

RESPONSES TO REVIEWER #1

General

The manuscript presents an original study investigating the potential use of opportunistic Earth-viewing observations from the Compact Total Irradiance Monitor (CTIM) CubeSat to support continuity of Earth Radiation Budget (ERB) observations. The topic is highly relevant to the climate and radiation budget communities, particularly in the context of increasing concern regarding possible observational gaps following the long-standing CERES record and the future Libera mission. The manuscript is generally well structured, clearly written, and scientifically interesting. The comparison between CTIM and CERES observations demonstrates encouraging agreement and provides a valuable proof of concept for future low-cost complementary ERB observing systems.

The study is also particularly relevant in the broader context of the ongoing transition at NASA and National Oceanic and Atmospheric Administration (NOAA) toward smaller, more autonomous satellite platforms such as CubeSats and SmallSats for ERB observations. These emerging architectures may provide more flexible and cost-effective approaches for ensuring continuity of ERB observations through constellations and increased observational redundancy. This broader context could be introduced more explicitly in the manuscript to further emphasize the relevance and timeliness of this type of work.

However, the manuscript would benefit from a broader discussion of ongoing CubeSat-based ERB initiatives and from positioning the present work within this rapidly evolving landscape. In particular, it would be valuable to discuss the relationship of this study to other recent small-satellite ERB missions and demonstrators, such as RAVAN and Uvsq-Sat / Inspire-Sat, which similarly explore the use of small satellite platforms for complementary ERB observations and climate data record continuity. I also encourage the authors to discuss whether the type of approach proposed here is envisioned as part of future operational or pre-operational ERB observing systems.

In addition, several methodological aspects require further clarification and stronger quantitative justification before the manuscript can be considered for publication. In particular, the collocation methodology, the treatment of viewing-geometry effects, and the interpretation of the residual differences between CTIM and CERES observations should be more thoroughly discussed and validated. More generally, important challenges remain regarding radiometric stability, intercalibration, temperature effects, straylight's, and the achievement of long-term climate-quality observations from small satellite platforms, and these aspects deserve further discussion in the manuscript.

Overall, I find the study promising and relevant for the future of complementary ERB observing systems, but I recommend revision of the manuscript prior to publication.

Specific Comments

*** Introduction

1. Line 50: the historical context could be made more precise by mentioning that satellite ERB

observations began with Explorer 7 in 1959, which carried the first satellite-based ERB instrument.

- a. *Authors' response:* We thank the reviewer for this helpful suggestion. We have updated the sentence to include the specific reference of Explorer 7, as well as added Vonder Haar et al. (2026) as an additional reference for ERB instrument history.
- b. *Proposed changes to the manuscript:* The following sentence has been updated in lines 49-51 of the introduction: "Since the launch of Explorer 7 in 1959, the first satellite with a dedicated ERB instrument to provide usable measurements, satellite missions have provided essential observations of the ERB on a global scale (House et al., 1986; Vonder Haar et al., 2026)."

2. Line 56: please verify the statement that "Six CERES instruments currently operating aboard four satellites". As of 2026, not all CERES instruments remain operational?

- a. *Authors' response:* We thank the reviewer for careful check. We agree that "currently operating" is incorrect at the time of this revision, as Terra Flight Model-2 (FM2) ceased operations on 10 January 2025. However, all six CERES instruments have collectively contributed to the 26-year ERB record referenced in this sentence, and Terra FM-2 is included in this study as our observational period spans August 2022 through November 2023, predating its decommissioning. We have therefore removed "currently operating" to accurately reflect the collective contributions of all six instruments without implying they all remain active.
- b. *Proposed changes to the manuscript:* The following sentence has been updated in the introduction (lines 58-61): "Six CERES instruments aboard four satellites—Flight Model-1 (FM-1) and FM-2 on Terra, FM-3 and FM-4 on Aqua, FM-5 on Suomi-National Polar-Orbiting Partnership (S-NPP), and FM-6 on NOAA-20—have collectively provided over 26 years of measurements of reflected solar radiation and emitted longwave radiation, delivering state-of-the-art, continuous observations of Earth's radiative energy budget (Priestley et al., 2018; Su et al., 2020)."

3. Line 84: please clarify:

the effective wavelength range associated with CTIM TSI observations,
the effective spectral sensitivity relevant to the opportunistic Earth-viewing longwave observations, and the CTIM field of view (FOV) for SSI and OLR observations.

- a. *Authors' response:* We thank the reviewer for these suggestions. We have updated the manuscript to be more explicit about the spectral range of the CTIM VACNT detectors, replacing "very broad spectral range" with "...nearly ideal optical absorbers over a very broad spectral range." Since the same detector is used for both TSI and Earth-viewing observations, this spectral sensitivity applies to both viewing modes. We have also mentioned the thermally integrated reflective dome that captured any unabsorbed incident radiation.
- b. *Proposed changes to the manuscript:* The following sentences have been updated in Sect. 2.2. First, we added detail about the dome (lines 139-141): "CTIM used electrical substitution radiometers (ESRs) with a vertically aligned carbon nanotube

(VACNT) absorber and a thermally integrated reflective dome to capture any remaining unabsorbed incident radiation.” Second, we updated lines 144-146: “The CTIM VACNT detectors were nearly ideal optical absorbers from the UV through the IR, with an effective absorptance (when used in tandem with the dome) exceeding 99.9% (Harber et al., 2019; Tomlin et al., 2020).”

4. Provide orbital information and Local Time of Ascending Node (LTAN) for CTIM and the CERES satellites used in the comparison.

- a. *Authors' response:* We thank the reviewer for this suggestion. We have added orbital information and LTAN/LDN for Terra, Aqua, S-NPP, NOAA-20, and CTIM in the manuscript. For the CERES satellites, Terra operates in a sun-synchronous orbit with a Local Time of Descending Node (LTDN) of approximately 10:30 A.M., while Aqua, S-NPP, and NOAA-20 operate in sun-synchronous orbits with an LTAN of approximately 1:30 P.M. (*JPSS Performance Status*, 2025; Loeb et al., 2018a; Meftah et al., 2025). Terra and Aqua orbit at 705 km, while S-NPP and NOAA-20 orbit at 824 km (Shankar et al., 2023). For CTIM, we have already clarified that it was launched into a non-sun-synchronous orbit at an approximate 500 km altitude and 45° inclination (see lines 137-138). As CTIM was designed primarily for TSI measurements, which do not require a fixed local equatorial crossing time, the equatorial crossing time was not a constraint on the primary mission.
- b. *Proposed changes to the manuscript:* The following sentences have been added to the CERES background section (Sect. 2.1, lines 120-123): “The CERES instruments have operated on satellites with sun-synchronous orbits: Terra operates with a Local Time of Descending Node (LTDN) of approximately 10:30 A.M., while Aqua, S-NPP, and NOAA-20 operate with a Local Time of Ascending Node (LTAN) of approximately 1:30 P.M. (*JPSS Performance Status*, 2025; Loeb et al., 2018a; Meftah et al., 2025). Terra and Aqua orbit at an altitude of 705 km, while S-NPP and NOAA-20 orbit at 824 km (Shankar et al., 2023).” Subsequently, Shankar et al. (2023) was added to the reference list.

The first sentence of the CTIM background section (Sect. 2.2, lines 137-138) has been updated: “On 2 July 2022, CTIM was launched into a 45° inclination, non-sun-synchronous orbit at an altitude of approximately 500 km with a 1-year mission lifetime goal to demonstrate next-generation technology for monitoring TSI.”

5. The manuscript would benefit from a broader discussion of ongoing CubeSat ERB initiatives, including RAVAN, Uvssq-Sat, Inspire-Sat, and Uvssq-Sat NG. This would help better position the present work within current international efforts on complementary ERB observations from small satellite platforms.

