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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● Project provides:
  ◆ characterization and calibration of \textit{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 only inventory of the global land surface over time
  - at a scale where human vs. natural causes of change can be differentiated
  - on a seasonal basis
- No other satellite system is capable/committed to even annual global coverage at this scale

Amazonian Deforestation

1986

1997

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
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 detialee)
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

Commercial Systems
- ~ 10 km
- Spatial resolution < 5m
- Global coverage, decades, if ever

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

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
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)

<table>
<thead>
<tr>
<th>Component</th>
<th>Country</th>
</tr>
</thead>
<tbody>
<tr>
<td>CCD (14)</td>
<td>China</td>
</tr>
<tr>
<td>IRMSS (7)</td>
<td>China</td>
</tr>
<tr>
<td>WFI (20)</td>
<td>Brasil</td>
</tr>
<tr>
<td>Data Transmission</td>
<td>China</td>
</tr>
<tr>
<td>Data collection</td>
<td>Brasil</td>
</tr>
</tbody>
</table>

### Service Module (1)

<table>
<thead>
<tr>
<th>Component</th>
<th>Country</th>
</tr>
</thead>
<tbody>
<tr>
<td>Structure</td>
<td>Brasil</td>
</tr>
<tr>
<td>Thermal Control</td>
<td>China</td>
</tr>
<tr>
<td>Attitude and Orbit Control</td>
<td>China</td>
</tr>
<tr>
<td>Power supply</td>
<td>Brasil</td>
</tr>
<tr>
<td>On-board computer</td>
<td>China</td>
</tr>
<tr>
<td>Telemetry</td>
<td>Brasil</td>
</tr>
</tbody>
</table>
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° 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

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

| Spectral Range (µm) and Ground Sample Distance (m) |
|---------------------------------------------|-----------------|-----------------|---------|
| Landsat | L5 TM | L7 ETM+ | HRCC | IRMSS | WFI | SPOT-4 | LISS-III |
| Band    |       |        |      |       |     |       |          |
| RC    | 10.65-0.520 (30) | 0.450-0.515 (30) | 0.45-0.52 (20) | 26 | 5 | 26 | 24 |
| 2     | 0.520-0.600 (30) | 0.525-0.605 (30) | 0.52-0.59 (20) | 26 | 5 | 26 | 24 |
| 3     | 0.630-0.690 (30) | 0.630-0.690 (30) | 0.63-0.69 (20) | 26 | 5 | 26 | 24 |
| 4     | 0.760-0.900 (30) | 0.775-0.900 (30) | 0.77-0.89 (20) | 0.76-0.90 (260) | 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) | 1.55-1.75 (80) | 1.55-1.75 (20) | 1.55-1.70 (23.5) |
| 6     | 10.40-12.50 (120) | 10.40-12.50 (60) | 10.4-12.5 (160) | 2.08-2.35 (80) | 2.08-2.35 (80) | 2.08-2.35 (80) | 2.08-2.35 (80) |
| 7     | 2.080-2.350 (30) | 2.090-2.350 (30) | 2.09-2.35 (80) | 2.09-2.35 (80) | 2.09-2.35 (80) | 2.09-2.35 (80) | 2.09-2.35 (80) |
| Pan   | 0.520-0.900 (15) | 0.510-0.73 (20) | 0.50-1.10 (80) | 0.51-0.73 (10) | 0.51-0.73 (10) | 0.50-0.75 (5.8) |
Relative Spectral Response (RSR) Profiles

L7 ETM+ RSR (Band-1,2,3,4)

L7 ETM+ RSR (Band-5,7)

L5 TM RSR (Band-1,2,3,4)

L5 TM RSR (Band-5,7)

CBERS-2 CCD RSR (Band-1,2,3,4)

CBERS-2 IRMSS RSR (Band-5,7)
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
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

\[
L^* = \frac{DN_n}{CC_n}
\]

