Cross-calibration of the L7 ETM+, L5 TM, IRS-P6 AWiFS/LISS-III, and CBERS-2 HRCCD sensors

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Contractor to the USGS EROS

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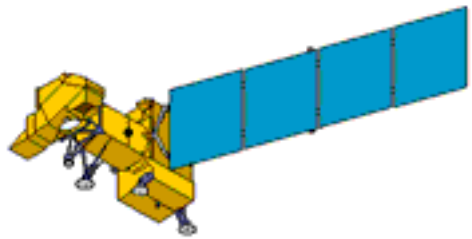
Outline

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

Landsat Mission Status

Landsat 5 TM

- **L5 celebrated 23-years of on-orbit operations!**
- **Solar Array Drive Malfunction (Nov. 2005)**
  - Both primary and redundant drives failed
  - On Aug. 14, 2006, placed solar array in fixed position
- **Imaging suspended due to battery-2 anomaly (Oct. 6, 2007)**



Landsat 7 ETM+

- **On orbit for 8 years**
- **Switch normal operations over to Bumper mode on Apr. 1, 2007**
- **Scan Line Corrector (SLC) malfunction (May 31, 2003)**
  - These gaps represent a data loss of ~ 25% for any given scene
  - New capability to improve the SLC-off data products

ResourceSat-1 (IRS- P6) Overview

- The IRS-P6 satellite was launched into a polar sun-synchronous orbit on October 17, 2003, with a design life of 5 years
- IRS-P6 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 sensors are “Pushbroom” scanners using linear arrays of CCDs
- IRS-P6 also carries an onboard SSR with a capacity of 120 GB

IRS-P6 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.
Repeat Cycle (LISS-III)	24 days
Repeat Cycle (LISS-IV)	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
Semimajor axis	7195.11
Eccentricity	0.001
Mission Life	5 years

IRS-P6 Sesnsor 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 B3: 0.62-0.68 B4: 0.77-0.86	B2: 0.52-0.59 B3: 0.62-0.68 B4: 0.77-0.86 B5: 1.55-1.70	B2: 0.52-0.59 B3: 0.62-0.68 B4: 0.77-0.86 B5: 1.55-1.70
Quantization (bits)	7	7	10
Repeat Cycle (days)	5	24	5
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

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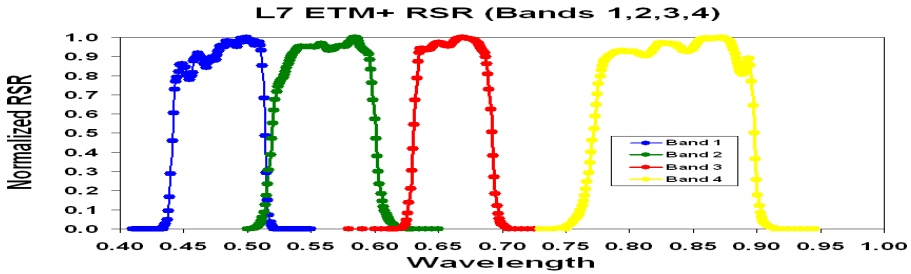

