

CROSS-CALIBRATION OF IRS-1C, -1D AND -P6: WIDE ANGLE SENSORS USING SYNCHRONOUS OR NEAR SYNCHRONOUS MATCHING SCENES

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ABSTRACT:

For many applications (e.g., disaster management, precision farming), it is required to monitor events using multi-date satellite imagery acquired over the same area. This requirement can be best met with a set of satellites whose radiometric characteristics are fully modelled. Even though there is a gamut of satellites with identical or near-identical radiometric characteristics, systematic difference between their measured radiance exists due to inherent variation in sensor response and viewing geometries. Inter-sensor calibration exercises are carried out to establish radiometric relationship between the sensors of similar spectral bands so that their products can be used in conjunction with the other for deriving the change in events. In this paper, we describe method followed and results of the inter-calibration of Wide Field Sensors (WIFS) of IRS-1C and -1D spacecraft and Advanced WIFS (AWIFS) of IRS-P6 spacecraft sensors using near synchronous acquisitions over the Thar desert, serving in this study as a stable natural target. The WIFS payload has 2 spectral bands, B3 (0.62 – 0.68 μm) and B4 (0.77 – 0.86 μm) at spatial (ground) resolution of 188m with 5 days revisit time. IRS-P6 AWIFS payload has 4 spectral bands, B2 (0.52 – 0.59 μm), B3 (0.62 – 0.68 μm), B4 (0.77 – 0.86 μm) and B5 (1.55 – 1.70 μm) at spatial (ground) resolution of 56m with 5 days revisit time. In this study, it is assumed that the surface and atmospheric properties are relatively unchanged between the two data acquisitions. Using pre-launch coefficients, the top-of-atmosphere radiance of the target was computed from these data sets. Intrinsic variation present in their spectral response curves of each sensor was normalized band-wise with the pre-launch measured data. Multiple data sets acquired at different dates were used to evaluate this coefficient to make it usable for all the seasons. A new set of data was taken for verifying accuracies of the inter-sensor coefficients obtained from this study. A good correlation was found to exist among the data sets of the sensors after the inter-sensor calibration methodology was put to use.

1. Introduction

Space-borne Multispectral (MS) images are in great demand for a variety of Earth resource studies, including geology, environmental assessment and monitoring, natural resource management, and agriculture. Availability of information from multiple satellites with different sensors with spatial, spectral and radiometric resolutions provide the user an opportunity to resolve uncertainties that may arise from using one single image data. For applications like flood disaster or crop monitoring, multi-temporal data analysis has become an important aspect in estimating the damage made.

The IRS - 1C, IRS - 1D and IRS - P6 (also known as IRS - RESOURCESAT-1) spacecrafts have been equipped with Wide Field Sensor (WiFS) payloads to cover wide swath of 740 km x 740 km area with a repetition cycle of 5 days (NRSA, 2003). The WiFS of IRS-1C/D operates in two spectral bands in the red (B3: 0.62-0.68 μm) and near Infra red (B4: 0.77-0.86 μm) regions at spatial ground resolution of 188 m, while Advanced WIFS (AWIFS) sensor in IRS-P6 operates, in addition to above channels, in Green (B2: 0.52 - 0.59 μm), in Red (B3: 0.6 -0.69 μm), in Near IR (B4: 0.77 - 0.86 μm) and Middle infrared (B5: 1.55 – 1.7 μm) at a spatial resolution of 56 m and 10 bit radiometric resolution to cover 100% albedo (excepting B5) in the linear dynamic range of the sensor. Some specific characteristics of these sensors are given in Table 1. Inter-sensor variability assumes importance when all the three WIFS camera data are to be used for a specific task.

