S3 Ocean Validation Cyclic Performance Report

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

**Title:** S3 Ocean Validation Cyclic Performance Report

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**Disclaimer**
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## Changes Log

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1 Introduction

The purpose of this document is to report the major features of the data quality from Sentinel-3A and Sentinel-3B missions. The document is associated with data dissemination on a cycle per cycle basis, based on Sentinel-3B cycle. This document reports results from SRAL/Sentinel-3A and SRAL/Sentinel-3B Non Time Critical (NTC) Marine Level 2 products processed by the Marine Centre using the software IPF-SM-2. The objectives of this document are:

- To provide a data quality assessment.
- To report any change likely to impact data quality at any level, from instrument status to software configuration.
- To present the major useful results over the period spanning from 08/02/2019 to 07/03/2019 and corresponding to Sentinel-3B cycle 22.
2 Cycle Overview

The main metric that describes the data quality is the one derived from the analysis of sea surface variability at crossovers. Using a selection to remove shallow waters (1000 m), areas of high ocean variability and high latitudes (> |50|°), the crossover standard deviation is 6.0 cm rms for Sentinel-3A cycle 41 and 5.8 cm rms for Sentinel-3B cycle 22. This first metric is in line with usual values that are obtained on altimetry mission.

Over the period covered by this report (spanning from 08/02/2019 to 07/03/2019), SRAL/Sentinel-3A and SRAL/Sentinel-3B both operate in SAR mode.

The version of the S3-MPC software used to compute the altimeter parameters for Sentinel-3A and Sentinel-3B datasets is the IPF-SM-2, version 06.15.
3 Data coverage and edited measurements

This section presents results that illustrate data quality over Sentinel-3B cycle 22 period. These metrics allow long term monitoring of missing and edited measurements.

3.1 Missing measurements

Missing measurements relative to the satellites nominal ground track are plotted on Figure 1. The maps below illustrate 1Hz missing measurements in NTC products for Sentinel-3A (top panel) and Sentinel-3B (bottom panel).

Over this cycle, several small sections of tracks are missing at high latitudes for Sentinel-3B:

- Part of half orbits number 191 and 192 are missing due to the instrument special operation occurring on the 15/02/2019 from 14:14 to 14:20. The percentages of missing measurement over ocean are 13.3% for track n°191 and 6.6% for track n°192.

- Part of half orbit number 193 is missing due to the instrument special operation occurring on the 15/02/2019 from 15:53 to 15:56. The percentage of missing measurement over ocean is 7.6% for this half orbit.

- Part of half orbit number 203 is missing on the 16/02/2019 from 0:14 to 0:18. The percentage of missing measurement over ocean is 10% for this half orbit.

For Sentinel-3A, the following data gaps occurred over ocean at high latitudes:

- 4.6% of half orbit number 214 (cycle 42): this is due to the instrument calibration occurring on the 05/03/2019 from 9:04 to 9:06.

- 6.2% of half orbit number 270 (cycle 42)

- 5.8% of half orbit number 273 (cycle 42)

- 9.6% of half orbit number 273 (cycle 42)

- 22.6% of half orbit number 276 (cycle 42).

Figure 2 shows the daily monitoring of available measurements over ocean during the cycle for Sentinel-3A and 3B. The mean percentage is close to 100 % for both missions.
Figure 1: Maps of missing measurements over ocean for Sentinel-3A (top panel) and Sentinel-3B (bottom panel), from 08/02/2019 to 07/03/2019 (Sentinel-3B cycle 22).
Figure 2: Daily monitoring of the percentage of available measurements for Sentinel-3A (red curve) and Sentinel-3B (black curve).

3.2 Edited Measurements

The editing criteria are defined as minimum and maximum thresholds for various parameters. Measurements are edited if at least one parameter is found to be outside those thresholds. These thresholds are expected to remain identical for Sentinel-3A and Sentinel-3B and constant throughout the missions. Therefore, monitoring the number of edited measurements allows a survey of the data quality.

