Cross Calibration of the L7 ETM+ and L5 TM with the IRS-P6 AWiFS and LISS-III Sensors

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Outline

- Orbit and Payload
- Sensor Overview
- RSR Profiles comparison
- Co-incident Image Pairs
- Cross-calibration Results
- Summary and Conclusion

Resourcesat-1 (IRS P6)

- **The RESOURCSAT-1 satellite was launched in to the polar sun-synchronous orbit (altitude of 817 km) by PSLV-C5 launch vehicle on October 17, 2003 with a design life of 5 years**
- **RESOURCSAT-1 is also called IRS-P6**
  - Most advanced Remote Sensing Satellite built by ISRO
  - Tenth satellite of ISRO in IRS series
  - Other ISRO operational satellites are IRS 1-C, IRS 1-D, IRS P-2, IRS P-3

Resourcesat-1 Orbit and Coverage Details	
Orbit Altitude	817 Km
Orbit Inclination	98.69 deg
Orbit period	101.35 min
Number of Orbits per day	14.2083
Equatorial crosing time	10.30 a.m.
Repetivity (LISS-3)	24 days
Repetivity (LISS-4)	5 days
Distance between adjacent paths	117.5 km
Distance between successive ground tracks	2,820 km
Lift-off Mass	1360 kg
Ground trace velocity	6.65 km/sec
Orbits/cycle	341
Semi major axis	7195.11
Eccentricity	0.001
Mission Life	5 years

ResourceSat-1 Overview

- **RESOURCESAT-1 carries three sensors**
  - High Resolution Linear Imaging Self-Scanner **(LISS-IV)**
  - Medium Resolution Linear Imaging Self-Scanner **(LISS-III)**
  - Advanced Wide Field Sensor **(AWiFS)**
- **All three cameras are “push broom” scanners using linear arrays of CCDs**
- **RESOURCESAT-1 also carries an On-board Solid State Recorder (OBSSR) with a capacity of 120 GB to store the images**

Advanced Wide Field Sensor (AWiFS)

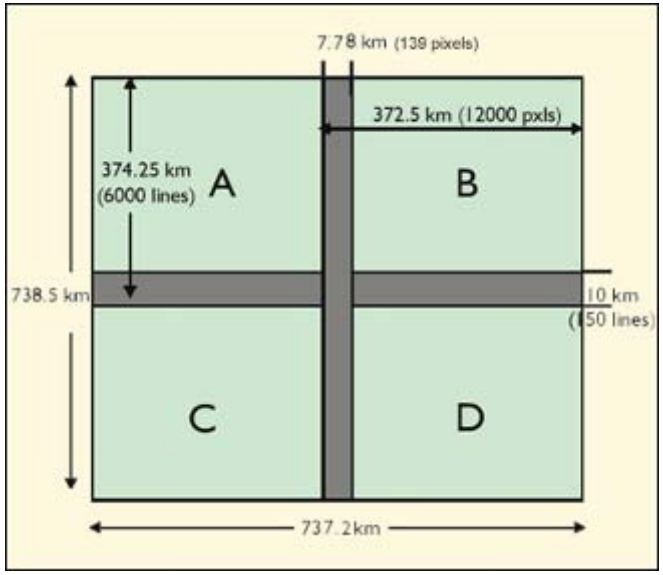
- **The AWiFS with twin cameras is a moderate-resolution sensor offering a GSD of 56m at nadir**
- **Quantization: 10 bits**
- **Combined ground swath is 740km with five day repeat cycle**
- **Operates in four spectral bands – three VNIR one SWIR**

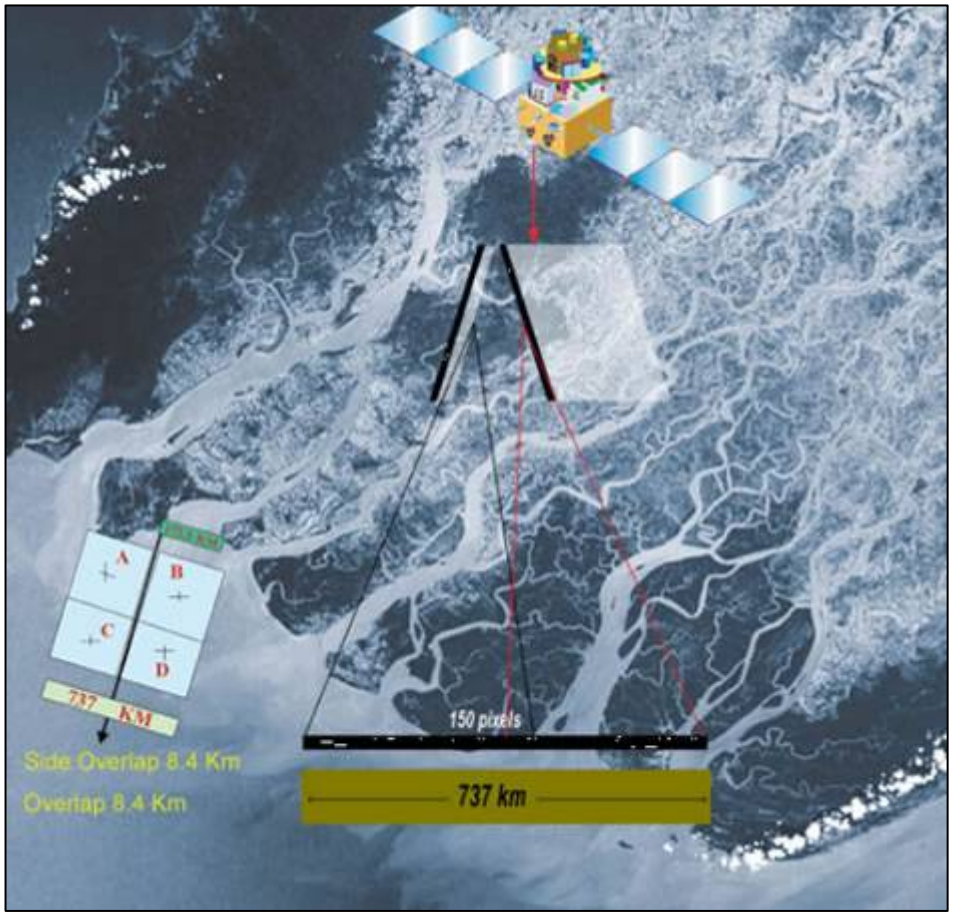
VITAL FACTS:

- **Instrument: Pushbroom**
- **Bands (4): 0.52-0.59, 0.62-0.68, 0.77-0.86, 1.55-1.70 µm**
- **Spatial Resolution: 56 m (near nadir), 70 m (near edge)**
- **Radiometric Resolution: 10 bit**
- **Swath: 740 km**
- **Repeat Time: 5 days**
- **Design Life: 5 years**

AWiFS Sensor Collection Mode

The AWiFS camera is split into two separate electro-optic modules (AWiFS-A and AWiFS-B) tilted by 11.94 degrees with respect to nadir





Medium Resolution Linear Imaging Self-Scanner (LISS-III)

- **The LISS-III is a medium resolution sensor offering a GSD of 23.5m**
- **Quantization: 7 bits (SWIR band 10 bits – selected 7 transmitted)**
- **Ground swath is 141 km with 24 day repeat cycle**
- **Operates in four spectral bands - three VNIR one SWIR**
- **Each band consists of a separate lens assembly & linear array CCD**
  - The VNIR bands use a 6000 element CCD with pixel size 10x7 microns
  - The SWIR band uses a 6000 element CCD with pixel size 13x13 microns
  - The data from the VNIR bands are digitized to 7 bits while the data from SWIR band are digitized to 10 bit
  - The VNIR bands could be operated in any one of the four selectable gains by command, while the SWIR band is configured with single gain setting covering the full dynamic range

IRS-P6 Radiometric Resolution

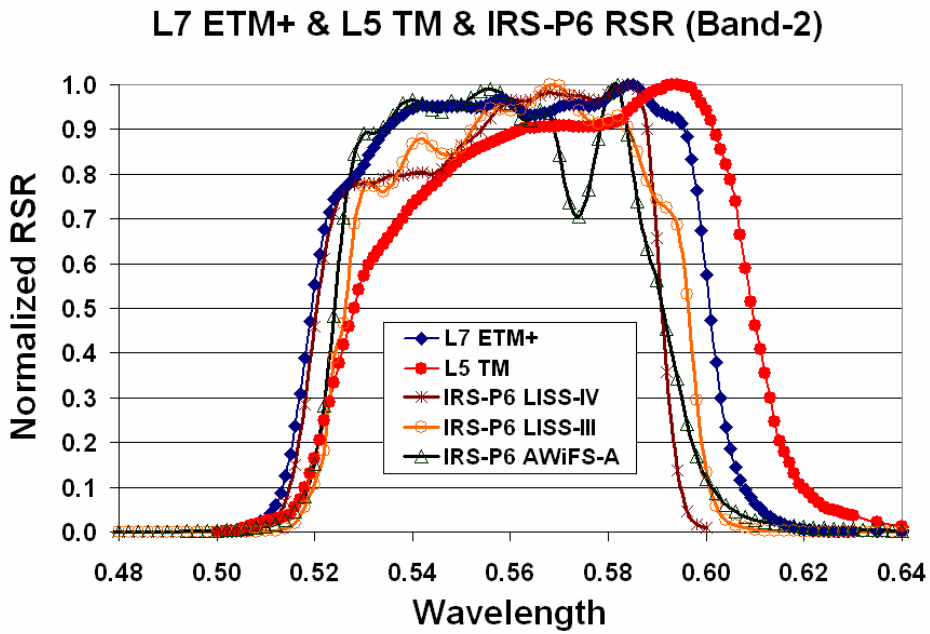
- **The radiometric resolution (quantization) of the IRS-P6 sensor is summarized below:**
  - AWiFS = 10 bits
  - LISS-III (VNIR) = 7 bits (with four gain settings)
  - LISS-III (SWIR) = 7 bits (out of 10 - sliding)
  - LISS IV = 7 bits (out of 10 - sliding)

