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

S3 SRAL Cyclic Performance Report		
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Cycle No. 070	Cycle No. 051	
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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
нктм	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

<u>S3A</u>

IPF	IPF / Processing Baseline version	Date of deployment
SR1	06.20 / 2.72	02/12/2020 09:07 UTC

<u>S3B</u>

IPF	IPF / Processing Baseline version	Date of deployment
SR1	06.20 / 1.49	02/12/2020 09:07 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

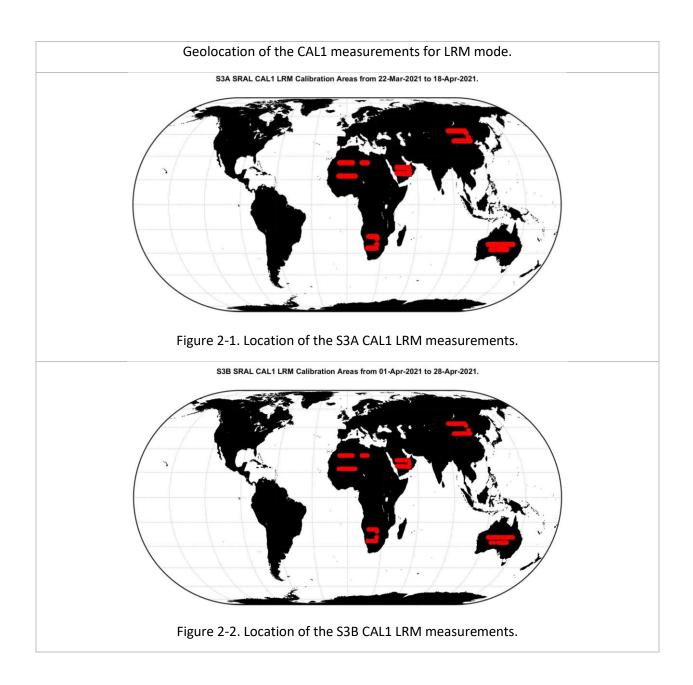


Autocal parameters monitor the actual attenuation values for each on-board ATT step, and are to be used for updating the on-board ATT table in case of need.

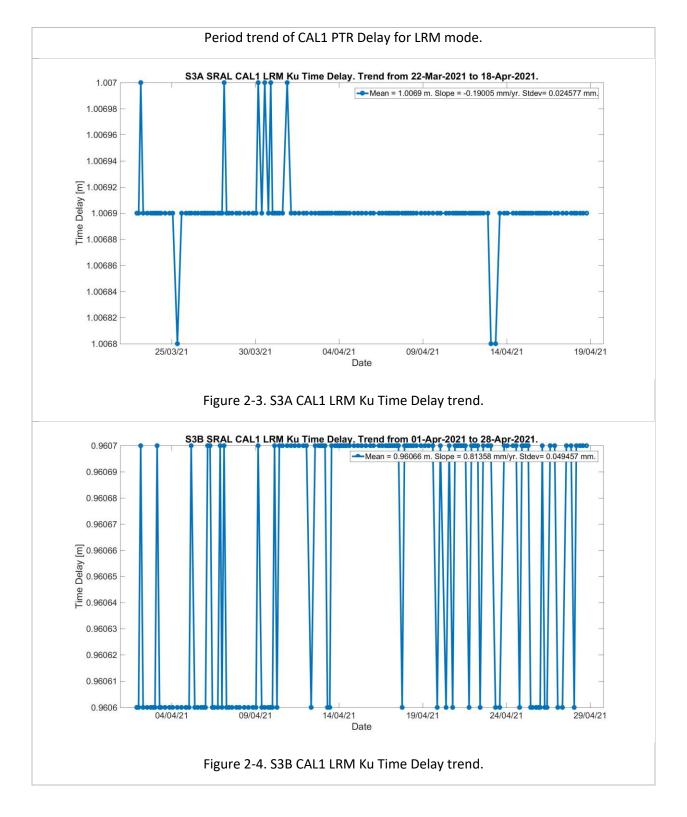
2.2 Cyclic In-Flight Internal Calibration.

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.

