Method for Uncertainty Evaluation of Vicarious Calibration of Spaceborne Visible to Near Infrared Radiometers

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***Abstract*—A method for uncertainty evaluation of vicarious calibration for solar reflection channels (visible to near infrared) of spaceborne radiometers is proposed. Reflectance based at sensor radiance estimation method for solar reflection channels of radiometers onboard remote sensing satellites is also proposed. One of examples for vicarious calibration of LISA: Line Imager Space Application onboard LISAT: LAPAN-IPB Satellite is described. Through the preliminary analysis, it is found that the proposed uncertainty evaluation method is appropriate. Also, it is found that percent difference between DN: Digital Number derived radiance and estimated TOA: Top of the Atmosphere radiance (at sensor radiance) ranges from 3.5 to 9.6 %. It is also found that the percent difference at shorter wavelength (Blue) is greater than that of longer wavelength (Near Infrared: NIR). In comparison to those facts to those of Terra/ASTER/VNIR, it is natural and reasonable.**

Keywords—Field experiment; vicarious calibration; image quality evaluation

I. Introduction

In order to calibrate optical mission instruments onboard remote sensing satellites in flight, vicarious calibration is strongly needed. One of the problems of vicarious calibration of optical instruments onboard remote sensing satellites is poor accuracy in comparison to the ground based calibration accuracy because estimation of atmospheric influences is not so easy.

Error budget analysis of vicarious calibration including uncertainty evaluation is reported. It, however, is still difficult to justify the uncertainty evaluation. Error budget analysis of reflectance based vicarious calibration method for satellite based visible to near infrared radiometers is discussed [1]. On the other hand, atmospheric correction and vicarious calibration of ADEOS[1] (Advanced Earth Observing Satellite) /AVNIR (Advanced Visible and Near Infrared Radiometer) and OCTS (Ocean Color and Temperature Scanner) is investigated [2]. Meanwhile, reflectance based vicarious calibration accuracy improvement by means of onsite measuring instruments calibration for satellite based visible to near infrared radiometers is proposed [3].

In this paper, one of the approaches for uncertainty evaluation is attempted. Major error would occur on surface reflectance measurements. Therefore, it is reasonable that uncertainty can be evaluated through surface measurement accuracy assessments. The proposed method is validated with Indonesian remote sensing mission instruments data of LISA: Line Imager Space Application is one main payload of the LISAT, LAPAN [2] (Indonesian National Institute of Aeronautics and Space) -IPB[3] (Bogor Agricultural University) Satellite[4]. This imager consists of four channels, blue, green, red, and NIR: Near Infrared. LISA is standard camera which can produce image with Digital Number (DN) representation. Radiometric model is formulated for prediction of radiance input value from the DN. With a limited mechanical and electronic of lens and CCD: Charge Coupled Device, focus can be adjusted through trials of image acquisition.

The accuracy of the pre-launch calibration is estimated to approximately 8 percent [4]. The items of radiometric characterization of the sensor are (1) linearity, (2) DSNU (Dark Signal Uniformity) and (3) PRNU (Photo Response Non-Uniformity) [5]. LISA has own mechanical, electronic models. Therefore, it is possible to remove radiometric and geometric errors from the acquired imagery data with telemetry data [6].

The related research works and research background are described in the following section. Then, the proposed uncertainty evaluation method is described followed by some experiments for validation of the proposed method. Finally, conclusion is described with some discussions,

II. Related Research Works of Vicarious Calibration

Previously, results of the EOS [5] (Earth Observation Satellite System) vicarious calibration joint campaign at Lunar Lake Playa, Nevada (USA) which was conducted in 1996 is reported [7] while preliminary vicarious calibration for EOS-

1 http://www.jaxa.jp/projects/sat/adeos/index_j.html

[2] https://en.wikipedia.org/wiki/National_Institute_of_Aeronautics_and_Space

[3] https://www.ipb.ac.id/

[4] https://directory.eoportal.org/web/eoportal/satellite-missions/content/-/article/lapan-a3