- \(L^*\) = spectral radiance at the sensors aperture \(W/(m^2.sr.um)\)
- \(DN = \) Digital number extracted from the image in band \(n\)
- \(CC_n = \) absolute calibration coefficient for band \(n\)

<table>
<thead>
<tr>
<th></th>
<th>Test-Site</th>
<th>CCD 1</th>
<th>CCD 2</th>
<th>CCD 3</th>
<th>CCD 4</th>
<th>CCD Pan</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-launch</td>
<td></td>
<td>0.9800</td>
<td>1.5900</td>
<td>1.2000</td>
<td>2.2900</td>
<td>1.2500</td>
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<tr>
<td><strong>Brazil</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>25th June 2004</td>
<td>Bahia</td>
<td>1.228</td>
<td>2.357</td>
<td>1.215</td>
<td>2.553</td>
<td>1.628</td>
</tr>
<tr>
<td>15th August 2004</td>
<td></td>
<td>1.0090</td>
<td>1.9300</td>
<td>1.1540</td>
<td>2.1270</td>
<td>1.4630</td>
</tr>
<tr>
<td>Oct 3th New</td>
<td></td>
<td>0.862</td>
<td>1.544</td>
<td>0.674</td>
<td>1.933</td>
<td>0.995</td>
</tr>
<tr>
<td>Oct 3th Old</td>
<td></td>
<td>0.978</td>
<td>1.721</td>
<td>1.057</td>
<td>1.936</td>
<td>1.223</td>
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<tr>
<td>Oct 6th New</td>
<td></td>
<td>0.84</td>
<td>1.558</td>
<td>0.89</td>
<td>2.095</td>
<td>1.03</td>
</tr>
<tr>
<td>Oct 6th Old</td>
<td></td>
<td>0.97</td>
<td>1.74</td>
<td>1.083</td>
<td>2.105</td>
<td>1.263</td>
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<tr>
<td><strong>China</strong></td>
<td></td>
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<td></td>
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<td></td>
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<td>19th August 2004</td>
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<td>0.9917</td>
<td>1.6761</td>
<td>1.0096</td>
<td>2.0613</td>
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<tr>
<td>25th August 2004</td>
<td>Dunhuang</td>
<td>1.0292</td>
<td>1.7254</td>
<td>1.0356</td>
<td>2.1515</td>
<td></td>
</tr>
<tr>
<td>24th August 2005</td>
<td>Dunhuang</td>
<td>1.0288</td>
<td>1.8096</td>
<td>1.1079</td>
<td>2.2783</td>
<td></td>
</tr>
</tbody>
</table>
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)

<table>
<thead>
<tr>
<th>Agency</th>
<th>Sensor</th>
<th>Date</th>
<th>DOY</th>
<th>Path</th>
<th>Row</th>
<th>Look angle</th>
<th>Sun Elevation</th>
<th>GMT</th>
</tr>
</thead>
<tbody>
<tr>
<td>CRSSDA</td>
<td>CBERS-2 CCD</td>
<td>8/25/2004</td>
<td>237</td>
<td>23</td>
<td>55</td>
<td>-6.03</td>
<td>56.60</td>
<td></td>
</tr>
<tr>
<td></td>
<td>L5 TM</td>
<td>8/25/2004</td>
<td>237</td>
<td>137</td>
<td>32</td>
<td>0.00</td>
<td>53.37</td>
<td></td>
</tr>
<tr>
<td>INPE</td>
<td>CBERS-2 CCD</td>
<td>12/30/2004</td>
<td>365</td>
<td>154</td>
<td>126</td>
<td></td>
<td>64.23</td>
<td>13:14:15</td>
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<tr>
<td></td>
<td>L5 TM</td>
<td>12/29/2004</td>
<td>364</td>
<td>219</td>
<td>76</td>
<td>0.00</td>
<td>69.32</td>
<td>12:50:15</td>
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<tr>
<td>INPE</td>
<td>CBERS-2 CCD</td>
<td>11/16/2005</td>
<td>320</td>
<td>151</td>
<td>126</td>
<td></td>
<td>66.47</td>
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<tr>
<td></td>
<td>L5 TM</td>
<td>11/16/2005</td>
<td>320</td>
<td>217</td>
<td>76</td>
<td>0.00</td>
<td>63.03</td>
<td>12:40:25</td>
</tr>
</tbody>
</table>
L5 TM and CBERS-2 CCD Image Pairs

