LANDSAT DATA GAP STUDY

Technical Report

Initial Data Characterization, Science Utility and Mission Capability Evaluation of Candidate Landsat Mission Data Gap Sensors

Version 1.0

January 31, 2007

USGS
science for a changing world

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The LDGST formed a tiger team to develop and analyze a set of technical and operational scenarios for receiving, ingesting, archiving, and distributing data from alternative, Landsat-like satellite systems. The tiger team conducted trade studies and developed scenarios for transferring data from ResourceSat and CBERS systems to USGS EROS for archive and distribution. The mission capability assessment work was performed by Shaida Johnston from the NASA GSFC.

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[1]Work performed under USGS contract 08HQCN0005. Any use of trade, product, or firm names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

Executive Summary

The Landsat suite of satellites has collected the longest continuous archive of multispectral data of any land-observing space program. From the Landsat program's inception in 1972 to the present, the earth science user community has benefited from a historical record of remotely sensed data. The archive of Landsat data constitutes the longest continuous record of satellite-based observations and, as such, is an invaluable resource for monitoring global change and is the source of Earth observations used in decision making tools that benefit society.

Landsat data have been used for a diverse array of applications because of their broad and regular satellite coverage of the Earth surface and their generally high quality and reliability.

The capabilities of currently operational Landsat satellites could be lost before the launch of the follow-on Landsat Data Continuity Mission (LDCM), causing a gap in the Landsat data record and the National Satellite Land Remote Sensing Data Archive (NSLRSDA). In anticipation of a gap, the Federal agencies responsible for Landsat program management, the National Aeronautics and Space Administration (NASA) and Department of Interior (DOI) U.S. Geological Survey (USGS), convened a Landsat Data Gap Study Team (LDGST). The Study Team assessed the basic characteristics of multiple systems and identified sensors aboard the China/Brazil Earth Resources Satellite-2 (CBERS-2), and the Indian Remote Sensing (IRS-P6) ResourceSat-1 satellite as the most promising sources of Landsat-like data. The sensors include the combination of CBERS-2 Infrared Multi-spectral Scanner (IRMSS) and High Resolution Charged Coupled Device (HRCCD), as well as the IRS-P6 Advanced Wide Field Sensor (AWiFS) and IRS-P6 Linear Imaging Self Scanning Sensor (LISS-III). The Study Team concluded that more robust technical evaluations of data and sensor performance are required before gap mitigation strategies can be fully formulated. This technical report summarizes the results from those evaluations, including the initial data characterization and science utility evaluation.

The data characterization was performed as a cooperative effort between the USGS Center for Earth Resources Observation and Science (EROS), the NASA Land Cover Satellite Project Science Office (LPSO) at Goddard Space Flight Center (GSFC), and NASA Earth Sciences Applications Directorate (ESAD) at Stennis Space Center (SSC). The three field centers formulated the Data Characterization Working Group (DCWG) to evaluate the data quality of the CBERS-2 and IRS-P6 datasets. The data qualities evaluated and summarized here include:

- Spectral Characterization
- Radiometric Characterization
- Geometric Characterization
- Spatial Characterization

The science utility evaluation was performed by USGS scientists and their DOI science and land management colleagues in coordination with the DCWG.

CBERS-2 Summary

Spectral characterization results for both the HRCCD and IRMSS sensors indicate a similarity with analogous L7 ETM+ Bands 1 through 4. The HRCCD acquires in analogous L7 Bands 1 through 4; IRMSS acquires in analogous L7 Bands 5 through 7. Differences ranged from six to fifteen percent, depending on sensor and band. Results for Band 7 are missing due to an incomplete IRMSS RSR dataset.

Product assessments revealed production inconsistencies for both HRCCD and IRMSS image products. IRMSS radiometric assessments indicated significant issues with data format and lack of technical information. Radiometric assessments found similar artifacts in both IRMSS and HRCCD that that can be characterized and probably corrected. Relative gain and bias corrections were applied during Level-1 processing and good cross-calibration agreements existed with L5 and L7.

A limited HRCCD geometric assessment indicated the presence of systematic errors. The one dataset processed through Instituto Nacional de Pesquisas Espaciais (INPE) showed errors on the order of 4 km in the along-track line or track direction. The dataset processed through Center for Resources Satellite Data and Applications (CRESDA) showed geometric errors on the order of 14 km in the line or track direction. Errors were less in the cross-track direction. Band-to-band registration was generally on the order of 0.4 pixels in both directions with one exception.

No spatial and science utility evaluations were performed on CBERS-2 image products due to the lack of availability of scenes over regions of interest.

IRS-P6 Summary

Spectral characterization results for both the AWiFS and LISS-III sensors indicate a similarity with analogous Landsat 7 ETM+ Bands 2 through 4. Differences were within five percent. At the time of processing, Band 5 data were incomplete; an assessment was not performed.

Radiometric assessments for both AWiFS and LISS-III indicated artifacts that can be characterized or corrected. A vicarious calibration assessment was performed on AWiFS image products obtained with the AWiFS-A camera and AWiFS-B camera. Results indicate that the calibration coefficients provided with the imagery are in reasonable agreement with those determined through vicarious methods.

Geometric assessment of six standard geometrically processed AWiFS images indicated relatively large (423 m to 1,887 m) but correctable systematic errors. These results are a combination of AWiFS-A and AWiFS-B acquired imagery and agree with previously published results. A second study noted Root Mean Square Errors (RMSE) measured between AWiFS data and control to be about 0.75 pixels. The second study also noted RMSEs measured between LISS-III data and control to be about 0.41 pixels. Band-to-band and image-to-image results appeared reasonable for both the AWiFS and

LISS-III image products.

This report provides a preliminary science utility evaluation and addresses the applicability of the IRS-P6 AWiFS data to the science and operational activities. A few of the science projects considered for these studies include:

- Land Cover Trends Project
- Emergency Response Burn Mapping and MTBS Projects
- FEWS International Crop Monitoring Project
- Forest and Rangeland Project
- AWiFS and Landsat Inter-comparison Project
- Viability of IRS-P6 Datasets for NLCD Products
- Global Agriculture Monitoring project (GLAM) Project
- USDA NASS Crop Monitoring

Preliminary Science Utility Evaluation indicates that the IRS-P6 AWiFS data is potentially a usable alternative to Landsat during the mission gap. The higher radiometric resolution (10-bits), larger swath area coverage (740 km), and a frequent repeat cycle (five days) will be an advantage for science applications, allowing for the increased likelihood of cloud-free acquisitions and reduction in the processing and handling of a lower number of images. The coarser spatial resolution (56-m) and lack of an AWiFS equivalent to the Landsat spectral Band 1 and Band 7 can have an adverse impact on a few assessments, likely resulting in reduced but acceptable derived-product accuracy and sensitivity. The lower spatial resolution of AWiFS could negatively impact the ability to discriminate fine-scale landscape features, especially those related to urban development. It is possible, however, that the disadvantage of lower spatial resolution could be offset by the more frequent repeat coverage of AWiFS.

Conclusions

The DCWG concluded that preliminary results for IRS-P6 AWiFS and LISS-III or CBERS-2 HRCCD datasets do not indicate any unresolvable issues. The IRS-P6 satellite is a more mature system and better able in the near-term to provide useful datasets. CBERS-2 IRMSS results are more problematic due to lack of information on data formats, processing, and operational modes; instrument inoperability (since 2005); and the lack of an identical or similar instrument slated for the follow-on CBERS-2B launched in September, 2007.

Additional characterizations for both CBERS-2 and IRS-P6 sensors are necessary to complete the characterizations as much as possible, which would allow equal assessments to be performed across all sensors. Additional characterizations would begin to correct for systematic errors, improve accuracies, and begin to assess the temporal stability of the sensors.

Additional DCWG efforts would also be useful to assess technical information already received from Indian Space Research Organization (ISRO) and Instituto Nacional de Pesquisas Espaciais (INPE) and to continue to foster technical exchanges with the sensor organizations for additional information. Support is required to continue follow-on activities pertaining to data acquisition, processing, and monitoring. One particular limitation is the lack of documentation. Most importantly, several data quality and science evaluations, including those assessing the impact of sensor characteristics, such as differing dynamic range and increased Bidirectional Reflectance Distribution Function (BRDF) effects associated with larger swaths and their impact to science, have yet to be performed.

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Contents

Section 1 Introduction

1.1 Landsat Data Gap Background

The Landsat suite of satellites has collected the longest continuous archive of multispectral data of any land-observing space program. From the Landsat program's inception in 1972 to the present, the earth science user community has benefited from a historical record of remotely sensed data. The archive of Landsat data constitutes the longest continuous record of satellite-based observations and, as such, is an invaluable resource for monitoring global change and is the source of Earth observations used in decision making tools that benefit society. To meet observation requirements at a scale revealing both natural and human-induced changes on the landscape, the Landsat program provides the only inventory of the global land surface over time on a seasonal basis.

The Landsat program has surpassed three decades of imaging the Earth's surface. The Landsat 5 (L5) Thematic Mapper (TM) sensor was launched on March 1, 1984. It has been in orbit for more than 24 years and has continued to perform well over a period of time far exceeding its design life of three years. Nevertheless, the instrument has aged and its characteristics have changed since launch. Currently, L5 TM has no capability to record and re-broadcast acquisitions; its duty cycle has been reduced and it could systematically fail at any time.

The Landsat 7 (L7) Enhanced Thematic Mapper Plus (ETM+) sensor was launched on April 15, 1999, with a design life of five years. It has been in orbit for more than nine years. L7 has suffered from a Scan Line Corrector (SLC) malfunction starting on May 31, 2003, and is marginally capable of acquiring global coverage in a timely manner. It is likely that either or both the L7 and L5 satellites could fail completely after several more years of curtailed operations, and both satellites will likely run out of fuel before the end of 2010. The Earth observation community is facing a probable gap in Landsat data continuity before Landsat Data Continuity Mission (LDCM) data arrive in approximately 2011. A data gap will interrupt a 34+ year time series of land observations.

Other than the anticipated LDCM, no other domestic or international satellite program current or planned has the onboard recording capacity, direct-downlink receiving station network, and archive/production systems to routinely perform the full Landsat mission. If L5 and L7 fail before the launch of LDCM, there will be no direct replacement available for the L7 data stream entering the Department of the Interior's (DOI) U.S. Geological Survey (USGS) National Satellite Land Remote Sensing Data Archive (NSLRSDA) in Sioux Falls, South Dakota.

1.2 Landsat Data Gap Study Team (LDGST)

The Federal agencies responsible for Landsat Program Management, NASA and USGS, recognized the possibility of a Landsat data gap and convened a Study Team beginning in early 2005. The Study Team recognized that no current or near-future satellite system could fully replace the Landsat satellites but concluded that the capture and archiving of data from comparable systems could reduce the impact of a data gap. The Study Team assessed the characteristics of multiple systems and identified sensors aboard India's ResourceSat satellite and sensors aboard the China-Brazil Earth Resources Satellite (CBERS) as the most promising sources of Landsat-like data. The Study Team also concluded that more in-depth technical evaluations of the data and capabilities of these systems are required before mission gap mitigation strategies can be fully formulated. The findings of the Study Team were presented to representatives of the Office of Science and Technology Policy (OSTP) and the Office of Management and Budget (OMB) on June 15, 2005.

An interagency Data Characterization Working Group (DCWG) was formed to coordinate and leverage expertise from the technical staffs at three field centers: the NASA Goddard Space Flight Center (GSFC), NASA Stennis Space Center (SSC), and the USGS Earth Resources Observation and Science (EROS) Center, along with several collaborating universities. The aim was to perform an initial data quality assessment of image products acquired from foreign systems having the potential to mitigate an expected Landsat Mission data gap.

1.3 Landsat Data Gap Requirements

The LDGST defined a set of minimum data acceptance criteria for these sources (Table I) that would most likely replace only a part of the Landsat data stream during a pre-LDCM data gap.

Table 1-1. Baseline Specifications

Performance Parameter	**Performance Goal: LDCM Specification**	**Baseline Specification[1]**
Spectral Bands[2]	Blue: 350-515 nm Green: 525-600 nm Red: 630-680 nm NIR: 845-885 nm [3] SWIR(1): 1560-1660 nm SWIR(2): 2100-2300 nm	Green: 525-600 nm Red: 630-680 nm NIR: 845-885 nm [2] SWIR(1): 1560-1660 nm
Radiometry	<5% error in at-sensor radiance, linearly scaled to image data	<15% error in at-sensor radiance, linearly scaled to image data
Spatial Resolution	30m GSD VNIR-SWIR; 15m panchromatic	10-100m GSD
Geographic Registration	<65m circular error	<65m circular error
Band-band registration	uncertainty <4.5m (0.15 pixel)	uncertainty <0.15 pixel
Geographic Coverage	All land areas between ± 81.2º north and south latitudes, including islands, atolls, and continental shelf regions of less than 50m water depth	All land areas between ± 81.2º north and south latitudes at least twice per year

[1] Acquired data must be characterized and verified against these specifications to ensure data quality and continuity.
[2] Landsat/LDCM bands given; show and discuss any differences from these nominal bandwidths.
[3] NIR bandwidth given for LDCM; Landsat bandwidth of 780-900 nm is also acceptable.

1.4 Document Structure

This document contains the following sections:

Section 1 outlines the Landsat Data Gap requirements and supplies a description of the document structure with summary.

Section 2 provides an overview of the sensors.

Section 3 provides a summary of the data quality characterization.

Section 4 provides a summary of the science evaluation.

Section 5 provides a summary of the mission capability evaluation.

Section 6 provides overall summary and conclusion.

Section 2 Overview of the Sensors

This section provides an overview of sensors from the Landsat 5, Landsat 7, ResourceSat-1, and China-Brazil Earth Resources Satellite (CBERS-2) satellites. The table below summarizes the orbit and coverage details.

Table 2-1. Comparison of Orbit and Coverage Details

Orbit and Coverage Details	**L7 ETM+**	**IRS-P6 AWiFS**	**CBERS-2 CD**
Launch date	15-Apr-99	17-Oct-03	21-Oct-03
Sensor Type	Whiskbroom	Pushbroom	Pushbroom
Orbit Altitude (km)	705	817	778
Orbit Inclination (degrees)	98.2	98.69 deg	98.48
Orbit period (min)	98.8	101.35 min	100.26
Number of Orbits per day	14.58	14.21	14.37
Equatorial crossing time	10:00 a.m.	10.30 a.m.	10:30 a.m.
Repeat Cycle (days)	16	5	26
Swath Width (km)	187	740	113
Spatial Resolution (m)	30	56	20
Quantization (bits)	8	8	10
Detectors	16	6144	12000

2.1 Landsat 5 (L5) Thematic Mapper (TM)

The L5 TM is an Earth-imaging sensor that was launched on March 1, 1984. It incorporated advancements in spectral, radiometric, and geometric capabilities relative to the Multi-spectral Scanner (MSS) flown on previous Landsat satellites. Onboard are two imaging sensors, the MSS and the TM. L5 TM bands 1 through 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. The detectors for bands 1 through 4 are located at the Primary Focal Plane (PFP), where the temperature is not controlled but normally varies between 292 and 300K. The detectors for bands 5 through 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 105K. 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.

2.2 Landsat 7 (L7) Enhanced Thematic Mapper Plus (ETM+)

The ETM+ sensor was launched on April 15, 1999, on the Landsat 7 platform; it is based on the TM sensors onboard the Landsat 4 (L4) and Landsat 5 satellites. Changes on the ETM+ sensor include a new panchromatic band, an increase in the spatial resolution of the thermal band to 60m, and the addition of two calibration devices to help improve the radiometric calibration. Landsat 7 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 IC, which consists of two lamps, a blackbody, a shutter, and optics to transfer the energy from the calibration sources to the focal plane. One of the requirements of the Landsat 7 mission is to achieve radiometric calibration accuracy of the ETM+ data within an uncertainty of less than five percent in at-sensor radiance. This requirement is more stringent than past requirements for the Landsat program.

The data quantization for Landsat 7 ETM+ and Landsat 5 TM is 8-bits. Landsat 7 employs two alternate gains that permit enhanced radiometric resolution in the high-gain mode and expanded dynamic range in the low-gain mode. The Level 1G (L1G) products are only available in 8-bit for Landsat sensors.

2.3 ResourceSat-1 (IRS-P6)

The Indian Remote Sensing ResourceSat-1 satellite (IRS-P6) is a three-axis body-stabilized satellite. Its near-polar, Sun-synchronous orbit has a mean altitude of 817km. IRS-P6 has an operational life of five years. Its payload consists of three sensors: Medium Resolution Linear Imaging Self-Scanner (LISS-III), Advanced Wide Field Sensor (AWiFS), and a high-resolution multispectral Linear Imaging Self-Scanner camera (LISS-IV). All three sensors work on the “pushbroom scanning” concept, using linear arrays of Charge Coupled Devices (CCDs). In this mode of operation, each line of 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.

Table 2-2. ResourceSat-1 Orbit and Coverage Details

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 crossing 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

The LISS-III is a multispectral camera operating in four spectral bands, three in the Visible and Near Infrared (VNIR) bands and one in the Short Wavelength Infrared (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.

The AWiFS camera operates in four spectral bands similar 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.

The data quantization for the IRS-P6 sensors is summarized below:
AWiFS = 10-bits
LISS-III (VNIR) = 7-bits with four gain settings
LISS-III (SWIR) = 7- out of 10-bits (sliding)
The analog-to-digital (A/D) converter is 12-bits for AWiFS and LISS-III SWIR. The data are 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 A/D converter is 7-bits for LISS-III VNIR bands. The data are captured and transmitted as 7-bits with four pre-gain setting options. The L1G products for LISS-III are available in 8-bits. However, the AWiFS data products are available in 8- and 10-bits.

Table 2-3. Resourcesat-1 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 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
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

2.4 China-Brazil Earth Resources Satellite (CBERS-2)

The second China-Brazil Earth Resources Satellite (CBERS-2) was launched in October 2003. The spacecraft carries identical payload as CBERS-1. It carries three remote sensing instruments: the High Resolution CCD Camera (HRCCD), the Infrared Multi-spectral Scanner (IRMSS), and the Wide Field Imager (WFI). The CCD camera and the WFI operate in the VNIR regions, while the IRMSS mainly operates in the SWIR. The three instruments are used together to provide images with different resolution and coverage. The data quantization for the CBERS-2 sensors is 8-bits.

The data quantization for the CBERS-2 sensors is 8-bits.

Table 2-4. CBERS-2 Specifications

CBERS-2 Specifications			
Parameter	**HRCC**	**IRMSS**	**WFI**
Spectral Bands (µm)	0.51 - 0.73 (PAN) 0.45 - 0.52 0.52 - 0.59 0.63 - 0.69 0.77 - 0.89	0.50 – 1.10 (PAN) 1.55 – 1.75 (SWIR) 2.08 – 2.35 (SWIR) 10.4 - 12.5 (TIR)	0.63 - 0.69 0.76 - 0.90
Spatial Resolution	20 m	80 m (PAN & SWIR) 160 m (TIR)	260 m
Swath Width (FOV)	113 km (8.32º)	120 km (8.78º)	885 km (60º)
Temporal Resolution	26 days	26 days	3-5 days
Cross-Track Pointing	±32º		
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

Section 3 Data Quality Characterization

Technical staffs at three field centers, the NASA GSFC, NASA SSC, and the USGS EROS, along with several collaborating universities, began evaluating data from the selected CBERS, ResourceSat-1, and IRS-P6 sensors. The goal of these efforts is to provide technical data for informed decision making as to the suitability of these sensors for populating the NSLRSDA.

The approach for this evaluation effort was formulated in the “Landsat Mission Data Gap Plan: Data Product Characterization for Moderate Resolution Satellites”, in August 2005. Plan details included formation of an interagency working group, i.e., the Data Characterization Working Group (DCWG), to coordinate and leverage each field center’s expertise to perform an initial data quality assessment of image products acquired from foreign systems having the potential to fill an expected Landsat Mission data gap. These assessments have focused on image products from the IRS-P6 ResourceSat-1 AWiFS and from the CBERS-2 IRMSS and HRCCD. The analyses performed by each field center was based upon their in-house expertise and the availability of data products, scoped to a one-year effort. The DCWG results were presented via PowerPoint presentations by respective agencies in December 2005. Each field center used their own funds for this evaluation.

The following sections describe preliminary results from the spectral, radiometric, geometric, and spatial characterizations performed on image products acquired from the CBERS-2 HRCCD and IRMSS sensors and the IRS AWiFS and LISS-III sensors. Due to data and resource restrictions, not all characterizations were performed on each sensor.

3.1 Spectral Characterization

Figure 3.1 shows the Relative Spectral Response (RSR) profiles of the L7 ETM+ and L5 TM sensors and compares them to IRS-P6 AWiFS, LISS-III, CBERS-2 HRCCD, and IRMSS profiles. The CBERS-2 obtains the full spectral range by combining data from the HRCCD (visible/near-infrared) and IRMSS (short wave infrared) sensors. Figure 3.1 also establishes that the CBERS-2 IRMSS spectral response function was not fully described. Table 3.1 summarizes the spectral of these sensors.

These spectral response differences in turn can yield apparent radiometric differences. This can be shown by involving two different spectral response curves with the same target, atmospheric, and solar irradiance spectra. For example, a comparison between Landsat 4 TM and Landsat 7 ETM+ indicates that the ratio of apparent radiometric response can be as large as 15 percent across some spectral bands. These TM to ETM+ results were derived using a capability that models the potential radiometric differences to be expected based on known RSR curves for sensors, atmospheric modeling code, and various target spectra. This capability was subsequently used for spectral comparisons between the candidate sensors and the Landsat 7 ETM+.

Table 3-1. Spectral Coverage

Spectral Range (µm)						
	Landsat		CBERS			IRS-P6
Band	**L5 TM**	**L7 ETM+**	**CCD**	**IRMSS**	**WFI**	**Sensors**
1	0.450-0.520	0.450 - 0.515	0.45 - 0.52			
2	0.520-0.600	0.525 - 0.605	0.52 - 0.59			0.52-0.59
3	0.630-0.690	0.630 - 0.690	0.63 - 0.69		0.63 - 0.69	0.62-0.68
4	0.760-0.900	0.775 - 0.900	0.77 - 0.89		0.76 - 0.90	0.77-0.86
5	1.550-1.750	1.550 - 1.750		1.55 - 1.75		1.55-1.70
6	10.40-12.50	10.40 - 12.50		10.4 - 12.5		
7	2.080-2.350	2.090 - 2.350		2.08 - 2.35		
Pan		0.520- 0.900	0.51 - 0.73	0.50 - 1.10		0.50-0.75

CBERS HRCCD and IRMSS Spectral Characterization (GSFC)

Using the spectral model described above, Top-Of-Atmosphere (TOA) reflectances for ten different bright and dark surface types (e.g., desert, forest, ocean, etc.) were generated for both the HRCCD and ETM+ sensors. Results indicated spectral differences within six to fifteen percent for analogous Landsat bands 1, 2, 3, and 4.

Using the spectral model described above, TOA reflectances for the same ten bright and dark surface types were generated for both IRMSS and ETM+ sensors. Results indicated a difference of approximately six percent in band 5. At the time of processing, results for band 7 were not attainable since the IRMSS RSR dataset was incomplete, as shown in Figure 3.1.

IRS-P6 AWiFS and LISS-III Spectral Characterization (GSFC)

Using the spectral model described above, TOA reflectances for ten different bright and dark surface types (e.g., desert, forest, ocean, etc.) were generated for both AWiFS and ETM+ sensors. Results indicated spectral differences within five percent for analogous Landsat bands 2, 3, and 4. At the time of processing, the spectral profile data available for AWiFS band 5 was incomplete. AWiFS does not have Landsat band 1 or band 7 equivalents.

Using the spectral model described above, TOA reflectances for the same ten bright and dark surface types were generated for both LISS-III and ETM+ sensors. Results duplicated AWiFS in that spectral differences were within ten percent for analogous Landsat bands 2, 3, and 4. At the time of processing, the spectral profile data available for LISS-III band 5 was incomplete. LISS-III does not have Landsat band 1 or band 7 equivalents.

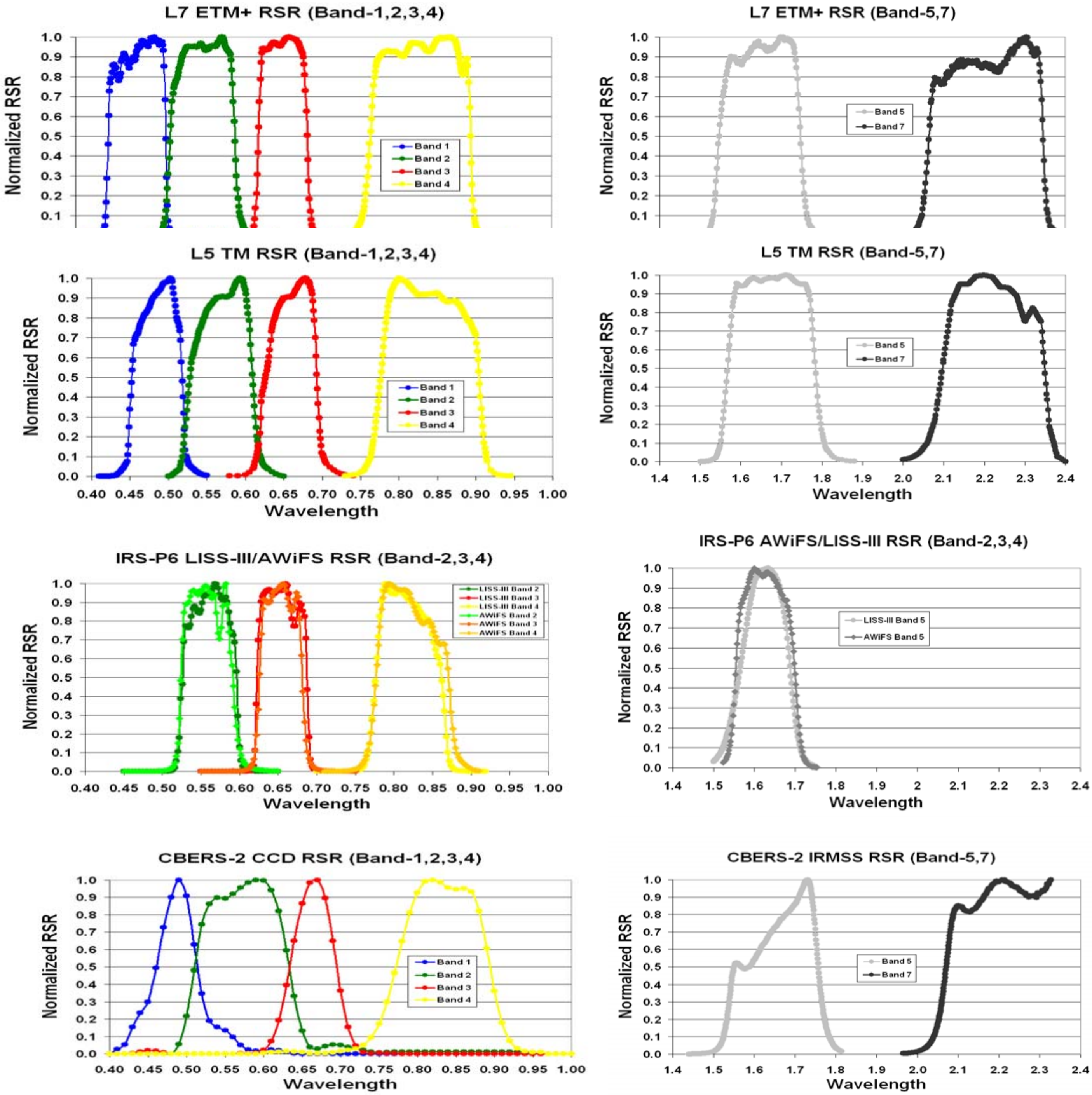

Figure 3-1. Comparison of the Relative Spectral Responses profiles

3.2 Radiometric Characterization

Radiometric characterizations encompass a variety of aspects. This evaluation focused on noise and artifact identification, bias and relative gain characterization, cross-calibration with near-coincident Landsat 5 and Landsat 7 acquisitions, and vicarious calibration approaches.

CBERS-2 assessments were based solely upon datasets acquired from the Center for Resources Satellite Data and Applications (CRESDA), the China ground processing project element. The scenes were evaluated at three different processing levels: Level-0 (raw), Level-1 (radiometrically corrected), and Level-2 (radiometrically and geometrically corrected), datasets.

IRS-P6 assessments were based upon Level-2 (radiometrically corrected) and Level-3 (radiometrically and geometrically corrected), datasets acquired through the U.S. Department of Agriculture (USDA) commercial imagery archive and directly from GeoEye, which has exclusive rights to sell AWiFS imagery outside India.

CBERS-2 HRCCD and IRMSS Artifacts (GSFC)

HRCCD delivered products consistently but had missing image band files, and incorrect or missing metadata files. The images themselves contained artifacts including striping, coherent and impulse noise, and saturated detectors. Discontinuities between each of the three CCD arrays were also noted. Some Level-1 products were observed to have residual patterns from image sharpening correction. Band 5 geometrically corrected products were observed to be mis-registered with respect to other bands.

IRMSS delivered products had missing image band files, embedded non-image and non-calibration metadata in scenes, different forward and reverse scan lengths due to clipped imagery, and inconsistent detection lamp pulse data per scan. Image artifacts included striping, scan correlated shift or bias state variations, and banding or memory effects.

CBERS-2 HRCCD and IRMSS Relative Gain and Bias Correction (GSFC)

Bias characterization of dark reference detectors was performed on three Level-0 scenes acquired by the HRCCD. Results over all bands and CCDs indicated a mean bias of approximately 25 digital number (DN) with the largest value in band 5. Over an 11 month period, there was a +/- 4 DN (or +/- 16 percent) variability over all bands, and noise variations of between 0.5 and 4 DN, per band, per odd-even detectors.

An independent determination of the bias and relative gain correction was performed comparing three HRCCD Level-0 to Level-1 product pairs. The products were generated from the same target acquired over three different dates. Results provided an independent verification of bias magnitude within 1.5 DN, and an undocumented relative gain and bias correction applied during processing to Level-1. A similar comparison was performed for the IRMSS using a single Level-0 to Level-1 product pair.

CBERS-2 HRCCD Cross-Calibration Studies (GSFC and USGS)

Two independent cross calibration assessments were performed between the HRCCD and Landsat 5 TM and Landsat 7 ETM+ image products.

The HRCCD versus Landsat 5 results were based upon derived radiances and reflectances using two Level-1 scenes of the same site acquired one year apart. The results indicated that there were approximately three to six percent differences in bands 1, 2, and 4 and an approximately 20 percent difference in band 3.

The HRCCD versus Landsat 7 results were based upon derived reflectances using eight Level-1 scene pairs of the same site acquired one and a half years apart. The results indicated less than six percent differences in bands 1, 3, and 4, and less than three percent differences in band 2. There was no apparent systematic decline in response across all bands. A worst case degradation of up to nine percent over one and a half years was noted in band 1. This compared to “three to seven percent degradation per month” cited from a published thesis on HRCCD and MODerate Resolution Imaging Spectroradiometer (MODIS) cross-calibration. (Xiaoying Li et. al, Detection of the degradation of CBERS-2 CCD camera)

IRS-P6 AWiFS and LISS-III Image Artifacts (GSFC and USGS)

LISS-III delivered products (all processing levels) contained missing image band files, undocumented scene-embedded metadata, and inconsistent detection of calibration lamp pulse data. Image artifact assessments revealed striping, scan-correlated shift (bias-state variations) and memory effect. A comparison of Level-0 to Level-1 scene data revealed an undocumented relative gain and bias correction applied during radiometric processing. Due to scan anomalies, results were obtained for forward scans only.

AWiFS Level-1 imagery revealed several artifacts including coherent noise, impulse noise, and memory effect, most visible in band 2 and band 5.

IRS-P6 AWiFS and LISS-III Cross-Calibration Studies (GSFC and USGS)

Mean radiances and reflectances were derived for subset regions of interest from near-coincident L7 ETM+ and AWiFS scenes. Regressions of AWiFS versus ETM+ values across all bands indicated good agreement (correlation coefficients. > .991) with small offsets.

Mean radiances and reflectances were derived for subset regions of interest from near-coincident L7 ETM+ and LISS-III scenes. Regressions of LISS-III versus ETM+ values across all bands indicated good agreement (correlation coefficients > .997) with small offsets.

AWiFS Vicarious Calibration Study (SSC)

Radiometric characterizations of AWiFS image products were performed under the Joint Agency for Commercial Imagery Evaluation (JACIE) project and were incorporated into this assessment. A reflectance-based vicarious calibration approach was used to predict at-sensor radiance. In this approach, ground-based measurements of surface target reflectance and atmospheric properties are made coincident with the satellite acquisition. A further discussion of this effort is included in the Appendix.

The table below summarizes the radiometric characterization results and associated uncertainties obtained during this evaluation for each of the four multi-spectral bands of the AWiFS sensor. Because of the limited number of datasets available, no attempt was made to separate radiometric calibration constants for the AWiFS-A and -B cameras. The calibration coefficients determined through the vicarious method agree reasonably well with those provided by the vendor.

Table 3-2. AWiFS radiometric characterization summary

	Band 2 (Green)	**Band 3 (Red)**	**Band 4 (NIR)**	**Band 5 (SWIR)**
NASA SSC Team				
Gain (W/m2 sr μm DN)	0.60 ± 0.02	0.46 ± 0.01	0.31 ± 0.02	0.056 ± 0.004
Offset (W/m2 sr μm)	-5.49 ± 5.36	2.60 ± 3.89	-3.11 ± 6.69	-2.82 ± 2.15
AWiFS Image Metadata				
Gain (W/m2 sr μm DN)	0.51	0.40	0.28	0.045
Offset (W/m2 sr μm)	0	0	0	0

3.3 Geometric Characterization

IRS-P6 AWiFS and LISS-III (USGS)

In one assessment, two LISS-III datasets and two AWiFS datasets were analyzed for geometric quality. The images were measured against data known to meet national map accuracies standards at 1:24000 scale, or a horizontal accuracy of approximately 6m. Due to the size of the swath width of the AWiFS instrument, an analysis of the full swath width could not be achieved using the available control. The control used typically covers one Landsat World Wide Reference System (WRS) nominal path width, or 185km which could cover the extent of one LISS-III dataset but fell far short of covering the image extent of one AWiFS dataset. The largest Root Mean Square Error

(RMSE) measured between the AWiFS datasets and the control used in the analysis was 0.7457 pixels, while the maximum RMSE measured for the LISS-III was 0.41462 pixels. The band alignment assessment produced a maximum RMSE, between any two band combinations, of 0.3055 pixels for the AWiFS instruments and 0.1956 pixels for the LISS-III instrument. For the band alignment analysis, the total RMSE must be weighed against the quality of the measurements themselves, which are usually assessed through the standard deviations of the measurements and visual inspection of the residuals. The band-to-band measurements are very sensitive to between band features, which must be viewable and consistent between spectral bands for reliable measurements.

Due to the large image extent of the AWiFS datasets obtained and the lack of coverage present in the 1:24000 scale controls, as compared to the image extent of the AWiFS products, alternative reference datasets were needed. A secondary reference dataset was chosen, which although possibly not as accurate as 1:24000 scale, would still assist in providing an assessment of the AWiFS datasets.

IRS-P6 AWiFS (SSC)

Geopositional characterizations of AWiFS image products were performed under the JACIE project and were incorporated into this assessment. Six standard AWiFS system corrected image quads (three from the AWiFS-A camera and three from the AWiFS-B camera) were analyzed. All scenes were acquired over the central United States. The basic measurements in each scene were 45 to 50 check points collected in accordance with the guidelines of the National Standard for Spatial Data Accuracy (NSSDA). Reference coordinates for each check point were obtained from Digital Orthophoto Quarter Quads (DOQQs) or from other high resolution imagery of similar horizontal accuracy. The reference sources were chosen to provide reference circular error at the 90 percent level (CE90) of 15m or better. A further discussion of this effort is included in the Appendix.

The mean CE90 of the AWiFS standard geometrically corrected images that were characterized was 760m, ranging from 423m to 1,887m. This result was largely in agreement with a Space Imaging assessment. Both analyses show generally grosser error than the estimate of 320m stated in the IRS-P6 Data User's Handbook (NRSA, 2003), but they also indicate that the data is correctable to near 1-pixel accuracy.

CBERS-2 CCD INPE Processing (USGS)

Four CBERS-2 images were analyzed for band-to-band registration quality. The RMSE band alignment offsets measured within the CBERS-2 data had values of up to 0.41 pixels in the line direction and 0.37 pixels in the sample direction. One of the four CBERS-2 images was assessed for geodetic accuracy. The CBERS-2 image that was assessed for geodetic accuracy was measured against a Multi-Resolution Land Characteristics (MRLC) Landsat TM scene covering the same area. The datasets within the MRLC archive have shown accuracies of better than 30 m. The mean offsets, as measured against the MRLC imagery, for the CBERS-2 image were calculated as 311.68m in the sample direction and 4,325.39m in the line direction.

CBERS-2 CCD CRESDA Processing (USGS)

Six CBERS-2 images were analyzed for band-to-band registration quality. The RMSE of the band alignment measured within each CBERS-2 dataset, excluding band 5, had values of up to 0.47 pixels in the line direction and 0.74 pixels in the sample direction. When available, band 5 was displaced by approximately 40 pixels from band 1, 2, 3, and 4. A comparison of the overlapping area showed mean offsets of up to 5.86 pixels in the line direction and 1.39 pixels in the sample direction. Two of the six CBERS-2 datasets covered essentially the same geographic area but were acquired on different dates. A temporal comparison between the two datasets showed mean offsets of 4.5km in the line direction and –7.8km in the sample direction. A final geometric assessment of the CBERS-2 data was made by comparing one of the CBERS-2 image files against an ETM+ image. Comparisons between the EMT+ and CBERS-2 imagery, neither of which had ground control applied or the effects of relief accounted for, showed mean offsets of 13.95km in the north/south direction and –8.52km in the east/west direction.

3.4 Spatial Characterization

IRS-P6 AWiFS Spatial Characterization (SSC)

Spatial characterizations of AWiFS image products were performed under the JACIE project and were incorporated into this assessment. Spatial resolution of the AWiFS multi-spectral images was characterized by estimating the value of the system Modulation Transfer Function (MTF) at the Nyquist spatial frequency. The Nyquist frequency is defined as half the sampling frequency, and the sampling frequency is equal to the inverse of the Ground Sample Distance (GSD). The MTF was calculated from a ratio of the Fourier transform of a profile across an AWiFS image of the Lake Pontchartrain Causeway Bridge and the Fourier transform of a profile across an idealized model of the bridge. The magnitude of the ratio normalized to the zero-frequency value provides the final MTF. A further discussion of this effort is included in the Appendix.

The resulting MTF at Nyquist frequency is shown in the below table. Values were calculated for images obtained with both the AWiFS-A and AWiFS-B cameras for the near infrared (NIR) and SWIR bands only. MTF at Nyquist values are somewhat more than 0.1 for the NIR and SWIR bands of the AWiFS-B camera image, while it is less than 0.1 for the AWiFS-A image bands. The NIR images have slightly larger MTF values than the SWIR images, which are consistent with diffraction blurring. While not particularly large, these values are derived for re-sampled images (using the Cubic Convolution method), and the re-sampling is typically expected to degrade spatial resolution.

Table 3-3. Results of spatial resolution characterization for images acquired by different AWiFS cameras over Lake Pontchartrain Bridge.

Band	MTF at Nyquist frequency	
	AWiFS-A	AWiFS-B
4 (NIR)	0.10	0.15
5 (SWIR)	0.05	0.10

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CBERS Spatial Characterization

Due to a lack of appropriate scene targets, no MTF characterizations were performed on imagery acquired from either the CBERS-2 HRCCD or IRS-P6 LISS-III sensors.

Section 4 Science Utility Evaluation

This section looks at the results obtained from using Data Gap candidate datasets in several typical Landsat data applications. While not exhaustive, these analyses are insights into the potential of the candidate datasets to meet ongoing Landsat research during the period of a data gap.

The science evaluation studies were conducted only for the IRS-P6 AWiFS sensor. These studies were made possible because of the availability of AWiFS data through the USDA data holdings. Figure 4.1 provides a summary of the AWiFS data from 2004 to 2006 available through the USDA. Each year has two charts, a world snapshot and a Conterminous United States (CONUS) snapshot. A small table is located on each chart for USDA data holdings per year, as well as how many unique path-row-quads exist. The difference between the two numbers is USDA's preference to have multiple dates over the same area. For instance, in 2006 USDA acquired 1,401 AWiFS scenes; however, only 478 are unique coverage (unique being defined as path-row-quad.) These snapshots are valid through December 15, 2006 and are subject to change as USDA is still acquiring data for the southern hemisphere.

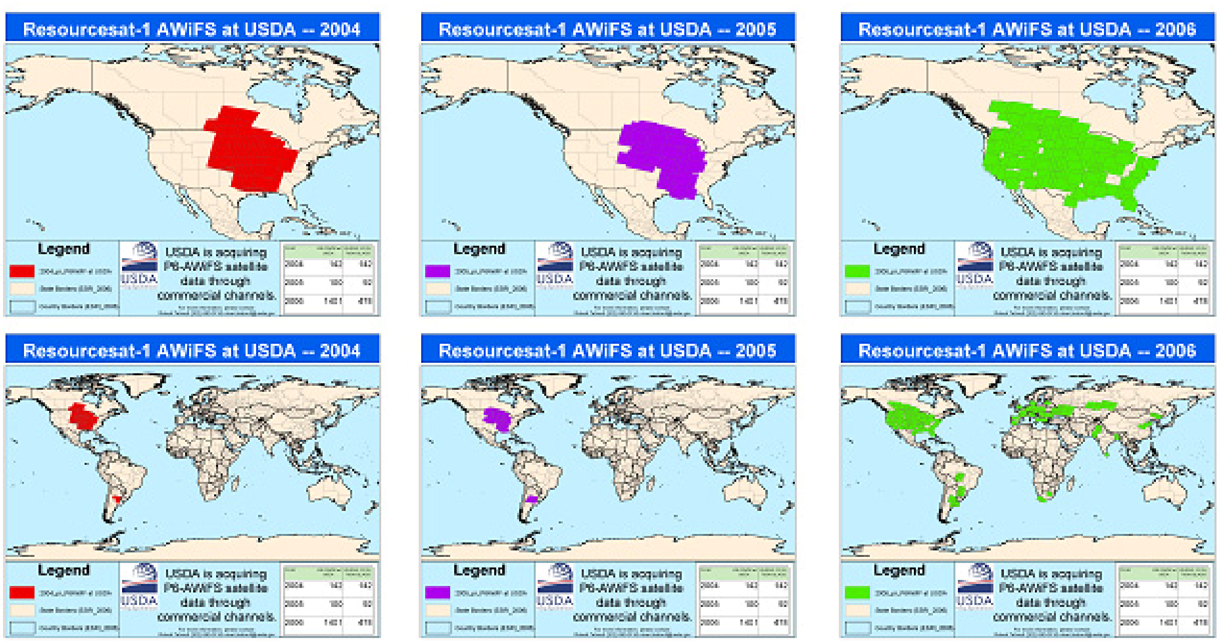


Figure 4-1. USDA AWiFS Data Holdings

4.1 Land Cover Trends Project

Terry Sohl and Roger Auch

Summary – Current Use of Landsat Data on Trends

The Land Cover Trends project is analyzing contemporary (1973 to 2000) land cover change in the conterminous United States. The analysis of land cover trends relies on the mapping of land cover for five years: 1973, 1980, 1986, 1992, and 2000. Landsat data (MSS, TM, and ETM+) are the primary data sources from which the Land Cover Trends project derives historical land cover information with higher resolution aerial photography used to assist in the land cover analysis. Due to the inherent accuracy limitations from all automated procedures for mapping land cover from remotely sensed data sources, the Land Cover Trends project uses a manual interpretation procedure to derive land cover information.

The comments on the utility of AWiFS are based on the possibility of the Land Cover Trends project becoming a long-term monitoring program, mapping land cover change on roughly a five-year repeat cycle. Therefore, the comments below detail how the use of AWiFS would impact the Land Cover Trends project if the project were mapping 2005, 2010, 2015, etc. land cover as part of a monitoring program.

Potential utility of AWiFS as a replacement for Landsat in the Land Cover Trends project.

File format

The provided geoTIFF format worked for the Land Cover Trends project's purpose. The Land Cover Trends project works almost exclusively within the ERDAS Imagine environment, and the geoTIFF is very simple to import into the software. One extra step was required for the Land Cover Trend project's purposes - stacking the provided four unstacked bands into one 4-band ERDAS image.

Projection

The geoTIFF imagery was provided in a Lambert Conformal Conic projection. The Land Cover Trends project uses the same Albers Equal Area Conic projection used by the National Land Cover Dataset (NLCD) and many other groups. However, the geoTIFF is straightforward to reproject to the Land Cover Trends project's required projection.

Radiometric resolution/Bit Depth

Some groups may express concern that native 10-bit AWiFS were compressed to 8-bit for the provided data files. This compression should not be a major concern for the Land Cover Trends project. The Land Cover Trends project use of a manual interpretation process limits the need for extremely high radiometric resolution. The Land Cover Trends project is accustomed to working with 8-bit Landsat data, and having 10-bit AWiFS compressed to 8-bit poses no problems.

Spectral Bands

The four AWiFS bands correspond closely to TM and ETM+ bands 2, 3, 4, and 5. While some applications will undoubtedly miss having TM and ETM+ band 1 and band 7, the impacts of having four versus six spectral bands would be minimal for the Land Cover Trends project. In the manual interpretation process, the vast majority of analyst time is spent using a 4, 3, 2 band combination. The lack of access to spectral bands corresponding to TM band 1 and band 7 would not impact the Land Cover Trends project.

Spatial Resolution

The primary data source for the 1992 date is Landsat TM data, and the primary data for 2000 is Landsat ETM+, both used at 30m resolution. The primary data source for 1973, 1980, and 1986 is Landsat MSS data, with a nominal resolution of approximately 56m x 79m. The Land Cover Trends project uses MSS resampled to 60m, which is also the minimum mapping unit size.

AWiFS provides a spatial resolution (56m) between TM and ETM+, and the lower-resolution MSS. On the Land Cover Trends project, the spatial resolution difference between TM and MSS has a very substantial effect on the ability to discriminate many land cover types occurring in relatively small geographic patches. Without the support of high-resolution photography to assist with the MSS interpretations, the accuracy of the land cover interpretations would undoubtedly be much lower for MSS-based interpretations versus TM-based interpretations.

From observations of the nine provided southern California AWiFS scenes, it is much easier to discriminate fine scale surface features from the 56m resolution AWiFS data than it is to discriminate such features from Landsat MSS data. However, it is also indisputable that fine scale surface features can be distinguished more easily from Landsat TM and ETM+ data than from AWiFS data. If the Land Cover Trends project were forced to rely on AWiFS instead of Landsat TM and ETM+, it is possible that spatial resolution differences would negatively impact the accuracy of the land cover interpretations.

Temporal Coverage

AWiFS potentially offers five-day repeat coverage versus 16-day for Landsat ETM+. Land cover change occurs on time scales of months to years, with negligible land surface change normally present within the repeat cycles of the two sensors.

However, AWiFS is likely to offer more high-quality, cloud-free scenes than Landsat ETM+ for a given year. The discrimination of many land cover features is greatly enhanced if multiple, seasonal satellite observations are available, as opposed to a single observation for one of the Land Cover Trends project analysis dates. If AWiFS could provide a greater selection of multi-season scenes, the ability to accurately map land cover classes might improve.

Summary

Because of the manual interpretation process, differences in the spectral bands offered or in the radiometric resolution between AWiFS and Landsat ETM+ would likely have little impact on the Land Cover Trends project. However, the lower spatial resolution of AWiFS could negatively impact the Land Cover Trends project's ability to discriminate fine-scale landscape features, especially those related to urban development. It is possible, however, that the disadvantage of lower spatial resolution could be offset by the more frequent repeat coverage of AWiFS, if that increased repeat coverage would translate into several multi-season scenes available for each of the Land Cover Trends project analysis dates.

4.2 Emergency Response Burn Mapping and MTBS Projects

Randy McKinley, Stephen Howard, Don Ohlen

Current use of Landsat data on ER Burn Mapping and MTBS

The Emergency Response (ER) Burn Mapping and Monitoring Trends in Burn Severity (MTBS) projects provide an emergency response burn severity mapping service for Department of the Interior (DOI) Burn Area Emergency Response (BAER) teams across the United States, including Hawaii and Alaska. This effort requires near real-time access to appropriate satellite imagery both pre-fire and immediately post-fire. Landsat data (TM and ETM+) are currently the primary data source from which burn severity datasets are generated. Although on occasion, when Landsat data are not available, Satellite Probatoire d'Observation de la Terre (SPOT), Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER), IKONOS, and other similar sensors are used. The MTBS project uses Landsat data (TM, ETM+, and MSS) exclusively but has less critical time requirements for data acquisition and turnaround.

Burn severity mapping algorithms are similar for both projects, based primarily upon the differenced Normalized Burn Ratio (dNBR), and require NIR and SWIR spectral data similar to Landsat band 4 (.76-.90) and band 7 (2.08-2.35). Alternatively, the processes could potentially be satisfied with only visible red (.63-.69) and NIR (.76-.9) spectral bands, similar to Landsat band 3 and band 4 and/or Landsat band 4 and band 5 (1.55-1.75). Further research is needed in this area to determine more quantitatively the acceptable spectral band characteristics.

Potential utility of AWiFS

File format

The provided geoTIFF format works for both the ER and MTBS Burn Severity mapping projects' purposes. Both projects work almost exclusively within the ERDAS Imagine environment, and the geoTIFF is easy to read or import into ERDAS. One extra step was required for both projects' purpose - stacking the provided four unstacked bands into one 4-band ERDAS image.

Projection

The geoTIFF imagery was provided in a Lambert Conformal Conic projection. Both the ER and MTBS Burn Severity mapping projects prefer the USGS Albers Equal Area Conic projection used by NLCD, Landfire, MTBS, and other large projects. However, the geoTIFF is straightforward to reproject to the required projection.

Radiometric resolution/Bit Depth

The 10-bit AWiFS data compressed to 8-bit is adequate for ER or MTBS Burn Severity mapping. Both projects currently work with Landsat 8-bit data.

Spectral Bands

The four AWiFS bands correspond closely to TM and ETM+ bands 2, 3, 4, and 5. The ER and MTBS Burn Severity mapping projects would prefer having spectral data similar to TM and ETM+ band 4 (.76-.90) and band 7 (2.08-2.35) for generating the differenced Normalized Burn Ratio (dNBR) data layer. However, preliminary tests indicate AWiFS band 4 (.77-.86) and band 5 (1.55-1.70) may be adequate surrogates for TM and ETM+ band 4 and band 7. Additionally, an alternative approach to burn severity mapping, using only visible and near infrared spectral bands (i.e., NDVI) could potentially prove successful and satisfy the requirements, although likely at reduced accuracy and sensitivity.

Calibration

The ER and MTBS Burn Severity mapping projects require calibrated imagery consistent with the USGS MRLC archive standard (TOA). Currently, the ER and MTBS Burn Severity mapping projects have correction procedures in place for Landsat and ASTER data. The development of similar correction procedures and scripts, to semi-automate the process, would likely be required for AWiFS. The ability to use AWiFS imagery for post-fire image coverage and the archive of Landsat and possibly ASTER data for pre-fire coverage may be optimal, and would require all data sources to be calibrated.

Spatial Resolution

The primary data source for current product generation is Landsat TM and ETM+ (SLC-on) data and when necessary ETM+ (SLC-off) data, both used at 30m resolution. AWiFS provides a spatial resolution of 56m at nadir and 70m at swath edge. Using AWiFS reduced resolution data, especially near the swath edge, would result in a slightly degraded output product with less mapping detail. However, initial evaluations suggest 56m to 70m would be adequate for most ER Burn Severity mapping services/applications.

The process requires pre-fire and post-fire images. In a potential Landsat data gap period, both projects would expect to use Landsat archive data at 30m resolution for the pre-fire scene and AWiFS 56m data for the post-fire scene. The AWiFS data would be re-sampled to 30m to facilitate input to existing models.

Temporal Coverage

AWiFS potentially offers a key advantage for ER Burn Severity mapping services. AWiFS five-day repeat coverage versus the current eight-day repeat coverage provided by Landsat 5 and Landsat 7 would be an improvement. ER Burn Severity mapping services are generally required within four to eight days of wildfire containment. Therefore, AWiFS would offer the potential opportunity to acquire two overpasses within the response window.

An unknown factor, critical to ER Burn Severity mapping services, is the turnaround time between satellite image acquisition and actual delivery of the data to staff. Currently, turnaround time is less than eight hours between Landsat data acquisition and when the data can be expected to be available via File Transfer Protocol (FTP). This turnaround time of eight hours also includes time necessary to create NLAPS format Landsat data that is precision terrain corrected. The service requires imagery that is tightly co-registered and preferably terrain corrected. If the turnaround time for AWiFS data products (including time for precision terrain correction) is significantly greater than eight hours, the utility of the data would be compromised. Turnaround times in the range of 24 to 48 hours could be acceptable. However, if this period was closer to 72 hours or greater the attractiveness of the product would be severely diminished. Project processes could potentially be modified to include processing the image rectification/correction step in-house. However, the feasibility of processing in-house would be dependent upon the overall cost of the data and availability of internal USGS EROS resources to perform the georectification work. The MTBS project does not have the same quick turnaround requirement.

Summary

AWiFS is potentially a good alternative to Landsat for the ER Burn Severity mapping services offered by EROS to the DOI and potentially the MTBS project. Reduced overpass repeat intervals would be advantages for the projects, resulting in more overpass opportunities within the response windows. The lack of an AWiFS equivalent to the Landsat band 7 SWIR band is a negative factor for both projects, likely resulting in reduced but acceptable product accuracy and sensitivity. Alternative ratios, using AWiFS band 5 and band 4 or band 4 and band 3 (NDVI) could be developed. Calibration of AWiFS data in a manner consistent with currently used MRLC data standards is mandatory. Cost of AWiFS data is a key consideration for both projects. Currently, the ER Burn Severity project is entirely supported by reimbursable income from DOI customers. Any increase in the total cost of generating the products will likely reduce customer demand. Geometric rectification, including terrain correction, is required by both projects due to the change detection (pre- and post-fire) nature of the data processing methodologies. Poor image to image registration would decrease the product accuracy by increasing overall derived image noise and the negative impact of clouds and shadow features.

4.3 FEWS International Crop Monitoring Project

Jodie Smith and Gabriel Senay

Summary – Current Use of Landsat Data for Crop Monitoring

The Famine Early Warning System Network (FEWS NET) project provides cropped area estimates to the United States Agency for International Development (USAID) for priority African countries to better determine potential food aid needs. The cropped area estimation work uses current Landsat imagery covering the entire country or the crop growing areas of the country. A typical project might consist of approximately 25 Landsat scenes. Additional high resolution imagery, such as IKONOS or Quickbird and ancillary data, is used to refine the estimates. Area estimates are derived from visual interpretations of regularly spaced sample points across the landscape along with statistical incorporations of ancillary data. While the visual interpretation of the imagery is more labor intensive than automated methods, a high level of accuracy is required for this project which cannot currently be attained with automated methods.

Other types of crop monitoring also utilize Landsat data within the FEWS project; these may include applications such as assessment of vegetation health, crop damage assessment after a disaster, or monitoring changes associated with land tenure issues.

The following assessments of the utility of AWiFS data are based on the probability that the cropped area estimation work will become a routine deliverable for many of the 25 countries currently monitored by FEWS. The comments on the utility of AWiFS data were made primarily with the crop area estimation work in mind, but thought was also given to other crop monitoring applications.

Potential utility of AWiFS

File format

The provided geoTIFF format was very familiar and easy to use. GeoTIFF format is easily used in the ArcGIS, ERDAS Imagine, and ENVI environments, which are the three primary software packages used by the FEWS project. The only image processing required before the data could be evaluated was compositing the four single bands into one multi-spectral image, which is a simple step in any of the software packages used.

Projection

The Lambert Conformal Conic projection used was fine for evaluation purposes and would also work for some specific monitoring applications. For the cropped area estimation work that the FEWS project performs, an equal area projection would be preferred. If this data is to replace Landsat, projection options should be available in the ordering process. In the past, the FEWS project used Universal Transverse Mercator (UTM) projection, which is the existing projection of the GeoCover dataset used to geo-reference the new images. UTM is not ideal in locations that cross zones. The FEWS project prefers to do as little re-sampling of the images as possible. If the AWiFS data is provided as an orthorectified product, this step and the use of the UTM projection is unnecessary.

Radiometric resolution/Bit Depth

The native 10-bit AWiFS radiometric resolution would be preferable over the compressed 8-bit data provided. For some applications, such as crop type discrimination, the added resolution may be particularly beneficial. The 8-bit data may be easier for some software packages, such as ArcGIS, to handle and is also sufficient for some binary crop classifications. Providing 8-bit data could also be an ordering option. If there is no option, the FEWS project recommends receiving the 10-bit data.

Spectral Bands

A Landsat 5, 4, 3 band combination is typically used for the current cropped area work. The AWiFS data provides bands that are similar to this. The lack of a thermal band will not be a problem for the current projects. Thermal bands from MODIS are currently used to estimate evapotranspiration but this work has not been translated to Landsat due to the repeat period. Landsat band 1 is rarely used due to the sensitivity to atmospheric effects. Because predefined automated classification methods are not used for FEWS crop monitoring projects, differences between the wavelength ranges of corresponding AWiFS and Landsat bands will not have a significant effect on the current work.

Spatial Resolution

The USDA has completed a comprehensive evaluation of the AWiFS data for national crop monitoring purposes and found that the data would be sufficient for their purposes. The cropping patterns in Africa are quite different from those found in the United States. The effect of the spatial resolution of the data could have a much larger impact on the usability of the data in areas such as Zimbabwe, where the field sizes are much smaller.

The only sample data available for evaluation in areas monitored by FEWS NET was over the “Maize Triangle” in South Africa. This sample data was not an ideal area for evaluation purposes because the agricultural system is quite advanced and more closely resembles that found in the United States rather than other parts of Africa. The AWiFS data would work well for monitoring and producing cropped area estimates in this type of agricultural land where there are large fields and center pivot irrigation systems.

In areas such as Zimbabwe, even 30m spatial resolution Landsat data is insufficient to distinguish small fields, although it can distinguish the primary crop growing areas. The FEWS project uses high resolution data sources, such as Quickbird (approximately 3m spatial resolution) or IKONOS (approximately 1m spatial resolution) to adjust the area estimates in these types of landscapes. Using AWiFS data with a spatial resolution of 56m would likely exacerbate the problems in these areas. However, the current high resolution adjustments could be applied to this data with the same results.

For FEWS crop monitoring projects, it would be beneficial to also receive the higher resolution LISS-III (spatial resolution of 23.5m) and LISS-IV (spatial resolution of 5.8m) data acquired during the same time. Resolving the scaling issues associated with area estimates is an important goal of this project. Having different resolution data acquired at the same time would be of great benefit to meeting this goal. While an attempt is currently being made to acquire high resolution data from the same time frame as the Landsat images, this option is not always possible. Differences in atmospheric conditions over even a few days can be problematic when dealing with scale issues. While the reduced spatial resolution of the AWiFS data may negatively impact some aspects of the FEWS crop monitoring work, the additional availability of the higher resolution LISS-III and LISS-IV could have positive long term impacts.

Temporal Coverage

Landsat ETM+ currently offers 16-day repeat coverage. When cloud contamination is considered, the FEWS crop monitoring projects may be able to acquire one to two good scenes per season. AWiFS can potentially provide five-day repeat coverage. This is a clear benefit of using this data. It is likely that there would be more clear scenes available over the growing period. It is necessary to monitor how crop signals change over the growing season to discriminate different crop types. Having a more complete time series over the season would be very beneficial to advancing work in this area. Optimal dates for crop classification could be chosen more specifically with a higher volume of data to choose from.

Data Delivery

One aspect of the AWiFS data that may be a concern to FEWS NET crop monitoring activities is the lack of a direct downlink capability over most of Africa. No significant archive of data exists over Africa. The data is said to be available 24 hours after a data dump, as compared to eight hours for data acquired in areas with a direct downlink capability. This short delay in availability should not be a problem. However, if a problem were to occur with the onboard storage capabilities of the instrument (like Landsat 5) this method would have a serious impact on the ability to continue FEWS crop monitoring activities. It would be important to the FEWS project to establish an additional ground station in Africa (possibly SAC) to ensure the continuity of the data.

History

It is important for FEWS crop monitoring activities to have a historical archive of data from which to make comparisons. ResourceSat-1 was launched on October 17, 2003, which does not provide a long history from which to calculate anomalies from a historical means. However, the current system is planned to be operational through 2012 and next generation systems should carry on through 2018.

Summary

The foreseen benefits of using AWiFS data for FEWS crop monitoring activities would primarily be the higher repeat coverage rate, simultaneous acquisition of multi-resolution data and higher radiometric resolution. Potential drawbacks would be the reduced spatial resolution, lack of a backup system to ensure data continuity over

Africa, and the lack of a substantial archived history. Steps could be taken to minimize any negative impacts. Consideration of these steps and weighing the potential benefits of the AWiFS data leads to the conclusion that this data could be a viable replacement for Landsat in current and future FEWS crop monitoring activities.

4.4 Forest and Rangeland Project

(Part of Landsat Science Team Activities) - Four Corners Study Area
James E. Vogelmann and Susan Maxwell (PI)

Summary – Current Use of Landsat data for Forest and Rangeland

The Forest and Rangeland project is currently working on a USGS-supported Landsat Science Team activity entitled "The Monitoring of Forest and Rangeland Condition Using Landsat Continuity and Alternative Sources of Satellite Data Project". One of the primary objectives of the work is to provide insight regarding the feasibility and reliability, as well as the potential pitfalls, of using historic and current Landsat and Landsat-like data for large area land characterization and monitoring efforts. Some specific goals of the proposed effort include, 1) Develop a better understanding of the effect of sensor calibration on improving land characteristics change information; 2) Evaluate the relevance of object-based classification approaches for characterizing and monitoring landscape change; 3) Assess the comparability of applications products developed using Landsat versus other sensors (e.g., AWiFS), thus providing perspective on the impact of the projected Landsat mission gap on major ongoing remote sensing-based natural resource applications projects; and 4) Characterize the relationships between natural vegetation gradients and Landsat data, with special emphasis on assessing gradual within-state changes taking place over time in response to climate change, drought, insects, and other factors.

Two primary study sites have been selected for the initial phases of this project: The Four Corners region located in the southwestern United States, and the Gombe National Park region located in Tanzania, Africa. For this report, the Forest and Rangeland project will concentrate on AWiFS data from the Four Corners Region. AWiFS and Landsat 5 data acquired on the same date (June 10, 2006) were used for the analysis. This analysis is a preliminary assessment and the Forest and Rangeland project will plan to conduct more detailed assessments as the project progresses.

Potential utility of AWiFS

File format

The provided geoTIFF format works for the Forest and Rangeland project's purpose. TIFF is a standard format that can automatically be ingested by the ERDAS Imagine software.

Projection

The geoTIFF imagery was provided in a Lambert Conformal Conic projection. The Forest and Rangeland project uses the Albers Equal Area projection. Reprojection is another processing step, but one that is not particularly cumbersome.

Radiometric resolution/Bit Depth

The Forest and Rangeland project will assess the radiometric properties of the AWiFS data in relation to Landsat data on a band-by-band basis. The first impression (visual inspection) when comparing AWiFS versus Landsat imagery is that the datasets look very similar. The Forest and Rangeland project suspects that the radiometry will work well for the investigations, especially if there is a good linear match between spectral bands. The Forest and Rangeland project understands that the AWiFS data currently being used has been rescaled to 8-bit. 10-bit would be preferable, but the change is probably not a major issue.

Spectral Bands

The four AWiFS bands correspond very closely to TM and ETM+ band 2 through band 5. The Forest and Rangeland project does not normally use TM band 1 for forest/rangeland monitoring, although in the more arid areas TM band 7 can be useful. The Forest and Rangeland project does not anticipate any major problems.

Spatial Resolution

In general, the 56m spatial resolution of AWiFS should be reasonable for natural resource applications (although the 30m resolution provided by Landsat TM and ETM+ is certainly better). For most of the applications, 56m resolution should be adequate (especially for assessing the large and contiguous forest and rangeland areas common throughout the Four Corners Region). The Forest and Rangeland project noticed that urban areas, such as around Albuquerque, New Mexico, are much less clear in the AWiFS imagery than in the TM imagery. On the whole, the Forest and Rangeland project does not feel that the AWiFS coarser spatial resolution will adversely impact the analyses.

Temporal Coverage

AWiFS potentially offers five-day repeat coverage, as compared to 16-day repeat coverage for Landsat TM and ETM+. As a result, AWiFS is likely to offer more high-quality, cloud-free scenes than Landsat TM or ETM+ for a given year. These cloud-free scenes are important to the project because clouds can be a major factor hindering the analyses, limiting access to the number of scenes. The Forest and Rangeland project must have access to multiple scenes throughout the growing season to enable the capturing of phenological changes.

Image Segmentation

The Forest and Rangeland project ran several object-based image segmentation experiments using E-Cognition software. In general, using comparable approaches, more segments were generated using Landsat TM data than AWiFS data, which is probably a function of spatial resolution, but is unclear why it occurred. However, segmentation of AWiFS data could be made to “mimic” Landsat data by altering segmentation parameters, implying that AWiFS data should be appropriate for these types of analyses.

