CalibSat: CalibrEO Cal/Val report

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SUMMARY

This report presents the CalibrEO performance evaluation of the CalibSat satellite, focusing on both radiometric and geometric aspects. The evaluation is structured into two main parts:

Part 1: Radiometric Report
This section provides an in-depth analysis of the radiometric performance of CalibSat using the CalibrEO absolute calibration tools. The absolute calibration assessment involves comparing satellite-measured TOA (Top-Of-Atmosphere) reflectance to simulated/reference values across multiple acquisitions and spectral bands. Cross-calibration against Sentinel-2 data further supports the assessment of radiometric consistency. Additional investigations include dark current behaviour, high-frequency (HF) non-uniformities, and the identification of bad pixels. Image quality is evaluated using signal-to-noise ratio (SNR) analysis over homogeneous desert areas, and geometric sharpness is assessed through the Modulation Transfer Function (MTF).

Part 2: Geometric Report
This section covers the geometric performance of the CalibSat sensor. It will include analyses and results related to absolute and interband geometric calibration accuracy.

Together, these components aim to provide a comprehensive evaluation of the CalibSat sensor's readiness for operational use and its suitability for scientific Earth observation applications.

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1 PART 1: RADIOMETRIC REPORT

1.1 Absolute Calibration

The absolute radiometric accuracy of the CalibSat satellite is assessed using the CalibrEO absolute radiometric calibration tools.

1.1.1 Input Data

Table 1 List of input data for the absolute calibration

	Filename
1	CalibSat_010324_2313_V1
2	CalibSat_010424_2005_V1
3	CalibSat_010524_1832_V1
4	CalibSat_010624_0052_V1
5	CalibSat_010724_0250_V1
6	CalibSat_010824_1313_V1
7	CalibSat_010924_1501_V1
8	CalibSat_011024_2059_V1
9	CalibSat_011124_2141_V1
10	CalibSat_011224_2002_V1
11	CalibSat_010125_0338_V1
12	CalibSat_010225_0719_V1
13	CalibSat_010325_0233_V1

1.1.2 Results

1.1.2.1 Average Results

Figure 2 and Table 2 present the mean ratio (averaged over all acquisitions) of the satellite-measured TOA reflectance to the simulated/reference TOA reflectance, as a function of spectral band and CWV. The results show that the TOA reflectance in CalibSat B3 is approximately 8% too low, while in B7 it is about 8.5% too high. All other bands fall within the 3% accuracy margin.

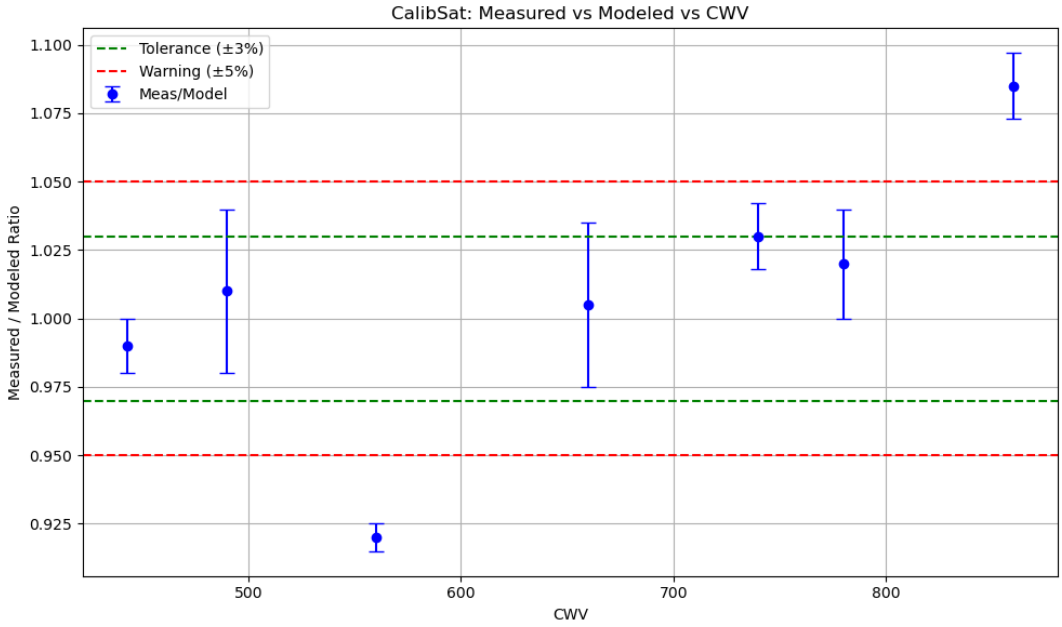


Figure 1 Average absolute calibration results (+/- 1 stdev) in function of spectral band/CWV

Table 2 Average absolute calibration results

Band	CWV	Meas/Model	Stdev
B1	443	0.990	0.010
B2	490	1.010	0.030
B3	560	0.920	0.005
B4	660	1.005	0.030
B5	740	1.030	0.012
B6	780	1.020	0.020
B7	860	1.085	0.012

1.1.2.2 Timeseries

Figure 2 shows the CalibSat absolute calibration results, expressed as the ratio of the satellite-measured TOA reflectance to the simulated/reference TOA reflectance, as a function of acquisition date. No trend is observed.

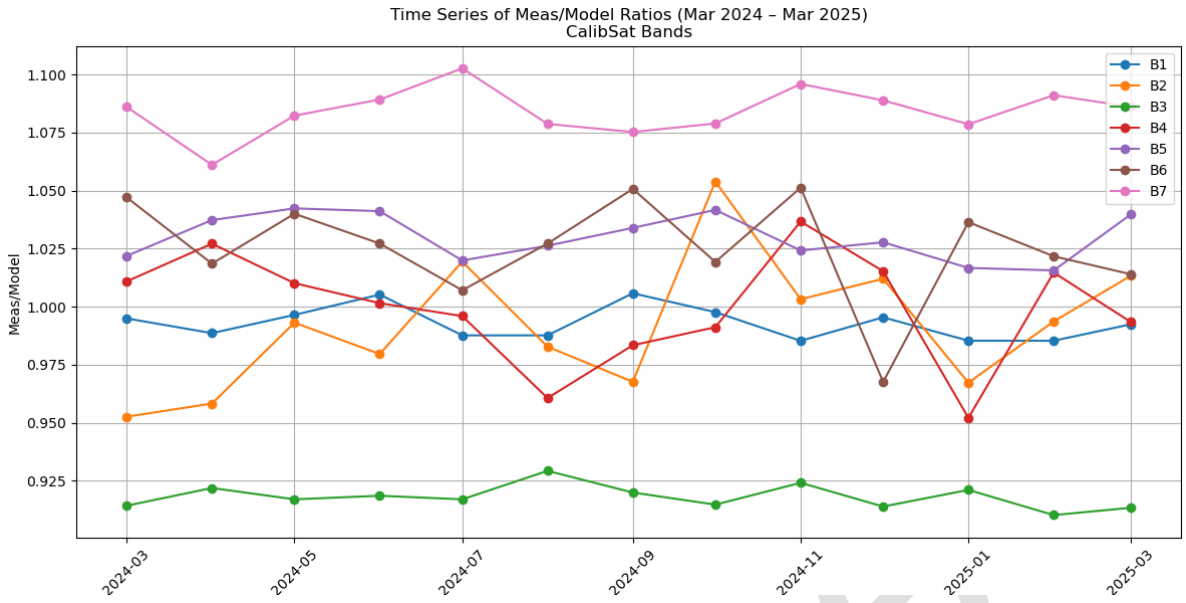


Figure 2 Calibration results per spectral band in function of acquisition date

1.2 Cross-Calibration against Sentinel-2

1.2.1 Input Data

Table 3 List of input data for cross-calibration against Sentinel-2

	Filename
1	CalibSat_011223_2313_V1
2	CalibSat_120124_2005_V1
3	CalibSat_010224_1832_V1
4	CalibSat_020324_0052_V1
5	CalibSat_010424_0250_V1
6	CalibSat_150524_1313_V1
7	CalibSat_060624_1501_V1
8	CalibSat_081024_2059_V1
9	CalibSat_101124_2141_V1
10	CalibSat_121224_2002_V1

1.2.2 Results

Figure 3 shows the scatterplot of CalibSat TOA reflectance versus Sentinel-2 TOA reflectance. The observations lie close to the 1:1 line, except for bands B3 and B7. Similar to the absolute calibration results, an underestimation and overestimation of TOA reflectance are observed in B3 and B7, respectively, compared to Sentinel-2.

