Landsat Data Gap Studies: Potential Data Gap Sources

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U.S. Department of the Interior

U.S. Geological Survey

Project Introduction

- **USGS Remote Sensing Technologies (RST) Project**
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  - Greg Stensaas - (605) 594-2569 - stensaas@usgs.gov
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- Project provides:
  - characterization and calibration of *aerial and satellite systems* in support of quality acquisition and understanding of remote sensing data,
  - and verifies and validates the associated data products with respect to ground and atmospheric truth so that accurate value- added science can be performed.
  - assessment of new remote sensing technologies
- Working with many organizations and agencies; US and International

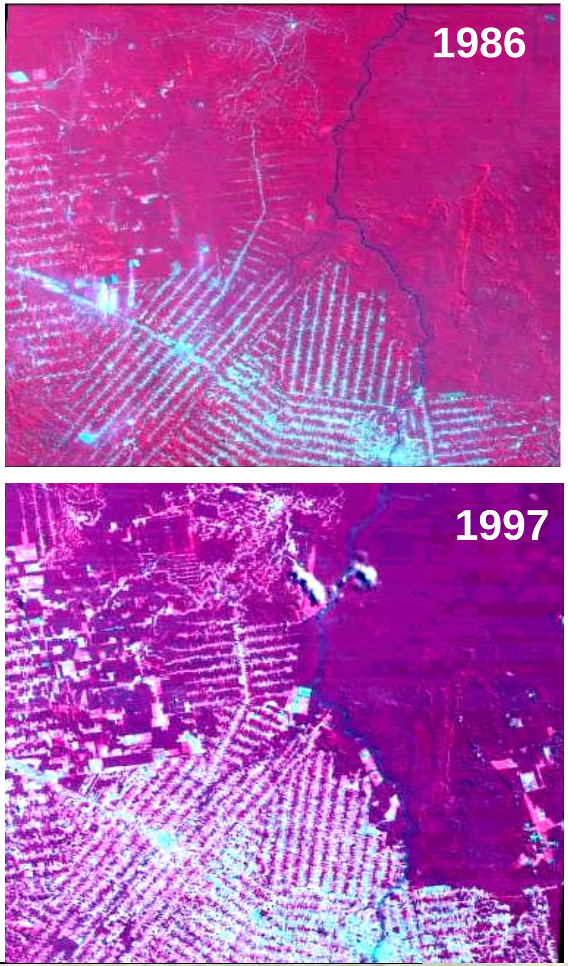
System/Product Characterization

- **System Characterization is related to understanding the sensor system, how it produces data, and the quality of the produced data**
- **Imagery attempts to accurately report the conditions of the Earth's surface at a given the time.**
  - Assessed by *product characterization* categories:
    - **Geometric/Geodetic:** The positional accuracy with which the image represents the surface (pixel coordinates vs. known ground points)
    - **Spatial:** The accuracy with which each pixel represents the image within its precise portion of the surface and no other portion
    - **Spectral:** The wavelengths of light measured in each spectral "band" of the image
    - **Radiometric:** The accuracy of the spectral data in representing the actual reflectance from the surface
    - **Dataset Usability:** The image data and understanding of the data is easily usable for science application

Landsat Importance to Science

- **Change is occurring at rates unprecedented in human history**
- **The Landsat program provides the <u>only</u> inventory of the global land surface over time**
  - at a scale where human vs. natural causes of change can be differentiated
  - on a <u>seasonal</u> basis
- **No other satellite system is capable/committed to even <u>annual</u> global coverage at this scale**

Amazonian Deforestation

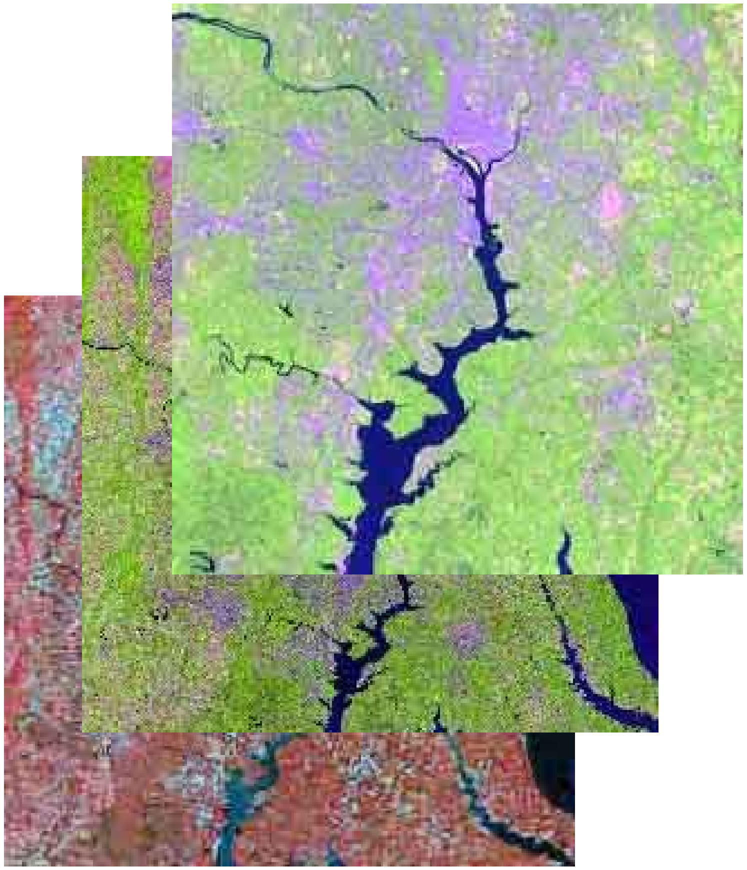


100 km

Courtesy TRFIC–MSU Houghton et al, 2000.

U.S. Landsat Archive Overview
(Marketable Scenes through September 25, 2006)

- **ETM+: Landsat 7**
  - 654,932 scenes
  - 608TB RCC and L0Ra Data
  - Archive grows by 260GB Daily
- **TM: Landsat 4 & Landsat 5**
  - 671,646 scenes
  - 336TB of RCC and L0Ra Data
  - Archive Grows by 40GB Daily
- **MSS: Landsat 1 through 5**
  - 641,555 scenes
  - 14TB of Data



Landsat Data Gap Study Team (LDGST)

- **The Earth observation community is facing a probable gap in Landsat data continuity before LDCM data arrive in ~2011**
- **A data gap will interrupt a 34+ yr time series of land observations**
- **Landsat data are used extensively by a broad & diverse users**
  - Landsat 5 limited lifetime/coverage
  - Degraded Landsat 7 operations
  - Either or both satellites could fail at any time: both beyond design life
- **Urgently need strategy to reduce the impact of a Landsat data gap**
  - Landsat Program Management must determine utility of alternate data sources to lessen the impact of the gap & feasibility of acquiring data from those sources in the event of a gap
  - A Landsat Data Gap Study Team, chaired by NASA and the USGS, has been formed to analyze potential solutions

Team Membership

Edward Grigsby, NASA HQ, Co- Chair
Ray Byrnes, USGS HQ, Co- Chair
Garik Gutman, NASA HQ, Co- Chair
Jim Irons, NASA GSFC, Community Needs Working Group Lead
Bruce Quirk, USGS EDC, System Capabilities Working Group Lead
Bill Stoney, Mitretek Systems, Needs-to-Capabilities Working Group Lead
Vicki Zanoni, NASA HQ Detail, Team Coordinator and Synthesis Working Group Lead

Mike Abrams, JPL
Bruce Davis, DHS (NASA detailee)
Brad Doorn, USDA FAS
Fernando Echavarria, Dept. of State
Stuart Frye, Mitretek Systems
Mike Goldberg, Mitretek Systems
Sam Goward, U. of Maryland
Ted Hammer, NASA HQ
Chris Justice, U. of Maryland
Jim Lacasse, USGS EDC

Martha Maiden, NASA HQ
Dan Mandl, NASA GSFC
Jeff Masek, NASA GSFC
Gran Paules, NASA HQ
John Pereira, NOAA/NESDIS
Ed Sheffner, NASA HQ
Tom Stanley, NASA SSC
Woody Turner, NASA HQ
Sandra Webster, NGA
Diane Wickland, NASA HQ
Darrel Williams, NASA GSFC

Team Strategy

Objective

- **Recommend options, using existing and near-term capabilities, to store, maintain, and upgrade science-quality data in the National Satellite Land Remote Sensing Data Archive**
    - Consistent with the Land Remote Sensing Policy Act of 1992

Approach

- **Identify data "sufficiently consistent in terms of acquisition geometry, spatial resolution, calibration, coverage characteristics, and spatial characteristics with previous Landsat data…"**
    - Consistent with Management Plan for the Landsat Program

Process

- **Identify acceptable gap-mitigation specifications**
- **Identify existing and near-term capabilities**
- **Compare capabilities to acceptable specifications**
- **Synthesize findings and make recommendations**

Team Assumptions

- Assume 2007 Landsat 7 failure for planning purposes
- Assume limited lifetime and capability for Landsat 5
- Focus on data acquisition vs. building a satellite
- Address DOI responsibility to store, maintain, and upgrade science-quality data in the National Satellite Land Remote Sensing Data Archive (NSLRSDA)
- OLI data available no earlier than 2010
- LDCM data specification used to define team’s data quality and quantity goals
- Landsat 7 unrestricted data policy will serve as the model for acquired data

TOOLS FOR OBSERVING THE LAND

Resolution and coverage for different needs….

VIIRS — **3300 km swath**

- spatial resolution, 400/800m (nadir (Vis/IR))
- global coverage, 2x/day/satellite

AVHRR/ MODIS — **2048 km swath**

- spatial resolution, 250m, 500m, 1000m
- global coverage, 2 days

MISR — **360 km**

- spatial resolution, 275m, 550m, 1100m
- global coverage, 9 days

Landsat — **183 km**

- spatial resolution, 15m, 30m, 60m
- 16 day orbital repeat
- seasonal global coverage

ASTER — **60 km**

- spatial resolution 15m, 30m, 90m
- 45-60 day orbital repeat
- global coverage, years

"Moderate Resolution Land Imaging (5-120m)"

Commercial Systems — **~ 10 km**

- spatial resolution < 5m
- global coverage, decades, if ever

…. PLUS RADAR, MAGNETICS, MICROWAVE, ETC., plus airborne and in situ methods

USGS

NASA

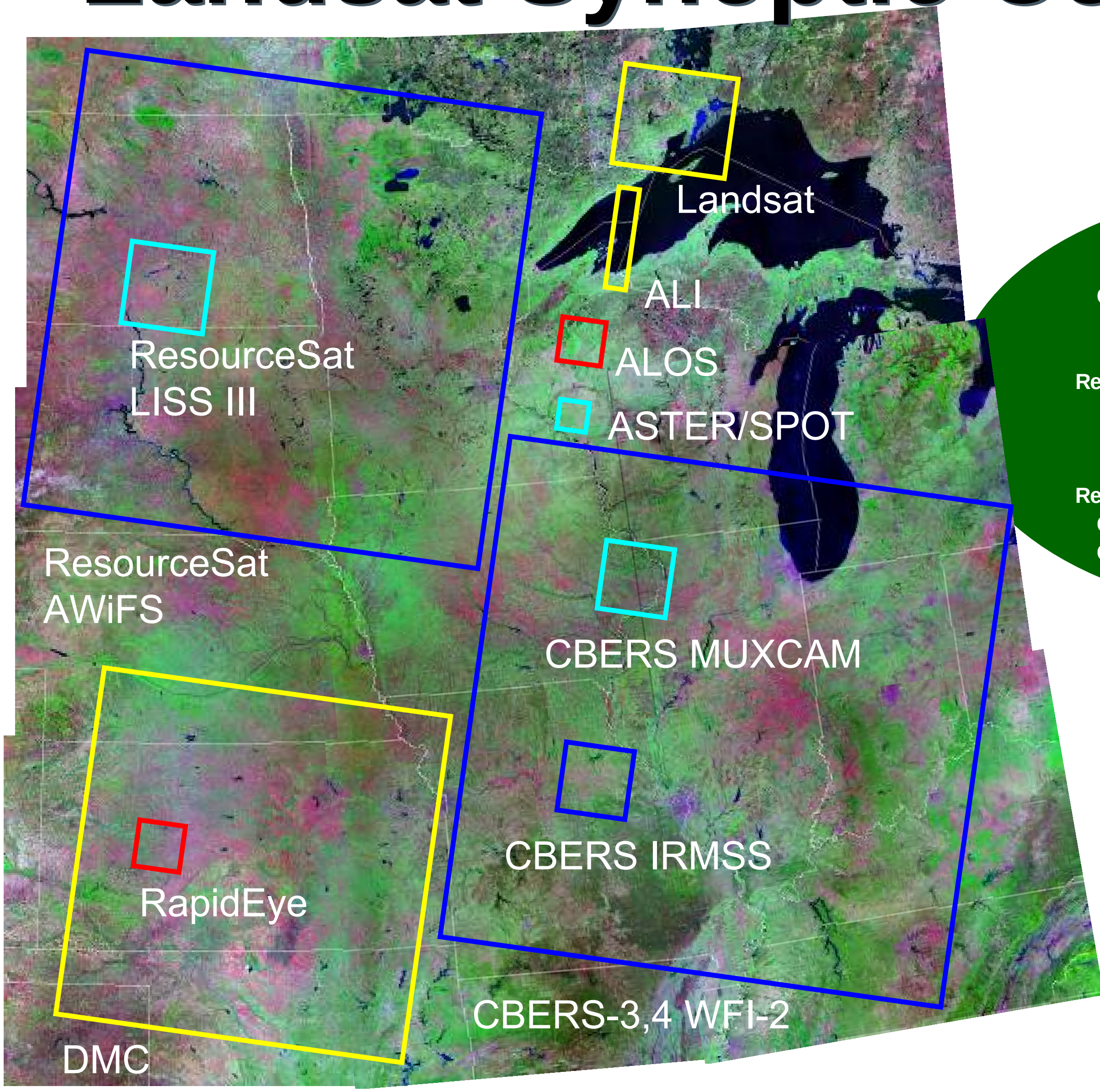
Requirements and Capabilities Analysis

- **LDCM Data Specification ("Goal") has been vetted by science and applications communities, and supports the full range of Landsat applications**
- **Obtaining data identical to LDCM from existing systems is not possible**
- **Minimum acceptable specifications were derived to support basic global change research given available sources of Landsat-like data**
  - 2x Annual Global Coverage
  - Spatial Resolution
  - Spectral Coverage
  - Data Quality

Systems Considered

✓IRS ResourceSat – 1, 2 (India)
✓CBERS – 2, 2A, 3, 4 (China & Brazil)
✓Rapid Eye – 1, 2, 3, 4, 5 (Germany)
✓DMC (Algeria, Nigeria, UK, China)
✓Terra/ASTER (US & Japan)
✓High-resolution U.S. commercial systems
✓IKONOS, Quickbird, OrbView-3
✓ALOS (Japan)
✓SPOT – 4, 5 (France)
✓EO-1/ALI (US)

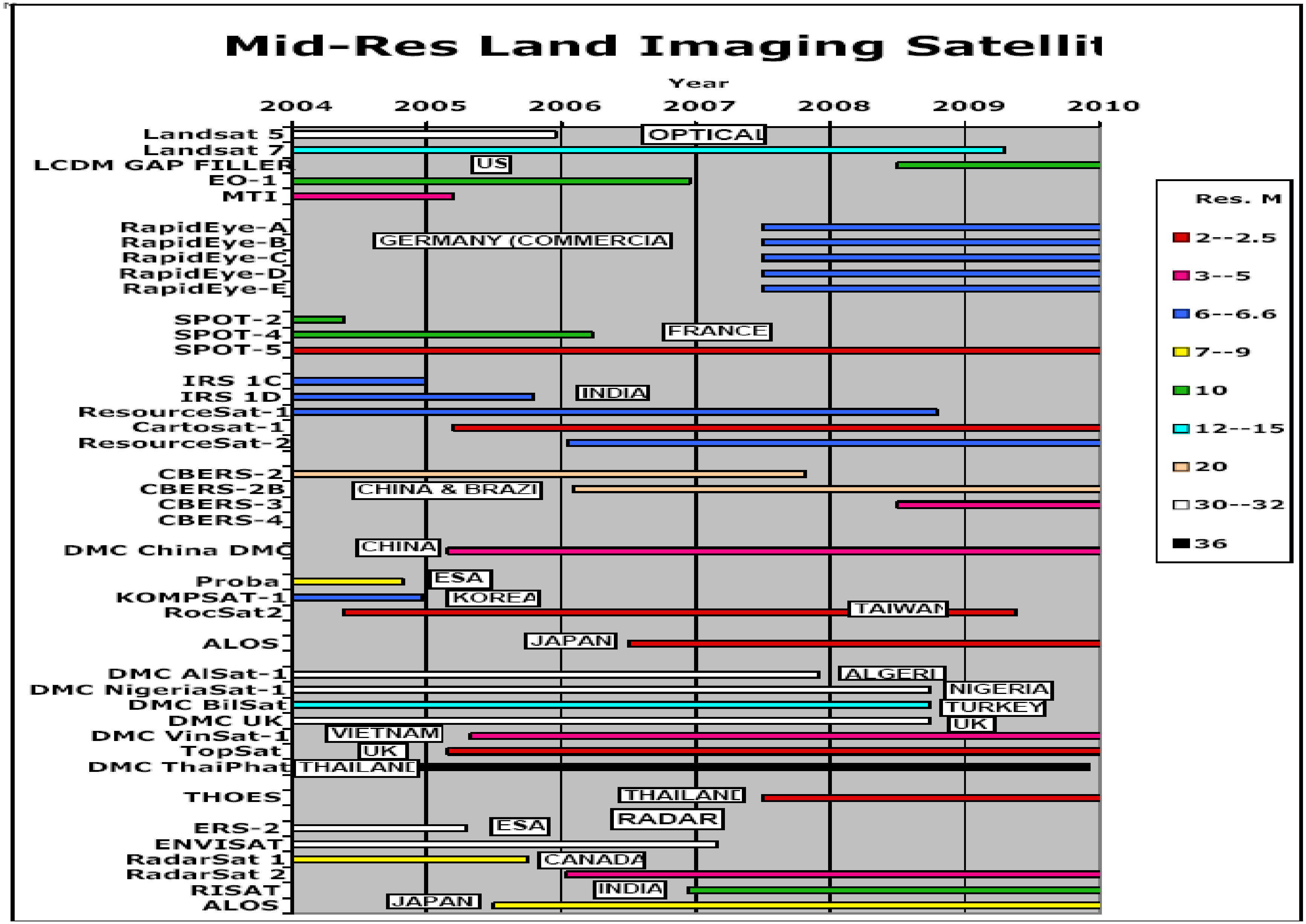
Landsat Synoptic Coverage



Satellite	Sensor	Ground Sample Distance (m)
RapidEye	REIS	6.5
ALOS	AVNIR	10
CBERS-3,4	MUXCAM	20
SPOT 5	HRG	10/20
Terra	ASTER	15/30/90
ResourceSat-1	LISS III+	23.5
Landsat 7	ETM+	15/30/60
EO-1	ALI	30
DMC	MSDMC	32
ResourceSat-1	AWiFS*	56
CBERS-3,4	WFI-2	73
CBERS-3,4	IRMSS	40/80

Note: For purposes of scene size comparison only. Locations do not represent actual orbital paths or operational acquisitions.

