Cross-Calibration of the Landsat-7 ETM+ and Landsat-5 TM with the ResourceSat-1 (IRS-P6) AWiFS and LISS-III Sensors

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ABSTRACT

Increasingly, data from multiple sensors are used to gain a more complete understanding of land surface processes at a variety of scales. The Landsat suite of satellites has collected the longest continuous archive of multispectral data. The ResourceSat-1 Satellite (also called as IRS-P6) was launched into the polar sun-synchronous orbit on Oct 17, 2003. It carries three remote sensing sensors: the High Resolution Linear Imaging Self-Scanner (LISS-IV), Medium Resolution Linear Imaging Self-Scanner (LISS-III), and the Advanced Wide Field Sensor (AWiFS). These three sensors are used together to provide images with different resolution and coverage. To understand the absolute radiometric calibration accuracy of IRS-P6 AWiFS and LISS-III sensors, image pairs from these sensors were compared to the Landsat-5 TM and Landsat-7 ETM+ sensors. The approach involved the calibration of nearly simultaneous surface observations based on image statistics from areas observed simultaneously by the two sensors.

Keywords: Landsat, TM, ETM+, IRS-P6, ResourceSat-1, AWiFS, LISS-III, Calibration, Characterization, Spectral bands, RSR, Reflectance

1. INTRODUCTION

The Landsat Program began in 1972 and provides continuous, consistent measurements of Earth surface features over seven mission generations. The Landsat-5 (L5) and Landsat-7 (L7) satellites are currently operational. The Indian Remote Sensing Satellites (IRS) constellation program consists of three currently operating satellites: RESOURCESAT-1 (IRS-P6), IRS-1C, and IRS-1D. The following section provides an overview of these sensors.

1.1 Landsat-5 (L5) Thematic Mapper (TM)

The L5 TM is an Earth-imaging sensor that was launched on March 1, 1984. It incorporates advancements in spectral, radiometric, and geometric capabilities relative to the Multispectral Scanner (MSS) flown on previous Landsats. Onboard are two imaging sensors, the MSS and the TM. L5 TM Bands 1-5 and 7 have 16 detectors with center wavelengths of approximately 0.49, 0.56, 0.66, 0.83, 1.67, and 2.24 μm, respectively[1]. The detectors for Bands 1-4 are located at the Primary Focal Plane (PFP), where the temperature is not controlled, but normally varies between 292 and 300 K. The detectors for Bands 5, 6, and 7 are located at the Cold Focal Plane (CFP). Because of their relatively long wavelengths, high noise signals result from the internal thermal excitation of the detector materials. To minimize this noise and allow adequate detection of scene energy, a radiative cooler maintains the CFP temperature between 95 and 105 K. The Internal Calibrator (IC) is incorporated as an onboard radiometric calibration system for the L5 TM. Onboard calibration of the MSS and TM uses lamps to calibrate the reflective bands and a blackbody source to calibrate the thermal band.

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1.2 Landsat-7 Enhanced Thematic Mapper Plus (ETM+)

The ETM+ sensor was launched on April 15, 1999, on the L7 platform; it is based on the TM sensors onboard the Landsat-4 (L4) and L5 satellites. Changes on the ETM+ sensor include a new panchromatic band, an increase in the spatial resolution of the thermal band to 60 m, and the addition of the two calibration devices to help improve the radiometric calibration. L7 ETM+ has three on-board calibration devices: a Full Aperture Solar Calibrator (FASC), which is a white painted diffuser panel; a Partial Aperture Solar Calibrator (PASC), which is a set of optics that allows the ETM+ to image the sun through small holes; and an Internal Calibrator (IC), which consists of two lamps, a black body, a shutter, and optics to transfer the energy from the calibration sources to the focal plane. One of the requirements of the L7 mission is to achieve radiometric calibration accuracy of the ETM+ data within an uncertainty of less than five percent in at-sensor radiance[1]. This requirement is more stringent than past requirements for the Landsat Program.

1.3 ResourceSat-1 Advanced Wide Field Sensor (AWiFS) and Linear Imaging and Self Scanning sensor (LISS-III)

The ResourceSat-1 (IRS-P6) is a three axes body-stabilized satellite. It has an operational life of five years, in a near-polar, sun-synchronous orbit, at a mean altitude of 817 km. Its payload consists of three sensors: a LISS-III, an AWiFS, and a high-resolution multi-spectral camera (LISS-IV). All three sensors work on the ‘push-broom scanning’ concept, using linear arrays of Charge Coupled Devices (CCDs). In this mode of operation, each line of an image is electronically scanned and contiguous lines are imaged by the forward motion of the satellite. Unique to the RESOURCESAT-1 is that these three sensors with different resolutions and swath widths are on the same platform[2].

LISS-III: The LISS-III is a multispectral camera operating in four spectral bands, three in the VNIR bands and one in the SWIR region with 23.5 m spatial resolution and a ground swath of 141 km. The LISS-III sensor is a nadir-looking sensor providing a 24-day revisit cycle.

AWiFS: The AWiFS camera operates in four spectral bands identical to LISS-III, providing a spatial resolution of 56 m at nadir and covering a ground swath of 740 km. To cover this wide swath, the AWiFS camera is split into two separate electro-optic modules, AWiFS-A and AWiFS-B.