[5] https://eospso.gsfc.nasa.gov/

AM1 (The first afternoon orbit satellite of EOS) /ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) with field campaign is also well reported [8]. Atmospheric correction and vicarious calibration of ADEOS/AVNIR and OCTS is proposed and validated [9] together with atmospheric correction and residual error in vicarious calibration of AVNIR and OCTS both onboard ADEOS [10]. Meanwhile, experimental study on vicarious calibration for ADEOS/AVNIR and OCTS (in particular for visible channels) is reported [11] and field experiments at Tsukuba test site which is situated in Japan for ASTER vicarious calibration (visible to shortwave infrared regions) is also reported [12] together with field experiments at Tsukuba test site for ASTER vicarious calibration (thermal infrared regions) [13].

Early results from vicarious calibration of ASTER/VNIR and SWIR at test site in Japan is well reported together with early results from vicarious calibration of ASTER/TIR at the test site in Japan [14]. Meantime, reflectance based vicarious calibration for solar reflection channels of radiometers onboard satellites with deserted area of data is proposed [15] together with vicarious calibration of ASTER/VNIR based on the results of aerosol optical property by sky-radiometer (aureole-meter[6]) at the test site in Saga, Japan [16].

Vicarious calibration of ASTER based on the reflectance based approach is reported [17]. Meanwhile, error analysis and sensitivity analysis in estimation of aerosol refractive index and size distribution using polarization radiance measurement data for vicarious calibration of remote sensing satellite carrying visible to shortwave infrared radiometer is conducted and reported [18].

Influence due to aerosol size distribution on vicarious calibration accuracy and influence of calibration accuracy of the used sky radiometer in estimation of aerosol refractive index and size distribution is investigated [19]. On the other hand, vicarious calibration based cross calibration (through a comparison between the different sensor images, calibration is conducted mutually) of solar reflective channels of radiometers onboard remote sensing satellite and evaluation of cross calibration accuracy through band-to-band data comparisons is proposed and reported [20]. Then, a comparison among cross, onboard, and vicarious calibration for Terra[7]/ASTER/VNIR is made [21].

Sensitivity analysis and error analysis of reflectance based vicarious calibration with estimated aerosol refractive index and size distribution derived from measured solar direct and diffuse irradiance as well as measured surface reflectance is conducted [22]. Also, vicarious calibration data screening method based on variance of surface reflectance and atmospheric optical depth together with cross calibration is proposed and discussed [23]. Furthermore, vicarious calibration data screening method based on variance of surface reflectance and atmospheric optical depth together with cross calibration is proposed and discussed [24].

[6] https://sites.google.com/site/aerosolpedia/yong-yurisuto/da-qiearozoru-guan-ce/9

[7] https://terra.nasa.gov/about/terra-instruments/aster

In this paper, the proposed method for vicarious calibration of solar reflection channels of mission instruments onboard satellites which includes estimation of at sensor radiance) is described in particular for "uncertainty evaluation" followed by the first attempt of the proposed uncertainty evaluation through vicarious calibration of LISA.

III. Proposed Uncertainty Evaluation Method for Vicarious Calibration of Optical Sensors

The vicarious calibration method is illustrated in Fig. 1.

Surface reflectance can be measured through a comparison between radiance from standard plaque (Spectralon[8] which is traceable to NIST [9] (National Institute of Standards and Technology) standard) and the surface in concern. There is Bi-directional Reflectance Distribution Function: BRDF [10] of standard plaque and the surface. Major error sources are (1) BRDF effects, (2) Instability of the hand held spectrometer for surface reflectance measurement, (3) Registration error between the pixels of the test site and measured surface, (4) Instability of sensitivity of the spectrometer, etc. On the other hand, solar irradiance is quite stable (solar constant). Therefore, incoming radiance is assumed to be stable when the sky is clear. Total optical depth[11] can be measured with fine accuracy together with column water vapor, ozone. Meanwhile, Rayleigh scattering component [12] can be calculated with atmospheric pressure and air temperature (compensation). From the total optical depth, it is possible to calculate aerosol optical depth with the calculated optical depth of Rayleigh component, optical depth of water vapor, ozone. Using MODTRAN[13] of atmospheric model (Software code), influence due to the atmosphere can be calculated precisely.

