Response to the review of "Estimation of Nighttime Aerosol Optical Depths Using the Ground-based Microwave Radiometer" (EGUSPHERE-2025-1871).

Responses to Review 01 's comments

Summary:

This study develops a novel microwave-based method for retrieving aerosol optical depth (AOD) using ground-based radiometer measurements at K- and V-bands. A random forest model trained with daytime sun-photometer data enables continuous day-night AOD monitoring, revealing higher nighttime values. Validation against lunar measurements, radiosonde data, and model simulations confirms the method's reliability. The approach overcomes traditional limitations of nighttime aerosol monitoring, providing new insights into diurnal AOD variations. This practical technique offers valuable applications for air quality assessment and climate studies, particularly for investigating nocturnal aerosol-cloud interactions and radiative effects. The operational simplicity and all-weather capability make it suitable for comprehensive environmental monitoring networks. While the study presents valuable findings, several aspects require further consideration prior to publication.

Reply: We are grateful to the reviewer for his/her insightful and very valuable suggestions, which have significantly contributed to the enhancement of our manuscript. We have carefully addressed the comments and made the necessary revisions, hoping that the updated version meets the journal's standards. Our responses to each of the comments and suggestions are as follows. The referee's original comments are shown in blue. Our replies are shown in black. The corresponding changes in the manuscript are shown in *Italic black.*

1. In Figure 2, the channel importance analysis in Figure 2 would be significantly improved by clearly labeling all channel names/frequencies. Additionally, please elaborate on the methodology used to calculate channel importance scores, as this is crucial for interpreting the variable selection process in your random forest model.

Reply: Thanks for your helpful suggestions. We have clearly labeled all frequencies in Figure 2 in the revised manuscript. We also cited it here for convenience (Figure R1).

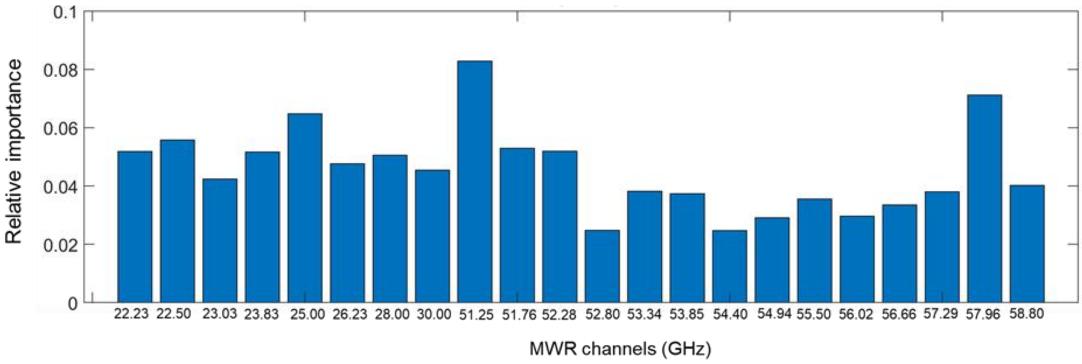

Figure R1. Relative importance of all BTs in different frequencies measured by MWR in the RFR model. *The vertical axis represents relative importance (unitless), and the horizontal axis corresponds to different variable inputs (BTs in different frequencies measured by MWR in the RFR model). These channels include K band (22.23 GHz, 22.50 GHz, 23.03 GHz, 23.83 GHz, 25.00 GHz, 26.23 GHz, 28.00 GHz, 30.00 GHz) and V band (51.25 GHz, 51.76 GHz, 52.28 GHz, 52.80 GHz, 53.34 GHz, 53.85 GHz, 54.40 GHz, 54.94 GHz, 55.50 GHz, 56.02 GHz, 56.66 GHz, 57.29 GHz, 57.96 GHz, 58.80 GHz).*

Moreover, we also elaborated on the methodology used to calculate the channel importance scores for random forest regression models and cited it here (Lines 256-269).