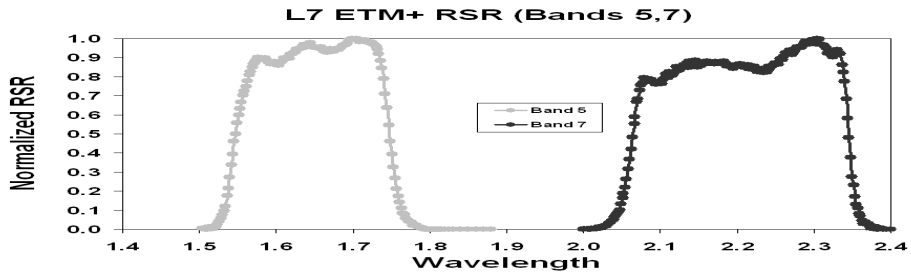

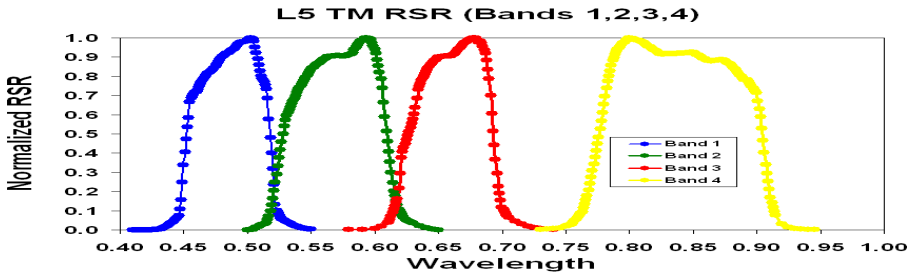

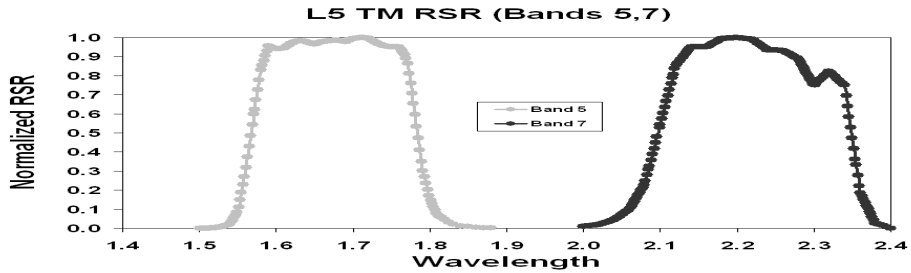

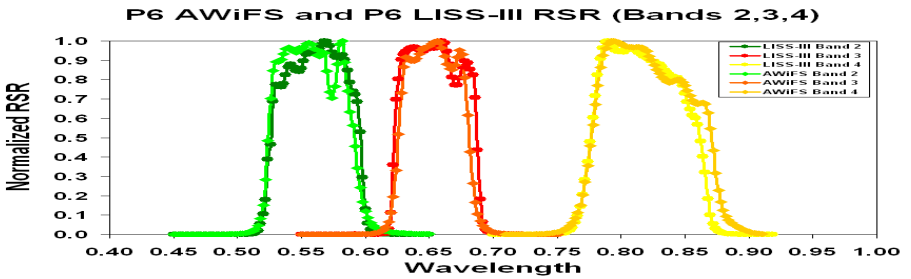

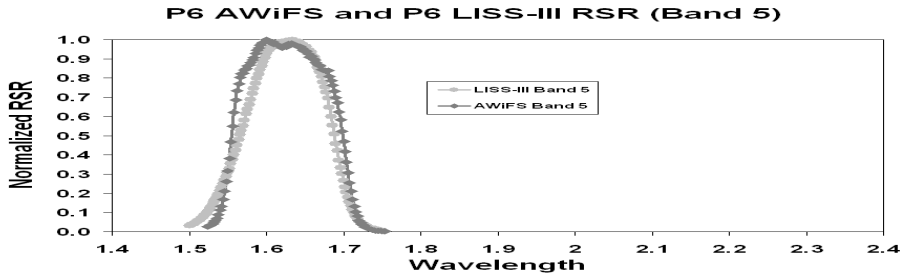

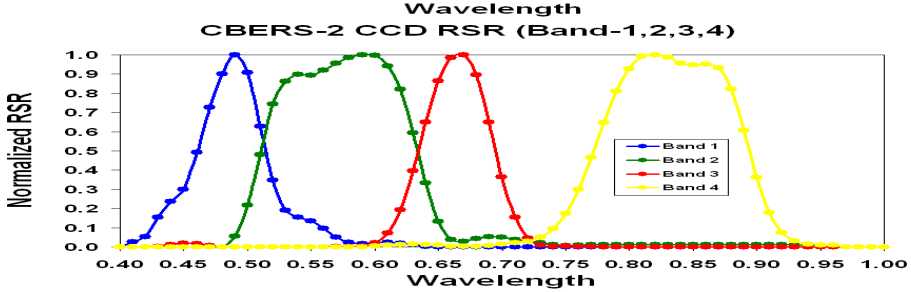

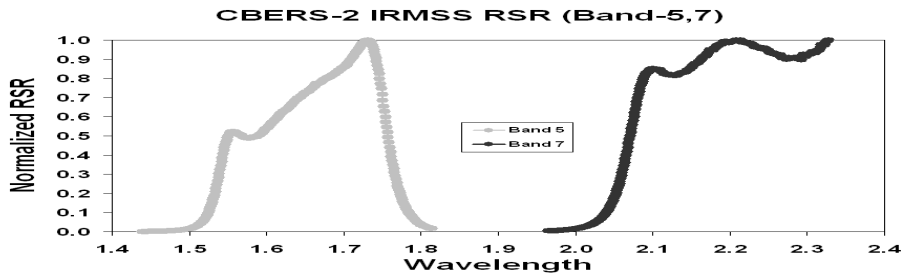

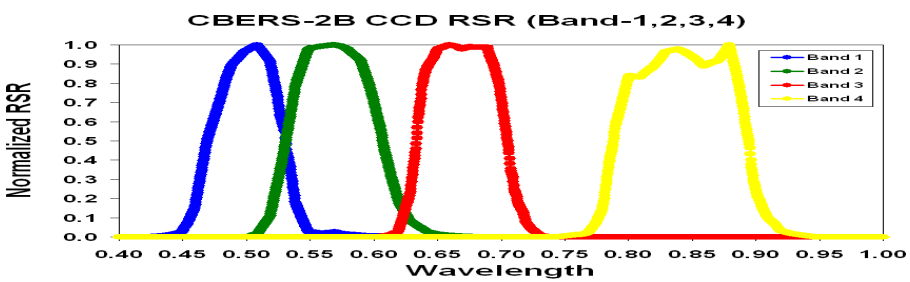

Normalized Relative Spectral Responses (RSR)

Conversion to Radiance

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

Where

- L* = spectral radiance at the sensor's aperture
- Qcal = Calibrated Digital Number
- Qcalmax = maximum possible DN value
  - 255 for LISS-IV & LISS-III products
  - 1023 for 10-bit AWiFS
  - 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

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

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

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

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Header File Information (Lmax & Lmin)

LISS-IV Mono Band 3:

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

LISS-III:

Onboard gain number for band 2 3
Onboard gain number for band 3 3
Onboard gain number for band 4 3
Onboard 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):

Onboard gain number for band 2 8
Onboard gain number for band 3 9
Onboard gain number for band 4 8
Onboard 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):

Onboard gain number for band 2 8
Onboard gain number for band 3 9
Onboard gain number for band 4 8
Onboard 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

Conversion to Reflectance

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

ESUN values using the CHKUR MODTRAN 4.0 spectrum (UNITS = W/m² µm)

Bands	L5 TM	L7 ETM+	P6 LISS-III	P6 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

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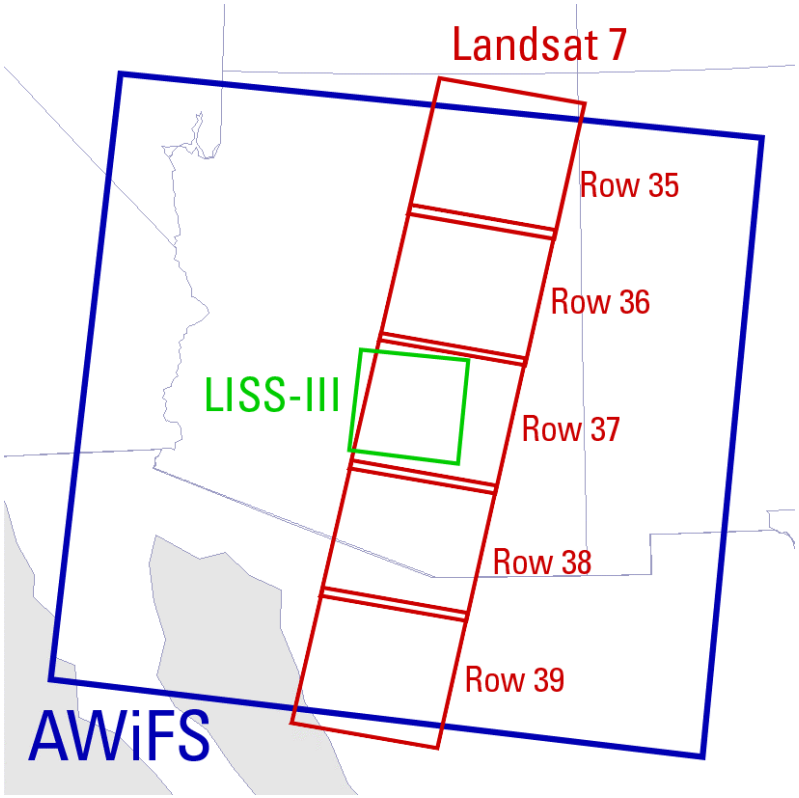
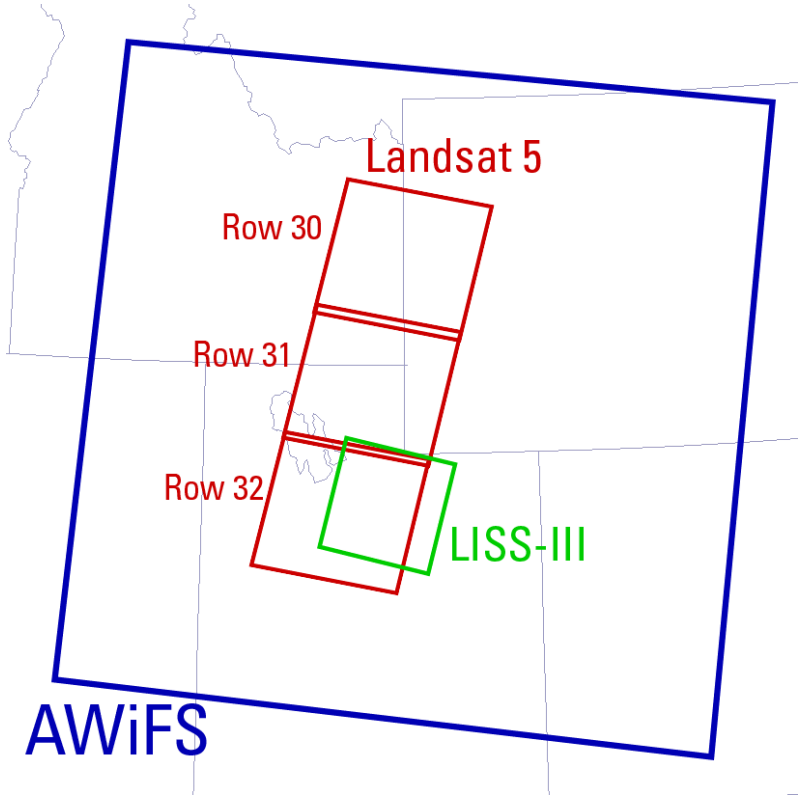
Cross-Calibration Methodology

- **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



Location: Mesa, AZ
Acquisition Date: June 29, 2005



Location: Salt Lake City, UT
Acquisition Date: June 19, 2005

Coincident Landsat and IRS-P6 scenes

Sensor	Product ID	Path	Row	Time (GMT)	Solar Elevation
Location: Mesa, AZ (June 29, 2005)					
Landsat 7 ETM+	L71036035_03520050629	36	35	17:46:25	65.21 °
Landsat 7 ETM+	L71036036_03620050629	36	36	17:46:49	65.53 °
Landsat 7 ETM+	L71036037_03720050629	36	37	17:47:13	65.77 °
Landsat 7 ETM+	L71036038_03820050629	36	38	17:47:37	65.94 °
Landsat 7 ETM+	L71036039_03920050629	36	39	17:48:01	66.02 °
AWiFS Quad A	AW257047A001	257	47	18:17:35	69.50 °
AWiFS Quad B	AW257047B001	257	47	18:17:35	72.60 °
AWiFS Quad C	AW257047C001	257	47	18:18:23	70.30 °
AWiFS Quad D	AW257047D001	257	47	18:18:23	73.60 °
LISS-III	L32570470101	257	47	18:18:14	71.48 °
Location: Salt Lake City, UT (June 19, 2005)					
Landsat 5 TM	LT5038030000517010	38	30	17:54:58	62.95 °
Landsat 5 TM	LT5038031000517010	38	31	17:55:22	63.59 °
Landsat 5 TM	LT5038032000517010	38	32	17:55:46	64.18 °
AWiFS Quad A	000010491201	255	40	18:23:45	65.50 °
AWiFS Quad B	000010491301	255	40	18:23:45	68.10 °
AWiFS Quad C	000010491401	255	40	18:24:39	67.50 °
AWiFS Quad D	000010491501	255	40	18:24:39	70.30 °
LISS-III	000010491601	255	41	18:24:51	68.64 °

