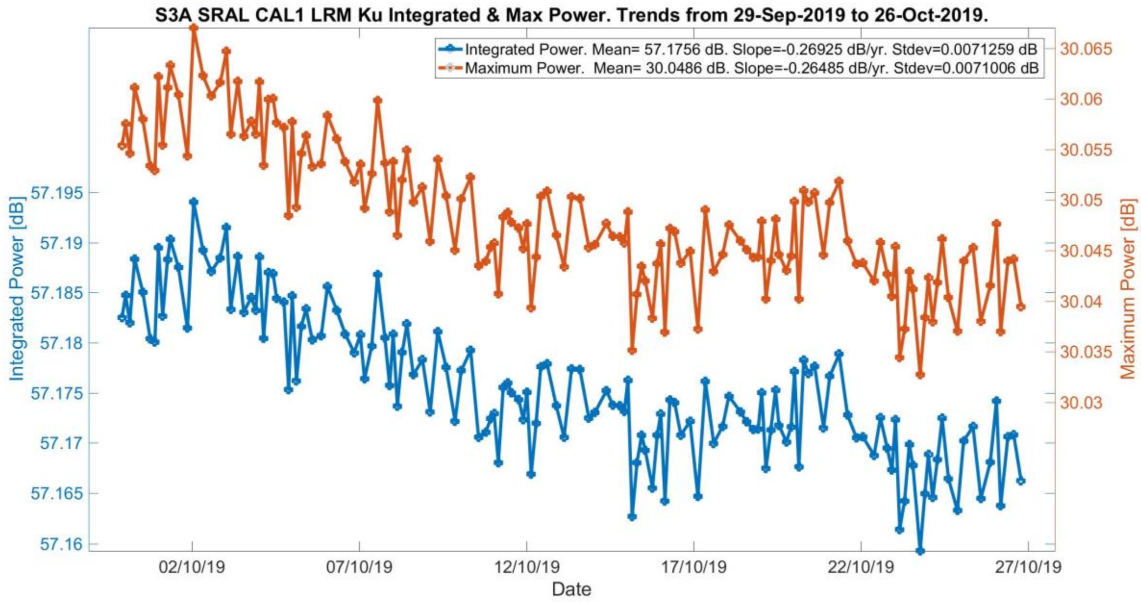


Figure 2-5. S3A CAL1 LRM Ku Power Trend.

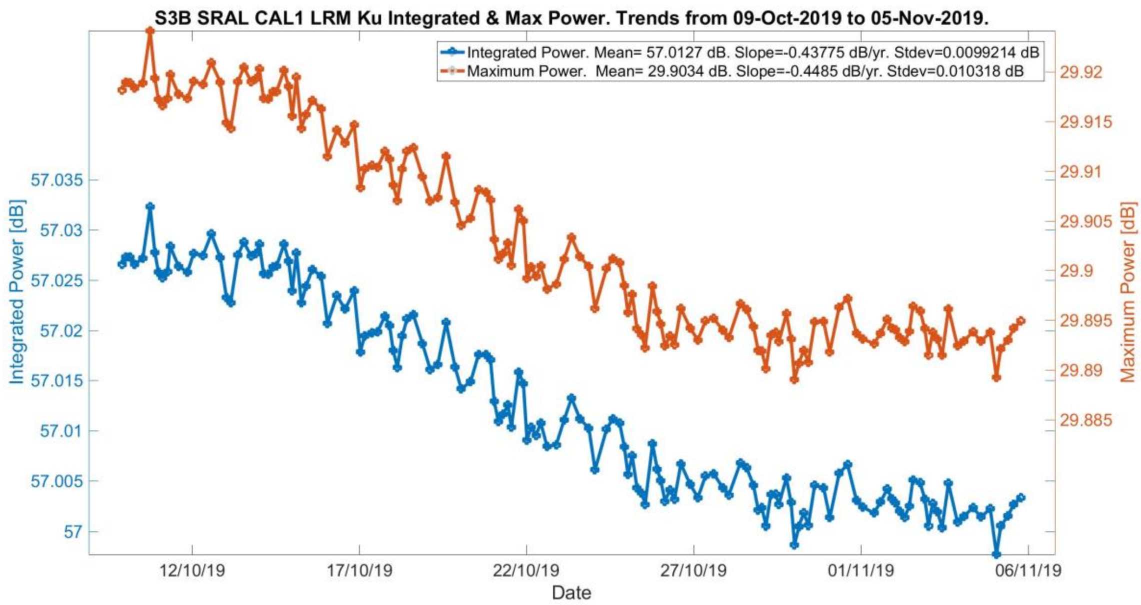


Figure 2-6. S3B CAL1 LRM Ku Power Trend.

Period trend of the CAL1 PTR width for LRM mode.

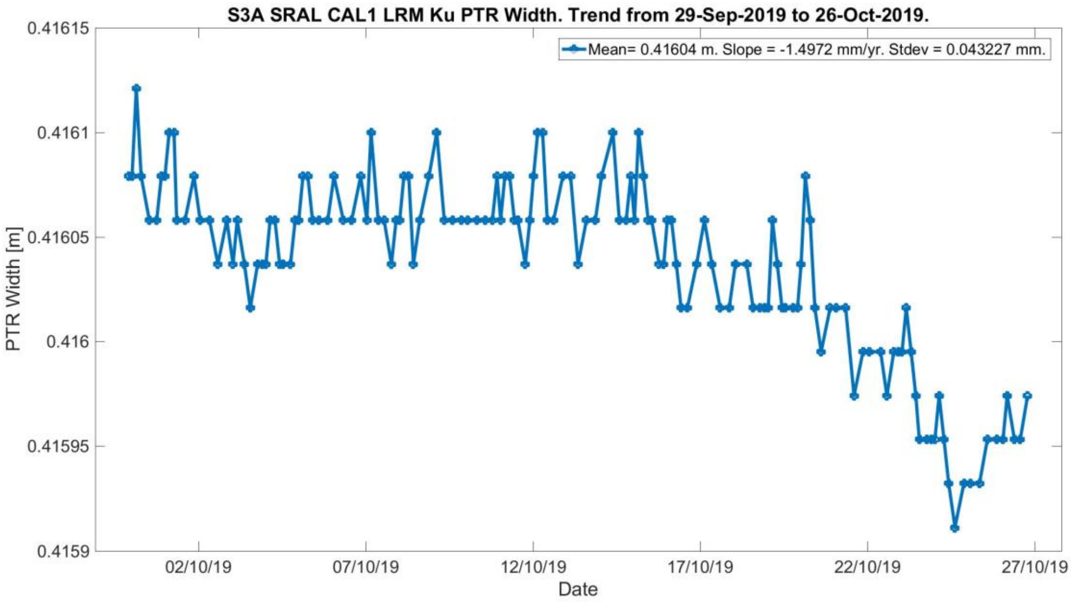


Figure 2-7. S3A CAL1 LRM Ku PTR width trend.

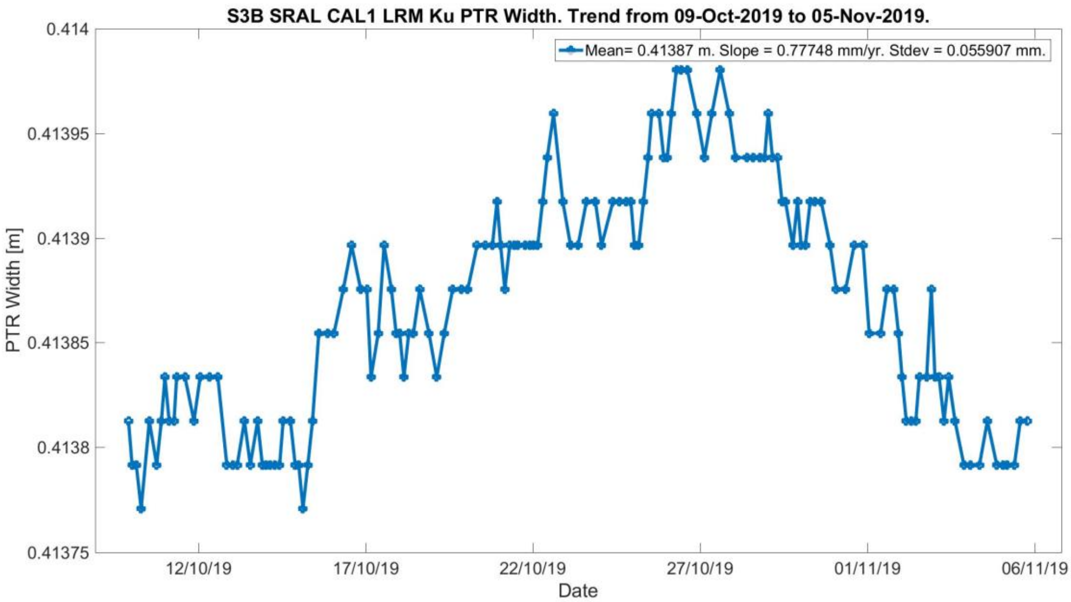


Figure 2-8. S3B CAL1 LRM Ku PTR width trend.

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

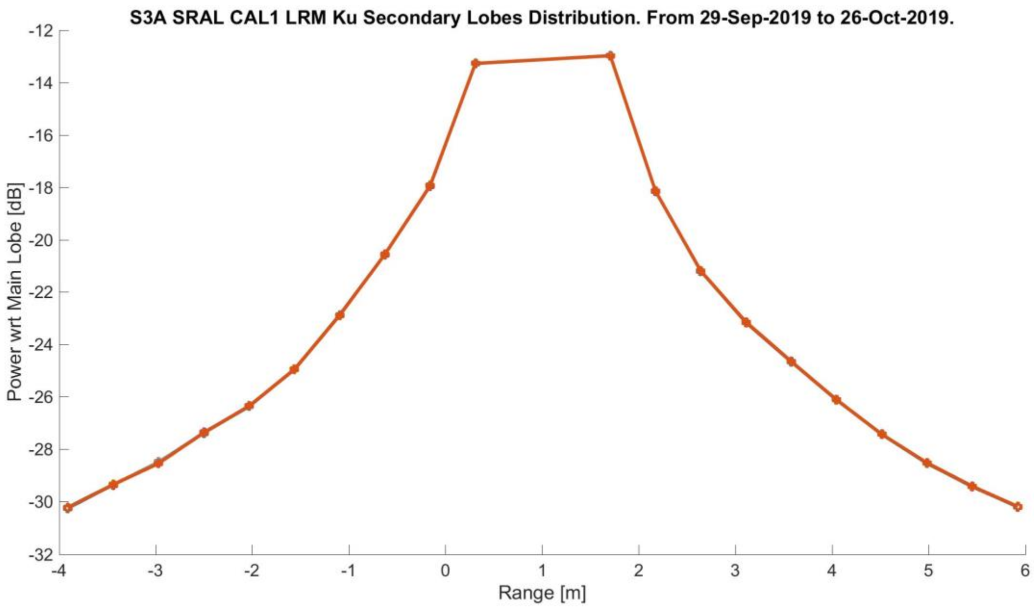


Figure 2-9. S3A CAL1 LRM Ku PTR secondary lobes Power and Position within the PTR waveform.

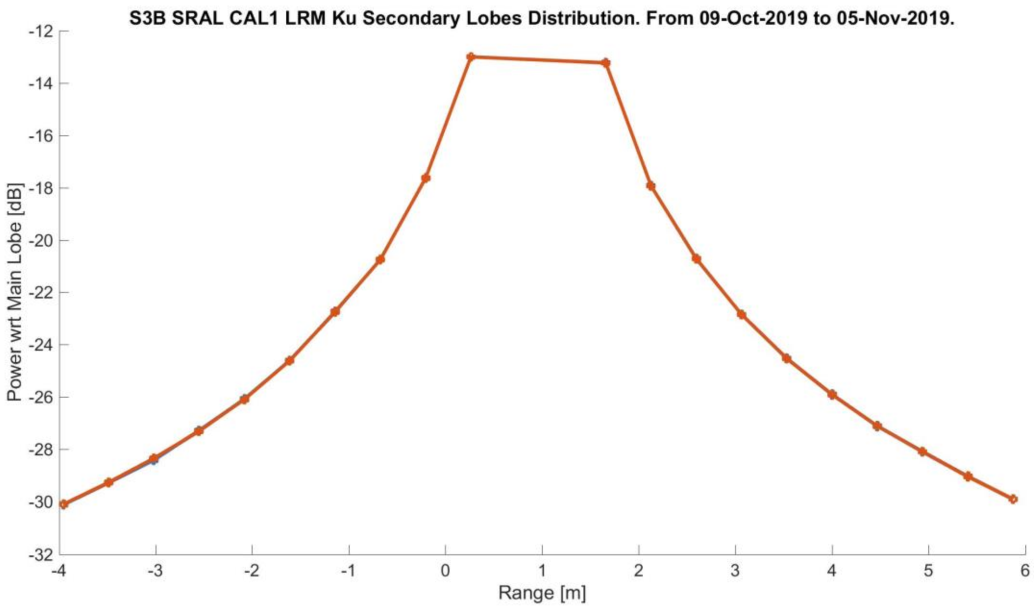


Figure 2-10. S3B CAL1 LRM Ku PTR secondary lobes Power and Position within the PTR waveform.

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

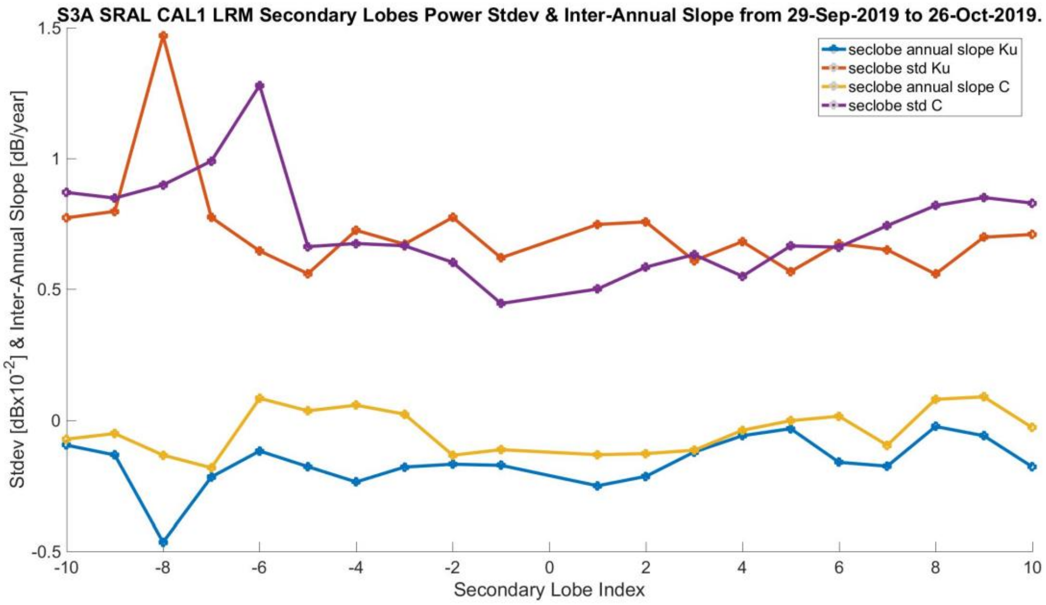


Figure 2-11. S3A CAL1 LRM Ku PTR secondary lobes characterisation. The inter-annual slope (in dB/year) and standard deviation (in dBx10^{-2}) of each of the secondary lobes are shown.

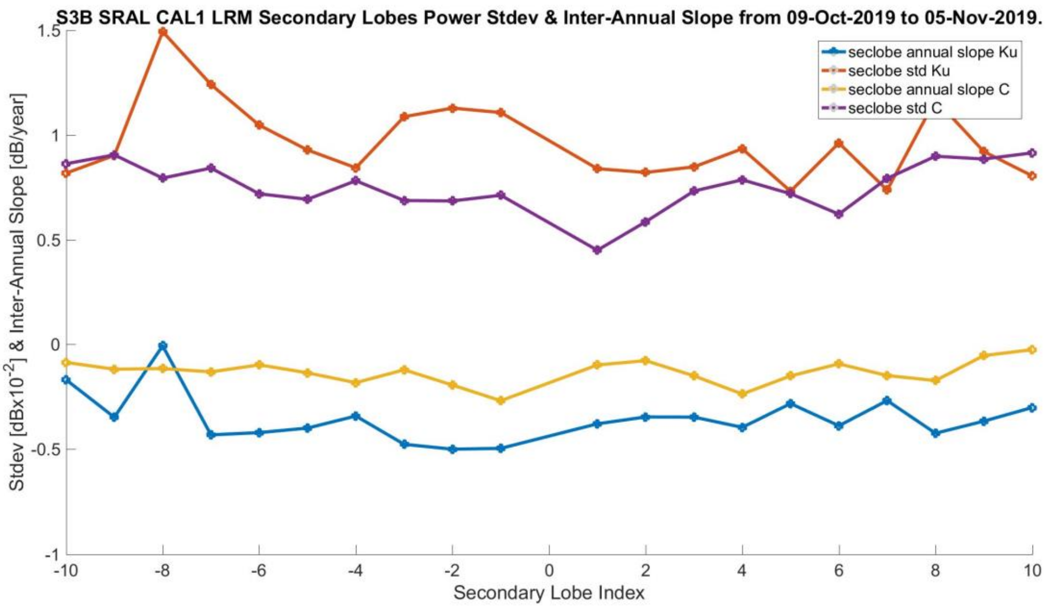


Figure 2-12. S3B CAL1 LRM Ku PTR secondary lobes characterisation. The inter-annual slope (in dB/year) and standard deviation (in dBx10^{-2}) of each of the secondary lobes are shown.

2.2.2 CAL1 SAR

Geolocation of the CAL1 measurements for SAR mode.

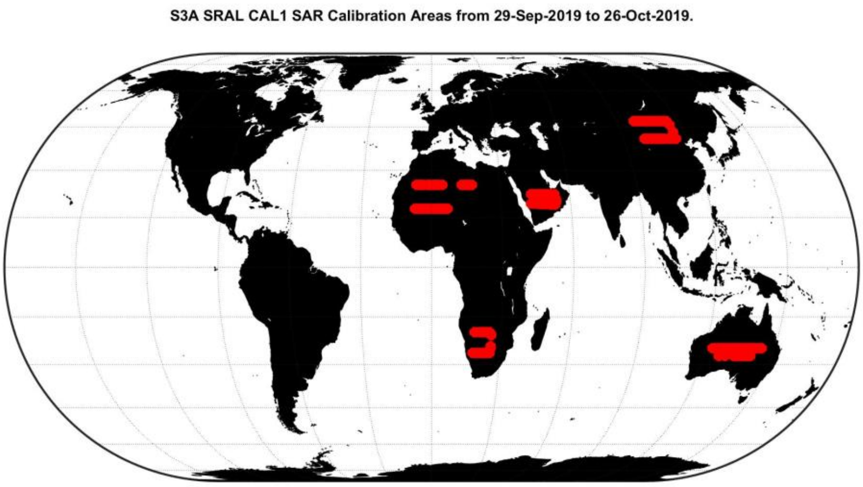


Figure 2-13. S3A Location of the CAL1 SAR measurements.

