Reviewer 2

The concept of a new method for measuring actinic flux is a worthwhile cause, however this work indicates that more effort is needed.

We thank the reviewer for the careful and detailed evaluation of this manuscript. The comments have significantly improved the clarity of the terminology, calibration description, angular-response interpretation, and uncertainty treatment. Below we address each comment individually and describe the corresponding revisions made to the manuscript.

The authors seem to lack a full understanding and appreciation for the complexities in making quality actinic flux measurements. Much of the terminology deviates from the traditional literature, such as mixing actinic flux, irradiance, and radiance seemingly interchangeably and the use of "phase angle" to describe angular response, leaving the reader to wonder which aspect of the measurement is truly being described and if they are interpreting the authors meaning correctly.

We appreciate this observation. The original manuscript contained imprecise radiometric terminology that could obscure the physical quantity being measured. The manuscript has been revised throughout to consistently distinguish radiance, planar irradiance, and hemispheric spectral actinic flux. Actinic flux is now explicitly defined in the Introduction, including its role in photolysis-rate calculations.

The Methods section now clarifies that the PTFE dome functions as a diffuse hemispheric collector and that the fibre samples internally scattered light, producing a signal proportional to 2π spectral actinic flux rather than planar irradiance. All instances of irradiance terminology previously used to describe the measurement have been corrected. References to cosine response, phase angle, and cosine correction have been removed or replaced with appropriate angular-response terminology. The angular characterization section was rewritten to clarify that the goniometric measurements evaluate deviation from an ideal hemispheric actinic-flux collector.

These revisions remove the ambiguity identified by the reviewer and clearly establish the radiometric quantity used in the J-value calculations.

An intercomparison with established methods should be considered in both laboratory and field conditions.

More documentation on the angular response is required as this is one of the most challenging hurdles to making actinic flux measurements. The optics must be well characterized in order to produce usable results.

The authors should also report on the variability between the performance of radiometer heads of the same design as slight aberrations in the manufacturing of the material and forming the shapes may change the results and introduce additional uncertainties. If this is to be a useful measurement the results should be repeatable across installations, with the heads being a critical component.

We appreciate the reviewer's emphasis on intercomparison and angular characterization, both of which are critical for actinic-flux measurements.

Intercomparison:

We agree that direct comparison with established actinic-flux radiometers would provide additional validation. The present study was designed as a proof-of-concept and calibration validation of a low-cost hemispheric receiver rather than as a full operational performance study. We have revised the manuscript to clarify this scope and now explicitly state that extended laboratory and field intercomparisons with established instrumentation are planned as future work.

Angular-response documentation:

The angular-response section has been substantially expanded. We now explicitly define the idealized hemispheric (top-hat) angular acceptance function for actinic-flux collectors and clarify that the goniometric measurements evaluate deviation from this ideal response. Both zenith and azimuthal tests are described, including rotational symmetry checks and discussion of finite angular acceptance and partial self-shadowing. These revisions are intended to provide a clearer and more rigorous description of the receiver's angular performance.

Variability between radiometer heads:

For this prototype study, one head per geometry was fabricated and characterized. Repeatability across independently fabricated heads was therefore not evaluated. We have added a clarifying statement in the manuscript noting that future work will include assessment of manufacturing repeatability and unit-to-unit variability, which are important considerations for broader deployment.

Line 97 – the outdoor tests were too short and only under one sky condition. Additional tests should be conducted for extended periods in real conditions to evaluate stability over time, under different sky and light conditions, and to evaluate the aging of the optics when exposed to weather.

We thank the reviewer for this important suggestion and agree that long-term environmental testing is necessary for full operational validation of a field-deployable radiometer. The outdoor measurements presented here were intended as a short-duration calibration validation and radiative-transfer comparison under controlled clear-sky conditions, rather than a comprehensive performance study.

The manuscript has been revised to clarify this scope in both the Methods and Conclusions sections. We now explicitly state that extended deployments under varying sky conditions and seasons are required to assess long-term stability, environmental durability, and potential optical aging. Such testing is planned for future work, including evaluation of calibration drift during sustained outdoor exposure.

Line 101 – The spectra collection seems quite fast, particularly for the shorter wavelengths

The 3 ms value refers to the individual CCD exposure time, not the total integration time of the measurement. To prevent detector saturation under full solar illumination, the spectrometer operated using short exposures that were co-added onboard. During field measurements, 20,000 consecutive exposures were averaged to generate a single spectrum, corresponding to an effective photon-collection time of approximately 60 seconds.

