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

## **S3 MWR Cyclic Performance Report**

**S3-A** 

Cycle No. 072

Start date: 15/05/2021

End date: 11/06/2021

**S3-B** 

Cycle No. 053

Start date: 25/05/2021

End date: 21/06/2021



Mission
Performance
Centre

SENTINEL 3



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## **Changes Log**

Version	Date	Changes
1.0	21/07/2021	First Version

## **List of Changes**

Version	Section	Answers to RID	Changes



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#### **Sentinel-3 MPC**

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## 1 Introduction

This document aims at providing a synthetic report on the behaviour of the radiometer in terms of instrumental characteristics and product performances as well as on the main events which occurred during cycle 072 of S3A and 053 of S3B.

This document is split in the following sections:

- Section 2 gives an overview on the status of the current cycle
- Section 3 addresses the monitoring of the MWR of the current cycle. This section covers the short term monitoring of internal calibration, brightness temperatures and geophysical parameters.
- Section 4 addresses the long term monitoring from the beginning of the mission. It provides a view of the internal calibration monitoring as well as two subsections covering the monitoring of vicarious calibration targets and geophysical parameters.

# SENTINEL 3 Mission Performance Centre

#### **Sentinel-3 MPC**

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## 2 Overview of S3A Cycle 072 - S3B Cycle 053

### 2.1 Status

The Table 1 and Table 2 give a summary of the instrument behavior for S3A and S3B respectively during this period.

#### Sentinel-3A MWR

Parameter	Status	Comments
Instrument		Nominal
Internal Calibration		Nominal
Geophysical products		Nominal
Long-term monitoring		Nominal for three analyses

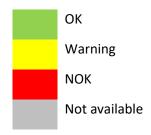
Table 1: General overview of the S3A MWR quality assessment

#### Sentinel-3B MWR

Parameter	Status	Comments
Instrument		Nominal
Internal Calibration		Nominal
Geophysical products		Nominal
Long-term monitoring		Nominal for three analyses

Table 2: General overview of the S3B MWR quality assessment

#### **Color legend:**



# SENTINEL 3 Missian Performance Centre

#### **Sentinel-3 MPC**

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## 2.2 IPF processing chain status

#### 2.2.1 IPF version

This section gives the version of the IPF processing chain used to process the data of the current cycle.

If a change of IPF version occurs during the cycle, the table gives the date of last processing with the first version and the date of first processing with the second version:

: processing time of the last product

#### **MWR L1B CAL**

	IPF version	NRT ( Svalbard )
S3A	06.11	
S3B	06.11	

#### **MWR L1B**

	IPF version	NTC ( LN3)
S3A	06.11	
S3B	06.11	

#### **SRAL/MWR Level 2**

	NTC ( Marine)		NTC (LAN)		
	IPF version		IPF version		
S3A	06.50		06.19		
S3B	06.50		06.19		



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### 2.2.2 Auxiliary Data files

This section gives the version of the auxiliary data files used to process the data of the current cycle.

## **Side Lobe Correction file**

	ADF version	NTC ( LN3)
S3A	003	
S3B	002	

### **MWR CCDB**

	ADF version	NTC ( LN3)
S3A	004	
S3B	002	

### **Level2 Configuration file**

	NTC ( WAT)		NTC (LAN)		
	ADF Version		ADF Version		
S3A	016		017		
S3B	007		008		



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## 3 MWR Monitoring over S3A Cycle 072 - S3B Cycle 053

This section is dedicated to the functional verification of the MWR sensor behaviour during S3A cycle 072 (15 May 2021 - 11 June 2021) and S3B cycle 053 (25 May 2021 - 21 June 2021). The main relevant parameters, monitored daily by the MPC team, are presented here.

## 3.1 Operating modes

The radiometers on-board S3A and S3B have several operating modes listed hereafter:

- Mode 0 : Intermonitoring (Earth observation)
- Mode 1 : Monitoring
- Mode 2 : Noise Injection calibration
- Mode 3 : Dicke Non-Balanced calibration (100% injection hot point)
- ❖ Mode 4 : Dicke Non-Balanced calibration (50% injection cold point)

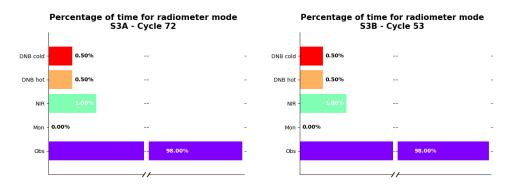


Figure 1: Distribution of operating mode (S3A: left; S3B: right)

The distribution has slightly changed with respect to the beginning of the mission due to update of calibration timeline of the 1<sup>st</sup> March 2018. Before the update, a calibration sequence is 9s long composed of and occurs 3 times per orbit. After that update, the calibration sequences are much shorter (~0.6s) but occurs every 30 seconds. Moreover, due to more frequent calibration, the monitoring measurements are no longer needed to monitore the noise diode.

For measurements in the Intermonitoring mode (Obs mode), two kind of processing can be used according to the measured brightness temperature. If this temperature is smaller than the reference load inside the instrument, the NIR processing is used; if the temperature is greater, the DNB processing is used. The transition from one processing to the other will occur more or less close to the coast depending on the internal temperature of the MWR. The internal temperature of the MWR is such that only a small percentage of measurements required a DNB processing in this cycle as shown by Figure 2 for S3A and S3B.

This figure shows also the passage over the US KREMS radar facility in the Kwajalein atoll (9°23′47″ N - 167°28′50″ E) in the Pacific. For safety reasons, the MWR is switched to a specific mode about 50 km

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#### **Sentinel-3 MPC**

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before the facility location and back to nominal mode 50km after. From the 17th January, the safing area was enlarged to 300km during the investigations. It was reduced to ~100km the 29<sup>th</sup> May 2019.

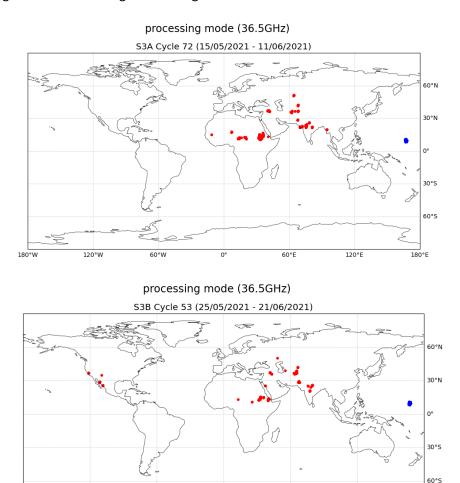


Figure 2 : Map of measurements with DNB processing for 36.5GHz channel (red) and safety mode for both channels over KREMS (blue) (S3A on top panel, S3B bottom panel)



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## 3.2 Calibration parameters

To monitor the instrument behavior during its lifetime, the relevant parameters of the MWR internal inflight calibration procedure are presented in the following subsections. These parameters are:

- the gain: this parameter is estimated using the two types of Dicke Non-Balanced calibration measurements (100% and 50% of injection). The DNB processing of the Earth measurements uses this parameter.
- the noise injection temperature: this parameter is measured during the Noise Injection calibration measurements. The NIR processing of the Earth measurements uses this parameter.

#### 3.2.1 Gain

#### 3.2.1.1 Sentinel-3A

Figure 3 shows the monitoring of the receiver gain for cycle 072 of S3A. The mean value over the cycle is 4.8mv/K and 4.6mV/K for channel 23.8GHz and 36.5GHz respectively. These values are close to values estimated on-ground during characterization of the instrument (4.8mV/K and 4.58mV/K for channels 23.8GHz and 36.5GHz respectively).

For both channels, nominal behavior is observed since only 1 cycle of data is considered in this section.