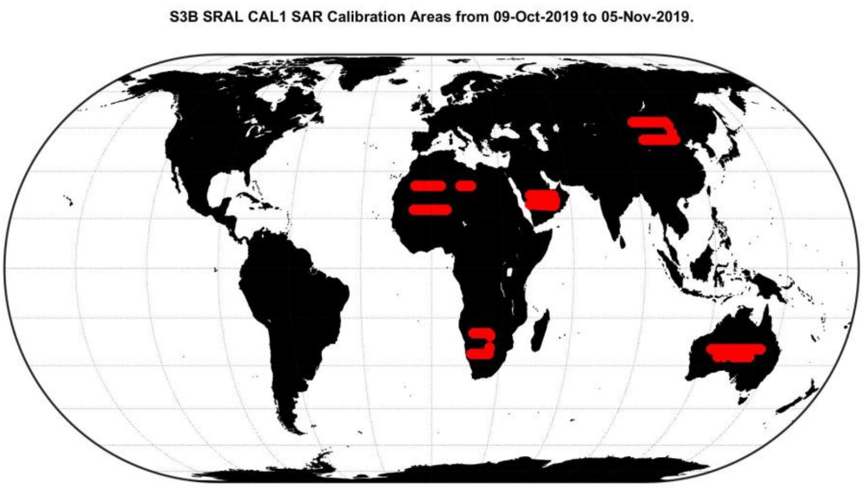


Figure 2-14. S3B Location of the CAL1 SAR measurements.

Period trend of CAL1 PTR Delay for SAR mode.

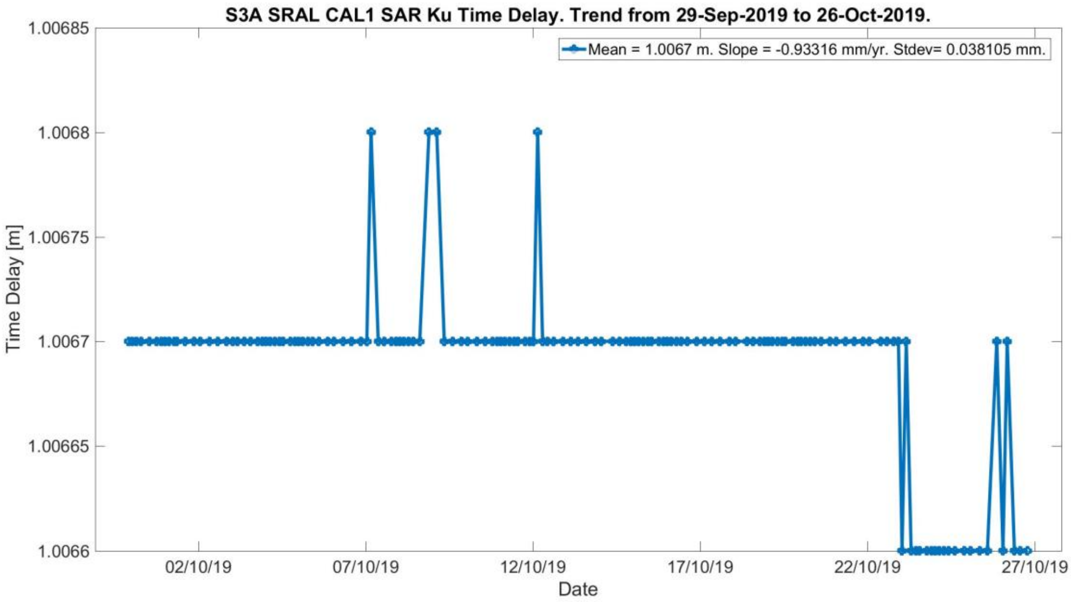


Figure 2-15. S3A CAL1 SAR Ku Time Delay trend.

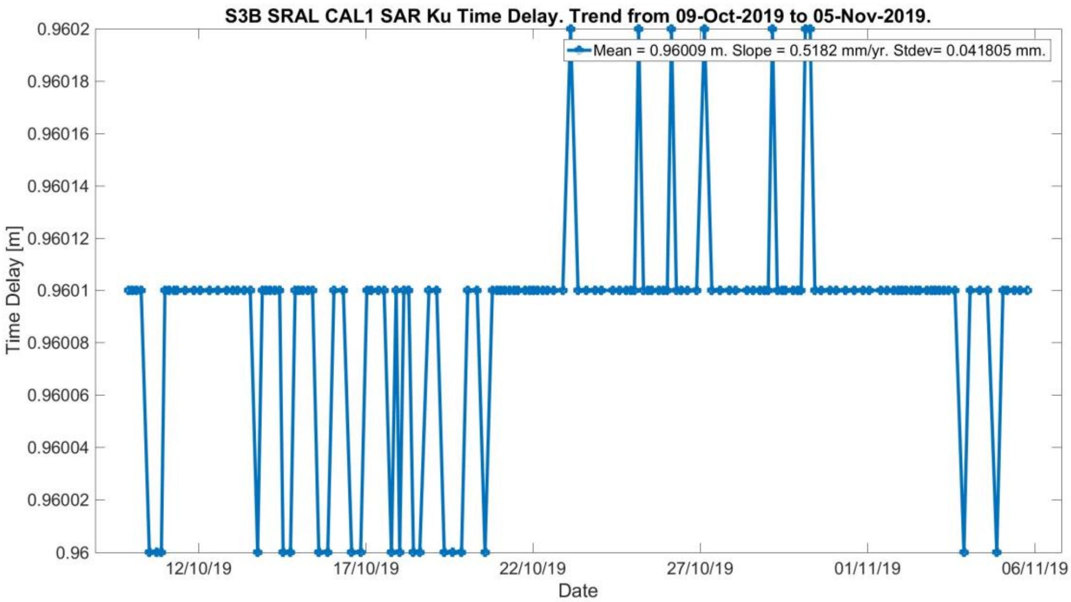


Figure 2-16. S3B CAL1 SAR Ku Time Delay trend.

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

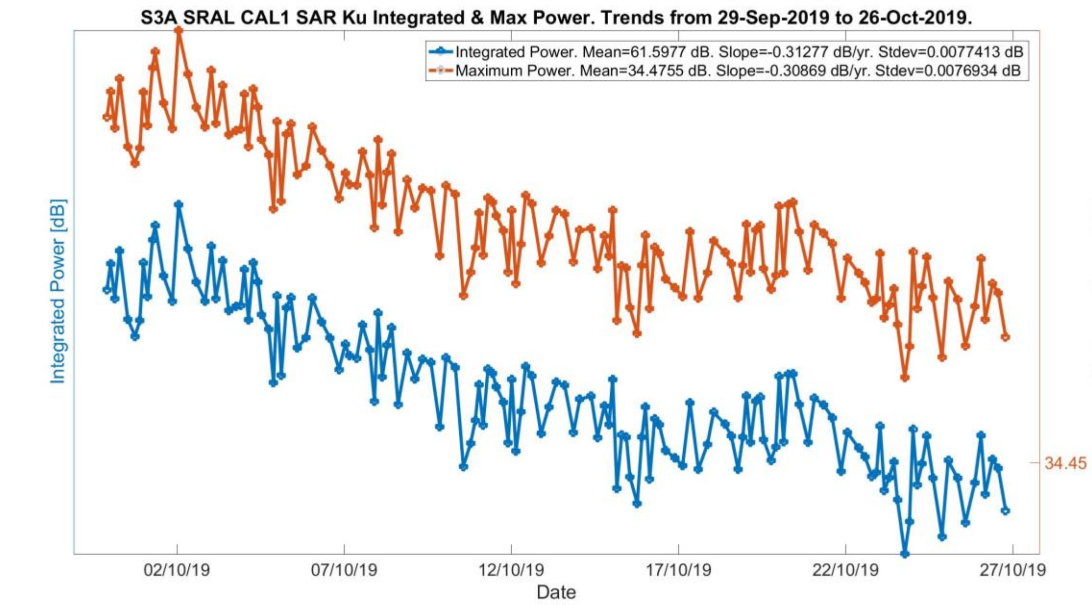


Figure 2-17. S3A CAL1 SAR Ku Power Trend.

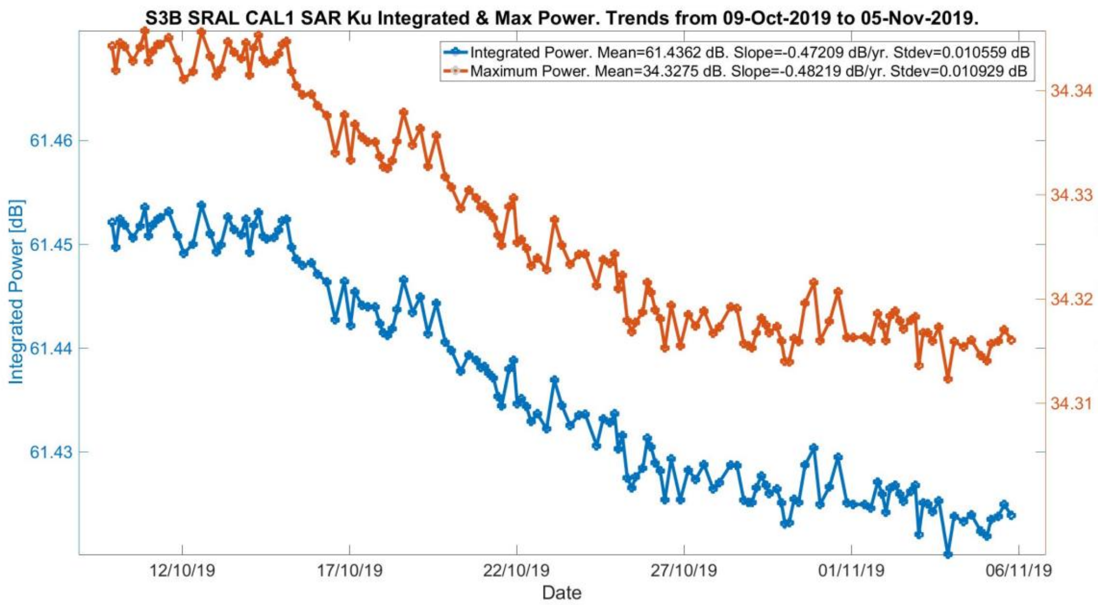


Figure 2-18. S3B CAL1 SAR Ku Power Trend.

Period trend of the CAL1 PTR width for SAR mode.

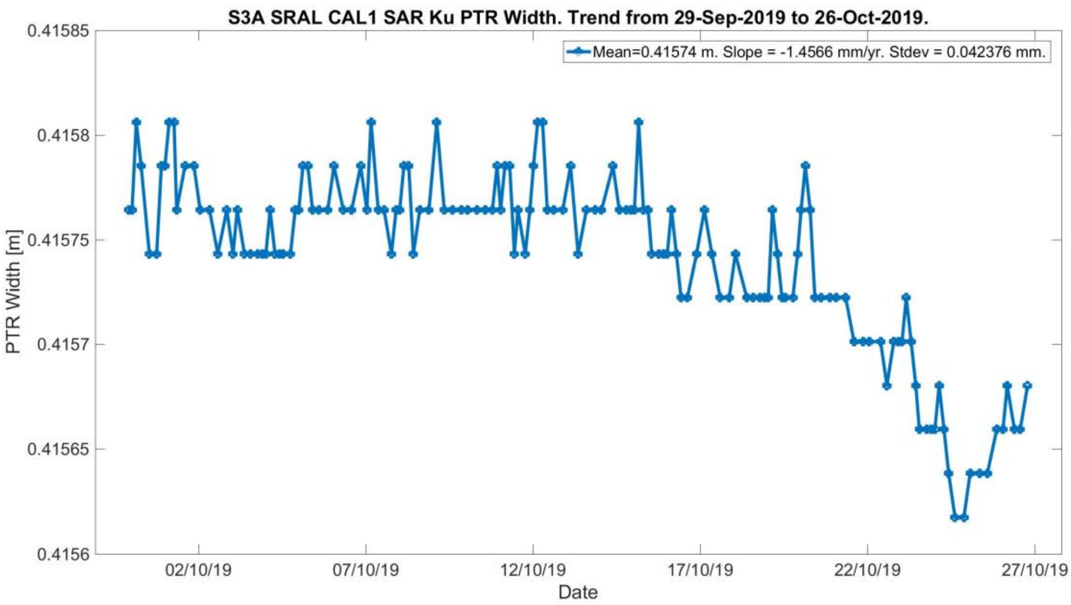


Figure 2-19. S3A CAL1 SAR Ku PTR width trend.

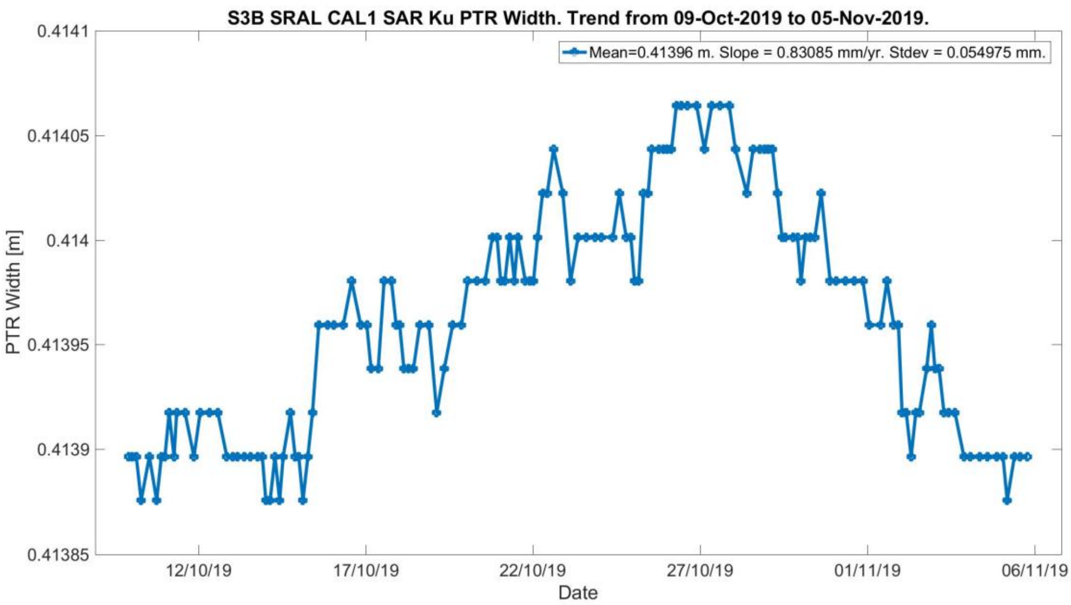


Figure 2-20. S3B CAL1 SAR Ku PTR width trend.

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

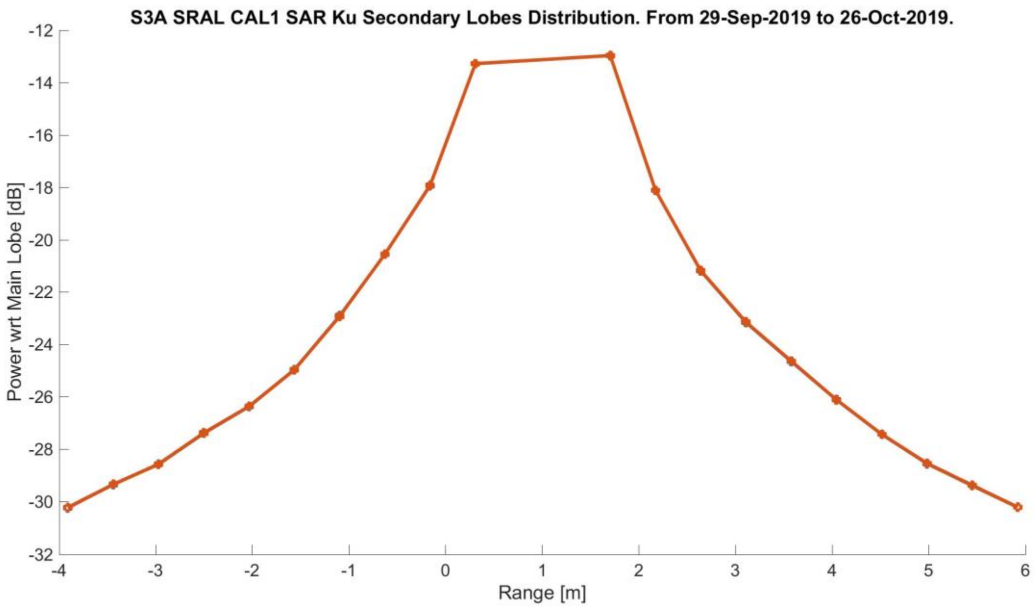


Figure 2-21. S3A CAL1 SAR Ku PTR secondary lobes Power and Position within the PTR waveform.

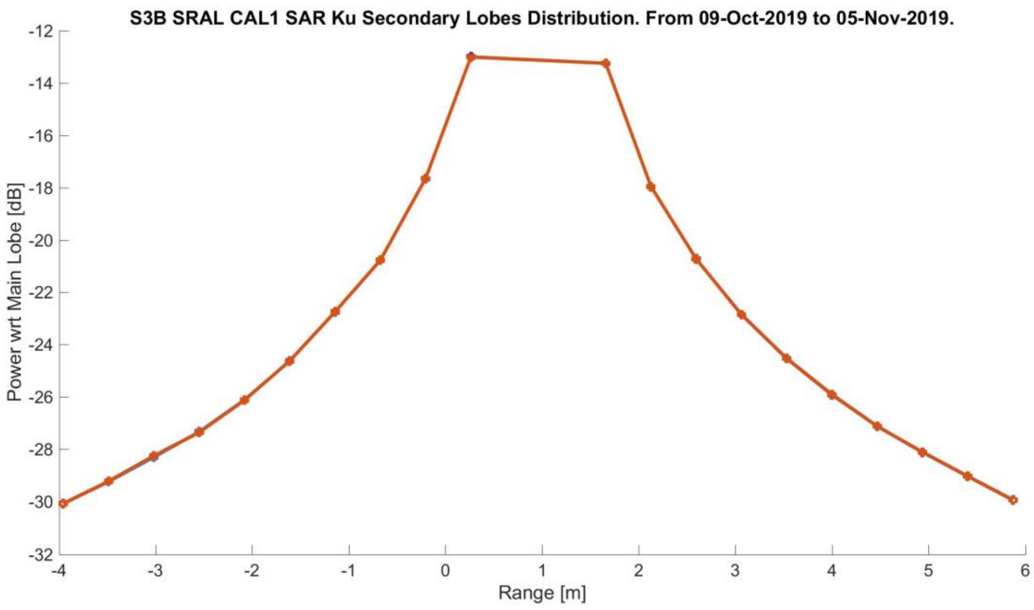


Figure 2-22. S3B CAL1 SAR Ku PTR secondary lobes Power and Position within the PTR waveform.

