RADIOMETRIC CALIBRATION COEFFICIENTS OF WATER-BODY FOR “HJ-1” SATELLITE MULTI-SPECTRAL CCD SENSORS BY CROSS-CALIBRATION BASED METHOD

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ABSTRACT: In this paper, the four visible and near-infrared spectral bands of HJ-1/CCD1, HJ-1A/CCD2, HJ-1B/CCD1 and HJ-1B/CCD2 were calibrated respectively using cross-calibration methods based on the EOS/MODIS. The latter has the high radiation precision, and simultaneously passed through the South China Sea. The radiometric calibration coefficients of water-body targets for “HJ-1” satellite multispectral CCD sensors were obtained and validated. The results showed that (1) there were a larger difference in cross-calibration coefficients on all bands of the four sensors of the CCD camera in HJ-1A/B, in which the cross-calibration coefficients on band 1 and 2 (blue and green bands) were relatively stable, while the calibration coefficients on band 3 and 4 (red and near-infrared band) appear obvious difference.(2) by comparison of the water-leaving radiance between the inversion of cross-radiometric calibration coefficients in this paper with the inversion of the absolutely radiometric calibration coefficients which were obtained in DunHuang land radiometric calibration field in China, it was found that the water-leaving radiance of the latter were much larger than the former, which indicates that the high reflectivity of the land field led to a higher water-leaving radiance from inversion. Therefore we recommend that on the research of water quality in quantitative remote sensing be very cautious by using the absolutely radiometric calibration coefficients from the land calibration field.

1. INTRODUCTION

In the use of satellite sensor data, the sensor calibration coefficient are essential, it is the basis of quantitative remote sensing, especially for quantitative ocean color remote sensing. Satellite sensor calibration generally requires two steps: pre-launch calibration and in-orbit calibration. Pre-launch calibration of sensor has two methods: one is in the laboratory using a standard source to calibrate the sensor response; the other is the field calibration, which is a method solving errors caused by the large differences between the light sources indoor and outdoor. Sensor in-orbit calibration is divided into: calibration of the onboard calibration system of the full aperture and full optical path Based on the sun / moon; external in-orbit calibration (instead of calibration); cross-calibration. The Onboard calibration system based on the Sun is to use the whole light path of sensors to observe the diffuse reflector whose reflectivity is known, and this diffuse reflector is irradiated by sun light directly. The Onboard calibration system based on the moon is to calibrate the devices by using the stable surface of the moon as a standard. External orbit calibration (substitutive calibration) is to obtain the satellite pupil radiance by using a large-area and symmetrical target and combining radiative transfer calculation on the basis of accurate measurement of surface features and atmospheric properties, thereby, calibration coefficient is obtained; Our radiometric calibration fields (DunHuang and QingHai Lake) are basically using this method[1-2]. Cross-Calibration is to calibrate a sensor by using a set of known remote sensor data of high-precision, the present methods of the cross-calibration are mainly these two[3-4]: (1) based on the remote sensor total pupil radiance ; (2) based on Water Leaving Radiance.

At home and abroad there have been some successful cross-calibration cases by using different sensors, for example Wang and Franz used SeaWiFS to cross-calibrate the India’s MOS/IRS-P3 (modular optoelectronic scanner) [5]. Hu and Frankused SeaWiFS/MODIS to cross-calibrate ETM+/LANDSAT-7[6].Pan t al. used SeaWiFS to cross-calibrate COCTS/HY-1A [7]. Tang et al. applied MODIS of high-precision to conduct the cross-calibration research on the CCD cameras of CBERS-02 associated with the water body target[8]. Yang et al. also conducted researches on the cross-calibration of the corresponding band between the CCD cameras of CBERS-01 and ETM+/LANDSAT, which provided a set of reference calibration coefficient[9]. Rong et al. did a relative calibration experiment by using observation data from relatively accurate NOAA(16,17) satellite's infrared channel(channel 4) and observation data from FY-2B's infrared channel[10]. Through these efforts the calibration coefficients of high precision are obtained, which makes the inter-sensor relative calibration one of the methods to improve the accuracy of sensors, and which is more and more widely applied.

