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On-ground testing facility refinement for calibration of Multi-viewing, Multi-channel, Multi-polarisation Imager (3MI) flight model 2

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ABSTRACT

The Multi-viewing, Multi-spectral, Multi-polarization Imager (3MI) is one of the payloads on board of the MetOp-SG "Satellite A", developed to provide infor mation on atmospheric aerosols. The 3MI payload on-ground calibration is very challenging due to its wide FoV (110°) and stringent requirements on radiometric, geometric, polarization and straylight calibration accuracy. CSL has calibrated the EM, PFM and FM2 models. During the FM2 calibration campaign in April 2024, efforts have been made on continuous improvement of the GSEs' stability and robustness to provide more reliable on-ground calibration results. We have proposed tailored solution to trace our absolute calibration GSE monitoring with the calibration standard during an over 90 days calibration campaign. Particularly, thanks to the periodical absolute radiometric and polarimetric stability measurements during the entire FM2 campaign, we are able to understand the uncertainties observed during the PFM and FM2 campaigns.

Keywords: 3MI, On-ground calibration, Earth Observation

1.INTRODUCTION

The Multi-viewing, Multi-spectral, Multi-polarization Imager (3MI) is one of the payloads on board of the MetOp-SG "Satellite A", developed to provide information on atmospheric aerosols. The instrument is a space-based, wide field-of-view polarimeter designed to acquire sequential images of the same ground target, which are then combined with multiple spectral views in both un-polarized and polarized channels. The 3MI payload on-ground calibration is very challenging due to its wide FoV (110°) and stringent requirements on radiometric, geometric, polarization and straylight calibration accuracy [1]-[3]. To meet the requirement, dedicated Optical – Mechanical – Electrical and Thermal Ground System equipment (O-M-E-T GSE) have been developed at Centre Spatial de Liège (CSL). Extensive tests are carried out in the thermal vacuum chamber with the adequate thermal environment [4]. On top of verification purposes, the measured data will serve for post-processing of in-flight data. For example, a stray light correction algorithm was developed to reduce the initial level of stray light down to acceptable level [7]-[10], ultimately demonstrating a remarkable reduction factor up to x1/91 [6].

The PFM calibration campaign, conducted from 2021 to 2022, covered the complete calibration plan and significantly advanced the understanding of the instrument [5]-[6],[12]. This campaign also revealed certain limitations in the current calibration approach and left some of the instrument's unexpected behaviors unresolved. Notably, testing under vacuum extended over 80 days, underscoring the need for more rigorous long-term monitoring of OGSE stability to detect and potentially correct any deviations. Prior to that, initial tests were also conducted on the engineering model (EM) [11].

Building on insights gained from previous campaigns, the FM2 calibration was completed in 2024. Efforts were focused on enhancing OGSEs' knowledge and stability, thereby improving the reliability of on-ground calibration results. Additional reference measurements and cross-verification methods were introduced across radiometric, geometric, spectral, polarimetric, and straylight calibration domains, refining parameter accuracy. This paper delves into the advancements in radiometric and polarimetric calibration that have proven instrumental in understanding previously uncharacterized 3MI behaviors observed since the PFM campaign.

2.RADIOMETRIC STABILITY DURING THE FM2 CAMPAIGN UNDER THE VACUUM

After the PFM campaign, we have identified the need of an independent monitoring setup to check OGSEs' long-term stability during the campaign, in order to better distinguish the deviation coming from the OGSEs and from 3MI's response. The independent setup should witness the input OGSE source in the same manner as the 3MI. Therefore, we setup a collimator inside the vacuum chamber next to the 3MI instrument. The signal collected by the collimator is guided outside of the thermal vacuum chamber to the independent monitoring breadboard shown in Figure 1. Two spectrometers (one for the VNIR wavelengths and one for the SWIR wavelengths) analyze the collected OGSE signal. A stable light source is used as a reference measurement each time. We performed the independent monitoring measurement every ten days during the FM2 campaign.

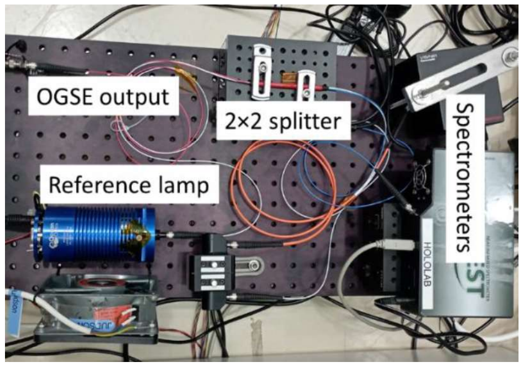

Figure 1 Independent monitoring setup

Figure 2 shows the OGSE signal evolution of each wavelength measured by the independent monitoring spectrometer (normalized by reference lamp spectrum simultaneous measurement). Up to 2% of the spectral dispersion has been observed on the 3MI measured signal as well, shown in Figure 3 left. After correcting the OGSE contribution, the relative variation of 3MI wrt OGSE radiance is within monitoring accuracy (~0.5%,shown in Figure 3 right). This independent monitoring allows dissociating any integrating sphere radiance deviation from any instrument evolution, with higher confidence and accuracy than during PFM campaign. In particular, it helps us to better understand the 3MI behavior in SWIR that was undetermined during PFM campaign.

