Interactive comment on “Determining the Daytime Earth Radiative Flux from National Institute of Standards and Technology Advanced Radiometer (NISTAR) Measurements” by Wenying Su et al.

Anonymous Referee #1

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11. In ERB calibration your definition of filtered radiance as IRRADIANCE/ SOLIDANGLE is only true if the instrument has a completely flat spectral response, which from fig 2 is certainly not the case for NISTAR SW & NIR channels.

We are not sure what the reviewer means here. NISTAR is a broadband instrument, it measures the energy from the spectral ranges defined in Fig. 2. The relationship between radiance and irradiance should not change with the spectral response function.

113-132. This is based on CERES unfiltering of Loeb et al 2001 I assume (where they are also labelled Eqns 3 & 4 at https://journals.ametsoc.org/doi/pdf/10.1175/1520-0450%282001%29040%3C0822%3ADOURFT%3E2.0.CO%3B2). Is it completely identical to CERES using the same decades old CERES radiative transfer database? This might be important to briefly mention as it could help eliminate mere inversion biases when you compare to CERES later in the paper.

The concept of unfiltering used here is the same as that by Loeb et al. (2001), but the database used here is different and was calculated specifically for this study. The current database contains 722 clear-sky cases and 1519 cloudy-sky cases (line 166), whereas the total number of cases used by Loeb et al. (2001) was 272. This information is added to the manuscript.

142. This is confusing, although I accept it probably amounts to same thing, are look up tables of a & b values (Eqns 3 & 4) or a table of kappa ratios actually used? Only if both techniques are used separately should there be 4 rather than just 2 eqns?

Thank you for catching this. The Equations 3 and 4 are the original method used to unfilter the CERES observations. As you know, we have scene-type information and Sun-viewing geometry for each CERES footprint, thus the regression can be applied based upon the scene type and Sun-viewing geometry of the CERES footprint. NISTAR views the entire Earth as a single pixel, and the cloud fraction, cloud type, and land/ocean portions differ from time to time. Luckily, the NISTAR SW spectral response function is such that the ratio between filtered and unfiltered radiances exhibit very little sensitivity to the scene types and Sun-viewing geometry. We rewrote the section on page 7 and 8 to correct this.

143. How are spectrally dependent changes to the transmission of the quartz filter due to outgassing contamination measured after launch and throughout the mission?

On-orbit measurements indicated that the filters have not degraded significantly since they were measured on the ground during calibration. On orbit measurements of the broadband transmission of the filter stack are continually made every three months using the earth as a source and the photodiode as a detector. The ratios of the on-orbit transmittances amongst each *of the two sets of 3 nominally identical filters of each type (SW and NIR) are within 0.2% of each other (as expected from ground measurements) and have remained stable to less than 0.1% throughout the mission. In the case of the SW filter (quartz), the on-orbit broadband transmittance is within 1% of the spectral transmittance of the filter stack over the wavelength range from 500 nm to 2500 nm.*

144. What about quartz filter leakage? Are you using the NIR channel for that somehow (similar to Loeb et al 2001 above)?

A thin quartz filter can transmit significantly at wavelengths greater than many tens of micrometers, however, the NISTAR filter stacks consists of a pair of 3 mm thick quartz substrates—one is a bare uncoated substrate and the other has dielectric coatings to block light below about 700nm. At 3 mm thickness per substrate the transmittance below 100 micrometers is negligible. Loeb et al (2001) did not use any NIR channel.

146. Are you sure no unfiltering of the total channel is required, if so how? Was its spectral response measured to be certain? How are you certain no changes to the effective gains of the cavity channels due to electronics radiation exposure are occurring? I'm assuming you do not have onboard blackbodies?

We do not unfilter the total channel. The total channel spectral response is determined by the spectral absorptance of its cavity absorber, which, like a blackbody, relies on multiple reflections to achieve a high degree of absorptance (emissivity). Each cavity is conical in shape to trap light and is painted with a specular black paint, Z302, which has a very small component of diffuse reflectance. Measurements of the cavity absorptance made on the ground at wavelengths of 488 nm, 514 nm and 632 nm confirmed that the cavity absorbed more than 0.9997 of the incident light. Given the known spectral reflectance of Z302 to long wavelengths and the cavity design (verified at visible wavelengths), un-filtering of the total channel is not required.