This extended effective integration provides sufficient signal-to-noise in the UV-B and UV-A regions while maintaining detector linearity. The manuscript has been revised to clearly distinguish between individual exposure time and effective integration time and to explicitly state the 60 s photon-collection period.

Line 107 – A surface albedo of 0.9999 seems unusually high, why was this chosen?

The reviewer is correct that a surface albedo of 0.9999 would be unrealistic for the conditions of this study. This value was not used in the analysis. The surface albedo applied in the TUV configuration was 0.4, selected to represent the reflective rooftop surface at the deployment site. The manuscript has been revised to clearly state the correct albedo value and remove any ambiguity.

Line 113 – The “phase angle” is not well defined. If this is the angular response, the idealized form should be that of a square wave, where there is uniform response from 0-180 degrees and zero response below 0 and above 180.

The original wording did not clearly define the expected angular response of a hemispheric actinic-flux receiver. The manuscript has been revised to remove the term “phase angle” and to explicitly describe the measured quantity as the receiver angular response.

The ideal response of a 2π actinic-flux collector is now defined as uniform sensitivity for all incident directions above the horizon (i.e., over the full hemispheric field of view) and zero response below the receiving plane. A clarifying paragraph has been added to the Methods section to define this idealized hemispheric (top-hat) response and to state that the goniometric measurements quantify deviation from it. The Results section has been updated accordingly to relate the measured angular behavior of the receiver to this hemispheric reference response.

Line 122 – A cosine response is far from ideal for actinic flux measurements.

The original wording was imprecise and could be interpreted as implying an irradiance-type cosine response. The receiver is not intended to measure planar irradiance. It employs a diffusely scattering PTFE collector designed to approximate a hemispheric (2π) actinic-flux response.

The manuscript has been revised to remove references to cosine response and to describe the angular behavior in terms of hemispheric sensitivity. The angular characterization section now explicitly defines the ideal actinic-flux response and clarifies that the measurements quantify deviation from this hemispheric reference.

Line 137 – The results of the stray lights tests should be shown. "Minimal leakage" is not a quantitative term and can strongly influence photolysis rate calculations, particularly for jO3.

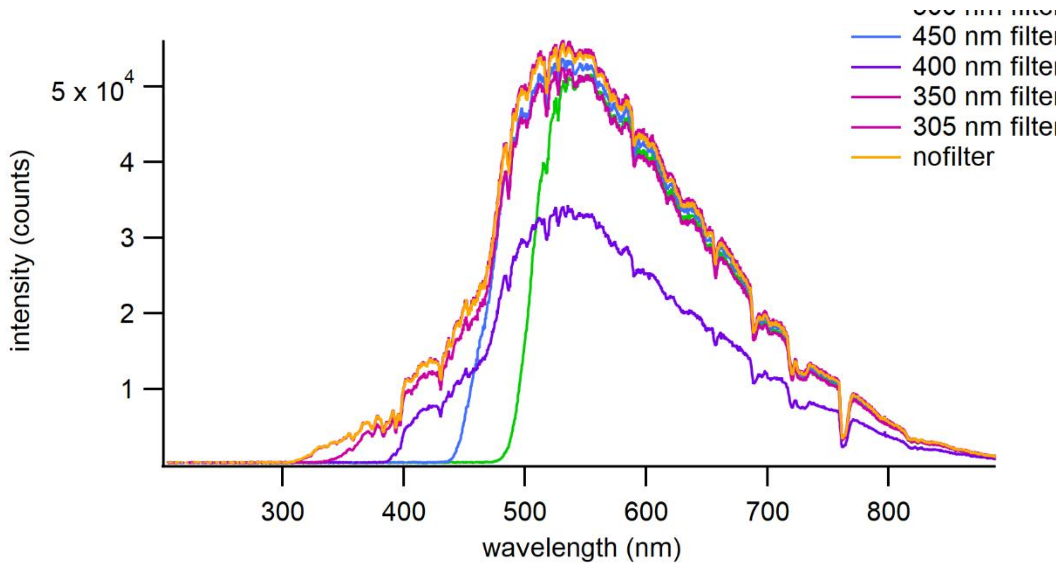
The manuscript has been revised to provide a quantitative stray-light characterization using the long-pass filter method described by Jäkel et al. (2007). A series of long-pass filters was applied under constant acquisition settings, and the signal recorded below each filter cut-on wavelength was used to bound out-of-band stray-light contributions. The resulting upper bound on UV-B stray light is <0.16% of the in-band signal (after dark correction), and this value is now explicitly reported in the manuscript.