Aerial Extent

One of the major advantages that AWiFS data has over Landsat data relates to the aerial extent of coverage. The area covered by a single AWiFS scene is much larger than a single Landsat scene. The size is an important consideration for large area characterization and monitoring activities. Patching a large area with many smaller scenes acquired on different dates, which the Forest and Rangeland project is forced to do with Landsat data, can be a major hurdle in the land characterization and monitoring activities.

Summary

The preliminary assessment is that AWiFS data are excellent, and may represent a good alternative source of data for natural resource monitoring and characterization activities. The overall radiometric quality appears to be excellent, although the Forest and Rangeland project needs to conduct further investigations. The aerial coverage is particularly good, as is the potential repeat cycle. Limitations may occur due to the lack of a band equivalent to TM and ETM+ band 7, and the coarser spatial resolution of AWiFS will have an adverse impact on some assessments. Object-based segmentation assessments have shown that AWiFS products can be made to “look like” TM segmentation products. The Forest and Rangeland project looks forward to conducting additional analyses of AWiFS with TM and ETM+ data.

4.5 AWiFS and Landsat Inter-Comparison Project

Susan Maxwell and Allan Janus

Summary – Current Use of Landsat Data for AWiFS and Landsat Inter-Comparison

The agricultural community is one of the largest users of mid-resolution imagery (approximately 30m resolution). The USDA was a major consumer of Landsat imagery, purchasing 2,000 to 3,000 images annually to support their national and international crop mapping and monitoring programs, until 2006 when they switched to using the ResourceSat-1 AWiFS system due to the uncertainties and problems of the Landsat 5 and Landsat 7 instruments. The USDA National Agricultural Statistics Service (NASS) performed comparisons of Landsat to AWiFS data and has found generally good results, especially in the Midwest United States. The Landsat Inter-Comparison project is coordinating with USDA/NASS to enhance the understanding of the impacts of using AWiFS versus Landsat imagery for crop type mapping applications. The activities of this task will focus on the inter-comparison of Landsat 5 and Landsat 7, and the AWiFS imagery requirements of agricultural applications.

Potential utility of AWiFS

File format

The provided geoTIFF format is acceptable for the Landsat Inter-Comparison project's work. GeoTIFF is a standard format that can automatically be ingested by ERDAS Imagine, Definiens eCognition, and ESRI ArcInfo.

Projection

The geoTIFF imagery was provided in a Lambert Conformal Conic projection. The Landsat Inter-Comparison project generally works in the UTM projection, which is the standard projection that USDA uses. The Landsat Inter-Comparison project can reproject the images; however, reprojecting images adds another step to processing.

Radiometric resolution/Bit Depth

The data was provided in 8-bit format. The Landsat Inter-Comparison project would have preferred to receive the data in the original 10-bit format to evaluate the potential loss in information. The USDA/NASS research team indicated that some crops are not as spectrally separable using AWiFS, which could be a result of the loss of bands 1, 6, 7, lower spatial resolution, or the reduced bit depth.

Spectral Bands

The four AWiFS bands correspond very closely to TM and ETM+ bands 2 through 5. The USDA/NASS program was using all Landsat bands for mapping crop types, including the thermal band, prior to 2006 when they switched to using AWiFS imagery. The impact of the lack of bands 1, 6, and 7 will be evaluated in detail over the next year. A comment by one of the USDA/NASS researchers indicated that the lack of one of these bands may have resulted in lower spectral separability between rice and cotton in the Arkansas region.

Spatial Resolution

The 56m spatial resolution of AWiFS should be adequate for the Midwest United States, where crop fields are relatively large. However, EROS expects that crop identification in the eastern regions may be impacted due to their smaller field size. Smaller features, such as roads and narrow wind breaks, may not be as easily distinguishable. Urban areas are generally mapped as one class (e.g., urban characteristics are not specifically distinguished, such as those mapped in the USGS/NLCD) and EROS expects the 56m resolution to be adequate for their identification.

Temporal Coverage

AWiFS potentially offers five-day repeat coverage, as compared to 16-day repeat coverage for Landsat TM and ETM+. USDA Foreign Agricultural Service (FAS) provided EROS with 35 AWiFS images covering the state of Iowa for the 2006 growing season (May 1 to September 30, 2006). Of the 35 images, only nine were useful for further crop mapping due to clouds (16 images were too cloudy to use; greater than 30 percent clouds), significant overlap (seven images were greater than 50 percent overlap with another image along the same path, a few had greater than 90 percent overlap), or inappropriate dates for distinguishing crops (crops begin senescing by September 1 in this region).

To successfully map crops in this region, generally only two image acquisitions over the growing season are required; early spring (May through early June) and late summer (late July through August). Near-cloud-free AWiFS imagery was available for both time periods for the study area (two Landsat scenes in central Iowa). Several other images acquired across the growing season were also available, covering portions of the study area. These images may be useful for crop monitoring applications.

Image Segmentation

The Inter-Comparison project ran several image segmentation experiments using eCognition software. Using consistent segmentation parameters resulted in a 75 percent reduction in the size of segments created from AWiFS imagery as compared to Landsat TM. A standard scale parameter of ‘10’ is typically used to segment Landsat imagery, resulting in an average patch size of 12.4 hectares in the small test area. A parameter of ‘5’ was required to approximate this patch size using AWiFS imagery. Even at a scale parameter of ‘5’, small or narrow features, such as roads and riparian areas, were not delineated in the AWiFS imagery.

Aerial Extent

The area of coverage for each image acquisition is much larger than Landsat. The larger coverage area is a major advantage to crop mapping applications as it increases the likelihood that cloud-free imagery will be acquired at appropriate times during the growing season. Processing and mosaicing images together are a very time-consuming effort. The increased footprint of AWiFS is expected to reduce that effort considerably.

Summary

Preliminary results demonstrate that AWiFS will likely be adequate for mapping crops in the Midwest United States, where crop fields are relatively large and only a few crop types are grown. Lower accuracies may occur in the eastern regions where fields are generally smaller and more diverse. The larger area coverage and repeat cycle will be an advantage for crop mapping applications, allowing for the increased likelihood of cloud-free acquisitions, and reduction in the processing and handling of a lower number of images. Indications show that the loss of Landsat bands 1, 6, and 7 will have an impact on crop discrimination in some areas. Segmentation of the AWiFS imagery for crop fields in the Iowa region was adequate; however, the segmentation parameters will need to be adjusted to produce segments comparable to those found in the Landsat imagery. Smaller features, such as roads, narrow riparian areas, and field drainage areas, were not distinguishable in the AWiFS imagery.

4.6 Viability of IRS-P6 Datasets for NLCD Products

Michael Coan

NLCD Background

The MRLC Consortium is a group of Federal agencies who first joined together in 1993 (MRLC 1992) to purchase Landsat 5 imagery for the conterminous United States and to develop a land cover dataset called the National Land Cover Dataset (NLCD 1992). In 1999, a second-generation MRLC consortium was formed to purchase three phenologic dates of Landsat 7 imagery for the entire United States (MRLC 2001) and to coordinate the production of a comprehensive land cover database for the nation called the National Land Cover Database (NLCD 2001).

The NLCD products are 30m pixel data layers, generated from at least three dates (leaf-off, leaf-on, spring) of Landsat 5 and Landsat 7 imagery. All Landsat imagery is preprocessed with precision terrain corrections, and normalized with at-satellite reflectance. The current national products are Land Cover, Percent Tree Canopy, and Percent Impervious Surface.

The second generation NLCD 2001 has been compiled across all 48 CONUS states as a cooperative mapping effort of the MRLC 2001 Consortium. NLCD 2001, including Alaska, Guam, Hawaii, and Puerto Rico, is scheduled for completion on or before December 31, 2007. Methodology and data sources for the next generation are being planned (NLCD 2006/2007).

Alternative data platform and providers are being considered due to the aging of Landsat 5 and the current scan-gap problems with Landsat 7.

Potential utility of IRS-P6 (AWiFS and LISS-III) for creating NLCD products

Two test sites were found to contain same-day acquisitions of Landsat 5, Landsat 7, and AWiFS. These sites were at Salt Lake City, Utah and Mesa, Arizona.

In Salt Lake City, a cloud-free Landsat 5 scene of Path 38, Row 31 was acquired on June 19, 2005. Approximately 30 minutes later, an IRS-P6 AWiFS and LISS-III scene of the same region was acquired.

In Mesa, a cloud-free Landsat 7 scene of Path 36, Row 37 was acquired on June 29, 2005. Approximately 30 minutes later, an IRS-P6 AWiFS and LISS-III scene of the same region was acquired. Because of the scan-gap issue, the pre- and post-scenes (June 13, July 15) were also obtained, making a complete Landsat 7-based dataset.

In both test sites, the area common to all images was evaluated for each available image source in terms of its ability to duplicate existing NLCD products. Artificial products were constructed by massively sampling existing products and assessing each image source's ability to generate a duplicate by comparing its version to the source. In contrast to the usual NLCD procedures, no ancillary information (e.g., DEM, Slope) was used in the classification. The intent was to generate results based solely on the spectral information unique to each dataset. The AWiFS and LISS-III sensors lack the equivalents of Landsat spectral band 1 and band 7.

Land Cover Estimation

Of the eleven NLCD classes present in the area mapped by decision tree methods, strong agreements existed with the capabilities of AWiFS/LISS-III and Landsat 5/Landsat 7. The below table summarizes the mean error estimates of each classification. The mean error estimates can be seen by the difference values. Landsat 5 has slightly lower estimated error than AWiFS and LISS-III, which is most likely due to the presence of more spectral content in the Landsat 5 data. The large magnitude of estimated error is not representative of the normal NLCD procedures, for reasons stated above, but the magnitude of the estimated error differences between the two sensors range from two to six percent.

Table 4-1. Mean Error Estimates of Land Cover Classifications

Mean Error Estimates	
AWiFS	44.9%
L5	42.8%
Difference	2.1%
LISS-III	50.7%
L5	44.8%
Difference	5.9%

The table below summarizes the eleven NLCD classes mapped by decision tree methods. Overall, strong agreements exist with the ability to determine most classes, with differences of less than five percent.

Bolded text in the table indicate exceptions where Landsat 5 was typically five percent or more accurate than AWiFS/LISS-III. These exceptions occur on the classification of evergreen, shrub/scrub, woody wetlands, and emergent wetlands. Historically, TM band 1 and band 7 have been widely used for vegetation and moisture discrimination; therefore explaining the increased difficulty with AWiFS/LISS-IIII to classify moist and dry vegetation.

Table 4-2. Landcover Classification Test

		AWiFS	**L5**	**L5-AWiFS**	**LISS-III**	**L5**	**L5-LISS-III**
	LC Class Name	% Correct	% Correct	delta %	% Correct	% Correct	delta %
1	open water	87.2	87.3	0.1	92.7	92.6	-0.2
2	barren land	86.3	87.1	0.7	76.2	81.9	5.7
3	deciduous forest	65.7	70.6	4.9	66.0	68.9	2.9
4	**evergreen forest**	**37.4**	**52.3**	**14.9**	**40.4**	**50.5**	**10.1**
5	mixed forest	69.4	68.8	-0.6	62.2	66.0	3.7
6	**shrub/scrub**	**39.7**	**46.6**	**6.9**	**36.0**	**44.5**	**8.4**
7	grassland	63.1	64.0	0.8	52.0	59.6	7.6
8	pasture/hay	29.6	30.6	0.9	22.5	26.4	3.9
9	cultivated crops	48.6	53.3	4.7	44.7	46.7	2.1
10	**woody wetlands**	**37.6**	**43.6**	**6.0**	**29.8**	**40.2**	**10.4**
11	**emergent wetlands**	**54.9**	**62.8**	**7.9**	**41.0**	**58.2**	**17.2**

Canopy Density Estimation

Canopy density estimates are a continuous estimate of the percentage of tree cover on a per-pixel basis. In this study, the estimates were generated from massively sampling approximately 1,000 points per value, from 1 to 100 (totaling approximately 100,000) out of existing canopy products of both the Salt Lake City and Mesa sites. Points common to all image pairs were used for multiple regressions, using cross-validation and committee model options.

The table below summarizes the canopy density cross-validation results for both the Salt Lake City and Mesa test sites. The results typically show very slight (one to two percent) differences in average absolute error between Landsat 5 in Salt Lake City and Landsat 7 in Mesa, versus AWiFS and LISS-III. Figure 4.1 contains graphs of each canopy estimate difference from the current NLCD standard product, where narrower bases and taller peaks imply closer agreement with the source. For the purpose of computing percent tree canopy, AWiFS and LISS-III appears useful.

Impervious Surface Estimation

Impervious surface estimates are a continuous estimate of the percentage of impervious surface, on a per pixel basis. In this study, the estimates were generated from massively sampling approximately 1,000 points per value, from 1 to 100 (total approximately 100,000) out of existing impervious surface products of both the Salt Lake City and Mesa sites. Points common to all image pairs were used for multiple regressions, using cross-validation and committee model options.

The table below summarizes the impervious surface cross-validation results for both the Salt Lake City and Mesa test sites. Similar to the canopy estimates, the results typically show very slight (one to two percent) differences in average absolute error between Landsat 5 in Salt Lake City and Landsat 7 in Mesa, versus AWiFS and LISS-III. Figure 4.2 contains graphs of each impervious estimate difference from the current NLCD standard product, where narrower bases and taller peaks imply closer agreement with the source. For the purpose of computing percent impervious surface, AWiFS and LISS-III appear useful.

Table 4-3. Cross-Validation Statistics for Percent Canopy Tests

Canopy Estimates				
SLC, UT (L5)	**AWiFS**	**LISS-III**	**L5(vs. AWiFS)**	**L5(vs. LISS-III)**
Average |error|	14.6	14.7	13.9	14.1
Relative |error|	0.58	0.58	0.55	0.56
Correlation coefficient	0.75	0.75	0.77	0.77
Mesa, AZ (L7)	**AWiFS**	**LISS-III**	**L7(vs. AWiFS)**	**L7(vs. LISS-III)**
Average |error|	12.0	12.1	11.8	11.5
Relative |error|	0.70	0.67	0.69	0.64
Correlation coefficient	0.67	0.68	0.68	0.71

Table 4-4. Cross-Validation Statistics for Percent Impervious Surface Tests

Impervious Estimates				
SLC, UT (L5)	**AWiFS**	**LISS-III**	**L5(vs. AWiFS)**	**L5(vs. LISS-III)**
Average |error|	14.8	15.5	14.5	14.1
Relative |error|	0.59	0.61	0.58	0.56
Correlation coefficient	0.75	0.72	0.75	0.77
Mesa, AZ (L7)	**AWiFS**	**LISS-III**	**L7(vs. AWiFS)**	**L7(vs. LISS-III)**
Average |error|	15.6	16.9	15.4	15.0
Relative |error|	0.65	0.78	0.64	0.70
Correlation coefficient	0.70	0.57	0.70	0.68

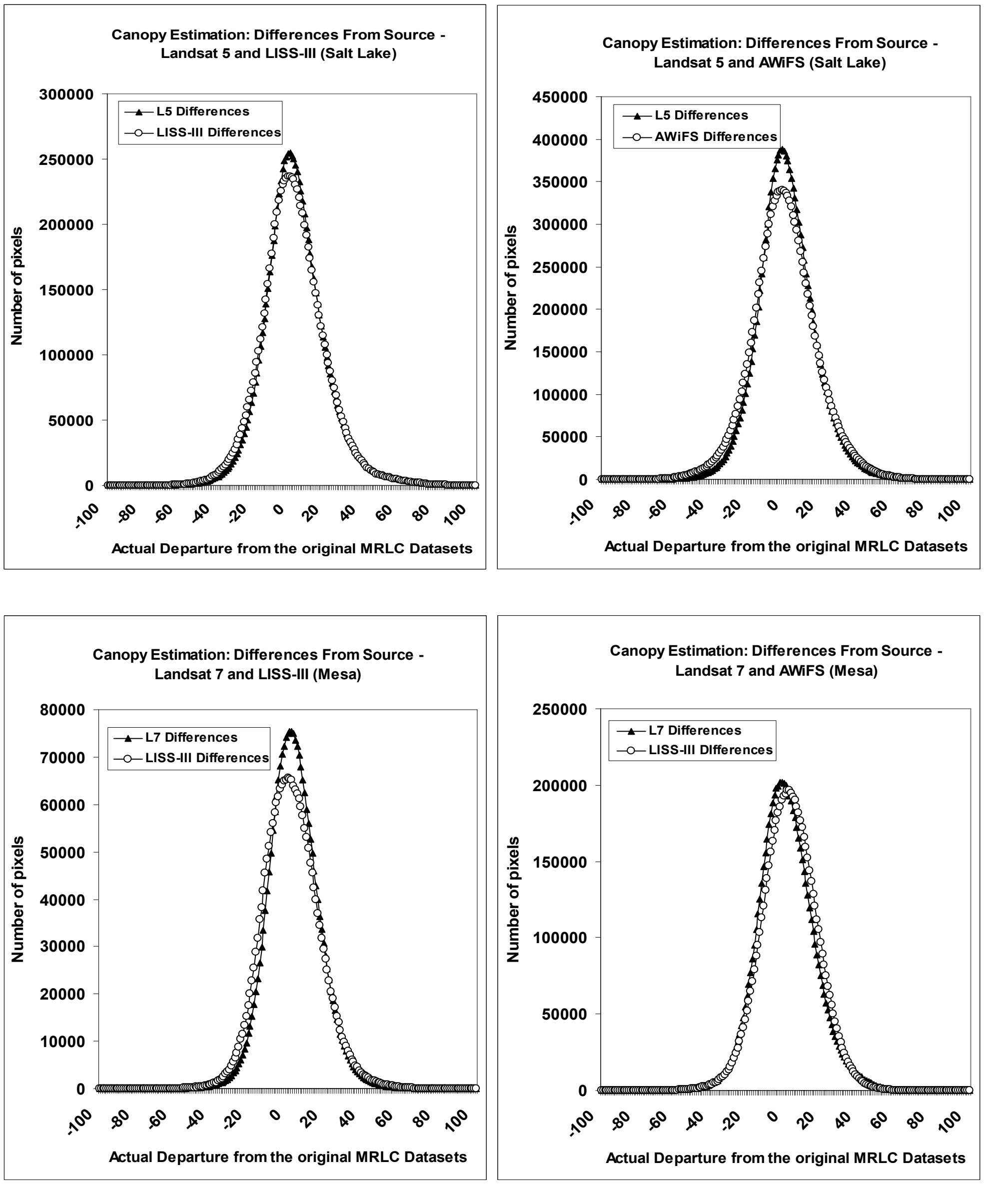


Figure 4-2. Difference of Canopy Estimations from the MRLC Source Data Sets

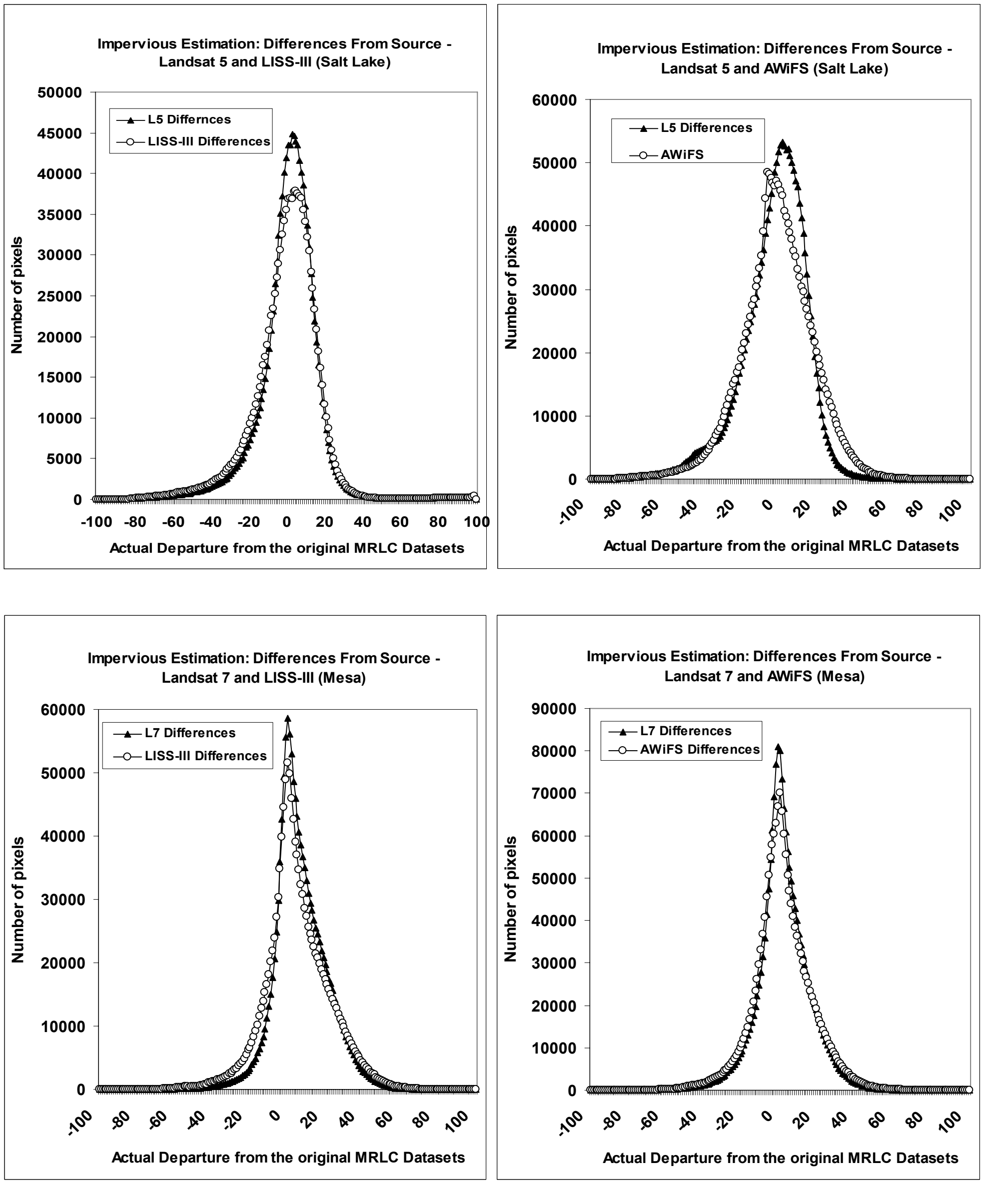


Figure 4-3. Difference of Impervious Estimates from the MRLC Source Data Sets

Further Discussions

Some anomalies were noted for both canopy and impervious estimates. For the Mesa site, the AWiFS data were composed of all four quadrants, and intensity artifacts can be seen due to the various quadrant overlaps. A similar situation can be found in the Landsat 7 mosaic of scan-gap data, with low intensity “stripes”. Further work is needed to identify an optimum method of using these datasets without generating the artifacts. The LISS-III impervious estimate did not contain any artifacts, and therefore, potentially outperforms the Landsat 7 scan-gap mosaic for canopy and impervious estimates.

Summary

The initial evaluation of the viability of the IRS-P6 platform for providing images suitable for the NLCD products, such as Land Cover, Percent Tree Canopy, and Percent Impervious Surface, gave encouraging results. Inspection of individual products revealed slightly lower overall accuracies in land cover classification of particular classes from the AWiFS and LISS-III datasets, but a very useful approximation to Landsat 5 and Landsat 7 for Percent Tree Canopy and Percent Impervious Surface estimations. Artifacts were noted in the areas of overlap, both of the AWiFS quadrants, and the scan-gap Landsat 7 mosaic. These drawbacks may be addressed by potential five-day revisits of the IRS-P6. More image acquisitions would be needed to investigate these issues.

4.7 Global Agriculture Monitoring project (GLAM) Project

Matthew C. Hansen and Chris Justice (PI)

Summary – Current Use of Landsat Data on GLAM

The Global Agriculture Monitoring project (GLAM), funded by NASA and USDA, has a goal to deliver planted crop area and crop type maps for key crop-producing regions of the Earth. Current work includes the use of MODIS time-series datasets to derive moderate spatial resolution planted area estimates for crops, such as soybeans and corn. Analysts with the USDA Foreign Agricultural Service report on croplands on a regional scale and partially rely on remotely sensed imagery to generate production and yield estimates for their respective regions. The GLAM project aims to employ new data sources and innovative derived thematic products to assist the analysts in their tasks. The planned use of AWiFS is to fuse it within season with MODIS data to capture planted areas for selected crops at the AWiFS spatial scale.

Potential utility of AWiFS

File format

The provided geoTIFF format is acceptable for the GLAM project's purpose. TIFF is a standard format that can automatically be ingested into the work flow.

Projection

The geoTIFF imagery was provided in a Lambert Conformal Conic projection. The GLAM project uses the MODIS Sinusoidal projection. Reprojection is another processing step, but one that should not materially affect the results.

Radiometric resolution/Bit Depth

The GLAM project understands that a rescaling of the AWiFS data occurs before delivery. The GLAM project would prefer retaining all of the native quantization, as they perform analyses that are automated, meaning the project does not rely on photo interpretation. For crop type mapping, a number of fine spectral-scale distinctions must be made. Any degradation of the imagery could mean a loss in mapping capability.

Spectral Bands

The four AWiFS bands correspond closely to TM and ETM+ bands 2, 3, 4, and 5. The GLAM project shall assess to what degree missing band 7 impacts mapping. The GLAM project typically does not need ETM+ band 1.

Spatial Resolution

AWiFS provides a spatial resolution (56m) between TM and ETM+, and the lower-resolution MSS. For the GLAM project, the AWiFS resolution is sufficient for areas of mechanized agriculture, but (like ETM+) may be more problematic in developing countries with less intensive farming practices. On the whole, the GLAM project does not feel that the AWiFS coarser spatial resolution will deleteriously impact the analyses.

Temporal Coverage

AWiFS potentially offers five-day repeat coverage, as compared to 16-day repeat coverage for Landsat ETM+. As a result, AWiFS is likely to offer more high-quality, cloud-free scenes than Landsat ETM+ for a given year. The ability to map cropland dynamics, crop types, and planted areas, is greatly enhanced if multiple, within-season observations are available. The more acquisitions the better, as many subtle features of crop emergence, growth, and senescence are lost with a sparse data acquisition capability.

Summary

Three important features of AWiFS are important for the GLAM project. First, it exists, and allows for wall-to-wall mapping in a more straightforward way than ETM+ SLC-off data. For example, sample-based analyses can still make good use of SLC-off imagery. Second, AWiFS offers more acquisitions, an important feature in developing multi-temporal spectral signatures for various crop types. Such signatures greatly enhance mapping capabilities. Third, the large swath width of AWiFS greatly enhances regional scale mapping capabilities, as required by the GLAM project.

4.8 Cropland Acreage Estimation and Mapping with USDA/NASS

Dave Johnson and Rick Mueller

Introduction

The National Agricultural Statistics Service (NASS) has been using the IRS-P6 AWiFS imagery for the past three growing seasons and will continue for 2007. The data has been used in conjunction with NASS ground survey data to produce crop-specific classifications and acreage estimation over certain U.S. States with intensive agriculture. In 2004 and 2005, the AWiFS data was used mainly for supplementing Landsat TM imagery, the *de facto* standard for NASS. In 2006, the USDA as a whole made the switch from TM to AWiFS.

Potential usability of AWiFS

File Format

The provided geoTIFF format is preferred for NASS's purposes. The geoTIFF is ultimately imported into ERDAS Imagine or an agency internal legacy format. Both formats take minimal effort.

Projection

The geoTIFF imagery was provided in a Lambert Conformal Conic projection. NASS converts the imagery either into UTM or the USGS Albers Equal Area Conic depending on the project. The effort required to convert the imagery is minimal.

Radiometric resolution/Bit Depth

The data provided to NASS was ordered in 8-bit format even though the original format was 10-bit. Originally, the data were scaled to 8-bit at the request of NASS in order to more easily accommodate the legacy image processing software. Because ERDAS requires 10-bit data to be stored as 16-bit, the site also reduces in half the disk space requirements. NASS compared classifications produced from both the 8-bit and 10-bit data and no significant differences were found.

Spectral Bands

For cropland discrimination the red, near-infrared, and shortwave infrared (Landsat bands 3, 4, and 5) are all important. AWiFS provides all of these bands, which sets it apart from other competing sensors. The lack of band 1 and band 7 is of minimal importance to cropland classification of the major commodities (corn, soybeans, wheat, and cotton). However, decreased mapping accuracy for wetland type crops such as rice has been suggested.

Spatial Resolution

Cropland classification by nature deals with fairly large homogenous land tract sizes. An average field size is approximately 40 acres, which equates to approximately 52 AWiFS pixels, while for TM it equates to approximately 180 pixels. The loss of spatial resolution is the biggest negative of AWiFS over TM, but accuracy results are only negated by a few percent. For mapping non-agricultural categories, which might be more heterogeneous in nature, performance may suffer more dramatically. NASS has seen suggestion of decreased classification accuracy when moving toward the eastern region of the United States where field sizes typically are smaller.

Temporal Coverage

The five day or better repeat cycle of AWiFS is the strongest suit and outweighs the decrease in spatial resolution. NASS has a high probability of obtaining one or more cloud-free scenes over the central growing area of the United States. With Landsat, oftentimes regions were never cloud-free, which made cropland classification efforts impossible. Also, because crop mapping inherently depends on the phenological characteristics of the commodities for discrimination, the ability to obtain multiple scenes over the same area increases mapping accuracy.

Swath Width

The total AWiFS swath is approximately 740km and is responsible for the increased temporal frequency over Landsat (AWiFS has a 26 day orbital repeat cycle versus Landsat's 16 day). The increased temporal frequency is very appealing for regional mapping and about four times greater than Landsat. NASS found little indication that the far from nadir pixels (which have approximately a 20 degree incident angle) are more compromised than those at nadir, which may not be true for non-agricultural cover types though. Simply put, a pixel far from nadir has more utility than no pixel at all.

Summary

NASS is pleased with the AWiFS data. The question always asked is, "How does it compare to Landsat?" In summary, the information gained from AWiFS is similar, if not better. NASS does believe in a simple scene-to-scene classification comparison; TM is slightly better, which is mainly due the increased pixel size of AWiFS and to a lesser extent the exclusion of band 1 and band 7. However, that loss in information is offset by the large swath width of AWiFS, giving its revisit frequency of approximately five days. At times NASS has been unable to obtain a single cloud-free scene over the growing season for certain areas and AWiFS allows one to derive increased phenologic information of crops. The large scene sizes also simplify analysis over large areas and allow for the inclusion of more training data into a classification. Finally, AWiFS is cheaper per unit area than Landsat per the USDA/Foreign Agricultural Service's Arctic Slope Regional Corporation purchasing contract.

4.9 Use of AWiFS data for Global Crop Production Assessments

Bradley Doorn and Robert Tetrault

Introduction

The Foreign Agricultural Service (FAS) has been using the Indian Remote Sensing AWiFS imagery for the past three years and will continue for 2007. The data has been used in conjunction with weather observations, news reports, and in-country travel to validate crop production monthly estimates and event reports. In years 2004 and 2005 the AWiFS data was used mainly for supplementing Landsat TM imagery. In 2006, the USDA as a whole made the switch from TM to AWiFS.

The USDA Satellite Imagery Archive (USDA-SIA) purchases satellite imagery for participating agencies within the USDA. Funding for purchases is for global agricultural monitoring and early warning of supply problems both for foreign crop areas and domestic crop areas. High temporal frequency, decent spatial resolution, and low cost are key variables to decide purchases. AWiFS imagery, as well as other data sources, meets these criteria. Participating agencies include FAS, NASS, and Farm Service Agency.

Utility of AWiFS as a replacement for Landsat for FAS purposes

File format:

GeoTIFF is the standard file format. Most any standard format is satisfactory as long as the delivery of the data is consistent. This is critical since we rely on automated processes to manage and distribute support multiple USDA agencies as well as global analysis

Projection:

The geoTIFF imagery was provided in a Lambert Conformal Conic projection. Any standard projection that preferably minimizes area distortion in the central latitudes is satisfactory as long as the delivery of the data is consistent. Same justification as File Format above.

Radiometric resolution/Bit Depth

The final analysis image product should be 8-bit. However, USDA SIA should have access to the 10-bit scene for scientific users and anyone that needs original DN values.

Spectral Bands

For cropland discrimination the red, near-infrared, and shortwave infrared (Landsat bands 3, 4, and 5) are all important. Blue and green bands would help for presentation purposes.

Spatial Resolution

Spatial resolution is directly tied to the size and homogeneity of the agriculture being analyzed. Global analysis deals with a large range of field sizes. In general 20-100 meters will and can be used.

Temporal Coverage

The five day or better repeat cycle of AWiFS is its strongest suit and outweighs the decrease in spatial resolution. The need for multiple scenes during the growing season is critical.

Swath width

The larger swath width of AWiFS imagery aides in the temporal coverage and consistency of information over large regions. Since FAS is concerned about global agriculture at the regional and national level, this characteristic is very appealing.

Summary

The acquisition characteristics of the ResourceSat AWiFS sensor combined with the ability to distribute timely imagery provides an opportunity to truly track in-season phonology and provide information that is timely and relevant. However, relying on a foreign-based sensor has risks and limitations. We do not have visibility or impact on short-term or long-term data distribution policy. Resourcesat, as are most medium resolution satellite sensors, have significant government control. For instance, at this time we do not have access to AWiFS imagery of India. This is an Indian government policy which we respect, but must address using alternative sensors.

4.10 Use of AWiFS Imagery for Wildfire Mapping in the USDA Forest Service

Brian Schwind, Jess Clark

Introduction

The USDA Forest Service Remote Sensing Applications Center (RSAC) has been providing imagery and derived products to Burned Area Emergency Response (BAER) teams operationally since 2001. BAER teams assemble to assess the damage potential to a landscape caused by wildfire. They are bound by tight time constraints and often required to submit their assessments within seven days of fire containment. To help with their effort, RSAC acquires medium-resolution imagery and creates maps highlighting the most sensitive burned areas on a landscape. With proper ground verification, these image-based data are instrumental in their burned area assessments.

Since 2001, RSAC has provided imagery and burned area maps to 328 incidents and mapped over 8.3 million acres in 15 states. Similar efforts on Department of the Interior lands have mapped another 140 fires representing over 9.1 million acres. Rapid acquisition, processing, and delivery of remotely-sensed imagery are imperative for this support to be successful.

Utility of AWiFS as a replacement for Landsat

File format

AWiFS imagery is provided to RSAC band by band in GeoTIFF format, which is then imported and stacked into a single ERDAS Imagine (*.img) file.

Projection

The geoTIFF imagery was provided in a Lambert Conformal Conic projection. After importing the GeoTIFFs, RSAC converts the imagery to USGS Albers Equal Area Conic. The imagery is also provided as an orthorectified product, eliminating the need to perform that registration at RSAC.

Radiometric resolution/Bit Depth

AWiFS data provided to RSAC is delivered as 8-bit images, similar to Landsat imagery provided by USGS EROS.

Spectral Bands

For burned area mapping the near-infrared and shortwave infrared (Landsat bands 4 and 7) are important. In the absence of Landsat band 7, band 5 can be used in its place, although band 7 is preferred. AWiFS is one of the few commercial sensors currently providing any reflectance information in the shortwave infrared portion of the electromagnetic spectrum, so it is a viable sensor to use for burned area mapping. While burned area patch delineation is better with the longer shortwave infrared band, it is not compromised enough to avoid using the sensor.

Spatial Resolution
The average fire size supported during the 2006 fire season was 21,000 acres. At this scale, the coarser pixel size of AWiFS when compared to Landsat is negligible. Many BAER teams will simplify the initial product they receive from RSAC as well, making the differences in spatial resolution between the sensors even less important.

Temporal Coverage
Temporal resolution is a very important factor when considering which sensor to use for burned area mapping. BAER teams are assembled to perform emergency assessments and require maps within a few days of fire containment, which means imagery needs to be acquired as soon as possible after the fire. Smoke and clouds often interfere with image acquisition, making Landsat's 16-day revisit time difficult to work with. AWiFS' large swath width provides for a much more frequent revisit and likely candidate to be used with greater frequency in years to come.

Swath width
The total AWiFS swath is about 740km, meaning one AWiFS scene covers nearly all of Ohio. The large footprint allows for scene overlap and more frequent revisit times.

Summary
RSAC has been pleased with the utility provided by the use of AWiFS imagery. In multiple cases during 2006, AWiFS imagery was acquired between Landsat 5 TM overpasses that had been foiled by clouds or smoke. AWiFS allowed RSAC to provide support to incidents that would not have otherwise received timely data for their burned area assessments. Because the archive of AWiFS imagery is expanding each year, RSAC will be able to leverage existing images as pre-fire image sources. The AWiFS sensor can be used as a suitable replacement for Landsat 5 TM once it fails.

Section 5 Mission Capability Evaluation

As the Data Characterization team continued to assess the quality of the data sets chosen for study, an additional *tiger team* was created to conduct trade studies and assess the technical feasibility and risk of various technical options for transferring from the ResourceSat and CBERS systems to the USGS EROS for archive and distribution. This section discusses the technical options available, the advantages and disadvantages of each and the technical challenges required to implement them. The assumption used for the mission capability assessments is that the archive is to be refreshed with global, essentially cloud-free coverage, including ice shelves, islands and coastal regions, twice a year, for the 2007-2010 time frame.

Data from both the Indian ResourceSat-1 and the Chinese-Brazilian CBERS-2 systems are being evaluated by the Data Characterization group for their use in the Landsat archive. But given that the currently on-orbit, CBERS-2 satellite is operating in degraded mode[1] and the next (CBERS-2B) satellite will not carry the instrument which generates data most comparable to Landsat data (IRMSS), the assumption is that the ResourceSat data are more readily available in the near term. As a result, the focus of the initial *tiger team* analyses, and therefore this section, is on the ResourceSat-1 capabilities and the capture of its data. Most of the calculations are computed for the wide-swath AWiFS data, but since the LISS-III instrument data are captured simultaneously and downlinked with the AWiFS data, much of the analyses apply to both instruments. The high-resolution LISS-IV data on the other hand are distinct and transmitted on a separate channel.

There are two fundamental formats in which to capture satellite remote sensing data. One way is to acquire the raw data coming from the spacecraft - what here is called Level zero (Level 0) data. The other way is to acquire data that has been processed to some level at a ground processing facility. Usually, that processing entails some amount of decoding and formatting, along with radiometric and geometric calibration and correction of artifacts. For the purpose of whittling down the number of possible acquisition scenarios, the *tiger team* considered acquiring processed data (Level 1G) that are radiometrically and geometrically corrected, and orthorectified, since this is the format acquired for the USDA Satellite Imagery Archive (SIA). The potential scenarios considered for acquiring Level 0 and Level 1 data are discussed in sections 5.1 and 5.2 respectively.

5.1 Acquiring Level 0 AWIFS Data

The ResourceSat-1 spacecraft has a shaped beam, X-band antenna on board for transmission of the image data to the ground. The shaped beam is not as flexible as an

[1] In April 2004 a power failure was detected and traced to one of the two batteries. Due to the power failure, CBERS-2 is operating in degraded mode such that only the CCD camera is allowed to operate. CCD imaging has been limited to 12 minutes per orbit. The IRMSS, WFI, and on-board recorder are not turned on.

omni antenna, but does allow multiple ground stations to acquire data simultaneously. The downlink data rates are 105 Mbps for each of the two data channels (I & Q channels) – one that carries the LISS-IV data and another that carries both the LISS-III and AWiFS together. There is also an on-board solid state recorder (SSR) that provides a store and forward capability for data and images that are collected outside of the real-time acquisition circles of the ground station network. The SSR holds 120 GB of data, which allows for the recording of 9 minutes of data collected for all three sensors, or a maximum of 16 minutes of data if recording a single channel (e.g. no LISS-IV data). The reconfiguration of the on-board SSR to such a single channel mode, though possible, is not a dynamic process and is currently not often performed; both data channels (LISS-IV and the combined LISS-III + AWiFS) are always recorded. Recorded data are downlinked only to ground stations in Shadnagar (near Hyderabad) and Svalbard (for use by GeoEye).

The primary data capture mode uses real-time downlinks to a series of ground stations. As the data are acquired by the sensors, they are downlinked to the international ground stations (IGS). The maximum sensor 'on' time for a single orbit is 16 minutes - a limiting factor for the system. About 14 orbits per day are completed such that the entire Earth is covered (but not necessarily acquired) in 341 orbits during a 24-day cycle. Only when the instrument(s) are on, and a ground station is within view, are the data captured for processing and archiving. ResourceSat-1 currently has five IGS as shown in Figure 5.1.

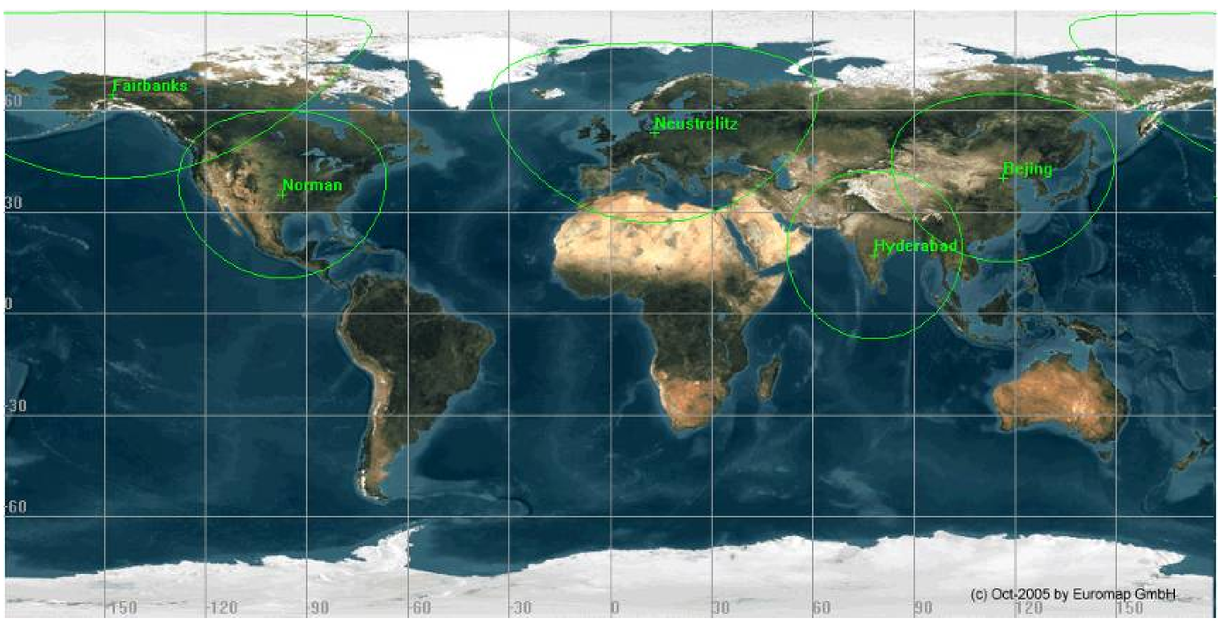


Figure 5.1 ResourceSat-1 Ground Stations

The ground stations are located in Hyderabad (ISRO), Norman and Fairbanks (GeoEye), Neustrelitz (Euromap), and Beijing (RSGS). In addition, SpaceImaging Middle East is putting a station in Abu Dhabi, and Russia and Tajikistan are upgrading their IRS IC/ID stations to receive ResourceSat-1 data as well. Currently, real-time data are not captured over South America, Africa, Australia, and a significant portion of Southeast Asia, along with Antarctica and most island regions, such as Hawaii. Only limited images, requested by users, are captured of these areas, recorded on-board and downlinked for processing and storage in the GeoEye or Indian National Remote Sensing Agency (NRSA) archives.

Four different scenarios of acquiring Level 0 data were assessed and are summarized below. In general, the advantages of acquiring Level 0 data and processing them to various Level 1 products within the EROS system revolve around processing flexibility and the potential to satisfy more users. With the acquisition and archiving of Level 0, data products can be reprocessed as more information is captured about the sensor characteristics (stability, accuracy, etc.) or as the sensor characteristics change over time. There is more control over the product quality since the processing system would have to have a thorough understanding of the calibration and characterization processes. More users may be satisfied as well, because processing the data from a Level 0 archive would allow multiple products to be offered to users; e.g., multiple projections, product sizes, and resampling techniques.

The disadvantages of acquiring the data in Level 0 format and processing them at EROS include the initial investment and continuing maintenance costs of the required processing system. It will take time to develop the algorithms, software, and operational procedures needed to support the processing system; more time than would be needed to start acquiring Level 1G data products tomorrow. There is also a potential conflict in the government developing a system that some would consider the purview of the value-added community. But one of the greatest disadvantages of acquiring Level 0 data, particularly directly from the spacecraft, is the amount of data that needs to be collected in order to fill the archive twice a year with global, essentially cloud-free data. A large percent of the images collected will be cloudy, as they are today. Multiple images of the same area have to be collected in order to get one or two clear images to satisfy the archive requirement. The acquisition strategy as a result would be complex given the limitations of the system.

Direct Downlink to EROS, Sioux Falls, SD

The first scenario considered for acquiring Level 0 AWiFS data from the ResourceSat-1 spacecraft involves downlinking data directly to EROS in Sioux Falls. This would entail either placing a dedicated 7.5 m antenna at the site to receive real-time data of North America from ResourceSat-1, or modifying existing receiving equipment to accomplish the same thing. It is technically feasible and well within the scope and capabilities of the personnel at EROS.

Primary coverage would be the conterminous United States (CONUS), Mexico, some of Canada and some of central America (essentially, most of North America). 14 passes would be required, the shortest of which would be 4 minutes and the longest would be 14.5 minutes. None are constrained by the instrument limit of 16 minutes. Acquisitions using a single antenna at Sioux Falls would not capture Alaska and the Canadian northern territories, but an additional antenna in Fairbanks could capture those data.

To capture the rest of the global data required to satisfy the archive requirements, additional cooperating ground stations are required. Certainly more than just the one ground station in Sioux Falls are required, but also more than the existing set of 5-8 ground stations are needed to capture data over South America, Africa, Australia, and Antarctica.

Direct Downlink to GeoEye, Norman, Oklahoma

The GeoEye facility in Norman, Okla., already has a data capture and processing capability for the ResourceSat-1 spacecraft and CONUS data are downlinked there regularly. The scenario of downlinking data to Norman would entail capturing the Level 0 data from this facility in a 'bent pipe' mode and forwarding it to EROS. This scenario provides essentially the same real-time coverage of North America that downlinking to Sioux Falls provides and has similar limitations in terms of requiring supplemental ground stations to cover the rest of the Earth's land masses. It does have the advantage that the real-time data received at the Fairbanks ground station would also be accessible from Norman, along with the recorded data received at the Svalbard ground station. Another potential advantage of this scenario could be the goodwill generated from such a public-private partnership. A separate processing system would still be required at EROS to generate Level 1 products for users.

Acquire Level 0 data from ISRO NRSA archive

As an alternative to acquiring Level 0 data directly from the satellite, data could be acquired from an archive. Each of the ground systems store to tape (or other media) the raw data captured from the satellite. The Indian National Remote Sensing Agency (NRSA) archive captures and holds Level 0 data of all of India and its surrounding regions along with the data captured via the on-board recorder at user request. It was hoped that this archive was systematically global in nature and complete, but that has not turned out to be the case. The ResourceSat-1 system was designed mostly to satisfy the needs of Indian national users, along with providing some commercial capability. It was not intended to generate a continuously refreshed global archive. As a result, what is in the NRSA archive is 80% data over India, with the additional 20% populated with data from focused areas of interest captured for specific users. The contents of the archives of the other ground stations would be essential to complete a global picture and a systematic approach to capturing the rest of the land masses would be required.

Acquire Level 0 data from GeoEye archive

A similar challenge for this scenario - acquiring Level 0 data from the GeoEye archive - is the limited nature of the archive. But with this scenario, the focus of the GeoEye archive is not India, but the United States. A small fraction of the archive is populated with other areas of the world. Here too, the global data are not systematically captured and reflect past user requests for acquisition.

5.2 Acquiring Level 1 AWIFS Data

Rather than capturing data in its raw form, there are existing processing systems and archives that can provide Level 1 data products to EROS for inclusion into the Landsat archive. These data products, or scenes, can be selected by assessing browse images generated when the product was generated, to avoid ordering scenes that are filled with clouds. There would be no initial investment or maintenance costs required for processing, since there would be no processing system to develop. Such a data transfer could be implemented rapidly if the Landsat satellites and/or sensors failed tomorrow. The product acquired for the archive and distributed to users would be a standard product, easy to describe and in a standard format.

Other the other hand, such a standard product may not satisfy all users and could be considered a liability. There would be no way for EROS to regenerate the products with updated sensor information and there is concern that science users may have less insight into the corrections and calibrations used to generate the products. Four scenarios were considered for acquiring Level 1G AWiFS data and are explained in the sections below.

How many Level 1 scenes or data products would be required to fill the archive each year? The approximate number of Landsat scenes being collected for the mid-decadal survey to cover all the land masses, including island regions and Antarctica is 9,500. Each Landsat scene product covers a geographic region 185 km x 170 km, while an AWiFS scene product covers 350 km x 350 km. Using the 4:1 ratio these dimensions imply and dividing 9,500 by 4, an estimated 2,400 AWiFS scene products would be needed to cover the globe once per year. The IRS systems, of which ResourceSat is one, use a unique path/row system similar to, but not the same as the WRS-84 used by Landsat, so these figures should be calculated using a transformation function to be more precise. But, for the purpose of a feasibility study, these figures were adequate. The archive requirement is for a twice a year refresh, so approximately 4,800 AWiFS Level 1G products would be needed each year.

From where can AWiFS data products be ordered?

• The ISRO (NRSA) archive, http://www.nrsa.gov.in, holds mostly data over India, with about 20% of the archive populated with other global data.

• The GeoEye archive, http://caterraonline.spaceimaging.com, holds data from the United States, Europe, and India and offers multiple search criteria, including maximum cloud cover.
• The USDA Satellite Imagery Archive (SIA) holds Level 1G AWiFS data products that have been ordered by USDA through its ASRC contract. It holds CONUS data, along with Eastern Europe and small parts of South America.
• EROS also has a commercial data archive that includes some AWiFS data products and can be found at http://earthexplorer.usgs.gov.

Purchase Level 1 data from GeoEye

Data products can be purchased from GeoEye through a commercial contract. Level 1 processing would be done by GeoEye and data could be ordered either from the existing archive, specifying maximum cloud cover allowed in the scene, or by requesting that data be acquired for order, also specifying the degree of cloud-freeness required. Limitations of the overall system must still be considered. Without additional ground stations, it is not feasible to expect global coverage twice a year. Without any sort of large volume discount or negotiations, the published price for a Level 1G AWiFS scene, 350 km x 350 km in size, is $850. Assuming the system had the capacity to generate 4800 scenes per year strategically covering the global land masses, the cost would be about $4.08M per year. This is the simplest scenario and the one against which other costs should be weighed.

Acquire Level 1 data directly from ISRO

This scenario would require a government-to-government agreement with India to capture the data products needed to satisfy the global archive. Indian data can be ordered from the NRSA archive, but the additional global data would need to be acquired and processed in Hyderabad as well. This scenario was originally based on the assumption that the NRSA archive already contained systematic global data, but it does not. ResourceSat-1 was not designed to populate and refresh a global archive but an India archive with some extra capacity for commercial products and objectives.

Acquire Level 1 data from ResourceSat IGSs

This scenario requires cooperation from all the ResourceSat IGSs, some level of standardization in product generation and formats, and would require independent negotiations with each of the ground station owners. In addition, to get full global coverage, additional ground stations are still needed to cover the continents that do not currently have ground stations. This scenario creates additional complexities for the EROS archive, but similar issues have been tackled with the Landsat international cooperators network as well.

Acquire Level 1 data through the ASRC Contract

This scenario takes advantage of an existing contract structure that seems to be working well, both for the value added community, and the government agency that receives the AWiFS data products (USDA). All the previously mentioned issues associated with the limited capacity of the current system apply, but an existing contract mechanism, a standard product, and a supported U.S. government archive of AWiFS data products are significant steps that do not need to be duplicated by another agency.

5.3 Conclusions to Date

A handful of questions must be answered to help decide what should be done about the inevitable data gap in the Landsat long-term archive. They will need to be asked more than once, as time passes, and as system statuses change. Assuming the ResourceSat-1 and CBERS data are of adequate quality for use by researchers, **today**, the key questions can be answered as follows.

• *Can ResourceSat-1 meet the global archive needs?*
No, not without additional ground stations.
• *Can CBERS meet the global archive needs?*
No, neither the current CBERS-2 nor near-term CBERS-2B systems can do so.
• *Can a combination of the two systems (CBERS & ResourceSat) meet global archive needs?*
Not today, but potentially yes, depending on the timing of satellite launches and orbital lifetimes.

> *-Given this as a potential longer-term solution, can a combination of the two data sets meet science needs?* This has yet to be evaluated.

Since the short-term answer to the key feasibility question of whether the ResourceSat system can today satisfy the global archive requirements is "no," what do we do next? We present two suggestions that may help change the answers to the key questions or may provide a clearer path to creating a system that does satisfy the archive’s needs.

• Assess the impact of reducing the global archive requirements. For example, refresh the archive once a year rather than twice, consider excluding island regions and Antarctica during the gap filling period. The impact of such a change in requirements on science users as well as on the mission capacity would need to be assessed.

• Develop a detailed model of the ResourceSat system that includes technical and operational limitations and allows ‘what if’ scenarios to be evaluated. For example, how long would it take to capture 2,400 AWiFS scene products if three more ground stations were added?

Section 6 Summary and Conclusion

CBERS-2 Summary

Spectral characterization results for both the HRCCD and IRMSS sensors indicate a similarity with analogous L7 ETM+ Bands 1 through 4. The HRCCD acquires in analogous L7 Bands 1 through 4; IRMSS acquires in analogous L7 Bands 5 through 7. Differences ranged from six to fifteen percent, depending on sensor and band. Results for Band 7 are missing due to an incomplete IRMSS RSR dataset.

Product assessments revealed production inconsistencies for both HRCCD and IRMSS image products. IRMSS radiometric assessments indicated significant issues with data format and lack of technical information. Radiometric assessments found similar artifacts in both IRMSS and HRCCD that that can be characterized and probably corrected. Relative gain and bias corrections were applied during Level-1 processing and good cross-calibration agreements existed with L5 and L7.

A limited HRCCD geometric assessment indicated the presence of systematic errors. The one dataset processed through Instituto Nacional de Pesquisas Espaciais (INPE) showed errors on the order of 4 km in the along-track line or track direction. The dataset processed through Center for Resources Satellite Data and Applications (CRESDA) showed geometric errors on the order of 14 km in the line or track direction. Errors were less in the cross-track direction. Band-to-band registration was generally on the order of 0.4 pixels in both directions with one exception.

No spatial and science utility evaluations were performed on CBERS-2 image products due to the lack of availability of scenes over regions of interest.

IRS-P6 Summary

Spectral characterization results for both the AWiFS and LISS-III sensors indicate a similarity with analogous Landsat 7 ETM+ Bands 2 through 4. Differences were within five percent. At the time of processing, Band 5 data were incomplete; an assessment was not performed.

Radiometric assessments for both AWiFS and LISS-III indicated artifacts that can be characterized or corrected. A vicarious calibration assessment was performed on AWiFS image products obtained with the AWiFS-A camera and AWiFS-B camera. Results indicate that the calibration coefficients provided with the imagery are in reasonable agreement with those determined through vicarious methods.

Geometric assessment of six standard geometrically processed AWiFS images indicated relatively large (423 m to 1,887 m) but correctable systematic errors. These results are a combination of AWiFS-A and AWiFS-B acquired imagery and agree with previously published results. A second study noted RMSEs measured between AWiFS data and control to be about 0.75 pixels. The second study also noted RMSEs measured between LISS-III data and control to be about 0.41 pixels. Band-to-band and image-to-image results appeared reasonable for both the AWiFS and LISS-III image products.

Preliminary Science Utility Evaluation indicates that the IRS-P6 AWiFS data is potentially a usable alternative to Landsat during the mission gap. The higher radiometric resolution (10-bits), larger swath area coverage (740 km), and a frequent repeat cycle (five days) will be an advantage for science applications, allowing for the increased likelihood of cloud-free acquisitions and reduction in the processing and handling of a lower number of images. The coarser spatial resolution (56-m) and lack of an AWiFS equivalent to the Landsat spectral Band 1 and Band 7 can have an adverse impact on a few assessments, likely resulting in reduced but acceptable derived-product accuracy and sensitivity. The lower spatial resolution of AWiFS could negatively impact the ability to discriminate fine-scale landscape features, especially those related to urban development. It is possible, however, that the disadvantage of lower spatial resolution could be offset by the more frequent repeat coverage of AWiFS.

Conclusions

The DCWG concluded that preliminary results for IRS-P6 AWiFS and LISS-III or CBERS-2 HRCCD datasets do not indicate any unresolvable issues. The IRS-P6 satellite is a more mature system and better able in the near-term to provide useful datasets. CBERS-2 IRMSS results are more problematic due to lack of information on data formats, processing, and operational modes; instrument inoperability (since 2005); and the lack of an identical or similar instrument slated for the follow-on CBERS-2B launched in September, 2007.

Additional characterizations for both CBERS-2 and IRS-P6 sensors are necessary to complete the characterizations as much as possible, which would allow equal assessments to be performed across all sensors. Additional characterizations would begin to correct for systematic errors, improve accuracies, and begin to assess the temporal stability of the sensors.

Additional DCWG efforts would also be useful to assess technical information already received from Indian Space Research Organization (ISRO) and Instituto Nacional de Pesquisas Espaciais (INPE) and to continue to foster technical exchanges with the sensor organizations for additional information. Support is required to continue follow-on activities pertaining to data acquisition, processing, and monitoring. One particular limitation is the lack of documentation. Most importantly, several data quality and science evaluations, including those assessing the impact of sensor characteristics, such as differing dynamic range and increased Bidirectional Reflectance Distribution Function (BRDF) effects associated with larger swaths and their impact to science, have yet to be performed.

Appendix A Acronyms

A/D	Analog to Digital
AWiFS	Advanced Wide Field Sensor
BAER	Burned Area Emergency Response
BDH	Band Data Handling
BRDF	Bi-directional Reflectance Factor
CBERS-2	China Brazil Earth Resources Satellite-2
CCD	Charge Coupled Devices
CE_{90}	90% Circular Error
CFP	Cold Focal Plane
CONUS	Conterminous United States
CRESDA	Center for Resources Satellite Data and Applications
DCWG	Data Characterization Working Group
DEM	Digital Elevation Model
DN	Digital Number
dNBR	Normalized Burn Ratio
DoC	Department of Commerce
DOI	Department of the Interior
DOQQ	Digital Orthorectified Quarter Quad
ER	Emergency Response
ERDAS	Earth Sciences Applications Directorate
EROS	Earth Resources Observation and Science
ETM+	Enhanced Thematic Mapper Plus
FASC	Full Aperture Solar Calibrator
FEWS	Famine Early Warning System
FAS	Foreign Agricultural Service
FTP	File Transfer Protocol
GLAM	Global Agriculture Monitoring
GSD	Ground Sample Distance
GSFC	Goddard Space Flight Center

HRCCD	High Resolution Charged Coupled Device Linear Self Scanner
IC	Internal Calibrator
INPE	National Institute for Space Research
IRMSS	Infrared Multispectral Scanner
IRS-P6	Indian Remote Sensing Resourcesat-1 satellite
ISRO	Indian Space Research Organization
JACIE	Joint Agency Commercial Imagery Evaluation
L1G	Level 1G
L4	Landsat 4
L5	Landsat 5
L7	Landsat 7
LDCM	Landsat Data Continuity Mission
LDGST	Landsat Data Gap Study Team
LISS-III	Linear Imaging Self-Scanner
LISS-IV	Linear Imaging Self-Scanner
LPSO	Land Cover Satellite Project Science Office
MODIS	Moderate Resolution Imaging Spectroradiometer
MRLC	Multi-Resolution Land Characteristics
MSS	Multispectral Scanner
MTBS	Monitoring Trends in Burn Severity
MTF	Modulation Transfer Function
NASA	National Aeronautics and Space Administration
NASS	National Agricultural Statistics Service
NIR	Near Infrared
NLCD	National Land Cover Dataset
NOAA	National Oceanic and Atmospheric Administration
NRSA	National Remote Sensing Agency
NSLRSDA	National Satellite Land Remote Sensing Data Archive
NSSDA	National Standard for Spatial Data Accuracy
OMB	Office of Management and Budget
OSTP	Office of Science and Technology Policy

PASC	Partial Aperture Solar Calibrator
PFP	Primary Focal Plane
RMS	Root Mean Square
RMSE	Root Mean Square Error
RSR	Relative Spectral Response
SAIC	Science Applications International Corporation
SSC	Stennis Space Center
SWIR	Short Wave Infrared
TIM	Technical Interchange Meeting
TM	Thematic Mapper
TOA	Top of Atmosphere
UTM	Universal Transverse Mercator
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey
VNIR	Visible to Near Infrared
WFI	Wide Field Imager
WRS	World Wide Reference System

Appendix B LDGST Technical & Operational Qs : L7 ETM+

Landsat-7 Enhanced Thematic Mapper Plus (ETM+)

Data Quality (calibration) Questions

Radiometry

4 How are your data calibrated radiometrically? Please describe the procedures used and provide any documentation?

This can be found in the Landsat 7 Image Assessment System (IAS) Radiometric Algorithm Theoretical Based Document (ATBD).http://landsat.usgs.gov/resources/project_documentation.php

5 Is there any special (Lunar, Solar, Stellar) calibration acquisitions performed?

Landsat 7 performs a Partial Aperture Solar Calibration (PASC) once per day, and a Full Aperture Solar Calibration (FASC) once per month. Night scenes (interstitial with PASCs) are also used in calibration. There is no Lunar and Stellar calibration acquisitions performed.

6 How are detector gains determined? (Prelaunch, vicarious, internal calibrator)

Landsat 7 calibration is based on both the internal calibrator shutter and the special PASC and FASC collections. FASC is yellowing and PASC saturated in few bands (B7). In the L7 Calibration Parameter File (CPF), the current detector gains are a combination of the PASC and FASC data. The vicarious data is used to validate the long term-trend.

7 Are the radiometric calibrations and corrections updated over time to reflect sensor changes?

Yes. The calibration of the instrument is adjusted with quarterly CPF updates as necessary.

8 Have you characterized the linearity and stability of the sensors response? If yes, how?

The Landsat 7 IAS has performed radiometric trending on four scenes per day since launch, enabling us to mine and model long-term sensor stability.

9 What are the known artifacts (such as Striping, noises) in the instrument?

The known ETM+ image artifacts are scan correlated shift (SCS), memory effect (ME), and coherent noise (CN). Dropped lines also exist as a result of decommutating errors and detector failure. Remnant artifacts which may exist include banding and striping. In most bands, Landsat 7 exhibits small levels of coherent noise, impulse noise due to charged particle hits, and over saturation over bright targets. There is also apparent striping in the thermal bands, and some rare artifacts that are specific to L7 – the ghost PASC glint and the band 1 detector ringing anomaly.

http://ltpwww.gsfc.nasa.gov/IAS/handbook/handbook_htmls/chapter7/chapter7.html

10 How are the artifacts compensated in the L1 products?

Striping is corrected by a rigorous detector relative gain calibration. Most other artifacts are deemed too minor to require correction, but correction code exists in the processing systems for banding, memory effect, scan correlated shift, and others.

11 If there are dead or inoperable detectors, how are they compensated for in the image products?

The Landsat 7 ETM+ has no dead or inoperable detectors, but code exists to fill such detectors with interpolated data if necessary.

12 How does the system respond to saturation point targets? What is the recovery time? Saturation radiance in products?

Bright point targets can over saturate the detectors, causing a ‘blind’ period of zero values. Recovery time varies with target brightness, but is usually between one and five pixels. Saturation radiance (LMAX) is provided in the metadata of each product.

13 How is detector-to-detector normalization performed to remove striping effects?

The striping correction algorithm can calculate normalization gains from a user-selected reference detector, from a band average gain, or from relative gain parameters in the CPF.

14 What levels of radiometric calibration/correction are applied to each of your product levels?

Level 0 products have no corrections. Level 1R product has full radiometric calibration and correction. Level 1G product has radiometric and geometric calibration and correction. Individual artifact corrections can be turned on or off by the user.

15 What is the absolute radiometric accuracy? What are this numbers based on?

The ETM+ design specifications are for 5% radiometric accuracy in all but the thermal band and 10% accuracy in the thermal band. Analysis of the IAS trending database has confirmed that the instrument is within spec.

16 How is the detector biases determined? How are biases applied during processing?

Bias is calculated using the dark region of the internal calibrator (IC) shutter. The biases are applied line-by-line based on the dark shutter responses acquired from each scan line. Details of calibration can be found in Chapter 11 of the Science Data User’s Handbook. http://ltpwww.gsfc.nasa.gov/IAS/handbook/handbook_htmls/chapter11/chapter11.html

17 The Spectral Response Profiles that we have seen are incomplete. Do you have complete profiles?

Yes. The complete Landsat-4/5 TM and Landsat-7 ETM+ RSR plots and data can be found at:
http://ltpwww.gsfc.nasa.gov/IAS/handbook/handbook_htmls/chapter8/chapter8.html

18 How is the spectral response determined? Is there variability in spectral response or filter response across the focal plane?

Relative spectral response were measured pre-launch. Spectral response does not vary across the focal plane for any ETM+ bands. There is no spectral smile or variability across the filters in L7.

19 Has there been any measurement of out-of-band spectral response?

None was found in pre-launch measurements, and none has been observed post-launch.

20 Have you found any problems with stray light? If so, please describe them and how they were measured.

There is a ‘ghost PASC glint’ caused by solar reflections during partial aperture solar calibrator acquisition. It does not affect PASC processing, but is avoided when selecting night data. There are no known stray light problems on the ETM+ that affect daytime imagery.

