Dear Anonymous Referee #1,

Thank you for taking the time to review our manuscript titled “Angular Sampling of a Monochromatic, Wide-Field-of-View Camera to Augment Next-Generation Earth Radiation Budget Satellite Observations” (amt-2023-7). We are pleased to receive your praise for the study, and for your recommendation to publish the paper as it is. We have corrected the one typo that you spotted, CIRES -> CERES, on L315 in the tracked-changes manuscript appended below.

Best regards,

Jake Gristey (on behalf of all authors)

Dear Anonymous Referee #2,

Thank you for taking the time to review our manuscript titled “Angular Sampling of a Monochromatic, Wide-Field-of-View Camera to Augment Next-Generation Earth Radiation Budget Satellite Observations” (amt-2023-7). We are pleased to receive your positive response, and appreciative of the thoughtful comments and suggestions. Please find our responses below that address your comments point-by-point and list the corresponding revisions made to the manuscript. Any line numbers stated hereon in correspond to those in the tracked-changes manuscript, which is appended to this response.

Best regards,

Jake Gristey (on behalf of all authors)

Reviewer comment	***Author Response***
The paper describes an alternative approach to rapidly derive empirical ADMs for the broadband VIS channel planned for the Libera mission. These ADMs are fundamental to the derivation of the primary user products, the irradiances, from radiance observations. The proposed approach provides a clear advantage in terms of the speed of building up the ADMs during the mission and avoids the need for the broad band instrument to spend a large amount of time in the non-standard scanning modes that are required to provide the ADM observations. The subject matter is clearly within the remit of the journal and of interest to future users of the products as well as to the flux retrieval community. I find the overall approach interesting, and the material presented relatively convincing but have some queries about the details of the application that I outline below. I have separated these by the section of the paper that they are relevant to.	• We thank the reviewer for the summary, which nicely captures the key points of the manuscript. • We are glad that the reviewer finds the approach interesting and relatively convincing. The reviewer's queries are addressed directly below.
Section 1 Is the conversion to broadband that is proposed (fig 1) required for some other purpose such as scene identification and is the accuracy of this step important, it seems superfluous in the ADM generation given the later averaging and normalisation that occurs for each scene? How is scene identification of the monochromatic observations performed and how will it be matched to the VIS scene classification, is this likely to be a significant error contribution?	• The conversion to broadband (specifically VIS) is not required for scene identification. It is required because the camera ADM samples will serve as a proxy for the radiometer VIS angular radiances. • Since the angular distribution at 555 nm is very similar to VIS (e.g., Fig. 8d), we *could* simply use the angular distribution inferred from 555 nm. This seems to be the reviewer's interpretation of the approach, which would indeed render the conversion to broadband superfluous. However, note that the angular distributions at 555 nm and VIS are not identical. For example, there are small but noticeable offsets around RAA=0° in Fig. 8d. Therefore, we maintain the option to first convert the 555 nm radiances to VIS, which itself is expected be a function of solar-viewing geometry and scene type. The later averaging and normalization for ADM generation occurs for each scene and SZA category, but does not account for spectral differences that depend on VZA and RAA (see the dependencies in the subscripts of Eq. 1). To clarify, we added *"by solar-viewing geometry and scene"* on L98. We believe this clarification of the approach also helps to address the reviewer comment on Section 4 (see below). • The Libera camera-based scene identification will initially be focused on cloud fraction at the radiometer footprint scale. It will use an adaptive thresholding approach to determine the cloud fraction by identifying each pixel in a camera ADM sample as cloudy or clear, then averaging the pixels in the ADM sample weighted by the radiometer point-spread function. Since this study is focused only on the camera angular sampling, further discussion of the

