Comparison Among Cross, Onboard and Vicarious Calibrations for Terra/ASTER/VNIR

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***Abstract*—Comparative study on radiometric calibration methods among onboard, cross and vicarious calibration for visible to near infrared radiometers onboard satellites is conducted. The data sources of the aforementioned three calibration methods are different and independent. Therefore, it may say that the reliable Radiometric Calibration Accuracy: RCC would be the RCC which are resemble each other two of three RCCs. As experimental results, it is found that vicarious and cross calibration are reliable than onboard calibration. Also vicarious calibration based cross calibration method is proposed here. The proposed cross calibration method should be superior to the conventional cross calibration method based on band-to-band data comparison. Through experiments, it is also found that the proposed cross calibration is better than the conventional cross calibration. The radiometric calibration accuracy of the conventional cross calibration method can be evaluated by using the proposed cross calibration method.**

Keywords—vicarious calibration; cross calibration; visible to near infrared radiometer; earth observation satellite; remote sensing; radiative transfer equation

I. INTRODUCTION

There are many previous research works on calibration of solar reflective wavelength coverage of mission instruments onboard remote sensing satellites [1]-[17]. It is obvious that onboard calibration sources are degraded for time being (Dinguirard and Slater (1999)). Not only radiometer, but also onboard calibration system is degraded together with calibration system monitoring systems. There are onboard, cross and vicarious calibrations. These calibrations use the different data sources. Therefore, Radiometric Calibration Coefficient: RCC for one of three calibration methods can be checked with the other calibration methods. Thus much reliable RCC would be obtained.

Usually, the conventional cross calibration can be done through comparisons of band-to-band data of which spectral response functions are overlapped mostly. There are the following major error sources due to observation time difference, spectral response function difference in conjunction of spectral surface reflectance and spectral atmospheric optical depth, observation area difference. These error sources are assessed with dataset acquired through ground measurements of spectral surface reflectance and spectral optical depth. Then the accuracy of the conventional cross calibration is evaluated with vicarious calibration data.

Several researchers investigated cross calibration. Teillet, Fedosejevs, Thome, and Barker (2007) investigated impact of spectral response difference effect between sensors as quantitative indication using simulated data of observation [19]. The effect is called SBDE (Spectral Band Difference Effect) in this research. Twenty sensors were considered in the simulation together with some ground types, various combinations of atmospheric states and illumination geometries. They argued, overall, if spectral band difference effects (SBDEs) are not taken into account, the Railroad Valley Playa site is a ’good ’ground target for cross calibration between most but not all satellite sensors in most but not all spectral regions investigated. ’Good ’is denoted as SBDEs within 3%.

Liu, Li, Qiao, Liu, and Zhang (2004) developed a new method for cross calibration, and then applied the method to sensors Multi-channel Visible Infrared Scanning radiometers (MVIRS) and Moderate Resolution Imaging Spectro-radiometer (MODIS) [18]. They argued, “'Error analysis indicates that the calibration is accurate to within 5%, which is comparable to, or better than, the vicarious calibration method".

The method considers surface bidirectional reflectance distribution function (BRDF) mainly. BRDF indicates distribution of angle of reflection depend on an angle of incidence of illumination on the surface. In these researches, differences of SRF do not be considered. If the impact of its difference can be considered on cross calibration, differences between observed data can be explained more exactly and we can implement cross calibration by higher reliability.

ASTER/VNIR is onboard Terra satellite and is calibrated with onboard calibration sources [20], vicarious calibration data as well as cross calibration. MODIS is onboard same platform and is calibrated with the aforementioned several types of data [21]. This situation is same thing for MISR [22] and ETM+ onboard the different platform, Landsat-7 [23].

The method proposed here is to check a reliability of the calibration sources through vicarious and cross calibrations for validations of these calibration accuracies. Namely, vicarious calibration requires spectral surface reflectance measurements and spectral optical thickness measurements. By using these ground based acquired data, cross calibration is conducted to improve a reliability of the calibration sources through comparison of vicarious calibration data. The results show that cross calibration accuracy can be done much more precisely if the influences due to the aforementioned three major error sources are taken into account.

II. Proposed Method

A. *Cross Calibration*

The mission instrument in concern is VNIR: Visible to Near Infrared Radiometer of ASTER: Advanced Spectrometer for Thermal Emission and Reflectance onboard Terra satellite. Other instruments of which wavelength coverage are overlapped are onboard the same Terra satellite. Namely, the wavelength coverage of MODIS and MISR are overlapped with ASTER/VNIR. The wavelength coverage of these mission instruments are shown in Table 1 together with IFOV: Instantaneous Field of View.