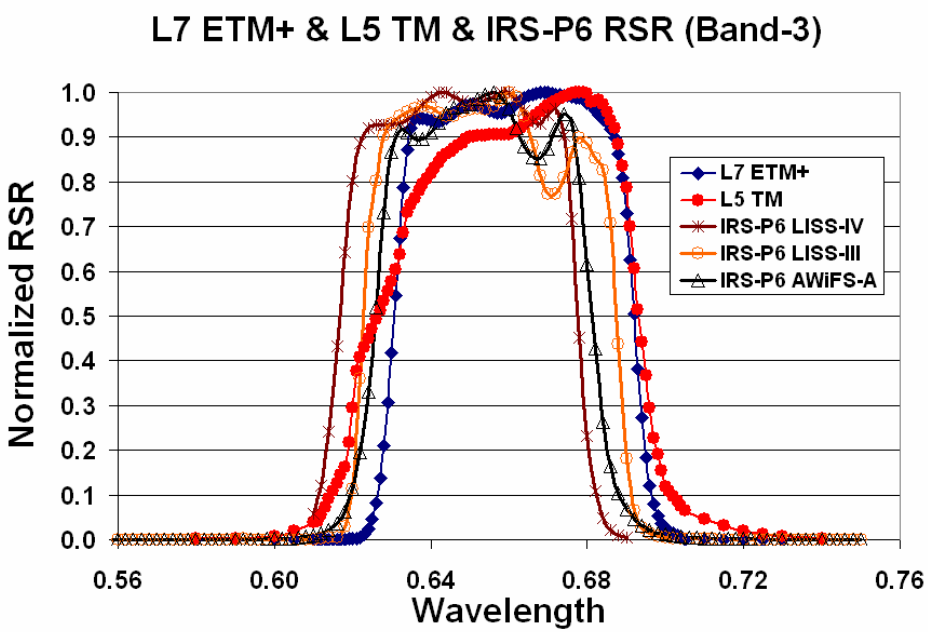
- **The A/D converter is 12 bits for AWiFS, LISS-III SWIR and LISS-IV (except LISS-III VNIR)**
  - The data is captured as 12 bits and the two least significant bits are ignored
  - The AWIFS data corresponding to all four bands are received as 10 bit parallel data
  - For the LISS-III SWIR bands, the selected 7 consecutive bits out of 10 bits generated at payload end are transmitted. The selection of 7 bits for SWIR band is done by bit sliding in the base band data handling (BDH) system formatter. In the formatter, any consecutive 7 bits out of 10 bits are selected by a data command before multiplexing the data
  - The BDH system of LISS-IV Camera receives the 10 bit parallel data from all 3 bands (B2, B3, B4), selects 7 consecutive bits out of the 10 bits received by bit sliding, formats the 7 bit data suitably depending on the mode of operation (Mono / Multispectral), appends the data with auxiliary information and after differential encoding transmits the data to RF system for QPSK modulation
  - The A/D converter is 7 bits for LISS-III VNIR bands. The data is captured and transmitted as 7-bits with four pre-gain settings options

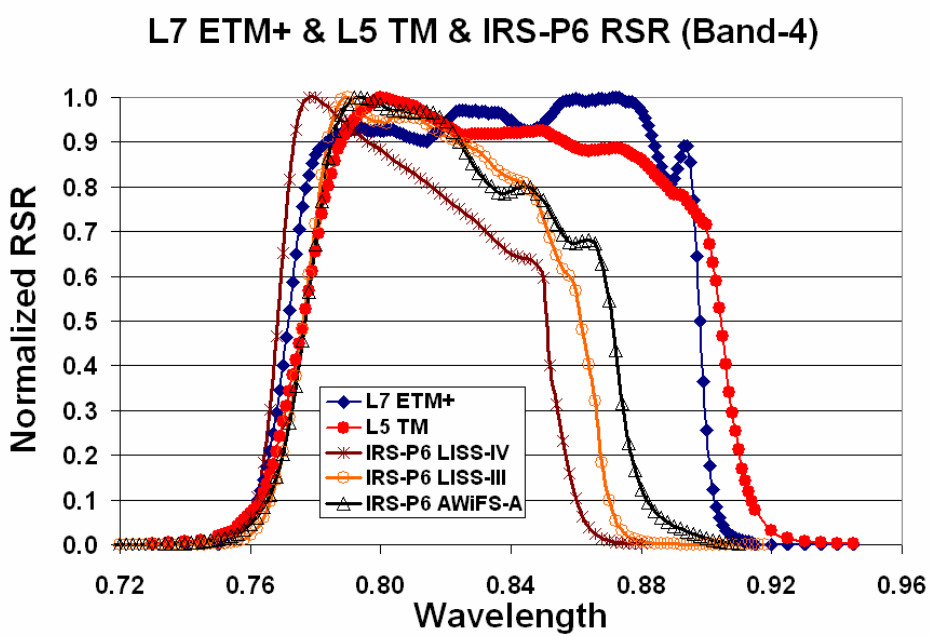
IRS-P6 Sensor Specifications

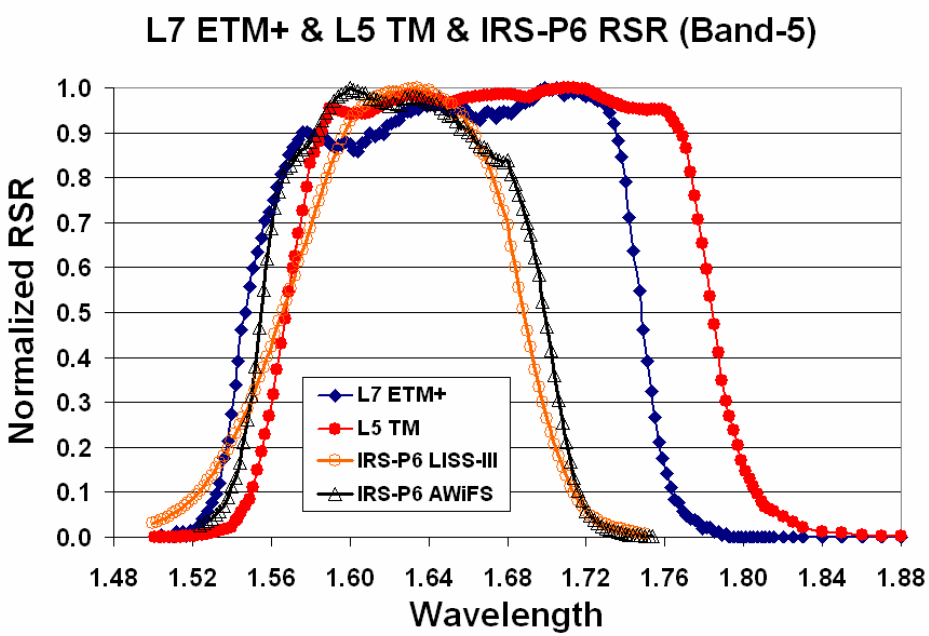
Resourcesat-1 Specifications			
	LISS IV	LISS III	AWiFS
Resolution (m)	5.8	23.5	56
Swath (km)	23.9 km (Mx)	141km	740 km
Spectral Bands (µm)	B2: 0.52-0.59	B2: 0.52-0.59	B2: 0.52-0.59
	B3: 0.62-0.68	B3: 0.62-0.68	B3: 0.62-0.68
	B4: 0.77-0.86	B4: 0.77-0.86	B4: 0.77-0.86
		B5: 1.55-1.70	B5: 1.55-1.70
Quantization (bits)	7	7	10
Integration Time (msec)	0.877714	3.32	9.96
No. of gains	Single gain	Four for B2,3,4	Single gain
Sensor	Pushbroom	Pushbroom	Pushbroom
CCD Arrays	1 * 12288	1 * 6000	2 * 6000
CCD Size (µm)	7 µm x 7 µm	10 µm x 7 µm	10 µm x 7 µm
Focal Length (mm)	982	347.5	139.5
Cross-track FOV for pixel (radiance)	0.0000071	0.0000288	0.0000717
Power (W)	216	70	114
Weight (kg)	169.5	106.1	103.6
Data Rate (MBPS)	105	52.5	52.5
Repeat Cycle (days)	5	24	5

Spectral Range (um) and Ground Sample Distance (m)							
	Landsat		CBERS			SPOT-4	IRS-P6
Band	L5 TM	L7 ETM+	HRCC	IRMSS	WFI		LISS-III
RC	16	16	26	26	5	26	24
1	0.450-0.520 (30)	0.450-0.515 (30)	0.45-0.52 (20)				
2	0.520-0.600 (30)	0.525-0.605 (30)	0.52-0.59 (20)			0.50-0.59 (20)	0.52-0.59 (23.5)
3	0.630-0.690 (30)	0.630-0.690 (30)	0.63-0.69 (20)		0.63-0.69 (260)	0.61-0.68 (20)	0.62-0.68 (23.5)
4	0.760-0.900 (30)	0.775-0.900 (30)	0.77-0.89 (20)		0.76-0.90 (260)	0.79-0.89 (20)	0.77-0.86 (23.5)
5	1.550-1.750 (30)	1.550-1.750 (30)		1.55-1.75 (80)		1.58-1.75 (20)	1.55-1.70 (23.5)
6	10.40-12.50 (120)	10.40-12.50 (60)		10.4-12.5 (160)			
7	2.080-2.350 (30)	2.090-2.350 (30)		2.08-2.35 (80)			
Pan		0.520-0.900 (15)	0.51-0.73 (20)	0.50-1.10 (80)		0.51-0.73 (10)	0.50-0.75 (5.8)