All these sensors have been calibrated prior to launch with a laboratory calibration source in a well controlled environment, and are expected to yield similar results. Nevertheless, their radiometric behaviour after launch is subjected to vary due to many problems, viz., the detector aging, satellite injection vibration, onboard electronic system anomalies etc. It is thus quite essential to carry out post-launch calibration while they operate onboard normally. This is normally achieved by acquiring the scenes with radiometrically stable targets in nature in a near synchronous overpass of these satellites over the same scene. The chance of getting such near synchronous matching scenes is, of course, dependent on the orbital characteristics of the spacecrafts.

Table 1 Characteristics of IRS-1C, -1D and -P6 Wide field sensors. Here RR and GIFOV denote, respectively, radiometric resolution (bits/pixel) and ground instantaneous field of view of the sensors.

Satellite	Sensor	Bands	RR	GIFOV
IRS-1C	WiFS	B3,B4	8 bit	188 m
IRS-1D	WIFS	B3 ,B4	8 bit	188 m
IRS-P6	AWIFS	B2,B3,B4,B5	10 bit	56 m

While, the IRS-1C and -P6 spacecrafts operate in a circular, near polar orbit at an altitude of 817 Km, the IRS-1D satellite orbits around the earth in an elliptical path with its mean eccentricity of almost more than five times that of the IRS-1C or IRS-P6. As a result, the IRS-1C covers the entire earth

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in 341 orbits during a 24 day cycle while IRS-1D covers takes 358 orbits in a 25 day cycle. Due to these differences in their orbital characteristics, there are occasions that both these satellites can view a scene at almost on the same day within a time difference of 15 min. Such synchronous and near-synchronous (within 3-5 days) pass data sets are made use of here for the cross-calibration of the WIFS sensors. It is also important to normalize ground measured spectral response inherently present in spectral transmission bandwidth of the sensors. Dependences on any one given sensor for our data needs will be a serious limiting factor for applications such as disaster management and precision framing, where timelines of data is of paramount importance.

In this paper, we address the procedure followed to carry out inter-sensor calibration of the three wide-angle sensors of IRS spacecrafts. In section 2, method and material employed for this study are described. Results and discussions are given in Sec. 3, and conclusions in Sec. 4.

2. Material and Method

The portion of the image to be selected as calibration site should have flat spectral and spatial responses with minimal seasonal variation for the reasons as follows (Thome, 1997). (1) A relatively bright site reduces the impacts of errors in determining the path radiance component during the radiative transfer calculations. A nominal site reflectance greater than 10% ensures that the site radiance is the dominant contributor to the TOA radiance. (2) High spatial uniformity over a large area minimizes the effects of misregistration when performing cross-calibration. (3) Minimal seasonal variations are desired if possible as well as a site that is free of vegetation that can affect seasonal variability, as well as BRF characteristics. An arid region is also desired to improve the probability of cloud – free days to minimize reflectance variations due to ground moisture content. (4) The site should be nearly lambertian to decrease uncertainties due to changing solar and view geometry when cross-calibrating sensors on different platforms. A flat site also has the advantage of reducing bi-directional reflectance effects and eliminating shadow problems. (5) Spectral uniformity of this site is considered important over as wide a region as possible to simplify sensor mismatch corrections.

Desert sand will satisfy most of the requirements to act as the calibration target. The present study is carried out with satellite imagery acquired over the Thar Desert (Lat 27.63 N, Long 71.86 E) of Rajasthan, India. Details of the scenes used are given in Tables 1 and 2.

Methodology: The procedure used for IRS inter-sensor calibration is much similar to the one proposed for cross calibration Landsat TM-5 & Landsat TM-7 (Teillet 2000), excepting that the coefficients are radiance based as against the Digital Count based as in the above reference.

The reason is that, as shown in Table 1, the IRS-P6 has 10 bits/pixels resolution as compared to IRS-1C/D WIFS at 8 bits, and hence it is convenient to work with radiance. As there were no opportunities met so far to acquire the proposed area by IRS-1C and IRS-P6, taking IRS-1D as reference, it is proposed to attempt cross calibration between IRS-P6 and IRS-1D, and between IRS-1C and IRS-1D separately, and combine their results at the end. It is assumed that surface and atmospheric properties are relatively unchanged between the acquisitions of pair of data sets. The

IRS-P6 AWIFS data were brought to resolution of IRS-1D WIFS by resampling to register the two pairing images.