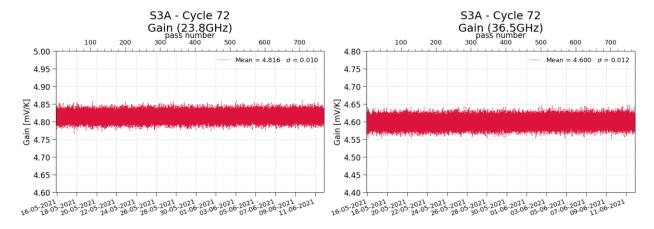


Figure 3: S3A Monitoring of receiver gain for both channels: 23.8GHz (left) and 36.5GHz (right)

#### 3.2.1.2 Sentinel-3B

Figure 4 shows the monitoring of the receiver gain for cycle 053 of S3B. The mean value over the cycle is 4.53mv/K and 4.47mV/K for channel 23.8GHz and 36.5GHz respectively. These values are close to values estimated on-ground during characterization of the instrument (4.52mV/K and 4.6mV/K for channels 23.8GHz and 36.5GHz respectively).

For both channels, nominal behavior is observed since only 1 cycle of data is considered in this section.



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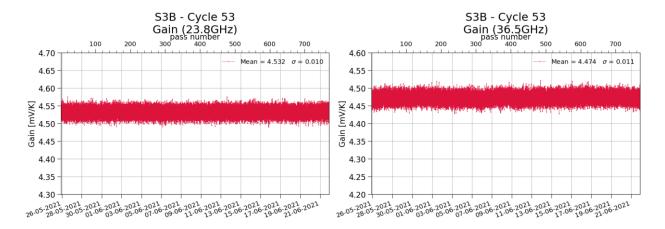


Figure 4: S3B Monitoring of receiver gain for both channels: 23.8GHz (left) and 36.5GHz (right)

#### 3.2.2 Noise Injection Temperature

#### 3.2.2.1 Sentinel-3A

Figure 5 shows the monitoring of the noise injection temperature for cycle 072 of S3A. The noise injection temperatures show no trend over the cycle for both channels. The average value of the noise injection temperatures are 313.3K/289.3K for channels 23.8GHz/36.5GHz respectively.

For both channels, nominal behavior is observed since only 1 cycle of data is considered in this section.

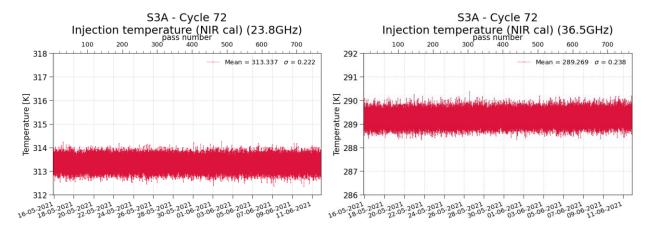


Figure 5: Monitoring of S3A Noise Injection temperature for both channels: 23.8GHz (left) and 36.5GHz (right)

#### 3.2.2.2 Sentinel-3B

Figure 6 shows the monitoring of the noise injection temperature for cycle 053 of S3B. The noise injection temperature shows no trend over the cycle for both channels. The average value of the noise injection temperatures are 311.1K/311.6K for channels 23.8GHz/36.5GHz respectively.

For both channels, nominal behavior is observed since only 1 cycle of data is considered in this section.

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#### **Sentinel-3 MPC**

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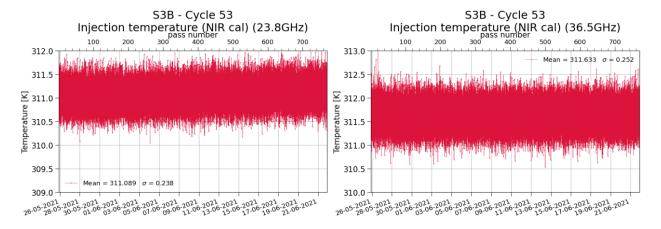


Figure 6: Monitoring of S3B Noise Injection temperature for both channels: 23.8GHz (left) and 36.5GHz (right)



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## 3.3 Brightness Temperatures

The two following figures show maps of brightness temperatures for the two channels of S3A split by ascending (right part) and descending (left part) passes. Figure 7 and Figure 8 concern the channels 23.8GHz and 36.5GHz respectively. These maps show a good contrast between ocean and land for both channels.

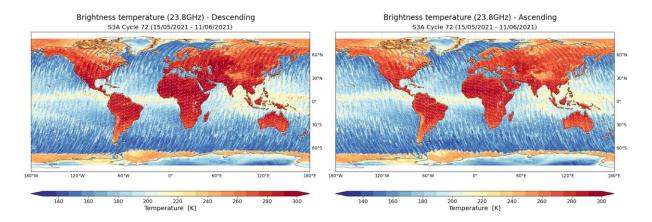


Figure 7 : Map of S3A Brightness temperatures of channel 23.8GHz for ascending (right) and descending (left) passes

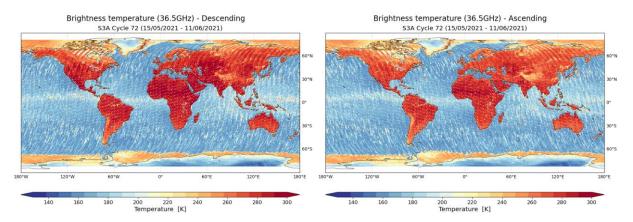


Figure 8 : Map of S3A Brightness temperatures of 36.5GHz channel for ascending (right) and descending (left)

passes

Figure 9 and Figure 10 concern the channels 23.8GHz and 36.5GHz respectively also split by ascending (right part) and descending (left part) passes. These maps show a good contrast between ocean and land for both channels. Level1 NTC files covering a period of about 3days were not received by the MPC explaining the gaps in the maps below.



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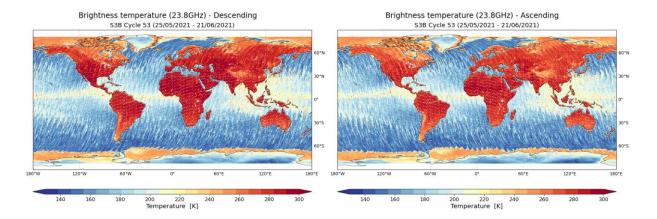


Figure 9 : Map of S3B Brightness temperatures of channel 23.8GHz for ascending (right) and descending (left)

passes

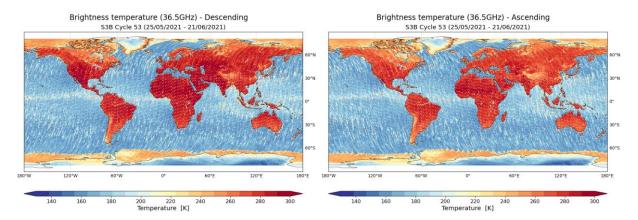


Figure 10 : Map of S3B Brightness temperatures of channel 36.5GHz for ascending (right) and descending (left)

passes

From these pictures, we can see that S3A and S3B brightness temperatures seem to be close, but they do not provide an accurate number. Figure 11 shows histograms of MWR brightness temperatures over ocean for S3A and S3B for the period corresponding to the Cycle 072 of S3A. We can see how close the two instruments are after the intercalibration. It subsists a bias of only 0.4K for 23.8GHz and 0.2K for 36.5GHz as expected from the commissioning results.