The number and percentage of points removed by each criterion is given in the following table. Note that these statistics are obtained with measurements over ocean only and already edited by ice flag. The percentage of measurements corrupted by sea ice is of 12.97 % for Sentinel-3A and 12.98 % for Sentinel-3B. Over this cycle, Sentinel-3A and Sentinel-3B present equivalent percentages of outliers for each parameter considered.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Min threshold</th>
<th>Max threshold</th>
<th>Unit</th>
<th>% removed</th>
</tr>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Sentinel-3A</td>
</tr>
<tr>
<td>Sea surface height (Orbit - Range)</td>
<td>-130</td>
<td>100</td>
<td>m</td>
<td>0.06 %</td>
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<tr>
<td>Sea Level Anomaly</td>
<td>-2</td>
<td>2</td>
<td>m</td>
<td>0.51 %</td>
</tr>
<tr>
<td>Std. deviation of range</td>
<td>0</td>
<td>0.12+0.02*SWH</td>
<td>m</td>
<td>1.08 %</td>
</tr>
<tr>
<td>Number of range</td>
<td>10</td>
<td>DV</td>
<td>count</td>
<td>0.06%</td>
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### Table 1: Table of parameters used for editing and the corresponding percentages of edited measurements for each parameters for Sentinel-3A and Sentinel-3B, over Sentinel-3B cycle 22.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Min threshold</th>
<th>Max threshold</th>
<th>Unit</th>
<th>% removed</th>
<th></th>
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<tr>
<td></td>
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<td></td>
<td>Sentinel-3A</td>
<td>Sentinel-3B</td>
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<tr>
<td>Dry tropospheric correction model (ECMWF Gauss)</td>
<td>-2.5</td>
<td>-1.9</td>
<td>m</td>
<td>0.00 %</td>
<td>0.00%</td>
<td></td>
</tr>
<tr>
<td>Sigma0</td>
<td>5</td>
<td>28</td>
<td>db</td>
<td>0.17%</td>
<td>0.16%</td>
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<tr>
<td>Std. deviation of sigma0</td>
<td>0</td>
<td>0.7</td>
<td>db</td>
<td>2.33 %</td>
<td>2.27%</td>
<td></td>
</tr>
<tr>
<td>Dual frequency ionosphere correction</td>
<td>-0.4</td>
<td>0.04</td>
<td>m</td>
<td>1.17%</td>
<td>1.48%</td>
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<tr>
<td>Sea State Bias (Tran 2012)</td>
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<td>m</td>
<td>0.04%</td>
<td>0.04%</td>
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<tr>
<td>Dynamical atmospheric correction (MOGD2)</td>
<td>-2</td>
<td>2</td>
<td>m</td>
<td>0.00%</td>
<td>0.00%</td>
<td></td>
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<tr>
<td>Ocean tide height model (GOT4V10)</td>
<td>-5</td>
<td>5</td>
<td>m</td>
<td>0.01 %</td>
<td>0.01%</td>
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<tr>
<td>Solid earth tide height model (Cartwright and Tayler 1971)</td>
<td>-1</td>
<td>1</td>
<td>m</td>
<td>0.00 %</td>
<td>0.00%</td>
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<tr>
<td>Pole tide height model (Wahr 1985)</td>
<td>-15</td>
<td>15</td>
<td>m</td>
<td>0.00 %</td>
<td>0.00%</td>
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<tr>
<td>WTC derived from MWR</td>
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<td>-0.001</td>
<td>m</td>
<td>0.09%</td>
<td>0.10%</td>
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<td>–</td>
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<td>2.77%</td>
<td>2.99%</td>
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The measurements rejected during the editing process are shown in Figure 3 (Sentinel-3A: top panel, Sentinel-3B: bottom panel). The two satellites are in perfect agreement. Equatorial wet zones or zones with sea ice appear on the maps as regions with less valid data, as it is also the case for other altimeters: measurements are corrupted by rain or sea ice. They were therefore removed by editing. Since the update of the MWR calibrations pattern for Sentinel-3A (February 2018), less measurements are edited.
Figure 3: Edited measurements for Sentinel-3A (top panel) and Sentinel-3B (bottom panel), from 08/02/2019 to 07/03/2019 (Sentinel-3B cycle 22).
4 Instrumental and geophysical parameter analysis

The monitoring of instrumental and geophysical parameters is crucial to detect potential drifts or jumps in long-term time series. These verifications are produced operationally so that they allow systematic monitoring of the main relevant parameters.