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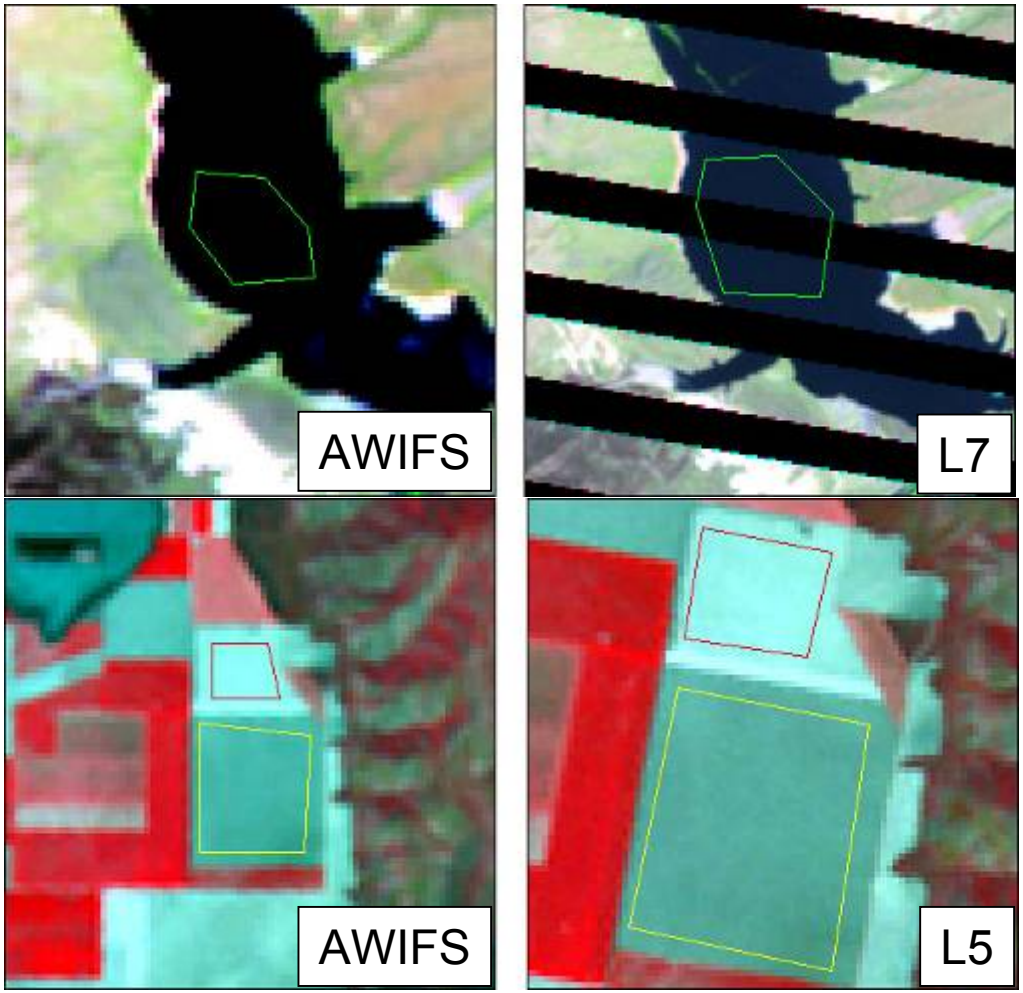
Regions of Interest (ROI)



- **ROI were selected in both AWiFS and Landsat data**
- **ROI were selected over homogenous regions (standard deviation < 10 DN)**
- **Gaps in L7 data were discarded**
- **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**

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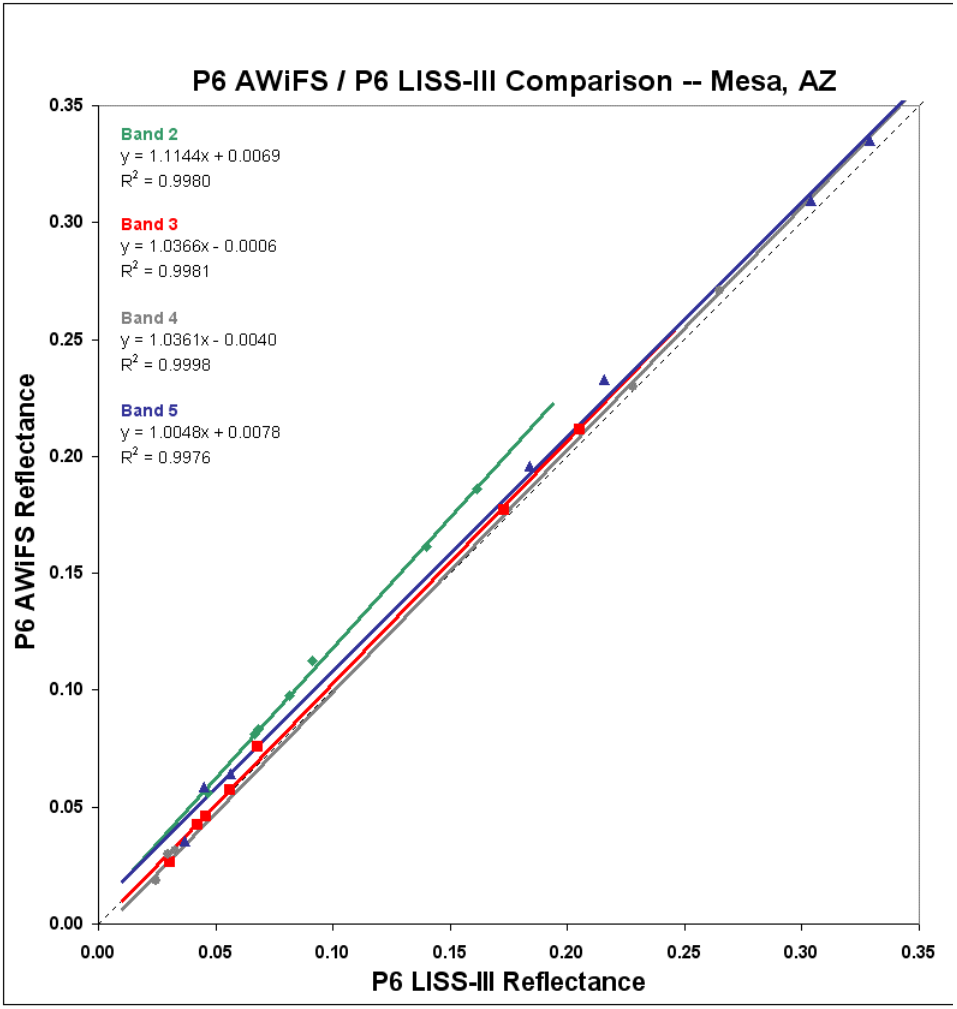
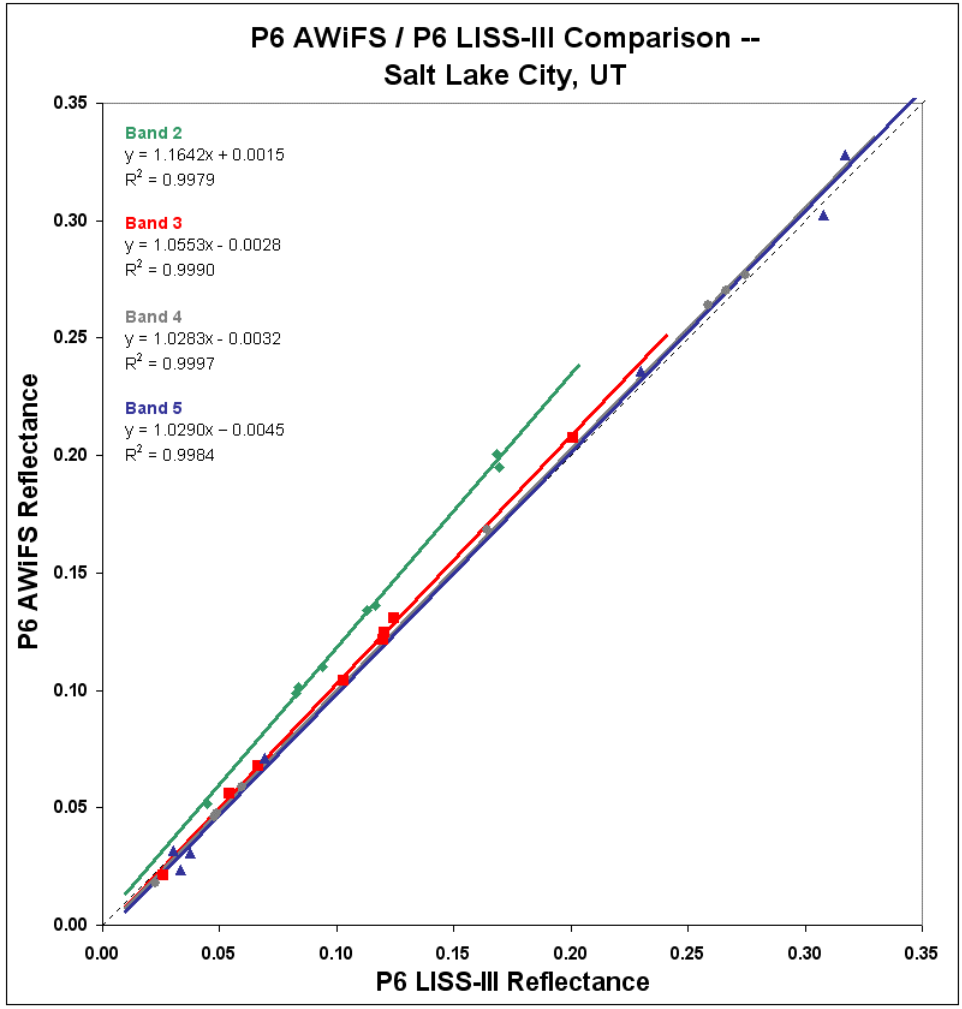
P6 AWiFS versus P6 LISS-III