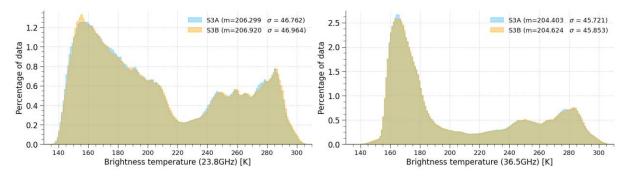


Figure 11 : Histogram of S3A and S3B brightness temperatures (all surfaces) for 23.8GHz (left) and 36.5GHz (right) channels



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## 3.4 Geophysical products monitoring

The inversion algorithms allow to retrieve the geophysical products from the measurements of the radiometer (brightness temperatures measured at two different frequencies) and the altimeter (backscattering coefficient ie sigma0). Four geophysical products are issued from the retrieval algorithms: the wet tropospheric correction, the atmospheric attenuation of the Sigma0, the water vapor content, the cloud liquid water content. This section provides an assessment of two of these retrievals used by the SRAL/MWR L2 processing: the wet tropospheric correction and the atmospheric attenuation of the Sigma0. The wet tropospheric correction is analysed through the MWR-ECMWF difference of this correction.

#### 3.4.1 Wet Tropospheric Correction

Figure 12 presents the histograms of the MWR-ECMWF differences of wet tropospheric correction ( $\Delta$ WTC) for cycle 072 of S3A. In this figure, S3A/B corrections are compared to the correction retrieved by Jason-3 (IGDR) and SARAL (IGDR) over the same period.

The standard deviation of the difference MWR-ECMWF corrections for S3A and S3B is around 1.4cm for SAR and PLRM corrections respectively while it is around 1.5cm for SARAL and 1.2cm for Jason-3. First Jason-3 benefits from its three channels radiometer (18.7GHz, 23.8GHz, 34GHz), providing a correction with a smaller deviation with respect to the model. SARAL/MWR is closer to S3A/B in this context with its two channels (23.8GHZ and 37GHz for SARAL, 23.8 and 36.5GHz for S3A/B). Then the standard deviation for SARAL is the closest reference, even though the Sigma0 in Ka band raises some questions. With the use of NTC products for S3A/B, the  $\Delta$ WTC for the three instruments are directly comparable since all use ECMWF analyses for the computation of the model correction. The standard deviation of  $\Delta$ WTC for S3A/B is smaller than for SARAL meaning that we have a better estimation of the correction for S3A according to these metrics. Jason-3 gives the best performances with the smallest deviation. Moreover, one can notice that S3A/B SAR and PLMR corrections have very similar performances as mean(std) of  $\Delta$ WTC are close to:

- 0.19cm(1.35cm) and 0.2cm(1.34cm) for S3A SAR and PLRM respectively
- -0.09cm(1.4cm) and -0.04cm(1.4cm) for S3B SAR and PLRM respectively

S3A and S3B corrections present a small bias of 0.2cm.



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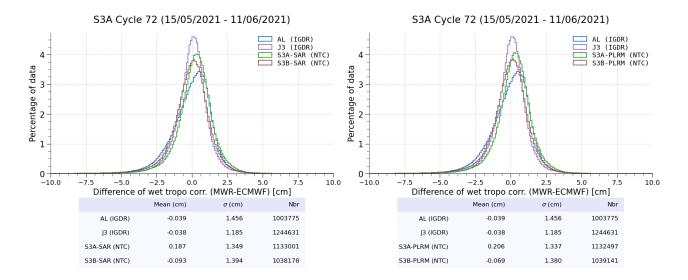


Figure 12: Histograms of MWR-ECMWF difference of wet tropospheric correction for SARAL, Jason3, S3A and S3B (selection of latitude between -60°/60° for all instruments, distance to shoreline >50km for S3A)

Left: Sentinel-3A/B SAR measurements; Right: Sentinel-3A/B PLRM measurements

Figure 13 presents a map of the  $\Delta$ WTC for cycle 072 of Sentinel-3A only for SAR correction on the left and PLRM correction on the right. Figure 14 concerns the Sentinel-3B  $\Delta$ WTC for its cycle 053. For that period, the maps show geographical patterns expected for this parameter. Note that the color scale is centered to the mean value. The comparison with Jason-3 map of  $\Delta$ WTC (Figure 15) shows similarities although Sentinel-3A/B  $\Delta$ WTC is larger than Jason3 because of their different instrument configuration.

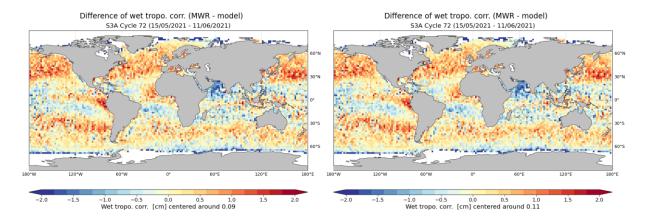


Figure 13 : S3A MWR-ECMWF difference of wet tropospheric correction for S3A cycle 072: using SAR (left) and PLRM altimeter backscatter (right)

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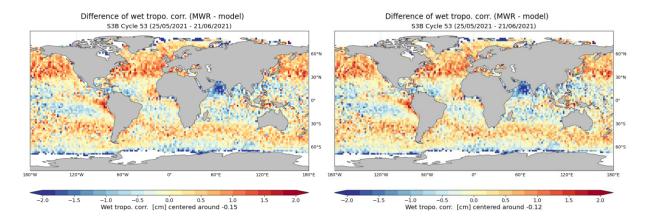


Figure 14 : S3B MWR-ECMWF difference of wet tropospheric correction for S3B cycle 053: using SAR (left) and PLRM altimeter backscatter (right)

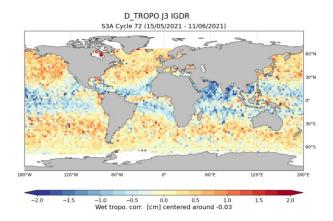


Figure 15 : Jason MWR-ECMWF difference of wet tropospheric correction (IGDR product)



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#### 3.4.2 Atmospheric Attenuation

The Figure 16 presents the histograms of the Ku band atmospheric attenuation of the Sigma0. In this figure, S3A and S3B attenuations are compared to the model attenuation computed from ECMWF analyses and Jason3 attenuation from IGDR products. The results for both instruments are very similar to model results with an average attenuation close to 0.21dB for S3A, 0.22dB for S3B, 0.2dB for Jason3 and 0.2dB for model attenuation. Note that the model attenuation showed in that histogram is the attenuation computed at S3A time and geolocation. Histogram shape and mode for model data are closer to Sentinel-3 A/B, while the mean value is closer to Jason3.

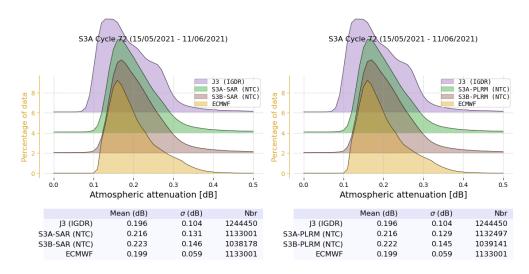


Figure 16: Histograms of Ku band Atmospheric attenuation of the Sigma0 for S3A, S3B, Jason3, Model attenuation (selection of latitude between -60°/60° for all instruments, distance to shoreline >50km for S3A&S3B) for the period of S3A cycle 072. Dotted lines indicate mean values.

Left: Sentinel-3A/B SAR measurements; Right: Sentinel-3A/B PLRM measurements



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## 4 Long-term monitoring

In this section, a long-term monitoring of the MWR behaviour is presented.

## 4.1 Internal Calibration parameters

This section presents a long-term monitoring of internal calibration parameters.

#### 4.1.1 Gain

#### 4.1.1.1 Sentinel-3A

Figure 17 shows the daily mean of the receiver gain for both channels. This calibration parameter is used in the DNB processing of the measurements. As seen previously in section 3.1, only a small part of the measurements are processed in DNB mode. The first part of the monitoring of the calibration parameters shown here is performed with products generated during the reprocessing using the processing baseline 2.15, the second part using NRT products from the day of the IPF update on the Svalbard ground station forward.