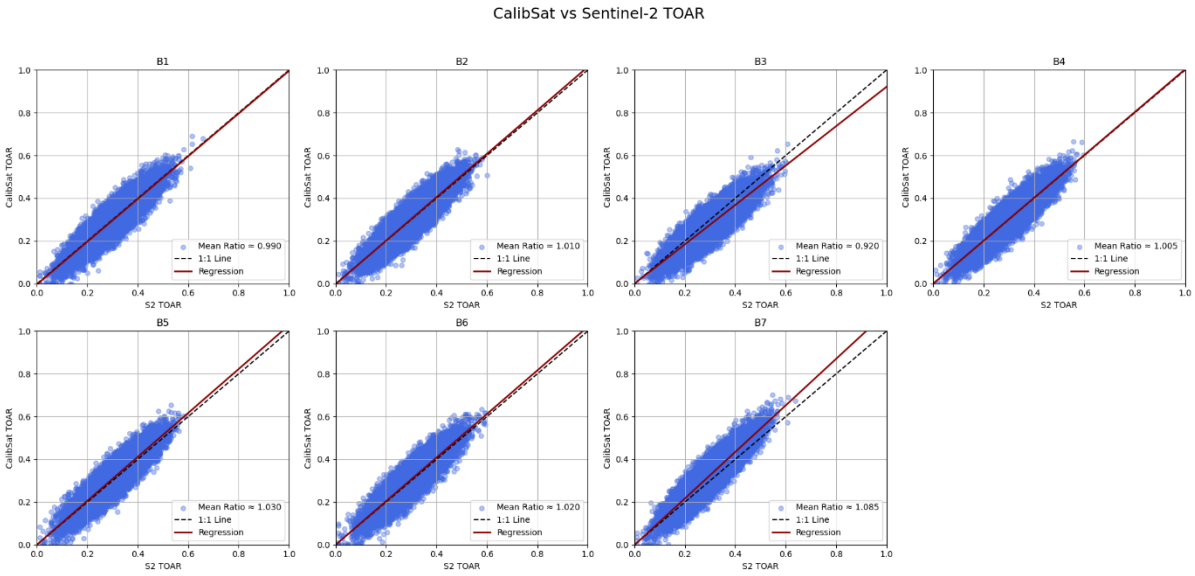


Figure 3 Calibsat vs Sentinel-2 Cross-calibration

1.3 Dark Current

1.3.1 Input Data

Table 4 List of input data for Dark Current calibration

	Filename
1	CalibSat_121223_2313_V1
2	CalibSat_200124_2005_V1
3	CalibSat_110224_1832_V1
4	CalibSat_120324_0052_V1
5	CalibSat_210424_0250_V1
6	CalibSat_050524_1313_V1
7	CalibSat_260624_1501_V1
8	CalibSat_181024_2059_V1
9	CalibSat_121124_2141_V1
10	CalibSat_161224_2002_V1

1.3.2 Results

1.3.2.1 Average Results

Figure 4 shows the average dark current values as a function of the across-track pixel for the various CalibSat bands. A few pixels with high dark current are observed across all bands. These pixels are marked in red in the plots and listed in

Table 5.

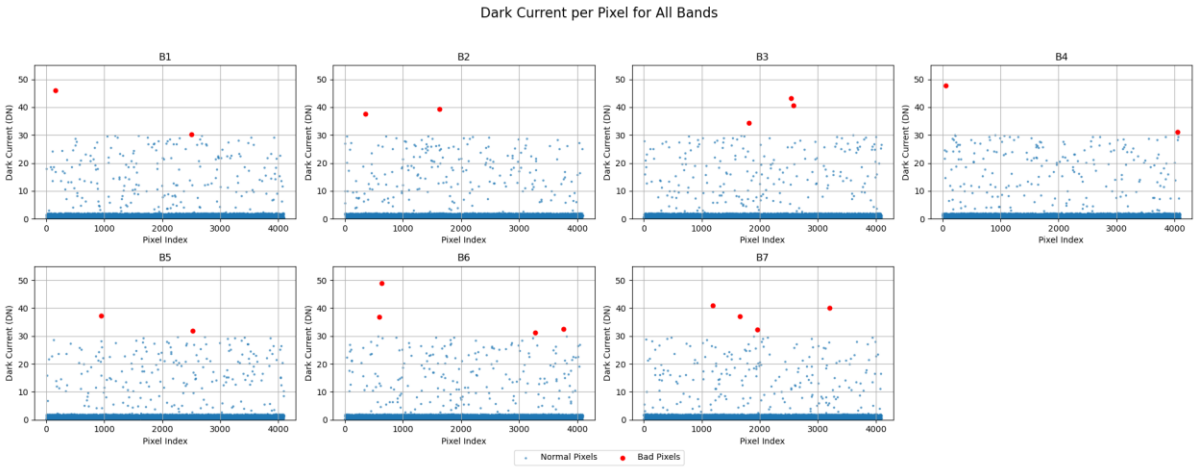


Figure 4 Average dark current results per spectral band in function of pixel number.

1.3.2.2 Dark Current Outliers

Table 5 Pixels with high dark currents.

	# Pixels DC > 30 DN	Pixel Indices
B1	2	2601;2692
B2	4	2905;3887;4006;4029
B3	4	872;1548;2916;3287
B4	2	485;3892
B5	1	20
B6	1	3689
B7	1	2838

1.4 HF equalisation corrections

1.4.1 Input Data

Table 6 List of input data for HF equalisation correction

	Filename
1	CalibSat_121123_2313_V1
2	CalibSat_200224_2005_V1
3	CalibSat_110324_1832_V1
4	CalibSat_120524_0052_V1
5	CalibSat_210724_0250_V1

1.4.2 Results

1.4.2.1 Average Results

High-frequency non-uniformities in the images can lead to vertical striping. To correct for this, high-frequency correction factors have been derived for all CalibSat bands, as illustrated iFigure 5. Pixels with outlier values are listed in Table 7.

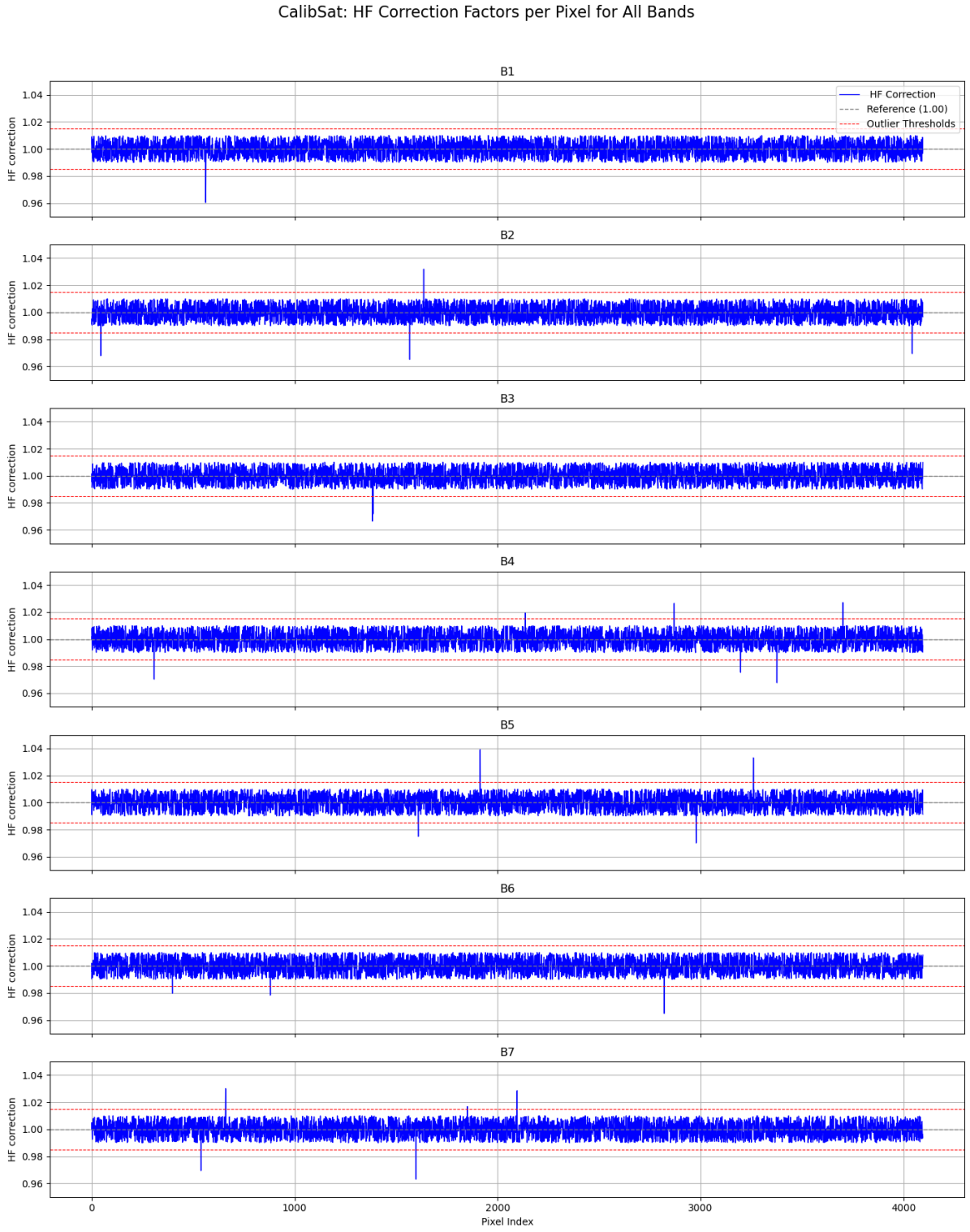


Figure 5 Average HF equalisation corrections per spectral band in function of pixel number.

1.4.2.2 HF equalisation Outliers

Table 7 Number of pixels with HF outlier values.