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

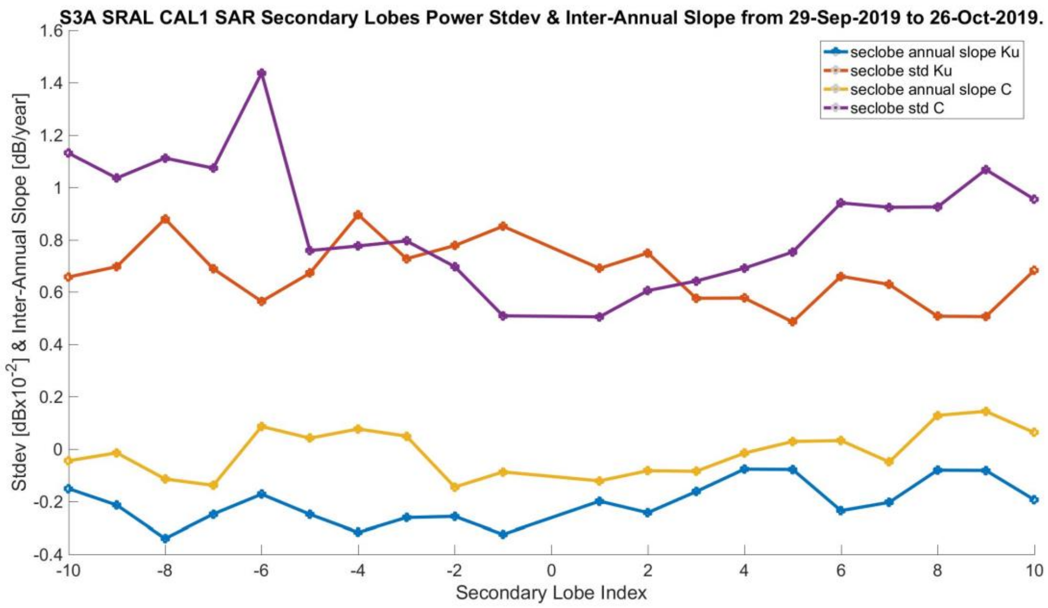


Figure 2-23. S3A CAL1 SAR Ku PTR secondary lobes characterisation. The inter-annual slope (in dB/year) and standard deviation (in dBx10^{-2}) of each of the secondary lobes are shown.

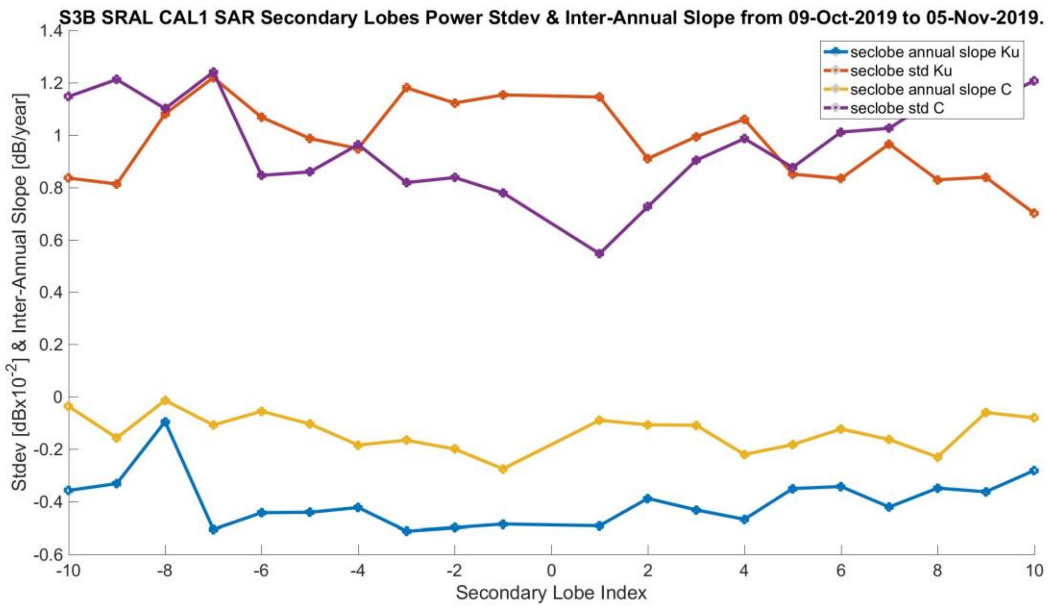


Figure 2-24. S3B CAL1 SAR Ku PTR secondary lobes characterisation. The inter-annual slope (in dB/year) and standard deviation (in dBx10^{-2}) of each of the secondary lobes are shown.

CAL1 Phase and Power intra-burst corrections slopes.

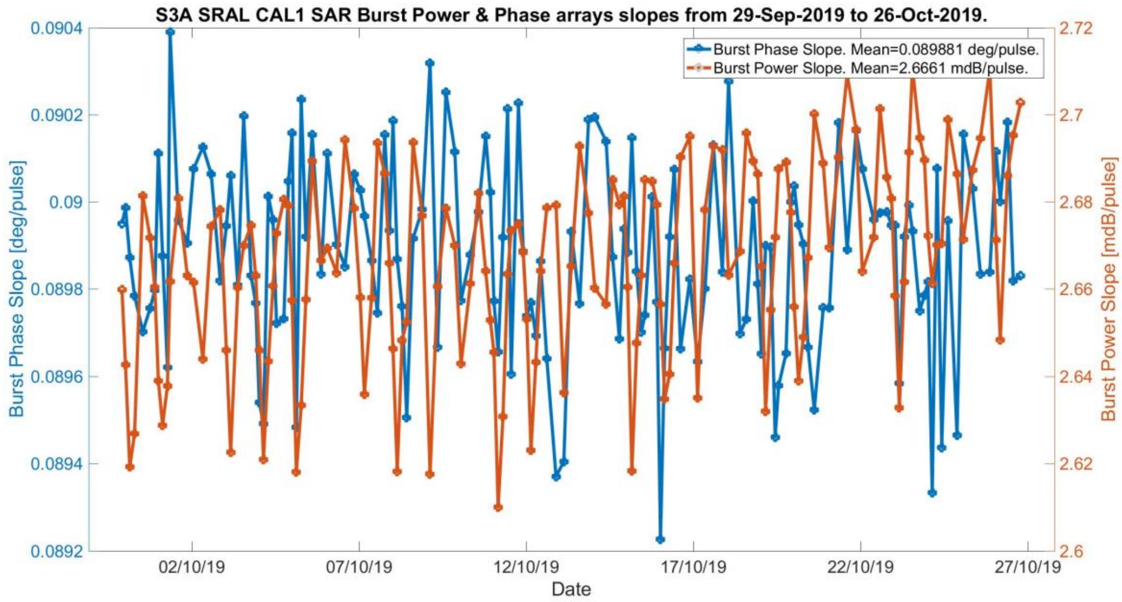


Figure 2-25. S3A CAL1 SAR Ku Phase & Power intra-burst corrections slopes over the cycle.

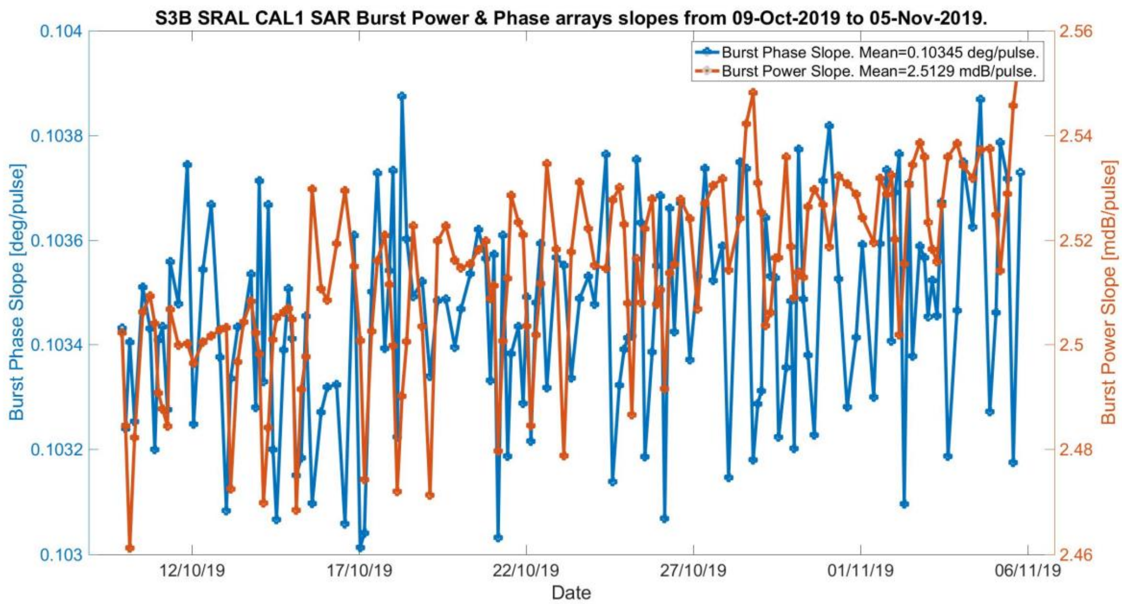


Figure 2-26. S3B CAL1 SAR Ku Phase & Power intra-burst corrections slopes over the cycle.

CAL1 Phase and Power intra-burst corrections standard deviations.

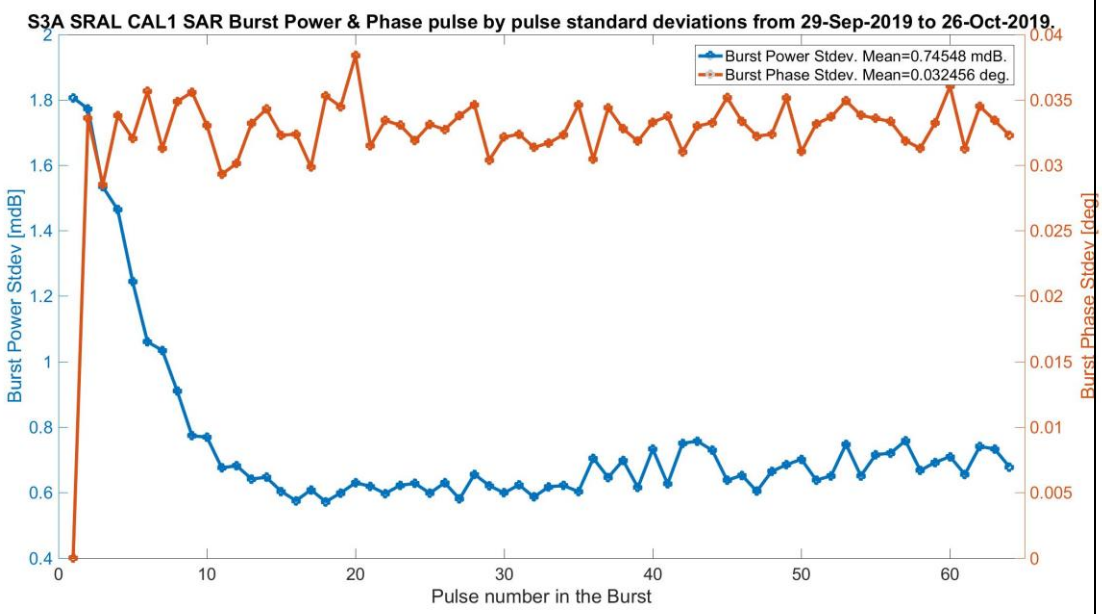


Figure 2-27. S3A Pulse by pulse standard deviations of the CAL1 SAR Ku Power and Phase intra-burst corrections.

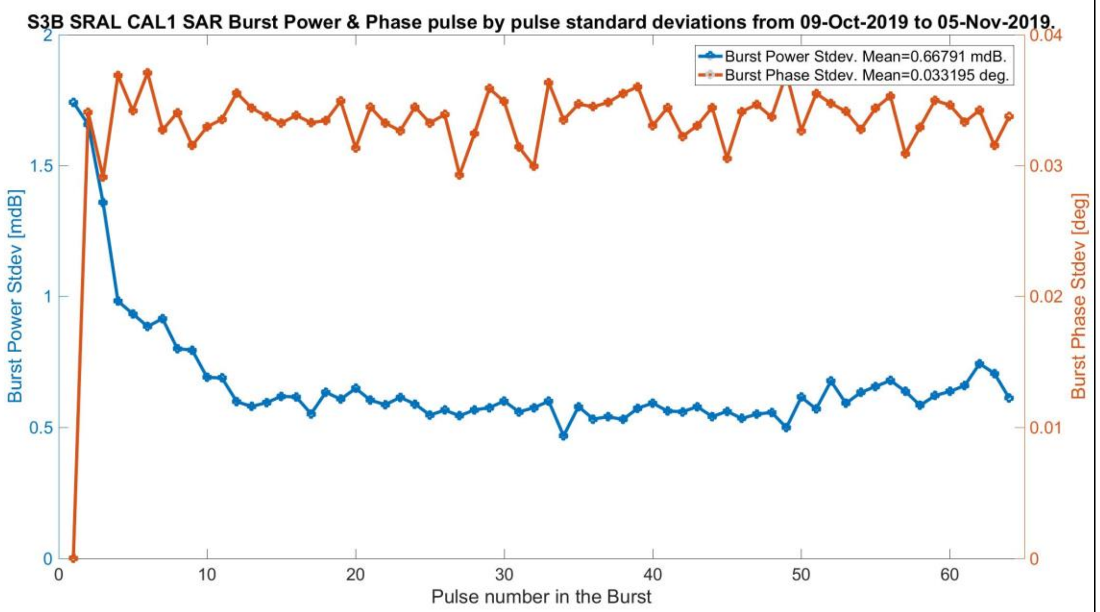


Figure 2-28. S3B Pulse by pulse standard deviations of the CAL1 SAR Ku Power and Phase intra-burst corrections.

2.2.3 System Transfer Function (CAL2)

Geolocation of the CAL2 measurements for SAR mode.

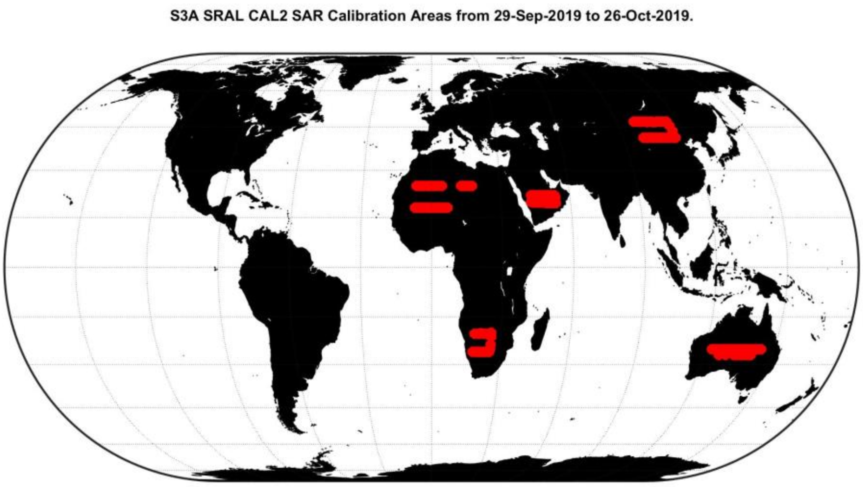


Figure 2-29. S3A Location of the CAL2 SAR measurements.

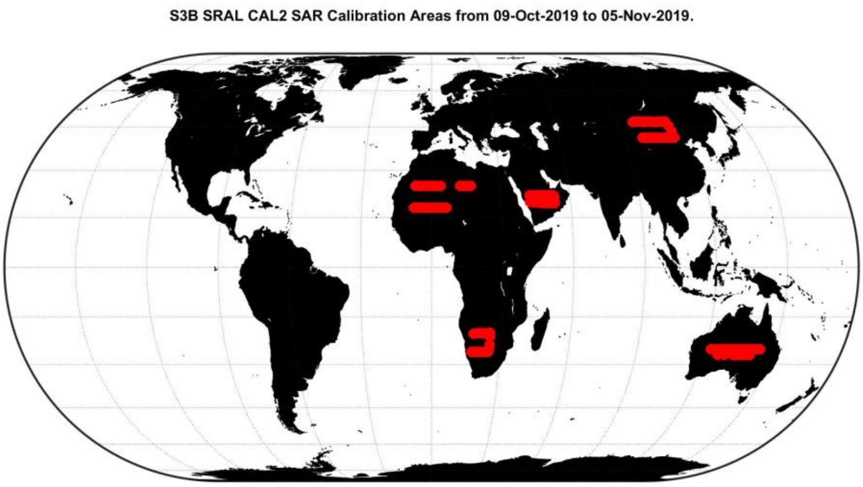


Figure 2-30. S3B Location of the CAL2 SAR measurements.

CAL2 SAR waveforms averaged over the cycle.

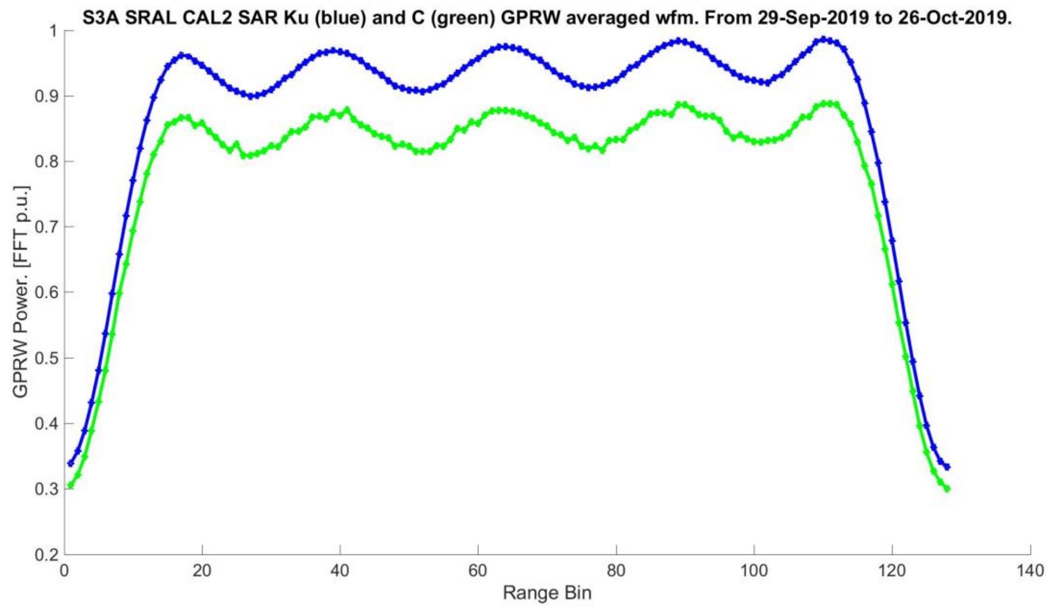


Figure 2-31. S3A Averaged CAL2 SAR Ku and C waveforms over the cycle.

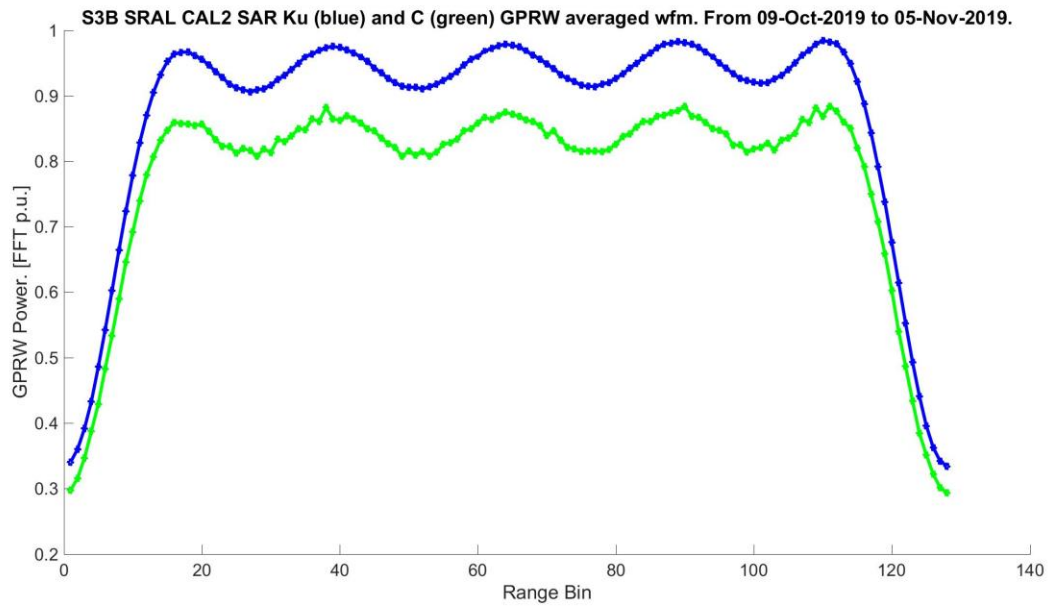


Figure 2-32. S3B Averaged CAL2 SAR Ku and C waveforms over the cycle.