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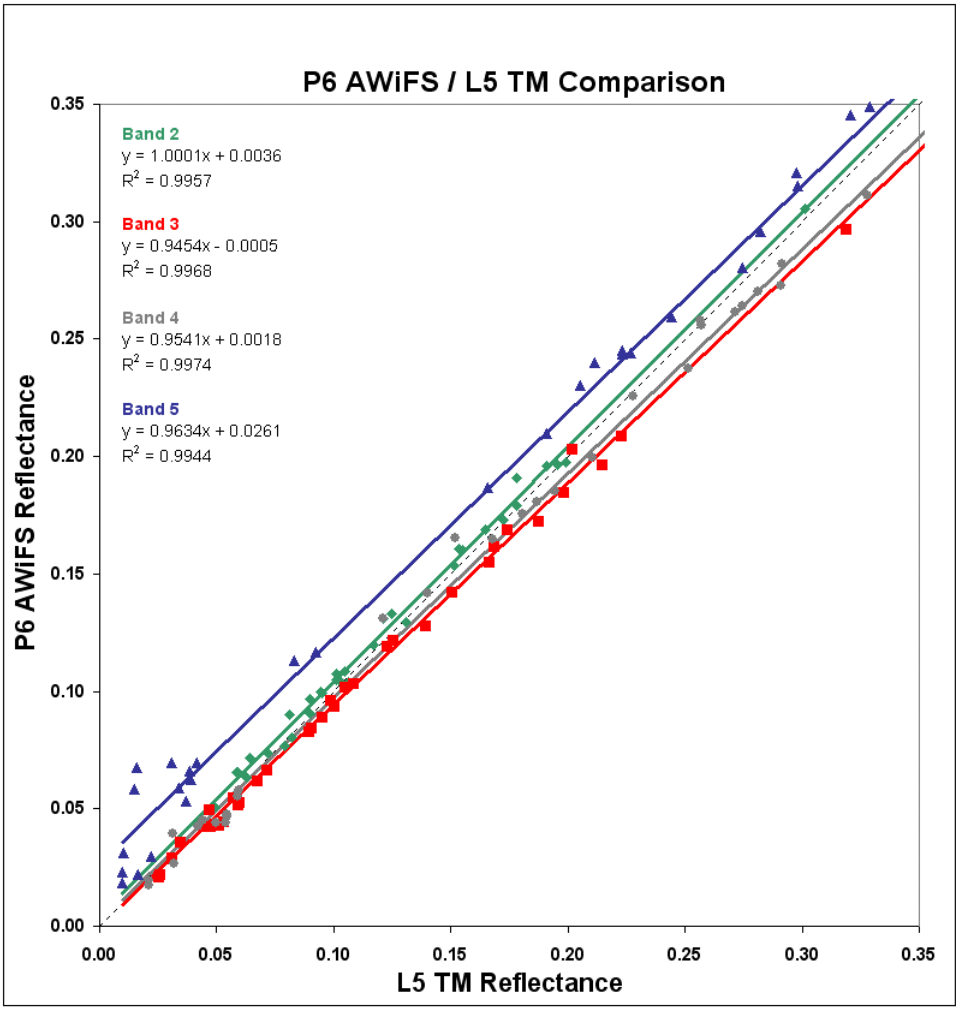
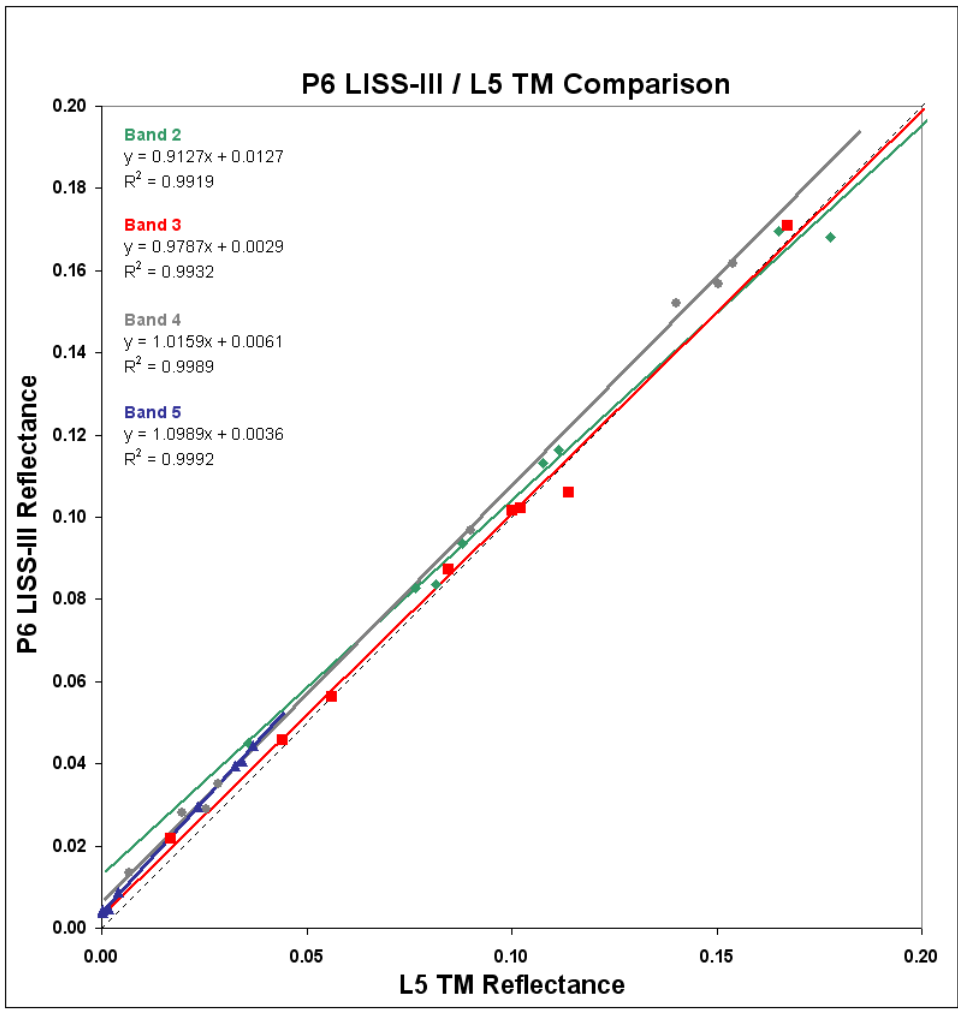
L5 TM versus P6 AWiFS/LISS-III
Salt Lake City, UT