Table 1 Data sets used for Cross Calibration IRS-P6 and IRS-1D. Here θ_{ele} denotes the sun elevation angle.

IRS P6			IRS 1D		
Path/Row	Date of Pass	θ_{ele}	Path/Row	Date of Pass	θ_{ele}
88/52	27.11.03	40.4	88/52	26.11.03	39.9
88/52	07.02.04	43.4	88/53	09.02.04	42.4
92/51	02.06.04	72.6	92/53	01.06.04	68.4
92/51	24.10.04	48.5	92/53	29.10.04	45.1

Table 2 Data sets used for Cross Calibration IRS-1C and IRS-1D. Here θ_{ele} denotes the sun elevation angle.

IRS P6			IRS 1D		
Path/Row	Date of Pass	θ_{ele}	Path/Row	Date of Pass	θ_{ele}
88/52	05.01.01	38.0	88/52	10.01.01	39.2
92/52	14.03.01	53.1	92/52	14.03.01	55.4
92/52	04.11.02	43.1	95/52	04.11.02	44.6
88/52	18.11.00	42.1	88/52	21.11.00	42.3
88/52	16.01.99	38.9	88/53	16.01.99	39.8

Several small size windows (maximum size: 3×3) common to pair of data sets were extracted first, and mean values of each window were converted to at-sensor spectral radiance by using DN-to-Radiance formula given in the data format. In an ideal case, the radiance emitted by a target recorded simultaneously by two independent sensors should be ideally same. The observed digital (DN) of an image pixel is converted to radiance of each band by

$$L_{\lambda} = DN * C \quad (2)$$

Where C denotes Calibration coefficients ($mw/cm^2-sr-\mu m$), computed during ground calibration, and provided along with the data products. These values represent radiance per count and arrived at by dividing the saturation radiance of the sensor for the gain operated with maximum allowable DN by sensor radiometric resolution. These values for IRS-WIFS sensors are as given in Table 3:

Table 3 Calibration Coefficients IRS P6/1D/1C WIFS sensor data. (in $mw/cm^2-\mu m-sr$)

IRS – P6		IRS -1D		IRS -1C	
B3	B4	B3	B4	B3	B4
0.0398	0.0278	0.0624	0.0598	0.0623	0.0585

The total spectral radiance at nadir, L_s , is given by

$$L_s = L_p + \rho E_o \text{Cos}(\Theta_z) \tau / \pi d^2 \quad (3)$$

Where L_p denotes path radiance (in $mw/cm^2-\mu m-sr$); Θ_z , solar zenith angle (in radians); ρ , the surface reflectance; $E_{o\lambda}$, the exo-atmospheric solar irradiance [$mW/cm^2-\mu m$] and τ , represents the atmospheric transmittance factor. Due to inherent spectral transmittances between the sensors under calibration, their difference is accounted by defining an adjustment factor, equal to ratio of spectral reflectances of

reference and to be calibrated band: i.e., $B = \rho_d / \rho_p$ where the spectral reflectance within pass-band is defined by:

$$\langle \rho_i \rangle = \int \rho_i(\lambda) S_i(\lambda) d\lambda / \int S_i(\lambda) d\lambda \quad (4)$$

Here $S_i(\lambda)$ is relative spectral response (RSR) function for the band i of the sensor. The RSR curves for IRS-1C/D and P6 WIFS sensor bands are shown in Figure 1. To estimate B, the RSR values greater than 5% of the peak were considered significant and used here for bands to keep uniformity. A standard spectral reflectance values of desert sand is employed for computing the factor B.

