EUMETSAT

# *Sentinel-3 SRAL Radar Budget Equation*

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| Doc.No. | : | EUM/RSP/TEN/23/1376566 |
| Issue | : | v1A e-signed |
| Date | : | 7 October 2024 |
| WBS/DBS | : | |

EUMETSAT
Eumetsat-Allee 1, D-64295 Darmstadt, Germany
Tel: +49 6151 807-7
Fax: +49 6151 807 555
http://www.eumetsat.int

# Signature Table

| | Name | Function | Signature | Date |
|---|---|---|---|---|
| Book-captain: | Salvatore Dinardo | Remote Sensing Scientist Altimetry | | |
| Reviewed by: | Carolina Loddo | Remote Sensing Scientist Altimetry Team Leader | | |
| Approved by: | Hilary Wilson | Copernicus Sentinel-3 Mission Manager | | |

# Co-authors/Contributors

| Name | Organisation |
|---|---|
| Bruno Lucas | EUMETSAT |

# *Change Record*

| ***Version*** | ***Date*** | ***Description of Changes*** |
|---|---|---|
| 1.0 | 27/10/2023 | First Issue |
| 1.1 | 6/11/2023 | Second Issue after revision |
| 1.2 | 4/10/2024 | Third issue with changes expected for BC006.2 and the addition of an use case over Salar de Uyuni in appendix A |

# *Table of Contents*



# *Table of Figures*



# *Table of Tables*

# 1 INTRODUCTION

This technical report describes how Copernicus Sentinel-3 altimeter SRAL is calibrated in power, the assumptions and limitation of this calibration scheme and how to derive from L1B/L1A data products the sigma0 scale factor which is provided as field in the afore-said products.

## 1.1 Scope

The scope of this document is the user community working in the data processing of Copernicus Sentinel-3 marine data products.

## 1.2 Applicable Documents

| | **Document Title** | **Reference** |
|---|---|---|
| AD-1 | | |
| AD-2 | | |

## 1.3 Reference Documents

| | **Document Title** | **Reference** |
|---|---|---|
| RD-1 | Sentinel-3 altimetry level-1 data guide<br>Sentinel-3 altimetry level-2 data guide | |
| RD-2 | Altimetry service data \| EUMETSAT - User Portal | |
| RD-3 | Sentinel-3 SRAL altimetry processing baseline | |
| RD-4 | Sentinel-3 Altimetry Reports | |
| RD-5 | F. T. Ulaby, R. K. Moore and A. K. Fung, "*Microwave Remote Sensing, Active and Passive, Volume II*," Artech House, Norwood, 1986. | |
| RD-6 | P. Beckmann and A. Spizzichino, *The Scattering of Electromagnetic Waves from Rough Surfaces* MacMillan, New York, 1963. | |
| RD-7 | Pouliguen, P., H´emon, R., Bourlier, C., Damiens, J.F., Saillard, J., 2008. Analytical formulae for radar cross section of flat plates in near field and normal incidence. Prog. Electromagn. Res. 9, 263–279. https://doi.org/10.2528/PIERB08081902 | |

## 1.4 Terminology

### Acronyms and Abbreviations

| Acronym/Abbr. | Explanation |
|---|---|
| ADF | Auxiliary Data File |
| BC | Baseline Collection |
| CAL-1 | Calibration-1 |
| DFT | Discrete Fourier Transform |
| IPF | Instrument Processing Facility |
| LRM | Low-Resolution Mode (i.e. pulse-width limited altimetry mode) |
| PB | Processing Baseline |
| RF | Radio-Frequency |
| SAR | Synthetic Aperture Radar |
| SRAL | Synthetic aperture Radar ALtimeter |

**Definitions**

| Definition/Term | Explanation |
|---|---|
| | |
| | |

## 1.5 Document Structure

In section 2, we present the SRAL architecture scheme. In section 3, we explain how derive the sigma0 scale factor from the L1B and L1A data products. Finally, in section 4, we summarize the changes undergone by the sigma0 scale factor during the course of the Sentinel-3 mission timeline

# 2 SENTINEL-3 SRAL CALIBRATION SCHEME

SRAL is the radar altimeter on board Copernicus programme constellation's Sentinel-3 satellites.
SRAL (Synthetic Aperture Radar Altimeter) is a redundant dual-frequency (C-band and Ku-band) radar altimeter for determining the two-way delay of the radar echo from the Earth's surface with a precision better than a nanosecond. SRAL altimeter measurements are performed either in Low Resolution Mode (LRM) or in Synthetic Aperture Radar (SAR) mode. LRM mode is the conventional altimeter pulse-limited mode with interleaved Ku-band and C-band pulses, while SAR mode is the high along-track resolution mode based on Synthetic Aperture Radar processing, made of Ku-band bursts of 64 pulses, each of them being surrounded by two C-band pulses (for ionosphere delay correction).
A basic and high-level architecture scheme of SRAL is shown in Figure 1.
The altimeter sensor is represented as made of a transmission (Tx) chain, receiving (Rx) chain, a duplexer (Dx) connecting the Tx and Rx chain together, a redundancy switch, harness (waveguides in Ku band and coaxial cables in C Band) and an antenna.
The duplexer has two **internal paths**: a calibration path and a science path. The calibration path is the path wherein the signal is routed during the CAL-1 "calibration" instrument mode.
The science path is the path wherein the signal is routed during the "science" instrument modes (as LRM and SAR).
The antenna is made of a parabolic reflector with a central feed connected to antenna flange through the antenna harness.
The antenna is characterized pre-flight in power in term of antenna power gain at boresight, which includes the loss from the antenna harness until the antenna flange.
At the antenna flange, the connection between antenna sub-system and altimeter transmitter/receiver is done.
During the calibration referred as to "CAL-1", the signal from the Tx chain is routed to the Rx chain passing by the duplexer calibration path and hence by-passing antenna, redundancy switch and the harness between duplexer and antenna flange. The path of the signal during CAL-1 calibration is depicted in Figure 1 in red dashed line and is referred as "internal group path" or CAL-1 channel path.
The path made of duplexer paths difference, redundancy switch, two-way harness between duplexer and antenna's flange and antenna itself is referred as "external group path".
The path of the channel from the Tx chain to antenna flange and then backwards from antenna flange to Rx chain is referred as "science channel path". It is in dashed blue in Figure 1.