Band	# Outliers	Outlier Pixel Indices
B1	1	562
B2	4	45;1567;1636;4043
B3	2	1383;1386
B4	6	308;2136;2870;3197;3376;3701
B5	4	1609;1914;2978;3260
B6	3	398;880;2821
B7	5	539;660;1598;1851;2096

1.5 Bad pixels

Table 8 lists the number and location of the bad pixels identified in the various CalibSat bands.

Table 8 CalibSat Bad Pixels

	# Bad Pixels	Bad Pixel Indices
B1	3	2268;2672;3480
B2	4	470;1107;1222;2175
B3	1	2766
B4	4	1095;1353;2730;3832
B5	2	384;2821
B6	2	372;1731
B7	1	1820

1.6 Image Quality - SNR

SNR (Signal to Noise Ratio) is an often-used image quality parameter. The basic formulation of spatial SNR is given by the following formula:

$$SNR = \frac{\mu}{\sigma}$$

with

- μ the mean signal
- σ the standard deviation of the signal

In the applied method we calculate the spatial SNR over CalibSat TOA radiance images from homogenous desert sites considering the statistical distribution over image patches of 5 x5

pixels where we filter out heterogenous regions with high frequency variations. The histogram (frequency distribution) of the SNR values within the individual patches is then generated. The location of the peak value of the histogram is a measure of the SNR.

We observe that the histograms are well Gaussian-distributed. It is noted that the highest SNR is observed for B1 and B3 and the lowest B6 and B8.

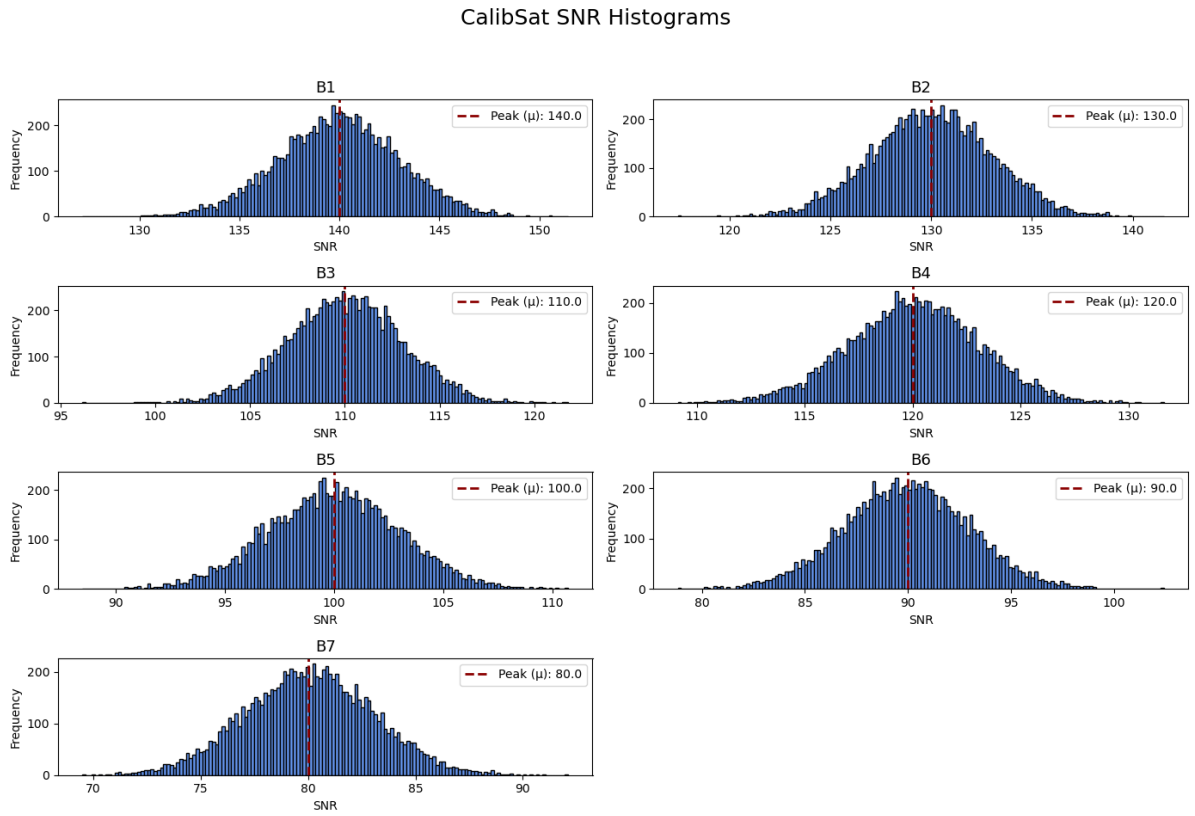


Figure 6 CalibSat SNR histograms.

Table 9 CalibSat SNR.

Band	SNR
B1	140
B2	130
B3	110
B4	120
B5	100
B6	90
B7	80

1.7 Image Quality – MTF

The MTF (Modulation Transfer Function) is a measure of the geometric image sharpness. In Table 1 the MTF@Nyquist are given for the various CalibSat spectral bands.

Table 10 CalibSat MTF.

Band	MTF@Nyquist
B1	0.312
B2	0.485
B3	0.42
B4	0.38
B5	0.247
B6	0.247
B7	0.217

2 PART 2: GEOMETRIC REPORT

2.1 Absolute geometric results

The geometric performance is measured for a set of CalibSat observations scene.

For every acquisition, we plot:
- Scene geographical location
- Scene quicklook
- Along track distortion vs detector position in the sensor geometry (in pixels)
- Across track distortion vs detector position in the sensor geometry (in pixels)
- Along track distortion vs Across track distortion (in pixels)

2.1.1 CalibSat_L1C_20231013T101650Z_V001

Segment location

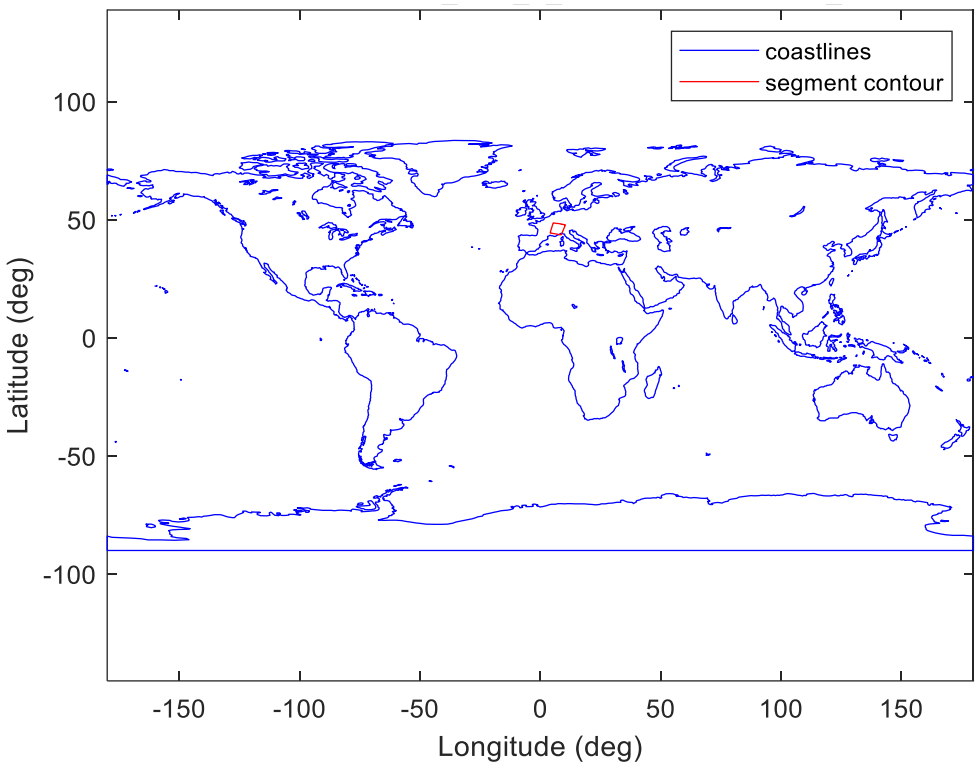


Figure 7: Segment contour of CalibSat_L1C_20231013T101650Z_V001.

Segment quicklook

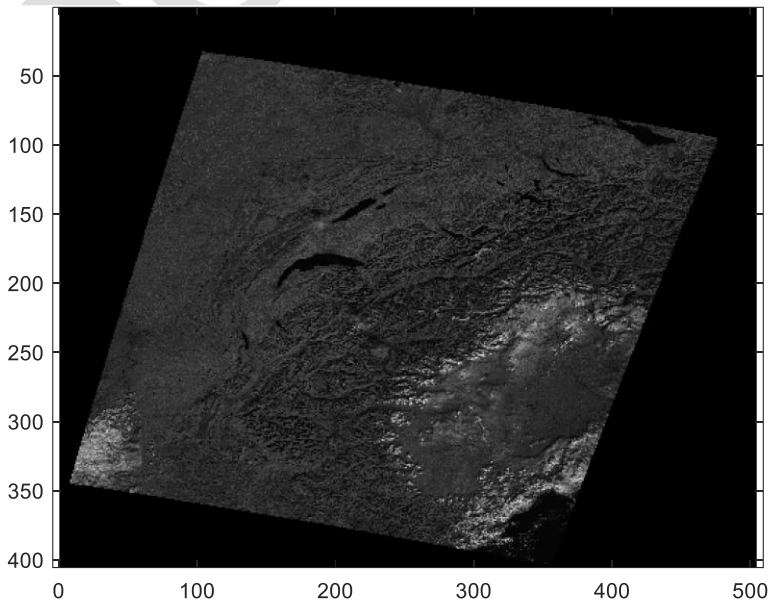


Figure 8: Quicklook of CalibSat_L1C_20231013T101650Z_V001.