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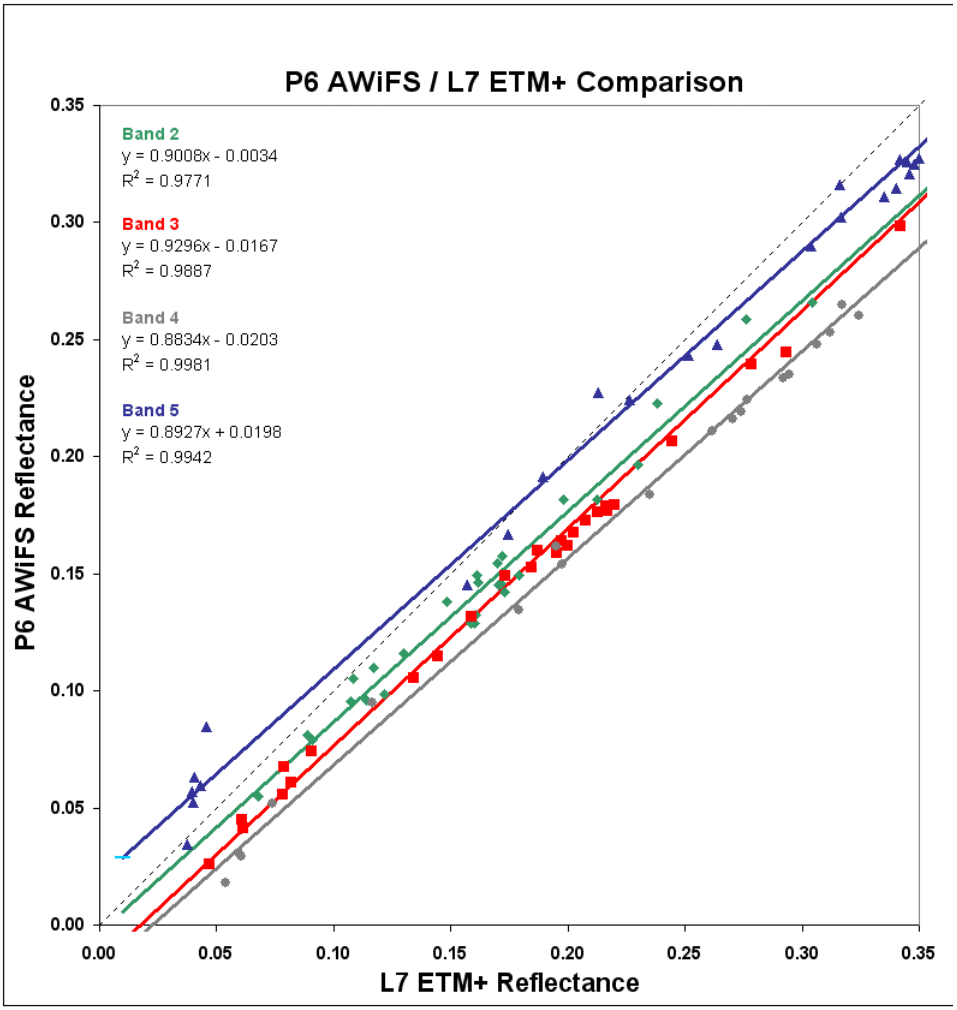
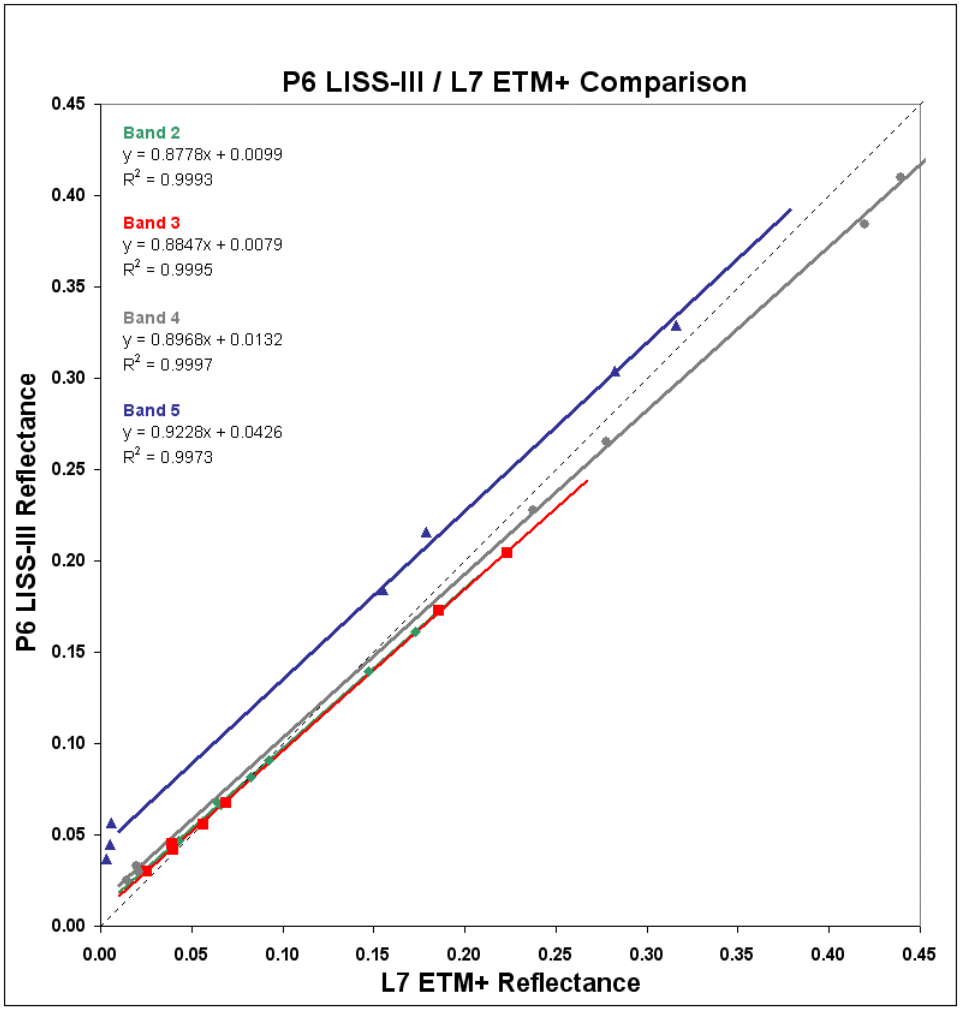
L7 ETM+ versus P6 AWiFS/LISS-III Mesa, AZ





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IRS-P6 Results

- **These preliminary results indicate that the IRS-P6 sensors can be cross-calibrated to the Landsat sensors to within an accuracy of 13 percent**
- **The IRS-P6 AWiFS and LISS-III sensors are within 5.5 percent of each other in all bands except Band 2, which has a 16.4 percent difference**

Cross-calibration results normalized to the AWiFS sensor

Sensor	Band			
	2	3	4	5
L5 TM	1.00	1.06	1.05	1.04
L7 ETM+	1.11	1.08	1.13	1.12
P6 AWiFS	***1.00***	***1.00***	***1.00***	***1.00***
P6 LISS-III (Mesa)	0.90	0.96	0.97	1.00
P6 LISS-III (SLC)	0.86	0.95	0.97	0.97

China Brazil Earth Resources Satellite - CBERS

- CBERS-1 was launched on Oct. 14, 1999
  - The spacecraft was operational for almost 4 years
  - The CBERS-1 images were not used by user community
  - On Aug. 13, 2003, CBERS-1 experienced an X-band malfunction causing an end of all image data transmissions
- CBERS-2 was launched on Oct. 21, 2003
  - The spacecraft carries the identical payload as CBERS-1
  - The IRMSS stopped working in Apr. 2005 due to power supply failure
- CBERS-2B was launched on Sept. 19, 2007
- CBERS-3: launch planned for 2009
- CBERS-4: launch planned for 2011