Other than these, the wavelength coverage of ETM+ onboard Landsat-5 is also overlapped with that of ASTER/VNIR. Therefore, cross calibration can be done between ASTER/VNIR and MODIS, MISR, ETM+. In MISR, these wavelengths are center wavelength of band. MISR bandwidth in Green, Red, and NIR are 0.028, 0.022, 0.039 *micrometer*, respectively.

TABLE I. Major Specification of Four Radiometers in Concern for Cross Calibration Between ASTER/VNIR and the other threee Radiometrs

	ASTER (15m/px)	MISR (275m/px)	MODIS (250m/px)	ETM+ (30m/px)
Green	0.52 - 0.60 (band1)	0.558	none	0.52 - 0.60 (band2)
Red	0.63 - 0.69 (band2)	0.672	0.62 - 0.67 (band1)	0.63 - 0.69 (band3)
NIR	0.76 - 0.86 (band3N)	0.867	0.84 - 0.87 (band2)	0.75 - 0.90 (band4)

B. *Vicarious Calibration*

Vicarious calibration coefficients, on the other hand, is defined as the difference between ASTER/VNIR pixel value derived radiance and the estimated radiance derived from the radiative transfer equation with the input parameters of surface reflectance measured on the ground, refractive index and size distribution estimated with atmospheric optical depths measured on the ground at the several wavelengths for aerosol scattering and absorption, and Rayleigh scattering derived from measured atmospheric pressure. Therefore, vicarious calibration coefficients are essentially absolute values.

Figure 1 shows flowchart of the vicarious calibration.

C. *Onboard Calibration*

ASTER VNIR use lamp-based onboard calibrators for monitoring temporal changes in the sensor responses. Space restrictions aboard the Terra platform disallow a solar based calibration, and therefore, onboard calibration is lamp-based. VNIR has two onboard calibration lamps, lamp-A and lamp-B. Both are used periodically, and as a backup system.

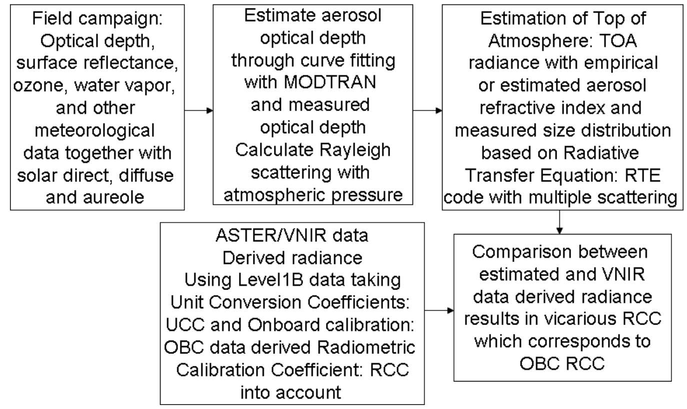


Fig. 1. Flowchart of the vicarious calibration

The VNIR calibration lamp output is monitored by a silicon photo monitor, and is guided to the calibration optics. The calibration optics output illuminates a portion of the VNIR aperture's observation optics and is monitored by a similar photo monitor. In the pre-flight phase, the onboard calibrators were well characterized with integration spheres calibrated with fixed freezing point blackbodies of Zn (419.5K). This was accomplished by comparing VNIR output derived from the integration sphere's illumination of the two sensors. The same comparison was made by the calibration lamp's (A and B) illumination of the two sensors. Next, the pre-flight gain and offset data (no illumination) were determined. In addition, MTF: Modulation Transfer Function was measured with slit light from a collimator while stray light effect was measured with the integration sphere illumination, which is blocked at the full aperture of the VNIR observation optics entrance. The pre-flight calibration data also includes (1) spectral response, (2) out-of-band response.

