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 #1
Received and published: 12 February 2018
The instrument constant of sky radiometer (POM-02), Part I: Calibration constant
Akihiro Uchiyama, Tsuneo Matsunaga , Akihiro Yamazaki
Review For Atmospheric Measurement Techniques

General Comments:
This paper overall is a useful contribution to the literature, as it includes discussion of several issues that are often overlooked in sunphotometry, such as the temperature dependence of the detectors. However in order to provide a complete assessment of the uncertainties and issues involved in calibrating sunphotometers, additional information needs to provided and discussed before final publication.
One aspect that is lacking is a description of the filters utilized in the POM-02 instruments, such as the bandpass width of the ion-assisted deposition interference filters for each wavelength, the filter transmittance values and the filter blocking to exclude out-of-bandpass energy. Filter issues such as insufficient blocking can also potentially contribute to calibration uncertainty.
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Reply
We add the new Table 1 to show the nominal specification of filter, and insert the following sentence after line 107.
"In Table 1, the nominal specification of filters is shown. JMA / MRI does not use thee 315 nm channel because the transmittance of the lens was low at this wavelength region. Instead, JMA / MRI added a 1225 nm channel."

Table ### Nominal filter specification

Channel No.	Wavelength (nm)	FWHM(nm)	Max. Transmittance	Blocking	Blocking wavelength	Detector
–	315(±0.6nm)*	3.0(±0.6nm)	>30%	$1.0x10^{-5}$	200 – 1200 nm	Si photodiode
1	340(±0.6nm)	3.0(±0.6nm)	>30%	$1.0x10^{-5}$	200 – 1200 nm	Si photodiode
2	380(±0.6nm)	3.0(±0.6nm)	>30%	$1.0x10^{-5}$	200 – 1200 nm	Si photodiode
3	400(±0.6nm)	10.0(±2.0nm)	>30%	$1.0x10^{-5}$	200 – 1200 nm	Si photodiode
4	500(±2.0nm)	10.0(±2.0nm)	>30%	$1.0x10^{-5}$	200 – 1200 nm	Si photodiode
5	675(±2.0nm)	10.0(±2.0nm)	>30%	$1.0x10^{-5}$	200 – 1200 nm	Si photodiode
6	870(±2.0nm)	10.0(±2.0nm)	>30%	$1.0x10^{-5}$	200 – 1200 nm	Si photodiode
7	940(±2.0nm)	10.0(±2.0nm)	>30%	$1.0x10^{-5}$	200 – 1200 nm	Si photodiode
8	1020(±2.0nm)	10.0(±2.0nm)	>30%	$1.0x10^{-5}$	200 – 3000 nm	Si photodiode
9	1225(±2.0nm)**	20.0(±2.0nm)	>30%	$1.0x10^{-5}$	600 – 3000 nm	InGaAs photodiode
10	1627(±2.0nm)	20.0(±2.0nm)	>30%	$1.0x10^{-5}$	600 – 3000 nm	InGaAs photodiode
11	2200(±2.0nm)	20.0(±2.0nm)	>30%	$1.0x10^{-5}$	600 – 3000 nm	InGaAs photodiode

FWHM : Full Width at Half Maximum

* : 315 nm channel is not used by JMA/MRI.

** : 1225 nm channel is used by JMA/ MRI.

Some important information about Langley calibrations done at the Mauna Loa Observatory (MLO) is missing, such as the well-known fact that only morning Langleys should be used for calibration due to unstable conditions in the afternoon as a result of vertical growth of the marine boundary layer to the observatory altitude. References describing the characteristics of the MLO site specifically as related to the Langley calibration method should be added to the manuscript (see Shaw, 1979 JAS; Shaw, 1983 BAMS; Perry et al., 1999 JGR).

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Reply

We added the following sentences in new section 4.2 Normal Langley method.

