Vicarious Calibration Data Screening Method Based on Variance of Surface Reflectance and Atmospheric Optical Depth Together with Cross Calibration

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Abstract—**Vicarious calibration data screening method based on the measured atmospheric optical depth and the variance of the measured surface reflectance at the test sites is proposed. Reliability of the various calibration data has to be improved. In order to improve the reliability of the vicarious calibration data, some screenings have to be made. Through experimental study, it is found that vicarious calibration data screening would be better to apply with the measured atmospheric optical depth and variance of the measured surface reflectance due to the facts that thick atmospheric optical depth means that the atmosphere contains serious pollution sometime and that large deviation of the surface reflectance from the average means that the solar irradiance has an influence due to cirrus type of clouds. As the results of the screening, the uncertainty of vicarious calibration data from the approximated radiometric calibration coefficient is remarkably improved. Also, it is found that cross calibration uncertainty is poorer than that of vicarious calibration.**

Keywords—Vicarious calibration; Surface reflectance; Atmospheric Optical Depth; Sky-radiometer; Terra/ASTER; Satellite remote sensing

I. INTRODUCTION

Visible and Near Infrared mounted on earth observation satellites and the short-wavelength infrared radiation thermometer, Alternative calibration using measurement data on the ground and onboard calibration by the calibration mounting system is performed. For example, Marine Observation Satellite-1 [1], Landsat-7 Enhanced Thematic Mapper Plus [2], SeaWiFS [3], High Resolution Visible: HRV/SPOT-1 and 2 [4], Hyperion [5], POLDER [6], etc. by ASTER [7]. The calibration results have been reported. Further, report according to reciprocity with a uniform ground surface [8] over a wide area such as desert radiometer each other overlapping of the observation wavelength range have been made [9].

Vicarious calibration are conducted with consideration of the influence due to the atmosphere obviously [11]. Furthermore, the well-known cross calibration through comparisons among visible to near infrared radiometers onboard same or the different satellites is effective for calibration of the visible to near infrared radiometers in concern [12]. [13], [14]. To conduct the error analysis in the vicarious calibration of visible and near infrared radiometer,

Arai et al. made it clear dominant error factors of vicarious calibration accuracy [15]. According to it, most dominant error factors are the surface reflectance measurement followed by optical depth measurement that allows estimation of aerosol property. It is still difficult to estimate the aerosol characteristic and surface reflectance estimations. In order to estimate refractive index of aerosol particles, it is strongly suggested to use skyradiometer[1] or aureole-meters [16], [17]. Since April 2003, Arai et al. have been doing the observation of aerosol by skyradiometer, POM-1 that is manufactured by PREDE Co. Ltd. [18]. The skyradiometer allows measurement of solar direct, diffuse and aureole that results in estimation of refractive index and size distribution of aerosol particles [19]. Nakajima proposes a method of estimating the volume particle size distribution and the complex refractive index [20]. Arai proposes a method for using the Simulated Annealing: SA as inverse problem-solving [21]. Furthermore, improved Modified Langley method as the calibration method of sky-radiometer and as the method for estimation of extraterrestrial solar irradiance as well as atmospheric optical depth is proposed by Arai. The method is for estimating the top of atmosphere radiance with consideration of not only down-welling but also up-welling p and s polarized irradiance and radiance [21].

Reliability of the vicarious calibration data has to be evaluated. Vicarious calibration data are used to be suffered from atmospheric conditions, existing cirrus clouds, smoke from wild fire that happens nearby test sites, enthused gasses from automobiles that situated nearby the test sites, and so on. These are invisible mostly. Therefore, vicarious calibration data are suffered from these influences even if we conducted field campaigns with great care about these. It is possible to find such these influences through careful screening test with the measured data of surface reflectance and optical depth. The method proposed here is to make a screening the vicarious calibration data suffered from the influences for improvement uncertainty of the vicarious calibration data.

In the next section, the method and procedure of the proposed screening method is described followed by experimental data and estimated results. Then conclusion is described with some discussions.

