

Replies to comments of Editor

Authors would like to express sincere gratitude to the Editor for his constructive comments. Our manuscript has greatly benefited from these insights. We have carefully revised the manuscript, taking the given comments into account. Our responses to the editor's comments are provided below.

(1) Please present a theoretical figure of the slope Eq. (1) against wavelengths and/or SZA to indicate the method is consistent with the principle of the atmospheric radiative transfer theory. It is OK to make a simple radiative transfer calculation with plane parallel models of aerosol and cloud laden atmospheres. Such a theoretical computation will contribute to answering some reviewers' comments.

→ We sincerely thank the Editor for this valuable and insightful comment. In response, we have substantially revised the methodology and made corresponding revisions throughout the manuscript. In addition, we performed radiative-transfer simulations and incorporated the results into the revised manuscript to clarify the physical mechanism underlying the proposed cloud-screening method. First, we revised the methodology as follows:

For the zenith sky radiance signals $S(\lambda_1)$ and $S(\lambda_2)$ observed at any two wavelengths λ_1 and λ_2 , the slope value (m_{obs}) can be expressed using the following equation:

$$m_{\text{obs}}(\lambda_1, \lambda_2) = \frac{\ln[S(\lambda_1)/S(\lambda_2)]}{\ln(\lambda_1/\lambda_2)}. \quad (\text{R1})$$

The measured zenith sky radiance can be further represented as

$$S(\lambda) = C(\lambda)L(\lambda), \quad (\text{R2})$$

where $L(\lambda)$ is the band-averaged atmospheric zenith radiance and $C(\lambda)$ is the wavelength-dependent relative instrumental response. Substituting Eq. (2) into Eq. (1), we can write

$$m_{\text{obs}}(\lambda_1, \lambda_2) = \frac{\ln[\frac{C(\lambda_1)L(\lambda_1)}{C(\lambda_2)L(\lambda_2)}]}{\ln(\lambda_1/\lambda_2)} \quad (\text{R3})$$

Using $\ln(ab) = \ln(a) + \ln(b)$,

$$m_{\text{obs}}(\lambda_1, \lambda_2) = \frac{\ln[\frac{C(\lambda_1)}{C(\lambda_2)}]}{\ln(\lambda_1/\lambda_2)} + \frac{\ln[\frac{L(\lambda_1)}{L(\lambda_2)}]}{\ln(\lambda_1/\lambda_2)}. \quad (\text{R4})$$

Thus,

$$m_{\text{obs}}(\lambda_1, \lambda_2) = m_{\text{atm}}(\lambda_1, \lambda_2) + m_{\text{inst}}(\lambda_1, \lambda_2), \quad (\text{R5})$$

where,

$$m_{\text{atm}}(\lambda_1, \lambda_2) = \frac{\ln[\frac{L(\lambda_1)}{L(\lambda_2)}]}{\ln(\lambda_1/\lambda_2)}, \quad (\text{R6})$$

and

$$m_{\text{inst}}(\lambda_1, \lambda_2) = \frac{\ln \left[\frac{C(\lambda_1)}{C(\lambda_2)} \right]}{\ln(\lambda_1/\lambda_2)}. \quad (\text{R7})$$

Similary, the extra-terrestrial instrument signal F_0 (i.,e calibration constant) at wavelength λ can be expressed as

$$F_0(\lambda) = C(\lambda)E_0(\lambda), \quad (\text{R8})$$

where $E_0(\lambda)$ is band-averaged extra-terrestrial solar irradiance at wavelength λ . For the two wavelengths λ_1 and λ_2 ,

$$\frac{C(\lambda_1)}{C(\lambda_2)} = \frac{F_0(\lambda_1) E_0(\lambda_2)}{F_0(\lambda_2) E_0(\lambda_1)} \quad (\text{R9})$$

Consequently, from Eqs. (7) and (9),

$$m_{\text{inst}}(\lambda_1, \lambda_2) = \frac{\ln \left[\frac{F_0(\lambda_1) E_0(\lambda_2)}{F_0(\lambda_2) E_0(\lambda_1)} \right]}{\ln(\lambda_1/\lambda_2)}. \quad (\text{R10})$$

Since $m_{\text{atm}}(\lambda_1, \lambda_2) = m_{\text{obs}}(\lambda_1, \lambda_2) - m_{\text{inst}}(\lambda_1, \lambda_2)$, from Eqs. (5), and (10) we can write,

$$m_{\text{atm}}(\lambda_1, \lambda_2) = \frac{\ln[S(\lambda_1)/S(\lambda_2)]}{\ln(\lambda_1/\lambda_2)} - \frac{\ln \left[\frac{F_0(\lambda_1) E_0(\lambda_2)}{F_0(\lambda_2) E_0(\lambda_1)} \right]}{\ln(\lambda_1/\lambda_2)} \quad (\text{R11})$$

represents the contribution arising from the wavelength-dependent relative response of the instrument.

Here, m_{atm} represents the atmospheric contribution arising from molecular, aerosol, and cloud scattering together with atmospheric absorption, and m_{inst} represents the wavelength-dependent instrumental contribution. To calculate m_{atm} , $F_0(\lambda)$ and $E_0(\lambda)$ are also required along with instrument-observed $S(\lambda)$ values. In this study, $F_0(\lambda)$ values determined from the Improved Langely method and $E_0(\lambda)$ values estimated by integrating the extraterrestrial solar spectrum of Gueymard (2004) over the spectral response function of each sky-radiometer channel were used. The resulting correction should be regarded as a first-order estimate of the wavelength-dependent instrumental contribution, because a single set of median spectral calibration constants was applied to each instrument over the corresponding analysis period. Nevertheless, a key advantage of this approach is that, even with such a first-order approximation, the corrected atmospheric spectral slope, m_{atm} , retains sufficient sensitivity to distinguish between cloud-free and cloud-contaminated conditions, as demonstrated and discussed in the Results and Discussion in the revised manuscript.