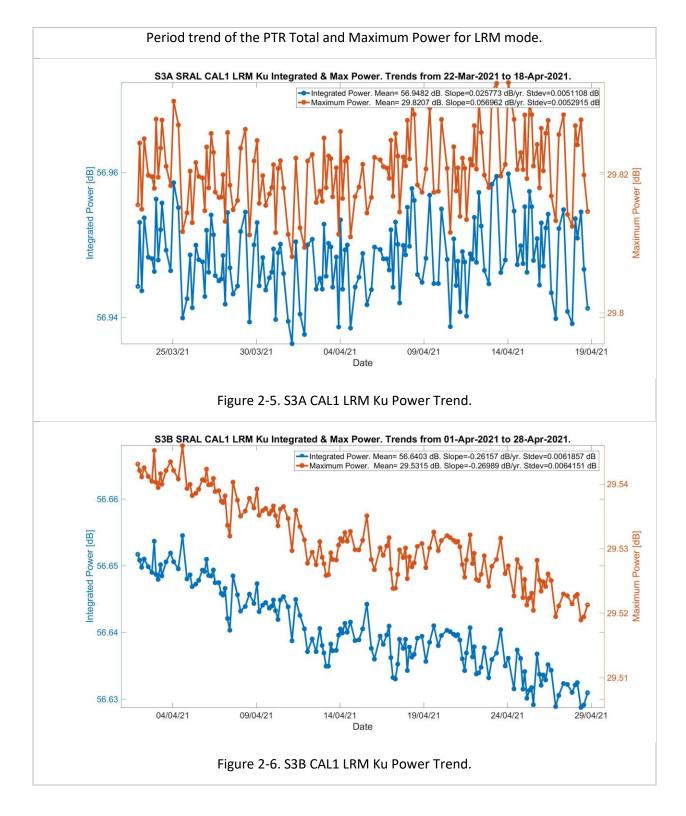
2.2.1 CAL1 LRM











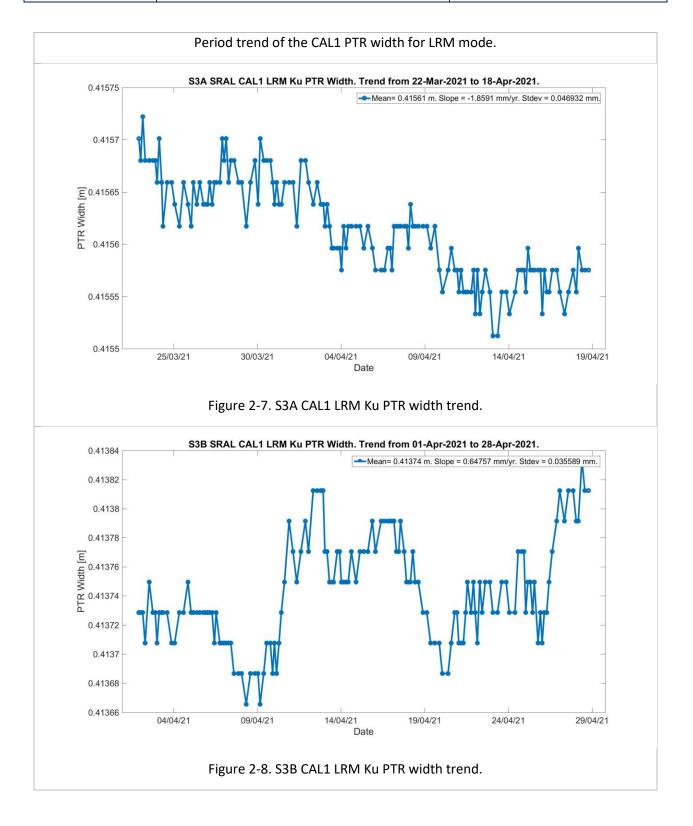


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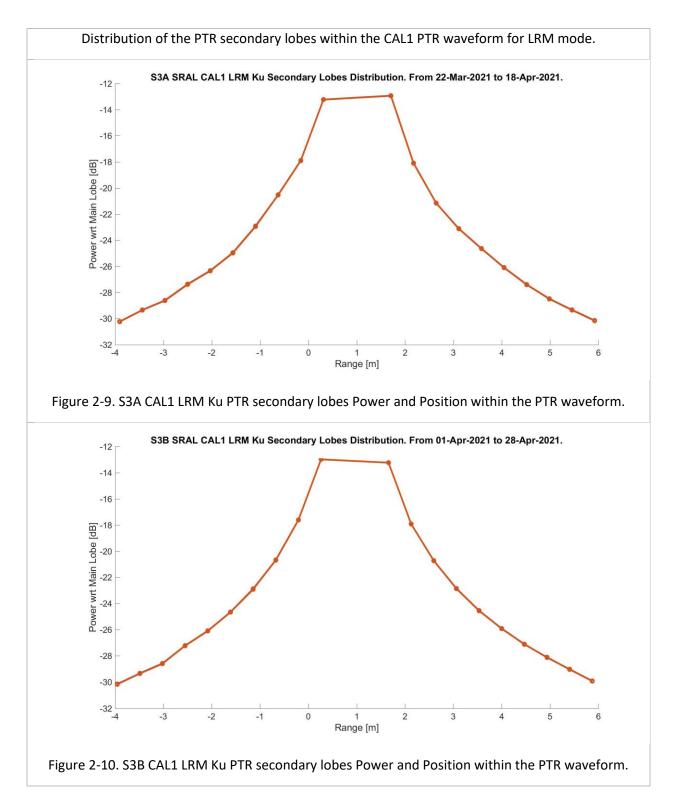
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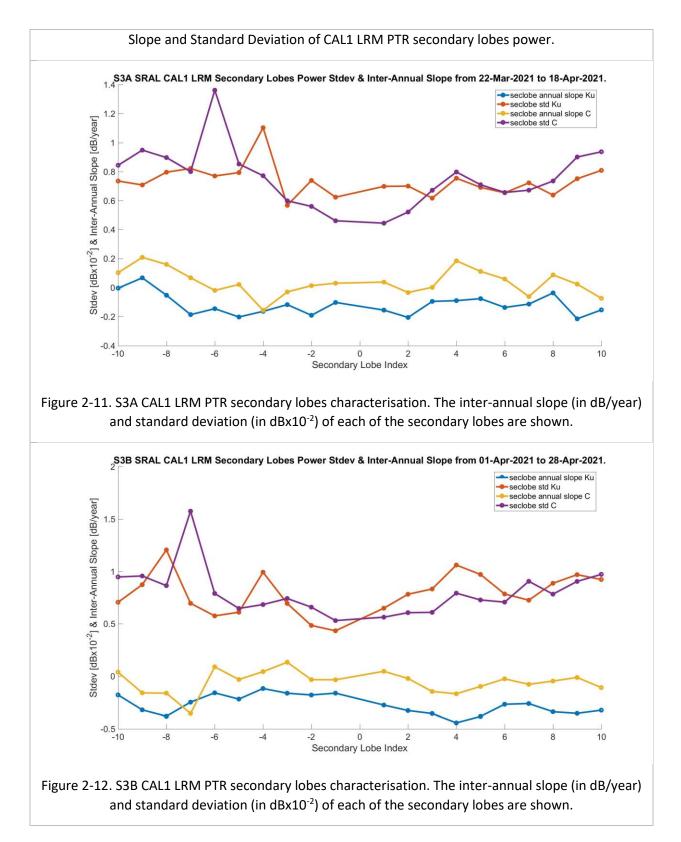
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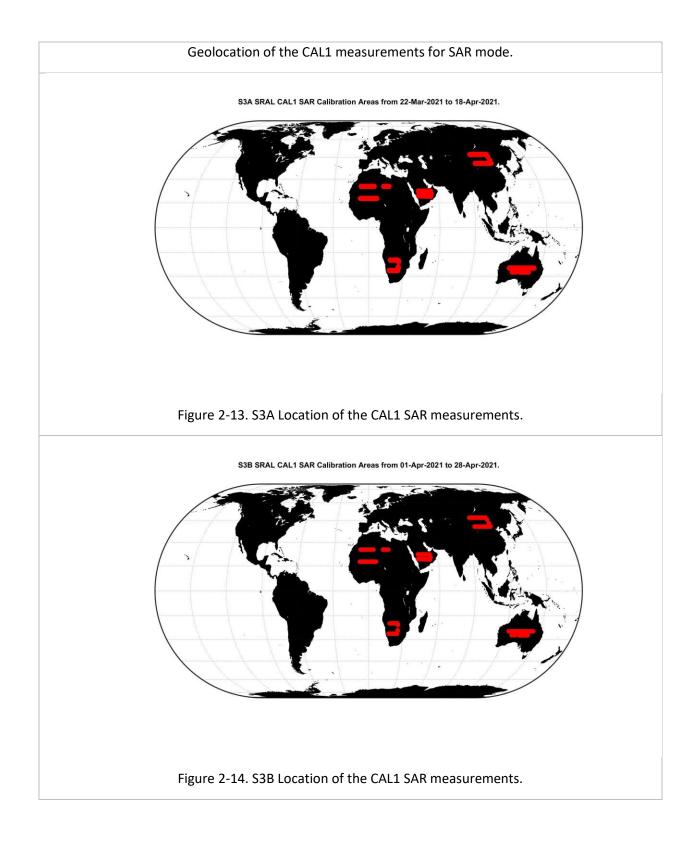
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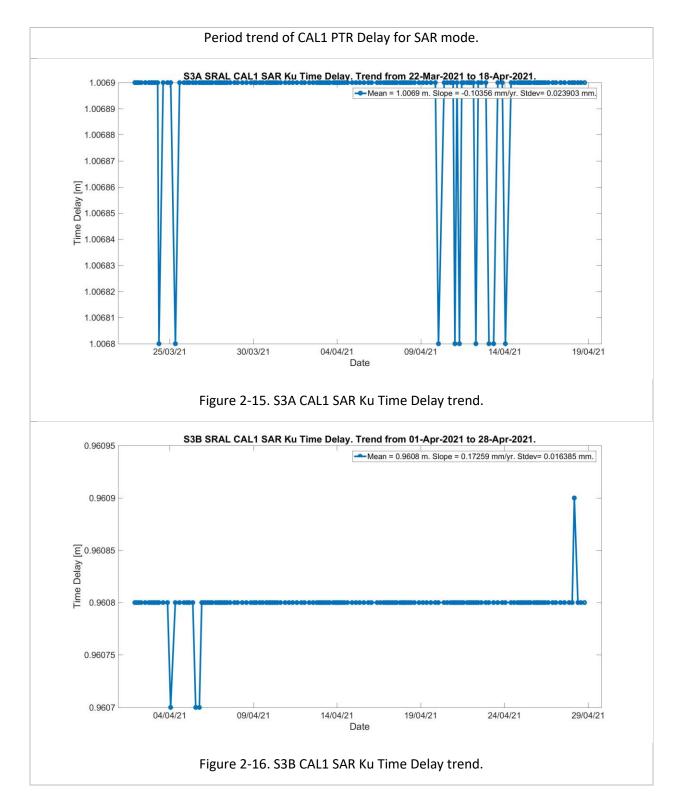
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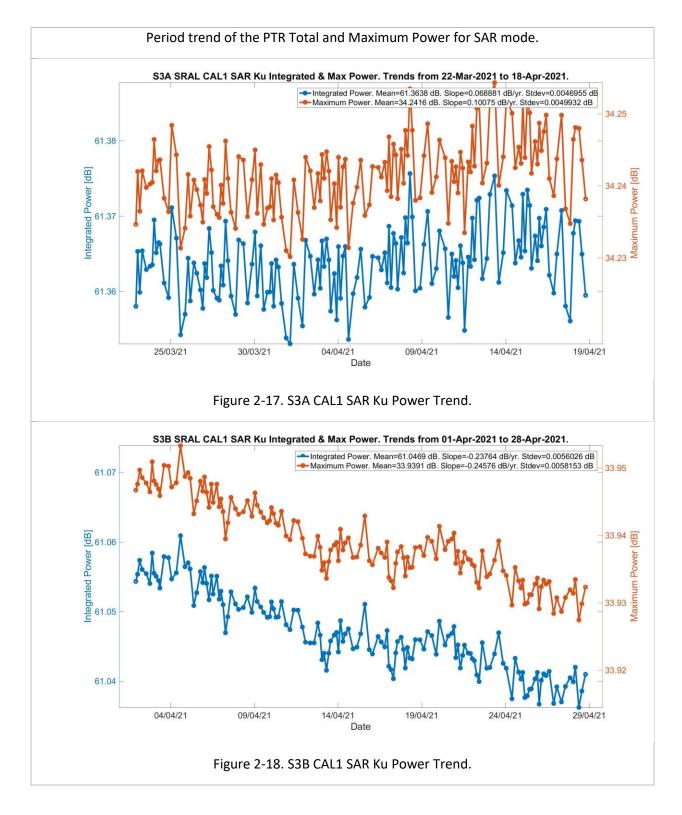
2.2.2 CAL1 SAR



