



Customer:	ESA	Document Ref.:	S3MPC.ACR.MEM.098
Contract No.:	4000111836/14/I-LG	Date:	18/05/2022
		Issue:	1.1

Project:	PREPARATION AND OPERATIONS OF THE MISSION PERFORMANCE CENTRE (MPC)
	FOR THE COPERNICUS SENTINEL-3 MISSION
Title:	Validation of OLCI L1 uncertainties
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Distribution:	
Filename	S3MPC.ACR.MEM.098 - i1r1 - Validation of OLCI L1 uncertainties.docx

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Validation of OLCI L1 uncertainties

# **Changes Log**

Version	Date	Changes	
28/03/2022	1.0	Initial version	
09/05/2022	1.1	Additions requested by EUMETSAT	

# List of Changes

Version	Section	Answers to RID	Changes	
1.1	2.2		Add a sub-section with uncertainty histograms and coverage intervals	



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# **Reference Documents**

RD	Document
[RD01]	GUM, JCGM. Evaluation of Measurement Data—Guide to the Expression of Uncertainty in Measurement; JCGM: Paris, France, 2008; Volume 100
[RD02]	<ul> <li>Hunt, S.E.; Mittaz, J.P.D.; Smith, D.; Polehampton, E.; Yemelyanova, R.; Woolliams, E.R.;</li> <li>Donlon, C. Comparison of the Sentinel-3A and B SLSTR Tandem Phase Data Using</li> <li>Metrological Principles. <i>Remote Sens.</i> 2020, <i>12</i>, 2893.</li> </ul>
[RD03]	OLCI Level 0, Level 1b Algorithm Theoretical Basis Document, Ludovic Bourg, S3-ACR- TN-007, issue 5.0, 10/12/2014
[RD04]	OLCI Level 1 uncertainties ATBD S3MPC.ACR.TN.008 - i1r3 – OLCI L1 uncertainties ATBD
[RD05]	Lamquin, N.; Clerc, S.; Bourg, L.; Donlon, C. OLCI A/B Tandem Phase Analysis, Part 1: Level 1 Homogenisation and Harmonisation. <i>Remote Sens.</i> <b>2020</b> , <i>12</i> , 1804. https://doi.org/10.3390/rs12111804



# **1** Context

Satellite sensor validation activities are mandatory to monitor and investigate instruments performances characteristics. In the case of the OLCI sensors on-board Sentinel-3A and Sentinel-3B satellites, the 6 months tandem phase was an essential source of data for an accurate sensor-to-sensor comparison and a possible inter-calibration of the instrument.

The lack of uncertainties associated to the satellite data is a common limitation to the validation activities, especially from a metrological point of view. In the case of OLCI, and contrary to the SLSTR instrument, the level-1 uncertainties were not available during the tandem-phase analysis. Since then, Sentinel-3 OLCI L1 per-pixel radiometric uncertainties have been computed from the level-0 measurement by propagating sources of uncertainty at each step of the global level-1 processing chain (see OLCI Level 1 ATBD [RD03] and Level 1 Uncertainty ATBD [RD04]), following the GUM methodology [RD01].

The uncertainty validation methodology is a qualitative way to assess the representativity of the uncertainties, it is not designed to produce quantitative results (as it is usually expected from "validation" analysis). This work presents an analysis of the OLCI tandem data aiming to validate the OLCI level-1 uncertainties. The overall methodology is based on the 2020 article by Hunt et al [RD02], used for the SLSTR tandem phase analysis. The objective of this study is to adapt the methodology to OLCI specificities to compare the distribution of computed uncertainties with the distribution of observed OLCI-A and OLCI-B differences during the tandem campaign.



# 2 Data and Methodology

### 2.1 Custom L1 reprocessing

At its launch, S3B was set up in a tandem phase with S3A for roughly 6 months, from 7th June to 16th October 2018. During this phase, the 2 satellites shared the same orbit with S3B 30 seconds ahead of S3A. For the current study, 4 full days of July 2018 (one per week) were used to produce inter-comparison regarding the per-pixel radiometric uncertainties: 2nd, 9th, 16th and 23rd of July 2018.

To reprocess the selected LO data into L1 products, with the L1-IPF uncertainty prototype that produces both TOA radiances and associated uncertainties, the radiometric gain models (RGM) were re-computed to produce the models and their associated uncertainties needed during the L1 processing.