CBERS-1/2 Sensor Compliment

- CBERS-1 and 2 carried three sensors
  - High Resolution CCD Camera (HRCCD)
  - Infrared Multispectral Scanner (IRMSS)
  - Wide-Field Imager (WFI)
- The CCD & the WFI camera operated in the VNIR regions, while the IRMSS operated in the SWIR and thermal region

CBERS-2 Specifications			
Parameter	**HRCCD**	**IRMSS**	**WFI**
Spectral Bands (µm)	0.51 - 0.73 (PAN)	0.50 - 1.10 (PAN)	0.63 - 0.69
	0.45 - 0.52	1.55 - 1.75 (SWIR)	0.76 - 0.90
	0.52 - 0.59	2.08 - 2.35 (SWIR)	
	0.63 - 0.69	10.4 - 12.5 (TIR)	
	0.77 - 0.89		
Spatial Resolution	20 m	80 m (PAN & SWIR) 160 m (TIR)	260 m
Swath Width (FOV)	113 km (8.32°)	120 km (8.78°)	885 km (60°)
Temporal Resolution	26 days	26 days	3-5 days
Cross-Track Pointing	±32°		
Data Rate	2 x 53 Mbit/s	6.13 Mbit/s	1.1 Mbit/s
Carrier Frequency (X-band)	8.103 and 8.321 GHz	8.216 GHz	8.203 GHz
EIRP	43 dBm	39.2 dBm	31.8 dBm
Modulation	QPSK	BPSK	QPSK
Tracking Beam Frequency	8.196 GHz	8.196 GHz	8.196 GHz

CBERS-2B

- **Same bus as CBERS-2**
- **Three onboard cameras (CCD, WFI, HRC)**
  - CCD and WFI cameras are the same as in CBERS-2
  - HRC is a high-resolution 2.5 m camera
  - No IRMSS sensor
- **HRC Camera**
  - 0.45 – 0.85 μm (pan)
  - TDI CCD technology (Three CCD arrays of 4096 x 36 detectors)
  - Resolution : 2.5 m
  - Swath : 27 km
  - Bit rate : 432 Mbps (w/o compression)
- **Two onboard solid-state recorders**
  - Transmission of CCD camera data is identical to CBERS-2
  - Transmission of WFI and HRC is made on one downlink channel
  - HRC data is compressed before transmission
- **One GPS receiver and two star sensors**

High Resolution CCD (HRCCD)

- The HRCCD is the highest resolution sensor offering a GSD of 20 m at nadir
- HRCCD is a Pushbroom scanner
- Quantization: 8 bits
- Ground swath is 113 km with 26 days repeat cycle
- Steerable up to +/- 32^{o} across track to obtain stereoscopic imagery
- Operates in five spectral bands - one pan & four VNIR
  - CCD has one focal plane assembly
  - The signal acquisition system operates in two channels
    - Channel 1 has Bands 2, 3, 4
    - Channel 2 has Bands 1, 3, 5
    - Four possible gain settings are 0.59, 1.0, 1.69, and 2.86

Conversion to Radiance

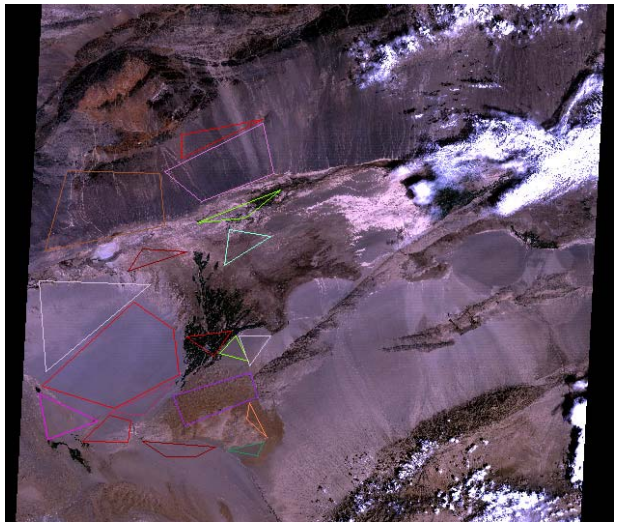
- **Independent studies are carried out by INPE & CRESDA**
  - INPE used calibration sites in the west part of State Bahia
  - CRESDA used Gobi desert (Dunhuang) test site in China

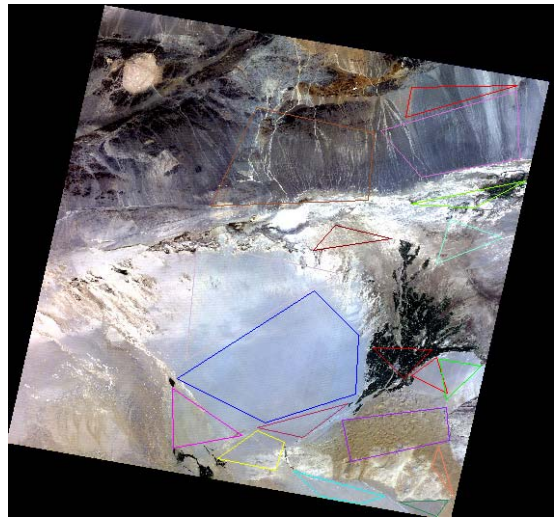
L* = DNn / CCn

L* = spectral radiance at the sensor's aperture W/(m2.sr.um)
DN = Digital number extracted from the image in band n
CCn = absolute calibration coefficient for band n

CBERS-2 CCD Vicarious Absolute Calibration Coefficients (CCn)						
	Test-Site	**CCD_1**	**CCD_2**	**CCD_3**	**CCD_4**	**CCD_Pan**
Pre-launch		0.9800	1.5900	1.2000	2.2900	1.2500
Brazil						
25th June 2004	Bahia	1.228	2.357	1.215	2.553	1.628
16th August 2004		1.0090	1.9300	1.1540	2.1270	1.4830
Oct_3th New		0.862	1.544	0.874	1.933	0.995
Oct_3th Old		0.978	1.721	1.057	1.936	1.223
Oct_6th New		0.84	1.558	0.89	2.095	1.03
Oct_6th Old		0.97	1.74	1.083	2.105	1.263
China						
19th August 2004		0.9917	1.6761	1.0096	2.0613	
25th August 2004	Dunhuang	1.0292	1.7254	1.0356	2.1515	
24th August 2005	Dunhuang	1.0288	1.8096	1.1079	2.2783	

L5 TM and CBERS-2 CCD Image Pairs

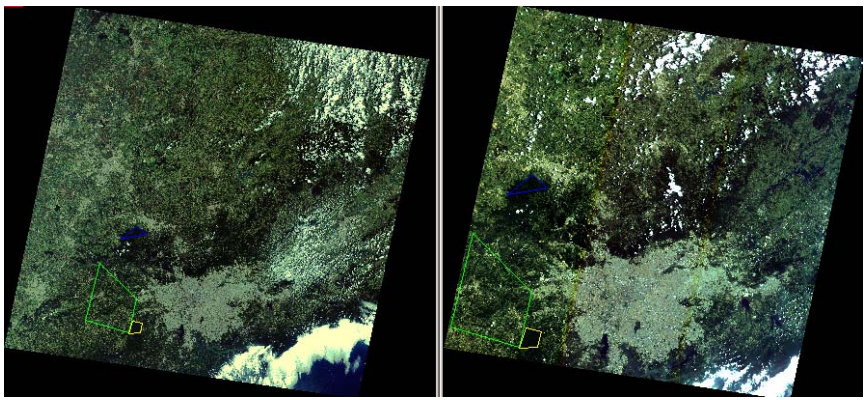




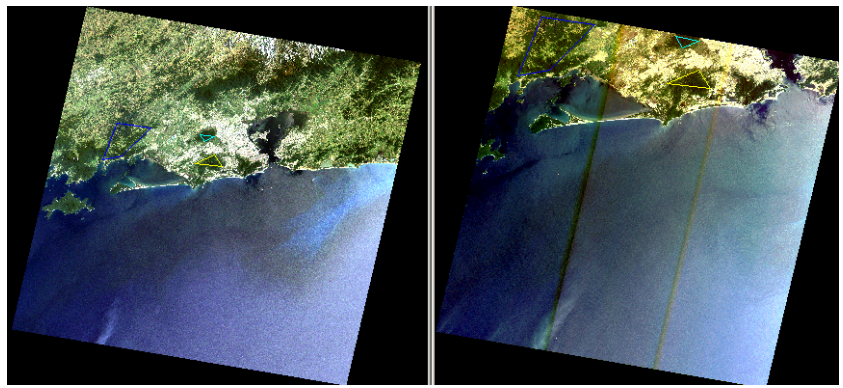
Gobi (Dunhuang) desert test site
Data acquired on
Aug. 25, 2004 (20 min apart)