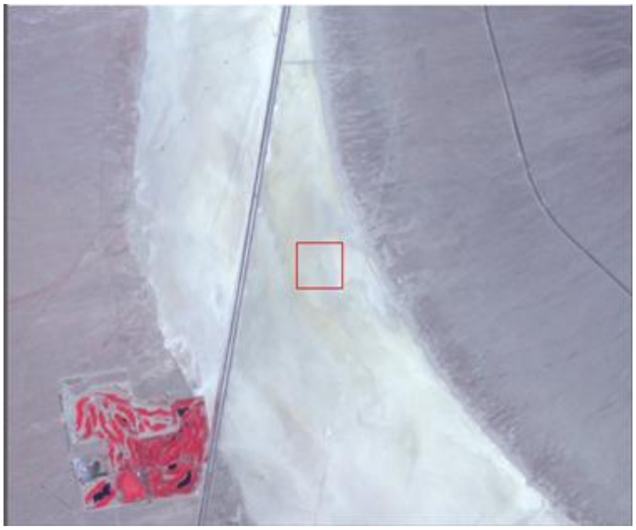
The VNIR has two onboard calibration halogen lamps (A and B). The light from these lamps is led to the VNIR optics via a set of calibration optics. Filters and photomonitors are located fore and aft of the calibration optics to monitor the output of the lamps as well as any possible degradation in the calibration optics. Lamp output and photo monitor data are collected every 33 days (primarily it was 16 days of the Terra orbital revisit cycle plus one day = 17 days and is 49 days now a day), and RCC: Radiometric Calibration Coefficients are calculated from the VNIR output taking into account the photo-monitor output. The RCC values are normalized by the pre-flight data to determine their final estimate. Thus, only data from a photo monitor that is aft of the calibration lamp is taken into account.

III. Experiments

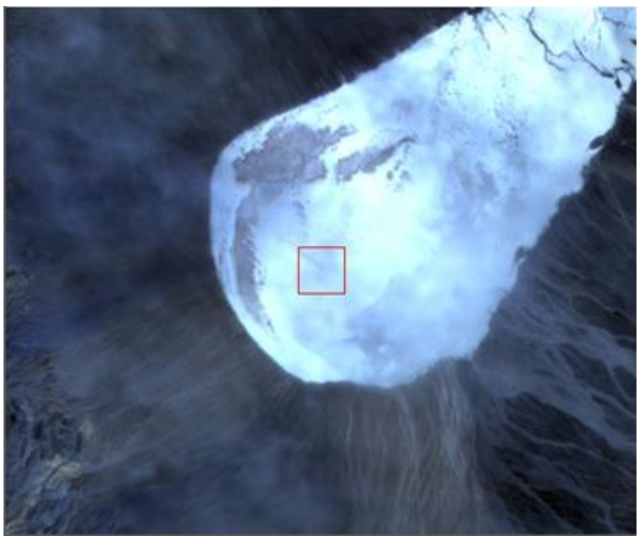
A. *Field Experiments Conducted*

Field campaigns are conducted at the following there test sites,

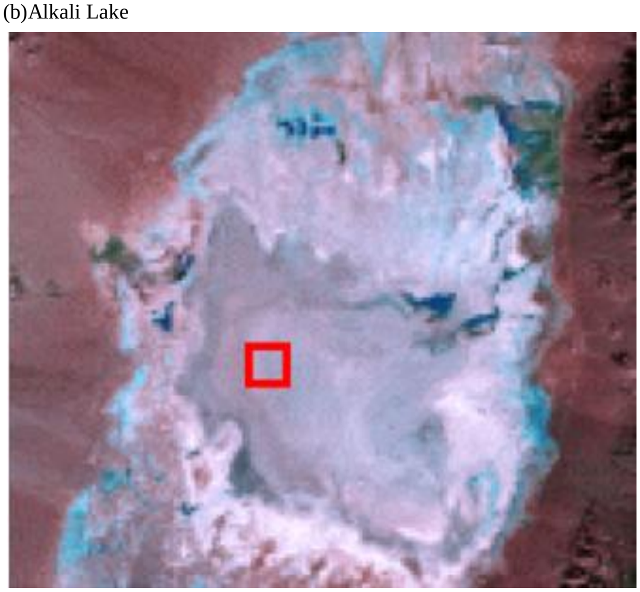
IV: Ivanpah Playa (35:34N, 115:24W, 790m), California
AL: Alkali Lake (37:51N, 117:25W, 1463m), Nevada
RV: Railroad Valley Playa (38:30N, 115:41N, 1440m) Nevada



(a)Ivanpah Playa



(b)Alkali Lake



(c)Railroad Valley Playa

Fig. 2. Satellite view of three test sites

Figure 2 shows Terra/ASTER/VNIR observed three test-sites images. The red squares show the test-sites locations.

Table 2 shows the dates of the field campaigns. Target pixel can be identified through visual perception of blue tarp on the test sites. Thus the test site locations are precisely identified with good registration accuracy.

