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 senence 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 clarfied "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**).

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- 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., $m_{obs} = m_{atm} + m_{inst}$, 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 methdoldogy. 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 distinguishishable 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 rewote the sentence as below (**Page 6, Lines 251-252**).

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

- L273-274: Isn't the wavelength pair of 0.500 and .0675 um 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 disucssion in the revised manuscirpt 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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