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

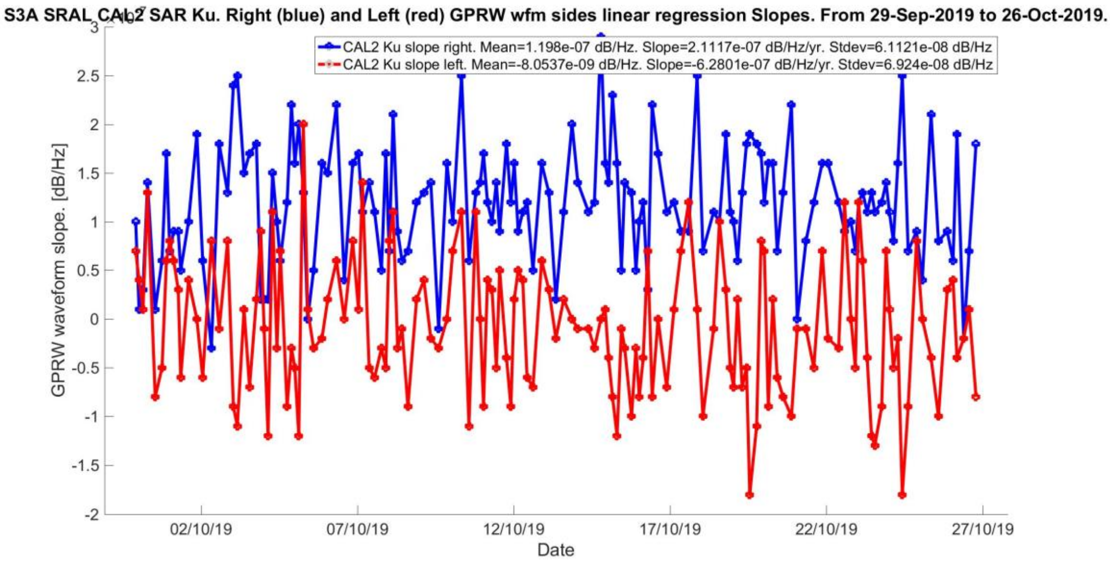


Figure 2-33. S3A CAL2 SAR Ku waveforms right (blue) and left (red) sides Slope over the period.

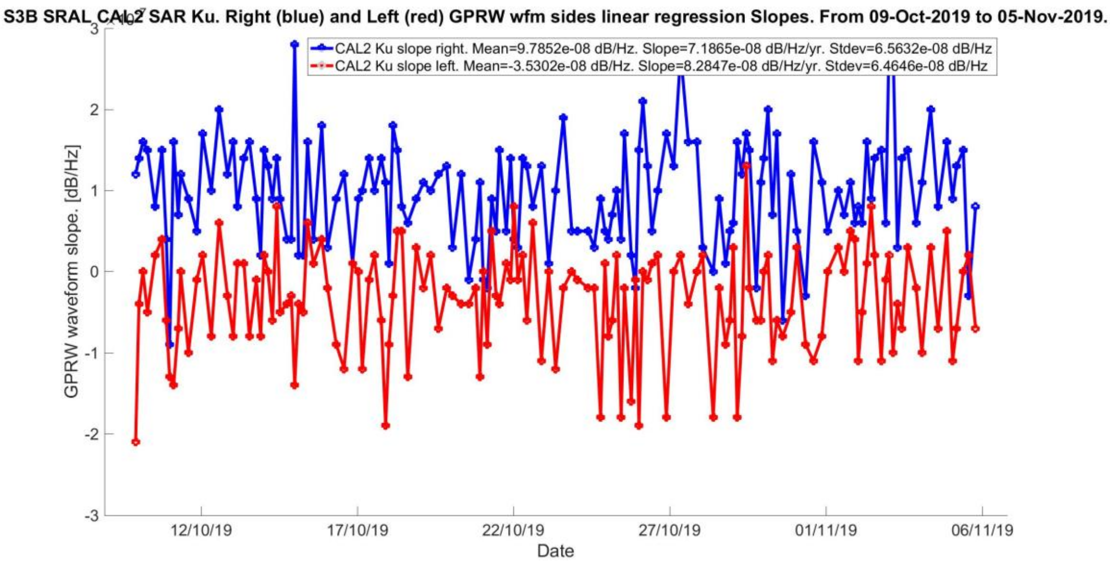


Figure 2-34. S3B CAL2 SAR Ku waveforms right (blue) and left (red) sides Slope over the period.

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

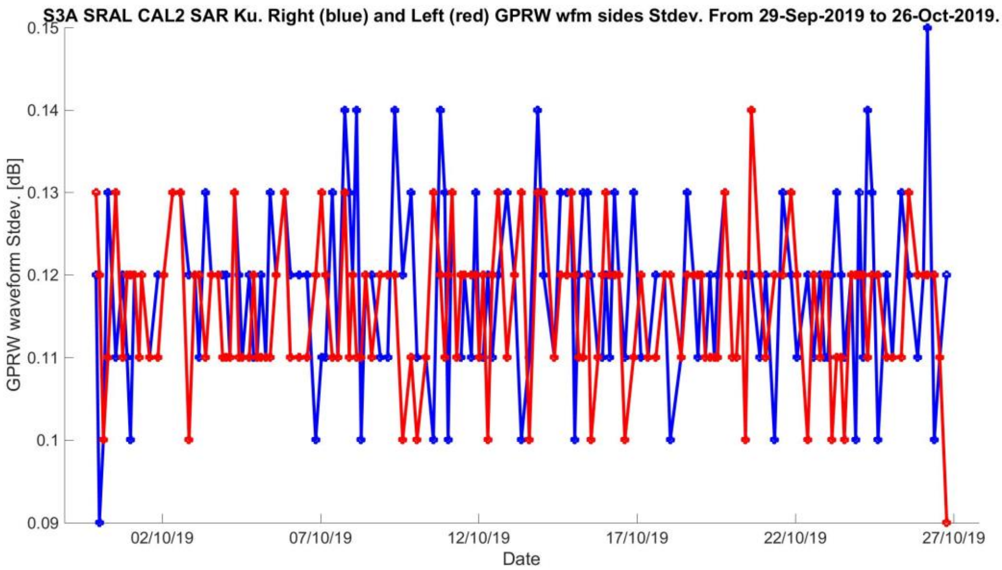


Figure 2-35. S3A CAL2 SAR Ku waveforms right (blue) and left (red) sides Standard Deviation over the period.

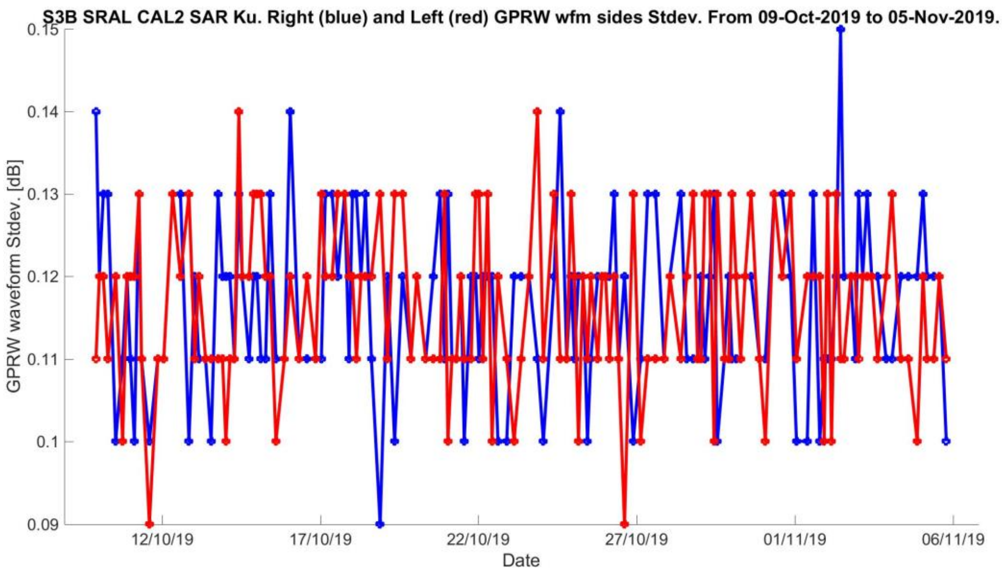


Figure 2-36. S3B CAL2 SAR Ku waveforms right (blue) and left (red) sides Standard Deviation over the period.

2.2.4 AutoCAL (CAL1 SAR Auto)

Geolocation of the AutoCal measurements for SAR mode.

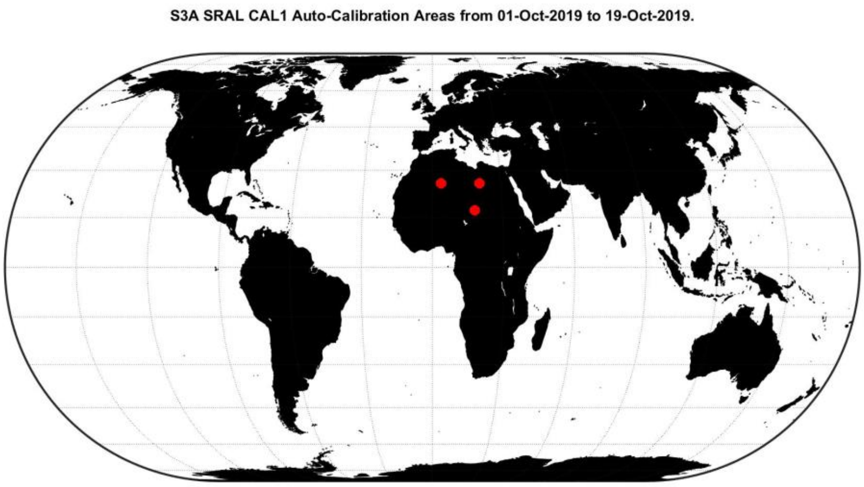


Figure 2-37. S3A Location of the AutoCal measurements.

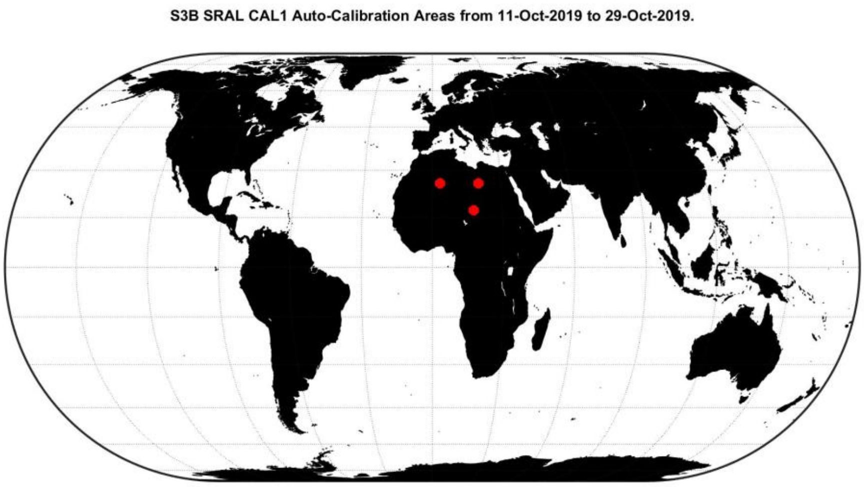


Figure 2-38. S3B Location of the AutoCal measurements.

Averaged AutoCal measurements (Corrected – Reference).

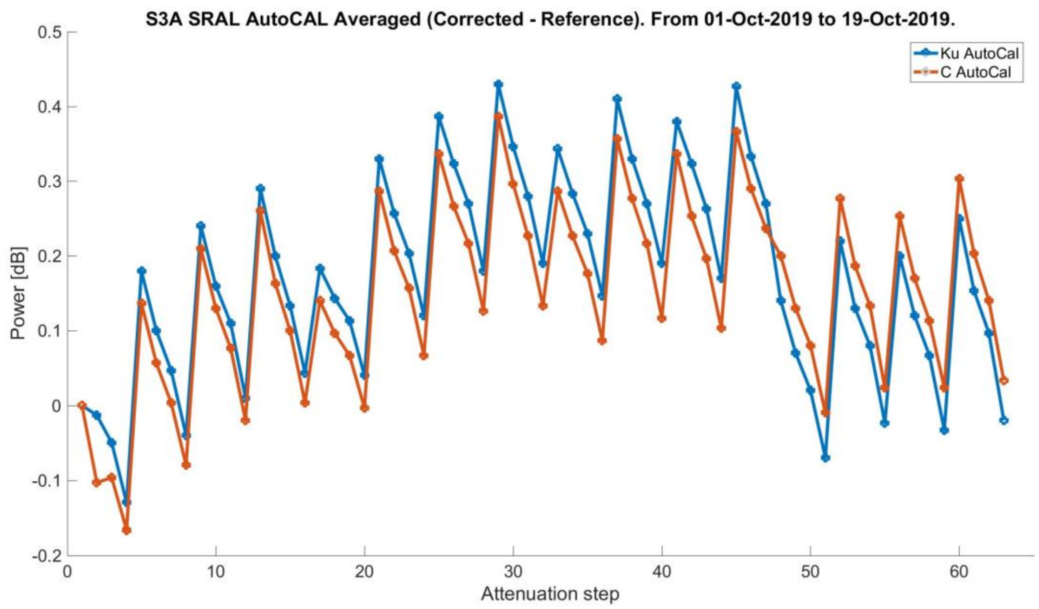


Figure 2-39. S3A AutoCal measurements: Corrected - Reference. Averaged over the cycle.

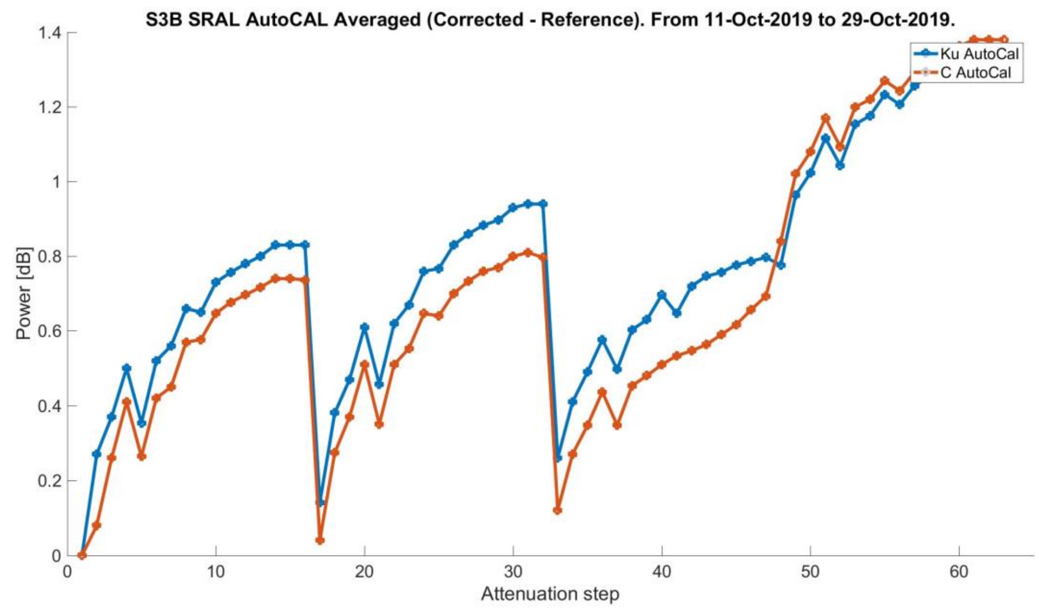


Figure 2-40. S3B AutoCal measurements: Corrected - Reference. Averaged over the cycle.

2.2.5 Housekeeping Temperatures

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

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

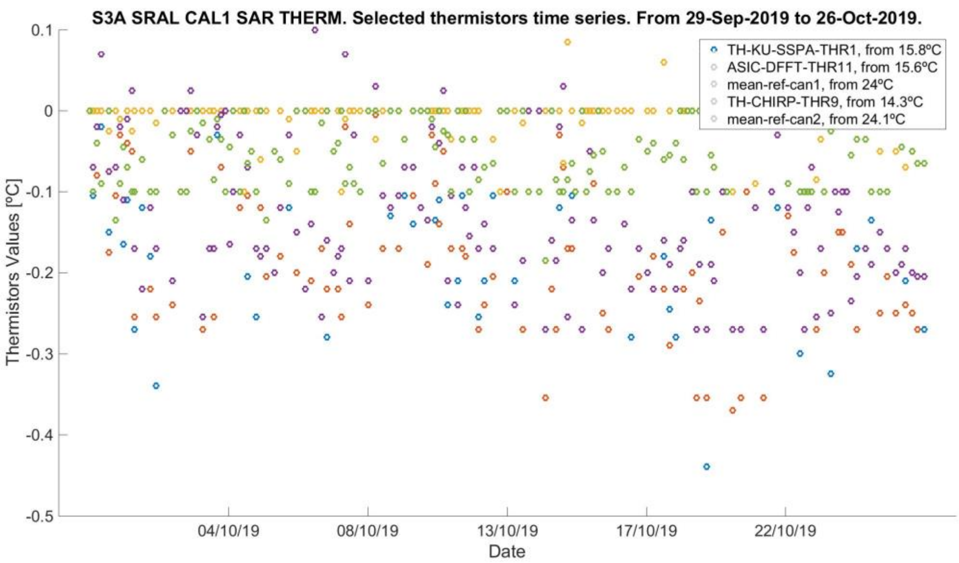


Figure 2-41. S3A Selected group of Thermistors time series on CAL1 SAR mode. The temperatures are averaged for each calibration product.

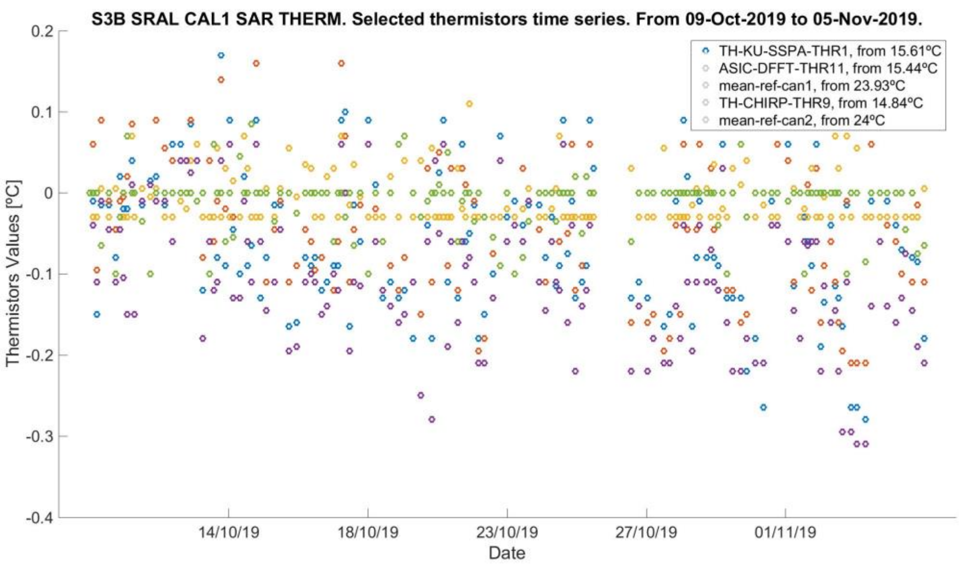


Figure 2-42. S3B Selected group of Thermistors time series on CAL1 SAR mode. The temperatures are averaged for each calibration product.