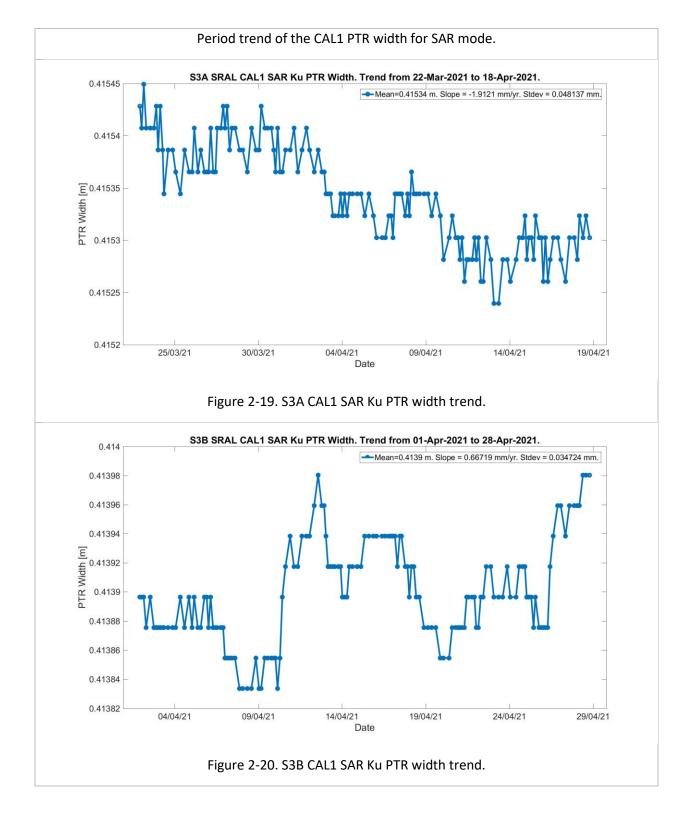




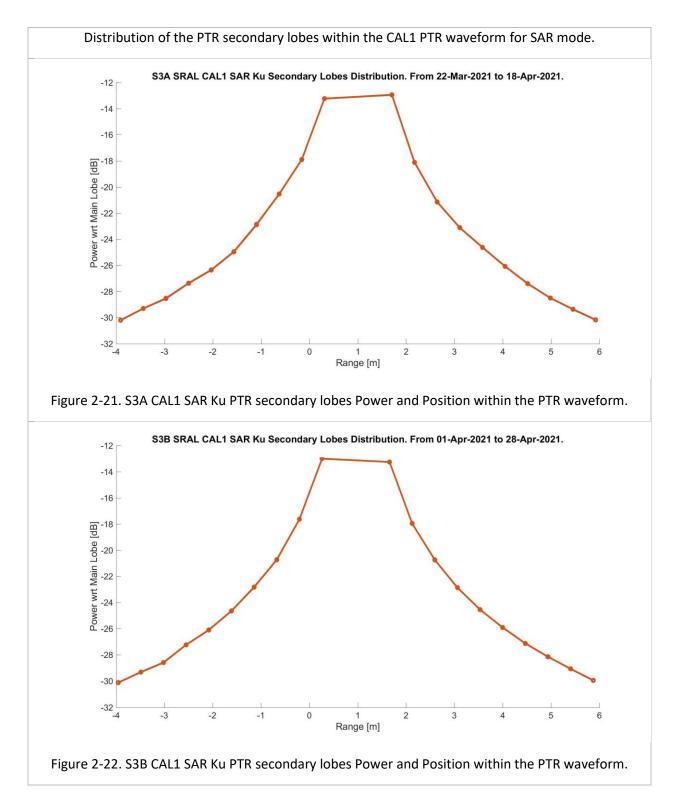




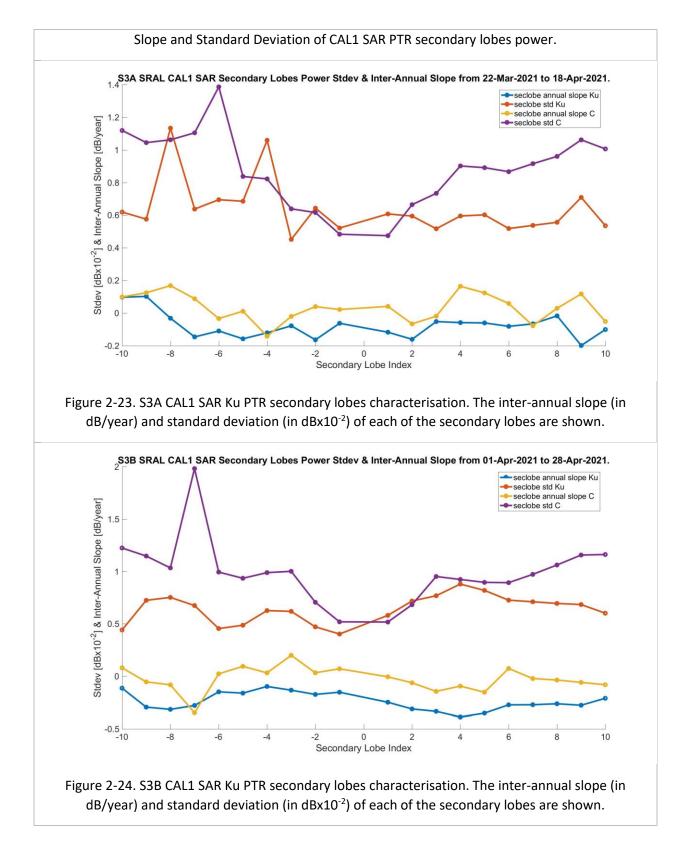




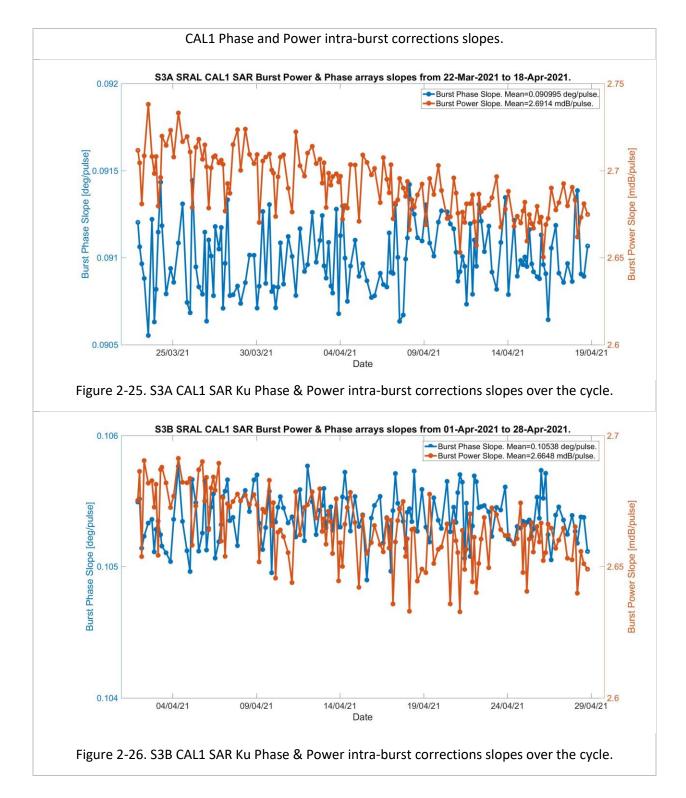




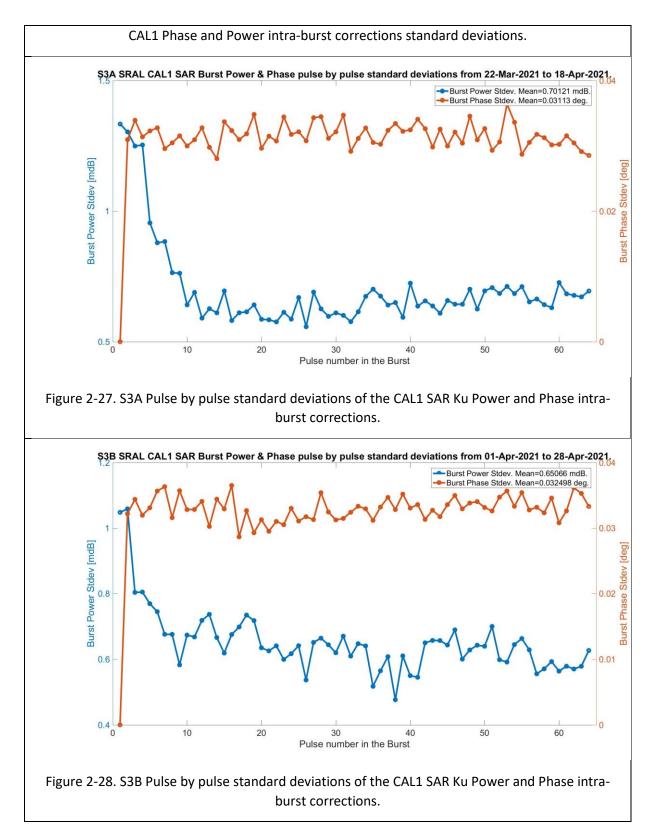






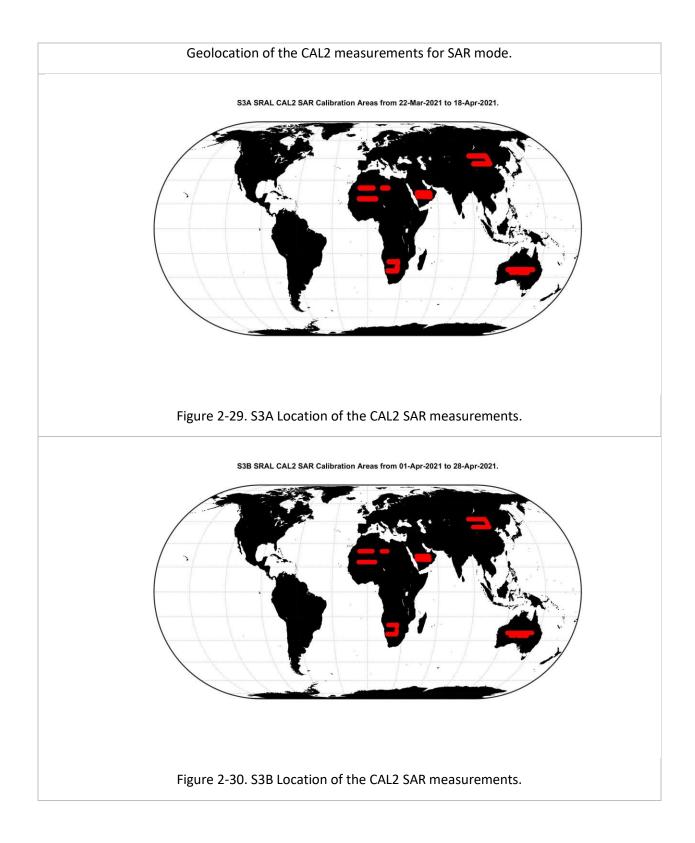




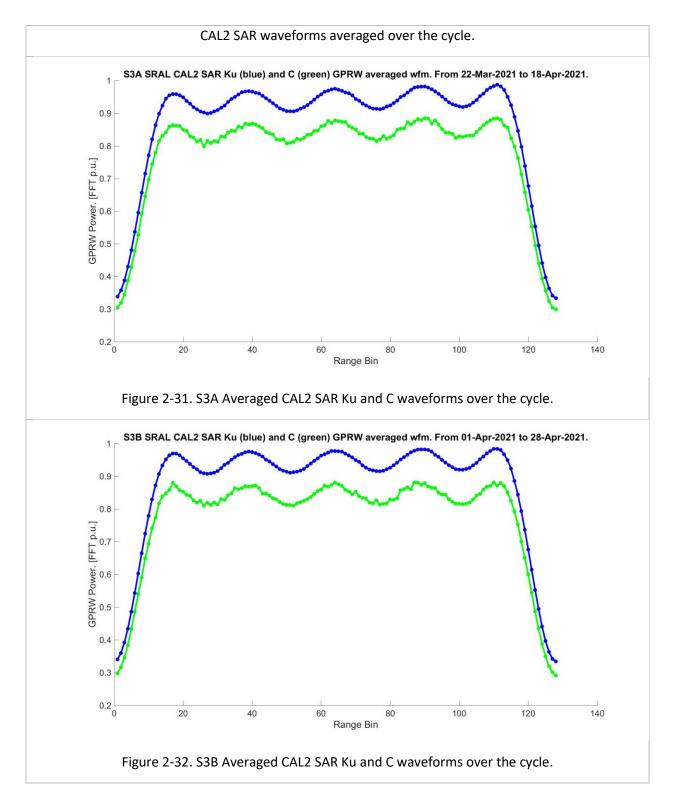