The table below shows the geometric statistics:

Band	Mean across distortion (pixel)	Mean along distortion (pixel)	Number of GCPs
BLUE	0.18537 (std=0.4106)	0.36149 (std=0.47671)	470
NIR	0.19523 (std=0.3232)	0.38301 (std=0.52484)	430
RED	0.20274 (std=0.29853)	0.44775 (std=0.77806)	444
SWIR1	0.19436 (std=0.72883)	0.20247 (std=0.46918)	81
SWIR2	0.13436 (std=0.41666)	0.18463 (std=0.30447)	116
SWIR3	0.18716 (std=0.14832)	0.21706 (std=0.26765)	117

Table 11: Geometric statistics of CalibSat_L1C_20231013T101650Z_V001.

The figure below shows the distortions plots (across, along track) for BLUE band.

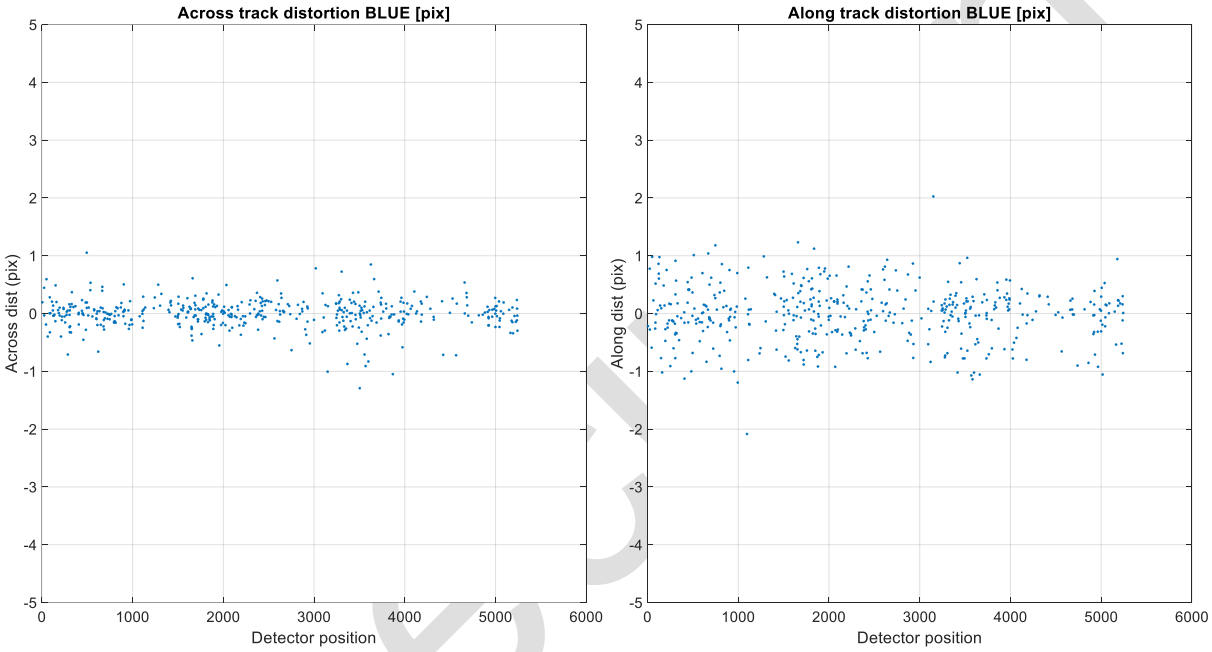


Figure 9: Distortions plots (across, along track) of CalibSat_L1C_20231013T101650Z_V001 for BLUE band.

The figure below shows the distortions plots (across, along track) for NIR band.

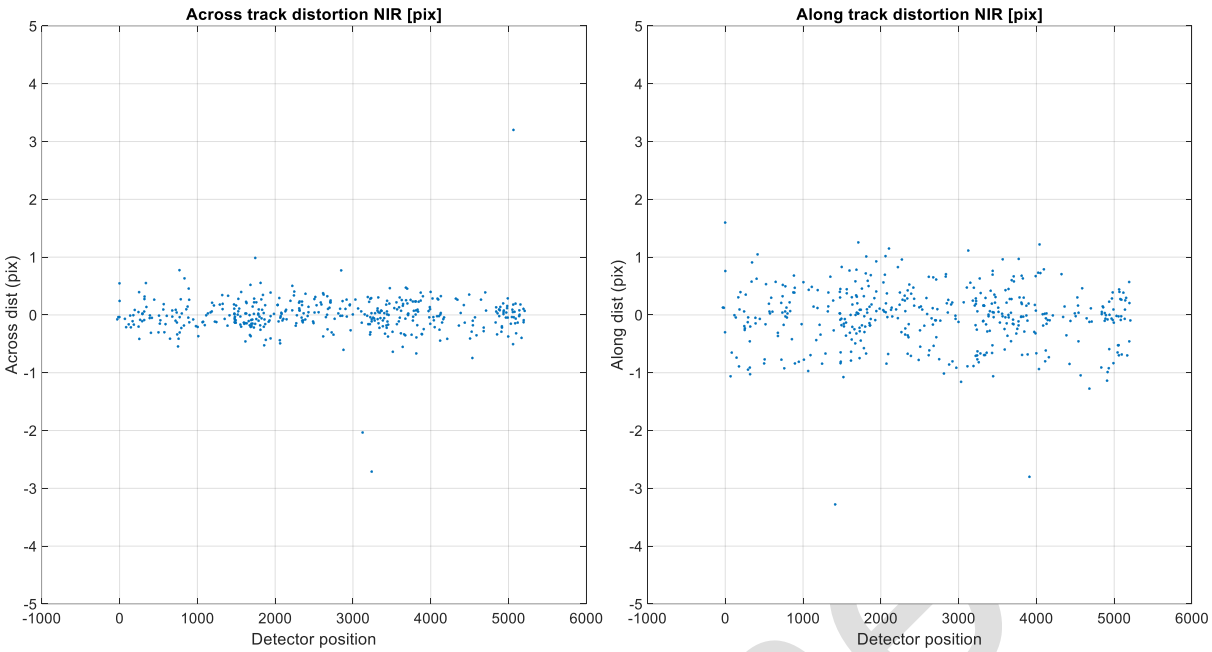


Figure 10: Distortions plots (across, along track) of CalibSat_L1C_20231013T101650Z_V001 for NIR band.

The figure below shows the distortions plots (across, along track) for RED band.

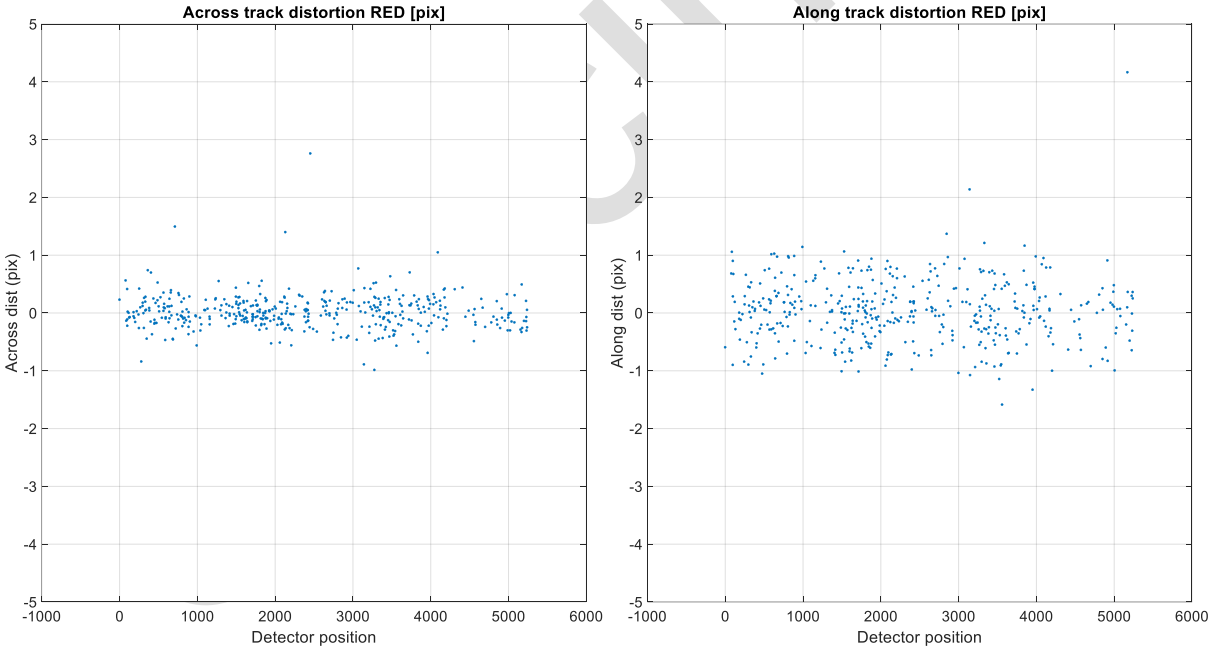


Figure 11: Distortions plots (across, along track) of CalibSat_L1C_20231013T101650Z_V001 for RED band.