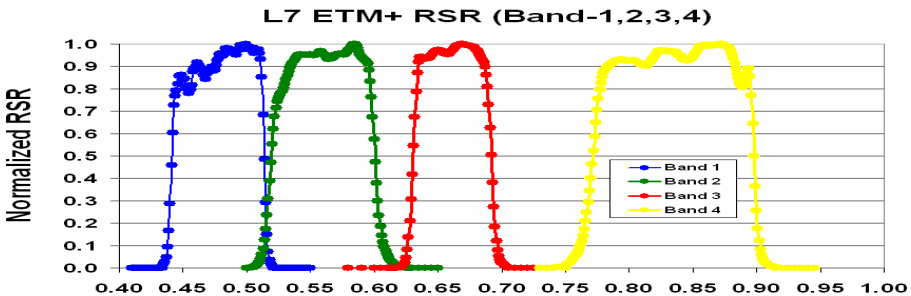

L7 ETM+ & L5 TM & IRS-P6 RSR (Band-2)
Normalized RSR
Wavelength
L7 ETM+
L5 TM
IRS-P6 LISS-IV
IRS-P6 LISS-III
IRS-P6 AWiFS-A

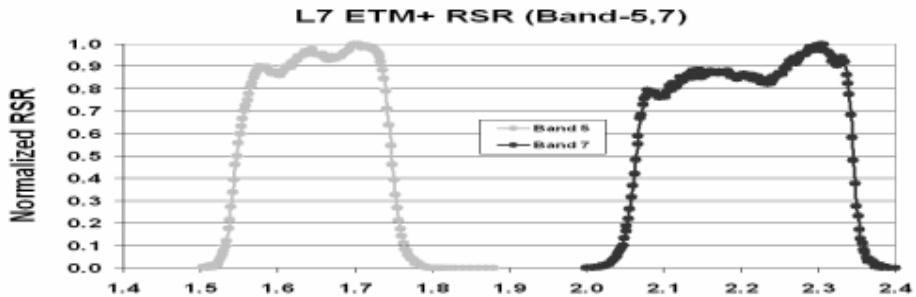

L7 ETM+ & L5 TM & IRS-P6 RSR (Band-3)
Normalized RSR
Wavelength
L7 ETM+
L5 TM
IRS-P6 LISS-IV
IRS-P6 LISS-III
IRS-P6 AWiFS-A

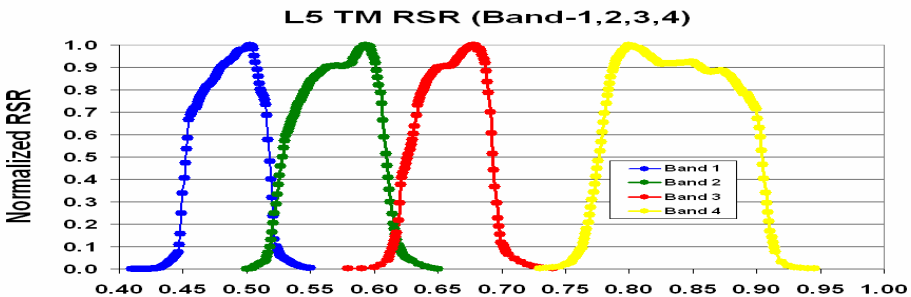

L7 ETM+ & L5 TM & IRS-P6 RSR (Band-4)
Normalized RSR
Wavelength
L7 ETM+
L5 TM
IRS-P6 LISS-IV
IRS-P6 LISS-III
IRS-P6 AWiFS-A

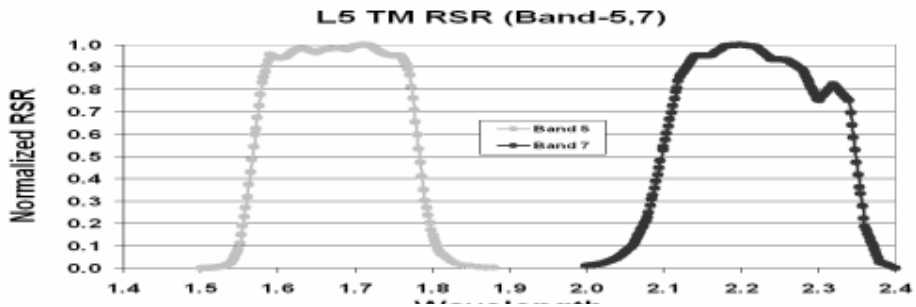

L7 ETM+ & L5 TM & IRS-P6 RSR (Band-5)
Normalized RSR
Wavelength
L7 ETM+
L5 TM
IRS-P6 LISS-III
IRS-P6 AWiFS

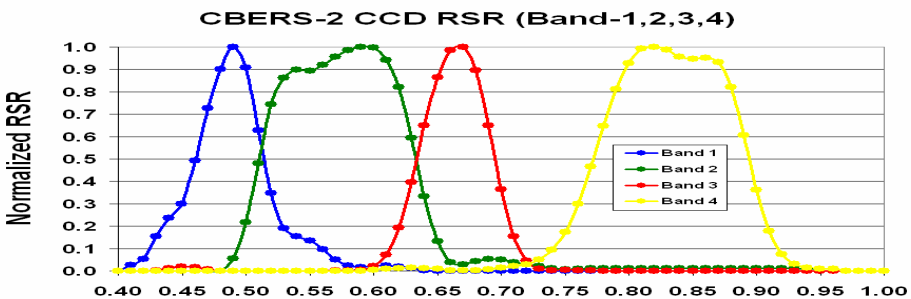
Relative Spectral Response (RSR) Profiles

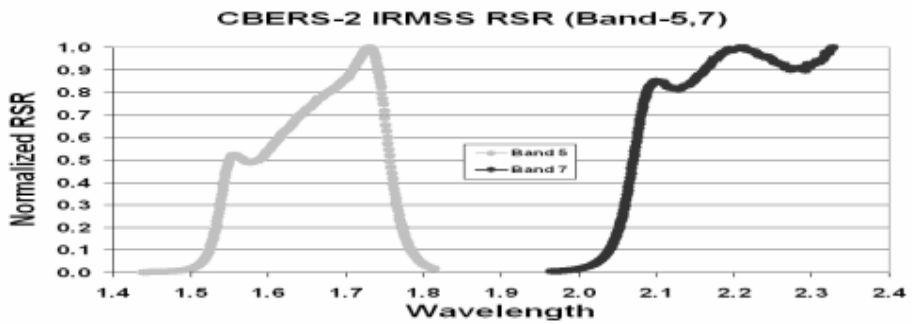


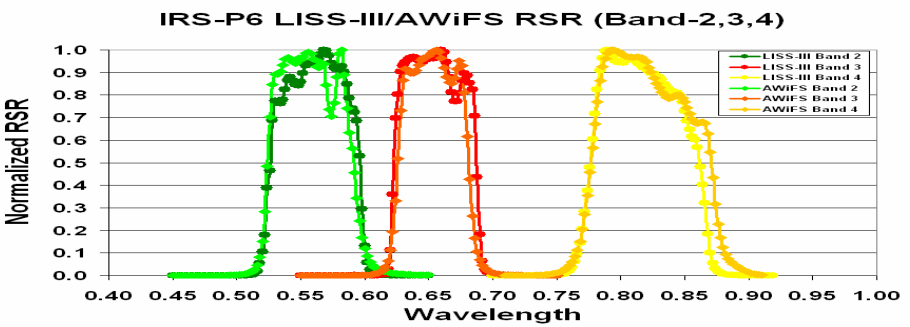


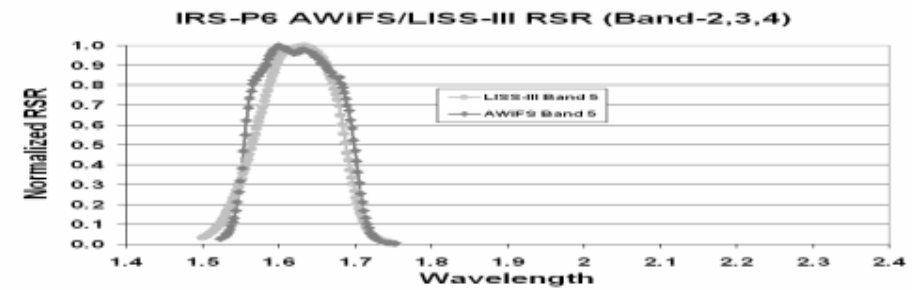












Corrections applied to IRS-P6 raw data

- **Raw data suffers from both geometric and radiometric distortions which have to be corrected**
- **The steps for performing the radiometric correction:**
  - Detector normalization
  - Failed degraded detector correction
  - Stagger correction for LISS-IV & SWIR bands of LISS-III & AWiFS
  - Line loss correction
  - Framing of required scene

Conversion to Radiance

$$L^* = \frac{(L_{max}-L_{min})}{Q_{calmax}} Q_{cal} + L_{min}$$

Where

- **L* = spectral radiance at the sensors aperture W/(m^2.sr.um)**
- **Qcal = Calibrated Digital Number**
- **Qcalmax = maximum possible DN value**
  - 255 for LISS-IV & LISS-III products,
  - 1023 for 10-bit AWiFS and 255 for 8-bit AWiFS products
- **Lmax & Lmin = scaled spectral radiance (provided in the header file)**
  - **For GeoTIFF products, these values are found in the Image Description field of the GeoTIFF header**
  - **For Fast Format products, values are in the HEADER.DAT**
  - **For LGSOWG products, values are in the leader file**

Ortho Generation: 10-to-8 bit rescaling

- **Ortho metadata provides DN-to-radiance scaling coefficients**

$$L_{rad} = \frac{DN_{10}}{1023} \cdot \left(L_{\max} - L_{\min}\right) + L_{\min}$$

DN_{10} = 10-bit pixel value

L_{min} = Min radiance value provided in scene metadata

L_{max} = Max radiance value provided in scene metadata

- **10- to 8-bit rescaling maintains integrity of DN-to-radiance coefficients**

$$DN_8 = DN_{10} \cdot \frac{255}{1023}$$

$$L_{rad} = \frac{DN_8}{255} \cdot \left(L_{\max} - L_{\min}\right) + L_{\min}$$

Header File Information (Lmax & Lmin)