The satellites environment A & B (HJ-1A/1B) was successfully launched on September 6, 2008, each HJ-1A and HJ-1B were loaded with two CCD cameras of exactly the same designed principle, which are 4-band wide-cover multi-spectral visible light camera CCD. Table 1 shows the technical parameters of the CCD on HJ-1A and 1B. HJ-1A and HJ-1B are not color satellite, but the CCD cameras still has some information of water, which may serve as a water color remote sensing device of environment [11].

Table 1 Technical parameters for and multi-spectral CCD sensors with wide coverage

Item		Performance
Nadir ground pixel resolution(m)		30
Band set(μm)	B1	0.43~0.52
	B2	0.52~0.60
	B3	0.63~0.69
	B4	0.76~0.90
Quantified value(bit)		8

In this paper, nearly 10 images of HJ-1A/CCD1,HJ-1A/CCD2,HJ-1B/CCD1,HJ-1B/CCD2 data and simultaneously transiting EOS/AQUA/MODIS are applied; cross-calibration method based on remote sensing total pupil radiance is adopted to obtain the radiometric calibration parameters adequate to water body target and to provide reference for HJ-1's application on water body, obtaining accurate water leaving radiance and further inversion of water quality parameters information.

2. CALIBRATION PRINCIPLE AND CALIBRATION AREA SELECTION

2.1 Calibration principle

When neglecting multiple scattering effects of atmospheric particles, and the reflected radiation from the bottom of water body ,and surface foam or "white hat" radiation , the total amount of water body radiation received by the CCD sensor of HJ-1 satellite can be expressed as follows[1],

$L_t(\lambda)= L_r(\lambda)+ L_a(\lambda) + t_0(\lambda,\theta_0) L_w(\lambda)$ (1)

Where λ is wavelength in um; $L_t(\lambda)$ is the radiance in wavelength λ detected by satellite ($Wm^{-2}um^{-1}sr^{-1}$); $L_r(\lambda)$ is the radiance of Rayleigh scattering of air molecules ($Wm^{-2}um^{-1}sr^{-1}$),$L_w(\lambda)$ is water leaving radiance ($Wm^{-2}um^{-1}sr^{-1}$), water leaving radiance is solar radiation scattered by surface water, not ocean spontaneous emission, so there is no need to be multiplied by the emission ratio,$t_0(\lambda,\theta_0)$ is the atmosphere diffuse transmittance at the direction of the sun (dimensionless); θ_0 is the solar zenith angle, θ_v is the sensor zenith angle.

Lwn is normalized water leaving radiance ($Wm^{-2}um^{-1}sr^{-1}$), which is the water leaving radiance neglecting the atmospheric influence, so it is comparable. The relationship between the water leaving radiance on surface Lw and the normalized water leaving radiance is:

$L_w= L_{wn}/(t_d(\lambda,\theta_v)*\cos(\theta_0))$ (2)

In formula (1), if the Rayleigh scattering $L_{r,}$ the Aerosol scattering L_a, the transmittance of atmospheric Diffuse scattering t_0 and the water leaving radiance are known, when the satellites are transiting, the detective radiance of HJ-1 can be simulated.

Relative radiometric calibration is to substitute the normalized radiance value provided by MODIS as the normalized water leaving radiance of the corresponding bands of HJ-1 into formula (2) to figure out the corresponding water leaving radiance L_w, and then to work out the Rayleigh scattering L_r, the Aerosol scattering La, the transmittance of atmospheric Diffuse scattering t_0, according to the observation geometry between sensors and the sun, the ozone concentration, the Aerosol concentration and the atmospheric pressure when the satellites transit, then the simulated HJ-1's radiance values are obtained from formula (1).