To explain the physical mechanism underlying the proposed method, we performed plane-parallel radiative-transfer simulations using the Santa Barbara DISORT Atmospheric Radiative Transfer (SBDART) model (Ricchiazzi et al., 1998) at wavelengths of 0.380, 0.400, 0.500, 0.675, 0.870, and 1.020 μm . The simulations were conducted over a range of solar zenith angles (SZAs) for four

representative atmospheric conditions: (1) a clean cloud-free atmosphere with an aerosol optical thickness at $0.55\ \mu\text{m}$ (AOT_{550}) of 0.10; (2) a polluted cloud-free atmosphere with $\text{AOT}_{550} = 0.50$; (3) a thin-cloud atmosphere with $\text{AOT}_{550} = 0.10$ and cloud optical thickness at $0.55\ \mu\text{m}$ (COT_{550}) = 2; and (4) a thick-cloud atmosphere with $\text{AOT}_{550} = 0.10$ and $\text{COT}_{550} = 20$. The simulations assumed a mid-latitude summer atmospheric profile, precipitable water vapor of 1.0 cm, total column ozone of 0.30 cm-atm, and a Lambertian surface albedo of 0.10, with clouds represented as plane-parallel layers.

For the radiative-transfer simulations, the wavelength-dependent instrumental response was set to unity, i.e., and $C(\lambda) = 1$, and hence $(C(\lambda_1) = C(\lambda_2) = 1)$ for each wavelength pair. Thus, no wavelength-dependent instrumental contribution was included in the simulated radiances, and the spectral slopes calculated from these radiances represent the atmospheric contribution, m_{atm} , directly.

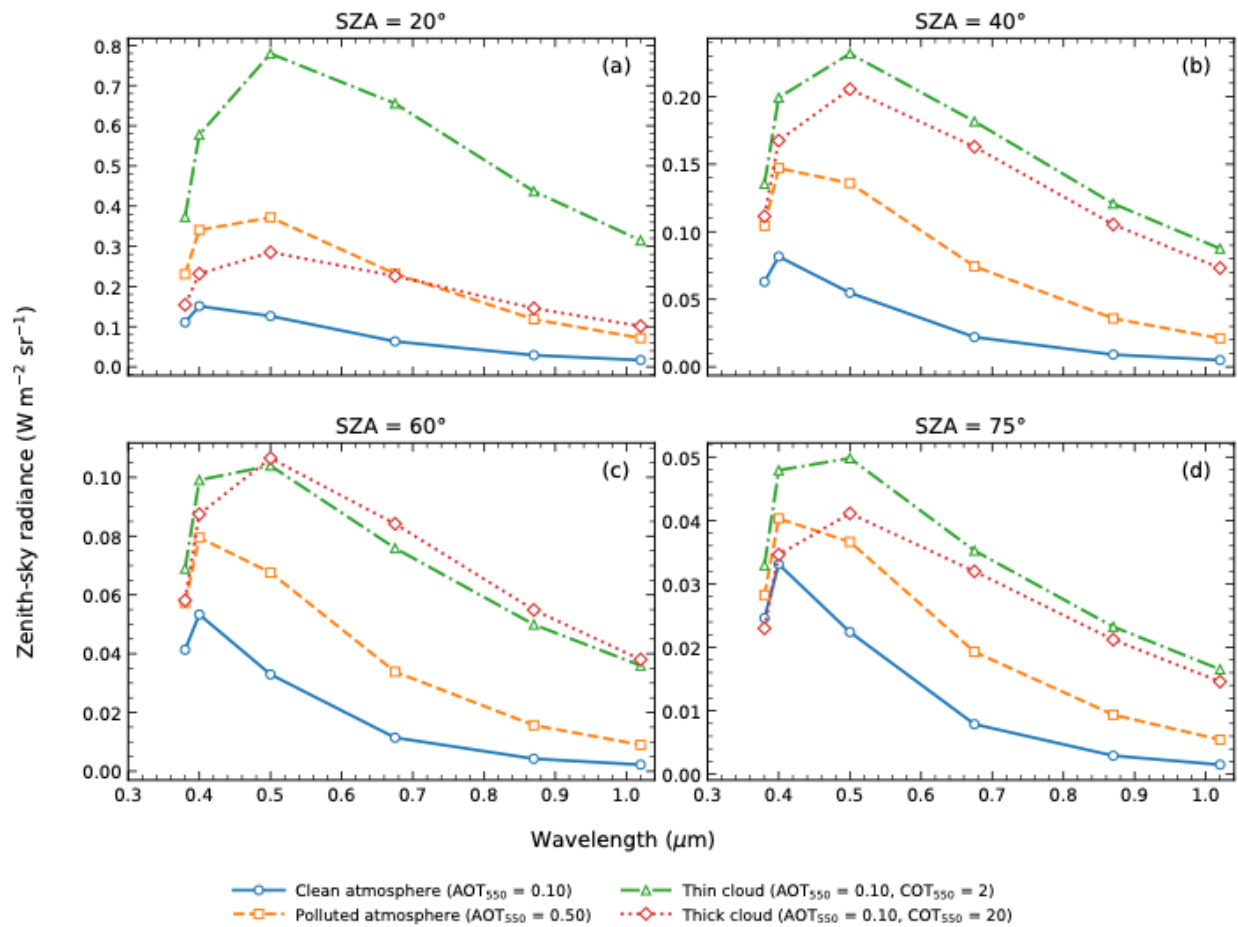


Figure R1. Zenith-sky radiance spectra computed using the SBDART radiative transfer model for solar zenith angles (SZAs) of (a) 20°, (b) 40°, (c) 60°, and (d) 75 for four representative atmospheric conditions: a clean cloud-free atmosphere with an aerosol optical thickness at $0.55\ \mu\text{m}$ (AOT_{550}) of 0.10, a polluted cloud-free atmosphere with $\text{AOT}_{550} = 0.50$, a thin-cloud atmosphere with $\text{AOT}_{550} = 0.10$ and cloud optical thickness at $0.55\ \mu\text{m}$ (COT_{550}) = 2, and a thick-cloud atmosphere with $\text{AOT}_{550} = 0.10$ and $\text{COT}_{550} = 20$. Simulations were performed with mid-