The band pass solar exo-atmospheric irradiance is an average of solar irradiance weighted by corresponding spectral band width respectively as (Pandya, 2003):

$$\langle E_o \rangle = \int E_o(\lambda) S_i(\lambda) d\lambda / \int S_i(\lambda) d\lambda \quad (6)$$

The term $E_o(\lambda)$ denotes solar irradiance at specified wavelength. We have used solar irradiance values reported by Neckel and Labs. Computed value of E_o for various band of IRS-1C, -1D and -P6 are given in Table 4.

Table 4 Computed exo-atmospheric solar irradiances for IRS-WIFS spectral bands (in $mw/cm^2-\mu m$)

IRS – P6		IRS-1D		IRS-1C	
B3	B4	B3	B4	B3	B4
155.68	108.27	157.83	110.94	157.78	110.87

Applying (3) to IRS-P6 IRS-1D and IRS-1C by neglecting the path radiance and atmospheric transmittance (no change in atmospheric conditions – a good approximation under the synchronous & near synchronous acquisitions), we get

$$L_{P6} = \rho_{P6} E_o^{P6} \text{Cos}(\theta_z^{P6}) / \pi d^2,$$

$$L_{1D} = \rho_{1D} E_o^{1D} \text{Cos}(\theta_z^{1D}) / \pi d^2,$$

and $L_{1C} = \rho_{1C} E_o^{1C} \text{Cos}(\theta_z^{1C}) / \pi d^2 \quad (7)$

The scaling factor for cross-calibration “m” (dimensionless) is computed by taking ratio of spectral radiances of the reference to that of the test band to be calibrated:

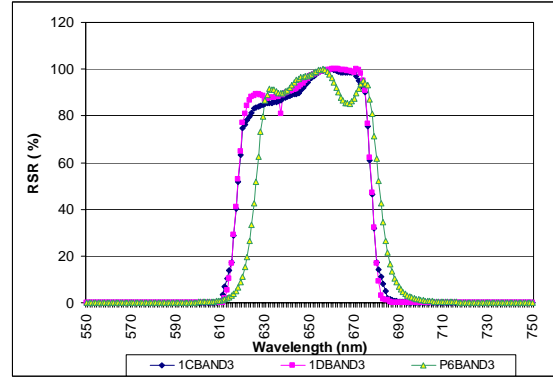
$$m = \frac{\rho_{1D} E_o^{1D}}{\rho_{P6} E_o^{P6}} * \frac{\text{Cos}(\theta_z^{1D})}{\text{Cos}(\theta_z^{P6})} \quad (8)$$

It can be seen from the above two factors: one corresponds to sensor specific static parameter which depends on measured spectral reflectance from satellite data and which needs to be monitored from time to time. The other factor is an external factor to be included for account for sun angle variation at the image area of analysis.

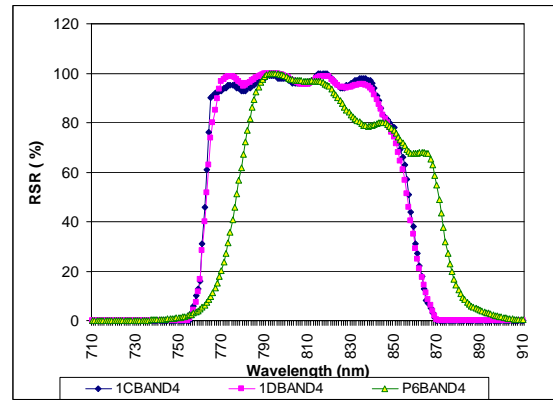
With the available set of data in hand (Table 2), some data sets were used to derive cross-calibration coefficients, while the one of them was kept as for validation. It was observed that the RMS errors obtained with the derived IRS-1D data from IRS-P6 and original IRS-1D were not concurrent, and hence, a corrective step was taken by iterating the procedure.

It was found to be sufficient for the required concurrence within one or two iterations.

Figure 1 Relative Spectral Response (RSR) of Wide field sensors of IRS-1C, -1D and -P6 for (a) B3 band and (b) B4 Band.