Systems Considered



Landsat Data Gap Synopsis

- **There is no substitute for Landsat**
  - Single source of systematic, global land observations
  - Alternate sources may reduce the impact of a Landsat data gap

- **Data quality and operational capability of potential candidate systems is currently being verified**
  - USGS currently working with ISRO ResourceSat-1 (India) and CAST/INPE CBERS (China Brazil)
- **Landsat data gap mitigation efforts could serve as prototype for Integrated Earth Observing System (IEOS -- U.S. contribution to GEOSS)**
  - Implementation plan correlates with IEOS Global Land Observing System concept

- **Several systems could meet special regional acquisition needs during some or all of the data gap period**

Data Gap Study Team Management

- **Landsat Data Gap Study Team (LDGST)**
  - Developing a strategy for providing data to National Satellite Land Remote Sensing Data Archive for 1-4 years
  - Policy and Management Team – Ed Grigsby and Ray Byrnes
  - Technical Team – Chaired by Jim Irons
- **Data Characterization Working Group (DCWG)**
  - Technical group from three field centers (USGS EROS, NASA GSFC, NASA SSC) to evaluated data from IRS-P6 and CBERS-2 sensors
- **Tiger Team Charter**
  - The tiger team is charged with developing & analyzing a set of technical & operational scenarios for receiving, ingesting, archiving, and distributing data from alternative, Landsat-like satellite systems.
  - The tiger team will conduct trade studies & assess the risk of the various scenarios & provide rough order magnitude costs for the alternatives

Overview of the CBERS-2 sensors

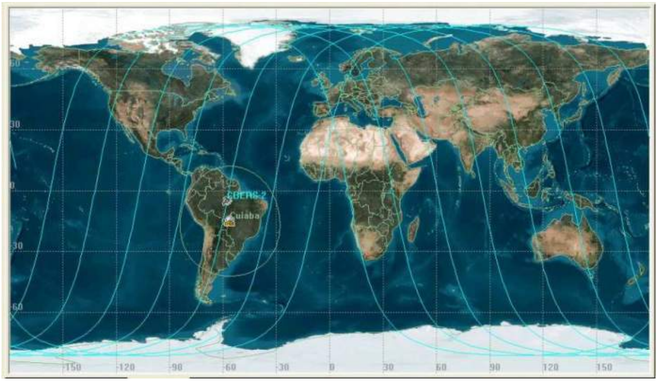
Cross-Calibration of the L5 TM and the CBERS-2 CCD sensor

U.S. Department of the Interior

U.S. Geological Survey

China Brazil Earth Resources Satellite - CBERS

- **CBERS-1, was launched on Oct. 14, 1999**
  - The spacecraft was operational for almost 4 years
  - The CBERS-1 images were not used by user community
  - On Aug. 13, 2003, CBERS-1 experienced an X-band malfunction causing an end of all image data transmissions
- **CBERS-2 (or ZY-1B) was launched successfully on Oct. 21, 2003 from the Taiyuan Satellite Launch Center**
  - The spacecraft carries the identical payload as CBERS-1
- **CBERS Orbit**
  - Sun synchronous
  - Height: 778 km
  - Inclination: 98.48 degrees
  - Period: 100.26 min
  - Equator crossing time: 10:30 AM
  - Revisit: 26 days
  - Distance between adjacent tracks: 107 km



CBERS- Sensor Compliment

- **CBERS satellite carries on-board a multi sensor payload with different spatial resolutions & collection frequencies**
  - HRCCD (High Resolution CCD Camera)
  - IRMSS (Infrared Multispectral Scanner)
  - WFI (Wide-Field Imager)
- **The CCD & the WFI camera operate in the VNIR regions, while the IRMSS operates in SWIR and thermal region**
- **In addition to the imaging payload, the satellite carries a Data Collection System (DCS) and Space Environment Monitor (SEM)**

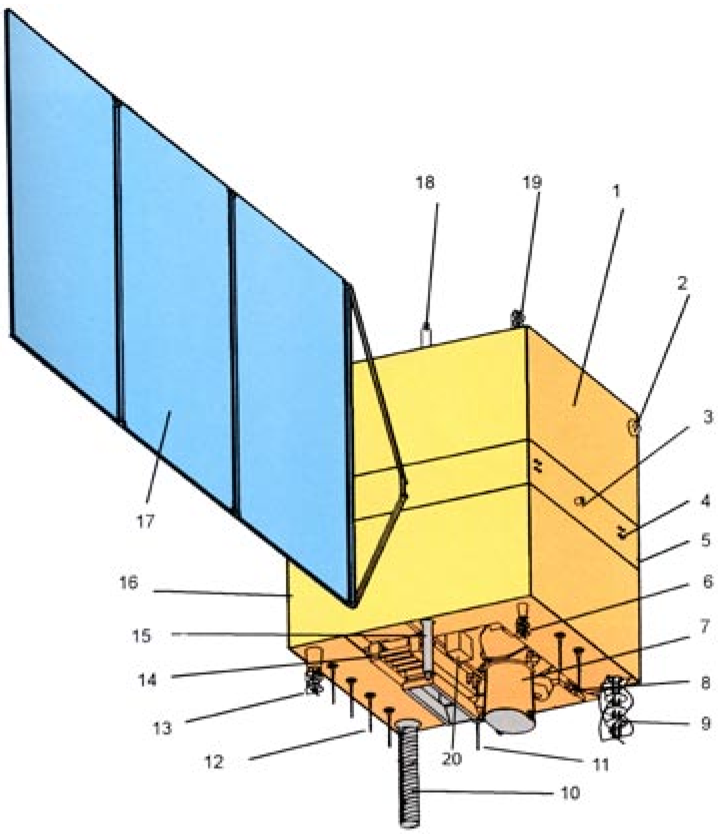
Work Share (70% China, 30% Brazil)

Pay load Module (16)

CCD (14)	China
IRMSS (7)	China
WFI (20)	Brasil
Data Transmission	China
Data collection	Brasil

Service Module (1)

Structure	Brasil
Thermal Control	China
Attitude and Orbit Control	China
Power supply	Brasil
On-board computer	China
Telemetry	Brasil



High Resolution CCD (HRCCD)

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

Infrared Multispectral Scanner (IRMSS)

- **The IRMSS is a moderate-resolution sensor offering a GSD of 80m (pan/SWIR) & 160m (thermal)**
- **Quantization: 8 bits**
- **Ground swath is 120 km with 26 days repeat cycle**
- **Operates in four spectral bands - one pan, two SWIR & one thermal**
  - The four spectral bands has eight detector staggered arrays mounted along track
  - IRMSS has three focal plane assemblies
    - The Pan band (Si photodiodes detectors) is located on the warm focal plane
    - The SWIR bands & the thermal band (HgCdTe detectors) are located on cold focal planes with cryogenic temps of 148K & 101K respectively
    - Four of eight thermal detectors are spare

Wide-Field Imager (WFI)

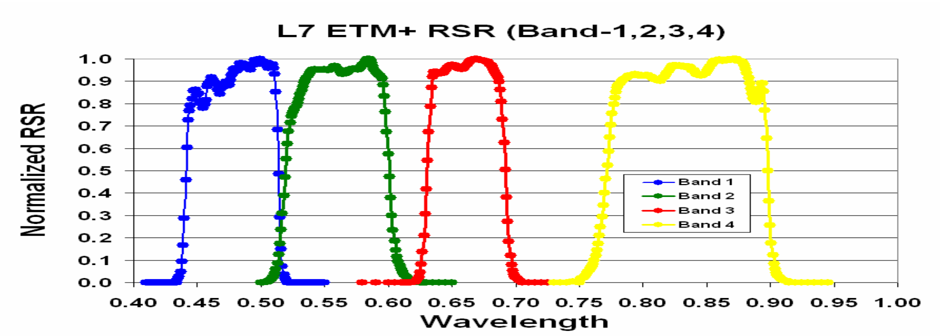
- **The WFI camera provides a synoptic view with spatial resolution of 260m**
- **Ground swath is 885km with 3-5 days repeat cycle**
- **Operates in two spectral bands – (Band 3 & 4)**
  - 0.63 - 0.69 μm (red) and 0.77 - 0.89 μm (infrared)
  - Similar bands are also present in the CCD camera providing complementary data

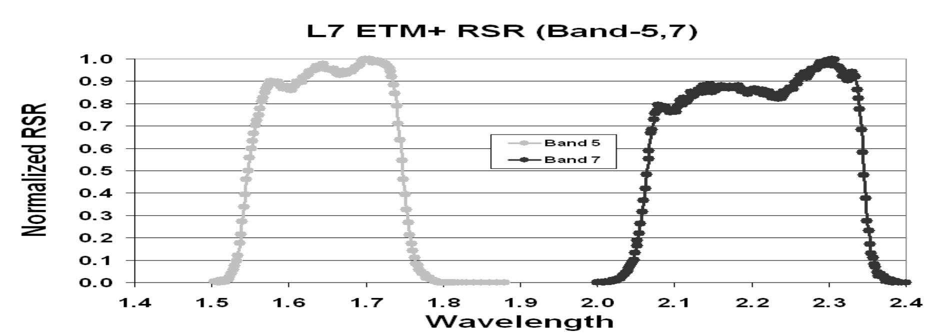
Overview of the CBERS instruments

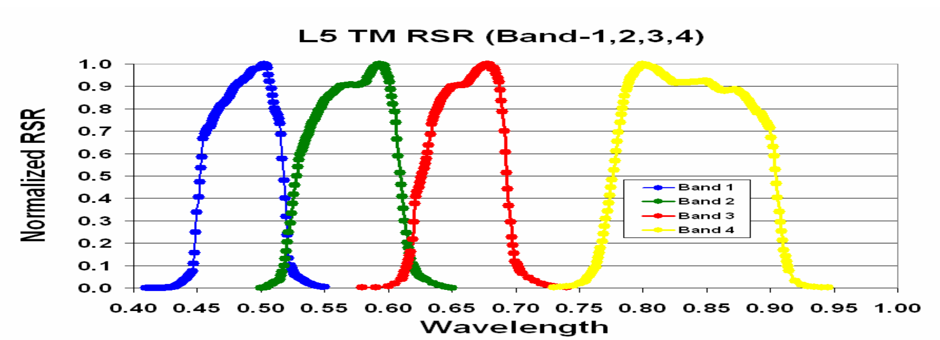
Parameter	HRCC	IRMSS	WFI
Spectral Bands (µm)	0.51 - 0.73 (PAN)	0.50 - 1.10 (PAN)	0.63 - 0.69
	0.45 - 0.52	1.55 - 1.75 (SWIR)	0.76 - 0.90
	0.52 - 0.59	2.08 - 2.35 (SWIR)	
	0.63 - 0.69	10.4 - 12.5 (TIR)	
	0.77 - 0.89		
Spatial Resolution	20 m	80 m (PAN & SWIR)	260 m
		160 m (TIR)	
Swath Width (FOV)	113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

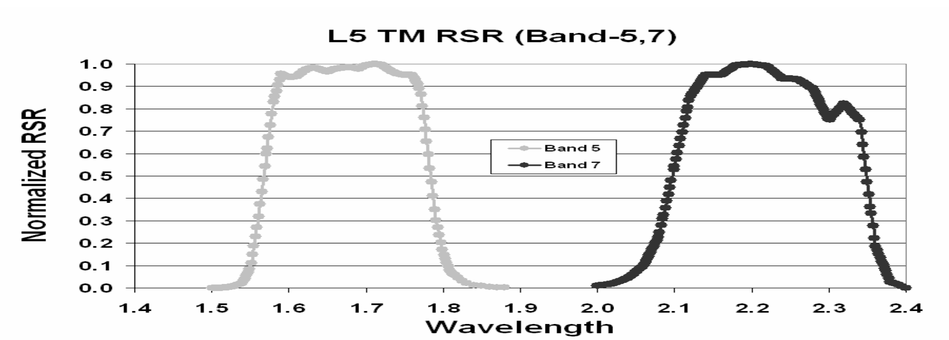
Spectral Range (um) and Ground Sample Distance (m)							
	Landsat		CBERS			SPOT-4	IRS-P6
Band	L5 TM	L7 ETM+	HRCC	IRMSS	WFI		LISS-III
RC	16	16	26	26	5	26	24
1	0.450-0.520 (30)	0.450-0.515 (30)	0.45-0.52 (20)				
2	0.520-0.600 (30)	0.525-0.605 (30)	0.52-0.59 (20)			0.50-0.59 (20)	0.52-0.59 (23.5)
3	0.630-0.690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

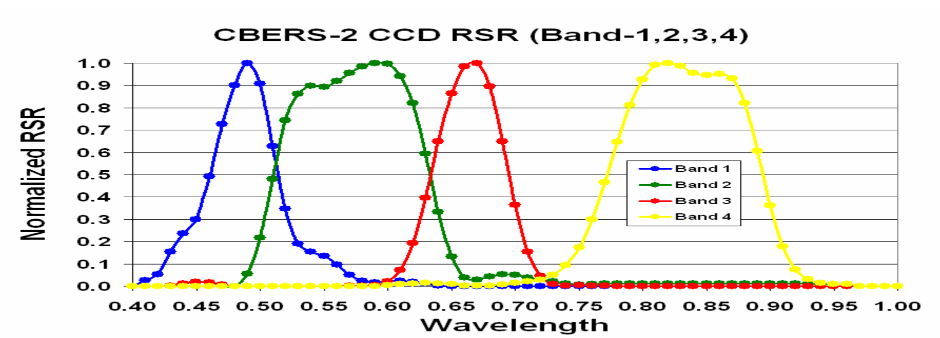
Relative Spectral Response (RSR) Profiles

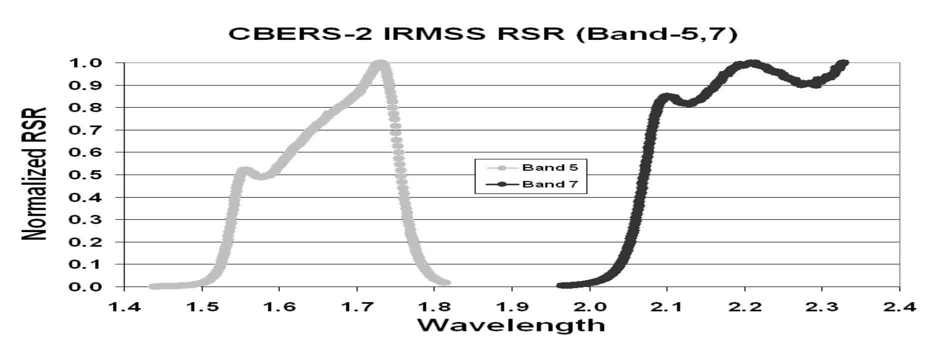




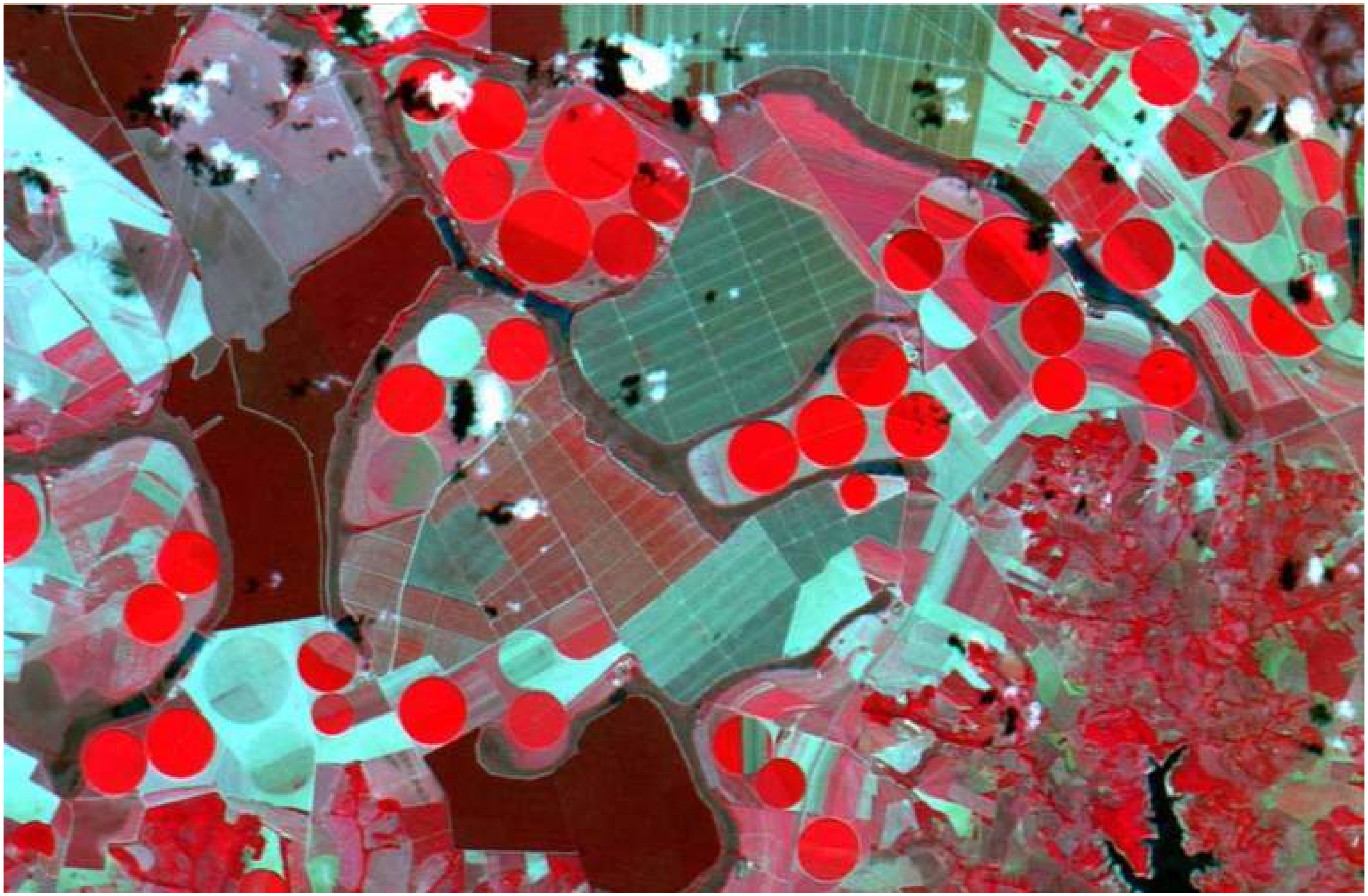








CBERS-2 CCD, Minas Gerais, Brazil

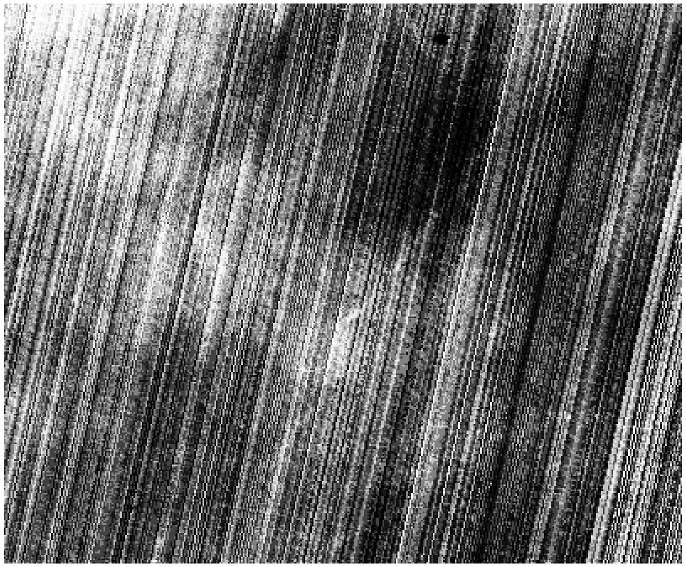


CBERS-2 IRMSS

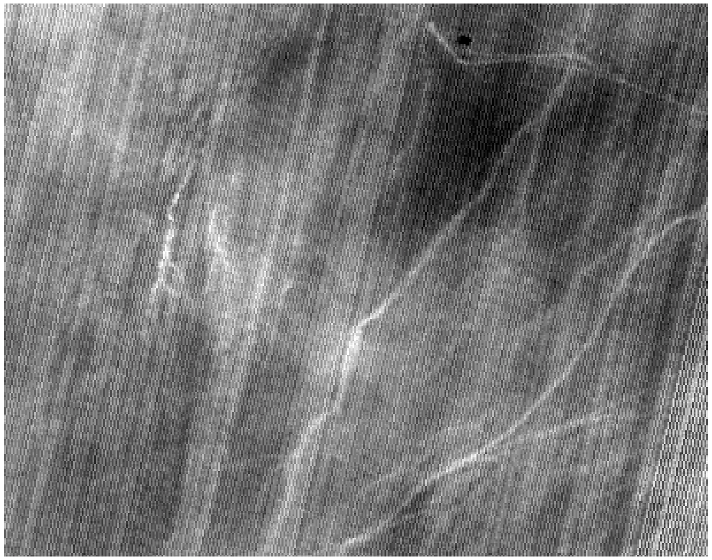
CBERS-2 CCD image, Louisiana
Obtained from on-board data recorder

CB2-IRM-157/124, 24/3/2004, Catanduva (Brazil)