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[1] http://skyrad.sci.u-toyama.ac.jp/

II. PROPOSED METHOD

A. Vicarious Calibration Method

Flowchart of the reflectance based vicarious calibration method is shown in Figure 1. At the test site (relatively high surface reflectance of homogeneous area of desert which is situated at comparatively high elevation (thin atmosphere) is desired, field campaign is used to be conducted. At the field campaign, atmospheric optical depth, surface reflectance, column ozone, column water vapor is measured. From the measured atmospheric optical depth, size distribution can be estimated using Angstrome exponent together with extraterrestrial solar irradiance through Langley plot. Total atmospheric optical depth can be divided into Rayleigh scattering component due to atmospheric continuant, and Mie scattering component due to aerosol particles in the scattering components. On the other hand, absorption components due to water vapor, ozone and aerosols are also estimated. Rayleigh scattering component can be estimated with air-temperature and atmospheric pressure on the ground. Absorption due to ozone can be estimated with the absorption coefficient of ozone and the measured column ozone in unit of Dobson Unit. In the visible to near infrared wavelength region, major contribution is from atmospheric continuant (O_2, N_2), water vapor, ozone, and aerosols. Therefore, these contributions in the forms of scattering and absorption have to be taken into account. Through radiative transfer equation solving process (mostly MODTRAN code is used to use) with the estimated influencing aforementioned parameters, Top of the Atmosphere: TOA radiance (at sensor radiance) can be estimated. Then the estimated TOA radiance is compared with satellite sensor data (Digital Number; DN is converted to radiance). Thus gain can be calibrated. This gain degradation is called as Radiometric Calibration Coefficient: RCC. It is referred to Vicarious Calibration Coefficient: RCCvic. On the other hands, most of visible to near infrared radiometer onboard satellites has own onboard calibration system. It provides Onboard Calibration Coefficient (OBC).
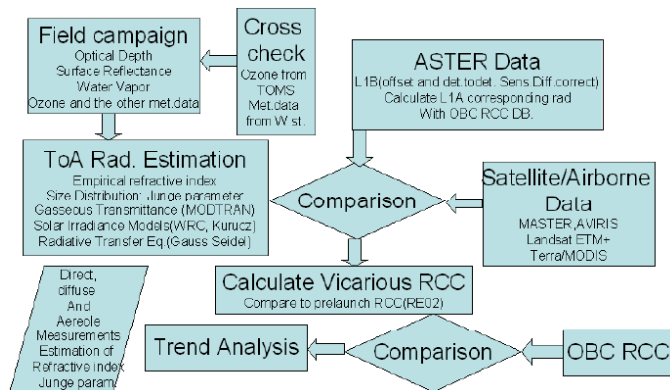

Fig. 1. Flowchart of reflectance based vicarious calibration method

Then it is possible to compare both coefficients.

B. Error Budget Analysis

There are 8 error sources for the vicarious calibration. The result from error budget analysis of the vicarious calibration method is shown in Table 1.

TABLE I. ERROR BUDGET FOR REFLECTANCE BASED VICARIOUS CALIBRATION METHOD

Error sources	Error Type	Error (%)
Optical depth	Random	1.5
Surface reflectance measurement instrument	Random	2
Standard plaque	Systematic	1
Averaging	Random	0
Refractive index	Random	1.8
Size distribution	Random	2
Radiative transfer code	Systematic	1
Registration	Random	1
RSS		4.06

Optical depth measurement has error of 1.5% while surface reflectance measurement instrument has 2% of error which includes Bi-Directional Reflectance Distribution Function: BRDF effect. Standard plaque is used as reference of reflectance and has 1% of error. Estimation accuracy of refractive index and size distribution is not high enough. 1.8 and 2 % of errors are suspected for each. Radiative transfer code has 1% of error while 1% of error is suspected due to registration of test site (location identification) in the satellite sensor image. Thus 4.06% error is suspected for vicarious calibration.

C. Vicarious Calibration Data Screening Method

Reliability of the vicarious calibration data has to be evaluated. Vicarious calibration data are used to be suffered from atmospheric conditions, existing cirrus clouds, smoke from wild fire which happens nearby test sites, enthused gasses from automobiles which situated nearby the test sites, and so on. These are invisible mostly. Therefore, vicarious calibration data are suffered from these influences even if we conduct field campaigns with great care about these. It is possible to find such these influences through careful screening test with the measured data of surface reflectance and optical depth. The method proposed here is to make a screening the vicarious calibration data suffered from the influences for improvement uncertainty of the vicarious calibration data. There are two major factors, optical depth and standard deviation of the measured surface reflectance. By using threshold, vicarious calibration data can be screened.

D. Uncertainty of Vicarious Calibration

Time series of RCCvic data can be approximated with appropriate function (Usually single exponential function of "a EXP(-b d) + c") in the sense of trend analysis. Let be RCCvic' denotes the approximated RCCvic. Then uncertainty of vicarious calibration can be expressed in equation (1).

$$U = SQRT(\Sigma(RCCvic - RCCvic')^2 / n_i(n_i - p_i)) \qquad (1)$$

where n and p denotes the number of vicarious calibration data and the condition number, respectively. Thus uncertainty of the vicarious calibration can be calculated.