- a. *Authors' response:* We thank the reviewer for these suggestions. We agree that explicitly situating this work within the broader CubeSat and SmallSat ERB landscape strengthens the manuscript's relevance and timeliness. We have added a new paragraph to the introduction that addresses both comments. The paragraph also discusses the National Academies' recommendations for increased NASA investment

in CubeSat science missions (National Academies of Sciences, 2016), the growing international momentum toward small satellite ERB platforms, and specific missions including RAVAN, PREFIRE, Uvsq-Sat, Inspire-Sat, Uvsq-Sat NG, and the proposed BABAR-ERI mission. We have also updated the conclusion paragraph to circle back to these missions concisely. The new paragraph explicitly frames the present work within this rapidly evolving landscape, directly addressing the reviewer's request to emphasize the relevance and timeliness of this approach (as discussed in the general comments of this review above).

- b. *Proposed changes to the manuscript:* A new paragraph has been added to the introduction starting at line 78 and ending at line 96:

“Recognizing that CubeSats have the potential to mitigate gaps in measurements where continuity is critical and to enable new approaches to Earth observations, the National Academies of Science (2016) recommended that NASA increase its investment and coordination of CubeSat missions across science disciplines, a recommendation reflected in the growing number of NASA-funded CubeSat missions for Earth science, including ERB observations. This momentum extends internationally, with several recent missions collectively demonstrating the viability of small satellite platforms for ERB observations. The Radiometer Assessment using Vertically Aligned Nanotubes (RAVAN) 3U CubeSat, launched in 2016 under NASA’s Earth Science Technology Office (ESTO) In-Space Validation of Earth Science Technologies (InVEST) program, was an early pathfinder demonstrating that broadband ERB observations of outgoing radiation could be made from a CubeSat platform, establishing an important benchmark for future CubeSat ERB constellation concepts (Swartz et al., 2019). NASA's Polar Radiant Energy in the Far-InfraRed Experiment (PREFIRE), a pair of polar-orbiting CubeSats launched in 2024, addresses a longstanding gap in Earth-observing capability by providing the first systematic spectral measurements of far-infrared emissions at Earth's poles (Drouin et al., 2026). The French Uvsq-Sat nanosatellite, launched in 2021, and its sister satellite Inspire-Sat, launched in 2023, constitute the first European CubeSat constellation demonstrator dedicated to broadband wide-field-of-view (WFOV) measurements of Earth’s outgoing radiation (Meftah et al., 2022; Meftah et al., 2025). The follow-on Uvsq-Sat NG, a 6U CubeSat mission launched in 2025, aims to extend and improve the ERB record with enhanced measurement stability and capabilities (Meftah et al., 2023). The proposed Black Array of Broadband Absolute Radiometers Earth Radiation Imager (BABAR-ERI) 12U CubeSat similarly aims to demonstrate inexpensive, low-risk ERB measurements complementary to larger missions, further exemplifying the growing role of small satellite platforms in future ERB observing strategies (Coddington et al., 2025b).”

The conclusion paragraph beginning at line 638 has been revised to concisely reference and revisit these missions collectively again after the longer discussion in the introduction. The paragraph has been updated:

“Still, the rapid advancement and miniaturization in technology and the rising accessibility of small satellite platforms create viable pathways for CubeSat constellations for ERB observations, complementary to larger missions. Missions such as RAVAN, PREFIRE, Uvsq-Sat, Inspire-Sat, and Uvsq-Sat NG collectively demonstrate the growing momentum toward small satellite ERB observations (Swartz et al., 2019; Drouin et al., 2026; Meftah et al., 2025). The proposed BABAR-ERI 12U CubeSat could further demonstrate inexpensive, low-risk ERB measurements in parallel with CERES and Libera (Coddington et al., 2025b). Similarly, CTIM demonstrates a potential pathway for CubeSat implementation in ERB observations from space.”

As result of these additions, the following references have been added to the reference list: Drouin et al. (2026), Meftah et al. (2021), Meftah et al. (2023), and National Academies of Sciences, Engineering, and Medicine (2016).

6. *** Collocation Methodology

- The choice of several collocation parameters appears somewhat arbitrary:

- +/-20 min temporal window,
- 100 km spatial radius,
- minimum of 75 CERES footprints,
- VZA threshold of 20°.

- Provide either:

- a sensitivity analysis,
- or a quantitative justification demonstrating that the results are robust to reasonable variations of these parameters.

- For example:

- impact of +/-10 min instead of +/-20 min,
- 75 km or 125 km radius,
- sensitivity to the selected VZA threshold.

- a. *Authors' response:* We thank the reviewer for this important comment. While addressing this comment, we conducted a detailed internal review of our collocation parameters and determined that the CTIM footprint radius should more closely follow the CTIM spatial response function derived from the instrument's angular response and orbital altitude (shown in the now updated Fig. 3.). This detailed review resulted in a corrected CTIM spatial footprint radius of 242 km (previously reported as 100 km). To accommodate the larger radius while maintaining comparable near-nadir sampling density, we increased the minimum CERES footprint threshold from 75 to 400 for Step 1 of the matching algorithm. Because the larger CTIM radius admitted CERES footprints at slightly greater viewing zenith angles (i.e., the previous

maximum VZA with the 100 km radius and 75 footprint minimum was 23.14° , but was 29.86° with the corrected 242 km radius and 400 footprint minimum), we conducted additional MODTRAN simulations to extend our limb-darkening lookup tables to $VZA = 30^\circ$ (previously 25°) to ensure the full range of collocated CERES footprints remained within the range of our clear-sky limb-darkening correction. We also found some CERES footprints collocated with CTIM under the new algorithm parameters had lower temperatures associated with mid-latitude winter observations. Because of this, we additionally conducted MODTRAN simulations for all VZA and surface emissivity values at 240 K and 250 K for the mid-latitude winter atmosphere. Altogether, these additions increased the number of MODTRAN simulations comprising our limb-darkening lookup tables from 504 to 700, reflecting the full combination of VZA, surface emissivity, surface temperature, and atmosphere model values shown in the updated Table 1. We conducted a full reanalysis for the CTIM–CERES collocation across all three satellites (Terra, Aqua, and NOAA-20) using these corrected parameters; all results, figures, and statistics reported in the revised manuscript reflect this updated analysis. We address the reviewer's specific request for justification of each collocation parameter below, using the new corrected values.

VZA Threshold: The threshold of 20° or less for the CERES VZAs in Step 1 was directly motivated by the CTIM angular response function, which reaches 0.0006, essentially zero, at 20° . By creating a threshold for initial filling of the CTIM footprint with CERES footprints that have a VZA of 20° or less, the primary matching of CERES footprints within CTIM footprints ensures the CERES footprints fall within the effective angular range of CTIM.

Spatial radius: The CTIM 242 km radius corresponds CTIM spatial response function (the ground-distance equivalent to the angular response function, derived with an altitude of 453 km and accounting for along-track motion blurring, Fig. 3, right).

Temporal window: A sensitivity analysis was conducted using ± 10 -, ± 20 -, and ± 30 -minute temporal windows, with all other collocation parameters held constant. The ± 10 -minute window yielded only 263 CTIM–CERES matches with a mean time difference of 4.81 minutes and 100% of footprints within 10 minutes of the CTIM timestamp. The ± 10 -minute window offered minimal gain, compared to the ± 20 -minute window, in temporal proximity over the selected window while substantially reducing the number of matches available for comparison. The ± 20 -minute window yielded 541 CTIM–CERES matches with a mean time difference of 9.75 minutes and 51.0% of footprints within 10 minutes of the CTIM timestamp. The ± 30 -minute window increased the match count even further to 811 CTIM–CERES matches, but raised the mean time difference to 14.65 minutes, with 32.0% of CERES footprints falling 20-30 minutes from the CTIM timestamp. The 32.0% of CERES footprints within the 20-30-minute window increased the risk of scene change between CTIM and CERES observations. The ± 20 -minute window was therefore selected to optimize the combined acquisition of sufficient CTIM–CERES matches with temporal proximity between observations.

