USGS
science for a changing world

USGS Report to the CEOS WGCV 26th Meeting

Dates: Oct 31 – Nov 03, 2006

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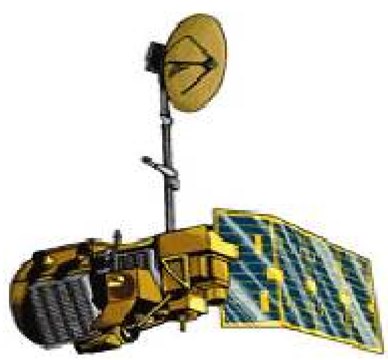


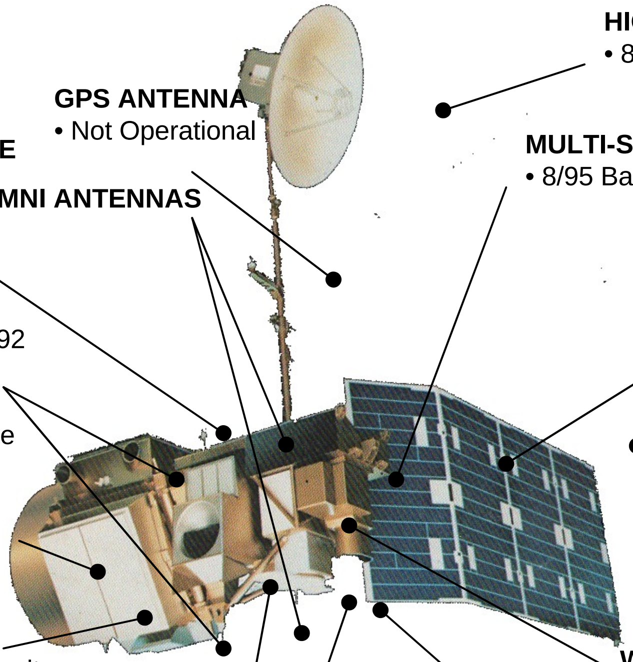
Outline

- **Landsat-5/7 Status**
- **EO-1 ALI, ASTER, and MODIS Updates**
- **Three principle initiatives in Land Remote Sensing (LRS)**
  - The Landsat Data Continuity Mission (LDCM)
  - The Landsat Data Gap Study Team (LDGST), and
  - The Future of Land Imaging (FLI)
- **Recommendations**

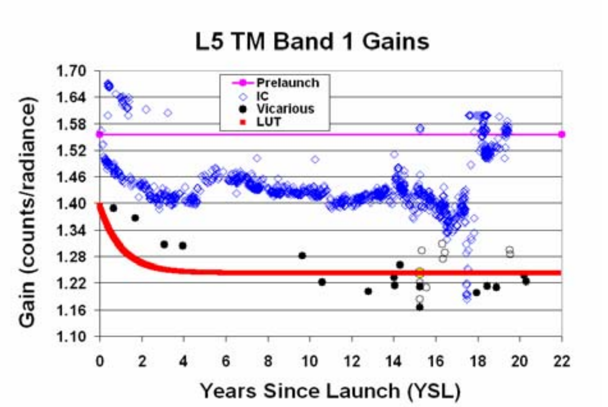
Landsat-5 TM Mission Status

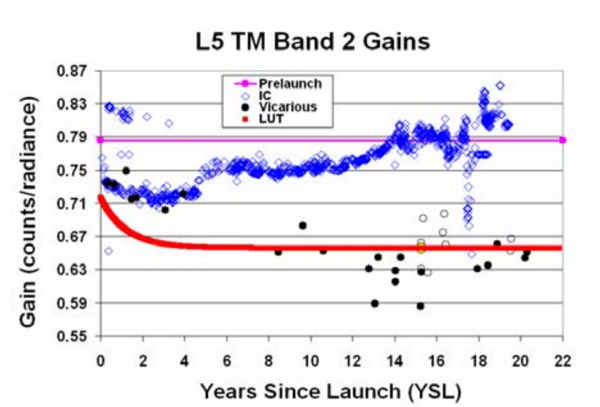
- **On orbit for 22 years! (Designed for 2-3 year mission life)**
- **Solar Array Drive Malfunction**
  - Both primary and redundant drives failed
  - On 8/14/2006, placed solar array in fixed position
  - Currently investigating imaging limitations due to power issues
- **TWTA Anomaly**
  - March 2006: 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**

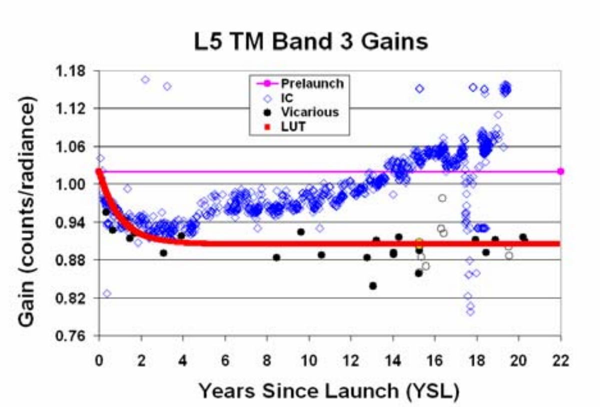
Landsat 5 Status

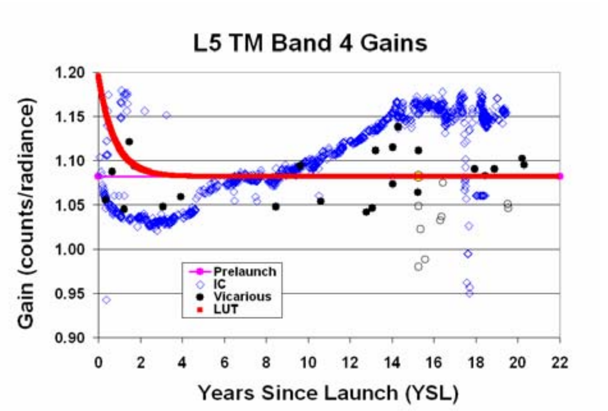


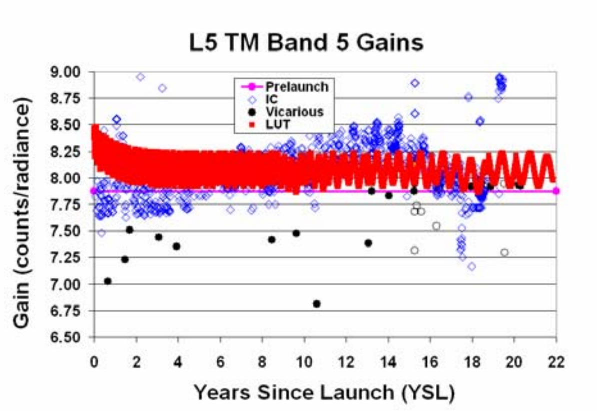
Comparison of L5 TM Radiometric Calibration Methods