Proposed uncertainty evaluation method is based on surface reflectance measurement data. It is reasonable that uncertainty is supposed to be caused by a homogeneity of the surface. Therefore, standard deviation of surface reflectance over double size areas of Instantaneous Field Of View: IFOV at the surface of the test site is considered to be uncertainty.

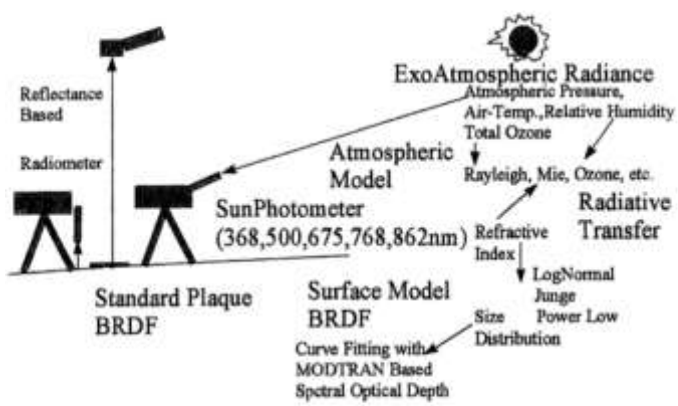


Fig. 1. Illustrative View of Vicarious Calibration.

[8] https://en.wikipedia.org/wiki/Spectralon

[9] https://www.nist.gov/

[10] https://ja.wikipedia.org/wiki/BRDF

[11] https://en.wikipedia.org/wiki/Optical_depth

[12] https://en.wikipedia.org/wiki/Rayleigh_scattering

[13] http://modtran.spectral.com/

IV. Validation of the Proposed Method Through Vicarious Calibration of LISA

A. *Method for Reflectance based Vicarious Calibration*

The proposed vicarious calibration of solar reflection channels of mission instruments onboard satellites is based on reflectance based method. The major influencing factor on the estimation of at sensor radiance (TOA: Top of the Atmosphere radiance) is surface reflectance measurements followed by absorption and scattering in the atmosphere. In order to improve surface reflectance measuring accuracy, wide areas of surface reflectance has to be measured. Then, mean and variance are checked for increasing reliability of the measurement data. Atmospheric absorption and scattering components are taken into account in the MODTRAN together with solar irradiance at the top of the atmosphere (extraterrestrial solar irradiance, solar constant that is Kurucz Model[14]).

From field experiments, surface reflectance is measured together with atmospheric conditions such as atmospheric optical depth, atmospheric pressure (atmospheric optical depth due to atmospheric molecule can be estimated with atmospheric pressure and air temperature), air temperature, relative humidity, water vapor in the atmosphere, to column ozone. From these measured data, the TOA radiance (it is totally equal to at sensor radiance is estimated by using atmospheric code of MODTRAN[15]. Then, the estimated TOA radiance is compared to the observed sensor radiance. The difference between both the radiances is calibration coefficient.

In order to minimize measuring error for surface reflectance, 10 by 10 pixels of homogenous area of test site is used together with standard plaque of Spectralon which is traceable to NIST standard. This is the key issue here for the proposed method together with the optical depth measuring instruments of MicroTops-II [16] of ozone meter and atmospheric transparency measurements.