2.2Calculation of the transmittance of atmospheric diffuse scattering

t_0's calculation formula is,

$t_0=\exp[-(\tau_r/2+\tau_{oz})/\cos\theta_0]t_a$ (3)

in this formular θ_0 is SZA(solar zenith angle), $t_a=\exp[(1-w_a f_a)\tau a/\cos_\theta]$,because of forward-scattered rate of aerosol fa-1,unless strong absorbing condition, the single-scattered albedo of aerosol: $w_a \to 1$, thus $t_a \to 1$.That is, one has known the SZA is θ_0, and then find out the Rayleigh optical thickness τ_r and Ozone optical thickness t_0, one can find out the atmospheric diffuse scattering transmittance t_0.

τ_r 's formula is as follows,

$\tau_r(\lambda,z)=(P(z)/P_0)\ \tau_{r0}(\lambda)$ (4)

Where P_0 is sea level's normal atmosphere, P_0=1013.$_{25mb}$; P(z) is the atmospheric pressure at the height of Z.

$\tau_{r0}(\lambda)=0.008569\lambda^{-4}(1+0.0113\lambda^{-2}+0.00013\lambda^{-4})$ (5)

τ_{oz} 's formula is as follows:

$\tau_{oz}=a_{oz}U_{oz}$ (6)

In this formula, a_{oz} is ozone's unit absorptions (cm^{-1}), U_{oz} is ozone concentration (cm)

2.3 Rayleigh's scattering calculation

L_r 's unit scattering formula is as follows:

$L_r(\theta_v,\varphi_v,\theta_0,\varphi_0)=(F_0'\omega_0\tau_r)/\cos\theta_v\ (P_r(\alpha-)+[\rho(\theta_v)+\ \rho(\theta_0)]\ P_r(\alpha+))$ (7)

Where τ_r is air molecule's scattering optical thickness, which is calculated from formula (4). + stands for the transmission from atmosphere to sea level, and then to the scanning direction.;"-" stands for the direction transmit from atmosphere to scanner directly. Pr(α-)is atmospheric backward scattering index, while $P_r(\alpha+)$ is atmospheric forward scattering index. $\rho(\theta_v)$ and $\rho(\theta_0)$ are zenith angle directed at satellite and solar zenith angle's meter reflectance respectively. $[\rho(\theta)+\ \rho(\theta_0)]$ Pr(α+) means that atmosphere scatter forwardly to the sea level, then there is the contribution of scattering to scanner after reflection. In the wave band where avoids absorbing H_2 O and O_2, there is $\omega_0=1$.

$P_r(\alpha\pm)$'s formula is as follows,

$P_r(\alpha\pm)=(3/16\pi)(1+\cos^2(\alpha\pm))$ (8)

cos(α±)'s formula is as follows:

$\cos(\alpha\pm)=\pm\cos\theta\cos\theta_0-\sin\theta\sin\theta_0\cos(\varphi-\varphi_0)$ (9)

Where, θ and φ are the zenith angle and azimuth angle respectively that is formed by vectors between the connections which corresponding pixel to remote sensor. θ_0 and φ_0, are the zenith and azimuth angle formed by the connection which correspond pixel to sun. $(\varphi-\varphi_0)$ is azimuth difference among solar satellites, which often adopts absolute value.

2.4 The calculation of aerosol scattering

L_a's unit scattering formula is [12].

$L_a(\theta_v,\varphi_v,\theta_0,\varphi_0)=(F_0'\omega_a\tau_a)/\cos\theta(P_a(\alpha-)+[\rho(\theta_v)+\ \rho(\theta_0)]\ P_a(\alpha+))$ (10)

In the formula, aerosol scattering reflectance ωa ,not include strong absorptions, $w_a=1$; τ_a is aerosol optical thickness, which is found out through the value of wave band MODIS 869nm in the study. $\rho(\theta_v)$ and $\rho(\theta_0)$ are meter reflectance aim at satellite and solar zenith angle separately. $P_a(\alpha-)$ and $P_a(\alpha+)$ are aerosol scattering function that can be calculated by TTHG which is similar with Henyey-Greenstein function.