21 What is the Signal-to-noise ratio (SNR)? At what radiance level was this determined?

Table-1 of the IEEE Dec 2004 TGRS paper provides NEdeltaL, which was measured across the dynamic range of the band.
Scaramuzza, P.L., Markham, B.L., Barsi, J.A, Kaita, E., “Landsat-7 ETM+ On-Orbit Reflective-Band Radiometric Characterization”, ” IEEE Transactions on Geoscience and Remote Sensing, vol. 42, No. 12, pp. 2796-2809, Dec, 2004.

22 Is there any night imaging capability?

Landsat 7 can and has been tasked for night acquisitions for calibration purposes and for thermal band imagery.

23 Are the data in Level 1 products linearly scaled to absolute radiance?

Landsat 7 ETM+ Level 1 data can be converted to top-of-atmosphere radiance. During Level 1 (L1G) product generation, pixel values (Q) from raw (L0Rp) unprocessed image data are converted to units of absolute radiance using 32-bit floating point calculations. The absolute radiance values are then scaled to eight-bit values representing calibrated digital numbers (Qcal) before output to the distribution media.

24 What is the equation used to convert the DN-to-radiance for each of the products?

Conversion from calibrated digital numbers (Qcal) in L1G products back to at-sensor spectral radiance (L*) requires knowledge of the original rescaling factors. The rescaling gains and biases can be found in Chapter 11 of the Science Data User’s Handbook. (http://landsathandbook.gsfc.nasa.gov/handbook/handbook_htmls/chapter11/chapter11.html). The product metadata also contains all the necessary parameters. Absolute surface radiance requires an atmospheric transfer correction, which we do not provide.

25 Is there any on-board radiometric calibration capability? If yes, please describe?

Landsat 7 has no on-board radiometric processing.

26 What is the Solar Exoatmospheric Spectral Irradiances (ESUN) values used for reflectance conversion?

They can be found in section 11.3.2 of the Science Data User’s Handbook.
http://landsathandbook.gsfc.nasa.gov/handbook/handbook_htmls/chapter11/chapter11.html

27 What solar spectrum profiles were used to calculate the ESUN values?

CHKUR solar spectrum in MODTRAN 4.0

28 Describe the focal plane layout and detector dimensions?

The basic sensor technology used in the ETM+ is similar to that of the Thematic Mapper (TM) instruments on Landsats 4 and 5 and the Enhanced Thematic Mapper (ETM) built for Landsat 6. The ETM+ instrument detectors are aligned in parallel rows on two separate focal planes: the primary focal plane (PFP), containing the visible (including panchromatic) and near infrared (VNIR) spectral bands, and the cold focal plane (CFP), containing the short wave and long wave (thermal) infrared bands (SWIR). The primary focal plane is illuminated by the ETM+ scanning mirror, primary mirror, secondary mirror, and scan line corrector mirrors. In addition to these optical elements, the cold focal plane optical train includes the relay folding mirror and the spherical relay mirror. The ETM+ scan mirror provides a nearly linear cross-track scan motion that covers a 183-km-wide swath on the ground. The scan line corrector compensates for the forward motion of the spacecraft and allows the scan mirror to produce usable data

in both scan directions. An image data set is built as a time sequence of cross-track scans, acquired as the spacecraft orbit carries the ETM+ over the target area.
http://ltpwww.gsfc.nasa.gov/IAS/handbook/handbook_htmls/chapter3/chapter3.html

29 What focal length(s) are your sensors?

Effective Focal Length is 96 in (243.8 cm). Details on the ETM+ Telescope are at http://ltpwww.gsfc.nasa.gov/IAS/handbook/handbook_htmls/chapter3/htmls/telescope.html

30 What is the aperture diameter for your sensor(s)?

F = 6.0. The ETM+ primary mirror outer aperture diameter is 16.0 in (40.64 cm); the inner diameter is 6.56 in (16.66 cm).

31 What types of detectors are used? (Material)

Bands 1-4 and 8 comprise the primary focal plane, and are composed of monolithic silicon (Si Photodiode). On the cold focal plane, bands 5 and 7 are composed of indium antimonide (InSb), and band 6 is mercury cadmium telluride (HgCdTe), all on a monolithic silicon substrate.

32 Is the sensor gain adjustable? Are there multiple gain settings?

There are two gain settings on all ETM+ bands. The ETM+ images are acquired in either a low or high gain state. Band 6 is simultaneously acquired in high and low gain; all other band gains are selected according to the brightness of the scene as predicted by the Long-Term Acquisition Plan (LTAP).

Gain selection for a scene is controlled by the Mission Office Control (MOC) and is performed by changing the reference voltage for the analog to digital converter. This occurs in the preceding scene. The science goal in switching gain states is to maximize the instrument's 8 bit radiometric resolution without saturating the detectors. This requires matching the gain state for a given scene to the expected brightness conditions. For all bands, the low gain dynamic range is approximately 1.5 times the high gain dynamic range. It makes sense, therefore, to image in low gain mode when surface brightness is high and in high gain mode when surface brightness is lower.

33 Geometry
34 How are your data calibrated geometrically? Please describe the procedures used and provide any documentation?

This can be found in the Landsat 7 Image Assessment System (IAS) Geometric Algorithm Theoretical Based Document (ATBD).http://landsat.usgs.gov/resources/project_documentation.php

35 What is the internal geometric stability? (relative geometric accuracy) How has it changed over time?

The internal accuracy of L7 ETM+ pre and post SLC-failure is 4 meters RMS. It has been very stable.
"Four Years of Landsat-7 on-Orbit Geometric Calibration and Performance", IEEE Transaction of GeoScience and Remote Sensing December 2004, pgs. 2786-2795.

36 What is the absolute geodetic/geopositional accuracy? How has it changed over time?

The Enhanced Thematic Mapper Plus (ETM+) was designed to provide a geometric accuracy of at least 250 meters (1 sigma) in low-relief areas at sea level. However, the use of definitive ephemeris for Level 1G systematic correction frequently provides a geometric accuracy within 30-50 meters.

37 What level of geometric calibrations and corrections are performed for each of your data product levels?

Systematic Correction (Level 1G)
Precision Correction (Level 1P
Terrain Correction (Level 1T)
http://eros.usgs.gov/products/satellite/landsat7.html#description

38 What is the band-to-band registration accuracy?

The registration errors are less than 0.08 IFOV when the thermal band is excluded from analysis. "Four Years of Landsat-7 on-Orbit Geometric Calibration and Performance", IEEE Transaction of GeoScience and Remote Sensing December 2004, pgs. 2786-2795.

39 What source of ground truth do you use to measure your geometric/geodetic accuracy, including elevation data?

The USGS National Elevation Dataset (NED) is used for calibration geometric calibration sites over the US.

40 Do you have any off-nadir capability if so what is the range?

The ETM+ only acquires nadir down looking data. The ground swath width is approx. 185 kilometers.

41 Spatial
42 How are your data characterized and calibrated spatially?

This can be found in the Landsat 7 Image Assessment System (IAS) Radiometric Algorithm Theoretical Based Document (ATBD).http://landsat.usgs.gov/resources/project_documentation.php

43 What measurements do you use? (Edge, FWHM line spread, MTF at Nyquist)

MTF at Nyquist. The MTF describes how the sensor optics and electronics modulate the original signal (image), as a function of spatial frequency, in the conversion of input radiance at the ETM+ aperture to an output digital image. The original Landsat 7 MTF performance specifications called for all ETM+ bands to exhibit modulation greater than 0.275 at the Nyquist frequency, in both the along- and across-scan directions

44 What is the sensor spatial response? How was it determined?

The ETM+ ground samples at three different resolutions; 30 meters for bands 1-5, and 7, 60 meters for band 6, and 15 meters for band 8.
http://landsathandbook.gsfc.nasa.gov/handbook/handbook_htmls/chapter6/chapter6.html#section6.2

45 How is the spatial response (MTF) monitored on orbit? How has it changed over time?

The Landsat 7 MTF is monitored on-orbit using the Lake Pontchartrain Causeway in Louisiana. It is a 24-mile long double span bridge that happens to be nearly aligned with the Landsat 7 ground track.
http://ltpwww.gsfc.nasa.gov/IAS/handbook/pdfs/L7_MTF_Storey_SPIE2001.pdf

46 Is there spatial compensation (MTF) performed on data products? If so, please describe the algorithms and effects.

The Modulation Transfer Function Compensation (MTFC) can be turned on as part of the processing if needed by the user. The new MTFC parameters for the Landsat 7 Calibration Parameter File (CPF) were submitted for inclusion in the 4Q2001 CPF release. The new coefficients used in the CPF are derived from on-orbit estimates of the ETM+ along- and across-scan MTF and replace the previous coefficients, which were based on pre-launch MTF measurements in the along-scan direction only. The goal in MTFC

resampling is to partially compensate for the system response by boosting the higher spatial frequencies attenuated by the MTF. This enhances fine spatial detail (e.g., edges) but has the side effect of also increasing the image noise somewhat. While no resampling method is perfect, the MTFC resampling provides a higher degree of image sharpness than other methods while maintaining fairly good truth in measured radiance. Users should evaluate the relative importance of image sharpness versus noise to their applications in deciding whether MTFC processing is appropriate.
http://landsat.usgs.gov/technical_details/image_processing/mtfc_parameters.php

47 Operational Questions
48 Image scheduling
49 Do you have an overall plan to acquire data regionally/globally? If so, please describe it.

This is the Long Term Acquisition Plan (LTAP). Basically the globe is divided into an array of 57,784 WRS path/rows spaced from center-to-center at approximately 24-second intervals. Of these, roughly 14,000 scenes contain enough landmass to be of interest to the Landsat 7 mission. This subset of land scenes are the target for regular seasonal acquisition. The minimum goal is for each land scene to be acquired cloud-free, 4 times a year, cloud free being defined as 20% or less cloud cover based on an automated cloud cover assessment.

The orbit of Landsat 7 is repetitive, circular, Sun-synchronous, and near polar at a nominal altitude of 705 km (438 miles) at the Equator. The spacecraft crosses the Equator from north to south on a descending orbital node from between 10:00 AM and 10:15 AM on each pass. 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.

http://landsathandbook.gsfc.nasa.gov/handbook/handbook_htmls/chapter5/chapter5.html#section5.4

50 What is the image request process from submission to competition?

For the majority of acquisitions there is no image request required as they are automatically scheduled based on the LTAP and the logic in the scheduler to fulfill the LTAP. There are other request options for scheduling acquisitions outside of the LTAP. Typically these are reserved for disaster monitoring, special studies such as field campaigns and other special requests.

51 How are the instruments scheduled?

There is an automated scheduling system that develops the acquisition schedule based on priority and resource availability.

52 Are images collected on the basis of on-demand tasking?

Yes. But only a small fraction.

53 How are imaging priorities determined?

There is a hierarchical scheme that is automatically applied by the scheduler.

54 What is the maximum amount of data that can be collected and received from your sensors?

Each day the spacecraft will traverse approximately 800 to 850 daytime scenes of potential interest. Duty cycle constraints on the spacecraft instruments limit the total scene acquisition to about 450 scenes per day.

55 What is the typical amount of data received at present?

Currently, the USGS Landsat archive receives 300 scenes per day. This was increased from 250 scenes per day following the SLC failure to acquire more scenes for potential compositing. Additional scenes are down linked at the International Ground Stations. (IGS)

56 What factors limit the amount of data that can be collected and received?

Landsat 7 is currently constrained by the 16% duty cycle limitation.

57 We would like to know the factors that affect imaging capabilities and capacities.

Power, thermal, SSR, sun-angle etc.

58 How quickly can the organization respond to emergencies?

This is really dependent on the location of the satellite in relation to the emergency in question.

59 Do you have internal plans to monitor disasters?

Yes as each situation warrants.

60 What is the longest continuous imaging swath that a sensor can collect?

35 full WRS-2 scenes for a 14-minute subinterval contact period.

61 Are there any geographical constraints to imaging anywhere around the world?

Landsats 5 and 7 can only image between latitudes 81 degrees north and south due to the WRS-2 orbit.

62 How precisely is your equatorial crossing time maintained?

The Landsat 7 system shall operate in a sun-synchronous orbit with an orbit track repeat cycle of 16 days completing 233 orbits. The spacecraft crosses the Equator from north to south on a descending orbital node from between 10:00 AM and 10:15 AM on each pass. This orbit shall have a nominal descending equatorial crossing time of 10:00 am +/- 15 minutes.
http://landsathandbook.gsfc.nasa.gov/handbook/handbook_htmls/chapter5/chapter5.html

63 How precisely is your ground track maintained?

The ground track of the Landsat 7 shall be maintained such that the Landsat 7 will fly over the Landsat Worldwide Reference System to an accuracy of 5 km at the equator. http://geo.arc.nasa.gov/sge/landsat/mgmtplan.html

64 What is the designed (and projected) life of the satellite?

Landsat 7 was designed for a 5 year mission starting in April 1999. It is expected to run out of consumables in 2010.

65 What are the follow-on missions?

The Landsat Data Continuity Mission (LDCM)

66 Can all of your sensors collect imagery simultaneously?

L7 has only one sensor. (ETM+)

67 Can you provide the acquisition calendar for the satellites?

A calendar of the potential WRS paths that are candidates for scheduling on a given day can be found at http://landsat.usgs.gov/technical_details/data_acquisition/l7_acquisition_calendar.php.

68 Can we get the image shape files? (Ability to locate where a path/row will be)

The WRS-2 shape file includes path row scene boundaries and geographic coordinates http://landsat.usgs.gov/technical_details/data_acquisition/wrs-2_shapefile.php

69 Ground receiving stations, On-board data storage and transmission
70 How are data transmitted to the ground and to the central archive/processing centers?

Data is down linked via 3 gimbaled X-band antennas. Once on the ground the data is routed via file transfer protocol or data tape exchange.

71 Can you store data and transmit data simultaneously?

Yes, it is possible to both downlink a scene in real-time and simultaneously record the scene on-board Solid State Recorder (SSR) for later playback. Also note that the SSR is capable of either recording or playing back payload data (but not both simultaneously) while simultaneously recording and/or playing back housekeeping narrowband telemetry data. S-Band telemetry data is stored separately from wideband image data and can be recorded during load shedding.

72 Do you compress the data on-board? If so, lossless or loss compression?

No.

73 Where are the ground receiving stations located?

Landsat 7 is currently down linked to three Landsat Ground Stations (LGS) for processing and archival in the EROS archive. The three ground stations are Sioux Falls (EDC), Poker Flats, AK (PFS), and Alice Springs, Australia (ASN). The data is also down linked in real-time to other International Cooperators (IC). The current participating Landsat 7 ICs are Argentina (COA), Australia (ASA, HOA), Indonesia (DKI), and Japan (HIJ).

74 What are the receiving antenna requirements?

All ground sites are equipped with 9-11 meter antennas and are capable of receiving both S-band (Housekeeping) and X-band (Science) data simultaneously.

75 What types of antennae are on board? (Omni-directional or spot?)

3 gimbaled X-band antennas.

76 What are the data transmission rates and frequencies?

Each format is transferred at 75 Mbps to a baseband switching unit (BSU) where the data is combined at an aggregate rate of 150 Mpbs. The data frequencies are 8082.5 MHz, 8212.5 MHz, and 8342.5 MHz.

77 Can data be transmitted to more than one receiving station simultaneously?

Yes.

78 Is there an on-board data recorder? If so, what is the capacity?

Landsat 7 has a 378 gigabit (GB) Solid State Recorder (SSR) that can hold 42 minutes (approximately 100 scenes) of instrument data and 29 hours of housekeeping telemetry concurrently. The SSR accepts two inputs at 75 Mbps. The SSR records and plays back wideband data in numbered logical blocks which are used by the MOC in commanding the recorder.

79 Data production and distribution
80 How are data processed and distributed?

In US, the L7 ETM+ data is processed and distributed at the U.S. Geological Survey (USGS) Earth Resources Observation and Science (EROS). There are two processing systems available to generate the data. (National Landsat Archive Production System (NLAPS) and the Landsat Product Generation System (LPGS). There are no licensing restrictions on the data. Our data citation can be found at: http://edc.usgs.gov/about/customer/citation.html

81 Are there more than one processing/distribution sites?

L7 has a very comprehensive IGS network. Each IGS has its own processing capabilities. Twice every year the IGS data is validated at the USGS.

82 Can we get a raw (L0Rp) product?

Yes.

83 Do you have a “default” processing level or configuration (resampling, projections, datum, etc.)?

In Earth Explorer (EE) there are no default processing parameters. In DORRAN (ordering interface), the parameters default to: NDF CDROM MAP 28.5 CC UTM WGS84

84 Are the products produced at variable lengths, i.e. multiple scenes in length?

Yes. We call it a floating scene.

85 Is there any data compression applied to the output products? If so, what method is used?

No data compression is applied.

86 What is the turn around time between imaging and the availability of the products?

Typically, the data are available to order the same day that the image was acquired (approximately 2-3 hours after the image was acquired over most of the US). At times, however, the image may not be available until the next day. This often depends on the path and row of the image.

87 Are the raw data archived? If so, who is responsible for the archive? How long are data held? What is the data storage media?

Yes, the raw data are archived in a Raw Computer Compatible (RCC) format. The Landsat Project is responsible for the archive. According to public law, this data is to be managed by the USGS indefinitely. The data is currently stored on a StorageTek silo on 9940B media.

88 What, if any, differences are there in the processing systems used at different IGS?

Each IGS has its own ground processing system. MacDonald Dettwiler Associates (MDA) and the Advanced Computing Systems (ACS) host a number of the ground processing system and they try to maintain consistency between the systems. The IGS data is validated twice per year at the USGS EROS.

89 What are the various product levels that are available?

For all Landsat 7 ETM+ data, the following levels of correction are available to the general public:

Raw Uncorrected (Level 0Rp) has no radiometric or geometric correction applied. Scan lines are reversed and nominally aligned. Image data is provided in 8-bit unsigned integer (DN) values.

Systematic Correction (Level 1G) includes both radiometric and geometric correction. Image data is provided in rescaled 8-bit unsigned integer (DN) values. The scene will be rotated, aligned, and georeferenced to a user-defined map projection. Geometric accuracy of the systematically corrected product should be within 250 meters (1 sigma) for low-relief areas at sea level. If the image was acquired in SLC-off mode, a scan gap mask will be included with the final product.

Precision Correction (Level 1P) includes radiometric and geometric correction, as well as the use of ground control points (GCPs) to improve accuracy. For locations outside the U.S., accuracy of the precision-corrected product will depend upon the availability of local GCPs.

Terrain Correction (Level 1T) 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. For locations outside the U.S., the accuracy of the terrain-corrected product will depend upon the availability of local ground control points (GCPs), as well as the resolution of the best available DEM.
http://eros.usgs.gov/products/satellite/landsat7.html

90 Are the products produced in different quantization levels (i.e. 8-bit, 10-bit, etc?) If so, what options are produced?

The data quantization for L7 ETM+ is 8 bits. Landsat 7 employs two alternate gains that permit enhancing radiometric resolution in the high gain mode. The L1G data is only available in 8-bit, and the L1R data is available in 16-bit integers.

Appendix C LDGST Technical & Operation Qs : IRS-P6

ResourceSat-1 (IRS-P6)

Data Quality (calibration) Questions
Radiometery

4 How are your data calibrated radiometrically? Please describe the procedures used and provide any documentation?

The following steps are performed for the radiometric correction:
- Detector normalization
- Failed degraded detector correction
- Stagger correction for LISS-IV & SWIR bands of LISS-III & AWiFS
- Line loss correction
- Apply Gains and biases
- Framing of required scene

No formal documentation or peer reviewed journal articles are available on the calibration procedures.

5 Is there any special (Lunar, Solar, Stellar) calibration acquisitions performed?

No special calibration acquisitions (Moon, Sun, and Stellar) are performed. Data is collected regularly over the invariant sites and over sites used for vicarious calibration campaigns.

6 How are detector gains determined? (Prelaunch, vicarious, internal calibrator)

Detector gains are determined Pre-launch. Vicarious calibration campaigns are performed to monitor and check the stability of the absolute detector gains. The gains determined using the vicarious calibration gains are in strong agreement (within 5%) with the pre-launch gains.

7 Are the radiometric calibrations and corrections updated over time to reflect sensor changes?

Yes, the radiometric and geometric calibrations and corrections are updated over time at the NRSA and other International Ground Stations (IGS) processing system to reflect sensor changes. The Look-up-table (LUT) based relative gains and biases are updated as necessary.

8 Have you characterized the linearity and stability of the sensors response? If yes, how?

The linearity and stability of the sensors were characterized pre-launch and regularly monitored on-orbit. Pre-launch testing was performed using the integrating spheres and the on-orbit characterization is performed using the on-board LED's.

9 What are the known artifacts (such as Striping, noises) in the instrument?

Striping, inoperable detectors in the SWIR bands, very low impulse and coherent noise.

10 How are the artifacts compensated in the L1 products?

The correction code exists in the processing system.

11 If there are dead or inoperable detectors, how are they compensated for in the image products?

Yes, there are inoperable detectors in the short wave infra red (SWIR) band (B5) of the IRS-P6 sensors. The 6000 element linear array CCD detectors are arranged as a combination of 600X10. So at the 10

butting points there are 2-3 inoperable detectors in the SWIR band. The number of inoperable detectors for LISS-III: 24, AWiFS A: 28, AWiFS B: 34
There are no inoperable detectors observed in the visible near infrared (VNIR) bands.

12 How does the system respond to saturation point targets? What is the recovery time? Saturation radiance in products?

Each detector has an anti-blooming circuit to prevent from over saturation response bleeding into adjacent pixels. Each pixel has a sink that is controlled by a single voltage. When the detector hits the saturation points target, the energy instead of bleeding into the neighboring pixels goes into the sink.

13 How is detector-to-detector normalization performed to remove striping effects?

The detector-to-detector normalization is performed using pre-launch coefficients. These pre-launch coefficients are stored in a Look-up-table (LUT). On a regular basis on-orbit characterization is performed using the calibration data from the LED's and the LUT coefficients are tweaked as necessary. During Level 1 product generation, striping is corrected using the latest LUT which is scene independent.

14 What levels of radiometric calibration/correction are applied to each of your product levels?

The Level 1 data has full radiometric calibration and correction applied to the products.

15 What is the absolute radiometric accuracy? What are this numbers based on?

The absolute radiometric accuracy is within 5-10%. These numbers are based on pre-launch and vicarious calibration campaigns are used for verification with in-situ ground truth data.

16 How is the detector biases determined? How are biases applied during processing?

Pre-launch bias measurements are stored in the LUT and used for radiometric processing. These detector biases are calculated from the offset observed when the detectors are illuminated with different intensities of LED's. Bias stability is monitored regularly using on-orbit LED's and it seemed to be very stable.

17 The Spectral Response Profiles that we have seen are incomplete. Do you have complete profiles?

Yes, the RSR data is complete and there are no holes.

18 How is the spectral response determined? Is there variability in spectral response or filter response across the focal plane?

The system response is determined at the optics level (filter + lens) and also at the detector level. These two responses are multiplied to get the spectral response. There is no variability in the spectral response or filter response across the focal plane.

19 Has there been any measurement of out-of-band spectral response?

There was no out-of-band spectral response observed in the IRS-P6 sensors response. Much aggressive out-of-band spectral response measurements are performed for the OceanSat instruments.

20 Have you found any problems with stray light? If so, please describe them and how they were measured.

There were no stray light problems observed in the imagery. Veiling glare at optical level is determined using the pre-launch testing.

21 What is the Signal-to-noise ratio (SNR)? At what radiance level was this determined?

AWiFS SNR @ Saturation = > 512
LISS IV and III SNR @ Saturation = > 128
Please refer to the slides on Radiometric Characterization of IRS-P6 Sensors by Mr. Chowdhury from SAC for additional information. The SNR and the NEdeltaL numbers are summarized in detail in the slides.

22 Is there any night imaging capability?

Yes, the LED based calibration is performed during the night.

23 Are the data in Level 1 products linearly scaled to absolute radiance?

Yes, the L1 data can be converted to top-of-atmosphere radiance and reflectance measurements.

24 What is the equation used to convert the DN-to-radiance for each of the products?

Similar to the Landsat calibration equation. The rescaling gains and biases are provided in the metadata with the products.

25 Is there any on-board radiometric calibration capability? If yes, please describe?

Pre-launch light transfer characteristics (LTC) of the overall Payload system are generated in the laboratory covering performance parameters like spectral response, dark current, dynamic range, temperature and linearity. This LTC data is used for radiometric corrections of the image data. However, to monitor the long term performance of the detector and processing electronics, an in-flight calibration scheme is implemented using LEDs. These LED's are used to monitor the linearity and stability of the detectors, but not used for the absolute detector gain measurements. The calibration of camera is carried out during night passes by illuminating the detectors using pulse width modulated constant current driven LEDs. Calibration is performed during once every cycle (24 days).

AWiFS: The in-flight calibration is implemented using 6 LEDs in front of each CCD. For the VNIR bands (B2, B3, B4), the calibration is a progressively increasing sequence of 16 intensity levels through exposure control. For the SWIR band, the calibration sequence is similar to that of LISS-III through a repetitive cycle of 2048 scan lines.

LISS-III: The In-flight calibration of the LISS-III camera is carried out using 4 LEDs per CCD in VNIR bands and 6 LEDs for the SWIR band. These LEDs are operated in pulsed mode and the pulse duration during which these LEDs are ON is varied in specific steps. Each LED has a cylindrical lens to distribute the light intensity onto the CCD. Each calibration cycle consists of 2048 lines providing six non-zero intensity levels. Each intensity level is generated sequentially by LED-1 ON, LED-2 ON and LED-1 and 2 ON.

LISS-IV: Eight LEDs are positioned in front of the CCD (without obstructing the light path during imaging). These LEDs are driven with a constant current and the integration time is varied to get 16 exposure levels, covering the dynamic range in a sequential manner. This sequence repeats in a cyclic form.

26 What is the Solar Exoatmospheric Spectral Irradiances (ESUN) values used for reflectance conversion?

ESUN Units = W/(m2.um)

	LISS-IV	LISS-III	AWIFS
Band 2	1853.6	1849.5	1854.7
Band 3	1581.6	1553	1556.4

Band 4	1114.3	1092	1082.4
Band 5	-	239.52	239.84

The ESUN numbers are summarized in the document called Computation of at-sensor Solar Exo-atmospheric Irradiance and Rayleigh Optical Thickness for IRS-P6 Sensors by A. Senthil Kumar.

27 What solar spectrum profiles were used to calculate the ESUN values?

Nickels and Labs.

28 Describe the focal plane layout and detector dimensions?

The AWiFS camera operates in four spectral bands which are identical to LISS-III. In order to cover the Wide field imaging with minimum geometric distortion, the AWiFS camera is realized using two separate electro-optic modules which are tilted by 11.94° with respect to nadir. Each module covers a swath of 370 Km providing a combined swath of 740 Km with a side lap between them. The electro-optic module contains refractive imaging optics along with band pass interference filter, a neutral density filter and a 6000 pixels linear array CCD detector for each spectral band. The CCDs used in AWiFS are identical to those of LISS-III. Each band has separate optics, detector & electronics. Performance is optimized separately.
The output signals from each CCD are amplified and digitized into 10 bit parallel data in the video processing electronics.

The LISS-III Camera operates in four spectral bands in the VNIR and SWIR range. Each band consists of a separate lens assembly and a linear array CCD. Each lens assembly is realized with 8 refractive lens elements (a combination of convex and concave lenses), an interference filter and a neutral density filter. The VNIR bands (B2, B3, and B4) use 6,000 element CCDs each with pixel size of 10 microns x 7 microns. The SWIR band (B5) uses a 6,000 element Indium Gallium Arsenide CCD with pixel size of 13 micron x 13 micron. This SWIR CCD is a new device employing CMOS readout technique for each pixel, thereby improving noise performance.

The LISS-IV camera is realized using the three mirror reflective telescope optics and 12,000 pixels linear array CCDs with each pixel of the size 7 micron x 7 micron. The CCDs employed in LISS-IV camera are of Thomson make THX31543A . Each CCD has 12K pixels, separated into 6K each of Odd and Even pixels. These odd and even pixel rows are separated by 35 microns (equal to 5 pixels). Three such CCDs are placed in the focal plane of the telescope along with their individual spectral band-pass filters. An optical arrangement comprising an isosceles prism is employed to split the beam into three imaging fields which are separated in the along track direction.

AWiFS Device: 2 x 6K CCDS, B2/B3/B4 - 7X10 micron, B5 - 13 X 13 micron. Integration time = 9.9584885 milliseconds
LISS-III Device: 6K CCDS, B2/B3/B4 - 7X10 micron, B5 – 13X13 micron. Integration time = 3.3194962 milliseconds
LISS-IV Device: Pixel size: 7 X 7 micron. Integration time: 0.8777142 ms
LISS-IV uses a staggered detector .The odd and even pixels are separated by 35 u.

29 What focal length(s) are your sensors?

AWiFS EFL: B2, 3, 4 = 139.5 mm and B5 = 181.3 mm
LISS III EFL: B2, 3, 4 = 347.5 mm and B5 = 452 mm
LISS IV Optics EFL: 980 mm

30 What is the aperture diameter for your sensor(s)?

The lens aperture is usually specified as an f-number, the ratio of focal length to effective aperture diameter. For AWiFS the F = 5, and for LISS-III the F = 4.

31 What types of detectors are used? (material)

The VNIR band (B 2, 3, and 4) detectors are composed of monolithic silicon (Si Photodiode). The SWIR band (B5) detectors are composed of indium antimonide (InSb).

32 Is the sensor gain adjustable? Are there multiple gain settings?

The saturation radiance of the camera can be selected with command. Multiple gain settings are realized with usage of programmable gain amplifier. The gain change is realized by switching resistors in feedback circuit. There are four gains possible for each of the bands. Maximum number of gain settings: 3 per P/L pass.

AWIFS: Single Gain (operated in single gain setting of Exposure E8, E9 and E8 gain for Band 2, 3 & 4 respectively).
LISS-III: 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.
LISSS-IV: Single Gain. (All three bands operated in B2: G4, B3: G3 and B4: G4)

33 Geometry
34 How are your data calibrated geometrically? Please describe the procedures used and provide any documentation?

There are systematic and precision products available. The data acquired by the satellite, have the following distortions:
- Distortion due to the relative motion of the satellite with respect to the earth
- Distortion due to Earth curvature
- Panoramic distortion arising out of the tilt angles
- Distortions arising out of the continuous yaw steering
- Distortions due the staggered array of LISS-IV

Corrections are needed for removing the above mentioned distortions and projecting onto the user specified map projection in the desired datum. In view of the payload configuration, the different bands of LISS-IV are not registered on-board. In fact, the two extreme bands are separated on the ground by a distance equivalent to 2.1 seconds. This calls for ground based registration, which also effects the geometric corrections. The distortions in the data from the satellite are corrected in two steps: By establishing a mapping between the output space, as defined by the user and secondly by transforming the input data into this defined output space.

35 What is the internal geometric stability? (relative geometric accuracy) How has it changed over time?

The average internal distortion (m) observed in the IRS-P6 sensors are:
LISS-III along track and across track = 2.3 and 2.6
AWiFS-A along track and across track = 1.5 and 2.5
AWiFS-B along track and across track = 1.4 and 2.9

36 What is the absolute geodetic/geopositional accuracy? How has it changed over time?

Product Specifications for IRS-P6
LISS-3 :+/- 250 meters
AWiFS: +/- 300 meters
LISS-4 : +/- 300 meters

The average location error (m) observed in the IRS-P6 sensors are
LISS-III along track and across track = 138 and 119 (Standard deviations observed are 109 and 86)
AWiFS-A along track and across track = 149 and 209 (Standard deviations observed are 121 and 160)

AWiFS-B along track and across track = 208 and 181 (Standard deviations observed are 86 and 112)

37 What level of geometric calibrations and corrections are performed for each of your data product levels?

Level-2 Radiometric and Geometric correction (STANDARD and Geo-Referenced) on DPGS
Level-3 Precision Correction using GCPs on VADS

38 What is the band-to-band registration accuracy?

AWiFS and LISS III BBR = +/- 0.25 pixel

39 What source of ground truth do you use to measure your geometric/geodetic accuracy, including elevation data?

ISRO has the ground truth geodetic and elevation data all over India using GPS and other field instruments.

40 Do you have any off-nadir capability if so what is the range?

AWiFS and LISS-III are nadir looking sensors. LISS IV is steerable up to +/- 26 deg across track (about roll corresponding to +/- 398 km about nadir) to obtain stereoscopic imagery.

41 Spatial
42 How are your data characterized and calibrated spatially?

Extensive spatial characterizations were performed during the pre-launch testing. The square wave response (SWR) measurements were used to characterize the data spatially.
AWiFS SWR @ Nyquist = B2 > 30, B3 > 30, B4 > 20, B5 > 20
LISS-III SWR @ Nyquist =B2 > 40, B3 > 40, B4 > 35, B5 > 20
LISS IV SWR @ Nyquist = > 20 All Bands

43 What measurements do you use? (Edge, FWHM line spread, MTF at Nyquist)

Square Wave Response (SWR)

44 What is the sensor spatial resolution (Ground Sample Distance)? How was it determined?

The Instantaneous Ground Field Of View (IGFOV) for the IRS-P6 sensors are:
AWiFS IGFOV (m) = 56 (Nadir) 70 (Off-Nadir)
LISS-III IGFOV (m) = 23.5
LISS IV IGFOV (m) = 5.8

45 How is the spatial response (MTF) monitored on orbit? How has it changed over time?

Few studies have been performed to characterize the LISS-IV SWR using ground targets. No studies have been performed to monitor and characterize the spatial response for LISS-III and AWiFS sensors.

46 Is there spatial compensation (MTF) performed on data products? If so, please describe the algorithms and effects.

No spatial compensation performed on data products.

47 Operational Questions
48 Image scheduling
49 Do you have an overall plan to acquire data regionally/globally? If so, please describe it.

Generally images collected on demand basis for systematic coverage. Data are also acquired as per the requirement of the users. All the data over India is acquired and archived for Indian users in a systematic way. Global data is planned country wise. IRS-P6 Payload Programming System (PPS) accepts requests from Users and the several International Ground stations (IGS) for their future requirements of IRS-P6 data acquisitions. The satellite acquisition has to be programmed when

- The LISS-IV camera has to be tilted to acquire a User's Area of Interest (AOI)
- Stereo imaging is requested
- There is a requirement for Merged LISS-III/LISSIV data
- Data outside the visibility of the Indian ground station is required
- A ground station requires IRS-P6 data to be transmitted over their station visibility

The satellite operates in a circular, sun-synchronous, near polar orbit with an inclination of 98.69 deg, at an altitude of 817Km. 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.

50 What is the image request process from submission to competition?

The overall of the programming activities are summarized in the IRSP6 data users hand book page 122.

51 How are the instruments scheduled?

The instruments are scheduled in advance after ISRO NRSA receives the schedule requirement from various ground stations and customers. The scheduling input in a definitive format is received from the customers and users at NDC, NRSA which will then be compiled to remove any clashes, assign any priorities and a final schedule is programmed for a week in advance. If there are changes to the schedules, a daily schedule is programmed at least 24 hours in advance. The 24 hours change is informed to all the reception stations or possibly notified on the web. All instruments are scheduled in advance as above. The scheduling input from the customers and users is required at least 7 days in advance.

52 Are images collected on the basis of on-demand tasking?

Yes images are collected on demand basis and systematically over the country.

53 How are imaging priorities determined?

The priorities are Natural Calamities, Ground Stations requests, User requests and then Archival Build up.

54 What is the maximum amount of data that can be collected and received from your sensors?

All sensors put together can operate 16 minutes per pass. If there are stations to cover the RT (Real Time) ISRO can schedule as many minutes. If not, a maximum of 8 minutes per pass is recorded on the OBSSR (On Board Solid State Recorder) that is dumped in the next immediate opportunity. However, intricate planning is required to optimize the data collection on OBSSR.

Minimum Payload Duration per orbit: 2 Min
Maximum Payload On duration for single session/orbit: 16 min
Maximum payload duration per day: 225 Min

Maximum number of payload operations per orbit: 3 (combination of sunlit & eclipse for RT,RC,PB,CAL Operations)
Maximum Payload duration for 3 sessions in the same orbit: 23 min (sunlit only).

Here are the payload details for scheme

	Line integration time (sec)	No. of lines per scene	Scene duration (sec)	No. of pixels
LISS-3	3.3194962d-3	6424	21.324	6000
AWiFS (main)	9.9584885d-3	11126	110.798	6000x2
AWiFS (sub)	9.9584885d-3	5638	56.146	6000
LISS-4 (mono)	878.2744791d-6	12000	10.539	12000
LISS-4 (MX)	878.2744791d-6	4000	3.513	4200

55 What is the typical amount of data received at present?

For Real Time stations IRS-P6 sensors downlink a minimum of 38 minutes to a maximum of 70 minutes. The rest is a planned collection of OBSSR based on the orders and archival requirements which varies between 50 to 70 minutes.

11 – 13 orbits are visible for the network any day
10 – 11 orbits are scheduled for IRS-P6

56 What factors limit the amount of data that can be collected and received?

Factors limiting are:
Payload Steering Motor (PSM) rotation
8 min time between turn ONs
Panel slewing

57 We would like to know the factors that affect imaging capabilities and capacities?

Same as above.

58 How quickly can the organization respond to emergencies?

Emergencies can be handled within 4-24 hr depending upon the feasibility of the satellites and the TTC station availability. Data can be supplied to the users with in 8hrs of acquisition in case of Real time Pass and OBSSR data can be supplied within 24 hrs of dump.

59 Do you have internal plans to monitor disasters?

Yes, ISRO is a part of the Internal Charter for disasters and also have a disaster management cell.

60 What is the longest continuous imaging swath that a sensor can collect?

The longest continuous imaging swath that a sensor can collect is 16 min.

61 Are there any geographical constraints to imaging anywhere around the world?

No geographical limitation for imaging. The data is only collected in the descending mode.

62 How precisely is your equatorial crossing time maintained?

Local Time: 10: 30 +/- 5 Minutes.

63 How precisely is your ground track maintained?

Ground track Maintenance planned: +/- 1 Km.

64 What is the designed (and projected) life of the satellite?

Designed life is 5 years. Not limited by fuel. About 14 Kg fuel is spent for initial maneuvers and about 101.4 Kg fuel is available for the rest of the mission. Nominal consumption for maintenance is about 1kg/year.

65 What are the follow-on missions?

There ResourceSat-2 is scheduled to launch in mid 2008. The hardware and the optical assembly development are in progress at the SAC facility. There are 20 other missions (CartoSat's, OceanSat's, Chandrayaan, etc.) that are in progress and to be launched in next 5 years.

66 Can all of your sensors collect imagery simultaneously?

IRS-P6 sensors can collect imagery simultaneously.

67 Can you provide the acquisition calendar for the satellites?

The typical acquisition calendar for the satellites can be found in the IRSP6_data_user_handbook.pdf page 75.

68 Can we get the image shape files? (ability to locate where a path/row will be)

Yes. We've the shape files.

69 Ground receiving stations, On-board data storage and transmission

70 How are data transmitted to the ground and to the central archive/processing centers?

The data is recorded on the Digital Linear Tapes (DLT) and then moved physically to the ground processing centers. Limited FTP option is also available.

71 Can you store data and transmit data simultaneously?

IRS-P6 can record and transmit simultaneously in a limited way.

72 Do you compress the data on-board? If so, lossless or loss compression?

No data compression on-board.

73 Where are the ground receiving stations located?

IRS-P6 currently has five ground stations. Hyderabad, Norman, Fairbanks, Neustrelitz, Beijing. A new IRS-P6 ground station coming up in UAE. It can accommodate up to 14 ground stations.

74 What are the receiving antenna requirements?

Require ground antenna with G/T of 31 db/deg k for 3 db link margin at 5 deg elevations. RHC reception. Two carrier reception. The ground station antenna system is dual shaped parabolic reflector of 7.5 m in diameter and the focal length is equal to 3.077m. The reflector surface is made of sixteen single radial stretch formed panels. These panels are made of 1.6mm thick aluminum sheeting and stiffened by aluminum Zee sections (Z section 90 X 32 X 1.6) for all panels. The stiffeners are glued to the aluminum skin by commercially available glue.

75 What types of antennae are on board? (Omni-directional or spot?)

Onboard antenna: shaped beam antenna, path compensated, +/-65 deg.

76 What are the data transmission rates and frequencies?

Two X band data handling chains
One for LISS-III and AWiFS data transmission and another for LISS-IV data transmission.
Payload data rate for each chain is 105 mbps
Bit error rate 1 x 10-6 for G/T of 31.5 db/deg k

The payload data handling system receives the digital data from each camera in bit parallel – byte serial mode, formats it with auxiliary data, modulates it on the RF carrier and transmits to the ground. There are two separate data handling chains, one to transmit LISS-III + AWIFS data and the second to transmit LISS-IV data, both operating at 105 M bits/sec data rate. The DH system essentially consists of two sub-systems – Base band Data Handling (BDH) and X-band data Transmitting system.

77 Can data be transmitted to more than one receiving station simultaneously?

Yes.

78 Is there an on-board data recorder? If so, what is the capacity?

Yes, there is an On-board Solid State Recorder (OBSSR) to record the Payload data during non-radio visible operation for later playback. The payloads can be operated either in Real Time mode by direct transmission to ground station or in Record and Playback mode using an on-board 120 GB capacity Solid State Recorder. The various modes of Payload operations can be programmed apriori through a Telecommand processor (TCP). The SSR has got four input channels and eight output channels (4 main + 4 redundant). The LISS-III and AWiFS data is recorded as I1 and Q1 on two channels and the LISS-IV data is recorded as I2 and Q2 in the remaining two channels. In each channel, both the recording as well as Playback is done at 52.5 MHz data rate. With the available capacity of the SSR, the LISS-IV and LISS-III + AWiFS data can be recorded for 9 minutes each.

Capacity: 120 GB
Stream 1(LISS-IV) = 9 minutes
Stream-2 (LISS-III + AWIFS) 2 = 9 minutes
If necessary, the OBSSR can be used to task only one of the two streams. However, the reconfiguration is not dynamic.
Stream 1(LISS-IV) ONLY = 16 minutes
Stream-2 (LISS-III + AWIFS) ONLY = 16 minutes
Minimum recoding time: 2.08 minutes
Data Dump from OBSSR on Shadnagar and Svalbard stations only.

79 Data production and distribution
80 How are data processed and distributed?

The Data Reception Station is at Shadnagar (near Hyderabad). The following activities take place at this location:
Reception, Data Pre Preprocessing and Direct archival and quick look browse system.

The Data Processing system is at Balanagar (near Hyderabad). The following activities take place at this location:

Data processing system, Digital QC, Filming, Data quality evaluation system, Information management system, Data selection and user order processing system, Payload programming system, FTP server, ADIF regeneration, PC based AWIFS processing, PC based DQC system, Value added product generation system.

IRS-P6 PC based data processing system specifications
Intel Xeon Server, Dual Processors, CPU 3.06 GHz, 2 GB RAM, 2 x USCSI wide I/f, 52 X CDROM (INT), 1 x 36GB SYS (INT), AGP Card, LINUX (OS), C , C++, Java ,CISAM

81 Are there more than one processing/distribution sites?

Each IGS has processing and distribution capabilities.

82 Can we get a raw (L0Rp) product?

Yes ISRO can supply raw product for LISS-III, AWIFS & LISS-1V MONO for calibration and characterization studies. It should be noted that the L0Rp is not a standard products for users.

83 Do you have a “default” processing level or configuration (resampling, projections, datum, etc.)?

Yes. The “default” processing level or configuration for the products generated in India by NRSA are Polyconic, Everest and Cubic convolution.

84 Are the products produced at variable lengths, i.e. multiple scenes in length?

Yes, the user can order the products at variable lengths.

85 Is there any data compression applied to the output products? If so, what method is used?

NO

86 What is the turn around time between imaging and the availability of the products?

Data can be supplied to the users with in 8hrs of acquisition in case of Real time Pass and OBSSR data can be supplied within 24 hrs of dump.

87 Are the raw data archived? If so, who is responsible for the archive? What is the data storage media? How long are data held?

Yes. The raw data is archived at National Remote Sensing Agency (NRSA) for all the data collected at Hyderabad and OBSSR facility. The data collected at other RT stations are not archived at NRSA. No policy of regular discarding of data. The data storage media is DLT (Digital Linear Tape).

Data is archived as per the data archival policy: Archival and preservation of all good data available from all satellites and sensors for a period of 5 years. For the data which is more than 5 years old the following archival policy will be followed. The data which is to be preserved is to be transcribed on a new media (DLT or SDLT)
Four cycles of data per year in the monsoon period is to be archived
February - (March)
April - (May)
October - (November)
December - (January)

If data from more than one sensor is available for a given period, data which is better of the two, in terms of quality and continuity may be archived. Users have already been informed about the archival policy and requested to procure their data requirements well in advance.

88 What, if any, differences are there in the processing systems used at different IGS?

The processing systems are provided to all IGS by Antrix. There should be no difference in the processing systems used by different IGS. When needed, the calibration and processing updates are performed on all the systems.

89 What are the various product levels that are available?

Level-1 Radiometric correction (RAD) on DPGS
Level-2 Radiometric and Geometric correction (STANDARD and Geo-Referenced) on DPGS
Level-3 Precision Correction using GCPs on VADS

Product Types: Path/Row Based Standard Products, Shift Along Track Products, Quadrant Products, Georeferenced Products (North Oriented) and Geocoded Products
Resampling Options supported: Cubic Convolution (CC), Nearest Neighbor (NN) and Kaiser-16 (K)
Output Resolution supported: LISS – IV: 5.0 and 6.25 meters; LISS-III: 12.5 and 25 meters; AWiFS: 50 and 75 meters
Map Projections supported: Polyconic (P), Lambert Conformal Conical (L), Universal Transverse Mercator (U) and Space Oblique Mercator (S)
Earth Ellipsoids supported: Clarke 1866 (C6), International 1909 (I9), GRS 1980 (GR), Everest (EV), WGS – 84 (W4), Bessel (BL) and Krassovsky (KW)
Special Products: Precision Corrected Products, Mosaic Products, and AOI Products, Merged Products, Image Map Composition, Natural Color Composite Products and Turn key data products for major projects.
Output Media: Disk (z), CDROM (J), and Photo product (B/W and FCC)
Digital Data Products Formats: LGSOWG Superstructure Format (6/7), Fast Format (B), Geo Tiff-Gary Scale (T) and Geo Tiff-RGB (R).

90 Are the products produced in different quantization levels (i.e. 8-bit, 10-bit, etc?) If so, what options are produced?

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 out of 10 bits (sliding)
LISS IV = 7 out of 10 bits (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.

a) The AWIFS data corresponding to all four bands are received as 10 bit parallel data.

b) 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.

c) 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.

d) 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.

The data products for LISS-III and LISS-IV are available in 8 bits. The AWiFS data products are available in 8, 10 & 12 bits.

Appendix D LDGST Technical & Operation Qs : CBERS-2

China-Brazil Earth Resources Satellite-2 (CBERS-2)

Data Quality (calibration) Questions

Radiometery

4 How are your data calibrated radiometrically? Please describe the procedures used and provide any documentation?

This can be found in the document titled “Radiometric Quality Assessment of CBERS-2”. The document reference number is APPL-06-2004.

5 Are there any special (Lunar, Solar, Stellar) calibration acquisitions performed?

No special calibration acquisitions (Moon, Sun, and Stars) are performed. Data is collected regularly over the invariant sites and over sites used for vicarious calibration campaigns.

6 How are detector gains determined? (Prelaunch, vicarious, internal calibrator)

Vicarious calibration campaigns are performed to determine the absolute detector gains. These field campaigns are performed independently by the Chinese and Brazilian teams.

7 Are the radiometric calibrations and corrections updated over time to reflect sensor changes?

The radiometric calibration and corrections (relative gain corrections using the look-up table) have been updated as necessary, but this is not done systematically.

8 Have you characterized the linearity and stability of the sensors response? If yes, how?

No.

9 What are the known artifacts (such as Striping, noises) in the instrument?

Striping, banding and over saturation of bright targets in band 4. The various noise sources are yet to be characterized.

10 How are the artifacts compensated in the L1 products?

There is a radiometric processing module that corrects the artifacts problems. Striping correction is the only radiometric artifact that is compensated and corrected in the current processing module.

11 If there are dead or inoperable detectors, how are they compensated for in the image products?

There are no dead or inoperable detectors in the CBERS sensors, but if this problem occurs an interpolation procedure can be applied. The interpolation procedure will replace the inoperable detector value by a linear interpolation on the nearest valid detector (columns) surrounding the inoperable detector.

12 How does the system respond to saturation point targets? What is the recovery time? Saturation radiance in products?

Bright point targets can over saturate the detectors, causing a 'blind' period of zero and/or saturated values. Recovery time varies with target brightness. The over saturation problem is usually observed during the summer time near the equatorial acquisitions.

13 How is detector-to-detector normalization performed to remove striping effects?

The detector-to-detector normalization is primarily performed using pre-launch coefficients. These pre-launch coefficients are stored in a Look-up-table (LUT). On a regular basis on-orbit characterization is performed using the image data and the LUT coefficients are tweaked as necessary. The on-orbit characterizations are usually performed by calculating the normalization gains obtained from the mean and variance values of the detectors. During Level 1 product generation, striping is corrected using the latest LUT which is scene independent.

14 What levels of radiometric calibration/correction are applied to each of your product levels?

Level 0 products have no corrections. Level 1 product has full radiometric calibration and correction. Level 2 product has radiometric and geometric calibration and correction.

15 What is the absolute radiometric accuracy? What are these numbers based on?

The absolute radiometric accuracy of CBERS-2 is unknown. These absolute detector gains are based on vicarious calibration campaigns. Cross-calibration with other instruments needs to be performed to understand and confirm the CBERS-2 absolute radiometric specification.

16 How are the detector biases determined? How are biases applied during processing?

The detector biases are calculated from the detectors responses of zero illumination images (calibration image). The CBERS detector array arrangement consists of three arrays of 2048 detectors, with a superposition region of 154 detectors and a dark current region of 8 detectors.

17 The Spectral Response Profiles that we have seen are incomplete. Do you have complete profiles?

The IRMSS B7 RSR profiles are incomplete.

18 How is the spectral response determined? Is there variability in spectral response or filter response across the focal plane?

The RSR characterization and measurements were performed in China. Very limited information is available regarding the pre-launch spectral characterizations.
B2 (CCD sensor) spectral range is out of specification due to technical difficulties in meeting the project specification.
Specification = 0.52 – 0.59 um +/- 10 nm
Measurement = 0.515 – 0.635 um +/ 1 0 nm
B6 (IRMSS sensor) spectral range is also out of specification.

19 Has there been any measurement of out-of-band spectral response?

No.

20 Have you found any problems with stray light? If so, please describe them and how they were measured.

No characterization has been performed on stray light issues.

21 What is the Signal-to-noise ratio (SNR)? At what radiance level was this determined?

Please see table 1.1.2 in document APPL-06-2004 – Radiometric Quality Assessment of CBERS-2B.

22 Is there any night imaging capability?

CBERS-2 has night imaging capability. However due to the battery problem since April 2005, no night imaging acquisitions can be scheduled.

23 Are the data in Level 1 products linearly scaled to absolute radiance?

Yes, the L1 data can be converted to top-of-atmosphere radiance and reflectance measurements. However, the L1 data are not scaled to absolute radiance. Only relative gain corrections are applied as part of the radiometric processing.

24 What is the equation used to convert the DN-to-radiance for each of the products?

This DN-to-radiance conversion can be performed using the absolute calibration coefficients that were derived using the "vicarious" (reflectance-based method) calibration methods. The field campaigns were carried out in Brazil (Northeast region) and in China (Gobi desert). Results are dependent of the L2 products.
The equation used to convert the DN-to-radiance is L(□)= DN(□)/CC(□); where L(□) is the spectral radiance; DN(□) is the digital number extracted from the images, and CC(□) is the absolute calibration coefficient (from the reflectance-based method). The full description of the applied methodology can be found in the SPIE paper.

25 Is there any on-board radiometric calibration capability? If yes, please describe?

CBERS-2 CCD has no on-board radiometric calibration capability. The IRMSS has internal calibrator.

26 What are the Solar Exoatmospheric Spectral Irradiances (ESUN) values used for reflectance conversion?

ESUN Units = W/(m2.um)
CCD = [1934.03; 1787.10; 1548.97; 1069.21; 1664.33]
IRMSS = [1347.75; 222.32; 83.46]
WFI = [1563.95; 1068.25]

27 What solar spectrum profiles were used to calculate the ESUN values?

The solar spectrum profiles from the 6S atmospheric correction code library were used to calculate the ESUN values.

28 Describe the focal plane layout and detector dimensions?

Each band in the focal plane of CCD camera is composed of 3 CCD linear arrays optically butted (the butting is similar to the DIVOLI in SPOT HRV camera). Each CCD array detector has 2048 elements of 13x13µm. One image line uses 2040 elements of each CCD and has 154 of effective pixels in each overlap region. So, the line image is composed of 5812 effective pixels.
Spectral Bands (B1 to B4) are registered. The Panchromatic Band (B5) is shifted by 20 mm in the focal plane or 2.2 degrees in the FOV.

29 What focal length(s) are your sensors?

The nominal focal length of CCD camera is 520 mm.

30 What is the aperture diameter for your sensor(s)?

The aperture diameter of CCD camera for CCD camera is 130 mm (f/4).

31 What types of detectors are used? (material)

CCD camera uses silicon CCD linear arrays.

32 Is the sensor gain adjustable? Are there multiple gain settings?

The gain is adjustable. The available gain settings are 0.59, 1, 1.69 and 2.86 for the CCD camera. However, the cameras have been to set to the default gain setting of 1. This information is provided in the GRAHLA file.

33 Geometry
34 How are your data calibrated geometrically? Please describe the procedures used and provide any documentation?

This can be found in the document titled “Geometric Quality Assessment of CBERS-2”. The document reference number is APPL-13-2004.

35 What is the internal geometric stability? (relative geometric accuracy) How has it changed over time?

Assessment of the internal geometric accuracy is also found in document “APPL-13-2004’. Although the internal geometric stability has not been systematically evaluated, the preliminary results indicate it is around 1 pixel (20m) for the CBERS-2 CCD camera. This analysis was performed using the geo-cover ETM+ orthorectified products as the baseline.

36 What is the absolute geodetic/geopositional accuracy? How has it changed over time?

The absolute geodetic accuracy of the CBERS-2 CCD camera has been systematically evaluated; the results indicate that CCD camera provides a geometric positioning accuracy that ranges from 2 km to 11 km.

37 What level of geometric calibrations and corrections are performed for each of your data product levels?

Level P0: Raw data
Level P1: Radiometrically corrected data
Level P2: Systematic Correction
Level P3: Systematic Correction refined using ground control points (GCP)
Level P4: Systematic Correction refined by use to DEM tied to GCPs.
This can be found in the document titled “INPE’s Proposal for CBERS-2 Products”. The document reference number is APPL-10-2004.

38 What is the band-to-band registration accuracy?

CBERS-2 CCD BBR = 0.3 pixel
Band-to-band mismatch is estimated by an intensity interpolation method.

39 What source of ground truth do you use to measure your geometric/geodetic accuracy, including elevation data?

Geo-cover orthorectified Landsat data and SRTM data.

40 Do you have any off-nadir pointing capability if so what is the range?

Only the CCD camera in CBERS-2 and CBERS-2B has an off-nadir viewing capability of ±32o.

41 Spatial
42 How are your data characterized and calibrated spatially?

Limited spatial characterizations were performed during the pre-launch testing.

43 What measurements do you use? (Edge, FWHM line spread, MTF at Nyquist)

MTF at Nyquist and effective instantaneous field of view (EIFOV). MTF values (pre-launch) are a little lower than the values defined in the camera project (MTF > 0.4 in the Nyquist frequency). These values are:
B6 = 0,3775
B7 = 0,3611
B9 = 0,3623
The on-orbit MTF values in the cross-track direction are worse than the pre-launch values, which results in blurred images (compared to SPOT images for instance). See table 1.4.3 in document APPL-06-2004 - Radiometric Quality Assessment of CBERS-2B.

44 What is the sensor spatial response? How was it determined?

The spatial resolution for CCD camera is 20 meters for all bands.

45 How is the spatial response (MTF) monitored on orbit? How has it changed over time?

Few studies have been performed to characterize the on-orbit MTF of the CCD camera using ground targets. The MTF is usually monitored on-orbit using the Lake Pontchartrain Causeway (across track) in Louisiana, Rio-Niteroi bridge (along track) in Brazil, Saint Louis Bridge, Ilha Solteira Bridge and black target on Gobi desert.

46 Is there spatial compensation (MTF) performed on data products? If so, please describe the algorithms and effects.

The users have an option to get the data processed by a set of restoration filters.
The algorithm is described in the paper Fonseca, L.M.G.; Prasad, G.S.S.D.; Mascarenhas , N. D. A. "Combined Interpolation-Restoration of Landsat images through a FIR Filter Design Techniques", International Journal of Remote Sensing, 14(13), pp. 1247-2561, 1993."

47 Operational Questions
48 Image scheduling
49 Do you have an overall plan to acquire data regionally/globally? If so, please describe it.

INPE daily acquires CBERS data over the continent of South America that is within the visibility range of Cuiaba ground station, while the Chinese acquire the imagery using three ground stations covering China and neighboring countries. CBERS image scheduling is routinely performed on a weekly basis.

50 What is the image request process from submission to competition?

An agreement was reached between Brazil and China regarding CBERS imaging categories.
1) Routine imaging, currently referring to real-time nadir imaging for all instruments within visibility range of ground-stations at Brazil or China, requires no imaging request submission.
2) Special imaging, i.e., any imaging operation that is not routine imaging, must be submitted to the CLTC unified operations plan for possible conflict verification. Brazilian users willing to request a special imaging product must submit target coordinates and desired image type to INPE. INPE then processes the request and determines the closest possible date of execution, which is returned to the requesting user

for confirmation and then is forwarded to CLTC for conflict verification. The duration from user request to CLTC confirmation is usually within one week, but actual execution is subject to CBERS revisit cycle of 26 days. If CLTC rejects the special imaging request, INPE notifies the requesting user about the refusal and informs the next closest possible date of execution and submitting it to CLTC. Else, the special imaging is performed and the data is made available to the user.

51 How are the instruments scheduled?

Routine imaging scheduling is performed on a weekly basis. The image acquisitions that need special imaging scheduling are performed on-demand and processed case-by-case.

52 Are images collected on the basis of on-demand tasking?

The data is collected on a regular basis whenever the satellite passes over the ground-station during daytime. No on-demand tasking is necessary for routine image scheduling.

53 How are imaging priorities determined?

Conflicts between routine imaging and special imaging within the range of the Cuiaba image receiving station are processed by the CBERS Brazilian Application Segment Imaging Mission Center upon request submission. Other conflicting cases are solved by CLTC under its unified operations plan.

54 What is the maximum amount of data that can be collected and received from your sensors? Daily average?

For CBERS-2B, each downlink channel of CCD data transmission (DT) has a bit rate of 53 Mbps (2 channels @ 53 Mbps each) while the high resolution and the WFI cameras have a DT bit rate of 60 Mbps (2 channels @ 60 Mbps each). CCD images can be recorded onboard and transmitted later at 53 Mbps (single channel) for 15 minutes. WFI and/or HRC images can also be recorded onboard and transmitted later both in one 60 Mbps channel for 15 minutes. Typical daily amount of data is estimated at: 15 minutes x 7 overpasses (3 Brazil + 4 China) x (53 Mbps + 60 Mbps) = 711.9 Gbits.

55 What is the typical amount of data received at present?

The typical amount of data received at present from the CBERS-2 is about:
12 minutes x 5 passes (2 Brazil + 3 China) x 53 Mbps (CCD only) = 190.8 Gbits.

56 What factors limit the amount of data that can be collected and received?

Factors limiting are:
The onboard power supply capability,
the duration and
the frequency of the pass over the ground station.
Onboard image recording (at illuminated phase) for nighttime (eclipse phase) transmission is particularly stressful for the onboard power supply, and cannot be used continuously. The duration and frequency of the passes is dependant on the ground station visibility range, combined with the satellite orbital traits.

57 We would like to know the factors that affect imaging capabilities and capacities.

Same as above – Power, thermal, recorder, and sun angles.
CCD is capable of side-looking imaging, restricted to +/- 32° at either left or right of the nadir orbit track with steps of 1'.

58 How quickly can the organization respond to emergencies?

This is really dependent on the location of the satellite in relation to the emergency in question.

Whenever there is an anomaly with the CBERS instruments, the anomaly resolution team requires close coordination between Brazilian and Chinese activities. Despite time zone differences, contingency procedures have been historically performed within 2 hours after failure detection, although finding definitive solutions and resuming imaging operations can take considerably time depending on the complexity and severity of the problem.

59 Do you have internal plans to monitor disasters?

Yes as each situation warrants. A special acquisition can be triggered in case of emergency to monitor disasters.

60 What is the longest continuous imaging swath that a sensor can collect?

After 20 minutes of continuous imaging, the satellite onboard data handling triggers a command to automatically turn off the operating payload.

61 Are there any geographical constraints to imaging anywhere around the world?

Due to orbital characteristics, nadir images are restricted to within +/- 81° latitude. This restriction can be technically lifted through use of steering mirror for off-nadir CCD images, but this would constitute a special imaging and requires approval.

62 How precisely is your equatorial crossing time maintained?

Design equatorial crossing time is 10:30 am +/- 10 minutes. However, in the past this constraint has been lifted due to battery problems and restrictions on out-of-plane orbit corrections.

63 How precisely is your ground track maintained?

Design ground track drift is restricted to +/- 5 kilometers. However, in the past this constraint has been lifted due to battery problems, unexpected solar activity and restrictions due to in-plane orbit corrections from negative to positive direction. However, this restriction can be technically lifted through use of steering mirror for off-nadir CCD images.

64 What is the designed (and projected) life of the satellite?

The design life of the CBERS-1, 2 and 2B satellites is 2 years. CBERS-1 lasted 3 years and 10 months in orbit after launch. CBERS-2 has been in orbit for more than 3 years and is still operational.

65 What are the follow-on missions?

CBERS-2B is expected to be launched in late 2007 with design life of 2 years. CBERS-3 and 4 are expected to be launched in 2008 and 2011, respectively.

The CBERS-2B is launched to fill the data gap between CBERS-2 and CBERS-3. CBERS-2B will be very similar to CBERS-1 and 2. It uses spare components and equipments of CBERS-2. The High Resolution Camera (HRC) replaces IRMSS. The operation mode of CBERS-2B is complex, e.g., the satellite has to make yaw and roll movements in order to make compatible the imaging by CCD and HR cameras; thus, the across track CCD mirror has to be moved periodically. Integration and testing is going on in Brazil and the satellite will be launched from China by Long March 4B rocket in 2007.

66 Can all of your sensors collect imagery simultaneously?

Yes.

67 Can you provide the acquisition calendar for the satellites?

A weekly acquisition calendar could be generated and made available as part of the routine imaging scheduling.

68 Can we get the image shape files? (Ability to locate where a path/row will be) Do you have a regular acquisition grid?

There is a map covering the visibility range of Cuiaba image receiving ground station, which identifies CBERS data acquisition grid (path/row) over northern South America (Check 'Files and Documents' at www.dgi.inpe/CDSR/).

69 Ground receiving stations, On-board data storage and transmission
70 How are data transmitted to the ground and to the central archive/processing centers?

After the satellite overpass, the Cuiaba ground station saves the raw data on the Digital Linear Tapes (DLT) and then the data is physically moved (air-transportation) to the ground processing centers at Cachoeira Paulista. Limited FTP option is also available.

The X-band downlink transmission of all image data in four channels, two for CCD-1 and 2 (8103 and 8321 MHz) at data rates of 2 x 53 Mbit/s, one for IRMSS (8216.84 MHz) at a data rate of 6.13 Mbit/s, and one for WFI data (8203.35 MHz) at a data rate of 1.1 Mbit/s. The modulation is QPSK for CCD and WFI data streams and BPSK for IRMSS.

71 Can you store data and transmit data simultaneously?

No, when CBERS-2 is recording data with the onboard recorder there is no direct image transmission to the ground. The recording capability is only for CCD1 (bands green, red and NIR). There is no capability for recording bands blue and pan of the CCD, and neither for IRMSS and WFI. When the tape recorder is in playback mode there is no direct image transmission to the ground either.

72 Do you compress the data on-board? If so, lossless or loss compression?

No data compression on-board for CBERS-2 data. However, the CBERS-2b high resolution data will be compressed 8:1 (lossy compression) before transmission.

73 Where are the ground receiving stations located?

As of now there are four ground stations for CBERS-2. Three of them are in China: Beijing, Guangzhou and Urumchi. The Brazilian ground station is in the city of Cuiaba, in the state of Mato Grosso, in central Brazil.

74 What are the receiving antenna requirements?

Require ground antenna with
Minimum G/T: 32.5 dB/K (margin of 3 dB for CCD)
4 receiving channels (3 x QPSK, and 1 x BPSK)
4 ingest and recording channels / subsystems
Should be able to track low earth polar orbiting satellites.

75 What types of antennae are on board? (Omni-directional or spot?)

Omni-directional.