B. *Major Specification of LISA*

LAPAN-A3/LAPAN-IPB (LISAT) was launched by PSLV: Polar Satellite Launch Vehicle Rocket[17], together with other 19 satellites from many countries from Sriharikota, India on Wednesday 22 June 2016. Major orbital parameters are as follows:

Altitude: 505 km (polar orbit)
Inclination: 98 degree

Major specification of LISAT satellite is as follows,

Weight: 115 kg
Dimension: 500 x 574 x 424 mm
LISAT carries the following equipment's,

a. AIS (Automatic Identification System)[18]

b. LISA: Push-broom 4 bands multispectral imager (300 mm). (Swath width: 122.4 km, Resolution: 18 m)

c. DSC: Digital Space Camera (1000 mm)

Outlook of LISAT is shown in Fig. 2. LISAT satellite is operated at the operational station situated at LAPAN, Norwegian, Berlin & Bogor, Indonesia. Revisit cycle of LISAT is 21 days. Major spectral specification of LISA is shown in Table 1.

LISA has four bands whose wavelength ranges from 410 to 900 nm, blue, green, red, and Near Infrared: NIR. IFOV of LISA is 18 m. Furthermore, swath width of LISA is 122.4 km. Also, LISA imagery data is acquired with 16 bit of quantization levels. Spectral response of each band is shown in Fig. 3.

TABLE I. FWHM and Average Radiance Voltage to Radiance Constanta

Band	FWHM	Bandwidth	Radiance (mW/cm2-sr-um)
Blue	0.410 - 0.490	0.080	41.76
Green	0.510 - 0.580	0.070	29.69
Red	0.630 - 0.700	0.070	20.45
NIR	0.770 - 0.900	0.130	23.43

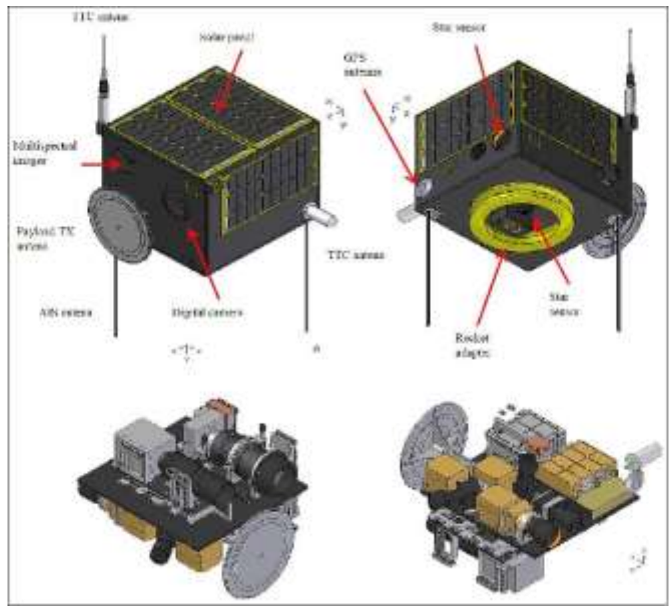


Fig. 2. Outlook of LISAT Satellite.

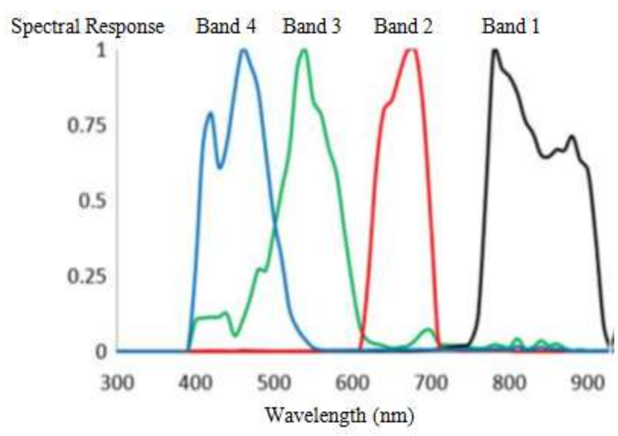


Fig. 3. Spectral Response of LISA.