We first apply the relative importance feature selection technique, which is based on the Gini importance measure (Nembrini et al., 2018), to identify significant independent variables and build a generalized model. In the context of random forests, *the relative importance of each predictor variable (feature) is quantified by a numeric array of size 1-by-Nvars. The importance measure for each variable is defined as the increase in prediction error that results from permuting the values of that variable across the out-of-bag observations. This measure is calculated for each tree in the ensemble, then averaged across all trees. To standardize the importance scores, the average values are normalized by dividing them by the standard deviation computed over the entire ensemble. This process yields a normalized importance measure that provides a robust assessment of each feature's contribution to the model's predictive performance. The relative importance of each factor is presented in Figure 3. It is observed that BTs across various frequency bands carry similar levels of importance, suggesting that the BTs are almost equally important for retrieving AOD.*

2. The criteria for identifying clean sky cases in Figure 5 require more detailed explanation, particularly since this selection directly impacts your nighttime algorithm performance. Given the microwave sensor's limited sensitivity to cloud layers, please clarify: (a) your cloud screening methodology, and (b) how potential cloud contamination was addressed in the analysis. I think this algorithm developed in this study will be the operational algorithm during nighttime, the first step is to determine the clean sky cases.

Reply: Thanks for your suggestion and sorry for the confusion. The Level 2 sun photometer AOD products from AERONET are validated and represent clear-sky conditions. Therefore, collocating MWR data with these AERONET products inherently excludes cloudy conditions, ensuring that the most collocated data are under clear-sky scenarios. While AERONET data can be cloud-free in the direction of the sun, the MWR, which measures in the zenith direction, may still detect the presence of clouds. Therefore, we have conducted additional cloud screening following the method by the previous study to ensure the clear-sky conditions in the analysis (Zhang, 2024). We have revised the corresponding explanation in the methods section and cited it here (Lines 183-190).

Notably, the Level 2 sun photometer AOD products from AERONET are already validated and represent clear-sky conditions. Therefore, the collocation of MWR data with these AERONET products inherently excludes cloudy conditions. While AERONET data can be cloud-free in the direction of the sun, the MWR, which measures in the zenith direction, may still detect the presence of clouds. Therefore, we have conducted additional cloud screening following the method by the previous study to ensure the clear-sky conditions in the analysis (Zhang, 2024).

3. The physical interpretation in section 3.3 would benefit from incorporating established microwave scattering theory. Specifically, please discuss how your findings relate to known scattering and penetration characteristics of microwave channels for different aerosol particles, citing relevant literature (e.g., [reference 1], [reference 2]). This would strengthen the theoretical foundation of your approach.

Reply: Thanks for your insightful suggestions. The primary signals in the microwave spectrum that are attributable to aerosols are predominantly generated by the scattering and absorption properties of aerosols. Specifically, large aerosol particles play a significant role in this context. Moreover, the alterations in temperature and humidity profiles, which are closely linked to the radiative and hygroscopic effects of aerosols, also contribute to these signals. Indeed, previous studies have demonstrated that large aerosol particles, particularly dust aerosols, can significantly influence microwave radiation and BT (Ge et al., 2008; Hong et al., 2008), the primary mechanism by which MWR estimates AOD in this study might be through the detection of temperature and RH profile differences.

Therefore, we have added the detailed discussion in the section 3.3 about the microwave channels in the K bands to strengthen the theoretical foundation of our approach in the revised manuscript. We also cited it here for convenience (Lines 564-572).

The increase of K band BT with AOD might be related to coherent changes of water *vapor and aerosols, either due to aerosol absorption of water or meteorological conditions that affect both water vapor and aerosols. When AOD is higher, RH is typically also higher, accompanied by more water vapor due to the hygroscopic growth effect of aerosols, as supported by previous analysis (Figure 11a & c). Since the K band includes the water vapor absorption line near 22.235 GHz, the BT in the K band is sensitive to water vapor, and thus the BT increases as AOD increases (Liu et al., 2014; Xie et al., 2013), further strengthening the theoretical foundation of the proposed approach.*

We also added the similar discussion in the section 3.3 about the microwave channels in the V bands and cited it here for convenience (Lines 581-586).