From the two panels of Figure 17, one can see that the receiver gain has a different evolution for each channel. The gain for the 23.8GHz channel has slowly increased since the beginning of the mission showing four slopes and three inflexion points at August 2016, Februray 2017 and June 2017. It seems to be almost stable since cycle 19 (July 2017). The gain has increased of +0.07mv/K since the beginning of the mission. The update of the calibration timeline of the 1st March 2018 has an impact on the standard deviation and minimum and maximum values of the gain for both channels (as explained in section 3.2.1), but there is no evidence of a change in the daily mean value.

The gain of the 36.5GHz channel is showing a slow decrease with a seasonal oscillation. The RFI with KREMS radar facility of November 2018 (cycle 38) changes the operating point of the radiometer and the level of the gain. After a period of stabilisation, the gain retrieved its slow decrease. In February 2019, an update of the ground processing software is responsible for the small jump visible for both channels. A spurious value in the statistics is observed for the 4<sup>th</sup> July 2020 (cycle 60) due to a special operation for the OLCI instrument that caused a gap in the data set.

Due to the small number of data processed using this parameter, it will be difficult to assess if this decrease has an impact on data quality. The monitoring will be pursued and data checked for any impact.



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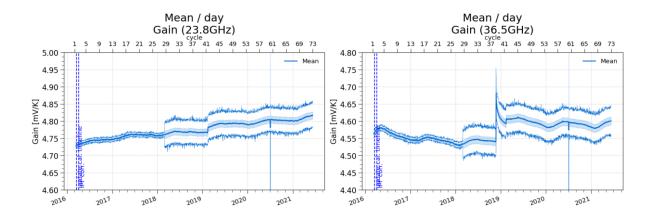


Figure 17: Daily mean of the gain for both channels: 23.8GHz (left) and 36.5GHz (right)

#### 4.1.1.2 Sentinel-3B

Figure 18 shows the daily mean of the receiver gain for both channels of Sentinel-3B. The monitoring of the calibration parameters shown here is performed with products generated operationally by the Land Processing center (LN3).

From the two panels of Figure 18, one can see that the receiver gain has a different evolution for each channel. The gain for the 23.8GHz channel has slowly increased since the beginning of the mission and seems stabilized since September 2018. The update of the MWR characterization file of the 6<sup>th</sup> December 2018 caused the change of value in the computed value of the gain observable at that date. The gain of the 36.5GHz channel is decreasing since the beginning of the mission and seems stabilized since September 2018. A small step at the beginning of December is also observable, with the same cause than for the 23.8GHz channel (update of the characterization file).

In February 2019, an update of the ground processing software is responsible for the small jump visible for both channels.

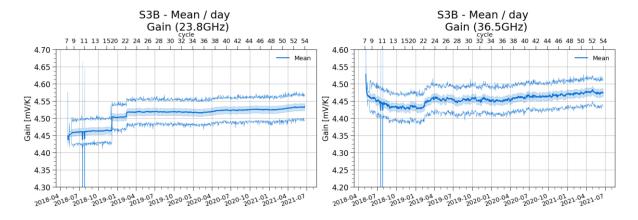


Figure 18: Daily mean of the gain for both channels: 23.8GHz (left) and 36.5GHz (right)



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#### 4.1.2 Noise Injection temperature

#### 4.1.2.1 Sentinel-3A

Figure 19 shows the daily mean of the noise injection temperature for both channels of Sentinel-3A. This calibration parameter is used in the NIR processing of the measurements. As seen previously in section 3.1, the main part of the measurements are processed in NIR mode. Moreover the first part of the monitoring of the calibration parameters is performed using products generated during the reprocessing of processing baseline 2.15, the second part using NRT calibration products from the day of the IPF update on the ground station.

From the two panels of Figure 19, one can see that the noise injection parameter has a different evolution for each channel. The noise injection temperature of 23.8GHz channel has decreased of less than 0.5K during the first 2 cycles, after what there has been no significant change of behaviour until cycle 13. During this cycle, the noise injection temperature seems to start a slow decrease. The injection temperature of the 36.5GHz channel is not stable: it seems to follow some kind of seasonal signal combined with a trend. The monitoring will be pursued and data checked for any impact.

The update of the calibration timeline of the 1<sup>st</sup> March 2018 has an impact on the standard deviation and minimum and maximum values of the gain (as explained in section 3.2.1), but there is no evidence of a change in the daily mean value.

Some peak values are noticeable at the end of cycle 4 (mainly channel 23.8GHz), at the end of cycle 6, during cycle 9, 10, 12 and 16. Some of these peaks concerns both channels at the same time, while a small part of them only one of them. The investigations performed in the cycle 6 report has shown that these measurements are localized around a band of latitude that may change along the time series. The source is not yet clearly identified but a intrusion of the Moon in the sky horn is suspected.

A step of ~0.2K is seen during cycle 38 as observed in section 3.2.2. Investigations carried out have shown that a RFI around the KREMMS facility caused a stress to the MWR.

A spurious value in the statistics is observed for the 4<sup>th</sup> July 2020 (cycle 60) due to a special operation for the OLCI instrument that caused a gap in the data set.



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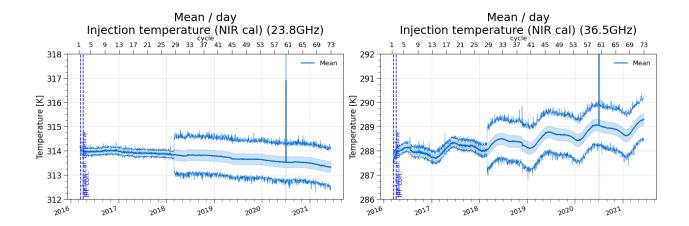


Figure 19 : Sentinel3-A Daily statistics of the noise injection temperature for channel 23.8GHz (left) and 36.5GHz (right): mean (bold line), min/max (thin line), standard deviation (shade)

#### 4.1.2.2 Sentinel-3B

Figure 20 shows the daily mean of the noise injection temperature for both channels of Sentinel-3B. This calibration parameter is used in the NIR processing of the measurements. The monitoring of the calibration parameters shown here is performed with products generated operationally by the Land Processing center (LN3).

From the two panels of Figure 20, one can see that the noise injection parameter has a different evolution for each channel. The noise injection temperature of the 23.8GHz channel has increased at the beginning of the mission and seems stabilized since September. The injection temperature of the 36.5GHz channel is not stable: it seems to follow a trend. The two peaks observed in July are due to a maneuver for cold sky seeing (17 July 2018) in preparation for Moon seeing maneuver (27 July 2018).

A step at the beginning of December 2018 is observable, due to the update of the MWR characterization file. A second one occurs in April 2019 and is observable only for this parameter (not the gain) and only for the 23.8GHz channel. Investigations showed that no RFI or known event are responsible for this change of behavior.

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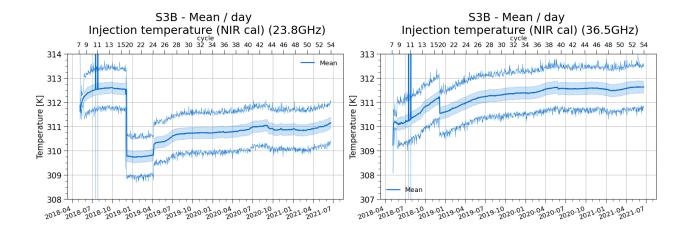


Figure 20 : Sentinel3-B Daily statistics of the noise injection temperature for channel 23.8GHz (left) and 36.5GHz (right): mean (bold line), min/max (thin line), standard deviation (shade)



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#### 4.2 Vicarious calibration

The assessment of the brightness temperatures quality and stability is performed using vicarious calibrations. Two specific areas are selected.