The only electronics that affect the cavity channel gains are those that measure the electric power applied to the cavity heaters. Those electronics were chosen for their radiation tolerance and long term stability. Given the on-orbit radiation exposure levels, such degradation is not expected to significantly affect heater power measurements. Similar techniques and electronics are used to measure the total solar irradiance from space with a stability of less than 0.1%, which is sufficient to resolve the 11 year solar cycle. Unlike those measurements, degradation from UV exposure is not an issue here. You are correct, there aren't any on-board blackbodies to use as a references. Such blackbodies would have to have phase transition temperature references to be less sensitive to radiation exposure than the radiometers. This is because electronic temperature measurements are much more challenging than measurement of the power applied to the cavity heaters.

147. How are the SW and Total channels balanced in the solar region as in Kratz et al 2002? (https://agupubs.onlinelibrary.wiley.com/doi/epdf/10.1029/2001JD001170)

Since the NISTAR instrument only views the sunlit side of the Earth, there are no measurements taking during nighttime that can be used in the same manner as Kratz et. al. (2002), in which they looked at the correlation between nighttime total channel and window channel.

261. what is a shutter cycle? Why is a boxcar filter used in the demodulation algorithm? Are details of these processes important?

NISTAR utilizes a shutter to modulate light from the Earth just as a chopper wheel is used in the laboratory to modulate a light source. The shutter is opened and closed continuously with a 50% duty cycle with a period of nominally 4 minutes. Each 4 minute period is a shutter cycle. The demodulation algorithm is analogous to what is performed in a digital lock-in amplifier. Use of a boxcar filter having the width of a shutter period strongly rejects higher harmonics of the shutter frequency. Other low pass filters could be used. Note that additional filtering at lower frequencies, e.g., 4 hour running averages, are used to further reduce noise levels. Description is added on page 5.

264. Recommended based on what, the URL does not work?

Based on the noise level. The URL was temporally unavailable due to internal web maintenance, it should be available now. Sorry about that.

266. Why 4 hour “running means” and how is this different from a 4-hour wide boxcar filter from the terminology you used earlier? Does this mean a 4-hour running mean is taken of the boxcar filtered then 2-hour averaged data? Why are the 4 hour means suggested by the NISTAR instrument team?

A running mean of 4 hours is conceptually the same as a boxcar filter. The 4 hour averages are additional filtering that occurs after the 4 minute wide boxcar filter to reduce noise levels. A four hour compromise is proposed as a trade-off between reducing noise and attenuating the signal of interest, however, the data is also provided without the additional filtering so the user may apply their own filter.

286. These GERB comparisons need a reference.

Reference "Doelling et al. (2013)" was provided on line 342, immediately after summarizing the comparison results.

311. Why does the onboard data processing cause this?

We removed this sentence in the revised version.

315. How are the offsets countered, space looks?

Yes. The shutter removes some, but not all offsets. Those that remain are removed with monthly space looks. Description is added on page 5.

332. With as few as 10 EPIC results per day are these always equally spaced in time? If not, could this not lead to biases?

When EPIC is in normal operations, it receives about 10 images daily during the winter cadence. They are normally spaced about 2 hours apart. EPIC receives about 20 images a day during the summer cadence and they are about 1 hour apart. If we simply compare the daily mean fluxes averaged using the EPIC image times with those averaged over the 24 hours, that would lead to biases. In this study, we only averaged the CERES SYN1deg using the hours that coincide with the EPIC times (line 376). Thus ensure both daily means are calculated using same number of hours.

338. So it seems the LW difference is greatest in Northern Hemisphere Winter, when more ocean is observed? This may be a calibration artifact or error in knowledge of the NISTAR SW channel for the UV region. As per the point above for line 147, how are you balancing SW and Total channels to assure accurate LW in daylight?