[14] https://aslopubs.onlinelibrary.wiley.com/doi/pdf/10.4319/lo.1990.35.8.1657
[15] http://modtran.spectral.com/
[16] https://solarlight.com/product/microtops-ii-sunphotometer/
[17] https://en.wikipedia.org/wiki/Polar_Satellite_Launch_Vehicle
[18] https://www.marinetraffic.com/

C. Field Campaign

Field experiments are conducted at the test site of Kupang on 11 and 12 April 2018. The location of Kupang test site is shown in Fig. 4. As shown in Fig. 4, it was partially cloudy condition for both 11 and 12 April. At the test site, blue tarp (15m by 15m) is set-up.

The conditions of the field campaign are as follows:

Location: 10:12'07.8"S, 123:33'05.2"
Air-temperature: 34.3 deg.(Apr.11), 32.2 Deg.(Apr.12)
Relative Humidity: 50.6% (Apr.11), 58.6%(Apr.12)
Atmospheric pressure: 1006 hPa
Column ozone: 290 DU
(ftp://toms.gsfc.nasa.gov/pub/omi/data/ozone/Y2018/L3_ozone_omi_20180412.txt)
Junge parameter: 6.49

Fig. 4. Location of Kupang Test Site.

As shown in Fig. 5, 15m by 15m of blue tarp is set-up at the test site for identification of the test site location in the acquired LISA image. In the test site, surface reflectance at 30 m by 30m of test site area is measured by 5 m intervals.

D. Measured Data

The surface reflectance is measured with the well-known FieldSpec Hand Held 2[19]. Specification manufactured by ASD Incorporation. The FieldSpec Hand Held 2 delivers precision full range spectral measurements through a hand-held system designed around a radically streamlined cable-free workflow. Outlook of FieldSpec Hand Held 2 Specification manufactured by ASD Incorporation is shown in Fig. 6.

(a) April 11 2018 (b) April 12 2018

Fig. 5. Photos of the Field Experiments.

[19] https://www.malvernpanalytical.com/en/products/product-range/asd-range/fieldspec-range/index.html

Fig. 6. Outlook of the FieldSpec Hand Held 2 Portable Spectrometers Used.

Also, major specification of the FieldSpec Hand Held 2 Specification manufactured by ASD Incorporation is shown in Table 2.

An example of the measured surface reflectance of the test site of Kupang is shown in Fig. 7. As a working standard plaque, back side of photoprint paper which is traceable to Spectralon manufactured by Labsphere Co. Ltd. is used.

LISA image of Kupang of the test site which is acquired on April 12 2018 is shown in Fig. 8(a) while the enlarged Kupang test site LISA image is shown in Fig. 8(b).

TABLE II. MAJOR SPECIFICATION OF THE FIELDSPEC HAND HELD 2 FIELDSPEC HAND HELD 2

Wavelength Range	325 - 1075 nm
Wavelength Accuracy	±1 nm
Spectral Resolution	<3 nm at 700 nm.
Integration Time	8.5 ms minimum (selectable)
Field-of-View	25° (Optional fore optics available)
Sampling Interval	1.5 nm for the spectral region 325-1075 nm.
Spectrum File size	Approximately 30 KB
Memory Storage	Up to 2,000 spectrum files
Weight	1.2 kg (2.6 lbs.) with batteries
Body Dimensions	Measurements with handle not attached (width x depth x height): 90 x140 x 215 mm (3.5 x 5.5 x 8.5 in)
Temperature Range	Operating Temperature: 0° to 40° C (32° to 104° F) Storage Temperature: 0°C to 45°C (32° to 113° F) Operating and Storage Humidity: 90% Non-condensing