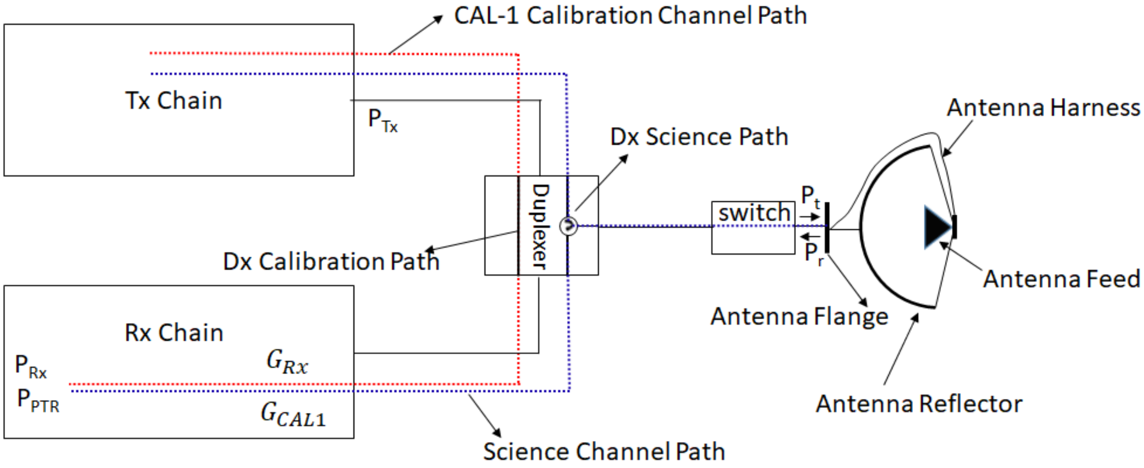


***Figure 1: Sentinel-3 SRAL Architecture***

## 2.1 Altimetry Radar Budget Equation

By definition, the altimetry's radar budget equation is given by:

$$P_r = \frac{P_t G_0^2 \lambda^2 \sigma_0 A_s}{(4\pi)^3 R^4 L_{atm}^2} \tag{1}$$

with the followings symbols:

| | |
|---|---|
| $P_r$ | Received Power at antenna flange |
| $P_t$ | Transmitted (Peak) Power at antenna flange |
| $G_0^2$ | two-way boresight Power Antenna Gain |
| $\sigma_0$ | backscattering coefficient or normalized radar cross section |
| $A_s$ | scattering cell area |
| $\lambda$ | RF wavelength |
| $R$ | range between antenna and scattering cell |
| $L_{atm}^2$ | two-way atmospheric attenuation |

The equation (***1***) is not directly applicable to retrieve $\sigma_0$ since the power $P_t$ and $P_r$ are not measurable quantities.

Defined:

| | |
|---|---|
| $P_{Rx}$ | Power at the output of the science channel |
| $P_{CAL1}$ | Power at the output of CAL-1 channel |
| $G_{Rx}$ | Gain of the receiver's science channel |
| $G_{CAL1}$ | Gain of the receiver's CAL-1 channel |
| $P_{Tx}$ | Power at the output of the Tx chain |
| $L_{CAL1}$ | Attenuation of the **duplexer** CAL-1 path |
| $L_{Dx}$ | Attenuation of the **duplexer** science path |
| $L_H$ | Attenuation of the harness between duplexer and antenna flange, **including** in it the redundancy switch's attenuation |

from Figure 1, it stands:

$$\begin{cases} P_{CAL1} = \dfrac{P_{Tx} \cdot G_{CAL1}}{L_{CAL1}} \\ \dfrac{P_r}{P_t} = \left(\dfrac{P_{Rx} \cdot L_{Dx} \cdot L_H}{G_{Rx}}\right) \cdot \left(\dfrac{L_{Dx} \cdot L_H}{P_{Tx}}\right) \end{cases} \quad (2)$$

Combining the two equations in (***2***), it results:

$$\frac{P_r}{P_t} = \left(\frac{P_{Rx} \cdot L_{Dx} \cdot L_H}{G_{Rx}}\right) \cdot \left(\frac{L_{Dx} \cdot L_H \cdot G_{CAL1}}{P_{CAL1} \cdot L_{CAL1}}\right) = \left(\frac{P_{Rx}}{P_{CAL1}}\right) \cdot \left(\frac{L_{Dx}^2 \cdot L_H^2}{L_{CAL1}}\right) \cdot \left(\frac{G_{CAL1}}{G_{Rx}}\right) \quad (3)$$

The gains $G_{CAL1}$ and $G_{Rx}$ are made of a part $G_{FIX}$ identical and "fixed" between them and of a part different and "variable". The latter one is represented by the variable attenuations steps set by the Rx chain's gain control circuit and by the processing gains, which result from the type of data processing performed on board or on ground.
Concerning the variable attenuations, $P_{Rx}$ and $P_{PTR}$ can be attenuated by the Rx chain's gain control circuit by a settable value of attenuation step. These attenuation step values are usually different between CAL-1 channel and the science channel.