2. RELATIVE SPECTRAL RESPONSE (RSR)

Figure 1 shows the RSR profiles between corresponding L7 ETM+, L5 TM, and IRS-P6 AWiFS and LISS-III spectral bands. Table 1 summarizes the wavelength coverage. The ETM+ bands were improvements upon the seven standard TM spectral bands, including Bands 1, 2, 3, 4, 5, 6, and 7. The IRS-P6 AWiFS and LISS-III Bands 2, 3, 4, and 5 are similar to the corresponding TM and ETM+ spectral bands.

Table 1. Spectral coverage

	Spectral Range (µm)		
Band	**L5 TM**	**L7 ETM+**	**IRS-P6**
1	0.450-0.520	0.450-0.515	
2	0.520-0.600	0.525-0.605	0.52-0.59
3	0.630-0.690	0.630-0.690	0.62-0.68
4	0.760-0.900	0.775-0.900	0.77-0.86
5	1.550-1.750	1.550-1.750	1.55-1.70
6	10.40-12.50	10.40-12.50	
7	2.080-2.350	2.090-2.350	
Pan		0.520-0.900	

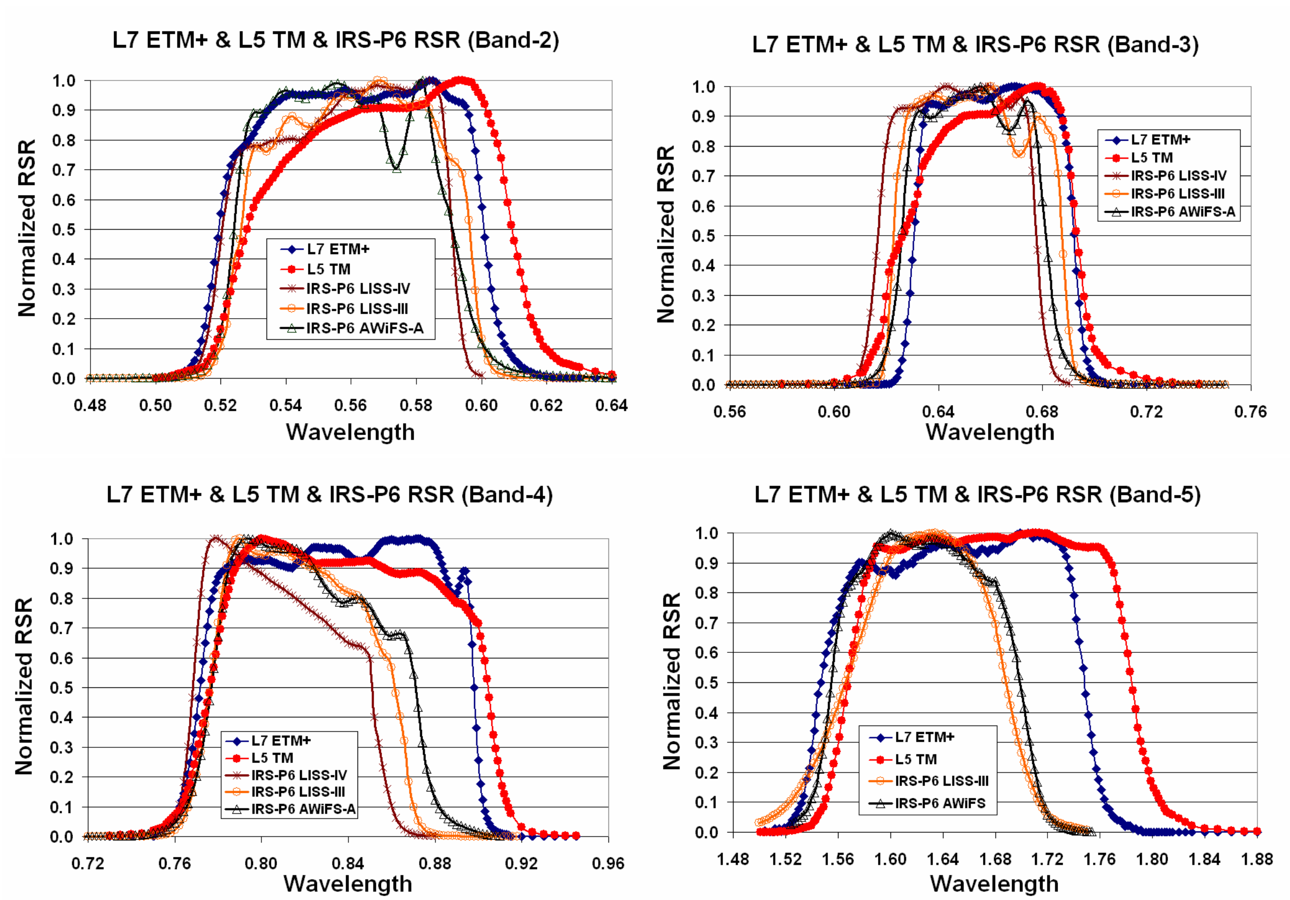

Figure 1. Relative Spectral Responses (RSR) profiles of L7 ETM+, L5 TM, and IRS-P6 sensors

3. CONCIDENT LANDSAT & IRS IMAGES

This section summarizes the data sets used for the evaluation.