"Measurements for calibration by the Langley method are recommended to be conducted at a high mountain observatory. MLO is one of the most suitable places to make measurements for calibration by the Langley method. Though the air at MLO is exceedingly transparent, it is affected in late morning and afternoon hours by marine aerosol that reaches the observatory as the marine inversion boundary layer breakdown under solar heating. Typically, by late morning the downslope winds switch to upslope winds, which bring moisture and aerosol-rich marine boundary layer air up the mountainside, resulting in an abundance of orographic clouds at the observatory (Show 1983, Perry et al. 1999). Therefore, using data taken in the morning is recommended and used (Show 1982, Dutton et al. 1994, Holben et al 1998).

In AERONET, the variability of the determined calibration coefficient as measured by the relative standard deviation or the coefficient of variation (RSD or CV, standard deviation/mean) is ~0.25–0.50% for the visible and near-infrared wavelength, ~0.5–2% for the ultraviolet and ~1–3% the for water vapor channel (Holben et al 1998).

In this study, though using data taken in the morning is recommended, both morning and afternoon data were used for the Langley plot. The observation period for calibration by Langley method is short, about 1 month, so we want to use all the data effectively. Furthermore, the quality of the Langley plot can be checked by an analysis of residuals; for acceptable data, no trend or systematic pattern is visible when the residuals versus airmass are plotted. Of course, the residuals were carefully checked and most results of the afternoons data were not adopted."

We also added the following sentences to the explanation of Fig.4.
"In these examples, the data in the afternoon is almost on the regression line in the morning. On such a day, the Langley plot was also applied to the afternoon data."

When discussing the calibration transfer of Vo from a reference instrument to another one in Section 4.2, it is critical to emphasize the importance of the AOD stability during the interval of simultaneous measurements as AOD temporal variability can incur additional uncertainty in Vo transfer. Additional information needs to be included such as how long a time interval was utilized and the time matching criteria used (how many seconds and how many observations matched) for the inter-comparison measurements. Additionally, some discussion on how you account for small differences in wavelengths between compared instruments (should use wavelength interpolations) needs to added to the text. Some mention should be made of the fact that near solar noon time intervals are typically the best for calibration transfer since optical airmass (m) changes most slowly at this time and therefore inexact time matching between the instrument measurements is minimized. Another advantage of the use of the solar noon time interval is that if there are differences in filter blocking between instruments then Vo transfers made at the smallest optical airmass are reduced by a factor of 1/m at the larger airmasses. Also, there is larger uncertainty in the computation of optical airmass at large values of optical airmass (see Russell et al., 1993; JGR).
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Reply

Though the temporal AOD stability is one of the important factors, we believe that simultaneity of data acquisition is important. We added sentences about data acquisition and the comparison method after line 253.

"The measurements for the comparison were made every minute using the same data acquisition system. It takes about 10 seconds to measure 11 channels each time. Measurement by all POM-02 is done at the same timing. Calibration of time is carried out every hour using NTP (Network Time Protocol) Server. For data comparison, only airmass data less than 2.5 was used on clear days. The comparisons were made on the assumption that the filter response function of POM-02 are same. When there is a difference in the filter, the relationship between the outputs of both becomes not linear. When it is greatly deviated from the linear relationship, the characteristics of either filter has changed, and it is necessary to replace the filter."

I recommend publication of this manuscript in AMT but only after significant revisions that address my general comments, and also after appropriate changes are made to address the specific comments listed below.

Specific comments:

Abstract, Line 15: Please add 'optical properties of' before the word 'aerosols'

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Reply

We add 'optical properties of' before the word 'aerosols'.

Abstract, Line 23: Please mention that the normal Langley method is performed at Mauna Loa Observatory here in the abstract as this is very important information.

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Reply

We changed the sentence as follows.

"The coefficient of variation (CV) of V0 from the normal Langley method based on the data measured at NOAA Mauna Loa Observatory is between 0.2 and 1.3%, except in the 940 nm channel."

Line 111: Remove 'Mt.' as Mauna Loa is never referred to as Mt.

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Reply

We remove “Mt.”