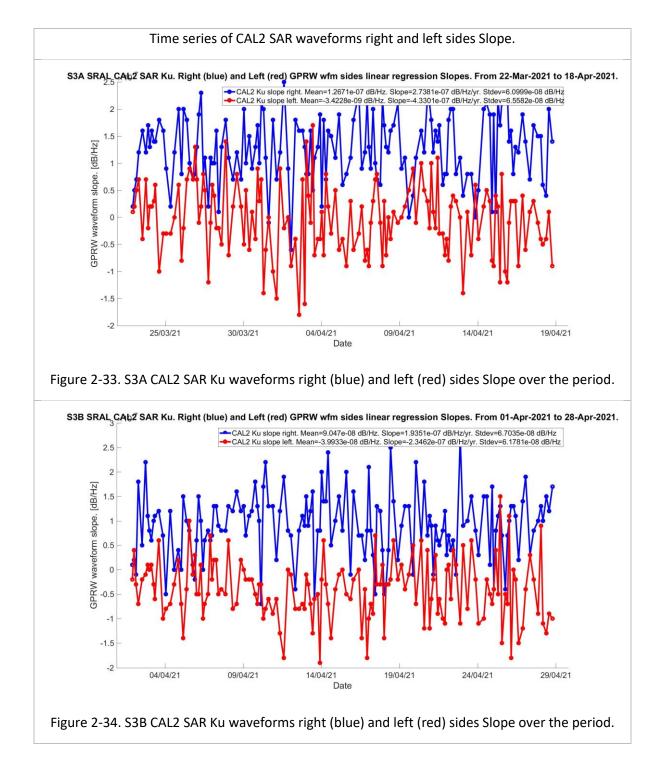
2.2.3 System Transfer Function (CAL2)



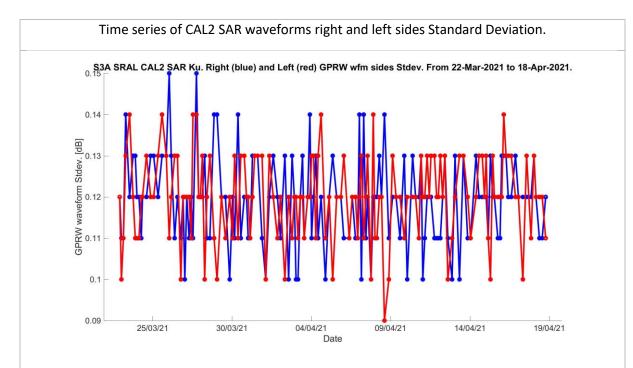


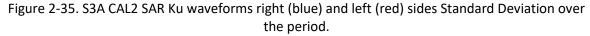


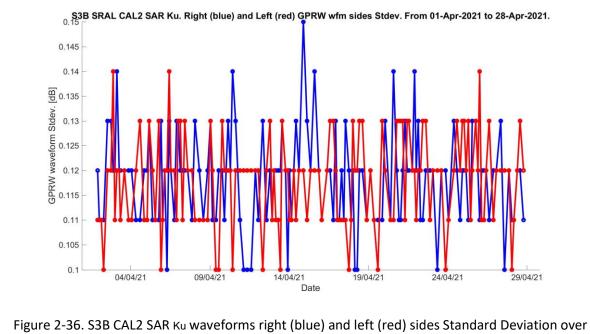








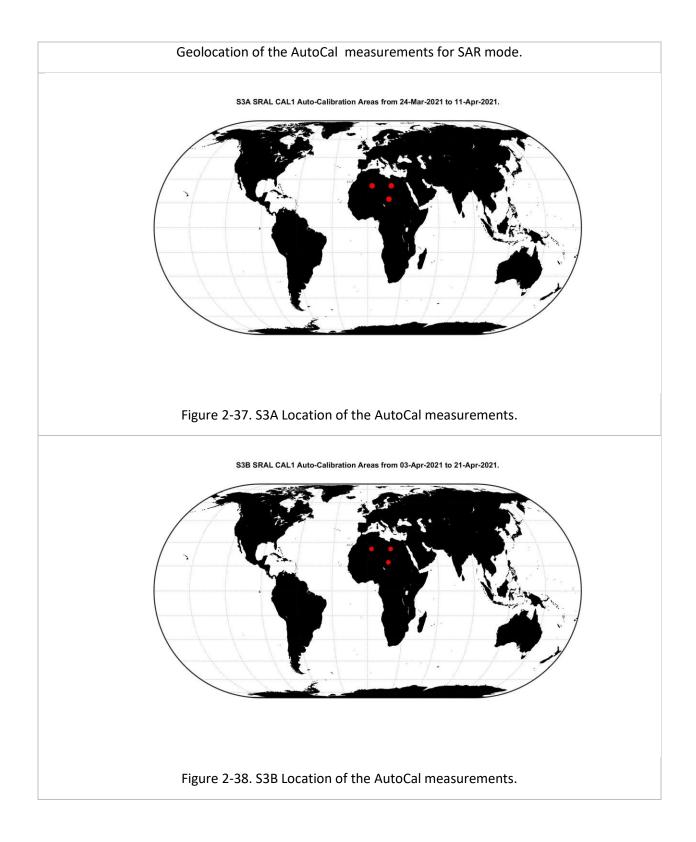




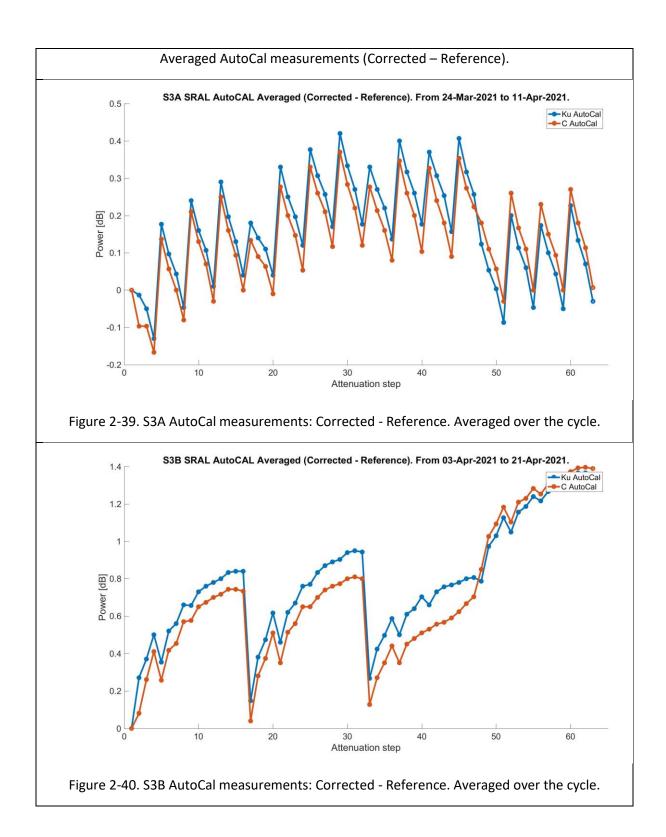
the period.