76 What are the data transmission rates and frequencies?

Two onboard data transmitters:

CCD – DT (RHCP)
RF frequencies: CCD1 = 8103 MHz; CCD2 = 8321 MHz, BW ≤ ±40 MHz
Data rate: 53 Mbps each CCD1 and CCD2
EIRP: 43 dBm (no less than 17 W)
Data is arranged according to a predefined format that includes time information, and attitude data
Modulation: QPSK
Bit interleaving (I and Q channels)
Independent gain control for CCD1 and CCD2 (no gain control for each band)

IRMSS – DT (RHCP)
IRMSS
RF Frequency: 8216.844 MHz; BW ≤ ± 6.5 MHz
Modulation: BPSK
Data rate: 6.1274 Mbps
EIRP: 39.2 dBm

WFI
RF frequency: 8203.35 MHz; BW ≤ ±0.6 MHz
Modulation: QPSK
Data rate: 1.1 Mbps
EIRP: 31.8 dBm

The modulation is QPSK for CCD and WFI data streams and BPSK for IRMSS.

77 Can data be transmitted to more than one receiving station simultaneously?

Yes.

78 Is there an on-board data recorder? If so, what is the capacity?

Yes, there is a tape recorder onboard CBERS-2.
CBERS-2B will have two solid state recorders with a capacity of 43 GB each. The CCD-DT unit will record CCD camera data, either from CCD1 or CCD2. The HW-DT unit will record data from HRC and WFI. The recording capability of the on-board recorder is approximately 15 min each.
The CBERS-3 and 4 will have a solid state recorder with capacity of 274 GB.

79 Data production and distribution
80 How are data processed and distributed?

In Brazil, INPE is responsible for receiving, processing, archiving and distributing CBERS data. The data is downlinked to the ground station in Cuiaba, sent on DLT tape to INPE's premises in Sao Jose dos Campos, SP and in Cachoeira Paulista, SP. INPE's Remote Sensing Data Center is located in Cachoeira Paulista where the data is processed, archived, and distributed to the users. Data are distributed free through the internet via FTP in full resolution, or can be purchased if in CDROM.

81 Are there more than one processing/distribution sites?

The Chinese and Brazilians have their own processing and distribution system. The main processing facility for INPE is in Cachoeira Paulista. However, INPE at São José dos Campos can also process the data if necessary, in a limited scale. Its basic function, though, is to function as a development and test facility for the system to be deployed in the Data Center at Cachoeira Paulista.

82 Can we get a raw (L0Rp) product? (Product that has not been corrected geometrically and radiometrically.)

Yes, INPE has already provided the Level-P0 data to USGS EROS during the CBERS-2 trial reception tests. The files with names like CBERS_2_CCD1XS_20060330_218_028.h5 are raw data files in HDF5 format.

Naming convention for raw data:
- A DRD stand for Dated Raw Data and it is a set of bit sent from CBERS-2 satellite to Cuiaba Station.
- GRALHA stands for Generic Raw Level Hierarchical Archive. It is a file that holds the data processed by the system. These data have been synchronized and decoded. The archive corresponds to a scene inside the reference grid for the satellite defined by a path and a row. It is a result of d2g (DRD to GRALHA).
- Level P0: raw data products are created from GRALHA. The Level 0 (HDF) file is segmented, there is one HDF file per scene. All pixels are from East to West.

The raw data is captured in one big file called the DRD. Once this file is captured by the ground station, it goes through the processing system to create GRAHLA. It consists of multiple HDF files. The GRAHLA files are the input to all the higher level processing. The browse images are created using this file and then L0, L1 and L2 products can be generated eventually.

83 Do you have a "default" processing level or configuration (resampling, projections, datum, etc.)?

Yes, the data distributed on the internet is always Level 2. As of now, the user cannot choose any other level of processing. The default processing parameters are standard datum SAD69, UTM projection, with no resampling.

84 Are the products created at variable lengths, i.e. multiple scenes in length?

No. Each image has the same size; the user cannot choose products with variable lengths.

85 Is there any data compression applied to the output products? If so, what method is used?

No data compression is applied during processing. However, the "zip" lossless compression is applied to products that are distributed via the internet.

86 What is the turn around time between imaging and the availability of the products?

Typically, the data are available to order in the browse catalog around four to five days after the acquisition. Once the data is the catalog, user data requests are fulfilled within the same day. However, if the scene were already processed during the same week of the request, the order is attended in less than 10 minutes.

87 Are the raw data archived? If so, who is responsible for the archive? How long are data held? What is the data storage media?

Yes, the raw data is stored indefinitely in INPE's Data Center at Cachoeira Paulista. As of now the recording media is LTO2/LT03 tape. Tape Library uses a cartridge LTO3 400/800 Gigabytes. Media type may change, following the development of storage technology.

88 What, if any, differences are there in the processing systems used at different IGSs?

The processing systems and the data formats are completely different and independent between the two agencies. The processing system of INPE's Data Center was developed by the Brazilian company named GISPLAN. The Chinese processing system was developed independently by another company. The differences in the processing systems between the two groups are unknown and needs to be characterized.

89 What are the various product levels that are available?

Here are the various product levels. Only the Level-2 data products are available to users via internet.
Level P0: Raw data
Level P1: Radiometrically corrected data
Level P2: same as P1 plus Systematic Correction
Level P3: same as P2 plus Systematic Correction refined using ground control points (GCP)
Level P4: same as P2 plus Systematic Correction refined by use to DEM tied to GCPs.
This can be found in the document titled "INPE's Proposal for CBERS-2 Products". The document reference number is APPL-10-2004.

90 Are the products produced in different quantization levels (i.e. 8-bit, 10-bit, etc?) If so, what options are produced?

The data quantization for the CBERS-2 is 8-bits.

91 Additional questions.
92 Understanding the CBERS data archive, access, processing, and distribution. Can you provide a system description document?

Yes. The documents were sent by email.

93 CBERS Operations Concept and Data Policy. Can you provide an operations concept document and data policy description?

Currently there is no operations concept document openly available regarding the CBERS mission. INPE could, however, write a new document containing all information if deemed necessary by the LDGST.

94 User Characterization and Data Availability.
Can you provide an overview/reports/research of the user profile using CBERS data and the effect on type and amount of data used? How does use of data change when associated data policies are changed? To what extent do you maintain an on-line archive (cache) of products that are readily accessible via ftp? And if you maintain an on-line archive, what instrument data and at what level of processing is the data available? How much of your data is available via a web enabled process?

CBERS data is distributed on the internet with no cost to the registered (by filling a brief form) users. The CBERS site was opened experimentally in April and then officially in June 2004. As of October 10th, 2006, there are 101,072 scenes in the CBERS-2 catalogue – 64,371 CCD, 33,589 IRMSS, and 3,112 WFI. In that timeframe INPE fulfilled 99,615 user requests, which amounts to 249,463 scenes. These requests came from 11,767 unique users that belong to 6,092 different institutions. From January 1st, 2005 to December 31, 2005 there were around 833 weekly requests, which corresponded to 2,025 scenes per week in an average. The average number of scenes per request is 2.43.

The INPE data policy has never been changed since the beginning of the CBERS-2 operations. This year, the same policy of free distribution was extended to Brazil neighboring countries under the footprint of our Cuiaba antenna. All the images are in the browse catalogue. In general, after the first request, the image is kept in disk cache for one week or so, and during that week it does not needs to be re-processed if requested by another user. Doing so, the second and following requests for the same scene can be fulfilled very fast usually within ten minutes of the request. The default processing level is level 2.

Most of the requests are for CCD images. Since April 2005, this is the only camera in operation. CBERS-2 had experienced problems with one of the two batteries. Because of the battery problem, the CCD is operational in limited way (12 minutes per orbit) while the IRMSS and WFI cameras were turned-off.

The profile of INPE's user is vast. It ranges all the way from the elementary school teachers to large commercial companies and federal agencies. Roughly, 25% of the institutions are government (local, state, and federal), 25% are educational, and 50% are private (companies, small business, NGOs, individuals, etc.). With such a large profile of user community, various kinds of applications can be identified, mainly considering that many of the Landsat-like applications can be done with CBERS data. New applications were developed or identified for CBERS, mainly because of its low cost, efficient distribution, and acceptable quality. Some institutions that had never used or had used very parsimoniously satellite images, now can use CBERS images, and consequently started new applications and projects. Some typical examples of that are marketing agencies, local governments for environment and planning, schools in various levels, small consulting and planning business/agencies, the agribusiness sector, NGOs, etc.

INPE has a qualitative report that clearly shows the high level of approval of CBERS data and the data policy adopted. In the report there are some examples about jobs and opportunities created by CBERS. There is no university or higher education institution in the country which has in some way link with remote sensing application (geography, agronomy, geology, etc.) that is not registered as CBERS user. In the last XII Brazilian Remote Sensing Symposium (Goiania city, April 2005 – taking into account that the deadline for papers was November 9th, and the CBERS site was just opened in June) there were more than 50 full papers (8 pages) dealing with CBERS-2.

95 Documentation. Can you provide a list of CBERS-2 documentation; such as, system handbooks, user manuals?

Yes. The documents were received by email.

96 Geometric and Radiometric Cross Calibration. What cross calibration efforts have been done with other sensors and systems?

A first attempt of an absolute radiometric cross calibration was performed using ASTER data. It was considered to be a training activity, but the results were not good enough.

Appendix E Minutes from TIM with ISRO June 13-19, 2006

SUBJECT: Summary of Landsat Data Gap Study Team Technical Interchange Meeting with the Indian Government, 13-19 June 2007

Executive Summary

A delegation consisting of members of the Landsat Data Gap Study Team (LDGST) successfully completed a series of Technical Interchange Meetings (TIM) with representatives from the Indian Department of Space (DOS), including representatives from the Indian Space Research Organization (ISRO) Headquarters and two of its field centers (the Space Applications Center (SAC) in Ahmedabad and ISRO Satellite Center (ISAC) in Bangalore), ISRO's commercial entity, ANTRIX, and the National Remote Sensing Agency (NRSA).

Within the Indian Department of Space:

- ISRO is responsible for the design, construction, launch, operations, and applications of India's earth observation and telecommunications satellites.
- NRSA is responsible for data archive and distribution.
- ANTRIX is responsible for international commercial distribution of the Earth observation data.

The LDGST delegation consisted of members from the National Aeronautics Space Administration (NASA), the United States Geological Survey (USGS), and United States Department of Agriculture (USDA). United States Government members included representatives from NASA, USGS, and USDA:

- Edward Grigsby – NASA Science Mission Directorate, Headquarters
- Edwin Sheffner - NASA Science Mission Directorate, Headquarters
- Liz Williams - NASA Office of External Relations, Headquarters
- Jim Irons – NASA Science Mission Directorate, Goddard Space Flight Center
- Brad Doorn - U.S. Department of Agriculture (USDA)
- Greg Stensaas - USGS EROS Data Center, Sioux Falls, SD
- Gyanesh Chander – SAIC, USGS EROS Data Center, Sioux Falls, SD

ISRO representatives from ANTRIX Corporation (the commercial arm of ISRO under the direction of the Indian Department of Space) and the National Remote Sensing Agency (NRSA – also under the Department of Space) met with the U.S. team at IRSO Headquarters in Bangalore on 13-14 June 2006. the meeting, included:

- K.R. Sridhara Murthi – Executive Director of ANTRIX
- Jacob Ninan – Director of International Cooperation – ISRO
- V. Jayaraman – Director, Earth Observation Systems
- G.V.S. Prakesh – Director, International Marketing, ANTRIX
- K.M.M. Rao – Deputy Director for Data Processing, NRSA
- P.J. Bhat – Mission Development Group – ISRO
- M.G. Rayakar – Mission Data Processing Division, ISRO
- R. Joseph Arokiadas – Group Head, NRSA Data Center, NRSA
- R.L.N. Murthy – Manager, Business Development, ANTRIX

- A.S. Manjunath – Group Director Special Products and Quality Evaluation, NRSA
- Rajeev Lochan – Assistant Scientific Secretary, ISRO (joined the meeting on June 14)
- P. S. Roy, SAC Deputy Director
- A. S. Kiran Kumar, Director, SAC Earth Observing Satellite Group

The US team met with ISRO and NRSA staff at SAC on 15-16 June 2006. The ISRO participants included Dr. R.R. Navalgund, the director of SAC, Dr. Rao Dr. Prakash and Dr. Jayaraman from the previous days' meetings in Bangalore, and several SAC staff members including Dr. P. S. Roy, the Deputy Director, and Dr. A.S. Kiran Kumar, the director of SAC's Earth Observing Satellite Group. The visit also included a discussion of agriculture and applications led by J.S. Parihar, Director of the Agricultural Resources Group and his staff, as well as a tour of the SAC instrument assembly facility

The fundamental objective of this technical interchange was to collect detailed technical information on the salient performance characteristics of the ResourseSat-1 mission (also known as IRS-P6) to help enable the LDGST's technical analysis of the complementarity and comparability of its land imaging data with Landsat-7 (L-7) data.

The LDGST delegation was very warmly received and was treated in a professional and courteous manner throughout the interchange. DOS provided access to all required technical expertise from the appropriate centers and answered all of our questions, including in-depth design detail and methodologies. ANTRIX hosted our technical discussions at its ISRO Headquarters location in Bangalore, and coordinated our meetings with ISAC and SAC. All of our discussions were open and at no time was any topic suppressed.

The LDGST delegation unanimously agreed that our primary objective was accomplished and that potential collaboration with India exists in Land Science. The following summarizes the LDGST's accomplishments:

- The LDGST team received answers to all of the technical and operational questions concerning IRS-P6 and a copy of the questions is provided as attachment 1;
- ISRO agreed to provide science data (L0Rp and radiometric correction data) for the LDGST assessment;
- Mutual agreement, in principal, to investigate the logistics required for a test downlink of IRS-P6 data at USGS EROS;
- Mutual agreement, in principal, to investigate a potential joint field campaign with coordinated calibration test sites to enable analysis of simultaneous vicarious calibration of L-7 and IRS-P6 data.

The LDGST delegation agreed to accomplish several actions (please see Attachment 2: ISRO supplied meeting minutes with actions attached to this report) that included an action to provide ISRO with the locations of preferred vicarious calibration sites that the LDGST would like to have IRS-P6 Level-0 data and the action to the USGS to provide download data requirements to ISRO.

On Monday, June 19, 2006, the LDGST delegation completed its journey with a visit to the US Embassy in New Delhi. Embassy representatives included Mr. Don Brown, Ms. Connie Johnson (US science officers) and Commercial Specialist Mr. Yash Kansal. The US science officers explained the breadth of their mission and requested a brief on the team's experience and outcomes with ISRO. Following a detailed discussion of our TIM, the Embassy offered to facilitate any further meetings or discussions and requested that we inform them of any such events.

The visiting team ended the journey with lengthy flights back to the US that began very early Tuesday morning, June 20, and landed safely in Washington, DC, and Sioux Falls, South Dakota, later that afternoon, approximately 24 hours later. Additional information can be provided upon request.

USGS and NASA points of contact for this information are Mr. Greg Stensaas, stensaas@usgs.gov and Mr. Edward Grigsby, Edward.C.Grigsby@nasa.gov.

ISRO Meeting Notes and Actions

Minutes of Meeting			
Subject	NASA Team's visit to ANTRIX-ISRO on RESOURCESAT-1		
Date	June 13-14,2006		
Venue	ANTRIX conference Hall, Bangalore		
PARTICIPANTS			
	ANTRIX/ISRO	**NASA/USGS/USDA**	
	V.Jayaraman	Edwin Sheffner, NASA	
	Jacob Ninan	Edward C. Grigsby, NASA	
	Manjunath	Gregory L.Stensaas, USGS	
	KS Sharma	Elizabeth Williams, NASA	
	CVS Prakash	Gyanesh Chander, SAIC	
	Dr. KMM Rao	Bradley Doorn, USDA	
	K.R.Sridhara Murthi	James R.Iron, NASA	
	Joseph Arokiadas		
	P.J.Bhat		
	M.G.Rayakar		
Background	Landsat data gap study team (LDGST) comprising 12 US agencies are working …USGS and NASA co-chair the LDGST		
Minutes prepared by:	RLN Murthy	Minutes Approved by:	CVS Prakash

Record of Discussions

Sl. No.	Subject: NASA Team's visit to ANTRIX-ISRO on RESOURCESAT-1	Action & end Date
1.	Welcome and Introductions	-
2.	ED, Antrix Mr. Sridhara Murthi has welcomed the delegates and conveyed the greetings from Chairman, ISRO for a successful visit. He has lauded the role of LANDSAT in creating user awareness and making data available worldwide. ED has recollected the long term association and cooperation between US and India in the fields of satellites and remote sensing data. He further elaborated India's readiness to join US in the efforts to provide the Landsat data continuity. The Indian EO programme in the last five years, mainly the launch of RESOURCESAT-1 and CARTOSAT-1 to continue the services initiated a decade back in RS are briefed in addition to the plans for future including the Radar and Hyper spectral imaging.	
3.	Mr. Edward C. Grigsby has thanked ANTRIX/ISRO for arranging the meeting and the hospitality and introduced the team delegates from NASA, USGS and USDA	-
4.	Mr.James R.Iron has briefed the interest of the team in finding a suitable data for the study of Land cover change. Highlighted the important requirements looking for, like spatial resolution less than 100 m, radiometric calibration …, Geo location and capacity for global coverage. Most of the missions studied don't promise the data availability of any where, anytime.	-
5.	Mr. Edward Grigsby briefed the initiatives. Suggesting the implementation plan as the key responsibility of the team.	-
6.	Mr. Gregory L.Stensaas presented the highlights of Landsat 5 -7 missions and the operations. L5 surpassed original design life (3/87). Due to the problem in solar array, suspended imaging from L5 in November 2005. . L5 became operational now and providing data to intl' stations. Investigating the ways to optimize the future operations.L7- Looking for Gyro software for necessary modification for possible extension of mission operations beyond 2010. Explained the gap filling exercise and key applications of LS data. Original L7 requirement was about 250 scenes, after the scan line character failure the requirement increased to 300 scenes. (at USGS from Alaska, US, Australia and Sioux Falls, US) + 150 at IGS. US Govt's total data requirements exceed Landsat data availability.	USGS to provide to ISRO details of download data requirement
7.	Potential data gap requirement from RESOURCESAT-1	USGS to provide the figures
8.	Mr. K.S.Sarma has presented the Mission, operations and broad specifications of RS-1coevring the orbit profile, mission life, systematic global coverage, downlinks, TTC system, Spacecraft bus system, payload system,	-
9.	Mr. Chander has mentioned that some where it is reported that that there are spectral response gaps in L3/B5. ISRO requested Mr. Chander to forward the source of information about this.	Chander
10.	Dr. KMM Rao presented the data processing aspects of IRS	-
June 14,2006		
11.	Mr. Joseph Arokiadas presented the data dissemination details and proposed online ordering mechanism etc.	
12.	Dr. James Irons wanted to know more details of the Disaster support services. Mr. Joseph and Dr. Rajeev Lochan explained the international disaster Management Charter initiated by CNES and India's participation in the same.	
13.	Browse and meta data format details documentation required by USGS.	Joseph/KMM

Appendix AMinutes from TIM with INPE Oct 23-25, 2006

TO: The Record

FROM: Landsat Data Gap Study Team

SUBJECT: Landsat Data Gap Study Team Visit to INPE Sao Jose dos Campos and Sao Paulo, Brazil, October 23-26, 2006

Executive Summary

A delegation consisting of members of the Landsat Data Gap Study Team (LDGST) successfully completed a series of Technical Interchange Meetings (TIM) with representatives from the Instituto Nacional de Pesquisas Espaciais (INPE). The LDGST delegation consisted of members from NASA and USGS. The fundamental objective of this technical interchange was to collect detailed technical information on the salient performance characteristics of the China Brazil Earth Resources Satellite (CBERS) mission to help enable the LDGST's technical analysis of the complementarily and comparability of its land imaging data with Landsat-7 (L7) data.

The LDGST delegation was very warmly received and was treated in a professional and courteous manner throughout the interchange. INPE hosted our technical discussions at its Headquarters location in Sao Jose dos Campos. All of our discussions were open and at no time was any topic suppressed.

The LDGST delegation unanimously agreed that our primary objective was accomplished and that potential collaboration with Brazil exists in Land Science. The following summarizes the LDGST's accomplishments:

- The LDGST team received answers to all of the technical and operational questions concerning CBERS-2
- Mutual agreement, in principal, to investigate the logistics required for a test downlink of CBERS-2B data at USGS EROS;
- Mutual agreement, in principal, to investigate a potential joint field campaign with coordinated calibration test sites to enable analysis of simultaneous vicarious calibration of Landsat-5/7 and CBERS-2B data.
- USGS EROS will host INPE's absolute calibration scientist (Dr. Flavio Ponzoni) for a TIM to discuss about the best practices in area of calibration and validation.

On Thursday, Oct 26, 2006, the LDGST delegation completed its journey with a visit to the US Consulate in Sao Paulo. Following a detailed discussion of our TIM, the Consulate offered to facilitate any further meetings or discussions and requested that we inform them of any such events. A detailed report follows this executive summary.

Detailed Description of the LDGST-INPE Technical Interchange

The Landsat Data Gap Study Team (LDGST) visited the *Instituto Nacional de Pesquisas Espaciais* (INPE – National Institute for Space Research) in Brazil to obtain information on the characteristics and operation of the CBERS (China Brazil Earth Resources Satellite) Earth observing system. The information will be used by the team to evaluate the potential of data from CBERS to meet the US National Satellite Land Remote Sensing Data Archive (NSLRSDA) acquisition requirements during the impending gap in acquisitions from the Landsat satellites. The visit to INPE began on October 23 at the main facility of INPE in Sao Jose dos Campos and included a morning at the INPE facility at Cachoeira Paulista on October 25 and a visit to the US Consul in Sao Paulo on October 26, 2006.

The U.S. Geological Survey (USGS) of the Department of the Interior organized the trip. Present at the meetings from the US were:

Robert E. Doyle: Deputy Director, USGS HQ
Barbara J. Ryan: Associate Director for Geography, USGS HQ
Bruce K. Quirk: Chief Scientist, Remote Sensing Systems, USGS HQ
James Verdin: Project Manager: USGS EROS
Gregory L. Stensaas: Project Manager, USGS EROS
Kristi L. Kline: Landsat Project Manager, USGS EROS
Brian Davis: SAIC, USGS EROS
Gyanesh Chander: SAIC, USGS EROS
Edward C. Grigsby: Landsat Program Executive, NASA HQ
Michael G. Moore: Office of External Relations, NASA HQ
Edwin Sheffner: Program Element Manager, NASA HQ
James R. Irons: Landsat and LDCM Project Scientist, NASA/GSFC

Gilberto Camara, the General Director of INPE, led the Brazilian delegation. Other participants from Brazil were:

Ricardo Cartaxo: CBERS Program General Coordinator
Joao Vianei: Earth Observation Coordinator
Jose Carlos Epiphanio: CBERS Applications Segment Coordinator
Leila Maria Fonseca: CBERS radiometry and calibration
Flavio Ponzoni: CBERS absolute calibration
Jose Bacellar: Manager of the CBERS receiving station
Julio d'Alge: CBERS geometric corrections
Pawel Rozenfeld: Head of the CBERS Satellite Tracking Center
Jun Tominaga: CBERS satellite control
Amauri Montes: Engineering and technology coordinator
Mario Selingardi: CBERS WFI camera project manager
Frederico Liporace: CBERS image production system

Members of the Landsat Data Gap Study Team, with the addition of administrators from USGS, left for Brazil on October 21 and arrived at Sao Jose dos Campos mid-morning on Sunday, October 22. INPE provided transport for the team throughout the teams visit. The meetings with the INPE delegation began at 9:30 am on October 23 in the conference room adjacent to the office of the INPE Director General.

Dr. Camara opened the meeting noting the close association between the US and Brazil on Earth imaging from space for more than 30 years. He described the interest of INPE in space science and technology, applications and weather prediction and focused on the contacts between the US and Brazil over the last three years regarding the continuation of Landsat data acquisitions and the potential role of CBERS in US earth observations. He noted especially the successful test of a downlink of CBERS data at the USGS EROS facility in Sioux Falls. Camara acknowledged the purpose of this meeting was to evaluate CBERS as a potential gap filler for Landsat, but he hoped that effort would open the way for a more robust collaboration between the two countries in earth observations. Dr. Camara stressed that the data policy for CBERS in Brazil was identical with the data policy for Landsat – a policy which he characterized as unrestricted distribution of data at no charge.

Dr. Cartaxo followed with an overview of the CBERS program. The overview described the history and current status of the collaborative program with China and noted the assignment of responsibilities for the CBERS components and operations between the two countries. The primary goals of the CBERS program are to improve the technical and industrial capabilities of Brazil and China and provide a reliable source of earth observations for both countries. The CBERS program does not provide for technology transfer between the participants. Each country is responsible for specific subsystems but share system integration and testing. For CBERS 1, 2 and 2B, China is responsible for 70% of the system components; Brazil, 30%. On CBERS 3 and 4, the subsystem responsibilities will be evenly shared.

CBERS 1 and 2 included three instruments – High Resolution CCD Camera (HRCCD), Infrared Multi spectral Scanner (IRMMS), and the Wide-Field Imager (WFI). The HRCCD, built by China is the closest to ETM+ with VNIR and pan coverage at 20m resolution and a 120km swath. CBERS 2B, expected to launch in May 2007, will include a high resolution camera (HRC: 2.5m pan, 27km swath) instead of the IRMSS. The HRCCD and HRC are built by China, the WFI by Brazil. On CBERS 3 and 4, the HRCCD will be replaced by a Pan instrument (5m, 10m VNIR, 60 km swath) built by China, and a MUX instrument (20m VNIR, 120km swath) supplied by Brazil. CBERS 3 and 4 will also house an IRS (40m NIR, MIR; 80m TIR, 120km swath) from China and a WFI from Brazil (73m, VNIR, 890km swath). The program is designed to supply data continuously through 2015.

CBERS data are collected by direct downlink at one receiving station in Brazil and three stations in China. CBERS 2B, 3 and 4 will have on-board solid state recorders to collect data beyond the range of the primary receiving stations, but Brazil is considering establishing additional receiving stations in Central America and the Antarctic. Due to duty cycle limitations, practical collection of a global land data set from one or more of the CBERS satellites will require additional ground receiving stations.

The morning session concluded with a presentation by Camara on the new Brazilian Multi-mission Platform. This will be a follow on to CBERS and will be a Brazil only system of Earth observing satellites. Payload options include a WFI, mid resolution camera, lightweight SAR and GPM sensor. Camara noted that Brazil has offered the US an AWFI instrument (VNIR, 40m, and 800 km swath) as a second payload on the LDCM.

Following lunch, the US delegation presented a summary of its interests and update on the Landsat program. Barbara Ryan and Bob Doyle gave brief greetings and introductions. Greg Stensaas and Ed Grigsby described the Landsat Data Gap Study Team purpose and intentions. In summary, it was noted that the team is looking for a system that can supply visible near infrared (VNIR) and short wave infrared (SWIR) data at no less than 100m resolution with well characterized radiometric accuracy, geolocation accuracy of no less than 1 pixel and global coverage of land twice per year. Dr. Camara replied that CBERS could fill the data gap for South America and possibly Central America and would do so at no charge to the US following a US-Brazil agreement. He speculated that China would also supply data but that would require a separate agreement. The remainder of the afternoon focused on review of the answers supplied by Brazil to the questions submitted by the US on CBERS technical and operational characteristics. The session adjourned at 4:45pm with about 2/3 of the questions remaining to be reviewed the next day.

Tuesday, October 24:

The session convened at 9:30am. The morning session was chaired again by Gilberto Camara. Barbara Ryan gave a brief presentation summarizing the programmatic considerations of the US presented the previous day. She noted the following elements for sustainable collection and distribution of earth observations: clear roles and responsibilities between public and private sectors, a stable data policy and open standards. She also reviewed the legislation and policy directives driving the earth observation program in the US. Camara responded by noting his agreement with “every word” in Ryan’s presentation and his appreciation of the US policy toward high resolution data.

Jose Epiphanio followed with a presentation on CBERS 2B operations. Much of the presentation concerned the high resolution camera and how it would operate in conjunction with the HRCCD and WFI. He stressed that the HRC was an experimental instrument, and, while the system was designed to accommodate systematic coverage of Brazil and China with the HRC, such coverage required on-going orbital maneuvering of the platform, and it would be discontinued if the maneuvering threatened acquisition of HRCCD data. Nevertheless, there is the potential for limited acquisition of HRC data outside of Brazil and China if additional ground stations are in place to receive it.

Camara finished the morning session with a presentation and discussion on CBERS data policy. The primary message from the data policy is that CBERS is considered a "public good" by Brazil and China and that data from it will be distributed at no charge. There will be a charge assessed to ground stations for data acquisition on a model similar to that for receiving Landsat data.

After lunch Jim Verdin described the International Charter on Space and Major Disasters. The charter is an agreement among space agencies to facilitate data acquisition in event of emergencies caused by natural disasters. ESA and CNES inaugurated the charter and began operations in 2000. Current participants are CONAE, ISRO, CSA, ESA, CNES, NOAA, JAXA, USGS, and DMC. Verdin made the presentation to stimulate INPE to become a participant. Camara responded with enthusiasm and asked for a clarification on how to commit INPE to the charter (a letter to the charter board is all that is required).

The afternoon session ended with concurrent events – Dr. Camara, B. Ryan, R. Doyle and E. Grigsby met separately in Camara's office to discuss data policy issues and the contents of a press release (and press conference) on the meeting. The other participants remained to finish reviewing the technical and operational questions. Some of the operational questions were deferred to the following day and the session at the INPE data center.

The conclusion of the question review left the following impressions:

1) Currently, CBERS data are available only for areas within the coverage circles of the three ground stations.
2) Although collection of a global data set with CBERS 2B and future systems may be technically possible, questions remain about the operational characteristics of the system and the radiometric and geometric characteristics of the data. These uncertainties are unlikely to be resolved because much of the information is held by the Chinese and has not been distributed.
3) INPE graciously offered to supply CBERS data of South and Central America to the US archive at no cost pending an agreement with the US. Although such data will likely meet some user requirements they do not meet the specifications for US archive data (e.g., no MIR band), and the lack of complete characterization of the data limits significantly their use for science and many applications.

Wednesday, October 25:

INPE transported the US team to the INPE Data Center in Cachoeira Paulista, about one hour from Sao Jose dos Campos. Flavio Reis and Denise Azevedo welcomed the team to the Data Center and provided a tour of the facility. Following the tour, presentations were given on the operations of the center. Dr. Epiphanio described the users of CBERS data and reviewed several of the applications. He noted that it is difficult to find organizations in Brazil who do not make use of the data, although statistics on data acquisition and applications and the impact of the data on users is hard to come by. Information on the impact of CBERS data remains mostly anecdotal. Nevertheless, the Brazilian government is convinced of the utility and economic viability of earth observations and is committed to continuing the Brazilian earth observation program.

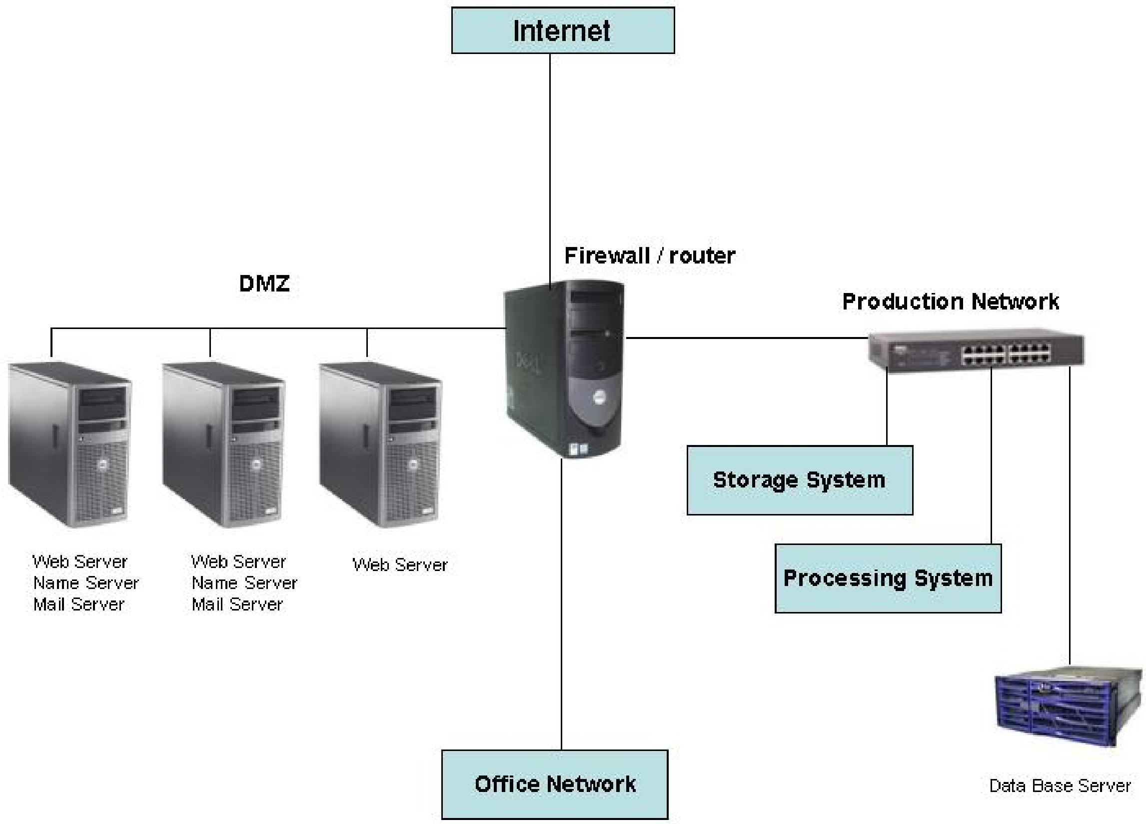
The meeting at the data center concluded about 12:30pm. INPE transported the team back to lunch, then back to the hotel at Sao Jose dos Campos to subsequently to Sao Paulo. The transfer to Sao Paulo was made to accommodate a meeting of the team at the American Consulate in Sao Paulo the following day. On October 26, a sunset of the US delegation met at the consul's office for a debriefing on the meetings with INPE.

All members of the team departed Brazil by the evening of October 26. The NASA representatives arrived in Washington DC the morning of October 27, 2006.

End

INPE Computer Network Configuration of INPE Remote Sensing Data Center

The computer network of Remote Sensing Data Center is shown on Figure 1.



We have three networks:

- Demilitarized Zone – DMZ
- Production Network
- Office Network

The computer that connects those networks is an Open Source solution. It has OpenBsd 4.0 and acts as a firewall (packet filter) and router. The configuration is shown below.

System manufacturer	Dell
Model number	PowerEdge 850
CPU	Pentium D 3.0 GHz Dual Core
Memory	2 GB
Disk	80 GB SATA
Network Card	6
Operational System	OpenBSD 4.0
Observation	Packet Filter Firewall. This host uses CARP protocol to provide high availability. The kernel was modified to improve security.

Demilitarized Zone – DMZ

DMZ is a network area that sits between an organization's internal network and an external network, usually the Internet.

On DMZ we have two computers IBM compatible that runs:

- Web server
- Name Server
- Mail Server

The third computer runs Apache Web Server and it is used by users to download products. The tables below show the DMZ hosts configuration.

System manufacturer	Dell
Model number	PowerEdge 1600 SC
CPU	Pentium IV 2.4 GHz Single Core
Memory	512 MB
Disk	40 GB
Network Card	1 interface
Operational System	FreeBSD
Mail Server	Postfix
Web Server	Apache
DNS Server - Primary	BIND
Observation	For Web Server we use Round Robin DNS. The kernel was modified to improve security.

System manufacturer	Dell
Model number	PowerEdge 1600 SC
CPU	Pentium IV 2.4 GHz Single Core
Memory	512 MB
Disk	40 GB
Network Card	1 interface
Operational System	FreeBSD 5.0
Mail Server	Postfix
Web Server	Apache
DNS Server - Secondary	BIND
Observation	For Web Server we use Round Robin DNS. The kernel was modified to improve security.

System manufacturer	Dell
Model number	PowerEdge 1500 SC
CPU	2 x Pentium III 1.2 GHz
Memory	2 GB
Disk	2x 146 GB SCSI
Network Card	1 interface
Operational System	FreeBSD
Web Server	Apache
Observation	User, to download products, uses this host to download products and they use HTTP Protocol instead of FTP protocol. The kernel was modified to improve security.

Production Network

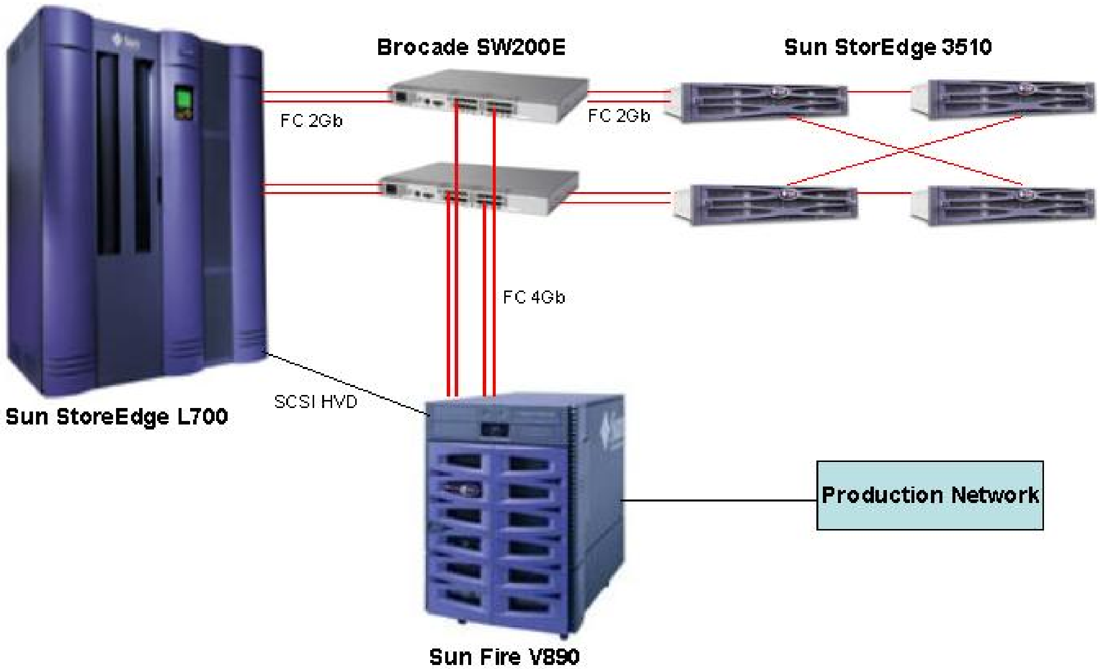
The Production Network is composed by:

- Storage System
- Data Base Server
- Processing System

A Storage Area Network (SAN) composes the storage system and it is shown on Figure 2.

Storage System

Storage Area Network - SAN



The tables below show the Storage hosts configuration.

System manufacturer	Sun Microsystems
Model number	Sun Fire V890
CPU	8x 1.5 GHz SPARC IV+ - Dual Core
Memory	32 GB
Disk	4x 146GB SCSI
Network Card	Six Gigabit Ethernet ports
Operational System	Solaris 10 06/06
HSM	SAMFS 4.5

System manufacturer	StorageTek (Tape Library)
Model number	StorEdge L700
Number of Cartridges	700
Number of used cartridges	400 LTO3 and 215 LTO2
Cartridge Type	LTO 3 – 400/800 GB
Cartridge Type	LTO 2 – 200/400 GB
Total Capacity	205 TB
Observation:	Cartridges LTO 2 is Read Only

System manufacturer	Sun Microsystems
Model number	Sun StorEdge 3510 FC Array
Number of disk	12x 300 Fibre Channel
Total Capacity	2.565 GB
File System	/TIFF

System manufacturer	Sun Microsystems
Model number	Sun StorEdge 3510 FC Array
Number of disk	12x 146 Fibre Channel
Total Capacity	1.278 GB
File System	/DRD

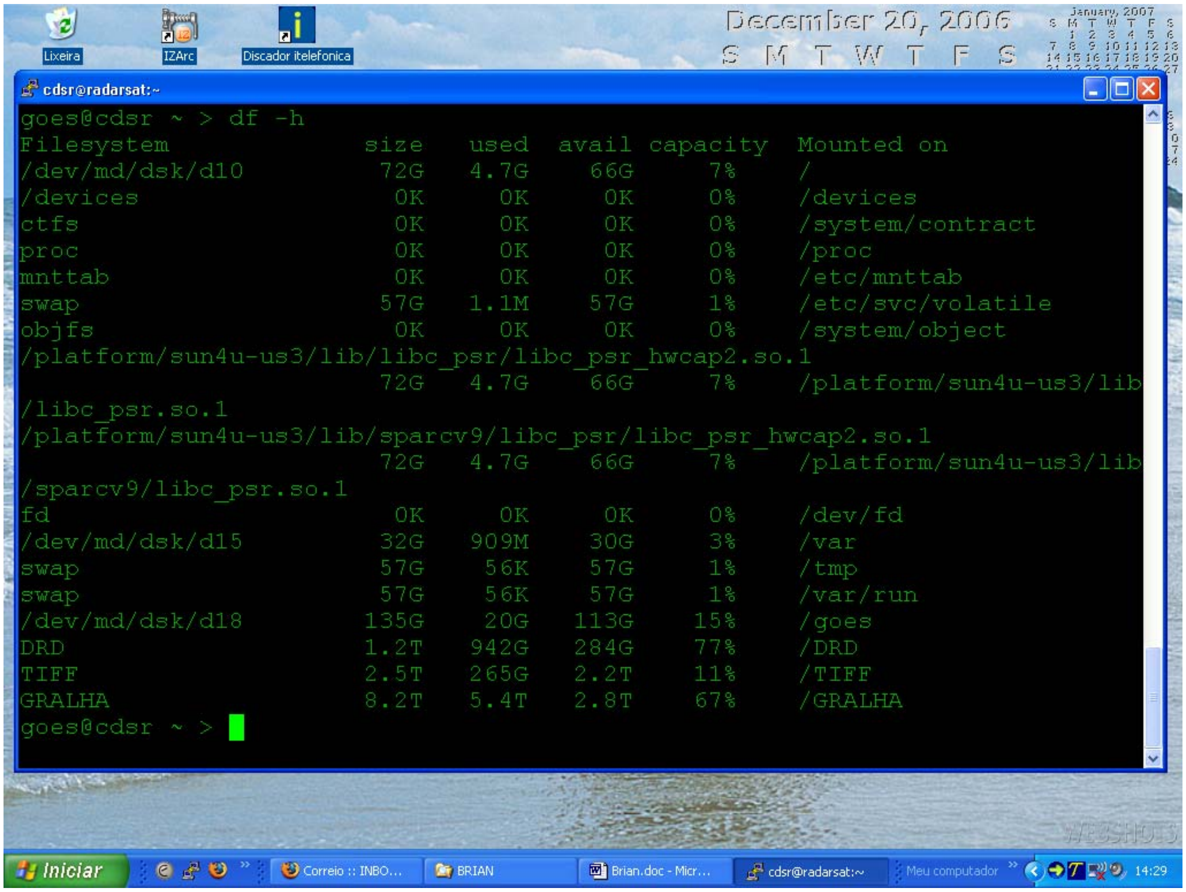
System manufacturer	Sun Microsystems
Model number	Sun StorEdge 3511 Array - JBOD
Number of disk	12x 500 SATA
Total Capacity	8.700 GB
File System	/GRALHA - Concatenation

System manufacturer	Sun Microsystems
Model number	Sun StorEdge 3511 Array - JBOD
Number of disk	12x 500 SATA
Total Capacity	8.700 GB
File System	/GRALHA - Concatenation

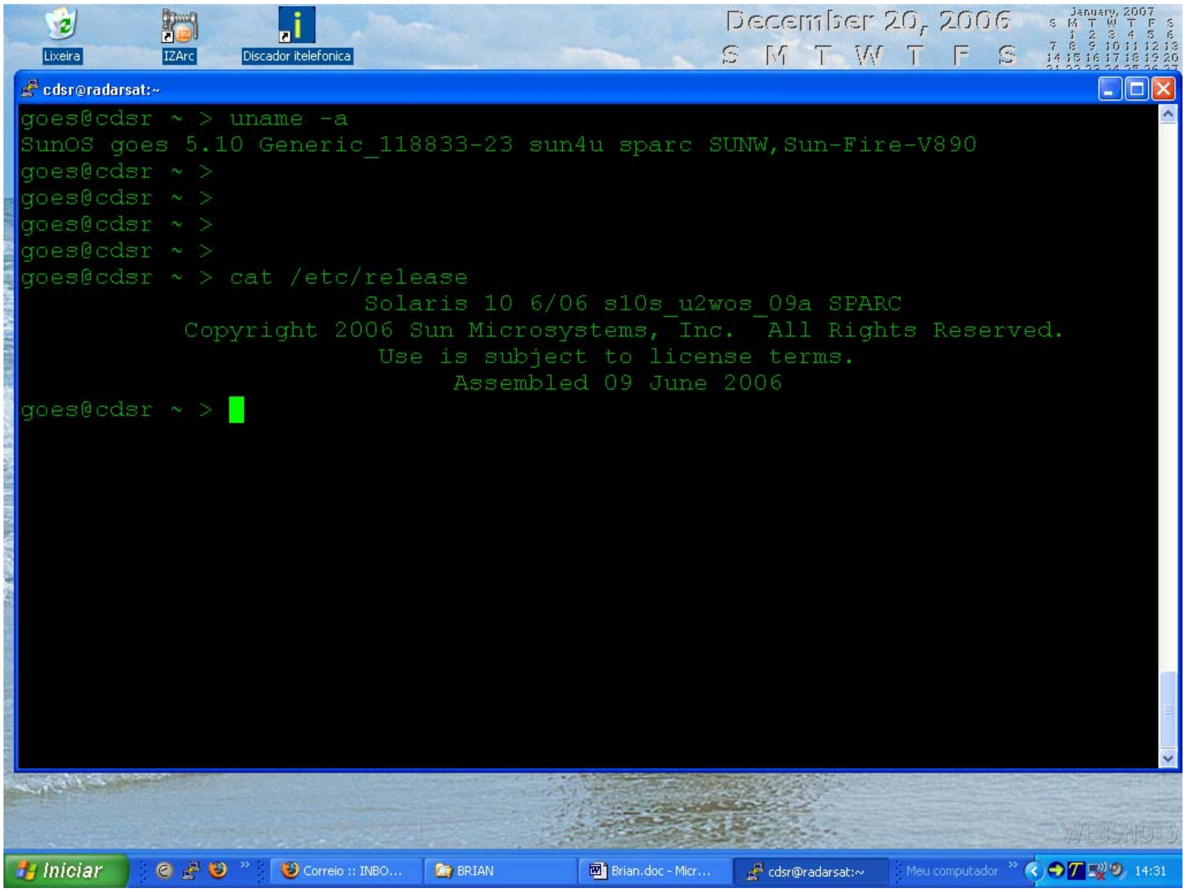
System manufacturer	Brocade
Model number	SW200E
Function	Storage Area Network - SAN

System manufacturer	Brocade
Model number	SW200E
Function	Storage Area Network - SAN

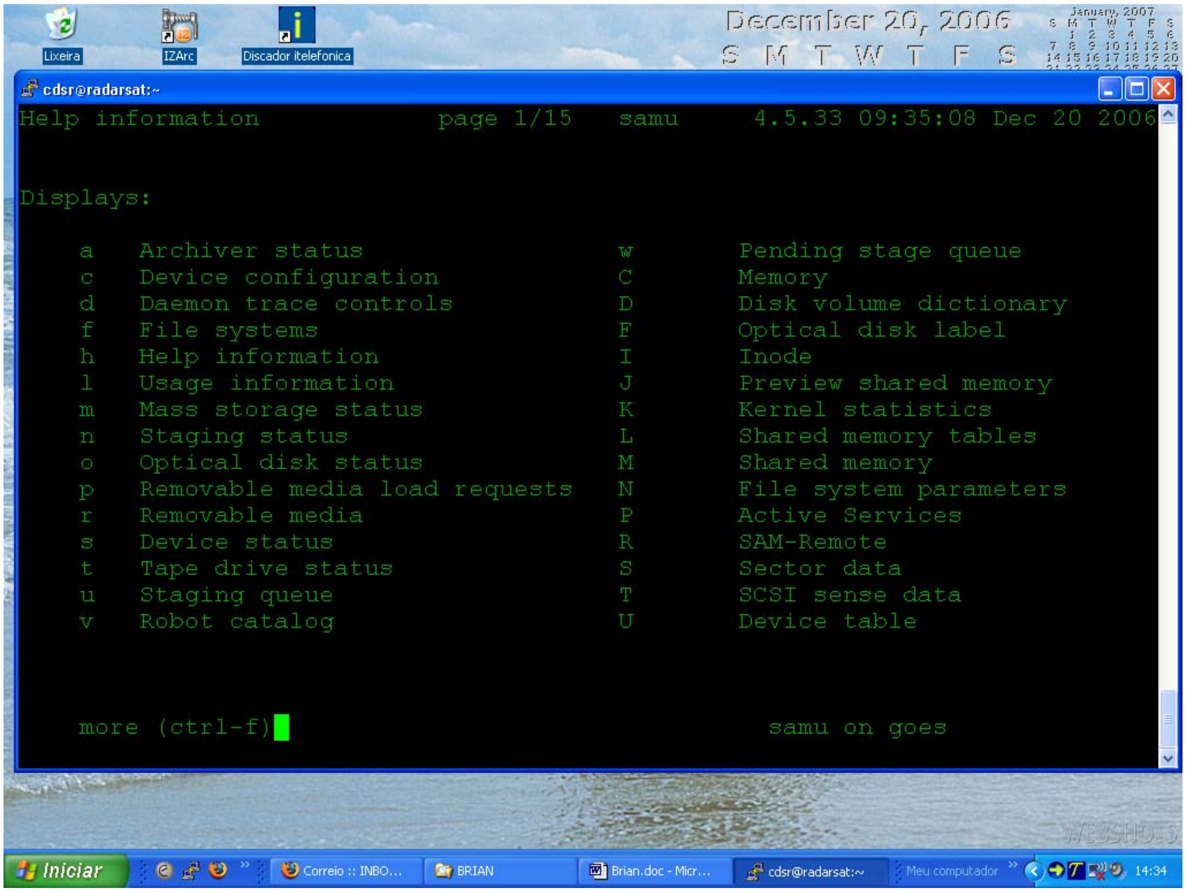
The Sun Fire V890 filesystem are shown on Figure 3.



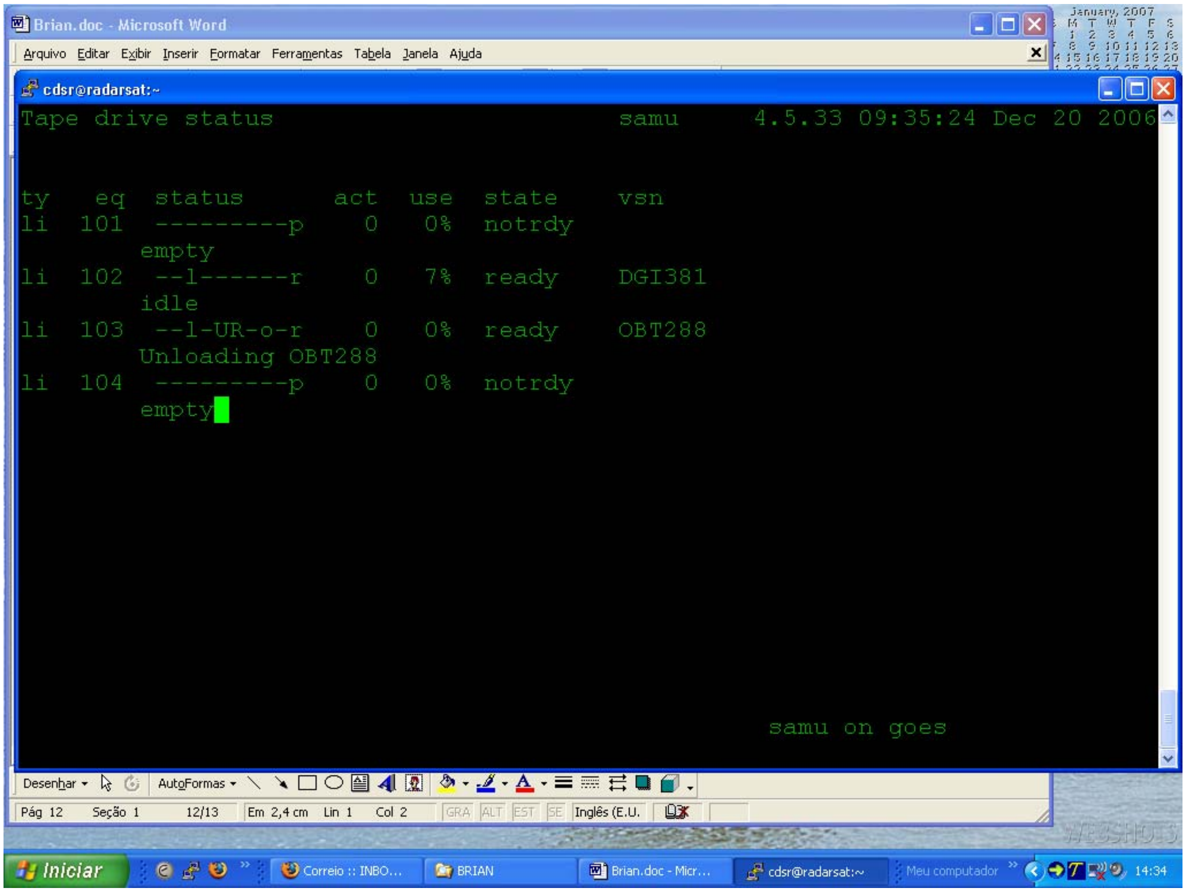
The Sun Fire V890 Operational System version is shown on Figure 4.



The Sun Fire V890 SAMFS Utility (samu) is shown on Figure 5. SAM-FS is a SUN´s solution to HSM - Hierarchical Storage Management.



The samu -Tape Drive Status - is shown on Figure 6.

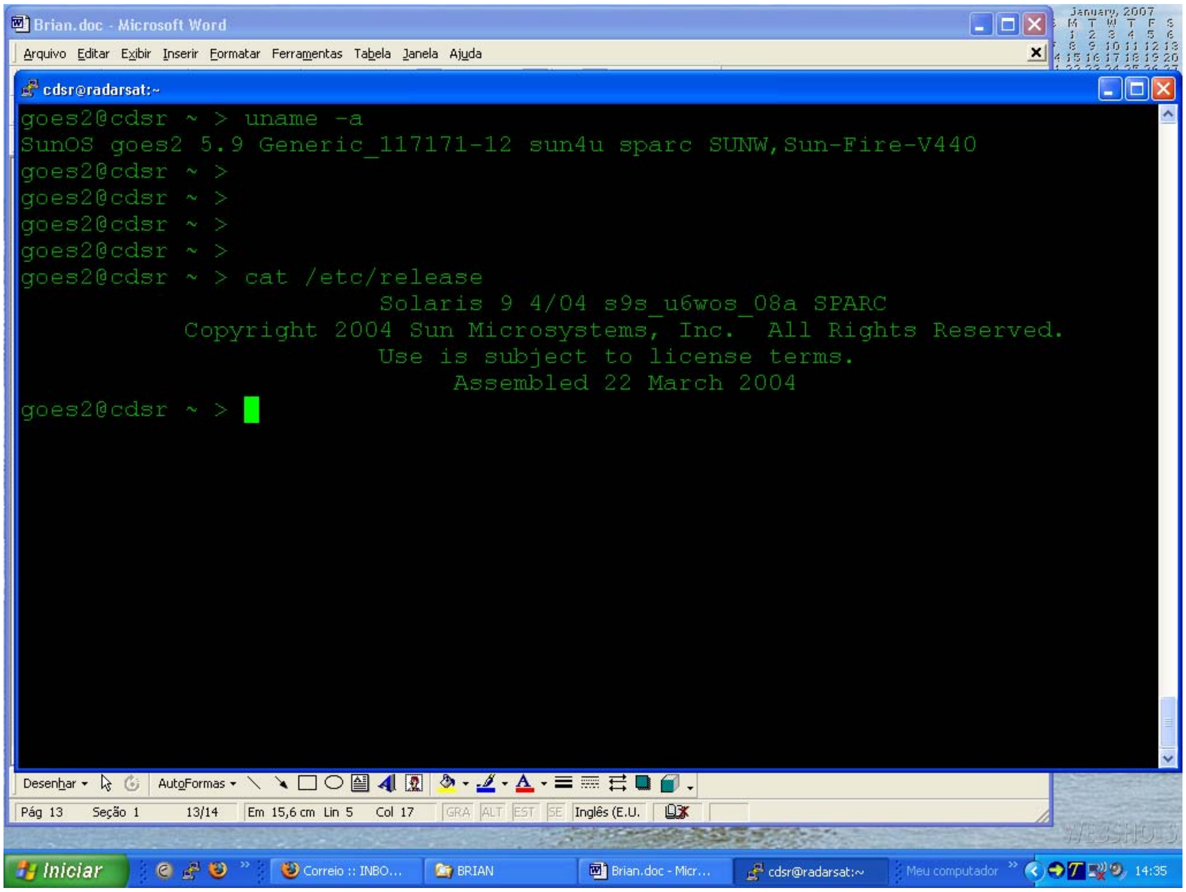


Data Base Server

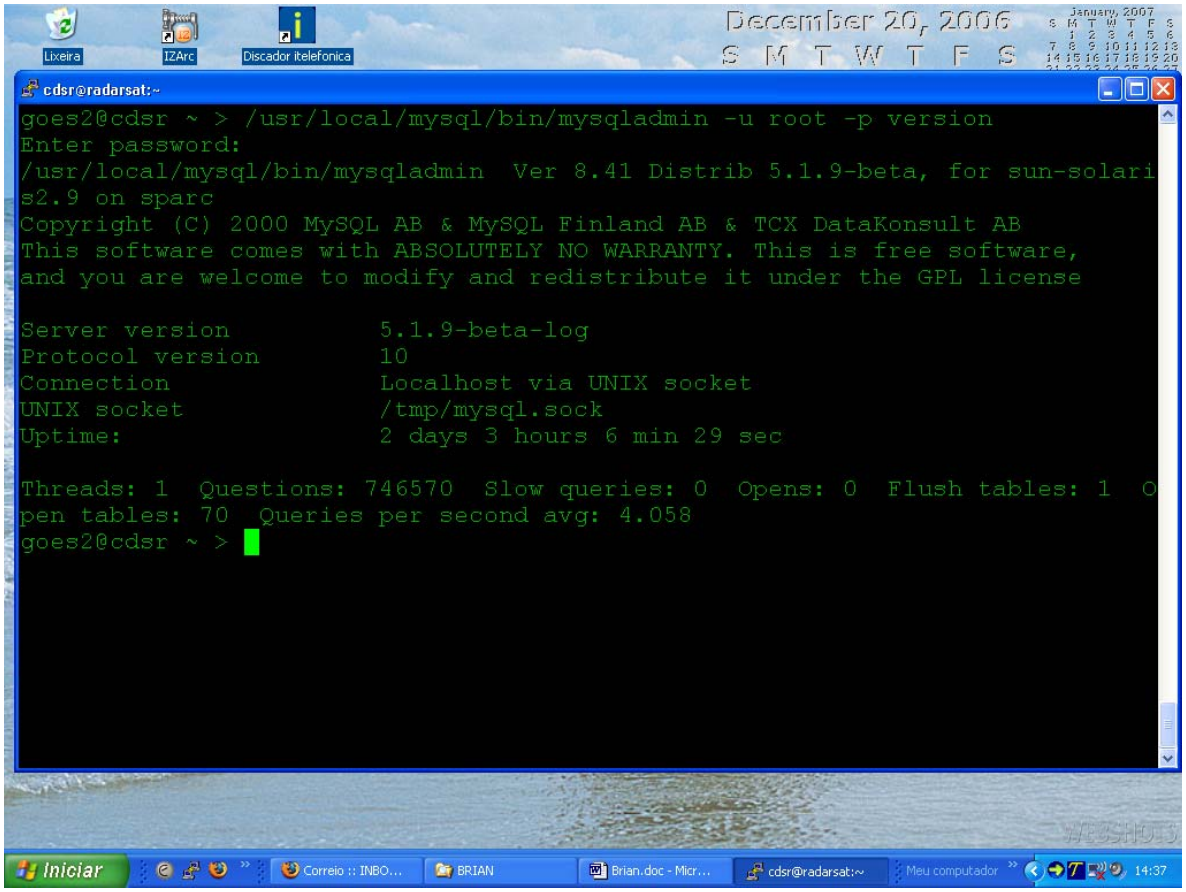
Data Base Server runs MySql Server with configuration below.

System manufacturer	Sun Microsystems
Model number	SUN Fire V440
CPU	4x 1.062 GHz SPARC III – Single Core
Memory	8 GB
Disk	4x 36GB SCSI
Network Card	Six Gigabit Ethernet ports
Operational System	Solaris 09
Data Base Server	MySql

The Sun Fire V440 Operational System version is shown on Figure 7.



The Sun Fire V440 Mysql Server version is shown on Figure 8.



Processing System

The Processing System is composed by:

1 Sun Ultra20 Workstation;
1 Sun Fire X2100;
12 IBM PC compatible.

Those hosts run multi satellite station processing and need four file systems on network exported through NFS. Those file systems are:

/DRD – keeps Dated Row Data files and it has 1.2 TB
/GRALHA – keeps Generic Raw Level Hierarchical Archive and it has 8.5 TB;
/TIFF – keeps TIFF files and it has 3.2 TB
/producao – keeps DGI´s Intranet that has software used to manage production.

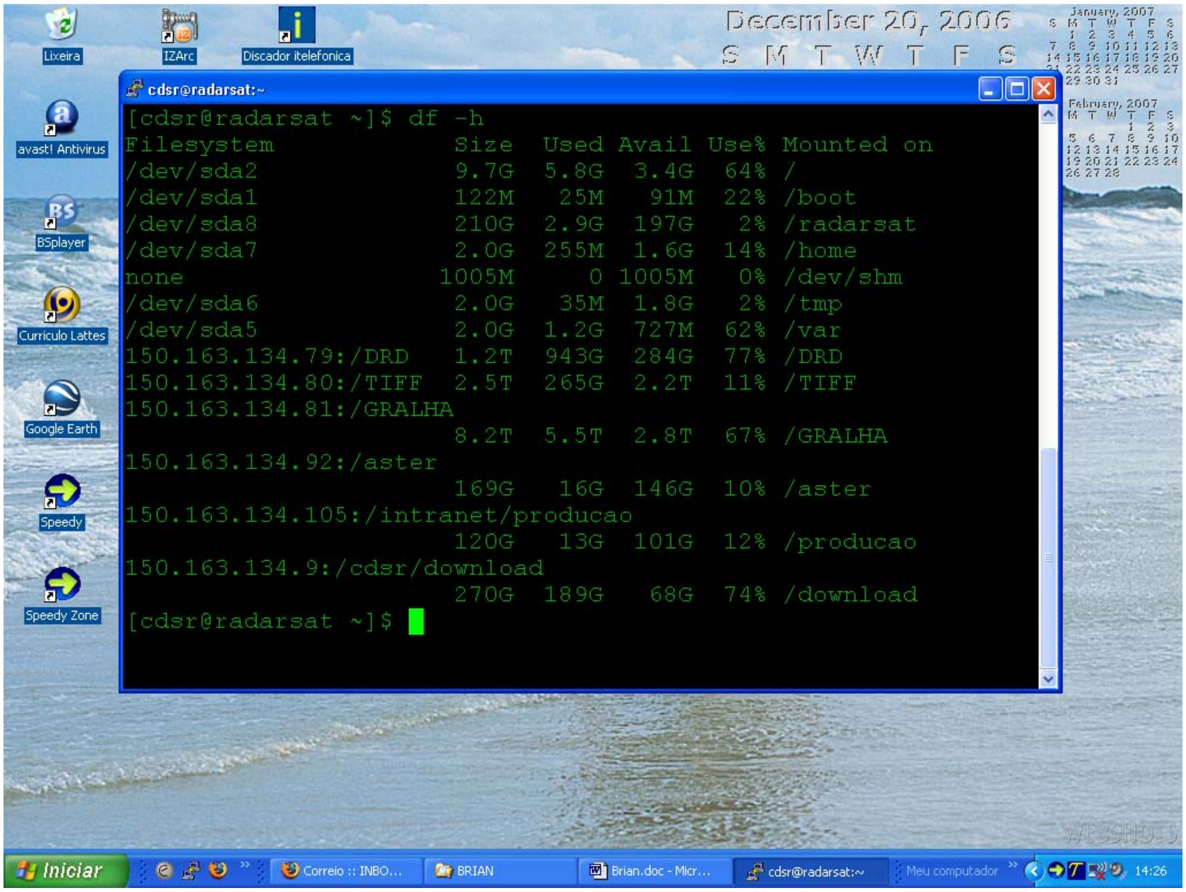
The tables below show the Processing System hosts configuration.