Minimum footprint threshold: A sensitivity analysis of the minimum CERES footprint threshold for Step 1 was conducted using values of 350, 400, 450, and 500, with all other collocation parameters held constant. We conducted this sensitivity analysis for each of the individual CERES satellites, since the orbits are different for Terra, Aqua, and NOAA-20, and we therefore anticipated different numbers of CTIM–CERES matches per satellite. Results are shown in Tables 1-3 below.

Table 1: Terra Footprint Minimum Sensitivity Analysis

CERES Footprint Minimum (Step 1)	CTIM-CERES Matches	% of Footprints with VZA >20°
350	302	11.8
400	238	8.9
450	146	5.2
500	21	1.6

Table 2: Aqua Footprint Minimum Sensitivity Analysis

CERES Footprint Minimum (Step 1)	CTIM-CERES Matches	% of Footprints with VZA >20°
350	152	12.9
400	109	9.0
450	59	4.7
500	4	1.5

Table 3: NOAA-20 Footprint Minimum Sensitivity Analysis

CERES Footprint Minimum (Step 1)	CTIM-CERES Matches	% of Footprints with VZA >20°
350	289	6.3
400	194	2.9
450	2	0.1
500	0	N/A

As expected, the number of CTIM–CERES matches decreased and the percentage of CERES footprints with VZA > 20° also decreased as the footprint threshold increased consistently across all three satellites. A minimum threshold of 400 CERES footprints represents a conservative middle ground: the lower threshold (i.e., 350 footprints) admitted substantially more off-nadir CERES footprints, while higher thresholds (i.e., 450 or 500 footprints) restricted the sample to near-nadir footprints but sharply reduce the number of CTIM–CERES matches. Most notably, NOAA-20 only yielded two matches at a threshold of 450 footprints and zero at 500. By selecting a threshold of 400 CERES footprints with a VZA ≤ 20° for Step 1 in the matching algorithm, we balanced a maximal near-nadir CERES sampling (less than 10% of footprints for each

satellite had a VZA > 20°) with maintaining a statistically meaningful number of matches across all three satellites (541 total CTIM–CERES matches, 238 CTIM–Terra matches, 109 CTIM–Aqua matches, 194 CTIM–NOAA-20 matches). For the 541 CTIM–CERES matches, the maximum CERES VZA was 29.86° with a mean VZA of 9.37° and only 6.9% of all CERES footprints (n = 261,010) had a VZA greater than 20°.

Notably, this new analysis also improved the consistency of our results: the combined CTIM–CERES mean relative difference remained similar (-1.186%, compared to -1.273% previously) with a comparable R^2 (0.948) and a slightly reduced standard deviation (4.159%, compared to 4.225% previously), while agreement among the three individual satellites tightened substantially, with the maximum pairwise difference in mean relative difference among Terra, Aqua, and NOAA-20 decreasing from 0.196% to 0.028%.

- b. *Proposed changes to the manuscript:* We have updated the following sentences in Sect. 4, Step 1. We added quantitative details to more clearly address the VZA threshold (lines 270-274): “CERES SSF Level-2 data were pre-processed to retain only those footprints with a VZA of 20° or less, ensuring observations were near-nadir and consistent with the effective range of the CTIM angular response (at 20° the CTIM angular response reaches 0.0006, essentially zero) and thus, more directly comparable to the CTIM nadir observations.”

We added details about the CERES orbital periods, lending extra details about the temporal bounds (lines 277-279): “The ± 20 -minute window represents approximately 40% of the CERES orbital periods, ensuring that only a single CERES overpass contributes to each CTIM match while remaining sufficiently long enough in time to maximize collocations.”

We also corrected and clarified the spatial parameter of 242 km (lines 279-281): “Given the CTIM footprint radius of 242 km, as determined by the CTIM spatial response function (Fig. 3, right) reaching zero at this ground distance, a spatial constraint of 242 km from the CTIM centroid was applied to maximize CERES coverage within each footprint.”

Since we have more qualitative analysis for the temporal threshold and the footprint minimum threshold, we added a note section immediately following the final step of the matching algorithm (see lines 314-337). We decided to include these notes after the final step, as the sensitivity analyses performed for these qualitative metrics were performed by holding all other parameters constant. For example, for the footprint minimum threshold, we varied the footprint amount while maintaining a temporal window of ± 20 minutes, a spatial threshold of 242 km, and a VZA threshold of 20° or less. The added paragraphs are below.

“Notes on parameter selection in Step 1:

The temporal window of ± 20 minutes and minimum CERES footprint number threshold of 400 were selected based on sensitivity analyses in which each parameter was varied individually while all others were held at their baseline values described in Steps 1-4.

A temporal window of ± 10 minutes yielded only 263 CTIM–CERES matches, with a mean time difference of 4.81 minutes. Conversely, a ± 30 -minute window yielded 811 CTIM–CERES matches, but 32.0% of all matching CERES footprints within a CTIM footprint were 20-30 minutes from the CTIM observations, increasing the potential for scene change between observations. The ± 20 -minute window balanced the need for ample matches and scene similarity between CTIM and CERES observations, yielding 541 CTIM–CERES matches with a mean time difference of 9.75 minutes (51.0% of CERES footprints within 10 minutes of the CTIM observation). Thus, the selected ± 20 -minute window was conservative, sampling CERES observations close in time to CTIM while acquiring sufficient CTIM–CERES matches for statistically meaningful comparisons.

The minimum of 400 CERES footprints was selected to ensure adequate spatial sampling of the CTIM footprint by near-nadir CERES observations. This sensitivity analysis was conducted individually for each satellite (Terra, Aqua, and NOAA-20), since the orbits of the three satellites yield different numbers of CTIM–CERES matches. As the CERES footprint threshold increased from 350 to 450, the Terra match count fell from 302 to 146 while the fraction of footprints with $VZA > 20^\circ$ dropped from 11.8% to 5.2%; Aqua matches fell from 152 to 59 with $VZA > 20^\circ$ dropping from 12.9% to 4.7%; and NOAA-20 matches fell sharply from 289 to just 2, with $VZA > 20^\circ$ dropping from 6.3% to 0.1%. At the selected threshold of 400 footprints, Terra, Aqua, and NOAA-20 yielded 238, 109, and 194 CTIM–CERES matches, respectively (541 matches combined) with 8.9%, 9.0%, and 2.9% of CERES footprints having a $VZA > 20^\circ$ for each satellite (6.9% collectively). This threshold ensured each CTIM footprint was predominantly filled with CERES observations within 20° of nadir for comparison with CTIM, while maintaining a statistically meaningful number of matches for all three satellites.”

7. *** Limb-Darkening Corrections: The limb-darkening correction appears oversimplified since it is only applied to nearly clear-sky scenes ($>95\%$ clear fraction), while cloud-related angular effects likely dominate the remaining spread. The analysis needs to:

- quantify the fraction of CERES footprints actually corrected,
- indicate the fraction of scenes satisfying the clear-sky criterion,
- and moderate statements regarding the impact of the MODTRAN corrections.