(a)



(b)

3. Results and Discussions

Relatively flat regions in the desert were chosen with a selection criterion that the std. deviation of the window was to be less than 3 counts for the analysis, and average of several windows was taken which were quite nearby geometrically so that solar irradiance angle variation across these locations of these windows is negligible.

The scaling factor, m , to convert IRS-P6 radiance to equivalent of IRS-1D, and from IRS-1C to IRS-1D estimated from the synchronous or near synchronous pass scenes were given Table 5. The derived scale factor from the IRS-P6 to IRS-1C was also given.

Table 5 Estimated scale factor(m) to convert from one WIFS sensor data to other sensor radiance for each band

P6 → 1D		1C → 1D		P6 → 1C	
B3	B4	B3	B4	B3	B4
1.0242	0.9782	1.0154	1.0005	0.9915	1.0228

Difference in radiances was computed between IRS-P6 and IRS-1D before and after applying the cross-calibration results. Table 6(a) gives the summary of the radiance difference (RMS) between the pairing bands. Reduction in difference can also be inferred by plotting the radiances of

the IRS-P6 vs. IRS-1D, and computing its slope and offset. It has been observed the slope after calibration tending toward 1.0 while the offset value was reduced. Table 6(b) depicts the results obtained before and calibration between the IRS-1C and IRS-1D WIFS data sets.

The above values are used to modify the calibration coefficients of IRS-P6 and IRS-1C prelaunch calibration coefficients given in Table 3. As the IRS-1D was used as reference, there would be no change from Table 3. Table 7 shows the suggested cross-calibration coefficients for IRS-P6 and IRS-1D. For comparison, the original calibration coefficients were also shown in parenthesis.

Table 6 Differences in radiance values for scenes selected before and after calibration is applied for (a) between the IRS-P6 and IRS-1D and (b) between the IRS-1C and IRS-1D.

(a)

NO	DATE OF PASS (P6)	ΔL_{B3} (RMS)		ΔL_{B4} (RMS)	
		Bef.	Aft.	Bef.	Aft.
1	07.02.04	0.4730	0.1846	0.1153	0.1014
2	02.06.04	0.4937	0.3040	0.6139	0.1639
3	27.11.03	0.2206	0.1245	0.3234	0.1019
4	24.10.04*	0.2205	0.1387	0.7594	0.4716
Avg.:		0.3519	0.1879	0.4530	0.2097

(b)

NO	DATE OF PASS (1C)	ΔL_{B3} (RMS)		ΔL_{B4} (RMS)	
		Bef.	Aft.	Bef.	Aft.
1	16.01.99	0.1773	0.1708	0.1166	0.0982
2	05.01.01	0.2963	0.2378	0.1619	0.1838
3	14.03.01	0.2148	0.1994	0.3390	0.2456
4	04.11.02	0.1748	0.2543	0.2119	0.1721
5	18.11.00*	0.0898	0.0514	0.1603	0.1249
Avg.:		0.1905	0.1827	0.1979	0.1649

* data set used for validation

Table 7 Calibration Coefficients IRS P6/1C WIFS sensor data after inter-sensor calibration to obtain radiance outputs equivalent to IRS-1D (in $mw/cm^2-\mu m-sr$).

IRS – P6		IRS -1C	
B3	B4	B3	B4
0.0408 (0.0398)	0.0272 (0.0278)	0.0633 (0.0623)	0.05853 (0.05851)

4. Conclusions

In the present study, an attempt was made to cross-calibrate wide field sensors of the IRS-1C, -1D and -P6 spacecrafts with synchronous and near-synchronous matching scenes. The uniform flat response regions were identified over the Thar desert scene, and inherent inter-sensor spectral response variations were compensated. It was found that, for the data set selected, the cross-calibration exercise has improved the one-to-one relationship in spectral radiance. Results encourage for extending this study to the LISS-3 sensors.

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