latitude summer atmospheric model, precipitable water vapor of 1.0 cm, total column ozone of 0.30 cm-atm, Lambertian surface albedo of 0.10, and clouds represented as plane-parallel layers.

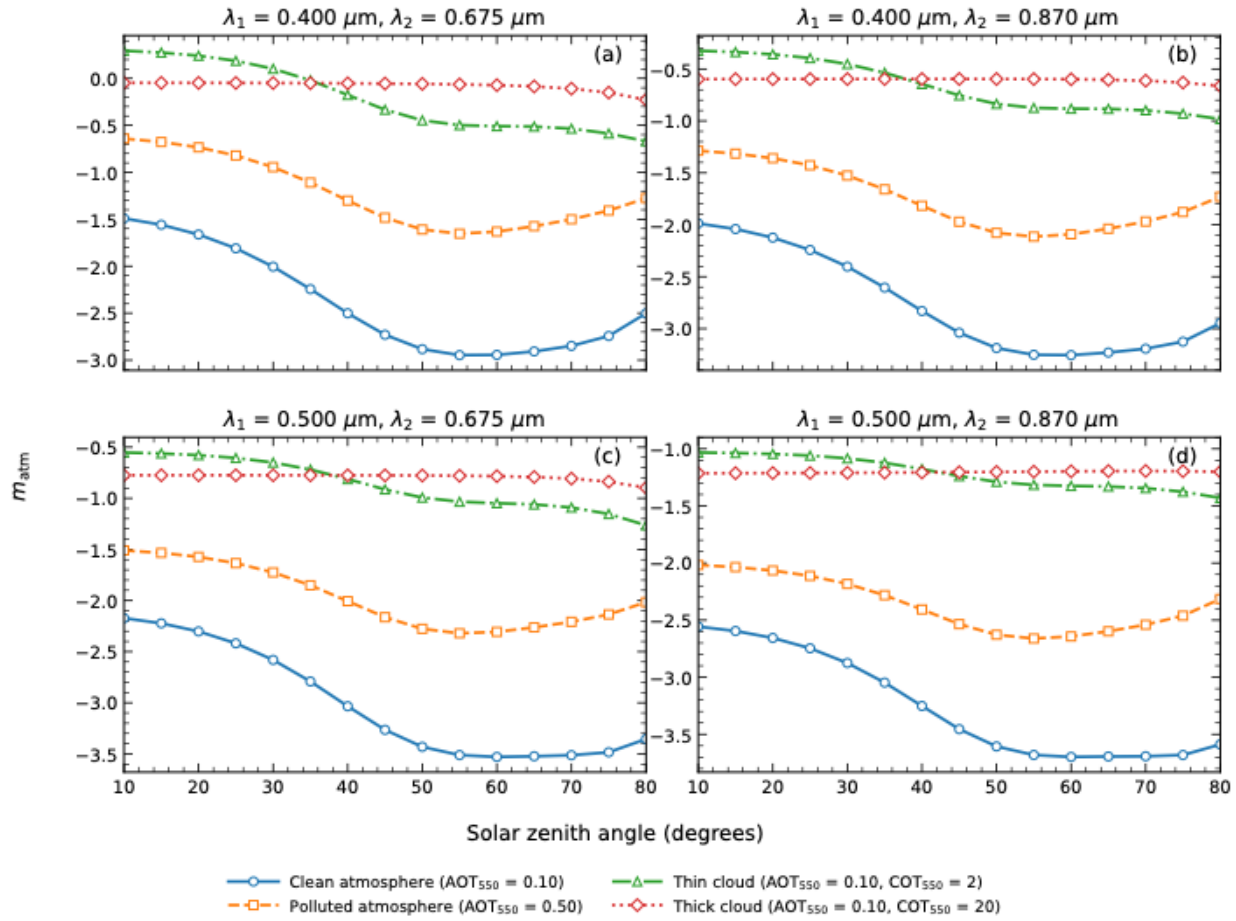


Figure R2. Atmospheric spectral slope (m_{atm}) as a function of solar zenith angle (SZA) simulated for four selected wavelength pairs: (a) 0.400–0.500 μm , (b) 0.400–0.870 μm , (c) 0.500–0.675 μm , and (d) 0.500–0.870 μm for four representative atmospheric conditions: a clean cloud-free atmosphere with an aerosol optical thickness at 0.55 μm (AOT_{550}) of 0.10, a polluted cloud-free atmosphere with $\text{AOT}_{550} = 0.50$, a thin-cloud atmosphere with $\text{AOT}_{550} = 0.10$ and cloud optical thickness at 0.55 μm (COT_{550}) = 2, and a thick-cloud atmosphere with $\text{AOT}_{550} = 0.10$ and $\text{COT}_{550} = 20$. Simulations were performed with mid-latitude summer atmospheric model, precipitable water vapor of 1.0 cm, total column ozone of 0.30 cm-atm, Lambertian surface albedo of 0.10, and clouds represented as plane-parallel layers.