Concerning instead the processing gains, usually, when deriving $P_{Rx}$ and $P_{PTR}$, a digital data processing is carried-out on board or on ground in order to build the waveform. These digital processing results in a processing gain (i.e. in an increase of the signal-to-noise ratio as consequence of the carried out data processing). Once again, the processing gain can be different between the CAL-1 calibration channel and the science channel since the digital processing carried out over these two channels can be different.
Hence, said this, we can write:

$$\begin{cases} G_{CAL1} = \dfrac{G_{FIX} \cdot G_{proc\_CAL1}}{ATT_{CAL1}} \\ G_{Rx} = \dfrac{G_{FIX} \cdot G_{proc\_Rx}}{ATT_{Rx}} \end{cases} \tag{4}$$

where:

| | |
|---|---|
| $ATT_{CAL1}$ | Applied attenuation for the CAL1 calibration channel |
| $ATT_{Rx}$ | Applied attenuation for the science channel |
| $G_{proc\_CAL1}$ | processing gain for the receiver's calibration channel |
| $G_{proc\_Rx}$ | processing gain for the receiver's science channel |

Hence, the equation (***3***) is re-written as:

$$\frac{P_r}{P_t} = \left(\frac{P_{Rx}}{P_{CAL1}}\right) \cdot \left(\frac{L_{Dx}^2 \cdot L_H^2}{L_{CAL1}}\right) \cdot \left(\frac{G_{proc\_CAL1} \cdot ATT_{Rx}}{ATT_{CAL1} \cdot G_{proc\_Rx}}\right) = \left(\frac{P_{Rx}}{P_{CAL1}}\right) \cdot L_{ext} \cdot \left(\frac{G_{proc\_CAL1} \cdot ATT_{Rx}}{ATT_{CAL1} \cdot G_{proc\_Rx}}\right) \tag{5}$$

The quantity $L_{ext}$ is the product between the **two-way** harness attenuation $L_H^2$ and the ratio between the **two-way** duplexer science path's attenuation $L_{Dx}^2$ and the duplexer calibration path's attenuation $L_{CAL1}$ :

$$L_{ext} = \left(\frac{L_{Dx}^2 \cdot L_H^2}{L_{CAL1}}\right) \tag{6}$$

Hence, the equation (***1***) rewrites:

$$\frac{P_{Rx}}{P_{CAL1}} = \frac{G_0^2 \lambda^2 \sigma_0 A_s}{(4\pi)^3 R^4 L_{atm}^2 L_{ext}} \cdot \left(\frac{ATT_{CAL1} \cdot G_{proc\_Rx}}{G_{proc\_CAL1} \cdot ATT_{Rx}}\right) \tag{7}$$

and hence finally the sigma nought is given by:

$$\sigma_0 = \frac{(4\pi)^3 R^4 L_{atm}^2 L_{ext}}{\lambda^2 G_0^2 A_s} \cdot \left(\frac{G_{proc\_CAL1} \cdot ATT_{Rx}}{ATT_{CAL1} \cdot G_{proc\_Rx}}\right) \cdot \left(\frac{P_{Rx}}{P_{CAL1}}\right)$$
(8)

The equation (***8***) is now applicable to measure $\sigma_0$ since all the quantities in it can be measured/computed in-flight (as $P_{Rx}$, $P_{PTR}$, $R$, $A_s$, $ATT_{Rx}$, $ATT_{CAL1}$) or pre-flight as $G_0^2$ or $L_{ext}$ or they are geophysical quantities provided by an auxiliary source (as $L_{atm}^2$) or they are known system constants (as $\lambda^2$, $G_{proc\_CAL1}$, $G_{proc\_Rx}$).
Clearly, the external group quantities $G_0^2$ and $L_{ext}$ can be different between Sentinel-3A and Sentinel-3B and for the other Sentinel-3 satellites which are going to be launched in future.
All the quantities in (***8***) are expressed in linear scale (i.e. not in dB).
The $P_{CAL1}$ is the power of the CAL-1 output signal (which is referred as PTR, Point Target Response). This PTR is usually computed after the range compression process (i.e. by a DFT process) with an over-sampling factor applied via zero-padding method.
The $P_{CAL1}$ value to use in equation (***8***) can be the PTR peak power or it can be also the integrated power of the PTR scaled by the applied over-sampling factor. In this latter case, it is referred as "total-power".
The $P_{Rx}$ is the power signal at the output of the Rx science channel (which is referred as data waveform) and is usually evaluated at the retracking point (i.e. at the time when the waveform bounces on the surface). This power is often referred as waveform amplitude and indicated by $P_u$ .
$A_s$ is a geometrical term given by the area of the scattering cell at the retracking point and is a processing-mode and scattering-regime depending term. That means that $A_s$ changes with the specific type of altimetry processing mode under consideration like SAR or PLRM (i.e. pulse-width limited) or with the scattering regime between radar waveform and target surface.
At the end, the equation (*8*) is usually expressed in dB as:

$$\sigma_0 = 10\log_{10}(L_{atm}^2) + 10\log_{10}(P_u) + 10\log_{10}(scale\_sigma0)$$
(9)

where:

$$\begin{aligned} 10\log_{10}(scale\_sigma0) &= 30 \cdot \log_{10}(4\pi) \\ &+ 40 \cdot \log_{10}(R) \\ &- 20 \cdot \log_{10}(\lambda) \\ &+ 10 \cdot \log_{10}(L_{ext}) \\ &- 20 \cdot \log_{10}(G_0) \\ &- 10 \cdot \log_{10}(A_s) \\ &+ 10 \cdot \log_{10}(G_{proc\_CAL1}) \\ &+ 10 \cdot \log_{10}(ATT_{Rx}) \\ &- 10 \cdot \log_{10}(ATT_{CAL1}) \\ &- 10 \cdot \log_{10}(G_{proc\_Rx}) - 10 \cdot \log_{10}(P_{CAL1}) \end{aligned}$$
(10)