Striping in the CCD data



B1



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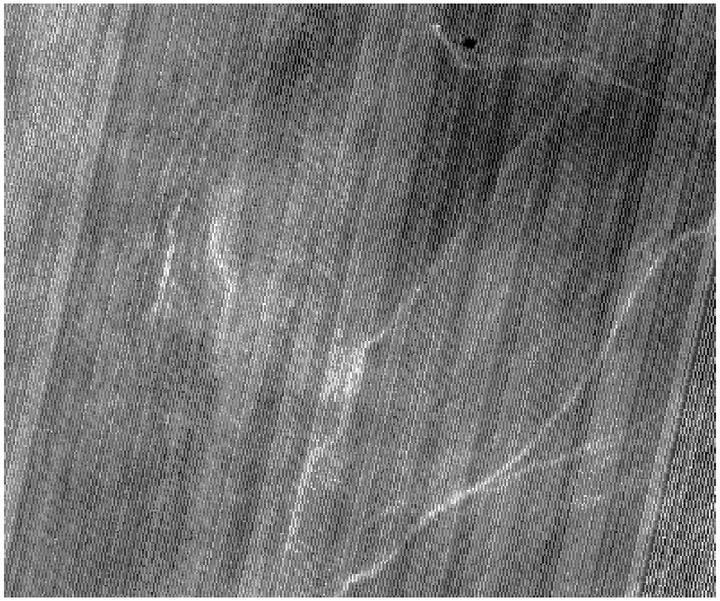
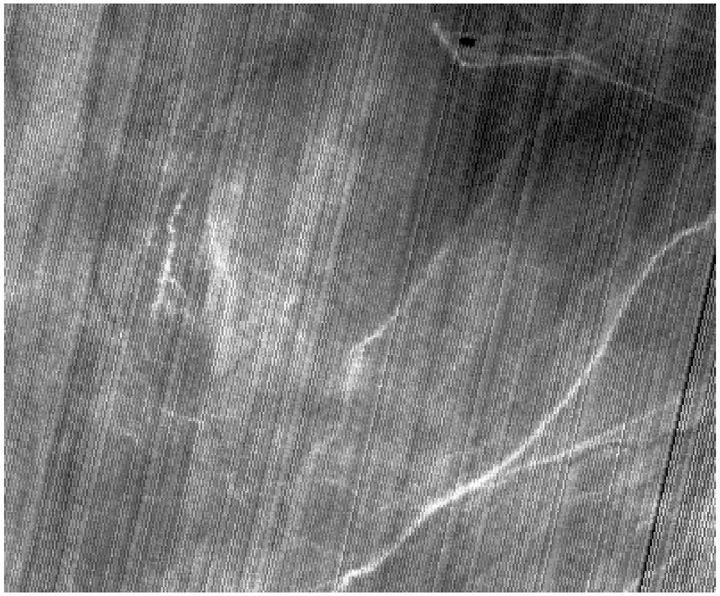


B3



B4

Absolute Calibration Coefficients

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

L* = DNn / CCn

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

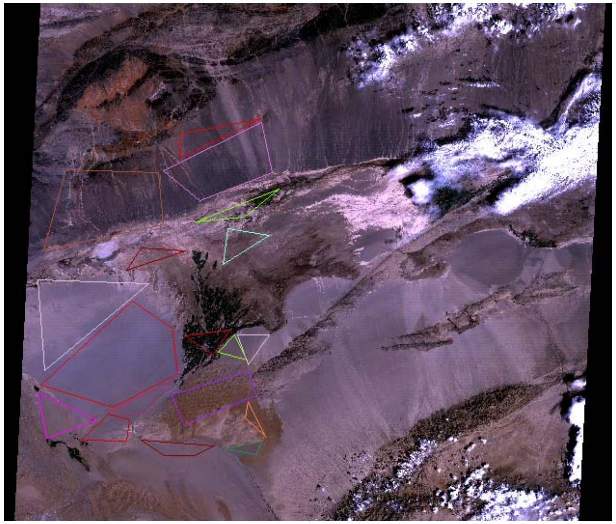
CBERS-2 CCD Vicarious Absolute Calibration Coefficients (CCn)						
	Test-Site	CCD_1	CCD_2	CCD_3	CCD_4	CCD_Pan
Pre-launch		0.9800	1.5900	1.2000	2.2900	1.2500
Brazil						
25th June 2004	Bahia	1.228	2.357	1.215	2.553	1.628
16th August 2004		1.0090	1.9300	1.1540	2.1270	1.4830
Oct_3th New		0.862	1.544	0.874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

CBERS-2 CCD absolute calibration accuracy relative to L5 TM

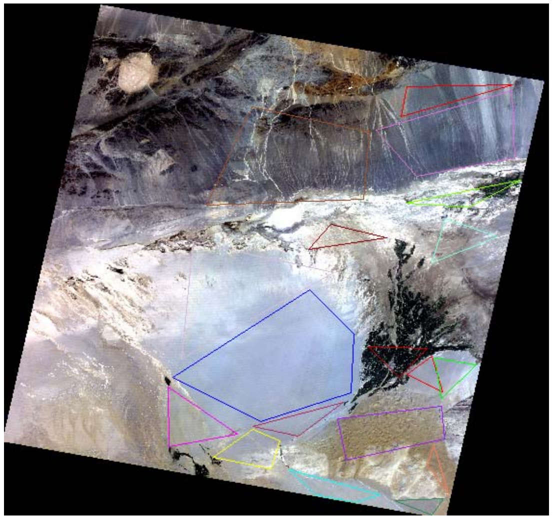
- **Data continuity within the Landsat Program requires consistency in interpretation of image data acquired by different sensors**
  - A critical step in this process is to put image data from subsequent generations of sensors onto a common radiometric scale
- **To evaluate CBERS-2 CCD utility in this role, image pairs from the CBERS-2 CCD & L5 TM sensors were compared**
  - The cross-calibration was performed using image statistics from large common areas observed by the two sensors
- **It is very difficult to get coincident image pairs from the two satellites (different WRS)**

Agency	Sensor	Date	DOY	Path	Row	Look angle	Sun Elevation	GMT
CRESDA	CBERS-2 CCD	8/25/2004	237	23	55	-6.03	56.60	
	L5 TM	8/25/2004	237	137	32	0.00	53.37	
INPE	CBERS-2 CCD	12/30/2004	365	154	126		64.23	13:14:15
	L5 TM	12/29/2004	364	219	76	0.00	59.32	12:50:15
INPE	CBERS-2 CCD	11/16/2005	320	151	126		66.47	12:58:05
	L5 TM	11/16/2005	320	217	76	0.00	63.03	12:40:25

L5 TM and CBERS-2 CCD Image Pairs

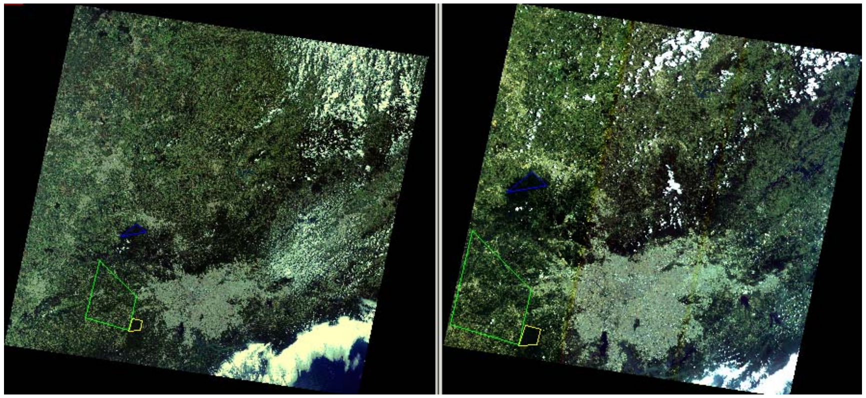


L5 TM WRS Path = 137 Row = 032
Nadir looking

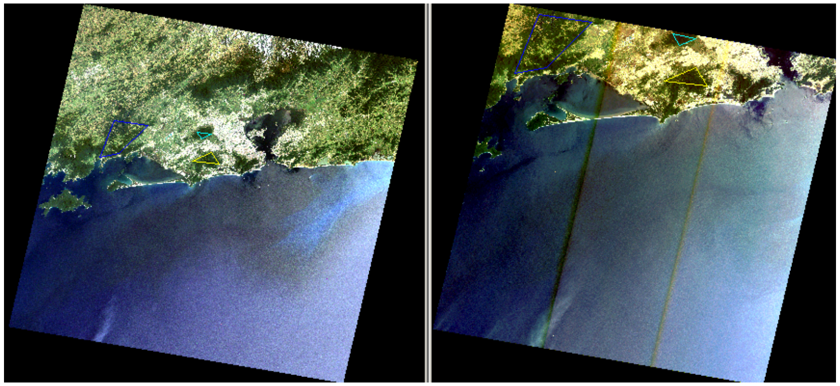


CBERS-2 CCD Path = 23 Row = 55 side-looking (off-nadir-look-angle=-6.0333)

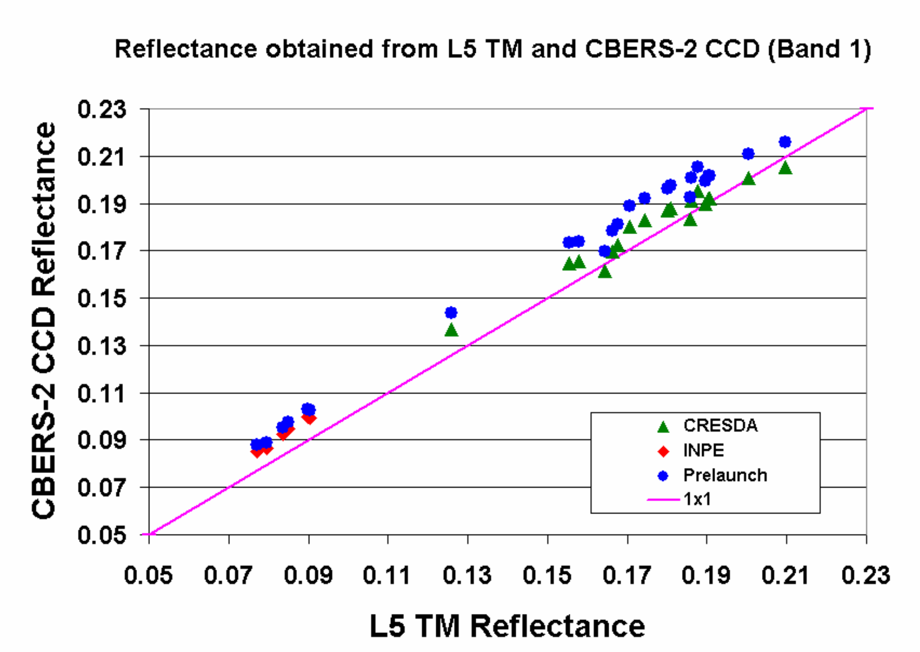
Gobi (Dunhuang) desert test site
Data acquired on
Aug 25, 2004 (20 min apart)

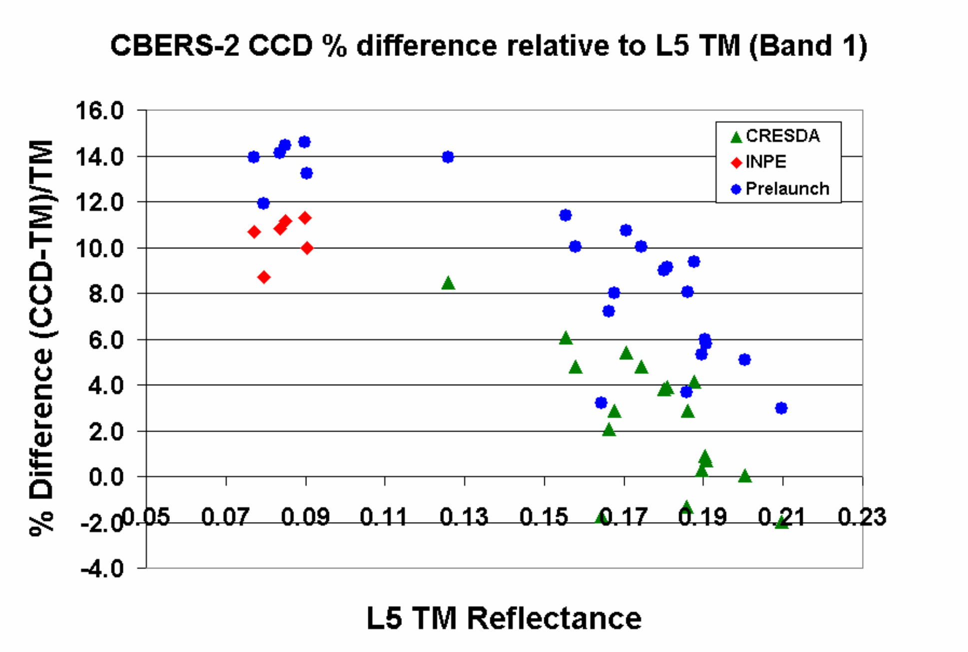


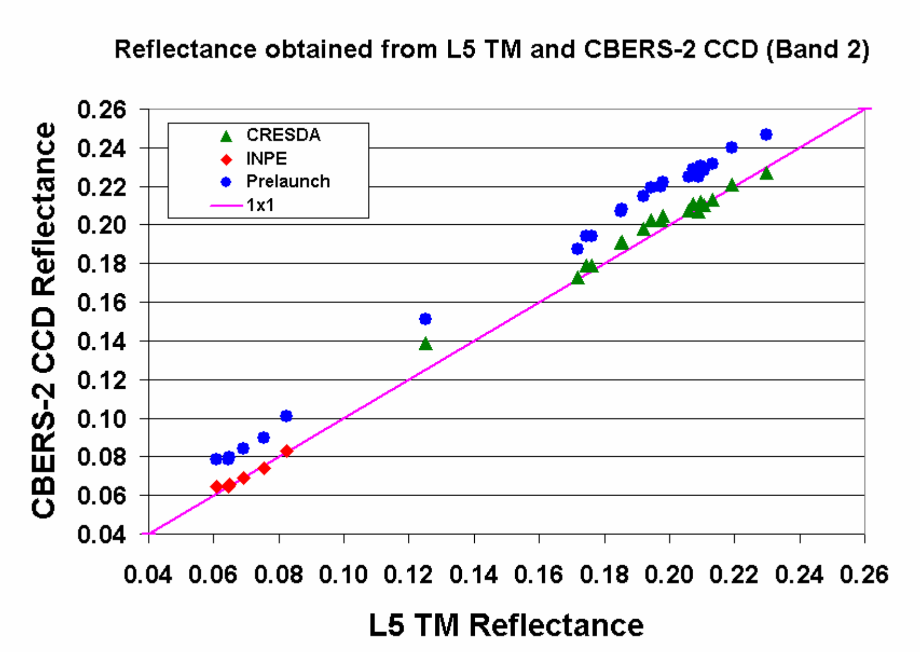
L5 TM WRS Path = 219 Row = 076
Nadir looking Acquisition Date: Dec 29, 2004
CBERS-2 CCD Path = 154 Row = 126
Acquisition Date: Dec 30, 2004

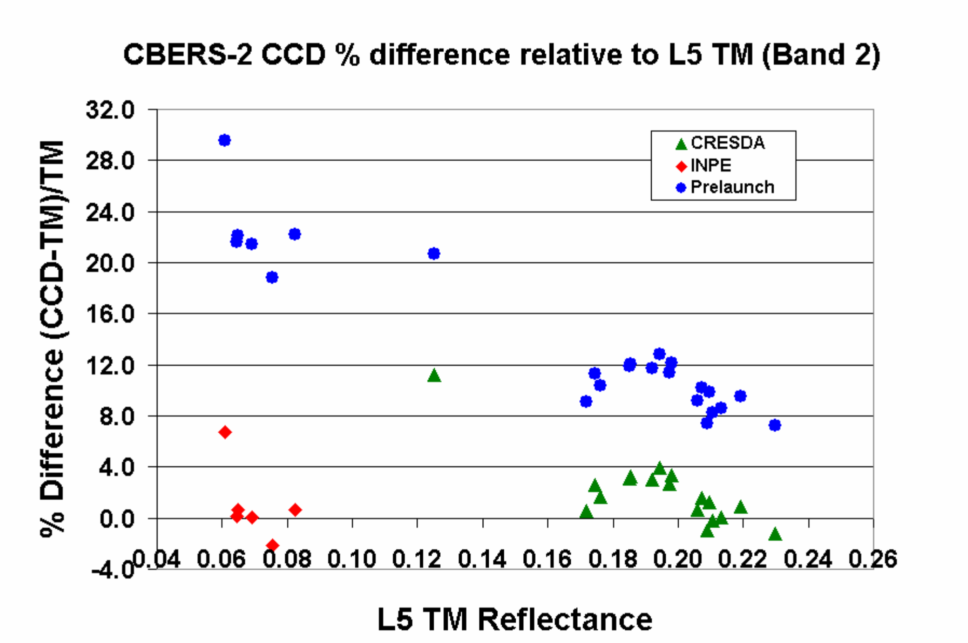


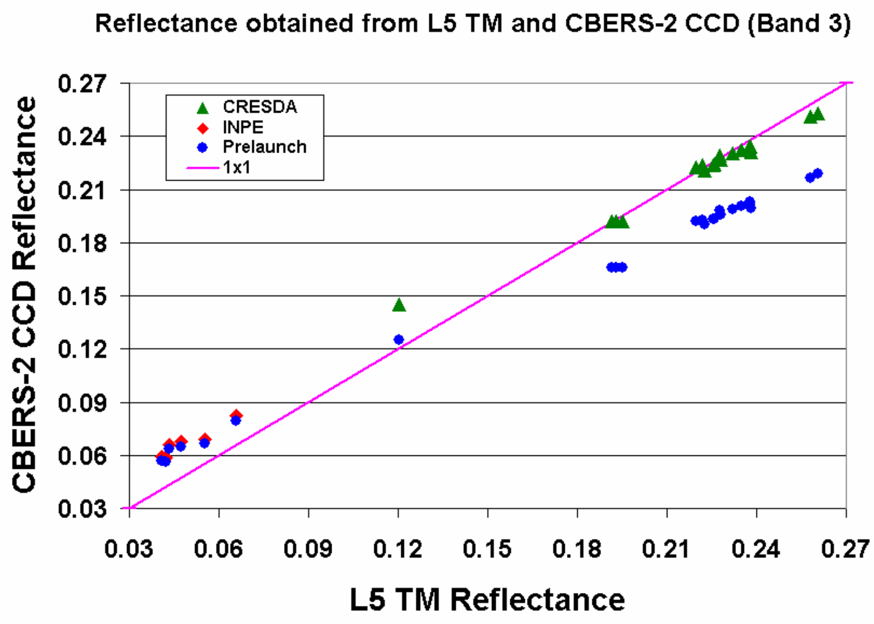
L5 TM WRS Path = 217 Row = 076
Nadir looking Acquisition Date: Nov 16, 2005
CBERS-2 CCD Path = 151 Row = 126
Acquisition Date: Nov 16, 2005

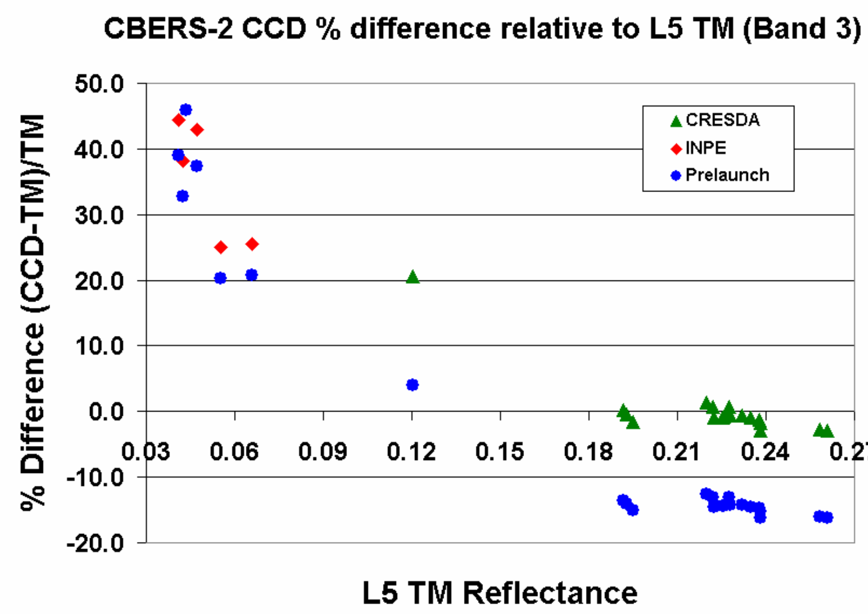

Reflectance obtained from L5 TM and CBERS-2 CCD (Band 1)
CBERS-2 CCD Reflectance
L5 TM Reflectance
0.05 0.07 0.09 0.11 0.13 0.15 0.17 0.19 0.21 0.23
CRESDA
INPE
Prelaunch
1x1