LISS-IV Mono Band 3:

On board gain number for band 3 3
Minimum / maximum radiance for band 3 [mw/cm2/str/um] ... 0.00000 9.92230

LISS-III:

On board gain number for band 2 3
On board gain number for band 3 3
On board gain number for band 4 3
On board gain number for band 5 2
Minimum / maximum radiance for band 2 [mw/cm2/str/um] ... 0.00000 12.06400
Minimum / maximum radiance for band 3 [mw/cm2/str/um] ... 0.00000 15.13100
Minimum / maximum radiance for band 4 [mw/cm2/str/um] ... 0.00000 15.75700
Minimum / maximum radiance for band 5 [mw/cm2/str/um] ... 0.00000 3.39700

AWiFS-A camera (A&C quadrant scenes):

On board gain number for band 2 8
On board gain number for band 3 9
On board gain number for band 4 8
On board gain number for band 5 9
Minimum / maximum radiance for band 2 [mw/cm2/str/um] ... 0.00000 52.34000
Minimum / maximum radiance for band 3 [mw/cm2/str/um] ... 0.00000 40.75000
Minimum / maximum radiance for band 4 [mw/cm2/str/um] ... 0.00000 28.42500
Minimum / maximum radiance for band 5 [mw/cm2/str/um] ... 0.00000 4.64500

AWiFS-B camera (B&D quadrant scenes):

On board gain number for band 2 8
On board gain number for band 3 9
On board gain number for band 4 8
On board gain number for band 5 9
Minimum / maximum radiance for band 2 [mw/cm2/str/um] ... 0.00000 52.34000
Minimum / maximum radiance for band 3 [mw/cm2/str/um] ... 0.00000 40.75000
Minimum / maximum radiance for band 4 [mw/cm2/str/um] ... 0.00000 28.42500
Minimum / maximum radiance for band 5 [mw/cm2/str/um] ... 0.00000 4.64500

Radiance to TOA Reflectance

$$\rho_p = \frac{\Pi \bullet L_\lambda \bullet d^2}{ESUN_\lambda \bullet \cos\theta_s}$$

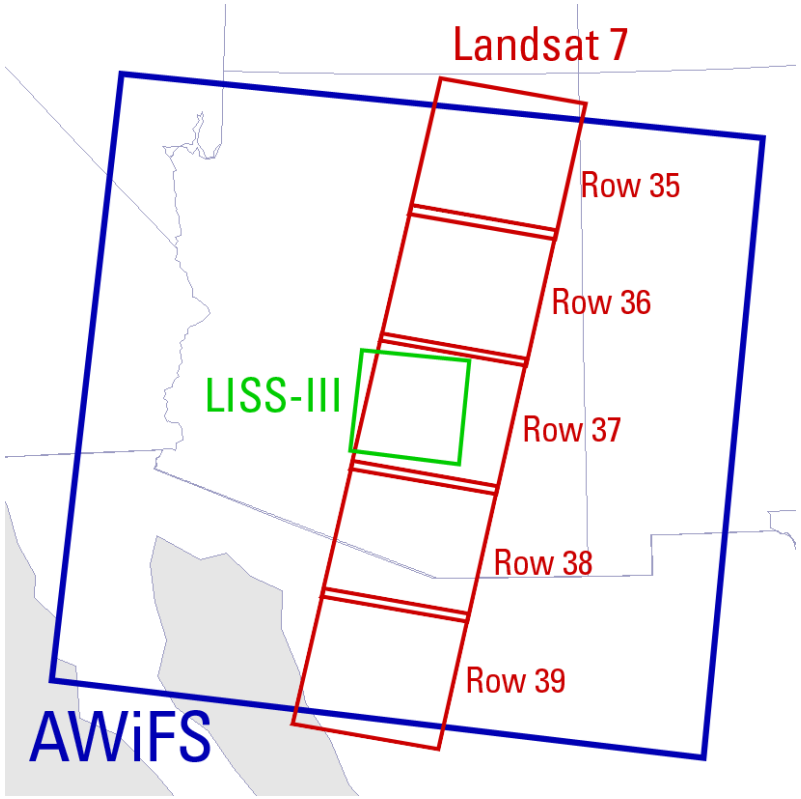
Solar Exoatmospheric Spectral Irradiances (ESUN) values using CHKUR MODTRAN 4.0 spectrum (ESUN units = W/m2 µm)

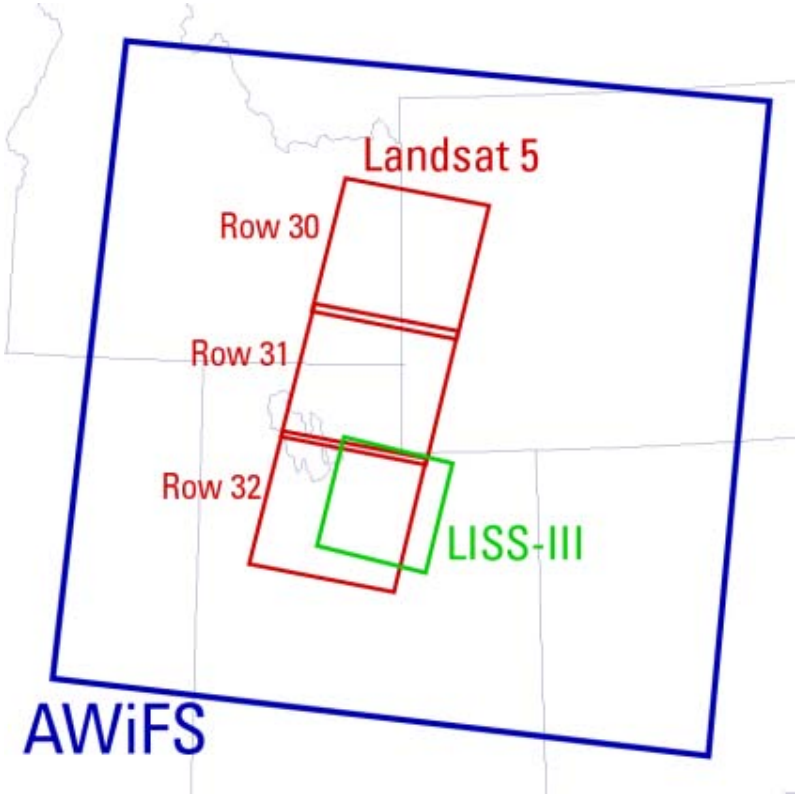
Bands	L5 TM	L7 ETM+	LISS-III	AWiFS
2	1826.000	1840.000	1846.770	1849.820
3	1554.000	1551.000	1575.500	1579.370
4	1036.000	1044.000	1087.340	1075.110
5	215.000	225.700	236.651	235.831

Cross-Calibration Methodology

- **Co-incident image pairs from the two sensors were compared**
- **The cross-cal was performed using image statistics from large common areas observed by the two sensors**
  - Define Regions of Interest over identical homogenous regions
  - Calculate the mean and standard deviation of the ROIs
  - Convert the satellite DN to reflectance
- **Perform a linear fit between the satellites to calculate the cross-calibration gain and bias**

Image boundaries of scenes used





Comparison Scenes Used -- Mesa, AZ

Mesa, Arizona collection, June 29, 2005

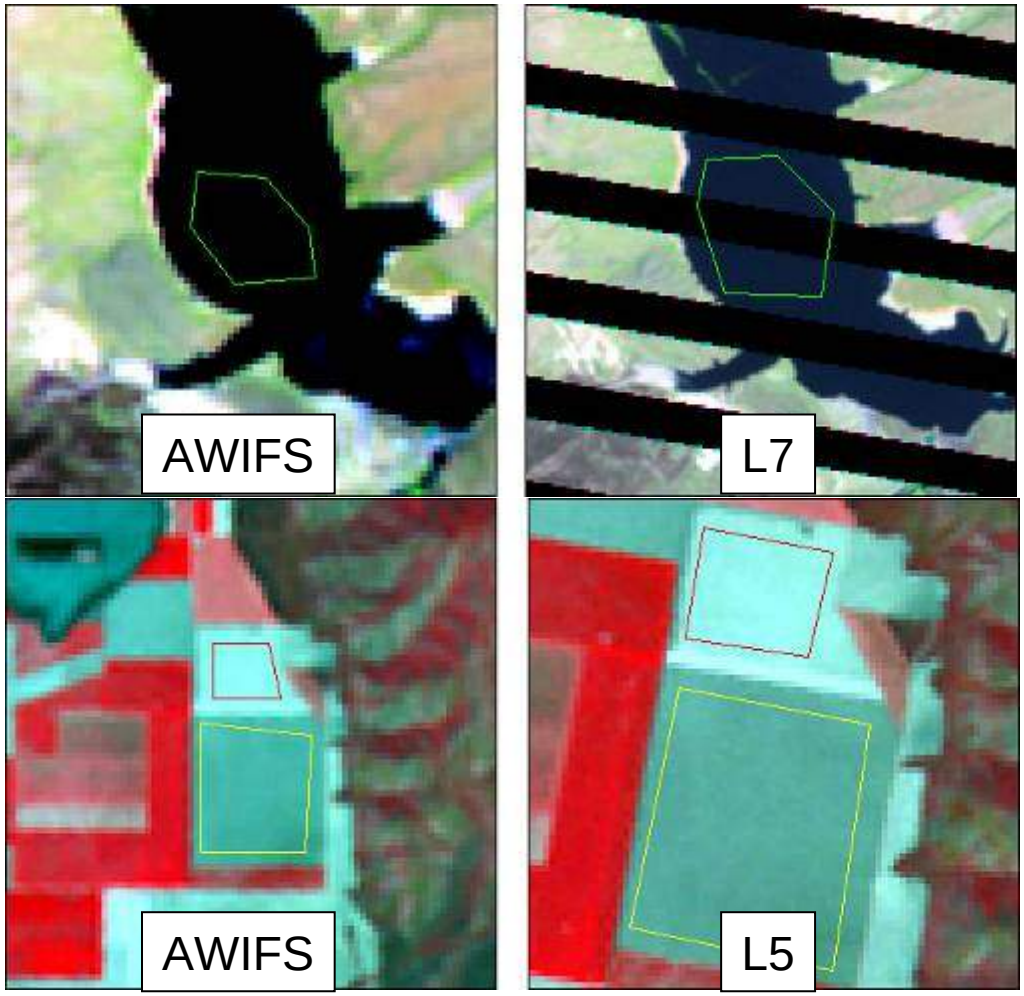
Instrument	Product ID	Path	Row	Solar Elevation
Landsat 7 ETM+	L71036035_03520050629	36	35	65.21 °
Landsat 7 ETM+	L71036036_03620050629	36	36	65.53 °
Landsat 7 ETM+	L71036037_03720050629	36	37	65.77 °
Landsat 7 ETM+	L71036038_03820050629	36	38	65.94 °
Landsat 7 ETM+	L71036039_03920050629	36	39	66.02 °
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 °