In case the Sentinel-3 data-processing mode is PLRM and the scattering-regime is diffusive (like over ocean), we have:

$$\begin{cases} A_s = \pi \cdot \left(\frac{R_{Earth}}{R_{Earth} + R}\right) \cdot \frac{R \cdot c_0}{BW} \\ G_{proc\_Rx} = N_{bins} \end{cases}$$
(11)

In case the Sentinel-3 data-processing mode is SAR and the scattering-regime is diffusive (like over ocean), we have:

$$\begin{cases} A_s = 2 \cdot \sqrt{\left(\frac{R_{Earth}}{R_{Earth} + R}\right) \cdot \frac{R \cdot c_0}{BW}} \cdot \left(\frac{\lambda \cdot R \cdot PRF}{2 \cdot V \cdot N_{pulse}}\right) \\ G_{proc\_Rx} = N_{bins} \cdot N_{pulse} \end{cases} \quad (12)$$

where:

| | |
|---|---|
| $BW$ | Receiver Bandwidth |
| $PRF$ | Pulse Repetition Frequency |
| $V$ | Satellite Velocity |
| $N_{pulse}$ | Number of pulses per SAR burst |
| $N_{bins}$ | Number of range bins in a pulse |
| $c_0$ | speed of light in the vacuum |
| $R_{Earth}$ | Local Earth Radius |

whereas:

$$G_{proc\_CAL1} = N_{bins} \quad (13)$$

## 2.2 Power calibration assumptions:

It is assumed that the altimeter components which can be measured only pre-flight (duplexer, switch, antenna and harness between antenna flange and duplexer) are stable in time (i.e. they don’t suffer of ageing) and stable with temperatures.

If this is not the case, this source of error has to be considered in the sigma nought measurement error budget.

# 3 APPLICATION TO SENTINEL-3 ALTIMETRY MARINE L1 DATA PRODUCTS

The Sentinel-3 marine L1 IPF uses the following conventions in computing the SAR and PLRM sigma0 scale factor:

- In order to operate the DFT (Discrete Fourier Transform), the FFT algorithm is used.
- The FFT algorithm is by definition not power-conservative. A correction for this effect is applied directly to the data waveform after the FFT operation (both in range and azimuth pulse-compression)
- The processing gain from the range-compression is applied **scaling the data waveform after the range FFT operation by this gain** and hence this term has not to be included in the radar budget equation
- The processing gain from the azimuth-compression is **not** applied scaling the data waveform after the azimuth FFT operation (hence it has to be included in the radar budget equation)
- $P_{CAL1}$ is the PTR **total power** (already scaled by the applied oversampling factor)
- The SAR and PLRM data are both calibrated using the **SAR** CAL1 PTR
- The range $R$ in the sigma0 scale factor is approximated by the orbit altitude
- The local Earth radius in the sigma0 scale factor is approximated by the mean Earth radius
- The I/Q data in the L1A data products (i_meas_ku_l1a_echo_sar_ku and q_meas_ku_l1a_echo_sar_ku) are un-calibrated. This means they are "raw data" out of the on-board digitizer, which are stored in L1A data products without any manipulation or pre-processing.

The following formulas are provided for SAR processing mode and PLRM processing mode but **only for Ku band**. The SRAL instrumental parameter values given below are relative to the **nominal side (side-A)** of the instrument.
Hence, the sigma0 scaling factor can be computed from equation (***10***) with this set of processing gains values:

| Parameter | Value |
|---|---|
| $G_{proc\_CAL1}$ | 1 |
| $G_{proc\_Rx}$ | 64 **for SAR**<br>1 **for PLRM** |

and scattering cell area:

| Parameter | Value |
|---|---|
| $A_S$ | equation (12) **for SAR**<br>equation (11) **for PLRM** |

Furthermore, these are the values for the attenuations steps (in dB):

| Parameter | Value |
|---|---|
| $10 \cdot \log_{10}(ATT_{CAL1})$ | 33.242 [dB] **for S3A**<br>34.476 [dB] **for S3B** |
| $10 \cdot \log_{10}(ATT_{Rx})$ | agc_ku_l1b_echo_sar_ku **for SAR**<br>agc_ku_l1b_echo_plrm **for PLRM** |

| | |
|---|---|
| agc_ku_l1b_echo_sar_ku | L1B product field [dB] |
| agc_ku_l1b_echo_plrm | L1B product field [dB] |

and the PTR total power can be derived by :

$$P_{CAL1\_SAR} = -sig0\_cal\_ku\_l1b\_echo\_sar\_ku + 10 \cdot \log_{10}(PTR\_Ref\_Power\_SAR) \tag{14}$$

$$P_{CAL1\_PLRM} = -sig0\_cal\_ku\_l1b\_echo\_plrm + 10 \cdot \log_{10}(PTR\_Ref\_Power\_PLRM) \tag{15}$$

| Parameter | Value |
|---|---|
| $10 \cdot \log_{10}(PTR\_Ref\_Power\_SAR)$ | 38.739 [dB] **for S3A**<br>37.435 [dB] **for S3B** |
| $10 \cdot \log_{10}(PTR\_Ref\_Power\_PLRM)$ | 58.471 [dB] **for S3A**<br>57.166 [dB] **for S3B** |
| $sig0\_cal\_ku\_l1b\_echo\_sar\_ku$ | L1B product field [dB] |
| $sig0\_cal\_ku\_l1b\_echo\_plrm$ | L1B product field [dB] |
| $P_{CAL1}$ | $P_{CAL1\_SAR}$ for **SAR**<br>$P_{CAL1\_PLRM}$ for **PLRM** |