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

L5 TM WRS Path = 137 Row = 032
Nadir looking

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

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

L5 TM WRS Path = 217 Row = 076
Nadir looking Acquisition Date: Nov 16, 2005
CBERS-2 CCD Path = 151 Row = 126 Acquisition Date: Nov 16, 2005
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
The RESOURCSAT-1 satellite was launched into 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

<table>
<thead>
<tr>
<th>Resourcesat-1 Orbit and Coverage Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Orbit Altitude</td>
</tr>
<tr>
<td>Orbit Inclination</td>
</tr>
<tr>
<td>Orbit period</td>
</tr>
<tr>
<td>Number of Orbits per day</td>
</tr>
<tr>
<td>Equatorial crossing time</td>
</tr>
<tr>
<td>Repetivity (LISS-3)</td>
</tr>
<tr>
<td>Repetivity (LISS-4)</td>
</tr>
<tr>
<td>Distance between adjacent paths</td>
</tr>
<tr>
<td>Distance between successive ground tracks</td>
</tr>
<tr>
<td>Lift-off Mass</td>
</tr>
<tr>
<td>Ground trace velocity</td>
</tr>
<tr>
<td>Orbits/cycle</td>
</tr>
<tr>
<td>Semi major axis</td>
</tr>
<tr>
<td>Eccentricity</td>
</tr>
<tr>
<td>Mission Life</td>
</tr>
</tbody>
</table>
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

±26° MECHANICAL STEERING THROUGH PSM

1/3 OF SWATH (ELECTRONIC STEERING)

70 Km

AWIFS-(A) & (B) GSD: 56m

LISS-3* GSD: 23.5m

LISS-4 GSD: 5.8m
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
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.
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

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

- L7 ETM+ RSR (Band-1,2,3,4)
- L7 ETM+ RSR (Band-5,7)
- L5 TM RSR (Band-1,2,3,4)
- L5 TM RSR (Band-5,7)
- CBERS-2 CCD RSR (Band-1,2,3,4)
- CBERS-2 IRMSS RSR (Band-5,7)
- IRS-P6 LISS-III/AWiFS RSR (Band-2,3,4)
- IRS-P6 AWiFS/LISS-III RSR (Band-2,3,4)
Conversion to Radiance

\[ L^* = \frac{(L_{\text{max}} - L_{\text{min}})}{Q_{\text{cal max}}} \times Q_{\text{cal}} \times L_{\text{min}} \]

Where

- \( L^* \) = spectral radiance at the sensors aperture \( \text{W}/(\text{m}^2\cdot\text{sr}\cdot\text{um}) \)
- \( Q_{\text{cal}} \) = Calibrated Digital Number
- \( Q_{\text{cal max}} \) = maximum possible DN value
  - 255 for LISS-IV & LISS-III products,
  - 1023 for 10-bit AWiFS and 255 for 8-bit AWiFS products
- \( L_{\text{max}} \) & \( L_{\text{min}} \) = 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