System manufacturer	Sun Microsystems
Model number	Ultra20 Workstation
CPU	AMD Opteron 2.4GHz Dual Core
Memory	2 GB
Disk	1x 250 GB
Network Card	One Gigabit Ethernet port
Operational System	CentOS 3.8

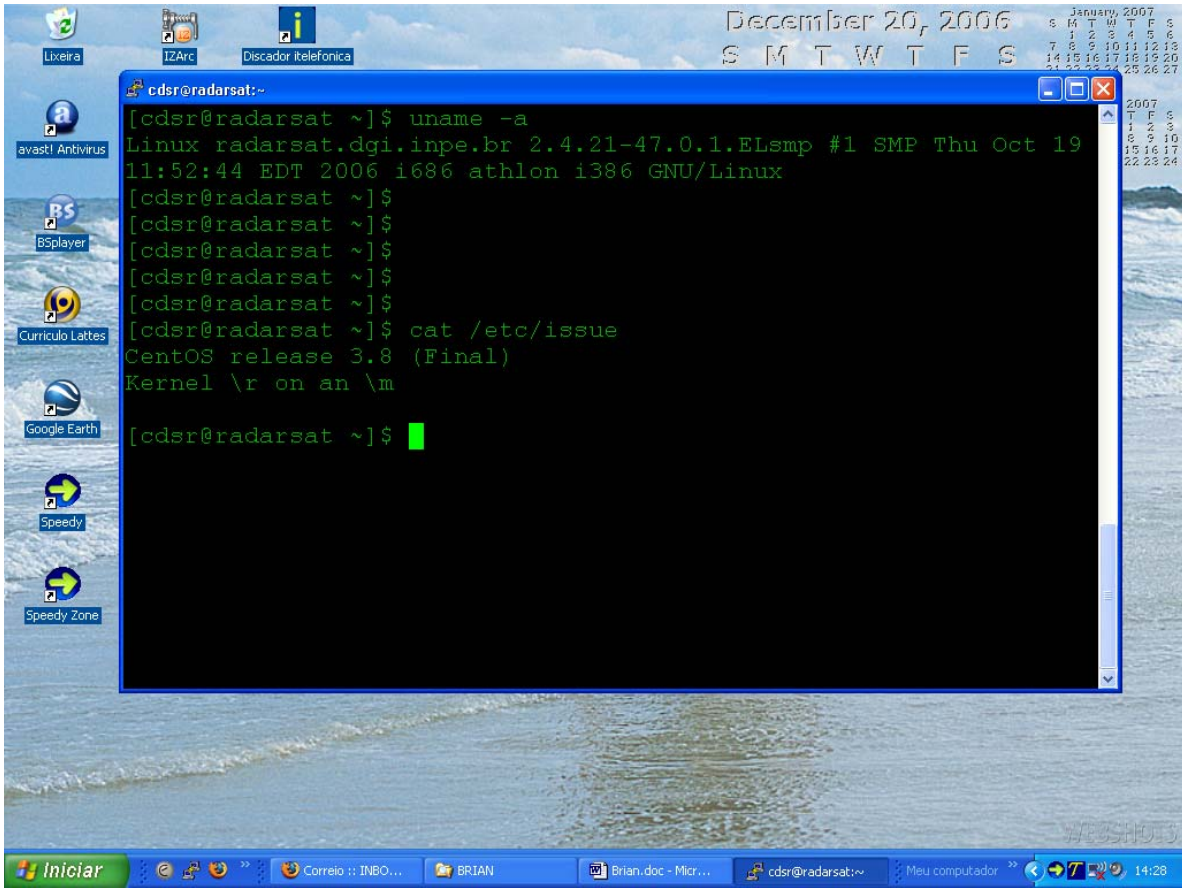
System manufacturer	Sun Microsystems
Model number	Sun Fire X2100
CPU	AMD Opteron 2.4GHz Dual Core
Memory	1 GB
Disk	1x 250 GB
Network Card	Two Gigabit Ethernet ports
Operational System	CentOS 3.8

System manufacturer	Dell
CPU	Pentium IV 2.4 GHz Single Core
Memory	1 GB
Disk	1x 200 GB
Network Card	One Gigabit Ethernet port
Operational System	CentOS 3.8

The File systems exported through NFS to processing System are shown on Figure 9.



The Operational System version and Linux Distribution version are shown on Figure 10.



INPE processes CBERS 2, Landsat 1, Landsat 2 and Landsat 3; nevertheless we are planning to process on this system Landsat 5, Landsat 7, Aqua (EOS PM-1) and Terra (EOS AM-1). Next February, the OBT IT team is going to connect a VPN between Remote Sensing Data Center and Cuiabá Ground Station that will be used to transfer DRD and other kinds of data from Cuiabá to Remote Sensing Data Center. Remote Sensing Data Center has almost 80% of Open Source software. (Linux, OpenBsd, FreeBSD, Mysql, Apache, BIND, Postfix, MRTG, OpenVPN and Squid).

Appendix B IRS-P6 Characterization

USGS EROS Radiometric Characterization

The Indian Remote Sensing Satellite (IRS-P6), also called ResourceSat-1 was launched in a polar Sun-synchronous orbit on Oct 17, 2003. It carries three sensors: the high resolution Linear Imaging Self-Scanner (LISS-IV), the medium resolution Linear Imaging Self-Scanner (LISS-III), and the Advanced Wide Field Sensor (AWiFS). These three sensors provide images of different resolutions 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 images from the Landsat 5 (L5) Thematic Mapper (TM) and Landsat 7 (L7) Enhanced Thematic Mapper Plus (ETM+) sensors. The approach involves calibration of surface observations based on image statistics from areas observed nearly simultaneously by the two sensors. This paper also evaluated the viability of data from these next-generation imagers for use in creating three National Land Cover Dataset (NLCD) products: Land Cover, Percent Tree Canopy, and Percent Impervious Surface. Individual products were consistent with previous studies but had slightly lower overall accuracies compared to data from the Landsat sensors.

I. DATA SETS AND TEST SITE EVALUATIONS

This section summarizes the data sets used for the evaluation.

A. Sun-synchronous Orbits

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 Sunlit side of the Earth and ascending passes are on the dark side of the orbit) is between 9:30 and 10:00 a.m. local time for all Landsat missions. 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-2 (WRS-2).

The IRS-P6 satellite operates in a circular, Sun-synchronous, near-polar orbit with an inclination of 98.69 degrees, 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.

B. Test Site Descriptions

Due to the limited number of co-incident image pairs between these sensors, the scene selection for these studies proved to be a challenge. 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.

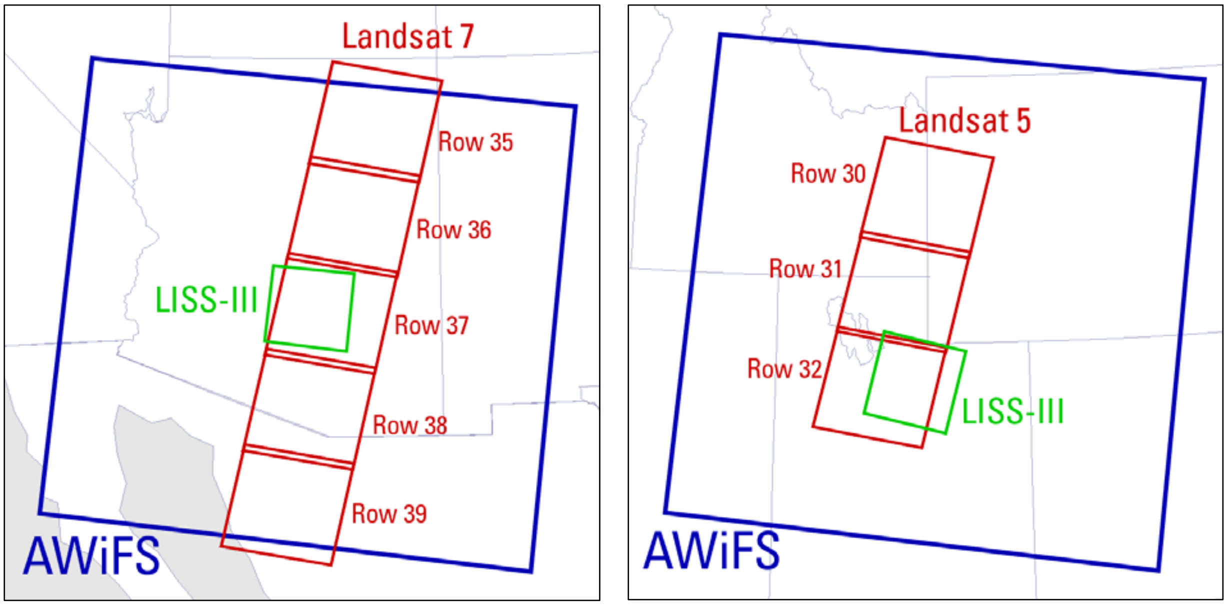
1) Mesa, AZ: A cloud-free L7 scene was acquired on June 29, 2005. About 30 minutes later, an IRS-P6 AWiFS and LISS-III scene covering part of the same footprint were acquired. Because of the scan-gap issue, the prior and post scenes (June 13 and July 15) were also obtained, making a completed L7-based data set for the NCLD validation. The Mesa, AZ is a desert site without much vegetation, and aerosol loading is typically low. The L7 ETM+ scenes are referenced in the WRS-2 with path 36 and rows 35-39.

Table I: Coincident IRS-P6 & Landsat scenes used for this study

Instrument	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 °

2) Salt Lake City, UT: A cloud-free L5 TM scene was acquired on June 19, 2005. About 30 minutes later, an IRS-P6 AWiFS and LISS-III scene of the same region was acquired. The L5 TM scenes are referenced in the WRS-2 system with path 38 and rows 30-32.

In both test sites, the area common to all images was evaluated for each available image source, in terms of its ability to duplicate existing NLCD products. Table I lists the scenes selected for the study, along with the scene ID number, location, path, row, the date and time of acquisition, and the Sun elevation angle for the scenes. Fig. 1 shows the approximate image boundaries of the scenes used.



C. Data Processing System

Orthorectified scenes were used for the NLCD 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)

A. Conversion to Reflectance

The sensors do not measure radiances directly, but rather 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 (DN). 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-aperture radiance. This radiance is then converted to TOA reflectance by normalizing for solar elevation and solar spectral irradiance. Table II summarizes the Solar Exoatmospheric Spectral Irradiances (ESUN) values.

Table II: Solar Exoatmospheric Spectral Irradiances (ESUN) values using CHKUR MODTRAN 4.0 spectrum. (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

To maintain consistency with the ETM+, this paper uses spectral radiance units of W/m^2 sr µm. Note that the conversion factor is 1:10 when going from mW/cm^2 sr µm units to W/m^2 sr µm.

II. CALIBRATION BY NEAR-SIMULTANEOUS SURFACE OBSERVATIONS

Data continuity requires consistency in interpretation of image data acquired by different imaging sensors. This section provides the comparisons of the reflectance measurements obtained from the L7 ETM+, L5 TM, and IRS-P6 AWiFS, LISS-III sensors.

Cross-calibration was performed with image statistics based on large common areas observed near-simultaneously by the two sensors. Because the image acquisitions occurred within a few minutes, it was assumed that the surface and atmospheric conditions did not change during that time. A more detailed treatment of the calibration methodology is provided in [5], and [6].

A. Region of Interest

The L7, L5, and IRS-P6 sensors differ in their along-track and across-track pixel sampling. A feature simultaneously observed by these sensors is 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 common in 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 (ROI) were defined within these areas for each image triplet (L5 or L7, AWiFS, and LISS 3). 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 TOA reflectance. These reflectance values were then plotted for each instrument pair, and a linear fit calculated, giving a relative gain and bias between each instrument pair.

B. Cross-Calibration Accuracy of L7 ETM+ with IRS-P6 AWiFS and LISS-III Sensors

Fig. 2 and 3 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 1:1 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 III.

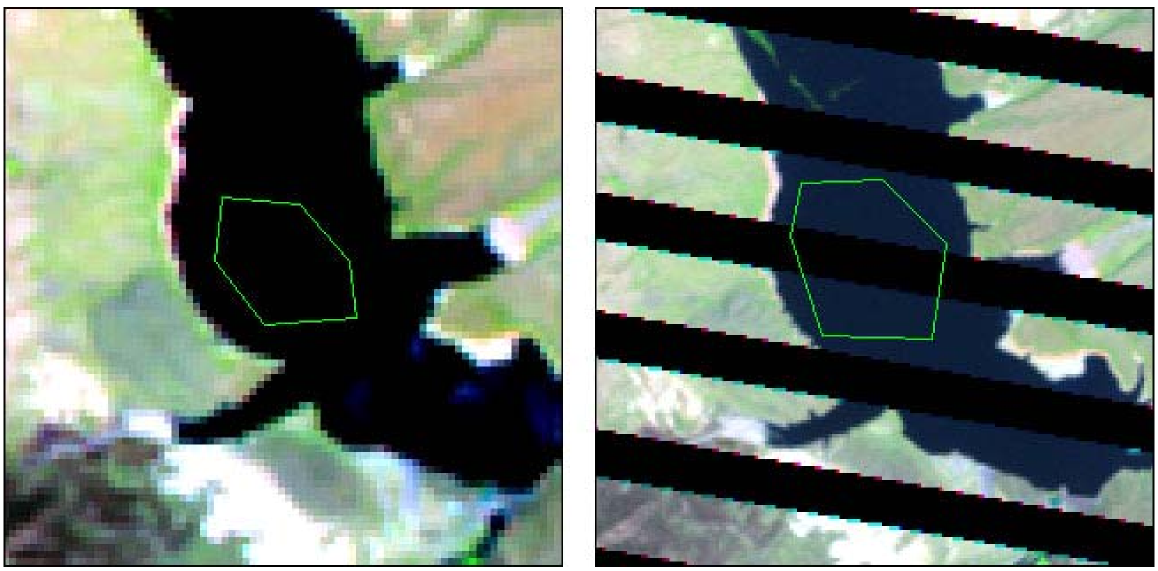


Fig. 2. Paired homogenous regions of interest.

Data from Mesa, AZ collection, with AWiFS (left) and Landsat 7 ETM+ (right)

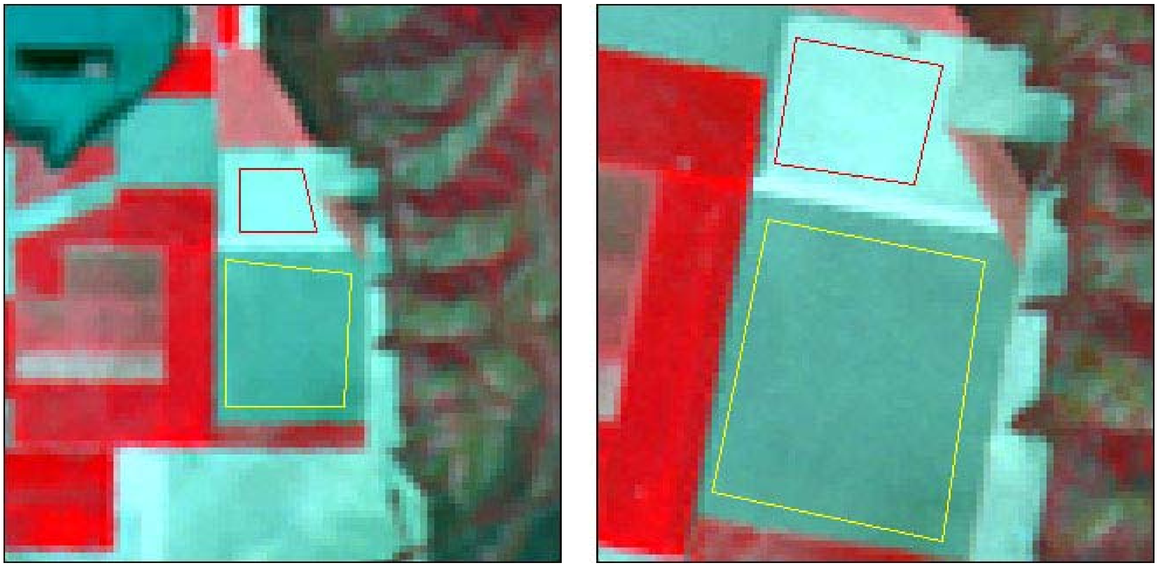


Fig. 3. Paired homogenous regions of interest.

Data from SLC, UT collection, with AWiFS (left) and Landsat 5 TM (right)

Table III: Cross-calibration results for the Mesa, AZ collection

AWiFS vs. ETM+ Reflectance					
Band	Gain	□ (gain)	Bias	□ (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 vs. ETM+ Reflectance					
Band	Gain	□ (gain)	Bias	□ (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

C. Cross-Calibration Accuracy of L5 TM with IRS-P6 AWiFS and LISS-III Sensors

Fig. 11 and 12 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 1:1 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 IV.

Table IV: Cross-calibration results for the Salt Lake City, UT collection

AWiFS vs. TM Reflectance					
Band	Gain	□ (gain)	Bias	□ (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 vs. TM Reflectance					
Band	Gain	□ (gain)	Bias	□ (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

D. Cross-Calibration Verification of AWiFS and LISS-III Sensors

As a check on the consistency of the satellite calibrations and the methodology used, a cross- calibration was calculated between the AWiFS and LISS-III sensors. Fig. 13 and 14 show the cross-calibration plots comparing AWiFS reflectances to LISS-III reflectances. A least-square fit has been made to the data in each band, and the expected 1:1 reflectance line is also plotted for reference. Linear fits to the reflectance measurement pairs give the cross-calibration gain and biases presented in Table V.

Table V: Cross-calibration results between the IRS-P6 sensors

AWiFS vs. LISS-III Reflectance – Mesa, AZ					
Band	Gain	□ (gain)	Bias	□ (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 vs. LISS-III Reflectance – SLC, UT					
Band	Gain	□ (gain)	Bias	□ (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

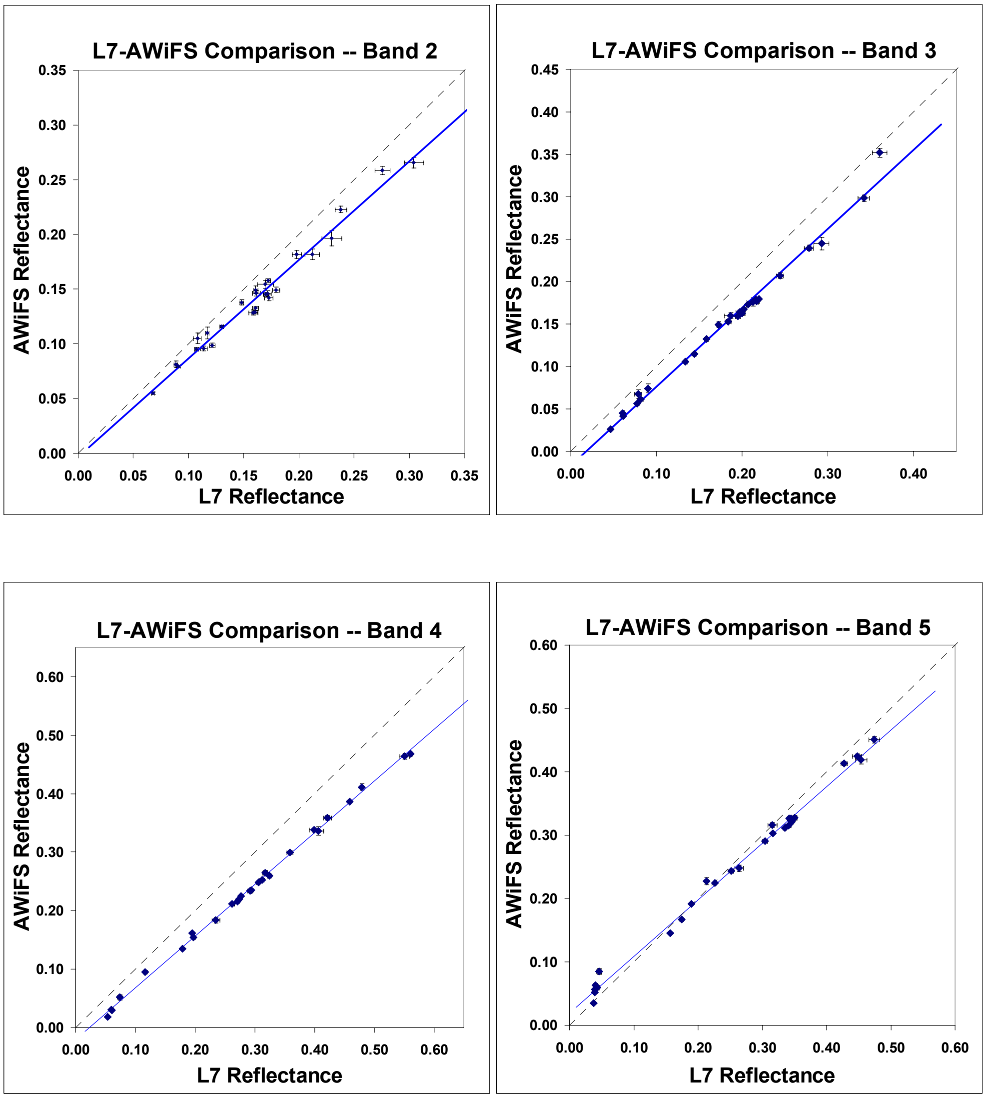


Fig. 9. Reflectance of homogenous regions viewed by the ETM+ plotted against the same regions viewed by AWiFS. Error bars indicate the standard deviation of the regions of interest

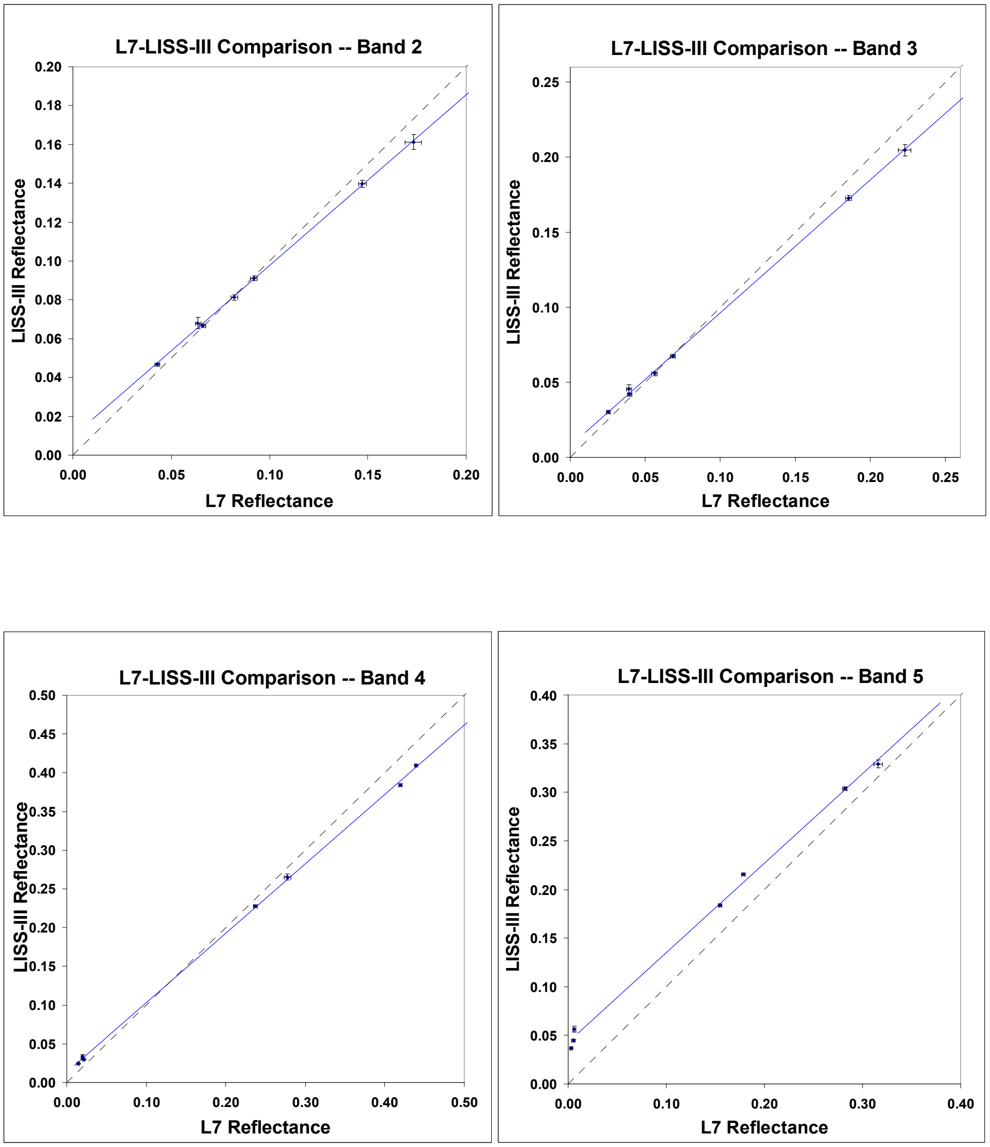


Fig. 10. Reflectance of homogenous regions viewed by the ETM+ plotted against the same regions viewed by LISS-III. Error bars indicate the standard deviation of the regions of interest

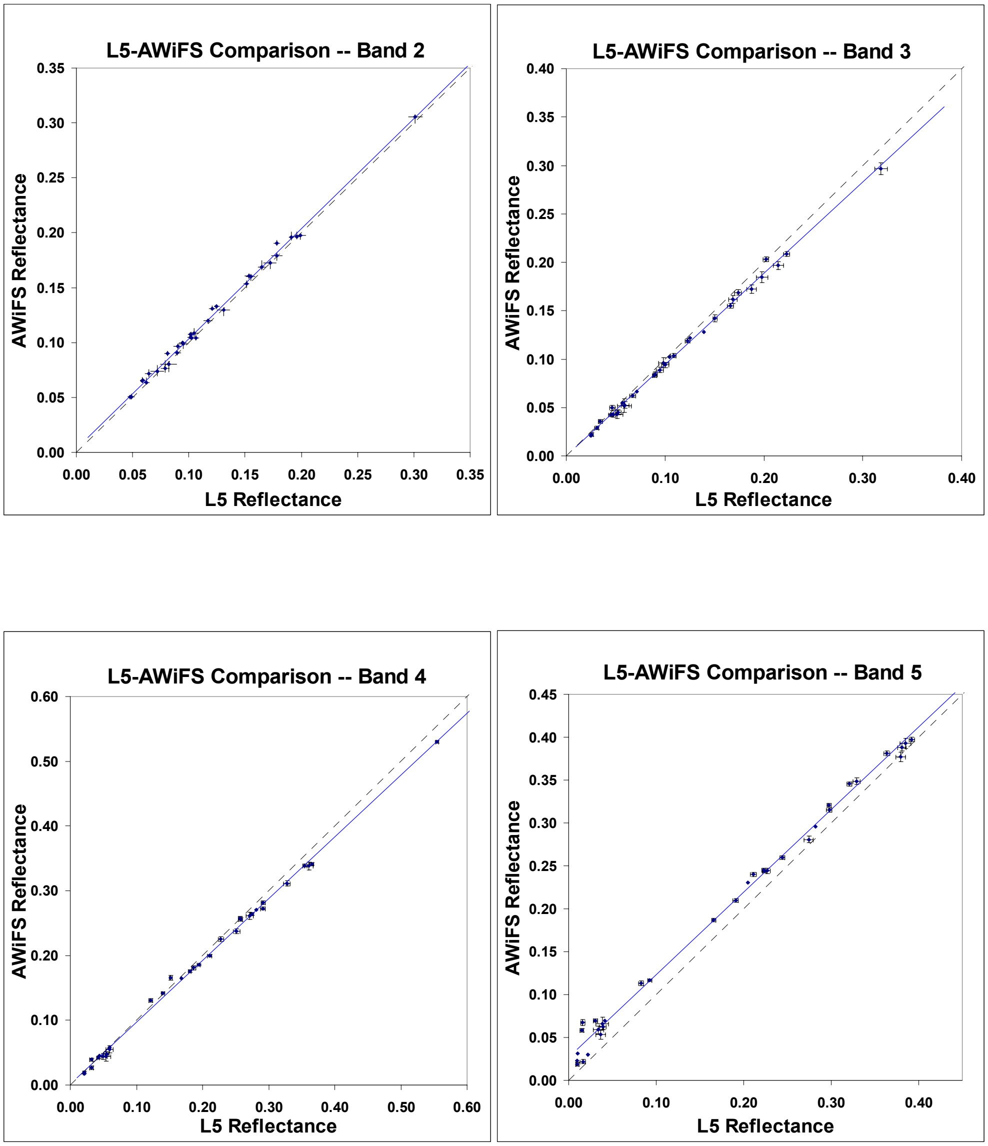


Fig. 11. Reflectance of homogenous regions viewed by the TM plotted against the same regions viewed by AWiFS. Error bars indicate the standard deviation of the regions of interest

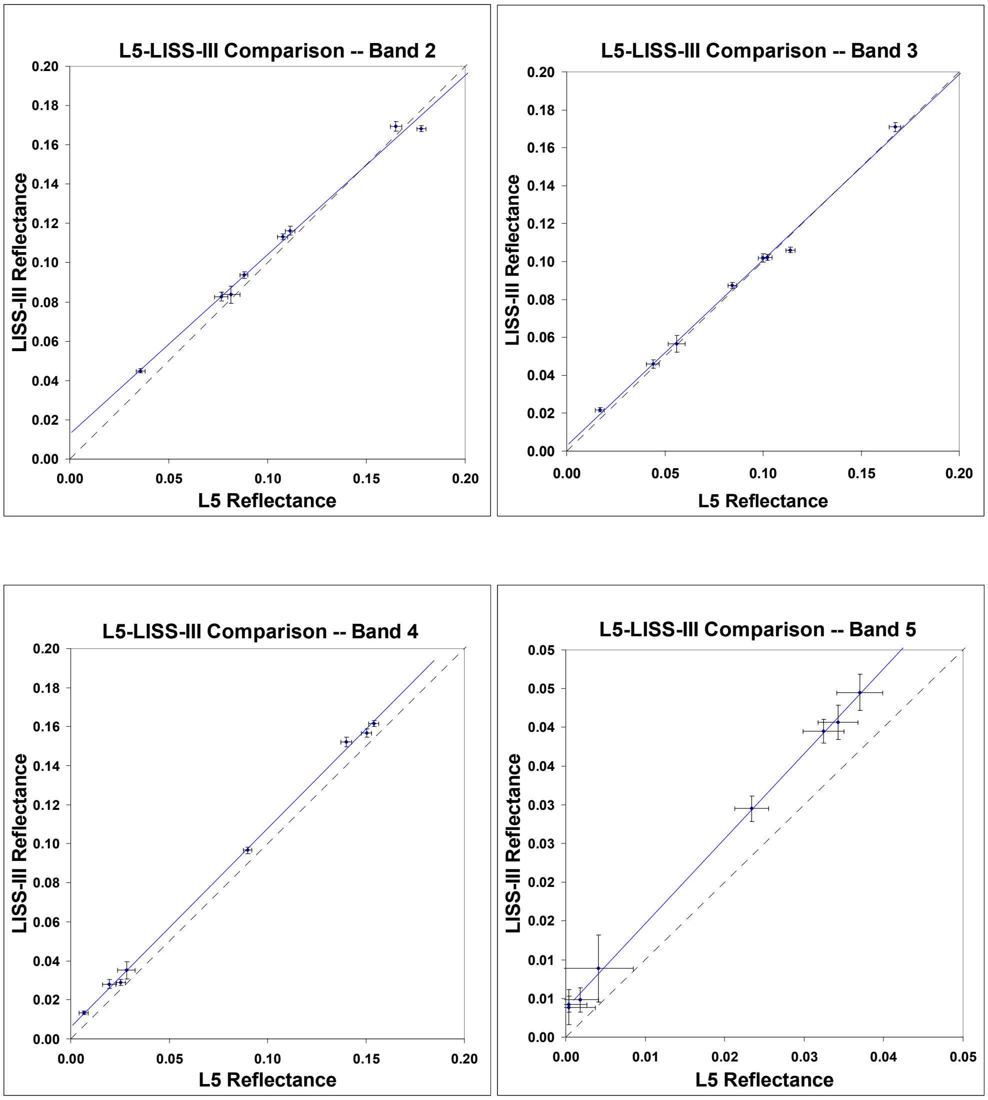


Fig. 12. Reflectance of homogenous regions viewed by the TM plotted against the same regions viewed by LISS-III. Error bars indicate the standard deviation of the regions of interest

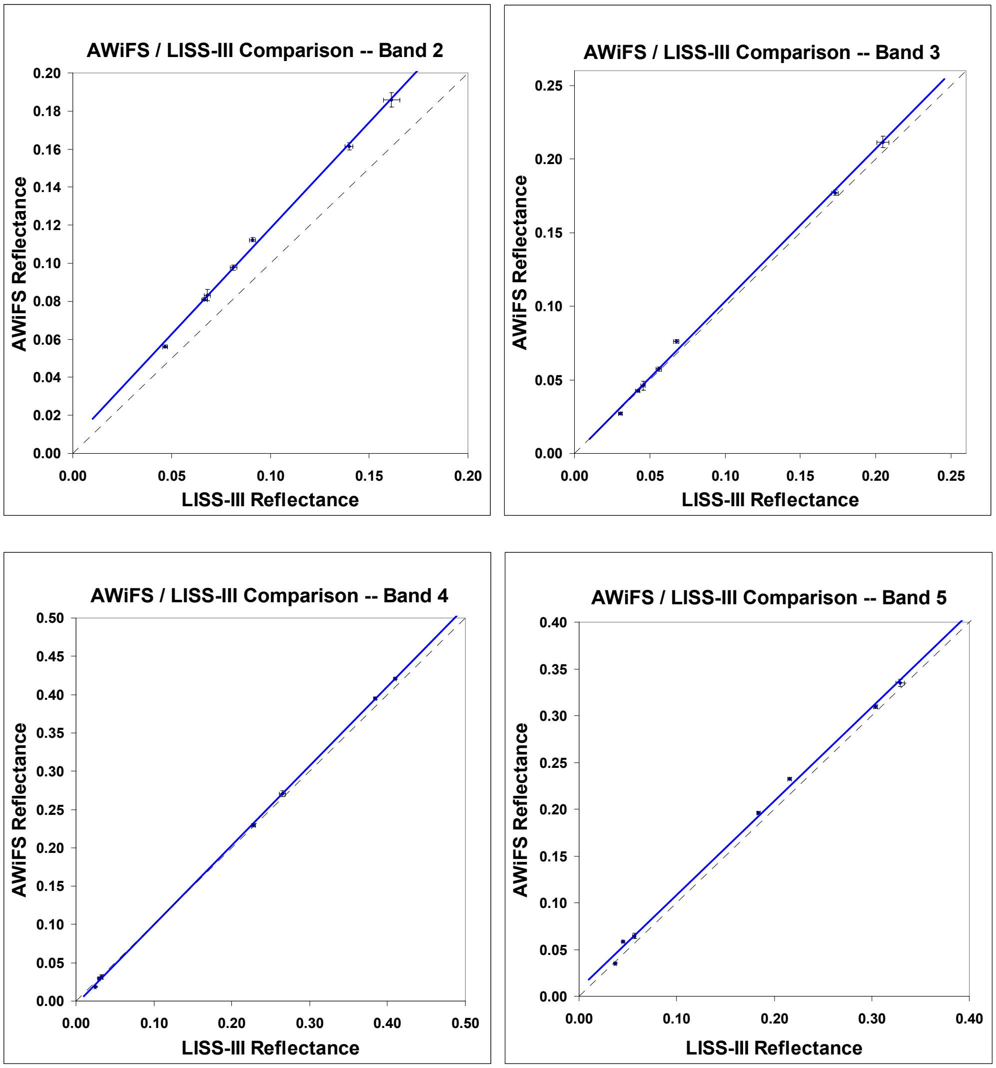


Fig. 13. Reflectance of homogenous regions viewed by both AWiFS and the LISS-III sensors for the Mesa, AZ collection. Error bars indicate the standard deviation of the regions of interest

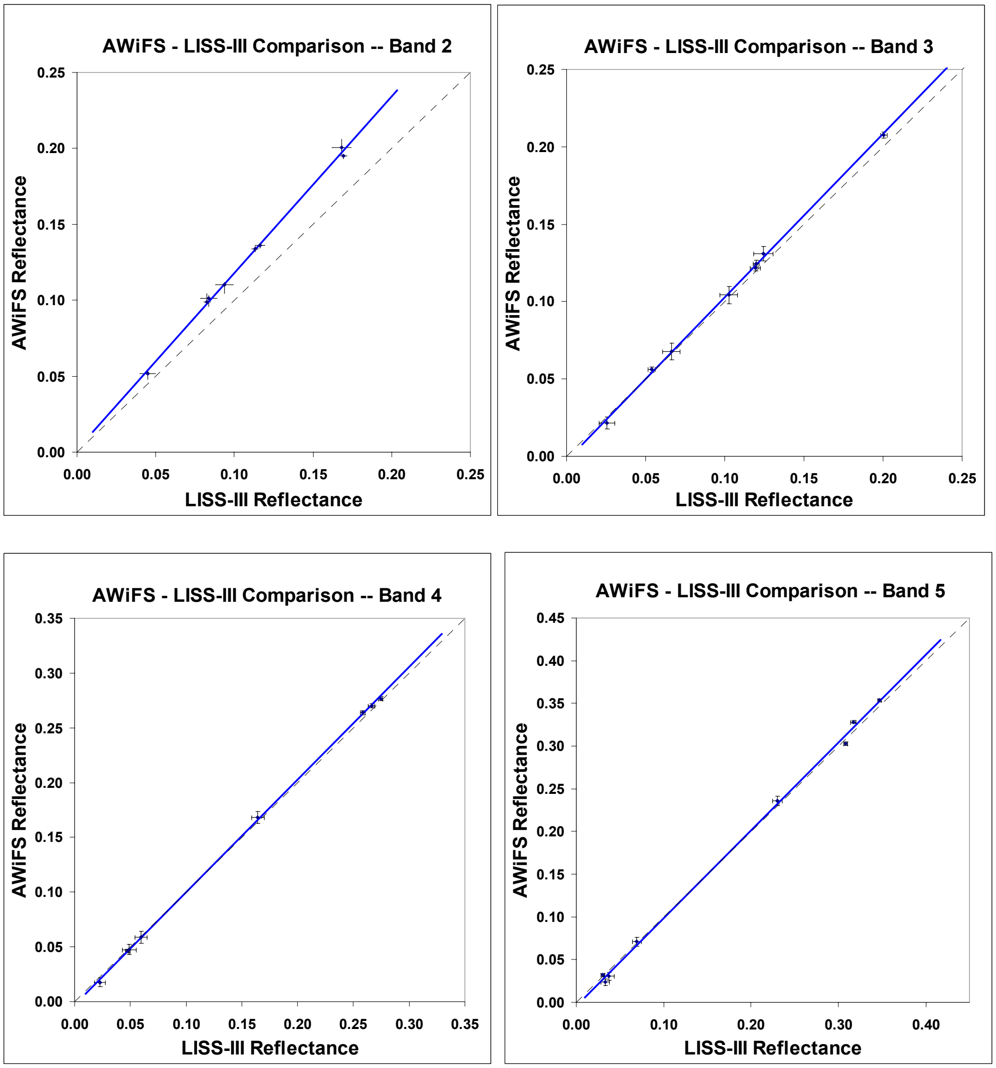


Fig. 14. Reflectance of homogenous regions viewed by both AWiFS and the LISS-III sensors for the Salt Lake City, UT collection. Error bars indicate the standard deviation of the regions of interest

E. Results and Discussions

An initial cross calibration of the L7 ETM+ and L5 TM with the IRS-P6 AWiFS, 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 preliminary results indicate that 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.

Since the AWiFS was present in both the collections, and because the calibration of the AWiFS instrument is generally closer to the Landsat sensors than LISS-III, it is instructive to look at the cross-calibration results as a function of difference from AWiFS. Table VI shows the cross-calibration gains of all four sensors normalized to AWiFS.

Table VI: Cross-calibration results normalized to the AWiFS sensor

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

The most likely cause of error is transient reflectance changes. One assumption made in the cross-calibration was that the TOA reflectance of all terrain in the study scenes underwent minimal changes between passes of the satellites – a timescale of 30 minutes. This may not be true for some regions of interest, including water regions, croplands in changing wind conditions, and areas near clouds that may have had drastic changes in humidity between satellite passes. As the Landsat TM and ETM+ sensors are known to be calibrated to within six percent of each other [7], [8] the normalized results appear to have a systematic error in the calibration to the ETM+, indicating possible problems in the Mesa, AZ scene, most likely due to transient changes.

The relative spectral response of the satellites is also a likely cause of error. Although measured in detail prelaunch, the RSRs of all the sensors used may have drifted since launch (WHY?). This is the most likely cause of the discrepancy in the cross-calibration between AWiFS and LISS-III in Band 2, although it may affect other bands as well.

With these results in mind, the cross-calibration of AWiFS to the L5 TM is the most useful result. This is indicated by a consistent close agreement between absolute calibrations of the TM and the AWiFS sensor, with differences of approximately six percent in all bands. An additional calibration error exists in comparisons to LISS-III, whose calibration differs from AWiFS and TM, especially in Band 2. Additional work to characterize the absolute differences between the two sensors over the entire mission is in progress.

III. SUMMARY AND CONCLUSION

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 TM and Landsat 7 ETM+ sensors. The approach involves 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 13 percent.

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USGS EROS IRS-P6 AWiFS and LISS-III Characterization

Introduction

This report was generated by the Remote Sensing Technologies Group (RSTG) at the USGS Center for Earth Resources Observation and Science (EROS). Satellite data from GeoEye was provided so that it could be analyzed for geometric stability. The medium resolution Linear Imaging Self-Scanner (LISS-III) and the Advanced Wide Field Sensor (AWiFS), both sensors that are aboard the RESOURCESAT-1 platform, were analyzed and the results are presented within this document. The RESOURCESAT-1 satellite was developed by the Indian Space Research (IRS). Table 1 lists the sensor characteristics for both instruments.

Instrument	LISS-III	AWiFS
Spatial Resolution (m)	23.5	56
Swath (km)	141	740
Spectral Bands (microns)	0.52-0.59 0.62-0.68 0.77-0.86 1.55-1.70	0.52-0.59 0.62-0.68 0.77-0.86 1.55-1.70
Quantization (bits)	7	10

Table 6-1 LISS-III and AWiFS Sensor Characteristics

The AWiFS instrument collects its image swath by using two separate sensor modules that are tilted by 11.94 degrees to the left and right of nadir [1]. The modules are identified as AWiFS-A and AWiFS-B. A full image product contains 4 separate files labeled as AWiFS A, B, C, and D. The A and C files are imaged by module A while the B and D files are imaged by module B. The four separate files when mosaiced together make up the full image collect.

The LISS-III instrument is made up of four separate telescopic assemblies. The telescopes are axis aligned such that there is near simultaneous acquisition of a point on the ground for all bands.

Executive Summary

Two LISS-III data sets and two AWiFS data sets were analyzed for geometric quality. The images were measured against data known to meet national map accuracies standards at 1:24000 scale, or a horizontal accuracy of approximately 6 meters. Due to the size of the swath width of the AWiFS instrument, an analysis of the full swath width could not be achieved using the available control. The control used typically covers one Landsat World Wide Reference System (WRS) nominal path width, or 185km which could cover the extent of one LISS-III data set but fell far short of covering the image extent of one AWiFS data set. The largest RMSE measured between the AWiFS data sets and the control used in the analysis was 0.7457 pixels, while the maximum RMSE measured for the LISS-III was 0.41462 pixels. The band alignment assessment produced a maximum RMSE, between any two band combinations, of 0.3055 pixels for the AWiFS instruments and 0.1956 pixels for the LISS-III instrument. It should be noted that especially for the band alignment analysis the total RMSE must be weighed against the quality of the measurements themselves, usually assessed through the standard deviations of the measurements and visual inspection of the residuals. The band-to-band measurements are very sensitive to between band features which must be viewable and consistent between spectral bands for reliable measurements.

As mentioned in the paragraph above, due to the large image extent of the AWiFS data sets obtained and the lack of coverage present in the 1:24000 scale control, as compared to the image extent of the AWiFS products, there became a need for alternative reference data sets. A secondary reference data set was chosen, that although may not be as accurate as 1:24000 scale, would still help in providing an assessment of the AWiFS data sets.

Description of Testing

Two LISS-III data sets and two AWiFS data sets were geometrically analyzed. All four data sets were ortho-rectified products, meaning ground control was applied to the data and relief displacements were removed. For the LISS-III data sets the ground track covered was equivalent to the Worldwide Reference System (WRS) 2 scenes, path 37 row 37, and path 40 row 33. For the first AWiFS data set paths 38, 37, and 36 of row 37 were stitched together to cover as wide a swath as possible from the available control. The ground controls used for geodetic accuracy were mosaiced Digital Orthophoto Quadrangles, or DOQs. The DOQs were mosaiced together such that one Landsat WRS scene is covered wall-to-wall by DOQ data. A group of these WRS DOQ data sets were created by the Landsat 7 Image Assessment System (IAS) and are used extensively in the characterization and calibration of the Enhanced Thematic Mapper Plus (ETM+) sensor and its' platform. One WRS wall-to-wall DOQ mosaic is often referred to as a geometric supersite. The mosaiced DOQs were resampled to match the resolution of the ResourceSat data. DOQs are designed to meet national map accuracy standards at 1:24000 scale, this corresponds to a horizontal Root Mean Squared (RMS) accuracy of approximately 6 meters. Due to the large image extent of the AWiFS data sets obtained, the DOQ supersite mosaics produced covering individual WRS-2 path/rows proved to be inadequate for assessing the geometric accuracy of the products. The lack of coverage presents in a DOQ supersite, as compared to the image extent of the AWiFS products, lead to the need for alternative reference data sets. The Multi-Resolution Land Characteristics (MRLC) data sets available through the National Land Cover Data (NLCD) were chosen as the alternative data set to be use as control against the AWiFS data sets. The MRLC data set contains orthorectified Thematic Mapper (TM) imagery produced from the Nation Land Archive Processing System (NLAPS). Mosaicing several single WRS-2 scenes from the MRLC database would create an image file covering the full extent of the AWiFS data sets. Each individual MRLC scene contains a work order file giving a quality assessment (QA) of the accuracy to which the image is registered to the control. Although an absolute number was not given for the MRLC as far as image registration goes, EROS Data Center scientist who have used the data in the past feel as if accuracies of less than one pixel in the multispectral range (30 meters) has been maintained. The MRLC comparison was performed only on the Railroad Valley data set (path 40 row 33) due to time and resource constraints.

The Landsat IAS was developed to assess the image quality of Landsat ETM+ data and to ensure that the data met the Landsat 7 ETM+ radiometric and geometric requirements throughout the instruments lifetime. Two tools that are available within this system are the Image-to-Image (I2I) Geometric Characterization tool and the Band-to-Band (B2B) Geometric Characterization tool. The I2I tool performs a geometric characterization between two image files by performing grey scale correlation on windowed image chips extracted from each file over evenly spaced locations throughout the image files. Outliers are removed by examining the correlation statistics for each correlation surface created from the image chips and by performing a student-t test on the set of good correlation points produced. The B2B tool works under the same premise as the I2I only each band pair available within one image file is compared rather than two separate image files. By comparing each band pair available a redundancy of measurements can be made which can help in the analysis in the case where one single band pair has poor correlation results; i.e. having compared band 1 to band 2 and band 2 to band 3 you should be able to infer something about the comparison between bands 1 and 3.

This document first discusses the results associated the AWiFS instrument assessment, discussing geodetic accuracy as compared to the mosaiced DOQs. These results were produced from the I2I process. After each I2I assessment a discussion of the band alignment results are given. The band alignment results were produced from the B2B process. After discussion of the AWiFS instrument, the same process is followed for the LISS-III instrument.

The AWiFS data was projected to a Lambert Conformal Conic (LCC) projection with a pixel size of 56 meters and with a datum of WGS84. Each of the four AWiFS data sets, A, B, C, D, have different projection parameters associated with the LCC projection, i.e. standard parallels, central meridians, and origin of latitude. The LISS-III data was projected to a UTM projection with a pixel size of 23.5 meters with a datum of WGS84. All data sets were provided in GeoTiff format.

USGS EROS Geometric Characterization

AWiFS Arizona Scene

Because of the large image swath of the AWiFS sensor, as compared to that of ETM+, a limited amount of the full field of view could be assessed for the AWiFS instrument. The reason for this is many of the mosaic DOQ data sets used by the Landat 7 IAS cover only one path and row of the Worldwide Reference System, which has a much smaller geographical extent than the swath of the AWiFS instrument, therefore the extent of the control available did not allow a complete geodetic assessment of the instrument. Figure 1 shows a mosaic of the AWIFS-A, B, C, D for the Arizona data set mosaiced together and the corresponding DOQ extent available for WRS path/rows 36/37, 37/37, and 38/37. Images displayed throughout the document were created from screen captures of images displayed with the Environment for Visualizing Images (ENVI) package. This figure shows the complete AWiFS coverage for the Arizona scene and the available control over the area.

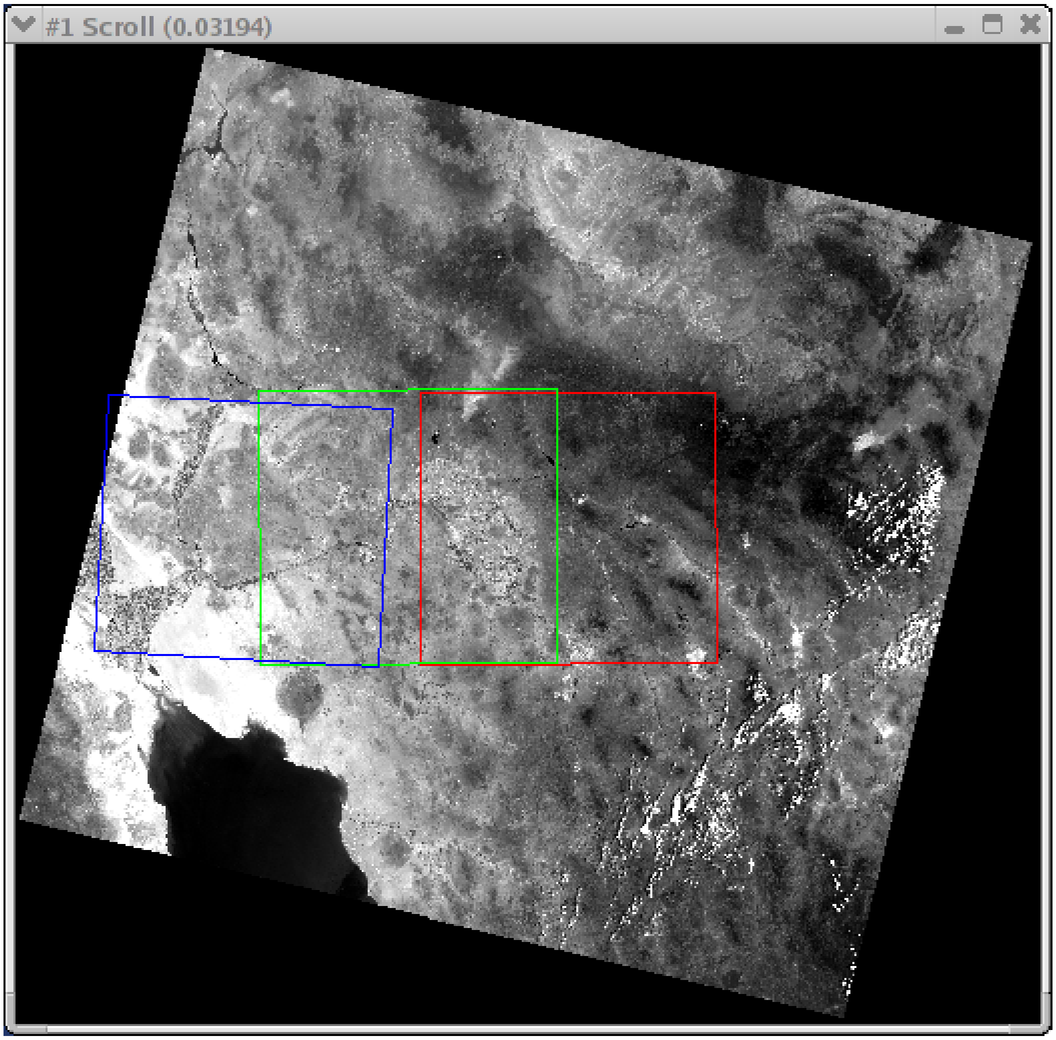


Figure 6-1 AWiFS-A,B,C,D Mosaiced Image

Path 38 Row 37 Geographic Extent
Path 37 Row 37 Geographic Extent
Path 36 Row 37 Geographic Extent

To simplify data handling and to avoid double resampling of the AWiFS data sets, the AWiFS-A and C images were analyzed separately using the control available. Figure 2 shows the same image extent for the AWiFS-C and DOQ mosaic data sets that are available for analysis. Figure 3 shows the same image extent for the AWiFS-A and DOQ mosaic data sets that are available for analysis. From figures 1, 2 and 3 it can be seen that there is control only over a very small percentage of the total swath width for the AWiFS data set. This leads to the question of how valid the image-to-image assessment of the instrument will be with such a small portion of it being involved in the assessment. Nevertheless, as an exercise, I2I was run over what small areas did overlap between the data sets. It is worth noting that due to radiometric differences between the DOQs used in the building the DOQ mosaic, a very apparent checkered, blocky pattern is visible within the imagery.

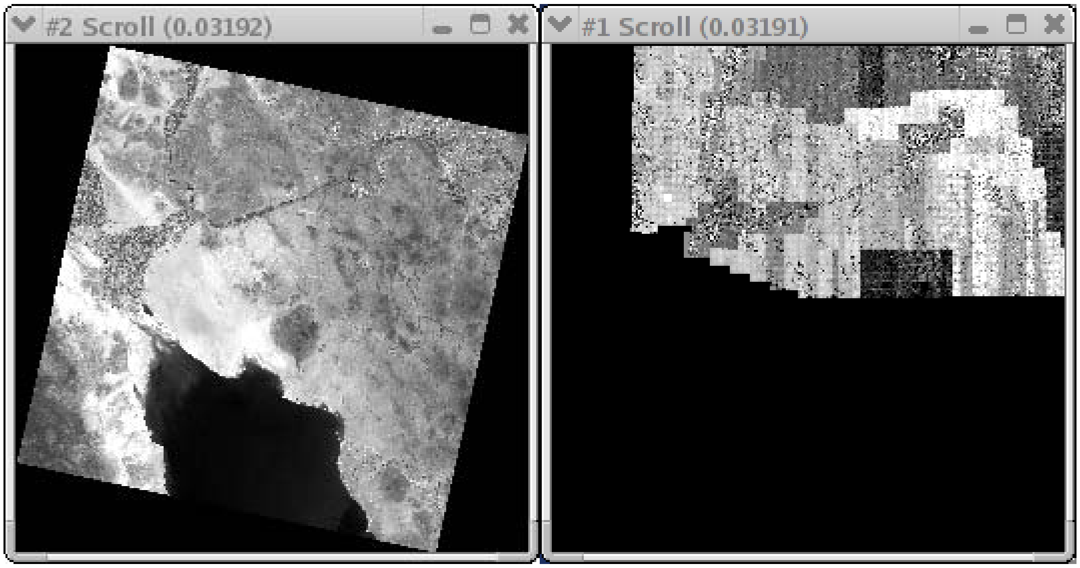


Figure 6-2 Image overviews of Arizona AWiFS-C and DOQ mosaic data sets

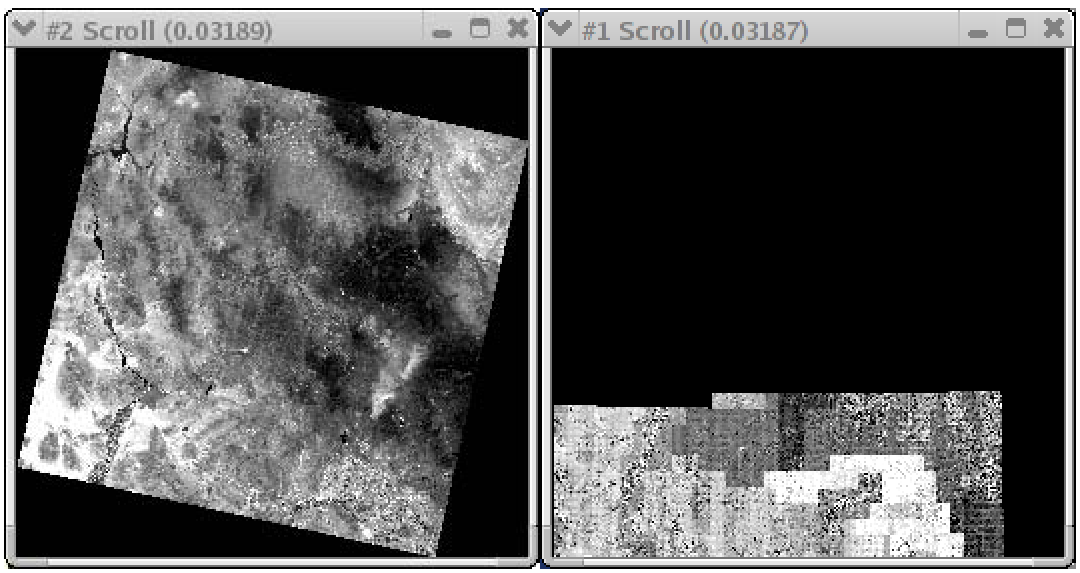


Figure 6-3 Image Overviews Arizona AWiFS-A and DOQ Mosaic

Geometric Accuracy Assessment

The I2I statistical results for comparing the Arizona AWiFS-C and D data sets to the DOQ mosaic are listed in table 2. Values are given in terms of 56-meter pixels. As can be seen from the table the data sets agree to within less than a pixel.

	Correlated	Kept	StDevL	StDevS	RMSEL	RMSES
AWIFS-C	139	104	7.832	6.031	11.581	7.375

AWIFS-A	78	55	19.191	12.326	39.742	12.8016

Table 6-2 I2I Statistics for AWiFS Arizona Data sets (Listed in Meters)

Kept – Point Kept After Outlier Rejection
Correlated – Points Used in Correlation
StDevL – Standard Deviation Line Direction
StDevS – Standard Deviation Sample Direction
RMSEL – Root Mean Squared Error Line Direction
RMSES – Root Mean Squared Error Sample Direction

Figure 4 shows vector plots of the I2I residuals for both the AWiFS-A and AWiFS-C data sets as compared to the DOQ mosaics. These plots also give an indication of how small an area is actually assessed from the I2I process. The vectors are scaled by a factor of 350 so that they are viewable within the imagery.

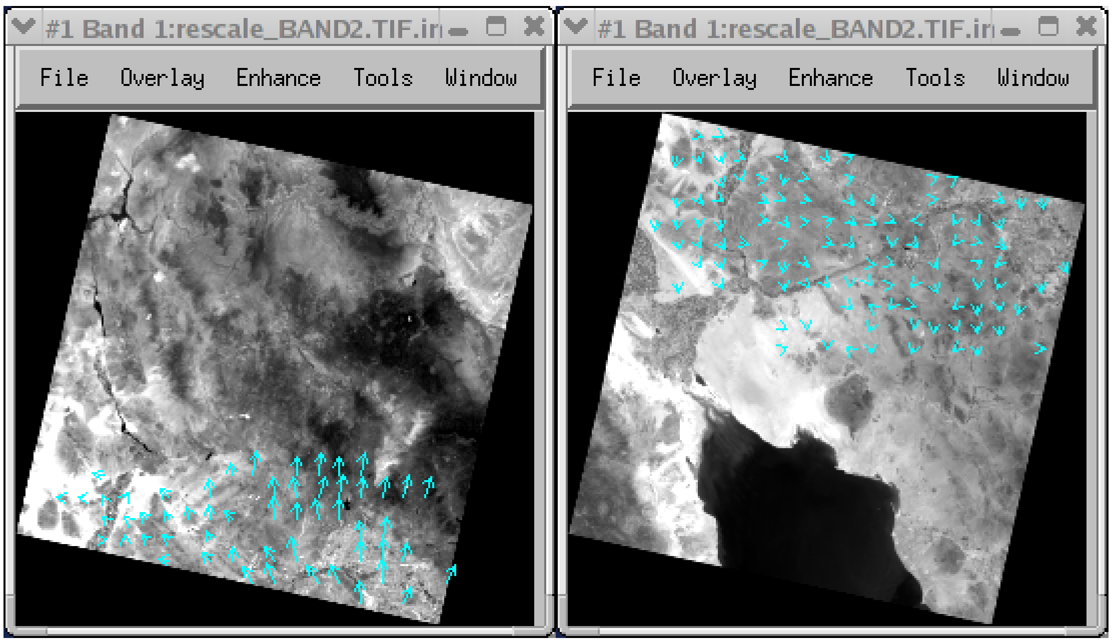


Figure 6-4 AWiFS-A and AWiFS-C I2I Residual Vector Plots (Scaled by 350)

Band-to-Band Registration Assessment

Due to the fact that control is not needed for performing a band-to-band registration assessment of a data set, all four AWiFS images, A, B, C, and D, were assessed for band registration. Table 3 gives the statistical values associated with the assessment. All values are given in terms of 56-meter pixels.

	Rband	Sband	Correlated	Kept	StDevL	StDevS	RMSEL	RMSES
AWIFSA	2	3	400	277	0.04226	0.04382	0.04382	0.06592
	2	4	385	191	0.06595	0.08581	0.08403	0.08600
	2	5	385	169	0.07565	0.08671	0.09238	0.11779
	3	4	387	199	0.06837	0.06114	0.07558	0.07016
	3	5	398	198	0.09356	0.08532	0.10121	0.15835
	4	5	387	215	0.10925	0.11055	0.10963	0.15464
AWIFSB	2	3	382	239	0.03524	0.03407	0.05388	0.10192
	2	4	375	189	0.06740	0.07265	0.12407	0.14688
	2	5	376	242	0.10609	0.16076	0.21235	0.16775
	3	4	371	178	0.03845	0.06093	0.07159	0.07729
	3	5	383	244	0.07445	0.20019	0.14464	0.23672
	4	5	376	246	0.12470	0.18588	0.15958	0.24792
AWIFSC	2	3	385	217	0.03390	0.04197	0.03736	0.05815
	2	4	365	200	0.07396	0.08361	0.07957	0.08418
	2	5	381	173	0.08964	0.10440	0.12030	0.15107
	3	4	368	156	0.04472	0.04065	0.04508	0.05547
	3	5	387	196	0.08591	0.11163	0.10627	0.19996
	4	5	381	167	0.07336	0.11273	0.07985	0.13505
AWIFSD	2	3	385	269	0.03979	0.03624	0.06174	0.09626
	2	4	376	220	0.06576	0.07917	0.12023	0.14688
	2	5	384	254	0.09942	0.16939	0.22521	0.16939
	3	4	376	206	0.05170	0.06046	0.07618	0.07560
	3	5	385	280	0.08614	0.19413	0.17400	0.23242
	4	5	380	214	0.10408	0.10795	0.14929	0.22538

Table 6-3 AWiFS Arizona B2B Statistics (Listed in Pixels)

Figures 5-8 show band-to-band vector residuals for each band pair for all four Arizona AWiFS image data sets. Band 2 to band 3 refers to the residuals associated with measuring the location of pixels in band 2 to those in bands 3. Band 2 to band 4 refers to residuals associated with measuring band 2 to band 4. The rest of the band pairings follow suit. Residuals are scaled by a factor or 1200 so that they will be viewable within the image. The purpose of the plots is to identify any measurable pattern between band pairings rather than trying to identify the magnitude of the differences.