The values of $10 \cdot \log_{10}(PTR\_Ref\_Power\_SAR)$ and $10 \cdot \log_{10}(PTR\_Ref\_Power\_PLRM)$ are different, tough both SAR and PLRM data are calibrated using CAL1 SAR PTR since, after their formation by FFT, the PLRM waveforms get multiplied by IPF by the number :

$$84 \cdot 2 \cdot \left(\frac{190}{256}\right)^2 \cdot \left(\frac{128}{127}\right)^2 \tag{16}$$

which amounts to 19.731 dB and this is exactly the difference between $10 \cdot \log_{10}(PTR\_Ref\_Power\_SAR)$ and $10 \cdot \log_{10}(PTR\_Ref\_Power\_PLRM)$ values. Basically, since the PRLM waveforms are multiplied by the number given in (16), we need to multiply also $PTR\_Ref\_Power\_PLRM$ by the same number in order to cancel the effect of this term out.

We have the following values for the geometric parameters, radar parameters and constants:

| Parameter | Value |
|---|---|
| PRF | 80e6/4488 [Hz] |
| BW | 320e6 [Hz] |
| $\lambda$ | $c_0/f_c$ [m] |
| $f_c$ | 13.575e9 [Hz] |
| $c_0$ | 299792458 [m/sec] |
| $R_{Earth}$ | 6371000 m |
| $20 \cdot \log_{10}(G_0)$ | 83.80 [dB] **for S3A**<br>83.90 [dB] **for S3B** |
| $10 \cdot log_{10}(L_{ext})$ | -98.66 [dB] **for S3A**<br>-98.88 [dB] **for S3B** |
| $N_{pulse}$ | 64 |

| $R$ | alt_l1b_echo_sar_ku **for SAR**<br>alt_l1b_echo_plrm **for PLRM** |
|---|---|
| alt_l1b_echo_sar_ku | L1B product field [m ] |
| alt_l1b_echo_plrm | L1B product field [m ] |

and finally:

$$V_s = \sqrt{x\_vel\_l1b\_echo\_sar\_ku^2 + y\_vel\_l1b\_echo\_sar\_ku^2 + z\_vel\_l1b\_echo\_sar\_ku^2} \quad (17)$$

with:

| Parameter | Value |
|---|---|
| $x\_vel\_l1b\_echo\_sar\_ku$ | L1B product field [m/s] |
| $y\_vel\_l1b\_echo\_sar\_ku$ | L1B product field [m/s] |
| $z\_vel\_l1b\_echo\_sar\_ku$ | L1B product field [m/s] |

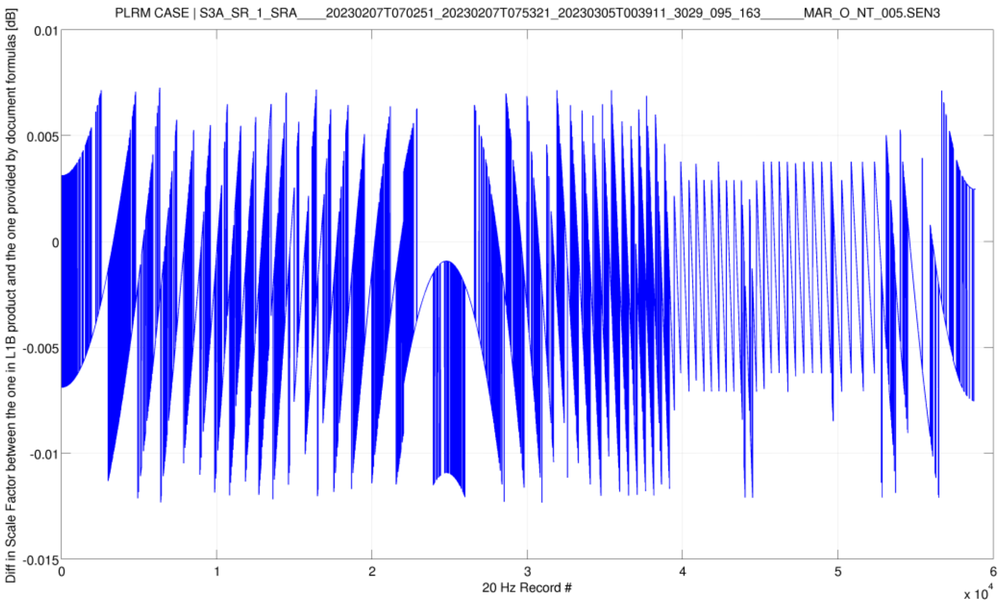


***Figure 2: Difference in dB between sigma0 scale factor provided in the L1B product (scale_factor_ku_l1b_echo_plrm) and the one recomputed using the document formulas. This is PLRM case***

