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Author response to reviews

Mok et al., "Comparisons of spectral aerosol absorption in Seoul, South Korea"

[Reviewer comments are in black, responses in red]

Anonymous Referee #3

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GENERAL COMMENTS

The paper by Mok et al. focuses on the comparison of aerosol single scattering albedo (SSA) retrieved by SKYNET (POM-02) and by a combination of instruments (AERONET, MFRSR and Pandora). The broad spectral range, including the ultraviolet band, covered by the comparison make this study original. Surface albedo is found to be one of the main sources of discrepancy (underestimation) in SKYNET compared to AMP.

The paper covers a very interesting research topic and is generally well written. I recommend the publication on AMT after addressing the following minor issues.

We thank the reviewer for the positive assessment and summary

SPECIFIC COMMENTS

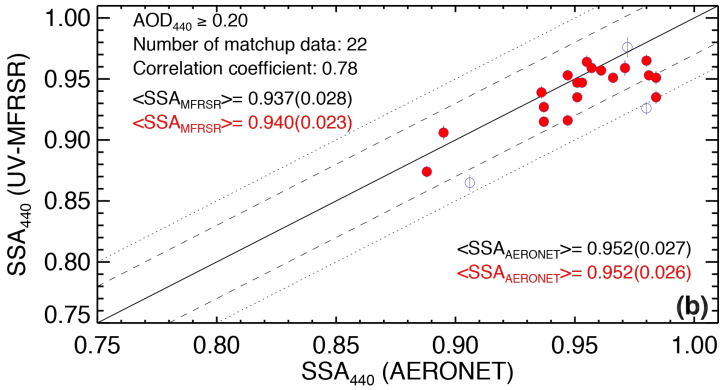
I have two remarks about the internal consistency of AMP retrievals.

1. Equation 1: in principle, to preserve consistency within the AMP triad, the gaseous optical depths used in MFRSR retrievals (tau_R, tau_NO2 and tau_O3), included in the right-hand side of Eq. 1, should be the same as the ones used by AERONET for the retrieval of the aerosol optical depth (tau_a) from the measurements of total optical atmospheric depth. Otherwise, slight differences in NO2 or O3 concentrations, pressure or used cross-sections could introduce some noise or fictitious biases (especially in the UV-VIS part of the spectrum). Can you discuss this point?

During MFRSR calibration, we correct AERONET AOD to account for differences between measured and climatological NO_2, ozone, and surface pressure values, making AMP retrievals internally consistent (Krotkov et al., 2009). We compare AERONET climatology with actual Pandora measurement in Seoul and see large underestimation (up to a factor of ~2) for high polluted episodes. Combining AERONET, MFRSR, and Pandora (AMP) retrievals ensures most accurate partitioning between aerosol and gaseous absorption, although this is not yet possible for all of ~400 AERONET sites.

2. At page 7, the authors affirm that PSD retrievals from AERONET (which accounts for non-spherical aerosols) are used to calculate SSA from MFRSR assuming spherical particles. Isn't it an inconsistency? The authors should explain that most aerosol are spherical at the measuring site or that non-spherical aerosol were excluded from the analysis (e.g., based on some AERONET output parameters).

We acknowledge the inconsistency of assuming spherical particles in MFRSR retrievals. Below Figure shows similar comparison (Figure 3b) for cases with AERONET sphericity exceeding 95%. We see similar results but this leads to much smaller statistical sample size, not allowing us to compare with SKYNET SSA retrievals.



On a different note, do the authors have an explanation why they do not find the SSA overestimation as the previous studies at VIS and IR ranges? Since emphasis is laid on this contrast with the previous literature (e.g., page 10. 4-5 and 21-23), some explanations should be provided.

The lack of overestimation is due, at least partly, to improved quality checks for the solar disk scan data used to determine FOV (referred to as SVA in previous literatures). In addition, the present study uses a slightly different approach for the determination of the calibration constant $\langle F_0 \rangle$. As mentioned in Section 3.3, while daily $\langle F_0 \rangle$ values for entire UV-VIS-NIR channels have not been given in previous studies, we think that reanalysis of their observation data by this approach is preferable to confirm the consistency.