The figure below shows the distortions plots (across, along track) for SWIR band.

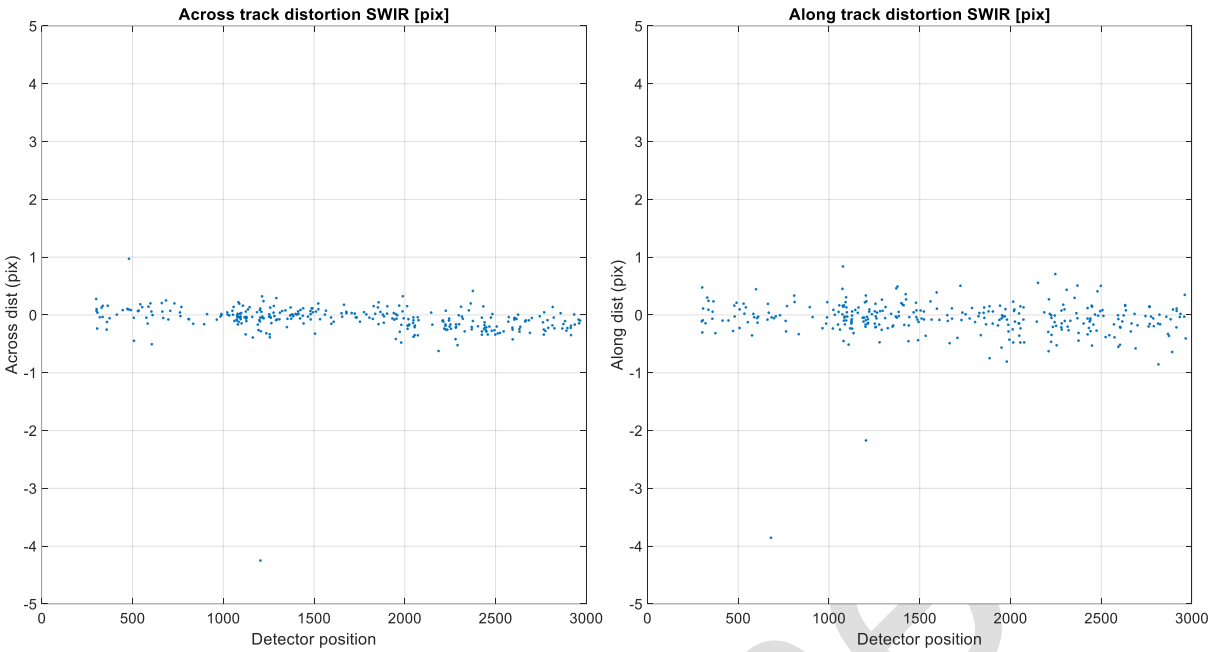


Figure 12: Distortions plots (across, along track) of CalibSat_L1C_20231013T101650Z_V001 for SWIR band.

The figure below shows the along track distortion in function of the across track distortion in pixels for all spectral bands.

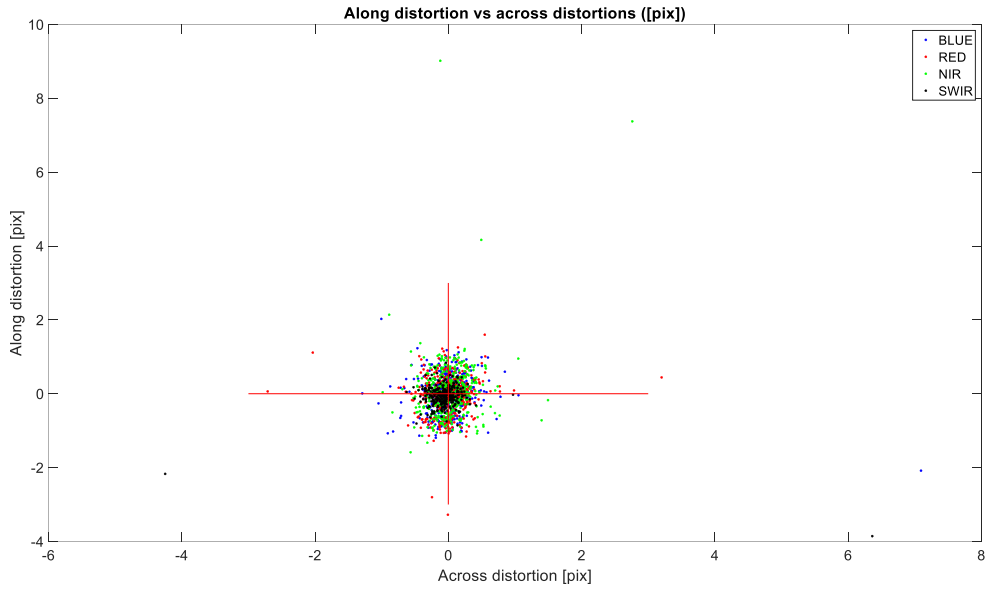


Figure 13: Along distortion vs across distortions ([pix]) of CalibSat_L1C_20231013T101650Z_V001.

2.1.2 CalibSat_L1C_20240403T175856Z_V001

Segment location

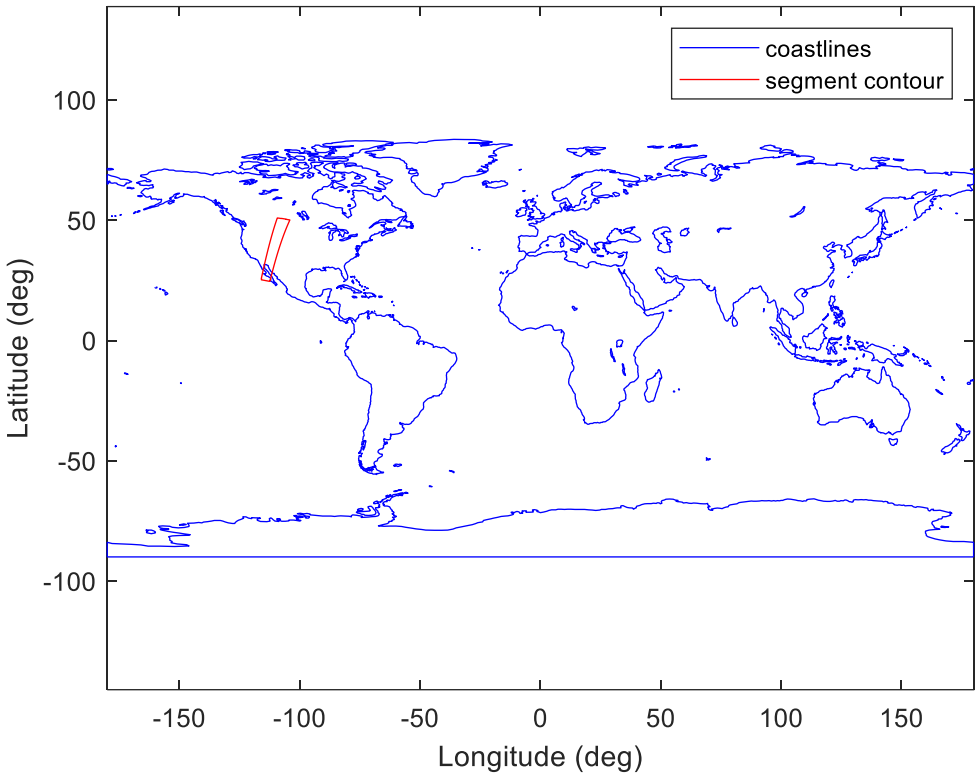


Figure 14: Segment contour of CalibSat_L1C_20240403T175856Z_V001.