3.1 Sun Synchronous Orbits

The L5 and L7 satellites operate in a repetitive, circular, sun-synchronous, and near-polar orbit at a nominal altitude of 705 km (438 miles) at the Equator. The sun-synchronous orbit means that all acquisitions over a given area occur at the same time of the day. The equatorial crossing time during descending passes (descending passes are on the sun-lit side of the Earth and ascending passes are always on the dark side of the orbit) is, for all Landsat missions, between 9:30 and 10:00 a.m. local time. Circling the Earth at 7.5 km/sec, each orbit takes nearly 99 minutes. The spacecraft completes just over 14 orbits per day, covering the entire Earth between 81 degrees north and south latitude every 16 days, completing 233 orbits per cycle on the World Reference System (WRS-2).

The IRS-P6 satellite operates in a circular, sun-synchronous, near-polar orbit with an inclination of 98.69 deg, at an altitude of 817 km. The satellite takes 101.35 minutes to complete one revolution around the Earth and completes about 14 orbits per day, with a ground track velocity of 6.65 km/sec. The entire Earth is covered by 341 orbits during a 24-day cycle.

3.2 Test site descriptions

The scene selection for these studies proved to be a challenge due to the limited number of coincident image pairs between these sensors. Due to the lack of near-simultaneous images available over the well-characterized and traditionally used calibration and application evaluation sites, alternate sites that have high reflectance, large dynamic range, high spatial uniformity, high sun elevation, and minimal cloud cover were investigated. As a result, the final scenes selected for the current work were over Mesa, AZ and Salt Lake City, UT.

1) Mesa, AZ: In Mesa, cloud-free IRS-P6 AWiFS and LISS-III scenes were acquired on June 29, 2005. About 30 minutes later, five L7 scenes covering part of the same footprint were acquired. It is referenced in the Worldwide Reference System 2 (WRS-2) with path 36 and rows 35-39.

2) Salt Lake City, UT: In Salt Lake, cloud-free IRS-P6 AWiFS and LISS-III scenes were acquired on June 19, 2005. About 30 minutes later, three L5 scenes covering part of the AWiFS footprint were acquired. It is referenced in the WRS-2 system with path 38 and rows 30-32.

In both test sites, the area in common to all images was evaluated for each available image source. Table 2 lists the scenes that were selected for the study, along with the scene ID number, location, path, row, date and time of acquisition, and the sun elevation angle for the scenes.

Table 2. Mesa, Arizona collection, June 29, 2005

Instrument	Product ID	Path	Row	Solar Elevation
Landsat 7 ETM+	L71036035_03520050629	36	35	65.21 °
Landsat 7 ETM+	L71036036_03620050629	36	36	65.53 °
Landsat 7 ETM+	L71036037_03720050629	36	37	65.77 °
Landsat 7 ETM+	L71036038_03820050629	36	38	65.94 °
Landsat 7 ETM+	L71036039_03920050629	36	39	66.02 °
AWiFS Quad A	AW257047A001	257	47	69.50 °
AWiFS Quad B	AW257047B001	257	47	72.60 °
AWiFS Quad C	AW257047C001	257	47	70.30 °
AWiFS Quad D	AW257047D001	257	47	73.60 °
LISS-III	L32570470101	257	47	71.48 °

Table 3. Salt Lake City, Utah collection, June 19, 2005

Instrument	Product ID	Path	Row	Solar Elevation
Landsat 5 TM	LT5038030000517010	38	30	62.95 °
Landsat 5 TM	LT5038031000517010	38	31	63.59 °
Landsat 5 TM	LT5038032000517010	38	32	64.18 °
AWiFS Quad A	000010491201	255	40	65.50 °
AWiFS Quad B	000010491301	255	40	68.10 °
AWiFS Quad C	000010491401	255	40	67.50 °
AWiFS Quad D	000010491501	255	40	70.30 °
LISS-III	000010491601	255	41	68.64 °

3.3 Data Processing System

Orthorectified scenes were used for this study. Terrain correction includes radiometric, geometric, and precision correction, as well as the use of a digital elevation model (DEM) to correct parallax error due to local topographic relief. The accuracy of the terrain-corrected product depends upon the availability of local ground control points (GCPs), as well as the resolution of the best available DEM. The absolute radiance values are then scaled to calibrated digital numbers before being output to the distribution media.

The following processing parameters were used to generate the Landsat products:

Map Projection:	Albers
Standard Parallel 1:	29.5
Standard Parallel 2:	45.5
Central Meridian:	-96
Latitude of Origin:	23
False Northing:	0
False Easting:	0
Horizontal Datum:	WGS84
Resampling method:	Cubic Convolution (CC)
Image orientation:	Map (north up)

The data quantization for L7 ETM+ and L5 TM is 8 bits. The Level 1G (L1G) products for TM and ETM+ are only available in 8-bit values for Landsat sensors. The L1G products for LISS-III are available in 8-bit values. However, the AWiFS data products are available in 8- and 10-bit values.