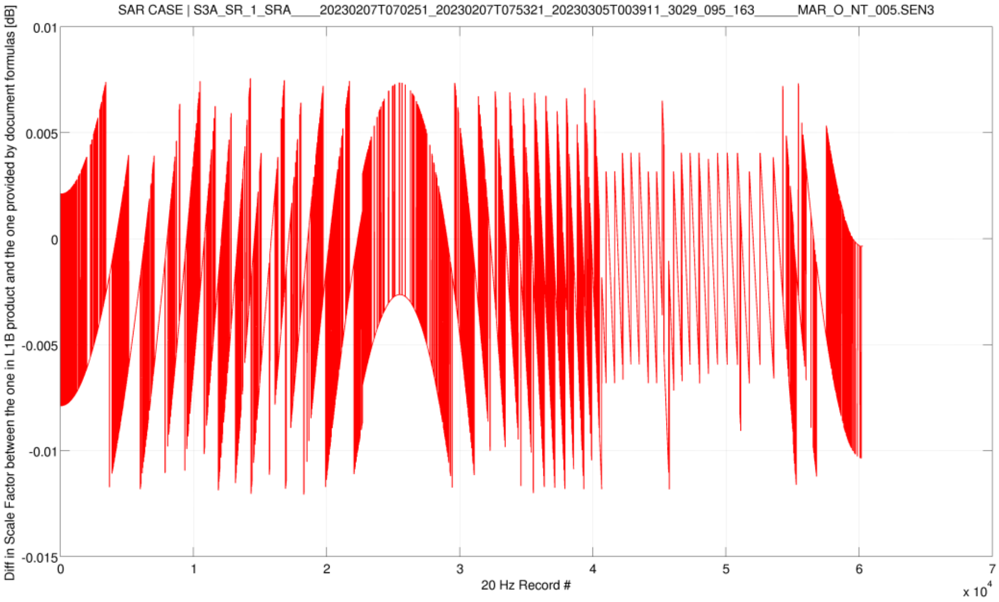


***Figure 3: Difference in dB between sigma0 scale factor provided in the L1B product (scale_factor_ku_l1b_echo_sar_ku) and the one recomputed using the document formulas. This is SAR case***

In case of L1A data products, the formulas written above are still valid replacing in the fieldname the tag "l1b" with "l1a".
As shown by Figure 2 and Figure 3, the equation (***10***) for *scale_sigma0* reproduces the L1B field *scale_factor_ku_l1b_echo_plrm* in case of PLRM mode and the L1B field *scale_factor_ku_l1b_echo_sar_ku* in case of SAR mode with an error better than 0.01 dB.

# 4 SENTINEL-3 ALTIMETRY MARINE PROCESSING BASELINE HISTORY

A processing baseline (PB) is the collection of an IPF version and a set of static ADFs.
A collection of several PBs that does not change the mission dataset in a significant way is known as a Baseline Collection (BC).
The baseline collection number is reported in the data product filename and also in the product itself. The Processing Baseline is currently reported on the products (since 2022 releases).
The Sentinel-3 Altimetry Processing Timeline can be found in RD-3.
More Sentinel-3 Altimetry resources are available in RD-2.

## 4.1 Marine Baseline Collection BC004

| Baseline Collection **004** | **PB 2.61** | **PB 2.68 - Marine** | **PB 2.79 - Marine** |
|---|---|---|---|
| IPF Versions | SRAL L1 (SR-1): 06.17<br>MWR L1 (MW-1): 06.11<br>SRAL/MWR L2 (SM-2): 06.18 | SRAL L1 (SR-1): 06.20<br>MWR L1 (MW-1): 06.11<br>SRAL/MWR L2 (SM-2): 06.50 | SRAL L1 (SR-1): 06.21<br>MWR L1 (MW-1): 06.12<br>SRAL/MWR L2 (SM-2): 06.52 |
| PB deployment date (NRT) | 21/01/2020 | 09/07/2020 | 14/12/2021 |
| Product notice | L2 PN | L2 PN | L1+L2 PN |

In baseline collection BC004 **PB 2.61**, the SAR sigma0 scale factor was changed in SRAL L1 IPF to include in its definition the term $G_{proc\_Rx}$ which was erroneously set to 1 whereas now it is set to the correct value of 64.

## 4.2 Marine Baseline Collection BC005

| Baseline Collection **005** | **BC005.01** | **BC005.02** |
|---|---|---|
| IPF Versions | SRAL L1 (SR-1): 07.01<br>MWR L1 (MW-1): 06.23<br>SRAL/MWR L2 (SM-2): 06.13 | SRAL L1 (SR-1): 07.03<br>MWR L1 (MW-1): 06.24<br>SRAL/MWR L2 (SM-2): 06.14 |

| | | |
|---|---|---|
| PB deployment date (NRT) | 07/07/2022 | 09/03/2023 |
| Product notice | PN | PN |

In this baseline collection, there is no change affecting the sigma0 scale factor.
The baseline collection BC005.02 was used to reprocess the full mission data. This reprocessed dataset is described in the product notice available here.

### 4.3 Changes expected for Marine Baseline Collection BC006.2 and impacting sigma0 scale factor

| Parameter | uncorrect value in former Baseline Collections | new correct value in Baseline Collection **006.2** |
|---|---|---|
| $10 \cdot log_{10}(L_{ext})$ | -98.66 [dB] **for S3A**<br>-98.88 [dB] **for S3B** | -97.70 [dB] **for S3A**<br>-97.92 [dB] **for S3B** |
| $20 \cdot \log_{10}(G_0)$ | 83.80 [dB] **for S3A**<br>83.90 [dB] **for S3B** | 84.30 [dB] **for S3A**<br>84.44 [dB] **for S3B** |

### 4.4 Conclusions

It is recommended to the users to not mix processing baselines but to use a dataset with the same baseline collection number.
A new baseline is defined when a major upgrade in the processing algorithms is performed and soon after the full mission is reprocessed in order to provide the user community with a consistent dataset.
The data products generated from a reprocessing campaign have the letter "**_R_**" identifying them as reprocessed products, instead of the letter "**_O_**" which identifies the data products generated in the operational environment.
In the product notice, it is explained how to have access to the data products from the operational environment and reprocessing campaign.