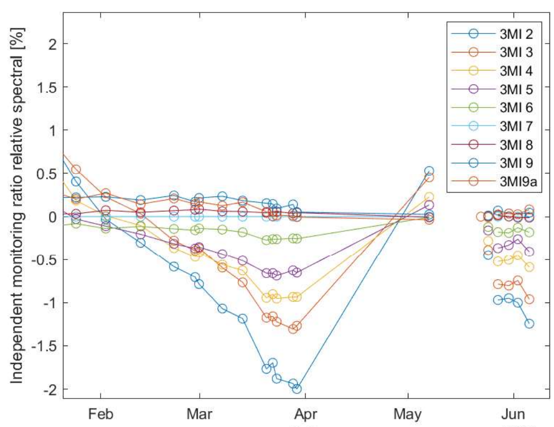

Figure 2 The OGSE signal evolution of each wavelength measured by the spectrometer of the independent monitoring

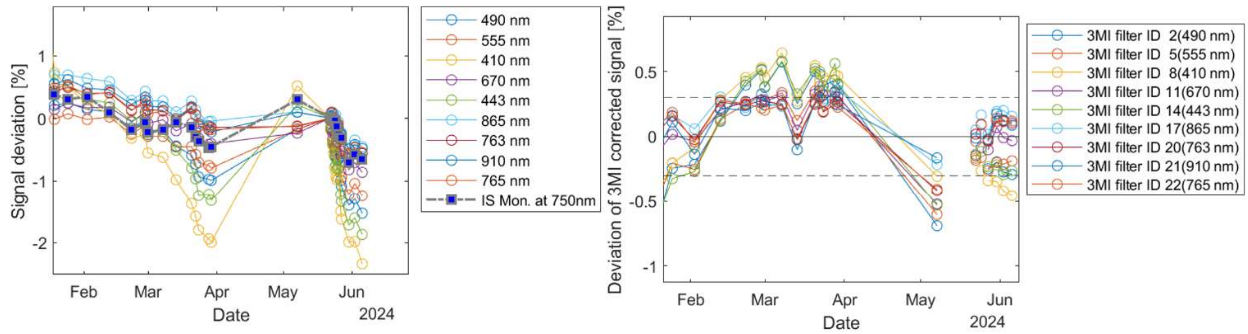

Figure 3 The 3MI signal evolution before correcting the OGSE signal evolution (left) and after correction (right).

It is worth noting that the nominal FM2 calibration was finished in April. After the one-month vacuum break, we performed additional tests from mid-May to June under vacuum again. Despite the vacuum break, the stability of 0.5% is maintained.

3.POLARIZATION SENSITIVITY MONITORING

Another anomaly we have encountered during the PFM campaign is that a significant drop in polarization sensitivity (PS) value was observed for shorter wavelengths. The deviation was up to 2% for 3MI-2. For longer wavelength, the effect was negligible. The cause remains unknown based on the available PFM measurement. During the FM2 calibration, we decided to monitor the PS value at the central field-of-view every ten days to verify the PS stability. The available FM2 PS stability measurement is plotted in Figure **4** left. The similar decrease was observed for the FM2 model as well. 3MI-2 encountered the most significant decrease up to 2% by the end of the campaign in April 2024. However, measuring the PS value of 3MI-2 with a monochromatic source gives nearly perfect (0.98~0.99) PS value, indicating that neither the 3MI's polarizer nor the OGSE's polarizer encountered any degradation during the campaign.

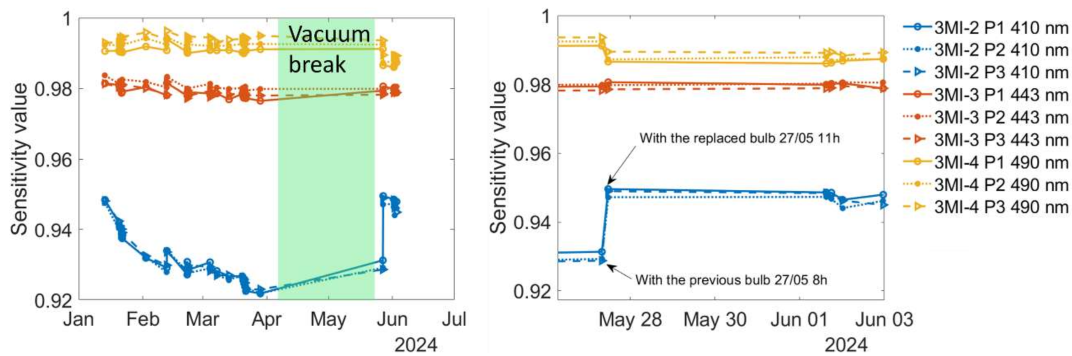

Figure 4 The Polarization sensitivity values at the reference FoV measured every 10 days during the FM2 campaign.

