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.

Comment.
Anonymous Referee #2
Received and published: 23 July 2019
Nocturnal aerosol optical depth measurements with modified skyradiometer POM-02 using the moon as a light source
by Akihiro Uchiyama et al.

General comments:
Overall, this is a well-written paper describing the modification of the current PREDE-POM radiometers to extend the aerosol monitoring at night-time using the moon as the light source. Considering this to be the reference instrument of one of the most important ground-based networks such as Skynet, the adoption of this new system will provide valuable information for atmospheric research and will certainly be widely used. I consider that this manuscript fits perfectly into the scope of AMT. I recommend publishing the manuscript, but there are some important discussion points and details that I would like the authors to address before its final publication:

· This referee is concerned about the lack of continuous lunar measurements shown in this paper. The authors measured 2 moon cycles in MLO but they do not show any results in terms of AOD. Furthermore, they have 6 moon cycles in Tsukuba, but only a few days are shown in figure 7. They claim they can perform measurements at higher phase angles, but there is no evidence of this in the text. Figure 7 offers no information as to what phase angle corresponds with these measurements, and they do not constitute proof of continuous lunar measurements in themselves (see also specific comments).
=>
In Tsukuba, clear days with few clouds do not last long; at best only 3 or 4 days. Even at MLO, in the late morning and afternoon hours, marine aerosol and clouds reaches the observatory during the marine inversion boundary layer breakdown under solar heating. Therefore, we selected the continuous days with few clouds and presented the data on these days as measurement examples.
The time series of AOD at 500 nm and PWV in Tsukuba for 5 months is shown in

Supplement. These are non-cloud screening data. In addition, the time series of comparison between HSRL and POM-02 AOD for 5 months and the time series of comparison between GPS and POM-02 PWV for 5 months are also shown in Supplement. In Fig.7 (new Fig. 8) and Fig.12 (new Fig. 13), the phase angles during the measurement periods were added to the captions.

· *Moreover, the choice of the NIES/HSRL as the only validation analysis of this paper seems to be an important weak point (it needs interpolation or the assumption of a constant extinction coefficient at altitudes of less than 500m). There is a Cimel CE318-T taking measurements at MLO during the period the Prede was calibrating there. I suggest the authors include this interesting comparison in their study. Furthermore, the statistics involved in the day/night/day continuity of AOD will give important information about the instrument's performance.*

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We think that the comparison requires data measured in a way independent of the skyradiometer measurement. The HSRL is one of the instruments that can determine the vertical distribution of the aerosol extinction coefficient. Although data processing of HSRL is done under some assumptions, we used HSRL data.

We compared AODs (PWVs) before and after the sunrise and the sunset.
Examining the continuity of AOD (PWV) is an effective means for observation site where the atmosphere remains stable. In Tsukuba, the stable condition does not last for a long time. The comparison was made by selecting data with small variations.

We compared AERONET and POM-02 data.
In the nighttime, the atmosphere observed at MLO was pristine, and most of the AOD at 500, 675, 870, and 1020 nm were below 0.02. Considering that the accuracy of the calibration constant is 0.5 to 1%, it is difficult to compare the AOD of AERONET and POM-02.
The AERONET data used here is "level 2.0" in the daytime and "level 1.5" in the nighttime. Because there is no level 2.0 nighttime data. AERONET "level 1.5" is cloud-screened data but may not have final calibration applied. These data are not quality assured. AERONET "level 2.0" is pre- and post-field calibration applied, cloud-screened, and quality-assured data.
The primary purpose of MLO measurements is to acquire data for Langley calibration.

· *In the manuscript there is sometimes a lack of required scientific and analytical rigor and therefore, I suggest that potential subjective sentences be avoided. I would like to highlight the following examples:*

- *The ability of POM-02 to perform measurements beyond the quarters. In the conclusions the authors stated that this instrument is able to measure up to 120 degrees in phase angle. This value is quite surprising because it is the first time I have read it in the text. Notwithstanding, considering this to be the limit of your instrument's measuring capabilities, the authors must provide proof of that. Sections 2 and 3 describe a sensor able to perform measurements between +/-90 degrees and the authors claim that it is possible to extend this range if the instrument is accurately installed. Firstly, this assumption is vague and imprecise, and secondly there is no evidence in the manuscript showing this instrument is capable of providing measurements in this claimed phase angle range.*

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The measurement example on Oct. 14, 2017 at MLO was shown. In this example, the phase angle is from 117.6 to 118.0 degrees.