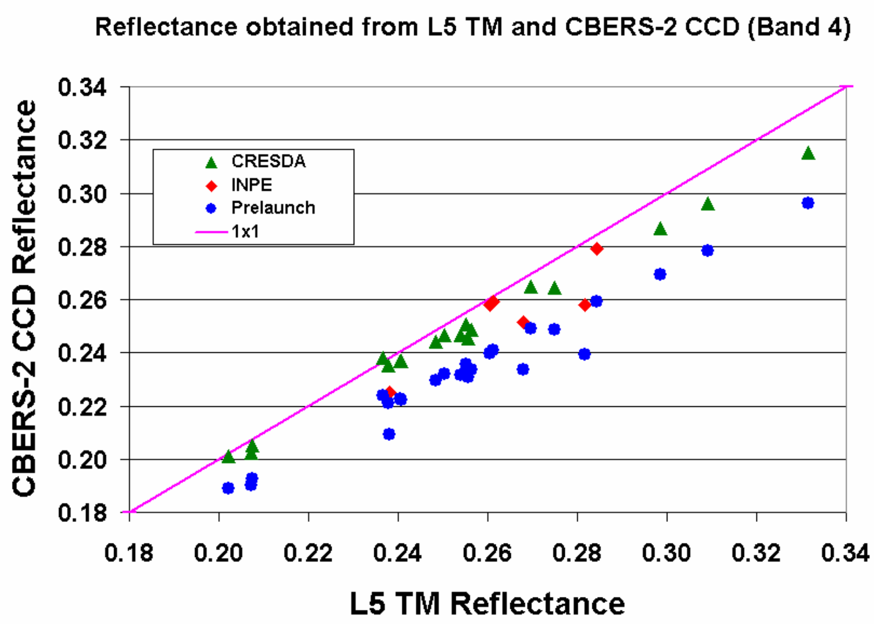

CBERS-2 CCD % difference relative to L5 TM (Band 1)
% Difference (CCD-TM)/TM
L5 TM Reflectance
16.0 14.0 12.0 10.0 8.0 6.0 4.0 2.0 0.0 -2.0 -4.0
0.05 0.07 0.09 0.11 0.13 0.15 0.17 0.19 0.21 0.23
CRESDA
INPE
Prelaunch

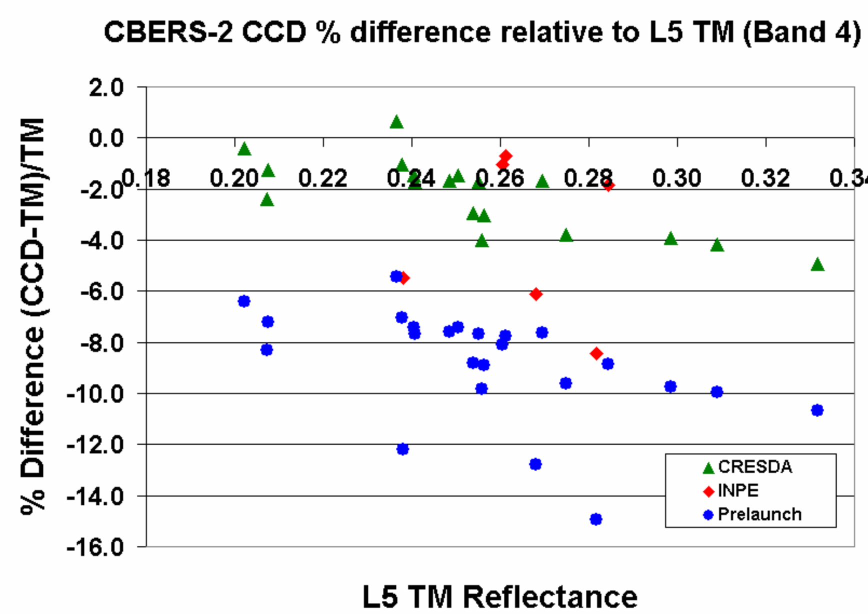

Reflectance obtained from L5 TM and CBERS-2 CCD (Band 2)
CBERS-2 CCD Reflectance
L5 TM Reflectance
0.04 0.06 0.08 0.10 0.12 0.14 0.16 0.18 0.20 0.22 0.24 0.26
CRESDA
INPE
Prelaunch
1x1

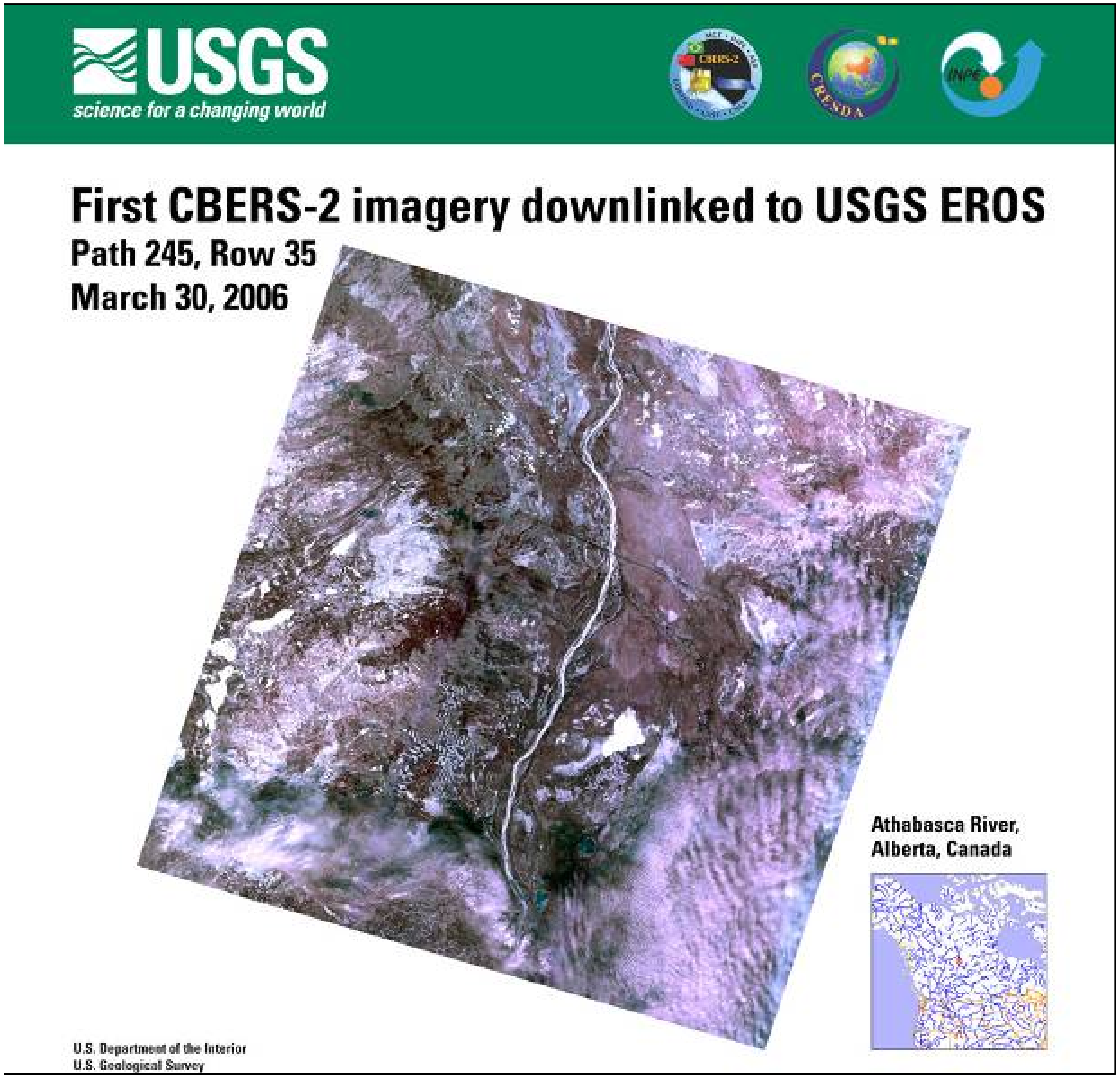

CBERS-2 CCD % difference relative to L5 TM (Band 2)
% Difference (CCD-TM)/TM
L5 TM Reflectance
32.0 28.0 24.0 20.0 16.0 12.0 8.0 4.0 0.0 -4.0
0.04 0.06 0.08 0.10 0.12 0.14 0.16 0.18 0.20 0.22 0.24 0.26
CRESDA
INPE
Prelaunch

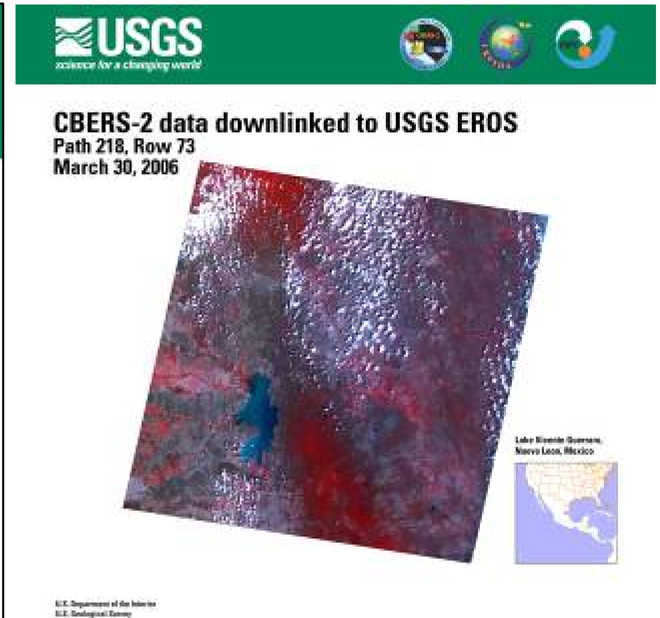

Reflectance obtained from L5 TM and CBERS-2 CCD (Band 3)
CRESDA
INPE
Prelaunch
1x1
CBERS-2 CCD Reflectance
L5 TM Reflectance

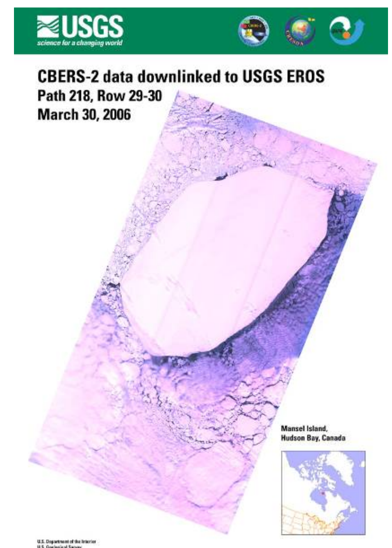

CBERS-2 CCD % difference relative to L5 TM (Band 3)
CRESDA
INPE
Prelaunch
% Difference (CCD-TM)/TM
L5 TM Reflectance


Reflectance obtained from L5 TM and CBERS-2 CCD (Band 4)
CRESDA
INPE
Prelaunch
1x1
CBERS-2 CCD Reflectance
L5 TM Reflectance


CBERS-2 CCD % difference relative to L5 TM (Band 4)
CRESDA
INPE
Prelaunch
% Difference (CCD-TM)/TM
L5 TM Reflectance







The first China-Brazil Earth Resources Satellite (CBERS-2) data downlink at USGS Center for EROS in support of the Landsat Data Gap Study

The USGS Center for EROS Director, R.J. Thompson, visiting with Jose Bacellar from Brazilian National Institute for Space Research (INPE) after a successful China-Brazil Earth Resources Satellite (CBERS-2) data downlink

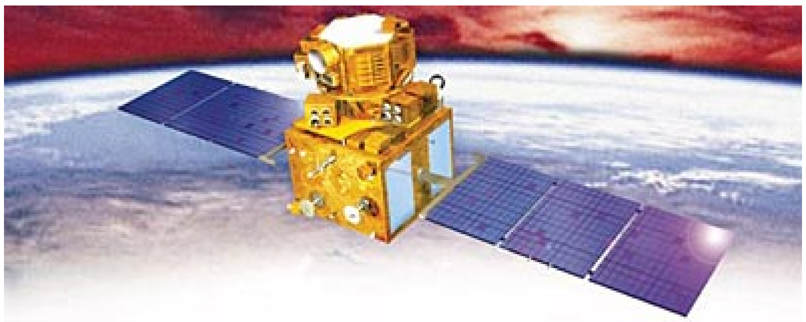
- **"CBERS in a box" works - The CBERS-2 capture and processing system is a small computer that can perform the following tasks**
    - ingest the raw data
    - show the image data in a "moving window" display
    - record the raw data in the computer's hard disk
    - process the raw data to level 1 products
    - generate quick looks to populate the Data Catalog of the system
    - make the level 1 data available to the users

Challenges and Future Plans

- **CBERS-2 High Density Data Recorder (HDDR) is not in use due to power limitations**
- **The IRMSS stopped working in Apr 2005 due to power supply failure**
- **Limited coincident Landsat/CBERS image-pairs**
  - Limited data distribution policies outside the country
  - Limited documentation available
  - No L7 data downlink in Brazil
- **CBERS-2B test downlink at USGS EROS (CBERS cal visit to EROS 2/20/07)**
- **Analyze IRMSS data**
- **Evaluate the raw data (artifacts, noises)**
  - Evaluate the relative calibration of the CCD data
  - Evaluate Bias estimates
  - Night time acquisitions
- **Perform similar cross-calibration experiment**
  - Data processed from INPE
  - Data processed from CRESDA
  - Same datasets processed at INPE and CRESDA
  - Temporal scale (image pairs from 2003-2005)
- **Perform joint field Vicarious calibration campaign**

Overview of the IRS-P6 Sensors

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



U.S. Department of the Interior

U.S. Geological Survey

Resourcesat-1 (IRS P6)

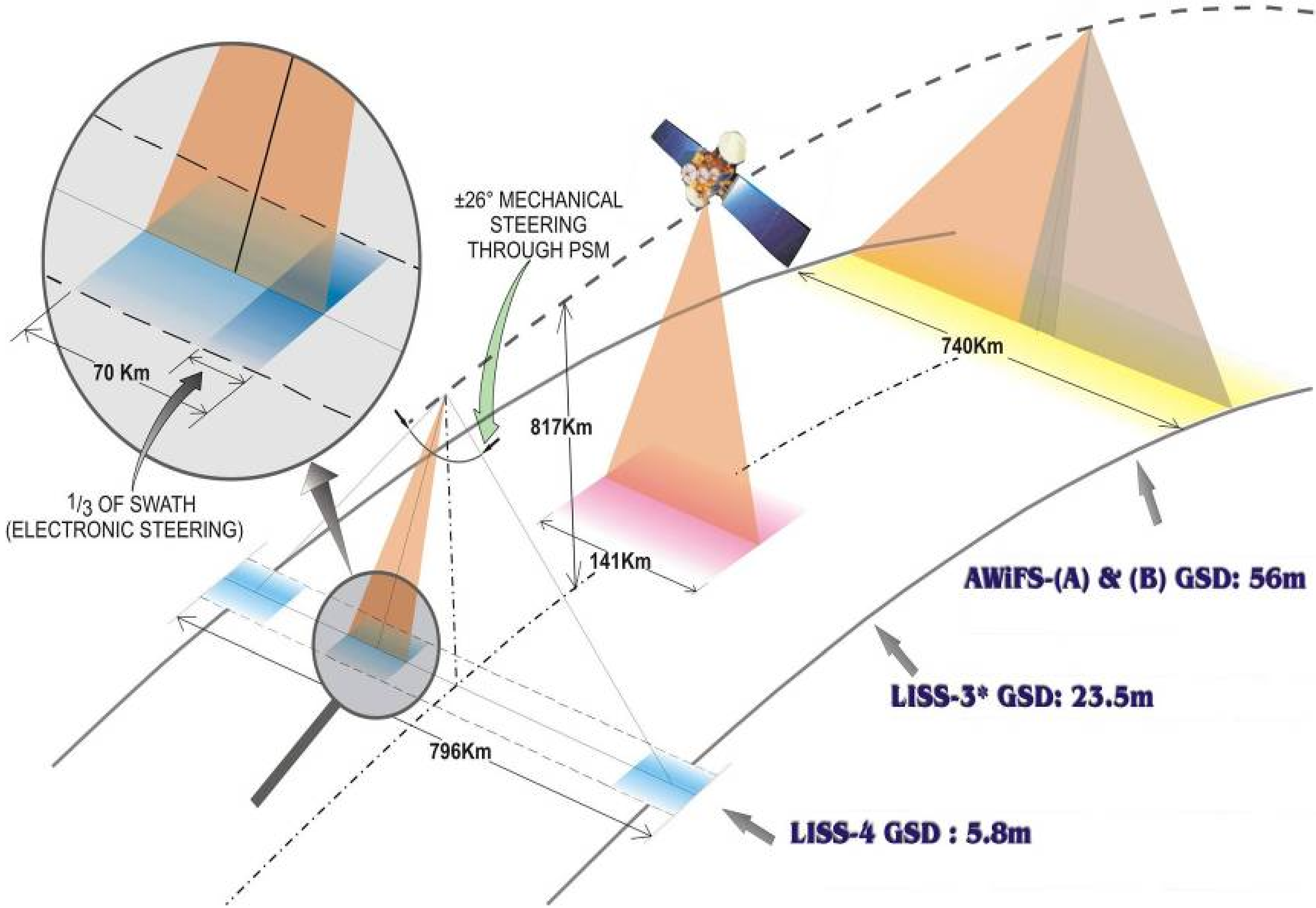
- **The RESOURCSAT-1 satellite was launched in to the polar sun-synchronous orbit (altitude of 817 km) by PSLV-C5 launch vehicle on October 17, 2003 with a design life of 5 years**
- **RESOURCSAT-1 is also called IRS-P6**
  - Most advanced Remote Sensing Satellite built by ISRO
  - Tenth satellite of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

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

ResourceSat-1 Overview

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

IRS-P6 THREE TIER IMAGING



Advanced Wide Field Sensor (AWiFS)

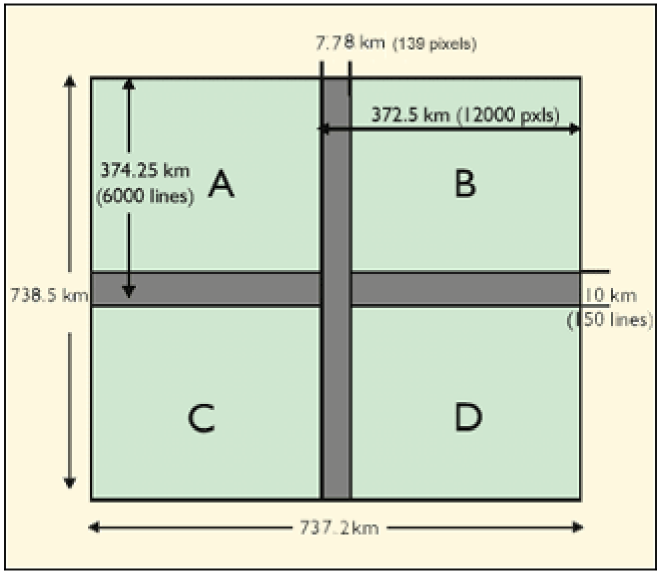
- The AWiFS with twin cameras is a moderate-resolution sensor offering a GSD of 56m at nadir
- Quantization: 10 bits
- Combined ground swath is 740km with five day repeat cycle
- Operates in four spectral bands – three VNIR one SWIR