3.4 Conversion to Reflectance

The sensors do not measure radiances directly. Rather, they record quantities that, once calibrated, are equal to or linearly related to radiances. The detectors exhibit linear response to the Earth's surface radiance or the internal calibration lamps; the response is quantized into 8-bit and/or 10-bit values that represent brightness values commonly called Digital Numbers (DNs). Rescaling gains and biases are created from the known dynamic range limits of the instrument. These gains and biases are used to convert the calibrated digital numbers to at-sensor radiance. This radiance is then converted to top-of-atmosphere (TOA) reflectance by normalizing for solar elevation and solar spectral irradiance. Table 4 summarizes the Solar Exoatmospheric Spectral Irradiances (ESUN) values. To maintain consistency with the ETM+, this paper uses spectral radiance units of W/(m2.sr.µm). Note that the conversion factor is 1:10 when going from mW/(cm2.sr. µm) units to W/(m2.sr. µm).

Table 4. Solar Exoatmospheric Spectral Irradiances (ESUN) values using CHKUR MODTRAN 4.0 spectrum. W/(m2.sr.µm)

Bands	L5 TM	L7 ETM+	LISS-III	AWiFS
2	1826.000	1840.000	1846.770	1849.820
3	1554.000	1551.000	1575.500	1579.370
4	1036.000	1044.000	1087.340	1075.110
5	215.000	225.700	236.651	235.831

4. CALIBRATION BY NEAR-SIMULTANEOUS SURFACE OBSERVATIONS

Data continuity requires consistency in the interpretation of image data acquired by different imaging sensors. This section provides the comparisons of the reflectance measurements obtained from the L7 ETM+, the L5 TM, and the IRS-P6 AWiFS and LISS-III sensors. Cross-calibration was performed with image statistics based on large common areas observed near-simultaneously by the two sensors[3]. Because the image acquisitions occurred within few minutes, it was assumed that the surface and atmospheric conditions did not change during that time.

The L7, L5, and IRS-P6 sensors differ in their along-track and across-track pixel sampling. A feature simultaneously observed by these sensors will be represented by slightly different numbers of image pixels because of the differences in viewing geometry and sensor scanning times. This makes it very difficult to establish sufficient geometric control to facilitate radiometric comparisons on a point-by-point and/or detector-by-detector basis. Therefore, the analysis approach made use of image statistics based on large homogenous areas that were common between the image pairs. These large areas were carefully selected using distinct features common to both of the images. Both bright and dark regions were selected to obtain maximum coverage over each sensor's dynamic range, but areas with clouds or cloud shadows were excluded. Regions of Interest (ROIs) were defined within these areas for each image triplet (L5 or L7, AWiFS, and LISS-III). Gaps in the L7 data due to the scan line corrector anomaly were discarded. Homogeneity of each ROI was then tested by rejecting any region with a standard deviation of more than 10 DN in any Landsat band. This left 27 ROIs for the Mesa, AZ collection and 34 ROIs for the Salt Lake City, UT collection.

Fig. 2 shows a pair of regions of interest from the Mesa, AZ test site, with AWiFS data on the left and L7 ETM+ data on the right. Fig. 3 shows a pair of regions of interest from the Salt Lake City, UT test site, with AWiFS data on the left and L5 TM data on the right.

Once all area ROIs were selected, image statistics were computed to obtain mean and standard deviation target values on a band-by-band basis. The mean target statistics were then converted to absolute units of radiance and then top-of-atmosphere (TOA) reflectance. These reflectance values were then plotted for each instrument pair, and a linear fit was calculated, giving a relative gain and bias between each sensor pair.

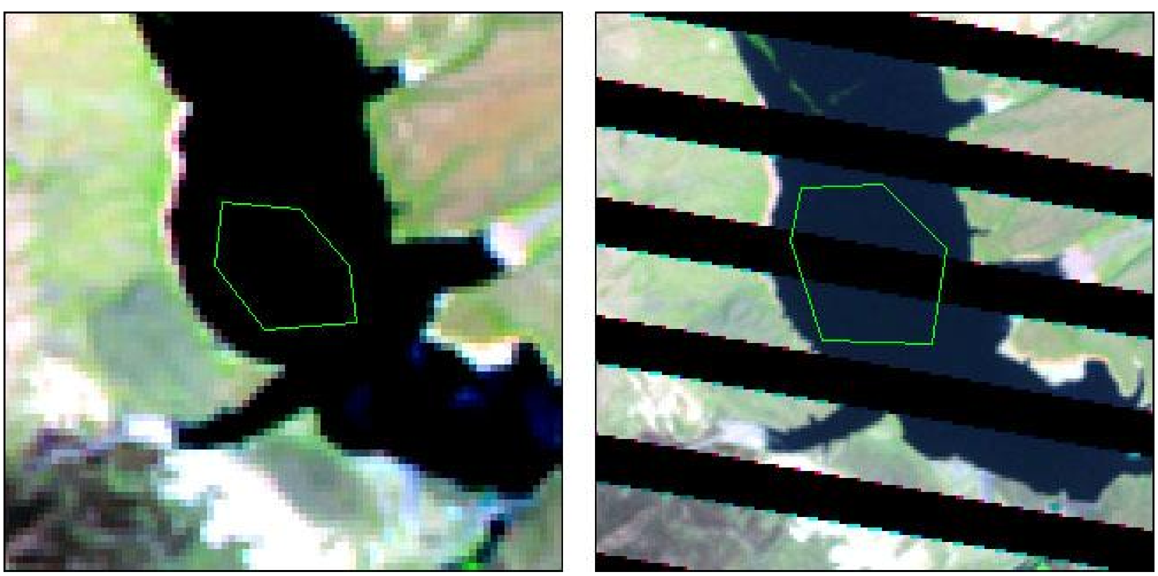

Figure 2. Paired homogenous regions of interest
Data from Mesa, AZ collection, with AWiFS (left) and Landsat 7 ETM+ (right)