Segment quicklook

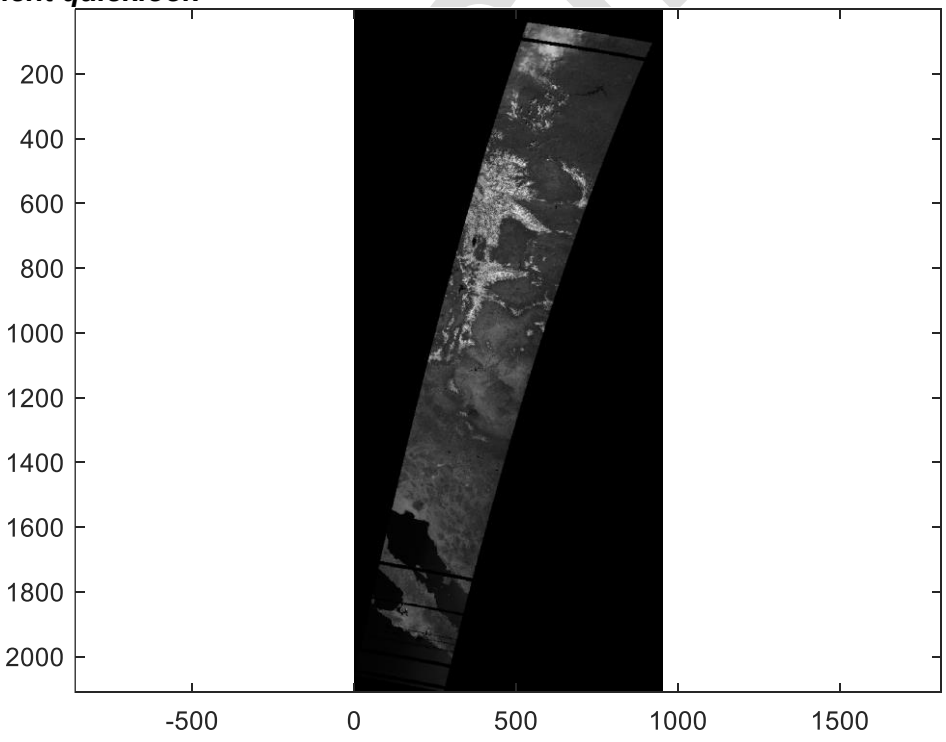


Figure 15: Quicklook of CalibSat_L1C_20240403T175856Z_V001.

The table below shows the geometric statistics:

Band	Mean across distortion (pixel)	Mean along distortion (pixel)	Number of GCPs
BLUE	0.30148 (std=0.67539)	0.43823 (std=0.79414)	594
NIR	0.31976 (std=0.73454)	0.48724 (std=0.76261)	453
RED	0.26536 (std=0.45955)	0.43203 (std=0.72994)	612
SWIR1	0.25952 (std=0.46188)	0.34409 (std=0.54153)	585
SWIR2	0.27655 (std=0.4693)	0.48301 (std=0.68961)	485
SWIR3	0.27281 (std=0.49467)	0.55823 (std=0.75671)	366

Table 12: Geometric statistics of CalibSat_L1C_20240403T175856Z_V001.

The figure below shows the distortions plots (across, along track) for BLUE band.

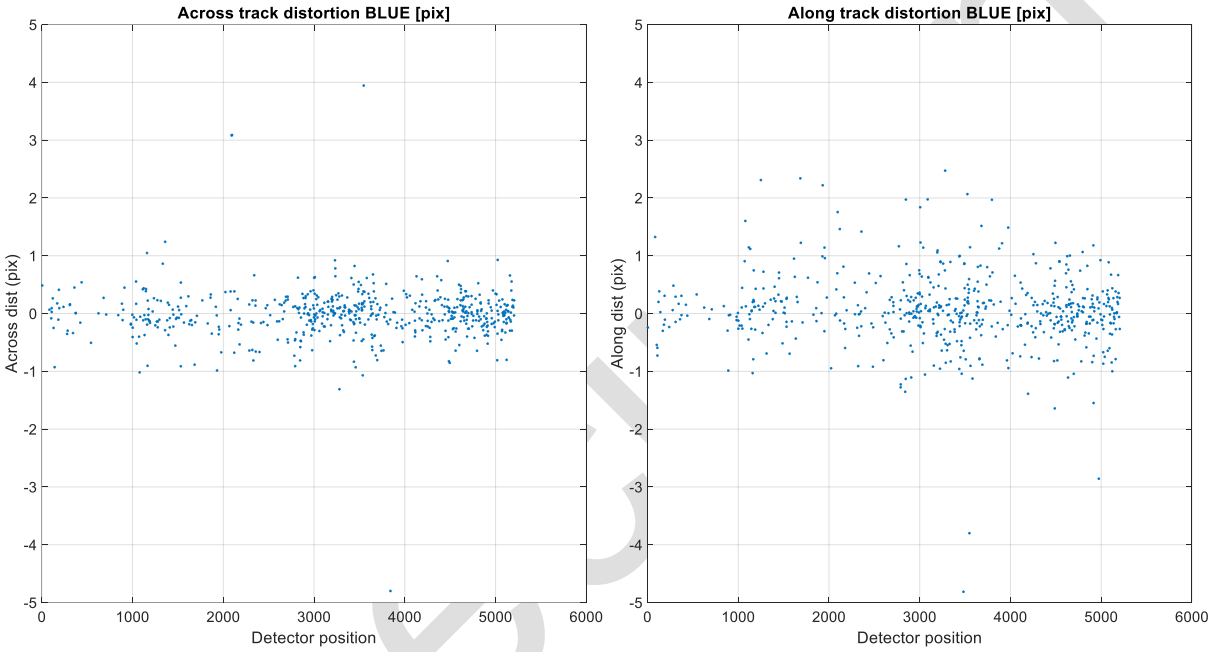


Figure 16: Distortions plots (across, along track) of CALIBSAT_L1C_20240403T175856Z_V001 for BLUE band.

The figure below shows the distortions plots (across, along track) for NIR band.

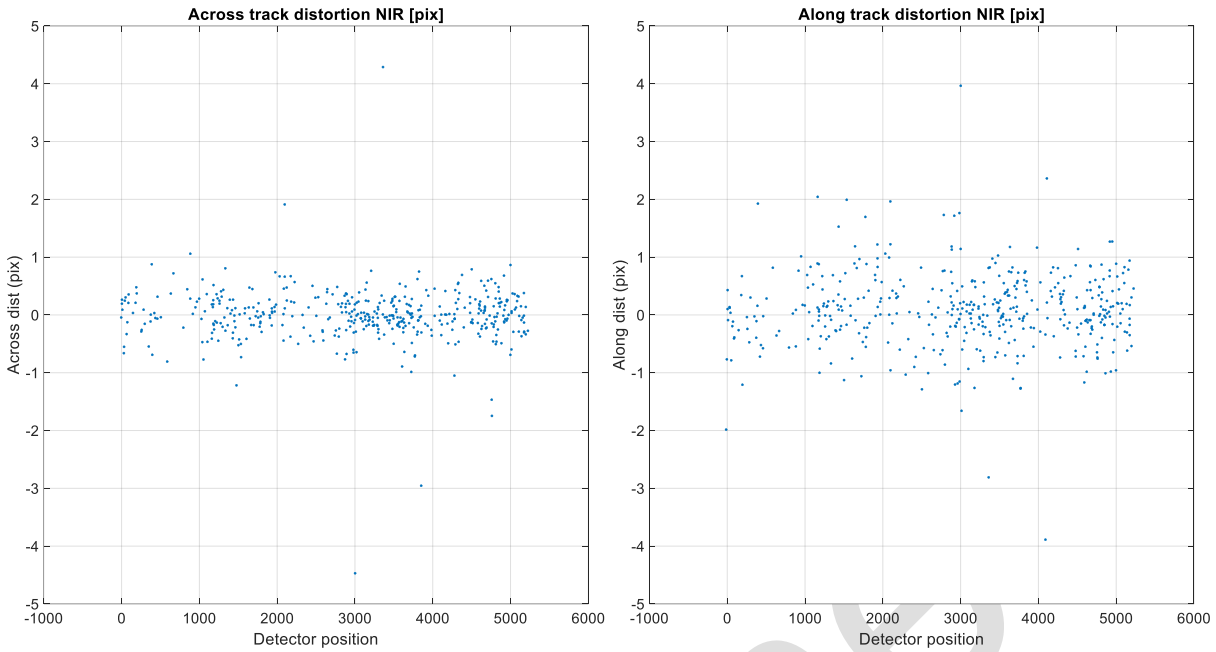


Figure 17: Distortions plots (across, along track) of CALIBSAT_L1C_1190_20240403T175856Z_V001 for NIR band.

The figure below shows the distortions plots (across, along track) for RED band.

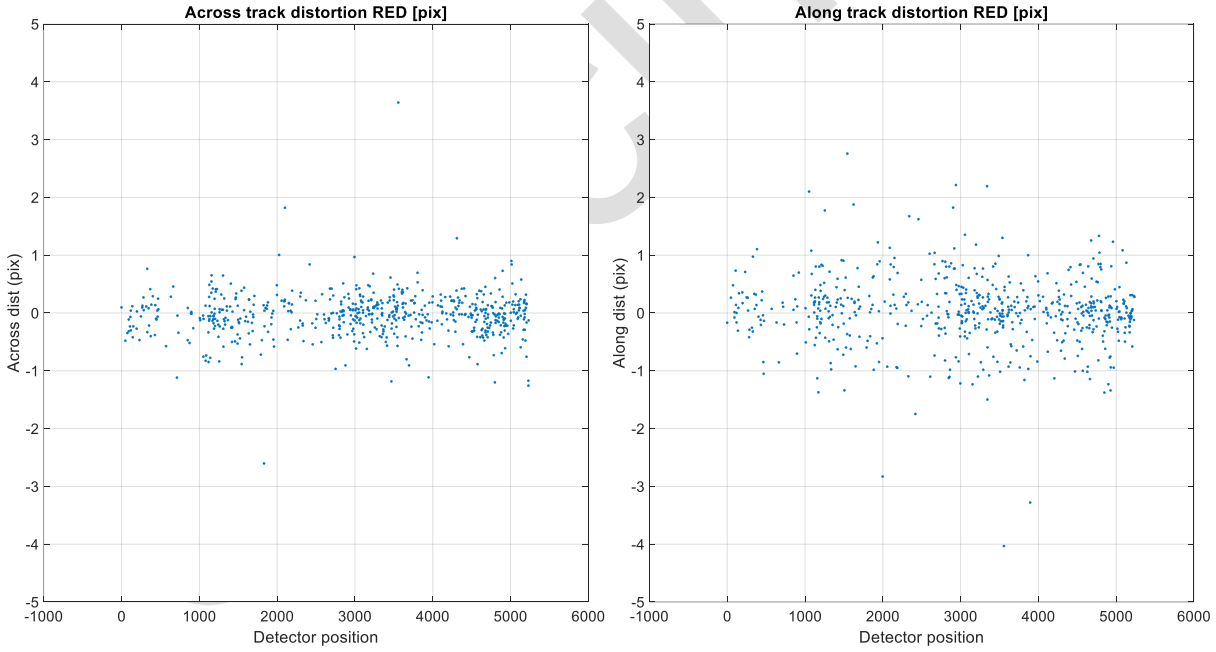


Figure 18: Distortions plots (across, along track) of CALIBSAT_L1C_20240403T175856Z_V001 for RED band.

