Reply to comments

We would like to thank you for reading our manuscript and commenting on it.

The comments are copied and shown below in italic.

The paper has been significantly improved. A second review round indicates minor, but numerous, editing corrections. In addition to those changes, the following three issues should be addressed.

1. The abstract contains too many technical details. It should be re-written including only high level conclusions. The technical details should be moved to conclusions section and supplement.

＝＝＞

The abstract of the first version included technical details. Since one of the reviewers commented on this point, in the revised version, technical details were removed according to the comment. Is further revision necessary?

2. The units of the sensor output and calibration constant (V0) need to be defined and indicated on V0 plots and captions. Plotting ln(v0) on Y axis in Figs. 4-5 and 8-9 is suggested.

＝＝＞

We added a description of the unit of V0 to the main text and the figure captions.

The Langley method is relative calibration, not absolute calibration. Therefore, we do not have to worry about units.

The sensor output depends on the instrument; voltage, current, digital count value etc.

Since the reviewers repeatedly points out the unit, we added an explanation and unit of sensor output of POM-02 in the revised version.

3. Additional justification should be given to support the use of the improved Langley Method.

The IML involves complex iterative inversion scheme, implemented in SKYRAD retrievals package, which requires single and multiple scattering radiative transfer calculations to iteratively estimate particle column volume size distribution, and calculate single scattering albedo and phase function. These inversions require assumptions about particle sphericity, fixed complex refractive index, and surface reflectance. It is difficult to estimate the accuracy of the retrieved effective aerosol parameters. For example, retrieved single scattering albedo could exceed unity (Line 558 and Fig. 9b). The authors admit that the fixed value of column effective refractive index

(1.5 – 0.001i) used in SKYRAD inversion "may not be appropriate" (L641). Moreover, these parameters are irrelevant if the goal is simply estimation of the calibration constant (V0), which requires only knowledge of the aerosol extinction optical depth and surface pressure, assuming gaseous absorption is negligible. Figure 8 clearly shows much higher noise of the IML method compared to calibration transfer from co-located reference instrument. The authors should justify using IML compared to the traditional calibration methods (e.g., transferring calibration from the reference POM-02, using calibrated light source), and estimate its uncertainties, e.g., in case of non-spherical dust particles.

==>

We do not necessarily recommend using the IML method.

We conduct observations by POM-02 independently of SKYNET. In JMA / MRI, the calibration reference POM-02 is calibrated by normal Langley method using the data taken at MLO, and the calibration constants of the other POM-02s for the continuous measurements are transferred from the reference POM-02. We have not used the IML method.

The objectives in this study are to investigate the current status of and problems with the sky radiometer POM-01 and POM-02.

We showed that the calibration constant determined by IML method has a seasonal variation of 1 to 3%, and in some cases, the maximum difference reaches about 5%. This indicates that the 2% error in the calibration constant is not significant in a turbid atmosphere, but it is significant in a clear atmosphere, such as in polar and ocean regions. Furthermore, there is a possibility that the seasonal variation of the calibration constant causes an artificial seasonal variation in the retrieved parameters.

However, many POM-01 and POM-02 users have been measuring without the periodic calibration by normal Langley method, and a lot of data has been accumulated. To use these data, we have to rely on the calibration with IML method.

A major concern is that the SKYRAD package combines calibration procedure with the optical inversion scheme, which involves many highly uncertain a-priori assumptions. It is always preferable to keep the calibration step (i.e., determining V0) independent from the inversion step.

==>

We also have the same idea, and we consider the calibration constant V0 to be determined independently from the inversion scheme.

As said above, however, many POM-01 and POM-02 users have been measuring without the periodic calibration by normal Langley method, and a lot of data has been accumulated. To use these data, we have to rely on the calibration with IML method.

Minor Technical suggestions:

L27,28. Indicate, which wavelengths?

==>

We inserted wavelength.

L48-49: add references for health effects of aerosols

==>

We added references.

51-54 : re-word

==>

Is this sentence long?

We rewrote this sentence as follows.

"Therefore, measurement networks covering an extensive area on the ground and from space have been developed and established to determine the spatiotemporal distribution of aerosols."

77: Add V0 after "calibration constant, V0, …". Provide units for the calibration constant here, e.g. counts/sec, voltages, etc.

==>

We inserted V0.

The unit of V0 depends on the instrument. The sensor output is voltage, current, digital count value, etc. Here, we do not specify the instrument. So, we do not provide the unit.

98: Add: precision of the calibration constant [transfer] obtained from …

==>

We inserted "transfer".

122 Add units: is located at an elevation of 3397.0 [meters]

==>

We inserted "meters".

157 where $V(T)$ is the sensor output [voltage] - ?
＝＝＞
We inserted the following sentence;
"In the case of POM-02, the sensor output is current, and the unit is Ampere (A)."