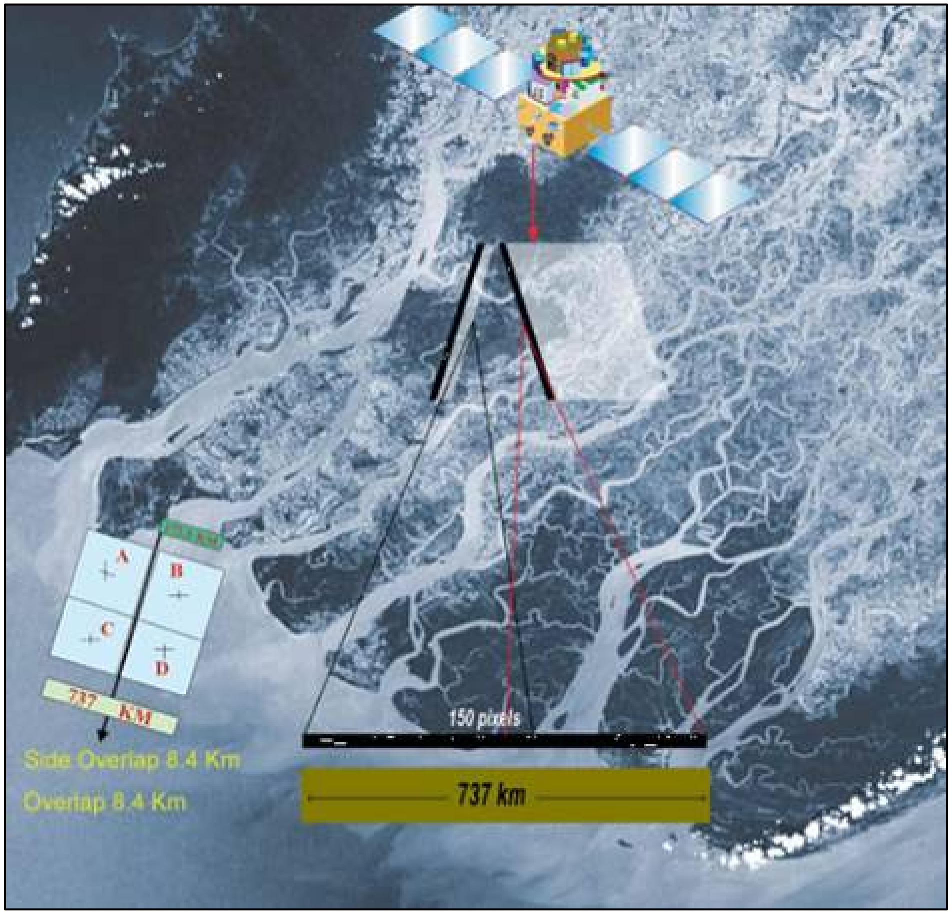
VITAL FACTS:

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

AWiFS Sensor Collection Mode

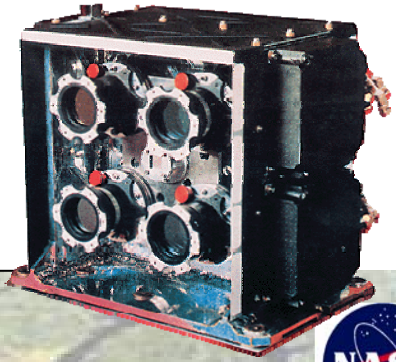
The AWiFS camera is split into two separate electro-optic modules (AWiFS-A and AWiFS-B) tilted by 11.94 degrees with respect to nadir





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

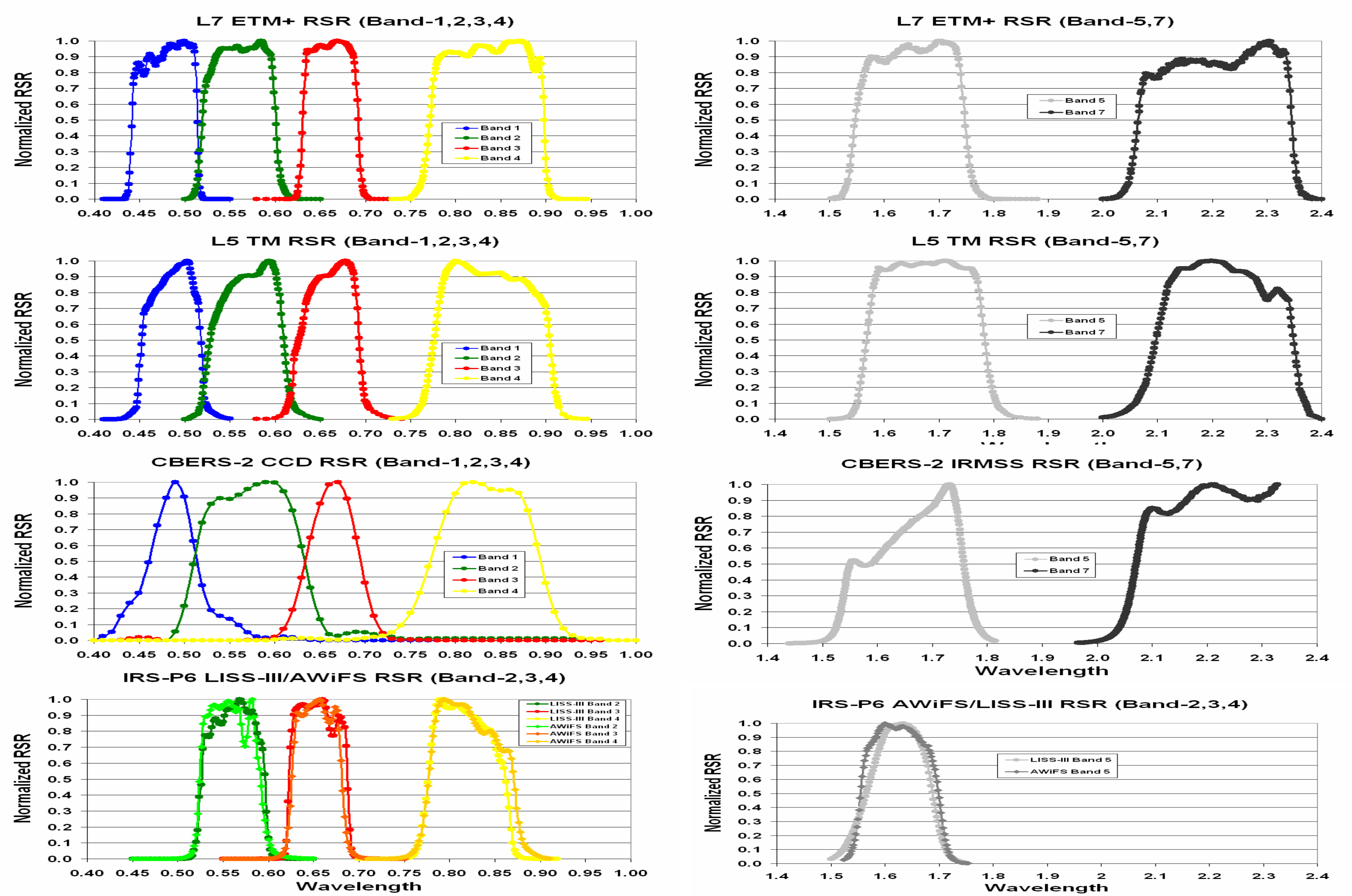
- **The LISS-III is a medium resolution sensor offering a GSD of 23.5m**
- **Quantization: 7 bits (SWIR band 10 bits – selected 7 transmitted)**
- **Ground swath is 141 km with 24 day repeat cycle**
- **Operates in four spectral bands - three VNIR one SWIR**
- **Each band consists of a separate lens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



IRS-P6 Sensor Specifications

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

Relative Spectral Response (RSR) Profiles



Conversion to Radiance

$$L^* = \frac{(Lmax - Lmin)}{Qcalmax} Qcal + Lmin$$

Where

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

Header File Information (Lmax & Lmin)

LISS-IV Mono Band 3:

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

LISS-III:

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

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

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

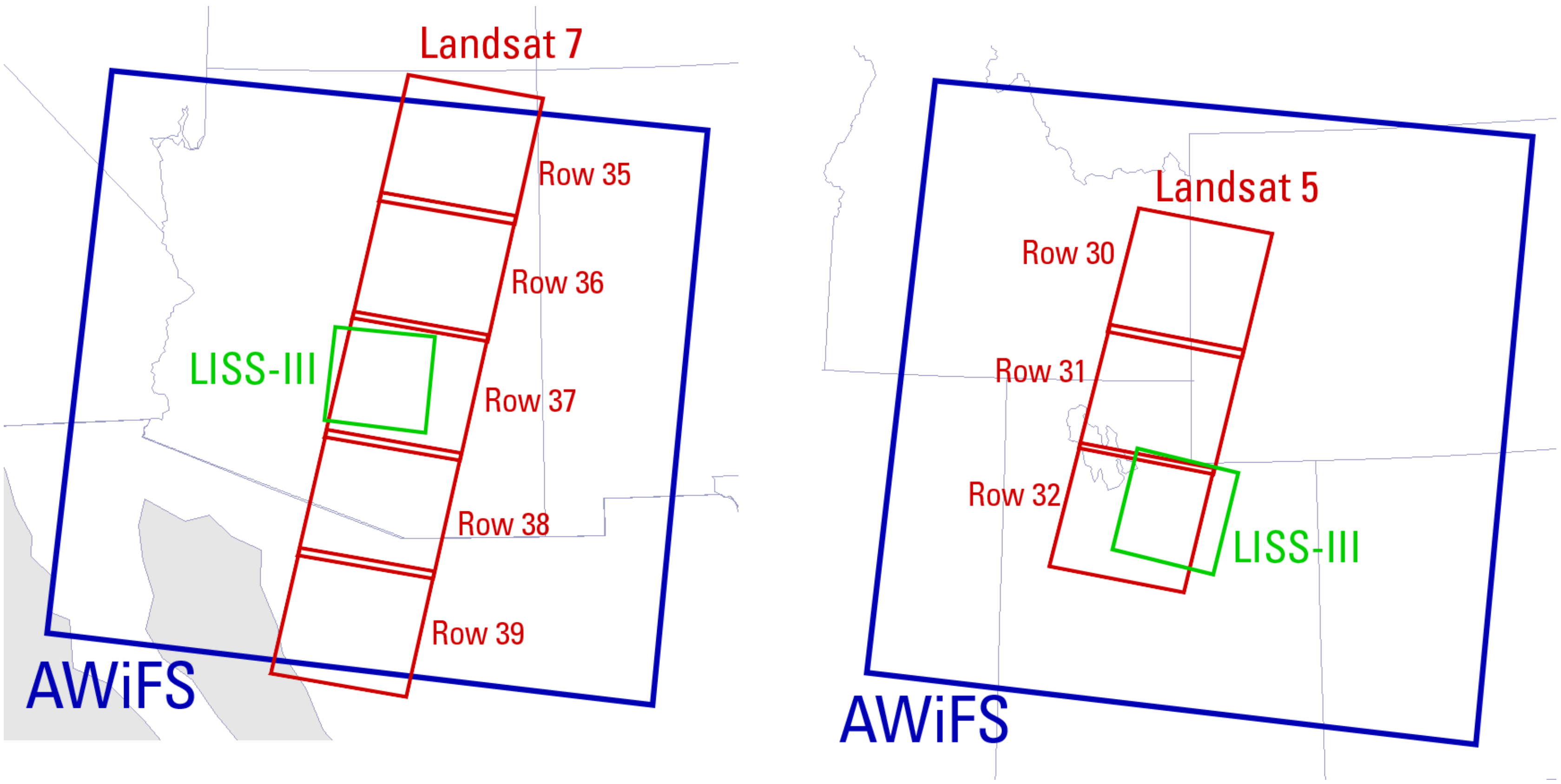
AWiFS-B camera (B&D quadrant scenes):

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

Cross-Calibration Methodology

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

Image boundaries of scenes used



Comparison Scenes Used -- Mesa, AZ

Mesa, Arizona collection, June 29, 2005

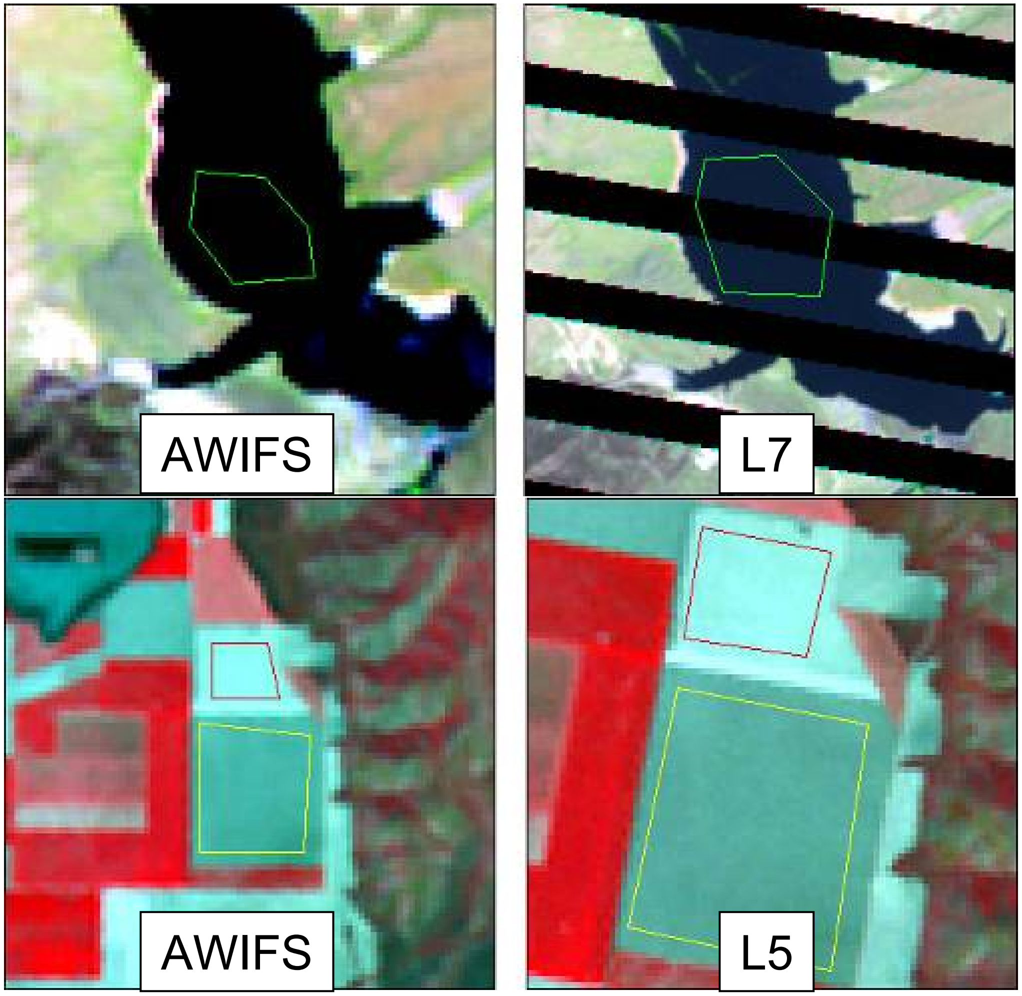
Instrument	Product ID	Path	Row	Solar Elevation
Landsat 7 ETM+	L71036035_03520050629	36	35	65.21 °
Landsat 7 ETM+	L71036036_03620050629	36	36	65.53 °
Landsat 7 ETM+	L71036037_03720050629	36	37	65.77 °
Landsat 7 ETM+	L71036038_03820050629	36	38	65.94 °
Landsat 7 ETM+	L71036039_03920050629	36	39	66.02 °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

Comparison Scenes Used -- SLC, UT

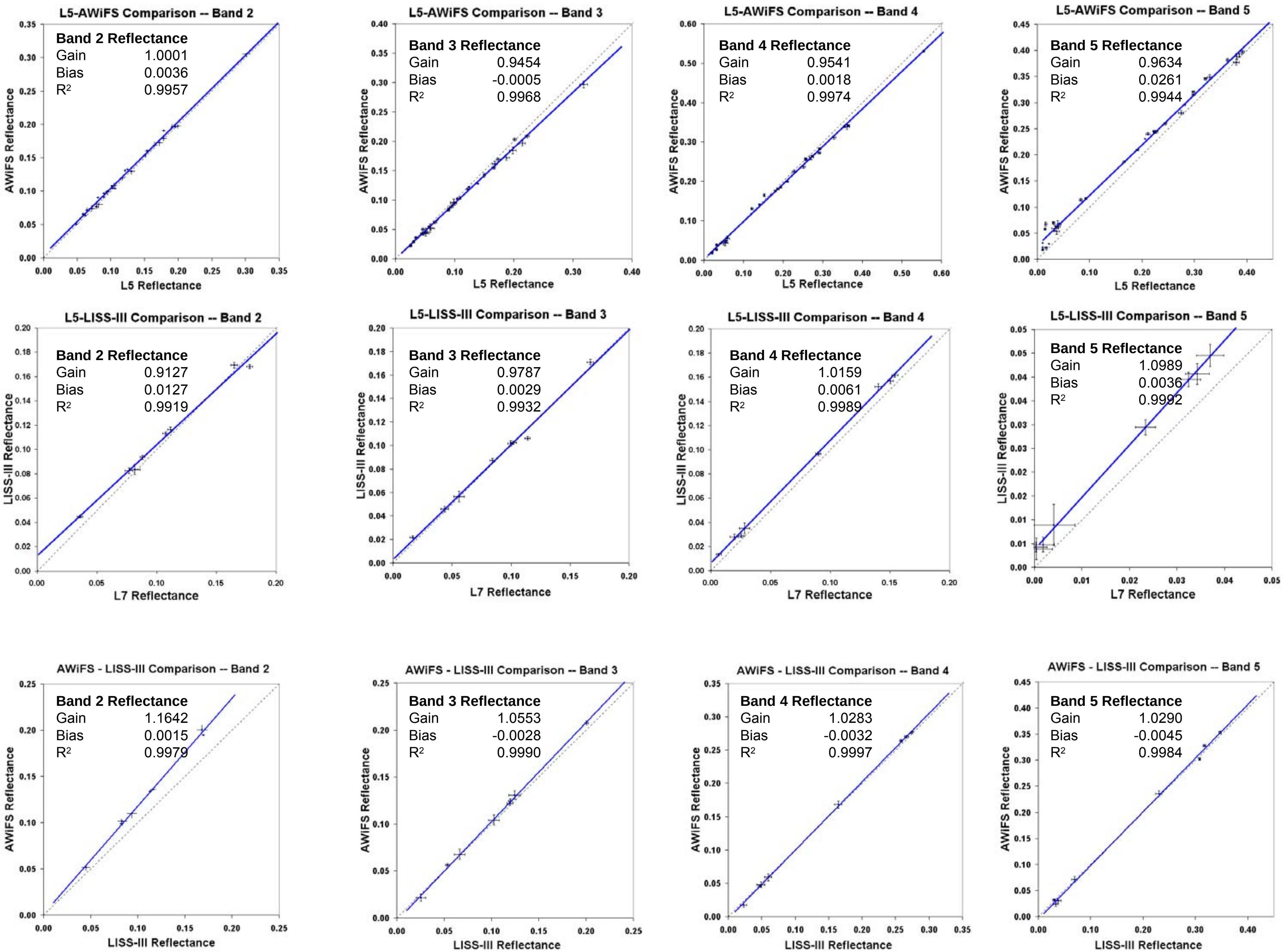
Salt Lake City, Utah collection, June 19, 2005