Line 122-123: ‘using special equipment’ to measure temperature dependence. Please provide much more information on this equipment and on how the measurements are taken with this equipment.

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Reply

The word "special" was not appropriate.

As written in the manuscript, this equipment is used originally to measure the temperature dependence of the pyranometer. This equipment is managed and maintained by a branch of the JMA Observation Department, which is one of the departments conducting routine observations.

We delete “special” and added the following sentences to explain measurements for temperature characteristics.

“The main components of this equipment are a temperature controlled chamber, light source, and stabilized power supply.

Measurements for investigating the temperature characteristics of POM-02 were made as follows.

In order to stabilize the equipment, the power supply of the equipment was put on the day before the measurement date. On the measurement day, first turn on the light source. Then, temperature setting is performed every 90 minutes, and temperature and output from POM-02 are recorded continuously. Temperature setting was performed in the order of 40, 20, 0, −20, 0, 20, 40, 20 °C. It took about 30 minutes for temperature rise and about 40 minutes for temperature decrease until the temperature and the output of POM-02 became stable. Temperature characteristics were investigated using data between 70 and 90 minutes.

In order to check the stability of the equipment, the staff of JMA recorded the output of the pyranometer CMP-22 (Kipp & Zonen, Netherland) continuously for 11 hours at a temperature setting of 20 °C. As a result, the variation of the mean values of the output per hour was ± 0.05% or less.

The temperature correction was performed for each measurement data. The temperature dependence of the sensor output was approximated by the following equation.

$$V(T)/V(T=Tr)=1.0+C_1(T-Tr)+C_2(T-Tr)^2 \quad (1)$$

where $V(T)$ is sensor output at temperature T, $V(T=Tr)$ is sensor output at reference temperature Tr, Tr is reference temperature, coefficients C_1 and C_2 were determined by the least squares method. Therefore, measured $V(T)$ is corrected by the following equation.

$$V(T=Tr)=V(T)/(1.0+C_1(T-Tr)+C_2(T-Tr)^2) \quad (2)"$$

Line 144: Please define 'turret' here, as it is not a commonly used term. I assume it is the rotating filter wheel that holds the individual filters?

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Reply

We replace "filter turret" with "rotating filter wheel that holds the individual filters".

Line 156-157: The nomenclature that you have utilized for wavelength regions is poor and not very specific. Note that visible is typically defined as 400 – 700 nm, nearinfrared (NIR) as 700 – 1000 nm and shortwave infrared (SWIR) as 1000 - 2500 nm.

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Reply

We changed the nomenclature according to your advice.

Line 181-182: Please give references for the 'normal Langley method' that you refer to here.

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Reply

I explained the Langley method we did in new section 4.1 and 4.2.

The term "normal Langley method" is used in Reagan et al (1986) and Kazadzis et al (2018). In the former, it is explained that the same airmass m_R is assumed for all attenuators, where m_R is airmass for molecular scattering. In the latter, there is no explanation.

Line 187-188: It is well known that afternoon Langley plots at Mauna Loa are much more variable due to marine boundary layer vertical growth. Please note this fact here. It would have been much more robust to use only morning Langleys as the AERONET project does.

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Reply

See above. We have already explained.

Line 194-196: This statement is too general, as some near-infrared channels (such as 870 nm) do not have water vapor absorption.

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Reply

We are writing about 1225, 1627 and 2200 nm channels here.

We replaced "near-infrared" with "shortwave-infrared".

Line 204-206: You should note that for 380 to 1020 nm the SD/Vo of ~0.2 to 0.5%, very similar to the repeatability values of Vo for AERONET as given in Holben et al. (1998).

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Reply

We add the following sentence after Line 209.

"In AERONET, the similar results were obtained (Holben et al. 1998)."

Line 206-207: Need to specify how the weighting is done to compute the weighted mean you refer to here.

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Reply

We recalculate weighted mean and standard deviation.

We attached an explanation of the weight to the appendix.