# APPENDIX A :

- **Use Case #1: the Radar Cross Section over Salar de Uyuni as measured by Sentinel-3A SRAL**

Salar de Uyuni is a very large salar pan located in Bolivia's Andean Altiplanos at coordinates (-20.173460, -67.570162) and at around 3650 meters above the sea level. Its extension is about 120x100 km$^2$ and it has been formed after the evaporation of a preistoric salt lake, leaving a thick salt sediment crust as a relic.
It is a extremely smooth surface with relief measured in centimeters and featuring a planar slope in the direction North-East to South-West of around half millidegree, which approximately follows the long-wavelength local geoid.
Furthermore, during the wet season (December to March), the entire surface is often flooded, with a thin layer of  still and hyper-saline water, creating a "mirror-like" effect and hence an highly bright "water table". This thin layer of brine water has a salinity of around 130-170 psu, a depth of around 25 cm and a day temperature of around 20 deg. It dissapears completly during the dry season.
The region is semi-arid with an average annual rainfall of about 150 mm and average annual temperature around 9 degree.
Since is a very broad, highly reflective and extremely flat terrestrial surface, the salar de Uyuni is an ideal calibration site for Earth-orbiting altimeters.
We have tried to compute the radar cross section (RCS) over a central part of the Salar de Uyuni using the Sentinel-3A pass occurred on **24 February 2018** (i.e. during the wet season**)**.
The duration of the short segment we have considered is around 1.5 sec.
The computation was done in PLRM processing mode case and starting from the L1A data product relative to that pass in **Baseline Collection 005**.
In order to compute the radar cross section, we have used the following formula:

$$RCS = 10\log_{10}(L_{atm}^2) + 10\log_{10}(P_u) + 10\log_{10}(scale\_RCS) \qquad (18)$$

where $10\log_{10}(scale\_RCS)$ is given by

$$10\log_{10}(scale\_RCS) = 10\log_{10}(scale\_sigma0) + 10\cdot\log_{10}(A_s) \qquad (19)$$

and $10\log_{10}(scale\_sigma0)$ is given by the equation (***10***).

Hence, equation (19) is rewritten simply as:

$$
\begin{aligned}
10\log_{10}(scale\_RCS) \\
&= 30 \cdot \log_{10}(4\pi) \\
&+ 40 \cdot \log_{10}(R) \\
&- 20 \cdot \log_{10}(\lambda) \\
&+ 10 \cdot \log_{10}(L_{ext}) \\
&- 20 \cdot \log_{10}(G_0) \\
&+ 10 \cdot \log_{10}\left(G_{proc\_CAL1}\right) \\
&+ 10 \cdot \log_{10}(ATT_{Rx}) \\
&- 10 \cdot \log_{10}(ATT_{CAL1}) \\
&- 10 \cdot \log_{10}\left(G_{proc\_Rx}\right) \\
&-10 \cdot \log_{10}(P_{CAL1})
\end{aligned} \tag{20}
$$

We have used in equation (20) the values reported in chapter 3 in case of Sentinel-3A and PLRM mode. They are:

| Parameter | Value |
|---|---|
| $R$ | alt_l1a_echo_sar_ku [m] |
| $\lambda$ | 299792458/13.575e9 [m] |
| $10 \cdot \log_{10}(L_{ext})$ | -97.70 [dB] |
| $20 \cdot \log_{10}(G_0)$ | 84.30 [dB] |
| $G_{proc\_CAL1}$ | 1 |
| $10 \cdot \log_{10}(ATT_{Rx})$ | agc_ku_l1a_echo_sar_ku [dB] |
| $10 \cdot \log_{10}(ATT_{CAL1})$ | 33.242 [dB] |
| $G_{proc\_Rx}$ | 1 |
| $10 \cdot \log_{10}(P_{CAL1})$ | -sig0_cal_ku_l1a_echo_sar_ku + 58.471 [dB] |

where we have used for the parameters $10 \cdot \log_{10}(L_{ext})$ and $20 \cdot \log_{10}(G_0)$ the updated values of Baseline Collection 006.2.
As shown in Figure 4 , the quantity scale_RCS over Salar takes the value of around **82.66 dBsqm:**

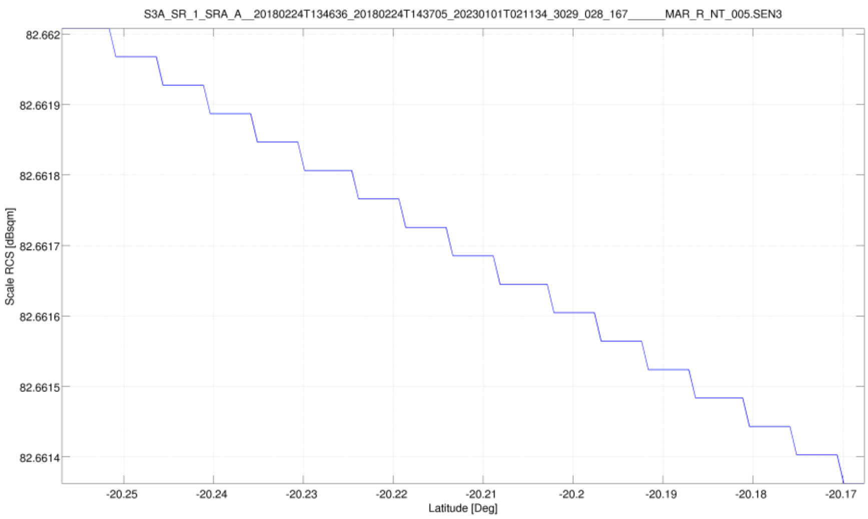


Figure 4: scale_RCS for the short segment over the Salar considered and in case of Sentinel-3A and PLRM mode