- a. *Authors' response:* We thank the reviewer for this important comment. We agree that the scope of the limb-darkening correction should be explicitly quantified. Of the

261,010 total CERES footprints across all 541 CTIM–CERES matches, 45,863 (17.6%) met the clear-sky criterion (Clear Sky 1 $\geq$ 95%) and received the limb-darkening adjustment. The remaining 83.4% of CERES footprints were cloudy (Clear Sky 1 $<$ 5%) and received no angular correction. Consequently, 409 of 541 CTIM–CERES scenes (75.6%) had at least one corrected footprint, while 132 scenes (24.4%) were entirely uncorrected. We have added these statistics to the manuscript and moderated the language describing the correction's impact to reflect its limited scope.

- b. *Proposed changes to the manuscript:* The following sentence has been added to Sect. 5.5 (starting at line 476): “Of the 261,010 total CERES footprints across all 541 CTIM–CERES matches, 45,863 (17.6%) met this criterion and received the limb-darkening adjustment. The remaining 82.4% of CERES footprints were cloudy (Clear Sky 1 $<$ 5%) and received no limb-darkening correction. Consequently, 409 of 541 CTIM–CERES scenes (75.6%) had at least one corrected CERES footprint, while 132 CTIM–CERES scenes (24.4%) were entirely uncorrected, as the majority of scenes contained non-negligible cloud cover.”

The following sentence has been added to line 530 of the results section: “The limb-darkening adjustment was limited to the 17.6% of CERES footprints that met the clear-sky criterion (Clear Sky 1 $\geq$ 95%), and its overall impact on the mean relative difference and standard deviation was modest (Table 2), as also reflected in the small difference between the pre- and post-adjustment results shown in Figs. 11 and 14.” Table 2 was created in response to comment #8 below.

8. *** Contribution of Each Correction Step

- It is currently difficult to assess the relative contribution of: CTIM spatial weighting, footprint area correction, and limb-darkening correction.
- Consider adding a summary table showing: mean bias, standard deviation, and R^2 , for: no correction, spatial weighting only, footprint area correction, and limb-darkening correction.

- a. *Authors' response:* We thank the reviewer for this suggestion. We have added a summary table (Table 2) to the results section showing the mean relative difference, standard deviation, and R^2 for each incremental correction step applied to the 541 CTIM–CERES matches. Without any correction, the unweighted mean relative difference was -0.877% ($\sigma = 5.378\%$, $R^2 = 0.917$). The addition of CTIM spatial response function weighting yielded -1.206% ($\sigma = 4.168\%$, $R^2 = 0.948$), and the further addition of the VZA-dependent footprint area ratio had negligible incremental effect (-1.206%, $\sigma = 4.157\%$, $R^2 = 0.948$). The full correction, which additionally applied the clear-sky LUT limb-darkening adjustment to CERES footprints with a clear-sky fraction $\geq 95\%$, yielded a final mean relative difference of -1.186%, $\sigma = 4.159\%$, and $R^2 = 0.948$. The negligible change in σ and R^2 across all corrections further suggested that the dominant source of spread was scene heterogeneity rather than the current correction methodology.

- b. *Proposed changes to the manuscript:* Table 2 and an accompanying paragraph have been added to Section 6 (starting at line 504), immediately following the introduction of the relative difference equation and preceding the results from all weightings and adjustments. Because of this addition, we have also rearranged the results section for better flow of the section. The paragraph corresponding the Table 2 begins at line 504 and ends at line 511:

“Table 2 summarizes the incremental contribution of each correction (Sect. 4, Step 3) to the CERES–CTIM radiance comparison. Without any correction, the unweighted mean relative difference across all 541 matches was -0.877% with $\sigma = 5.378\%$ and $R^2 = 0.917$. The addition of CTIM spatial response function weighting shifted the mean slightly to -1.206% ($\sigma = 4.168\%$, $R^2 = 0.948$), reflecting the greater weight given to CERES footprints closer to the CTIM centroid. The further addition of the VZA-dependent footprint area ratio had negligible incremental effect (-1.206% , $\sigma = 4.157\%$, $R^2 = 0.948$). The full correction, which additionally applied the clear-sky LUT limb-darkening adjustment to CERES footprints with a clear-sky fraction $\geq 95\%$, yielded a mean relative difference of -1.186% , $\sigma = 4.159\%$, and $R^2 = 0.948$, the values shown in Fig. 14 and reported throughout the remainder of this section.”

9. *** Figure 7 / CTIM Longwave Observations

- Figure 7 clearly shows the expected tropical OLR structures. However: some artefacts appear visible in the CTIM distribution and should be discussed, clarify explicitly that these are nighttime descending-orbit OLR observations.

- It would also be interesting to compare the same 2022-2023 period with another independent CubeSat ERB dataset, such as UvSq-Sat observations:

visualization portal: [UVSQ-SAT data visualization portal](#)

NetCDF archive: [UVSQ-SAT NetCDF archive](#)

- A comparison of latitude-longitude distributions or time series over the same 2022-2023 period, together with CERES observations, could provide additional insight into the consistency of small-satellite ERB observations.

- a. *Authors' response:* We thank the reviewer for these suggestions. We have added a discussion (lines 229-234) of the spatial artifacts visible in the CTIM distribution, explicitly attributing them to the limited sampling of a single CubeSat over 15 months of nighttime eclipse observations compared to the multi-instrument, 17-year CERES average of both daytime and nighttime outgoing longwave radiation. We have also clarified in both the Fig. 7 caption and manuscript text that CTIM observations are restricted to nighttime orbital eclipse periods.

Regarding the suggested comparison with UvSq-Sat, we agree this is a compelling idea that would provide valuable context for the consistency of small-satellite ERB observations. However, such a comparison would require additional background on

the Uvsq-Sat mission and measurement approach, potentially the development of a dedicated collocation algorithm between the two datasets, and careful treatment of the fundamental differences in measurement geometry and sampling. We consider this a worthwhile direction for a dedicated future study rather than an addition to the present paper, which focuses on the CTIM–CERES comparison methodology.

- b. *Proposed changes to the manuscript:* The following sentences have been added to Sect. 3.3 discussing Fig. 7 (lines 229-234): “Compared to CERES outgoing longwave radiation (Fig. 7, bottom), some spatial artifacts are apparent in the CTIM longwave radiance (Fig. 7, top), attributable to the limited sampling of a single CubeSat over 15 months of nighttime eclipse observations compared to the multi-instrument, 17-year CERES average of both daytime and nighttime outgoing longwave radiation. The comparison here is qualitative, as the two datasets differed fundamentally in spatial sampling, temporal coverage, viewing geometry, and measurement period.”

The Figure 7 caption has been updated to explicitly state that CTIM observations are from nighttime orbital eclipse periods and that the CERES data includes both daytime and nighttime observations (lines 243-244): “Bottom: CERES all-sky outgoing longwave radiation (daytime and nighttime) averaged over seventeen years of observations from Terra and Aqua (adapted from Dewitte and Clerbaux, 2018).”

10. *** Radiance versus Irradiance

- The distinction between radiance and irradiance should be clarified more carefully throughout the manuscript.

- Figure 7 compares:

CTIM longwave radiance,

CERES outgoing longwave irradiance.

Although the unit differences are mentioned, the comparison may still be misleading. Please either normalize the quantities more consistently or discuss more explicitly the limitations of this qualitative comparison.

- a. *Authors' response:* We thank the reviewer for this important point. The radiance/irradiance distinction is formally defined in Section 3.1, where we derive the conversion from CTIM-measured irradiance to radiance using the CTIM angular response function and effective solid angle. For Fig. 7, we have updated the caption to more explicitly acknowledge that CTIM reports outgoing longwave radiance ($\text{W m}^{-2} \text{sr}^{-1}$), while the CERES figure adapted from Dewitte and Clerbaux (2018) shows outgoing longwave irradiance (W m^{-2}). We have also added a statement to the caption noting that a direct quantitative comparison is not straightforward, as converting radiance to irradiance requires assumptions about the angular distribution of emitted radiation that will not hold uniformly across all scene types. The comparison in Fig. 7 is therefore explicitly qualitative, intended only to demonstrate that the large-scale spatial patterns of longwave emission observed by CTIM are physically consistent with the long-term CERES average.