Comparison Scenes Used -- SLC, UT

Salt Lake City, Utah collection, June 19, 2005

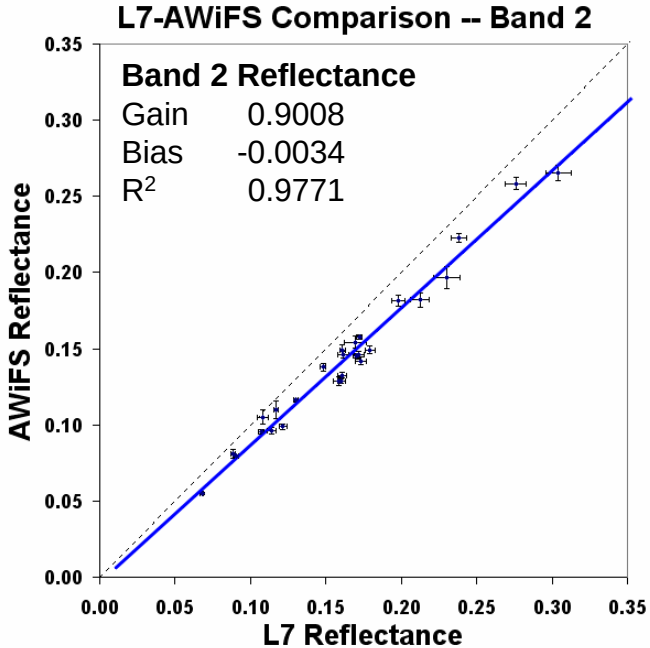
Instrument	Product ID	Path	Row	Solar Elevation
Landsat 5 TM	LT5038030000517010	38	30	62.95 °
Landsat 5 TM	LT5038031000517010	38	31	63.59 °
Landsat 5 TM	LT5038032000517010	38	32	64.18 °
AWiFS Quad A	000010491201	255	40	65.50 °
AWiFS Quad B	000010491301	255	40	68.10 °
AWiFS Quad C	000010491401	255	40	67.50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

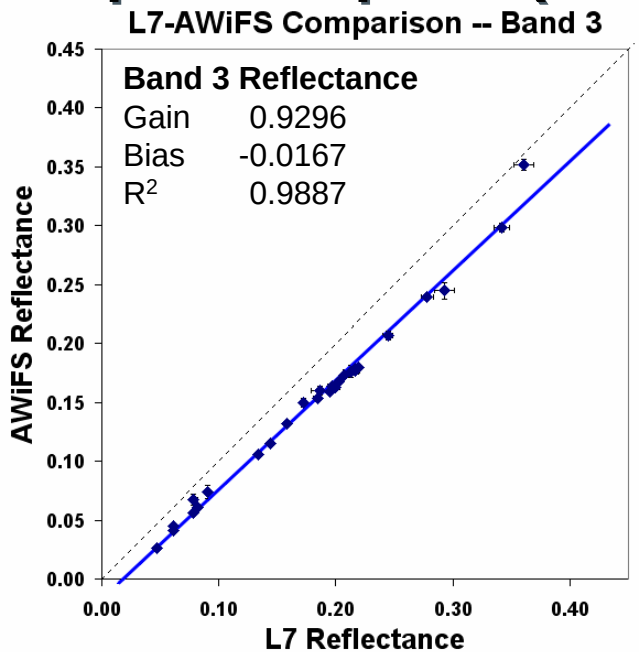
Regions of Interest (ROI)

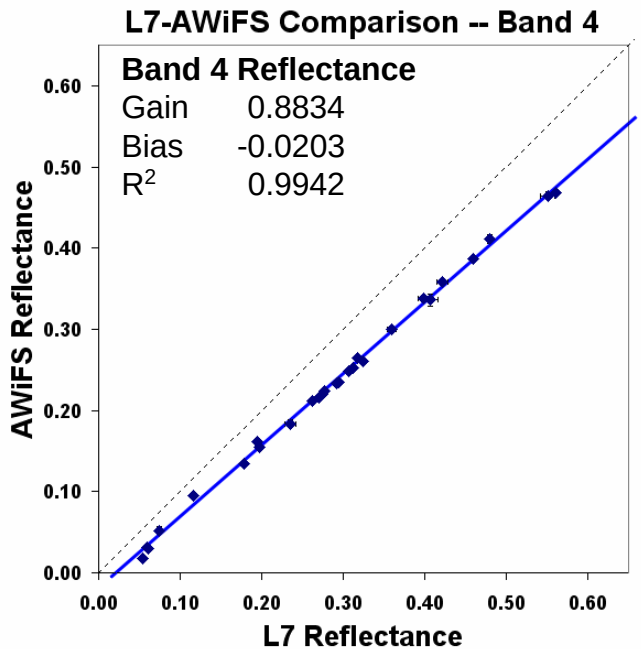


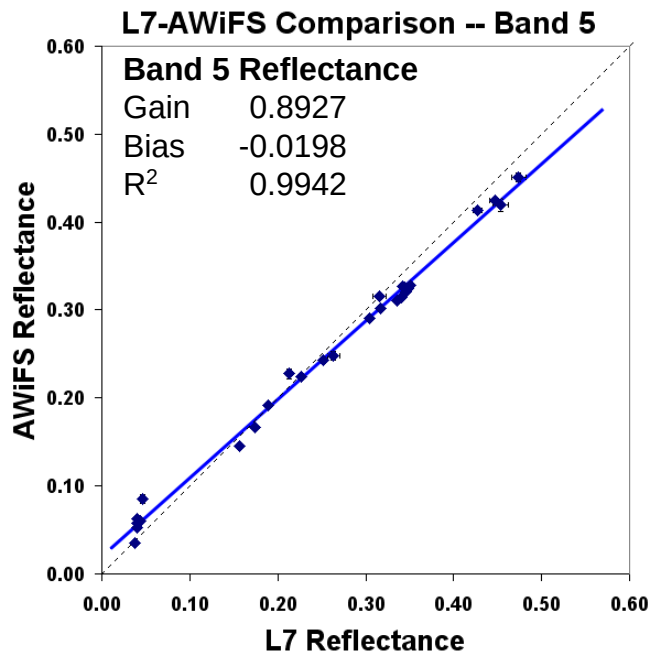
- **ROI were selected in both AWiFS and Landsat data**
- **Mesa, AZ collection --**
  - Five WRS-2 L7 scenes
  - 27 ROIs
- **SLC, UT collection --**
  - Three WRS-2 L5 scenes
  - 34 ROIs
- **All AWiFS quadrants were represented in both collections**
- **ROIS were selected over homogenous regions (standard deviation < 10 DN)**
- **Gaps in L7 data were discarded**

AWiFS / ETM+ reflectance comparison plots (Mesa, AZ)