	scene identification approach is beyond scope. A separate manuscript is in preparation that will be dedicated to the Libera camera scene identification approach.
Section 3 It is not entirely clear to me if the intention of the ADM sampling with the camera pixels is to match the nadir footprint of the Libera radiometer at all angles or to match the view angle variation in footprint size that would occur if the radiometer itself was obtaining the samples.	• The intention is to match the camera ADM samples to the view-angle varying Libera footprint in order to replicate the radiometer sampling characteristics as closely as possible. The nadir footprint result is shown as an example, and represents the worst case for camera ADM sample coverage of the radiometer footprint. This is because both the radiometer footprint and camera pixels become stretched away from nadir due to the view projection and Earth curvature, but the camera has an additional distortion due to the fish-eye type lens that will result in increased coverage of the radiometer footprint in off-nadir view directions. • To clarify, we added *"at nadir"* on L191, and *"The camera ADM samples will therefore match the view-angle variation in Libera footprint size with increasing fidelity."* on L198-199.
Section 4 I think I need a bit more convincing that the correlation across scenes optimizes within scene angular fidelity and more information to assess the likely accuracy and the derived ADMs and hence the flux determined using them. As the ADMs only need to provide information on the angular distribution of energy within each scene class and solar zenith angle, it is not obvious to me that correlation between the monochromatic and broadband radiances across these variables is important. Rather ADM accuracy would only seem to require good correspondence across angles within each scene and solar zenith class as the ADM data is averaged and normalised on a scene by scene basis. I wonder if trying to have good correlation across these additional variables to ensure you can perform a monochromatic to broadband VIS (or NIR) conversion with high fidelity is overly restrictive. In feel that the expanded dynamic range that results from combing scenes and/or solar zenith angles would likely dominate the correlation and hinder the search for the optimum wavelength for ADM derivation in favour of the optimum wavelength for overall broadband fidelity. For the restricted angular coverage data primarily used in this section (the nadir OSSE data and the near nadir SCIAMACHY observations and simulations) this across	• Please see the response to the question regarding Section 1 above, which we believe helps to address some of the points raised here also. The idea is to start with a monochromatic (555 nm in this case) angular distribution of energy that is very similar to the broadband channel of interest (VIS in this case). Since the 555 nm and VIS angular distributions will not be identical due to the inherently spectral nature of radiation interactions with Earth system properties, using the 555 nm angular variations as is could introduce a bias in the VIS radiance-to-irradiance conversion. It is therefore desirable to first convert the monochromatic radiances to broadband, as a function of solar-viewing geometry and scene. The purpose of Section 4 is to explore this scene and angular dependency, and shows that, for the selected wavelength of 555 nm, this conversion is straightforward across angles and scenes, and therefore minimizes the additional uncertainty introduced by the spectral conversion. • We feel that the reviewer's comment that we used *"the across scene correlation at nadir and near nadir wavelength as the only basis on which to justify the optimum wavelength for capturing the broadband angular variation within scene classes"* does not fairly represent our study. We point the reviewer to L274-276 where we already acknowledged this point directly: *"It is necessary that the spectral relationships hold at nadir, but not sufficient; since a spectral conversion is desired for angular sampling, it is also important to confirm that these results hold at off-nadir view geometries"*. The SCIAMACHY (Fig. 5b) and AVIRIS (Fig. 6) observations each contain the full range of respective view geometries. The CERES unfiltering dataset (Fig. 8a-c) and libRadtran calculation (Fig. 8d) then explore the breakdown of the relationships directly by solar-viewing geometry. These results were a key factor in the identification of 555 nm as an ideal camera wavelength.