III. EXPERIMENT

A. Trend of the Vicarious Calibration Data

One of examples of vicarious calibration data of ASTER/VNIR onboard Terra satellite is shown in Figure 2
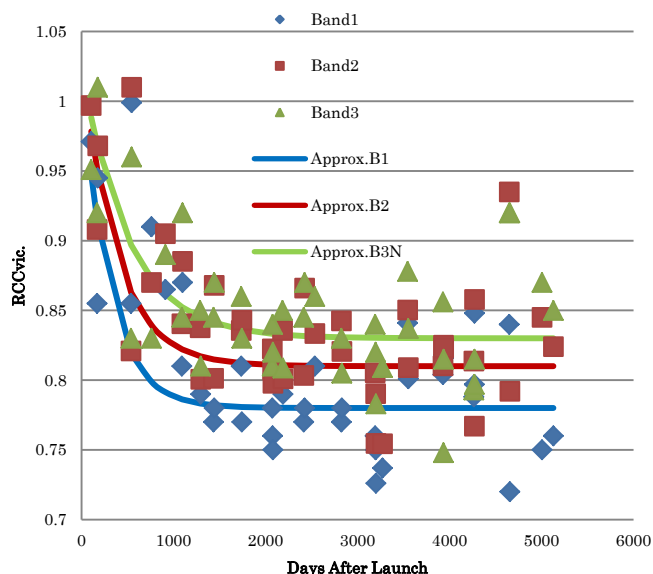

Fig. 2. Vicarious calibration data of ASTER/VNIR onboard Terra satellite

ASTER/VNIR onboard Terra satellite was launched in December 1999. This is approximately 15 years data. Solid lines are approximated function with the single exponential function. It is clear that vicarious calibration data are scattered because there are many data which are influenced by the smoke due to wild fire, exhausted gasses from automobile, cirrus, etc. VNIR has three spectral bands, 1 to 3 which are corresponding to green, red and near infrared bands.

Table 2 shows the coefficients of the approximation function of vicarious calibration data as a function of days after launch, x.

TABLE II. COEFFICIENTS OF THE APPROXIMATION FUNCTION OF VICARIOUS CALIBRATION DATA AS A FUNCTION OF DAYS AFTER LAUNCH, X

y = b0 * exp(-b1 * x) + b2	Band1	Band2	Band3
b0	0.2374657	0.2227815	0.194918
b1	0.0033325	0.0026667	0.0019807
b2	0.7551861	0.83	0.8468567

The difference between vicarious calibration data and the approximated vicarious calibration data is shown in Table 3 while uncertainty of vicarious calibration data defined in equation (1) is shown in Table 4, respectively.

TABLE III. DIFFERENCE BETWEEN VICARIOUS CALIBRATION DATA AND THE APPROXIMATED VICARIOUS CALIBRATION DATA

Band1	Band2	Band3
0.161	0.071	0.071

TABLE IV. UNCERTAINTY OF VICARIOUS CALIBRATION DATA DEFINED IN EQUATION (1)