2.3 Cyclic SRAL Status Summary

This section is dedicated to a summary of the cyclic performances and status of the altimeter parameters exposed in section 2.2. It covers both S3A and S3B missions.

For the analysed cycle, none of the calibration parameters is showing a significant anomalous behaviour. Nonetheless, some specific observations are explained here below.

The absolute values of the S3A parameters are similar to the S3B ones.

In general, the LRM and SAR performances are similar for a given band (Ku or C).

The main CAL1 parameters cyclic statistics are detailed in Table 2-1 and Table 2-2, respectively for S3A and S3B missions.

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

All Ku band CAL1 time delay slopes have maximum absolute values around 1 mm/year.

The Ku band 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.

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 2.4.

S3A Calibration Parameter	Ku band			C band		
	mean	annual slope	standard deviation	mean	annual slope	standard deviation
LRM CAL1 time delay	1.0067 m	-1.02 mm	0.05 mm	0.8924 m	-0.01 mm	0.05 mm
SAR CAL1 time delay	1.0067 m	-0.93 mm	0.04 mm	0.8931 m	-0.07 mm	0.05 mm
LRM CAL1 power	57.18 dB	-0.27 dB	0.01 dB	50.86 dB	-0.08 dB	0.00 dB
SAR CAL1 power	61.60 dB	-0.31 dB	0.01 dB	48.37 dB	-0.06 dB	0.00 dB
LRM CAL1 PTR width	0.4160 m	-1.50 mm	0.04 mm	0.4542 m	-0.32 mm	0.02 mm
SAR CAL1 PTR width	0.4157 m	-1.46 mm	0.04 mm	0.4541 m	-0.37 mm	0.02 mm

Table 2-1. Collection of S3A calibration parameters statistics for all modes and bands covering the cycle period.

S3B Calibration Parameter	Ku band			C band		
	mean	annual slope	standard deviation	mean	annual slope	standard deviation
LRM CAL1 time delay	0.9603 m	0.49 mm	0.04 mm	0.9579 m	-0.21 mm	0.04 mm
SAR CAL1 time delay	0.9601 m	0.52 mm	0.04 mm	0.9577 m	-0.32 mm	0.05 mm
LRM CAL1 power	57.01 dB	-0.44 dB	0.01 dB	50.50 dB	-0.19 dB	0.01 dB
SAR CAL1 power	61.44 dB	-0.47 dB	0.01 dB	47.85 dB	-0.20 dB	0.01 dB
LRM CAL1 PTR width	0.4139 m	0.78 mm	0.06 mm	0.4660 m	0.66 mm	0.05 mm
SAR CAL1 PTR width	0.4140 m	0.83 mm	0.05 mm	0.4662 m	0.61 mm	0.05 mm

Table 2-2. Collection of S3B calibration parameters statistics for all modes and bands covering the cycle period.

2.4 Mission SRAL Status Summary

The main SAR Ku L1b calibration parameters series of S3A and S3B missions are gathered and plotted in this section, in order to observe their whole missions behaviour.

The plotted calibration parameters are:

- CAL1 time delay
- CAL1 power
- PTR width
- Burst corrections (power and phase) and their slopes
- CAL2 waveform ripples shape, plus the waveforms slopes and de-trended standard deviations
- Autocal averaged differences and attenuation progression

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 for 20 years of mission, in order to foresee how long the SRAL Power would meet the mission requirements based in the current behaviour. This need comes from the warning raised at BOM due to high CAL1 Power trends.

The "whole mission" figures and tables 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.

CAL1 SAR mode Ku Time Delay Whole Mission Trend.

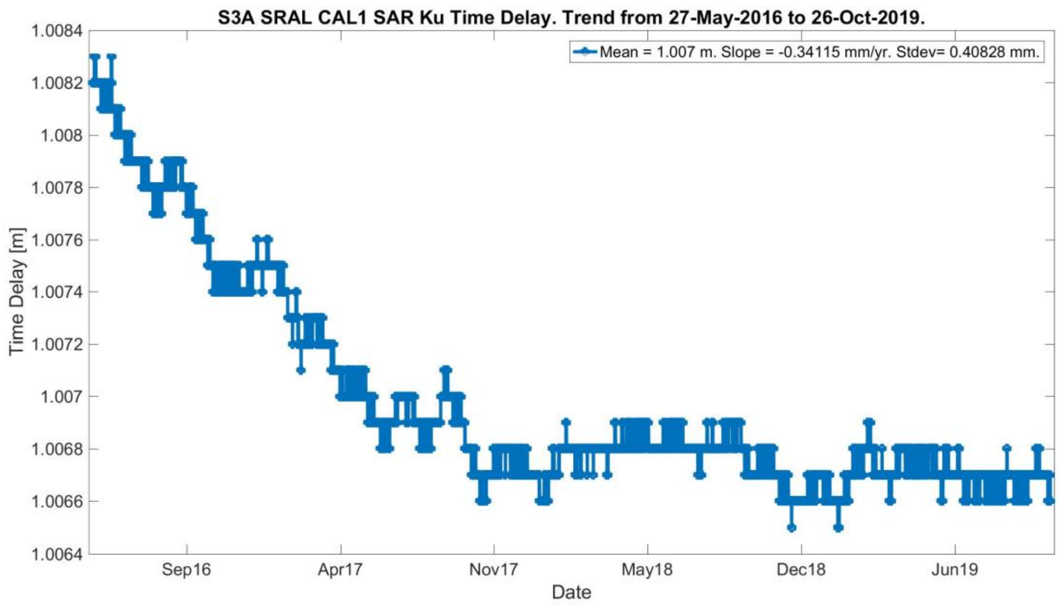


Figure 2-43. S3A CAL1 SAR Ku Time Delay Whole Mission Trend.

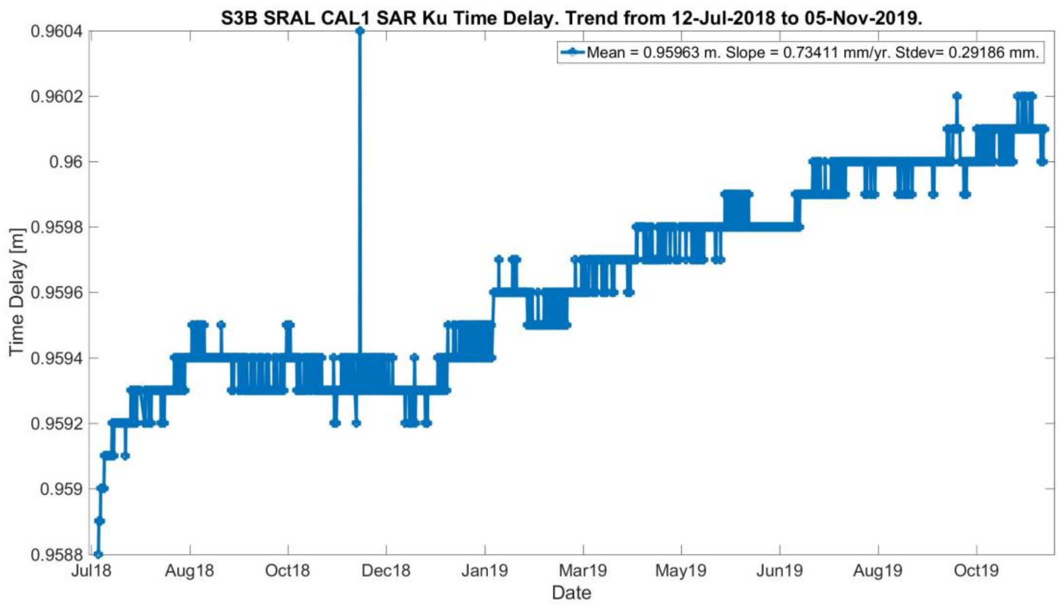


Figure 2-44. S3B CAL1 SAR Ku Time Delay Whole Mission Trend.

CAL1 SAR mode Ku Power Whole Mission Trend.

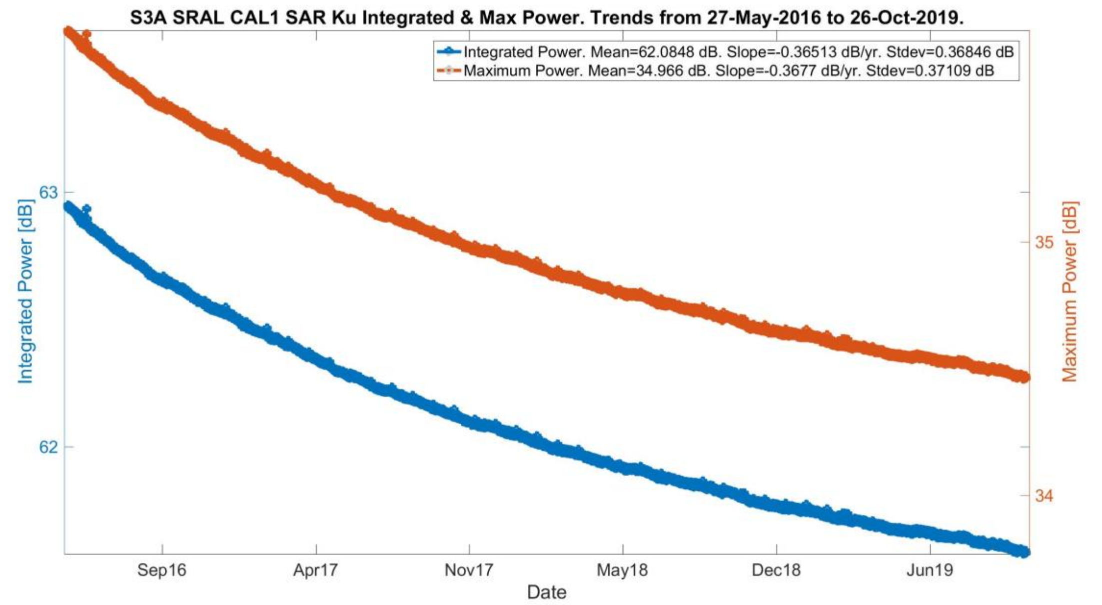


Figure 2-45. S3A CAL1 SAR Ku Power Whole Mission Trend.

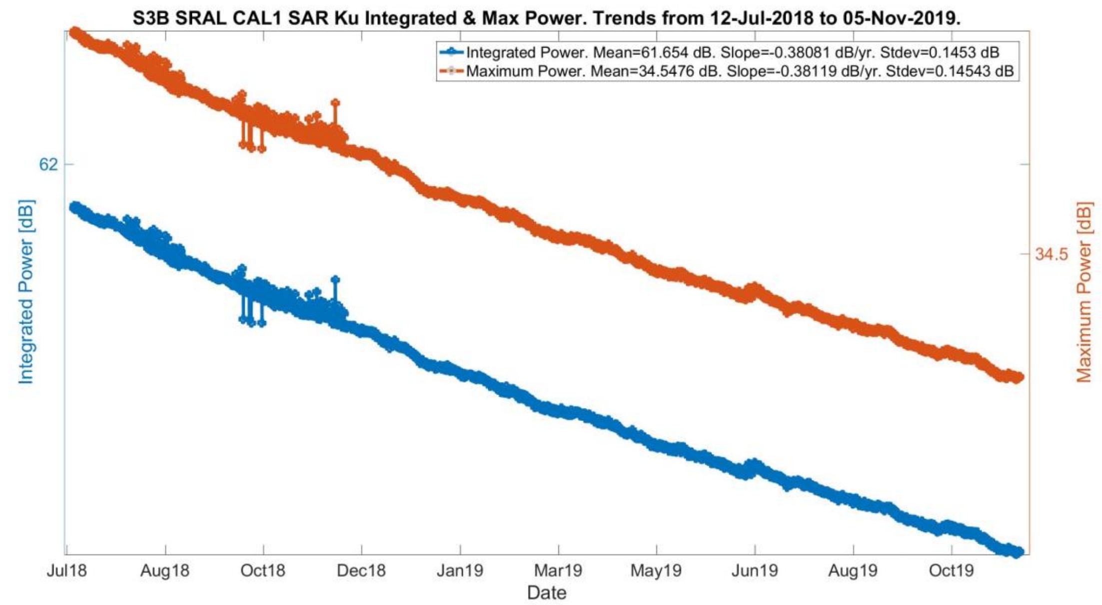


Figure 2-46. S3B CAL1 SAR Ku Power Whole Mission Trend.

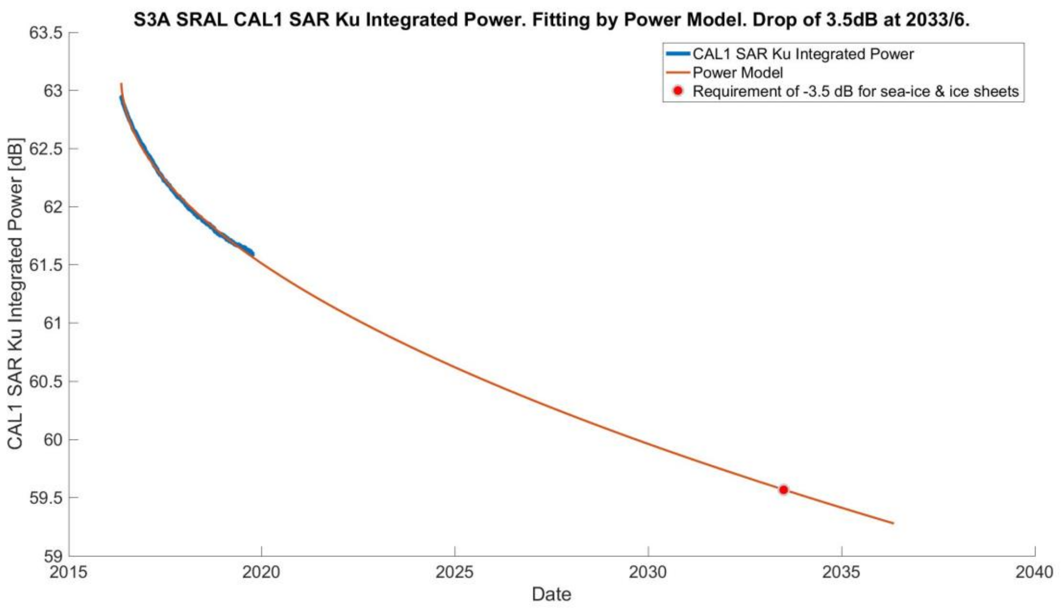
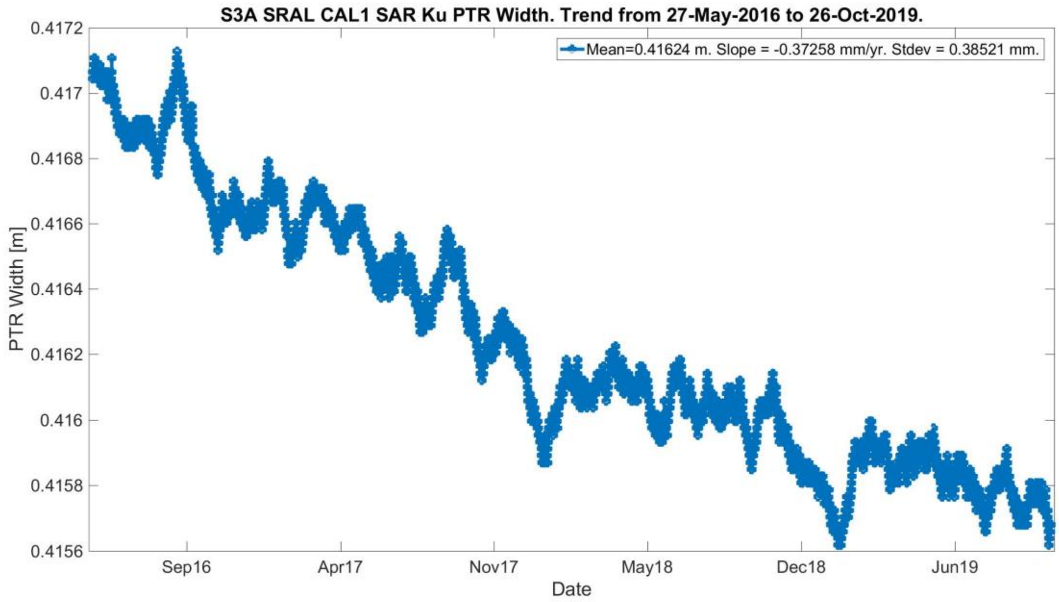
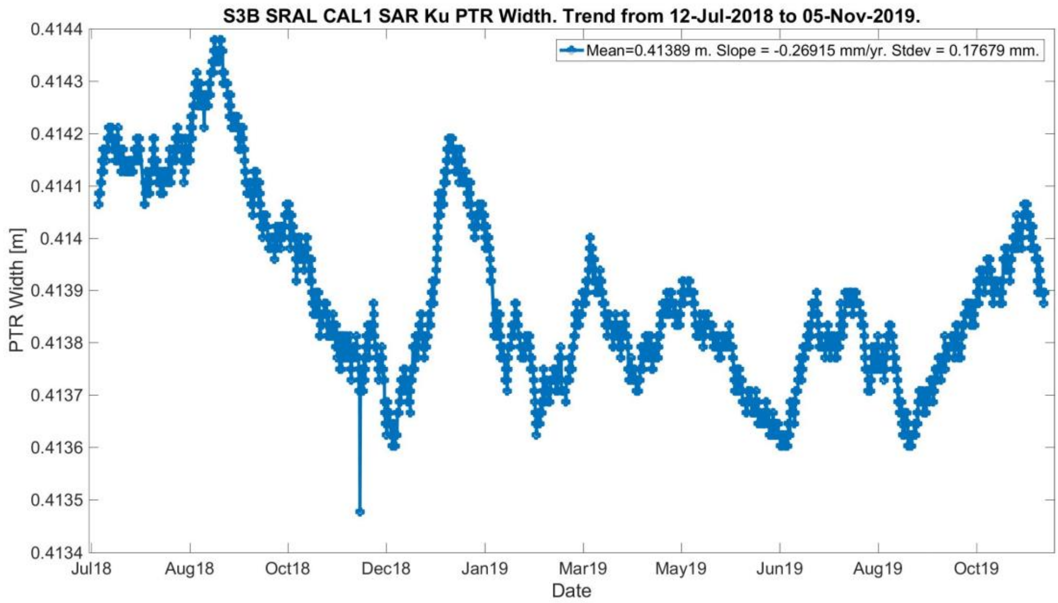


Figure 2-47. S3A CAL1 SAR Ku Power series and long term trend extrapolation with power model.

CAL1 SAR mode Ku PTR Width Whole Mission Trend.
 Figure 2-48. S3A CAL1 SAR Ku PTR Width Whole Mission Trend.
 Figure 2-49. S3B CAL1 SAR Ku PTR Width Whole Mission Trend.