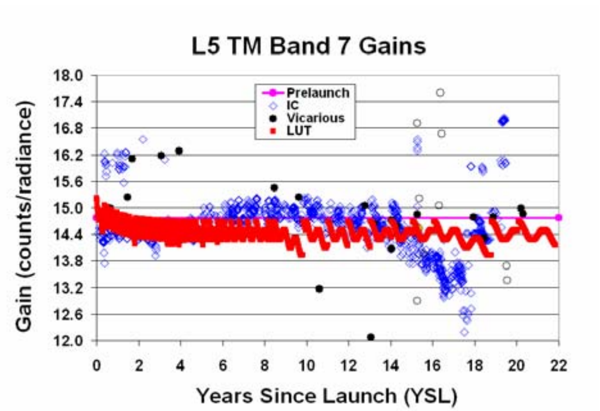












Landsat-7 ETM+ Mission Status

- **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
- **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**

Landsat 7 Status

Enhanced Thematic Mapper +

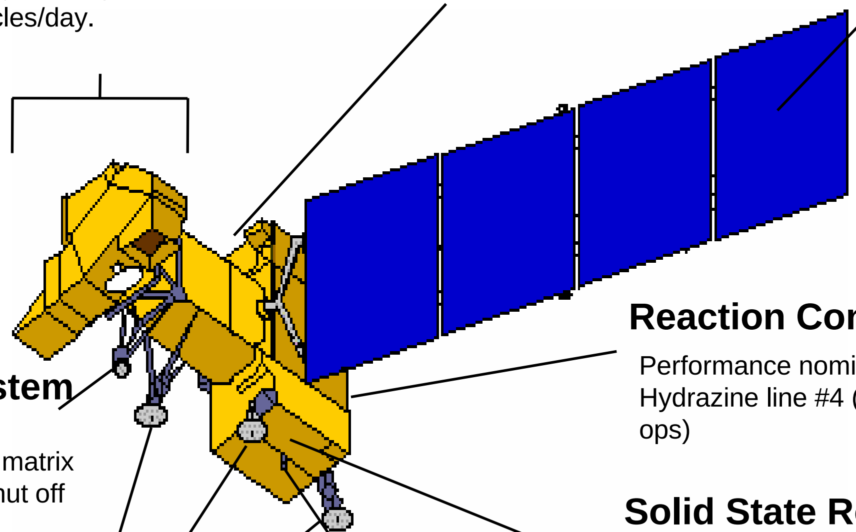
SLC Failure in May 2003. Occasional Scan Mirror anomalies. Currently running about 13% duty cycle, 25-30 cycles/day.

Electrical Power System

Batteries: Nominal

Solar array:

Two power circuit failed + natural degradation - 14% drop in power generation capability (no impact to ops)



Reaction Control System

Performance nominal: 2 thermostat failed Hydrazine line #4 (1/7/04). (no impact to ops)

Attitude Control System

Performance nominal: Softwareupdated (alignment matrix and Star catalog). Gyro 3 Shut off 5/5/04.

Solid State Recorder

Four memory boards failed (temporary).

X-band System

Performance Nominal: Same hardware configuration since launch.

S-band System

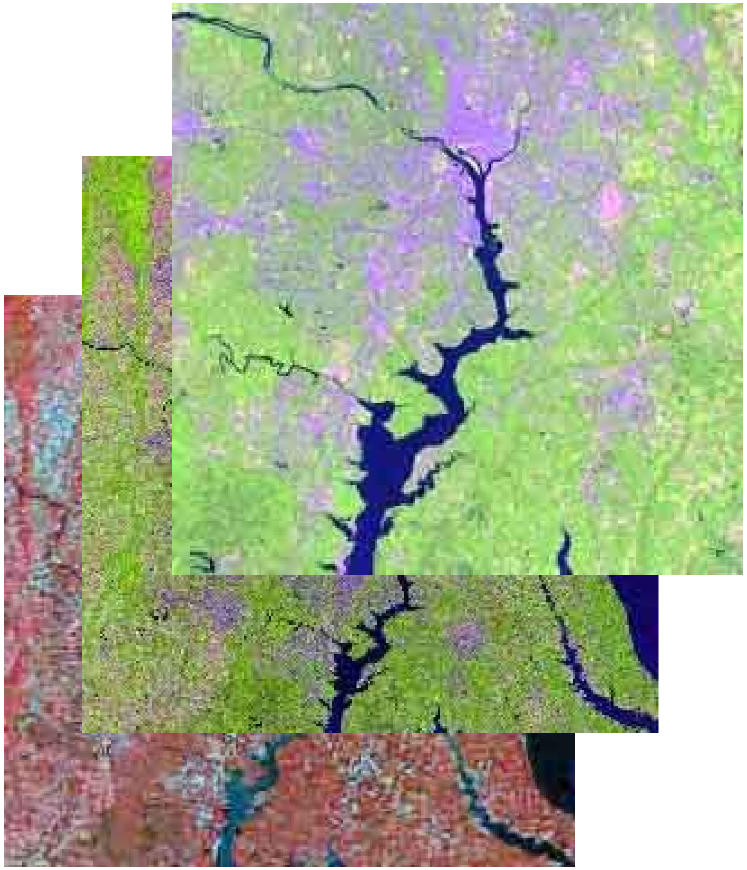
Performance Nominal: Same configuration since launch