TABLE II. THE DATES OF THE FIELD CAMPAIGNS

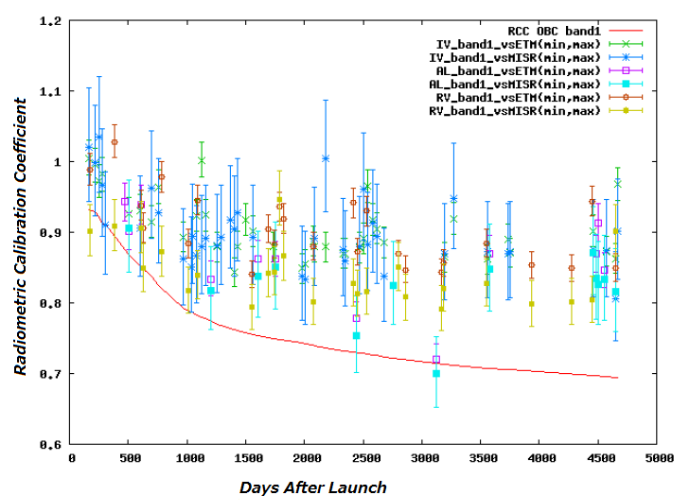
IV	AL	RV
0905 06/10/2002	2159 12/16/2005	2415 07/30/2006
2184 12/11/2005	2829 09/17/2007	3199 09/21/2008
2424 08/08/2006	3197 09/19/2008	3551 09/08/2009
2536 11/28/2006	3549 09/06/2009	3935 09/27/2010
2824 09/12/2007	3935 09/25/2010	4272 08/29/2011
3192 09/14/2008	4270 08/27/2011	4656 09/16/2012
3727 12/03/2008		
3544 09/01/2009		
3928 09/20/2010		
4265 08/22/2011		
4649 09/09/2012		

The first column shows the days after launch

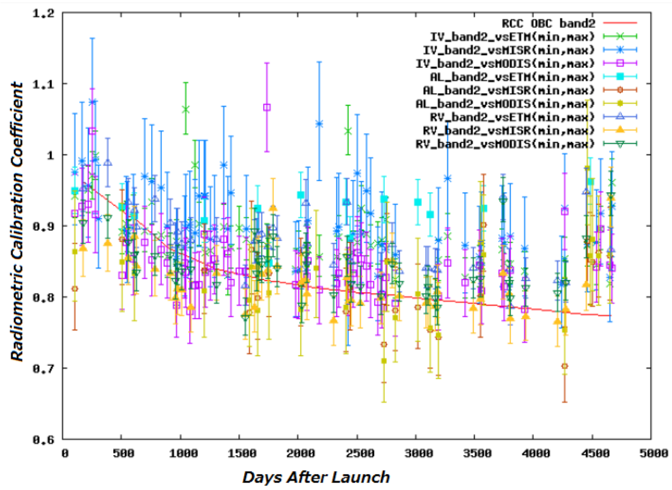
B. *Radiometric Calibration Coefficient Comparisons*

Figure 3 shows the Radiometric Calibration Coefficient: RCC of the onboard, vicarious and cross calibration. Red solid line in the figure shows RCC derived from Onboard Calibration: OBC data. OBC data derived RCC differs from both the conventional and the proposed cross calibration RCC.

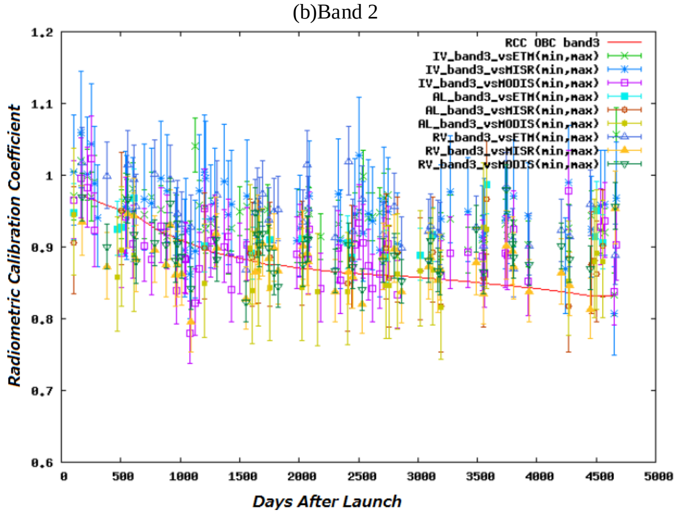
These cross calibration coefficients are summarized with their averaged RCC and Standard Deviation: SD together with their Confidence Interval: CI at 95% of confidence level as shown in Table 3. As shown in Table 4, RMSD between the vicarious RCC and the proposed cross calibration RCC is less than that between the vicarious RCC and the cross calibration RCC.