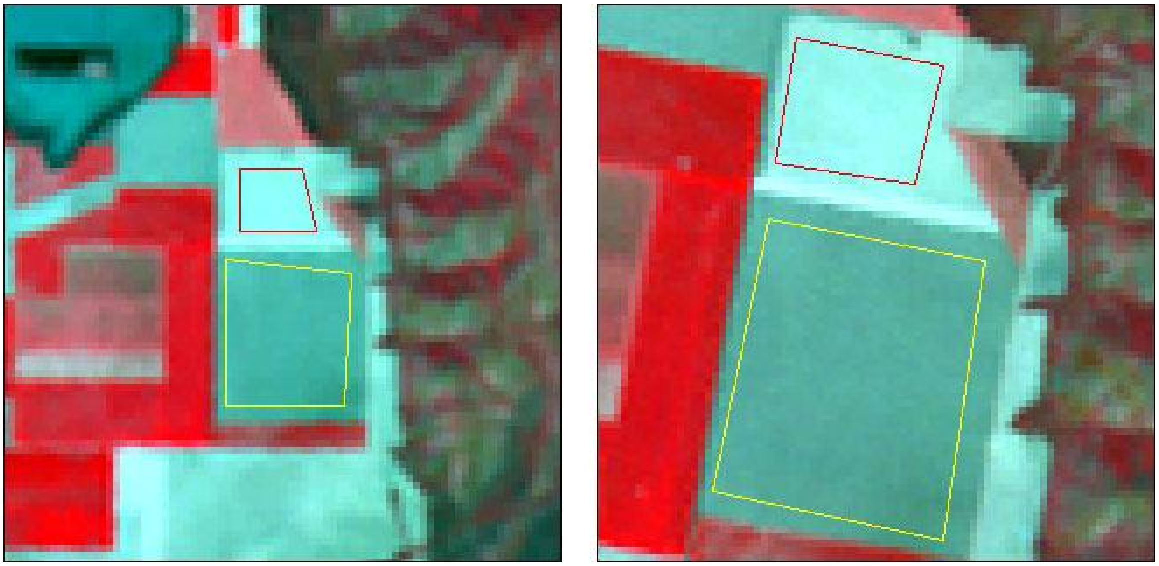

Figure 3. Paired homogenous regions of interest
Data from SLC, UT collection, with AWiFS (left) and Landsat 5 TM (right)

5. CROSS-CALIBRATION ACCURACY of L7 ETM+ with IRS-P6 AWiFS & LISS-III SENSORS

Figures 4 and 5 show the cross-calibration plots for the Mesa, AZ collection, comparing L7 ETM+ reflectance against AWiFS and LISS-III reflectances. A least-square fit has been made to the data in each band, and the expected 1-to-1 reflectance line is also plotted for reference. Linear fits to these pairs of reflectance measurements give cross-calibration gains and biases, as presented in Table 5.

Table 5. Cross-calibration results for the Mesa, AZ collection.

	IRS-P6 AWiFS/L7 ETM+ Reflectance				
Band	Gain	s(gain)	Bias	s(bias)	R^2
2	**0.9008**	0.0276	**-0.0034**	0.0047	0.9771
3	**0.9296**	0.0199	**-0.0167**	0.0039	0.9887
4	**0.8834**	0.0077	**-0.0203**	0.0024	0.9981
5	**0.8927**	0.0136	**0.0198**	0.0039	0.9942

	IRS-P6 LISS-III/L7 ETM+ Reflectance				
Band	Gain	s(gain)	Bias	s(bias)	R^2
2	**0.8778**	0.0107	**0.0099**	0.0011	0.9993
3	**0.8847**	0.0088	**0.0079**	-0.0010	0.9995
4	**0.8968**	0.0075	**0.0132**	0.0020	0.9997
5	**0.9228**	0.0214	**0.0426**	0.0039	0.9973