#### 4.2.1 Coldest ocean temperatures

The first area is the ocean and more precisely the coldest temperature over ocean. Following the method proposed by Ruf [RD 1], updated by Eymar [RD 3] and implemented in [RD 7], the coldest ocean temperatures is computed by a statistic selection. Ruf has demonstrated how a statistical selection of the coldest BT over ocean allows detecting and monitoring drifts. It is also commonly used for long-term monitoring or cross-calibration [RD 4] [RD 5] [RD 6].

The Figure 21 presents the coldest ocean temperature computed following method previously described at 23.8GHz channel for Sentinel-3A/MWR and four other microwave radiometers: AltiKa/MWR, Jason3/AMR and Metop-A/AMSU-A. For AMSU-A, the two pixels of smallest incidence (closest to nadir) are averaged. The Figure 22 presents the same results for the liquid water channel of the same four instruments: 36.5GHz for Sentinel-3A, 37GHz for AltiKa, 34GHz for Jason3 and 31.4GHz for Metop-A.

Concerning the 23.8GHz channel presented on Figure 12, one can see that the temperature of the coldest ocean points is very closer to the other sun-synchroneous missions (Metop-A, SARAL/AltiKa). Jason-3 coldest temperature is almost 6K lower than the other missions because of its orbit [RD 9].

The analysis for the liquid water channel (Figure 22) is more complicated due to the different frequency used by these instruments for this channel: 36.5GHz for S3A/B, 37GHz for AltiKa, 34GHz for Jason3 and 31.4Ghz for AMSU-A. But the coldest temperatures can be used relatively one with another. For instance, one can see that the difference between AltiKa and Jason3 is about 6K which is in line with the theoretical value estimated by Brown between the channel 34 GHz of JMR and the channel 37 GHz of TMR (-5.61 K ± 0.23 K) [RD 8]. Then we can expect that Sentinel3 should be closer to AltiKa than Jason2 due to the measurement frequency. The Sentinel-3B on-the-fly NTC products show a jump in the temperatures with the update of MWR characterisation file. After the update of the MWR characterization file the 6<sup>th</sup> December, S3B presents values consistent with S3A as expected. S3B monitoring shown below represents on-the-fly data, and not the reprocessed data. Monitoring over reprocessed data would not shown the steps due to IPF configuration update, such as MWR characterisation file.

Monitoring of both channels show a small annual cycle due to the annual cycle of water vapor. This signal can be determined and removed to facilitate the comparison between mission and the assessment of the stability. Figure 23 and Figure 24 present the residuals after such processing for both channels. The residuals are small for all missions, below 0.5K in absolute value. Sentinel-3A/B are perfectly consistent with the other missions. S3B is lightly more noisier than S3A, because the timeseries is not homogeneous and relativately short. Over the period of study, no drift is noticed for S3A or S3B.

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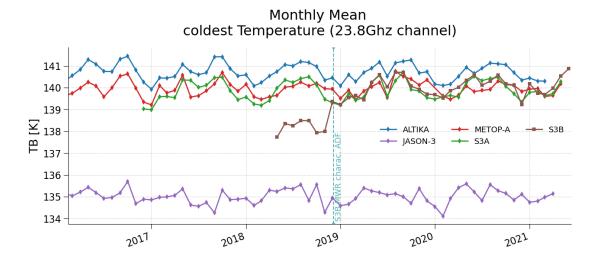


Figure 21 : Coldest temperature over ocean at 23.8GHz for S3A/B, SARAL/AltiKa, Jason2, Jason3 and Metop-A/AMSU-A

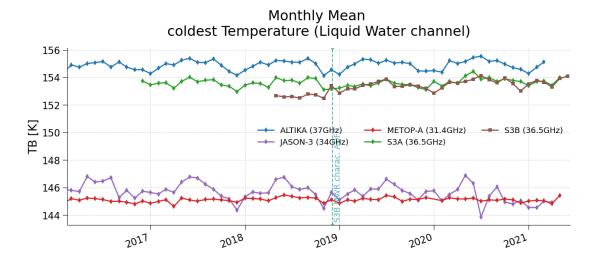


Figure 22 : Coldest temperature over ocean for the liquid water channel S3AB, SARAL/AltiKa, Jason2, Jason3 and Metop-A/AMSU-A



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#### Residuals of ocean coldest Temperature (23.8Ghz channel)

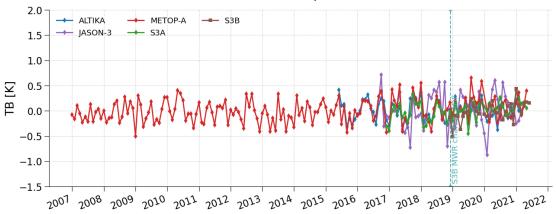


Figure 23 : Residuals after removal of yearly signal over ocean at 23.8GHz for S3A/B, SARAL/AltiKa, Jason3 and Metop-A/AMSU-A

#### Residuals of ocean coldest Temperature (Liquid Water channel) 2.0 ALTIKA (37GHz) METOP-A (31.4GHz) S3B (36.5GHz) IASON-3 (34GHz) - S3A (36.5GHz) 1.5 1.0 $\subseteq$ 0.5 IΒ 0.0 -0.5 -1.0-1.52008 2009 2010 2020 2011 2012 2013 2014 2015 2016 2017 2018 2019

Figure 24 : Residuals after removal of yearly signal over ocean at 23.8GHz for S3A/B, SARAL/AltiKa, Jason3 and Metop-A/AMSU-A

#### 4.2.2 Amazon forest

The second area is the Amazon forest which is the natural body the closest to a black body for microwave radiometry. Thus it is commonly used to assess the calibration of microwave radiometers [RD 2][ RD 3]. The method proposed in these papers have been used as a baseline to propose a new method implemented in [RD 7]. In this new approach, a mask is derived from the evergreen forest class of GlobCover classification over Amazon. The average temperature is computed here over a period of one month for all missions.

The averaged temperature over the Amazon forest is shown on Figure 25 and Figure 26 for water vapor channel (23.8GHz) and liquid water channel respectively. These two figures show the very good consistency of S3A/B with the three other radiometers on the hottest temperatures: around 286K for the first channel, and 284K for the second channel. The mean value as well as the annual cycle is well



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respected. These results show the correct calibration for the hottest temperatures. At the beginning of S3B mission, no bias is observed for the hottest temperatures. After the update of the MWR characterization file the 6<sup>th</sup> December 2018, a small bias of 0.3K is introduced between S3B and S3A as expected from the commissioning phase results. S3B monitoring shown below represents on-the-fly data, and not the reprocessed data. Monitoring over reprocessed data would not shown the steps due to IPF configuration update, such as MWR characterisation file.

In autumn 2017, Metop-A starts drifting from its normal orbit to extend the mission lifetime of four years (source: https://www.eumetsat.int/science-blog/extending-working-lifetime-metop-weather-satellite). At the beginning of the mission, the Local Time of Ascending Node was 21h30. As the orbit will be drifting, the LTAN will move up to 18:00. The drift of LTAN is not constant but is accelerating with time. It did have no impact on hottest temperature selection up to end of 2019 approximately. After 2020, time of overflight shall be updated for the selection of Amazon points in order to have a sufficient number of point. In the long-term, a drift may be observable anyway if the local time of observation is not accounted for.

The annual signal can be determined and removed to facilitate the comparison between mission and the assessment of the stability. Figure 27 and Figure 28 present the residuals after such processing for both channels. El Nino event of 2016 is clearly observable with the residuals, showing an anomaly up to +1.5K The residuals are small for all missions, below 0.5K in absolute value. There are however a little large than the residuals for the coldest ocean points. The signal is noisier and more sensible to interannual variations. Sentinel-3A/B are perfectly consistent with the other missions. Over the period of study, no drift is noticed for S3A or S3B.