The PS was continuously monitored during the post-calibration activities. On 27th May 2024, after replacing the OGSE's light bulb, the subsequent measured PS showed increased PS value, similar to the first measurement in January (Figure **4** right). Comparing the two light bulb spectra shown in Figure **5**, the used light bulb have less short wavelength component due to aging.

Based on the observed evidence, we hypothesize that the PS value measured with a polychromatic light is also impacted by the out-of-band (OOB) incoming spectra, despite the high performance filter, since the polarizer's contrast ratio could be poor for OOB lights according to the datasheet provided by the polarizer subcontractor.

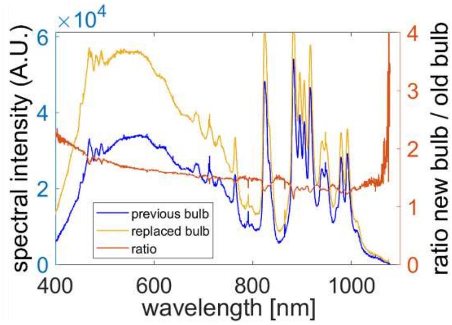

Figure 5 The spectra of the previous bulb and the replaced bulb.

We validated the hypothesis by estimating the measured PS values of 3MI-2 using both bulbs' spectra given in Figure **5** and the ISRF given in Figure **6**, assuming the polarizer has excellent contrast-ratio (PS=0.99) for in-band signal and full non-polarized (PS=0) for OOB signal.

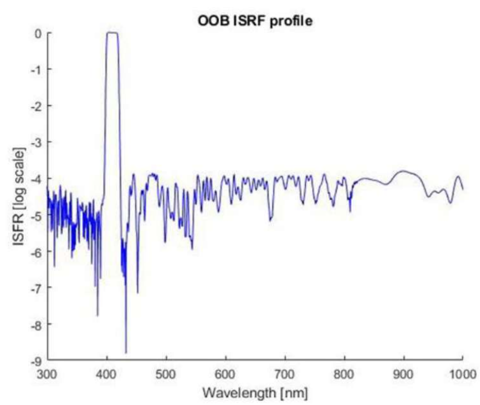

Figure 6 The out-of-band (OOB) IRSF profile of 3MI-2

According to the definition of the contrast ratio, the measured PS can be written as

$$PS = \frac{I_{max} - I_{min}}{I_{max} + I_{min}}, \tag{1}$$

With

$$I_{max} = 0.995 \sum_{\lambda_{IB,min}}^{\lambda_{IB,max}} ISRF(\lambda)\, Spectrum(\lambda) Gain(\lambda) \Delta\lambda + \sum_{\lambda_{OB,min}}^{\lambda_{OB,max}} OB(\lambda)\, Spectrum(\lambda) Gain(\lambda) \Delta\lambda, \tag{2}$$

and

$$I_{min} = 0.005 \sum_{\lambda_{IB,min}}^{\lambda_{IB,max}} ISRF(\lambda)\, Spectrum(\lambda) Gain(\lambda) \Delta\lambda + \sum_{\lambda_{OB,min}}^{\lambda_{OB,max}} OB(\lambda)\, Spectrum(\lambda) Gain(\lambda) \Delta\lambda. \tag{3}$$

The OOB contribution appears in both the maximum and the minimum signal since it is not polarized by the polarizer. The calculated PS values with the two given spectra are 0.93 and 0.95, respectively, which matches well the experimental values. The estimation confirmed the hypothesis. It indicates that 0.01% OOB contribution (overall OOB integrated signal <0.01) can lead up to 2% PS decrease for 3MI-2.

4.CONCLUSIONS

The FM2 calibration campaign, benefitting from all the OGSE upgrades, was completed by June 2024. A better monitoring of the OGSEs' long-term stability for the long-lasting campaign is essential to dissociate any deviation resulted from the OGSE to better understand the instrument's behavior. The independent monitoring allows tracing the OGSE's radiometric deviation along the campaign. The unexpected polarizer behavior was understood thanks to the reference check performed periodically during the campaign.

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