Band1	Band2	Band3
0.0101579	0.0067297	0.0067447

B. Vicarious Calibration Data After the Screening

Figure 3 shows the vicarious calibration data trend after the screening.
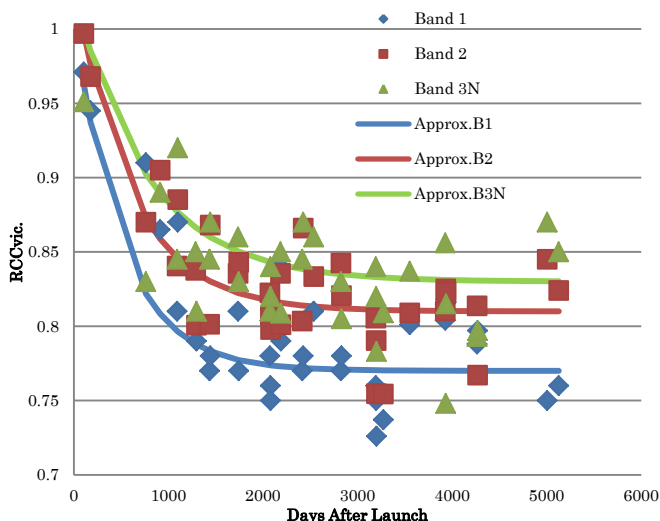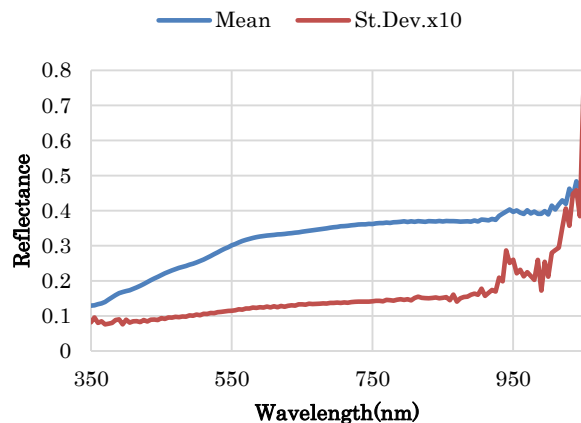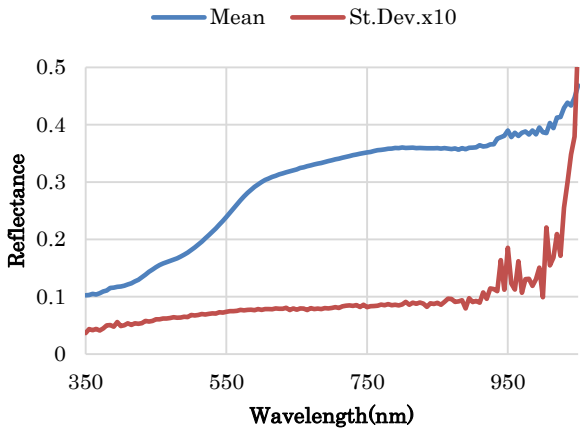

Fig. 3. Vicarious calibration data trend after the screening

One of the examples of the measured surface reflectance for test site of Railroad Valley Playa in Nevada, USA which is acquired on 25 September 2015 is shown in Figure 4 while one if examples of the measured surface reflectance without screening of the test site Ivanpah Playa in California, USA which is acquired on 18 September 2015 is shown in Figure 4 (b), respectively.

(a)Railroad Valley Playa

(b)Ivanpah Playa

Fig. 4.   Measured surface reflectance at the test sites

As shown in Figure 4, the measured surface reflectance between Ivanpah and Railroad Valley Playas are almost same while standard deviation of surface reflectance is quite different (standard deviation of Ivanpah playa is approximately 50% greater than that of Railroad Valley playa). Figure 5 (a) shows ASTER/VNIR image of Ivanpah playa while Figure 5 (b) shows that of Railroad Valley playa. Meanwhile, Figure 5 (c) shows ASTER/TIR image of Railroad Valley playa which shows the suspected existing cirrus. Although cirrus clouds cannot be seen in the ASTER/VNIR image of Railroad Valley playa, ASTER/TIR image shows existing of cirrus clouds almost all over the test site area. During the surface reflectance measurement, solar irradiance is changed a lot due to the existing cirrus. Therefore, the standard deviation of the measured surface reflectance is 50% much greater than that of Ivanpah playa. We would better to omit such unreliable vicarious calibration data.
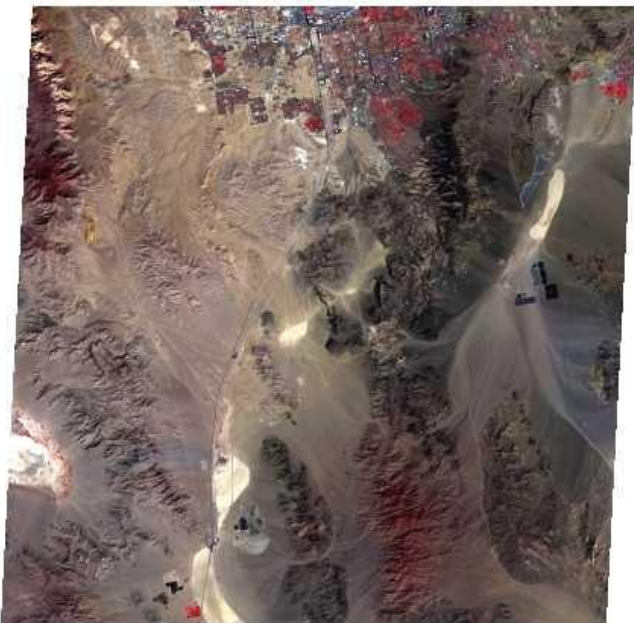

(b)VNIR image of Railroad Valley

(c)TIR image of Railroad Valley

Fig. 5.   ASTER/VNIR and TIR images of Ivanpah and Railroad Valley playas

Table 5 shows the coefficients of the approximation function of vicarious calibration data after the screening as a function of days after launch, x.