Landsat 7
Row 35
Row 36
Row 37
Row 38
Row 39

AWiFS

LISS-III

Landsat 5
Row 30
Row 31
Row 32

LISS-III

AWiFS
## Comparison Scenes Used -- Mesa, AZ

**Mesa, Arizona collection, June 29, 2005**

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Product ID</th>
<th>Path</th>
<th>Row</th>
<th>Solar Elevation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Landsat 7 ETM+</td>
<td>L71036035_03520050629</td>
<td>36</td>
<td>35</td>
<td>65.21 °</td>
</tr>
<tr>
<td>Landsat 7 ETM+</td>
<td>L71036036_03620050629</td>
<td>36</td>
<td>36</td>
<td>65.53 °</td>
</tr>
<tr>
<td>Landsat 7 ETM+</td>
<td>L71036037_03720050629</td>
<td>36</td>
<td>37</td>
<td>65.77 °</td>
</tr>
<tr>
<td>Landsat 7 ETM+</td>
<td>L71036038_03820050629</td>
<td>36</td>
<td>38</td>
<td>65.94 °</td>
</tr>
<tr>
<td>Landsat 7 ETM+</td>
<td>L71036039_03920050629</td>
<td>36</td>
<td>39</td>
<td>66.02 °</td>
</tr>
<tr>
<td>AWiFS Quad A</td>
<td>AW257047A001</td>
<td>257</td>
<td>47</td>
<td>69.50 °</td>
</tr>
<tr>
<td>AWiFS Quad B</td>
<td>AW257047B001</td>
<td>257</td>
<td>47</td>
<td>72.60 °</td>
</tr>
<tr>
<td>AWiFS Quad C</td>
<td>AW257047C001</td>
<td>257</td>
<td>47</td>
<td>70.30 °</td>
</tr>
<tr>
<td>AWiFS Quad D</td>
<td>AW257047D001</td>
<td>257</td>
<td>47</td>
<td>73.60 °</td>
</tr>
<tr>
<td>LISS-III</td>
<td>L32570470101</td>
<td>257</td>
<td>47</td>
<td>71.48 °</td>
</tr>
</tbody>
</table>
## Comparison Scenes Used -- SLC, UT

Salt Lake City, Utah collection, June 19, 2005

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Product ID</th>
<th>Path</th>
<th>Row</th>
<th>Solar Elevation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Landsat 5 TM</td>
<td>LT5038030000517010</td>
<td>38</td>
<td>30</td>
<td>62.95 °</td>
</tr>
<tr>
<td>Landsat 5 TM</td>
<td>LT5038031000517010</td>
<td>38</td>
<td>31</td>
<td>63.59 °</td>
</tr>
<tr>
<td>Landsat 5 TM</td>
<td>LT5038032000517010</td>
<td>38</td>
<td>32</td>
<td>64.18 °</td>
</tr>
<tr>
<td>AWiFS Quad A</td>
<td>000010491201</td>
<td>255</td>
<td>40</td>
<td>65.50 °</td>
</tr>
<tr>
<td>AWiFS Quad B</td>
<td>000010491301</td>
<td>255</td>
<td>40</td>
<td>68.10 °</td>
</tr>
<tr>
<td>AWiFS Quad C</td>
<td>000010491401</td>
<td>255</td>
<td>40</td>
<td>67.50 °</td>
</tr>
<tr>
<td>AWiFS Quad D</td>
<td>000010491501</td>
<td>255</td>
<td>40</td>
<td>70.30 °</td>
</tr>
<tr>
<td>LISS-III</td>
<td>000010491601</td>
<td>255</td>
<td>41</td>
<td>68.64 °</td>
</tr>
</tbody>
</table>
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
Band 2 Reflectance
Gain 1.0001
Bias 0.0036
R² 0.9957

Band 3 Reflectance
Gain 0.9454
Bias -0.0005
R² 0.9968

Band 4 Reflectance
Gain 0.9541
Bias 0.0018
R² 0.9974

Band 5 Reflectance
Gain 0.9634
Bias 0.0261
R² 0.9944

Band 2 Reflectance
Gain 0.9127
Bias 0.0127
R² 0.9919

Band 3 Reflectance
Gain 0.9787
Bias -0.0028
R² 0.9990

Band 4 Reflectance
Gain 1.0159
Bias -0.0032
R² 0.9997

Band 5 Reflectance
Gain 1.0989
Bias 0.0036
R² 0.9992

Band 2 Reflectance
Gain 1.1642
Bias 0.0015
R² 0.9979

Band 3 Reflectance
Gain 1.0553
Bias -0.0028
R² 0.9990

Band 4 Reflectance
Gain 1.0283
Bias -0.0032
R² 0.9997

Band 5 Reflectance
Gain 1.0290
Bias -0.0045
R² 0.9984
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).