2.5 The Choice of Cross Site Mark Region

The choice of relative site mark region requires clean water system. The Eastern Ocean, Bo Ocean and Huang Ocean in CHINA are mainly secondary water system, and only Southern Ocean includes secondary water system and part of first-class water system. Thus, being a cross site mark region, Southern Ocean would be the ideal one.

3. CALIBRATION DATA ACQUISITION AND COMPARISON ANALYSIS

3.1 The source of calibration data

Due to the return cycle of HJ-1 are 31 days and the fact that the South China Sea is mostly covered by clouds, the acquisition and the quality of data are limited; in addition to the simultaneous transiting MODIS data, each sensor only 2 images can be used for cross-calibration.

3.2 The calculation of calibration coefficients

Substituting the Rayleigh's scattering L_r, the aerosol scattering La, the transmittance of atmospheric diffuse scattering t_0 that are calculated above into formula (1), the simulated sensor pupil radiance Lt of HJ-1/CCD were obtained. The general method of calibration in ocean remote sensing is using calibration model, and the easiest calibration formula is linear formula that can easily describe the relationship of the effective sensor counts DN and sensor pupil radiance Lt as linear relationship,

$$L_t = a^* \, DN \tag{11}$$

Where a is the calibration coefficients in $DN/W \cdot m^{-2} \cdot sr^{-1} \cdot \mu m^{-1}$. The corresponding calibration coefficients of each sensor can be acquired according to formula (11), see table 2.

Table 2 Coefficients of cross-calibration coefficients for HJ-1/CCD using MODIS

Sensor name	Transit date	Band1	Band2	Band3	Band4
HJ-1A/CCD1	20081228	0.43891	0.45358	0.80456	0.44181
HJ-1A/CCD1	20090205	0.43825	0.55844	0.59491	0.85486
HJ-1A/CCD2	20090312	0.50353	0.59179	0.82355	0.47542
HJ-1A/CCD2	20090116	0.28992	0.41588	0.57093	0.39035
HJ-1B/CCD1	20081129	0.63335	0.52586	0.45696	1.07027
HJ1B-CCD1	20090611	0.17049	0.13053	0.09683	0.08181
HJ-1B/CCD2	20090417	0.44811	1.28324	3.05915	0.76829
HJ-1B/CCD2	20090526	0.43825	0.55844	0.59491	0.85486

The number in table 2 shows that the difference between the calibration coefficients from each 2 images of different sensors is large, that is in different period the radiometric calibration coefficients between the corresponding sensors are different. It has been known from the former analysis that some problems exist in the sensor detection of HJ-1's infrared band (b4), which should be one of the reasons that lead to the instability of coefficients.

3.3 Differential analysis

Applied the cross-calibration coefficients in table 2 and the absolute radiometric calibration coefficients into the HJ-1 LiaoDong Bay data of 2008 and 2009 to obtain the water leaving radiance value in each corresponding band of the 4 sensors HJ-1A/CCD1,HJ-1A/CCD2,HJ-1B/CCD1 and HJ-1B/CCD2 respectively, see table 3~6.