scene and solar zenith variation becomes the only variable of interest. Whilst some across scene variation effects would mimic angular variations others such as spectral variation in surface reflection are I think not so relevant. Thus, I think using the across scene correlation at nadir and near nadir wavelength as the only basis on which to justify the optimum wavelength for capturing the broadband angular variation within scene classes needs more support. The CERES unfiltering database scene specific correllations shown in figure 8 would need to be further statrified by solar zenith to provide this support I think. As currenlty presented the variation in incoming shortwave with solar zenith which isn't relevant for the ADMs becomes a factor dominating the correlations shown. It is also not obvious to me how the relationships shown in section 4 can be easily translated into an error in the ADM and hence the derived flux. Some exploration of this would be helpful and may identify some scenes or angles that are particularly problematic. Figure 8 (d) comes the closest to addressing this but as it shows reflectance and only explores a single viewing zenith can't be understood in terms of the likely flux error. What I would like to understand is the difference in the inferred anisotropy between a broadband and monochromatic derived ADM.	• It appears the reviewer might have missed one of our results when they ask for stratifying the CERES unfiltering database by SZA. That is precisely what is done in Fig. 8a. Perhaps the reviewer is suggesting to hold SZA fixed and look more closely at the VZA and RAA variations, and their correspondence between 555 nm and VIS. This is shown for an example in Figure 8d. Since the reviewer asked for some further exploration of this, we added Appendix A on L430-445, updated Table 1 accordingly, and added *"The correspondence between 555 nm and VIS also holds with varying SZA, VZA and cloud optical depth (see Appendix A)."* on L297-298 for this purpose. The new Appendix A includes some additional plots and related discussion, showing that the angular variation between 555 nm and VIS holds just as well, or better, across a range of SZA and VZA combinations, and varying cloud optical depth. • Note also that, while the consistency between 555 nm and VIS angular variations is preferred such that we start very close to the answer, it is not strictly necessary. What is more important is that any angular differences are rectified during the conversion to broadband. For example, it is possible that a worse starting correspondence between the angular variations of a monochromatic channel and VIS (or NIR) could result in an even better prediction of the VIS (or NIR) angular distribution given a near-perfect broadband conversion. This is why we place emphasis on the tight relationship between 555 nm and VIS across angles and scenes in this section. We hope this detailed explanation and theoretical example clarify to the reviewer the importance of the conversion to broadband. To avoid the possibility for misinterpretation, we added *"for a given solar-viewing geometry and scene, and subsequently be used for split-SW ADM generation"* on L212-213. • Full quantification of the associated error in ADMs and the derived flux would be a substantial additional effort and is not the target of this study. It would require the development and implementation of ADMs that apply the spectral conversion and other processing steps shown in Fig. 1, which none of the existing datasets are capable of. We agree that such an activity is important and is planned during the years leading up to the Libera mission, so we encourage the reviewer to stay tuned to the mission developments.
Section 5 I'm not sure that the results in this section really answer the question of how long will be needed to build the required ADMs. Angular coverage that isn't stratified by solar zenith angle (figures 10 and 11) whilst likely a minimum requirement doesn't provide reassurance that the ADMs will be filled at the solar zenith angles of the scenes observed	• The reviewer is correct that an answer of exactly how long is needed to derive ADMs with the Libera camera approach is not answered by this section. Equally, it is not our intention to provide an exact answer to this question. Rather, the intention here is to clearly demonstrate that it would be substantially quicker than alternative approaches (i.e., Libera radiometers in occasional RAPS mode). • Part of the reason that we do not target an exact time needed to generate ADMs is that we are using a single day of Cookie Dough data to provide a sense of the