(a)Band1



(b)Band 2



(c)Band 3

Fig. 3. Comparison of RCC among onboard, vicarious and cross calibration

TABLE III. SUUMARY OF CROSS CALIBRATION COEFFICIENTS

(a)Cross RCC for Green and Red bands

		Green		Red		
		vsETM	vsMISR	vsETM	vsMISR	vsMODIS
IV	average (SD)	1.80 (0.54)	1.38 (0.45)	0.03 (0.15)	3.33 (0.90)	1.15 (1.33)
	95% CI	[1.38, 2.24]	[1.02, 1.74]	[-0.09, 0.15]	[2.61, 4.04]	[0.09, 2.21]
AL	average (SD)	1.41 (0.69)	1.46 (0.58)	-0.05 (0.16)	2.47 (1.02)	2.26 (0.72)
	95% CI	[0.52, 2.31]	[0.72, 2.21]	[-0.26, 0.15]	[1.16, 3.79]	[1.33, 3.19]
RV	average (SD)	0.88 (0.11)	2.34 (0.20)	-0.08 (0.12)	2.23 (0.28)	2.12 (0.29)
	95% CI	[0.74, 1.02]	[2.09, 2.60]	[-0.23, 0.07]	[1.87, 2.59]	[1.75, 2.50]

(b)Cross RCC for NIR band

		NIR		
		vsETM	vsMISR	vsMODIS
IV (N=11)	average (SD)	-1.81 (1.14)	-6.71 (1.83)	-5.09 (1.76)
	95% CI	[-2.72, -0.90]	[-8.17, -5.25]	[-6.49, -3.69]
AL (N=6)	average (SD)	-2.80 (0.97)	-8.94 (1.62)	-7.37 (1.41)
	95% CI	[-4.06, -1.55]	[-11.04, -6.85]	[-9.19, -5.54]
RV (N=6)	average (SD)	-2.67 (0.33)	-7.96 (1.37)	-6.65 (1.14)
	95% CI	[-3.10, -2.24]	[-9.72, -6.19]	[-8.12, -5.18]

Therefore, it is said that the proposed cross calibration method is superior to the conventional cross calibration method obviously. Percent difference of RMSD between the conventional and the proposed cross calibration is shown in Table 5. It may said that the proposed cross calibration method shows 6 to 89% better cross calibration accuracy in comparison to the conventional cross calibration.

TABLE IV. AVERAGED ROOT MEAN SQUARE DIFFERENCE BETWEEN VICARIOUS CALIBRATION RCC AND CROSS CALIBRATION RCC

	Conventional			Proposed		
Site	ETM+	MISR	MODIS	ETM+	MISR	MODIS
Ivanpah	0.0733	0.0798	0.0338	0.0690	0.0645	0.0169
Alkali	0.0280	0.0625	-	0.00312	0.0387	-
Railroad	0.0889	0.0194	0.0619	0.0807	0.0031	0.0346

TABLE V. PERCENT DIFFERENCE OF RMSD BETWEEN CONVENTIONAL AND PROPOSED CROSS RCC

	% Difference between Conventional and Proposed Cross RCC		
Site	ETM+	MISR	MODIS
Ivanpah	5.866	19.173	50.000
Alkali	88.857	38.080	-
Railroad	9.224	84.021	44.103

IV. CONCLUSION

Accuracy evaluation of cross calibration through band-to-band data comparison for visible and near infrared radiometers which onboard earth observation satellites is conducted. The conventional cross calibration for visible to near infrared radiometers onboard earth observation satellites is conducted through comparisons of band-to-band data of which spectral response functions are overlapped mostly.

There are the following major error sources due to observation time difference, spectral response function difference in conjunction of surface reflectance and atmospheric optical depth, observation area difference. These error sources are assessed with dataset acquired through ground measurements of surface reflectance and optical depth. Then the accuracy of the conventional cross calibration is evaluated with vicarious calibration data. The results show that cross calibration accuracy can be done more precisely if the influences due to the aforementioned three major error sources are taken into account.

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