4.1 Sentinel-3A and 3B Sensors

A detailed assessment of Sentinel-3A and 3B sensors SRAL and MWR is made in separate bulletins:

- S3 SRAL Cyclic Performance Report (S3MPC.ISD.PR.04-41-22).
- S3 MWR Cyclic Performance Report (S3MPC.CLS.PR.05-41-22).

4.2 Significant wave height

Figure 4 shows along-track significant wave height derived from altimeter measurements. Wave height may reach several meters. Sentinel-3A SWH is in perfect agreement with Sentinel-3B SWH over this cycle.
The SAR parameters are compared to Pseudo Low Resolution Mode (PLRM) processing. The PLRM is an LRM like processing of the SAR observations. It provides a reliable reference to compare with. The daily average of Ku-band SWH for Sentinel-3A and Sentinel-3B SARM and P-LRM is plotted as a function of time on Figure 5. They show similar features. A bias of 8 cm is observed between Sentinel-3A P-LRM and SARM SWH and between Sentinel-3B P-LRM and SARM SWH. Looking at the temporal evolution over this cycle, Sentinel-3A SARM (respectively PLRM) SWH follows the same variation than Sentinel-3B SARM (respectively PLRM) SWH, with only a small bias of about 2 cm between the missions.

For more details concerning the SWH assessment, please refer to the:

- S3 Winds and Waves Cyclic Performance Report (ref. S3MPC.ECM.PR.07-41-22)
Figure 5: Daily monitoring of Ku-band significant wave height for Sentinel-3A and Sentinel-3B (top panel) and the corresponding histograms (bottom panel). Both plots are computed over Sentinel-3B cycle 22.
4.3 Backscattering coefficient

Figure 6 shows along-track backscatter coefficient derived from altimeter measurements. Sentinel-3A and Sentinel-3B present similar backscatter coefficient over this cycle.

![Figure 6: Backscattering coefficient for Sentinel-3A (top panel) and Sentinel-3B (bottom panel), from 08/02/2019 to 07/03/2019 (Sentinel-3B cycle 22).]
The daily average of the backscattering coefficient for Sentinel-3A and Sentinel-3B SARM and P-LRM (Ku-band) is plotted as a function of time on Figure 7. There is no bias observed between SARM and P-LRM backscattering coefficient, and the two satellites are in good agreement.

**Figure 7:** Daily monitoring of backscattering coefficient for Sentinel-3A and Sentinel-3B (top panel) and the corresponding histograms (bottom panel). Both plots are computed over Sentinel-3B cycle 22.
4.4 Altimeter wind Speed

Figure 8 shows wind speed estimations derived from along-track altimeter measurements. The wind speed is derived from the one parameter (backscatter coefficient) Saleh Abdalla’s algorithm. As for the backscatter coefficient, Sentinel-3A wind speed is consistent with Sentinel-3B.
Figure 8: Altimeter wind speed for Sentinel-3A (top panel) and Sentinel-3B (bottom panel), from 08/02/2019 to 07/03/2019 (Sentinel-3B cycle 22).

The daily average of altimeter wind speed for Sentinel-3A and Sentinel-3B SARM and P-LRM is plotted as a function of time on the top of Figure 9. SARM and P-PLRM wind speed are fully in line, and the two missions are in good agreement.