The computation of RGM involves fitting data on different time periods to account for different gains evolution dynamics. While fitting data on relatively short duration can be necessary to represent rapid transitional effect (especially at the beginning of S3B mission, including during the tandem phase), it can be harmful to the associated uncertainties, as fewer fitting points leads to a global increase of the variances and covariances of the fit results. In the context of the uncertainty validation study, specific "uncertainty RGM" has been computed with a particular attention to provide the best radiometric accuracy possible, while preserving a comparable fitting duration for both S3A and S3B. This translates into a degradation of the radiometric accuracy for the tandem phase restricted to the 2 first bands of S3B, and without impact on the S3A results.

# 2.2 Uncertainty histogram and coverage interval

Before the tandem metrological comparison, uncertainty products are analysed by histograms and scatterplots. Data from a complete day of reprocessing are accumulated in histograms to derive the figures presented at the end of this sub-section.

Histograms are presented for the radiances, with the uncertainties in physical unit and the uncertainties expressed in percentage of radiance, for both OLCI-A and OLCI-B. Figure 1, *Figure* 2 and Figure 3 respectively present the results for the band Oa01, Oa5 and Oa21. For the percentage uncertainties (right column of the plots) the 95% coverage interval is represented in colour (red for S3A and blue for S3B) and the remaining 5% histogram points are plotted in grey colour. The 95% coverage interval is the interval containing the central 95% of the uncertainty values, i.e. the interval defined by the 2.5<sup>th</sup> and 97.5<sup>th</sup> percentiles.



Figure 1 : Oa01 histograms for L1 radiances (left column), uncertainties in physical unit (middle column) and uncertainties in percentage (right column). In red for S3A (top row) and blue for S3B (bottom row). For the latter plot (uncertainties in %) the coloured area illustrates the 95% coverage.



Figure 2: Same as Figure 1 for Oa05.



2.5

2.0

1.0

0.5

0.0

1.5 Occurence

8

Sce

Occu

2

0 .

50

100

150

Radiance [mW.m-2.sr-1.nm-1]

200

250

Figure 3: Same as Figure 1 for Oa21. Note: the last bin of the percentage uncertainties (right column) contains all values above 35%.

4

Uncertainties [mW.m-2.sr-1.nm-1]

6

1.4 1.2

1.0

0.8

0.6 0.4

0.2

0.0

0

5 10 15 20 25 30 35+

Uncertainties [%]

Occu

The median uncertainty and the 95% coverage interval of the percentages are computed for each band and represented in Figure 4. While the 95% coverage remains roughly below 5% up to band Oa12, a stronger dispersion is seen for band Oa20 and Oa21. Ocean signal is very low for band Oa21, and some uncertainty contributors, like the gain modelling, are uncompressible and not based on the input flux, which may lead to high percentage uncertainty for very low signal pixels. For band Oa21, Figure 3 middle graphs, highlight the fact that the uncertainties in physical unit remain largely above a minimum value (roughly 0.5) and do not present outlier values either.

The median value of uncertainties computed over a full day of acquisition, remains below 2% for all visible bands, up to Oa12, as shown in *Table* 1. Higher medians are visible on the absorption bands as expected; and in the NIR as explained above. A strong asymmetry is visible on the 95% coverage interval with a median value closer to the inferior limit, especially in the NIR. This reflects the very wide shape of the percentage histograms (right column of Figure 3).

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Figure 4 : Median uncertainty values and 95% coverage intervals for A and B.

Pand		wavelength	S3A unc median	S3B unc median
Ваг	ıa	[nm]	[%]	[%]
Oa	1	400	1.5	1.85
Oa	2	412.5	1.44	1.64
Oa	3	442.5	1.37	1.79
Oa	4	490	1.5	1.73
Oa	5	510	1.45	1.82
Oa	6	560	1.6	1.76
Oa	7	620	1.56	1.87
Oa	8	665	1.44	1.73
Oa	9	673.75	1.65	1.82
Oa1	10	681.25	1.49	1.76
Oa1	11	708.75	1.42	1.76
Oa1	12	753.75	1.4	1.64
Oa1	13	761.25	3.96	4.25
Oa1	14	764.375	2.84	3.13
Oa1	15	767.5	1.82	2.51
Oa1	16	778.75	1.02	1.36
Oa1	17	865	1.35	1.67
Oa1	18	885	2.08	2.38
Oa1	19	900	2.44	2.75
Oa2	20	940	4	4.79
Oa2	21	1020	3.17	3.81

Table 1 : Per band uncertainty median values computed on a full day of acquisition.