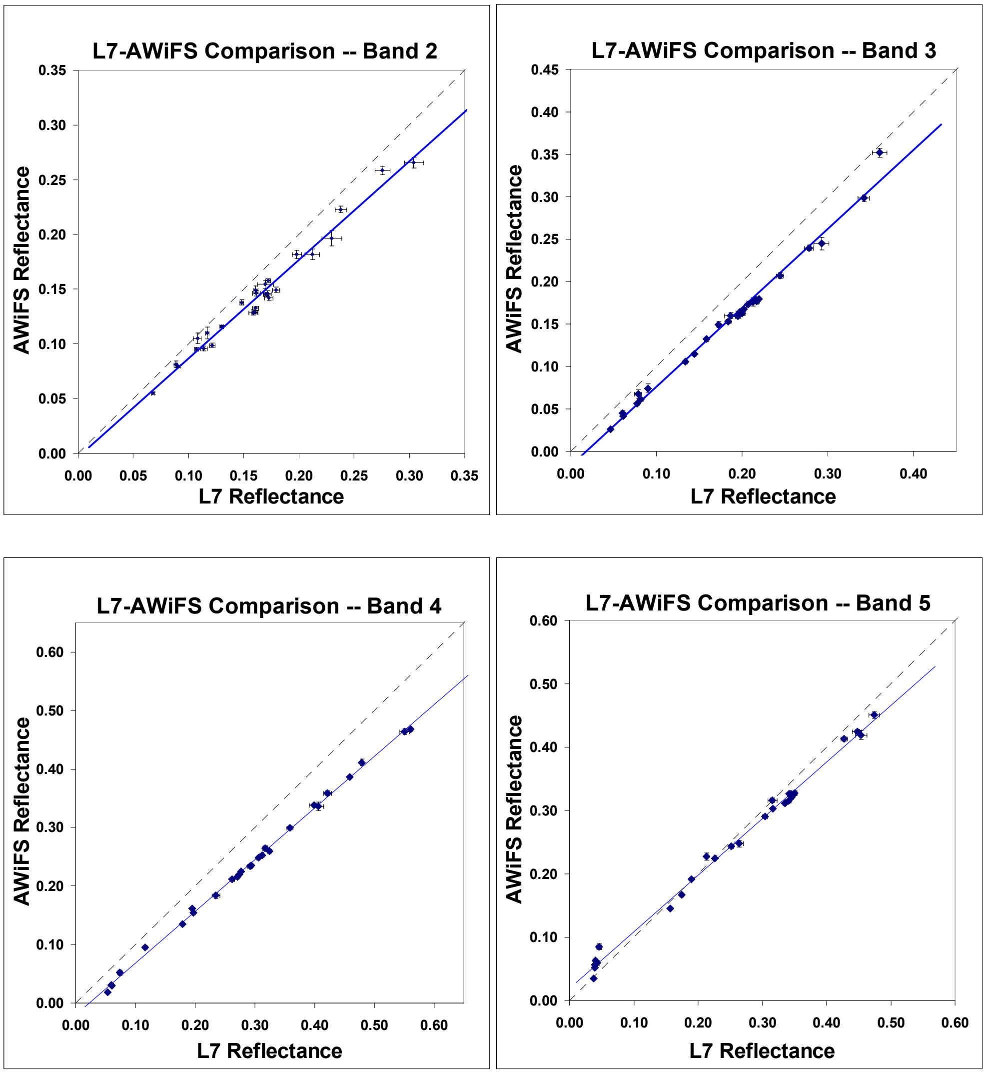

Figure 4. Reflectance of homogenous regions viewed by the ETM+, plotted against the same regions viewed by AWiFS. Error bars indicate the standard deviation of the regions of interest.