Also, we rewrote Sections 2.2 and 2.3.

- *The authors use only the ROLO model in terms of reflectance, assuming the relative change in the model's reflectance is correct. But as Kieffer and Stone (2005) stated, direct dependence on solar model will cancel itself out as long as the same model is used in going from irradiance to reflectance and back again. That means, the authors are introducing an "uncounted" error in this step, and they are not correcting their model implementation by using the Apollo spectra either. The authors should give some discussion about this effect, taking into account that they attribute the residuals of the C coefficient solely to errors of the ROLO model itself or to lunar librations. There are also other sources of error such as interpolation/extrapolation of the ROLO coefficients, temperature correction, Langley fitting, possible nonlinearity of PREDE-POM sensor, noise, among others.*

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As you said, Kieffer & Stone (2005) recommends using the same solar model (Wehrli, 1985) as Kieffer & Stone (2005) when converting ROLO reflectance to irradiance. This is because the Wehrli solar model was used to convert the original ROLO irradiance data to reflectance for developing the disk reflectance model. As you known, the value of the solar spectrum is different from model to model.

We don't use irradiance here. We use only reflectance data.

The coefficient C used here includes a coefficient for smoothing based on Apollo 16 Samples. Kieffer & Stone (2005) does not show the values of coefficients a and b of Aapollo = (a + bλ) Arolo (7,7,0,0), where Aapollo is reflectance based on Apollo 16 samples, Arolo(7,7,0,0) is ROLO reflectance for specific geometric configuration $(g = 7\,\mathrm{deg}, \Phi = 7\,\mathrm{deg}, \theta = 0, \phi = 0)$. These coefficients are necessary for smoothing. If we determine coefficients a and b by ourselves, there is a possibility that a new error will occur. Therefore, the original ROLO reflectance (Arolo) was used instead of the smoothed Arolo. However, the values of coefficients a and b that we determined are shown in Appendix A. The values interpolated into the wavelength of POM-02 are also shown in Table 3. To determine coefficients a and b, Apollo samples reflectance data is necessary. The values of coefficients a and b are dependent on the interpolation method of reflectance table and the accuracy of the value read from the figure.

As you pointed out, the residuals of C come from many factors.
We rewrote the text.

- *Similar precision and accuracy of night-time measurements in comparison to daytime: I suggest the authors present some evidence which justifies this statement or avoid giving vague assumptions. I understand that an uncertainty analysis could be out of the scope of this paper (although it would be very illuminating). However, without this study, the authors should not state that the uncertainty at daytime is similar to the one at night-time.*

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We want to know if there is a difference between daytime and nighttime measurements. We compared the measurements for the daytime and nighttime with measurement data which was recorded independently of POM-02 and has the same accuracy and precision in the daytime and nighttime.

The accuracy of the nighttime calibration constant is lower than that for the daytime. The measurement S/N in the nighttime is also worse than that in daytime. Considering these facts, even if there is no statistically significant difference, the magnitude of the error in the AOD (PWV) during the nighttime is not always the same as during the daytime. Further research and development are required.

Specific comments:

This is not the first time that an attempt for ROLO correction has been published. Therefore, I recommend including some discussion about similar corrections already presented in previous publications.

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We cited references.

Amplification in the new PREDE-POM: I am not sure by reading the text if the new instrument includes amplification or not. I read on page 3, lines 170-172, that it can use amplifiers in the visible and nIR spectral range (1 to 7). However, in Eq. 2, there is no amplification used between sun and lunar measurements. Could you please clarify this?

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The same amplifier was used for both the solar and lunar measurements.

The sensor output takes into account the magnification of the amplifier

We rewrote Section 2.

This is a technical paper aiming to extend AOD capabilities to night-time. Nonetheless, the authors presented a correction of the lunar irradiance model without showing its impact in terms of AOD. Furthermore, this goal seems very ambitious, taking into account that the continuous operation of this instrument has not been appropriately verified.

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The purpose of this paper is to show that POM-02 can measure AOD and PWV using the moon as the light source. If the ROLO reflectance is not corrected, the calibration constant has an error depending on the phase angle. If not corrected, there will be an error in the optical thickness depending on the phase angle.