L5 TM WRS Path = 137 Row = 032
Nadir looking

CBERS-2 CCD Path = 23 Row = 55 side-looking (off-nadir-look-angle=-6.0333)

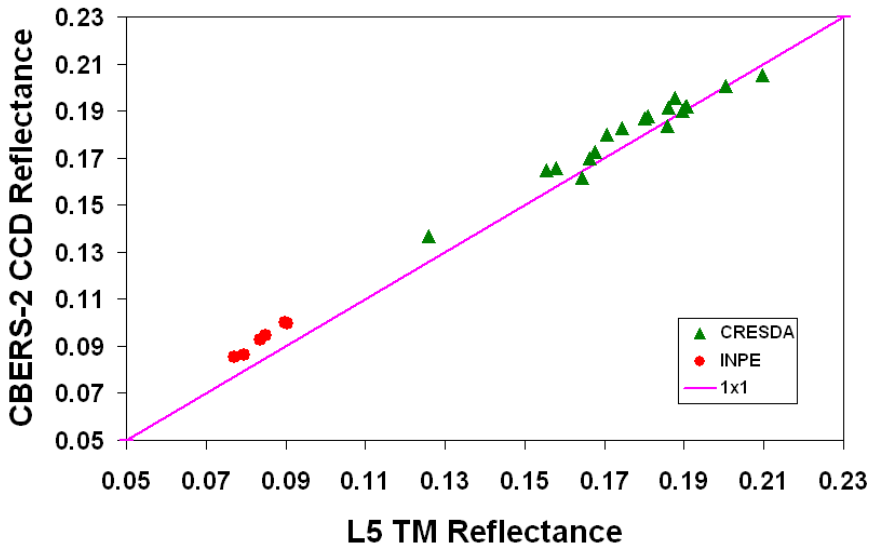


L5 TM WRS Path = 219 Row = 076
Nadir looking Acquisition Date: Dec. 29, 2004
CBERS-2 CCD Path = 154 Row = 126
Acquisition Date: Dec. 30, 2004

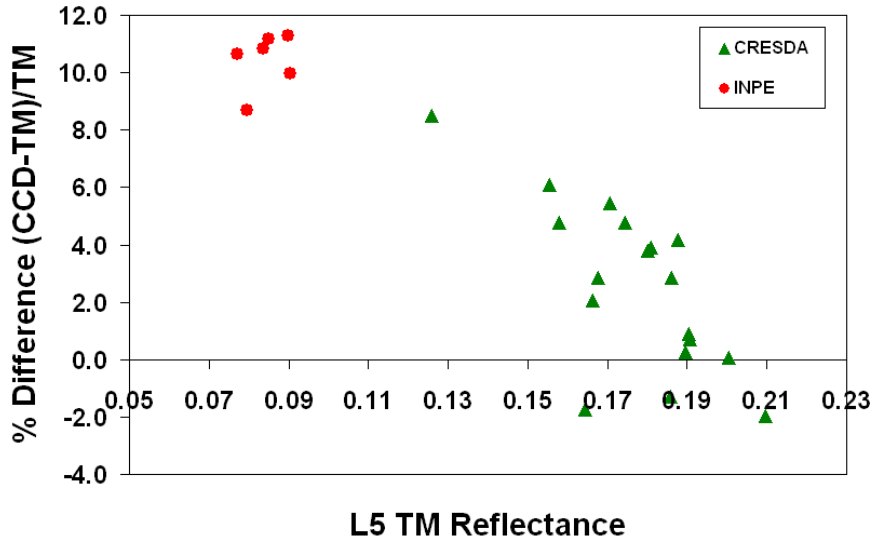


L5 TM WRS Path = 217 Row = 076
Nadir looking Acquisition Date: Nov. 16, 2005
CBERS-2 CCD Path = 151 Row = 126
Acquisition Date: Nov. 16, 2005

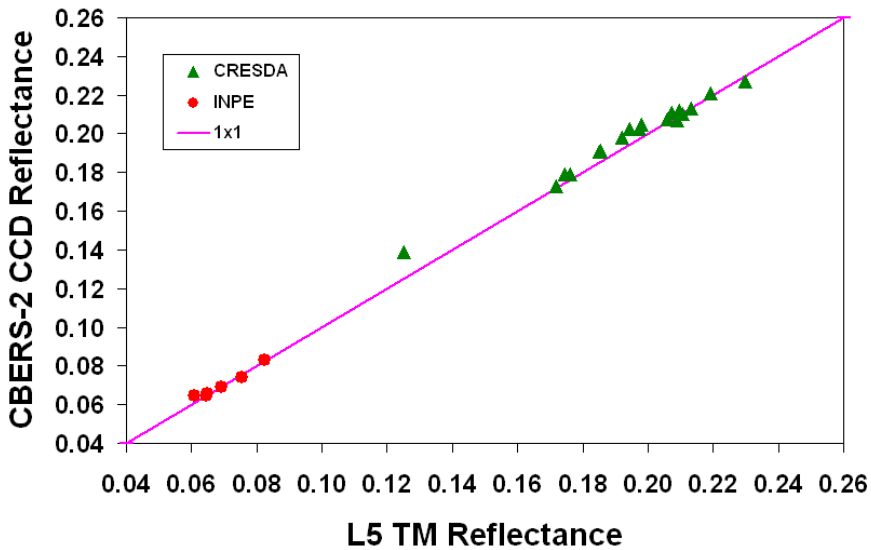
Reflectance obtained from L5 TM and CBERS-2 CCD (Band 1)



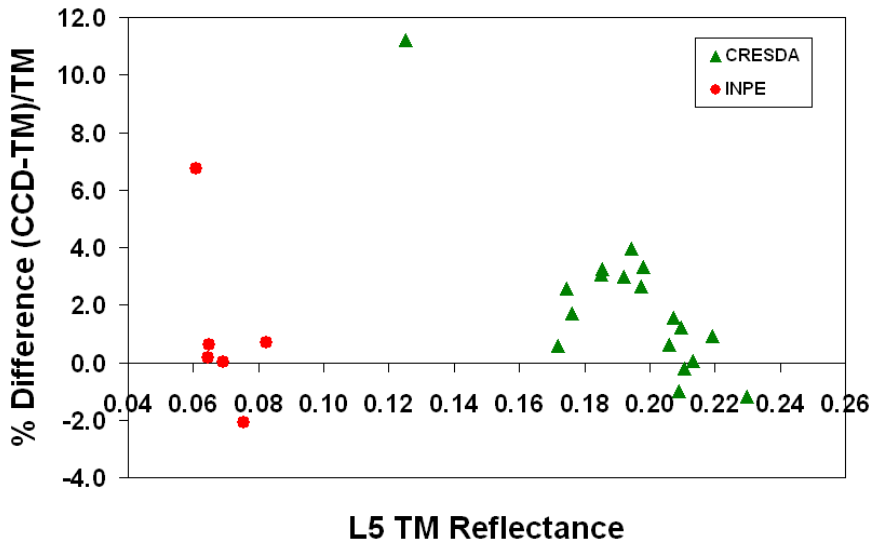
CBERS-2 CCD % difference relative to L5 TM (Band 1)