Line 224-231: Please specify here or in the later section on this topic (section 7) how important it is to account to the vertical profile of water vapor. What is the percentage *difference if just an average vertical profile is utilized rather than a specific profile for that date and location?*

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Reply

In Uchiyama et al (2014), the transmittance of 940nm channel is calculated using the vertical profile of water vapor. In this section, we do not use the modified Langley method. The fluctuation of water vapor is large, and using the average vertical profile, the transmittance cannot be calculated accurately and the Langley plot cannot be done. The modified Langley method requires airmass for water vapor. At that time, it may be useful to use the average vertical distribution

Line 247-248: What are the channels (give wavelengths) that had annual changes of <1% from 2009 to 2013?

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Reply

Here, we wrote about the channel of shortwave-infrared channels (1225, 1627, 2200 nm). We replace "near-infrared region" with "shortwave-infrared channels (1225, 1627, 220 nm)" in line 245, and add "in the shortwave-infrared channels" in line 247.

Line 291-294: Please show the monthly mean AOD over the annual cycle and/or add this information to the discussion.

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Reply

Roughly speaking, the optical thickness is thick in summer and thin in winter at Tsukuba. However, I do not know if the statistics on the day when Improved Langley method is applied are the same.

We rewrote Fig. 9. In the new Fig.9, since the error of V_0 and the optical thickness were found to be correlated, we do not show the annual cycle of optical thickness here.

In the old Fig.9, V_0 determined by the IML method was directly compared with the optical thickness. In this comparison, the trend of V_0 is not excluded, so the relationship between V_0 determined by the IML method and the optical thickness was not clear. For this reason, we investigated the relationship between ΔV_0 and the optical thickness of the day when the IML method was applied, where ΔV_0 is the difference between V_0 determined by the IML method and V_0 interpolated from V_0 determined by the normal Langley method. As a result, it was found that there was a correlation between the two. This result is consistent with the large amplitude of the seasonal change at short wavelengths (the shorter the wavelength, the optically thicker). Therefore, the optically thicker the accuracy of the multiple scattering estimation is poor. And the accuracy of the IML method may be poor. However, since the differences also depend on single scattering albedo, we cannot explain all of the errors with optical thickness.

We do not show the annual cycle of optical thickness, but we rewrote Fig.9 and added the above contents.

Line 298-300: Please be clear here, are you talking about the difference between the IML and the inter-calibration Vo values?

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Reply

Yes, we are.

We rewrote line 299 and 300.

"The calibration constant (V_0) determined by the IML method changes by up to 6%. Even if the effect of the temperature change is subtracted from the seasonal variation, there is a difference of about 4% between the V_0 determined by IML method and V_0 interpolated from V_0 determined by inter-comparison with the POM-02 (Calibration Reference)."

Line 307-308: Please note that these maximum differences are highly dependent on wavelength.

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Reply

Yes, they depend on the wavelength.

Since the differences depend on the optical thickness and usually the shorter the wavelength, the thicker the optical thickness, so the shorter the wavelength, the larger the amplitude of the seasonal change of V0 by the IML method. Therefore Max. Difference can be large.

We add the above sentences to the text.

Line 311-320: Do you have any ideas what may cause the seasonal trends in IML errors? Temperature is accounted for, and AOD is higher in summer when errors are smaller. Possibly optical airmass differences (larger m in winter) in conjunction with filter blocking differences may be bigger factors in winter. Some discussion of possible reasons for the seasonality of IML errors should be added to the text.

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Reply

We said that the value of V0 by IML method is small in the summer and large in the winter. However, we did not say that the error (difference) is small in the summer and large in the winter (see Fig. 8).

We do not know exactly the cause, but We want to show facts and draw attention to users of IML method.

The optical thickness changes seasonally, and seasonal change of V0 of IML method seems to be related to optical thickness. The V0 of the IML method also depends on W0, and simply the optical thickness is not the cause of the error.

Since W0 is a parameter related to single scattering albedo, I think there is a possibility that the seasonal variation of V0 by IML method may also be related to the seasonal variation of the refractive index. In the current processing, since the refractive index is fixed, I think that it is necessary to try a method to determine V0 while changing the refractive index.