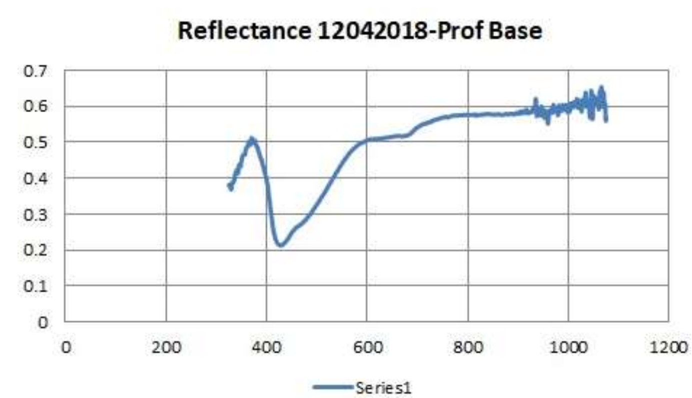
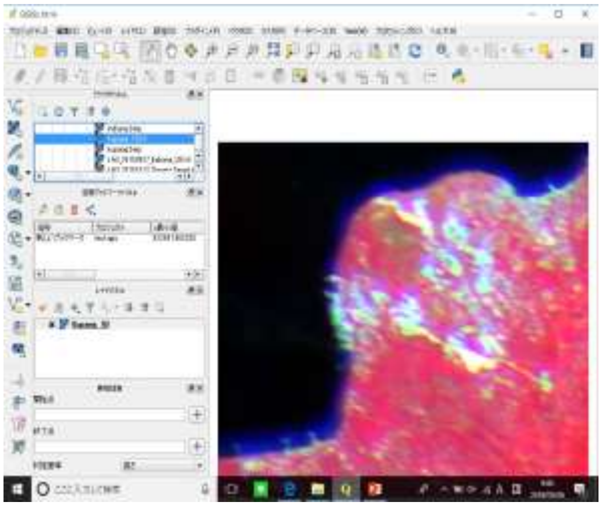
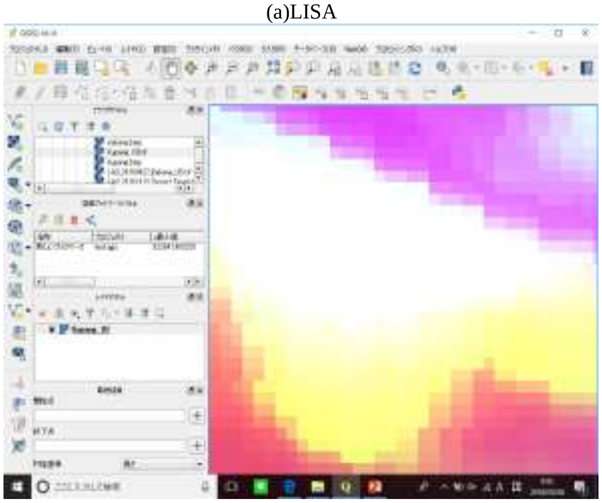


Fig. 7. Surface Reflectance of the Test Site Kupang on April 12 2018.



(a)LISA



(b)Enlarged LISA

Fig. 8. LISA Image of Kupang Test Site Acquired on April 12 2018.

The locations of the 10 pixels of the surrounding pixels of the test site of Kupang in the LISA image are shown in Fig. 9.

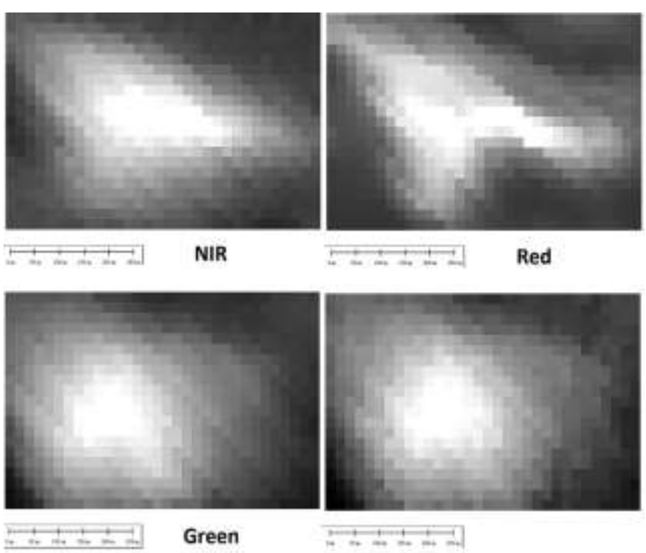


Fig. 9. LISA Image of the Test Site, Kupang.