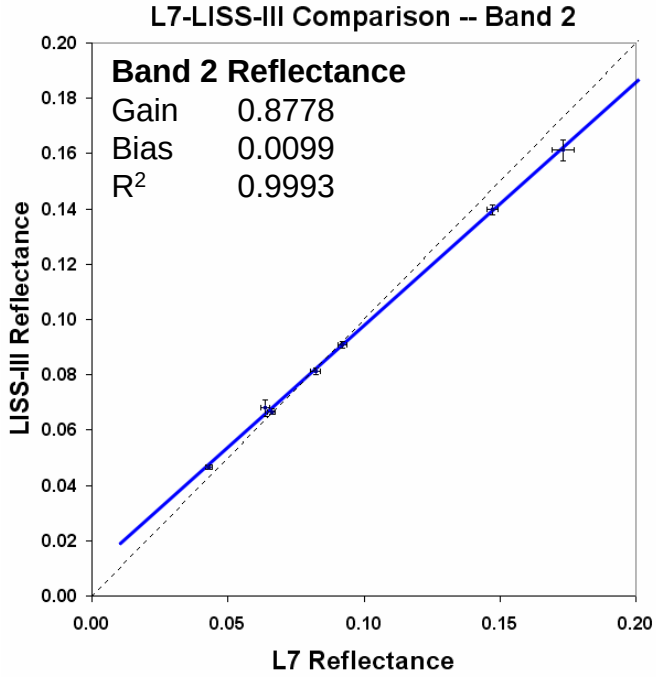


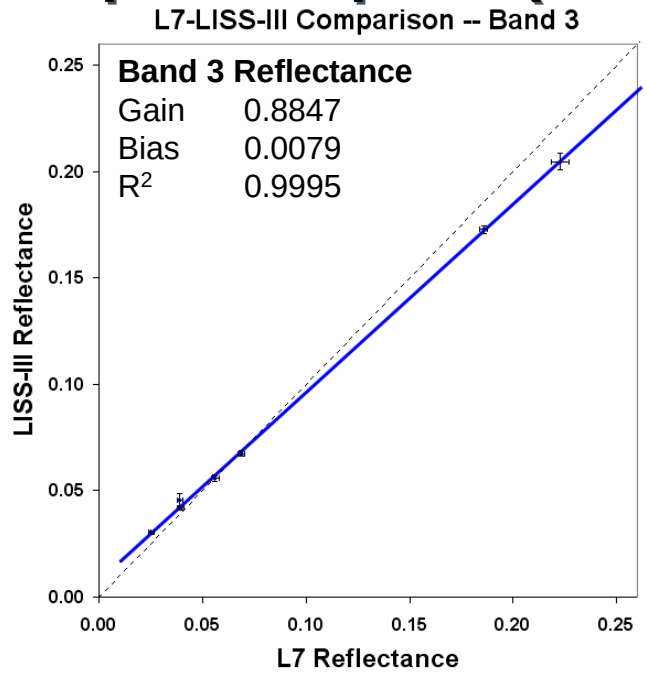


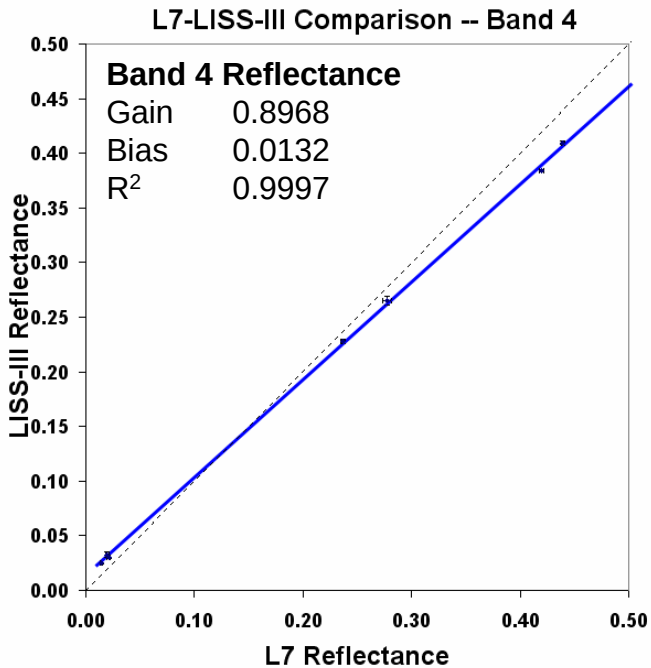


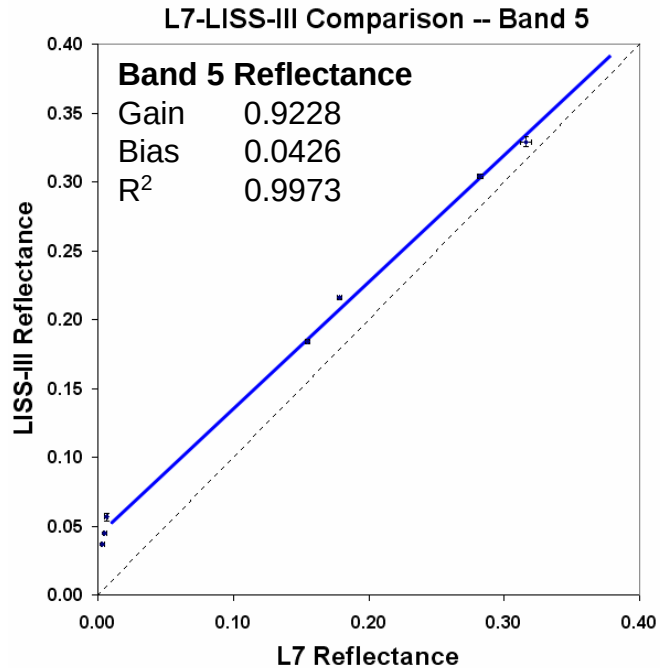


LISS-III / ETM+ reflectance comparison plots (Mesa, AZ)

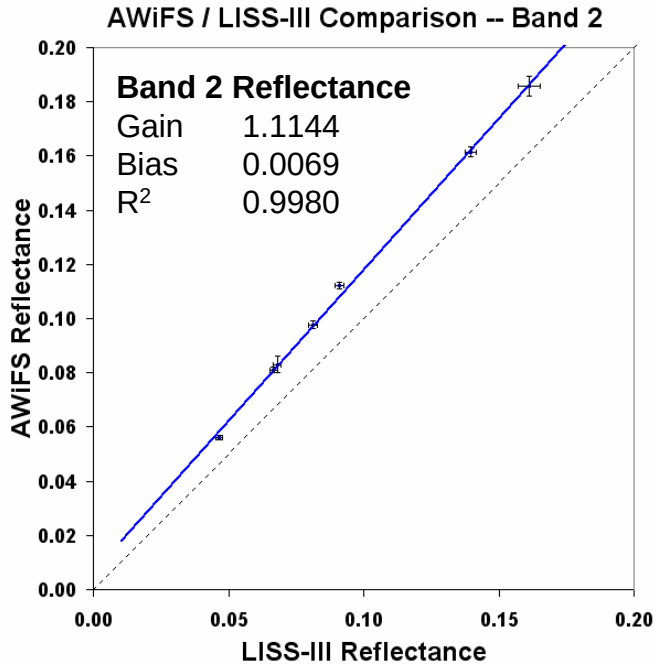


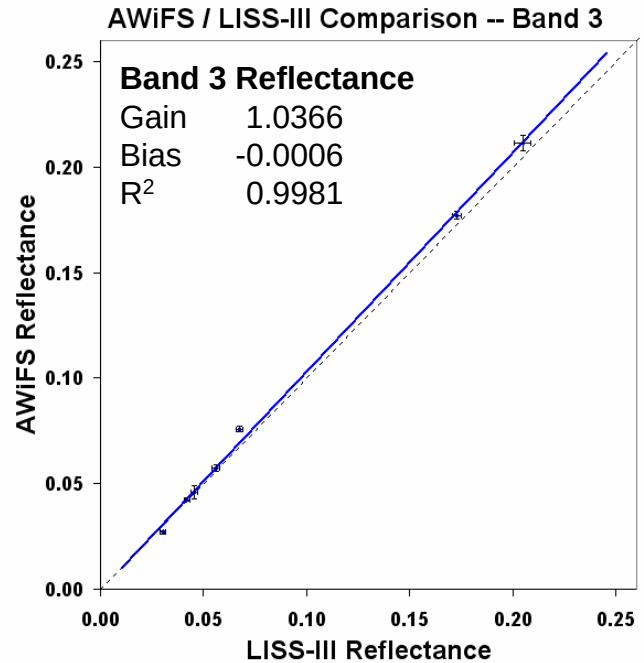


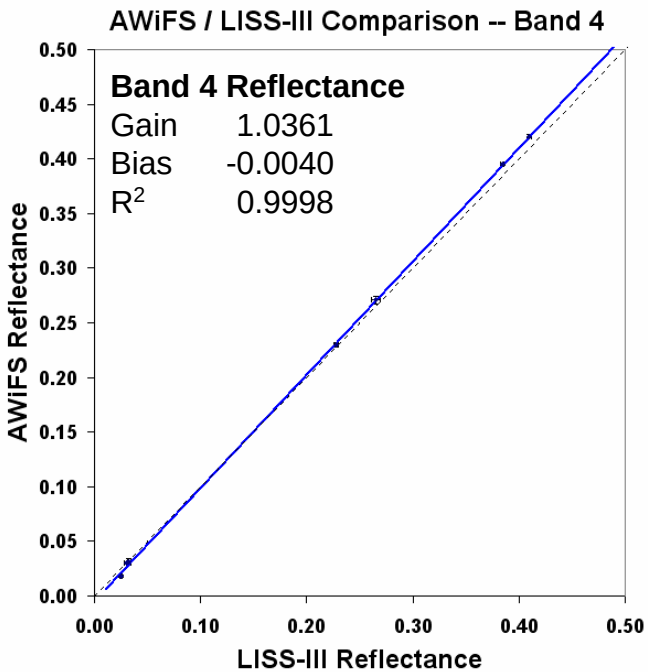


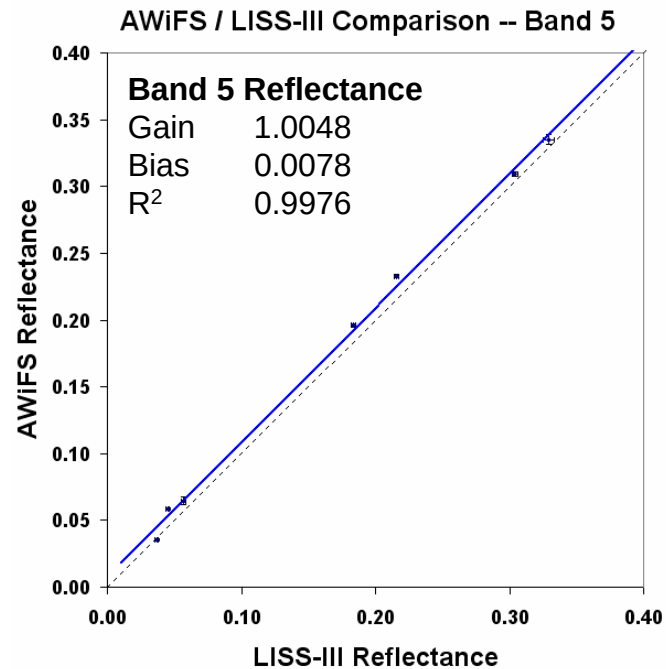


AWiFS / LISS-III reflectance comparison plots (Mesa, AZ)