2.2.4 AutoCAL (CAL1 SAR Auto)



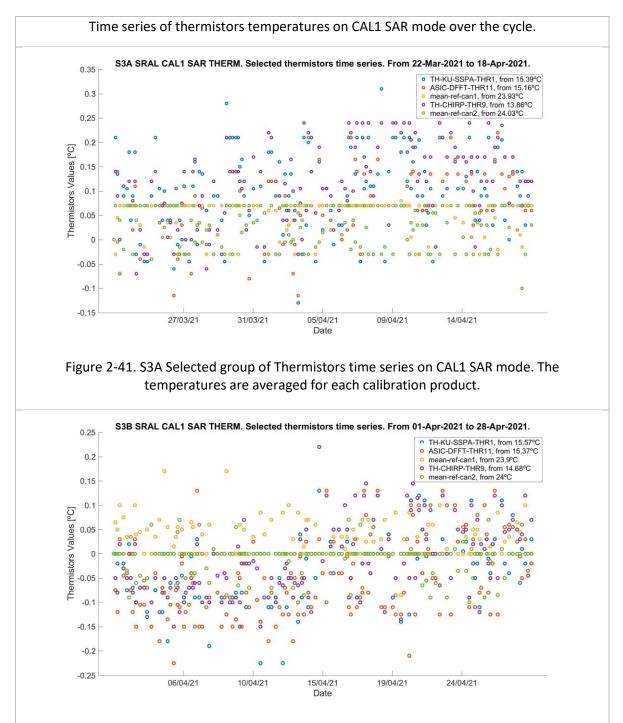


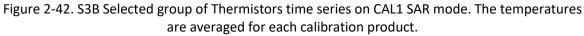




2.2.5 Housekeeping Temperatures

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







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.

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

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 steep than at BOM.

All 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.

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. 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.



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S3A Calibration Parameter	Ku band			C band		
	Mean	annual slope	standard deviation	mean	annual slope	standard deviation
LRM CAL1 time delay	1.0069 m	-0.19 mm	0.02 mm	0.8926 m	-0.47 mm	0.06 mm
SAR CAL1 time delay	1.0069 m	-0.10 mm	0.02 mm	0.8933 m	-0.07 mm	0.05 mm
LRM CAL1 power	56.95 dB	0.03 dB	0.01 dB	50.83 dB	0.14 dB	0.00 dB
SAR CAL1 power	61.36 dB	0.07 dB	0.00 dB	48.34 dB	0.13 dB	0.00 dB
LRM CAL1 PTR width	0.4156 m	-1.86 mm	0.05 mm	0.4543 m	-1.58 mm	0.04 mm
SAR CAL1 PTR width	0.4153 m	-1.91 mm	0.05 mm	0.4541 m	-1.64 mm	0.04 mm

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

	Ku band			C band		
S3B Calibration Parameter	Mean	annual slope	standard deviation	Mean	annual slope	standard deviation
LRM CAL1 time delay	0.9607 m	0.81 mm	0.05 mm	0.9573 m	- 0.18 mm	0.03 mm
SAR CAL1 time delay	0.9608 m	0.17 mm	0.02 mm	0.9571 m	- 0.63 mm	0.05 mm
LRM CAL1 power	56.64 dB	- 0.26 dB	0.01 dB	50.47 dB	- 0.02 dB	0.00 dB
SAR CAL1 power	61.05 dB	-0.24 dB	0.01 dB	47.82 dB	0.00 dB	0.00 dB
LRM CAL1 PTR width	0.4137 m	0.65 mm	0.04 mm	0.4659 m	0.70 mm	0.03 mm
SAR CAL1 PTR width	0.4139 m	0.67 mm	0.03 mm	0.4661 m	0.74 mm	0.03 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.

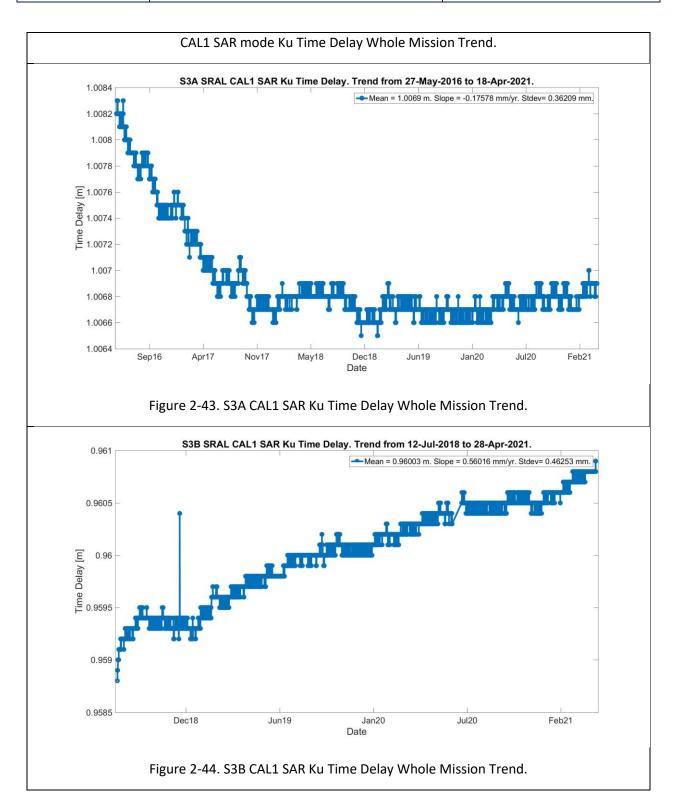
The "whole mission" figures and tables avoid a period at BOM. For the S3A mission, the considered series starts at 27/5/2016 (Cycle 4, orbit 302). For the S3B mission it starts at 12/7/2018 (Cycle 10, orbit 210). The BOM period include calibration parameters behaviours that, if included in our monitoring 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.