TABLE III. DN OF THE PIXELS OF THE SURROUNDING THE TEST SITE OF KUPANG

Band	4	3	2	1
Point	Blue	Green	Red	NIR
1	4138	13318	22469	14012
2	4686	15248	28234	14031
3	4621	15007	28213	14383
4	4726	15595	27004	13627
5	4599	14680	23497	14462
6	4698	15611	28339	14212
7	4592	15098	25828	14575
8	4680	15525	28549	14014
9	4621	15007	28213	14383
10	4656	15646	26624	13220
Average	4601.7	15073.5	26697	14091.9
Standard Deviation	168.9096	696.738	2161.678	414.5633

From the LISA imagery data, Digital Number: DN of the pixels of the surrounding the test site point of Kupang is shown in Table 3.

E. Uncertainty

Uncertainty of the vicarious calibration of this case is evaluated with the measured data in the Kupang test site described in the previous sub-section. Taking the ratio of standard deviation and the average in the Table 3, the uncertainty, U can be evaluated. The result is shown in Table 4. In the table, averaged uncertainty over the all bands is also shown. It is found that the averaged uncertainty of the vicarious calibration in Kunag test site is 0.048.

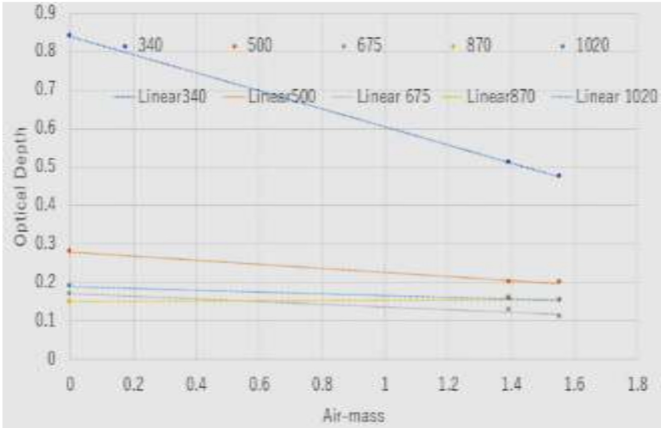
TABLE IV. UNCERTAINTY OF VICARIOUS CALIBRATION IN KUNAG TEST SITE

Band No.	4	3	2	1	Average
U	0.036706	0.046223	0.080971	0.029419	0.048329

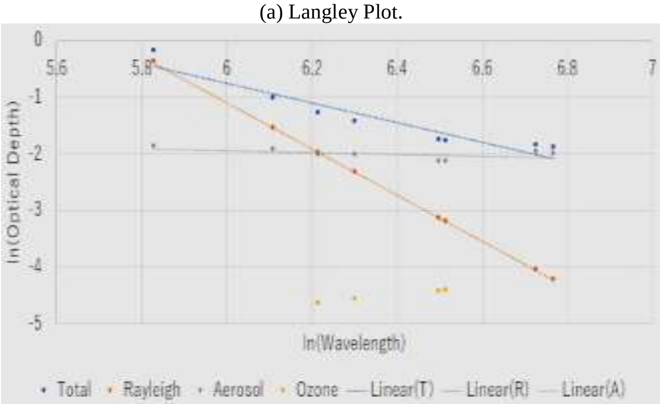
F. Atmospheric Data

Microtops II of measuring instrument manufactured by Solar Light Co. Ltd. is used for Langley plot and optical depth. Solar Light's Model 540 Microtops II Sunphotometer is a light weight, portable 5 channel instrument for measuring aerosol optical thickness, direct solar irradiance, and water vapor column easily, accurately and dependably. Fig. 10 shows outlook of the MIcrotops II. Microtops II measures solar direct irradiance at the following five wavelength, 340, 500, 675, 870, 1020 nm.

Fig. 10. Outlook of Microtops II.



(a) Langley Plot.



(b)Total Optical Depth.

Fig. 11. Measured Langley Plot and Total Atmospheric Optical Depth.