We added the following statements at L5 in P10:

"Differently from previous studies, we found that average SKYNET SSA is in good agreement with average AMP SSA at VIS and NIR ranges (Figure 5 and Table 3). This is at least partly because we used the improved quality checks for the solar disk scan data used to determine the FOV. In addition, we used daily $\langle F_0 \rangle$ values for entire UV-VIS-NIR channels have not been given in previous studies (See details in Section 3.3)."

3. Finally, I would suggest to expand the conclusions, e.g. by including a special remark for terrains covered by snow and recommendations on how to determine the optimal surface albedo to be used in SKYNET inversions if no other co-located instrument is available at a specified measuring station.

We agree with reviewer's suggestions.

Since the surface albedo has a significant impact on SSA retrievals, future studies relevant to SKYNET inversions might determine the optimal surface albedo from the MODIS climatology (Moody et al., 2008) combined with bidirectional reflectance distribution function (BRDF) models to account for change as a function of solar zenith angle, like AERONET inversions.

In the Version 3 database the AERONET input for surface reflectance is based on the BRDF determined from MODIS data (V005 product) for all locations as described in:

Wang, Z., Schaaf, C. B., Sun, Q., Shuai, Y. and Román, M. O.: Capturing rapid land surface dynamics with Collection V006 MODIS BRDF/NBAR/Albedo (MCD43) Products, Remote Sens. Environ., 207, 50–64, doi: 10.1016/j.rse.2018.02.001, 2018.

In presence of snow and ice, the global daily surface albedo from the National Snow and Ice Data Center can be used. However, the snow/ice albedos have very high uncertainty due to very dynamic nature of snow and ice reflectance. This will be addressed in our future paper.

We added the following sentence in conclusion (L8 in P13) as reviewer suggested.

"Future studies relevant to SKYNET SSA inversions might determine the optimal surface albedo from the MODIS climatology (Moody et al., 2008) and/or combined with BRDF models (Wang et al., 2018) if no other co-located instrument is available."

TECHNICAL CORRECTIONS

4. page 1 title: the title refers to "spectral aerosol absorption" without mentioning explicitly the "single scattering albedo", which is the main topic of the paper and the only physical quantity provided as a result (apart from AOD and Angstrom exponent). I would suggest to change the title accordingly and not to mention in the abstract the quantities that are not directly discussed in the paper (column effective imaginary refractive index (k) and aerosol absorption optical depth (AAOD));

We agree with suggestion. We changed the title as

"Comparisons of spectral aerosol single scattering albedo in Seoul, South Korea"

Also, we removed column effective imaginary refractive index (k) and AAOD in the abstract as:

"Measurements of column average atmospheric aerosol single scattering albedo (SSA) are performed on the ground by the NASA AERONET in the visible (VIS) and near-infrared (NIR) wavelengths and in the UV-VIS-NIR by the SKYNET networks."

5. page 2. 1-16: this first paragraph puts together too many topics that should be dealt with separately (radiative effects - consisting in scattering and absorption (not only absorption), health effects, photochemical smog, etc.). The result is a bit confusing for the reader and somehow disconnected from the main topic of the paper. I would suggest to rewrite this whole paragraph;

We agree with suggestion. We rewrite this paragraph to show clear message of the main topic of this paper to the reader as below.

"Aerosols affect both the surface and outgoing radiation affecting Earth's radiative balance. To quantify the radiative effects of aerosols, the aerosol optical depth (AOD) and single scattering albedo (SSA) are monitored using ground-based, orbital and sub-orbital platforms. The potential climate effects of absorbing aerosols have received considerable attention lately (Myhre et al., 2013). In addition to climatic effects, aerosol absorption effects on surface UV irradiance and photolysis rates have important implications for tropospheric photochemistry, human health, and agricultural productivity (Dickerson et al., 1997; Krotkov et al., 1998; He and Carmichael, 1999; Castro et al., 2001; Mok et al., 2016). Measurements of column atmospheric aerosol absorption and its spectral dependence in the UV remain one of the most difficult tasks in atmospheric radiation measurements due to the lack of co-incident measurements of aerosol and gaseous absorption properties in the UV."

6. page 2. 15: "in the UV remain one of the most difficult tasks..." -> this is a key point.