(a)VNIR image of Ivanpah

TABLE V.   COEFFICIENTS OF THE APPROXIMATION FUNCTION OF VICARIOUS CALIBRATION DATA AFTER THE SCREENING AS A FUNCTION OF DAYS AFTER LAUNCH, X

$y = b0 * \exp(-b1 * x) + b2$	Band1	Band2	Band3
b0	0.2374657	0.2227815	0.194918
b1	0.002	0.0016667	0.0013
b2	0.77	0.81	0.83

The difference between vicarious calibration data and the approximated vicarious calibration data is shown in Table 6 while uncertainty of vicarious calibration data defined in equation (1) is shown in Table 7, respectively.

TABLE VI.   DIFFERENCE BETWEEN VICARIOUS CALIBRATION DATA AND THE APPROXIMATED VICARIOUS CALIBRATION DATA

Band1	Band2	Band3
0.040	0.024	0.036

TABLE VII.   UNCERTAINTY OF VICARIOUS CALIBRATION DATA DEFINED IN EQUATION (1)

Band1	Band2	Band3
0.0061288	0.0047501	0.0058725

It is found that uncertainty of vicarious calibration can be improved remarkably in particular for Band 1.

C. Error Budget Analysis of Cross Calibration

MISR and MODIS sensors are onboard Terra satellite as well. The spectral coverage of MISR and MODIS are overlapped with ASTER/VNIR. Therefore, cross calibration can be done for VNIR and MISR (VNIR Band 1, 2, 3) and VNIR and MODIS (VNIR Band 2 and 3). Due to the fact that MODIS does not have the corresponding band for VNIR Band 1, cross calibration cannot be done. The results from error budget analysis are shown in Table 8. In the proposed cross calibration, it is conducted at the same dates for field campaigns because the vicarious calibration data can be used for cross calibration.

TABLE VIII.   ERROR BUDGET FOR CROSS CALIBRATION

Error items	Error sources	Error (%)
Uncertainty of the instruments for comparison	MISR,MODIS	4.06
Registration	Uniformity of the surface reflectance	2
Spectral response	Surface reflectance	1.5
	Atmospheric effect	1
RSS		4.87

D. Cross Calibration Results with MISR

Figure 6 shows the cross calibration data trend derived RCC (RCCcross) with MISR. It is possible to approximate with the same function of the single exponential function as a function of days after launch, x. The coefficients of the approximation function are shown in Table 9 while the difference between cross calibration data and the approximated data are shown in Table 10. Uncertainty defined as equation (1) for cross calibration with MISR is shown in Table 11. In comparison to the uncertainty of the vicarious calibration, cross calibration accuracy is not better than vicarious calibration obviously. It, however, is useful to find the biases between ASTER/VNIR and MISR.
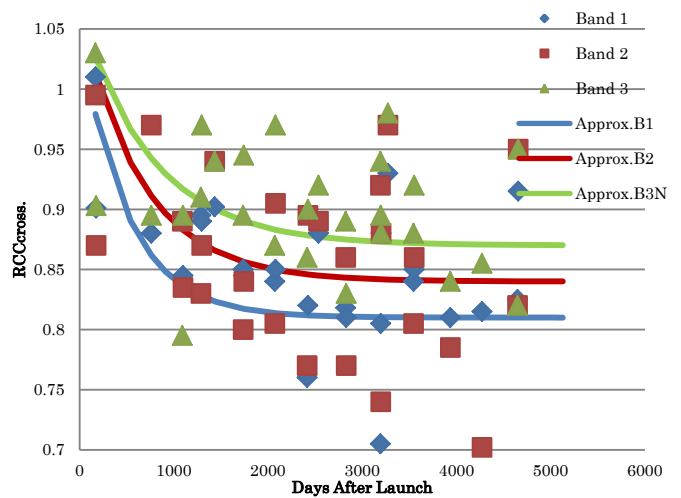

Fig. 6.   Cross calibration data of ASTER/VNIR with MISR onboard Terra satellite

TABLE IX.   COEFFICIENTS OF THE APPROXIMATION FUNCTION OF CROSS CALIBRATION DATA AFTER THE SCREENING AS A FUNCTION OF DAYS AFTER LAUNCH, X