L7 ETM+ SLC-off Product Development

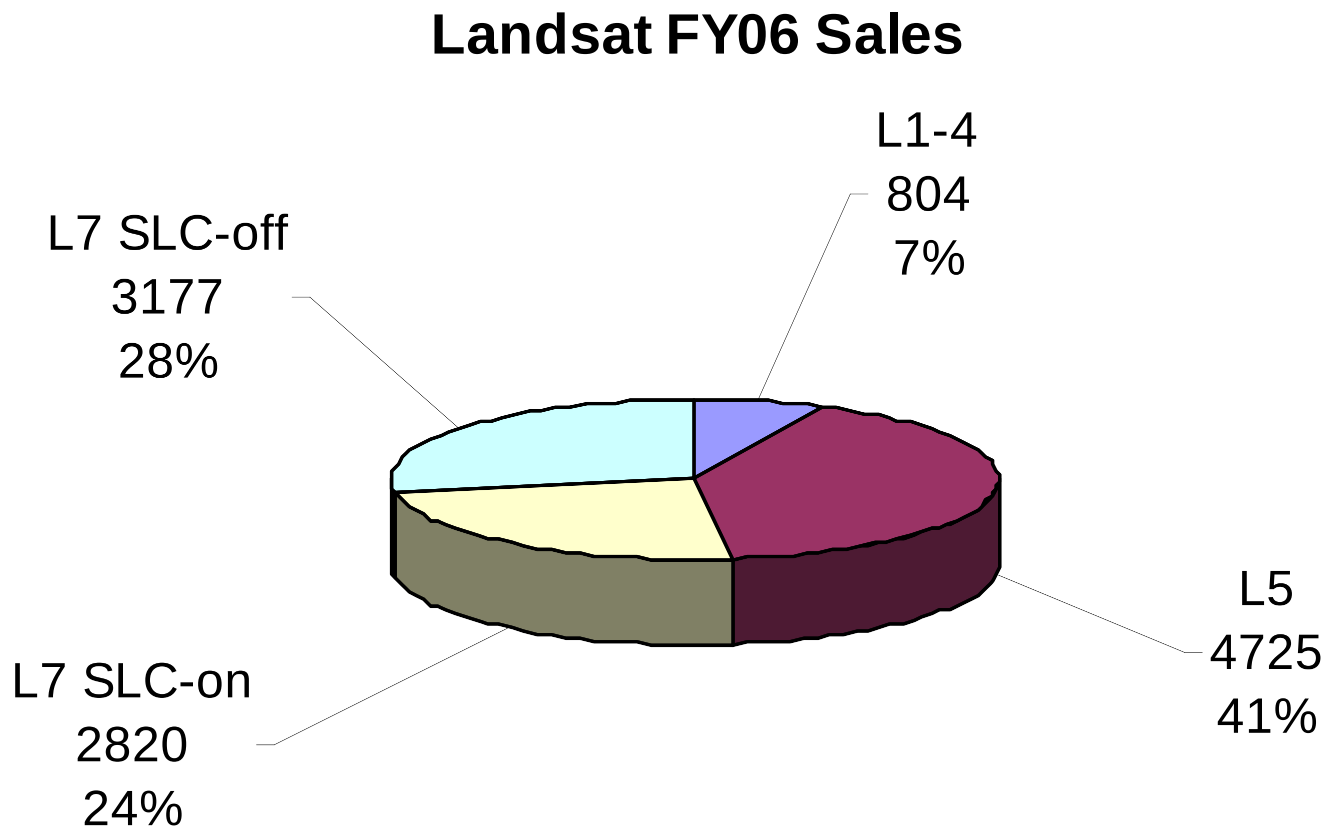
- **Phase 0 – SLC-off Products – Released in October 2003**
  - Standard L0R and L1G Products that Include Scan Gaps
  - Search and Order Systems Use Lines and Numerical Scale on Existing Browse to Illustrate Impacts on Data Products
  - Selectable Interpolation for L1G Products Followed Soon After
- **Phase 1 – Initial Gap-filled L1G Products – Released May 2004**
  - SLC-off to SLC-on Gap-filled Product Using Histogram Matching
  - Scan Gap Mask Included to Indicate the Origin of Each Pixel
- **Phase 2 – SLC-off / off Gap-filled Products – Released Nov 2004**
  - Modified the Histogram Matching Gap-fill Approach to Use an “Adaptive Window” Size to Generate Improved Fill Pixel Values
  - Scan Gap Mask Modified to Accommodate Multiple “Fill” Scenes
  - Developed a Gap Phase Statistic and New Browse to Aid in Ordering
- **Phase 3 – Segmentation Gap-filled Products – Release date TBD**

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

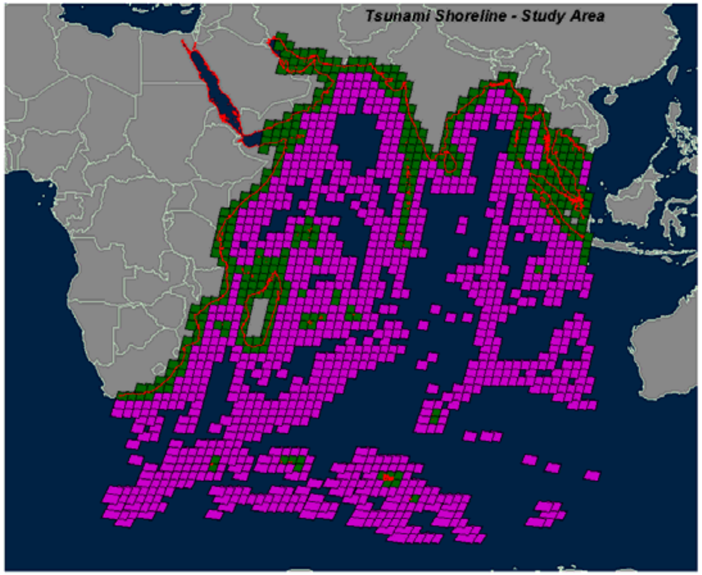
- **ETM+: Landsat 7**
  - 654,932 scenes
  - 608TB RCC and L0Ra Data
  - Archive grows by 260GB Daily
- **TM: Landsat 4 & Landsat 5**
  - 671,646 scenes
  - 336TB of RCC and L0Ra Data
  - Archive Grows by 40GB Daily
- **MSS: Landsat 1 through 5**
  - 641,555 scenes
  - 14TB of Data