Explain why it is a difficult task;

Compared to longer visible and NIR wavelengths, the gaseous absorption of ozone and NO_2 becomes important when trying to retrieve the column aerosol absorption in the UV. This problem occurs because there are lack of co-incident measurements of aerosol and gaseous absorption properties in the UV.

We changed the statements:

"Measurements of column atmospheric aerosol absorption and its spectral dependence in the UV remain one of the most difficult tasks in atmospheric radiation measurements due to the lack of co-incident measurements of aerosol and gaseous absorption properties in the UV."

7. page 3. 23: "equipped with" -> "mounted on" or "fitted to";

We agree with suggestion:

"The ability for UV (340 and 380 nm) channels mounted on the PREDE POM-02 sky radiometer used by SKYNET is investigated in this study."

8. page 5. Eq. 1: the equation should be introduced by a sentence;

We agree with suggestion. We changed the location of this sentence to L21 in P5 to show the equation is introduced by a sentence as below.

We use an estimate of the calibration constant for each individual 1-minute MFRSR measurement at each wavelength (i.e., extraterrestrial voltage, $V_0(\lambda,t)$) calculated using equation (1) to normalize measured direct and diffuse voltages (same calibration in shadowing technique) and as a quality assurance tool to retain only the best quality measurements consistent with the AERONET AOD measurements.

$$\ln V_0(\lambda,t) = \ln(V_{dir}(\lambda,t)) + \sec(SZA(t)) [\tau_a(\lambda,t) + \tau_R(\lambda,t) + \tau_{NO_2}(\lambda,t) + \tau_{O_3}(\lambda,t)] , \quad (1)$$

9. page 5. 29: "second order polynomial interpolation/extrapolation least-squares fit in logarithmic space..." -> replace this complex sentence with a formula;

We agree with suggestion. We changed the statement by adding a formula as below.

"$\tau_a(\lambda,t)$ is gaseous corrected and spectrally interpolated/extrapolated AOD to the MFRSR wavelengths applying a least-squares fit of the equation ($\ln \tau_a = a_0 + a_1 \ln \lambda + a_2 (\ln \lambda)^2$) (Eck et al., 1999) using AERONET spectral level 2 AOD"

10. page 5. 31: "a Pandora" -> "Pandora";

We agree with suggestion:

"For cases when NO_2 and O_3 values are not available from Pandora spectrometer,"

11. page 6. 3: "from the OMI" -> include a link to the data or explain which product was used;

We agree with suggestion:

"For cases when NO_2 and O_3 values are not available from Pandora spectrometer, satellite NO_2 (OMNO2 L2 v3.0) and ozone (OMTO3 L2 v8.5) measurements from the OMI are used (data are available at http://avdc.gsfc.nasa.gov under the Aura sub-menu)."

12. page 6. 32: "either from MFRSR... or AERONET" -> explain how either one or the other quantity is chosen;

We can manually choose which AOD retrievals (MFRSR or AERONET) are used for the AMP SSA inversion. In this study, we only used gaseous corrected AERONET AOD for consistency.

We added the statement to L1 in P7:

"In this study, we only used gaseous corrected AERONET AOD for consistency."

13. page 7. 23: "the static calibration" -> "the so-called static calibration";

We agree with suggestion:

"The first approach is to use the so-called static calibration constants."

14. page 7. 25: "use dynamic ... method" -> "use the dynamic ... method";

We agree with suggestion:

"The second approach is to use the dynamic on-site calibration method, based on the Improved Langley method (Campanelli et al., 2007; Khatri et al., 2016)."

15. page 7. 27-28: "during very hot summer" -> does this mean that the agreement is better in the cold season because of lower temperature? Also, I do not understand how the daily temperature variations (line 27) can be taken into account using a two-month average period (page 8);

Yes, it means that the agreement is better in the cold season because of lower temperature. However, this would not be the case, when the temperature is too low. Since the present study focuses on the season from spring to summer, we state "during very hot summer for instance".

We also agree with the reviewer that the daily temperature variations cannot be taken into account.

Accordingly, the sentence has been rewritten as "... on a monthly time scale ...".

16. page 8. 1-2: "to minimize the temporal stability" -> "to account for the temporal variability" ? "consider the consistency with the above-mentioned static calibration constants" -> what do you mean? Could you rephrase?