<table>
<thead>
<tr>
<th>Differences between Sensors</th>
<th>ETM+</th>
<th>TM</th>
<th>AWiFS</th>
<th>LISS-III</th>
</tr>
</thead>
<tbody>
<tr>
<td>ETM+</td>
<td>-</td>
<td></td>
<td>8-12%</td>
<td>8-13%</td>
</tr>
<tr>
<td>TM</td>
<td>-</td>
<td></td>
<td>0-6%</td>
<td>2-10%</td>
</tr>
<tr>
<td>AWiFS</td>
<td>8-12%</td>
<td>0-6%</td>
<td></td>
<td>1-16%</td>
</tr>
<tr>
<td>LISS-III</td>
<td>8-13%</td>
<td>2-10%</td>
<td>1-16%</td>
<td></td>
</tr>
</tbody>
</table>

Cross-calibration results normalized to the AWiFS sensor

<table>
<thead>
<tr>
<th>Sensor</th>
<th>Band 2</th>
<th>Band 3</th>
<th>Band 4</th>
<th>Band 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>L5</td>
<td>1.00</td>
<td>1.06</td>
<td>1.05</td>
<td>1.04</td>
</tr>
<tr>
<td>L7</td>
<td>1.11</td>
<td>1.08</td>
<td>1.13</td>
<td>1.12</td>
</tr>
<tr>
<td>AWiFS</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>LISS-III (Mesa)</td>
<td>0.90</td>
<td>0.96</td>
<td>0.97</td>
<td>1.00</td>
</tr>
<tr>
<td>LISS-III (SLC)</td>
<td>0.86</td>
<td>0.95</td>
<td>0.97</td>
<td>0.97</td>
</tr>
</tbody>
</table>
### LDGST Qs