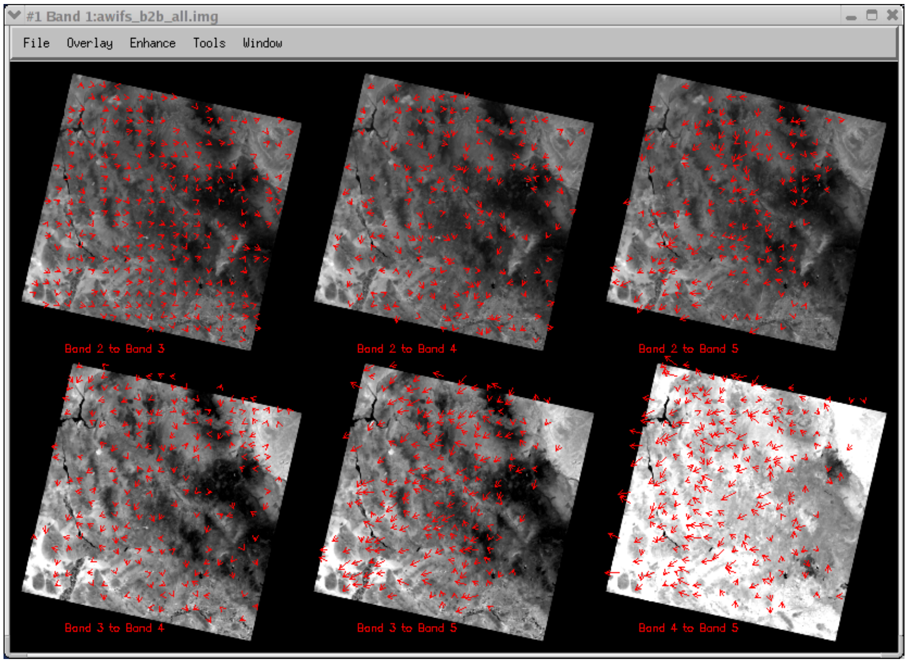


Figure 6-5 AWiFS-A Arizona B2B Residual Vectors (Scaled by 1200)

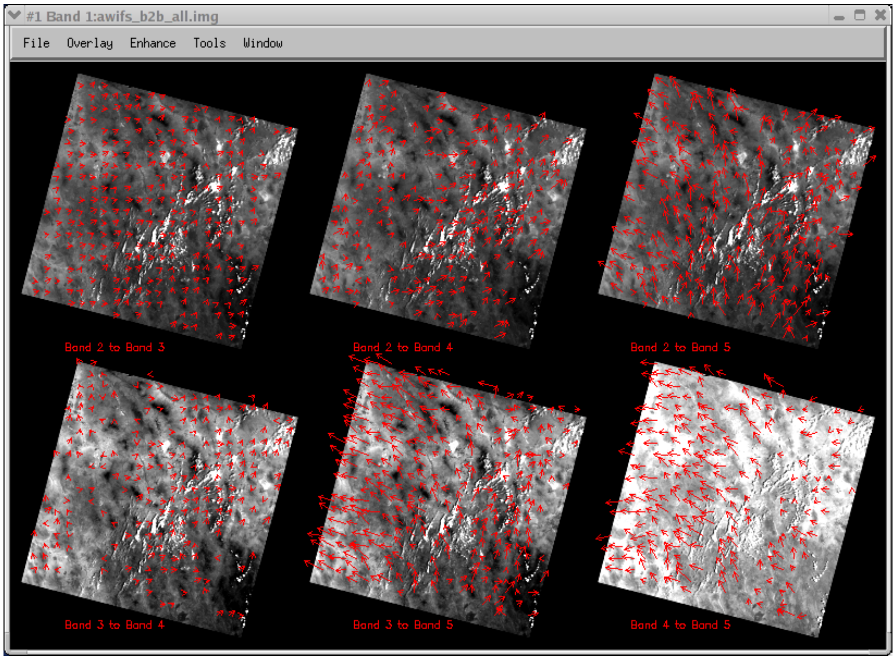


Figure 6-6 AWiFS-B Arizona B2B Residual Vectors (Scaled by 1200)

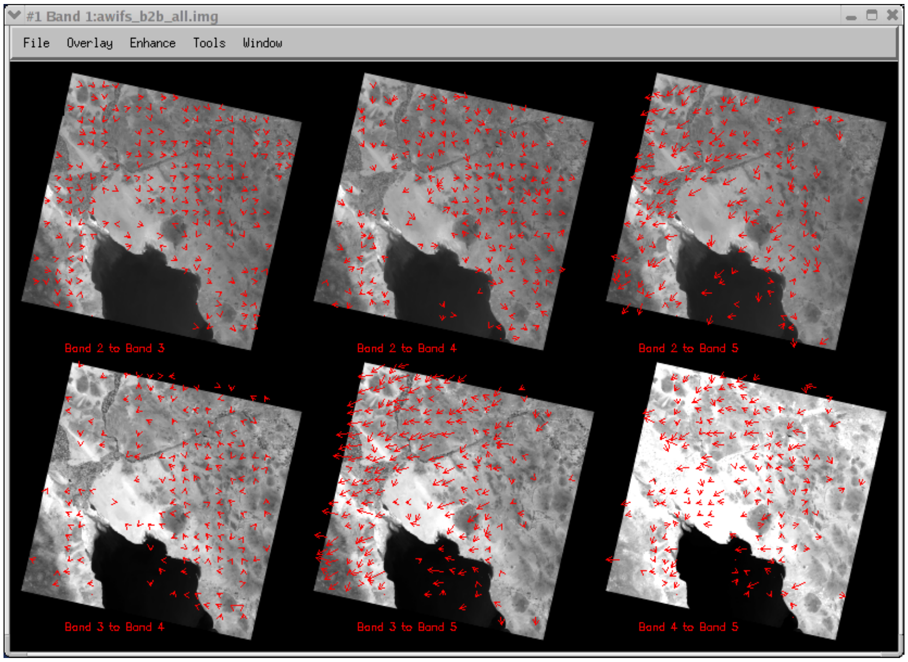


Figure 6-7 AWiFS-C Arizona B2B Residual Vectors (Scaled by 1200)

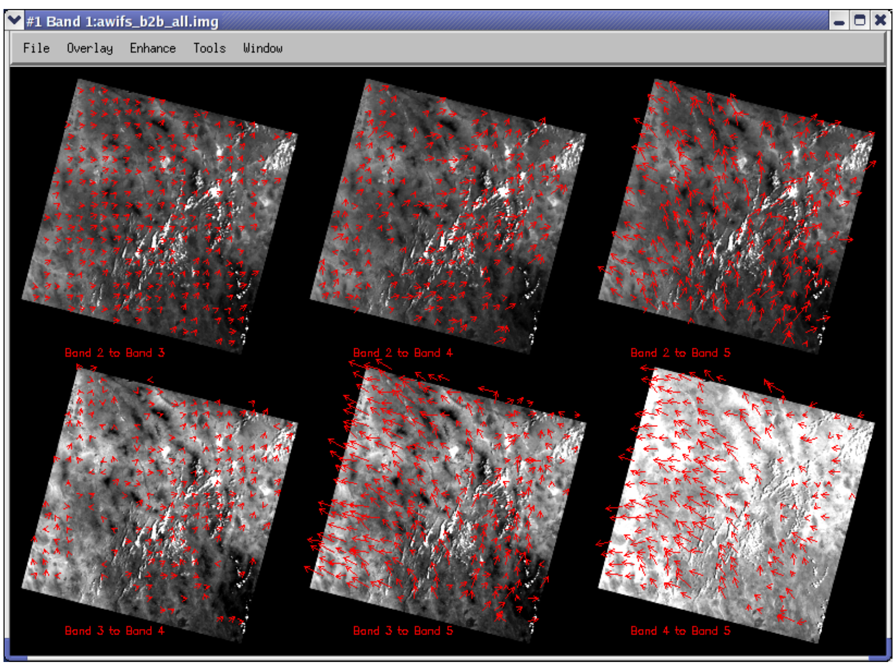


Figure 6-8 AWiFS-D Arizona B2B Residual Vectors (Scaled by 1200)

As can be seen from the statistics in table 2 and figures 5-8, although the band-to-band residuals are small, some systematic displacement between bands is visible.

LISS-III Arizona Scene

Due to the smaller field of view with the LISS-III instrument, as compared to the AWiFS instrument, the ground control available provided complete coverage of the LISS-III Arizona data set. Figure 9 shows the LISS-III image and DOQ mosaic available for the Arizona data set. Again, the radiometric differences between individual DOQs produce the blocking pattern in the mosaic.

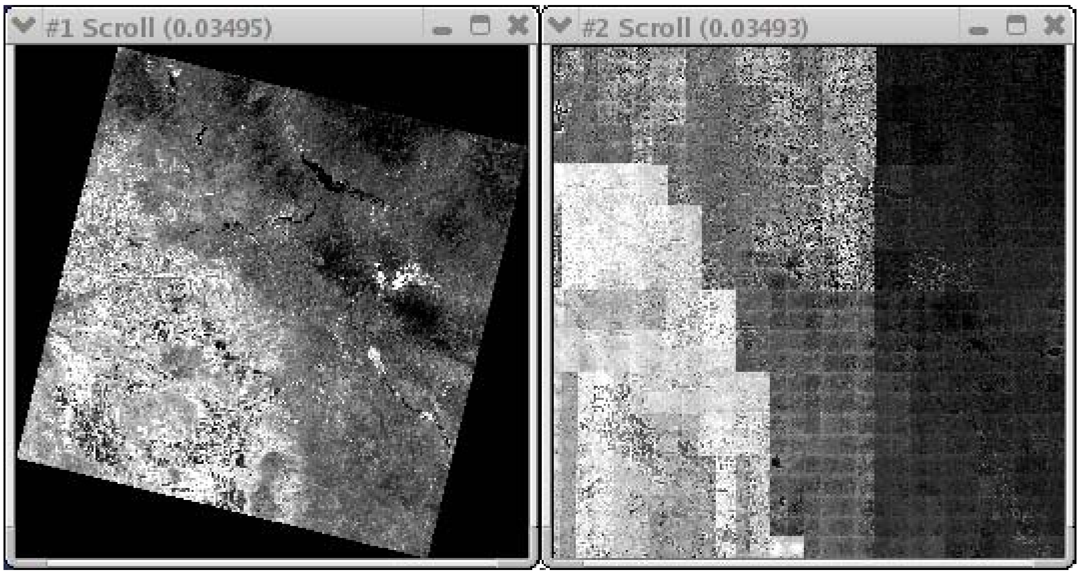


Figure 6-9 Arizona LISS-III and DOQ Mosaic Data Set

Geometric Accuracy Assessment

The I2I statistics for the LISS-III Arizona data set are listed in table 4. Values are listed in meters. From the table it can be seen that the LISS-III data set and the DOQ mosaic are in close agreement.

	Correlated	Kept	StDevL	StDevS	RMSEL	RMSES
LISS-III	272	125	3.657	2.705	3.727	2.836

Table 6-4 LISS-III Arizona I2I Statistics (Listed in Meters)

Figure 10 show a vector plot for the I2I residuals between the LISS-III and DOQ mosaic data sets. Vectors are scaled by a factor of 350 so that they can be viewed within the image. The small values listed in table and the “randomness” of the vector plot show that the LISS-III and DOQ mosaic have good co-registration. The vector plot and statistics show only very small differences that are most likely due to radiometric differences and changes in features on the ground between the two.

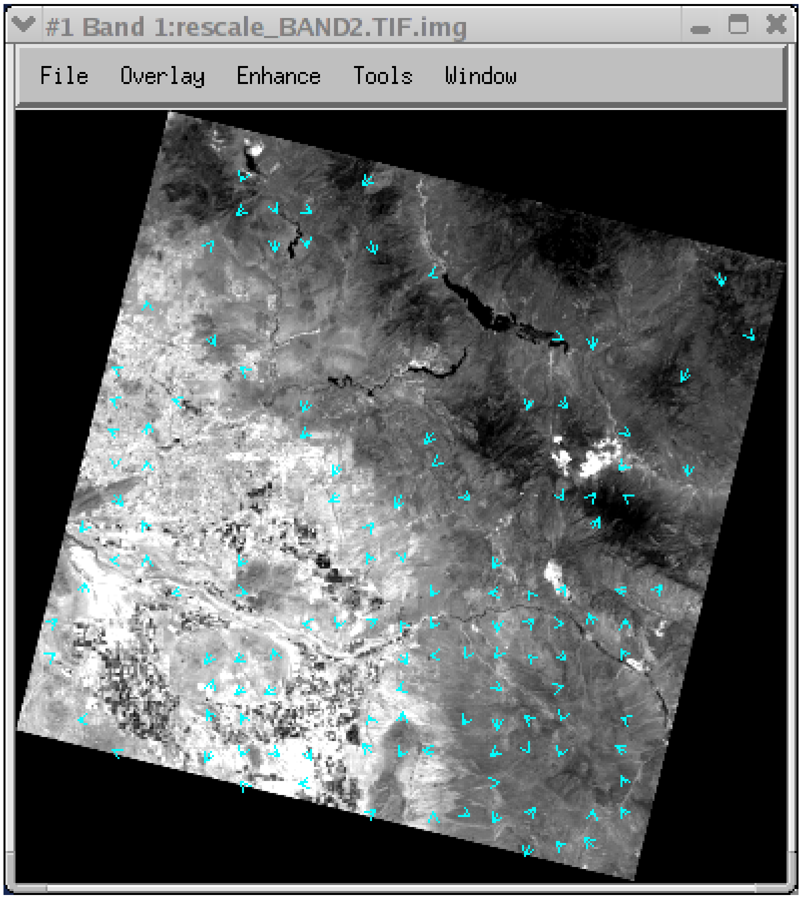


Figure 6-10 LISS-III Arizona I2I Vector Residuals (Scaled by 350)

Figure 11 shows one full resolution window over the same area for both the LISS-III image and the DOQ mosaic. The images appear to line up well. It is also worth noting that there are several changes between the features on the ground that are noticeable within the figure.

Figure 6-11 Full Resolution LISS-III and DOQ Windows

Band-to-Band Registration Assessment

Table 5 gives the statistical values associated with the B2B assessment for the Arizona LISS-III data set. All values are given in terms of 23.5-meter pixels.

Rband	Sband	Correlated	Kept	StDevL	StDevS	RMSEL	RMSES
2	3	387	309	0.07114	0.02327	0.18845	0.05252
2	4	370	214	0.06762	0.08491	0.07830	0.14568
2	5	378	251	0.09012	0.06464	0.13489	0.11831
3	4	367	151	0.03944	0.06010	0.11135	0.08848
3	5	386	201	0.04210	0.04960	0.07953	0.07113
4	5	377	152	0.03947	0.10423	0.04325	0.10920

Table 6-5 LISS-III Arizona B2B Statistics (Listed in Pixels)

Figures 12 show band-to-band vector residuals for each band pair. Residuals are scaled by a factor of 1200 so that they will be viewable within the plot. The purpose of the plots is to identify any measurable systematic pattern between band pairings rather than trying to identify the magnitude of the differences. Under this premise, a noticeable systematic shift exists between bands 2 and 3. The possibility of other systematic differences appears within other band pairings.

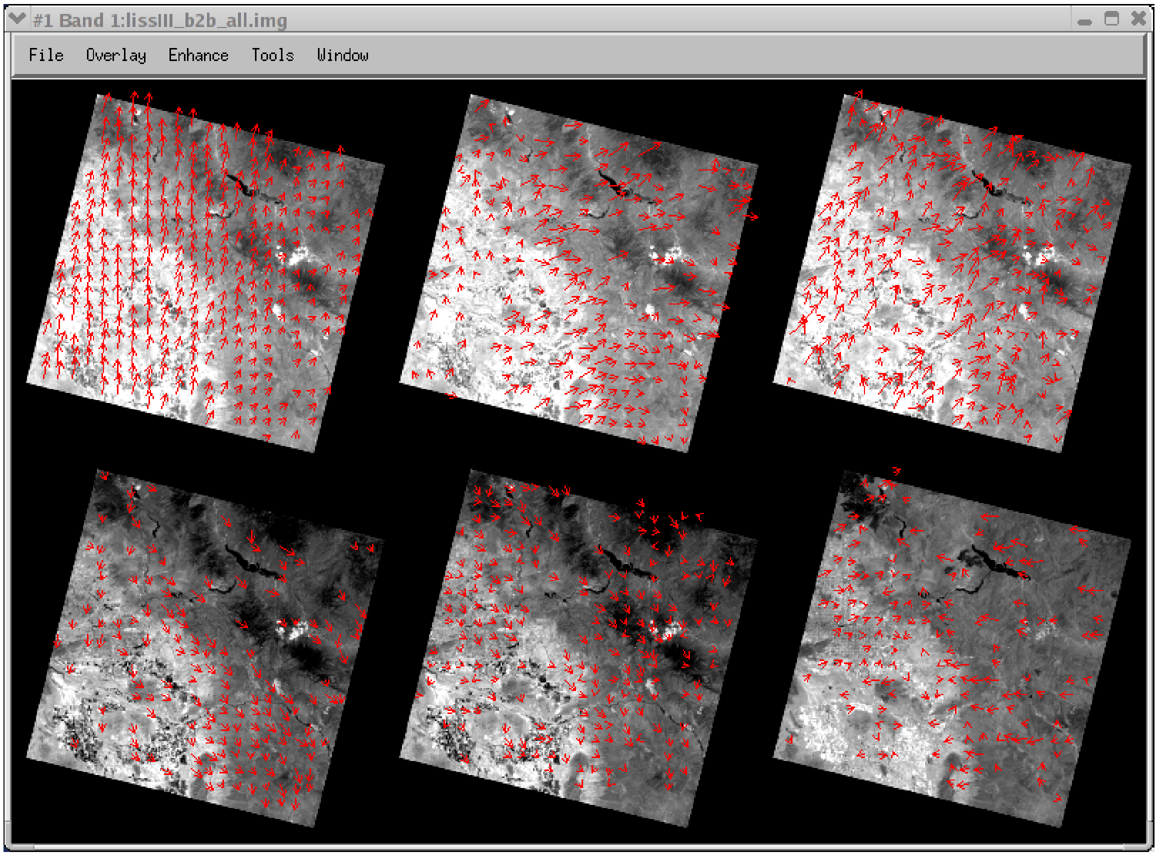


Figure 6-12 Arizona LISS-III B2B Residual Vectors (Scaled by 1500)

AWiFS Railroad Valley Scene

The Railroad Valley AWiFS scene had an even smaller area of DOQ coverage available from the IAS supersite library than that of the Arizona scene. This made any kind of geometric accuracy very limited in its' scope. Never the less a geodetic assessment was still performed over the region in which control was available. Figure 13 shows a mosaic of all four AWiFS Railroad Valley data sets mosaiced together along with an outline of the area in which there is control available from the IAS supersite data sets. Again in order to avoid having to perform an assessment on double resampled data, only the individual AWiFS data sets will be used for the geodetic accuracy assessment. Since the majority of the control available lies within the AWiFS-D data set, only this image file was compared to the DOQ mosaic. Figure 14 shows the AWiFS and DOQ data sets that were compared for the geometric accuracy assessment. Figure 14 helps to further illustrate the very limited coverage of control available for any type of geodetic assessment. Since a band-to-band assessment can be performed without control, B2B was performed on all four AWiFS data sets.

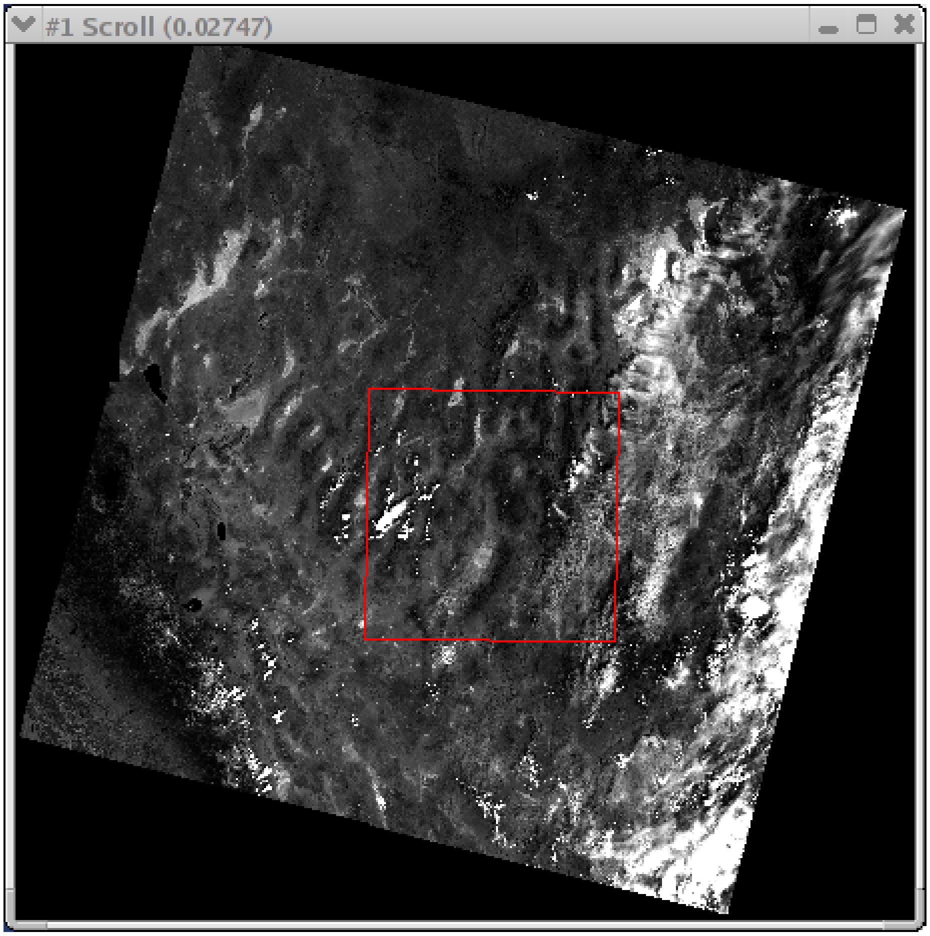


Figure 6-13 AWiFS Railroad Valley Mosaic With Outline of Available Control

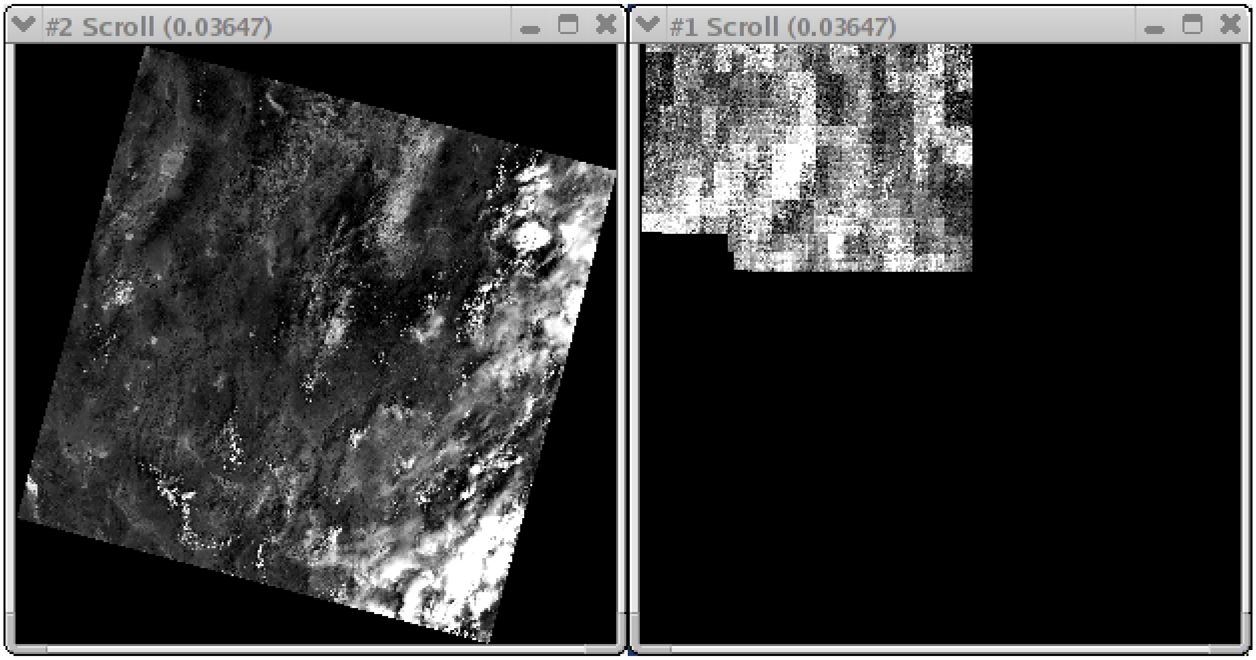


Figure 6-14 AWiFS-D and DOQ Mosaic Available

Mosaicing several MRLC data sets alleviated the problem associated with image extent when assessing the AWiFS data sets, although most likely at a cost in accuracy associated with the control data. The MRLC data sets, mosaiced together and indicating the WRS-2 path/rows used, is shown in figure 15. The MRLC data sets were resampled to match the projection space and pixel size of the AWiFS data sets.

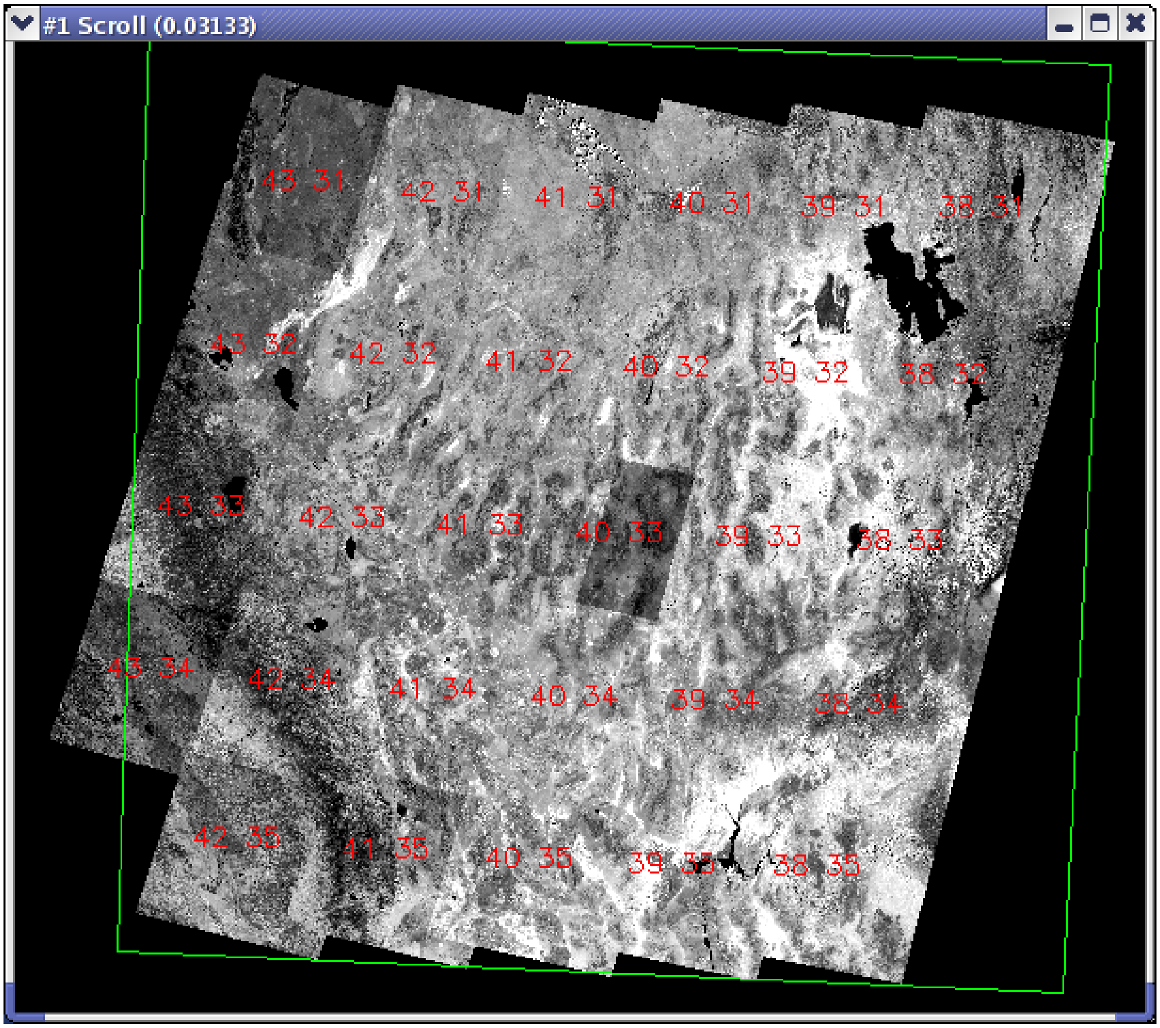


Figure 6-15 MRLC mosaic.
Green outline indicates AWiFS image extent. Numbers indicated WRS-2 path/rows.

Each individual MRLC data set, covering one WRS-2 path/row, contains a corresponding work order file. Within each work order file a quality assessment (QA) of the registration for that data set is given. The number of points chosen for QA, the along and across track mean, root mean squared error (RMS), and standard deviation (StDev) is given within the work order file. The mean, RMS, and StDev along with the acquisition date for each path/row used in the MRLC mosaic is listed in table 6. Values are given in terms of meters.

Path	Row	Date	Num Points	Across Mean	Along Mean	Across RMS	Along RMS
38	31	6/29/2000	9	2.22	0.96	13.94	9.17
38	32	5/28/2000	10	-4.59	4.35	11.37	10.67
38	33	6/13/2000	9	0.49	-1.83	11.75	9.9

38	34	6/13/2000	9	1.18	1.88	7.96	9.87
38	35	6/13/2000	10	-0.01	-1.88	10.74	11.47
39	31	6/20/2000	10	2.9	2.47	11.97	8.1
39	32	6/4/2000	9	-1.16	5.09	9.06	9.51
39	33	6/20/2000	9	-5.4	-5.79	7.94	12.38
39	34	7/6/2000	9	-1.28	5.18	12.98	8.79
39	35	7/6/2000	11	3.09	0.21	12.43	6.69
40	31	7/13/2000	10	0.61	4.61	10.13	10.76
40	32	7/13/2000	9	6.38	-0.37	8.93	8.61
40	33	8/14/2000	9	3.14	2.13	9.26	7.49
40	34	6/11/2000	10	-0.55	-5.5	12.2	9.88
40	35	7/13/2000	11	-8.15	-2.72	12.84	8.34
41	31	7/20/2000	10	-6.72	-2.91	9.71	8.16
41	32	7/20/2000	9	0.79	2.88	7.64	8.44
41	33	7/20/2000	9	-4.2	0.41	9.85	7.67
41	34	7/20/2000	11	1.02	-5.86	8.22	12.07
41	35	9/20/1999	10	1.21	5.9	9.06	8.95
42	31	7/27/2000	9	-0.04	-7.33	4.07	11.88
42	32	7/27/2000	11	-1.1	-3.3	9.51	8.17
42	33	7/27/2000	11	1.37	1.25	8.37	4.76
42	34	7/27/2000	10	-2.94	2.83	7.71	8.9
42	35	9/29/2000	11	0.14	3.68	9.14	5.84
43	31	10/6/2000	9	-5.3	-6.19	11.5	9.9
43	32	4/29/2000	11	0	-2.8	8.5	6.8
43	33	7/18/2000	9	-7.94	-0.79	13.43	8.01
43	34	10/22/2000	13	2.58	-0.07	8.42	7.91

Table 6-6 Quality assessment of MRCL data. Values are listed in meters.
RMS – Root Mean Squared Error
StDev – Standard Deviation

From table 6 it can be seen that the largest RMS in any one direction is 13.94 meters or 13.94/57.0 = 0.245 pixels. From table 6 it can also be calculated that the largest combined RMS is16.69 meters or 16.69/57.0 = 0.2928 AWiFS pixels. To avoid double resampling each individual AWiFS image, A, B, C, and D, is assessed independently against the MRLC mosaic.

Geometric Accuracy Assessment

The I2I statistics for the AWIFS-D Railroad Valley data set are listed in table 7. Values are listed meters. From the table it can be seen that the AWiFS data set and the DOQ mosaic are in close agreement.

	Correlated	Kept	StDevL	StDevS	RMSEL	RMSES
AWIFS-D	43	32	5.953	12.740	7.526	17.953

Table 6-7 AWiFS-D Railroad Valley I2I Statistics (Listed in Meters)

Figure 16 shows a vector plot of the I2I residuals. Residuals are scaled by a factor of 350 so that they are viewable within the imagery

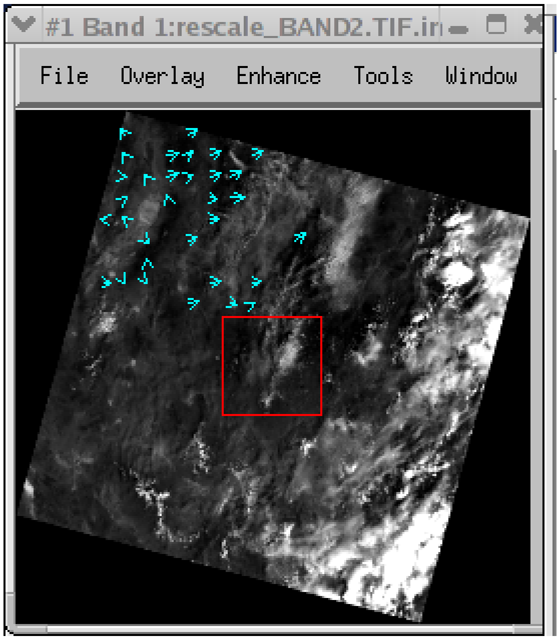


Figure 6-16 AWiFS-D Railroad Valley I2I Residual Vectors (Scaled by 350)

The I2I statistical results for comparing the Railroad Valley AWiFS data sets to the MRLC mosaic are listed in table 8. Values are given in meters. As can be seen from the table the data sets agree to within less than one AWiFS pixel.

	Points	**Mean**		**RMSE**	
		Line	**Sample**	**Line**	**Sample**
AWiFSA	234	-4.592	-9.352	14.784	14.224
AWiFSB	133	-27.160	-19.320	27.720	25.648
AWiFSC	166	1.848	-7.056	5.264	10.248
AWiFSD	103	-20.944	-21.504	22.736	24.360

Table 6-8 Image-to-Image assessment between Railroad Valley AWiFS data sets and MRLC mosaic (Listed in Meters).

From table 8, and taking into account the registration accuracy reported in the QA statistics for the MRLC data, the AWiFS data set is well registered to the MRLC data. Figures 17-20 show vector residuals between each AWiFS data set and MRLC mosaic. Vector residuals are scaled by a factor of 450 so that they are more easily visible within the figures. It is worth noting that considering the possible differences in the accuracy of the control used, the DOQ and MRLC assessments give similar results.

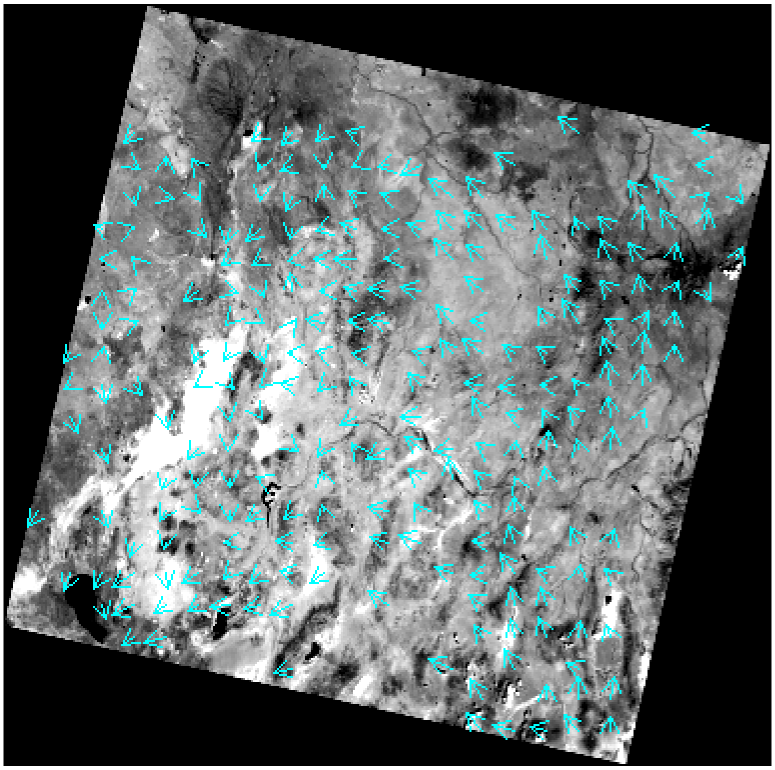


Figure 6-17 AWiFS-A Image-to-Image Vector Residuals Using MRLC Mosaic
Residuals are scaled by a factor of 450

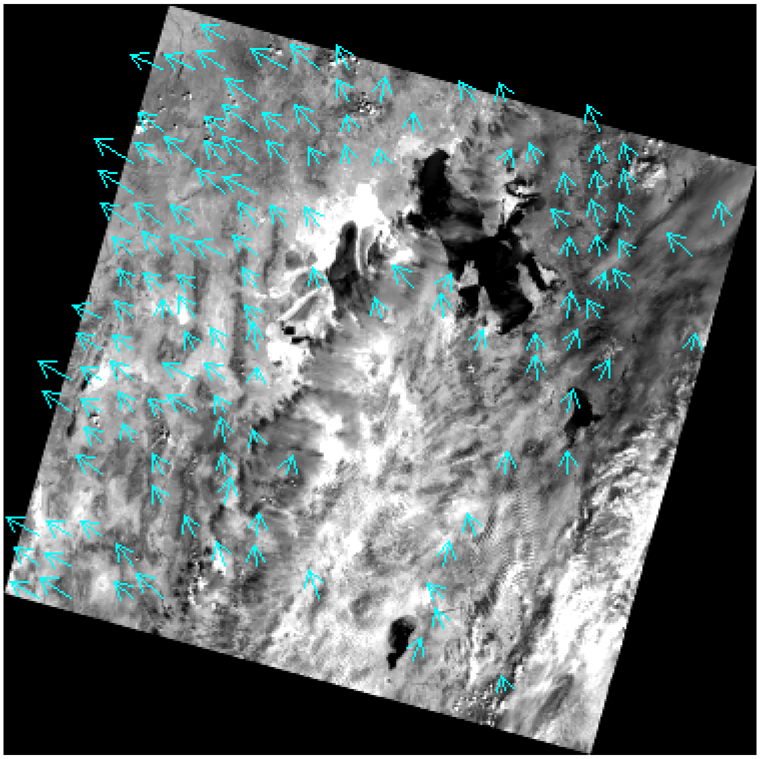


Figure 6-18 AWiFS-B Image-to-Image Vector Residuals Using MRLC Mosaic
Residuals are scaled by a factor of 450

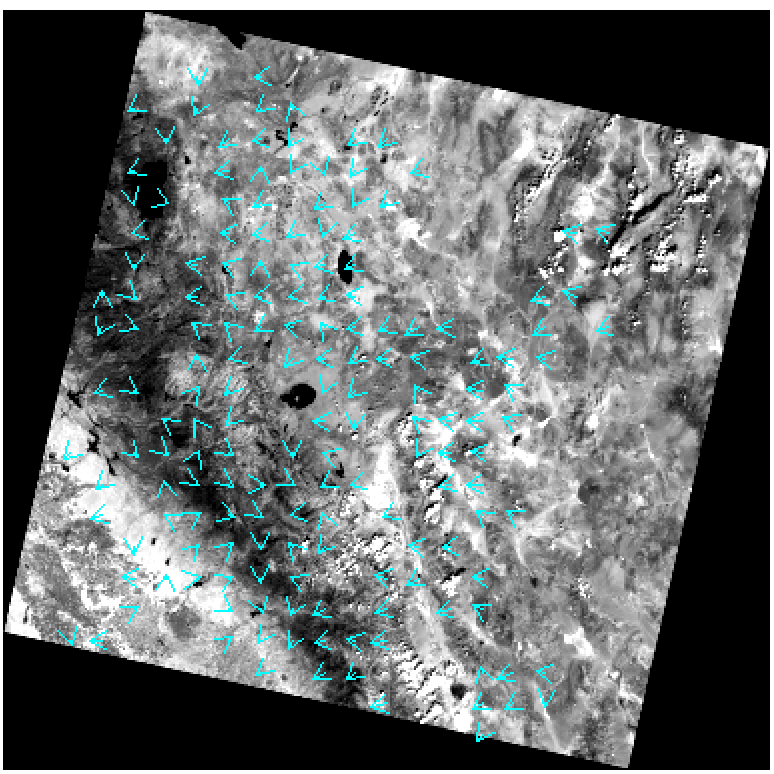


Figure 6-19 AWiFS-C Image-to-Image Vector Residuals Using MRLC Mosaic
Residuals are scaled by a factor of 450

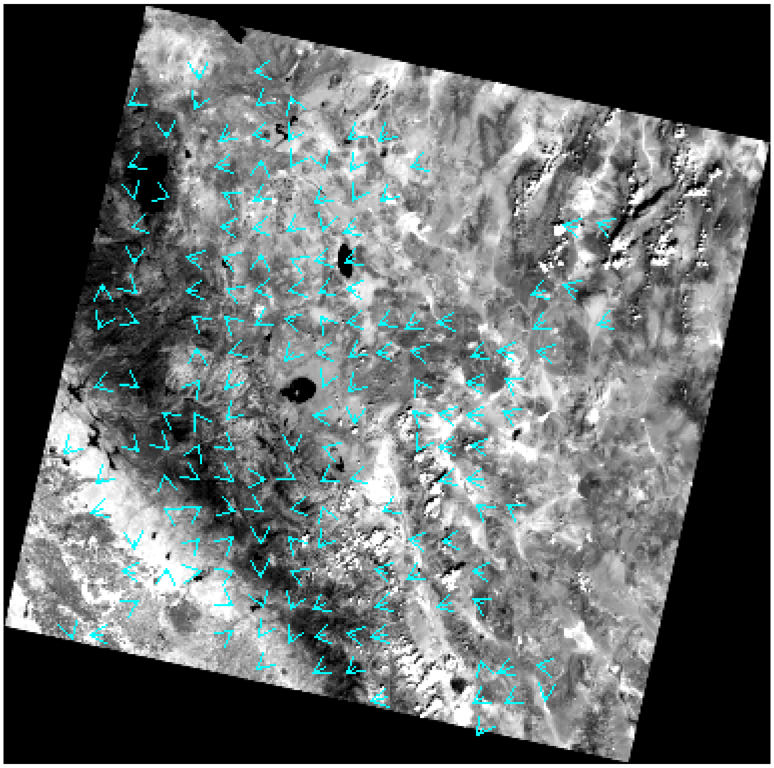


Figure 6-20 AWiFS-D Image-to-Image Vector Residuals Using MRLC Mosaic
Residuals are scaled by a factor of 450

Band-to-Band Registration Assessment

Table 9 gives the statistics associated with the B2B assessment done on the AWiFS Railroad Valley data set.

	Rband	Sband	Correlated	Kept	StDevL	StDevS	RMSEL	RMSES
AWIFSA	2	3	399	279	0.03602	0.04776	0.04135	0.07413
	2	4	387	187	0.07630	0.08233	0.09105	0.08618
	2	5	393	211	0.1122	0.12855	0.14919	0.15088
	3	4	389	170	0.05387	0.06460	0.05547	0.07090
	3	5	396	195	0.09002	0.13150	0.11036	0.21430
	4	5	380	142	0.07946	0.09086	0.08373	0.16688
AWIFSB	2	3	377	259	0.03842	0.03672	0.04473	0.11329
	2	4	359	181	0.06190	0.07686	0.09917	0.12965
	2	5	372	234	0.12667	0.20486	0.19267	0.20619
	3	4	359	153	0.03807	0.05668	0.06560	0.07051
	3	5	371	226	0.10473	0.22581	0.14773	0.25554
	4	5	362	218	0.14401	0.20931	0.16418	0.24253
AWIFSC	2	3	400	240	0.02833	0.03724	0.03397	0.06240
	2	4	368	137	0.07316	0.03811	0.07659	0.04298
	2	5	396	218	0.08465	0.10226	0.11299	0.15503

	3	4	373	150	0.03658	0.04852	0.03651	0.06133
	3	5	398	169	0.05943	0.08506	0.08081	0.20627
	4	5	372	223	0.10425	0.18362	0.10639	0.18669
AWIFSD	2	3	383	204	0.03383	0.02352	0.03808	0.10849
	2	4	380	227	0.05506	0.06319	0.09495	0.14275
	2	5	381	260	0.09961	0.20816	0.17632	0.20891
	3	4	380	223	0.05212	0.03589	0.07748	0.05903
	3	5	381	284	0.10137	0.22873	0.15645	0.26241
	4	5	379	280	0.11741	0.18018	0.13605	0.23520

Table 6-9 AWiFS Railroad Valley B2B Statistics (Listed in Pixels)

Figures 21-24 show band-to-band vector residuals for each band pair for all four AWiFS image data sets. As can be seen from the statistics in table 9 and figures 21-24, although the band-to-band residuals are small, some systematic displacement between bands is visible.

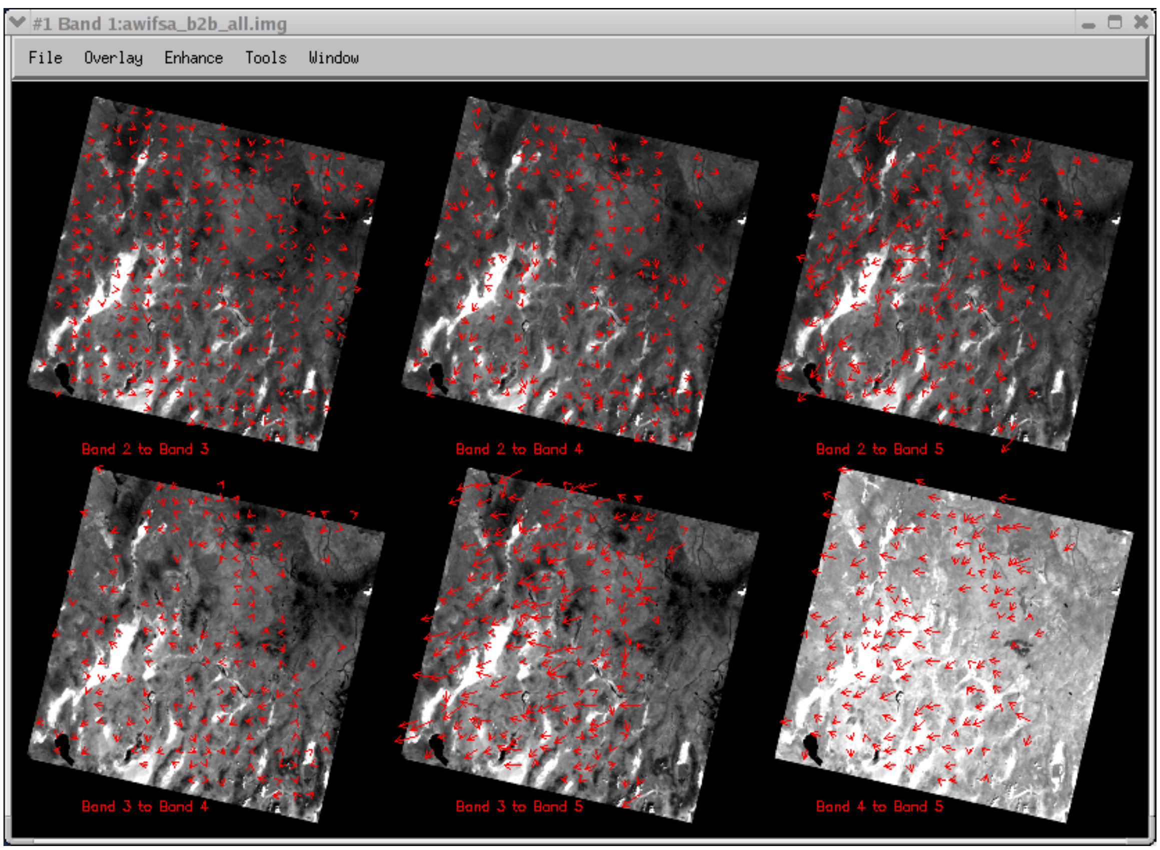


Figure 6-21 AWiFS-A Railroad Valley B2B Residual Vectors (Scaled by 1200)

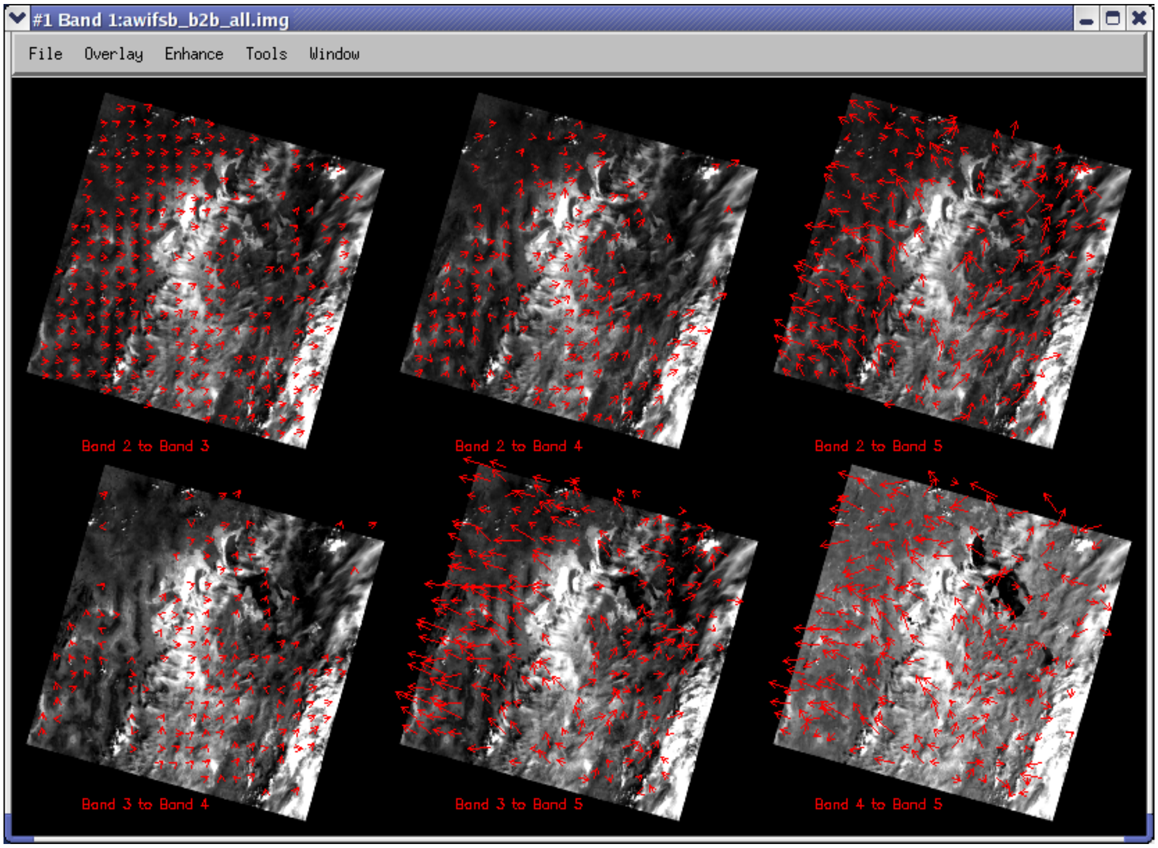


Figure 6-22 AWiFS-B Railroad Valley B2B Residual Vectors (Scaled by 1200)

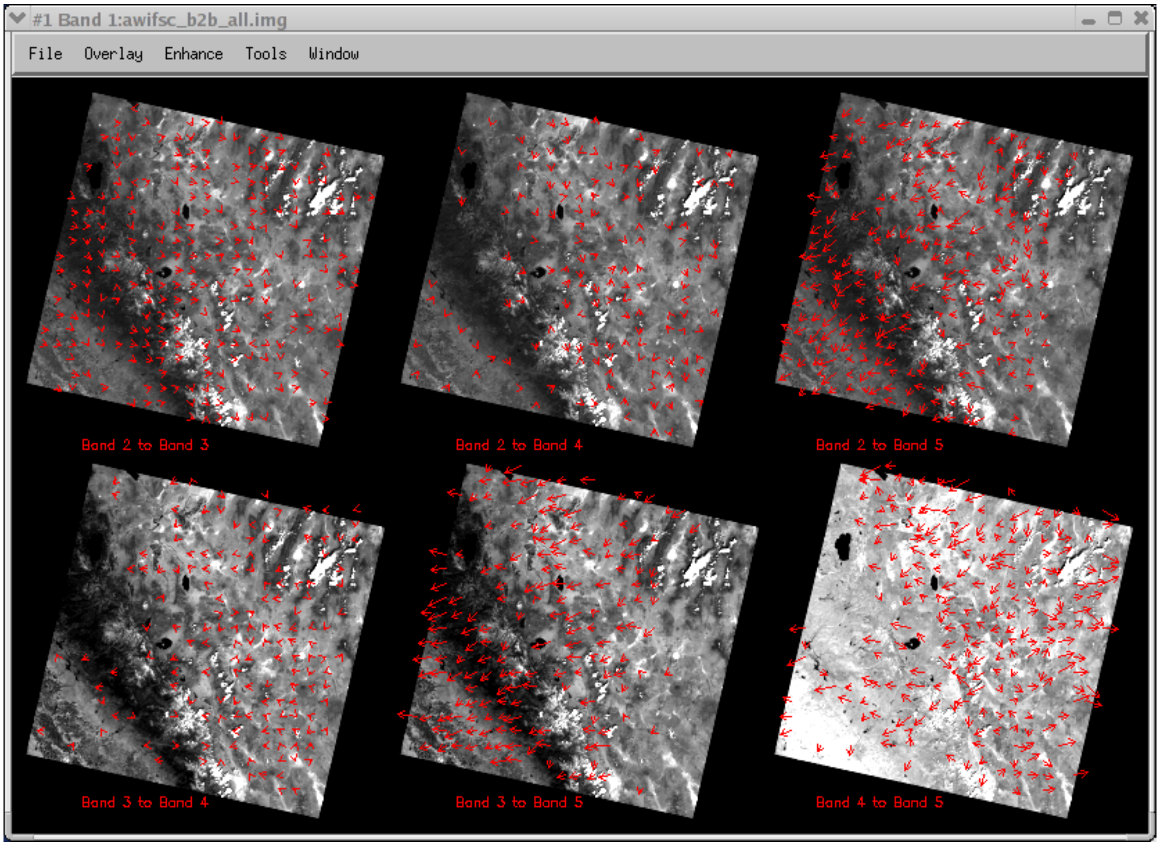


Figure 6-23 AWiFS-C Railroad Valley B2B Residual Vectors (Scaled by 1200)

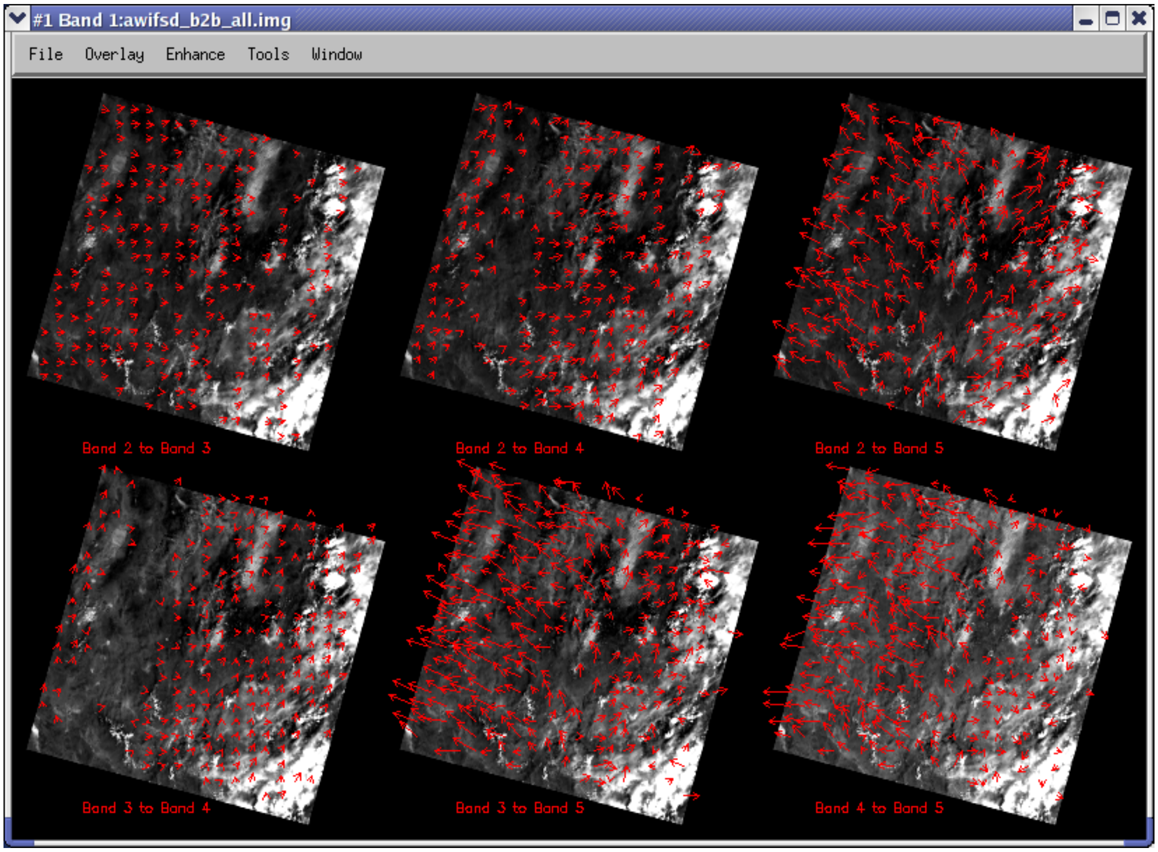


Figure 6-24 AWiFS-D Railroad Valley B2B Residuals Vectors (Scaled by 1200)

LISS-III Railroad Valley

Like the case involving the LISS-III Arizona scene, the Railroad Valley LISS-III data set had complete coverage with the DOQ mosaic. Figure 25 shows side-by-side views of the Railroad Valley LISS-III data set and the corresponding DOQ mosaic coverage available. As with the earlier DOQ mosaics, the radiometric differences between individual DOQs are readily apparent, showing up as checkered pattern throughout the image file.

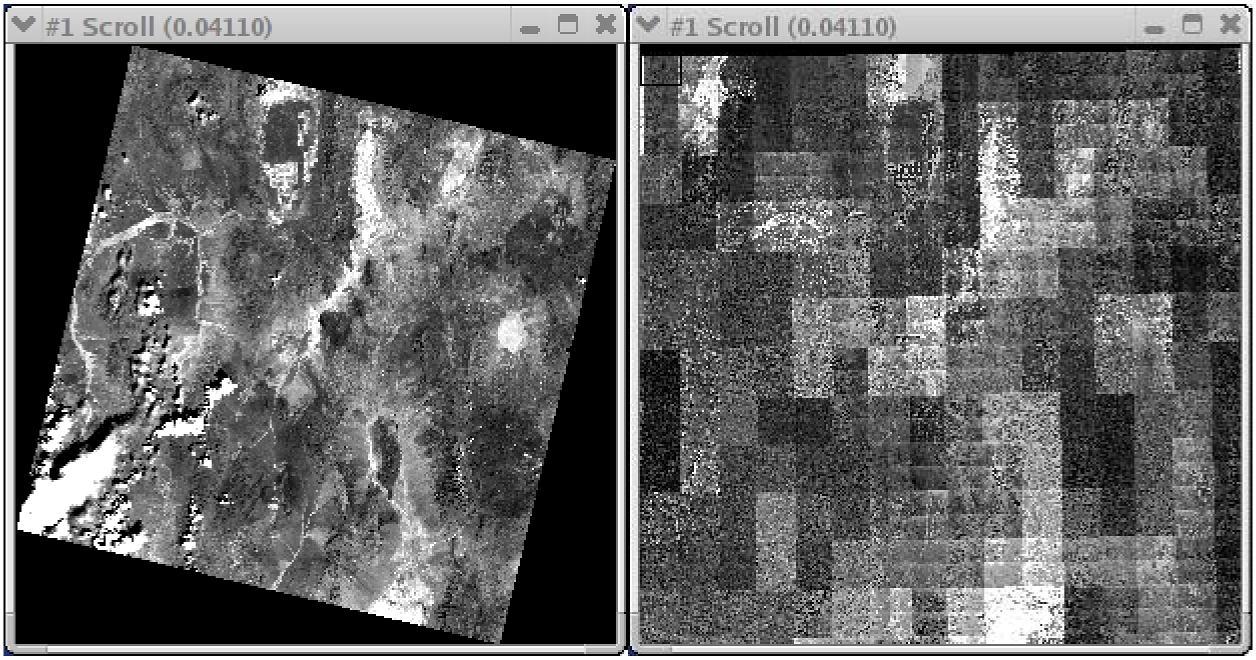


Figure 6-25 LISS-III and DOQ Mosaic of Railroad Valley

Geometric Accuracy Assessment

The I2I statistics for the LISS-III Railroad Valley data set are listed in table 10. Values are listed in terms meters. From the table it can be seen that the LISS-III data set and the DOQ mosaic are in close agreement.

	Correlated	Kept	StDevL	StDevS	RMSEL	RMSES
LISS-III	342	199	3.25945	2.912	3.487	9.097

Table 6-10 AWiFS-D Railroad Valley I2I Statistics (Listed in Meters)

Figure 26 shows a vector plot for the I2I residuals between the LISS-III and DOQ Railroad Valley data set. Vectors are scaled by a factor of 350 so that they can be viewed within the image. Like the LISS-III Arizona data, the Railroad Valley data set is in close agreement to that of the DOQ mosaic.

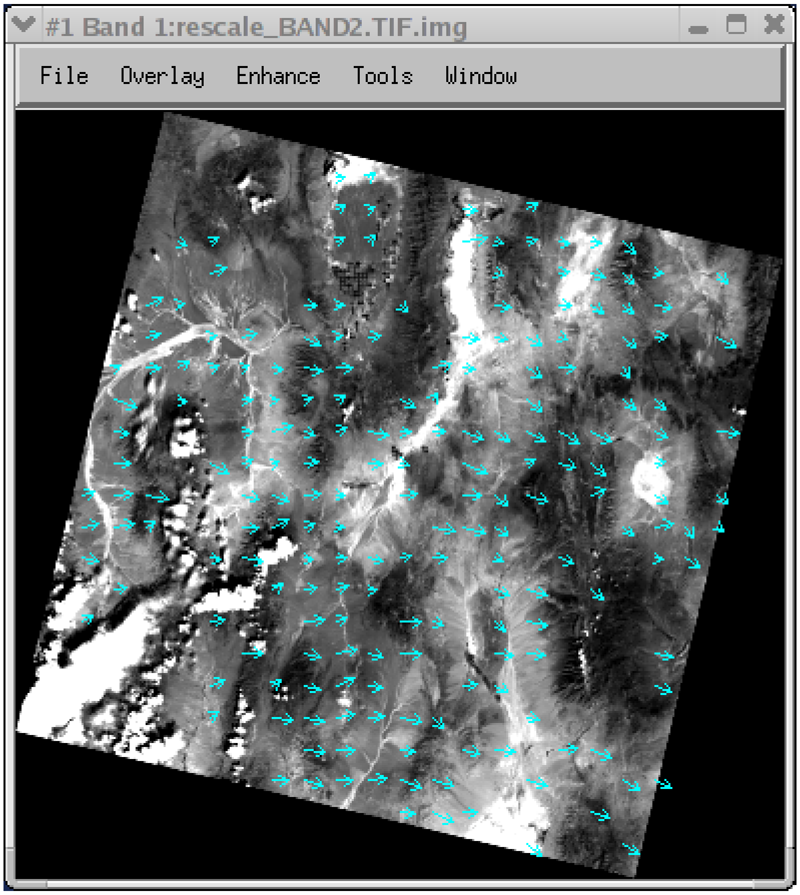


Figure 6-26 LISS-III Railroad Valley I2I Residual Vectors (Scaled by 350)

Band-to-Band Registration Assessment

Table 11 gives the statistical values associated with the B2B assessment for the Railroad Valley LISS-III data set. All values are given in terms of 23.5-meter pixels.

	Rband	Sband	Correlated	Kept	StDevL	StDevS	RMSEL	RMSES
LISS-III	2	3	395	273	0.08324	0.02066	0.16589	0.07507
	2	4	393	241	0.06012	0.08167	0.08314	0.13762
	2	5	394	256	0.09039	0.07859	0.09415	0.11794
	3	4	394	200	0.04144	0.05549	0.12041	0.07635
	3	5	394	237	0.04947	0.08265	0.12463	0.08754
	4	5	392	174	0.06117	0.05555	0.06140	0.06184

Table 6-11 LISS-III Railroad Valley B2B Statistics (Listed in Pixels)

Figures 27 show band-to-band vector residuals for each band pair. Residuals are scaled by a factor or 1200 so that they will be viewable within the plot. The purpose of the plots is to identify any measurable systematic pattern between band pairings rather than trying to identify the magnitude of the differences.

Under this premise, as in the Arizona LISS-III data set, there appears to be a small systematic displacement between bands 2 and 3. From table 11 it can be noted that in both LISS images the sample RMSEs are significantly larger than the StDevs (indicating the presence of a bias) for all combos that include band 2. Similarly, the line RMSE/StDev comparison indicates a bias in all combos including band 3.

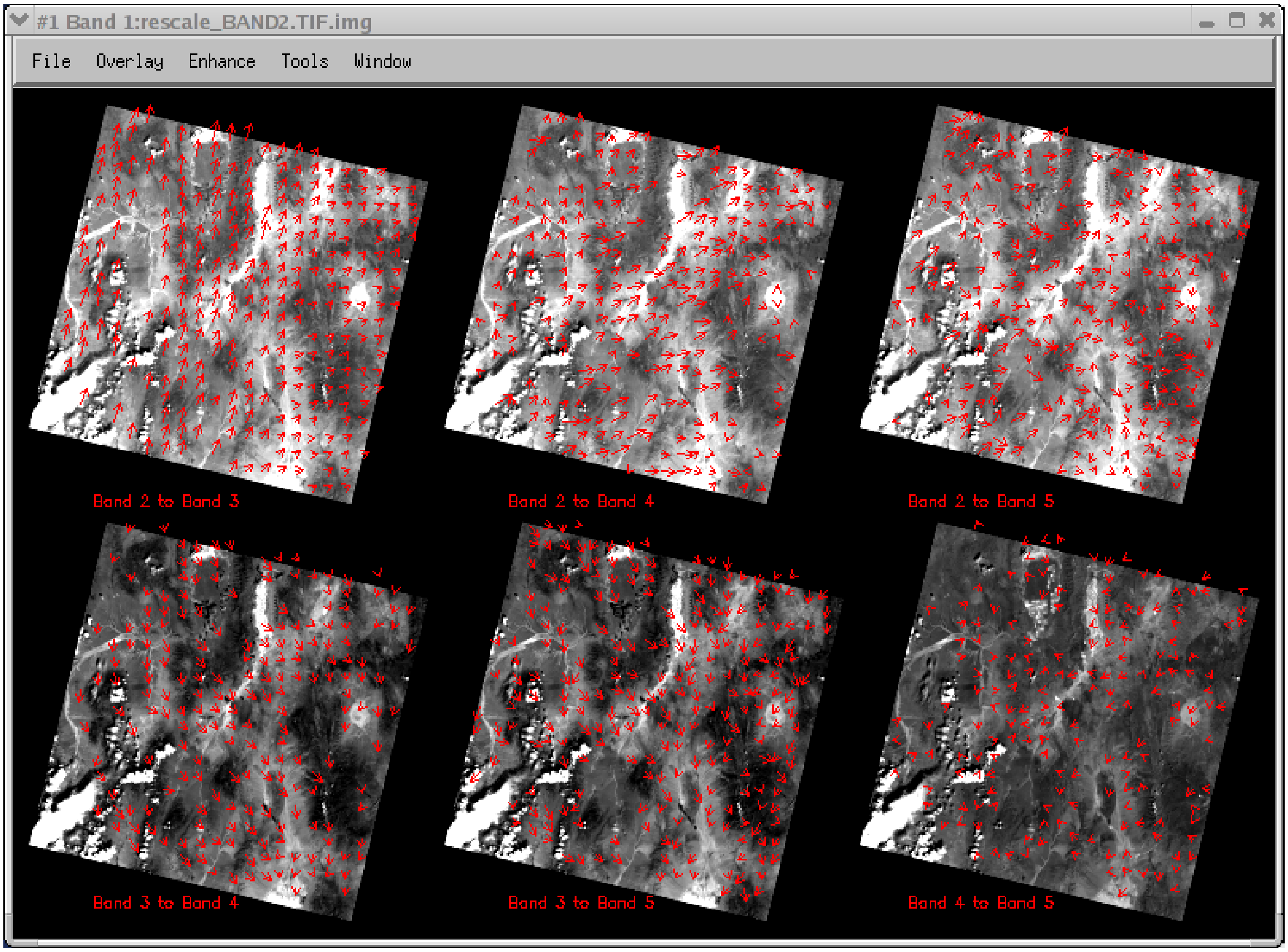


Figure 6-27 LISS-III Railroad Valley B2B Residual Vectors (Scaled by 1500)

Geometry Summary and Final Comments

Although the extent of available DOQ control severely limited the ability to make a geodetic assessment of the AWiFS instrument, the small field of view that was assessed showed relatively good agreement with the DOQs that was used as control during processing. The image-to-image statistics produced for the AWiFS instrument, as compared to the DOQ, are listed in table 12. The LISS-III instruments smaller field of view allowed for a more thorough geodetic assessment than that performed for the AWiFS instrument. The LISS-III image-to-image statistics, as compared to the DOQ used as control, are listed in table 13.