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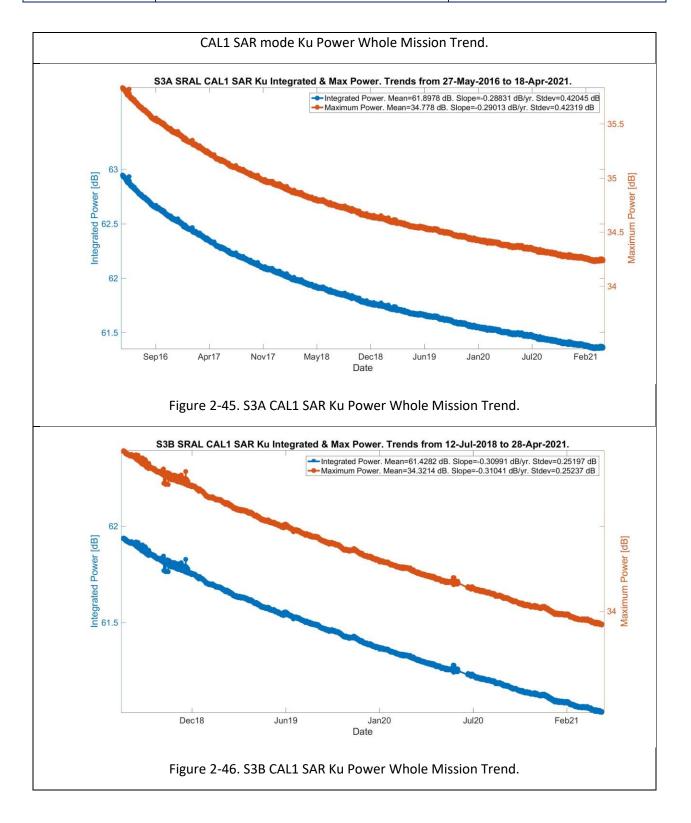
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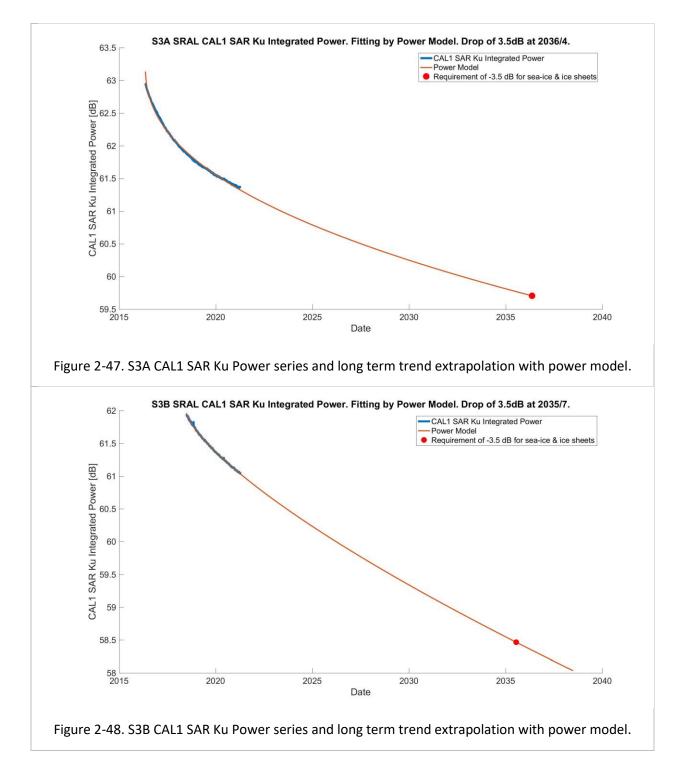
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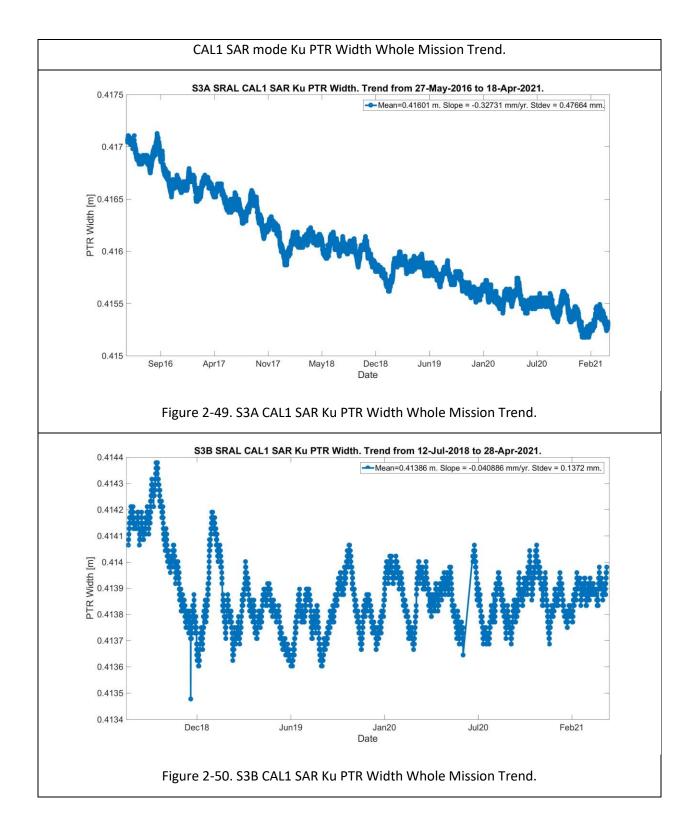




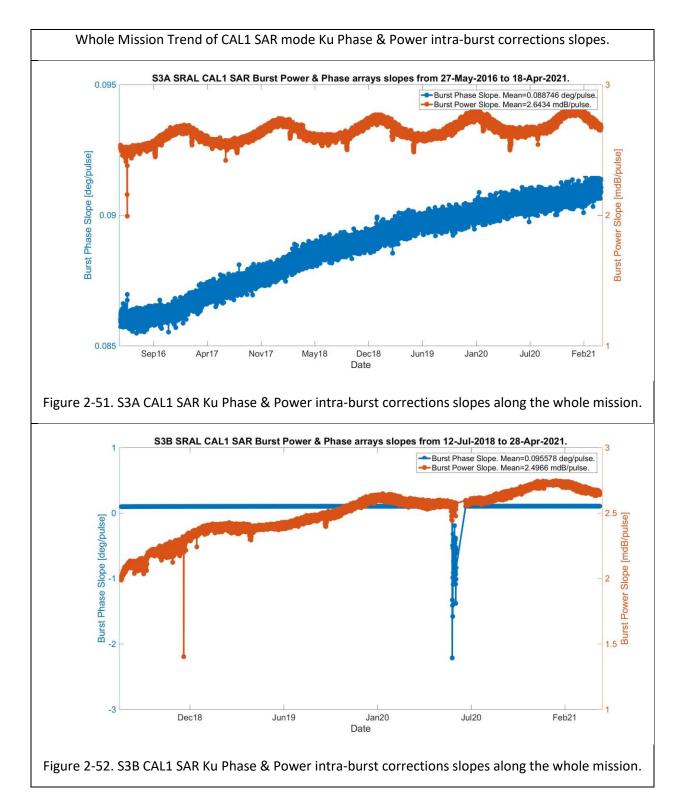
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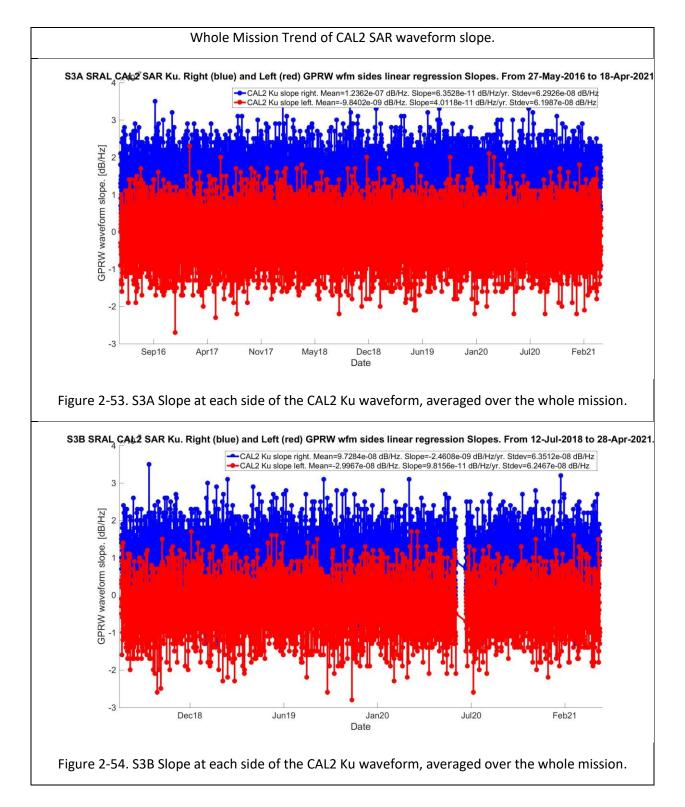
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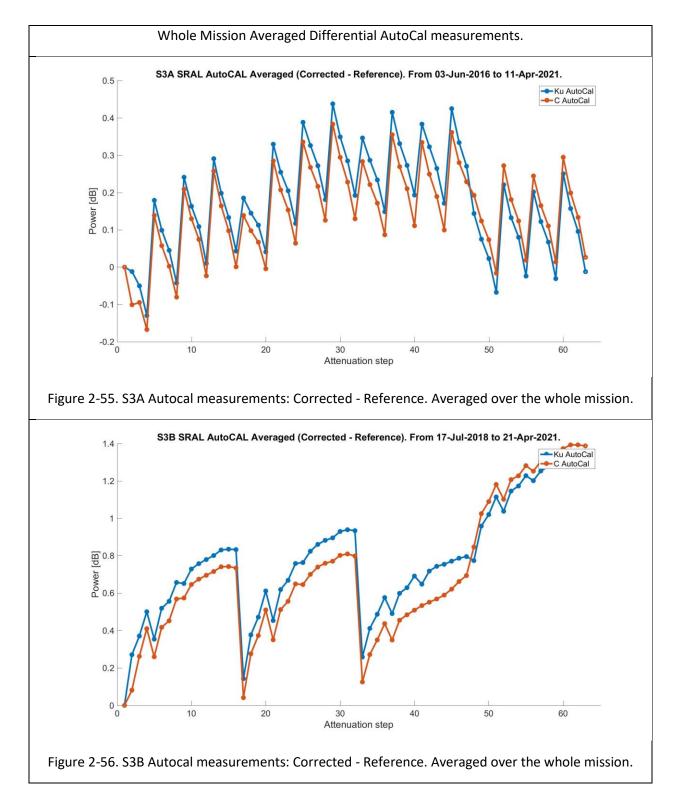