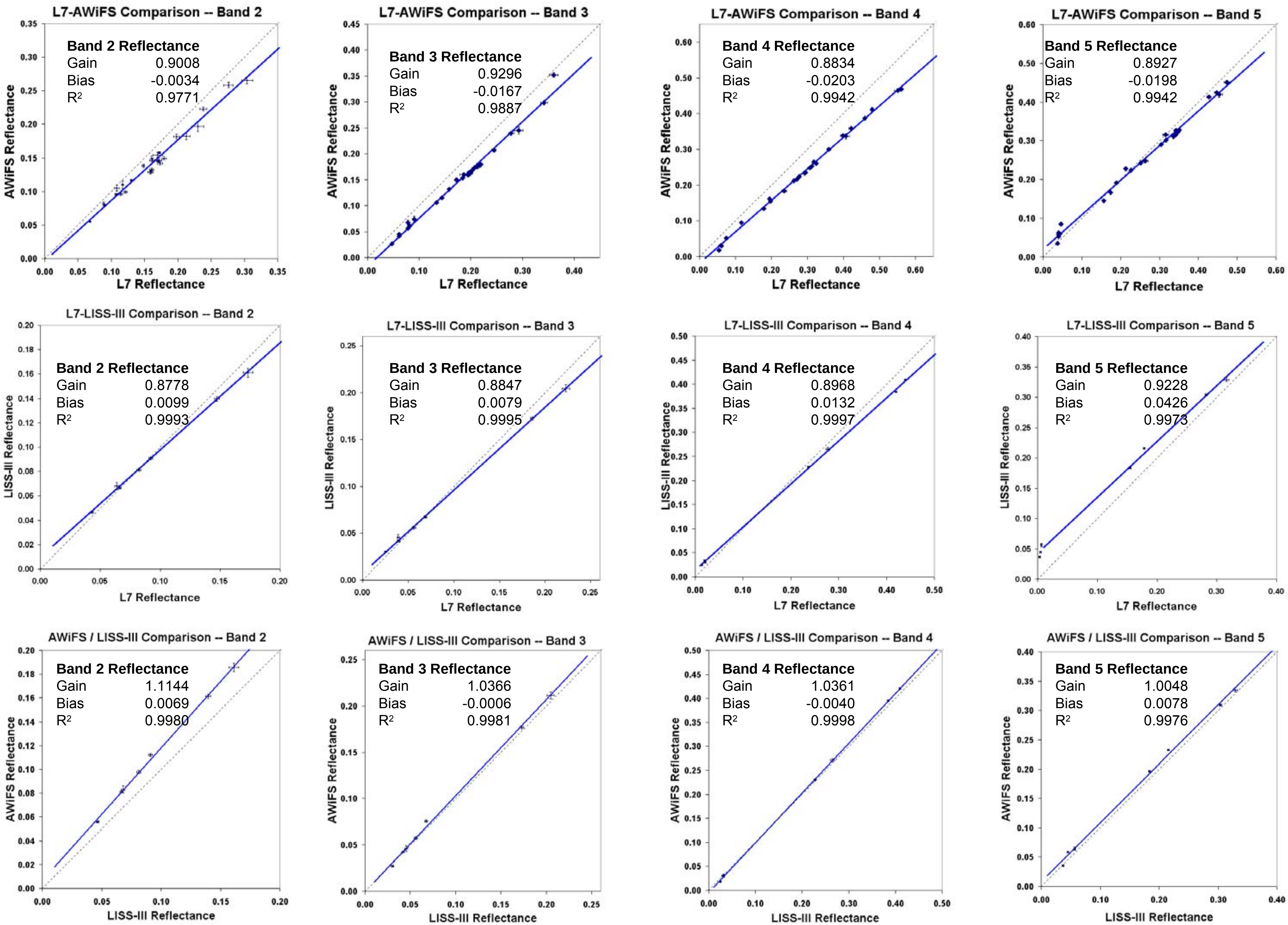
Instrument	Product ID	Path	Row	Solar Elevation
Landsat 5 TM	LT5038030000517010	38	30	62.95 °
Landsat 5 TM	LT5038031000517010	38	31	63.59 °
Landsat 5 TM	LT5038032000517010	38	32	64.18 °
AWiFS Quad A	000010491201	255	40	65.50 °
AWiFS Quad B	000010491301	255	40	68.10 °
AWiFS Quad C	000010491401	255	40	67.50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

Regions of Interest (ROI)



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


L5-AWiFS Comparison -- Band 2
Band 2 Reflectance
Gain 1.0001
Bias 0.0036
R2 0.9957
AWiFS Reflectance
L5 Reflectance
L5-AWiFS Comparison -- Band 3
Band 3 Reflectance
Gain 0.9454
Bias -0.0005
R2 0.9968
AWiFS Reflectance
L5 Reflectance
L5-AWiFS Comparison -- Band 4
Band 4 Reflectance
Gain 0.9541
Bias 0.0018
R2 0.9974
AWiFS Reflectance
L5 Reflectance
L5-AWiFS Comparison -- Band 5
Band 5 Reflectance
Gain 0.9634
Bias 0.0261
R2 0.9944
AWiFS Reflectance
L5 Reflectance
L5-LISS-III Comparison -- Band 2
Band 2 Reflectance
Gain 0.9127
Bias 0.0127
R2 0.9919
LISS-III Reflectance
L7 Reflectance
L5-LISS-III Comparison -- Band 3
Band 3 Reflectance
Gain 0.9787
Bias 0.0029
R2 0.9932
LISS-III Reflectance
L7 Reflectance
L5-LISS-III Comparison -- Band 4
Band 4 Reflectance
Gain 1.0159
Bias 0.0061
R2 0.9989
LISS-III Reflectance
L7 Reflectance
L5-LISS-III Comparison -- Band 5
Band 5 Reflectance
Gain 1.0989
Bias 0.0036
R2 0.9992
LISS-III Reflectance
L7 Reflectance
AWiFS - LISS-III Comparison -- Band 2
Band 2 Reflectance
Gain 1.1642
Bias 0.0015
R2 0.9979
AWiFS Reflectance
LISS-III Reflectance
AWiFS - LISS-III Comparison -- Band 3
Band 3 Reflectance
Gain 1.0553
Bias -0.0028
R2 0.9990
AWiFS Reflectance
LISS-III Reflectance
AWiFS - LISS-III Comparison -- Band 4
Band 4 Reflectance
Gain 1.0283
Bias -0.0032
R2 0.9997
AWiFS Reflectance
LISS-III Reflectance
AWiFS - LISS-III Comparison -- Band 5
Band 5 Reflectance
Gain 1.0290
Bias -0.0045
R2 0.9984
AWiFS Reflectance
LISS-III Reflectance


L7-AWiFS Comparison -- Band 2
Band 2 Reflectance
Gain 0.9008
Bias -0.0034
R² 0.9771
AWiFS Reflectance
L7 Reflectance
L7-AWiFS Comparison -- Band 3
Band 3 Reflectance
Gain 0.9296
Bias -0.0167
R² 0.9887
AWiFS Reflectance
L7 Reflectance
L7-AWiFS Comparison -- Band 4
Band 4 Reflectance
Gain 0.8834
Bias -0.0203
R² 0.9942
AWiFS Reflectance
L7 Reflectance
L7-AWiFS Comparison -- Band 5
Band 5 Reflectance
Gain 0.8927
Bias -0.0198
R² 0.9942
AWiFS Reflectance
L7 Reflectance
L7-LISS-III Comparison -- Band 2
Band 2 Reflectance
Gain 0.8778
Bias 0.0099
R² 0.9993
LISS-III Reflectance
L7 Reflectance
L7-LISS-III Comparison -- Band 3
Band 3 Reflectance
Gain 0.8847
Bias 0.0079
R² 0.9995
LISS-III Reflectance
L7 Reflectance
L7-LISS-III Comparison -- Band 4
Band 4 Reflectance
Gain 0.8968
Bias 0.0132
R² 0.9997
LISS-III Reflectance
L7 Reflectance
L7-LISS-III Comparison -- Band 5
Band 5 Reflectance
Gain 0.9228
Bias 0.0426
R² 0.9973
LISS-III Reflectance
L7 Reflectance
AWiFS / LISS-III Comparison -- Band 2
Band 2 Reflectance
Gain 1.1144
Bias 0.0069
R² 0.9980
AWiFS Reflectance
LISS-III Reflectance
AWiFS / LISS-III Comparison -- Band 3
Band 3 Reflectance
Gain 1.0366
Bias -0.0006
R² 0.9981
AWiFS Reflectance
LISS-III Reflectance
AWiFS / LISS-III Comparison -- Band 4
Band 4 Reflectance
Gain 1.0361
Bias -0.0040
R² 0.9998
AWiFS Reflectance
LISS-III Reflectance
AWiFS / LISS-III Comparison -- Band 5
Band 5 Reflectance
Gain 1.0048
Bias 0.0078
R² 0.9976
AWiFS Reflectance
LISS-III Reflectance

Cross-Cal Summary

- **An initial cross calibration of the L7 ETM+ and L5 TM with the IRS-P6 AWiFS and LISS-III Sensors was performed**
- **The approach involved calibration of nearly simultaneous surface observations based on image statistics from areas observed simultaneously by the two sensors**
- **The results from the cross calibration are summarized in the table below**
  - The IRS-P6 sensors are within 5.5% of each other in all bands except Band 2 (16.4% difference)
  - Differences due to the Relative Spectral Responses (RSR) were not taken into account
  - Atmospheric changes between the two image-pairs were not accounted
  - acquisition time between the two sensors were 30-min apart
  - Registration problems while selecting the regions of interest (ROI)

Differences between Sensors

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

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

LDGST Qs

	A	B
1	Questions	Priority
2	Data Quality (calibration) Questions	1=Primary
3	**Radiometery**	2=Secondary
4	How are your data calibrated radiometrically? Please describe the procedures used and provide any documentation?	1
5	Is there any special (Lunar, Solar, Stellar) calibration acquisitions performed?	1
6	How are detector gains determined? (Prelaunch, vicarious, internal calibrator)	1
7	Are the radiometric calibrations and corrections updated over time to reflect sensor changes?	1
8	Have you characterized the linearity and stability of the sensors response? If yes, how?	1
9	What are the known artifacts (such as Striping, noises) in the instrument?	1
10	How are the artifacts compensated in the L1 products?	1
11	If there are dead or inoperable detectors, how are they compensated for in the image products?	1
12	How does the system respond to saturation point targets? What is the recovery time? Saturation radiance in products?	1
13	How is detector-to-detector normalization performed to remove striping effects?	1
14	What levels of radiometric calibration/correction are applied to each of your product levels?	1
15	What is the absolute radiometric accuracy? What are this numbers based on?	1
16	How are the detector biases determined? How are biases applied during processing?	1
17	The Spectral Response Profiles that we have seen are incomplete. Do you have complete profiles?	1
18	How is the spectral response determined? Is there variability in spectral response or filter response across the focal plane?	1
19	Has there been any measurement of out-of-band spectral response?	1
20	Have you found any problems with stray light? If so, please describe them and how they were measured.	1
21	What is the Signal-to-noise ratio (SNR)? At what radiance level was this determined?	1
22	Is there any night imaging capability?	1
23	Are the data in Level 1 products linearly scaled to absolute radiance?	2
24	What is the equation used to convert the DN-to-radiance for each of the products?	2
25	Is there any on-board radiometric calibration capability? If yes, please describe?	2
26	What is the Solar Exoatmospheric Spectral Irradiances (ESUN) values used for reflectance conversion?	2
27	What solar spectrum profiles were used to calculate the ESUN values?	2
28	Describe the focal plane layout and detector dimensions?	2
29	What focal length(s) are your sensors?	2
30	What is the aperture diameter for your sensor(s)?	2
31	What types of detectors are used? (material)	2
32	Is the sensor gain adjustable? Are there multiple gain settings?	2
33	**Geometry**	
34	How are your data calibrated geometrically? Please describe the procedures used and provide any documentation?	1
35	What is the internal geometric stability? (relative geometric accuracy) How has it changed over time?	1
36	What is the absolute geodetic/geopositional accuracy? How has it changed over time?	1
37	What level of geometric calibrations and corrections are performed for each of your data product levels?	1
38	What is the band-to-band registration accuracy?	1
39	What source of ground truth do you use to measure your geometric/geodetic accuracy, including elevation data?	1
40	Do you have any off-nadir capability if so what is the range?	2
41	**Spatial**	
42	How are your data characterized and calibrated spatially?	1
43	What measurements do you use? (Edge, FWHM line spread, MTF at Nyquist)	1
44	What is the sensor spatial response? How was it determined?	1
45	How is the spatial response (MTF) monitored on orbit?How has it changed over time?	1
46	Is there spatial compensation (MTF) performed on data products? If so, please describe the algorithms and effects.	1
47	Operational Questions	
48	**Image scheduling**	
49	Do you have an overall plan to acquire data regionally/globally? If so, please describe it.	1
50	What is the image request process from submission to competition?	1
51	How are the instruments scheduled?	1
52	Are images collected on the basis of on-demand tasking?	1
53	How are imaging priorities determined?	1
54	What is the maximum amount of data that can be collected and received from your sensors?	1
55	What is the typical amount of data received at present?	1
56	What factors limit the amount of data that can be collected and received?	1
57	We would like to know the factors that affect imaging capabilities and capacities.	1
58	How quickly can the organization respond to emergencies?	1
59	Do you have internal plans to monitor disasters?	1
60	What is the longest continuous imaging swath that a sensor can collect?	1
61	Are there any geographical constraints to imaging anywhere around the world?	1
62	How precisely is your equatorial crossing time maintained?	1
63	How precisely is your ground track maintained?	1
64	What is the designed (and projected) life of the satellite?	1
65	What are the follow-on missions?	1
66	Can all of your sensors collect imagery simultaneously?	2
67	Can you provide the acquisition calendar for the satellites?	2
68	Can we get the image shape files? (ability to locate where a path/row will be)	2
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?	1
71	Can you store data and transmit data simultaneously?	1
72	Do you compress the data on-board? If so, lossless or loss compression?	1
73	Where are the ground receiving stations located?	2
74	What are the receiving antenna requirements?	2
75	What types of antennae are on board? (Omni-directional or spot?)	2
76	What are the data transmission rates and frequencies?	2
77	Can data be transmitted to more than one receiving station simultaneously?	2
78	Is there an on-board data recorder? If so, what is the capacity?	2
79	**Data production and distribution**	
80	How are data processed and distributed?	1
81	Are there more than one processing/distribution sites?	1
82	Can we get a raw (L0Rp) product?	1
83	Do you have a "default" processing level or configuration (resampling, projections, datum, etc.)?	1
84	Are the products produced at variable lengths, i.e. multiple scenes in length?	1
85	Is there any data compression applied to the output products? If so, what method is used?	1
86	What is the turn around time between imaging and the availability of the products?	1
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?	1
88	What, if any, differences are there in the processing systems used at different IGS?	1
89	What are the various product levels that are available?	2
90	Are the products produced in different quantization levels (i.e. 8-bit, 10-bit, etc?) If so, what options are produced?	2

USGS

NASA

Landsat Data Gap Studies: Summary

U.S. Department of the Interior

U.S. Geological Survey

NASA/USGS LDSGT technical group with Dr. Navalgund, the director of ISRO SAC, Ahmedabad, India

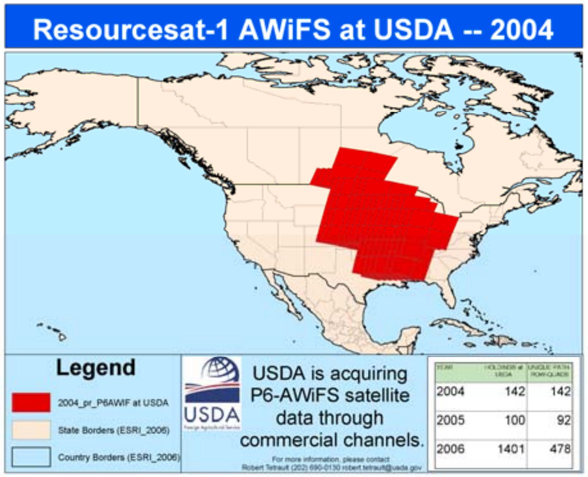
NASA/USGS LDSGT technical group at IRSO HQ in Bangalore, India

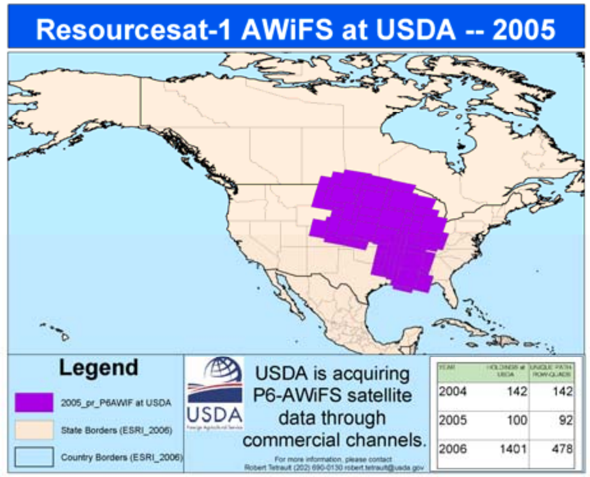
June 10-20, 2006

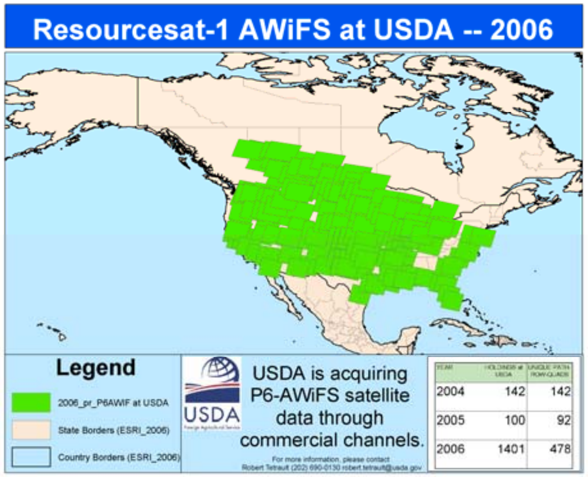
NASA/USGS technical group with Dr. Camara, the director of INPE, Brazil

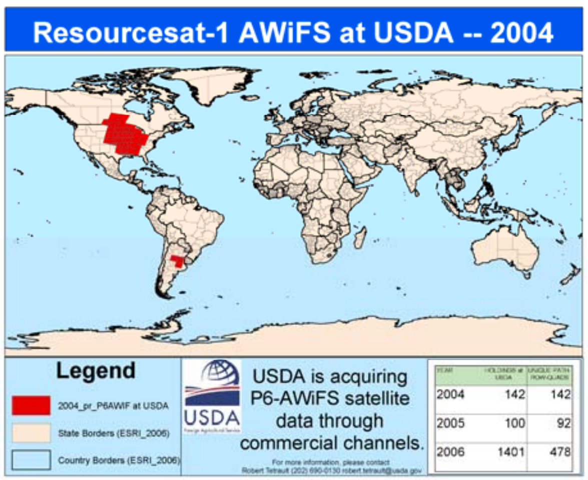
USGS Deputy Director and NASA Program Executive with INPE Director