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

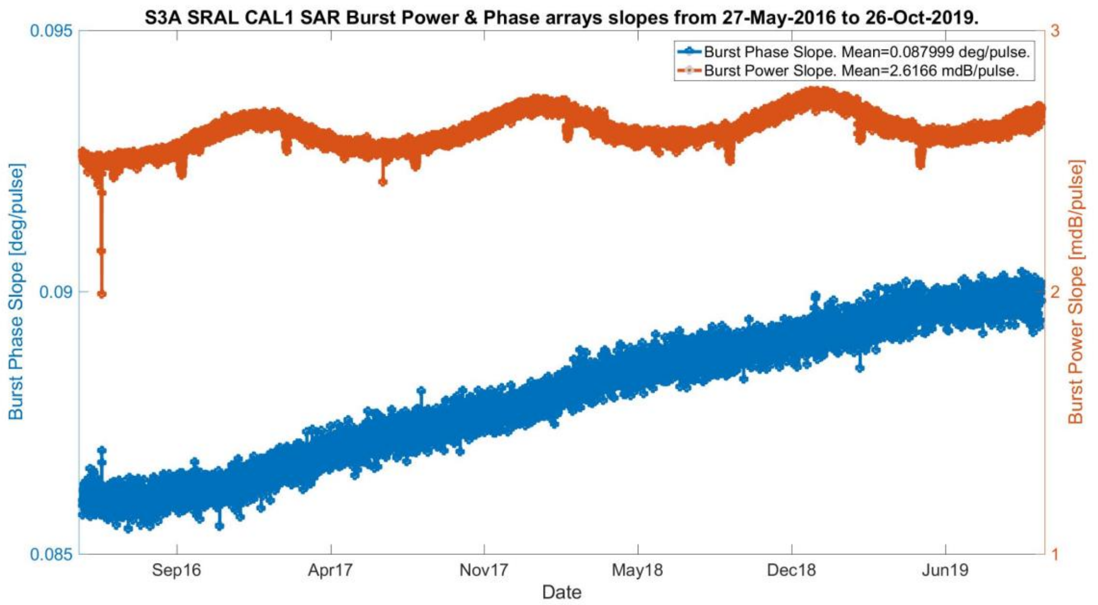


Figure 2-50. S3A CAL1 SAR Ku Phase & Power intra-burst corrections slopes along the whole mission.

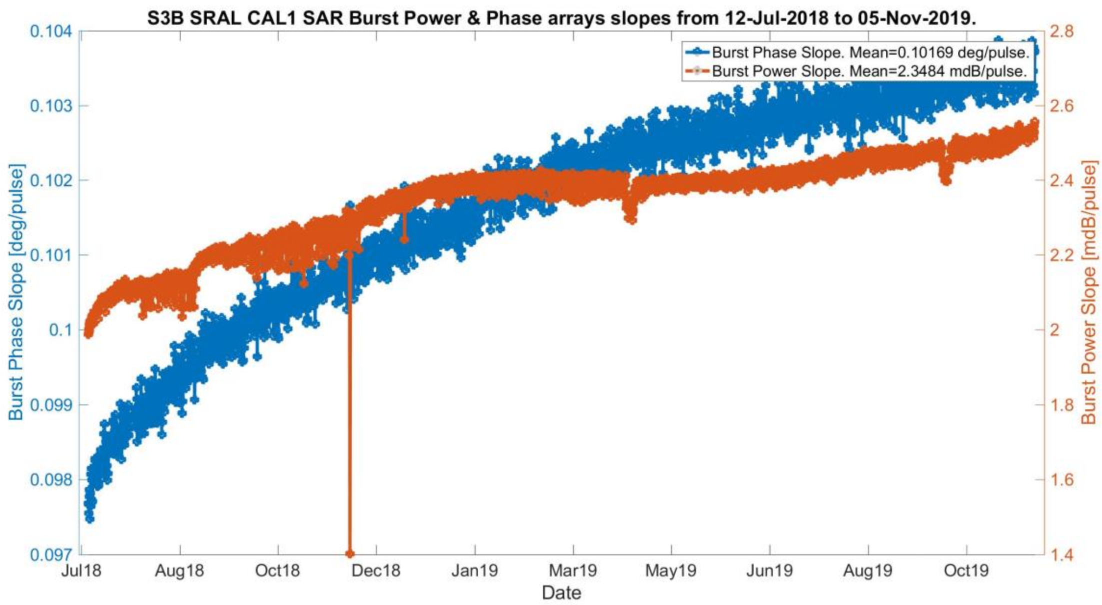


Figure 2-51. S3B CAL1 SAR Ku Phase & Power intra-burst corrections slopes along the whole mission.

Whole Mission Trend of CAL2 SAR waveform slope.

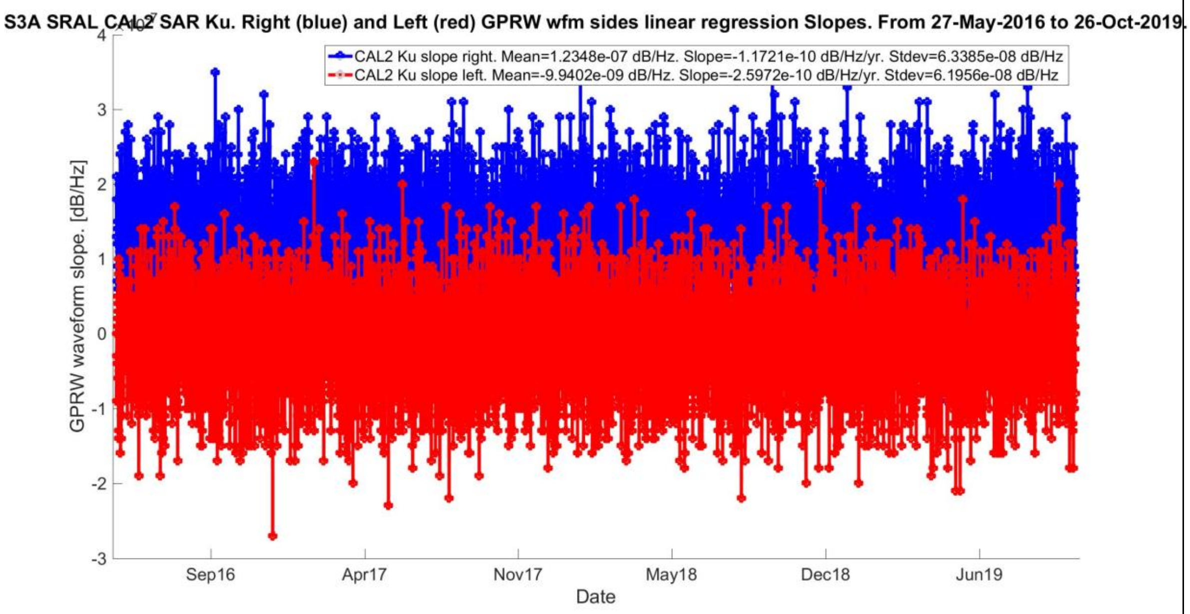


Figure 2-52. S3A Slope at each side of the CAL2 Ku waveform, averaged over the whole mission.

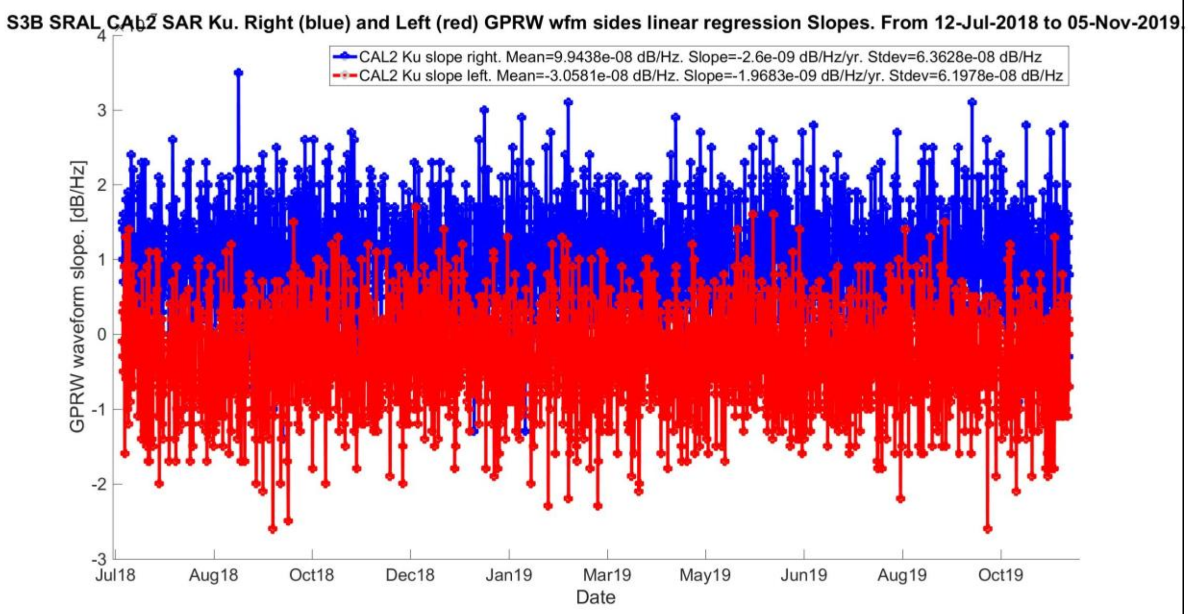


Figure 2-53. S3B Slope at each side of the CAL2 Ku waveform, averaged over the whole mission.

Whole Mission Averaged Differential AutoCal measurements.

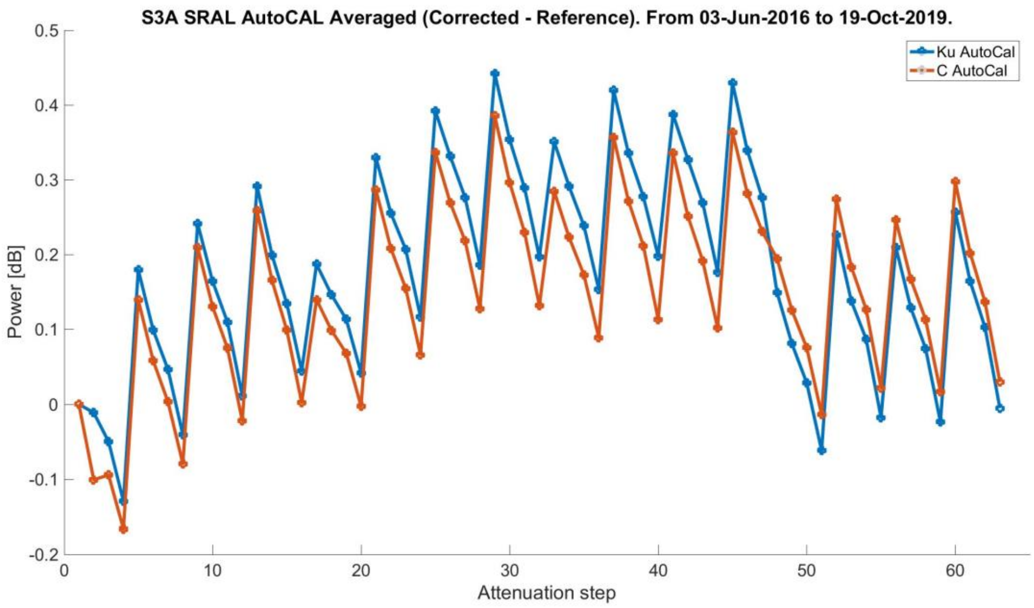


Figure 2-54. S3A Autocal measurements: Corrected - Reference. Averaged over the whole mission.

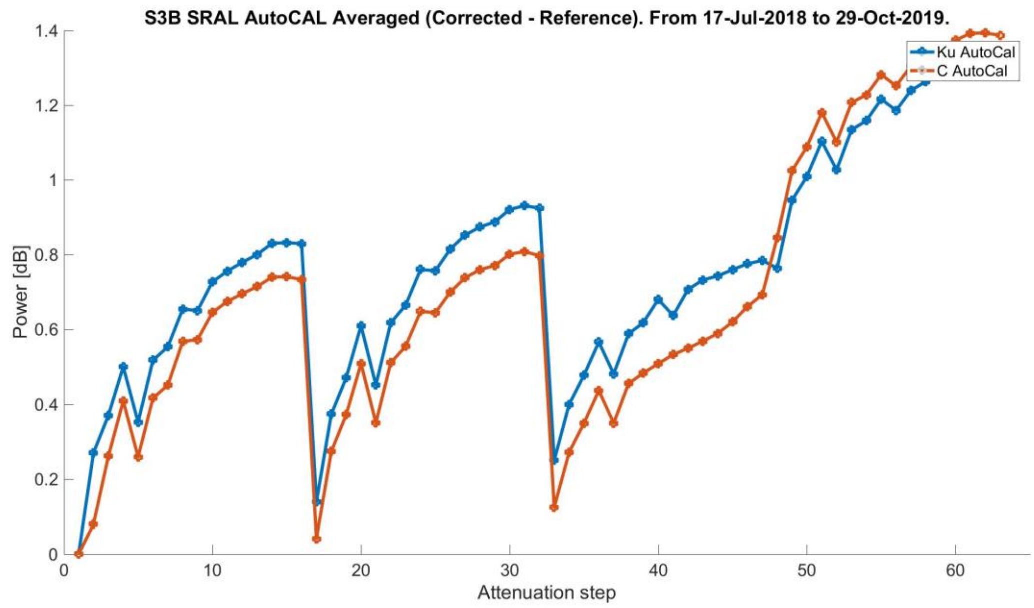


Figure 2-55. S3B Autocal measurements: Corrected - Reference. Averaged over the whole mission.

AutoCAL Ku band attenuation progression series.

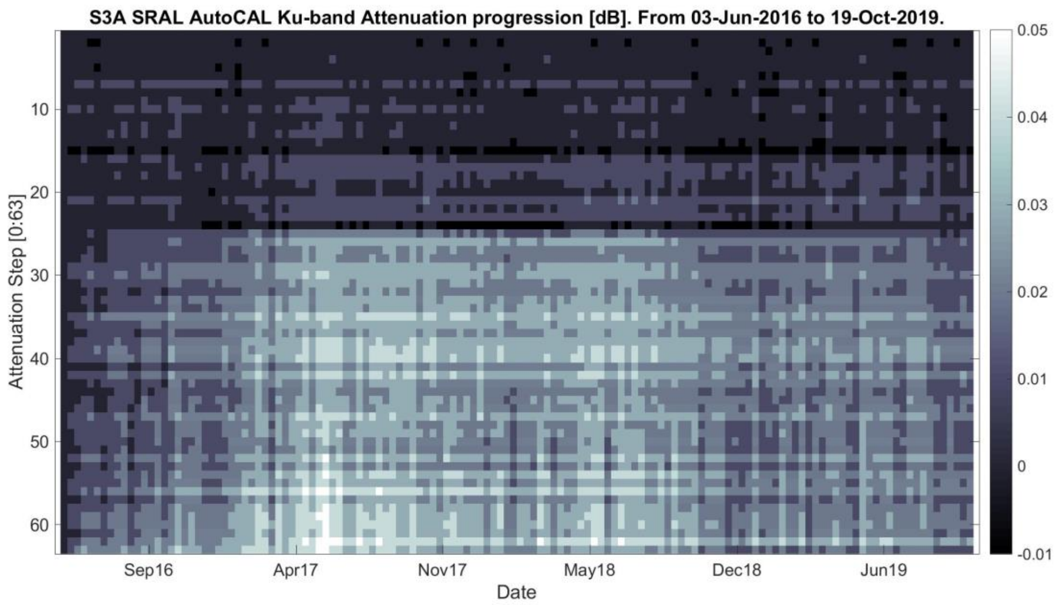


Figure 2-56. S3A AutoCAL Ku attenuation whole mission progression. Difference in dB with respect to the first attenuation value, for each attenuation step.

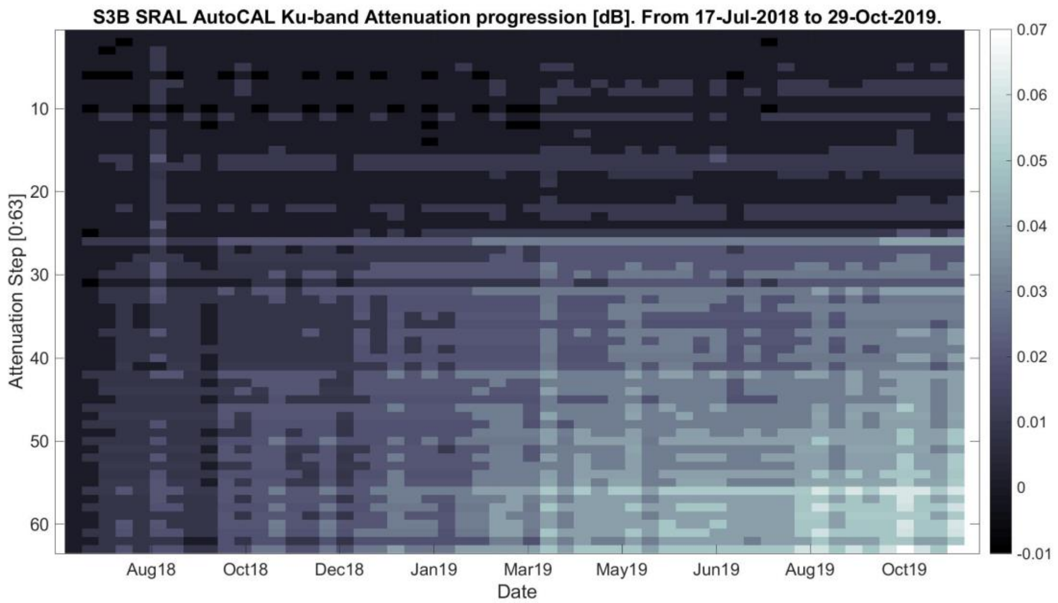


Figure 2-57. S3B AutoCAL Ku attenuation whole mission progression. Difference in dB with respect to the first attenuation value, for each attenuation step.

CAL1 SAR thermistors series.

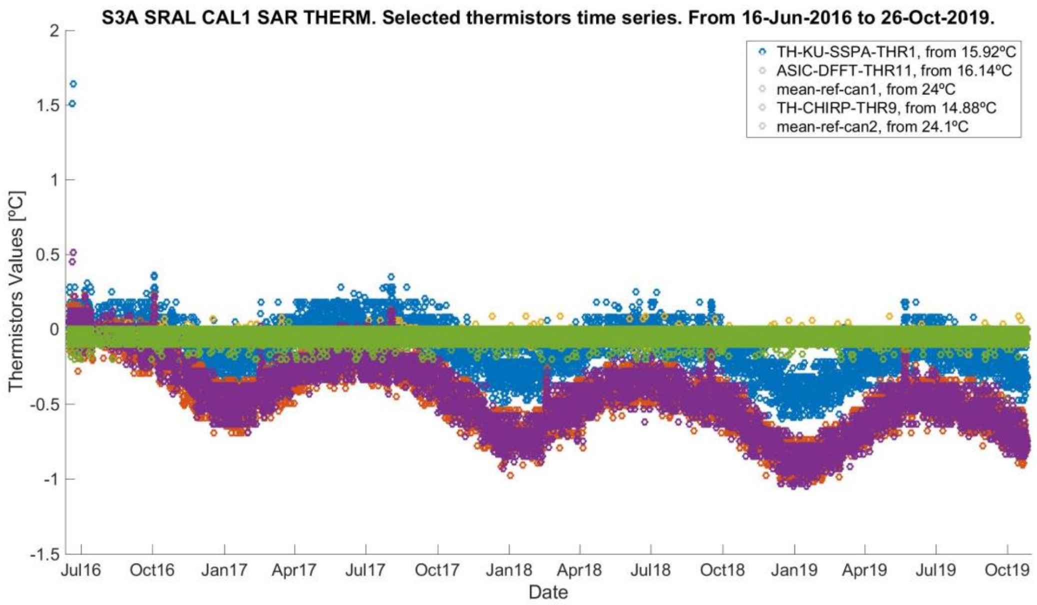


Figure 2-58. S3A Selected CAL1 SAR thermistors series along the whole mission.