The histogram is shown on the bottom. A bias of only 0.03 m/s is observed between Sentinel-3A modes and of 0.06 m/s between Sentinel-3B modes. For more details concerning the wind speed assessment, please refer to the:

- S3 Winds and Waves Cyclic Performance Report (ref. S3MPC.ECM.PR.07-41-22)
Figure 9: Daily monitoring of altimeter wind speed for Sentinel-3A and Sentinel-3B (top panel) and the corresponding histograms (bottom panel). Both plots are computed over Sentinel-3B cycle 22.
5 Crossover Analysis

5.1 Overview

SSH crossover differences are the SSH differences between ascending and descending passes at their crossing point. Crossover differences are systematically analyzed to estimate data quality and the Sea Surface Height (SSH) performances. SSH crossover differences are computed from valid data on a cyclic basis. A maximum time lag of 10 days is set in order to limit the effects of ocean variability which are a source of error in the performance estimation. The mean SSH crossover differences should ideally be close to zero and standard deviation should ideally be small. Nevertheless, SLA varies also within 10 days, especially in high variability areas. Furthermore, due to lower data availability (due to seasonal sea ice coverage), models of several geophysical corrections are less precise in high latitude. Therefore, an additional geographical selection - removing shallow waters, areas of high ocean variability and high latitudes (> |60|°) - is applied for cyclic monitoring.

5.2 Maps of SSH crossover differences

The maps of the mean differences at crossovers (4 by 4 degree bin) is plotted for Sentinel-3B cycle 22 on Figure 10. Although the results are a little bit noisy because of the short time period (27 days), Sentinel-3A and Sentinel-3B maps do not highlight strong anomalies. The same large geographical patterns are observed, they will be investigated using a larger time period.
Figure 10: Sea Surface Height differences at crossovers, after data editing, applying additional geographical selection (removing shallow waters, areas of high ocean variability and high latitudes (> 60°)) for Sentinel-3A (top panel) and Sentinel-3B (bottom panel). Maps computed over Sentinel-3B cycle 22.
The map of the mean SSH differences at Sentinel-3A/Sentinel-3B crossovers (4 by 4 degree bin) is plotted for Sentinel-3B cycle 22 on Figure 11. Once again, this map does not show strong anomalies and highlight the consistency between the two Sentinel-3 missions.

**Figure 11: Sea Surface Height differences at Sentinel-3A/Sentinel-3B crossovers, after data editing, applying additional geographical selection (removing shallow waters, areas of high ocean variability and high latitudes (>|60|°)). Map computed over Sentinel-3B cycle 22.**
5.3 Cycle by cycle monitoring

The mean and standard deviation of SSH differences at crossovers are plotted for Sentinel-3A and Sentinel-3B and compared with Jason-3 in function of time on a cyclic basis (Figure 12 top panel). The statistics are computed after data editing and using the geographical selection criteria (|latitude| < |60|°, bathymetry < −1000m, ocean variability (computed over several years) < 0.2m). Note that statistics are computed for each cycle (with a repeat period of approximately 27 days for Sentinel-3A and 3B and 10 days for Jason-3). Furthermore, figures are computed by averaging in boxes of 4 ° by 4° resolution. This is done in order to reduce weight of crossover points in high latitudes (there are much more crossover points in high and very high latitudes than in mean and low latitudes).

The mean difference is slightly positive (0.35 cm in average for Sentinel-3A and 0.2cm for Sentinel-3B) indicating that the bias between ascending and descending tracks is not null. Over Sentinel-3B period, the two Sentinel-3 satellites present identical mean SSH difference at crossovers. From Sentinel-3A cycle 3B, the temporal evolution slightly changed for both satellites. This is linked to the change of orbit solution from POE-E to POE-F on the 09/11/2019 in NTC products.

The standard deviation metrics show performances close to the Jason-3 ones. A part of the differences observed between Sentinel-3 missions and Jason-3 metrics could be explained by the mean time lag at crossovers. This parameter varies as function of the satellite orbit. For the Jason-3 mission it is around 3 days whereas it reaches more than 4 days for Sentinel-3A and 3B.
Figure 12: Mean and standard deviation of SSH differences at crossovers for Sentinel-3A (blue curve), Sentinel-3B (red curve) and Jason-3 (black curve) as a function of time.