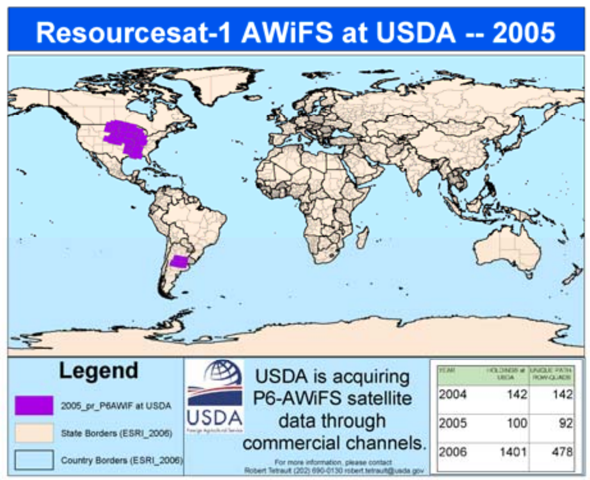
AWiFS USDA Data Holdings

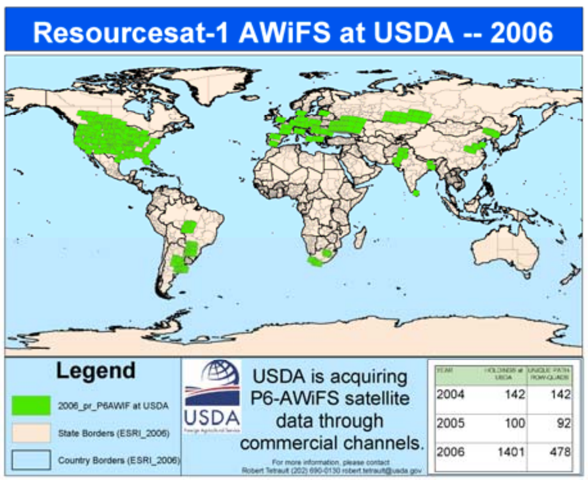






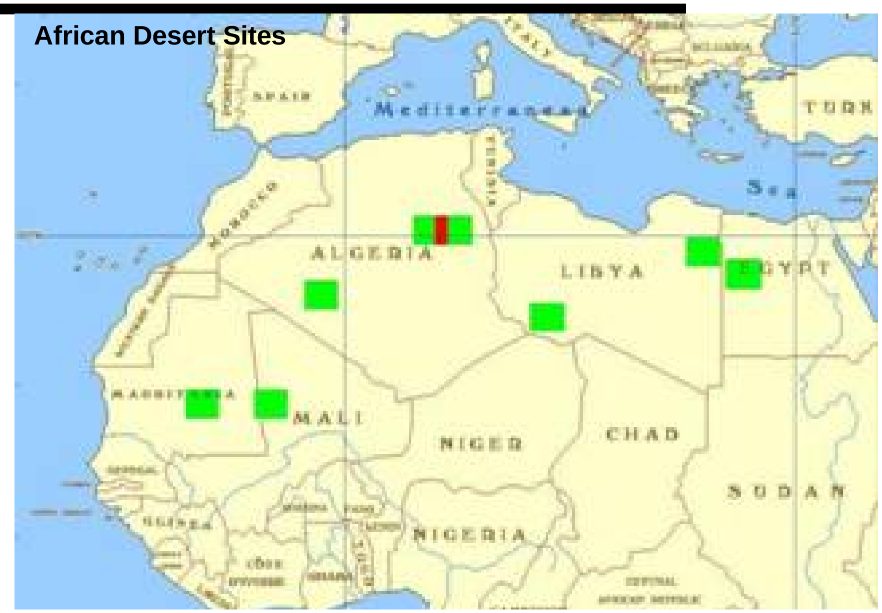


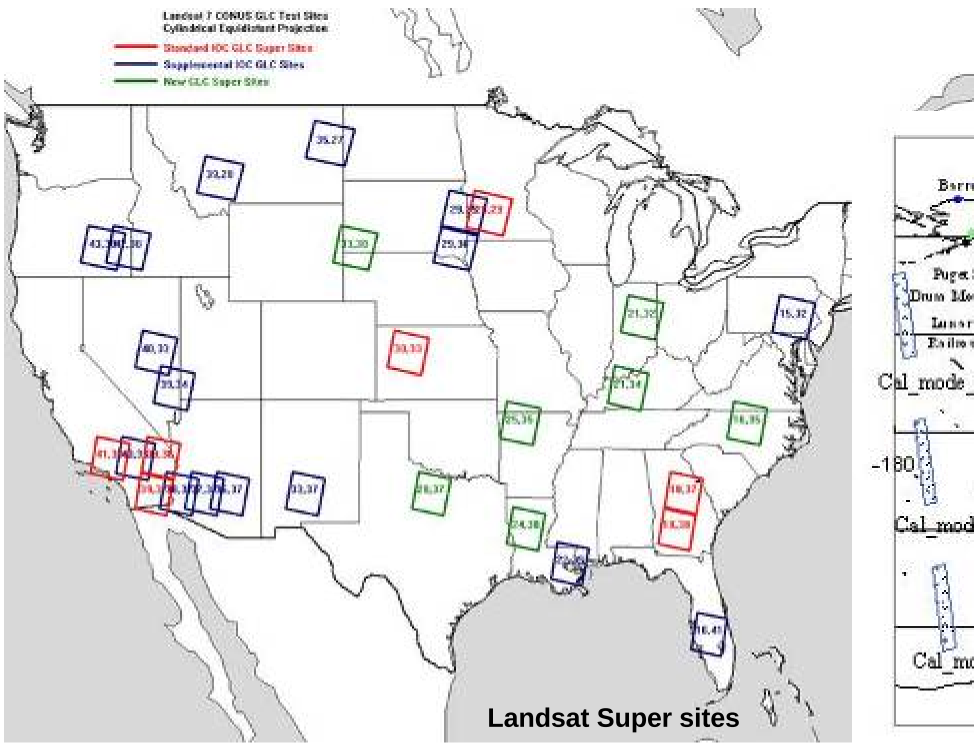


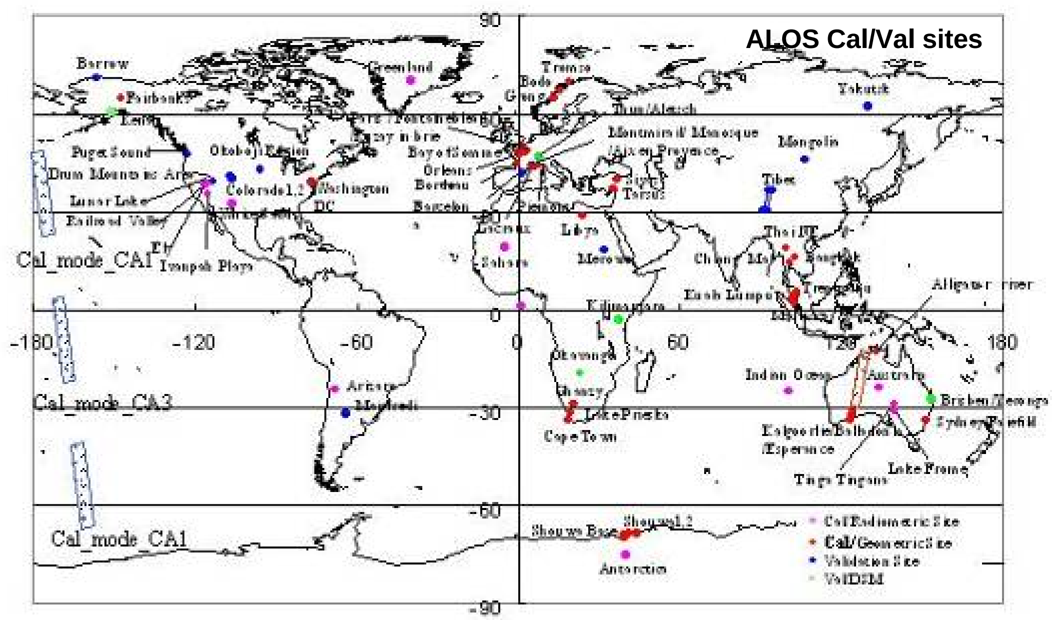


CEOS Calibration-Validation Sites

- **World-wide Cal/Val Sites for**
  - Monitoring various sensors
  - Cross calibration
  - Integrated science applications
- **Prime Sites for data collection**
  - Site description
  - Surface Measurements
  - FTP access via Cal/Val portals







USGS Recommendations to CEOS

- **Coordinate and provide world-wide Cal/Val sites**
  - Coordinate and provide ground control points
  - Coordinate and plan vicarious calibration field campaigns
- **Maintain a fully accessible Cal/Val portal to provide**
  - instrument characteristics of current & future systems,
  - seamless access of Cal/Val site data for users
  - database of in-situ data, documentation of best practices
  - Info regarding co-incident imagery
- **Reinvigorate IVOS subgroup**
  - Workshop at ESA ESTEC (2004) was a great success!
  - Coordinate and schedule regular communication between IVOS sub-group members
  - Members provide monthly Cal/Val Status on action items
- **Update CEOS WGCV IVOS web pages with membership information, IVOS presentations, and technical links**

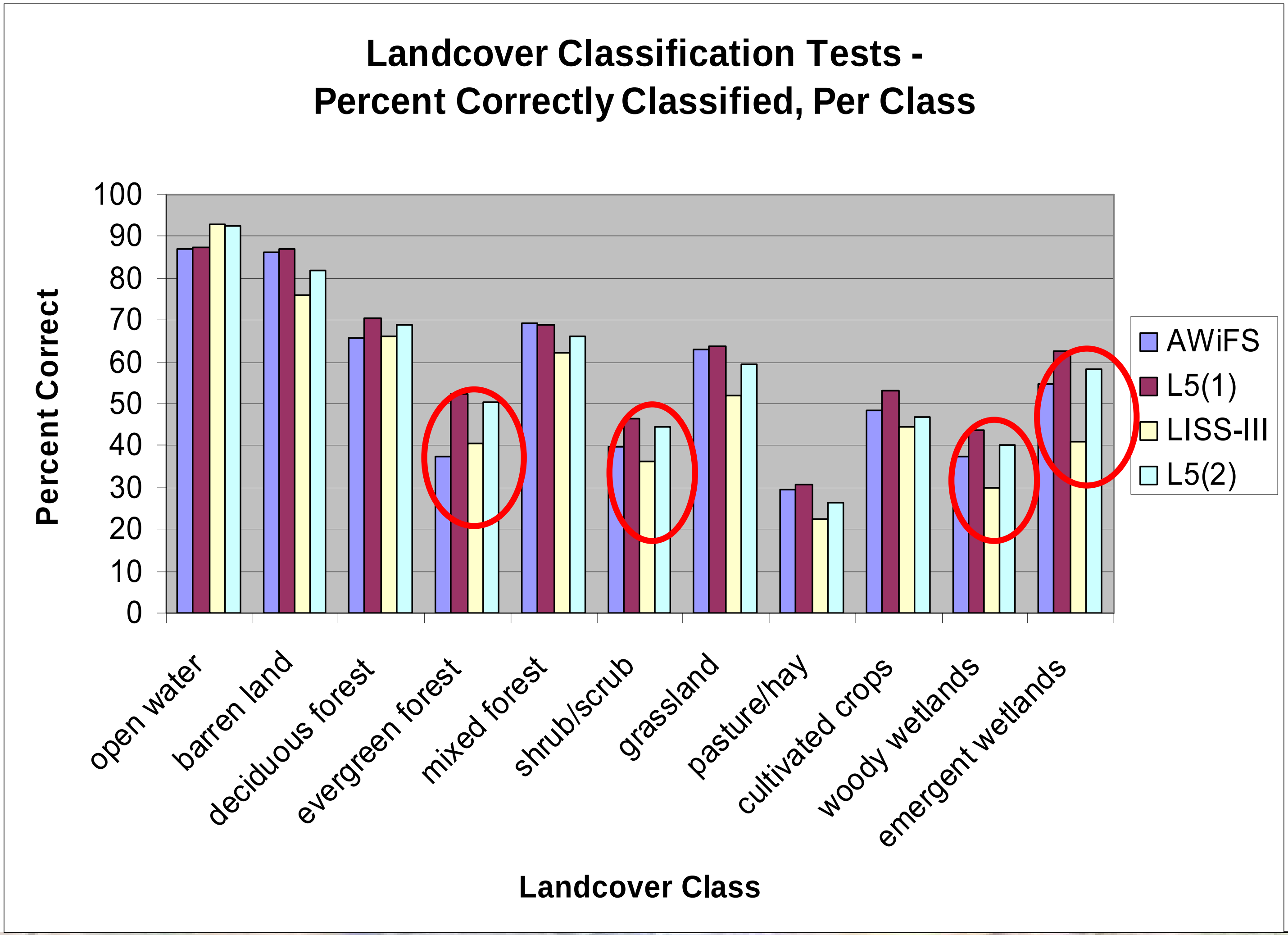
On-going Cross-cal work at USGS

- **L7 ETM+ and L5 TM sensor**
- **L5 TM and L4 TM sensor**
- **L7 ETM+ (L5 TM) and EO-1 ALI sensor**
- **L7 ETM+ (L5 TM) and Terra MODIS and ASTER sensors**
- **L7 ETM+ (L5 TM) and CBERS-2 CCD sensor**
- **L7 ETM+ (L5 TM) and IRS-P6 AWiFS and LISS-III sensor**
- **L7 ETM+ (L5 TM) and ALOS AVNIR-2 sensor**
- **L7 ETM+ (L5 TM) and DMC SurreySat**

Joint Agency Commercial Imagery Evaluation (JACIE) Team

- JACIE team formed in 2000 - NASA, NGA, USGS (added USDA this year!)
- USGS is chair of JACIE; preparing to host 6th Annual Conference on March 20-22, 2007 in Fairfax, VA
- http://www.usm.edu/ncpc/jacie/index.html
- Demonstrate relevance of JACIE to US role in terrestrial monitoring
- Enhanced scope to Satellite & Aerial sensors useful to the remote sensing community – U.S. and International systems
- Provide imagery users with an independent assessment with respect to product quality and usability
- Support new applications and understanding of remotely sensed data
- Provides government/industry communication/cooperation model

NLCD Viability Sample test - Salt Lake Land Cover, AWiFS, LISS-III & L5 Combined - 2006



Landsat 5 was markedly better than AWiFS/LISS-III with these classes: evergreen, shrub/scrub, woody wetlands, emergent wetlands.

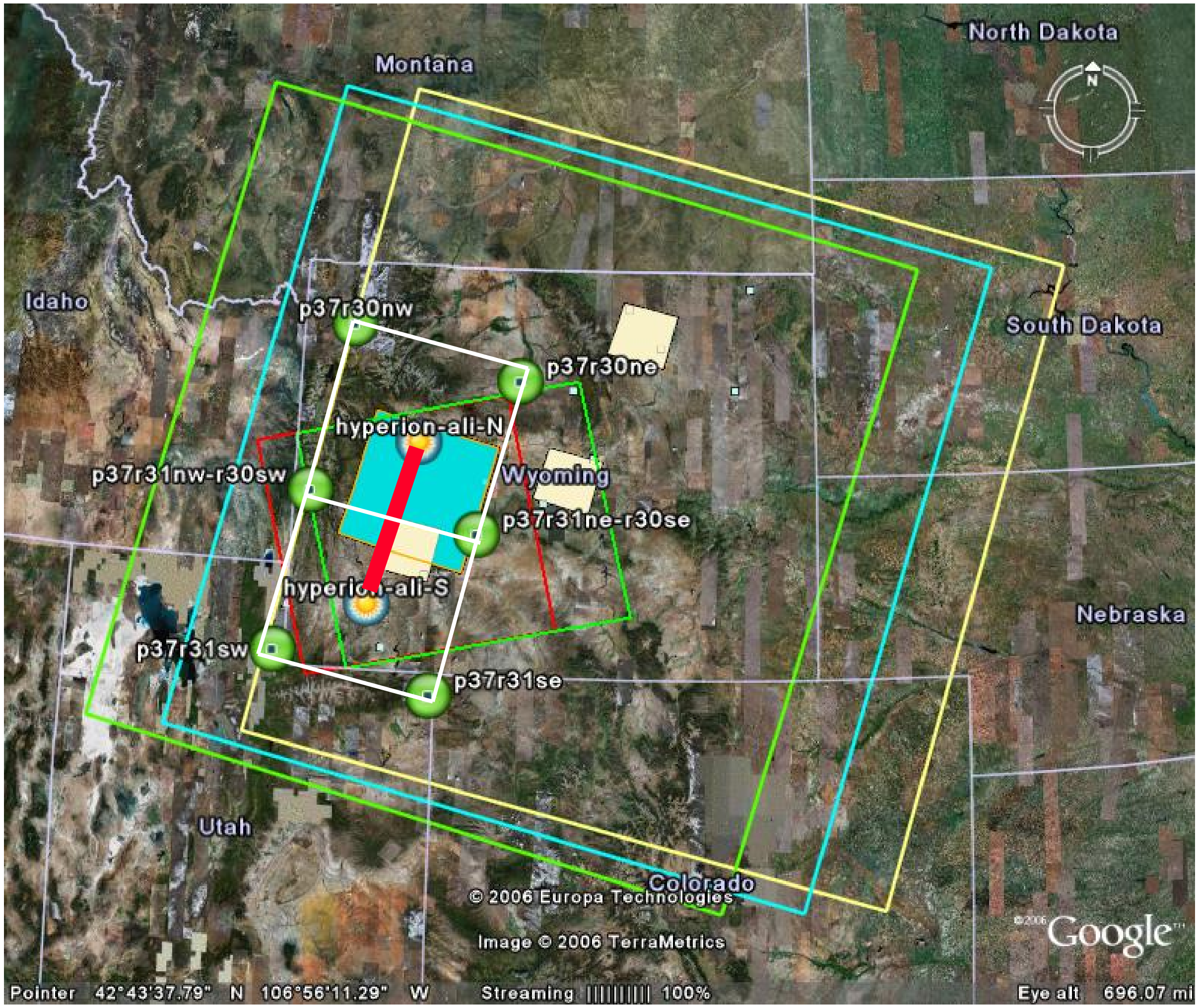
Landcover class differences most likely due to lack of Bands 1&7 on IRS-P6.

AWiFS temporal benefits are exceptional.

Experimental results w/limited data – more testing required!

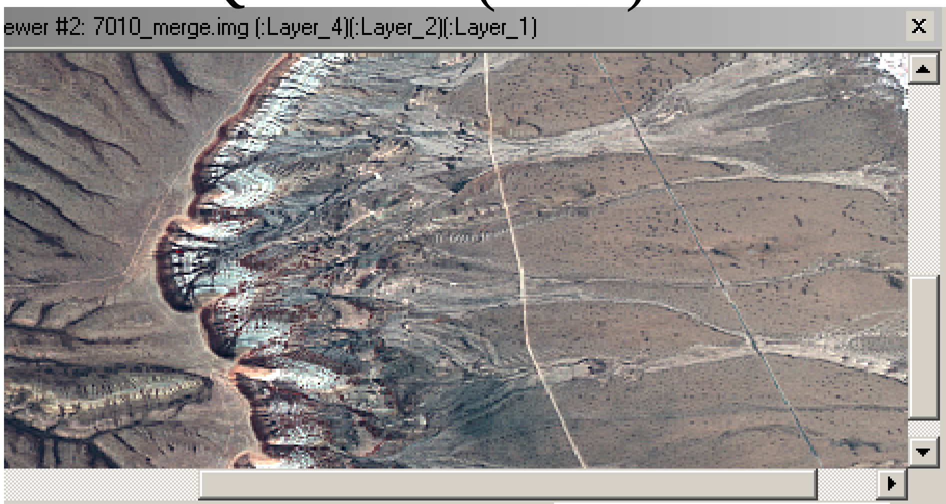
Multiple Satellites Used in Science

- **2006 Data included:**
  - Landsat-5
  - Landsat-7
  - EO-1 ALI
  - EO-1 Hyperion
  - ASTER
  - IRS AWiFS
  - IRS LISS-III
  - Surrey DMC
  - DG Quickbird
- **To support Sagebrush study in Wyoming, USA**

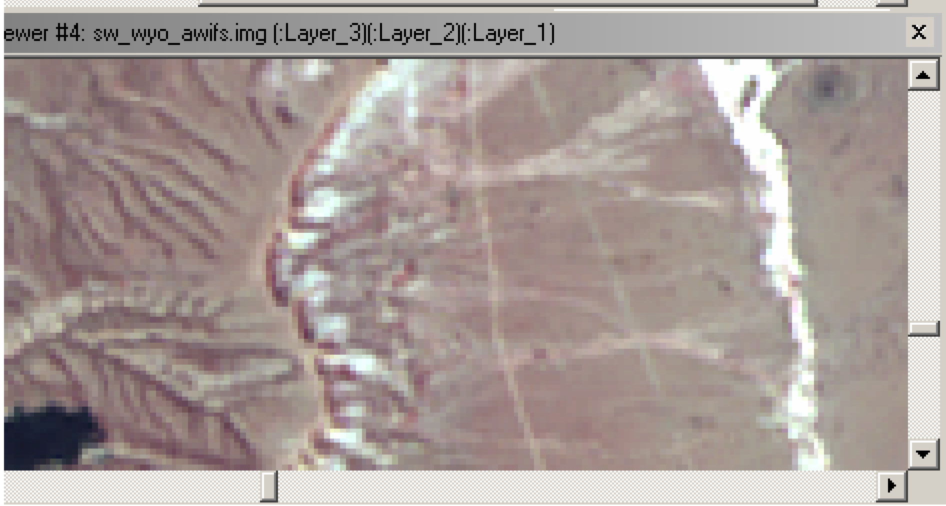


The result is three scales of models, grounded to field measurements

Quickbird (2.4m)



Landsat TM (30m)



IRS AWIFS (56m)

Viewer #5

Proposed products include models of % shrub, % sagebrush, % herbaceous, % bare ground, % litter, shrub height, and % shrub species

LDGST Information Resources

- Briefing Slides – current presentation
- DCWG Slides – available
- DMC Report – bring finalized for JACIE
- ResourceSat report – technical report completed, waiting for combined report – est. availability Feb 07
- CBERS report - technical report completed, waiting for combined report – est. availability Feb 07
- LDGST Qs Answers
- ISRO trip report - complete
- INPE trip report – being finalized

Characterization & Data Gap Summary

- There are many instruments providing image data for civil science purposes
  - GEOSS, GEO, CEOS, Future of Land Imaging Team, LDGST
- Some instruments may be able to meet <u>at least some</u> of the Landsat user community needs
- Technical advances have enabled the creation of many multi-spectral satellites
  - 20+ countries medium to high resolution satellites and 66 Civil Land Imaging Satellites by 2010
- All the data has value but it needs to be well understood
  - Calibration/Validation required
  - Stable base mission (LANDSAT/LDCM) with cross band coverage
- USGS continues to assess Landsat Data Gap mission and future technologies
  - USGS is interested in datasets for assessment purposes, please contact USGS if interested
- Precise high resolution data provides a great compliment to global science assessment and is a must for ER

LDGST Summary

- **There is no substitute for Landsat**
  - Single source of systematic, global land observations
  - Alternate sources may reduce the impact of a Landsat data gap
- **We are characterizing multiple systems to understand which data sets may be compatible with the Landsat data record and can potentially supplement the Landsat data archive, but no decisions have been made yet**
- **Landsat Data Gap Study Team will:**
  - Finalize recommendations and strategy for implementation
  - Present findings to U.S. civil agency management and the White House Office of Space and Technology Policy
  - Implement recommendations