The figure below shows the distortions plots (across, along track) for SWIR band.

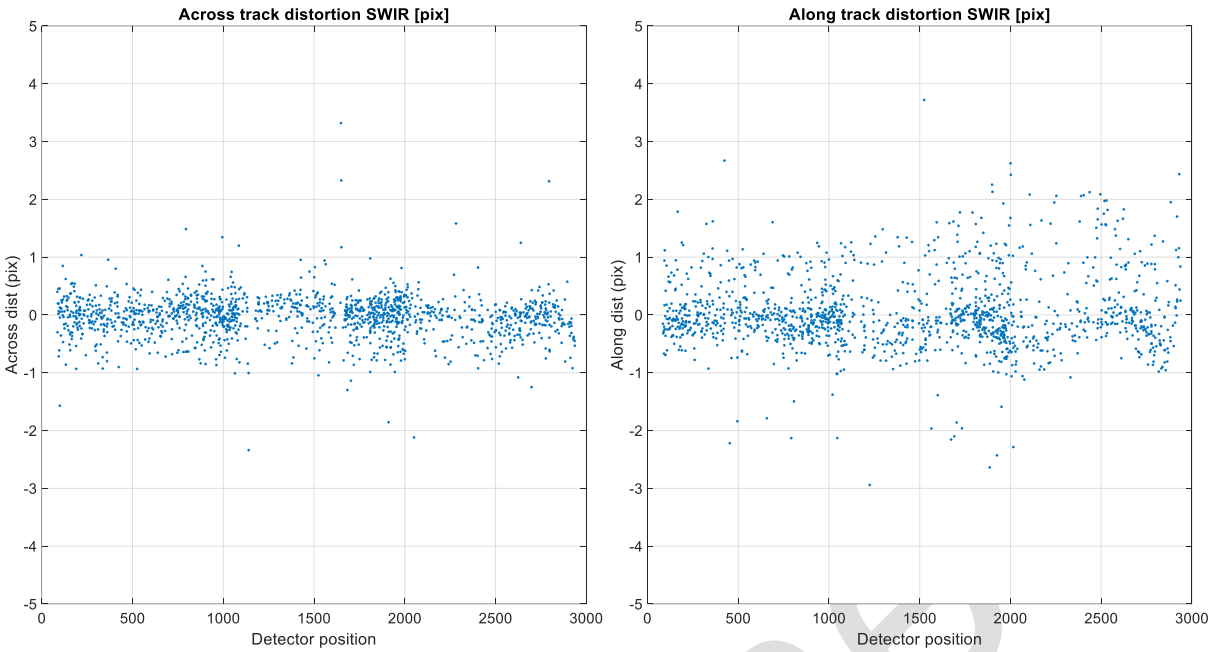


Figure 19: Distortions plots (across, along track) of CALIBSAT_L1C_20240403T175856Z_V001 for SWIR band.

The figure below shows the along track distortion in function of the across track distortion in pixels for all spectral bands.

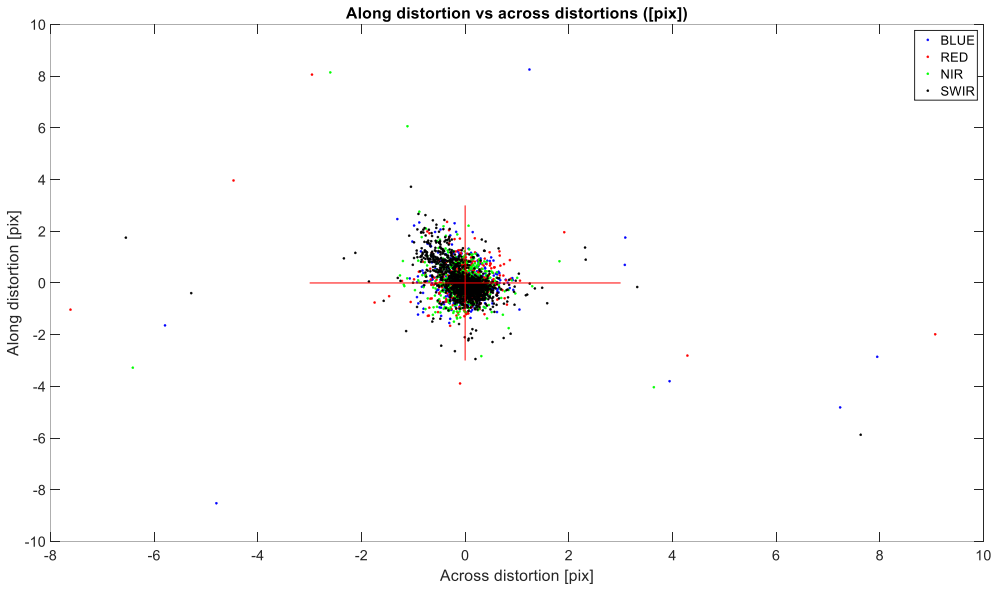


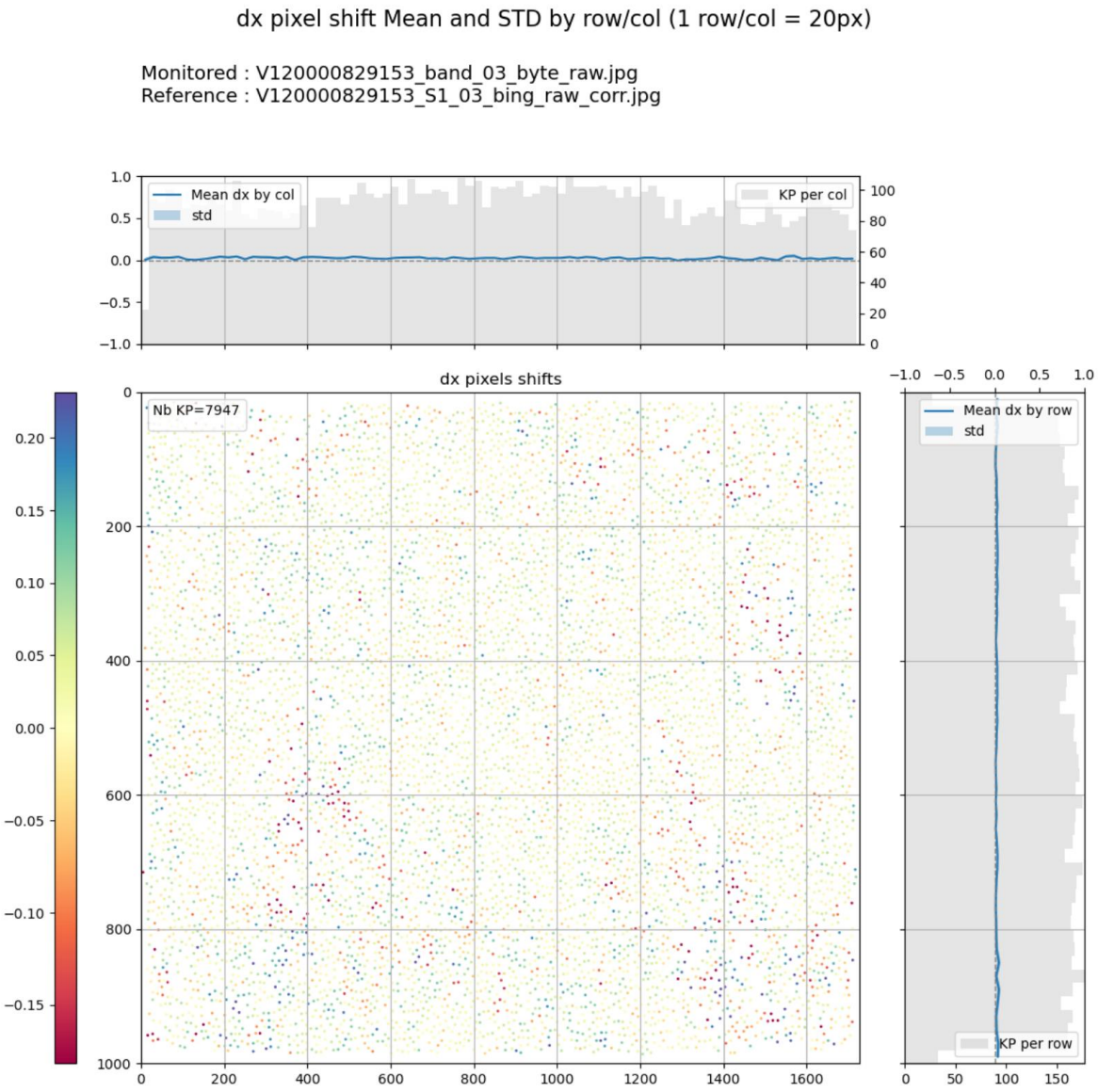
Figure 20: Along distortion vs across distortions ([pix]) of CALIBSAT_L1C_20240403T175856Z_V001.