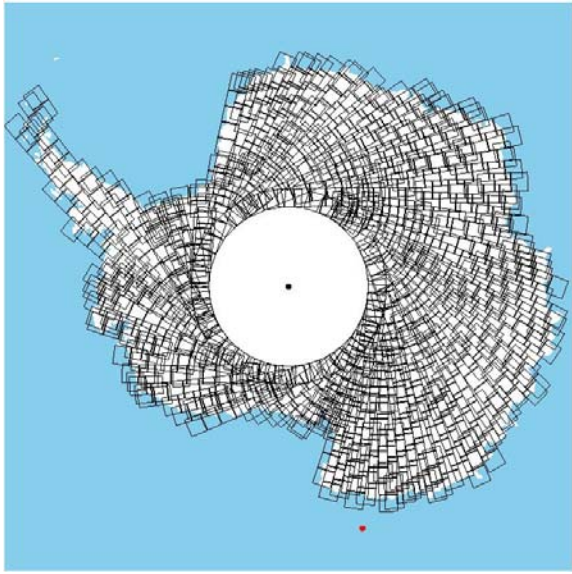


Sales of Landsat



Landsat active data collection campaigns





Burn Severity Atlas support

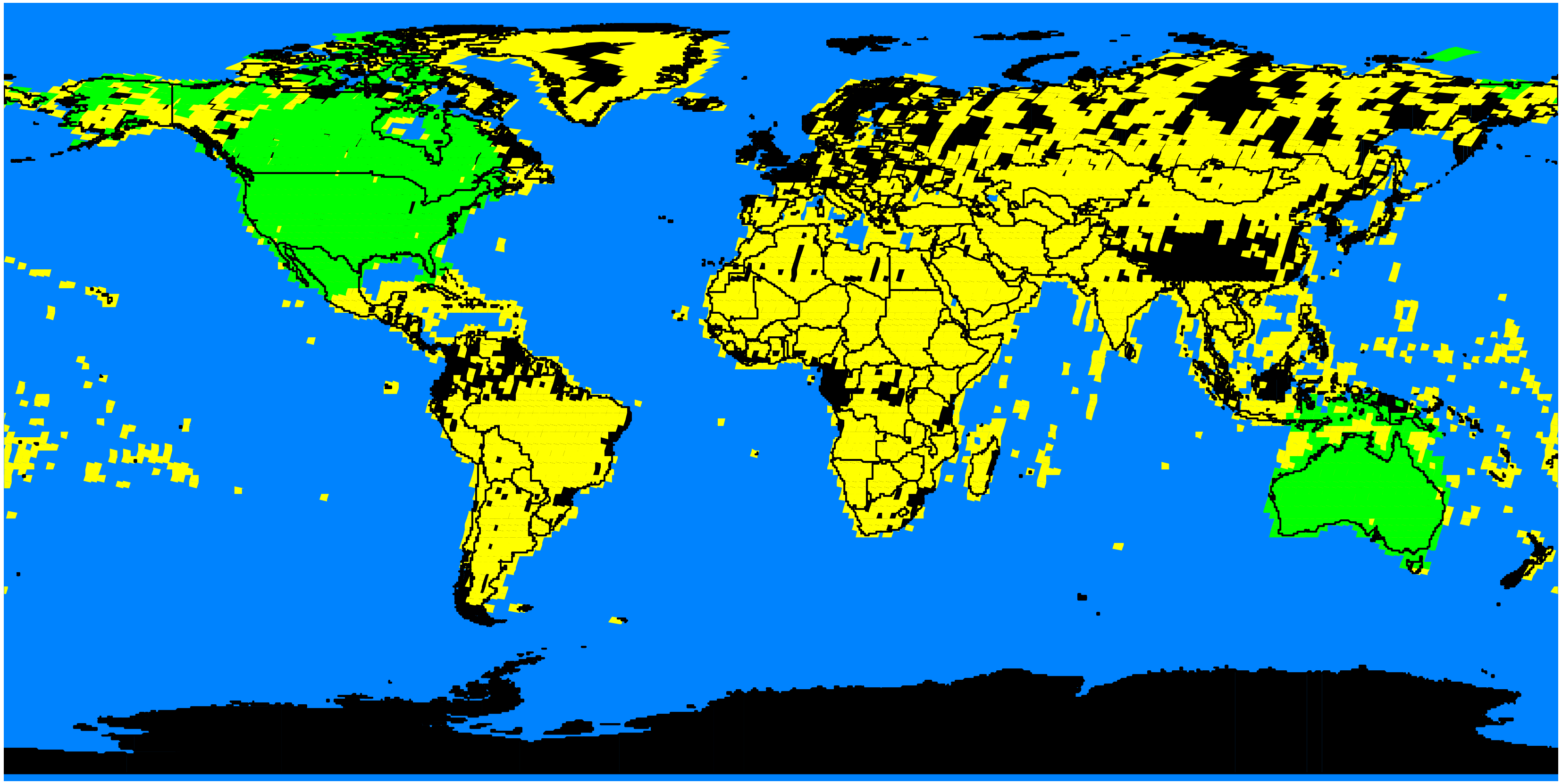
Sawtooth and Millard Fires, CA

13 July 2006 Night image: 6,7,5

Indian Ocean Campaign

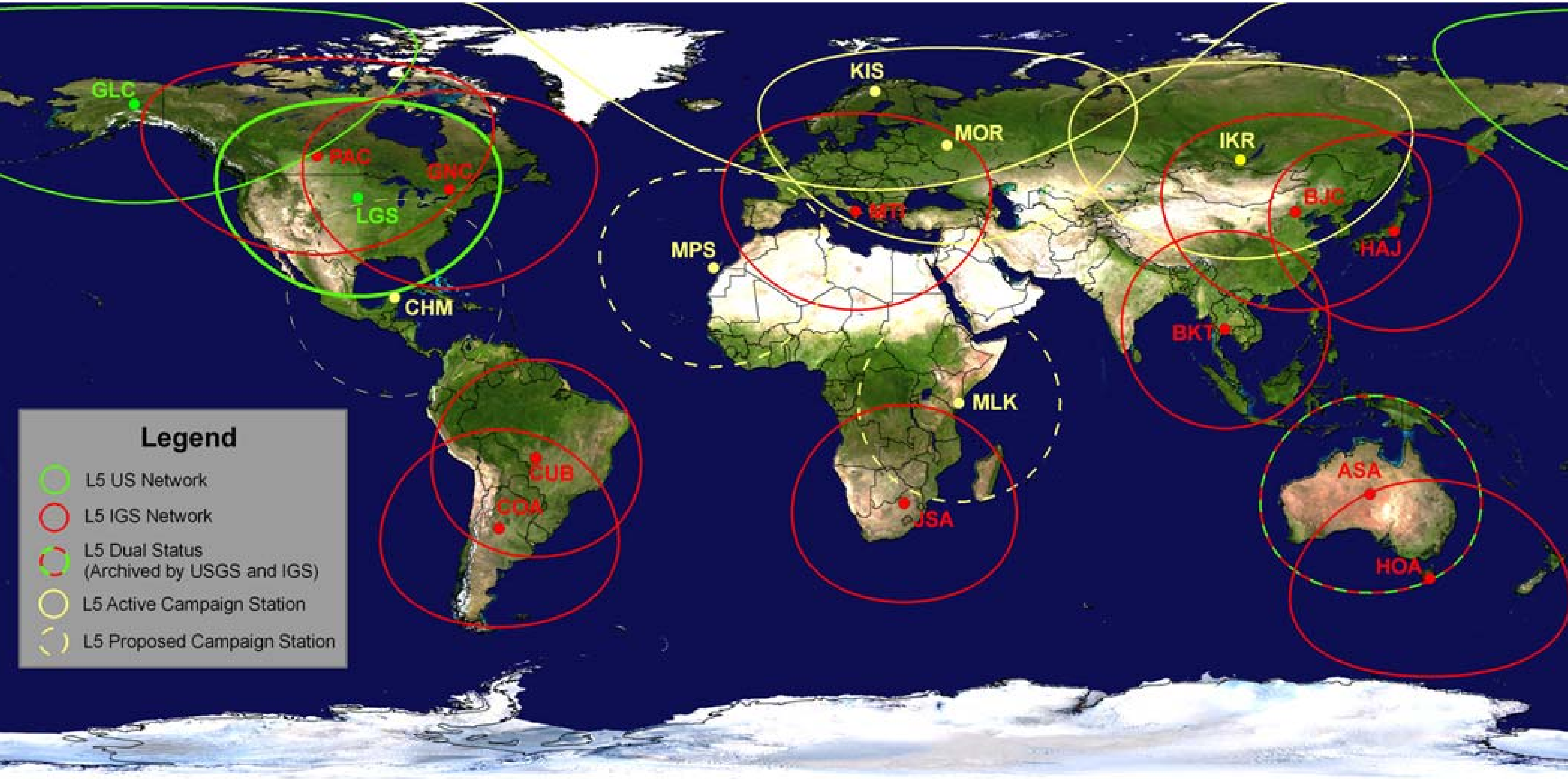
Mosaic of Antarctica

Mid-Decadal Global Land Survey



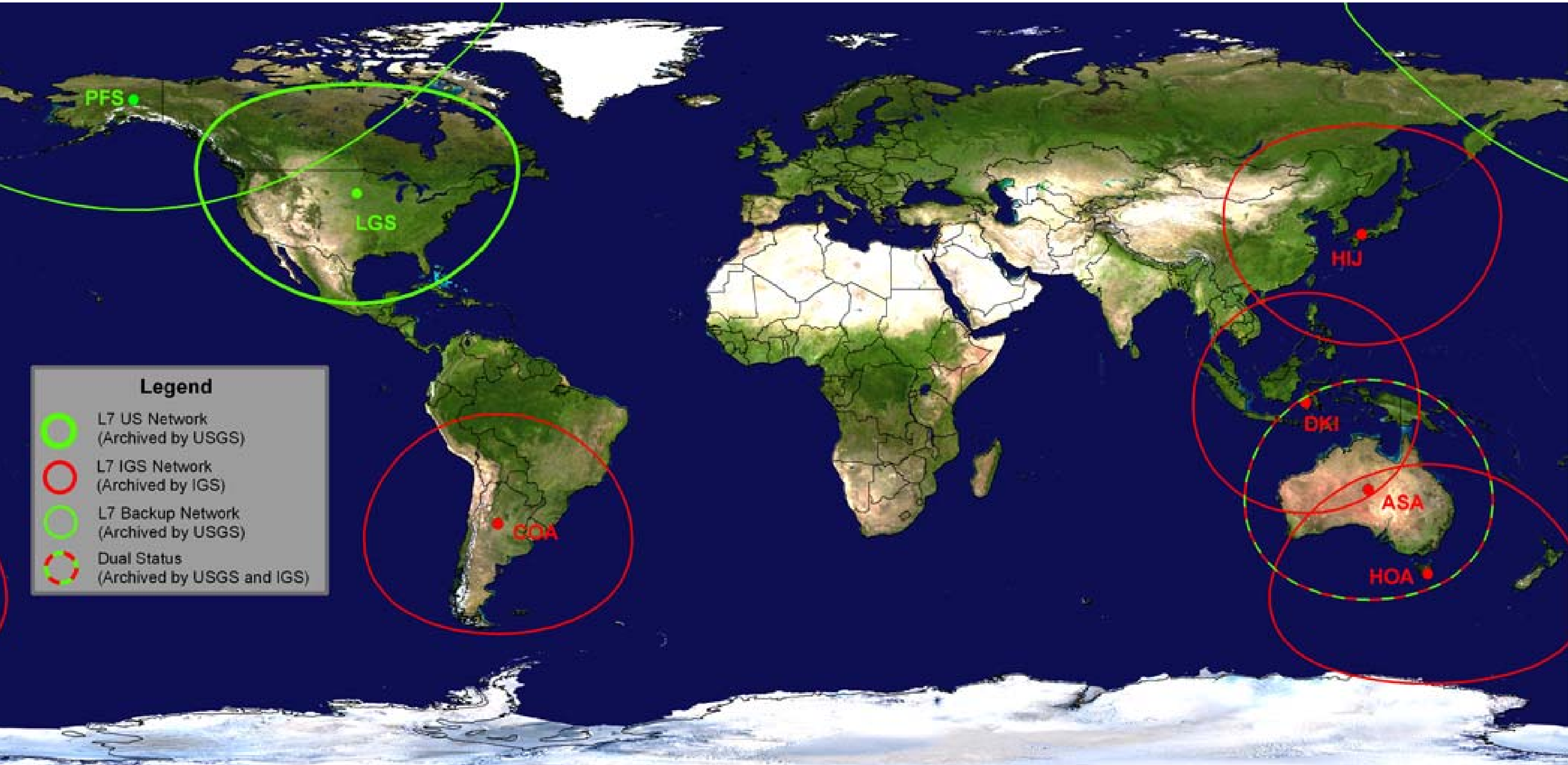
Landsat 7 Landsat 5

Landsat 5 Station Network



No on-board data recorder
Only U.S. (Sioux Falls, Australia & Alaska during fire season)
8 International Cooperators (ICs) with 10 ground stations capture TM data

Landsat 7 Station Network



- On-board recorder allows for full U.S. and global data coverage
  - Four (of 24) recorder boards shut off due to anomalous behavior
  - Minimal impact to acquisition plan due to redundancy
  - Data downlinked to US stations (Sioux Falls and Australia) plus 3 International Cooperators

ASTER & MODIS Update

- **ASTER corrections being implemented**
  - Geometric errors and SWIR cross-talk stray light issues corrected in Level 2 PGEs
- **LP DAAC implemented on-demand ASTER Level-1B, Level-2, and DEM products from large archive**
- **MODIS Land Version 5 reprocessed datasets being ingested and archived by the LP DAAC**
  - New algorithms being run by MODAPS
- **Integrating MODIS Direct Broadcast NDVI product with historical AVHRR data in support of Drought Monitoring and Fire Danger Forecast products**

Revised LDCM Strategy

- **OSTP Director Marburger signed Dec. 23, 2005 memorandum with subject line, "Landsat Data Continuity Strategy Adjustment"**
  - supersedes previous direction to fly Landsat sensors aboard NPOESS satellites (Aug. 04, 2004 memorandum)