159 Therefore, the measured $V(T)$ is corrected [using equation (1)]
161: equation (2) is the same as equation (1) and could be deleted.
＝＝＞
We rewrote the sentence, and deleted eq. (2).

218 ".. is large? for this POM-02" – the temp sensitivity numbers are roughly the same or smaller than for the calibration reference POM-02 given in previous paragraph.
＝＝＞
We made a mistake.
We rewrote the sentence as follows..
"The temperature dependence of the sensor output in the 380 nm (2200 nm) channel for this POM-02 is larger (smaller) than that for the calibration reference POM-02."

223 The temperature dependence of the detector sensitivity – suggest: detector response
＝＝＞
Yes.

224 specifications of the detector – which specifications? Provide reference.
＝＝＞
"specifications" means "specifications data sheet".
We replaced "specifications" with "specifications data sheet".
And the address of the web is shown as a reference.
https://www.hamamatsu.com/resources/pdf/ssd/s1336_series_kspd1022e.pdf
https://www.hamamatsu.com/resources/pdf/ssd/g12183_series_kird1119e.pdf

241 comparing the side-by-side – remove "the"
＝＝＞
We removed "the".

254 When the extinction coefficient is divided? - is defined?
＝＝＞

We rewrote the sentence as follows,
“When the extinction coefficient is composed of several components,”

256 Introducing the normal? optical thickness (or optical depth). – replace with vertical optical thickness

＝＝＞

We replaced “normal” with “vertical”.
In the textbook written by Liou, “normal” is used.

262 is the airmass for the i-th - “th” should be subscript

＝＝＞

We replaced “i-th” with “i-$_{th}$”.

290, Remove the first part of Eq (10), which is the same as Eq (9)

＝＝＞

We removed the first part of Eq (10).

304 depth[s]

＝＝＞

We replaced “depth” with “depths”.

305 If the sensor output [voltage]

＝＝＞

The sensor output depends on the instrument: voltage, current, digital count value, etc. Here, we do not specify the instrument. So, we do not provide the unit.

357 is proportional to the sum of the line absorption strength[s]

＝＝＞

We replaced “strength” with “strengths”.

417 measurements for the calibration at MLO were being conducted. – remove “being”

＝＝＞

We removed “being”.

436 Figure 5 shows the annual [multiyear] variation of the calibration constants - in *what units?*

==>

We inserted “multiyear”.

The unit is shown in the Fig. 5 caption.

450: annual variation -> interannual variations?

==>

We replaced “annual” with “interannual”.

451 from 2009 to 2016 - There is no 2016 in the plots

==>

When we revised the manuscript and figure, we added 2016 data.

484-485: "The results of the comparison showed that the JMA's POM-02 met the WMO criterion (WMO 2005)." Please state the accuracy criteria of the WMO here.

==>

We inserted the following sentence.

“The WMO criterion for the absolute differences of all instruments compared to the reference is defined as follows: “95% of the measured data has to be within 0.005±0.001/m” (where m is the airmass).”

498 The single scatter[ed radiance] …

==>

We replace “scattering” with “scattered radiance”.

518 Equation 25 is the same as Equation (15)

==>

The eqs. (25) and (26) help to understand the contents of the next paragraph.

We combined equations (25) and (26) together and left both equations.

520 “If m, mτ, and , mτscat can be obtained …” – If this is the case, ln(V0i) can be simply calculated using equations (25)-(26) for each individual measurement (Vi) and averaged for any time period.

==>

Here, we just explain how V0 is determined in the SKYRAD package.

526-529: The SKYRAD retrieved/assumed effective parameters, such as single scattering albedo (SSA) and scattering aerosol optical thickness are irrelevant if the goal is determination of the calibration constant (V0), which requires only knowledge of the aerosol extinction optical depth and surface pressure, assuming gaseous absorption is negligible.

＝＝＞

As said above, here we just explain how V0 is determined in the SKYRAD package.

In this paper, the accuracy was evaluated by comparing V0 determined by the IML method with V0 determined by the normal Langley method. We think that there are some problems with the IML method.

540-552: Clarify if SKYRAD inversion procedure assumes spherical particles only?

＝＝＞

We inserted the following sentence after "….are calculated"

"assuming the spherical homogeneous particle".

We developed another retrieval software based on the spheroid model. But, this software is not officially adopted by the SKYNET group.

Kobayashi E, A. Uchiyama, A. Yamazaki, R. Kudo, 2010: Retrieval of Aerosol Optical Properties Based on the Spheroids Model. J. Meteor. Soc. Japan, 88, 847-856, Doi:10.2151/jmsj.2010-505.

550 "..procedure, the complex refractive indexes for each channel are fixed" – clarify what ref. index values are assumed? How they compare with the AERONET retrieved values?