The corresponding long-pass filter spectra are included in the response package to document the test outcome and the derivation of this bound.

Line 140 – Quantify "residual stray light" and the associated wavelength dependence

Residual stray light is now quantified using the long-pass filter method. For each filter, the signal recorded below the cut-on wavelength provides a wavelength-resolved upper bound on out-of-band stray-light contributions. The maximum bound in the UV-B region relevant for $j(O_3)$ is <0.16% of the in-band signal after dark correction. Across the tested wavelength range, residual signal below each cut-on wavelength was at or near the detection limit, indicating negligible wavelength-dependent stray-light contamination.

Figure R1 (included in this response) shows the long-pass filter spectra used to derive this bound. When short wavelengths are physically blocked, the remaining UV-B counts fall below 0.16% of the visible signal, demonstrating that scattered longer wavelengths do not significantly contribute to UV-B pixels.



Line 152 – The radiometer head is one of the most challenging aspects of quality actinic flux measurements. If the variable-cone design was determined to be the best choice for the angular response, it should have also been used in the chamber tests. The use of the flat-top radiometer makes this a different instrument with a cosine response and should not be used for actinic flux measurements.

The term “flat-top radiometer” in the original manuscript was imprecise and has been clarified. The receiver used in the chamber experiments is not a planar irradiance sensor. It consists of a cylindrical PTFE diffuser with a flat upper surface; light is collected through both the top and the cylindrical sidewalls. Internal multiple scattering within the PTFE randomizes photon direction, and the receiver therefore functions as a hemispheric (2π) actinic-flux collector, although with a different angular acceptance profile than the dome geometry.

The chamber illumination differs fundamentally from solar illumination. The lamps surround the receiver and generate a multi-directional radiation field rather than a predominantly overhead beam. Under these conditions, the cylindrical geometry provided more uniform sampling of the chamber light field. The Methods and Results sections have been revised to clearly describe the receiver geometry and the rationale for its use in the chamber experiments.

Line 180 – Suspect it should read “The measurements are in close...”

Correction has been made.

Line 181 – A factor of three different (3 should be spelled out) is very significant and should be discussed, however in the next line the authors state that there is close agreement with TUV results. How did the measurements compare with the AtChem results, and how did AtChem and TUV compare to each other?

The manuscript has been revised to clarify the context of the “factor of three” difference. This larger deviation occurs at high solar-zenith angles, where angular-response limitations of the receiver and assumptions inherent in the clear-sky TUV configuration become more significant. During midday conditions, when the solar-zenith angle is small and the radiation field is more stable, the measured and modeled J-values agree within the stated measurement uncertainty. The phrase “close agreement” has been revised to refer specifically to this midday period.

AtChem was not used as an independent radiative-transfer comparison tool. It was employed solely as a chemical plausibility check to confirm that the calculated J-values produced realistic photochemical behaviour within a chemical box-model framework. The manuscript has been revised to clarify this distinction and to remove any implication that AtChem served as a direct comparison dataset alongside TUV.

Line 184 – With the demonstrated angular response of the radiometer heads, it may be premature to assign the overestimation to the model results as opposed to an under reported measurement value.

The original wording was ambiguous and has been clarified. The intent was not to attribute the discrepancy to the radiative-transfer model but to note that the available dataset does not permit unique attribution of the difference. The manuscript has been revised to state explicitly that the comparison represents a consistency check rather than a diagnostic evaluation of model performance.

The revised text now indicates that the deviation may arise from a combination of atmospheric scattering assumptions and finite angular sensitivity of the receiver at larger solar-zenith angles. Because the deployment was short and no independent reference instrument was operated simultaneously, definitive attribution is not possible.

Line 186 – To ensure comparability, the same absorption cross-section and quantum yield values should be used for all calculations.

The manuscript has been revised to clarify this point. The same absorption cross-sections and quantum yields were used in both the measurement-derived J calculations and the

TUV model. These parameters are therefore not responsible for the differences between modeled and measured values.

The remaining discrepancies are instead attributed to factors influencing the radiative field rather than the photochemical parameters, including clear-sky assumptions in the model (e.g., omission of aerosol or cloud scattering), finite angular-response sensitivity of the receiver at larger solar-zenith angles, and minor effects from wavelength interpolation and spectral binning. The text has been updated accordingly.