Figure R1 presents the simulated zenith-sky radiance spectra for the four representative solar zenith angles (SZAs). Both the magnitude and spectral dependence of the zenith sky radiance vary systematically with atmospheric state and SZA. Under clean cloud-free conditions, the zenith sky radiance generally decreases strongly toward longer wavelengths, primarily reflecting the pronounced wavelength dependence of molecular (Rayleigh) scattering. Increasing aerosol loading modifies both the magnitude and spectral dependence of the radiance because aerosol

scattering has a weaker wavelength dependence than Rayleigh scattering. The presence of clouds produces a further substantial modification of the spectral distribution. In particular, cloud scattering tends to flatten the zenith-radiance spectrum, resulting in a considerably weaker wavelength dependence than that observed under clean cloud-free conditions. These simulations therefore demonstrate that cloud-free and cloudy atmospheres produce distinct spectral signatures in zenith-sky radiance, providing a physical basis for using the spectral slope as an indicator of cloud contamination.

To quantify the spectral differences shown in Figure R1, Figure R2 presents m_{atm} , calculated directly from the simulated zenith sky radiances for representative wavelength pairs as a function of SZA. Because $C(\lambda_1) = C(\lambda_2) = 1$ was assumed in these simulations, the calculated spectral slopes represent the atmospheric contribution without any wavelength-dependent instrumental contribution. The clean cloud-free atmosphere generally exhibits the largest negative values of m_{atm} , reflecting the strong decrease in radiance with increasing wavelength associated primarily with Rayleigh scattering. Increasing the aerosol loading from $\text{AOT}_{550} = 0.10$ to 0.50 substantially reduces the magnitude of the negative spectral slope because aerosol scattering has a weaker spectral dependence than molecular scattering. The presence of clouds further modifies the spectral slope, with both the thin- and thick-cloud cases generally producing substantially less negative values of m_{atm} than the cloud-free cases. The magnitude and SZA dependence of this response vary among wavelength pairs, reflecting differences in the relative contributions of aerosol and cloud scattering at the respective wavelengths.

Importantly, the simulations show that the four atmospheric cases occupy distinctly different ranges of m_{atm} over much of the investigated SZA range. In particular, the cloudy cases exhibit considerably weaker spectral dependence than the clean cloud-free case, while the polluted cloud-free atmosphere generally lies between the clean and cloudy regimes. These results demonstrate that m_{atm} is physically sensitive to changes in atmospheric scattering associated with cloud contamination and therefore provide theoretical support for the proposed cloud-screening method.

Taking this valuable comment into account, we substantially revised the methodology and updated the figures and the Results and Discussion throughout the revised manuscript by using the atmospheric spectral slope, m_{atm} , instead of the observed spectral slope, m_{obs} , derived directly from the measured detector signals. We further discussed about the results of radiative transfer calculation to demonstrate the theoretical ground of methodology in the revised manuscript (**Page 7, Lines 268- Page 8, Line 304**). As a result, the revision provides a more physically consistent interpretation of the spectral behavior by accounting for the wavelength-dependent instrumental contribution and thereby isolating the atmospheric contribution to the spectral slope. Although the revision changes the quantitative values and physical interpretation of m_{atm} , the principal findings and overall conclusion of the study remain unchanged.

(2) What is the unit of TN , FP , TP in Eqs. (3), (4), and (5)?

→ They are counts of classification outcomes, which are dimensionless. We have clarified in the revised manuscript (**Page 13, Lines 439–440**).

(3) Please explain the cloud screening method of SR-CERES. As the referees commented, in addition to the comparison with the SR-CERES method, it will be useful for the research

community to see some quantitative comparison of the present cloud screening performance and those of other methods such as Khatri and Takamura (2009).

→ In the revised manuscript, we have added a detailed explanation of the cloud screening method included in SR-CEReS package (**Page 19, Lines 608–615**). In addition, following the reviewers' suggestions, we have carefully revised the manuscript to include a comparison of the proposed cloud screening method with existing approaches, including the method of Khatri and Takamura (2009), as detailed in Section 4.3 in the revised manuscript. The corresponding revisions and detailed responses to each reviewer comment are provided in separate response sheets to the reviewers.

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Replies to comments of Reviewer 1

Authors would like to express sincere gratitude to an anonymous reviewer for his/her valuable comments and suggestions. Our manuscript has greatly benefited from these insights. We have carefully revised the manuscript, taking all comments into account. Our responses to the reviewer's comments are provided below.

General comment

The authors develop the identification method of clear- and cloudy-sky conditions from the zenith radiances measured by the sky radiometer for reliable retrievals of aerosols and clouds. The characteristics of zenith radiances are investigated in detail. The process of developing the new method is easy to understand, and it is a reasonable technique. However, the results for aerosol retrieval are similar to those of the previous method. Although the authors suggest that the new method is easy-to-use and effective, I believe it does not contribute significantly to scientific progress and, in its current form, is insufficient for journal publication. Most of the cloud retrieval methods using zenith radiances are based on one-dimensional radiative transfer model. For this reason, it is necessary to select cases of overcast skies where the parallel-plate approximation holds. Since the new method distinguishes overcast conditions, I am more interested in its usefulness for cloud analysis than for aerosol analysis. I recommend adding an assessment of its impact on cloud retrieval.

→ We thank the reviewer for this useful comment. We agree that the proposed method has potential relevance to cloud analysis, in addition to its application to the quality control of observations used for aerosol retrieval. We also realize that the scope and intended role of the proposed method were not sufficiently clear in the previous manuscript, and we have revised the manuscript accordingly .