  - Authorized NASA to "acquire a single LDCM in the form of a free-flyer spacecraft" and deliver the data to the USGS
  - Specified that USGS would be responsible for the operations of the LDCM and for collection, archiving, processing, and distribution of land surface data
  - States goal of developing "a long-term plan to achieve, technical, financial, and managerial stability for operational land imaging"
- **OSTP / NSTC Operational Future Land Imaging Planning Group**
  - "The National Science and Technology Council, in coordination with NASA, DOI/USGS, and other agencies and EOP offices as appropriate, will lead an effort to develop a long-term plan to achieve, technical, financial, and managerial stability for operational land imaging"

LDCM Synopsis

- **On February 22, 2006, NASA released a synopsis to potential offerors of the Agency's planned procurement strategy for the LDCM**
  - **http://prod.nais.nasa.gov/cgi-bin/eps/synopsis.cgi?acqid=119145**
  - NASA is planning a single award for the development and delivery of a spacecraft, instrument, observatory integration and test, and operational systems/sustaining engineering support
- **On Oct 24, 2006, NASA released a revised synopsis of NASA's LDCM procurement approach**
  - **http://prod.nais.nasa.gov/cgi-bin/eps/synopsis.cgi?acqid=122610**
  - NASA is now revising the acquisition approach for LDCM to include separate procurements for the instrument, spacecraft, and mission operations elements
- **NASA GSFC will serve as the system integrator for the mission and launch services will be provided by the NASA Launch Services (NLS) contract managed by the Kennedy Space Center (KSC)**