Instrument/Data set	RMSE Line Direction (meters)	RMSE Sample Direction (meters)
Arizona AWiFS-C	11.581	7.375
Arizona AWiFS-A	39.742	12.802
Railroad Valley AWiFS-D	7.526	17.954

Table 6-12 AWiFS I2I Statistics (Listed in Meters)

6.1.1.1.1 Instrument/Data Set	RMSE Line Direction (meters)	RMSE Sample Direction (meters)
Arizona LISS-III	3.729	2.836
Railroad Valley LISS-III	3.487	9.097

Table 6-13 LISS-III I2I Statistics (Listed in Meters)

To try to get a better assessment of the overall geometric accuracy of the AWiFS data sets, MRLC data sets were used as control. Although this more than likely led to using less accurate control than what could be obtained using the DOQs it did allow the full AWiFS data set to be assessed. Results are listed in table 14, values are given in meters.

	Points	Mean		RMSE	
		Line	Sample	Line	Sample
AWiFSA	234	-4.592	-9.352	14.784	14.224
AWiFSB	133	-27.160	-19.320	27.720	25.648
AWiFSC	166	1.848	-7.056	5.264	10.248
AWiFSD	103	-20.944	-21.504	22.736	24.360

Table 6-14 Image-to-Image assessment between Railroad Valley AWiFS data sets and MRLC

Values are listed in terms of pixels

The AWiFS band-to-band statistics are listed in table 15. The LISS-III band-to-band statistics are listed in table 16. The need to have good, identifiable features throughout all bands when doing a band-to-band assessment can make the measurement of band alignment a difficult task. Experience gained during assessment of the Landsat ETM+ instrument shows that dry arid regions work best. Both the Arizona and Railroad Valley sight have exhibited qualities that allow them to be used in band-to-band assessment; however the offsets must be weighed against the standard deviation of the residuals, which can indicate poor features or correlation, and the patterns associated with a plotting of the residuals. Taking these factors into account and noting that the Landat Data Continuity Mission specification for band-to-band registration is 0.15 pixels; both the AWiFS and LISS-III instruments band alignment would need further investigation before they could be stated to meet the necessary requirements.

Data Set	Reference Band	Search Band	RMSE Line	RMSE Sample		Reference Band	Search Band	RMSE Line	RMSE Sample
AWIFSA	2	3	0.04382	0.06592	AWIFSA	2	3	0.04135	0.07413
Arizona	2	4	0.08403	0.08600	Railroad	2	4	0.09105	0.08618
	2	5	0.09238	0.11779	Valley	2	5	0.14919	0.15088

	3	4	0.07558	0.07016		3	4	0.05547	0.07090
	3	5	0.10121	0.15835		3	5	0.11036	0.21430
	4	5	0.10963	0.15464		4	5	0.08370	0.16688
AWIFSB Arizona	2	3	0.05388	0.10192	AWIFSB Railroad Valley	2	3	0.04473	0.11329
	2	4	0.12407	0.14688		2	4	0.09917	0.12965
	2	5	0.21235	0.16775		2	5	0.19267	0.20619
	3	4	0.07159	0.07729		3	4	0.06560	0.07051
	3	5	0.14464	0.23672		3	5	0.14773	0.25554
	4	5	0.15958	0.24792		4	5	0.16418	0.24253
AWIFSC Arizona	2	3	0.03736	0.05815	AWIFSC Railroad Valley	2	3	0.03397	0.06240
	2	4	0.07957	0.08418		2	4	0.07659	0.04298
	2	5	0.12030	0.15107		2	5	0.11299	0.15503
	3	4	0.04508	0.05547		3	4	0.03651	0.06133
	3	5	0.10627	0.19996		3	5	0.08081	0.20627
	4	5	0.07985	0.13505		4	5	0.10639	0.18669
AWIFSD Arizona	2	3	0.06174	0.09626	AWIFSD Railroad Valley	2	3	0.03808	0.10849
	2	4	0.12023	0.14688		2	4	0.09495	0.14275
	2	5	0.22521	0.16939		2	5	0.17632	0.20891
	3	4	0.07610	0.07560		3	4	0.07748	0.05903
	3	5	0.17400	0.23242		3	5	0.15645	0.26241
	4	5	0.14929	0.22538		4	5	0.13605	0.23520

Table 6-15 AWiFS B2B Statistics (Listed in Pixels)

Data Set	Reference Band	Search Band	RMSE Line	RMSE Sample	Data Set	Reference Band	Search Band	RMSE Line	RMSE Sample
LISS-III Arizona	2	3	0.18845	0.05252	LISS-III Railroad Valley	2	3	0.16589	0.07507
	2	4	0.07830	0.14568		2	4	0.08314	0.13762
	2	5	0.13489	0.11831		2	5	0.09415	0.11794
	3	4	0.11135	0.08848		3	4	0.12041	0.07635
	3	5	0.07953	0.07113		3	5	0.12463	0.08754
	4	5	0.04325	0.10920		4	5	0.06140	0.06184

Table 6-16 LISS-III B2B Statistics (Listed in Pixels)

References

[1] Lutes, James, “RESOURCESAT-1 Geometric Accuracy Assessment”, ASPRS 2005 Annual Conference, March 7-11, 2005 Baltimore Maryland

NASA SSC AWiFS Radiometric Characterization

Methodology

Radiometric characterizations of AWiFS image products were performed by members of the NASA Applied Sciences Directorate JACIE (Joint Agency Commercial Imagery Evaluation) team comprised of NASA SSC personnel and personnel from the UofA (University of Arizona) College of Optical Sciences, Remote Sensing Group and the SDSU (South Dakota State University) Electrical Engineering Department. All three groups employ a reflectance-based vicarious calibration approach to predict at-sensor radiance. In this approach, ground-based measurements of surface target reflectance and atmospheric properties are made coincident with the satellite acquisition (Pagnutti et al., 2002). The ground-based measurements along with AWiFS spectral response functions serve as input to radiative transfer codes to generate at-sensor radiance estimates. Calibration coefficients are determined by comparing the at-sensor radiance estimate to the average digital number (DN) associated with the target area found within the AWiFS image. Calibration coefficients derived from each radiometric calibration target were combined to generate an overall radiometric gain and offset for each of the four AWiFS multispectral bands assuming a linear response over the full dynamic range of the instrument. These calibration gain and offset values were compared to those provided in the metadata of the AWiFS image products.

The SSC group performed radiometric characterizations using data from four relatively homogeneous naturally occurring targets selected around the town of Wiggins in southeastern Mississippi and in the vicinity of Park Falls Wisconsin near an AERONET (Aerosol Robotic Network) site. The UofA group performed radiometric characterizations using data collected over two large bright playas in the southwestern United States, Railroad Valley Playa in Nevada and Ivanpah Playa in California. The SDSU group performed radiometric characterizations using data collected over a large grassy field near the university in Brookings, South Dakota.

The four southeastern Mississippi target sites used by the SSC group are shown in Figure 6-28. Two of the radiometric target sites are sand fields formed by gravel mining; one site is a rye grass agricultural field; and the last site is a grassy field within an amateur golf course. With the exception of the golf course cut grass, the target sites are at least 4×4 AWiFS pixels in extent to minimize local adjacency effects caused by spatial blurring or MTF effects. Specifics associated with the two south Mississippi data collections are shown in Table 6-17. Both acquisitions were obtained in the spring of 2005 and were made with the AWiFS-B camera.

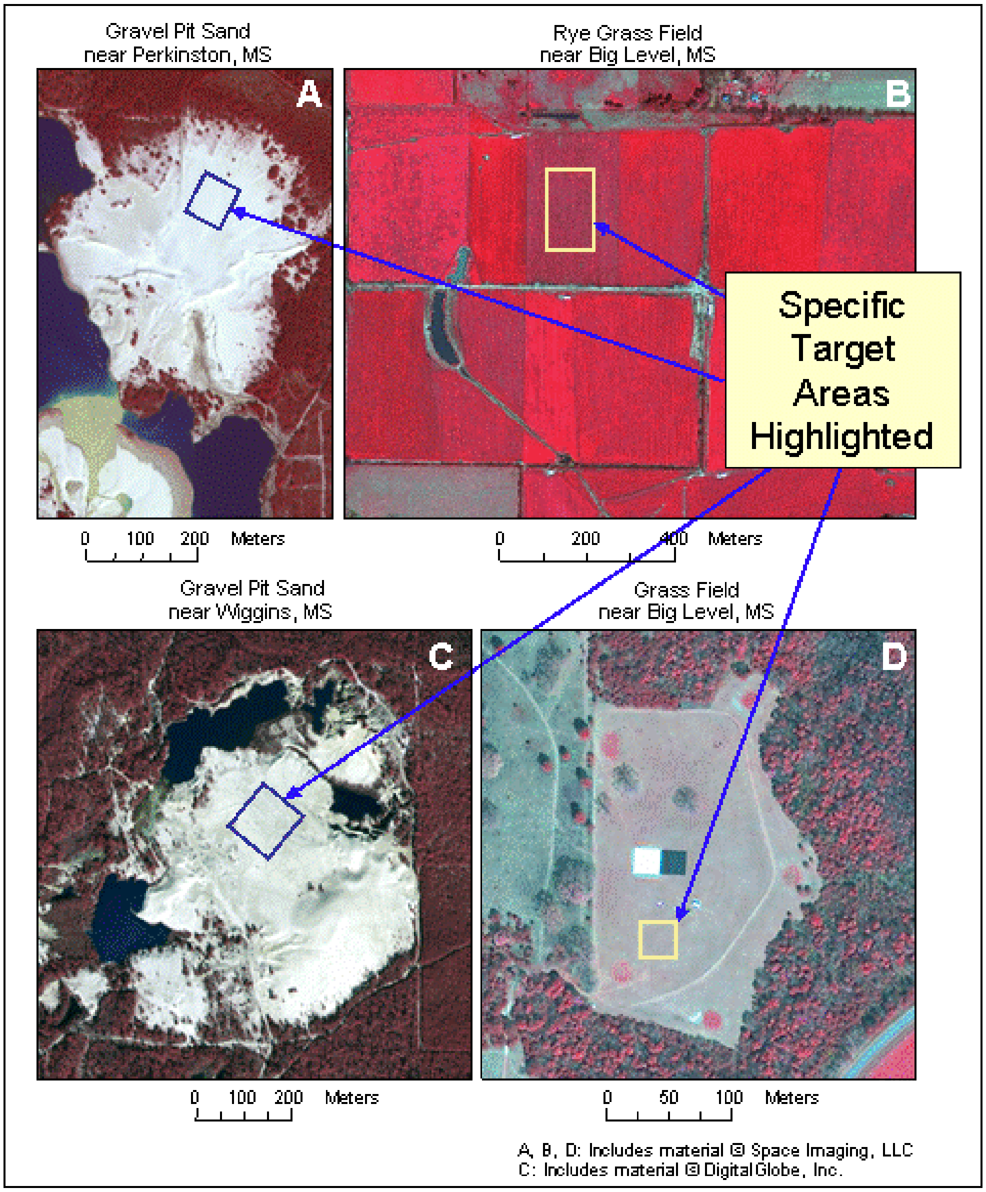


Figure 6-28. *AWiFS radiometric target sites in South Mississippi.*

Table 6-17. *South Mississippi data acquisitions.*

Date	Camera	Overpass Time (UTC)	Satellite Elevation	Satellite Azimuth	Sun Elevation	Sun Azimuth
24-Mar-2005	B	16:59	71.1 deg	285 deg	57.2 deg	149.8 deg
27-Apr-2005	B	16:50	84.5 deg	285 deg	67.7 deg	135.4 deg

The large grass field characterization site near Park Falls Wisconsin used by SSC is shown in Figure 6-29. The image was acquired by the AWiFS-A camera. Specifics associated with the Wisconsin data collection are shown in Table 6-18.

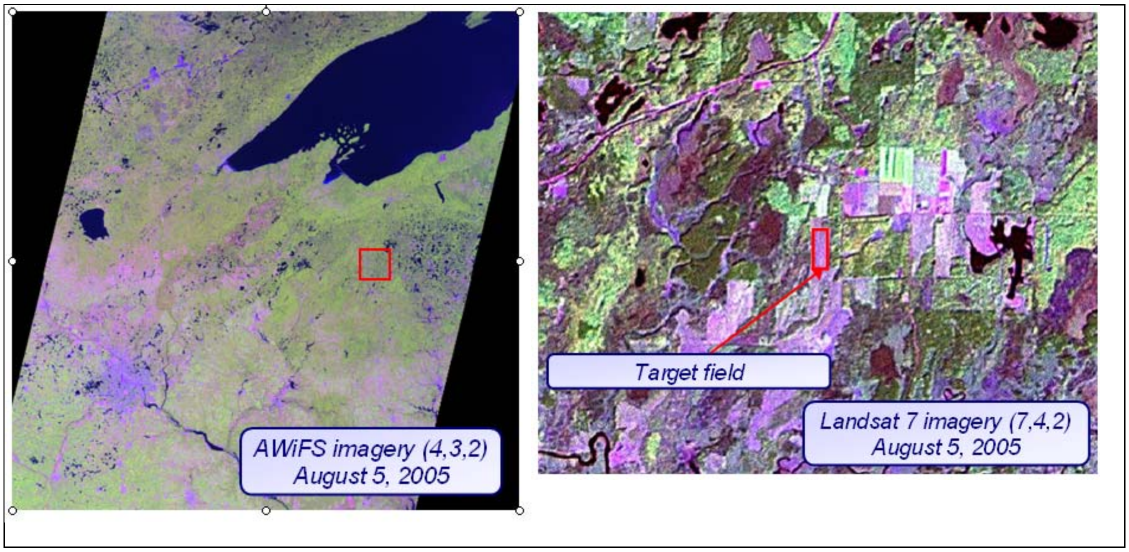
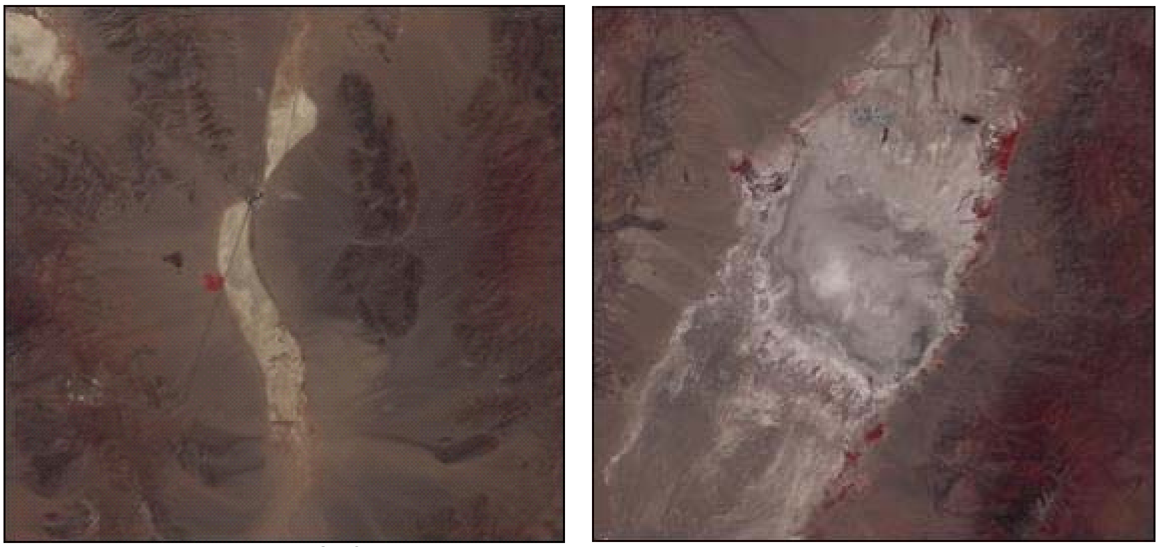


Figure 6-29. *AWiFS radiometric target site near Park Falls, Wisconsin.*

Table 6-18. *Park Falls Wisconsin data acquisitions.*

Date	Camera	Overpass Time (UTC)	Satellite Elevation	Satellite Azimuth	Sun Elevation	Sun Azimuth
5-Aug-2005	A	17:02	83.9 deg	103 deg	57.8 deg	149.7 deg

The two southwestern U.S. playa characterization sites used by the UofA group are shown in **Error! Reference source not found.**. The two playas are relatively bright and uniform. Their high elevation (over 1000 m) and high reflectance minimizes atmospheric uncertainties, and their large extent minimizes any MTF effects. Specifics associated with the four southwestern U.S. playa data collections are shown in Table 6-19. Both radiometric target sites were acquired simultaneously with a single AWiFS acquisition on June 18. All of the acquisitions were made with the AWiFS-B camera.



Ivanpah Playa , California
35.53° N, 115.38° W

Railroad Valley Playa, Nevada
38.51° N, 115.69° W

Figure 1. Landsat imagery of southwestern playa radiometric characterization sites.

Table 6-19. *Southwestern U.S. playa data acquisitions.*

Date/ Location	Camera	Overpass Time (UTC)	Satellite Elevation	Satellite Azimuth	Sun Elevation	Sun Azimuth
18-Jun-2005 Ivanpah	B	18:46	73.6 deg	285 deg	72.7 deg	130.8 deg
18-Jun-2005 RRV	B	18:46	80.6 deg	285 deg	70.5 deg	136.5 deg
23-Jun-2005 Ivanpah	B	18:42	79.6 deg	285 deg	71.9 deg	128.0 deg

10-Aug-205 RRV	B	18:41	86.8 deg	283 deg	64.5 deg	143.7 deg

The grassy field site used by the SDSU group in Brookings South Dakota, is shown in Figure 6-30. A portion of the grassy field was mowed and used as a cut grass target. The remainder of the field was left as is and used as a tall grass target. Specifics associated with the AWiFS acquisition is shown in Table 6-20. Both sites were acquired with a single acquisition in June of 2005 with the AWiFS-A camera.

SDSU cut grass target

SDSU long grass target

Figure 6-30. *SDSU grass field characterization sites.*

Table 6-20. *Southwestern U.S. playa data acquisitions.*

Date/ Location	**Camera**	**Overpass Time (UTC)**	**Satellite Elevation**	**Satellite Azimuth**	**Sun Elevation**	**Sun Azimuth**
22-Jun-2005 SDSU	A	17:20	75.6 deg	103 deg	65 deg	138 deg

The SSC group conducted reflectance measurements of each target using Analytical Spectral Devices, Inc. (ASD), spectroradiometers and Spectralon® reference panels that were characterized to National Institute of Standards and Technology (NIST)-traceable standards. The spectroradiometers were calibrated in the SSC Instrument Validation Laboratory before being fielded. Radiometric, spectral, and environmental testing were performed on each spectroradiometer. Radiometric calibrations were conducted using a NIST calibrated tungsten-halogen lamp illuminated integrating sphere as the known spectral radiance source. Spectral calibrations were performed using an integrating sphere illuminated with both lasers and a pen lamp. Temperature stability tests were performed by monitoring the performance of spectroradiometers measuring a known source while in an environmental chamber. The chamber was set to temperatures spanning expected field conditions.

At each SSC site, target reflectance measurements were taken at the same azimuth and elevation angles as those acquired by the AWiFS sensor. All measurements were taken while walking to increase spatial averaging. Spectralon reflectance measurements were corrected with laboratory measurement data to account for the bi-directional reflectance based on solar and satellite viewing geometries. Solar irradiance was measured with Automated Solar Radiometers (ASRs) and Yankee Environmental Systems Multifilter Rotating Shadowband Radiometers. Sky conditions and cloud cover were monitored during the data collection period using full sky imagers. Ground pressure measurements were also taken to determine Rayleigh scattering within the atmosphere.

The UofA and SDSU groups also obtained reflectance measurements using ASD spectroradiometers and Spectralon reference panels that are characterized to NIST-traceable standards. UofA personnel did not directly measure the reflectance of the Railroad Valley playa on June 18. Instead, they corrected reflectance measurements taken the day before with their newly designed autonomous radiometer setup (Thome et al., 2005). Solar irradiance values were obtained from the aerosol robotic network (AERONET) of Cimel sun photometers (Holben et al., 1998). All other ground measurements were taken with the spectroradiometers and ASRs simultaneously to the AWiFS sensor acquisition.

MODTRAN, the Moderate Resolution Transmittance code developed by the Air Force Research Laboratory (Berk et al., 2003), was used by all three teams to predict radiative transport. The surface and atmospheric data taken at each site coincident with each AWiFS acquisition were used to define a radiative transport model within MODTRAN, which then propagated the measurements through the atmosphere to the sensor in space. Additional required model parameters include sensor spectral response, sensor geometry, solar geometry, and target location in Earth coordinates. The result is a prediction of at-sensor average spectral radiance per band.

All three groups' predicted target at-sensor radiance values were compared to the radiance values measured by the AWiFS sensor. The pixel DNs associated with each target were obtained from each band of the image and then area-averaged. This area-average comprised pixel DNs from the center of each target so that no edge pixels were included in the average. The average DN values for each target were plotted against the predicted at-sensor radiance to estimate the gain and offset of each band. The overall estimated sensor gain and offset for each band was calculated using a least square fit regression line fitted through all of the plotted values. The uncertainty in the estimation was found using a one-sigma standard deviation of the individual values. The overall estimated gain and offset were compared to those provided in the image metadata to determine accuracy of the radiometric calibration.

Results

In total, ten radiometric calibration targets were measured by the AWiFS-B sensor and three radiometric targets were measured by the AWiFS-A sensor in the spring and summer of 2005. The images were geometrically and radiometrically corrected and provided at the standard (non-orthorectified) product level. A cubic convolution re-sampling method was used by the data provider to process the images. Table 6-21 contains a summary of the acquisitions and targets used for the radiometric characterization.

Table 6-22 summarizes the radiometric characterization results obtained during this evaluation for each of the four multispectral bands of the AWiFS sensor. Because of the imited number of data sets available, no attempt was made to separate out radiometric calibration constants for the AWiFS-A and -B cameras. The table provides the overall team estimated gain and offset values, with uncertainty, along with the gain and offset values provided in the image metadata

Table 6-21. *Radiometric characterization scene and target summary.*

Characterization Scene	Acquisition Date	AWiFS Image ID Path-Row-Quad	Radiometric Target
Wiggins, MS	24-Mar-2005	276-47-D	Cut grass (golf course)
			Rye grass agricultural field
			Sand field (Perkinston)
Wiggins, MS	27-Apr-2005	278-47-D	Rye grass agricultural field
			Sand field (Perkinston)
			Sand field (Diamond)
Railroad Valley, NV	18-Jun-2005	250-45-B	Playa
Ivanpah Playa, CA	18-Jun-2005	250-45-B	Playa
Brookings, SD	22-Jun-2005	270-37-C	Cut grass field
			Tall grass field
Ivanpah Playa, CA	23-Jun-2005	251-45-B	Playa
Park Falls, WI	5-Aug-2005	274-35-C	Grass field
Railroad Valley, NV	10 Aug-2005	251-42-D	Playa

Table 6-22. *AWiFS radiometric characterization summary.*

	Band 2 (Green)	**Band 3 (Red)**	**Band 4 (NIR)**	**Band 5 (SWIR)**
NASA SSC Team				
Gain (W/m2 sr µm DN)	0.60 ± 0.02	0.46 ± 0.01	0.31 ± 0.02	0.056 ± 0.004
Offset (W/m2 sr µm)	-5.49 ± 5.36	2.60 ± 3.89	-3.11 ± 6.69	-2.82 ± 2.15
AWiFS Image Metadata				
Gain (W/m2 sr µm DN)	0.51	0.40	0.28	0.045
Offset (W/m2 sr µm)	0	0	0	0

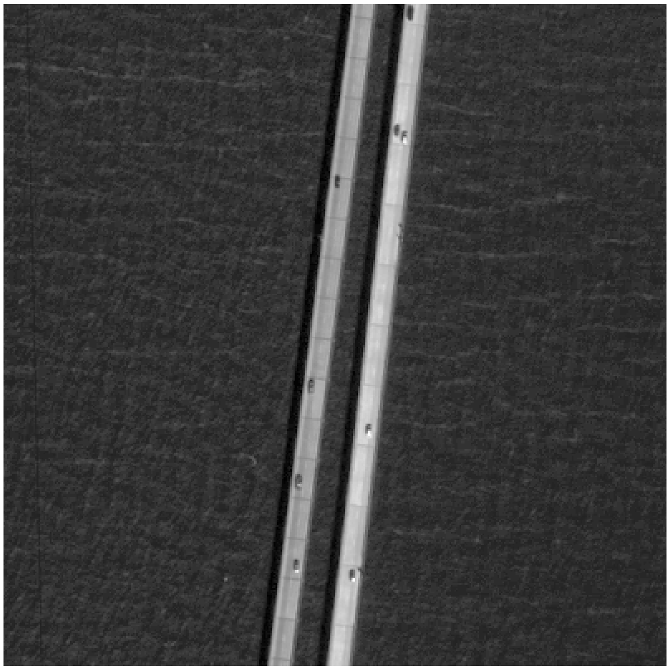
NASA SSC AWiFS Spatial Resolution Characterization

Methodology

Spatial resolution of the AWiFS multispectral images was characterized by the SSC team by estimating the value of the system MTF at the Nyquist spatial frequency. The Nyquist frequency is defined as half the sampling frequency, and the sampling frequency is equal to the inverse of the GSD. The MTF was calculated from a ratio of the Fourier transform of a profile across an AWiFS image of the Lake Pontchartrain Causeway Bridge and the Fourier transform of a profile across an idealized model of the bridge Figure 6-31. Magnitude of the ratio normalized to the zero-frequency value provides the final MTF.

Figure 6-31. *Image of the Lake Pontchartrain Causeway Bridge acquired by AWiFS on January 16, 2005. Spectral bands 4, 3, and 2 are shown as the red, green, and blue colors, respectively.*

The Lake Pontchartrain Causeway was selected as a target in this characterization because it forms a long double bar target on a background of relatively dark and uniform water surface (Figure 6-31) and a model profile of this target can be constructed. Direction of the bridge is also conveniently tilted from the pixel lines in the AWiFS images, and this tilt creates sub-sampling in the image of the bridge profile that allows for sub-pixel reconstruction of the spatial response.



Includes material © DigitalGlobe, Inc.

Figure 6-32. *Close-up image of a short span of the Lake Pontchartrain Causeway Bridge acquired with the panchromatic camera of the commercial QuickBird satellite on January 2, 2003. Ground sample distance of the original image is 70 cm.*

Two images acquired by the AWiFS sensor in 2005 were used for the current spatial resolution characterization with each of the images captured by a different camera of the AWiFS sensor. Details about the acquisitions and the resulting image products are shown in Table 6-23. The image products used in the spatial resolution characterization were resampled during the production cycle to a GSD of 56 m using the Cubic Convolution (CC) method. The images contained 10-bit data per band for each pixel.

Table 6-23. *AWiFS images used for spatial resolution characterization in 2005.*

Path-Row-Quad	Acquisition		Quantization (bits)	GSD (m)	Resampling
	Date	Time (UTC)			
277-051-B	16-Jan-2005	16:56:38	10	56	CC
279-048-C	19-Jun-2005	16:45:41	10	56	CC

Because of the presence of suspended matter in Lake Pontchartrain at the time of the image acquisitions, the water background was not as uniform as expected (as can be seen in Figure 6-31). Therefore, smaller sections of the bridge images were selected for the analysis (Figure 6-33).

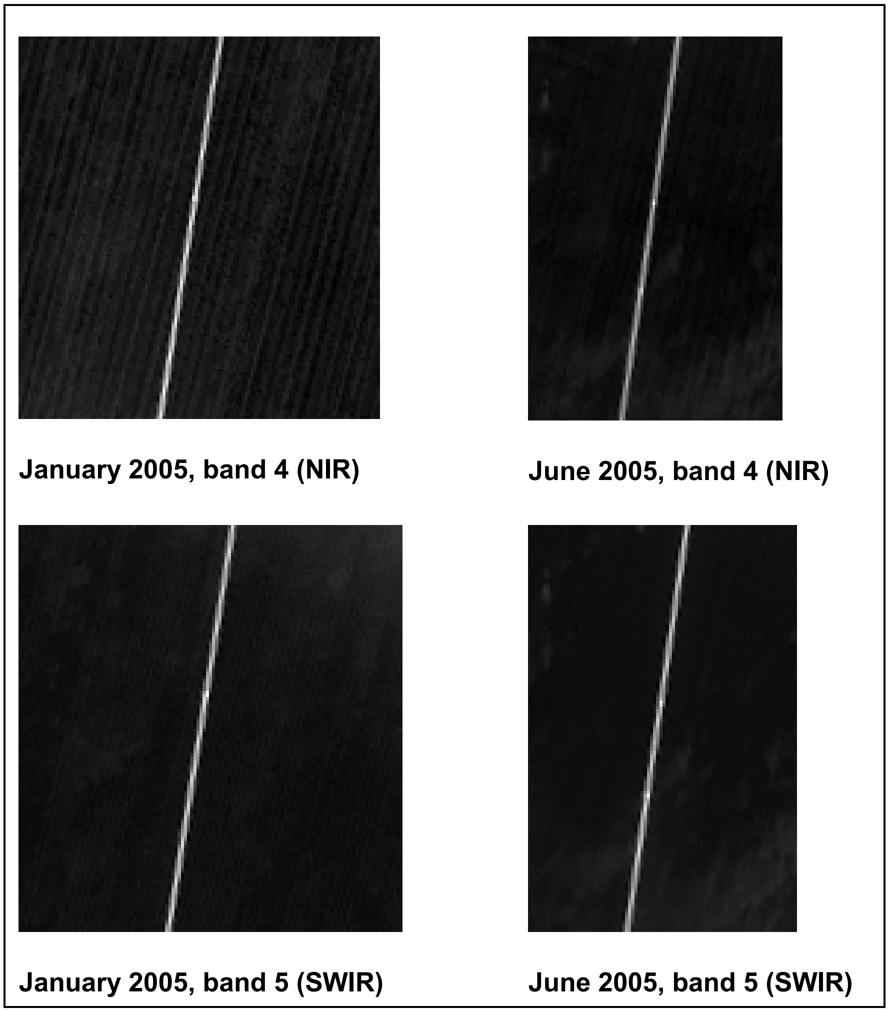


Figure 6-33. *Enlarged (2×) fragments of the AWiFS infrared images of the Lake Pontchartrain Causeway Bridge used for MTF measurements and spatial resolution characterization. The images were acquired in January and June 2005, as indicated.*

In the first step of the analysis, the rows of image pixels were aligned to each other to remove the bridge tilt and to create a bridge profile with multiple, sub-pixel sampling. The pixels were then aggregated over small, sub-pixel distance ranges to reduce noise in the measured bridge profile at a cost of decreasing spatial sampling. The aggregated bridge profile was subsequently Fourier transformed and divided by the transform of the model bridge profile.

The model of the bridge profile was created based on known dimensions of the Lake Pontchartrain Causeway Bridge and on measurements from the high-resolution imagery Figure 6-32. Two spans of the Causeway were built over a number of years. The first span opened to the public in 1956; the second opened in 1969, which is probably the reason for the reflectance difference between the spans. Based on the high-resolution, panchromatic images of the Causeway, reflectance of the older (western) span was assumed to be only 70 percent of the newer (eastern) span's reflectance. Validity of this assumption in the shortwave infrared spectral range must still be verified. Width and intensity of the bridge shadows were estimated based on the high-resolution images as well. Besides the spectral response differences, these images were acquired with different geometry of solar illumination, and thus the model of the shadows can be considered only as a first-order approximation.

Results

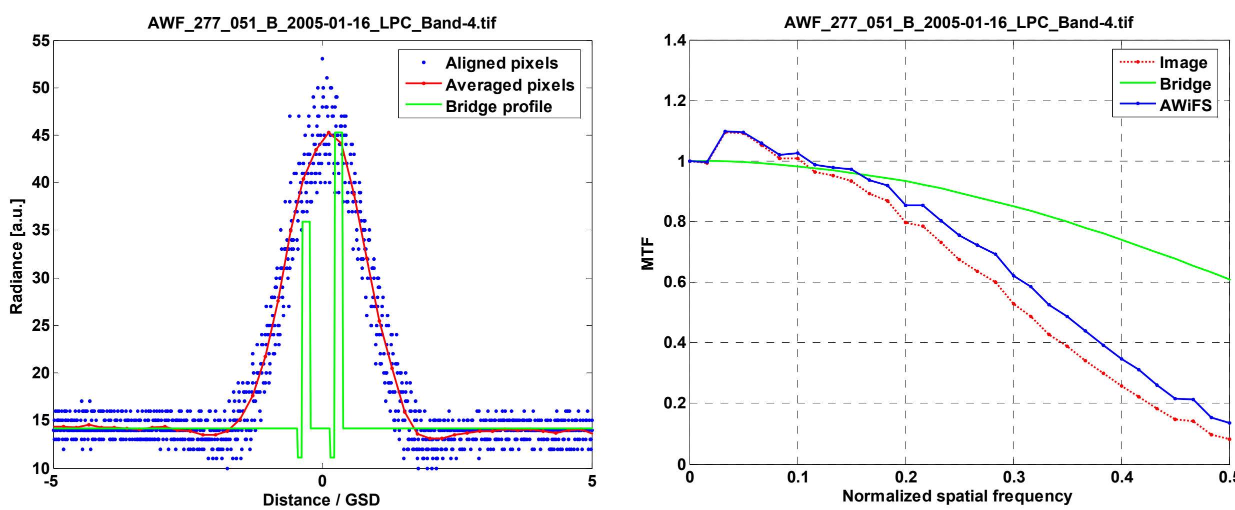
Left panels of Figure 6-34 and Figure 6-35 show bridge profiles created from actual, aligned image pixels, aggregated image pixels, and the bridge model. The aggregated profiles indicate that the AWiFS-B (Quad B) camera generated a sharper image than the AWiFS-A (Quad C) camera. When the Fourier transform is applied to the profiles and the ratios of the results are calculated, values of the derived MTFs confirm that observation (see right panels of the figures). MTF at Nyquist frequency is somewhat more than 0.1 for the NIR and SWIR bands of the AWiFS-B camera image, while it is less than 0.1 for the AWiFS-A image bands. The NIR images have slightly larger MTF values than the SWIR images, consistent with diffraction blurring. The estimates of MTF at the Nyquist frequency are shown in Table 6-24.

Table 6-24. *Results of 2005 spatial resolution characterization for images acquired by different AWiFS cameras.*

Band	MTF at Nyquist frequency	
	AWiFS-A	AWiFS-B
4 (NIR)	0.10	0.15
5 (SWIR)	0.05	0.10

While these values are not particularly large, these values are derived for resampled images (using the Cubic Convolution method), and the resampling is typically expected to degrade spatial resolution. Moreover, the small number of the Causeway images available for analysis allowed only for this preliminary characterization of spatial resolution provided by the AWiFS images. In the future, at least five images of the Causeway should be analyzed for each AWiFS camera to fully characterize their spatial resolution. Effects of uncertainties in the shape and dimensions of the bridge model should be assessed as well by conducting sensitivity studies.

NIR



A **B**

SWIR

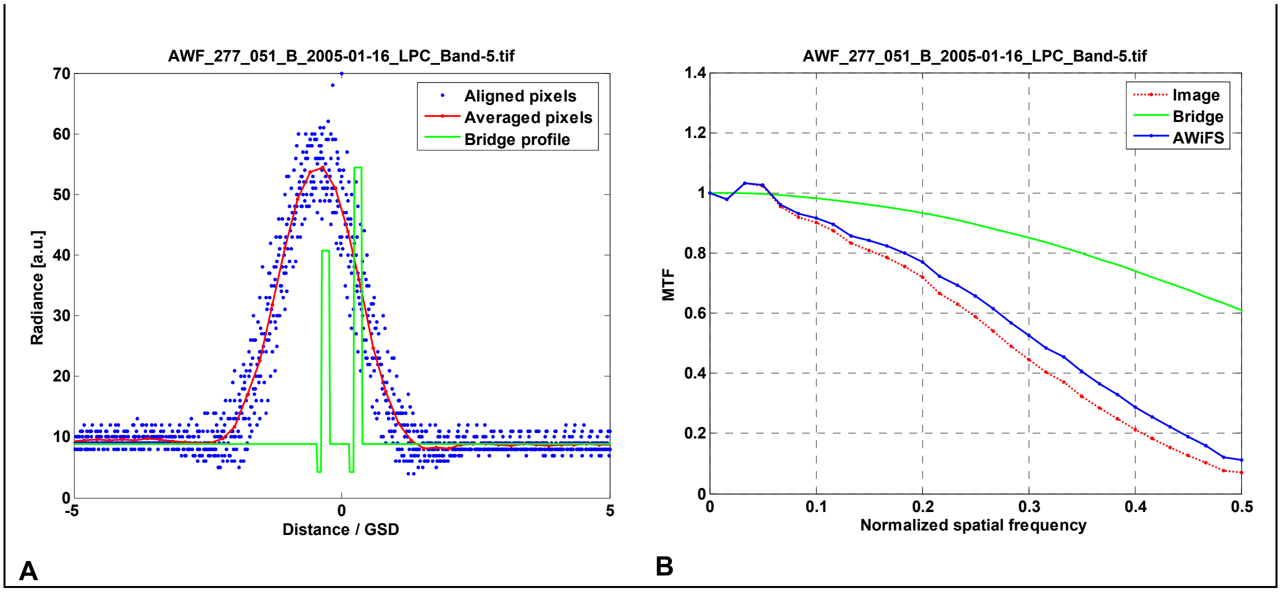


Figure 6-34. *MTF analysis for the NIR and SWIR bands of the AWiFS image acquired on January 16, 2005.*

A: Bridge profiles created from actual, aligned image pixels (blue dots), aggregated image pixels (red line), and the bridge model (green line). **B**: MTF curves derived from the aggregated (red line) and model (green line) bridge profile, and their ratio (blue line).

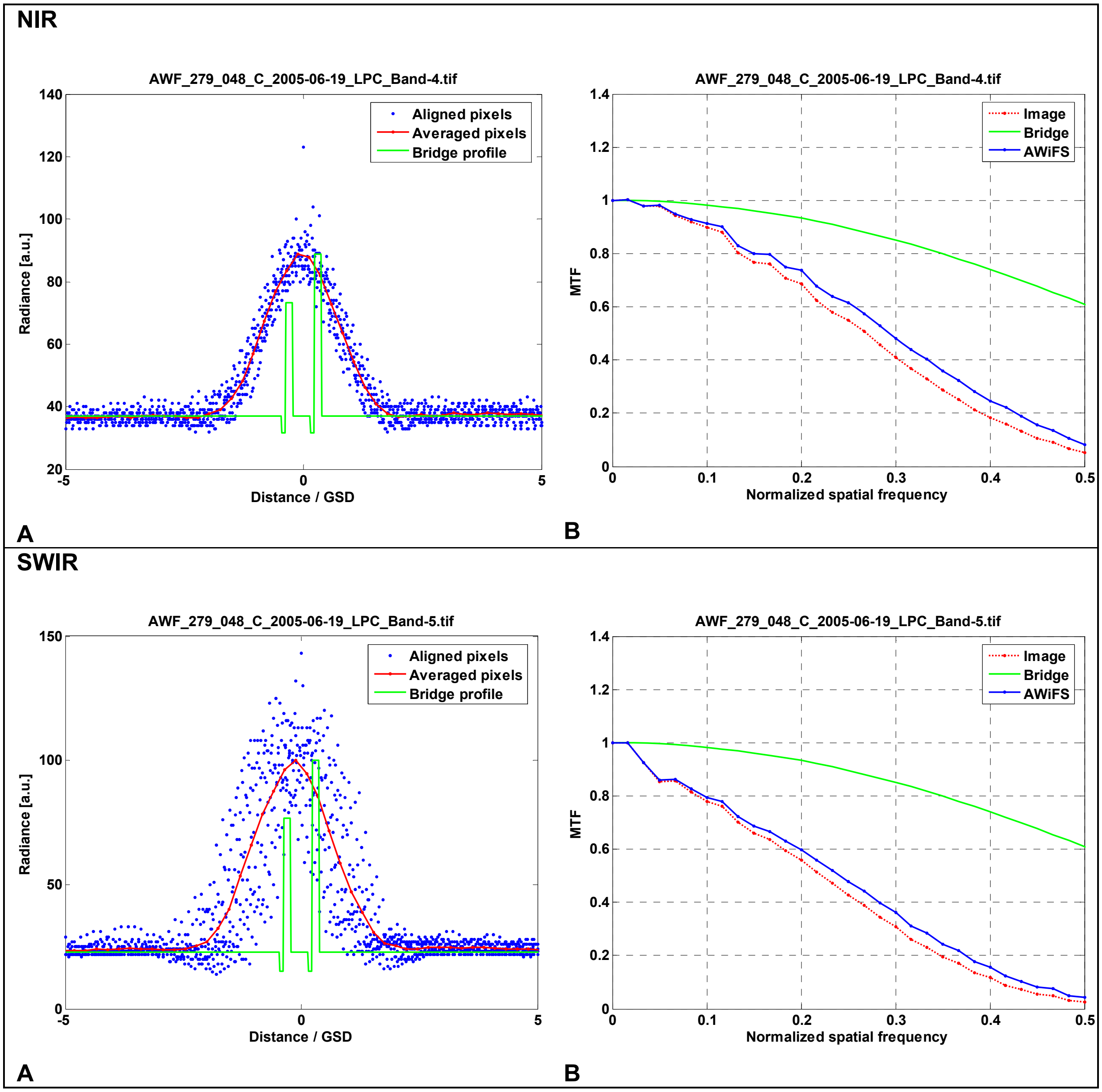


Figure 6-35. *MTF analysis for the NIR and SWIR bands of the AWiFS image acquired on June 19, 2005.*

A: Bridge profiles created from actual, aligned image pixels (blue dots), aggregated image pixels (red line), and the bridge model (green line). **B**: MTF curves derived from the aggregated (red line) and model (green line) bridge profile, and their ratio (blue line).

NASA SSC AWiFS Geopositional Characterization

Methodology

Data

The SSC geopositional characterization of standard AWiFS system corrected products was based on analysis of six AWiFS image quads (three from the AWiFS-A camera and three from the AWiFS-B camera). Acquisition dates ranged from August 14, 2004, through April 27, 2005. All scenes were acquired over the central United States.

The basic measurements in each scene were 45 to 50 check points collected in accordance with the guidelines of the National Standard for Spatial Data Accuracy (NSSDA) (FGDC, 1998). Reference coordinates for each check point were obtained from DOQQs or from other high resolution imagery of similar horizontal accuracy. The reference sources were chosen to provide reference circular error at the 90 percent level (CE_{90}) of 15 m or better.

The procedure for obtaining the check points started with the AWiFS image. First the largest usable parallelogram of image space was outlined as in Figure 6-36. Then the analysis space was broken into quadrants by bisecting opposing sides of the parallelogram. At least 20 percent of the check points were drawn from each quadrant. Selection of the check points was an iterative process. First, the check points were tentatively identified in areas of AWiFS image space where it was presumably most difficult to find well-defined points. Once tentative points were chosen in image space, the complements were sought in the reference space. Sometimes a potential check point was ambiguous in reference imagery or perhaps even missing because of differences in time of acquisition. In these cases, the reference and test images were compared until a suitable check point could be found, or a new reference was chosen and the process was repeated. Because of the total number of check points and the sparsity of well-defined points in some rural areas, it was not possible to maintain the minimum spacing advised by the NSSDA. Subjectively, however, an attempt was made to maximize spacing and to keep distribution as even as possible throughout the analysis area. Only one check point was allowed per reference image. An example check point distribution is shown in Figure 6-37.

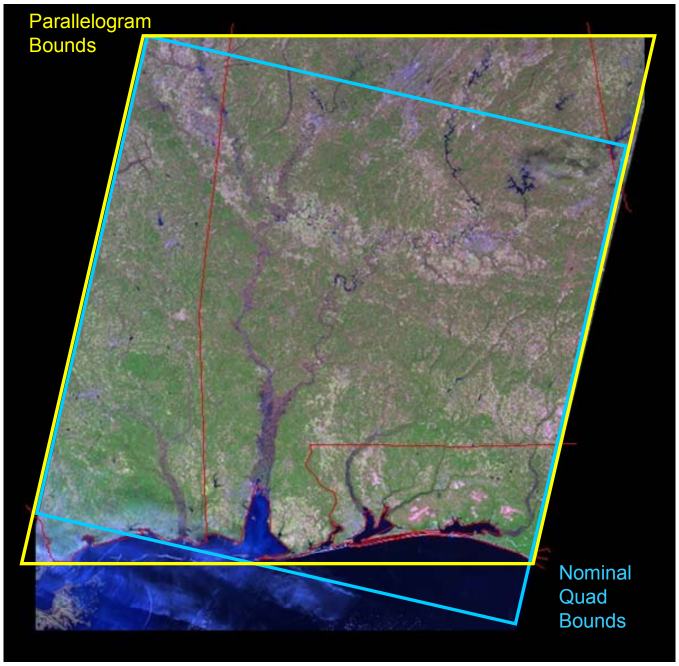


Figure 6-36. *Analysis parallelogram in comparison with nominal AWiFS quad boundary.*

It is important to note for this analysis that co-registration error was considered to be less than analyst pointing error, so the image analyst was allowed to collect points from a multispectral view.

Error Model

The computations used to estimate AWiFS product accuracy are more understandable if the geopositional error model employed is explicitly defined. The statistical measures used in the NSSDA imply the following simple additive error model:

$$X_{image} = X + \varepsilon \qquad (1)$$

Where X_{image} represents image coordinates, X represents reference coordinates and ε represents error.

Identification of the constant component of image error (sometimes called the *horizontal bias*), although not required by the NSSDA, is often helpful. This divides the error into two parts

$$\varepsilon = \varepsilon_{constant} + \varepsilon_{zero-mean} \qquad (2)$$

With AWiFS, the zero-mean error was found to have a strong systematic component that was functionally dependent on across-position, u:

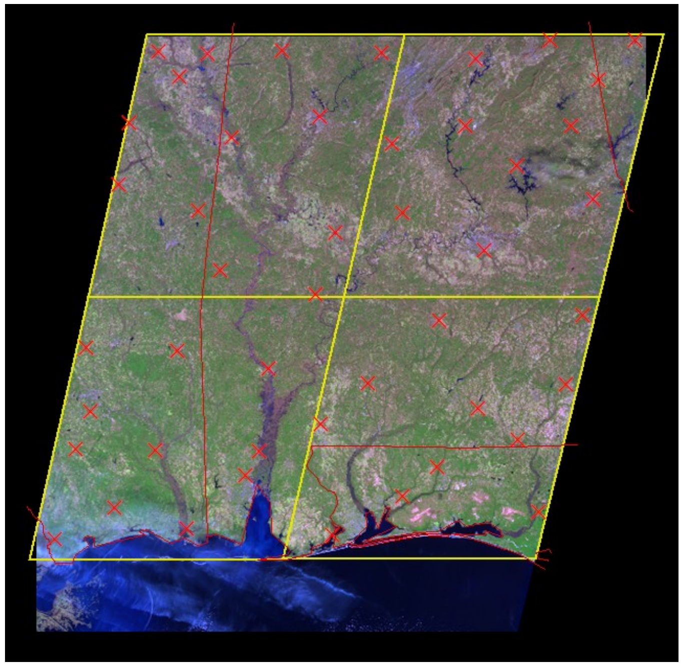


Figure 6-37. *Example distribution of check points for AWiFS Path 282, Row 50, Quad C acquired on January 17, 2005.*

$$\varepsilon_{zero-mean} = \varepsilon_{along\text{-}track}(u) + \varepsilon_{across-track}(u) + \varepsilon_{non-systematic} \qquad (3)$$

Where $\varepsilon_{non-systematic}$ represents the residual error after all systematic components have been removed.

Error Estimates

All error estimates were based on the residuals, which were simply difference in the image and reference check point coordinates

$$\Delta X_i = X_{image,\ i} - X_{reference,\ i}$$
$$\Delta Y_i = Y_{image,\ i} - Y_{reference,\ i} \qquad (4)$$

The NSSDA treated total error in terms of circular error statistics. Circular error represents the radius of the circle that if placed at any given reference coordinate would capture the fraction of corresponding image points that corresponds to a chosen confidence level. The NSSDA preferred a 95 percent confidence level, but in common practice many still use 90 percent confidence levels, as established by the National Map Accuracy Standards (U.S. Bureau of the Budget, 1947). This report computed circular error at the 90 percent confidence level (CE_{90}). Rather than computing CE_{90} based on assumptions about the distribution of error, it was computed as the 90th percentile of the magnitude the residuals, ΔR, where

$$\Delta R_i = \sqrt{\Delta X_i^2 + \Delta Y_i^2} \qquad (5)$$

The constant geopositional error or horizontal bias, μ_H, was estimated as magnitude of the mean of the residuals

$$\hat{\mu}_H = \sqrt{\overline{\Delta X}^2 + \overline{\Delta Y}^2} \qquad (6)$$

The zero-mean mean error may be characterized with a scalar that summarizes the standard deviation of error in both the *X* and *Y* dimensions. Greenwalt and Shultz (1962) argued that the proper estimate is a simple average of standard deviation of residuals in both dimensions, which they called *circular standard error* (i.e., zero-mean circular error at a confidence level equivalent to one standard deviation). It is computed as follows:

$$s_C = \frac{s_{\Delta X} + s_{\Delta Y}}{2} \quad (7)$$

To estimate error dependent on across-track and along-track position, it was desirable to transform from the *X* and *Y* dimensions of the image projection to the line and sample dimensions of the original image acquisition. However, the AWiFS standard product in the GeoTIFF format does not provide the necessary metadata to perform the 3-dimensional calculations necessary to perform this transformation in a rigorous way. For this analysis, it was judged to be sufficient to make a simple 2-dimensional transformation, rotating the coordinate about one corner of the dataset until the sides of the acquired image were represented as approximately straight up and down. In this pseudo across-track (*u*)/along-track (*v*) space, residuals components (both *u* and *v*) were computed versus position components (both *u* and *v*). Given that there was no clear relationship between error and along-track position, further calculations were restricted to relationships of error with across-track position. For both across-track and along-track error components, first or second order polynomial functions (chosen by observation) were fitted to the data using least squares. After subtracting all the systematic error components, a "non-systematic" error remainder was left, but the analyses carried out thus far did not distinguish to what degree this error remainder was characteristic of the AWiFS images and to what degree it was characteristic of analyst, algorithm, or reference.

Results

An image-by-image summary is shown in Table 6-25**Error! Reference source not found.**.

Table 6-25. *Results for AWiFS imagery used for the 2005 geopositional characterization.*

Camera	Path-Row-Quad	Acquisition Date	Bias X	Bias Y	μ_H (Bias)	σ_C (Circular Standard Error)	Empirical CE_{90}	Empirical CE_{95}
AWiFS-A	270-36-C	14-Aug-2004	300	189	354	41	423	432
	282-50-C	17-Jan-2005	630	73	635	73	823	863
	277-42-C	5-Mar-2005	473	-40	475	54	599	634
AWiFS-B	270-36-D	14-Aug-2004	-110	239	263	92	438	453
	276-47-D	24-Mar-2005	4	274	274	110	413	449
	278-47-D	27-Apr-2005	-221	-1813	1827	89	1887	1889

A scatterplot of all residuals for all images is shown in Figure 6-38.

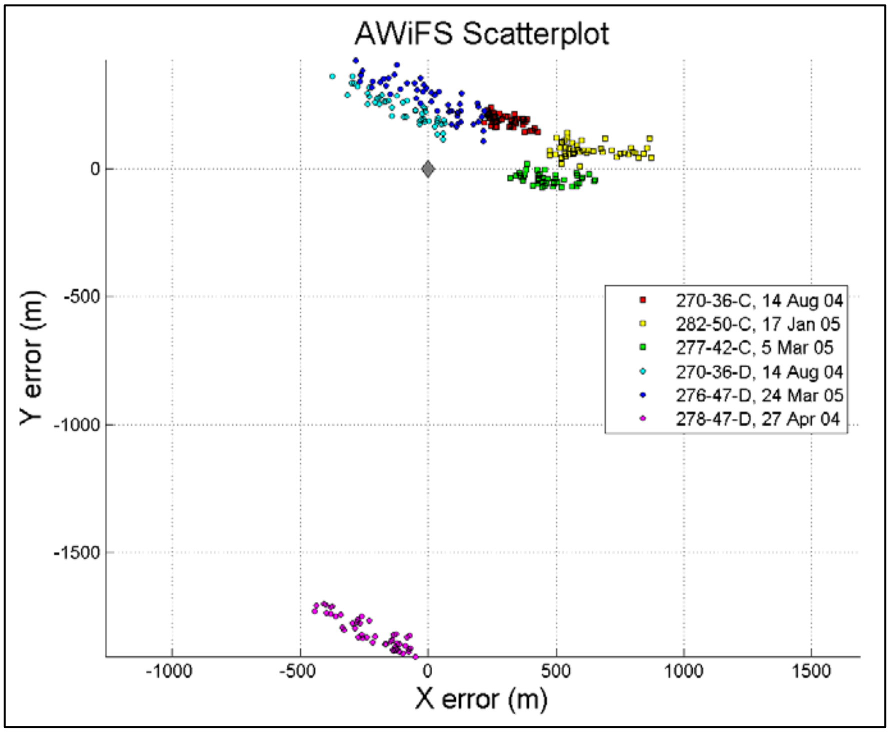


Figure 6-38. *Scatterplot of X and Y errors or residuals as measured in six standard geometrically corrected AWiFS products.*

The along-track and across-track systematic errors remaining after removing horizontal bias are shown in Figure 6-39. Note that across-track error is generally greater in magnitude than along-track error. Also note the clear non-linearity in across-track error/across-track position relationship for the AWiFS-A camera.

The mean CE_{90} of AWiFS standard geometrically corrected images characterized was 760 m, ranging from 423 m to 1887 m. This result was largely in agreement with the assessment of Lutes of Space Imaging (Lutes, 2005) who analyzed eight AWiFS scenes and found a mean CE_{90} of 610 m and a range from 294 m to 756 m. The SSC study yielded one exception to the overall trend: the April 27, 2005, results showed more than double the horizontal bias present in all other scenes. Both analyses show generally grosser error than the estimate of 320 m stated in the IRS-P6 Data User's Handbook (NRSA, 2003), but they also indicate that the data is correctable to near 1-pixel accuracy.

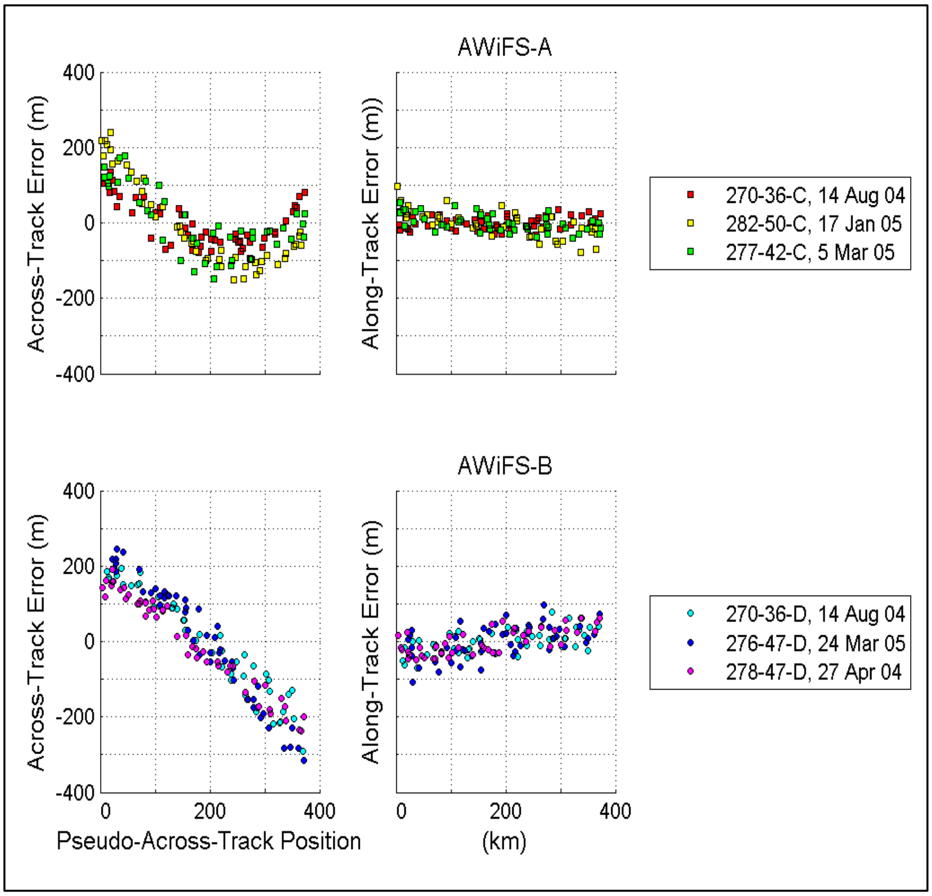


Figure 6-39. *Error as a function of across-track position in the AWiFS-A and AWiFS-B cameras.*

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Appendix C CBERS-2 Characterization

USGS EROS CBERS-2 CCD Characterization

Introduction

This report was generated by the Remote Sensing Technologies Group (RSTG) at the USGS National Center for Earth Resources Observation and Science (EROS). Geometric analyses were conducted on a set of the China-Brazil Earth Resources Satellite (CBERS) images. Two separate “groups” of data were acquired. The first group of images files were acquired and processed from the China Center for Resource Satellite Data and Applications (CRESDA). The second group of images were acquired over the United States and downlinked at EROS. This group of data sets were captured and processed in cooperation with the Brazilian National Institute for Space Research (INPE). All images were acquired by the CBERS-2 High resolution CCD camera (HRCCD). Although the HRCCD has five spectral bands aboard the spacecraft, the data sets involved in the comparison process did not always contain all five bands.

The data sets provided by CRESDA contained a mixture of band combinations. Sometimes all five bands were present, sometimes only a subset of bands 1, 2, 3, 4, and 5. The ground resolution of the CRESDA imagery was 19.5 meters while the ground resolution of the INPE imagery was 20 meters. Data sets produced from INPE came in a UTM projection with a South American Datum of 1969 (SAD69) datum. Data sets produced from CRESDA were in a UTM projection with a WGS84 datum. The CRESDA and INPE data sets were processed to the most basic level of systematic geometric correction with no control point or terrain correction applied.

For the INPE data sets a geodetic accuracy assessment was performed over one image that primarily resided within the US. A band-to-band (B2B) registration assessment was performed on four INPE data sets. All four data sets that B2B was performed on were acquired along the same pass. For the six CRESDA data sets a temporal comparison was made between two images covering approximately the same geographic area but acquired on two different dates, a within pass comparison was performed for several adjacent scenes by measuring the difference between image files in the overlap region, and one scene was geometrically compared against a Landsat 7 Enhance Thematic Mapper (ETM+) image. A band-to-band assessment was performed on all six CRESDA data sets.

Executive Summary

INPE Processing

Four CBERS-2 images were analyzed for B2B registration quality. The RMSE band alignment offsets measured within the CBERS-2 data had values of up to 0.41 pixels in the line direction and 0.37 pixels in the sample direction. One of the four CBERS-2 images was assessed for geodetic accuracy. The CBERS-2 image that was assessed for geodetic accuracy was measured against a Multi-Resolution Land Characteristics (MRLC) Landsat Thematic Mapper (TM) scene covering the same area. The data sets within the MRLC archive have shown accuracies of better than 30 meters. The mean offsets, as measured against the MRLC imagery, for the CBERS-2 image was calculated as 311.68 meters in the sample direction and 4325.39 meters in the line direction.

CRESDA Processing

Six CBERS-2 images were analyzed for B2B registration quality. The RMSE of the band alignment measured within each CBERS-2 data set, excluding band 5, had values up to 0.47 pixels in the line direction and 0.74 pixels in the sample direction. When available, band 5 was displaced by approximately 40 pixels from band 1, 2, 3, and 4. Three of the data sets involved within-pass adjacent scenes, allowing comparison between the overlapping areas. A comparison of the overlapping area showed mean offsets of up to 5.86 pixels in the line direction and 1.39 pixels in the sample direction. Two of the six CBERS-2 data sets covered essentially the same geographic area but were acquired on different dates. This temporal comparison between the two data sets showed mean offsets of 4.5km in the line direction and –7.8km in the sample direction. A final geometric assessment of the CBERS-2 data was made by comparing one of the CBERS-2 image files against a Landsat Enhanced Thematic Mapper Plus (ETM+)

image. Comparisons between the Landsat and CBERS-2 imagery, neither of which had ground control applied or the effects of relief accounted for, showed mean offsets of 13.95km in the North/South direction and –8.52km in the East/West direction.

CBERS-2 CCD Radiometric Characterization

Conversion to Reflectance and reflectance

The sensors do not measure radiances directly, but rather 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 (DN). 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-aperture radiance. This radiance is then converted to TOA reflectance by normalizing for solar elevation and solar spectral irradiance. The below table 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.

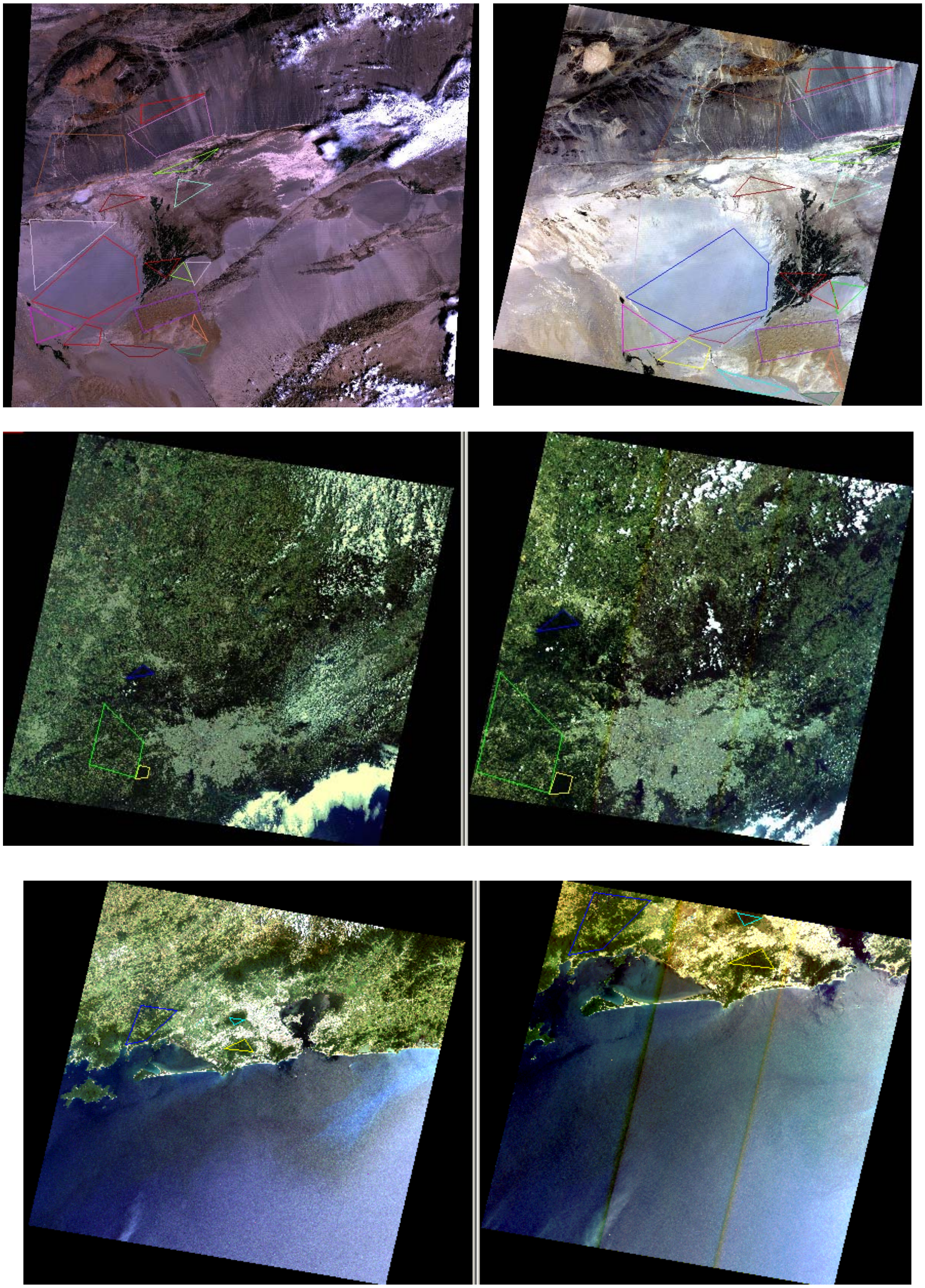
CBERS-2 CCD Vicarious Absolute Calibration Coefficients (CCn)						
	Test-Site	CCD_1	CCD_2	CCD_3	CCD_4	CCD_Pan
Pre-launch		0.9800	1.5900	1.2000	2.2900	1.2500
Brazil						
25th June 2004	Bahia	1.228	2.357	1.215	2.553	1.628
16th August 2004		1.0090	1.9300	1.1540	2.1270	1.4830
Oct_3th New		0.862	1.544	0.874	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	

Solar Exoatmospheric Spectral Irradiances										
Units:	ESUN = W/(m^2.um)									
Model :	Neckel and Labs		Chance Spectrum CHKUR (MODTRAN 4.0)							
Band	L4 TM	L5 TM	L4 TM	L5 TM	L7 ETM+	E0-1 ALI	HRCCD	IRMSS	LISS-III	AWiFS
1	1958	1957	1957	1957	1969	1967.6	1928.18			
2	1828	1829	1825	1826	1840	1837.2	1799.51		1846.77	1849.82
3	1559	1557	1557	1554	1551	1551.47	1535.35		1575.5	1579.37
4	1045	1047	1033	1036	1044	1164.53	1053.38		1087.34	1075.11
5	219.1	219.3	214.9	215.0	225.7	230.03		220.11	270.66	254.24
7	74.57	74.52	80.72	80.67	82.07	79.61		83.3		
Pan					1368	1747.86				
1P						1851.8				
4P						957.46				
5P						451.37				

Region of Interest

The L7, L5, and CBERS-2 sensors differ in their along-track and across-track pixel sampling. A feature simultaneously observed by these sensors is 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 common in 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 (ROI) were defined within these areas for each image triplet.