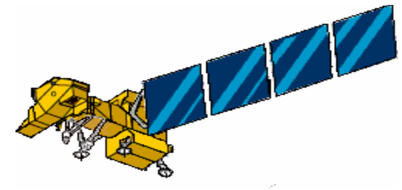
Back-Up Slides

Landsat-5 TM Mission Status

- **On orbit for 22 years! (Designed for 2-3 year mission life)**

- **Solar Array Drive Malfunction**
  - Both primary and redundant drives failed
  - On 8/14/2006, placed solar array in fixed position
  - Currently investigating imaging limitations due to power issues
- **TWTA Anomaly**
  - March 2006: Over Current Protection Circuit (OCP) trip prevented majority of acquisition attempt
- **Flight Operations Anomaly Team received international spaceops award for outstanding achievement**
  - "for dedicated efforts in recovering Landsat 5 from two potentially mission-ending hardware anomalies and restoring the mission to full operations."
- **Estimated end of mission: December 2009 based on remaining fuel and assuming 9:30AM MLT crossing minimum criteria**

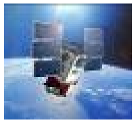
Landsat-7 ETM+ Mission Status



- **On orbit for 7 years (Designed for 5 year mission life)**
- **Scan Line Corrector (SLC) malfunction (May 31, 2003)**
  - These gaps represent a data loss of ~ 25% for any given scene
  - New capability to improve the SLC-off data products
    - Phase 0: SLC-off Products – Released in October 2003
    - Phase 1: SLC-off / on Gap-filled Products – Released May 2004
    - Phase 2: SLC-off / off Gap-filled Products – Released Nov 2004
    - Phase 3: Segmentation based Gap-filled Products – coming Jan 2007
- **On May 5, 2004, Gyro #3 was powered off**
  - L7 has 3 Teledyne gyros packaged into a Honeywell IMU
  - Each gyro outputs movement information for 2 axes
  - Each control mode assumes at least 2 good gyros are operating
  - Developing software to fly spacecraft with 1-gyro (spacecraft maneuver capability now; not full science operations)
- **Estimated end of mission: January 2011 based on remaining fuel and assuming 9:30AM MLT crossing minimum criteria**

Available Spectral Satellite Systems

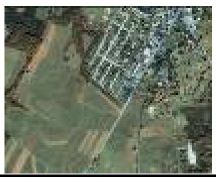
Quickbird



Imagery Type: E/O, Pan, MSI
Nationality: USA
Spatial Res: 0.61m Pan
2.4m - 4 x Band MSI
Swath Width: 16.5km
Revisit Time: 3-4 Days
Cost /km^2: $18-35

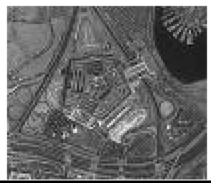
IKONOS

Imagery Type: E/O, Pan, MSI
Nationality: USA
Spatial Res: 1 m Pan
4m - 4 x Band MSI
Swath Width: 11km
Revisit Time: 2-3 Days
Cost /km^2: $18-35



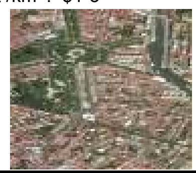
EROS A1

Imagery Type: E/O Pan
Nationality: Israel
Spatial Res: 1.8m Pan
Swath Width: 12.5km
Revisit Time: 1-2 Days
Cost /km^2: $9.60



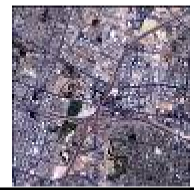
SPOT 5

Imagery Type: E/O, Pan, MSI
2 x CCDs (Sensors)
Nationality: France
Spatial Res: 2.5 m & 5m Pan
10m 3 x Band MSI
20m SWIR Band
1km Vegetation
Swath Width: 60-120km
Revisit Time: 2-3 Days
Cost /km^2 : $1-3



DOE-MTI

Imagery Type: E/O MSI
Nationality: US Dept of Energy
Spatial Res: 5m 4 x Band MSI
20m 11 x Band MSI
(S/LWIR)
Swath Width: 12km
Revisit Time: 7 Days
Cost /km^2: Free



IRS 1C

Imagery Type: E/O Pan MSI
Nationality: India
Spatial Res: 6m Pan
23m 3 x Band MSI
71m 1 x Band MWIR
Swath Width: 70km Pan
130km MSI MWIR
Revisit Time: 5 Days Pan
3 Days MSI
Cost /km^2: $0.13 - 0.51

SPOT 1,2,4

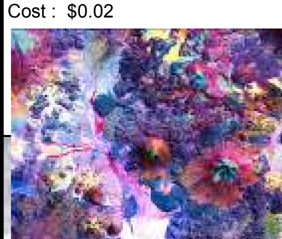
Imagery Type: E/O Pan MSI
Nationality: France
Spatial Res: 10M Pan
20m 4 x Band MSI (Vis
20m 1 x Band SWIR
(SPOT 4, only)
1km 1 x "Veg Band"
(SPOT 4, only)
Swath Width: 60-120km
Revisit Time: 1-2 Days
Cost /km^2: $0.43-0.81

EO1-ALI

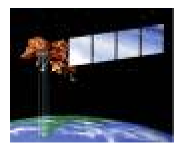
Imagery Type: E/O, MSI
Nationality: USA NASA
Spatial Res: 10m PAN
30m 9 x Band MSI
Swath Width: 37 km
Revisit Time: 14 Days
(Co-Fly 1 min behind LANDSAT 7)
Cost /km^2: $0.90

Terra EOS AM-1 (ASTER)

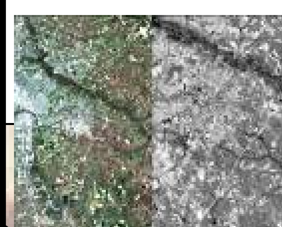
Imagery Type: E/O, MSI
Nationality: USA NASA
Japan NASDA
Spatial Res:
15m 3 x Band MSI (VNIR)
30m 6 x Band MSI(V/MWIR)
90m 5 x Band MSI(M/LWIR)
Swath Width: 60km
Revisit Time: 16 Days
Cost : $0.02



LANDSAT 7

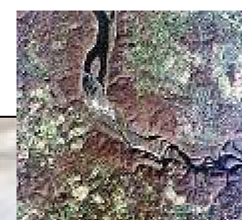


Imagery Type: E/O, Pan,MSI
Nationality: USA NASA
Spatial Res: 15m Pan
30m 6 x Band MSI
60m 1 x Band LWIR
Swath Width: 185 km
Revisit Time: 14 Days
Cost /km^2 : $0.19

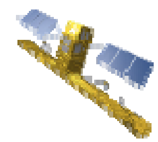


EO1-Hyperion

Imagery Type: E/O, HSI
Nationality: USA NASA
Spatial Res: 30m 220 x Band HSI
(V/SWIR)
Swath Width: 7.5 km
Revisit Time: 14 Days
(Co-Fly 1 min behind LANDSAT 7)
Cost /km^2 : $1.77 - 2.67



RADARSAT



Imagery Type: Synthetic Aperture
Radar (SAR)
Nationality: Canada
Spatial Res: 8-100m (User Select)
Swath Width: 50-500km
Revisit Time: 3 Days
Cost /km^2 : $0.40 - 1.20

E/O - Electro-Optical Pan - Panchromatic MSI - MultiSpectral Imagery HSI - HyperSpectral Imagery VIS - Visible Light NIR - Near Infrared SWIR - Shortwave Infrared MWIR - Midwave Infrared LWIR - Longwave Infrared

Mid-Resolution Scene Coverages

Satellite	Sensor	Scene size (cross)	Scene size (along)	Ration of scene size (cross) - instrument/Landsat
EO-1	ALI	37	185	0.22
Terra	Aster - VNIR	60	60	0.35
Terra	Aster - SWIR	60	60	0.35
Terra	Aster - TIR	60	60	0.35
SPOT 5	HRG	60	60	0.35
SPOT 5	HRS	60	60	0.35
ALOS	AVNIR	70	70	0.41
RapidEye	REIS	80	80	0.47
CBERS-1,2,2A	IRMSS	120	120	0.70
CBERS-3,4	IRMSS	120	120	0.70
CBERS-3,4	MUXCAM	120	120	0.70
ResourceSat-1	LISS III+	141	141	0.82
Landsat 7	ETM+	172	185	1.00
Landsat 5	TM	172	185	1.00
ResourceSat-1	AWiFS	350	350	2.03
DMC	MSDMC	600	600	3.49
CBERS-3,4	WFI-2	866	866	5.03
CBERS-1,2,2A	WFI-1	890	890	5.17

Advanced Land Observing Satellite (ALOS)

- ALOS was launched on Jan 24, 2006 by Japan Aerospace EXploration Agency (JAXA)
- Revisit time is 46 days, but it can observe any area within 2 days
- Orbital altitude/inclination: 692 km/~98 degrees
- Nodal crossing: 10:30 a.m.
- System life: 3 - 5 years
- Three instruments devoted to land imaging
  - **Panchromatic Remote Sensing Instruments for Stereo Mapping (PRISM)**
  - **Advanced Visible and Near Infrared Radiometer (AVNIR-2)**
  - **Phased Array L-band Synthetic Aperture Radar (PALSAR)**
- Availability of data and products, data policy, and pricing is TBD
- Website: http://alos.nasda.go.jp/

	PRISM	AVNIR-2	PALSAR
Sprectral bands	0.52-0.77um	0.42-0.50um 0.52-0.60um 0.61-0.69um 0.76-0.89um	1.27GHz (L-band)
Resolution	2.5m	10m	10m/100m
Swath width	35km/70km	70km	70km/350km
Pointing (+-)	1.5 degrees	44 degrees	10-51 degrees
Revisit	-	2 days	2 days
Actual revisit	46 days	46 days	46 days

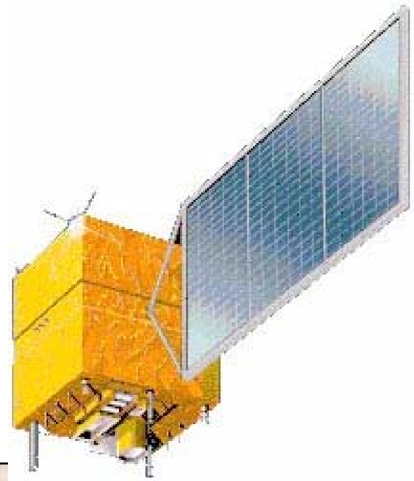
Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER)

- ASTER was launched on December 18, 1999 on the Terra satellite
- Orbital altitude/inclination: 705 km/98.2 degrees
- Nodal crossing: 10:30 a.m.
- System life: 6 years
- Three instruments are
  - **Visible and Near-Infrared Radiometer(VNIR)**
  - **Short Wave Infrared Radiometer (SWIR)**
  - **Thermal Infrared Radiometer(TIR)**
- Archive data sets are available at $60/scene
- Website: http://asterweb.jpl.nasa.gov/

	VNIR	SWIR	TIR
Sprectral bands	0.52-0.60um 0.63-0.69um 0.76-0.86um	1.60-1.70um 2.14-2.18um 2.18-2.22um 2.23-2.28um 2.29-2.36um 2.36-2.43um	8.12-8.47um 8.47-8.82um 8.92-9.27um 10.25-10.95um 10.95-11.65um
Resolution	15m	30m	90m
Swath width	60km	60km	60km
Pointing (+-)	24 degrees	8.55 degrees	8.55 degrees
Revisit	-	-	-
Actual revisit	16 days	16 days	16 days

China-Brazil Earth Resources Satellite (CBERS 1-2)

- CBERS-1 launched on October 14, 1999; CBERS-2 on October 21, 2003; CBERS-2B to be launched in May 2007
- Revisit time is 26 days
- Orbital altitude/inclination: 778 km/98.5 degrees
- Nodal crossing: 10:30 a.m.
- System life: 2 years
- Data only downlinked to Brazil and China, may commercialize in future
- Each satellite has 3 cameras (see below)
- Availability of data and products, data policy, and pricing is TBD
- Website: http://www.cbers.inpe.br/en/

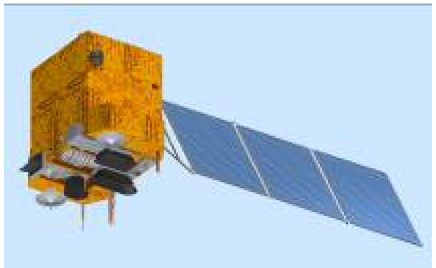


	CCD	IRMSS	WFI
Sprectral bands	0.51-0.73um 0.45-0.52um 0.52-0.59um 0.63-0.69um 0.77-0.89um	0.50-1.10um 1.55-1.75um 2.08-2.35um 10.4-12.5um	0.63-0.69um 0.77-0.89um
Resolution	20m	80m/160m	260m
Swath width	113km	120km	890km
Pointing (+-)	32 degrees	none	none
Revisit	3 days	-	
Actual revisit	26 days	26 days	6 days

USGS

China-Brazil Earth Resources Satellite (CBERS 3-4)

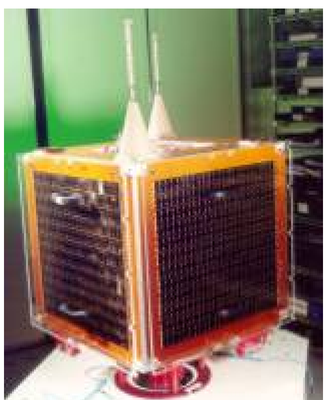
- CBERS-3 to be launched in 2007 or 2008; CBERS-4 after 2007
- Revisit time is 26 days
- Orbital altitude/inclination: 778 km/98.5 degrees
- Nodal crossing: 10:30 a.m.
- System life: 2 years
- Each satellite will have 4 cameras (see below)
- Availability of data and products, data policy, and pricing is TBD
- Website: http://www.cbers.inpe.br/en/



	MUXCAN	PANMUX	IRMSS	WFI
Sprectral bands	0.45-0.52um	0.51-0.75um	0.76-0.90um	0.52-0.59um
	1.55-1.75um	0.51-0.85um	0.76-1.10um	0.63-0.69um
	0.52-0.59um	0.52-0.59um	1.55-1.75um	0.77-0.89um
	0.63-0.69um	0.63-0.69um	2.08-2.35um	1.55-1.75um
	0.77-0.89um	0.77-0.89um	10.4-12.5um	
Resolution	20m	5m/10m	40m/80m	73m
Swath width	120km	60km	120km	866km
Pointing (+-)	32 degrees	32 degrees	none	none
Revisit	3 days	5 days	-	-
Actual revisit	26 days	none	26 days	5 days

Disaster Monitoring Constellation (DMC)

- DMC is a constellation of microsatellites being developed by Surrey Satellite Technology Limited (SSTL) that would provide daily global coverage
- A five satellite constellation could collect 400-600 scenes/day
- Four satellites are currently operational; AISAT-1 was launched on November 28, 2002; UK-DMC, NigeriaSat-1, and BILSAT-1 were launched on September 27, 2003
- An enhanced satellite for China will be launched in 2005
- Orbital altitude/inclination: 686 km/98 degrees
- Nodal crossing: 10:30 a.m.
- System life: 5 years
- Data characteristics are satellite dependent
- Availability of data and products, data policy, and pricing is TBD
- Website: http://www.sstl.co.uk/



	Standard	BILSAT-1	China DMC +4
	0.52-0.60um	0.52-0.60um	0.52-0.60um
	0.63-0.69um	0.63-0.69um	0.63-0.69um
Sprectral bands	0.77-0.90um	0.77-0.90um	0.77-0.90um
		pan	pan
Resolution	32m	28m/ 12m	32m/ 4m
Swath width	600km	55km/ 24.5km	600km/
Pointing (+-)	-	30	-
Revisit	-	4-5 days	-
Actual revisit	4-5 days	16 days	4-5 days

Standard = AlSAT-1, NigeriaSat-1, UK-DMC

USGS

NASA

Earth Observing-1 (EO-1)

- EO-1 was launched on November 21, 2000 by NASA, and continues today as the EO-1 Extended Mission operated by NASA and the USGS
- Revisit time is 16 days
- Cross track pointing: Three times in a 16 day cycle
- Orbital altitude/inclination: 705 km/98.2 degrees
- Nodal crossing: 10:15 a.m.
- System life: 1 year
- Two instruments devoted to land imaging
  - **Advanced Land Imager (ALI)**
  - **Hyperion**

- ALI, 9 multispectral bands at 30 m (0.43-0.45um, 0.45-0.51um, 0.52-0.60um, 0.63-0.69um, 0.77-0.80um, 0.84-0.89um, 1.20-1.30um, 1.55-1.75um, 2.08-2.35um) and 1 pan band at 10 m (0.48-0.69um)
- Swath width: 37 km by 42 km
- Capable of acquiring approximately 20 scenes/day on WRS-2 grid
- Archived data available at $250 or $500/scene; data acquisition requests are additional $1,500/scene
- Website: http://eo1.usgs.gov/ or http://eo1.gsfc.nasa.gov/

RapidEye

- RapidEye to be launched in late 2007, a total of 5 satellites is proposed, all launched at once and 19 minutes apart on orbit
- Commercial effort focused on providing information to the agricultural and cartographic communities
- Revisit time is 1 day, average coverage repeat is < 5 days with all satellites operating
- Orbital altitude/inclination: 622 km/97.8 degrees
- Imaging area: +/- 75 degrees
- Cross track pointing: +/- 25 degrees
- Nodal crossing: 11:00 a.m.
- System life: 7 years
- Multi-Spectral Imager (push-broom scanner), 5 bands (0.44-0.51um, 0.52-0.59um, 0.63-0.685um, 0.69-0.73um, 0.76-0.85um)
- Ground resolution: 6.5 m
- Swath width: 78-80 km by 1,500 km
- Availability of data and products, data policy, and pricing is TBD
- Website: http://www.rapideye.de/

ResourceSat-1 (IRS-P6)

- ResourceSat-1 was launched on October 17, 2003 by Indian Remote Sensing (IRS)
- Orbital altitude/inclination: 817 km/98.69 degrees
- Nodal crossing: 10:30 a.m.
- System life: 5 years
- Three instruments devoted to land imaging
  - **Linear Imaging Self-Scanner (LISS-IV)**
  - **Linear Imaging Self-Scanner (LISS-III)**
  - **Advanced Wide Field Sensor (AWiFS)**
- Space Imaging has distribution rights outside of India
  - **LISS-III and LISS-IV are $2,750/scene; AWiFS is $850/scene**
- Website: http://www.spaceimaging.com/products/irs/

	LISS-IV	LISS-III	AWiFS
Sprectral bands	0.52-0.59um 0.62-0.68um 0.77-0.86um	0.52-0.59um 0.62-0.68um 0.77-0.86um 1.55-1.70um	0.52-0.59um 0.62-0.68um 0.77-0.86um 1.55-1.70um
Resolution	5.8m	23.5m	56m
Swath width	23.9km/70km	141km	740km
Pointing (+-)	26 degrees	-	-
Revisit	5 days	-	-
Actual revisit	24 days	24 days	5 days

USGS

NASA

SPOT

- SPOT 2 was launched on January 22, 1990; SPOT 4 was launched on March 24, 1998; and SPOT 5 was launched on May 4, 2002
- Orbital altitude/inclination: 822 km/98.7 degrees
- Nodal crossing: 10:30 a.m.
- System life: 3 and 5 years for SPOT 2, and SPOT 4 and 5, respectively
- Instruments on each satellite
  - **SPOT 2 - High Resolution Visible (HRV)**
  - **SPOT 4 - High Resolution Visible Infra Red (HRVIR)**
  - **SPOT 5 - High Geometric Resolution (HRG)**
- Single user price of geometrically (systematic) corrected archive scene (systematic) ranges from $2,400 (10m/20m) to over $10,000 (2.5m color)
- Website: http://www.spotimage.fr/

	HRV	HRVIR	HRG
Sprectral bands	0.50-0.73um 0.50-0.59um 0.61-0.68um 0.78-0.89um	0.61-0.68um 0.50-0.59um 0.61-0.68um 0.78-0.89um 1.58-1.75um	0.48-0.71um 0.50-0.59um 0.61-0.68um 0.78-0.89um 1.58-1.75um
Resolution	10m/20m	10m/20m	2.5m/5m/10m/20m
Swath width	60km	60km	60km
Pointing (+-)	27 degrees	27 degrees	27 degrees
Revisit	2-3 days	2-3 days	2-3 days
Actual revisit	26 days	26 days	26 days

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Stuart Frye, Mitretek Systems
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