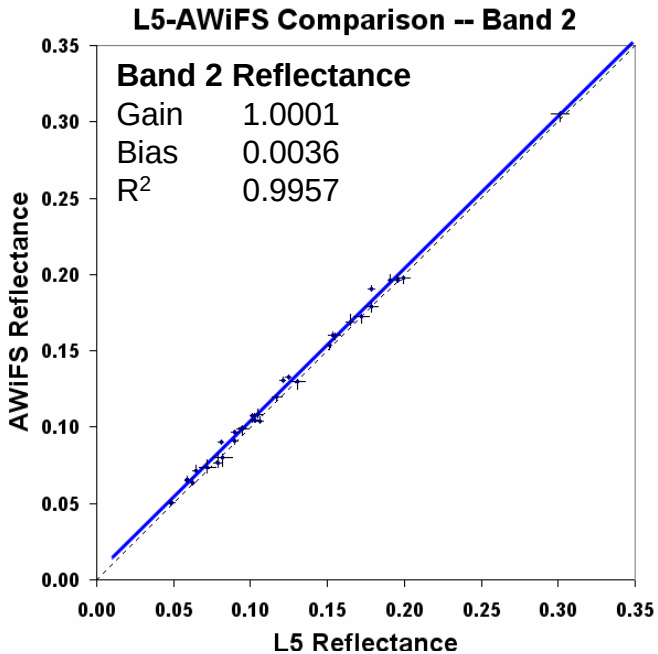
Mesa, AZ Cross Calibration Results

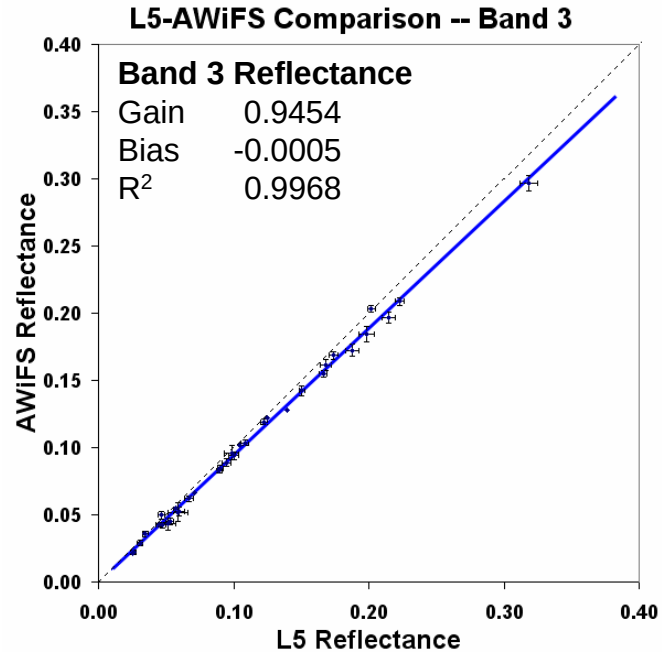
	AWiFS/ETM+ Reflectance (Mesa, AZ)				
Band	**Gain**	**σ(gain)**	**Bias**	**σ(bias)**	**R^2**
2	**0.9008**	0.0276	**-0.0034**	0.0047	0.9771
3	**0.9296**	0.0199	**-0.0167**	0.0039	0.9887
4	**0.8834**	0.0077	**-0.0203**	0.0024	0.9981
5	**0.8927**	0.0136	**0.0198**	0.0039	0.9942

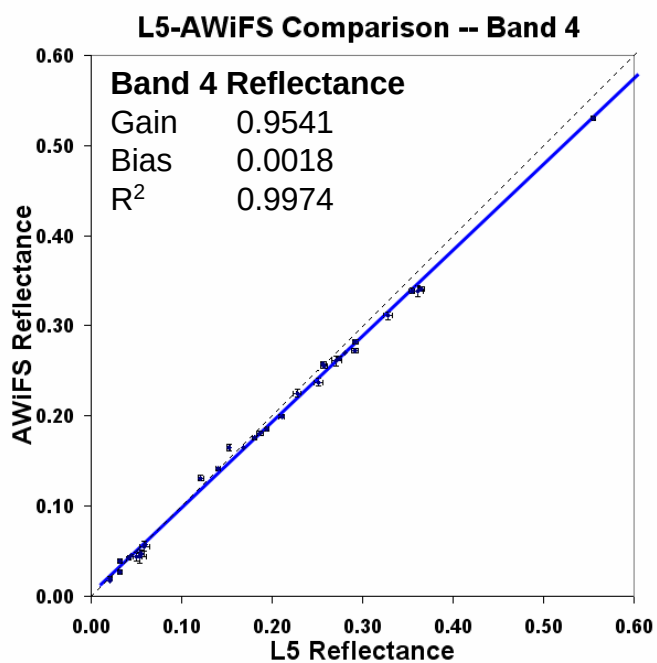
	LISS-III/ETM+ Reflectance (Mesa, AZ)				
Band	**Gain**	**σ(gain)**	**Bias**	**σ(bias)**	**R^2**
2	**0.8778**	0.0107	**0.0099**	0.0011	0.9993
3	**0.8847**	0.0088	**0.0079**	-0.0010	0.9995
4	**0.8968**	0.0075	**0.0132**	0.0020	0.9997
5	**0.9228**	0.0214	**0.0426**	0.0039	0.9973

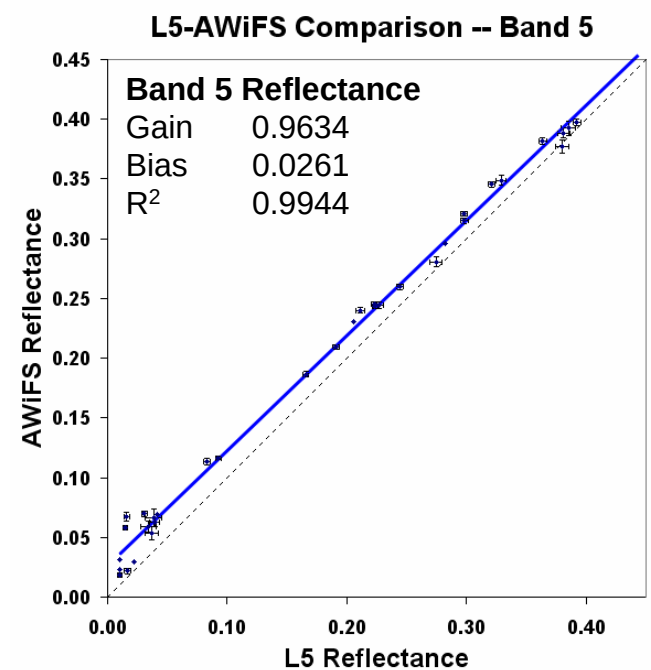
	AWiFS/LISS-III Reflectance (Mesa, AZ)				
Band	**Gain**	**σ(gain)**	**Bias**	**σ(bias)**	**R^2**
2	**1.1144**	0.0223	**0.0069**	0.0023	0.9980
3	**1.0366**	0.0204	**-0.0006**	0.0022	0.9981
4	**1.0361**	0.0058	**-0.0040**	0.0015	0.9998
5	**1.0048**	0.0221	**0.0078**	0.0045	0.9976

AWiFS / TM reflectance comparison plots (SLC, UT)