Preliminary analysis of the 2018 measurements does not show the same difference pattern (i.e. larger difference over the boreal summer months than the winter months), thus not supporting the hypothesis of the reviewer. As we mentioned earlier, NISTAR only views the sunlit side of the Earth and the same method used by Kratz et al (2002) cannot be applied here.

352. "A comprehensive spectral database has been developed", so is it different from that used by CERES?

Yes, and more details are added on page 7-8.

355. So is a constant of 0.8690 used for all NISTAR unfiltering? Unfiltering of LEO scenes varies greatly by several percent especially for ocean scenes etc. So, it seems a value of 0.3% difference for primarily land vs Pacific Ocean scenes would vary more (and maybe adds to your seasonal cycle). What results lead to the 0.3% conclusion and did you try a scene by scene unfiltering?

Based on the simulated filtered and unfiltered radiances for 722 clear-sky cases and 1519 cloudy-sky cases for each Sun-viewing geometry, the ratio between filtered and unfiltered radiances is extremely stable (see Table 2). Table 2 summarized the ratios and their standard deviation for each solar zenith angle bin for each scene type. For clear-sky case, each solar zenith angle bin contains over 57,000 simulations; and for cloudy-sky case, each solar zenith angle bin contains over 120,000 simulations. The largest ratio difference over different scene types happens under overhead sun, where the ratio for clear ocean is 0.8659 and is 0.8694 for clear land. Using constant unfiltering ratio of 0.8690, it could cause up to 0.3% unfiltering uncertainty if a clear ocean scene is encountered. However, NISTAR views the sunlit side of the Earth as a single pixel. There are always clouds and land mixed in. Thus we state the unfiltering *uncertainty should be less than 0.3%. We rewrote the unfiltering portion of the paper on page 7 and 8 to clarify the reviewer's concerns.*

370. Is this the PSF of the EPIC telescope separate from its array of detectors? How was it measured?

We are not sure we understand the reviewer's question. The PSF tells us where does the light measured in one pixel come from. It's a function of the instrument's entire optical system, telescope and detector. The EPIC PSF was measured in the laboratory before launch, nominal PSF is given in Khlopenkov et al. (2017, SPIE).

388. Again, this could be due to a constant unfiltering factor?

Please see response above.

392. Loeb et al 2018 only quotes the 1% accuracy figure as do you, please provide a peer reviewed SI traceable reference.

The following CERES calibration references are added:

J. M. McCarthy, H. Bitting, T. A. Evert, M. E. Frink, T. R. Hedman, P. Skaguchi, and M. folkman. A summary of the performance and long-term stability of the pre-launch radiometric calibration facility for the Clouds and the Earth's Radiant Energy System (CERES) instruments. In 2011 IEEE International Geoscience and Remote Sensing Symposium, pages 1009–1012, 2011.

K. J. Priestley, G. L. Smith, S. Thomas, D. Cooper, R. B. Lee, D. Walikainen, P. Hess, Z. P. Szewczyk, and R. Wilson. Radiometric performance of the CERES Earth radiation budget climate record sensors on the EOS Aqua and Terra spacecraft through April 2007. J. Atmos. Oceanic Technol., 28:3–21, 2011.

396. Please give a peer reviewed reference for the 2.1% NISTAR SW accuracy figure.

NISTAR is a relatively new instrument and so far no peer reviewed publication describing the calibration is available. The presentation describing the NISTAR calibration is available at: https://avdc.gsfc.nasa.gov/pub/DSCOVR/Science_Team_Meeting_Sept_2019/L1/NISTAR_Goddard%20Science%20Team%2020190917.pdf

404. With so many error sources not well known it is wrong to simply add them all in quadrature, which assumes they are all random and independent. A more sophisticated error analysis is needed.