The amplitude term Pu is computed after building the PLRM individual echoes from the L1A I/Q data over the Salar.
Since the Salar during the wet season is a mirror-like surface, the PLRM individual echoes will be very specular and impulsive. They will mimic therefore a squared sinus cardinal (sinc) function.
The PLRM individual echoes have been built from L1A I/Q data by making :

- FFT and FFTshift operation in range dimension
- Power Extraction Operation
- Scaling the echoes down by the FFT normalization factor in power ( which is given by $N_{bins}$=128) and the range gain compression factor (which is given by $N_{bins}$ =128)
- Scaling the echoes up by the number given (16)
- Taking the maximum of each PLRM echo and average the maximum over each burst (in order to decrease the noise level).

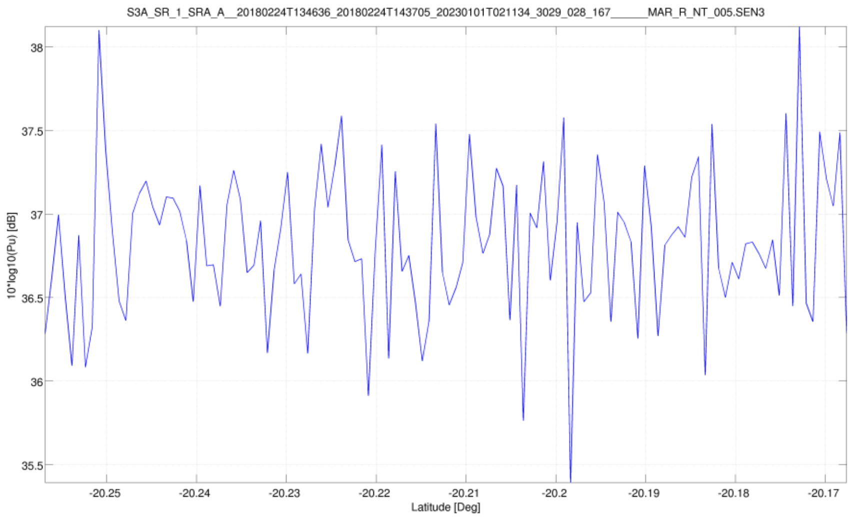


Figure 5: 10*log10(Pu) for the short segment over the Salar considered and in case of Sentinel-3A and PLRM mode

The average value of Pu over the central part of the Salar is around **36.85 dB**.
Furthermore, for the time and position of the considered Salar' overflight, $10\log_{10}(L_{atm}^2)$ takes the value of around 0.14 dB, as computed from the numerical weather model maps.
Using the equation (18), the average RCS over the Salar is given by:

$$\mathrm{RCS} = 0.14 + 36.85 + 82.66 = \mathbf{119.65}\ \mathrm{dBsqm} \tag{21}$$

As expected, this value is lower than the theorethically maximum value for the RCS at nadir direction which is generally modelled as (RD-5, chapter 12) in case of quasi-specular surface (i.e. surface roughness $\sigma_z << \lambda$):

$$RCS = |R_0|^2 \cdot \left(\frac{4 \cdot \pi \cdot A^2}{\lambda^2}\right) \cdot \left(e^{-\frac{(4\pi)^2 \cdot \sigma_Z^2}{\lambda^2}}\right) \tag{22}$$

with:

$$R_0 = \frac{1 - \sqrt{(\varepsilon' - j\varepsilon'')}}{1 + \sqrt{(\varepsilon' - j\varepsilon'')}}$$

(23)

In case of a perfectly conductive surface (i.e. $|R_0|^2 = 1$) and a perfectly smooth surface (i.e. $\sigma_z = 0$), the equation (22) is simplified to:

$$RCS = \left(\frac{4 \cdot \pi \cdot A^2}{\lambda^2}\right)$$

(24)

in line with [RD-7].

Taking A as first Fresnel Disk area (RD-6) since the surface is assumed to be specular, A is hence given by:

$$A = \pi \cdot \left(\frac{R \cdot \lambda}{2 \cdot k_{Earth}}\right)$$

(25)

being the first Fresnel Disk radius given in case of round-Earth by :

$$r_f = \sqrt{\frac{R \cdot \lambda}{2 \cdot k_{Earth}}}$$

(26)

with:

$$k_{Earth} = \frac{R_{Earth} + R}{R_{Earth}}$$

(27)

Replacing (***25***) in (***24***), therefore the RCS in case of a perfectly conductive surface (i.e. $|R_0|^2 = 1$) and a perfectly smooth surface (i.e. $\sigma_z = 0$) is given by :

$$RCS = \pi^3 \cdot \left(\frac{R}{k_{Earth}}\right)^2$$

(28)

and is independent of the wavelength $\lambda$ and just function of the range R between target and radar.

From equation (28) and using as range R the Sentinel-3A altitude over the Salar, the maximum theoretical RCS over the Salar is given by **132 dBsqm.**

| Symbol | Significance |
|---|---|
| $\sigma_z$ | surface roughness (i.e. surface elevation standard deviation ) |
| $R_{Earth}$ | 6371000 m |
| $R$ | Range between radar and target, taken here as orbit altitude |
| $\varepsilon'$ | real part of complex relative permittivity of the surface |
| $\varepsilon''$ | imaginary part of complex relative permittivity of the surface |
| $\|R_0\|^2$ | Power Reflection Coefficient ($\leq$ 1) |