Landsat Science Team

- **The measure of success of the overall LDCM mission is the complete integration of LDCM data with past, present, and future Landsat and remotely sensed data for the purpose of observing and monitoring global environmental systems**
- **Science Team Purposes:**
  1. The USGS is sponsoring a Landsat Science Team that will conduct research on issues critical to the success of the LDCM mission
  2. The Landsat Science Team will offer informed advice and recommendations to the USGS and NASA on topics that will affect the overall success of the LDCM mission

Science Team Expertise

- Applications – with emphasis on those applications that have historically been reliant on Landsat data
- Technical needs – especially those of large operational customers (e.g., global change studies, agricultural surveys, disaster assessment, etc.)
- Instrument functions – including long-term calibration and image geometry and radiometer performance
- Data issues – including acquisition strategies, data access requirements and specifications, product characteristics, data management capabilities, data archiving

USGS and NASA Select Landsat Science Team

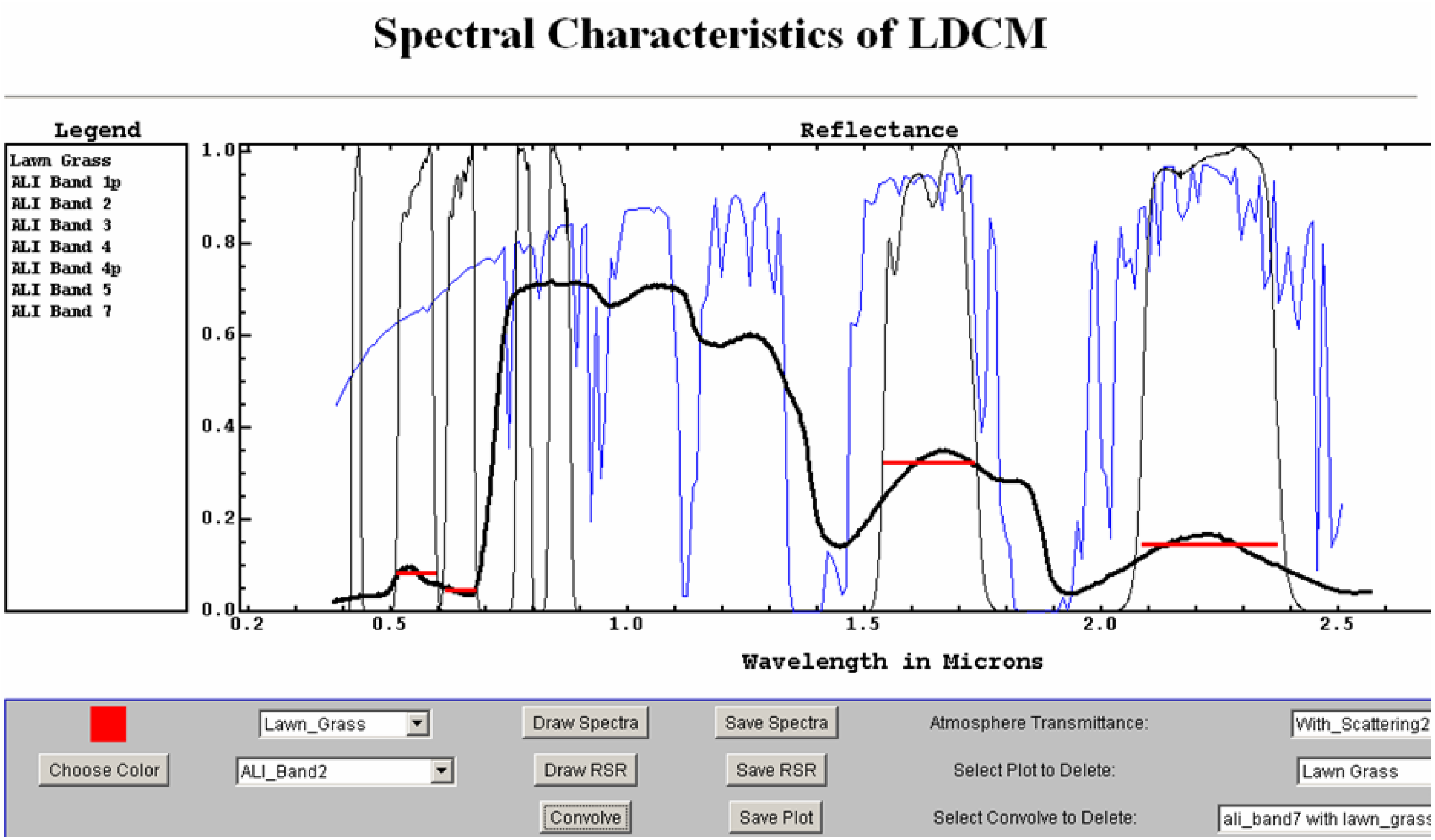
Allen, Richard	University of Idaho	Operational Evapotranspiration Algorithms for LDCM as a Member of the Landsat Data Continuity Mission Science Team	Applications - agriculture, water resources
Anderson, Martha	USDA Agricultural Research Service	Mapping Drought and Evapotranspiration at High Spatial Resolution Using Landsat Thermal and Surface Reflectance Band Imagery	Applications - agriculture
Belward, Alan	EC Joint Research Center	Natural Resources Management - Meeting Millennium Development Goals	Applications - land cover, resource management
Bindshadler, Robert	NASA Goddard	Advancing Ice Sheet Research with the Next Generation Landsat Sensor	Applications - cryosphere
Cohen, Warren	U.S. Forest Service Pacific Northwest Research Station	Landsat and Vegetation Change: Towards 50 Years of Observation and Characterization	Applications - forestry
Gao, Feng	Earth Resources Technology	Developing a Consistent Landsat Data Set from MSS, TM/ETM+ and International Sources for Land Cover Change Detection	Data products - ortho-imagery, surface reflectance
Goward, Sam	University of Maryland	The LDCM Long Term Acquisition Plan: Extending and Enhancing the Landsat 7 LTAP Approach	Data acquisition - LTAP
Helder, Dennis	South Dakota State University	A Systematic Radiometric Calibration Approach for LDCM and the Landsat Archive	Data quality - radiometric calibration

Landsat Science Team Selections

Helmer, Eileen	U.S. Forest Service International Institute of Tropical Forestry	Cloud-Free Landsat Image Mosaics for Monitoring Tropical Forest Ecosystems	Applications - forestry
Nemani, Rama	NASA Ames	Developing Biophysical Products for Landsat	Data products - biophysical
Oraiopoulos, Lazaros	University of Maryland Baltimore County	Cloud Detection and Avoidance for the Landsat Data Continuity Mission	Data acquisition - cloud detection
Schott, John	Rochester Institute of Technology	The Impact of Land Processes on Fresh and Coastal Waters	Applications - water resources; calibration/validation
Thenkabail, Prasad	International Water Management Institute	Global Irrigated Area Mapping using Landsat 30-m for the Years 2000 and 1975	Applications - agriculture
Vermote, Eric	University of Maryland	A Surface Reflectance Standard Product for LDCM and Supporting Activities	Data products - surface reflectance
Vogelmann, Jim	EROS	Monitoring Forest and Rangeland Change using Landsat Continuity and Alternative Sources of Satellite Data	Applications - rangeland, forestry
Woodcock, Curtis	Boston University	Toward Operational Global Monitoring of Landcover Change	Applications - land cover change
Wulder, Michael	Canadian Forest Service	Large-Area Land Cover Mapping and Dynamics: Landsat Imagery to Information	Applications - forestry and land cover