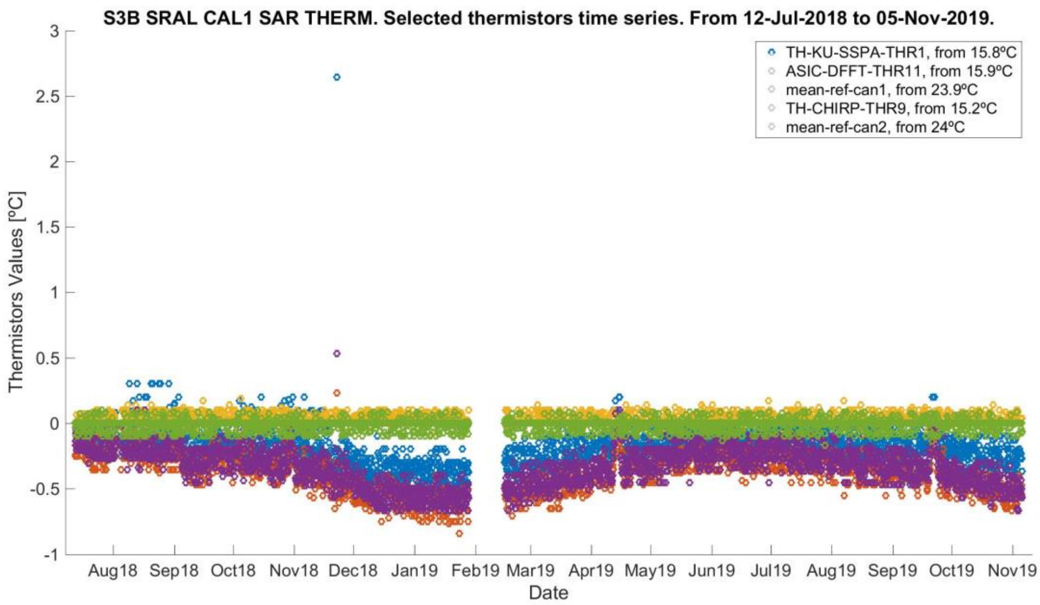


Figure 2-59. S3B Selected CAL1 SAR thermistors series along the whole mission.

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

The most important and notable drift observed in the whole missions 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 -0.5 dB/year from cycle 31.

A mission requirement of the CAL1 SAR Ku power is a maximum power drop of 3.5dB from beginning of mission. Below that power bound, the sea-ice and ice sheets geophysical measurements could be impacted, due to a poor SNR. A power model fitting has been computed for the S3A mission, and the assumption is to reach the limit by 2033.

For S3B, there are some spikes of CAL1 SAR Ku power of around 0.05 dB. These values coincides 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 operating tracking 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. A different behaviour has been noticed in cycle 26, changing locally its drift sign.

The S3A PTR time delay has also decreased its negative trend, being currently almost flat. The S3B time delay trend shows periods of diverse drifts along the mission, but at a long term, it is positive.

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

The intra-burst corrections along the missions are quite stable. The S3A burst power slope shows a clear annual behaviour (oscillations of less than 0.2 mdB/pulse) and a sensibility to instrumental thermal changes. The annual behaviour is more difficult to be detected in the S3B figure yet, due to a shorter period of observation and an added slope, but we detect also a correlation with thermal conditions on-board (see April and September 2019 events). The burst phase slope is increasing along the missions, around 1.5 mdeg/pulse per year for S3A and around 6 mdeg/pulse per year for S3B.

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 band case, with excursions (see colour code at right hand side) of less than 0.1 dB for both missions.

The CAL2 parameters behaviour is stable and nominal along the missions. The flagging of certain CAL2 parameters is dismissed in order to properly plot the series: it is needed a mission L1b reprocessing for homogenizing the flagging along the mission, for instance in the CAL2 slope.

The thermistors data series are showing an annual oscillation, and a long-term cooling. At some dates there are increases of the S3A thermistors values of around 0.2ºC, returning in a short term to its precedent values, with a very limited impact in the calibration series.

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

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 collection of statistics for the main calibration parameters for both modes and bands of S3A and S3B missions is depicted below in Table 2-3 and Table 2-4 respectively.

The long term drift for the S3A time delay and 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 are computed without detrending.

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

S3A Calibration Parameter	Ku band			C band		
	mean	annual slope	standard deviation	mean	annual slope	standard deviation
LRM CAL1 time delay	1.0072 m	-0.50 mm	0.57 mm	0.8930 m	-0.37 mm	0.39 mm
SAR CAL1 time delay	1.0070 m	-0.34 mm	0.41 mm	0.8936 m	-0.30 mm	0.32 mm
LRM CAL1 power	57.65 dB	-0.36 dB	0.36 dB	50.91 dB	-0.03 dB	0.03 dB
SAR CAL1 power	62.08 dB	-0.37 dB	0.37 dB	48.42 dB	-0.03 dB	0.03 dB
LRM CAL1 PTR width	0.4165 m	-0.36 mm	0.37 mm	0.4543 m	-0.07 mm	0.08 mm
SAR CAL1 PTR width	0.4162 m	-0.37 mm	0.39 mm	0.4542 m	-0.08 mm	0.10 mm

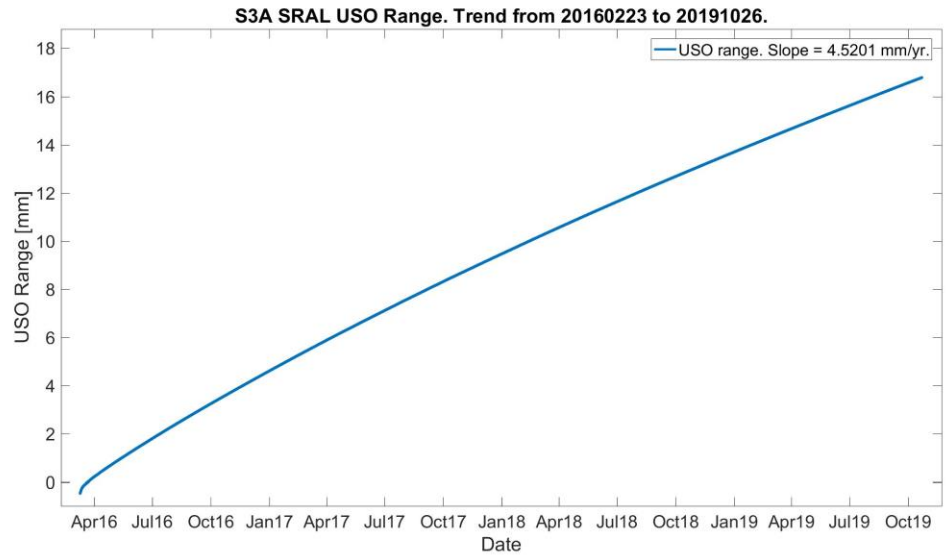
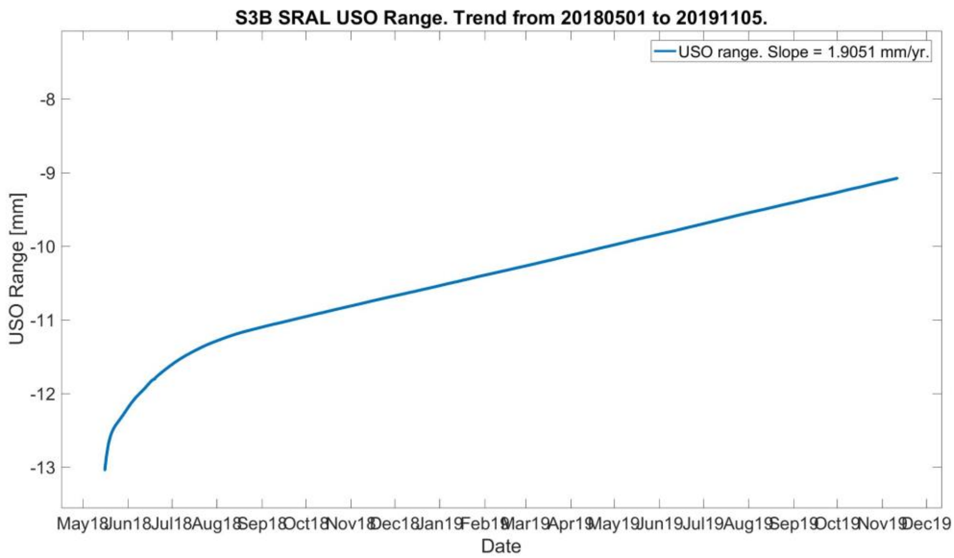
Table 2-3. Collection of S3A calibration parameters statistics for all modes and bands covering the whole mission.

S3B Calibration Parameter	Ku band			C band		
	mean	annual slope	standard deviation	mean	annual slope	standard deviation
LRM CAL1 time delay	0.9602 m	0.06 mm	0.12 mm	0.9582 m	-0.33 mm	0.15 mm
SAR CAL1 time delay	0.9596 m	0.73 mm	0.29 mm	0.9580 m	-0.32 mm	0.15 mm
LRM CAL1 power	57.21 dB	-0.35 dB	0.13 dB	50.47 dB	0.09 dB	0.04 dB
SAR CAL1 power	61.65 dB	-0.38 dB	0.15 dB	47.82 dB	0.09 dB	0.04 dB
LRM CAL1 PTR width	0.4138 m	-0.36 mm	0.20 mm	0.4659 m	0.03 mm	0.11 mm
SAR CAL1 PTR width	0.4139 m	-0.27 mm	0.18 mm	0.4660 m	0.04 mm	0.11 mm

Table 2-4. Collection of S3B calibration parameters statistics for all modes and bands covering the whole mission.

2.5 On-board Clock Performance

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. Here below are depicted the USO frequency impact on the altimeter range for S3A (Figure 2-60) and S3B (Figure 2-61).

Time series of the USO frequency.
 Figure 2-60. S3A USO frequency impact in the range.
 Figure 2-61. S3B USO frequency impact in the range.

The USO clock frequency impact in the range has a constant trend around 4.5 mm per year for the S3A mission and around 2 mm for the S3B mission.

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 can see in the previous figures, there are no visible effects of this kind so far.

2.6 SRAL Dedicated Investigations

This chapter is devoted to the investigations derived from observations along the mission. The on-going investigations results will be updated in each new version of the report; solved issues will be dismissed from the report.

3 Calibration with Transponder

isardSAT has processed the TRP data from a list of L1A products. Passes with IPF-SR-1 Version 06.13 (cycle 3 to 23) use reprocessed L1A and L2 data provided on the ftp.s3rep.acri-cwa.fr FTP server. Passes from cycle 24 to 45 increase in IPF-SR-1 Version as newer ones become available, up to Version 06.14 for the most recent passes.

The range bias results are of the order of millimetres. The datation bias is of the order of hundreds of microseconds.

For S3A, the passes on cycles 13 and 21 have not been analysed because the transponder was not switched on due to extreme climate conditions and pass on cycle 48 and 50 have not been analysed due to maintenance work . For S3B, cycles 1 to 7 and 15 to 18 have not been included as the satellite was not overflying the TRP. The TRP was not switched on due to extreme snow event for cycle 20.

Figure 3-1 to Figure 3-4 depicts the series of TRP processing results for the two missions and the two transponders, including range, datation, stack alignment and stack range noise.

Table 3-1 present the results from the Crete TRP passes processing. The range bias is computed as measured minus theoretical. The results for S3A show a positive measured range, 6.18 mm larger than expected (elevation 6.18 mm shorter than expected), and a datation bias of -125.86 microseconds, both extracted from the minimisation of the RMS between theoretical and measured series. They also show a 0.82 mm stack noise. For S3B, the results show a negative measured range, 10.01 mm smaller than expected (elevation 10.01mm higher than expected), and a datation bias of -30.02 microseconds, both extracted from the minimisation of the RMS between theoretical and measured series. They also show a 0.83 mm stack noise. It is interesting to note that for S3B this is the first seven successful acquisitions in the new orbit (previous passes were in tandem orbit following S3A). The new results for cycles [21-31] show that the datation bias and the stack alignment has been reduced from -114.60 microseconds to residual values for cycles [21-31]. More passes will be needed to conclude something.

The regression line in Figure 3-1 shows a drift of -1.93mm/year, but it has a very low significance.

Table 3-2 presents the results from the TRP passes over Svalbard. The results for S3B show a negative bias range, -139.38mm smaller range than expected (elevation -139.38mm higher than expected), and a datation bias of -53.05microseconds, both extracted from the minimisation of the RMS between theoretical and measured series. They also show a 7.47 mm stack noise (we have less than 1 mm with S3A/B over Crete and 7.4 mm with CryoSat-2 over Svalbard). For S3A, the results show a negative measured range, 199.79 mm smaller than expected (elevation 199.79mm higher than expected), and a datation bias of -89.22 microseconds, both extracted from the minimisation of the RMS between theoretical and measured series. They also show a 18.78mm stack noise.

Cycle – Mission	Date	Range bias [mm]	Datation bias [microseconds]	Alignment [mm/beam]	Noise [mm]	IPF-SR-1 Version
3 - S3A	2016/04/09	2.48	-127.34	0.07	0.41	06.13
4 - S3A	2016/05/06	18.84	-114.60	0.06	0.41	06.13
5 - S3A	2016/06/02	-3.91	-165.54	0.09	0.86	06.13
6 - S3A	2016/06/29	1.09	-152.81	0.06	0.93	06.13
7 - S3A	2016/07/26	-2.78	-152.81	0.07	1.02	06.13
8 - S3A	2016/08/22	-0.29	-127.34	0.09	0.80	06.13
9 - S3A	2016/09/18	2.47	-114.60	0.04	0.73	06.13
10 - S3A	2016/10/15	8.83	-178.27	0.12	0.66	06.13
11 - S3A	2016/11/11	19.89	-140.07	0.09	0.79	06.13
12 - S3A	2016/12/08	22.47	-127.34	0.07	0.80	06.13
13 - S3A	Transponder not switched on due to heavy snow.					
14 - S3A	2017/01/31	26.38	-114.60	0.07	0.73	06.13
15 - S3A	2017/02/27	2.49	-127.34	0.07	0.87	06.13
16 - S3A	2017/03/26	0.51	-127.34	0.06	0.84	06.13
17 - S3A	2017/04/22	13.61	-140.07	0.08	0.41	06.13
18 - S3A	2017/05/19	28.20	-127.34	0.06	1.15	06.13
19 - S3A	2017/06/15	-4.72	-165.54	0.07	1.18	06.13
20 - S3A	2017/07/12	-16.89	-114.60	0.08	0.71	06.13
21 - S3A	Transponder not switched on due to high temperatures.					
22 - S3A	2017/09/04	19.37	-127.34	0.07	0.68	06.13
23 - S3A	2017/10/01	11.85	-114.60	0.07	0.68	06.13
24 - S3A	2017/10/28	1.30	-127.34	0.07	0.96	06.11
25 - S3A	2017/11/24	18.22	-101.87	0.07	0.79	06.12
26 - S3A	2017/12/21	-2.41	-114.60	0.06	0.68	06.12
27 - S3A	2018/01/17	11.56	-101.87	0.06	0.94	06.12
28 - S3A	2018/02/13	15.27	-127.34	0.06	0.74	06.13
29 - S3A	2018/03/12	-0.38	-101.87	0.09	1.00	06.14
30 - S3A	2018/04/08	6.25	-127.34	0.08	0.83	06.14
31 - S3A	2018/05/05	3.59	-140.07	0.06	0.88	06.14

Cycle – Mission	Date	Range bias [mm]	Datation bias [microseconds]	Alignment [mm/beam]	Noise [mm]	IPF-SR-1 Version
32 - S3A	2018/06/01	-7.61	-127.34	0.09	0.91	06.14
8 - S3B	2018/06/01	S3B in LRM mode, results to be computed				
33 - S3A	2018/06/28	1.72	-101.87	0.04	0.72	06.14
10 - S3B	2018/06/28	S3B in LRM mode, results to be computed				
34 - S3A	2018/07/25	6.18	-140.07	0.07	0.87	06.14
11 - S3B	2018/07/25	S3B in LRM mode, results to be computed				
35 - S3A	2018/08/21	-9.00	-114.60	0.07	0.99	06.14
12 - S3B	2018/08/21	-20.38	-114.60	0.04	0.86	06.14
36 - S3A	2018/09/17	-0.72	-114.60	0.07	0.79	06.14
13 - S3B	2018/09/17	-12.60	-89.14	0.03	0.97	06.14
37 - S3A	2018/10/14	5.89	-114.60	0.05	0.93	06.14
14 - S3B	2018/10/14	-0.83	-89.14	0.05	0.75	06.14
38 - S3A	2018/11/10	15.85	-127.34	0.07	0.82	06.14
39 - S3A	2018/12/07	16.72	-50.94	0.08	1.13	06.14
40 - S3A	2019/01/03	11.93	-114.60	0.06	0.80	06.14
20 - S3B	2018/01/09	Transponder not switched on due to heavy snow				06.14
41 - S3A	2019/01/30	27.00	-140.07	0.07	0.76	06.14
21 - S3B	2019/02/05	10.29	-25.47	0.02	0.69	06.14
42 - S3A	2019/02/26	-10.21	-140.07	0.09	0.79	06.14
22 - S3B	2019/03/04	17.18	0.00	0.02	0.90	06.14
43 - S3A	2019/03/25	-7.42	-127.43	0.06	0.90	06.14
23 - S3B	2019/03/31	-24.49	-12.73	0.02	0.79	06.14
44 - S3A	2019/04/21	-1.03	-114.60	0.07	0.77	06.14
24 - S3B	2019/04/27	-13.57	-12.73	0.01	0.84	06.14
45 - S3A	2019/05/18	3.50	-140.07	0.08	0.85	06.14
25 - S3B	2019/05/24	-5.47	-12.73	0.00	0.84	06.14
46 - S3A	2019/06/14	-7.70	-140.07	0.08	0.78	06.14
26 - S3B	2019/06/20	-9.07	-25.47	0.02	0.92	06.14
47 - S3A	2019/07/11	9.16	-152.81	0.06	0.85	06.14

Cycle – Mission	Date	Range bias [mm]	Datation bias [microseconds]	Alignment [mm/beam]	Noise [mm]	IPF-SR-1 Version
27 - S3B	2019/07/17	-20.26	-12.73	0.01	0.79	06.14
48 - S3A	2019/08/07	Transponder not switched on due to maintenace work				06.14
28 - S3B	2019/08/13	-25.82	-12.73	0.02	0.84	06.14
49 - S3A	2019/09/03	4.55	-114.60	0.06	0.80	06.14
29 - S3B	2019/09/09	-19.44	0.00	0.02	0.84	06.14
50 - S3A	2019/09/30	Transponder not switched on due to maintenace work				06.14
30 - S3B	2019/10/06	-11.08	-12.73	0.01	0.67	06.14
31 - S3B	2019/11/02	-4.55	0.00	0.01	0.96	06.14
Mean S3A		**6.18**	**-125.86**	**0.07**	**0.82**	-
Standard Deviation S3A		**10.83**	**20.46**	**0.01**	**0.17**	-
Mean S3B		**-10.01**	**-30.02**	**0.02**	**0.83**	-
Standard Deviation S3B		**12.61**	**37.91**	**0.01**	**0.09**	-

Table 3-1. Results of Crete TRP passes processing

Cycle – Mission	Date	Range bias [mm]	Datation bias [microseconds]	Alignment [mm/beam]	Noise [mm]	IPF-SR-1 Version
26 - S3B	2019/06/14	-119.35	-50.93	-0.04	17.05	06.14
46 - S3A	2019/06/29	-193.83	-114.60	0.04	31.42	06.14
27 - S3B	2019/07/11	-128.35	-50.93	0.02	8.97	06.14
47 - S3A	2019/07/26	-225.43	-38.20	0.05	12.05	06.14
28 - S3B	2019/08/07	-144.16	-25.47	0.03	6.48	06.14
48 - S3A	2019/08/22	-183.29	-114.60	0.08	35.52	06.14
29 - S3B	2019/09/03	-171.42	-25.47	0.03	3.36	06.14
49 - S3A	2019/09/18	-225.37	-76.40	0.08	7.70	06.14
30 - S3B	2019/09/30	-164.53	-50.93	0.04	4.70	06.14
50 - S3A	2019/10/15	-171.32	-101.87	0.08	7.17	06.14
31 - S3B	2019/10/27	-108.62	-114.60	0.06	4.27	06.14
Mean S3A		**-199.79**	**-89.22**	**0.07**	**18.78**	-
Standard Deviation S3A		**24.69**	**32.54**	**0.02**	**13.63**	-
Mean S3B		**-139.38**	**-53.05**	**0.02**	**7.47**	-

Cycle – Mission	Date	Range bias [mm]	Datation bias [microseconds]	Alignment [mm/beam]	Noise [mm]	IPF-SR-1 Version
Standard Deviation S3B		**25.11**	**32.63**	**0.03**	**5.09**	-

Table 3-2. Results of Svalbard TRP passes processing

Regarding the geophysical corrections, for the Crete measurements the ionospheric and wet/dry tropospheric corrections were extracted from the transponder auxiliary files provided by the MPC team.