The 40 spectral data measured in LiaoDong Bay in May 2008 show that considering the water leaving radiance of the corresponding 4 bands of HJ-1 CCD, the water leaving radiance in this area is generally between 4-35 $Wm^{-2}um^{-1}sr^{-1}$. Generally speaking, the water leaving radiances of the corresponding 4 bands of HJ-1 CCD are respectively: b1:8-25 $Wm^{-2}um^{-1}sr^{-1}$;b2: 10-29 $Wm^{-2}um^{-1}sr^{-1}$;b3: 10-26 $Wm^{-2}um^{-1}sr^{-1}$;b4: 6-15 $Wm^{-2}um^{-1}sr^{-1}$. It can be seen in table 3~6 that for HJ1A-CCD2, the calibration coefficient on 28/12/2008 is more closely to the actual observed value, while that for HJ-1A/CCD2、HJ-1B/CCD1、HJ-1B/CCD2 are on 12/3/2009, 29/11/2008,/26/5/2009 respectively. In addition, the tables also illustrate that the water leaving radiance figured out by absolute radiometric calibration coefficients is not only much larger than that obtained from cross radiometric calibration coefficient, but also larger than the actual observed value, which shows that targets of high reflectivity in ground fields lead to the high water leaving radiance, in fact, DunHuang calibration field consists mainly of gravel whose spectral curve is different from water body target, the water leaving radiance calculated by the calibration coefficients obtained from DunHuang should be considered carefully. According to the above analysis, we initially determined that the cross-calibration radiometric coefficients of HJ-1 that can be used for reference are showed in table 7.

Table 3 the inversion of water-leaving radiance with the three coefficients of HJ-1A/CCD1

Band	B1	B2	B3	B4
Gray value	22	15	16	12
The water leaving radiance from the calibration coefficients on 28/12/2008	**9.6560**	**6.8037**	**12.8729**	**5.3017**
The water leaving radiance from the calibration coefficients on 5/2/2009	9.6415	8.3766	9.5185	10.2583
The water leaving radiance from the absolutely radiometric calibration coefficients	47.4928	36.9022	30.9538	20.7942

Table 4 the inversion of water-leaving radiance with the three coefficients of HJ-1A/CCD2

Band	B1	B2	B3	B4
Gray value	23	13	12	6
The water leaving radiance from the coefficients on 12/3/2009	**11.5811**	**7.6932**	**9.8826**	**2.8525**
The water leaving radiance from the coefficients on 16/1/2009	6.6681	5.4064	6.8511	2.3421
The water leaving radiance from the absolutely radiometric calibration coefficients	43.7210	29.0910	18.8702	8.0662

Table 5 the inversion of water-leaving radiance with the three coefficients of HJ-1B/CCD1

Band	B1	B2	B3	B4
Gray value	24	19	15	3
The water leaving radiance from the coefficients on 29/11/2008	**15.2004**	**9.9913**	**6.8544**	**3.2108**
The water leaving radiance from the coefficients on 11/6/2009	4.0917	2.4801	1.4524	0.2454
The water leaving radiance from the absolutely radiometric calibration coefficients	46.6512	39.9254	28.1187	6.9827

Table 6 the inversion of water-leaving radiance with the three coefficients of HJ-1B/CCD2

band	B1	B2	B3	B4
Gray value	26	14	15	3
The water leaving radiance from the coefficients on 17/4/2009	**11.6508**	**17.9653**	**45.8872**	**2.3048**
The water leaving radiance from the coefficients on 26/5/2009	11.3945	7.8181	8.9236	2.5646
The water leaving radiance from the absolutely radiometric calibration coefficients	48.4279	33.3980	29.9849	13.4965

Table 7 the coefficients of cross-calibration coefficients for HJ-1/CCD

Sensor name	b1	b2	b 3	b 4
HJ-1A/CCD1	0.4389	0.4536	0.8045	0.4418
HJ-1A/CCD2	0.5035	0.5918	0.8235	0.4754
HJ-1B/CCD1	0.6333	0.5258	0.4569	1.0703
HJ-1B/CCD2	0.4382	0.5584	0.5949	0.8548

4 CONCLUSION

The analysis of HJ-1 data shows that in clean waters under clear sky, the gray value at each band is very low, especially at near infrared band. No matter it is in water body case I or case II, its value is mostly 0, which shows that there is something wrong with the sensor detection at this band and relevant parties should pay attention to this and modify the following satellite sensor detection concerned.