Spectral Characterization Tool – LDCM Webpage

http://ldcm.usgs.gov/spectral_plotter.html



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

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
- **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

Requirements and Capabilities Analysis

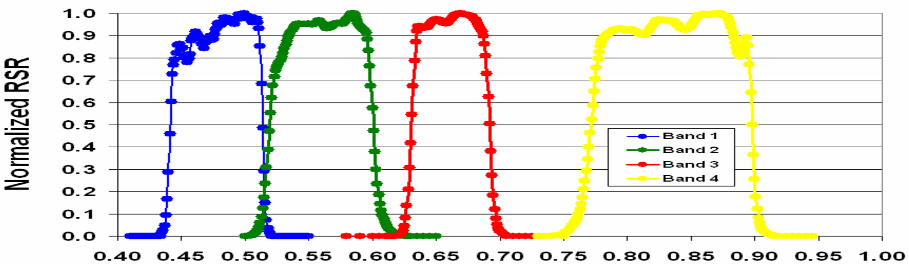
- **LDCM Data Specification ("Goal") has been vetted by science and applications communities, and supports the full range of Landsat applications**
- **Obtaining data identical to LDCM from existing systems is not possible**
- **Minimum acceptable specifications were derived to support basic global change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

Systems Considered

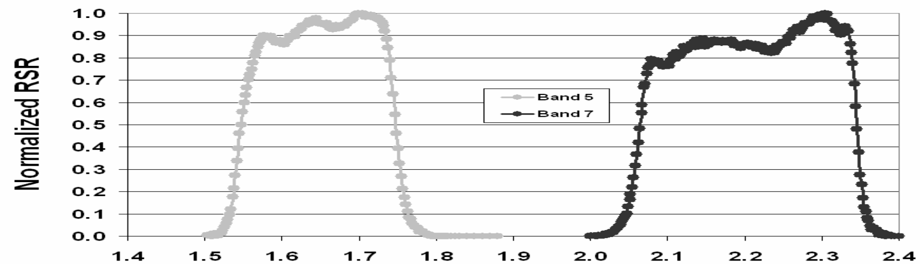
✓IRS ResourceSat – 1, 2 (India)
✓CBERS – 2, 2A, 3, 4 (China & Brazil)
✓Rapid Eye – 1, 2, 3, 4, 5 (Germany)
✓DMC (Algeria, Nigeria, UK, China)
✓Terra/ASTER (US & Japan)
✓High-resolution U.S. commercial systems
✓IKONOS, Quickbird, OrbView-3
✓ALOS (Japan)
✓SPOT – 4, 5 (France)
✓EO-1/ALI (US)

Relative Spectral Response (RSR) Profiles

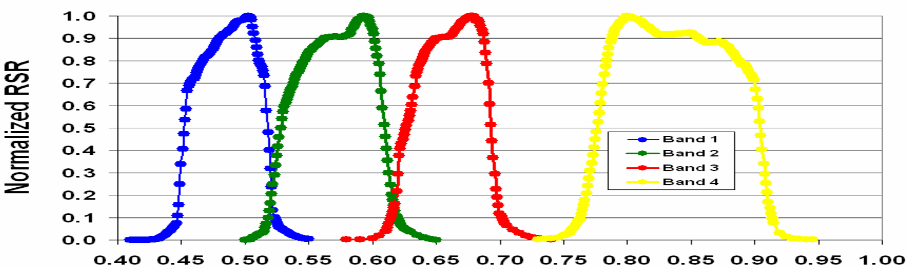
L7 ETM+ RSR (Band-1,2,3,4)



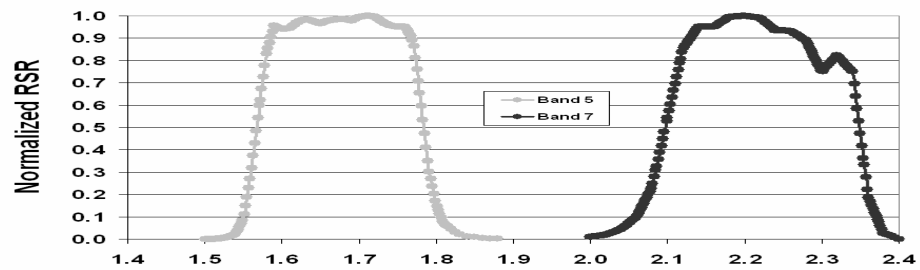
L7 ETM+ RSR (Band-5,7)



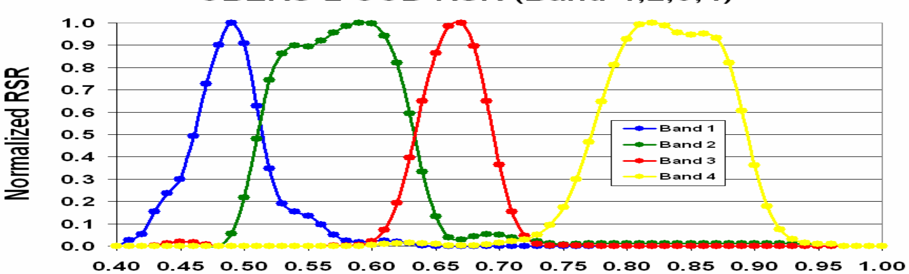
L5 TM RSR (Band-1,2,3,4)



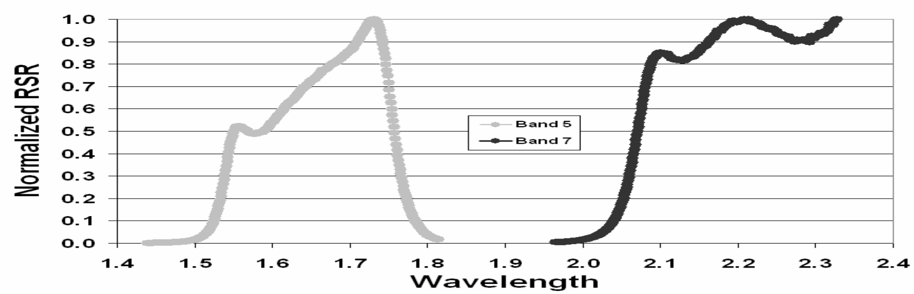
L5 TM RSR (Band-5,7)