The detailed physical interpretation as follows: due to the presence of the oxygen absorption band within the frequency range of the V band, it is highly sensitive to changes in atmospheric temperature (Van Leeuwen et al., 2001). Variations in AOD can influence the atmospheric temperature profile as shown by observation and simulation (Figure 11b &d). Consequently, in cases when AOD is high, the BT in the V band will decrease.

We also added the detailed physical interpretation summary at the end of section 3.3 and cited it here (Lines 589-595).

In conclusion, MWR has the potential to estimate AOD by identifying the differences in temperature and humidity profiles, as well as the direct scattering and absorption signals that arise from varying aerosol loadings. While previous studies have demonstrated that large aerosol particles, particularly dust aerosols, can significantly influence microwave radiation and BT (Ge et al., 2008; Hong et al., 2008), the primary mechanism by which MWR estimates AOD in this study might be through the detection of temperature and RH profile differences.

4. Figure 10 current layout makes data interpretation challenging. I recommend reorganizing it using a 2×2 panel format to: (a) better separate day/night comparisons,

(b) improve visualization of temporal trends, and (c) allow direct visual comparison between different measurement types.

Reply: Thanks for your suggestions. We have modified the Figure 10 using a 3×1 panel format for better data interpretation. We also cited it here for convenience.

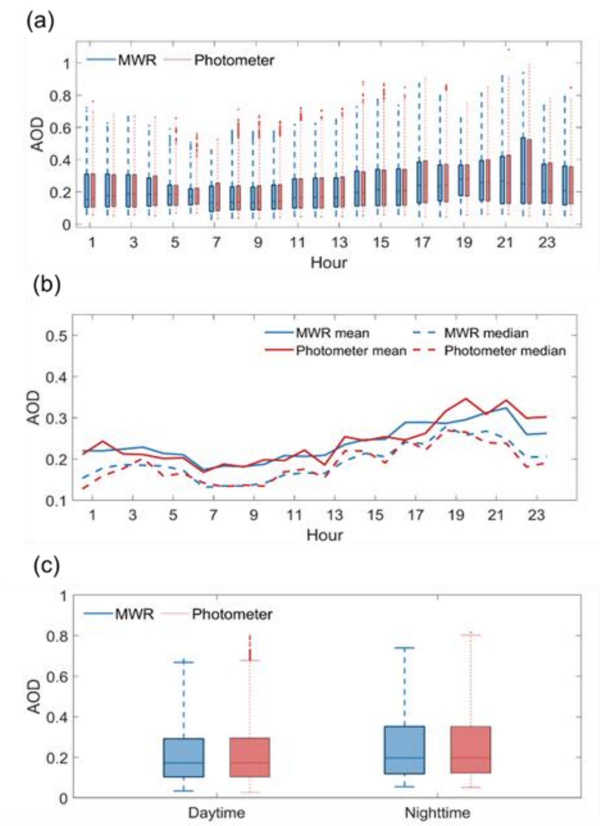

Figure R2. The diurnal cycle of MWR AOD and photometer AOD at 500 nm. *(a) The boxplot of hourly MWR AOD (red boxplots) and photometer AOD (blue boxplots). The small dots represent outliers greater than* $q_{75} + 1.5(q_{75} - q_{25})$ *or less than* $q_{25} - 1.5(q_{75} - q_{25})$*, where* q_{75} *and* q_{25} *correspond to 75th and 25th percentile. (b) The time series of mean AOD (solid lines) and median AOD (dashed lines) of MWR AOD (red lines) and photometer AOD (blue lines). (c) The boxplot of daytime and nighttime AOD. Blue boxes correspond to MWR data, and red boxes correspond to photometer data.*

References

Ge, J., Huang, J., Weng, F., and Sun, W.: Effects of dust storms on microwave radiation based on satellite observation and model simulation over the Taklamakan desert, ATMOSPHERIC CHEMISTRY AND PHYSICS, 8, 4903-4909, 10.5194/acp-8-4903-2008, 2008.

Hong, G., Yang, P., Weng, F. Z., and Liu, Q. H.: Microwave scattering properties of sand particles: Application to the simulation of microwave radiances over sandstorms, J. Quant. Spectros. Radiat. Transfer, 109, 684-702, 10.1016/j.jqsrt.2007.08.018, 2008.