We would first like to clarify that the objective of the present study is not to develop or improve aerosol or cloud retrieval algorithms themselves. Rather, the study aims on identifying clear- and cloudy-sky conditions directly from the spectral characteristics of zenith-sky radiance measurements. The resulting sky-state classification is intended to serve as a preprocessing or postprocessing quality-control (QC) step that is independent of the subsequent aerosol or cloud retrieval procedure. In this context, the similarity between aerosol retrieval results obtained using the proposed and existing screening approaches does not necessarily indicate limited utility of the proposed method. Rather, it demonstrates that the proposed method can identify observations appropriate for aerosol analysis without requiring preliminary aerosol retrievals, temporal variability analyses, or ancillary observations.

We appreciate the reviewer's suggestion concerning the potential application to cloud retrieval. Cloud optical properties can be retrieved from zenith-sky radiances measured by SKYNET sky radiometers, as demonstrated by Khatri et al. (2019). In this respect, an important feature of the present method is that the presence of clouds is identified directly from the same zenith-sky radiance measurements that can subsequently be used for cloud retrieval. Thus, the proposed method can provide an efficient initial screening step for identifying cloudy observations before application of a cloud-retrieval algorithm, without requiring preliminary aerosol or cloud retrievals, temporal variability analyses, or ancillary observations.

A quantitative assessment of the influence of the proposed screening method on retrieved cloud properties would require its implementation within a specific cloud-retrieval framework and subsequent validation of the retrieved cloud products. Although such an assessment is beyond the scope of the present study, we consider it an important direction for future research and plan to investigate the applicability and potential benefits of the proposed method for cloud retrieval in a future study.

Following the reviewer's valuable suggestion, we have also revised the Introduction to clarify the relevance of the proposed method to cloud retrieval and its potential role as a screening procedure for subsequent cloud analysis by adding the description given below (**Page 3, Lines 94-108**).

The present study aims to systematically evaluate the capability of spectral zenith radiance measurements for discriminating between clear and cloudy sky conditions. Rather than retrieving aerosol or cloud properties, the proposed method provides an efficient preprocessing or postprocessing screening procedure to support subsequent or preceding aerosol and cloud retrievals. In this framework, sky-state detection is performed based on the spectral dependence of zenith-sky radiance after removing the wavelength-dependent instrumental contribution, thereby eliminating the need for preliminary aerosol retrievals, temporal variability analyses, or ancillary observations. Based on theoretical analyses, together with observational analyses at multiple sites representing diverse atmospheric environments, including urban, maritime, tropical continental, and polar regions, the study establishes simple criteria for sky-state classification. The proposed method is intended to complement existing cloud-screening techniques for aerosol studies while remaining independent of the subsequent retrieval methodology. Furthermore, the method has direct relevance to cloud retrieval approaches based on zenith-sky radiance measurements, such as that demonstrated by Khatri et al. (2019), because cloud presence can be identified from the same measurements used for cloud retrieval. Thus, the method can provide an initial screening step prior to cloud retrieval. Because the proposed method relies on the physical characteristics of spectral zenith radiance rather than network-specific processing procedures, it also has the potential to be extended to other observational networks, such as AERONET (Holben et al., 1998), that acquire comparable measurements.

Specific comments

- L30: Is the standard cloud-screening procedure of the SKYNET?

→ We rewrote the sentence by replacing “standard” with “an existing” (**Page 1, Line 30**).

- L62: The definition of clear-sky is ambiguous. The clear-sky is used to describe both completely cloudless skies and skies with just a few clouds.

→ We agree that the term “clear sky” can have different interpretations depending on the context. In meteorology, “clear sky” may refer to completely cloud-free sky, whereas in ground-based aerosol remote sensing, the relevant criterion is whether the observation is unaffected by clouds and therefore suitable for aerosol analysis. To avoid this ambiguity, we clarified “clear-sky” term in the revised manuscript (**Page 2, Line 61**).

- L87-89: The authors mention that the zenith radiance measurements are more useful than the irradiance-based screening methods or purely statistical approaches. However, there is insufficient evidence. Why don't you compare those with the new method in this study?
→ We agree that the original wording could be interpreted as implying that the proposed method is superior to existing irradiance-based or statistical cloud-screening methods. This was not our intention. Our primary intention was to emphasize the physical motivation for selecting spectral zenith radiance as the observational quantity. To avoid any unintended implication, we have revised the corresponding sentence by removing the comparative wording (**Page 2, Lines 91-92**).
- L101: If it is possible to compare the new method with that of AERONET, the authors would be able to demonstrate the advantages of this study.
→ Our intention was not to imply that the proposed method has already been demonstrated for AERONET observations, but rather to highlight its potential applicability to other ground-based aerosol monitoring networks. In order to avoid any ambiguity, We have modified the original sentence in the revised manuscript (**Page 3, Lines 105-108**).
- L127: The more detailed information or references regarding sky radiometer is required. The sky radiometer measures not only the zenith irradiances but also the direct irradiance, and the distribution of sky irradiances.
→ We have expanded the instrument description to clarify that the POM-02 sky radiometer is a multifunctional ground-based radiometer capable of measuring direct solar irradiance, spectral sky radiance distributions, and zenith radiance at multiple wavelengths (**Page 3, Lines 132-135**) as below.

The POM-02 is a multifunctional ground-based radiometer widely used in the SKYNET observation network. It performs automated measurements of direct solar irradiance, spectral sky radiance distributions (e.g., almucantar and principal-plane scans), and zenith sky radiance at multiple wavelengths, enabling the retrieval of aerosol, cloud, and atmospheric optical properties (Choi et al., 2020; Nakajima et al., 2020; Khatri et al., 2010,2019).