- b. *Proposed changes to the manuscript:* The Fig. 7 caption has been updated (lines 247-249): “A direct quantitative comparison between the two is not straightforward, as converting radiance to irradiance requires assumptions about the angular distribution of emitted radiation that do not hold uniformly across all scene types.”

11. *** Conclusions

- Some conclusions regarding future CubeSat ERB capability appear somewhat ambitious.

Could you clarify the conclusions.

- The present study demonstrates promising complementarity with CERES, but several important challenges remain insufficiently addressed, including: long-term radiometric stability, absolute Earth-viewing calibration, cloud anisotropy corrections.

Statements suggesting reduced dependence on large dedicated missions should therefore be moderated.

Conclude that it's extremely difficult to determine the absolute value of ERB and EEI from satellite. Satellites are far better at determining the variability/trend.

- a. *Authors' response:* We thank the reviewer for this important feedback. We have moderated the conclusions to explicitly acknowledge the key challenges that remain (including long-term radiometric stability, absolute Earth-viewing calibration, and cloud anisotropy corrections) while maintaining that these could be addressed and improved through intentional design in future implementations. We have also replaced language suggesting reduced dependence on large, dedicated missions with language that emphasizes CubeSat platforms as low-cost redundancy that complements rather than replaces dedicated large-scale missions. Additionally, these CubeSat platforms could potentially serve as gap fillers for the ERB record between successive missions. We have added a closing statement acknowledging that determining the absolute value of ERB and Earth's energy imbalance from space-borne instruments remains an extremely challenging measurement problem, and that while current satellite observations are better suited to monitoring variability and long-term trends, improving absolute accuracy remains a critical goal that future intentionally designed Earth-viewing TSI CubeSats may help address.

- b. *Proposed changes to the manuscript:* The final paragraph of the conclusions section (lines 656-668) has been revised as follows. We have added the sentence (lines 659-661): “While challenges remain, including long-term radiometric stability, absolute Earth-viewing calibration, and cloud anisotropy corrections, these could be directly addressed and improved through intentional design in future implementations.”

We have also moderated the verbiage around reducing dependence on large, dedicated missions (lines 661-665): “The routine inclusion of Earth-viewing capabilities in future TSI instrument designs emerges as a natural extension of this work, with the

potential to meaningfully contribute to ERB observation continuity, maximize scientific utility, and strengthen the resilience of the ERB record by providing low-cost redundancy that complements rather than replaces dedicated large-scale missions. Additionally, CubeSat platforms could potentially fill gaps in the ERB record between successive missions in the future.”

Finally, we added a final sentence that addresses the difficulties of measuring absolute values of ERB and EEI from space-borne instruments, while remaining optimistic that CubeSats may play a role in more absolute and accurate measurements in the future (lines 665-668): “It is worth noting that determining the absolute value of ERB and Earth’s energy imbalance from space-borne instruments remains an extremely challenging measurement problem; while current satellite observations are better suited to monitoring ERB variability and long-term trends, improving absolute accuracy remains a critical goal—one that future intentionally designed Earth-viewing TSI CubeSats may help address.”

To align with this verbiage in the conclusion, the last sentence of the abstract has been amended: “The routine inclusion of Earth-viewing capabilities in future TSI instrument designs represents a natural extension of this work, with the potential to meaningfully contribute to ERB observation continuity and reduce the risk of gaps in future ERB observations from space.”

*** Minor comments

12. - Equation (1), clarify: the angular integration limits, and why integration to $\pi/2$ is appropriate given the effective cutoff near 23° shown in the response function.

- a. *Authors’ response:* We thank the reviewer for this clarification request. We have added a sentence explicitly noting that although the integration limits extend to $\pi/2$, the CTIM angular response $r(\theta)$ reaches absolute zero at approximately 23° , rendering the integrand negligible beyond this angle and making the effective upper integration limit equivalent to 23° .
- b. *Proposed changes to the manuscript:* The following sentence has been added beginning at line 177: “Note that while the integration limits in Eqs. (1), (3), and (4) extend to $\pi/2$, the CTIM angular response $r(\theta)$ reached zero at approximately 23° .”

13. - Figure 3: The figure is useful, but the manuscript should specify: the orbital altitude used for the ground-distance conversion, and the explicit relationship between incidence angle and surface distance.

- a. *Authors’ response:* The CTIM footprint radius of 242 km was derived from an orbital altitude of 453 km. The equation for relating the orbital altitude ($h = 453$ km), the CTIM off-boresight angle (θ), and cross-track ground distance (d) is as follows:

$$d = h * \tan(\theta)$$

Applying this relationship to the angle at which the CTIM angular response reaches zero (23°; Fig. 3, left) yields a cross-track ground distance of approximately 192 km. Because CTIM forward motion during each observation's integration period introduces additional along-track motion blurring, the effective along-track footprint extent is larger than the cross-track extent. The reported CTIM footprint radius of 242 km reflects the mean of the cross-track and along-track ground-distance extents, representing the average spatial response of the CTIM instrument (Fig. 3, right).

- b. *Proposed changes to the manuscript:* The caption for Fig. 3 has been updated to include the sentence: "The spatial response (derived from a CTIM altitude of 453 km, accounting for along-track motion blurring) reached zero at 242 km, which was determined to be the CTIM footprint radius."

Further, we have added a small paragraph (lines 188-193): "The relationship between the CTIM off-nadir angle (θ) and the cross-track ground distance (d) at nadir follows the equation:

$$d = h * \tan(\theta) \tag{5}$$

Where $h = 453$ km is the CTIM orbital altitude. Applying this relationship at the angle where the CTIM angular response reaches zero (23°) yielded a cross-track ground distance of approximately 192 km. Because CTIM forward motion during each observation integration period introduced additional along-track blurring, the reported footprint radius of 242 km reflects the mean of the cross-track and along-track ground-distance extents."

14. - Figure 8: The manuscript notes that only 0.5% of CERES footprints have VZA > 20°. If so, the practical impact of the footprint-area and limb-darkening corrections may be extremely limited. This should be discussed more explicitly.

- a. *Authors' response:* We thank the reviewer for this observation. Since the reanalysis (discussed in our response to comment # 6), the percent of CERES footprints with a VZA > 20° has increased to 6.93%. While this is significantly greater than the 0.5% value for the original results, the reanalysis does include 261,010 CERES footprints total (compared to the previous amount, 60,739). Thus, 45,863 CERES footprints were adjusted with the clear-sky limb-darkening LUTs. We agree the practical impact of the corrections should be discussed more explicitly and have done so through two additions to the manuscript. First, we have added Table 2 (in response to comment #8) to the results section quantifying the incremental contribution of each correction step, which shows that the footprint area correction has negligible incremental effect

and the LUT adjustment shifts the mean modestly from -1.206% to -1.186% with no significant change in σ or R^2 . Second, we have added text to both the methods and results sections explicitly noting that the limb-darkening adjustment was limited to 17.6% of CERES footprints and its overall impact was modest. We note that these corrections were applied as incremental steps toward the most physically rigorous comparison possible between CTIM and CERES, accounting for differences in viewing geometry even where their practical impact is small. The correction steps table (Table 2) confirms that the overall CTIM–CERES agreement is robust regardless of whether these corrections are applied.