The reviewer is correct that the error sources considered here were simply added to approximate the uncertainty. I would say this is a simplified estimate of the uncertainty, but not the wrong estimate. We know the sources of the uncertainty, but don't know the correlation of all the error sources and therefore unable to estimate the covariances of the sources considered here. The *uncertainty given here can be regarded as the upper bound, and this method has been used by Loeb et al. (2009) and Loeb et al. (2018).*

407. The 1.8Wmˆ2 accuracy for CERES LW applies for nighttime LW only. During the day which is always the case for NISTAR it is less accurate. This is because it requires the earlier discussed balancing of the SW and Total channel which if done wrong can result in measuring the Earth warmer at night than during the day for example (see Fig11b, Page 14 at https://journals.ametsoc.org/doi/pdf/10.1175/2010JTECHA1521.1). Hence for NISTAR which only views day LW, this is an important consideration.

The reviewer is correct that the accuracy of the daytime and nighttime LW is different. The daytime LW uncertainty due to calibration is 2.5 Wm-2 (1 sigma). The combined uncertainty is updated based on the daytime LW flux uncertainty (line 461).

415. Guesstimate? This is most unsatisfactory for any science paper, let alone one on climate measurements. Please do better.

Changed to "estimate".

423. Again, adding in quadrature for so many uncertain, often modelling terms is not acceptable. For example, consider how the error in knowledge of SW vs Total solar response could be systematic because of an error in the ground lab, it will partly cancel in the Total – SW subtraction.

Please see our response above regarding the uncertainty estimation. The daytime LW flux uncertainty due to calibration is estimated by accounting for the calibration uncertainty in both total channel and SW channel, and the correlations between these two channels.

428. This is true, in addition to the above-mentioned systematic nature of SW and Total errors not considered in your quadrature additions. A more sophisticated analysis is needed.

As we stated above, the error analysis considered both SW and total channel. However, changes in error analysis won't affect the correlation between the LW flux from CERES and from NISTAR.

Overall this paper has merit but needs work to fill in the blanks on some of the processes/references used. The large differences of NISTAR from CERES appears strange and would seem at first look to be largely from algorithm errors. I feel this could be acceptable being a new measurement, but needs to be stated more clearly in the paper as such.

The NISTAR instrument is the first ever cavity radiometer placed at the L-1 point to measure the Earth's radiation. EPIC on board the DSCOVR also provides 10 narrowband observations from the same Sun-viewing geometry and the visible channels of EPIC are calibration against MODIS. When the global SW anisotropic factors were applied to the EPIC broadband radiance *(derived by applying narrowband-to-broadband regressions to EPIC blue, green, and red measurements), the EPIC SW flux agrees with the CERES SYN SW flux to within 2%. The good agreement indicates that the algorithm that we developed is accurate and is not the cause for the large discrepancy between NISTAR and CERES SYN. Even though there are discrepancies between the NISTAR fluxes and CERES SYN fluxes, we feel it is important to document the measurement, the algorithm, and the validation for future reference.*

The use of constant SW unfiltering also raises concern and leads to the possibility it is a cause of the larger than expected seasonal cycles, but more investigation is needed. Also some insight in the introduction into the purpose of NISTAR would be good, such as giving illustration if and how it complements the climate observing system discussed by Weilicki et al 2013 (https://journals.ametsoc.org/doi/pdf/10.1175/BAMS-D-12-00149.1).
In summary, this paper could become suitable for publication, given more work, research and additions that address the points above. It should then be re-considered under peer review.

Based on the simulated filtered and unfiltered radiances for 722 clear-sky cases and 1519 cloudy-sky cases for each Sun-viewing geometry, the ratio between filtered and unfiltered radiances is extremely stable (see Table 2). Table 2 summarized the ratios and their standard deviation for each solar zenith angle bin for each scene type. For clear-sky case, each solar zenith angle bin contains over 57,000 simulations; and for cloudy-sky case, each solar zenith angle bin contains over 120,000 simulations. The largest ratio difference over different scene types happens under overhead sun, where the ratio for clear ocean is 0.8659 and is 0.8694 for clear land. Using constant unfiltering ratio of 0.8690, it could cause up to 0.3% unfiltering uncertainty if a clear ocean scene is encountered. However, NISTAR views the sunlit side of the Earth as a single pixel. There are always clouds and land mixed in. Thus we state the unfiltering uncertainty should be less than 0.3%. We rewrote the unfiltering portion of the paper on page 7 and 8 to clarify the reviewer's concerns.