Then, the solid earth, geocentric tide and ocean loading corrections are selected from the L2 products. A table with the Geophysical corrections used is shown in Table 3-3. The TRP internal delay is 4.954 meters.

Cycle A-S3A B-S3B	Date	Wet Tropo [m]	Dry Tropo [m]	Iono [m]	Solid Earth [m]	Geocentric Tide [m]	Ocean Loading [m]
3A	2016/04/09	-0.09	-2.03	-0.02	-0.13	0.003	0.003
4A	2016/05/06	-0.07	-2.04	-0.03	-0.04	0.003	0.010
5A	2016/06/02	-0.12	-2.05	-0.04	0.03	0.001	0.009
6A	2016/06/29	-0.11	-2.05	-0.03	0.00	-0.001	0.003
7A	2016/07/26	-0.07	-2.05	-0.02	-0.09	-0.003	-0.002
8A	2016/08/22	-0.08	-2.05	-0.02	-0.12	-0.004	0.003
9A	2016/09/18	-0.13	-2.06	-0.02	-0.03	-0.005	0.004
10A	2016/10/15	-0.06	-2.07	-0.02	0.14	-0.005	0.007
11A	2016/11/11	-0.07	-2.07	-0.02	0.20	-0.004	0.003
12A	2016/12/08	-0.01	-2.08	-0.01	0.09	-0.003	-0.003
14A	2017/01/31	-0.01	-2.07	-0.02	-0.08	0.000	-0.002
15A	2017/02/27	-0.09	-2.05	-0.02	-0.01	0.001	0.003
16A	2017/03/26	-0.07	-2.05	-0.02	0.12	0.002	0.005
17A	2017/04/22	-0.04	-2.05	-0.03	0.14	0.002	0.002
18A	2017/05/19	-0.04	-2.05	-0.03	0.03	0.001	-0.003
19A	2017/06/15	-0.08	-2.06	-0.03	-0.08	0.000	-0.002
20A	2017/07/12	-0.08	-2.05	-0.02	-0.12	-0.002	0.002
22A	2017/09/04	0.00	-2.06	-0.02	0.03	-0.005	0.009

Cycle A-S3A B-S3B	Date	Wet Tropo [m]	Dry Tropo [m]	Iono [m]	Solid Earth [m]	Geocentric Tide [m]	Ocean Loading [m]
23A	2017/10/01	-0.06	-2.06	-0.02	0.05	-0.005	0.005
24A	2017/10/28	-0.12	-2.04	-0.02	0.00	-0.004	0.000
25A	2017/11/24	-0.06	-2.06	-0.01	-0.04	-0.003	-0.003
26A	2017/12/21	-0.12	-2.05	-0.02	-0.01	-0.002	-0.002
27A	2018/01/17	-0.06	-2.04	-0.02	0.09	0.000	0.001
28A	2018/02/13	-0.05	-2.05	-0.02	0.17	0.001	0.001
29A	2018/03/12	-0.11	-2.05	-0.02	0.16	0.002	-0.001
30A	2018/04/08	-0.07	-2.05	-0.02	0.06	0.002	-0.004
31A	2018/05/05	-0.03	-2.04	-0.04	-0.07	0.001	-0.002
32A	2018/06/01	-0.06	-2.05	-0.03	-0.11	0.000	0.003
33A	2018/06/28	-0.07	-2.04	-0.02	-0.08	-0.002	0.008
34A	2018/07/25	-0.10	-2.04	-0.03	-0.03	-0.003	0.009
35A/12B	2018/08/21	-0.09	-2.05	-0.02	-0.01	-0.004	0.006
36A/13B	2018/09/17	-0.09	-2.06	-0.02	-0.04	-0.004	0.001
37A/14B	2018/10/14	-0.12	-2.06	-0.01	-0.06	-0.004	-0.002
38A	2018/11/10	-0.08	-2.06	-0.01	0.01	-0.004	-0.001
39A	2018/12/07	-0.02	-2.05	-0.02	0.14	-0.003	0.001
40A	2019/01/03	-0.05	-2.04	-0.02	0.21	-0.001	0.001
41A	2019/01/30	-0.04	-2.03	-0.02	0.18	0.000	-0.003
21B	2019/02/05	-0.04	-2.04	-0.02	-0.02	0.000	0.009
42A	2019/02/26	-0.04	-2.04	-0.02	0.06	0.001	-0.005
22B	2019/03/04	-0.05	-2.05	-0.03	0.03	0.001	0.008
43A	2019/03/25	-0.04	-2.04	-0.02	-0.08	0.001	-0.003
23B	2019/03/31	-0.05	-2.04	-0.03	0.03	0.001	0.003
44A	2019/04/21	-0.06	-2.06	-0.02	-0.12	0.001	0.004
24B	2019/04/27	-0.06	-2.05	-0.03	-0.02	0.001	-0.001
45A	2019/05/18	-0.08	-2.05	-0.02	-0.05	0.000	0.009
25B	2019/05/24	-0.05	-2.05	-0.02	0.02	0.000	-0.003
46A	2019/06/14	-0.09	-2.05	-0.03	0.00	-0.001	0.009
26B	2019/06/20	-0.09	-2.05	-0.03	0.06	-0.001	-0.000
47A	2019/07/11	-0.04	-2.04	-0.02	-0.01	-0.002	0.004
27B	2019/07/17	-0.16	-2.03	-0.03	0.17	-0.002	0.000
28B	2019/08/13	-0.07	-2.04	-0.03	0.22	-0.004	-0.000
49A	2019/09/03	-0.13	-2.05	-0.02	-0.11	-0.004	-0.002

Cycle A-S3A B-S3B	Date	Wet Tropo [m]	Dry Tropo [m]	Iono [m]	Solid Earth [m]	Geocentric Tide [m]	Ocean Loading [m]
29B	2019/09/09	-0.09	-2.05	-0.02	0.16	-0.004	-0.003
30B	2019/10/06	-0.08	-2.05	-0.03	0.03	-0.004	-0.004
31B	2019/10/27	-0.11	-2.05	-0.03	-0.08	-0.003	0.000

Table 3-3. Geophysical Corrections of Crete TRP passes processing

For the Svalbard transponder, the ionospheric and wet/dry tropospheric, the solid earth, geocentric tide and ocean loading corrections are selected from the L2 products. A table with the Geophysical corrections used is shown in Table 3-4. The TRP internal delay is 9.88 meters.

Cycle A-S3A B-S3B	Date	Wet Tropo [m]	Dry Tropo [m]	Iono [m]	Solid Earth [m]	Geocentric Tide [m]	Ocean Loading [m]
26B	2019/06/14	-0.09	-2.31	-0.02	-0.03	-0.001	0.001
46A	2019/06/29	-0.16	-2.31	-0.02	0.03	-0.002	-0.002
27B	2019/07/11	-0.11	-2.31	-0.02	-0.03	-0.001	0.000
47A	2019/07/26	-0.20	-2.33	-0.02	0.01	-0.003	0.009
28B	2019/08/07	-0.12	-2.32	0.01	-0.04	-0.004	-0.004
48A	2019/08/22	-0.14	-2.31	-0.02	-0.01	-0.004	0.009
29B	2019/09/03	-0.11	-2.31	-0.01	-0.05	-0.004	-0.003
49A	2019/09/18	-0.16	-2.33	-0.02	-0.03	-0.004	0.002
30B	2019/09/30	-0.09	-2.33	-0.01	-0.05	-0.004	0.006
50A	2019/10/15	-0.11	-2.32	-0.02	-0.03	-0.004	-0.006
31B	2019/10/27	-0.04	-2.32	-0.01	-0.04	-0.003	0.009

Table 3-4. Geophysical Corrections of Svalbard TRP passes processing

Transponder processing results.

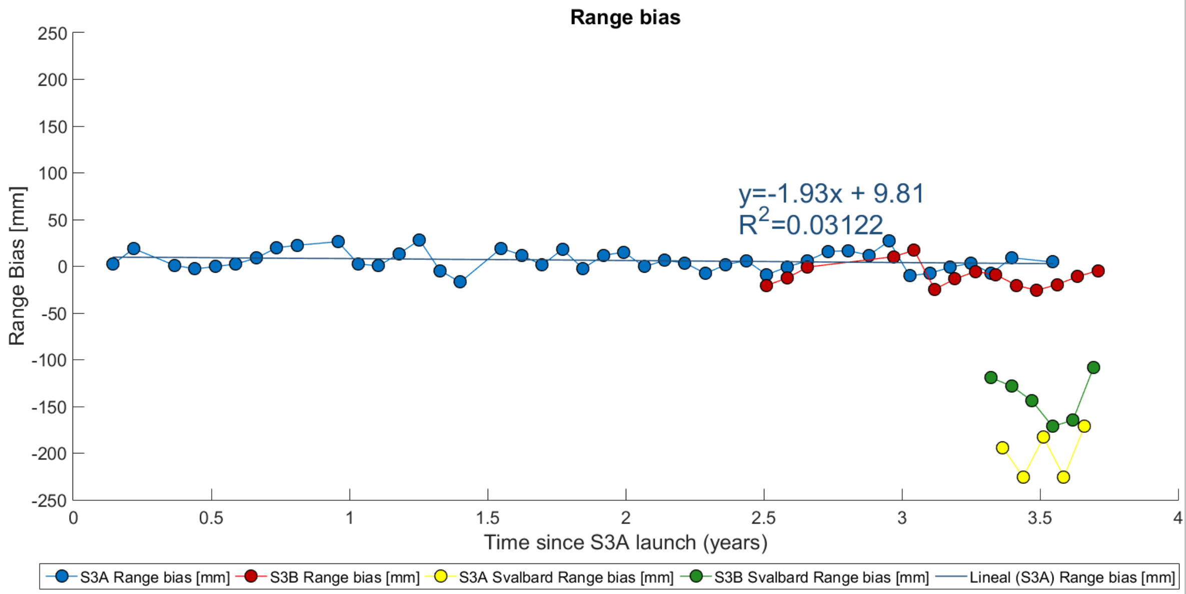


Figure 3-1. Range Bias Results.

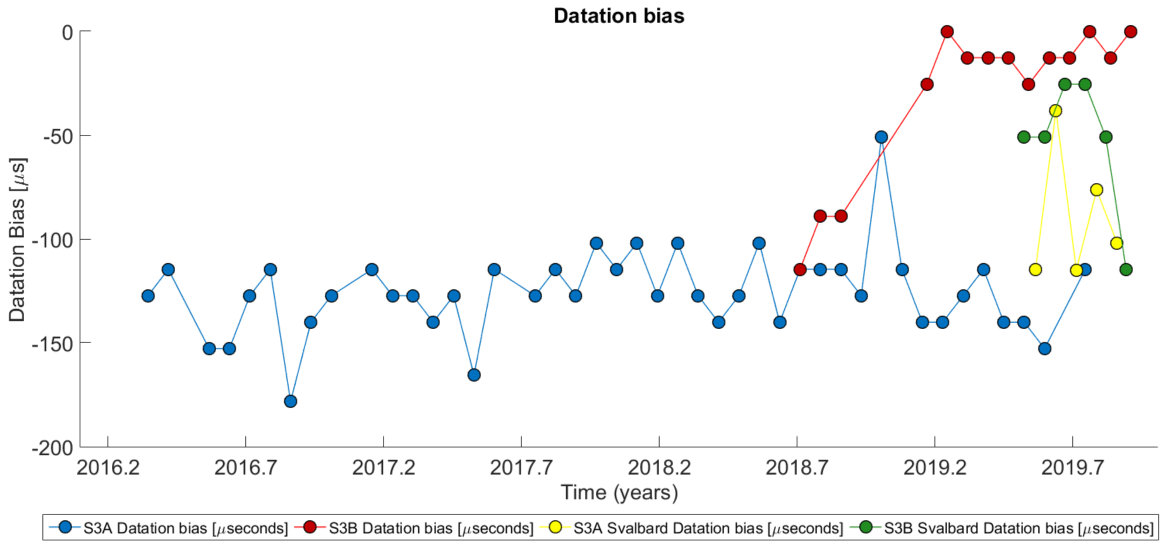


Figure 3-2. Datation Bias Results.

Transponder processing. Stack analysis.

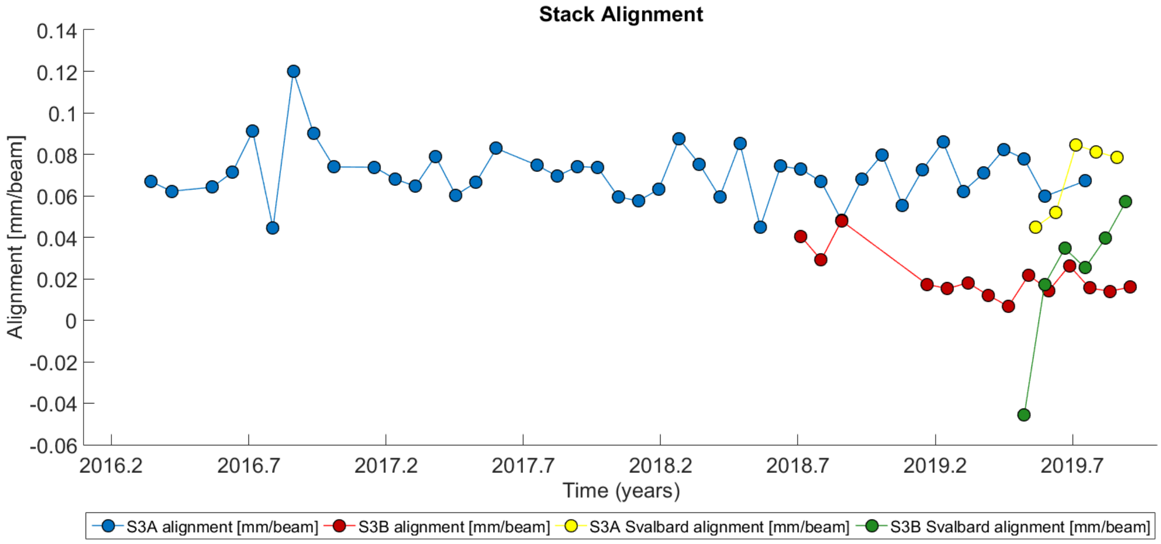


Figure 3-3. Alignment Results.

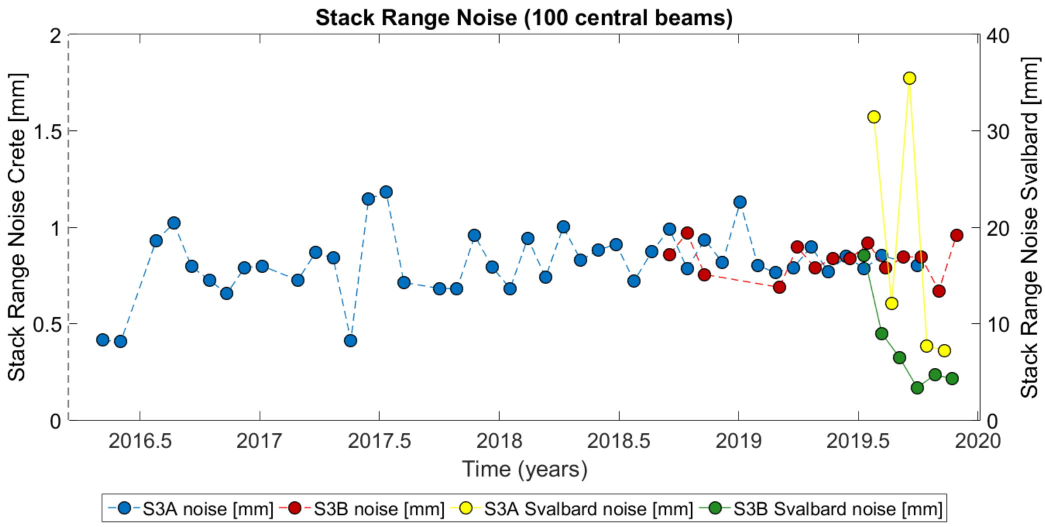


Figure 3-4. Stack Noise Results.

4 Events

No SRAL special events have been observed during this cycle.

5 Appendix A

Other reports related to the Optical mission are:

- S3 MWR Cyclic Performance Report, S3A Cycle No. 050, S3B Cycle No. 031 (ref. S3MPC.CLS.PR.05-050-031)
- S3 Ocean Validation Cyclic Performance Report, S3A Cycle No. 050, S3B Cycle No. 031 (ref. S3MPC.CLS.PR.06-050-031)
- S3 Winds and Waves Cyclic Performance Report, S3A Cycle No. 050, S3B Cycle No. 031 (ref. S3MPC.ECM.PR.07-050-031)
- S3 Land and Sea Ice Cyclic Performance Report, S3A Cycle No. 050, S3B Cycle No. 031 (ref. S3MPC.UCL.PR.08-050-031)

All Cyclic Performance Reports are available on MPC pages in Sentinel Online website, at: https://sentinel.esa.int

End of document