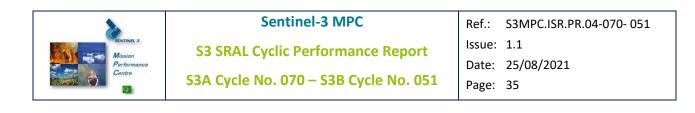


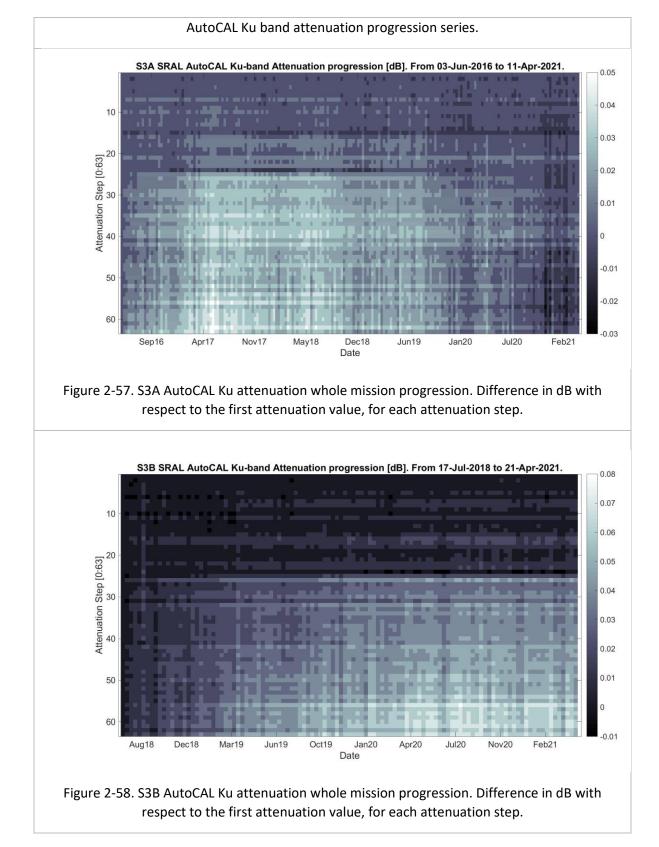














S3 SRAL Cyclic Performance Report

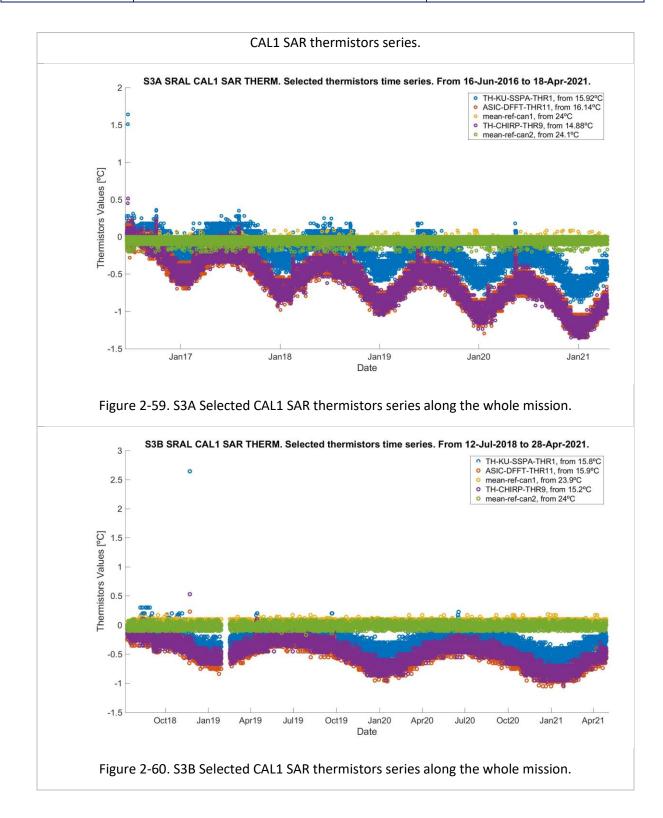
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We can see from the above figures a general agreement between the S3A and S3B calibration parameters absolute values.

The most important and notable drift observed in the whole 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 both S3A and S3B missions, and the assumption is to reach the limit by 2036 and 2035 respectively.

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 currently almost flat. The S3B time delay long term trend is positive, although it shows a flat period around end of 2018.

The Ku band PTR widths of both missions have trends that 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). 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 it was fixed, and a gap in the S3B series will be present until a new reprocessing is completed from the 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 missions, around 1 mdeg/pulse per year for S3A and around 9 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 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 thermistors data series are showing annual oscillations, and a long-term cooling. At some dates there are increases of the S3A thermistors values of around 0.2°C, 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 (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 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.

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 are computed without detrending.

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



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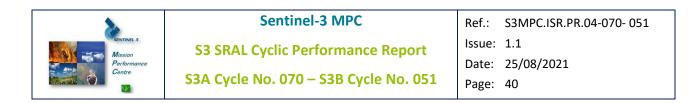
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	Ku band			C band			
S3A Calibration Parameter	mean	annual slope	standard deviation	mean	annual slope	standard deviation	
LRM CAL1 time delay	1.0071 m	-0.28 mm	0.52 mm	0.8928 m	-0.30 mm	0.46 mm	
SAR CAL1 time delay	1.0069 m	-0.18 mm	0.36 mm	0.8934 m	-0.24 mm	0.38 mm	
LRM CAL1 power	57.47 dB	-0.28 dB	0.41 dB	50.89 dB	-0.03 dB	0.04 dB	
SAR CAL1 power	61.90 dB	-0.29 dB	0.42 dB	48.40 dB	-0.03 dB	0.04 dB	
LRM CAL1 PTR width	0.4163 m	-0.33 mm	0.47 mm	0.4543 m	-0.04 mm	0.09 mm	
SAR CAL1 PTR width	0.4160 m	-0.33 mm	0.48 mm	0.4542 m	-0.05 mm	0.10 mm	

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

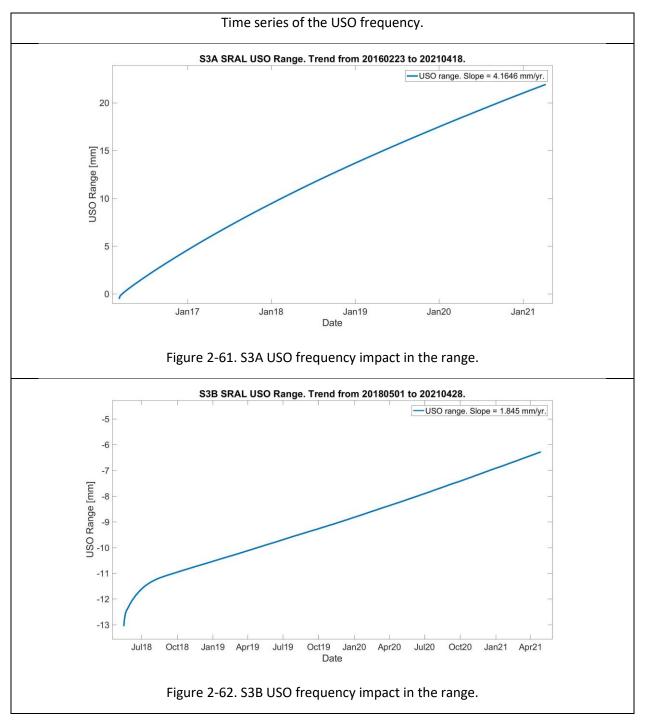
	Ku band			C band			
S3B Calibration Parameter	mean	annual slope	standard deviation	mean	annual slope	standard deviation	
LRM CAL1 time delay	0.9603 m	0.15 mm	0.16 mm	0.9579 m	-0.43 mm	0.36 mm	
SAR CAL1 time delay	0.9600 m	0.56 mm	0.46 mm	0.9577 m	-0.41 mm	0.35 mm	
LRM CAL1 power	57.00 dB	-0.29 dB	0.23 dB	50.48 dB	0.02 dB	0.03 dB	
SAR CAL1 power	61.43 dB	-0.31 dB	0.25 dB	47.83 dB	0.01 dB	0.03 dB	
LRM CAL1 PTR width	0.4138 m	-0.10 mm	0.16 mm	0.4659 m	0.00 mm	0.10 mm	
SAR CAL1 PTR width	0.4139 m	-0.04 mm	0.14 mm	0.4660 m	0.00 mm	0.10 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 2-61) and S3B (Figure 2-62).





The USO clock frequency impact in the range have trends around 4.3 mm per year for the S3A mission and around 1.8 mm per year for the S3B mission. Both mission trends are slowly becoming more flat; for S3A from cycle 40 to cycle 57 the whole mission trend has flattened in 0.39 mm/year; for S3B from cycle 21 to cycle 38 it has changed in 0.61 mm/year.

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

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 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.

For S3A, the passes over Crete on cycles 13, 21, 54 and 70 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. 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 snow event for S3B cycle 20.

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.

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 L2 products.

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 3-1 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 positive measured range, 6.94 mm larger than expected (elevation 6.94 mm shorter than expected), and a datation bias of -126.92 microseconds. They also show a 0.79 mm stack noise. For S3B, the results show a negative measured range, 8.73 mm smaller than expected (elevation 8.73 mm higher than expected), and a datation bias of -18.35 microseconds. They also show a 0.78 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 3-2 presents the same kind of results, from the TRP passes over Svalbard. For S3A, the results show a negative measured range, 76.73 mm smaller than expected (elevation 76.73 mm higher than expected), and a datation bias of -85.42 microseconds. They also show a 16.67 mm stack noise. The results for S3B show a negative bias range, 60.57 mm smaller range than expected (elevation 60.57 mm higher than expected), and a datation bias of -48.97 microseconds. They also show a 8.41 mm stack noise (we have less than 1 mm with S3A/B over Crete and 7.4 mm with CryoSat-2 over Svalbard)



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.