- L173-174: The nine MODIS pixels are used for the references of cloudy sky. Can this be interpreted as an extraction of overcast conditions?
→ Yes, the use of the 3×3 MODIS pixels (nine pixels) was intended to preferentially extract homogeneous cloudy scenes that approximate overcast conditions. This criterion was adopted to ensure that the collocated satellite observations represented a uniformly cloudy scene. We added a statement below to add clarity in the revised manuscript (**Page 5, Lines 178-181**)

For each ground-based observation, the nine MODIS pixels closest to the observation site, corresponding to a 3×3 pixel area centered the observation site, were extracted. This criterion was adopted to ensure that the collocated satellite observations represented a uniformly cloudy scene.

• L185-186: Since the radiometric calibration constants vary by instruments, the ratios of radiance spectrum are different from instruments. Is it necessary to determine a threshold for each instrument? The sky radiometer has a self-calibration method. Shouldn't the calibrated radiances be used? The authors determined the threshold using the long-term observation data, but did the changes in the calibration constants over time have any influences to the threshold?

→ We sincerely thank the reviewer for this important and insightful comment. We agree that the wavelength-dependent instrumental response can affect the ratio of the measured signals and, consequently, the spectral slope and classification threshold derived directly from uncalibrated observations. We also agree that temporal changes in the relative response of different wavelength channels may influence the spectral slope when long-term observations are analyzed. These issues were not sufficiently considered in the original manuscript.

Following the reviewer's comment, we have revised the methodology to explicitly account for the wavelength-dependent instrumental contribution. The observed spectral slope (m_{obs}) is now expressed as the sum of atmospheric and instrumental contributions, i.e., $m_{\text{obs}} = m_{\text{atm}} + m_{\text{inst}}$, where m_{atm} represents the spectral dependence of the atmospheric zenith radiance and m_{inst} represents the contribution arising from the wavelength-dependent relative instrumental response. The instrumental contribution is estimated using the calibration constants determined by the Improved Langley method together with the band-averaged extraterrestrial solar irradiance and is removed from m_{obs} , as described in the methodology. Consequently, the revised classification is based on m_{atm} , rather than directly on the instrument-dependent raw spectral slope. This treatment substantially reduces the instrument dependence of the classification criterion and provides a more physically meaningful basis for comparison among different instruments and observation sites.

We acknowledge that the instrumental correction remains approximate because a single set of calibration constants was applied to each instrument over the corresponding analysis period. Temporal changes that affect the two wavelength channels by similar relative amounts tend to cancel in their ratio, whereas differential wavelength-dependent degradation may introduce a residual uncertainty in m_{atm} . In this regard, Uchiyama et al. (2018) reported relatively small temporal changes in the calibration constants of POM-02 at wavelengths longer than 500 nm compared with the substantially larger degradation observed at shorter wavelengths. Among the wavelength combinations examined in the present study (400–675, 400–870, 500–675, and 500–870 nm), the 500–675 nm pair provided the best overall discrimination performance and was therefore selected for operational application of the proposed method. The use of this wavelength pair also reduces potential sensitivity to the stronger wavelength-dependent degradation associated with the shorter-wavelength channels.

Most importantly, despite the use of this first-order instrumental correction, the observational results demonstrate a distinct separation between clear- and cloudy-sky conditions in m_{atm} , as shown in Figs. 2-9. This indicates that the residual uncertainty associated with the approximate instrumental correction does not prevent discrimination between the two sky conditions in the present dataset. We consider this robustness to be a practical advantage of the proposed method: clear- and cloudy-sky conditions can remain distinguishable even when the wavelength-dependent instrumental contribution is approximated using a single set of calibration constants for each instrument.

We have revised the methodology and corresponding Results and Discussion throughout the manuscript to address this valuable comment.

- L205: DNI is sensitive to only the presence of clouds near the sun.

→ Thank you for this suggestion. We rewrote the sentence as below (**Page 6, Lines 251-252**).

DNI is highly sensitive to the clouds located along the direct solar beam, particularly those near the solar disk.

- L273-274: Isn't the wavelength pair of 0.500 and .0675 μm the most distinct pair?

→ We agree that the 0.500–0.675 μm wavelength pair provides the most distinct separation between clear- and cloudy-sky conditions. Following the reviewer's comment and the revision of our methodology to account for the wavelength-dependent instrumental contribution, we re-evaluated the discrimination performance of the different wavelength pairs using the atmospheric spectral slope, (m_{atm}). Among the wavelength combinations examined (0.400–0.675, 0.400–0.870, 0.500–0.675, and 0.500–0.870 μm), the 0.500–0.675 μm pair showed the best overall discrimination between clear- and cloudy-sky conditions. The corresponding results and discussion have been revised accordingly.

- Figure 3 and 4: The authors discuss the characteristics of spectral slope using only their mean values. Can we assume that the variability is small?

→ In Figures 3 and 4 (Figures 4 and 5 in the revised manuscript), only the mean values are presented because the primary objective of these figures is to illustrate the overall dependence of the spectral slopes on the atmospheric parameters (i.e., SZA, AOT, Ångström exponent, COT, and CER) and to facilitate comparison among the observation sites. Including measures of variability (e.g., standard deviation or interquartile range) for all sites and parameter bins would considerably increase the complexity of the figures and reduce their readability. To clarify this point, we have revised the manuscript to explicitly state that the figures present mean spectral slopes to highlight the overall trends and that the variability differs among parameter bins.

In order to add clarity, we revised the figure captions of those figures (**Pages 11 and 12**) and also added a sentence as given below in the revised manuscript (**Page 11, Lines 379-380**).

In those figures, only the mean values are presented because the objective is to illustrate the dependence of m_{atm} values on the atmospheric parameters over different atmospheric conditions together.