Considering the reviewer's comments, the sentence has been rephrased to

"To account for the temporal variability of $<F_0>$ by ±1–3% caused by temperature variation, the following method was used in this study."

17. page 8. 6: "the known field of view of the instrument" -> this seems to be a key point from previous literature. Could you explain what method you used to determine the FOV?

The FOV was determined by the solar disk scan method (Nakajima et al., 1996; Uchiyama et al., 2018). For the present study, careful quality check for the solar disk scan data was made by identifying and excluding apparent low-quality data, in which the measured normalized intensity showed an unexpected increase as the scattering angle increases.

Nakajima, T., Tonna, G., Rao, R., Boi, P., Kaufman, Y. and Holben, B.: Use of sky brightness measurements from ground for remote sensing of particulate polydispersions, Appl. Opt., 35, 2672–2686, doi:10.1364/AO.35.002672, 1996.

Uchiyama A., Matsunaga, T. and Yamazki, A.: The instrument constant of sky radiometers (POM-02), Part II: Solid view angle, Atmos. Meas. Tech. Discuss., doi:10.5194/amt-2017-432, 2018.

We added the following statement at L4 in P8:

"Assuming the field of view (FOV) of the SKYNET instrument is known by the solar disk scan method (Nakajima et al., 1996; Uchiyama et al., 2018),"

18. page 8. 21: "UV- and VIS-MFRSR retrieved SSA at 440 nm" -> "SSA retrieved at 440 nm by the UV- and VIS-MFRSR instruments";

We agree with suggestion:

"First, the individual 1-minute SSA retrieved at 440 nm (SSA_{440}) by the UV- and VIS-MFRSR instruments are compared to demonstrate the high degree of consistency for a combined set of modified UV- and VIS-MFRSR instruments (Figure 3a)."

19. page 9. 14: "Comparing" -> "Compared to the";

We agree with suggestion:

"Compared to the low scatter in SSA_{440} differences between UV-MFRSR and VIS-MFRSR (Figure 3a), Figures 3b and 3c show larger scatter between either UV-MFRSR (Figure 3b) or VIS-MFRSR (Figure 3c) and AERONET SSA_{440}."

20. page 9. 20: "NO2 that is not completely accounted for in the AERONET retrievals" -> explain why;

AERONET Version 2 AOD measurements are corrected for NO_2 absorption using monthly average satellite climatologies from SCIAMACHY satellite retrievals (https://aeronet.gsfc.nasa.gov/new_web/Documents/version2_table.pdf). However, NO_2 absorption is not taken into account in the sky radiances that are inverted in the AERONET SSA inversion (Dubovik) algorithm in Version 2.

21. page 10. 18-23: are these lines a typo? They are a repetition of the previous paragraph;

Considering the reviewer's comments, we removed this paragraph.

22. page 11. 12: "significantly increases the SSA (by 0.01)" -> how can a 0.01 increase be defined "significant"? Same at line 15: "significantly";

Considering the reviewer's comments, we remove "significantly".

23. page 11. 19: "is a critical pre-condition" -> then, since this is a pre-condition, why not move this section before the SSA discussion?

We think that to discuss possible factors for discrepancy between the AMP and SKYNET SSA in one section (Section 4.3) is better way for readers to understand like Khatri et al. (2016) did.

Khatri, P., Takamura, T., Nakajima, T., Estellés, V., Irie, H., Kuze, H., Campanelli, M., Sinyuk, A., Lee, S.-M., Sohn, B. J., Pandithurai, G., Kim, S.-W., Yoon, S. C., Martinez-Lozano, J. A., Hashimoto, M., Devara, P. C. S. and Manago, N.: Factors for inconsistent aerosol single scattering albedo between SKYNET and AERONET, J. Geophys. Res.-Atmos., 121, 1859-1877, doi:10.1002/2015JD023976, 2016.

24. page 11. 28-29: "gaseous absorption ... not taken into account in the sky radiances... inverted in the AERONET Version 2 retrievals" -> could you add a bibliographic reference about this issue?

There is no bibliographic reference that discusses this issue. When papers in the early stages of preparation for the new AERONET Version 3 database are available in the future, this issue will be discussed.