- b. *Proposed changes to the manuscript:* We explicitly show the modest impact of the footprint area VZA and clear-sky limb-darkening adjustments in Table 2, with a short discussion (lines 504-511), which are shown in our response to comment #8. Further, we added a sentence quantifying the fraction of clear-sky footprints adjusted for limb darkening (lines 530-533): “The limb-darkening adjustment was limited to the 17.6% of CERES footprints meeting the clear-sky criterion (Clear Sky $1 \geq 95\%$), and its overall impact on the mean relative difference and standard deviation was modest (Table 2), as also reflected in the small difference between the pre- and post-adjustment results shown in Figs. 11 and 14.”

15. - Figure 15

The high correlation ($R^2 = 0.948$) is encouraging but partially expected given: the large dynamic range of outgoing longwave radiances, and the dominance of geophysical variability.

Additional diagnostics such as: RMSE, latitude-dependent statistics, or scene-type-dependent statistics, would provide a more complete evaluation of agreement.

- a. *Authors' response:* We thank the reviewer for this suggestion. We agree that R^2 alone is insufficient given the large dynamic range of outgoing longwave radiances and have added three additional diagnostics to the manuscript. First, we have added $RMSE = 3.015 \text{ W m}^{-2} \text{ sr}^{-1}$ to Fig. 15 and the accompanying text. Second, we have added a new figure (Fig. 17) showing the mean relative difference and $\pm 1\sigma$ envelope binned by 10° latitude intervals, which reveals that the mean relative difference remains close to -1.186% across most latitude bins with no clear latitudinal trend, while the two largest spreads occur in the -10° to 0° ($n = 44$, $\sigma = 5.97\%$) and 0° to 10° ($n = 34$, $\sigma = 9.54\%$) latitude bins, consistent with enhanced cloud heterogeneity in the ITCZ. Third, scene-type-dependent statistics are already presented in the updated Fig. 16, which stratifies the 541 matches into clear-sky ($n = 27$, $\sigma = 1.17\%$) and cloudy ($n = 514$, $\sigma = 4.26\%$) subsets, demonstrating the hypothesis that cloud presence is the dominant contributor to the overall spread.

- b. *Proposed changes to the manuscript:* RMSE = $3.015 \text{ W m}^{-2} \text{ sr}^{-1}$ has been added to Fig. 15 and the results text (lines 546-548): “Linear regression of all 541 CTIM-CERES matching cases yielded a coefficient of determination of $R^2 = 0.948$ and a root mean square error (RMSE) of $3.02 \text{ W m}^{-2} \text{ sr}^{-1}$ (Fig. 15), indicating a high degree of correlation between CTIM radiances and CERES mean radiances.”

A new figure (Fig. 17) and accompanying paragraph have been added to Section 6 following the cloud fraction discussion. The paragraph for Fig. 17 (lines 597-603): “Figure 17 further examines the latitudinal dependence of the CTIM–CERES agreement by showing the mean relative difference and $\pm 1\sigma$ envelope binned by latitude. The mean relative difference remains close to the overall mean of -1.19% across most latitude bins, with no clear trend with latitude. However, the two largest spreads in relative difference occur in the -10° to 0° ($n = 44$, $\sigma = 5.97\%$) and 0° to 10° ($n = 34$, $\sigma = 9.54\%$) latitude bins, compared to all other bins ($\sigma = 2.38\text{--}4.71\%$), consistent with the persistent deep convective cloud cover and enhanced cloud heterogeneity associated with the ITCZ. The large spread in these two latitude bins further supports the notion that cloud presence is the dominant contributor to the overall spread ($\sigma = 4.16\%$) in the relative difference between CTIM and CERES.”

RESPONSES TO REVIEWER #2

Major Comments

We thank Reviewer 2 for the constructive comments. Before addressing each comment individually, we note that in response to a comment from Reviewer 1 regarding our collocation methodology, we conducted a detailed internal review that identified a discrepancy in our reported CTIM footprint radius. This led to a corrected spatial radius of 242 km (previously reported as 100 km), an updated minimum CERES footprint threshold of 400 (previously 75), and an extension of our limb-darkening lookup tables to accommodate the resulting range of CERES viewing zenith angles and surface temperatures. We subsequently conducted a full reanalysis of the CTIM–CERES collocation across all three satellites (Terra, Aqua, and NOAA-20) using these corrected parameters. As a result, several of the values, figures, and statistics referenced in our responses to Reviewer 2's comments below reflect this updated analysis rather than the original submission. We indicate where this is the case throughout our responses.

1. The limb-darkening adjustment results: if we compare Figure 11 and Figure 14 (bottom panel), we can conclude that the adjustment is essentially inconsequential: the μ and σ are so close in the two figures. However, the result of Figure 14, which is after adjustment, doesn't agree with Table 3 (mean -1.273% and standard deviation 0.309%). I wonder whether Figure 14 is incorrect, or how to reconcile the inconsistency between Figure 14 and Table 3?
 - a. *Authors' response:* We thank the reviewer for the careful comparison. The apparent inconsistency arises from two different statistics being reported (and the

results from the reanalysis have been updated through the text, also reported here). The Figs. 11 and 14 now show the mean relative difference and standard deviation values for easy comparison. In Fig. 14, though, the mean ($\mu = -1.186\%$) and standard deviation of the relative differences ($\sigma = 4.159\%$) are fully consistent with Table 3, which reports the same values. The $\pm 0.345\%$ in Table 3 is the half-width of the bootstrapped 95% confidence interval on the mean (a measure of uncertainty in the estimated mean, not the spread of the data). We have made these statistical values clearer for the reader.

b. *Proposed changes to the manuscript:* To avoid this confusion, we have made the following changes:

(1) The manuscript text has been revised to report σ alongside the mean and 95% CI for each individual satellite (see lines 521-529): “Figure 14 shows the relative differences between CTIM and CERES on each satellite (top) and the relative differences between CTIM and all CERES instruments aboard all three satellites (bottom). Terra had 238 matches with CTIM with a relative difference of $-1.18\% \pm 0.45\%$ and a standard deviation of $\sigma = 3.56\%$. Aqua had 109 matches with a relative difference of $-1.21\% \pm 1.08\%$ ($\sigma = 5.70\%$). NOAA-20 had 194 cases with a relative difference of $-1.18\% \pm 0.53\%$ ($\sigma = 3.83\%$) (Table 3). It is important to note that the Aqua dataset was limited in time, as the SSF Level-2 data production stopped on 21 March 2023. Because of this, the Aqua data had significantly fewer matches than Terra and NOAA-20. Both Terra and NOAA-20 individually provided data over the entire CTIM lifetime. Collectively (labelled CERES in Fig. 14 and in Table 3), the three satellites had 541 matches with CTIM with a mean relative difference of $-1.19\% \pm 0.35\%$ and a standard deviation of $\sigma = 4.16\%$. Uncertainties represent the half-width of bootstrapped 95% confidence intervals (10,000 resamples).”

(2) Both a 95% CI column and a σ column have been added to Table 3 so that both statistics are visually separated and clearly distinct.

(3) The Table 3 caption has been updated to explicitly define both quantities: “Table 3: Relative differences for each CERES satellite compared to CTIM, including the number of matching CTIM footprints per satellite based on our matching methods. The 95% CI values are half-widths of bootstrapped confidence intervals on the mean (10,000 resamples). σ is the sample standard deviation of the individual relative differences.”