by the VIS channel. In fact when the effect of of the sun synchronous orbit is considered on the pixel array angular sampling the mis-match between solar zenith for particular angular bins would seem inevitable. Perhaps I misunderstand but the reassurance that these figures give about the ability build up the ADMs is unclear to me. The solar zenith angle stratified results shown in figure 12 and that could be derived for other scenes, including those stratified by optical depth, also don't directly translate into incomplete ADMs for scenes that are actually required, as the orbital characteristics and illumination conditions for any particular time of year will restrict the solar zenith angle - scene combinations observed by the VIS channel. I feel that to understand how quickly the camera can build the required ADMs, the angular coverage needs to be stratified by solar zenith and scene (including cloud optical depth if this will be used for the ADMs), but the resulting coverage needs to be considered in the context of the actual ADMs required at that point in the record. So, the question of how long it will take in practice to build the required ADMs with this technique is a question about how quickly good angular coverage can be obtained for the scenes viewed by the broad band instrument (in the centre of the pixel mask I assume), by the camera pixel array. I expect this can be answered with the data used here, and I wonder if this analysis would change the scenes considered difficult to acquire, the length of time needed or point to a need for a few days every month or season of monochromatic observations to keep up with the evolving make up of the observed scenes. Given the sun synchronous orbit and the effect this will have on the solar zenith sampling of the different camera pixels I also wonder if this analysis might impact the choice of optimum subsampling of the camera pixels. For the case of the random pixel mask, I also wonder if this study shows if random coverage of the ADM angular bins is achieved once the scene variation and orbit effects are superimposed.	anticipated sampling improvements. We repeated the simulations for 4 separate days spread across the annual cycle, but these are not consecutive days. To robustly answer this question, we believe that an extended set of continuous Cookie Dough data is required, perhaps a few months, or ideally a full year to capture the superimposed orbit and scene sampling that the reviewer mentions (see below). This would then enable calculation of cumulative synthetic camera sampling stratified by the full angular-scene space for ADM generation, which can then be compared with the ADMs that are required by the radiometer. This would also need to be coupled with a comprehensive ADM approach that establishes, for example, the number of samples required in each angular bin to determine a reliable average, how to fill missing angular bins that are inevitable, etc. While we are actively pursuing such an effort and recognize its value, we are simply not at that stage of development yet, and it follows that it is not the goal of the present study. • The mis-match that the reviewer points out between SZAs viewed by the radiometer (cross-track directions only) and the camera (all observable directions) is true for a given scene and at a given time. However, this mis-match actually becomes an advantage for ADM generation because of how the observations are aggregated over time. For example, a desert scene viewed by the camera at a given SZA that is slightly different to what the radiometer can see at that time, will provide a useful observational constraint if the radiometer can view that desert scene at that SZA a month later. In addition, because of the binning into broader scene types during ADM generation, thinking about this in terms of the SZA and scene at a given location and time becomes less relevant. Returning to the example, a desert scene viewed by the camera at a given SZA that is different to what the radiometer can see at that time, could still provide a useful observational constraint for when the radiometer views a different desert scene at that SZA, given that both desert scenes belong to the same broader scene type. This situation could even occur during the same orbit. In short, the camera matches and then substantially expands the angular-scene combinations that are possible to encounter with the radiometer at a given time, leading to more complete ADMs that will be required for the radiometer at other times. That is the reassurance that these figures give. • As suggested by the reviewer, after stratifying by solar zenith angle as is typically done in ADM generation, there are unavoidable sampling gaps due largely to the sun-synchronous orbit of the satellite. This is shown for a single day of sampling in Fig. 12. There is indeed a seasonal change in these sampling gaps when stratifying by SZA as the reviewer suggests. To provide a sense of how the angular sampling changes with season, we added Appendix B on L446-460, and replaced *"(not shown) as Earth's declination angle varies and therefore Earth's surfaces are tilted either toward or away from the Sun"*

	with *"(see Appendix B)"* on L375. The new Appendix B includes some additional plots and related discussion, showing that the missing angular bins can shift depending on the season, and points out that combining observations across a full annual cycle would be ideal. • The random pixel mask is designed to ensure even coverage of the VZA and RAA dimensions, but the SZA sampling is indeed largely dictated by the orbital characteristics as already mentioned above. Discussions of the reasons for this are given on L371-374. A more targeted approach to acquire ADM samples from the camera that are evenly distributed across SZA could be considered, but may not be desirable since we seek better statistics for the SZA-scene combinations that are encountered most often with the radiometer. It follows that we do not need to be overly concerned about SZA-scene sampling gaps from the camera if the radiometer does not encounter these combinations either, since those ADMs will never be required. A key point is that the observable SZA-scene combinations from the radiometer are a subset of those from the camera, which ensures that the camera ADM samples capture the relevant combinations as a minimum. We thank the reviewer for bringing this point to our attention and we added the following text on L377-382: *"It should be noted that, since these sampling gaps are related to the orbital characteristics, they are not unique to the camera approach presented here; similar sampling gaps can be expected with the traditional radiometer RAPS approach. In fact, the sampling is in a sense self-balanced, in that the superimposed SZA and scene statistics built up from camera sampling for ADM generation encounter a similar frequency of occurrence to the radiometer that will use these ADMs, given that they are flying on the same platform and that the radiometer cross-track scan always falls within camera field-of-view."*