The mean and standard deviation of SSH difference at Sentinel-3A/Sentinel-3B crossovers is plotted on Figure 13. The difference between the satellites is small in both SARM and P-LRM (0.01cm). This shows the consistency between the two satellites.
Figure 13: Mean and standard deviation of SSH differences at Sentinel-3A/Sentinel-3B crossovers as a function of time.
5.4 Comparison of pseudo time tag bias

The pseudo time tag bias is found by computing at SSH crossovers a regression between SSH and orbital altitude rate (H), also called satellite radial velocity:

\[ \text{SSH} = \alpha H \]

This method allows to estimate the time tag bias, but it also absorbs other errors correlated with H as for instance orbit errors. Therefore, it is called "pseudo" time tag bias.

Figure 14 shows the monitoring of the pseudo time tag bias for Sentinel-3A and Sentinel-3B on a cyclic basis. Using SARM data, a value of -43 microseconds is found for Sentinel-3A cycle 41 and of -28 microseconds for Sentinel-3B cycle 22. The variability from one cycle to the other makes difficult the interpretation of this parameter. Dedicated studies are ongoing to characterize the time tag bias more precisely.

![Pseudo time tag bias](image)

**Figure 14:** Cyclic monitoring of pseudo time tag bias for Sentinel-3A (blue curve) and Sentinel-3B (red curve).
6 Along Track Analysis

6.1 Mean of along-track SLA

6.1.1 Temporal analysis

The monitoring of mean SLA and its standard deviation (Figure 15) is done in order to detect possible jumps or drifts.

We note:

- A mean bias between SARM and P-LRM Sea Level time series of 0.7 cm for Sentinel-3A and of 1.7 cm for Sentinel-3B
- A bias of 0.9 cm between Sentinel-3A and Sentinel-3B SARM SLA.
- A perfect agreement between Sentinel-3A and Sentinel-3B P-LRM SLA.

The monitoring of the SLA standard deviation also highlights the good agreement between the two missions and between the two modes.
Figure 15: Daily monitoring of mean (top panel) and standard deviation (bottom panel) of SLA computed using the radiometer wet tropospheric correction (sla_rad) over Sentinel-3B cycle 22, for Sentinel-3A SARM (blue) and P-LRM (cyan) and Sentinel-3B SARM (red) and P-LRM (orange).

6.1.2 Maps

Figure 16 shows the maps of Sentinel-3A and Sentinel-3B SLA relative to the Mean Sea Surface. Both maps highlight similar geophysical variation.
Figure 16: Along track of Sea level anomaly relative to MSS computed over Sentinel-3B cycle 22 for Sentinel-3A (top panel) and Sentinel-3B (middle panel). For both maps, an offset equal to the mean value has been applied.
7 Long term monitoring

7.1 Significant wave height monitoring

Figure 17 shows the daily average of Ku-band SWH for Sentinel-3A, Sentinel-3B and Jason-3 products as a function of time. For this long-term monitoring diagnosis, Sentinel-3A data have been concatenated with the latest reprocessed dataset (IPF-SM2 V06.12).

The bias between SARM and P-LRM SWH is around 5 cm for Sentinel-3A and 4 cm for Sentinel-3B. Over Sentinel-3A period, the two Sentinel-3 satellite are in good agreement. Compared to Jason-3, the Sentinel-3 SWH are slightly under-estimated.

![Daily mean of SWH](image)

*Figure 17: Daily monitoring of Ku-band significant wave height for Sentinel-3A, Sentinel-3B and Jason-3.*

7.2 Backscattering coefficient monitoring

Figure 18 shows the daily average of the backscattering coefficient for Sentinel-3A, Sentinel-3B and Jason-3 (Ku-band) as a function of time. For this long-term monitoring diagnosis, Sentinel-3A data have been concatenated with the latest reprocessed dataset (IPF-SM2 V06.12).