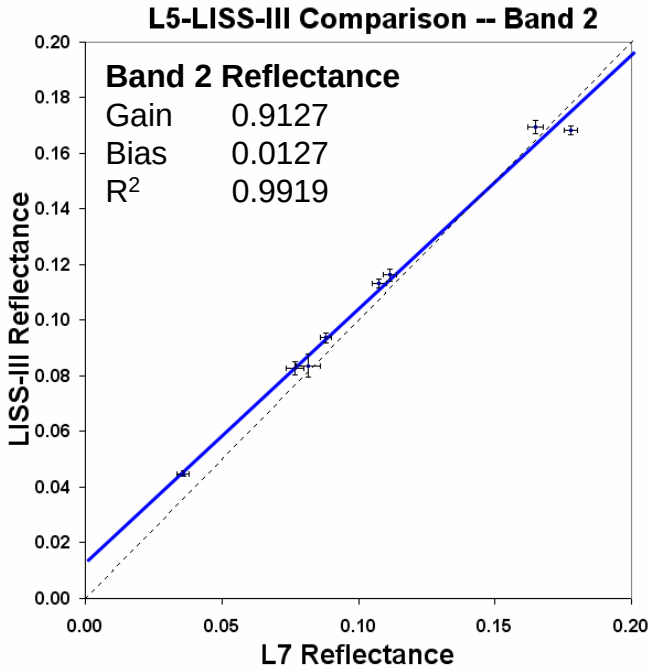


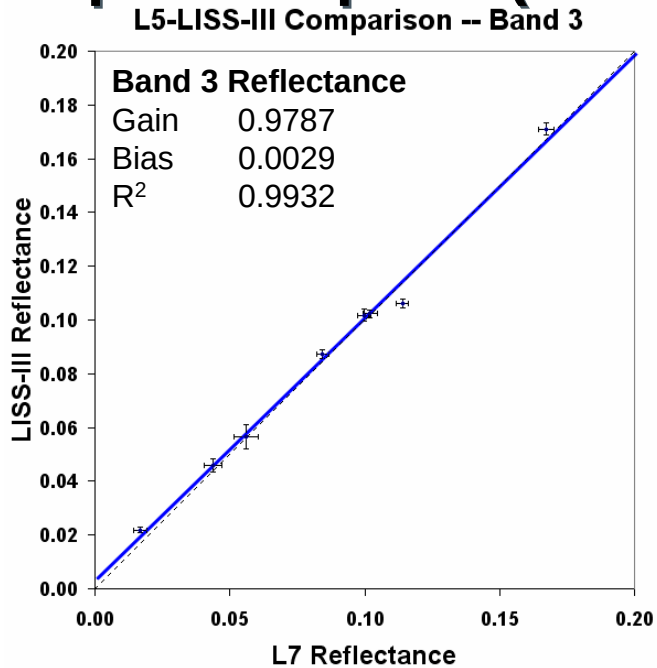


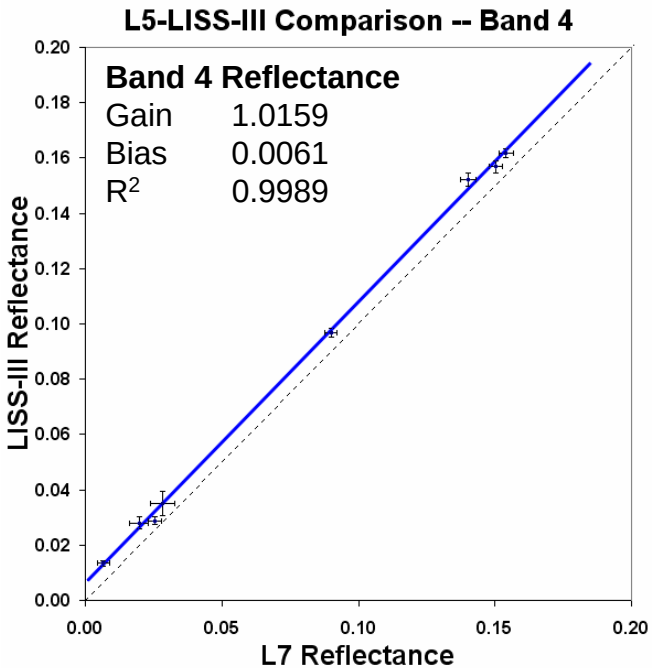


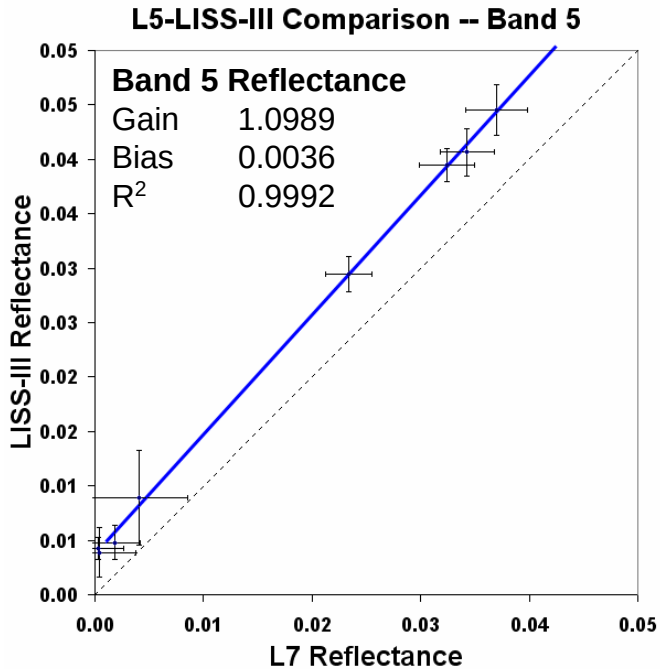


LISS-III / TM reflectance comparison plots (SLC, UT)

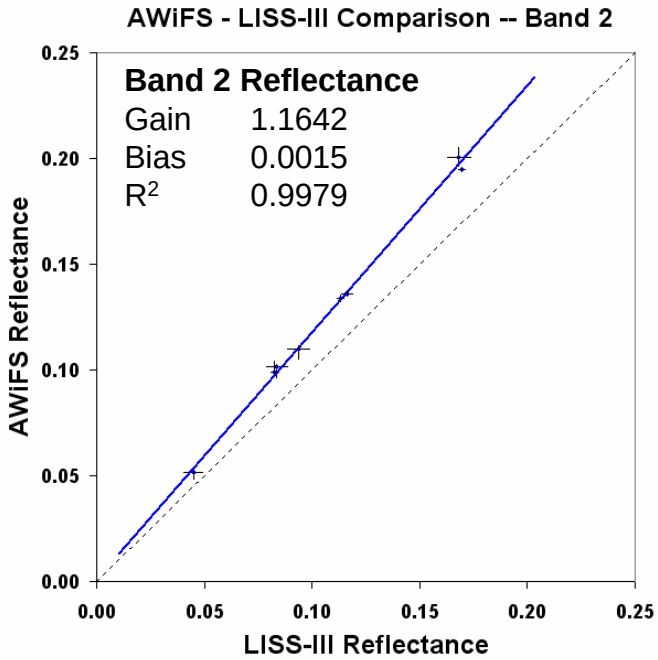


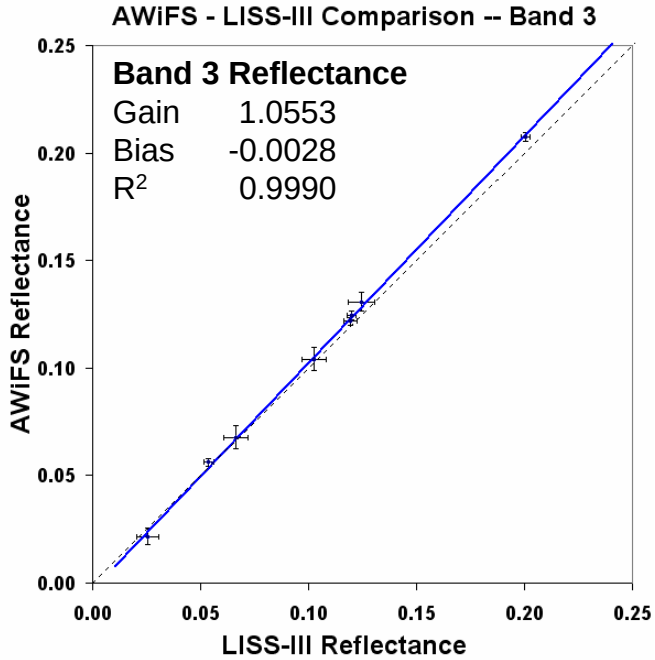


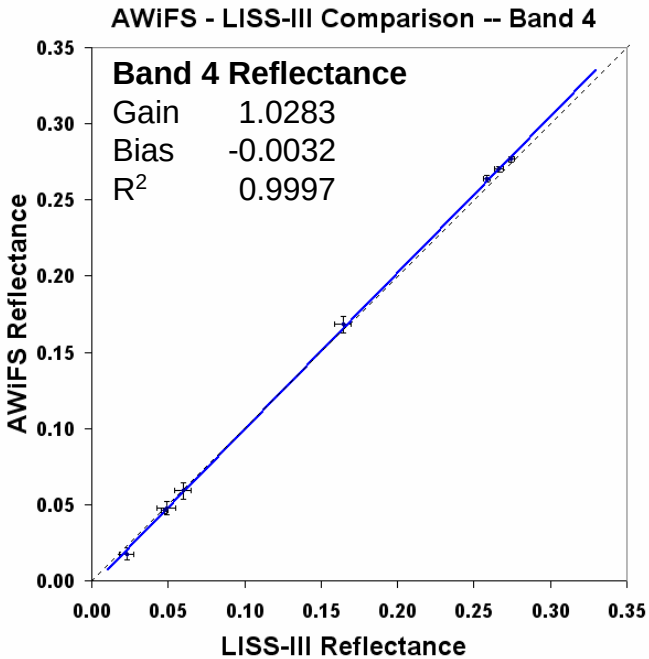


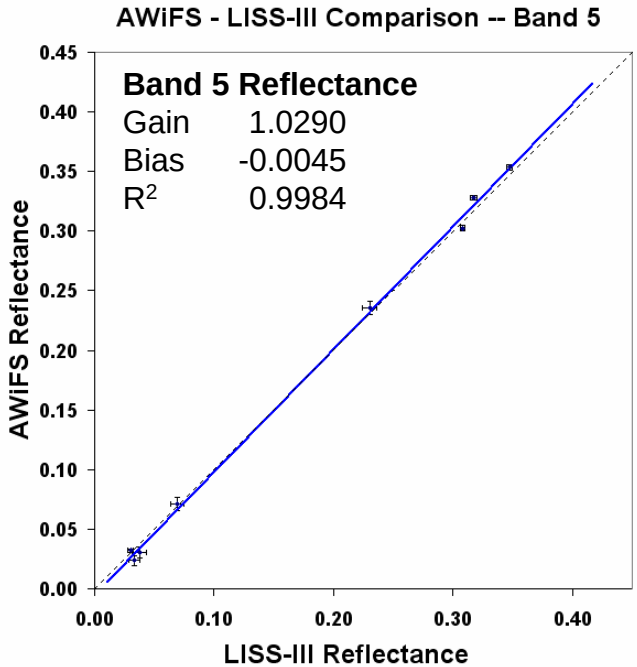


AWiFS / LISS-III reflectance comparison plots (SLC, UT)









SLC, UT Cross Calibration Results

AWiFS/TM Reflectance (SLC, UT)					
Band	**Gain**	**σ(gain)**	**Bias**	**σ(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

LISS-III/TM Reflectance (SLC, UT)					
Band	**Gain**	**σ(gain)**	**Bias**	**σ(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

AWiFS/LISS-III Reflectance (SLC, UT)					
Band	**Gain**	**σ(gain)**	**Bias**	**σ(bias)**	**R^2**
2	**1.1642**	0.0218	**0.0015**	0.0025	0.9979
3	**1.0553**	0.0139	**-0.0028**	0.0016	0.9990
4	**1.0283**	0.0067	**-0.0032**	0.0012	0.9997
5	**1.0290**	0.0170	**-0.0045**	0.0037	0.9984

Conclusion

- An initial cross calibration of the L7 ETM+ and L5 TM with the IRS-P6 AWiFS and LISS-III Sensors was performed
- The approach involved calibration of nearly simultaneous surface observations based on image statistics from areas observed simultaneously by the two sensors
- The results from the cross calibration are summarized in the table below

Differences between Sensors

	ETM+	TM	AWiFS	LISS-III
ETM+		-	8-12%	8-13%
TM	-		0-6%	2-10%
AWiFS	8-12%	0-6%		1-16%
LISS-III	8-13%	2-10%	1-16%	