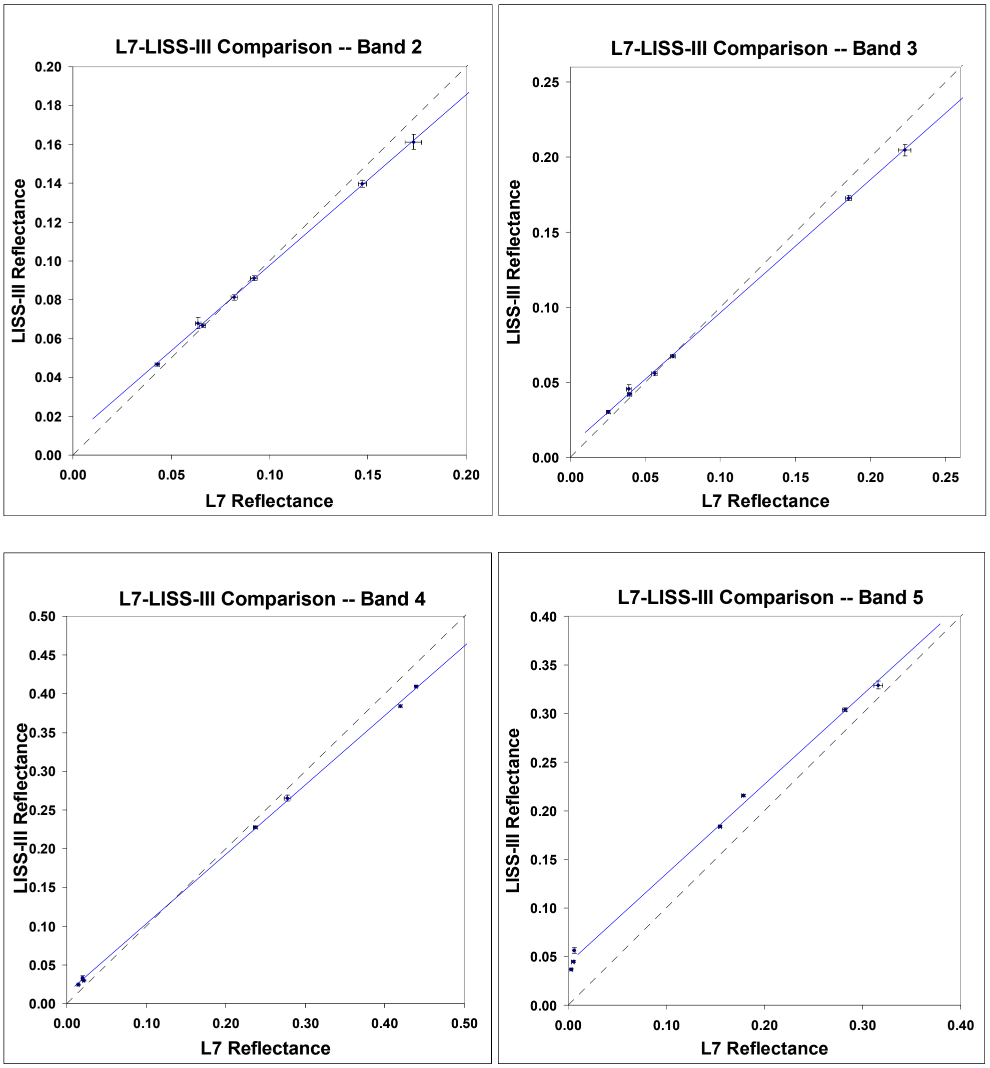

Figure 5. Reflectance of homogenous regions viewed by the ETM+, plotted against the same regions viewed by LISS-III. Error bars indicate the standard deviation of the regions of interest.

6. CROSS-CALIBRATION ACCURACY of L5 TM with IRS-P6 AWiFS & LISS-III SENSORS

Figures 6 and 7 show the cross-calibration plots for the Salt Lake City, UT collection, comparing L5 TM reflectance against AWiFS and LISS-III reflectances. A least-square fit has been made to the data in each band, and the expected 1-to-1 reflectance line is also plotted for reference. Linear fits to these pairs of reflectance measurements give cross-calibration gains and biases, as presented in Table 6.

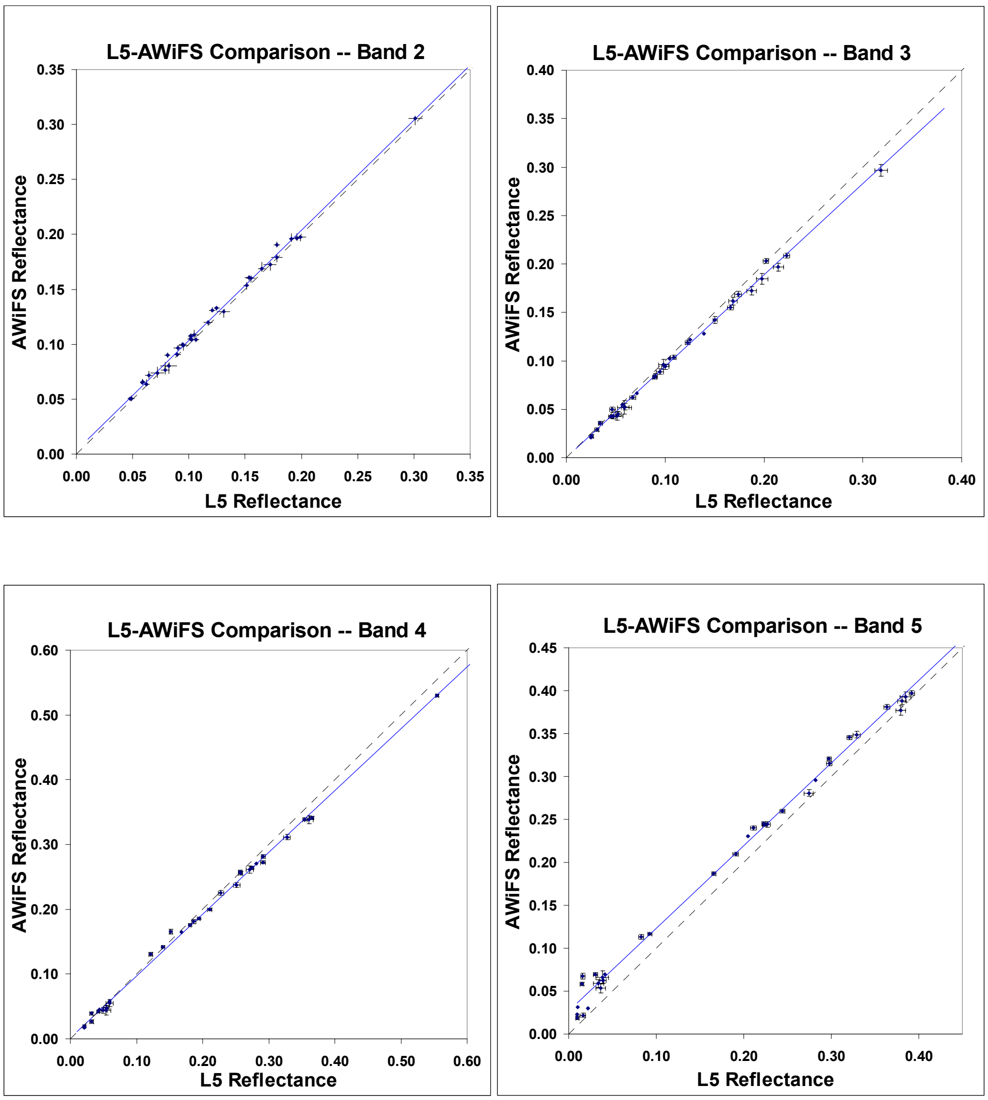

Figure 6. Reflectance of homogenous regions viewed by the TM, plotted against the same regions viewed by AWiFS. Error bars indicate the standard deviation of the regions of interest.

