Response to the Anonymous Referee #2 comments for the manuscript "Star photometry with all-sky cameras to retrieve aerosol optical depth at night-time" By Roberto Román et al. in AMT

First of all, we would like to thank the time and effort of the referee for the detailed review of the manuscript. Reviewer comments (RC) are in black font and author comments (AC) are in red.

Author's answer to Anonymous Referee #2

General comment

RC: Strengths:

- **Innovation**: The study proposes all-sky cameras for star photometry, addressing the nighttime AOD data gap.
- **Cost-Effectiveness**: Using commercial imaging devices could make aerosol monitoring more accessible if proven robust.

AC: We think the reviewer remarked two really important points of our work. We would also like to thank the reviewer for highlighting the strengths of the work in each section.

RC: Analysis:

- **Assumptions**: Star intensity stability and uniform aerosol distribution are supposed, but intrinsic variability and atmospheric inhomogeneity could introduce biases.
- **Comparative Advantage**: The study lacks discussion on trade-offs in spectral response, sensitivity, and precision compared to dedicated photometers.

AC: We acknowledge the limitations associated with the assumptions of star irradiance stability and spatial homogeneity of aerosol distribution. To address potential variability in star irradiance, a dynamic method is applied to determine the log(USI0) value at each moment, which helps minimize the influence of intrinsic star irradiance variability.

As for the spectral response, the manuscript partially addresses this issue by evaluating a second camera model (OMEA-3C-TF) equipped with narrower-band filters. This allows us to assess the influence of spectral bandwidth on the accuracy of the retrieved AOD values.

Finally, the performance and precision of the proposed method have been evaluated using co-located measurements from moon photometers as reference, thereby quantifying the reliability of the system under real observational conditions.

Methodological and Calibration Challenges

RC: Strengths:

- **Data Extraction:** Extracting starlight signals from wide-field images is technically innovative and promising for remote sensing.

Analysis:

- **Calibration:** All-sky cameras are not designed for absolute radiometry, requiring robust calibration strategies.
- **Data Processing:** Background subtraction, optical corrections, and noise propagation need clearer methodological details.

- Spectral Considerations: The study should address how it handles spectral mismatches affecting AOD retrieval.
AC: One advantage of this method is that absolute calibration is not required, thanks to the use of the Langley technique. We believe that a large part of the methodology is explained in considerable detail in the article, such as in the case of background subtraction, where we specify which Python libraries were used and with which input parameters.

Although the error propagation is not described in full detail, the manuscript does state which sources of uncertainty are propagated and that this propagation is done quadratically. In our opinion, going further into these aspects would make the article harder to read by introducing overly technical information.

Data Validation & Comparative Analysis

RC: Strengths:
- **Preliminary Validation:** Initial consistency with existing measurements suggests potential feasibility.

Analysis:
- **Systematic Biases:** Possible AOD overestimation needs deeper investigation.
- **Comparative Studies:** A broader validation campaign against reference instruments across various aerosol regimes is necessary.
- **Temporal & Spatial Variability:** The method's ability to resolve short-term and spatial variations requires further evaluation.

AC: We fully agree that further investigation is needed to better understand the causes of the observed overestimation in AOD. Although this study presents an extensive comparison against lunar photometer data (covering nine different sites around the world with varying latitudes and aerosol conditions), we also acknowledge the need for a broader validation effort in the future. This would not only allow us to address a wider range of aerosol regimes but also to compare results with other instruments, such as star photometers. This would be especially valuable for assessing the performance of the proposed methodology during moonless nights. This need has been reflected in the conclusions section of the manuscript.

Radiative Transfer Modeling & Algorithmic Considerations

RC: Strengths:
- **Model Integration:** Radiative transfer models provide a strong theoretical basis.

Analysis:
- **Model Assumptions:** Question: Should the impact of multiple scattering and horizon effects be analyzed?.
- **Algorithm Robustness:** Star identification and retrieval parameter sensitivity require systematic validation.

AC: The impact of multiple scattering should be considered, as with any other photometric instrument. However, in our case, since only a few pixels corresponding to the star are selected, the effective field of view is relatively small, and thus this effect should not be too significant. Additionally, multiple scattering is expected to play a more relevant role under high aerosol loads and in the presence of coarse and super coarse particles, which are not the most frequent conditions.

Regarding the effect of the horizon, it is true that certain lights in the skyline of some sites may introduce additional brightness in the sky. While the background correction algorithm is generally able to remove this effect, in some stations these lights can saturate portions of the image. To minimize possible issues near the horizon, stars with zenith angles greater than 80° were excluded. Nevertheless, the impact of these factors (multiple scattering and horizon) should be analyzed in future studies, but we think this lies beyond the scope of the present work.

As for the star identification algorithm, it has been found to work with high accuracy, provided that the geometric calibration of the camera is correctly performed. It has also been observed that, in some rare cases, the algorithm does not detect the target star and instead selects a nearby brighter one. To address this, outlier detection algorithms were implemented as described in the manuscript. This helps filtering out such cases, since the signal from a misidentified star will deviate from expectations and will not pass the applied filters.

Operational Considerations & Generalization

RC: Strengths:

- **Scalability:** The approach could enhance nighttime aerosol monitoring at low cost!

Analysis:

- **Environmental Dependence:** The influence of clouds, light pollution, and geographic variability should be better addressed.

Hardware Variability: Standardized calibration across different camera models and long-term stability assessments are necessary.

AC: Cloud filtering is definitely one of the key challenges to be addressed in future work, as mentioned in the conclusions of the manuscript. In this study, we worked with two very similar camera models, and the proposed methodology appears to yield promising results. We consider this work to be a first step toward extending the approach to a wider range of camera types in the future. In fact, we are currently working on adapting this methodology to other camera models. We also believe that this study highlights the importance of being able to record raw images from all-sky cameras, as well as the benefits of using narrower spectral filters.

Future Directions & Recommendations

RC:

- Improve calibration for sensor aging and optical distortions.
- Quantify uncertainties using advanced statistical methods.
- Enhance star detection and background subtraction algorithms.
- Participate or organize more validation campaigns under diverse conditions.

AC: We appreciate these recommendations, which we fully agree should guide future work. In fact, most of them are aligned with the future directions already outlined in the conclusions section of the manuscript.

Conclusion

RC: This study presents a very promising, cost-effective method for nighttime aerosol monitoring. Refining the calibration, the validation, and maybe the error analysis will be crucial to ensuring its reliability and broader adoption in atmospheric research.

AC: We would like to thank the reviewer for this comment. While there are still several aspects of the methodology that can be further refined, particularly in terms of quality data filtering, cloud screening, and more effective calibration, we believe this work represents a first step towards the systematic use of cost-effective instruments such as all-sky cameras for night-time AOD retrieval.