### 2.3 Tandem comparison methodology

Overall methodology is based on the SLSTR analysis [RD02] and adapted to the OLCI characteristics. To mitigate the impact of the match-up error during the comparison of L1 radiance at pixel-level, data are first reprojected on a co-registered grid and then binned into macro pixels; uncertainty is propagated through re-gridding process following the GUM recommendation.

#### Reprojection

OLCI L1 FR granules are reprojected on 0.003°x0.003° grid cells, a resolution similar to the instrument full resolution (roughly 300 meters). A "nearest neighbour" method is used for the reprojection allowing a direct use of radiances and associated uncertainties.

#### **Flag selection**

L1 quality flags are used to discard irrelevant pixels from the study, especially SATURATED, BRIGHT, INVALID and COSMETIC pixels. Bright pixel roughly covers major cloud area which are not the focus of this work.

#### Binning

Then data are binned into 4x4 macro pixel to produce a pseudo "Reduced Resolution" pixel (around 1.2 km). Macro-pixel radiance, L<sub>MP</sub>, is the mean of the N individual pixels radiances, L<sub>i</sub>, contributing to the macro-pixel. Macro-pixel uncertainties are obtained by propagating the pixel uncertainties through the binning process, equation 1, following the standard method available in the GUM. OLCI uncertainties are composed of independent uncertainties (i.e., uncorrelated) dominated by the random processes. Propagation of individual uncorrelated pixels uncertainties through equation 1 lead to a macro pixel uncertainty expressed as in equation 2.

Radiance: 
$$L_{MP} = \frac{1}{N} \sum_{i=1}^{N} L_i$$
 1

Νī

$$u^{2}(L_{MP}) = \frac{1}{N^{2}} \sum_{i=1}^{N} u^{2}(L_{i})$$
<sup>2</sup>

#### Coefficient of variation criteria

A coefficient of variation criteria is applied to macro-pixels in order to select homogenous pixels. Coefficient of variation id defined as the ratio of the standard deviation and the mean value.

CV test: 
$$CV = \frac{\sigma}{\mu} < 0.15$$
 3

#### Aggregation

For each macro-pixel passing the selection criteria, radiances and uncertainties are aggregated into "sets", which typically contain macro-pixels information from roughly 50 different granules, all originated from

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the same day of acquisition. Aggregation in sets is performed to achieve a better statistic as some granules are severely screened due to the flag selection. It also assures the reproducibility of the results as it is fairly stable between the different sets.

#### **Uncertainty-Normalised differences**

The validation methodology commonly used is based on the analysis of the distribution of the difference of radiances normalised by the propagated uncertainty of the difference, this ratio is called "Epsilon" in the following document. In the case of OLCI-A/B the sensor-to-sensor covariance is not known, and no information allows to take it into account, in any case, it is expected to be negligeable. Therefore, the uncertainty of the difference can directly be expressed as the quadratic sum of the sensor individual uncertainties, and epsilon can be computed as follow:

Epsilon

$$\varepsilon_{i} = \frac{\Delta L}{u(\Delta L)} = \frac{L_{MP}^{S3A} - L_{MP}^{S3B}}{\sqrt{u^{2}(L_{MP}^{S3A}) + u^{2}(L_{MP}^{S3B})}}$$
4

Epsilon is computed individually for each macro-pixel of a set, then the global Epsilon distribution is analysed. If  $u(\Delta L)$  correctly represents the uncorrelated uncertainties of  $\Delta L$ , then the Epsilon distribution should be a standard normal distribution (i.e., a Gaussian centred on 0 with a standard deviation of 1). A standard deviation above 1 indicates and under-estimation of the uncertainties, while a standard deviation below 1 means an over-estimation of the uncertainties.