2. The dominant residual driver — clouds — is identified but insufficiently addressed. Figure 16 clearly shows that residual spread increases with cloud fraction, and Section 5.3 acknowledges that cloud limb darkening is the harder, more important problem. Given that the dominant majority of CTIM nadir observations contain non-negligible cloud cover, a lack of any cloud-scene correction is the single largest limitation here. A couple of suggestions:
 - (a) the comparison stratified by cloud fraction so that a clear-sky-only mean and standard deviation can be reported separately
 - (b) a more quantitative discussion of how the $\sigma = 4.23\%$ decomposes into scene heterogeneity, viewing-geometry effects, and instrument-level terms.
- a. *Authors' response:* We agree that the lack of any cloud-scene correction is a large limitation of this study, and we thank the reviewer for the suggestions. We have updated Fig. 16 to include a comparison between clear-sky CTIM scenes and cloudy-sky CTIM scenes. Clear-sky scenes were defined at the CTIM scene level using the footprint-area-weighted mean of CERES SSF clear-sky fractions across all CERES footprints within a given CTIM footprint, consistent with the $\geq 95\%$ clear-sky threshold applied to individual CERES footprints for the LUT adjustment. Scenes with a scene-level cloud fraction ≤ 0.05 were classified as clear-sky ($n = 27$), and the remaining 514 matches were classified as cloudy. Clear-sky scenes yield a mean relative difference of $\mu = -1.12\%$ and a standard deviation of $\sigma = 1.17\%$, compared to $\mu = -1.19\%$ and $\sigma = 4.26\%$ for cloudy scenes, and $\mu = -1.19\%$ and $\sigma = 4.16\%$ for all scenes. Focusing on Fig. 16, right, the reduction in σ from 4.26% to 1.17% under clear-sky conditions confirms that cloud presence is the dominant contributor to the overall spread about the mean. Regarding the reviewer's second suggestion (b), a full quantitative decomposition of σ into scene heterogeneity, viewing geometry, and instrument-level terms would require additional controlled analyses beyond the scope of this paper. However, the clear-sky stratification provides a practical upper bound on the instrument-level and viewing geometry contributions ($\sigma = 1.17\%$), with the remaining spread attributable primarily to unresolved cloud variability within the large CTIM footprint. We have updated the manuscript accordingly.
- b. *Proposed changes to the manuscript:* Figure 16 has been updated to include a third panel showing the mean relative difference and standard deviation for clear-sky ($n = 27$) and cloudy ($n = 514$) CTIM scenes. Clear-sky CTIM scenes were defined as those with a footprint-area-weighted mean cloud fraction ≤ 0.05 , consistent with the $\geq 95\%$ clear-sky threshold applied to individual CERES footprints for the limb-darkening adjustment but applied here at the CTIM scene level. The figure caption has been revised to reflect these additions (lines 587-595): “Figure 16: CTIM–CERES radiance relative differences as a function of CTIM scene cloud fraction for all 541 matches. Top left: Scatter plot of relative difference versus CTIM scene cloud fraction, where cloud fraction represents the footprint-area-weighted mean of CERES SSF cloud fractions (1 – clear-sky

fraction) within each CTIM footprint. Bottom left: Standard deviation of relative differences binned by CTIM scene cloud fraction. The standard deviation generally increases with cloud fraction, consistent with scene heterogeneity driven by cloud variability within the large CTIM footprint. Right: Mean relative difference and standard deviation for clear-sky CTIM scenes (CTIM cloud fraction ≤ 0.05 , $n = 27$) and cloudy CTIM scenes (CTIM cloud fraction > 0.05 , $n = 514$). Clear-sky scenes yield a slightly reduced mean bias (-1.12% vs. -1.19%) and lower spread about the mean ($\sigma = 1.17\%$ vs. $\sigma = 4.26\%$), further suggesting that cloud presence is the dominant contributor to the overall $\sigma = 4.16\%$ observed across all 541 matches.”

We also modified the text starting at line 573 through 582: “Figure 16 supports the notion that clouds play a role in the spread in radiance in the CTIM–CERES matches. There is a greater spread in relative difference with increased CTIM scene cloud fraction, as determined by the footprint-area-weighted mean of the CERES SSF cloud fractions ($1 - \text{clear-sky fraction}$) within the CTIM footprint. The standard deviation of relative difference binned by CTIM cloud fraction (Fig. 16, bottom left) generally increases with cloud fraction, consistent with scene heterogeneity driven by cloud variability within the large CTIM footprint. To further quantify this effect, CTIM scenes were stratified into clear-sky (cloud fraction ≤ 0.05 , $n = 27$) and cloudy (cloud fraction > 0.05 , $n = 514$) subsets. Clear-sky scenes yield a mean relative difference of $\mu = -1.12\%$ and $\sigma = 1.17\%$, compared to $\mu = -1.19\%$ and $\sigma = 4.26\%$ for cloudy scenes (Fig. 16, right). The results shown in Fig. 16 support the hypothesis that the presence of clouds viewed at different geometries may be responsible, at least in part, for the spread in our results, which was only negligibly reduced after clear-sky limb-darkening adjustments (Fig. 14).”

Minor Comments

3. End-of-mission date is inconsistent: abstract says "November 2023" (l. 28 of the body), Section 1 says "December 2023" (the introduction), Section 2.2 says "early December 2023", and Section 3 says "through November 18, 2023". Pick one.
 - a. *Authors' response:* We thank the reviewer for finding this mistake. Data collection for this project spans from August 2022–November 2023, while CTIM was in orbit from July 2022–December 2023.
 - b. *Proposed changes to the manuscript:* For consistency, we changed the abstract date to December 2023 to represent the entire lifetime of CTIM. The Earth observation dates for this study are clearly defined in Section 3.
4. Detector-head labels are inconsistent: Section 3.2 says heads are "A1 and B1," but Fig. 2 caption says "A1 and B2."
 - a. *Authors' response:* We thank the reviewer for finding this mistake.
 - b. *Proposed changes to the manuscript:* Fig. 2 now correctly says A1 and B1.

5. Date-format inconsistency in Section 3: "26 August 2022" appears in one sentence; the very next sentence uses "August 27, 2022" and "November 18, 2023."
 - a. *Authors' response:* We thank the reviewer for finding this mistake.
 - b. *Proposed changes to the manuscript:* We have standardized the date format throughout the paper to Day Month Year.
6. "Priestely et al., 2018" in the introduction (Sect. 1) is misspelled — should be "Priestley"
 - a. *Authors' response:* We thank the reviewer for finding this mistake.
 - b. *Proposed changes to the manuscript:* This has been corrected.
7. "the number of ERB instruments decrease from four to one" — should be "decreases"
 - a. *Authors' response:* We thank the reviewer for finding this mistake.
 - b. *Proposed changes to the manuscript:* This has been corrected.
8. "Loeb et al., 2024 further show" — should be "Loeb et al. (2024) further show" for citation-style consistency.
 - a. *Authors' response:* We thank the reviewer for finding this mistake.
 - b. *Proposed changes to the manuscript:* This has been corrected.
9. Sect 4: "matching the instruments' ground-projected footprints space and time" — missing "in" before "space."
 - a. *Authors' response:* We thank the reviewer for finding this mistake.
 - b. *Proposed changes to the manuscript:* This has been corrected.
10. Sect 5.5: "responsible, at least in part, to the spread" — should be "for the spread."
 - a. *Authors' response:* We thank the reviewer for finding this mistake.
 - b. *Proposed changes to the manuscript:* This has been corrected.
11. Sect 5.5: "the limb-darkening adjustments factors" — should be "adjustment factors" (no -s on adjustment).
 - a. *Authors' response:* While we did not find this mistake in Sect. 5.5, we did find this mistake in Sect. 7.
 - b. *Proposed changes to the manuscript:* This has been corrected.
12. Figure 16 caption: "Total cloud compared to radiance" — should be "Total cloud fraction compared to radiance."
 - a. *Authors' response:* We thank the reviewer for finding this mistake.
 - b. *Proposed changes to the manuscript:* This has been corrected.