A bias of ~4 dB is observed between Sentinel-3A and Jason-3. This is expected since Sentinel-3A has been aligned on Envisat mean value. The Sentinel-3A backscatter curves are flat, this traduces the stability of this parameter.
During the beginning of Sentinel-3B mission, a bias of 0.5dB was observed between Sentinel-3B and Sentinel-3A backscatter coefficients. This is not consistent with the parametrization used for the altimeter wind speed calculation. Sentinel-3B sigma0 needs to be aligned to Sentinel-3A (i.e. Envisat) sigma0 in order to provide a correct wind speed. This alignment has been done in the implementation of Sentinel-3B processing baseline 1.13, deployed on the 6th December 2018 for NRT data. The impact on NTC data is visible from November 2018, as shown on the daily monitoring on Figure 18. Sentinel-3A and 3B backscatter coefficients are now in line and centred around 11dB.

Figure 18: Daily monitoring of backscattering coefficient for Sentinel-3A, Sentinel-3B, and Jason-3.

7.3 Altimeter Wind Speed monitoring

Figure 19 shows the daily average of altimeter wind speed for Sentinel-3A, Sentinel-3B and Jason-3 as a function of time. For this long-term monitoring diagnosis, Sentinel-3A data have been concatenated with the latest reprocessed dataset (IPF-SM2 V06.12).

The SARM and P-LRM wind speed features are in agreement but exhibit a mean bias of ~0.4 m/s compared to Jason-3.

Sentinel-3B wind speed monitoring presents a jump from about 6.5m/s to 7.9m/s in November 2018. This is linked to the implementation of the processing baseline 1.13 presented in the previous section. Before this implementation, Sentinel-3B wind speed was underestimated. It is now in line with Sentinel-3A.
7.4 Mean of along-track SLA monitoring

The comparison between mean SLA for Sentinel-3A, Sentinel-3B and Jason-3 (Figure 20 top panel) is done in order to detect possible jumps or drifts. For this long-term monitoring diagnosis, Sentinel-3A data have been concatenated with the latest reprocessed dataset (IPF-SM2 V06.12). The sea level is computed using the radiometer wet tropospheric correction.

Between SARM and P-LRM time series, we note a mean bias of 1.1 cm for Sentinel-3A and of 1.7 cm for Sentinel-3B. The Sentinel-3A sea level in SARM is centered around 4.7 cm in average and is consistent with Jason-3 metric (computed with consistent geophysical correction standards). Except for a small bias, Sentinel-3B sea level presents the same temporal variation than Sentinel-3A.

The monitoring of the SLA standard deviation (Figure 20 bottom panel) allows to detect potential changes in the long-term stability of the altimeter’s system performances. The metrics for the three satellites are consistent. Over the mission lifetime, Sentinel-3B SARM and P-LRM variances are in perfect agreement with Sentinel-3A SARM and PLRM respectively, both in magnitude and in temporal variation.
**Figure 20:** Daily monitoring of mean SLA for Sentinel-3A, Sentinel-3B, and Jason-3.

**Figure 21:** Daily monitoring of SLA standard deviation for Sentinel-3A, Sentinel-3B, and Jason-3.
8 Conclusions

These results over Sentinel-3B cycle 22 highlight a good quality of Sentinel-3A and Sentinel-3B NTC Marine products. The performances observed at crossovers over this cycle are in perfect agreement for Sentinel-3A and Sentinel-3B and close to Jason-3 ones. The sea level and other parameters derived from the altimeter (backscatter coefficient, SWH, wind speed) show good metrics and good constistency between Sentinel-3A and Sentinel-3B, close to Jason-3 performance.
Other reports related to the Optical mission are:

- S3 SRAL Cyclic Performance Report, S3A Cycle No. 41, S3B Cycle No. 22 (ref. S3MPC.ISD.PR.04-41-22)
- S3 MWR Cyclic Performance Report, S3A Cycle No. 41, S3B Cycle No. 22 (ref. S3MPC.CLS.PR.05-41-22)
- S3 Winds and Waves Cyclic Performance Report, S3A Cycle No. 41, S3B Cycle No. 22 (ref. S3MPC.ECM.PR.07-41-22)
- S3 Land and Sea Ice Cyclic Performance Report, S3A Cycle No. 41, S3B Cycle No. 22 (ref. S3MPC.UCL.PR.08-41-22)

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

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