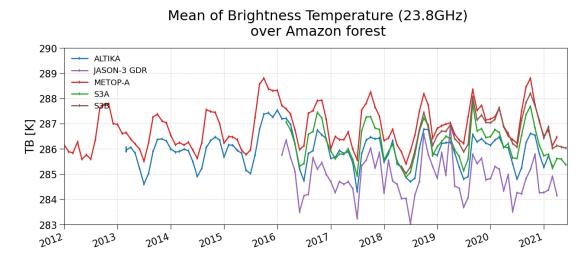


Figure 25 : Average temperature over Amazon forest at 23.8GHz channel for S3A/B, SARAL/AltiKa, Jason2, Jason3, and Metop-A/AMSU-A

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## Mean of Brightness Temperature (Liquid Water channel) over Amazon forest



Figure 26 : Average temperature over Amazon forest at 36.5GHz channel for S3A/B, SARAL/AltiKa, Jason3 and Metop-A/AMSU-A

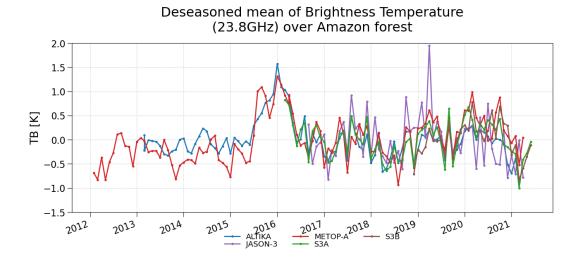
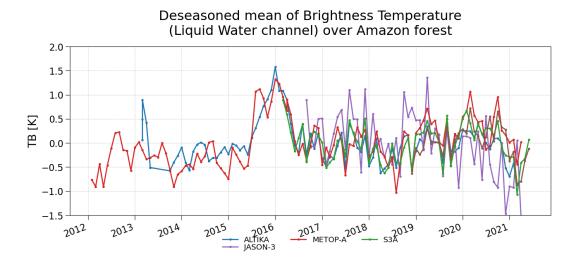


Figure 27 : Residuals after removal of yearly signal over Amazon forest at 23.8GHz channel for S3A/B, SARAL/AltiKa, Jason3, and Metop-A/AMSU-A





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Figure 28 : Residuals after removal of yearly signal over Amazon forest at 23.8GHz channel for S3A/B, SARAL/AltiKa, Jason3, and Metop-A/AMSU-A

#### 4.2.3 References

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- RD 2 S. Brown, C. Ruf, 2005: Determination of an Amazon Hot Reference Target for the on-orbit calibration of Microwave radiometers, Journal of Atmos. Ocean. Techno., 22, 1340-1352
- RD 3 L. Eymard, E. Obligis, N. Tran, F. Karbou, M. Dedieu, 2005: Long term stability of ERS-2 and TOPEX microwave radiometer in-flight calibration, IEEE Trans. Geosci. Remote Sens., 43, 1144-1158
- RD 4 C. Ruf, 2002: Characterization and correction of a drift in calibration of the TOPEX microwave radiometer, IEEE Trans. Geosci. Remote Sens., 40, 509-511
- **RD 5** R. Scharoo, J. Lillibridge, W. Smith, 2004: Cross-calibration and long-term monitoring of the microwave radiometers of ERS, TOPEX, GFO, Jason and Envisat, **Marine Geodesy, 27, 279-297**
- RD 6 R. Kroodsma, D. McKague, C. Ruf, 2012: Inter-Calibration of Microwave Radiometers Using the Vicarious Cold Calibration Double Difference Method, Applied Earth Obs. and Remote Sensing, 5, 1939-1404
- **RD 7** Estimation des dérives et des incertitudes associées pour les radiomètres micro-ondes. Revue des méthodes existantes, **SALP-NT-MM-EE-22288**,
- **RD 8** Brown, S., C. Ruf, S. Keihm, and A. Kitiyakara, "Jason Microwave Radiometer Performance and On-Orbit Calibration," Mar. Geod., vol. 27, no. 1–2, pp. 199–220, 2004.
- **RD 9** M. L. Frery et al., "Sentinel-3 microwave radiometers: Instrument description, calibration and geophysical products performances," Remote Sens., vol. 12, no. 16, pp. 1–24, 2020.

## 4.3 Geophysical products

#### 4.3.1 Monitoring of geophysical products

In this section, comparisons of MWR-model fields are performed for several instruments. The selected instruments are Jason3/AMR and SARAL/AltiKa. For a long-term monitoring perspective, GDR products are used to compute the difference with respect to model values. Model values for each field are computed using ECMWF analyses data. GDR products for each mission have their own latency due to cycle curation and mission constraints such as the cold-sky calibration for and Jason-3 missions. Indeed, AltiKa GDR is available with delay of 35 days, while for Jason3 this delay is up to 60 days.

#### 4.3.1.1 Wet tropospheric correction

Figure 29 shows the monitoring of the MWR-model differences of wet tropospheric correction (ΔWTC) using Level2 NTC products from the Marine Center. S3A/B corrections are compared to Jason3 and SARAL corrections. GDR products were selected for SARAL (annoted AL in Figure 29) and Jason3 (J3). A



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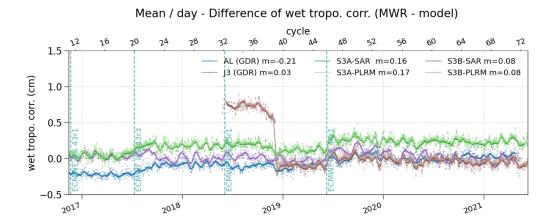
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30-days moving window averaging is applied in order to smooth the day-to-day variations. The daily data is shown by the points, and the averaging shown by the line, both with the same color corresponding to each mission. S3B monitoring shown below represents on-the-fly data, and not the reprocessed data. Monitoring over reprocessed data would not shown the steps due to IPF configuration update, such as MWR characterisation file.

The daily average of  $\Delta$ WTC for S3A is moving from0cm to 0.2cm while it is around -0.2cm for SARAL and Jason-3. S3B  $\Delta$ WTC daily average was around 0.7cm from May to November 2018, close to AltiKa and J3 values. In December 2018, the update of the characterization file modified the average to -0.1cm. This difference is small and results partially from the inversion algorithm. The more relevant parameter to assess the performance of a correction is the standard deviation of  $\Delta$ WTC. First, Jason3 benefits from their three channels radiometer (18.7GHz, 23.8GHz, 34GHz), providing a correction with a smaller deviation with respect to the model. SARAL/MWR is closer to S3A/B/MWR in this context with its two channels (23.8GHz, 37GHz). Then the standard deviation for SARAL is the closest reference, even though the Sigma0 in Ka band raises some questions. With the use of NTC products for S3A/B, the  $\Delta$ WTC for the three instruments are directly comparable since all missions use ECMWF analyses for the computation of the model correction. The standard deviation of  $\Delta$ WTC for S3A/B is smaller than for SARAL meaning that S3A/B have a better consistency with the model. Jason-3 shows the best consistency with the smallest deviation. Moreover, one can notice that both SAR and PLMR corrections have very similar deviations with respect to the model.