Meanwhile, measured Langley plot[20] and total atmospheric optical depth on April 12 2018 is shown in Fig. 11(a) and (b), respectively.

From the measured total optical depth, optical depth of Rayleigh scattering (atmospheric molecule), ozone, water vapor, and aerosol (Mie scattering[21]) are calculated. There are absorption due to water vapor, ozone and scattering of Rayleigh (atmospheric molecule) and Mie (aerosol). As shown before, total column ozone is retrieved from the aforementioned Web site. On the other hand, water vapor profile can be retrieved from the MODTRAN with the Typical tropic atmospheric model (relative humidity on the ground is adjusted with the measured humidity on April 12 2018).

Meanwhile, Rayleigh scattering component is derived from the measured atmospheric pressure. Optical depth of aerosol can be calculated with equation (1).

ODaero=ODtotal-ODrayleigh-ODwater-ODozone (1)

G. Vicarious Calibration Coefficients

Continuous atmospheric optical depth of total, Rayleigh, water vapor, ozone and aerosol are then calculated with MODTRAN through curve fitting between observed and calculated optical depth with MODTRAN in a least square mean. Also, TOA radiance (at sensor radiance) is calculated based on MODTRAN with input parameters of the measured surface reflectance, geometric relation among the satellite position, test site location, and sun elevation and azimuth angle (direction of direct solar irradiance) as well as atmospheric parameters including optical depth. Therefore, TOA radiance can be calculated with the integration of TOA radiance multiplied by the LISA spectral response. Then, at sensor radiance is compared to the LISA imagery data derived radiance. Thus, vicarious calibration coefficient can be calculated.

Surface reflectance, atmospheric optical depth, and the other required parameters are input to MODTRAN for calculation of Top of the Atmosphere: TOA radiance for each band of LISA. The calculated DN derived radiance and the TOA radiance are shown in Table 5 together with percent difference between both. As the results of the vicarious calibration, it is found that vicarious calibration coefficients are calculated as shown in Table 5. Table 5 shows the percent difference between DN derived radiance and estimated TOA radiance (at sensor radiance) ranges from 3.5 to 9.6 %.

TABLE V. CALCULATED DN DERIVED RADIANCE AND THE TOA RADIANCE

Average of near Blue Trap Position					
Band	4	3	2	1	
Name	B	G	R	N	
Reflectance	0.312	0.535	0.648	0.767	Unitless
DN Radiance	0.525	0.925	0.899	0.409	$W/m^2/sr/nm$
DN Radiance	52.472	92.452	89.885	40.909	$mW/cm^2/sr/um$
ToA Rad.	50.64	87.55	83.5	37	$mW/cm^2/sr/um$
%Diff.	3.49	5.3	7.1	9.56	%

V. CONCLUSION

The proposed uncertainty evaluation method for vicarious calibration is validated with the LISAT/LISA vicarious calibration in Kupang test site. The uncertainty is 0.048% which is reasonable from the point of view of the empirical field experiments.

Reflectance based at sensor radiance estimation method for solar reflection channels of radiometers onboard remote sensing satellites is proposed. Also, one of examples for vicarious calibration of LISA: Line Imager Space Application onboard LISAT: LAPAN-IPB Satellite is described.

Through the preliminary analysis, it is found that the percent difference between DN: Digital Number derived radiance and estimated TOA: Top of the Atmosphere radiance (at sensor radiance) ranges from 3.5 to 9.6 %. It is also found that the percent difference at shorter wavelength (Blue) is greater than that of longer wavelength (Near Infrared: NIR). In comparison to those facts to those of Terra/ASTER/VNIR, it is natural and reasonable.

Further investigations are required for vicarious calibration and image quality evaluations together with validation of the proposed method for uncertainty evaluation. Also, cross

[20] https://en.wikipedia.org/wiki/Langley_extrapolation
[21] https://en.wikipedia.org/wiki/Mie_scattering

calibration between LISAT/LISA and the other same spectral range of remote sensing imagers onboard satellites.

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