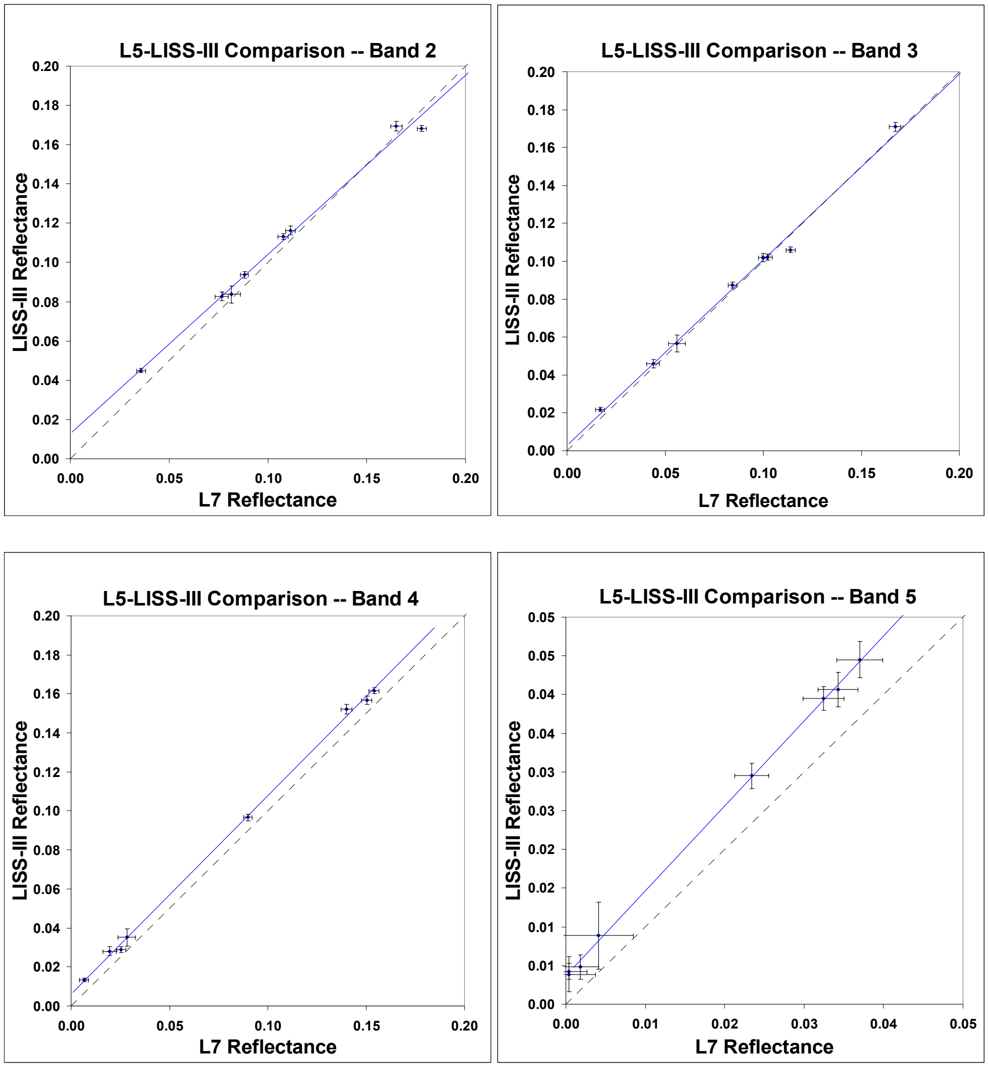

Figure 7. Reflectance of homogenous regions viewed by the TM, plotted against the same regions viewed by LISS-III. Error bars indicate the standard deviation of the regions of interest.

Table 6. Cross-calibration results for the Salt Lake City, UT collection.

	IRS-P6 AWiFS/L5 TM Reflectance				
Band	Gain	s(gain)	Bias	s(bias)	R^2
2	**1.0001**	0.0116	**0.0036**	0.0015	0.9957
3	**0.9454**	0.0095	**-0.0005**	0.0012	0.9968
4	**0.9541**	0.0087	**0.0018**	0.0019	0.9974
5	**0.9634**	0.0127	**0.0261**	0.0028	0.9944

	IRS-P6 LISS-III/L5 TM Reflectance				
Band	Gain	s(gain)	Bias	s(bias)	R^2
2	**0.9127**	0.0337	**0.0127**	0.0039	0.9919
3	**0.9787**	0.0332	**0.0029**	0.0032	0.9932
4	**1.0159**	0.0140	**0.0061**	0.0014	0.9989
5	**1.0989**	0.0127	**0.0036**	0.0003	0.9992

7. SUMMARY

To understand the absolute radiometric calibration accuracy of IRS-P6 AWiFS and LISS-III sensors, image pairs from these sensors were compared to images from the Landsat-5 Thematic Mapper (TM) and Landsat-7 Enhanced Thematic Mapper Plus (ETM+) sensors. The approach involves the calibration of nearly simultaneous surface observations based on image statistics from areas observed simultaneously by the two sensors. The average percent differences in reflectance estimates obtained from these sensors agree within 12 percent. Additional work to characterize the absolute differences between the two sensors over the entire mission is in progress.

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