Std / day - Difference of wet tropo. corr. (MWR - model) cycle 12 Δ0 36 48 AL (GDR) m=1.42 S3A-SAR m=1.40 S3B-SAR m=1.42 1.8 S3B-PLRM m=1.40 13 (GDR) m=1.19 S3A-PLRM m=1.39 wet tropo. corr. (cm) 2017 2019 2020 2021



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Figure 29 : Monitoring of difference MWR-model wet tropo. correction: daily average (left) and standard deviation (right). Selection of points with latitude between -60° and 60°, distance to coast >50km for S3A

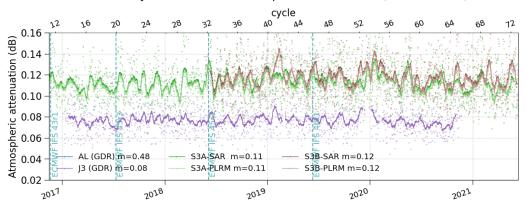
#### 4.3.1.2 Atmospheric attenuation

Figure 30 shows the monitoring of the MWR-model differences of atmospheric attenuation (ΔATM\_ATT) using Level2 NTC products from the Marine Center. Sentinel-3A/B corrections in Ku band are compared to Jason3/AMR. SARAL/AltiKa is not shown here because the altimeter uses the Ka band. A 30-days moving window averaging is applied in order to smooth the day-to-day variations. The daily data is shown by the points, and the averaging shown by the line, both with the same color corresponding to each mission. S3B monitoring shown below represents on-the-fly data, and not the reprocessed data. Monitoring over reprocessed data would not shown the steps due to IPF configuration update, such as MWR characterisation file.

Figure 30 shows that the mean of  $\Delta$ ATM\_ATT for Jason-3 is close to 0dB, a little larger for S-3A with 0.02dB. The evolution is stable for Jason3 and Sentinel-3A. The timeseries of S3B shows a small bias on the daily average with respect to S3A at the beginning of S3B mission. This bias seems closer to zero after the IPF update of the 6<sup>th</sup> December 2018 (S3B MWR characterisation file and SRAL configuration file). Standard deviation is similar for S3A and S3B.

Mean / day - Difference of atmospheric attenuation (MWR - model) cycle 20 32 44 12 0.03 Atmospheric attenuation (dB) 0.02 0.01 0.00 -0.01 -0.02AL (GDR) m=0.24 S3A-SAR m=0.02 S3B-SAR m=0.02 J3 (GDR) m=0.00 S3A-PLRM m=0.02 S3B-PLRM m=0.02 -0.03 2018 2019 2020 2017 2021

Std / day - Difference of atmospheric attenuation (MWR - model)





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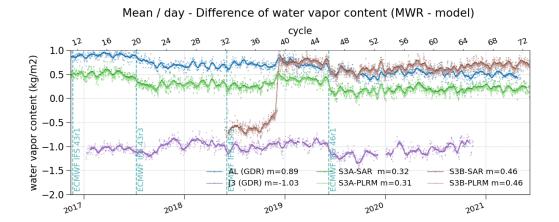
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Figure 30 : Monitoring of difference MWR-model atmospheric attenuation: daily average (left) and standard deviation (right). Selection of points with latitude between -60° and 60°

#### 4.3.1.3 Water vapor content

Figure 31 shows the monitoring of the MWR-model differences of atmospheric attenuation (ΔWV) using Level2 Non Time Critical (NTC) products from the Marine Center. Sentinel-3A/B correction is compared to Jason3/AMR and AltiKa. A 30-days moving window averaging is applied in order to smooth the day-to-day variations. The daily data is shown by the points, and the averaging shown by the line, both with the same color corresponding to each mission. S3B monitoring shown below represents on-the-fly data, and not the reprocessed data. Monitoring over reprocessed data would not shown the steps due to IPF configuration update, such as MWR characterisation file.

Figure 31 shows that the mean of ΔWV for AltiKa is around -0.58kg/m2, around -1.05kg/m2 for Jason3, and a little larger for Sentinel-3A: around 0.35kg/m2 in average. AltiKa timeseries is impacted by the update of the processing of the GDR at the end of 2019, changing the mean value from -0.5kg/m2 to 0.5kg/M2, now very close to S3B values. The standard deviation of ΔWV is very similar between AltiKa (2.46kg/m2), S3A (2.24kg/m2 for PLRM) and S3B (2.28kg/m2 for PLRM), and a little smaller for Jason3 around 1.9kg/m2. A finer tuning of the retrieval algorithm is expected to correct for the small difference of the daily average. In S3B timeseries, a bias of about 1kg/m2 is observed on the daily average with respect to S3A at the beginning of the mission. This bias is reduced to 0.2kg/m2 after the IPF update of the 6<sup>th</sup> December 2018 (S3B MWR characterisation file and SRAL configuration file). Standard deviation is similar for S3A and S3B.





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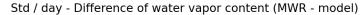
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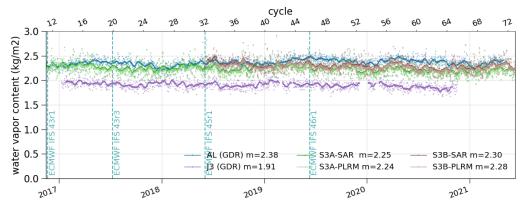
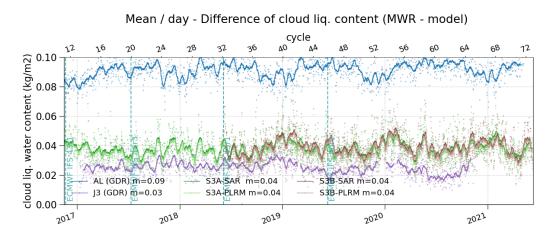


Figure 31 : Monitoring of difference MWR-ECMWF water vapour content: daily average (left) and standard deviation (right). Selection of points with latitude between -60° and 60°

#### 4.3.1.4 Cloud liquid water content

Figure 32 shows the monitoring of the MWR-model differences of cloud liquid water content ( $\Delta$ WC) using Level2 STC products from the Marine Center. Sentinel-3A/B fields is compared to Jason2/AMR, Jason3/AMR and SARAL/AltiKa. A 30-days moving window averaging is applied in order to smooth the day-to-day variations. The daily data is shown by the points, and the averaging shown by the line, both with the same color corresponding to each mission. For AltiKa, the update of the processing of the GDR at the end of 2019 has an impact on the  $\Delta$ WC, changing the mean value from 0.05 to 0.08 kg/m2.

Figure 32 shows that the several evolutions affected mainly the average value of  $\Delta$ WC: the daily average show steps when the configuration of the IPF is updated but with a smaller effect than for the other geophysical parameters, while the standard deviation is stable over the whole period. The mean of  $\Delta$ WC is close to 0.04kg/m2 for AltiKa, and S3A/B but around 0.03kg/m2 for Jason3. The standard deviation of Sentinel-3A is little higher than for the three other missions:  $\sim$  0.3kg/m2 for S3-A,  $\sim$  0.2 kg/m2 for the other missions. This point needs to be analyzed. For S3B, daily average is very close to S3A results since the beginning of the mission. The IPF update of the 6<sup>th</sup> December 2018 for S3B (MWR characterisation file and SRAL configuration file) had no significant impact on this parameter. Standard deviation is similar for S3A and S3B.





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Std / day - Difference of cloud liq. content (MWR - model)

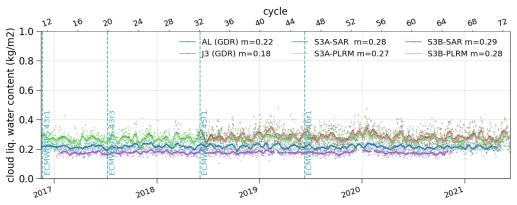


Figure 32 : Monitoring of difference MWR-ECMWF cloud liquid water content: daily average (left) and standard deviation (right). Selection of points with latitude between -60° and 60°

### 4.3.2 Comparison to in-situ measurements

#### 4.3.2.1 Comparison to radiosonde observations

The database is under construction and validation. Studies are on-going.

Several networks exist as provider of radiosonde data. For time being, we are using radiosonde observations provided by IGRA network (Integrated Global Radiosonde Archive). This archive [http://www.ncdc.noaa.gov/oa/climate/igra/] gathers around 1500 stations from 1963 up to now. A quality control is applied on each station but there is no bias correction of the raw measurements.