$y = b0 * exp(-b1 * x) + b2$	Band1	Band2	Band3
b0	0.2374657	0.2227815	0.194918
b1	0.002	0.0015	0.0013
b2	0.81	0.84	0.87

TABLE X.   DIFFERENCE BETWEEN CROSS CALIBRATION DATA AND THE APPROXIMATED VICARIOUS CALIBRATION DATA

Band1	Band2	Band3
8.985	9.844	10.508

TABLE XI.   UNCERTAINTY OF CROSS CALIBRATION DATA DEFINED IN EQUATION (1)

Band1	Band2	Band3
0.0759393	0.0794899	0.0821237

E. Cross Calibration Results with MODIS

Figure 7 shows the cross calibration data trend derived RCC (RCCcross) with MODIS. It is possible to approximate with the same function of the single exponential function as a function of days after launch, x. The coefficients of the approximation function are shown in Table 12 while the difference between cross calibration data and the approximated data are shown in Table 13. Uncertainty defined as equation (1) for cross calibration with MODIS is shown in Table 14. In comparison to the uncertainty of the vicarious calibration, cross calibration accuracy is not better than vicarious calibration obviously. It, however, is useful to find the biases between ASTER/VNIR and MODIS.
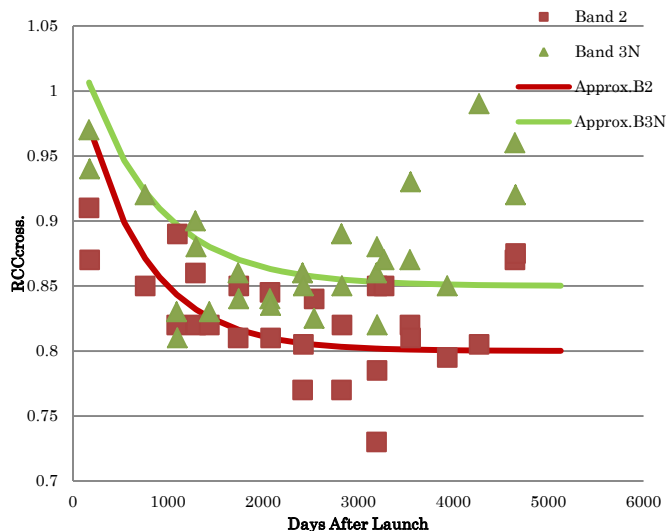
Fig. 7.   Cross calibration data of ASTER/VNIR with MODIS onboard Terra satellite

TABLE XII.   COEFFICIENTS OF THE APPROXIMATION FUNCTION OF CROSS CALIBRATION DATA AFTER THE SCREENING AS A FUNCTION OF DAYS AFTER LAUNCH, X

y = b0 * exp(-b1 * x) + b2	Band1	Band2	Band3
b0	-	0.222781456	0.194918032
b1	-	0.0015	0.0013
b2	-	0.8	0.85

TABLE XIII.   DIFFERENCE BETWEEN CROSS CALIBRATION DATA AND THE APPROXIMATED VICARIOUS CALIBRATION DATA

Band1	Band2	Band3
-	8.884	10.035

TABLE XIV.   UNCERTAINTY OF CROSS CALIBRATION DATA DEFINED IN EQUATION (1)

Band1	Band2	Band3
0	0.075513481	0.080253544

As the results from the uncertainty evaluations of the cross calibration between ASTER/VNIR and MISR as well as MODIS, it is almost same between cross calibrations of ASTER/VNIR and MISR as well as MODIS. It is also found that the uncertainty of cross calibration is poorer than that of vicarious calibration.

IV.   CONCLUSION

Vicarious calibration data screening method based on the measured atmospheric optical depth and the variance of the measured surface reflectance at the test sites is proposed. Reliability of the various calibration data has to be improved. In order to improve the reliability of the vicarious calibration data, screening has to be made. Through experimental study, it is found that vicarious calibration data screening would be better to apply with the measured atmospheric optical depth

and variance of the measured surface reflectance due to the facts that thick atmospheric optical depth means that the atmosphere contains serious pollution sometime and that large deviation of surface reflectance from the average means that the solar irradiance has influence due to cirrus type of clouds. As the results of the screening, the uncertainty of vicarious calibration data from the approximated radiometric calibration coefficient is remarkably improved. Also, it is found that cross calibration uncertainty is poorer than that of vicarious calibration.

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