#### **Outlier filtering**

Despite the initial filtering some selected macro-pixel have outlier values that can impact the distribution, especially if residual match-up error dominates the macro-pixel radiance difference. To avoid the perturbation of the Epsilon distribution by these outliers, an additional filtering is applied removing all the macro-pixels above and below the following threshold:

$$Threshold = mean(Epsilon) + /- 3 * stdev(Epsilon)$$
5

### 2.4 OLCI-A/B instrumental differences impact

Conducting the analysis, as described in the previous section, leads to somewhat unsatisfying results, difficult to analyse. Figure 5 presents the results for Oa07 (620 nm): the Epsilon distribution mean value and standard deviation are higher than the expected values for a representative uncertainty. But more problematic, the shape of the Epsilon distribution is not Gaussian, it presents a clear bi-modal behaviour that complicates any proper analysis. Results are similar for other bands as shown on Figure 6, which gives the mean value and the standard deviation of the uncertainty-normalised difference for each band and for several days of processing.

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Figure 5 : Oa07 Epsilon distribution histogram for non-harmonised tandem data. The dotted-black curve represents the expected standard normal law (Gaussian of mean 0 and standard deviation of 1).



Figure 6 : Epsilon mean value and standard deviation of each band for results without harmonisation. Both are clearly above the expected values (0 for the mean and 1 for the standard deviation)

As shown in the Tandem data analysis [RD05], radiometric and spectral discrepancies between the two instruments must be considered for the evaluation of the radiance differences linked to random processes. As per [RD05], this process will be referred to below as data harmonisation.

The tandem data used in this study are calibrated individually for each instrument, level-1 TOA radiances are not harmonised between the OLCI-A and OLCI-B. Since the Epsilon distribution is computed from a

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radiance difference (and not from a radiance ratio), the known radiometric bias existing between the two instruments, around 2% in the blue and 1% in the NIR, impacts differently the low and the high radiances.



*Figure 7 : Left: L1 TOA radiance histograms for band Oa02, in red for OLCI-A and blue for OLCI-B. Right: Epsilon mean (red cross), and standard deviation (blue dot) computed per bin of radiance.* 

To highlight the effect of this bias on the uncertainty-normalised difference distribution, an analysis by bins of similar radiances is performed. L1A and L1B radiances histograms are used to compute the Epsilon distribution for macro-pixels within the same range of radiances, see Figure 7 (left plot) where the bins of radiance are represented with vertical lines over the histograms. For each radiance range, Epsilon distribution mean value and standard deviation are computed individually, see Figure 7 (right plot).

The mean value of Epsilon shows a clear relation with the radiance range. The individual Epsilon distributions for each radiance bin are represented as a Gaussian law, using the individually computed mean and standard deviation, and plotted on Figure 8 as orange curves. The dynamic impact of the uncorrected radiometric bias on the uncertainty-normalised difference distribution is then understandable as follows: the bi-modal behaviour of the global distribution is caused by a shift of the mean epsilon value between the low radiances and the high radiances. The consequences of the lack of harmonisation between OLCI-A and B are:

- A non-Gaussian shape of the Epsilon distribution.
- A strongly biased mean value.
- A higher standard deviation driven by the shift of the mean value.

This effect, shown here for band Oa07 but similar for all other bands, is making any conclusion regarding the validation of L1 uncertainties highly complicated.

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Figure 8: Epsilon histogram for the full distribution (in blue) and individual gaussian representation for Epsilon distribution per radiance range (in orange).

#### 2.5 Mean Delta L correction

The relation between the mean Epsilon value and the radiance range is directly inherited from the linear relation between the mean  $\Delta L$  and the radiance, as shown in Figure 9. In order to mitigate the non-harmonisation effect, the following correction was introduced: first a linear model between the mean  $\Delta L$  and the mean value of L1A over the radiance bin is fitted as follow:

$$\Delta L_{model} \qquad Mean(\Delta L_{bin}) = a * Mean(L1A_{bin}) + b \qquad 6$$

Then OLCI-A TOA radiance is corrected from the linear coefficient of the  $\Delta L_{model}$  in order to harmonise it with L1B, as describe in equation 7. This correction is not meant to be a full calibration harmonisation, it is used as a mitigation of the radiometric bias effect, in order to allow the analysis of the uncertainty-normalised difference.

$$L1A_{corr} = L1A * (1 - a)$$
 7

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Figure 9 : Delta L mean value (red cross) computed per bin of L1A radiance. A linear model is computed in green.