- L499: The more information of the standard SR-CEReS package is required. How does the standard method discriminate the clear- and cloud-sky conditions?

→ We agree that the description of the standard SR-CEReS cloud-screening procedure was too brief in the original manuscript. We expanded the discussion in the revised manuscript as below (**Page 19 Lines 609-615**)

The SR-CEReS processing package employs a multi-step cloud-screening procedure to identify cloud-contaminated observations before aerosol retrieval. The algorithm follows the method of Khatri and Takamura (2009), but excludes the pyranometer-based global irradiance test to allow consistent processing across SKYNET sites where pyranometer observations are

unavailable. The cloud-screening procedure combines (1) a spectral variability test (Kaufman et al., 2006) and (2) statistical quality-control tests based on Smirnov et al. (2000), including checks of the number of observations, diurnal stability, smoothness of aerosol optical thickness, and the three-standard-deviation criterion. Observations failing one or more of these tests are classified as cloud contaminated and excluded from the aerosol retrieval process.

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Replies to comments of Reviewer 2

Authors would like to express sincere gratitude to an anonymous reviewer for his/her valuable comments and suggestions. Our manuscript has greatly benefited from these insights. We have carefully revised the manuscript, taking all comments into account. Our responses to the reviewer's comments are provided below.

The proposed cloud-screening approach appears physically consistent with the different spectral behavior of aerosols and clouds. Author found that the spectral slope derived from the logarithmic contrast between zenith radiances at 0.400 and 0.675 μm has strong sensitivity to cloudy-sky conditions but limited capability for detecting clear-sky conditions, whereas slopes based on the 0.500 and 0.675 μm and 0.400 and 0.675 μm wavelength pairs exhibits more balanced detection performance for both clear and cloudy-sky conditions. The proposed method cannot be considered a fundamentally new concept, but represents a useful and practical cloud-screening technique to apply to sun-sky radiometers.

→ We sincerely thank the reviewer for this constructive comment and for recognizing the practical utility of the proposed cloud-screening approach. We agree that the physical basis underlying the proposed method, namely the different spectral scattering characteristics of aerosols and clouds, is well established. However, the use of these spectral differences in zenith-sky radiance measurements for sky-condition classification has received limited attention. To the best of our knowledge, the spectral slope of simultaneously measured zenith-sky radiances has not previously been systematically investigated and utilized for discriminating between clear- and cloudy-sky conditions in ground-based sun-sky radiometer observations.

Previous cloud-screening approaches for sun-sky radiometers have primarily relied on retrieved aerosol optical properties, temporal or spectral variability, statistical quality-control procedures, or complementary irradiance measurements (e.g., Smirnov et al., 2000; Khatri and Takamura, 2009). Zenith-sky radiance measurements have also been used for retrieving cloud optical properties (e.g., Chiu et al., 2006; Khatri et al., 2019); however, these studies used zenith radiances as input to cloud-property retrieval algorithms rather than exploiting their spectral slope as a direct clear/cloudy classification criterion. The methodological contribution of the present study therefore lies in systematically characterizing this spectral behavior and developing it into a simple sky-condition classification approach for sun-sky radiometer observations.

Following the reviewers' comments, we have further revised the methodology to explicitly account for the wavelength-dependent instrumental response. The observed spectral slope is separated into atmospheric and instrumental contributions, $m_{\text{obs}} = m_{\text{atm}} + m_{\text{inst}}$, and the estimated instrumental contribution, m_{inst} , is removed before sky-condition classification. The resulting atmospheric spectral slope, m_{atm} , is therefore used as the basis for evaluating the spectral differences between clear- and cloudy-sky conditions while reducing the influence of the wavelength-dependent instrumental response.

The practical advantage of the proposed approach is that sky-condition classification can be performed using the spectral characteristics of zenith-sky measurements without first conducting aerosol or cloud retrievals, temporal variability analyses, or using ancillary observations. Furthermore, although the wavelength-dependent instrumental correction employed in the present study represents a first-order approximation, the observational results demonstrate that m_{atm} retains a distinct separation between clear- and cloudy-sky conditions. Thus, the proposed approach

provides a simple and computationally efficient preprocessing or postprocessing quality-control procedure for sun–sky radiometer observations.

In response to this comment, we have revised the Methodology section to more clearly explain the physical basis and methodological contribution of the proposed approach.

There are some points that the authors should address:

1) In line 138, it is stated that the SKYNET archive is available at atmos3.cr.chiba-u.jp/skynet. However, this is not the official SKYNET website, which is www.skynet-isdc.org. The latter provides two processing modes, namely CERES and ESR-MRI. Are the products downloaded from the former website exactly the same as those available from the official SKYNET portal? If not, it would not be accurate to state that the database is obtained from SKYNET without further clarification.

→ We agree that the original description was ambiguous and could be interpreted as implying that the data were obtained directly from the official SKYNET website. In this study, the observational data were downloaded from the CEReS SKYNET archive (<https://skynet.irie-lab.jp>), rather than from the official SKYNET ISDC portal (<https://www.skynet-isdc.org>). Specifically, we used the SR-CEReS processed products distributed through the CEReS archive. To avoid confusion regarding the data source, we have revised the manuscript to explicitly identify the CEReS SKYNET archive as the source of the observational data and clarified that the analyses were performed using the SR-CEReS processed products (**Page 3, Line 143 – Page 4, Line 144**).

2) To what extent does the value of the epsilon parameter (line 406) depend on the measurement site? Please discuss its site dependence and whether a site-specific tuning is required.