＝＝＞

The values of the complex refractive indexes for each channel can be given by the SKYRAD package user. The values that we used are described in section 5.2.

The objective of this paper is not the comparison with AERONET.

Che et al (2008) compared aerosol optical properties by a PREDE skyradiometer and CIMEL sunphotometer over Beijing, China.

H. Che, G. Shi, A. Uchiyama, A. Yamazaki, H. Chen, P. Goloub, and X. Zhang, 2008: Intercomparison between aerosol optical properties by a PREDE skyradiometer and CIMEL sunphotometer over Beijing, China, *Atmos. Chem. Phys.*, **8**, 3199–3214.

554: "Comparing this equation with eq. (26)," - Why not using simpler equation (25) directly?

＝＝＞

As said above, here we are just explaining how V0 is determined in the SKYRAD package. We are not in a position to answer this question. Because, we did not develop the SKYRAD package.
We also want to know why eq. (26) is used, but there is no written material.
In this paper, we only evaluated the accuracy of V0 obtained by the method currently used.

577: " In Fig. 8, the calibration constants .." – Explain V0 units. Change to as Y-axis ln(v0) to express % changes directly and comparable across all spectral channels. Fig. 8 shows much higher noise of the IML method compared with calibration transfer method (red points). This should be clearly stated in conclusions and abstract.
==>
We added an explanation of the unit of V0 in the figure caption.
I appreciate your advice. However, we want to keep the figure as it is.
We added the following sentences to the main text and abstract.
"Furthermore, Fig. 8 shows much higher noise of the IML method compared with calibration transfer method"
"Furthermore, the calibration constants determined by the IML method had much higher noise than those transferred from the reference."

733. pwv is PWV – explain abbreviation
==>
"PWV" has already been explained above.

743. "V is the measurement value" – clarify the units, i.e., voltage , count rate, etc.
==>
The unit of sensor output depends on the instrument. The sensor output is voltage, current, digital count value, etc. Here, we do not specify the instrument. So, we did not provide the unit. However, we applied this method just below. Therefore, we added the following sentence.
"In the case of POM-02, the sensor output is current, and the unit of the measurement value V is Ampere (A)."

749 be fitted by a linear function of mb – Left hand side also includes m
==>
The airmass "m" is not an unknown. We can calculate the value of "m" from the solar

zenith angle.

755 "2.2973Å~10−4 A". – what is A?

＝＝＞

"A" is Ampere.

One of the reviewers requested to enter the unit repeatedly, so I entered the unit.

The Langley method is relative calibration, not absolute calibration. Therefore, we do not have to worry about units.

The unit of the current is ampere and the notation in the SI unit system is "A".

761 (2.2973Å~10−4/2.3364Å~10−4 − 1 = −0.0167) – delete

＝＝＞削除した。

We delete it.

762 (2.2954Å~10−4/2.3157Å~10−4 − 1 = −0.0087) – delete

＝＝＞削除した。

We delete it.

Lines 780-782: "....the calibration constant of the 940 nm channel could be determined by applying the above-mentioned method on a suitable stable and fine day at the observation site." Please define how stable the water vapor needs to be over the interval of Langley observations for this technique to be accurate to within ~1%.

＝＝＞

We applied Langley method to data in the airmass range between 2 and 6. The range of airmass is 2 to 5 in AERONET (Holben et al 1998) and 2 to 7 in Schmid and Wehrli (1995). Therefore, a stable interval of 1 to 2 hours is necessary. The stable condition of the atmosphere depends on the observation site. In Tuskuba, the outbreak of clod air-mass from the continent may continue for a few days in winter. In such a case, the atmospheric change is small. In this study, this method was applied on such a day. As described below this sentence, it is an important point that the quality of the Langley plot can be checked by an analysis of the residuals.

We added the following sentences.

"We applied Langley method to data in the airmass range between 2 and 6. Therefore, a stable interval of 1 to 2 hours is necessary."

894. The changes in the 340 nm channel were −10% per year" – this is very large *degradation rate and requires recommendations for upgrading this channel*

==>

As can be seen from Fig. 5, the degradation of V0 became smaller after replacing the lens in 2013. The manufacturer may have upgraded the lens.

We added the following sentence in section 4.2.

"After replacing the lens in 2013, the degradation of the 340 and 380 nm channels became smaller. The manufacturer of the skyradiometer may have upgraded the lens."

1195-1198: Define units of V/V0

==>

The units of V and V0 are the same. Therefore, V/V0 has no unit.

1208: Define V0 units

==>

We added a description of the unit of V0.

1214: 9(c): Define V0 units

==>

We added a description of the unit of V0.

Table 2: (unit is A) – Explain meaning of A (Ampere)

==>

We added a description of the unit of V0.