The Epsilon ratio is then recomputed as described in equation 4, but using  $L1A_{corr}$  instead of L1A. The bias harmonisation does not impact the uncertainty of L1A since only the random components of the uncertainties are considered in the OLCI analysis. The bias between OLCI-A and B was not represented by the uncertainties and need to be corrected for to obtain a coherent analysis.

With harmonised data (Figure 10), the global shape distribution is now close to a Gaussian. The individual Epsilon distributions per range of radiance are now all aligned and centred on 0, correcting the bi-modal behaviour of the non-harmonised data, see Figure 10 right plot (to be compared with Figure 8). The individual mean values and standard deviation of distribution per bin are showing a good stability along the radiance range, see Figure 10 left plot (to be compared to Figure 7 right plot). Harmonised data correct the 3 effects of the bias on the Epsilon distribution: the bi-modal behaviour, the biased mean value, and the large standard deviation.



Figure 10 : Harmonised data results for Oa07. Left: Epsilon mean (red cross), and standard deviation (blue dot) computed per bin of radiance. Right: Epsilon histogram and individual distribution per bin of radiance.

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### 2.6 Stability of the mean delta L model

For each set of granules processed, a mean  $\Delta L$  model is generated, but the results shows that the model coefficients are identical for each band between the different days processed. The linear coefficient is matching the known order of magnitude of the bias computed from the Tandem analysis, ~2% in the blue and ~1% in the NIR. The stability of the linear coefficient between the different days of processing is a good indication that the proposed method corrects the systematic bias and not a random error. Model parameters for Oa01 and the 3 absorption bands (Oa13 to Oa15) have a different behaviour, see section 3.2.



Figure 11: Mean Delta L model coefficients computed per band for different days of processing. Model slope on the left plot and model intercept on the right plot.



# **3** Results

# **3.1** Global harmonisation

The uncertainty validation methodology has been conducted on 4 sets of L1 granules, one per reprocessing day. If the variance of differences is correctly described by their uncertainties the resulting distribution should be a standard normal law – Gaussian centred on 0 with a standard deviation of 1. As previously shown for Oa07, the global harmonisation correction explains and solves the bi-modal effect polluting the epsilon distributions, resulting in Gaussian shaped histograms for most of the bands.

The overall statistic of the uncertainty-normalised difference computed for each set are presented below, in Figure 12, to be compared to Figure 6. The mean values are close to 0, and standard deviations remain around 1 for all the bands, to the exception of Oa01 and of the absorption bands (Oa13, Oa14 and Oa15). For these bands a remaining bias is not corrected by the global harmonisation and a more accurate method is needed.



Figure 12 : Uncertainty-normalised difference statistics per bands for several days of processing: mean values on left plot and standard deviations on right plot.

# 3.2 Per camera harmonisation

The first OLCI band, Oa01 at 400 nm, and the absorption bands, Oa13 – Oa14 – Oa15 respectively at 761, 764 and 767.5 nm, behave differently than others. The associated characteristics visible in Figure 12 are clearly degraded and the uncertainty-normalised differences distribution do not present a Gaussian shape: even with a globally harmonised data the multi-modal behaviour is not corrected, see Figure 13.





Figure 13 : Multi-modal Epsilon histogram for Oa01 and Oa15, even with globally harmonised data.

Contrary to other bands, the bias between L1A and L1B is driven by strong inter-camera differences and spectral differences rather than a calibration bias, which are poorly represented by the global harmonisation. The Figure 14 presents individual results per camera of OaO1, which highlight the inter-camera differences: Camera 2 mean value is negative (-1.106) while other cameras have a positive bias, 0.885 for camera 1 and between 1.8 and 2.8 for cameras 3, 4 and 5. When the 5 cameras are aggregated together, the full field of view distribution reflects 3 modes : a first one centred on "-1" matching camera 2, a second one centred on "1" matching camera 1 and a third one centred around "2" matching cameras 3, 4, 5.



Figure 14 : Band Oa01 Uncertainty-normalised difference per camera, for globally harmonised data. The 3 distinct modes of the full FoV distribution come from different cameras.

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The inter camera differences are linked, amongst others, to the spectral differences between the 2 instruments presented in Figure 15. The band Oa01 is the most impacted by the inter camera wavelength differences, especially for camera 2, matching the results seen in Figure 14. The bands Oa13 to Oa15 – dedicated to the measure of atomic oxygen absorption – do not appear to be more affected than other bands, but they are indeed more sensitive to the spectral differences due to sharpness of the O<sub>2</sub>-A atmospheric absorption line. To a lesser extent, the same applies to Oa19 and Oa20 affected by the water vapor atmospheric absorption at those wavelengths.