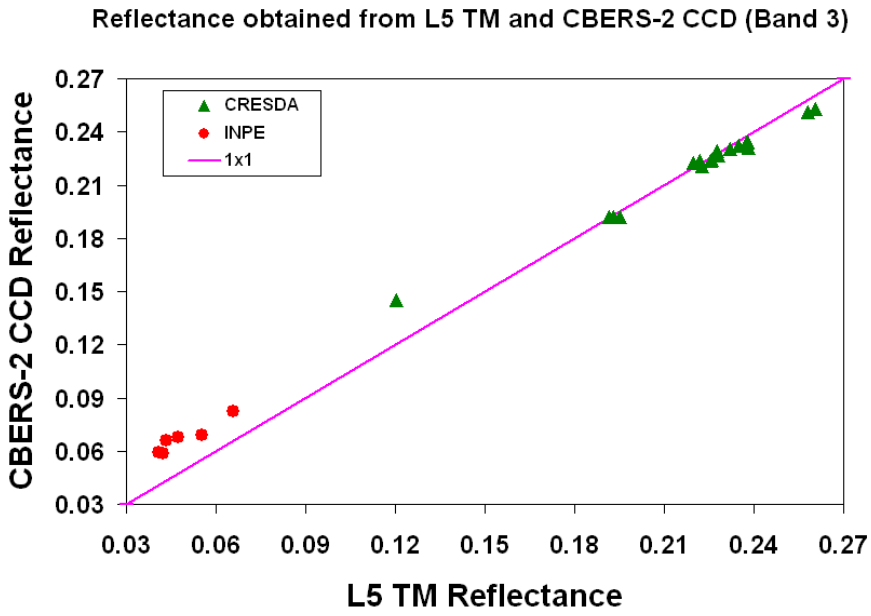


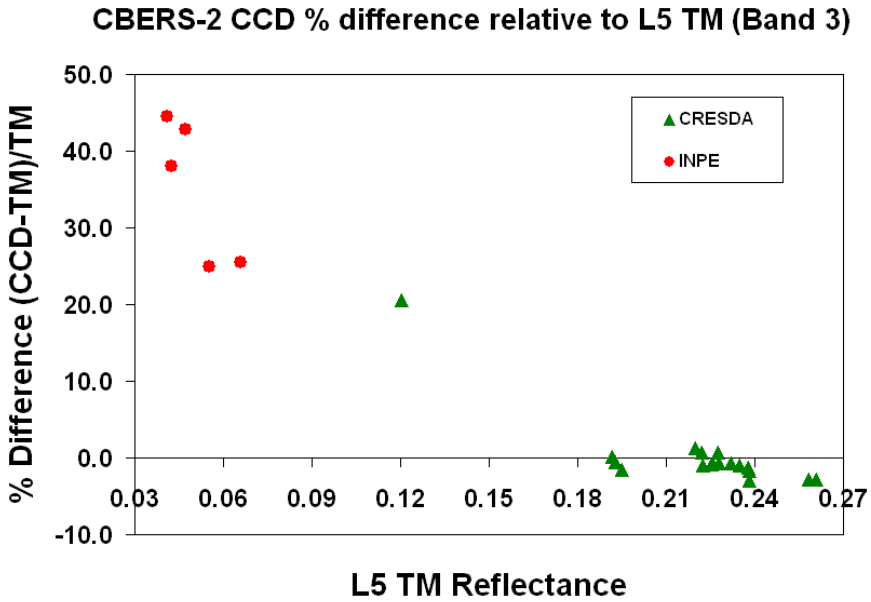
Reflectance obtained from L5 TM and CBERS-2 CCD (Band 2)

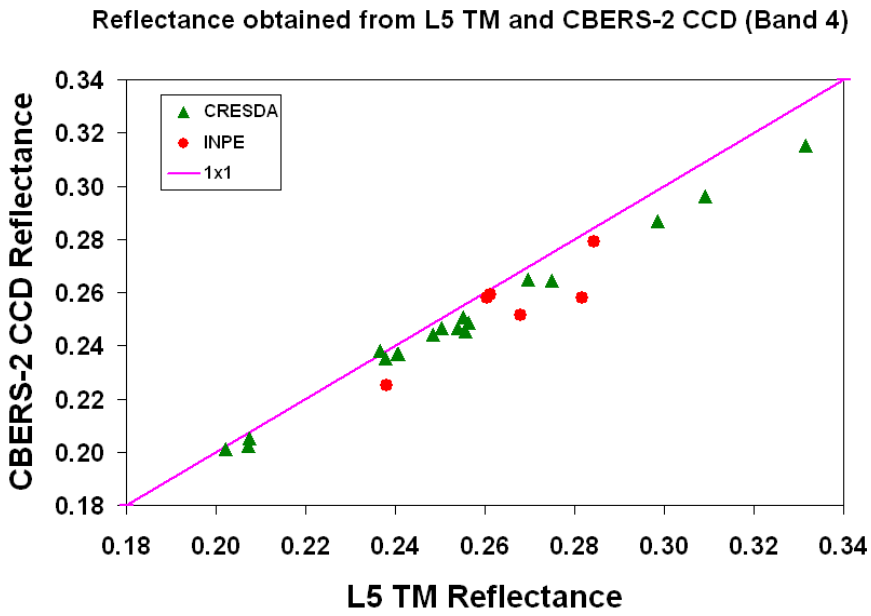


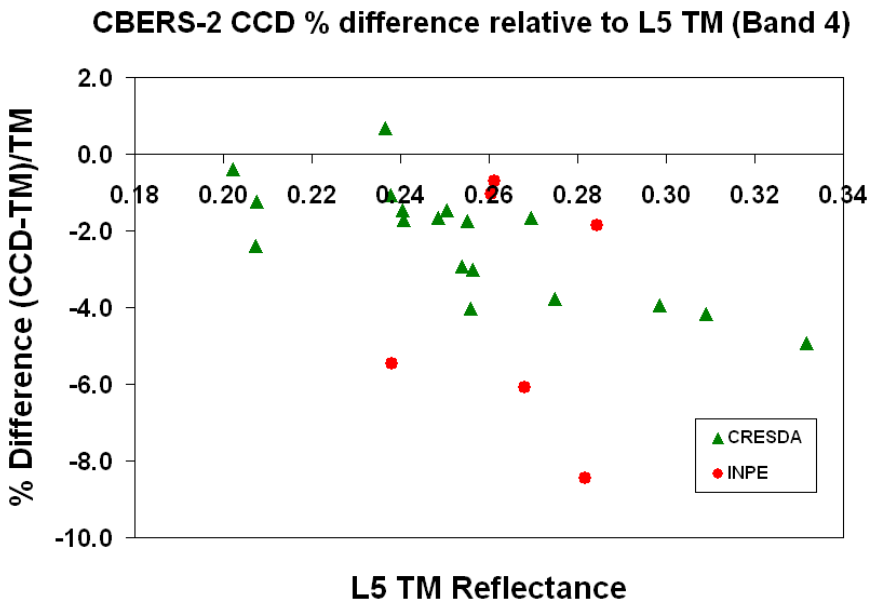
CBERS-2 CCD % difference relative to L5 TM (Band 2)




Reflectance obtained from L5 TM and CBERS-2 CCD (Band 3)
CBERS-2 CCD Reflectance
L5 TM Reflectance
CRESDA
INPE
1x1
0.03
0.06
0.09
0.12
0.15
0.18
0.21
0.24
0.27


CBERS-2 CCD % difference relative to L5 TM (Band 3)
% Difference (CCD-TM)/TM
L5 TM Reflectance
CRESDA
INPE
50.0
40.0
30.0
20.0
10.0
0.0
-10.0
0.03
0.06
0.09
0.12
0.15
0.18
0.21
0.24
0.27


Reflectance obtained from L5 TM and CBERS-2 CCD (Band 4)
CBERS-2 CCD Reflectance
L5 TM Reflectance
CRESDA
INPE
1x1
0.18
0.20
0.22
0.24
0.26
0.28
0.30
0.32
0.34


CBERS-2 CCD % difference relative to L5 TM (Band 4)
% Difference (CCD-TM)/TM
L5 TM Reflectance
CRESDA
INPE
2.0
0.0
-2.0
-4.0
-6.0
-8.0
-10.0
0.18
0.20
0.22
0.24
0.26
0.28
0.30
0.32
0.34

Summary

- An initial cross-calibration of the L7 ETM+ and L5 TM with the IRS-P6 AWiFS/LISS-III and CBERS-2 CCD sensors was performed
- The preliminary studies were performed using a single image-pair between the sensors, additional scenes needs to be analyzed
- The approach involved calibration of nearly simultaneous surface observations based on image statistics from areas observed simultaneously by the two sensors
- Need to identify individual sources of error
  - Differing spectral profiles
  - Spatial and radiometric resolution differences
  - Temporal stability
  - Geometric registration
  - Bidirectional Reflectance Distribution Function (BRDF) effects
  - Atmospheric effects