The analysis of the calibration coefficients shows that in various periods, the radiometric calibration coefficients between the corresponding sensors are different, among which band b1 and b2 are relatively stable, while b3 and b4 are instable, which shows that the instability of calibration coefficients is still large. This could relate to environmental changes and the sensors itself, so we suggest that different calibration coefficients should be applied to different sensors and in actual applications, the relative calibration by using each transiting image of HJ-1 and the intraday MODIS data should be considered to obtain present calibration coefficients, and then to reverse the radiance to calculate other water quality parameters in order to ensure its accuracy.

The comparison of the calibration data obtained in DuHuang and the water leaving radiance reversed from the calibration coefficients obtained in this paper shows that the radiance values obtained from the calibration coefficients in ground fields are generally larger than the accuracy of the water leaving radiance obtained by cross-calibration coefficients, which shows that the high reflectivity in ground fields leads to a high obtained water leaving radiance, so in the research of quantitative remote sensing of water quality, the direct use of the calibration coefficients obtained in ground fields should be very careful.

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REFERENCES

[1] Liu Liangming, 2005. An Introduction to Satellite Oceanic Remote Sensing [M]. WUHAN UNIVERSUTY PRESS, , pp 69-74, pp182-183.

[2] Huang Miaofen,Xing Xufeng,Song Qingjun, et al., 2009. Radiometric Calibration Coefficients for “Beijing-1” Micro-satellite Multi-spectral CCD Sensors by Reflectance-based Method [J]. RESOURCES SCIENCE, 31(3):509-514.

[3] Tang J W,2002.The System Calibration and Validation of HY-1 COCTS Ocean Color Sensor[A].SPIE[C], 4892, AE108 Addendum.

[4] Jiang Xingwei, Niu Shengli, Tang Junwu, et al. , 2005. The System Cross-calibration Between SeaWiFs and HY-1 COCTS[J]. JOURNAL OF REMOTE SENSING, 9(6):680-687.

[5] Wang M and Franz B A, 2000.Comparing the Ocean Color Measurements between MOS and SeaWiFS: A Vicarious Inter-calibration Approach for MOS [J]. IEEE Trans. Gemci. Remote Sensing, 38(1):184-197.

[6] Hu C M, Frank E, Carder K L, et al, 2001. Atmospheric correction and cross calibration of LANDSAT-7/ETM+ imagery over aquatic environments: A multiplatform approach using SeaWiFS/MODIS[J]. Remote Sensing of Environment, 78:99-107.

[7] Pan Delu, He Xian,qiang, Zhu Qiankun, 2004. The on-orbit Cross-calibration of HY-1A COCTS [J].Chinese Science Bulletion, , 49(21):2239-2244.

[8] Tang Junwu. Gu Xingfa, Niu Shengli, 2005. The Cross-calibration coefficients based onwater-body targets for CBERS-02 /CCD with MODIS [J]. CHINA SCIENCE (E), supplement, pp59-69.

[9] Yang Zhongdong. Gu Songyan, Qiu hong, et al.,, 2004. CBERS-1's CCD Image Quality Evaluating and Cross Calibrating Study [J]. JOURNAL OF REMOTE SENSING, 8(2):113-120

[10] Rong Zhiguo, Zhang Yuxiang, Lu Feng, et al.,2005.Inter-calibration of Fy-2B IR Channel with NOAA Satellite[J]. ACTA METEOROLOGICA SINICA, 4:408-412

[11] Huang Miaofen,Niu Shengli,Sun Zhongpingi,et al. 2010. Analysis on Characteristic of the Water Body Information Collected by “HJ-1” satellite Multispectral CCD Sensors[J]. Remote Sensing Information, (4):68-75.

[12] Tang J W, 2002. The System Calibration and Validation of HY-1 COCTS ocean Color Sensor [A]. SPIE[C],4892, AE108 Addendum.