Figure 15 : Spectral differences between OLCI-A and OLCI-B per band.

To go further, the harmonisation methodology presented in section 2.5 is applied per camera, instead of across the full field of view. A corrective model is then fitted on each camera and applied on the corresponding pixels. Figure 16 presents the individual harmonisation models fitted for each camera for the bands Oa01 and Oa15, the global model (blue cross) is obviously not a good representative of the individual per camera models (coloured dots). By correcting each pixel with the appropriate model, the inter-camera differences are accounted for and the remaining multi-modal behaviour visible for the degraded bands is corrected, see results from Figure 17 to be compared to Figure 13.





Figure 16 : harmonisation models per camera, for band Oa01 (left) and Oa15 (right)



Figure 17: Epsilon histogram for Oa01 and Oa15, with "Per camera" harmonised data. The multi modal behaviour is now corrected.

### 3.3 Interpretation

The per camera harmonisation method is generalised to all the bands for the 4 sets used for the analysis. For most of the bands, the results are almost identical between the global harmonisation and the per camera one, but for the bands where the bias is driven by inter-camera differences the method greatly improves the results, presented on the Figure 18, as compared to Figure 12 or even to Figure 6.





Figure 18: Uncertainty-normalised difference statistics per bands, with the per camera harmonisation. Left: Mean Epsilon values. Right: Epsilon standard deviation.

For each band, the uncertainty-normalised difference is a Gaussian distribution without any multi-modal shape, see individual figures given in annex A. The mean values of the epsilon distributions are close to 0 for all bands, meaning that the main sources of biases have been corrected by the per camera harmonisation. The standard deviation presented on the right plot of the Figure 18 are analysed as follows:

- Bands Oa01 to Oa15 [400 to 767 nm]: the standard deviation remains between 1 and 1.50, and even below ~1.3 up to band Oa10 [681 nm], indicating a very good representation of the variance by the uncertainties for the visible bands.
- Bands Oa16 and Oa17 [779 and 865 nm]: shows are slightly higher standard deviations, around ~1.75 for Oa16, indicating a possible small under-estimation of the uncertainties.
- Bands Oa18 to Oa21: present standard deviations truly close to expected value of 1.

Overall results are certainly good: gaussian shape distributions, low biased mean values, and standard deviations within acceptable range for all the bands. The OLCI uncertainties correctly represent the variance of level-1 TOA radiance.

Detailed analysis shows that improvements are still possible, especially an increasing trend is visible in the standard deviation from Oa02 to Oa17, this progressive rise of the STD with the wavelength could indicate a possible under-estimation of an uncertainty component evolving with the wavelength, or some term that might be more representative for the blue bands than for the red ones.



# 4 Conclusion

The validation of uncertainty methodology presented in [RD02] for SLSTR was successfully adapted to OLCI specificities. It was shown that a rough level-1 harmonisation of OLCI-A and OLCI-B is required to correct the radiometric biases that prevent any conclusive analysis of the uncertainty-normalised difference. For some bands where biases are driven by the inter-camera differences the methodology had to be applied on each camera separately to account for most of the biases.

Overall results are really satisfying: the uncertainty-normalised difference distribution follows the standard normal gaussian law, validating that the uncertainties correctly describe the variance of the radiometric differences for all the bands.

The proposed uncertainty validation remains a qualitative tool to assess the representativity of the uncertainties, quantitative estimation per band is not foreseen by the methodology, only comparative analysis can be done. For example, the slightly higher standard deviations obtained around band Oa16 might indicate a small under-estimation of at least one component of the uncertainties around this wavelength.



10.0

10.0

7.5

7.5

# A. Detailled results for 23rd of July set.

The following figures detailed the uncertainty-normalised distribution, obtained from per-camera harmonised data, for each band of the 23rd of July set.





0.0

Epsilon

0.0

Epsilon

2.5

5.0

2.5

5.0



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0.1

0.0

-10.0

-7.5

-5.0

-2.5

0.0

Epsilon

2.5

5.0

7.5

10.0



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Epsilon











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