→ In the present study, ϵ is a tolerance parameter used to define the uncertainty margin associated with the sky-condition classification criterion. The primary role of ϵ is therefore to control the trade-off between classification coverage and confidence. A smaller ϵ narrows the uncertain region and allows a larger fraction of observations to be classified, but may retain more ambiguous cases near the classification boundary. Conversely, a larger ϵ provides a more conservative classification by excluding more observations close to the boundary, at the expense of increasing the fraction of undetermined cases.

In the present study, a common value of ϵ was applied to all observation sites rather than optimizing it separately for each site. The multi-site analysis, covering diverse atmospheric environments, indicates that this common tolerance provides effective discrimination between clear- and cloudy-sky conditions without site-specific tuning. Nevertheless, some site dependence may remain because the distribution and variability of m_{atm} can differ among sites due to differences in atmospheric conditions and measurement uncertainty. Therefore, its value may be adjusted for particular applications depending on the desired balance between classification coverage and confidence.

We have clarified the role of ϵ , its possible site dependence, and the use of a common value across all observation sites in the revised manuscript (**Page 13, Line 488 – Page 14, Line 463**).

Here, the parameter ϵ controls the degree of conservativeness of the classification. A smaller ϵ results in a narrower undetermined region and allows more observations to be classified as clear or cloudy, whereas a larger ϵ broadens the undetermined region and provides a more conservative classification. The value of ϵ may be adjusted according to the desired balance between classification coverage and confidence or to meet specific operational requirements.

3) Instead of the qualitative comparison presented in Figure 9, I recommend providing a quantitative assessment of the different cloud-screening methods. For example, the authors could report the percentage or number of data points rejected by each method.

→ In response to this comment, we have replaced the primarily qualitative comparison in the original manuscript with an expanded quantitative evaluation by including additional Table 4 and Figures 12 and 13 in Section 4.3 of the revised manuscript.

4) The proposed method should be evaluated under a wider range of atmospheric conditions. In particular, it would be useful to compare the performance of the different cloud-screening approaches during representative case studies, such as desert dust outbreaks, wildfire smoke events, and cirrus cloud conditions, in order to demonstrate any improvement achieved by the proposed method.

→ We agree that evaluation under a wider range of atmospheric conditions is important for assessing the robustness and applicability of the proposed cloud-screening method. In response to this comment, we have substantially expanded the evaluation in the revised manuscript.

Specifically, we compared aerosol optical thickness (AOT) at 0.5 μm and Ångström exponent (AE) obtained after application of the proposed m_{atm} -based cloud-screening method with those obtained using the SR-CEReS cloud-screening procedure at eight SKYNET sites representing substantially different atmospheric environments. These include five Japanese sites, a tropical site (Burgos), and two polar sites (Syowa and Ny-Ålesund), thereby providing an evaluation over a wide range of aerosol loadings and atmospheric conditions.

In addition to the AOT–AE relationship, we have added probability-density distributions of AOT and AE to provide a more quantitative comparison of the aerosol populations retained by the two screening approaches. Overall, the distributions obtained using the proposed method substantially overlap those obtained using SR-CEReS at most sites, indicating that the proposed screening method retains broadly similar aerosol populations under the different atmospheric environments examined.

We further evaluated the consistency of the two approaches under seasonally varying atmospheric conditions. The revised manuscript now includes a seasonal comparison of the number of retained observations and the mean $\pm$ standard deviation of AOT and AE for both screening methods. The five Japanese sites were evaluated separately for DJF, MAM, JJA, and SON, while seasonally appropriate periods were used for Burgos, Syowa, and Ny-Ålesund. In most cases, the seasonal mean AOT and AE values obtained using the proposed method are close to those obtained using SR-CEReS and remain within the corresponding variability. Some differences are observed at individual sites and seasons, particularly at Fukue during periods of relatively high aerosol loading, indicating that the two screening approaches do not classify all observations identically. Nevertheless, the overall AOT and AE distributions remain broadly consistent.

Taken together, these multi-site, distributional, and seasonal comparisons substantially broaden the range of atmospheric conditions under which the proposed method is evaluated and indicate that its performance is generally consistent with SR-CEReS across the different environments examined.

We agree with the reviewer that dedicated case studies of desert-dust outbreaks, wildfire-smoke events, and thin-cirrus conditions would provide an additional and more stringent event-specific evaluation. However, such an assessment requires independent identification of aerosol and cloud types using coincident observations, such as lidar measurements, satellite aerosol/cloud products,

or other ancillary datasets. Such observations are not consistently available across the eight sites and analysis periods considered in the present study. Therefore, we do not interpret the present results as an event-by-event validation for these specific conditions. We consider such dedicated event-specific validation an important direction for future research.

Accordingly, the revised manuscript now includes the expanded multi-site comparison (Fig. 11), the AOT and AE probability-density comparisons (Figs. 12 and 13), the seasonal quantitative comparison (Table 4), and an expanded discussion of the performance and limitations of the proposed method under diverse atmospheric conditions in Section 4.3

5) The title should clearly specify that the proposed cloud-screening method applies only to direct-sun measurements.

→ We thank the reviewer for this comment. We would like to clarify that the proposed cloud-screening method does not use direct-sun measurements. Rather, the method is based on the spectral characteristics of zenith-sky radiances measured by a surface-based sun-sky radiometer. Specifically, sky-condition classification is performed using the atmospheric spectral slope, m_{atm} derived from simultaneous zenith-sky measurements at different wavelengths after accounting for the wavelength-dependent instrumental contribution. Direct-sun measurements are not used as input to the proposed sky-condition classification.

We recognize that the use of direct-sun-derived aerosol products in the subsequent evaluation of the cloud-screening results may have caused this misunderstanding. However, these aerosol products are used only to evaluate the observations retained after cloud screening and are not part of the proposed classification method itself.

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