13. Section 7: "increases to 33% in 2028 and a 60% probability in 2035" — broken parallel structure; should be "and to 60% in 2035."
 - a. *Authors' response:* We thank the reviewer for finding this mistake.
 - b. *Proposed changes to the manuscript:* This has been corrected.
14. Units throughout: "(W/m 2)" and "(W/m 2 sr)" appear with stray spacing instead of proper superscripts ($W\ m^{-2}$, $W\ m^{-2}\ sr^{-1}$).
 - a. *Authors' response:* We thank the reviewer for finding this mistake.
 - b. *Proposed changes to the manuscript:* This has been corrected.
15. Degree symbols: several instances of "15 o", "4 o" where a proper "°" or "°" is intended.
 - a. *Authors' response:* We thank the reviewer for finding this mistake. This might have occurred due to file processing, as our original submission had proper "°" symbols.
 - b. *Proposed changes to the manuscript:* This has been double checked thoroughly.

RESPONSES TO REVIEWER #2, MINOR REVISIONS

I appreciate the substantial work the authors have done in response to the comments. The manuscript is much improved. I still have a couple of technical comments. I recommend a minor revision.

1. The claim of inter-CERES agreement to 0.03% (line 557) needs to be objectively stated. The three satellite means agree to 0.03%, but each mean has a bootstrapped 95% CI of $\pm 0.45\%$ (Terra), $\pm 1.08\%$ (Aqua), $\pm 0.53\%$ (NOAA-20), and each satellite samples different scenes and local times. In my view, the three are statistically indistinguishable at the $\sim 0.5\text{--}1\%$ level. The numbers in the manuscript cannot substantiate a claim of 0.03% agreement.
 - a. *Authors' response:* We thank the reviewer for this important comment. The reviewer is correct that reporting the raw difference between the mean values of the three CERES instruments (0.03%) without accounting for the uncertainty on each individual mean overstates the precision of the inter-CERES agreement. As the reviewer notes, the 95% confidence intervals for the individual CERES instruments (Terra $\pm 0.45\%$; Aqua $\pm 1.08\%$; NOAA-20 $\pm 0.53\%$) overlap, meaning the three means are statistically indistinguishable from one another rather than distinguishably "agreeing to 0.03%." We have revised the manuscript to state this more objectively.
 - b. *Proposed changes to the manuscript:* The sentence in line 565 has been revised from:
 "The comparisons in Fig. 14 and Table 3 show that CTIM and CERES agree to well within their respective uncertainties and that the CERES instruments used in

this study agree with one another (within less than 0.03% based on this comparison).”

to:

“The comparisons in Fig. 14 and Table 3 show that CTIM and CERES agree to well within their respective uncertainties and that the Terra, Aqua, and NOAA-20 CERES instruments used in this study agree are statistically indistinguishable from one another.”

2. About footprint geometry: The 242 km radius is derived from $h = 453$ km, while Sect. 2.2 says ~ 500 km. CTIM re-entered in December 2023, so its altitude must have decayed substantially over the 15-month observing period; with $d = h \cdot \tan(23^\circ)$, a 400 km altitude gives 170 km cross-track rather than 192 km. Please state the altitude range over the analysis period and either (a) compute the footprint per observation from the actual altitude, or (b) show that using a fixed 453 km changes nothing. My hunch is (b) would be true, as the spatial response is near zero beyond ~ 165 km anyway.
 - a. *Authors' response:* We thank the reviewer for bringing up this important point. CTIM was launched into an approximately 500 km altitude, correctly stated in Sect. 2.2. The 453 km altitude used in Sect. 3.1 for the footprint-geometry calculation represents the median CTIM altitude across the analysis period; the CTIM altitude ranged from 503.9 km to 299.4 km over this period (26 August 2022–30 November 2023) as its orbit decayed ahead of re-entry in December 2023. A rigorous per-observation altitude and radius correction (Reviewer's option a) would require the minimum CERES footprint threshold to change for each CTIM footprint; thus, each CTIM footprint would require extensive sensitivity analysis for determining the statistically significant number of CERES footprints for Step 1 of the matching algorithm. (The process is demonstrated in our response to Reviewer 1). We instead evaluated option (b): whether the fixed 453 km altitude meaningfully affects our results.

For each of the 541 CTIM–CERES matches, we recomputed each CTIM footprint radius using that observation's altitude using the equation:

$$d = h \tan(23^\circ)$$

This provided a conservative approximation, as it excluded along-track motion blurring, which increases the true footprint size relative to this calculation. Thus, this conservative approximation should provide a larger difference between the fixed-altitude and altitude-varying approaches than a motion-blur-inclusive correction would, since it produces smaller footprints overall.

With each new altitude-specific CTIM radius smaller than 242 km, we used a “cookie cutter” approach: any CERES footprint farther from the CTIM centroid than that observation's radius was excluded entirely. The remaining CERES footprints were weighted using the same CTIM spatial response function,

footprint area ratio, and clear-sky limb-darkening adjustments as in the original analysis. The weighting itself was unchanged; only the set of CERES footprints included in the weighted mean for each CTIM–CERES match differed. Excluding the far-field footprints increased the relative contribution of the remaining, near-edge footprints to the weighted mean, compared to the original fixed 242 km radius.

The altitude-varying analysis yielded a combined mean relative difference of -1.203% ($\sigma = 4.169\%$) across all 541 matches, compared to -1.186% ($\sigma = 4.159\%$) using the fixed 453 km altitude (a difference of 0.017 percentage points in the mean and 0.010 percentage points in the standard deviation). At the level of individual CTIM–CERES matches, the altitude-varying analysis produced a mean per-match shift of -0.018% ($\sigma = 0.194\%$), with a maximum absolute shift of 2.959% occurring at 299.5 km (near the minimum altitude observed over the analysis period). The per-match relative differences between the two methods were highly correlated overall ($R^2 = 0.998$; RMSE = 0.194%), which further confirmed that the altitude correction does not substantially alter individual CTIM–CERES match-level results.

We therefore concluded that the fixed 453 km altitude used for the footprint-geometry calculation did not meaningfully affect the results reported in this study, consistent with option (b) suggested by the reviewer.

- b. *Proposed changes to the manuscript:* We have added the altitude range explicitly to the manuscript (Lines 190-191):

“Where $h = 453$ km was the median CTIM orbital altitude across the analysis period (see Sect. 6 for a sensitivity analysis of the fixed-altitude assumption).”

As indicated by our changes to the sentence in Lines 190-191, we added a note following the first paragraph in the results section (Lines 537-544):

“Notes on the fixed-altitude footprint geometry assumption:

To evaluate the sensitivity of our results to the fixed 453 km altitude used in Sect 3.1, each CTIM footprint radius was recomputed using that observation’s altitude in Eq. (5), excluding along-track motion blurring (a conservative approximation that yielded smaller footprints and therefore an upper bound on the expected sensitivity). Using the same 541 CTIM–CERES matches, the CERES footprints falling outside of the altitude-specific CTIM radius were excluded in the CERES mean radiance calculation. The resulting altitude-varying analysis yielded an overall mean relative difference of -1.20% ($\sigma = 4.17\%$), with per-match relative differences highly correlated between the two approaches ($R^2 = 0.998$). These results indicated that the fixed 453 km altitude did not introduce a meaningful bias in the reported CTIM–CERES comparisons.”

In addition, a few typos and inconsistencies.

3. NOAA-20 σ : text (line 524) and response say 3.83%; Table 3 says 3.89%. Please check and reconcile.
 - a. *Authors' response*: We thank the reviewer for finding this typo. The value in Table 3 should have been reported as 3.829%, which is where the rounded value of 3.83% comes from in (now) line 525.
 - b. *Proposed changes to the manuscript*: The value in Table 3 has been corrected.

4. Line 78: "National Academies of Science (2016)" vs. "National Academies of Sciences (2018)" elsewhere
 - a. *Authors' response*: We thank the reviewer for finding this typo.
 - b. *Proposed changes to the manuscript*: This has been corrected to "National Academies of Sciences (2016)".