POM-02 has been shown to be capable of continuous measurement during daytime measurements. The current POM-02 has the ability to measure the direct irradiance from the moon for some channels in the visible and near-infrared wavelength region without requiring modification. In this paper, only the function to track the moon has been added. We believe that POM-02 can measure continuously even during the nighttime as well as during the daytime.

Page 13, lines 404-417: How many points do you use (C coefficients) to perform your ROLO correction? What about the residuals? Do you use the residuals to estimate the precision of this correction by 1%? Please clarify.

=>

The number of data used to determine the coefficient of C and the residual are added to Table 3. The residual value is the error of the calibration constant.

Page 15, lines 469-472: there are references to "similar time variations" or "systematic differences" without quantifying them. The authors also claimed that this figure constitutes a continuous series, but it contains only 11 different nights from 3 different moon cycles (with 4, 4 and 3 nights, respectively). You do not provide any more data for an entire moon cycle, and is this because of clouds, technical problems… Please clarify.

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See reply to general comment.

In Tsukuba, it is unlikely that a clear day during the entire moon cycle lasts. At best, a clear day with no clouds lasts only for 3 or 4 days. In these figures, clear days with few clouds during the 3 or 4 days and with a long measurement time of the moon were selected. We added the word "qualitatively" to the text.

I feel lost with units in Section 2.1. You write Amps almost everywhere, but sometimes I think you are talking about physical units (irradiance or radiance units). Figure 1 presents solar direct and scattered irradiance in Amps. Why do you convert everything into current intensity?

=>

We have never converted the measurement values into irradiances. The raw sensor output value of POM-02 is current (unit: A). The transmittance is necessary for the estimation of the AOD. To obtain transmittance, a calibration constant is required; the instrument's output for the sun or moon outside the atmosphere.

Technical comments:

Page 1, line 33: Please define MLO.

=>

We rewrote.

Page 1, line 33: I read in the text (page 8 line 258) that the calibration period is September-November. Please verify.

=>

We rewrote.

Page 2, line 44: Please define MRI/JMA.

=>

We rewrote.

Page 2, line 44: Please define NIES.

=>

We rewrote.

Page 2, line 50: As written in general comments, the authors should avoid making vague assumptions.

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See above.

Page 2, line 65: there is a typo in AERONET.

=>

We rewrote.

Page 3, lines 79-84: Please homogenize if you write acronyms or not.

=>

We rewrote.

Page 3, line 98: "in many cases" Please be more specific. Are the authors talking about elastic lidars?

=>

We rewrote this paragraph.

Page 5, section 2.2: I feel the FOV of the instrument is missing here. I assume it is the same as the non-modified Prede, but I consider it will be useful for the reader to include this information.

=>

We added the sentences in Section 2.

In the modification of the POM-02 for solar observation, only the amplifier and the position sensor were changed. The other components, e.g., detectors, filters, and lenses,

are not changed. Therefore, the magnitude of the solid view angle (field of view) for the new POM-02 is the same as in the non-modified POM-02.

Page 8, line 257: How many measurements?

=>

We wrote the number of days and nights used to determine the calibration constants.

Page 9, section 5.1: I recommend the authors to separate this section into two, one for daytime calculations and another one for the methodology applied to night-time. I consider it will certainly improve the readability of this section.

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We divided section 5.1 into two sections.

Page 9, line 370: Is the Rm distance also expressed in AU? ROLO refers the reference to the mean Earth-Moon distance in km (384400km).

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As you pointed out, it is a mistake.

Page 10, line 325: Why the authors say "it is often used"? Because they use it sometimes and sometimes not? Please clarify.

=>

We deleted "often".

Page 10, line 351: Please be clearer about "several atmospheric models".

=>

Please see a reference.

Page 13, line 407: "…the moon and the sun".

=>

We rewrote the text.

Page 19, line 639: This is the first time I have read 120 degrees in the text.

=>

We showed an example of measurement.

Figure 2: Please label each figure and include some information about each sub-plot. According to page 12, line 392 and Eq. 10, the y-axis of this plot must be $\ln(\pi \cdot V \cdot R_S^2 \cdot R_m^2 / A \cdot \Omega)$ *?*

=>

The y-axis is the equation in parentheses on the left-hand side of eq. (11).

Figures 6 and 7: Please include information about wavelength.

=>

We add wavelength.