Responses to comments from Review # 2

In second round

Comment from Editor: Dear Juseon et al., R#2 has some comments on your revised paper that require attention. I think it is important that choices made in the calibration are properly evaluated, among others the limitations clearly addressed and discussed. Best wishes, Mark

Reply to Editor: We appreciate the valuable feedback from both you and Reviewer #2, and we will carefully revise the manuscript to more thoroughly address the limitations as suggested

Specific comment #1:

I understand that the authors' approach to soft calibration of the GEMS Level 1 product is constrained by the contents of that product. I recommend that they include more information about *the state of the Level 1C product* they are using so that the readers can better understand their chosen soft calibration approach.

Reply to comment #1:

As mentioned in Section 2.1 (GEMS operations), "*Currently, Version 2 irradiance and Version 1.2.4 radiance products are used as the standard Level 1C inputs for subsequent Level 2 processing. Neither product has been reprocessed since the initial on-orbit testing, and the official data period began on November 1, 2020.*"

Kang et al. (2024) reported on the status of the GEMS Version 2 irradiance, highlighting geometry-dependent biases resulting from the missing BTDF correction and the effects of time-dependent degradation. The newly implemented calibration process in the GEMS ozone profile Version 3.0 provides a clearer representation of the irradiance status in the 310–330 nm range as following:

In 2.5.1 Spectral correction, as shown in Figure 2, substantial discrepancies are evident in both the magnitude and spatial pattern of the spectral shift between radiance and irradiance, ranging from 0.02 to 0.04 nm, with larger differences toward the northern edge of the spatial domain. Additionally, as degradation progresses, pixel-to-pixel perturbations increase toward the central spatial pixels in both radiance and irradiance measurements. Therefore, independent shift correction is implemented to radiance and irradiance. To ensure computational efficiency, the radiance shift is determined from the first mirror step and applied uniformly along the scan direction, based on the observation that spectral shifts in the radiance data remain relatively uniform across mirror steps.

In 2.5.2 Radiometric correction, the GEMS irradiance is **spatially and seasonally biased** due to a missing calibration component for the BTDF, which defines how light transmits through a diffuser based on incident and outgoing angles—a well-known issue (Kang et al. 2024; Bak et al. 2025b). Additionally, Bak et al. (2025b) identified **progressive radiometric degradation**, resulting in an annual irradiance decrease of **~5%** in the shorter UV range. They also reported that the measured irradiance is roughly **40%** lower than the solar reference near 325 nm. ➔ status of radiometric accuracy

As presented **in Figure 3**, the derived values of *C* exhibit significant seasonal and spatial variations in irradiance offset related to angular dependence, along with a gradual temporal decline attributable to optical degradation, most prominently at the middle spatial pixels. In version 3, only the scaling factor *C* is applied in the irradiance correction, by dividing the irradiance by C.

Residual wavelength-dependent uncertainties are instead addressed through the soft calibration process, which has been newly implemented in version 3.

Specific comment #2:

Firstly, it seems that the Level 1 irradiance product derives only from the Working diffuser and has no calibration correction to account for time-dependent degradation of the instrument or diffuser. Secondly, the Earth radiances reported also have no time-dependent corrections applied. These facts leave the Level 2 products with few good options to deal with instrumental changes. One option involves use of the Reference diffuser data, but apparently that option is not open to the Level 1C user.

Reply to comment #2:

Yes, as we addressed in the previous revision, we had no option to choose between the reference and working irradiance, as the reference diffuser data was not shared with the L2 team. Instead, the L1C team is preparing an update to the irradiance calibration that will address both geometry dependence and degradation. And I would like to mention that this work deal with the operational product. Therefore, we should use the common radiance and irradiance inputs that are applied consistently in all L2 processing.

Specific comment #3:

The authors have chosen one approach to soft calibration that has its own unique set of problems. I encourage the authors to identify and acknowledge those problems in their paper. First and foremost is that they are effectively normalizing the GEMS solar irradiance measurements to solar irradiance reference standard. Therefore, any construction of a BSDF measurement quantity will involve a denominator that does not include instrument drift and a numerator that does include instrument drift. The resulting BSDF values will drift in time as the instrument response degrades. It will be helpful if the authors can acknowledge this and estimate the magnitude of this error in the paper.

Reply to comment #3:

We appreciate the reviewer's careful consideration of the limitation inherent to our soft-calibration approach. We agree that caution is needed when applying the empirical method, we have used, which involves scaling corrections based on the normalization of irradiance to a reference and soft calibration applied to the normalized radiance. As review mentioned, the irradiance correction might lead to over-correction, thereby preventing the cancellation of radiometric errors that are present in both the radiance and irradiance. Therefore, we apply a simple correction scaling value corresponding the sum(irradaiance)/sum(reference). In earlier tests, we also experimented with polynomial fitting to reduce wavelength dependent offsets in irradiance:

$$F = F_G - \sum_{0}^{N-1} P_b(i)\left(\lambda - \bar{\lambda}\right)^{i-1} \; (N = 0 \dots 3)$$

We found that higher-order corrections tend to over-correct the irradiance. Therefore, we applied a single scaling value to reduce the irradiance offset, followed by soft calibration to mitigate the wavelength-dependent biases in the normalized radiance. We acknowledge that our approach does not perfectly address degradation and other calibration issues; however, it represents a clear improvement compared to previous versions. Evaluating the long-term consistency of ozone profiles is particularly challenging for GEMS due to the limited availability of ozonesonde data. Nevertheless, our companion paper (Hong et al., under review) demonstrates the reliability of integrated column ozone from the ozone profiles through comparisons with Pandora measurements.