We added this content to the explanation of the new Fig. 9.

Line 395-396: Is this 2% uncertainty based on one standard deviation uncertainty?

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Reply

We delete this sentence. We only calculated the statistics of difference between IML V0 and the inter-calibrated V0.

We replace Fig.9 with new Fig. 9. Therefore, we rewrote the three paragraphs from line

387 to line 403 in section 5.2 and moved them after line 321. And, we moved the rest of section 5.2 to the beginning of section 5.

Line 400: What is the fixed value that is assumed for the refractive index? Are both real and imaginary parts assumed?

==>

Reply

We use (1.5, -0.001) for all wavelengths as initial value of refractive index when using the Skyrad package. This value was used here. Since V0 determined by the IML method depended on W0, this value of refractive index may not be appropriate. We will consider the method of determining V0 while changing the refractive index in the future.

We added the above contents.

Line 441 – 442: Please give the wavelength ranges here rather than just channel numbers so that the reader does not have to keep referring to the Table when reading the text.

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Reply

We rewrote lines 441 and 442 as follows.

"At POM-02 (Calibration Reference), the relative difference was 0.7 to 7.6% in channels 2 to 8 (380 to 1020 nm), and 0.5 to 1.8% in channels 9 to 11 (1225, 1627, and 2200 nm). The integrating sphere used in channels 2 to 8 is different from that in channels 9 to 11."

Line 508: Please clarify how you computed the percentage differences in this sentence. Describe more completely what you are talking about here.

==>

Reply

We rewrote as follows.

"Though the difference of calibration coefficient between the Langley method with consideration of gas absorption and the modified Langley method is 1.7% ($2.2973\times10^{-4}/2.3364\times10^{-4}-1=-0.0167$) in 2014 and 0.9% ($2.2954\times10^{-4}/2.3157\times10^{-4}-1=-0.0087$) in 2015, these calibration coefficients are very similar."

Line 525-528: Please note that both AOD and columnar water vapor need to be stable over the full Langley airmass range of measurements. It is very risky to use only one 'stable and fine day' since repeatability cannot be determined and therefore uncertainty cannot be assessed.

==>

Reply

Assuming that V0 at 875 nm and 1020 nm are known, AOD at 940 nm is interpolated from AOD at 875 nm and 1020 nm. We only assume that pwv is constant.

By checking the residuals of the regression line, we can check whether the calibration constant is determined accurately. The 940 nm channels at many observation sites in SKYNET have not been calibrated and are not used. The application of the modified Langley method to the on-site observation data is the next best solution.

We add the following sentences after line 528.

"The quality of the Langley plot can be checked by an analysis of residuals; for acceptable data, no trend or systematic pattern is visible when the residuals versus airmass are plotted. The 940 nm channels at many observation sites have not been calibrated and are not used. The application of the modified Langley method to the on-site observation data is the next best solution".

Line 531: Please replace 'near-infrared' with 'shortwave infrared'.

==>

Reply

We replaced 'near-infrared' with 'shortwave infrared'.

Line 680-681: Please state the wavelength of this channel that has the maximum error.

==>

Reply

We add channel no. and wavelength.

Line 389-403。

We redrew Fig. 9 and rewritten the text as follows.

For the 500 nm channel, Figs. 9 shows a scatter plot of ΔV_0 and the optical depth at

500 nm, a scatter plot of ΔV_0 and W_0, and a time series of ΔV_0 from January 2014 to December 2015, where ΔV_0 is the difference between V_0 determined by the IML method and V_0 interpolated from V_0 determined by inter-comparison with the POM-02 (Calibration Reference). In this case, the V_0 values by IML method with errors less than 0.01 were chosen, where error is root mean square difference between measurement value and fitting line. As shown in Fig. 8, Fig. 9 (c) shows that ΔV_0 changes seasonally.