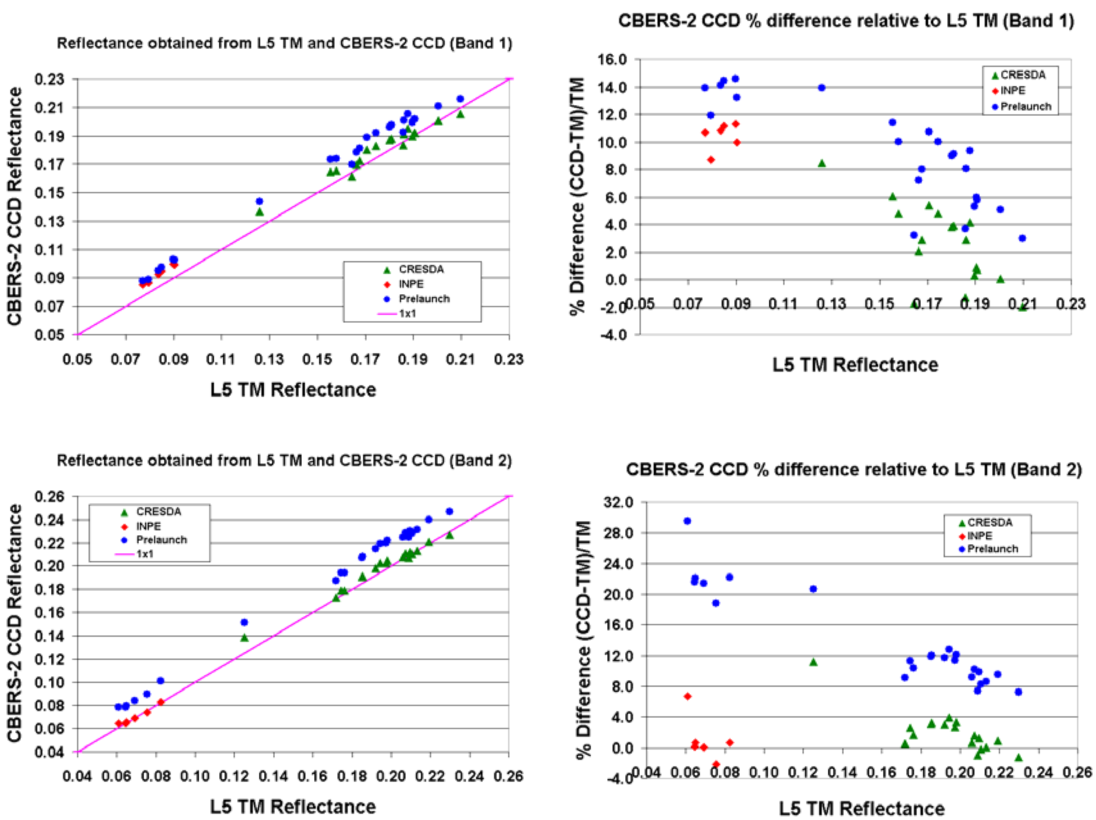
The below images shows a pair of regions of interest from the CBERS-2 and Landsat-5 TM data. Once all area ROIs were selected, image statistics were computed to obtain mean and standard deviation target values on a band-by-band basis. The mean target statistics were then converted to absolute units of radiance and then TOA reflectance. These reflectance values were then plotted for each instrument pair, and a linear fit calculated, giving a relative gain and bias between each instrument pair.



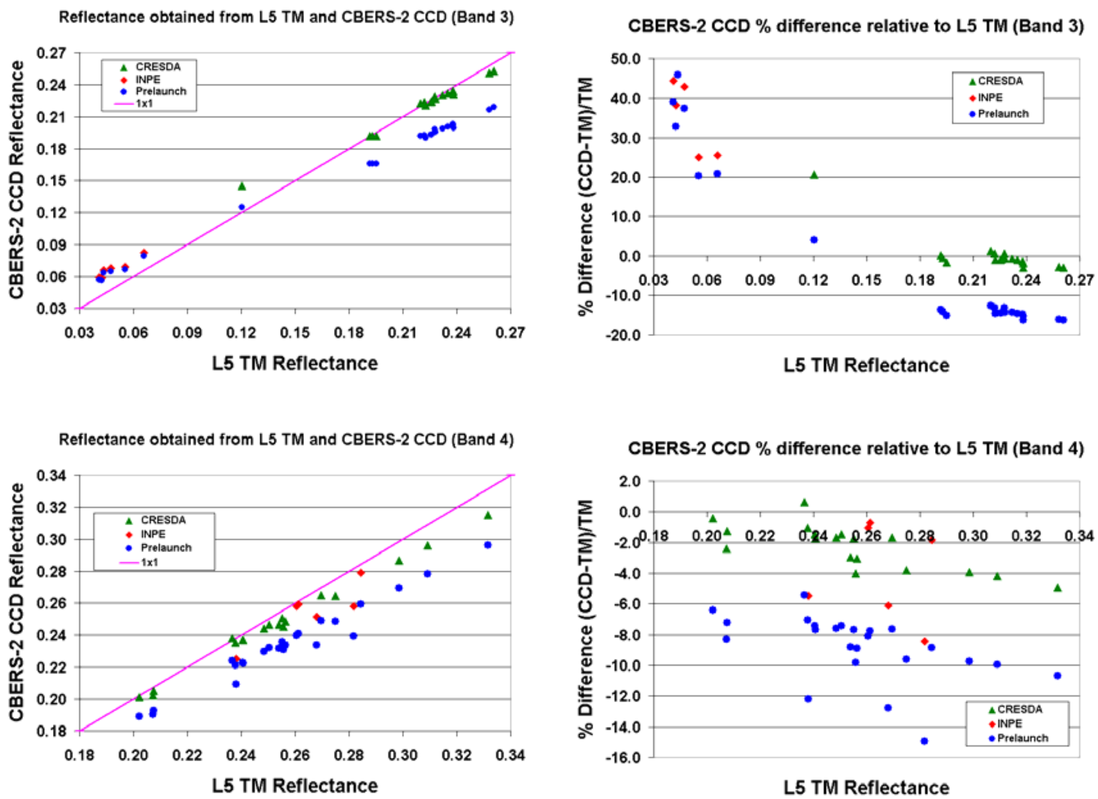
Regions of interest common between Landsat-5 TM and CBERS-2 CCD sensors

Cross-Calibration Accuracy of L7 ETM+ with IRS-P6 AWiFS and LISS-III Sensors

An initial cross calibration of the L5 TM with the CBERS-2 CCD 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 preliminary results indicate that the two sensors are within 6 percent of each other in all bands except Band 3. The below figures and table summarizes the cross-calibration plots for the reflectance against TM and CCD. A least-square fit has been made to the data in each band, and the expected 1:1 reflectance line is also plotted for reference. Linear fits to these pairs of reflectance measurements give cross-calibration gains and biases.



Reflectance of homogenous regions viewed by the L5 TM plotted against the same regions viewed by the CBERS-2 CCD sensor



Reflectance of homogenous regions viewed by the L5 TM plotted against the same regions viewed by the CBERS-2 CCD sensor

CBERS-2 CCD Geometric Characterization

Description of Testing

INPE Processing

For the INPE processed imagery a geodetic accuracy assessment was performed on one CBERS-2 image that was acquired over the Montana/Canadian border. This area covers the Landsat Worldwide Reference System 2 (WRS-2) path and row 37/26. The Multi-Resolution Land Characteristics (MRLC) data were used as a reference to the CBERS-2 imagery 236/45 acquired 3/31/2006. MRLC data sets are available through the National Land Cover Data (NLCD). The MRLC archive contains orthorectified Thematic Mapper (TM) imagery produced from the National Land Archive Processing System (NLAPS). The MRLC images have ground control applied to the data and displacement due to terrain are removed. Although the specific type and quality of ground control applied to the MRLC data is not know, data sets have been observed to be registered to within 30 meters. Digital Terrain Elevation Data (DTED) and Global 30 Arc Second Elevation Data (GTOPO30) were used in the correction process to remove the effects of relief. The MRLC data sets are in an ALBERS projection with a NAD83 datum. For the purposes of this study the NAD83 datum was considered to be the same as the WGS84 datum.

The MRLC data sets come with a geometric quality assessment listed within the work order file. The geometric quality assessment for the MRLC 37/26 image file is listed in table 1.

Error	Mean (meters)	RMS (meters)	Std Dev (meters)
Along Track	-0.14	9.92	9.92
Across Track	-0.58	9.66	9.64
Combined	0.59	13.85	13.84

Table 6-26. Geometric Quality Assessment of MRLC Data

CRESDA Processing

For the CRESDA processed imagery, a geodetic assessment was done by comparing a CBERS-2 image with a Landsat ETM+ image. The CBERS-2 data set corresponded to the Landsat WRS path/row 37/55. The acquisition date of the CBERS-2 data was 1/14/2004. A Landsat ETM+ systematic (Level L1Gs) image was used for comparison. A L1Gs image does not have ground control applied during processing nor does it have the effects due to relief displacement removed. The definitive, post-pass, ephemeris provided by the Landsat Mission Operations Center (MOC) consistently allows corrections of 30-50 meters (not including relief displacement) to the ETM+ imagery without the use of ground control.

Two of the CBERS-2 data sets covered the same geographic area. The acquisition dates for this imagery were 1/14/2004 and 3/5/2005. The two dates allowed a temporal assessment of the CBERS-2 system. The two images were compared against each other to demonstrate the repeatability of the system.

Several of the CBERS-2 data sets acquired from CRESDA were of adjacent scenes within the same pass. The adjacent scenes allowed an assessment of the overlap between the data sets. Since the overlapping imagery between adjacent scenes is the same data, acquired at the same time, this test would demonstrate the consistency within the processing system for data sets acquired along the same path.

The multiple date and within pass test are included in the geodetic accuracy assessment of the CBERS-2. These results are listed in the section pertaining to the CRESDA imagery.

General Methodology

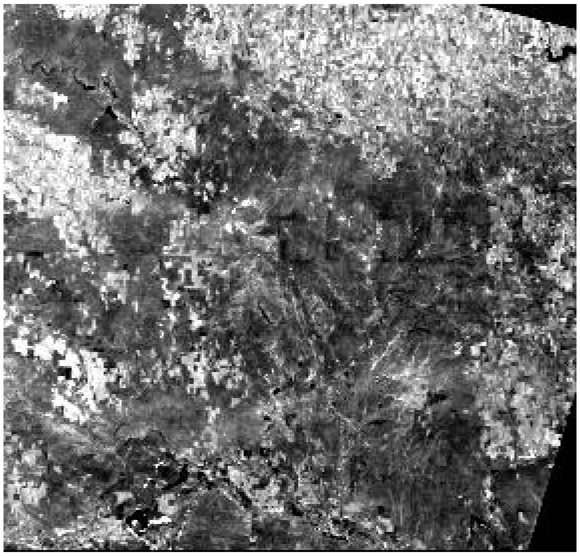
Where applicable, the IAS Image-to-Image (I2I) tool was used to assess the geodetic accuracy of the CBERS-2 imagery. The IAS I2I tool assesses the geometric difference between two image files by performing normalized grey scale correlation on windowed image pairs between two data sets. Several criteria are used for determining if a single correlation measurement is successful. Some of these criteria include strength of the correlation peak and maximum allowable displacement. Offsets are measured as the peak location of the correlation surface. The offset is calculated to the sub-pixel level by fitting a three-dimensional surface around the peak of the correlation surface. A student-t test is performed on the measured offsets to remove any outliers produced from the correlation process. Band 2 of the CBERS-2 imagery was used for geodetic assessment. The geometric registration of the other CBERS-2 bands was then inferred through the band-to-band assessment (B2B) of the CBERS-2 data sets.

The IAS B2B tool was used to perform the assessment of the band-to-band registration of the CBERS-2 data. The IAS B2B tools works in a manner that is very similar to that of the I2I tool. This tool works by first choosing an evenly distributed set of points between each band pair within the imagery. The process then performs a normalized grey scale correlation between two bands at each location and follows the same procedures as I2I in determining sub-pixel location. After each band combination is measured a student-t test is performed on each individual set of band pairs to remove any remaining outliers. In the tables that follow corresponding to the band-to-band assessment, “Points” refers to the number of points kept for statistical analysis, “Ref” refers to reference band, arbitrarily chosen as the smaller band number, used in the correlation process and “Sear” refers to the search band, arbitrarily chosen as the larger band number, used in the correlation process.

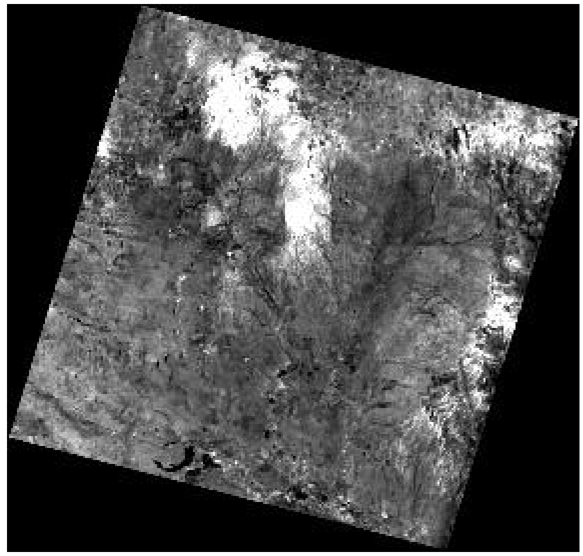
Since the INPE CBERS-2 data was projected to a UTM projection with a datum of SAD69, comparing the imagery was somewhat more difficult than just performing the usual image-to-image assessment with the IAS tools. The difficulty arises due to the fact that the I2I tools do not account for datum shifts between data sets when performing an assessment. As a work around for the datum issue, the images were processed through the I2I tools ignoring the datum issues. Since the I2I tool reports line and sample locations in the reference image, and the corresponding line and sample location in the search image, projection information between the two data sets can be easily calculated and manipulated. Therefore as long as the data distortions within an image correlation window remain as only linear shifts and first order scaling errors, the line and sample locations can be converted to whatever projection is needed. Once the data points are converted to a common datum, the statistics of the measurements can be calculated. Datum conversions were calculated using the Land Analysis System (LAS). LAS performs datum conversion using the Moledensky method. The following steps were then performed for a geodetic assessment of the INPE imagery:

1) The MRLC data set was reprojected from ALBERS to UTM projection.
2) An image-to-image assessment was made between the reprojected MRLC data set, UTM NAD83, and the CBERS-2 UTM SAD69 image.
3) UTM SAD69 X and Y projection coordinates were calculated from the line and sample locations generated from the I2I process of the CBERS-2 imagery.
4) The UTM SAD69 X and Y coordinates were reprojected to UTM WGS84.
5) UTM WGS84 X and Y projection coordinates were calculated from the line and sample locations of the reprojected ALBERS imagery generated from the I2I process.
6) The coordinates from steps 4) and 5) were compared and statistics were calculated on the differences.

From 3/30/2006 to 4/01/2006 data from the CBERS-2 satellite was downlinked at the EROS Data center. During this time several passes over the US were acquired. Unfortunately due to cloud cover and several other issues, the number of images acquired that could be used for a geometric assessment of the system was limited. One pass, 236, however did provide several cloud free scenes. One of the fairly cloud free scenes along this pass also partially resides within the US. For the images that were outside the US, a band-to-band alignment characterization was performed. For the one scene that resides partially within the US, a B2B and geodetic accuracy assessment of the image was performed. The reference data set used to perform the geodetic accuracy assessment was a Multi-Resolution Land Characteristics (MRLC) data set. The CBERS-2 image data with the corresponding MRLC coverage are shown in figure 1.



MRLC 37/26 UTM Imagery



CBERS-2 236/45 UTM Imagery

Figure 6-40. MRLC and CBERS data sets used in study

The final image-to-image statistics generated from the CBERS-2 to MRLC data sets is listed in table 2.

	X-Direction (meters)	**Y-Direction (meters)**
RMS	343.63	4329.62
Standard Deviation	144.69	191.42

Table 6-27. Statistics of Image-to-Image comparison between MRLC and CBERS data sets

A vector plot of the residuals, shown in figure 2, helps to illustrate that the dominant portion of the difference between the two data sets lies within the line direction.

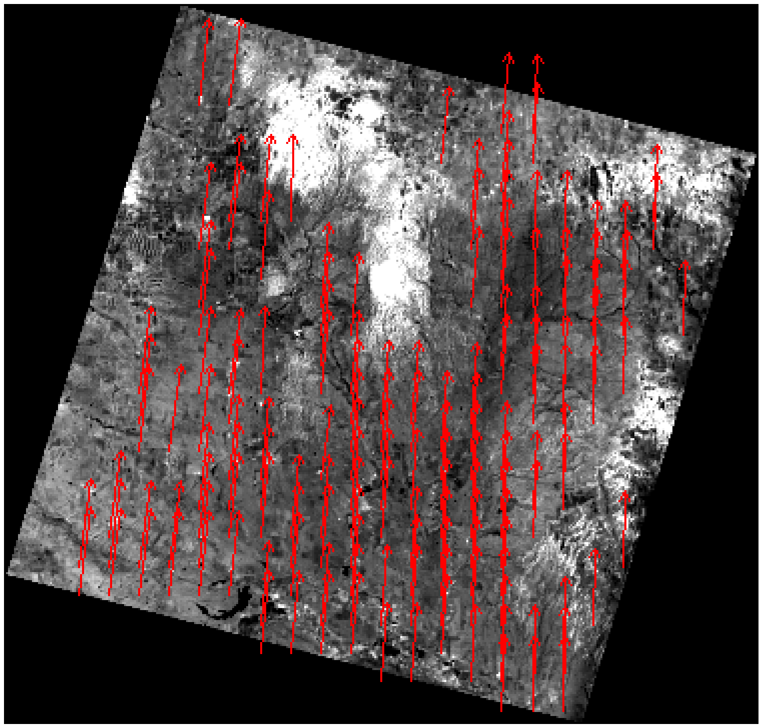


Figure 6-41. Comparison between MRLC and CBERS-2 data sets
Vectors are scaled by a factor of 19

The statistics when comparing the two data sets has rather large standard deviations. A concern with large standard deviations is that they could indicate large non-systematic errors that may not be easily correctable. A plot of residuals with the mean offset removed would allow a method of viewing what the higher order, other than a simple bias, geometric distortions are within the imagery. The plot of residuals with the mean offset removed is shown in figure 3.

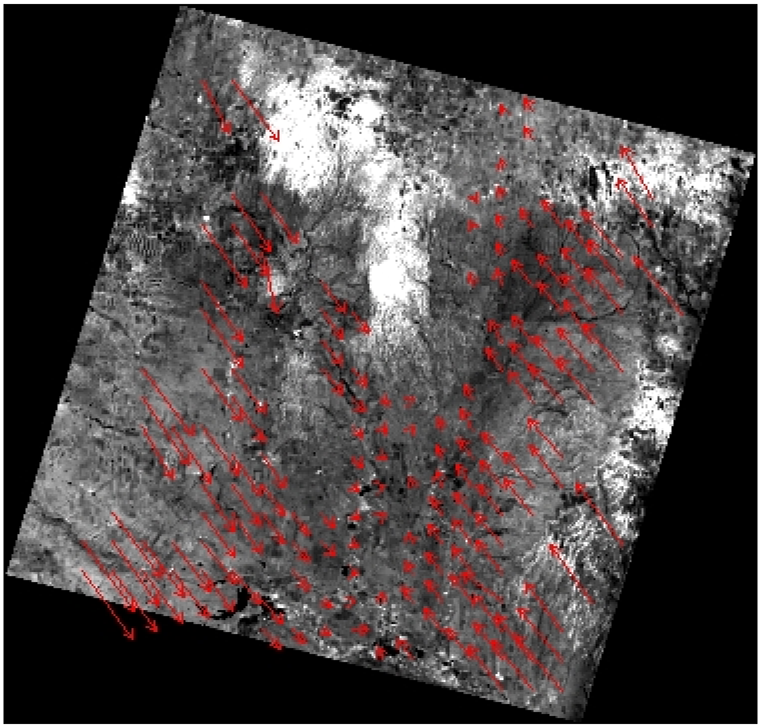


Figure 6-42. Residuals between CBERS-2 and MRLC Data set with bias removed

The plot of residual with the mean removed appears to indicate either possible errors in satellite altitude and attitude or displacement due to elevation. The cross-track component or the errors could also be terrain displacement in the CBERS image, these errors are smaller at nadir (after subtracting the mean). It may be possible to remove this error with the help of ground control and elevation data.

To verify that the geometric changes between the SAD69 and WGS84 datum were mainly linear, statistics were calculated on the SAD69 and WGS84 converted CBERS-2 coordinates. The differences between the SAD69 and WGS84 coordinates, as calculated by LAS, are shown in table 3.

	Y-Direction (meters)	**X-Direction (meters)**
RMS	59.62	57.33
Standard Deviation	0.000208	0.000238

Table 6-28. Statistical differences between datums SAD69 and WGS84

The statistics listed within table 3 helps to verify the methodology used in handling the differences between the datums of the two data sets. Since the size of correlation windows during I2I processing was 256x256, and the standard deviations listed above are small, the difference between datums within a correlation window can be assumed to be linear.

CRESDA Data Sets

Three of the data sets produced from CRESDA were acquired within the same pass. As a test of consistency of the data processing system, the overlap between adjacent scenes was compared. Since the data within this area is essentially the same, and is acquired at the same time, the offsets should be very small. The results from performing I2I on these data sets are listed in table 4.

Scene Boundary	Mean Offset (L/S)	RMS Offset (L/S)
P037R055-R056	5.862/1.393 pixels	5.893/1.470 pixels
P037R056-R057	3.273/-0.144 pixels	3.811/0.340 pixels

Table 6-29. Statistics from Image-to-Image comparison for scenes acquired along the same pass.

As shown in table 4, the test between adjacent scenes showed larger than expected offsets. The offsets measured should be in the sub-pixel range but were in fact multiple pixels in magnitude.

Two CBERS-2 data sets covered essentially the same geographic area were acquired on different days, 1/14/2004 and 3/5/2005. These data sets were compared as a temporal study and internal geometric stability test of the CBERS-2 instrument. Due to the large offsets between data sets the IAS I2I tools could not be used in assessing the two data sets, therefore offsets between the two images were measured by hand. Common features were visually identified between the images and using the corner coordinates given for each image, offsets were measured between the files. The calculated offsets were 4.5km in the line direction and -7.8km in the sample direction. The line errors measured were correlated with image line, or time, suggesting an uncompensated pitch error between the data sets. A plot representing this correlation is shown in figure 4.

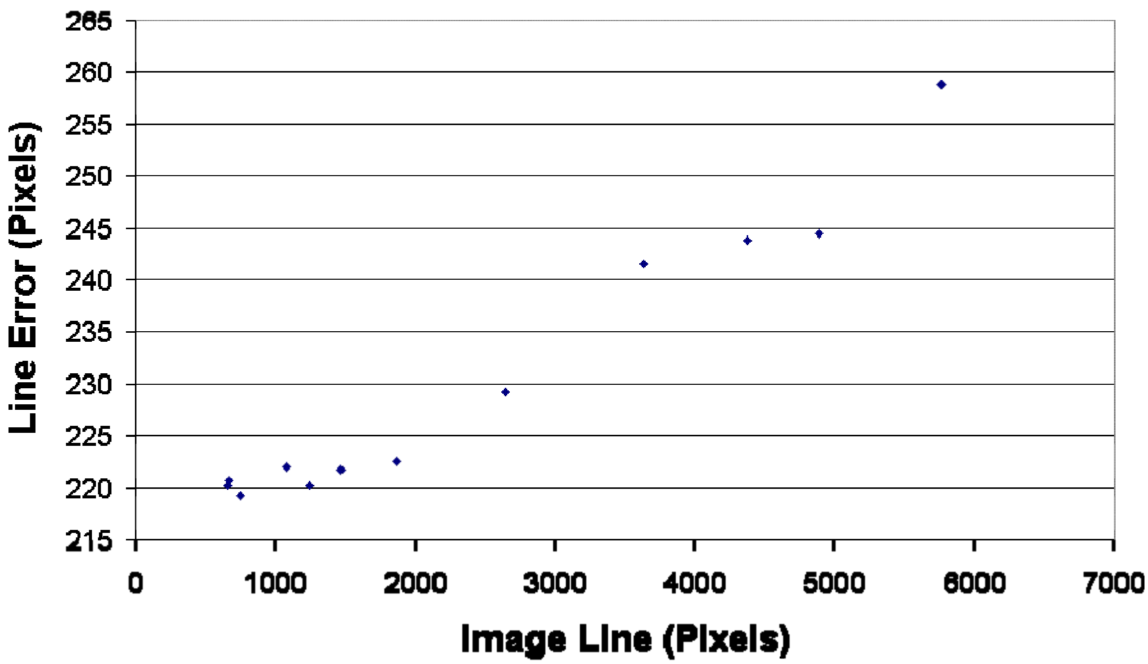


Figure 6-43. Measured offsets in CBERS-2 for Coverage 37/55

Acquisition Dates 1/14/2004 and 3/5/2005

One CBERS-2 data set produced from CRESDA was compared to a Landsat 7 ETM+ image. The image corresponded to the Landsat path/row 37/56. The CBERS-2 imagery was acquired on 1/14/2004. Neither data set had ground control applied or the effects due to relief removed. Due to the large offsets among the two image files the differences in registration between the images was measured by hand. The mean offsets measured were 13.94km in the North-South direction and –8.52km in the East-West direction. The standard deviation associated with these measurements was 59 meters N-S and 163 meters E-W. Although the mean offsets were rather large the standard deviations were modest, especially in the cross-track (E-W) direction where error is expected to be more variable since neither image was terrain corrected.

Band Alignment

INPE Data Sets

Four data sets along the CBERS-2 236 pass acquired on 3/31/2006 had a B2B assessment performed. None of the INPE data sets assessed for band alignment contained either band 1 or band 5. The vector residuals for each band pair for all four images are shown in figures 5-8.

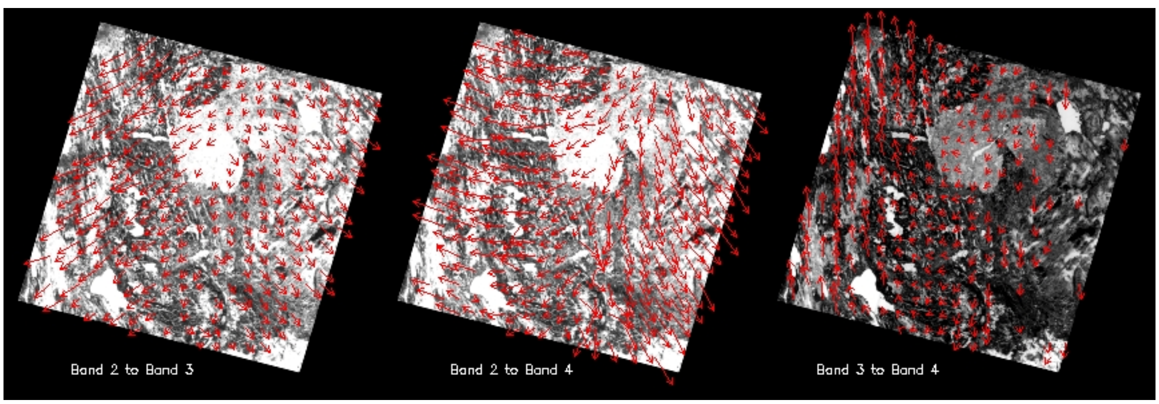


Figure 6-44. CBERS-2 Acquired 3/31/2006 236/039 Band-to-Band Registration

Vectors scaled by a factor of 850

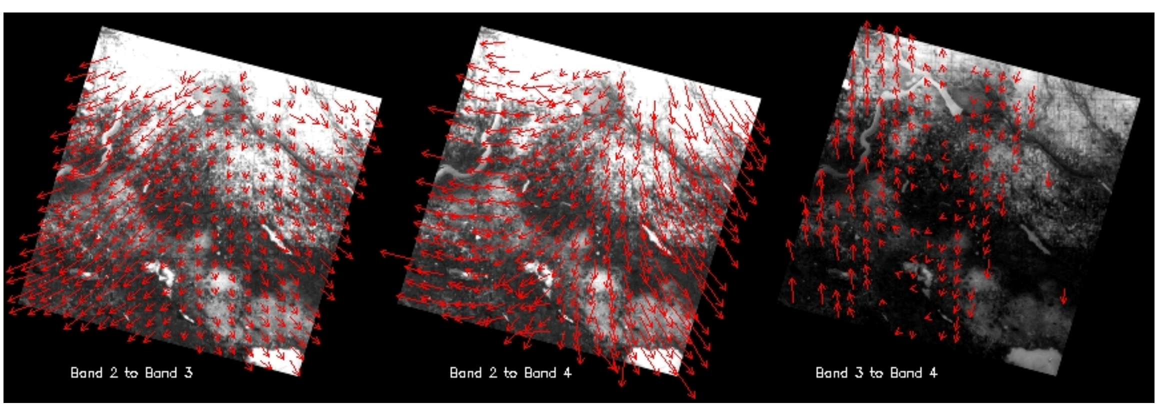


Figure 6-45. CBERS-2 Acquired 3/31/2006 236/043 Band-to-Band Registration

Vectors scaled by a factor of 850

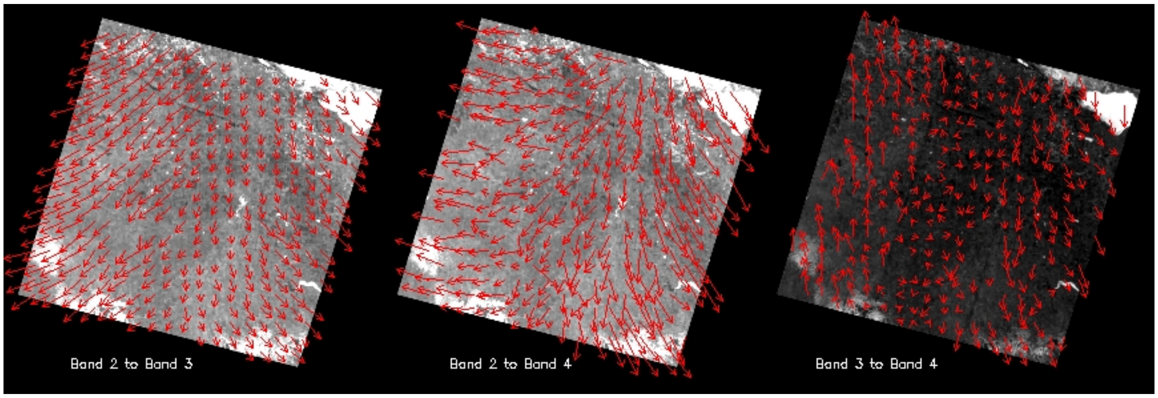


Figure 6-46. CBERS-2 Acquired 3/31/2006 236/044 Band-to-Band Registration

Vectors scaled by a factor of 850

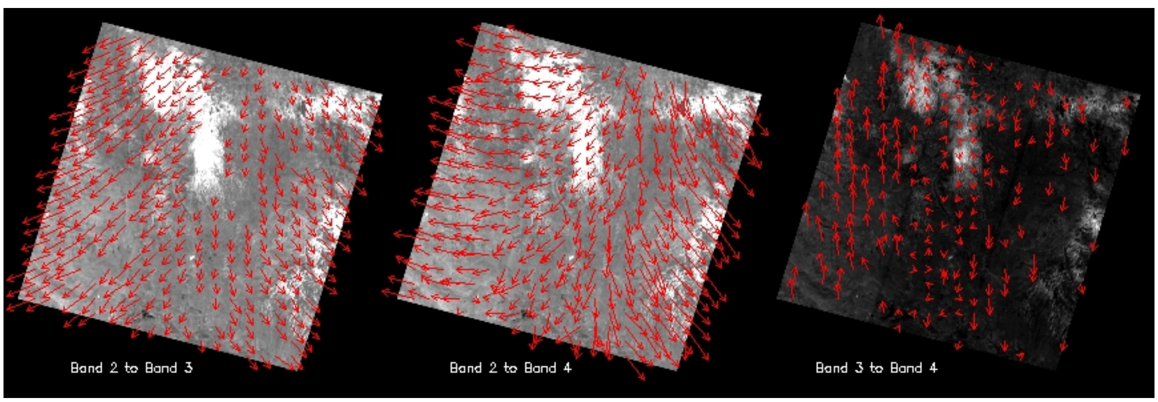


Figure 6-47. CBERS-2 Acquired 3/31/2006 236/045 Band-to-Band Registration

Vectors scaled by a factor of 850

The vector residuals plotted in figures 5-8 are scaled to greatly exaggerate the offsets. This is done so that the vectors are easily viewable within the plots. The plots show a consistent pattern and mis-alignment between band 2 to both band 3 and 4. The B2B statistics are listed in figures 9 and 10.

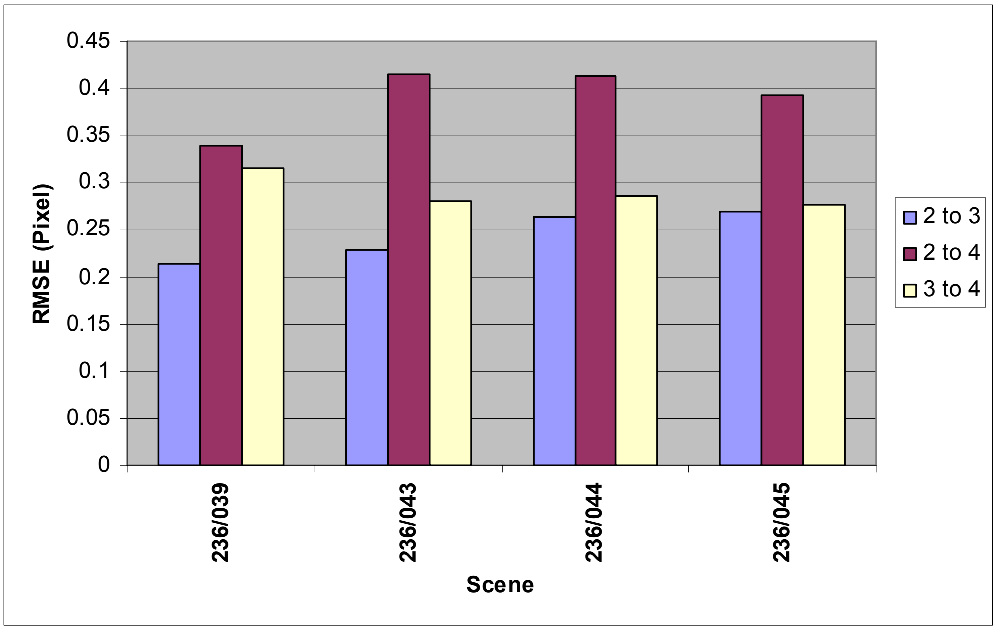


Figure 6-48. Band Alignment RMSE in Line Direction

INPE Imagery Acquired 3/31/2006

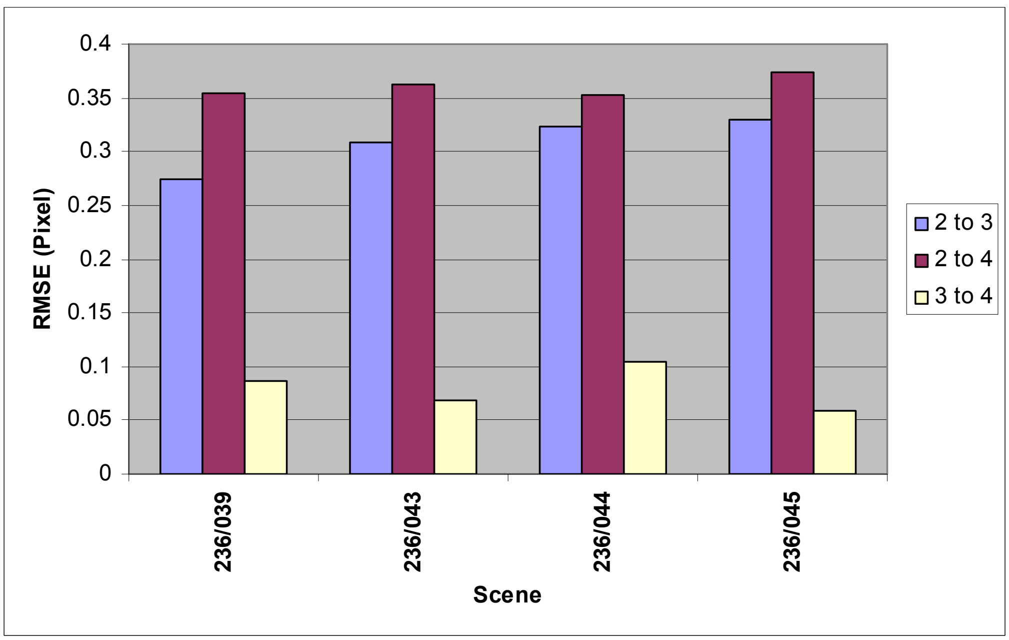


Figure 6-49. Band Alignment RMSE in Sample Direction

INPE Imagery Acquired 3/31/2006

CRESDA Data Sets

The band registration assessment of the CRESDA data proved to be much more of a challenge than that of the INPE data sets. Unlike the INPE data sets, at least some of the CRESDA data sets contained bands 1 and 5. The challenges arose from the issues associated with band 5. Since band 5 (panchromatic) is not boresighted with bands 1-4
there is approximately a 5 second offset between the times bands 1-4 image a target and when band 5 images the same target. This timing delay introduces offsets due to alignment error, terrain, and uncompensated pointing dynamics. Because of these issues, band 5 had to be manually shifted by around 40 lines to achieve an approximate band alignment so that the IAS B2B tools would work with the data sets. To further complicate the issue the magnitude of this shift changed from scene to scene, even for imagery acquired within the same pass. The band combinations displayed in figure 11 show the fairly close band alignment for band 3, 2, and 1 and the offset of band 5 to bands 4 and 3. The image displayed is 37/55 from 3/5/2005:

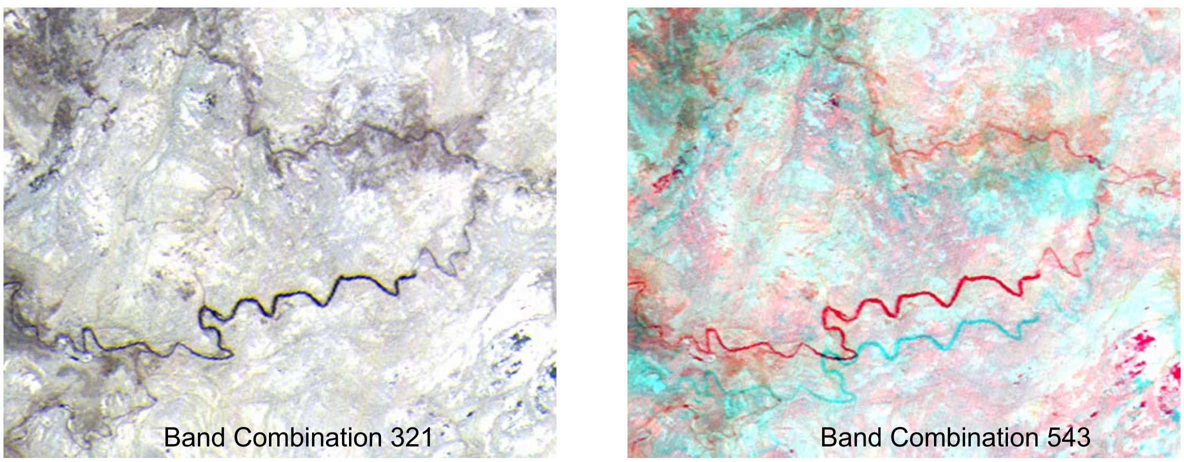


Figure 6-50. CRESDA band combinations.

CRESDA Image 37/55 Acquired 3/5/2005

Plots of the B2B vector residuals for image 37/55 acquired on 1/14/2004 are shown in figures 12-15 (the plot involving band 5 are residuals after manual alignment):

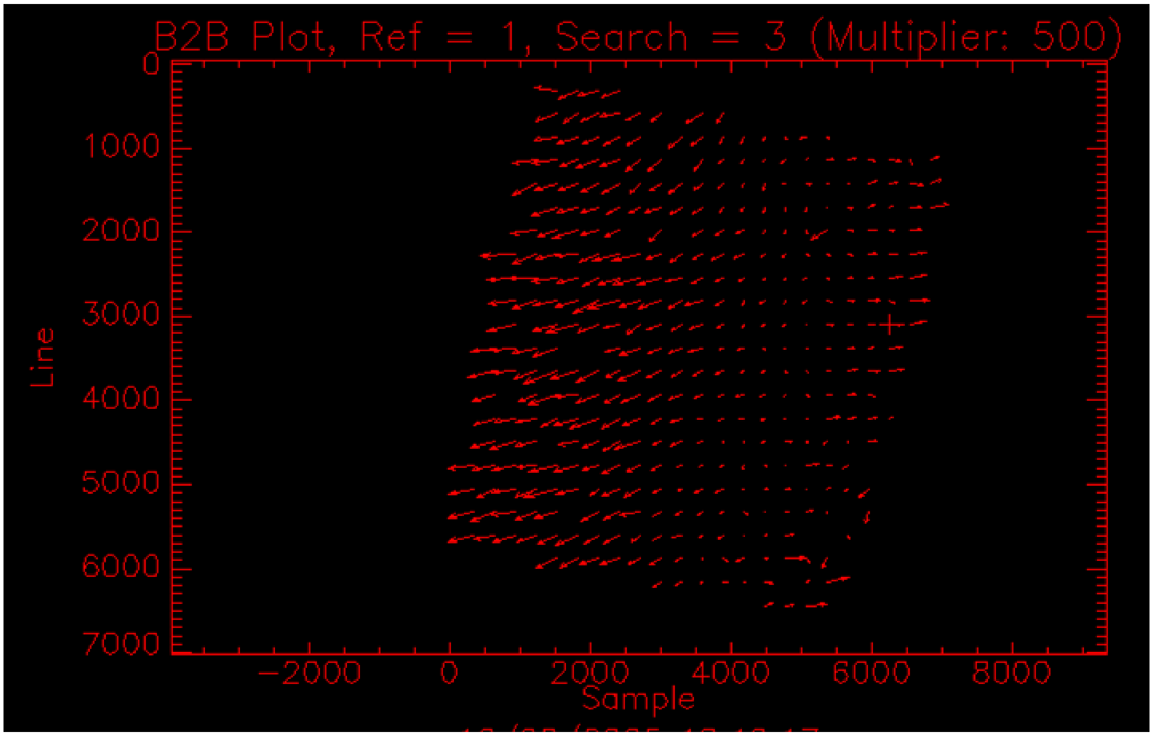


Figure 6-51. Band Registration Vector Residuals Band 1 to Band 3

CRESDA data 37/55 1/14/2004

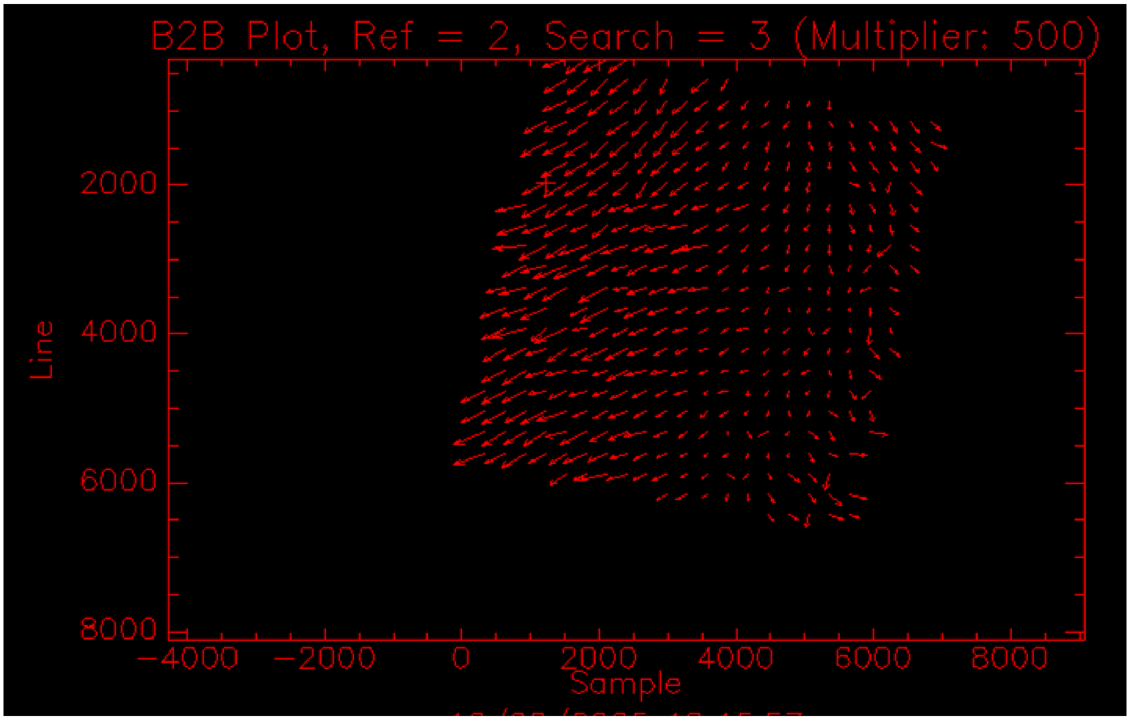


Figure 6-52. Band Registration Vector Residuals Band 2 to Band 3

CRESDA data 37/55 1/14/2004

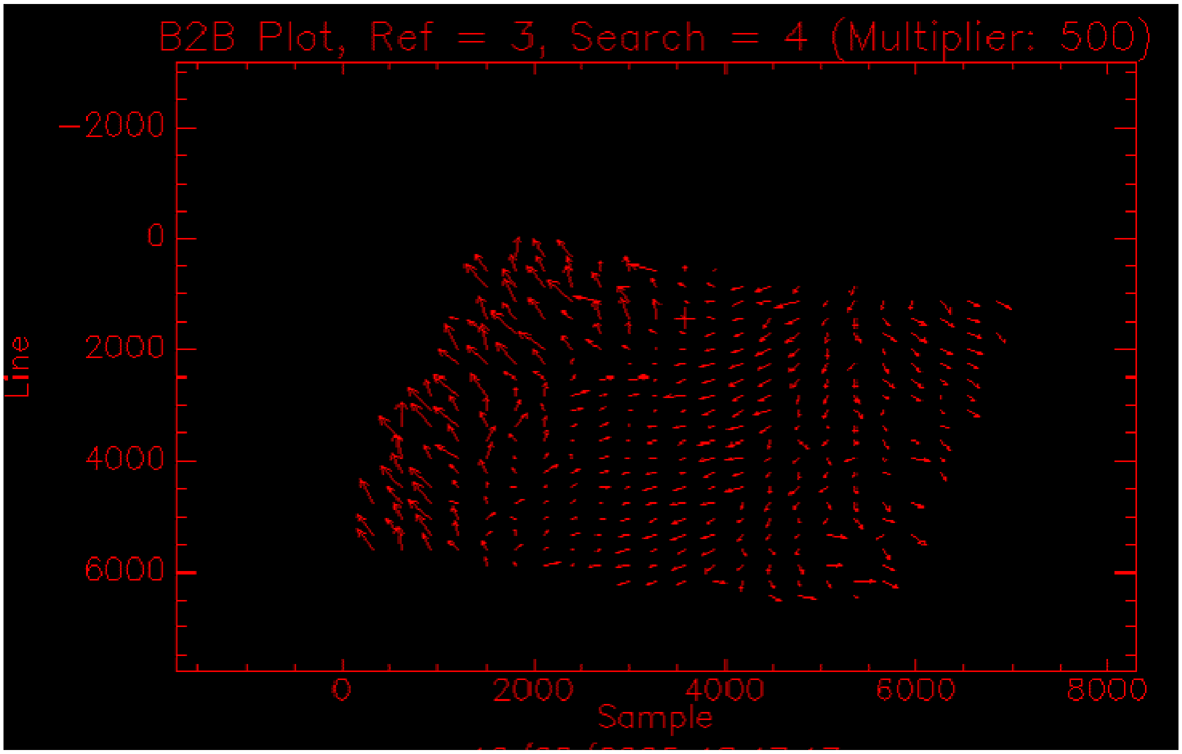


Figure 6-53. Band Registration Vector Residuals Band 3 to Band 4

CRESDA data 37/55 1/14/2004

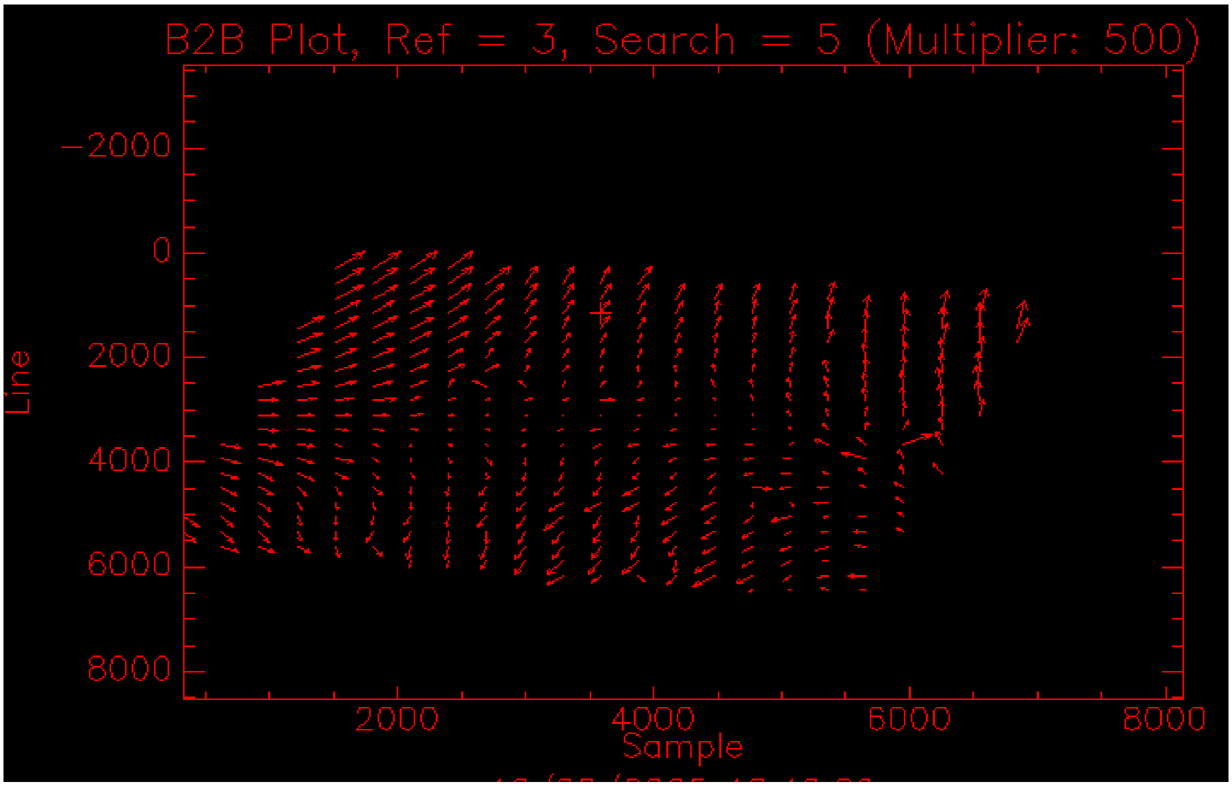


Figure 6-54. Band Registration Vector Residuals Band 3 to Band 5

CRESDA data 37/55 1/14/2004

The RMSE for band alignment of all six CRESDA images, minus band 5, are shown in figures 16 and 17.

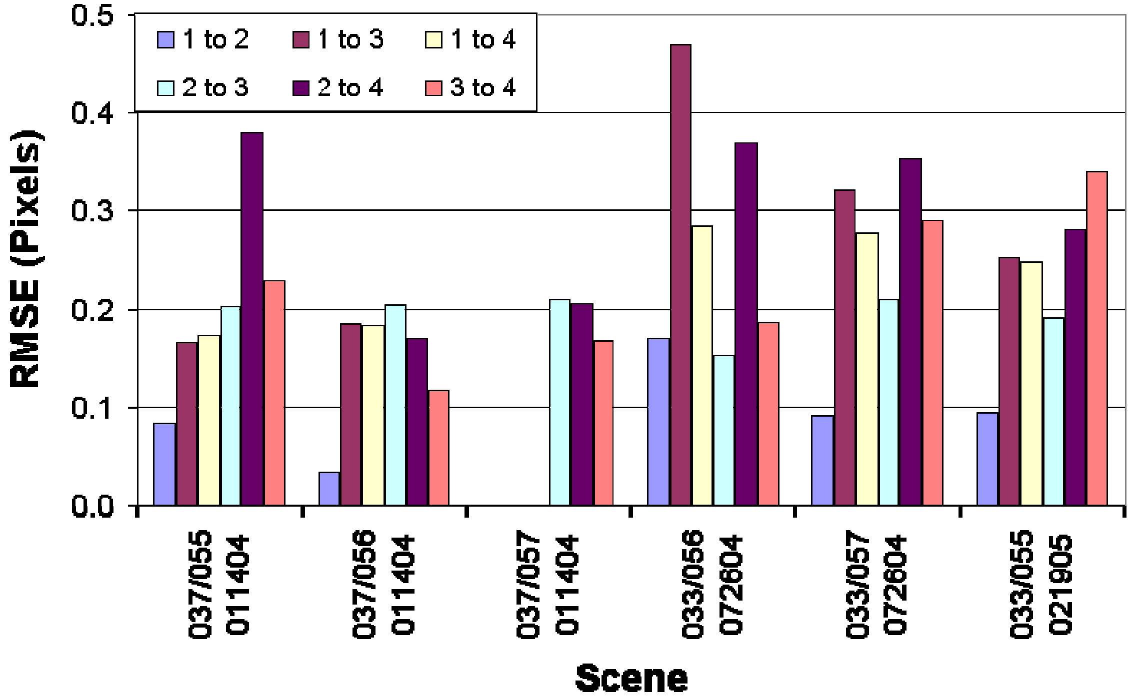


Figure 6-55. Band Alignment RMSE in Line Direction

CRESDA Imagery (Band 5 not included)

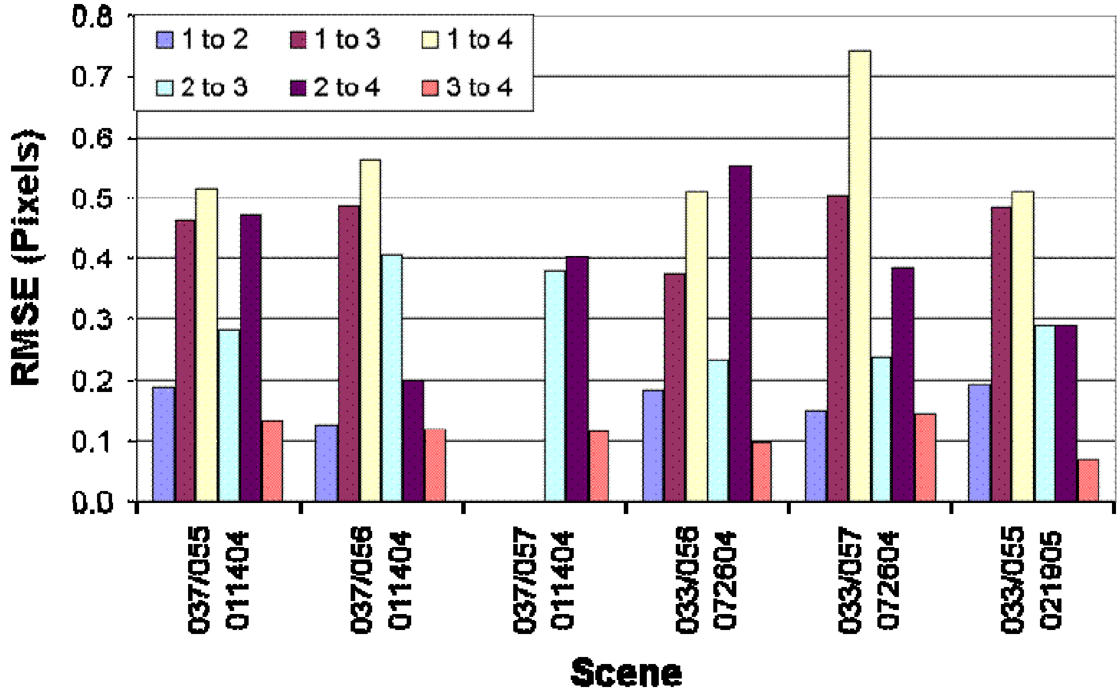


Figure 6-56. Band Alignment RMSE in Sample Direction

CRESDA Imagery (Band 5 not included)

The mean line offset between band 5 and the other bands available within the data sets are shown in figure 18.

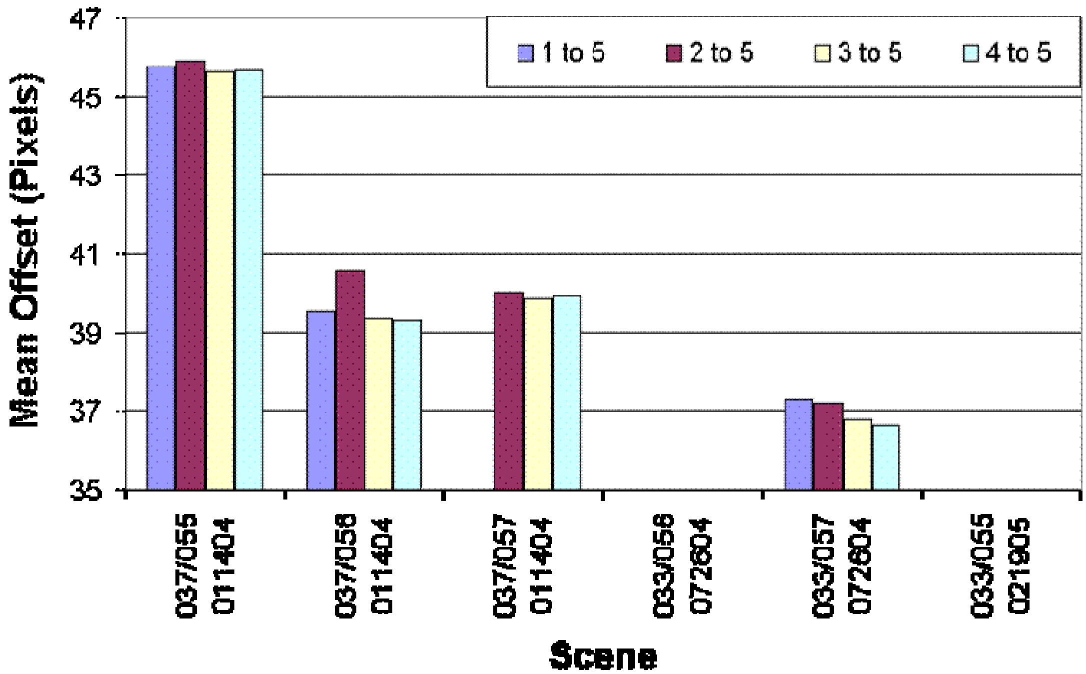


Figure 6-57. Mean Band Offset in Line Direction

CRESDA Imagery (Band 5 included)

The band registration for some of the CRESDA images, most noticeable 37/55 acquired on 3/5/2005, show significant time-varying registration errors between band 5 and bands 1-4. The registration errors measured involving band 5 suggests possible uncompensated attitude rate errors within the imagery. If disregarding band 5, bands 1 (when available), 2, 3, and 4 showed reasonable registration.

Conclusion

CBERS-2 data from two different ground stations, INPE and CRESDA, were assessed for geometric performance. The INPE data sets did not contain bands 1 or 5, leaving only the CRESDA assessment to have these bands analyzed. The following general observations were made from studying the two groups of imagery:

There are inconsistencies in data products produced between the two ground station and even within the grounds stations themselves. Not all bands were present within all data products. For the imagery produced from CRESDA, sometimes bands 1 and 5 were missing from the data sets. For the imagery produced from INPE, bands 1 and 5 were not present.

The systematic images produced from both grounds stations had rather large systematic offsets with smaller higher order differences observable when biases were removed from the measurements. However the higher order differences appeared as if they could possibly be removed with the help of ground control and elevation information.

Bands 1 (when available), 2, 3, and 4 showed a small amount of band misregistration. The residuals measured showed higher order differences, other than simple bias offsets. Band 5 of the CRESDA imagery had very large offsets when compared with the other bands present.

Examining the overlap areas of within pass imagery showed larger than expected differences. Differences on the order of several pixels were observed, larger values than would be expected even for systematically corrected imagery.

INPE Data Sets

A geometric assessment was performed on four CBERS-2 image data sets. One data set was compared against a Landsat MRLC image, this test served as a test of the geodetic accuracy of the CBERS-2 data set. The RMS between the two data sets was calculated as 343.63 meters in the X direction and 4329.62 meters in the Y direction. A band-to-band alignment assessment was performed on four CBERS-2 image files. The results are listed in table 5.

Scene	Ref	Sear	Points	StDev Line	StDev Samp	RMSE Line	RMSE Samp
236/39	2	3	266	0.0568	0.2621	0.2140	0.2747
	2	4	313	0.2676	0.3376	0.3389	0.3545
	3	4	233	0.2943	0.0485	0.3155	0.0869
236/43	2	3	332	0.0558	0.2802	0.2280	0.3090
	2	4	327	0.2721	0.3521	0.4146	0.3617
	3	4	168	0.2667	0.0279	0.2809	0.0685
236/44	2	3	337	0.0530	0.2904	0.2631	0.3232
	2	4	316	0.2824	0.3324	0.4122	0.3528
	3	4	275	0.2855	0.1046	0.2850	0.1047
236/45	2	3	312	0.0483	0.3010	0.2694	0.3295
	2	4	343	0.2900	0.3553	0.3931	0.3739
	3	4	195	0.2670	0.0537	0.2759	0.0594

Table 6-30. Band-to-Band alignment for INPE CBERS imagery.

The band alignments measured appeared to contain offsets other than simple biases, plotting the vector residuals showed nonlinear displacement.

CRESDA Data Sets

Several geometric assessments were performed on the six CRESDA data sets available. A within pass assessment was performed on several adjacent scenes. Common areas within the adjacent scenes were compared for geometric consistency. This test showed RMSEs of up to 5.89 pixels in the line direction and 1.47 pixels in the sample direction. One of the CRESDA data sets was compared to an ETM+ systematic image and produced mean offsets of 4.5km in the line direction and -7.8km in the sample direction. These measurements had a standard deviation of 13.3 pixels in the line direction and 1.8 pixels in the sample direction. Pixel size within the imagery was 19.5 meters. An assessment of band alignment showed band 5, the panchromatic band, to be significantly displaced from bands 1, 2, 3, and 4. The displacement measured was around 40 pixels. With the large offset removed, band 5 still contained a small displacement from the other bands, including what looked like time varying effects. The band alignment for bands 1 (when available), 2, 3, and 4 had sub-pixel displacement from each other and appeared to contain differences that were more complex than a simple bias. The maximum RMSE measured in the band alignment, excluding band 5, were 0.47 pixels in the line direction and 0.74 pixels in the sample direction.