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1.</strong></td>
<td><em>The sensor gain adjusted?</em>** What does this indicate about the source of the signal?***</td>
</tr>
<tr>
<td><strong>2.</strong></td>
<td><em>Do you have any other Gain adjustments?</em>** What are these used for?***</td>
</tr>
<tr>
<td><strong>3.</strong></td>
<td><em>How do you measure the gain</em>**?***</td>
</tr>
<tr>
<td><strong>4.</strong></td>
<td><em>What are the internal gain settings?</em>**</td>
</tr>
<tr>
<td><strong>5.</strong></td>
<td><em>What role do you have in calibration?</em>**</td>
</tr>
<tr>
<td><strong>6.</strong></td>
<td><em>What is the expected output of the sensor?</em>**</td>
</tr>
<tr>
<td><strong>7.</strong></td>
<td><em>How do you ensure the sensor is calibrated?</em>**</td>
</tr>
<tr>
<td><strong>8.</strong></td>
<td><em>What is the sensor gain?</em>**</td>
</tr>
<tr>
<td><strong>9.</strong></td>
<td><em>What is the sensor's dynamic range?</em>**</td>
</tr>
<tr>
<td><strong>10.</strong></td>
<td><em>What is the sensor's sensitivity?</em>**</td>
</tr>
<tr>
<td><strong>11.</strong></td>
<td><em>What is the sensor's resolution?</em>**</td>
</tr>
<tr>
<td><strong>12.</strong></td>
<td><em>What is the sensor's noise?</em>**</td>
</tr>
<tr>
<td><strong>13.</strong></td>
<td><em>What is the sensor's spectral response?</em>**</td>
</tr>
<tr>
<td><strong>14.</strong></td>
<td><em>What is the sensor's calibration range?</em>**</td>
</tr>
<tr>
<td><strong>15.</strong></td>
<td><em>What is the sensor's accuracy?</em>**</td>
</tr>
<tr>
<td><strong>16.</strong></td>
<td><em>How do you ensure the sensor's calibration?</em>**</td>
</tr>
<tr>
<td><strong>17.</strong></td>
<td><em>What is the sensor's linearity?</em>**</td>
</tr>
<tr>
<td><strong>18.</strong></td>
<td><em>What is the sensor's stability?</em>**</td>
</tr>
<tr>
<td><strong>19.</strong></td>
<td><em>What is the sensor's sensitivity to noise?</em>**</td>
</tr>
<tr>
<td><strong>20.</strong></td>
<td><em>What is the sensor's noise level?</em>**</td>
</tr>
<tr>
<td><strong>21.</strong></td>
<td><em>What is the sensor's response time?</em>**</td>
</tr>
<tr>
<td><strong>22.</strong></td>
<td><em>How do you determine the sensor's response time?</em>**</td>
</tr>
<tr>
<td><strong>23.</strong></td>
<td><em>What is the sensor's noise-to-signal ratio?</em>**</td>
</tr>
<tr>
<td><strong>24.</strong></td>
<td><em>How do you ensure the sensor's noise-to-signal ratio?</em>**</td>
</tr>
<tr>
<td><strong>25.</strong></td>
<td><em>What is the sensor's dynamic range?</em>**</td>
</tr>
<tr>
<td><strong>26.</strong></td>
<td><em>How do you ensure the sensor's dynamic range?</em>**</td>
</tr>
<tr>
<td><strong>27.</strong></td>
<td><em>What is the sensor's spectral response?</em>**</td>
</tr>
<tr>
<td><strong>28.</strong></td>
<td><em>How do you ensure the sensor's spectral response?</em>**</td>
</tr>
<tr>
<td><strong>29.</strong></td>
<td><em>What is the sensor's calibration range?</em>**</td>
</tr>
<tr>
<td><strong>30.</strong></td>
<td><em>How do you ensure the sensor's calibration range?</em>**</td>
</tr>
<tr>
<td><strong>31.</strong></td>
<td><em>What is the sensor's accuracy?</em>**</td>
</tr>
<tr>
<td><strong>32.</strong></td>
<td><em>How do you ensure the sensor's accuracy?</em>**</td>
</tr>
<tr>
<td><strong>33.</strong></td>
<td><em>What is the sensor's linearity?</em>**</td>
</tr>
<tr>
<td><strong>34.</strong></td>
<td><em>How do you ensure the sensor's linearity?</em>**</td>
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<td><strong>35.</strong></td>
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<td><strong>37.</strong></td>
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<td><em>How do you ensure the sensor's sensitivity to noise?</em>**</td>
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<td><strong>39.</strong></td>
<td><em>What is the sensor's noise level?</em>**</td>
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<td><em>How do you ensure the sensor's noise level?</em>**</td>
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<td><strong>41.</strong></td>
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<tr>
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<td><strong>43.</strong></td>
<td><em>What is the sensor's noise-to-signal ratio?</em>**</td>
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<td><strong>44.</strong></td>
<td><em>How do you ensure the sensor's noise-to-signal ratio?</em>**</td>
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<tr>
<td><strong>45.</strong></td>
<td><em>What is the sensor's dynamic range?</em>**</td>
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<td><em>How do you ensure the sensor's dynamic range?</em>**</td>
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<tr>
<td><strong>47.</strong></td>
<td><em>What is the sensor's spectral response?</em>**</td>
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<td><em>How do you ensure the sensor's spectral response?</em>**</td>
</tr>
</tbody>
</table>
Landsat Data Gap Studies: Summary
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

Oct 23-26, 2006
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

[Map of African Desert Sites]
**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 subgroup 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](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
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)**

Proposed products include models of:

- % shrub
- % sagebrush
- % herbaceous
- % bare ground
- % litter
- shrub height
- % 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 **at least some** 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