Figure 9 (a) shows that there is a negative correlation between ΔV_0 and the optical depth. This result is consistent with the large amplitude of the seasonal change at short wavelengths. Since usually the shorter the wavelength, the thicker the optical depth, so the shorter the wavelength, the larger the amplitude of the seasonal change of V_0 by the IML method.

In Tsukuba, the aerosol optical depth is thick in the summer and thin in the winter. Therefore, the seasonal change of V_0 by the IML method seems to be related to optical thickness. However, Fig. 9 (b) also shows that ΔV_0 and W_0 are negatively correlated, and that even if the correct W_0 is determined, the ΔV_0 are scattered with a width of about 1.0×10^{-5}. Since W_0 is a parameter related to single scattering albedo or refractive index, this indicates that the error depends not only on the optical depth but also on the refractive index. There is a possibility that the seasonal variation of V_0 by the IML method may also be related to the seasonal variation of the refractive index.

In the current Improved Langley method, the refractive index is fixed. We used (1.5, −0.001) for all wavelengths as initial value of refractive index when using the Skyrad package. This value may not be appropriate. It is necessary to develop the method to determine V_0 while changing the refractive index in the future.

newFig. 9

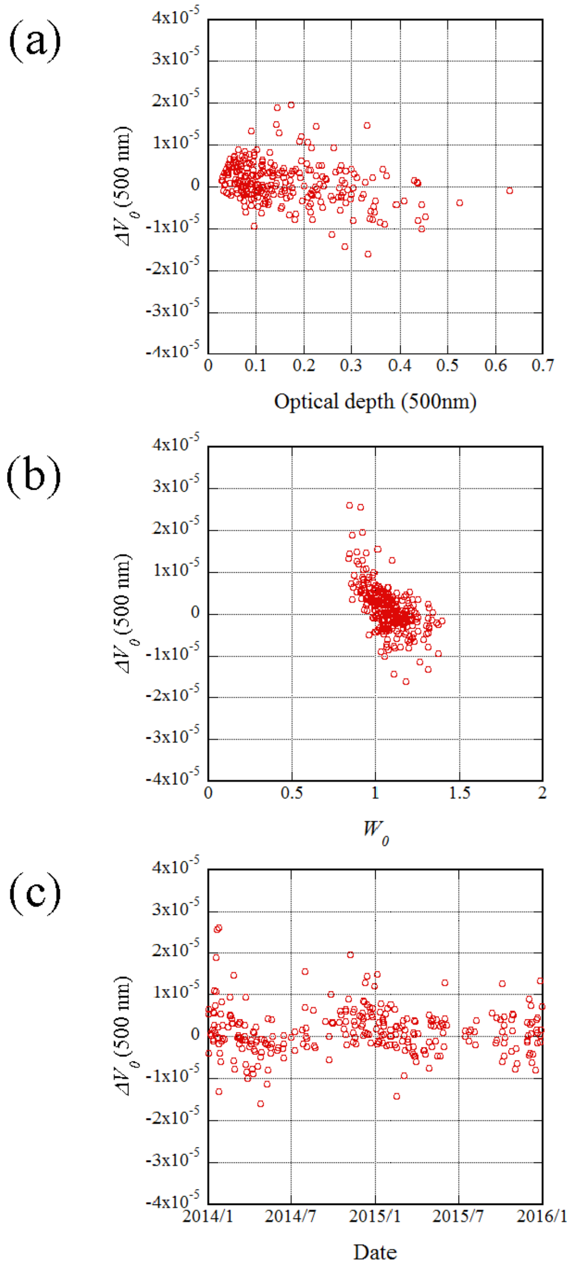

Fig. 9 (a) scatter plot of optical thickness at 500nm and ΔV_0 for 500nm channel, (b) scatter plot of ΔV_0 and W_0 for 500nm channel, (c) time series of ΔV_0 for 500nm channel in the period from January 2014 to December 2015 are shown. ΔV_0 is the difference between V_0 determined by the IML method and V_0 interpolated from V_0 determined by inter-comparison with the POM-02 (Calibration Reference).

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