This network provides measurements for open ocean islands, coastal and land stations. On this study, we applied the method proposed by S. Brown during the JMR on-orbit calibration (S. Brown, C. Ruf, S. Keihm, and A. Kitiyakara, "Jason Microwave Radiometer Performance and On-Orbit Calibration," Mar. Geod., vol. 27, no. February 2015, pp. 199–220, 2004.). The first step is to select a subset of open ocean stations. Over this batch of open ocean station, we will work with stations close enough in space and time of S3A track (500km;9h) and a number of coincident measurements sufficient for the analysis. Figure 33 shows the coverage of all stations (blue and red points), red points are the stations selected for the analysis of S3A data.

The wet tropospheric correction derived from profile's humidity and temperature measurements are compared to the MWR correction at the closest approach point with no land contamination. To avoid land contamination, a minimum distance from shoreline of 25km is required.



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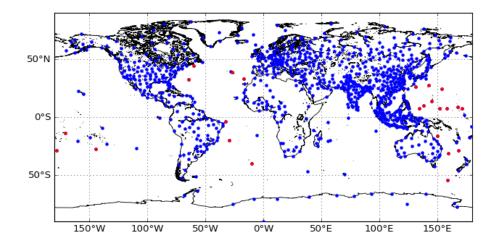


Figure 33: IGRA archive coverage (blue+red). Red points are the stations selected for comparison to S3A wet tropospheric correction.

Results of the comparison are provided in Table 3 for various spatial and temporal separation. The mean bias is 1.1cm and standard deviation of 3.38cm for all weather conditions with 315km and 6h as the bounds for the closest approach point. The std difference decreases as the closest approach bounds are reduced.

MWR Liquid water (kg/m2)	Wind	Spatial (km)	Temporal (hrs)	Mean (cm)	Std (cm)	Nbr of samples
All	All	<315	<6	1.13	3.39	13269
All	All	<150	<3	1.48	2.72	4603
All	All	<75	<1	1.60	2.28	930
<0.3	All	<75	<1	1.41	2.12	676

Table 3: Mean and Std of the MWR-RaOb WTC differences

Timeseries of the comparison of path delays from MWR and RaOb from selected stations is shown in Figure 34. The same bias and standard deviation than in Table 3. In that plot, is shown all data collocated within the following selection criteria: dist≤315km and dT≤6h. A small drift seems to be noticeable in that plot. It is too early to conclude on that "drift". More analysis and editing are required on the RaOb data.



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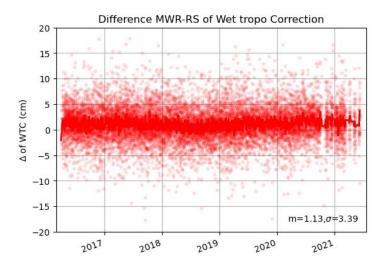


Figure 34: Timeseries of MWR-RaOb path delay for selected stations from IGRA network (selection criteria: dist≤315km and dT≤6h)

#### 4.3.2.2 Comparison to GPS observations

For the comparison to GPS measurements, we started by using the Suominet database (https://www.suominet.ucar.edu). The project is a university-based GPS network developed for atmospheric research presented in this paper:

Ware, R.H., D.W. Fulker, S.A. Stein, D.N. Anderson, S.K. Avery, R.D. Clark, K.K. Droegemeier, J.P. Kuettner, J.B. Minster, and S. Sorooshian, 2000: SuomiNet: A Real-Time National GPS Network for Atmospheric Research and Education. Bull. Amer. Meteor. Soc., 81, 677–694, https://doi.org/10.1175/1520-0477(2000)081<0677:SARNGN>2.3.CO;2

The network exploits the ability of ground-based GPS receivers to perform hourly measurements of the lower and upper atmospheres. Estimations of the wet and dry path delay can be performed from these GPS measurements. Measurements are provided every half-hour.

For this analysis, a selection of stations is performed with the following criteria:

- Providing data along the full period 2016-2018
- Providing valid value of the wet delay
- Close to S3A ground track
- Position of the station far from ice: some stations can be rounded by ice seasonally, thus MWR will be contaminated and the retrieved wet tropospheric correction will not be accurate.

Using the criteria mentioned above, we selected 19 stations indicated by the red points in Figure 35.



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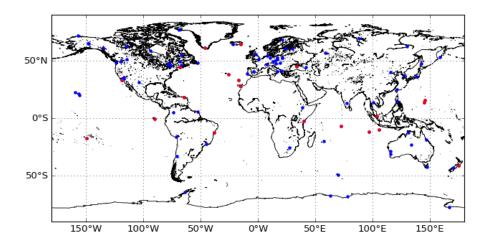


Figure 35: Map of stations of Suominet network: all (blue), selected for comparison to S3 MWR (red)

The selection in space is the same than for the radiosonde. The selection in time is easier in the context of the comparison with GPS as it provides measurements every 30 minutes. It means that if the ground track of S3A or S3B is close to a GPS station, the minimum time difference between MWR and GPS will be 30 minutes at maximum. To avoid land contamination, a minimum distance from shoreline of 25km is required.

Statistics of the comparison of MWR-GPS wet path delay are shown in Table 4. We observe a mean bias of 0.19 cm in the MWR-GPS wet path delay with a standard deviation of 2.82cm, both are smaller than in the comparison of MWR to RaOb. The number of points which is greater in that context can explain a part of it.

MWR Liquid water (kg/m2)	Wind	Spatial (km)	Temporal (hrs)	Mean (cm)	Std (cm)	Nbr of samples
All	All	<315	<6	0.19	2.83	24378
All	All	<150	<3	0.20	2.09	11109
All	All	<75	<1	0.25	1.79	4805
<0.3	All	<75	<1	0.17	1.70	4526

Table 4: Mean and Std of the MWR-GPS WTC differences

Figure 36 show the timeseries of MWR-GPS wet path delay. As one can see, there is dates with no comparison. It is more likely to be due to missing measurements in the GPS database. This must be confirmed. The mean bias of 0.19cm is retrieved from Table 4 as well as the standard deviation of 2.79cm. A slope of -0.03cm per year is estimated from the MWR/GPS comparison.

# Mission Performance Centre

## **Sentinel-3 MPC**

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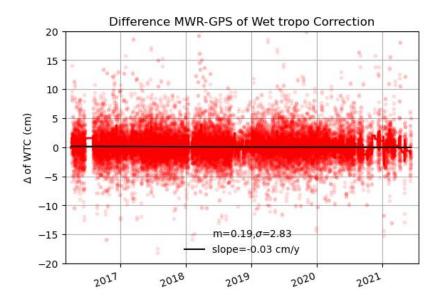


Figure 36: Timeserie of MWR-GPS wet delay for Sentinel-3A



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## **5** Events

Add here the list of all MWR events happened during the cycle.

# SENTINEL 3 Mission Performance Centre

#### **Sentinel-3 MPC**

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## 6 Appendix A

Other reports related to the Optical mission are:

- S3 SRAL Cyclic Performance Report, S3A Cycle No. 072, S3B Cycle No. 053 (ref. S3MPC.ISD.PR.04-072-053)
- S3 Ocean Validation Cyclic Performance Report, S3A Cycle No. 072, S3B Cycle No. 053 (ref. S3MPC.CLS.PR.06-072-053)
- S3 Winds and Waves Cyclic Performance Report, S3A Cycle No. 072, S3B Cycle No. 053 (ref. S3MPC.ECM.PR.07-072-053)
- S3 Land and Sea Ice Cyclic Performance Report, S3A Cycle No. 072, S3B Cycle No. 053 (ref. S3MPC.UCL.PR.08-072-053)

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

**End of document**