Since April passes over Svalbard notice a low received signal respect to the preceding passes, obtaining unclear values due to certain interferences in the TRP location. Although the results improved during a few cycles, we continue obtaining unclear values, especially with S3A.

Cycle – Mission	Date	Range bias [mm]	Datation bias [microseconds]	Alignment [mm/beam]	Noise [mm]	IPF-SR-1 Version
70 - S3A	2021/02/24	-	-	-	-	06.14
51 - S3B	2021/04/25	-37.94	-12.73	0.02	0.48	06.14
Mean S	3A (61 passes)	6.94	-126.92	0.07	0.79	-
Standar	d Deviation S3A	12.37	19.31	0.01	0.16	-
Mean S3B (34 passes)		-8.73	-18.35	0.01	0.78	-
Standard Deviation S3B		Standard Deviation S3B 14.27		0.01	0.13	-

Cycle – Mission	Date	Range bias [mm]	Datation bias [microseconds]	Alignment [mm/beam]	Noise [mm]	IPF-SR-1 Version
70 - S3A	2021/034/07	-61.14	-127.34	0.09	34.10	06.14
51 - S3B	2021/04/19	-74.70	-50.93	0.04	12.18	06.14
Mean S	3A (24 passes)	-76.73	-85.42	0.08	16.67	-
Standar	d Deviation S3A	48.05	94.04	0.05	9.87	-
Mean S3B (26 passes)		-60.57	-48.97	0.03	8.41	-
Standard Deviation S3B		31.22	49.99	0.04	5.83	-

Table 3-2. Results of Svalbard TRP passes processing

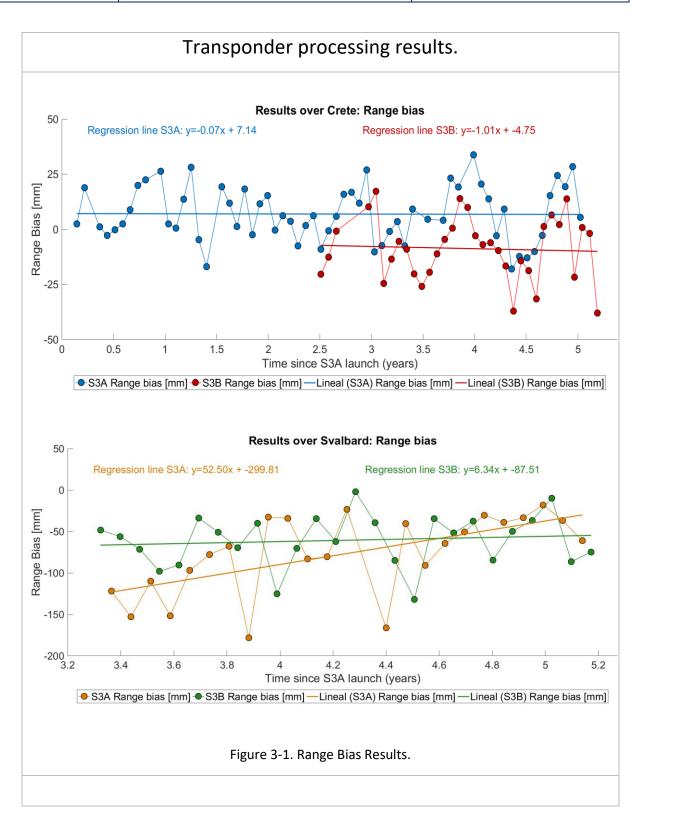


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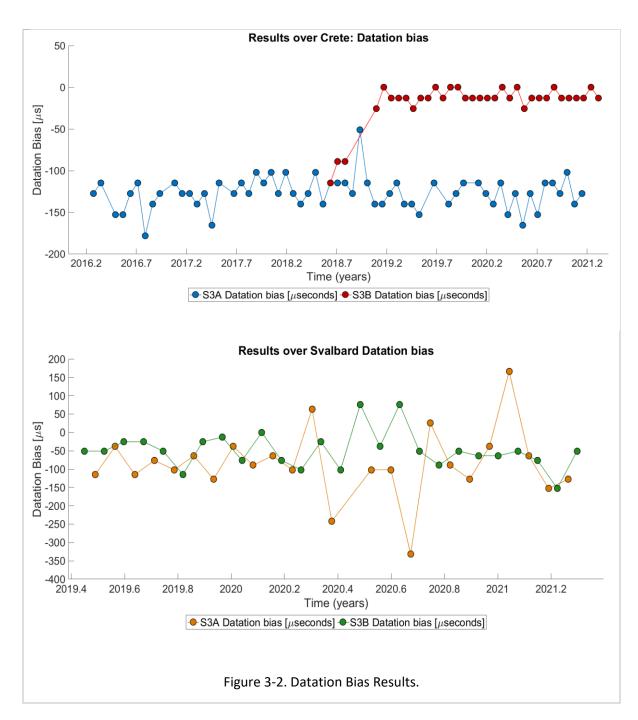
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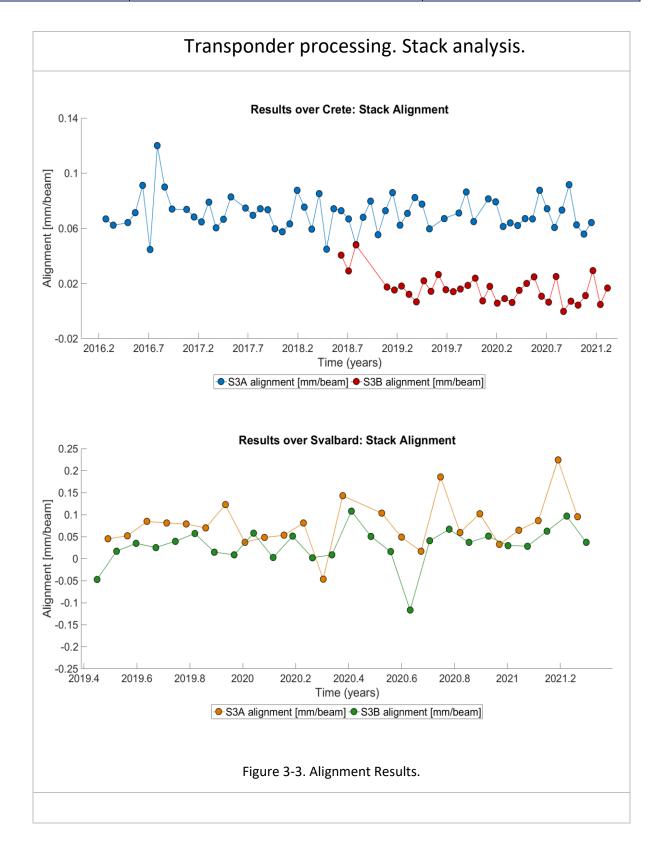


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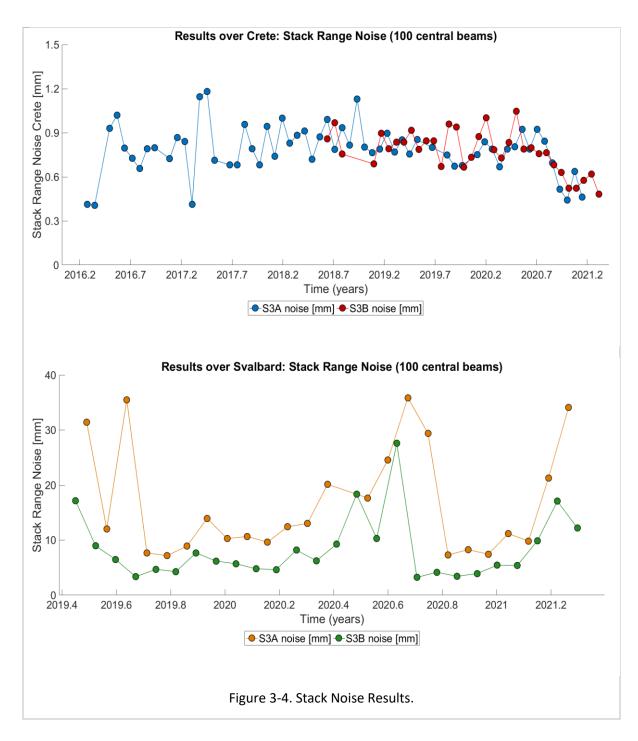
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4 Events

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. 070, S3B Cycle No. 051 (ref. S3MPC.CLS.PR.05-070-051)
- S3 Ocean Validation Cyclic Performance Report, S3A Cycle No. 070, S3B Cycle No. 051 (ref. S3MPC.CLS.PR.06-070-051)
- S3 Winds and Waves Cyclic Performance Report, S3A Cycle No. 070, S3B Cycle No. 051 (ref. S3MPC.ECM.PR.07-070-051)
- S3 Land and Sea Ice Cyclic Performance Report, S3A Cycle No. 070, S3B Cycle No. 051 (ref. S3MPC.UCL.PR.08-070-051)

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

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