2.2 Interband geometric results

2.2.1 CalibSat_L1C_20240403T175856Z_V001 (Band 0 vs Band 1)

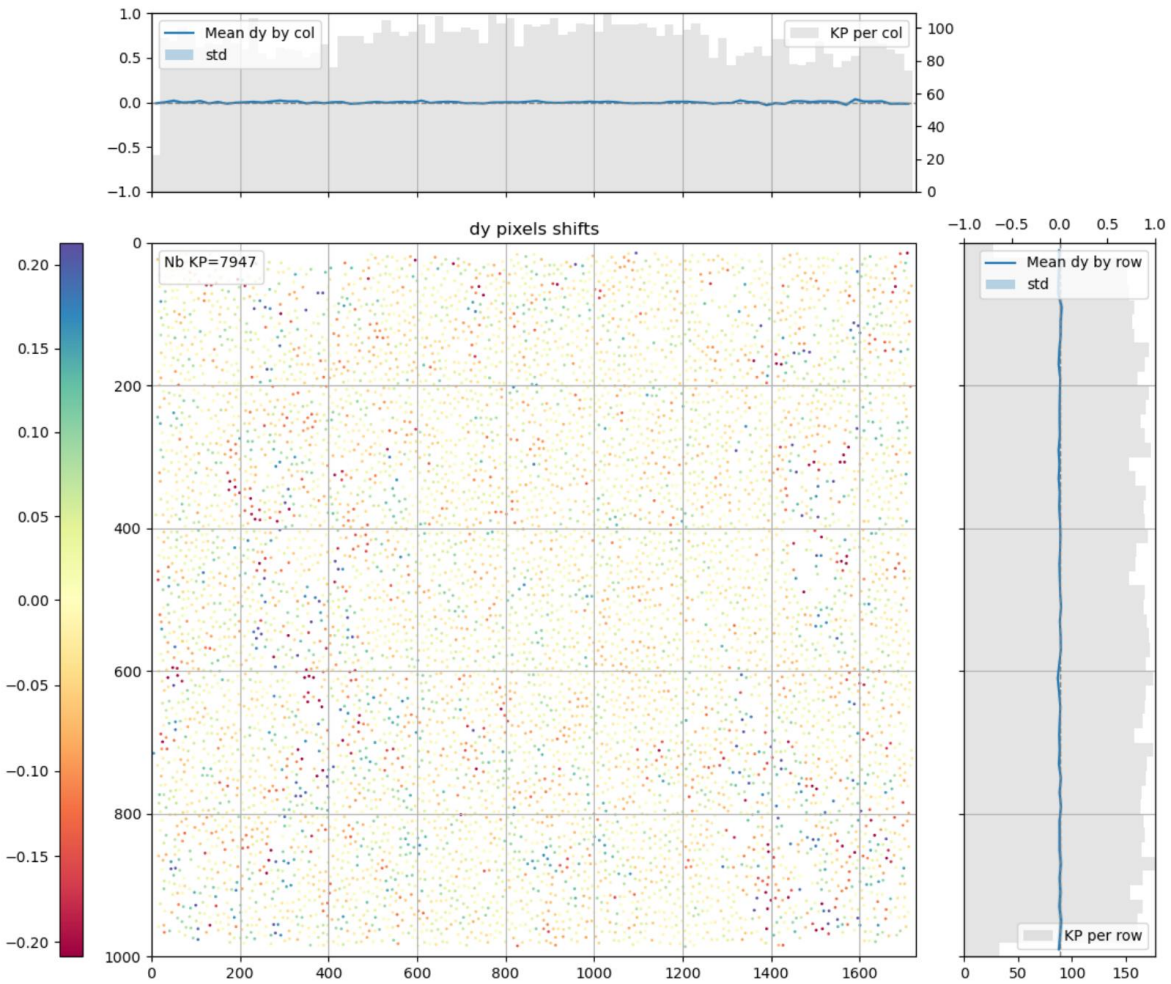
2.2.1.1 Across track inter-band error after calibration (dx)

The figure below shows the across track interband error between band 0 and band 1 after band co-registration. The above plot represents the average interband error across the swath while the right plot represents the average interband error across the flight direction.

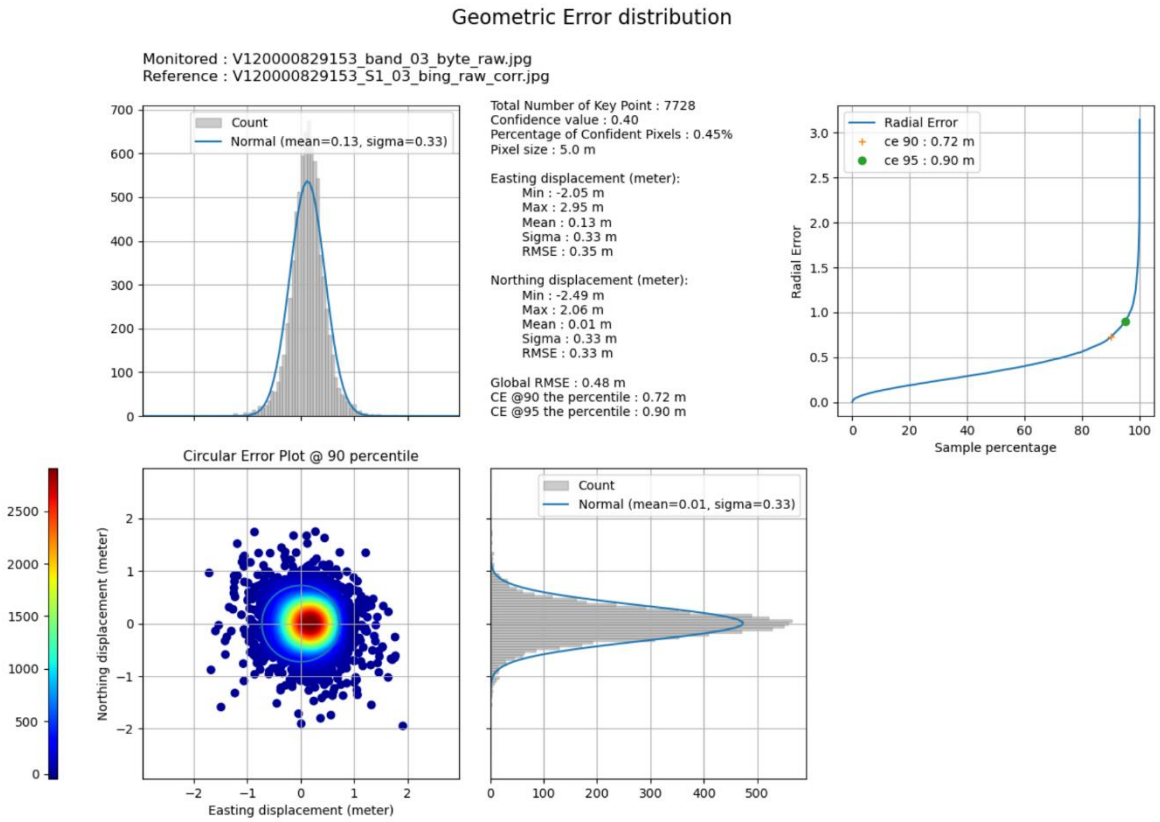


2.2.1.2 Along track inter-band error after calibration (dy)

The figure below shows the along track inter-band error between band 0 and band 1 after band co-registration. The above plot represents the average inter-band error across the swath while the right plot represents the average inter-band error across the flight direction.



2.2.1.3 Overall inter-band statistics



2.2.2 CalibSat_L1C_20240403T175856Z_V001 (Band 0 vs Band 2)

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3 CONCLUSION

The radiometric analysis of CalibSat reveals consistent performance across most spectral bands, with absolute calibration results generally within the 3% accuracy margin—except for B3 and B7, which show under- and overestimations, respectively. Cross-calibration with Sentinel-2 confirms these deviations, highlighting the need for band-specific adjustments.

Dark current analysis identifies a limited number of pixels with elevated values, while HF equalisation reveals some high-frequency noise, both of which are addressed through corrective measures.

Image quality assessments demonstrate good spatial SNR characteristics and acceptable MTF values, confirming the radiometric suitability of CalibSat for scientific and operational applications.

Interband error across the different spectral bands is reaching subpixel accuracy(<=0.3 pixels).
Absolute geolocation error was estimated on cloud free images and CE90 is approximately less than 1 pixel for 95% of the processed scenes.

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