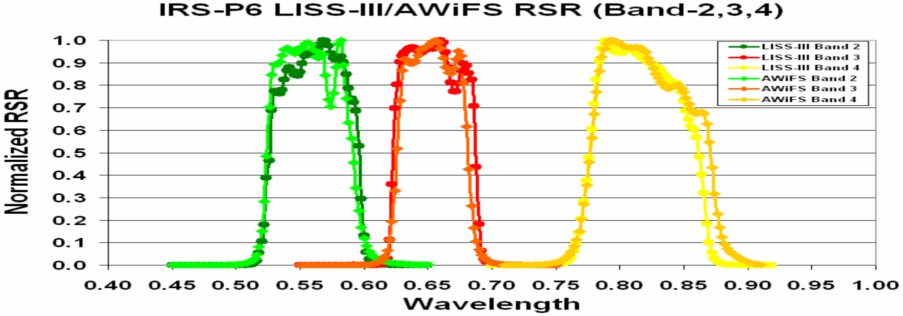
CBERS-2 CCD RSR (Band-1,2,3,4)



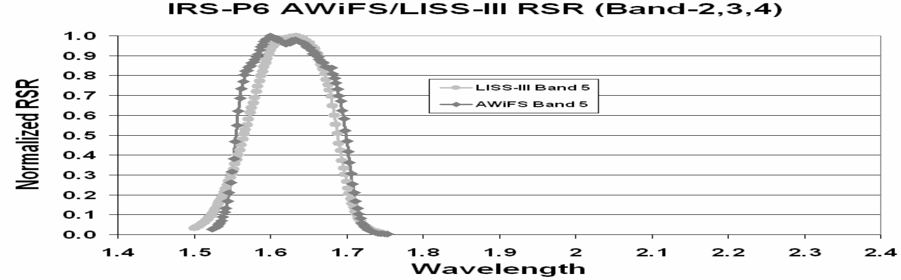
CBERS-2 IRMSS RSR (Band-5,7)



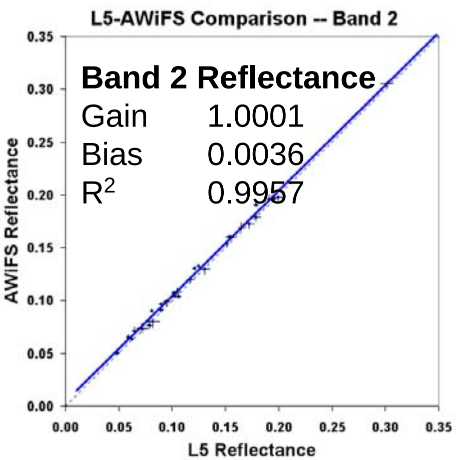
IRS-P6 LISS-III/AWiFS RSR (Band-2,3,4)

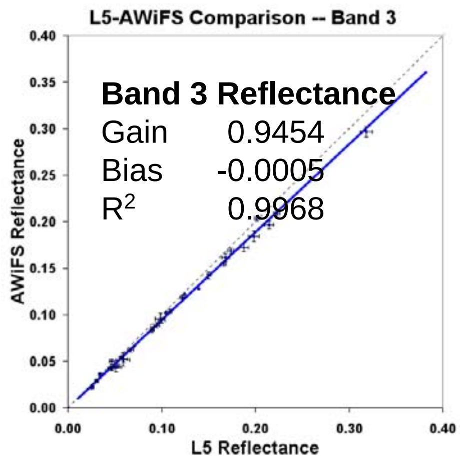


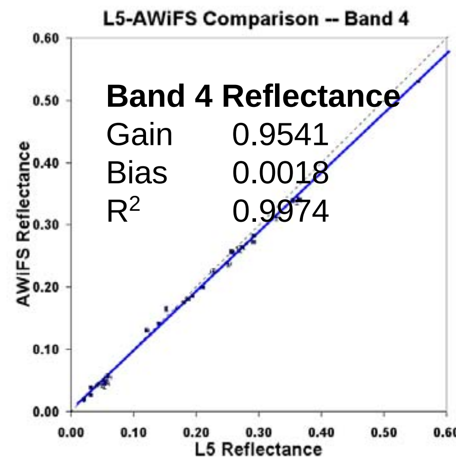
IRS-P6 AWiFS/LISS-III RSR (Band-2,3,4)

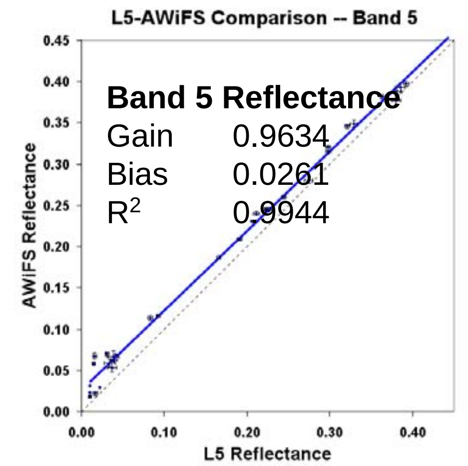


IRS-P6 AWiFS / TM reflectance comparison plots (SLC, UT)

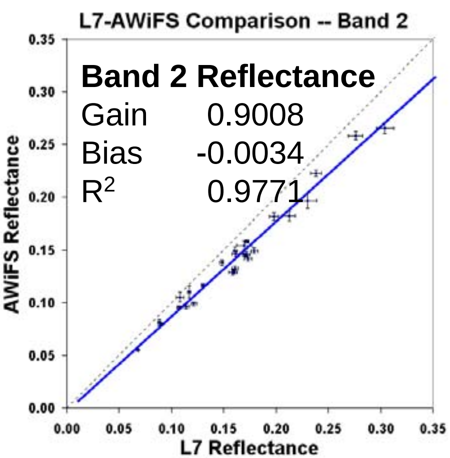


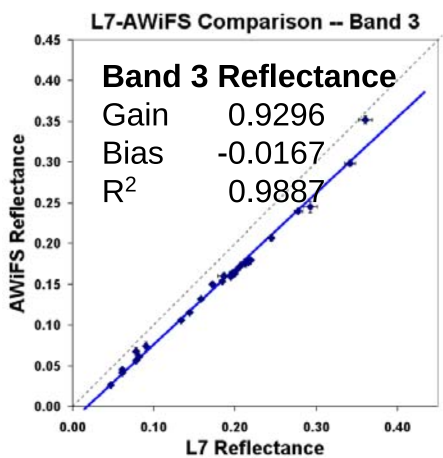


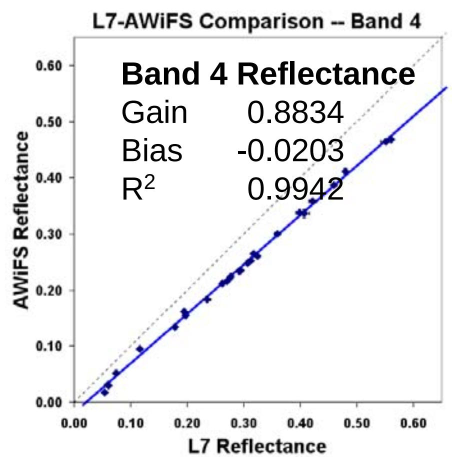


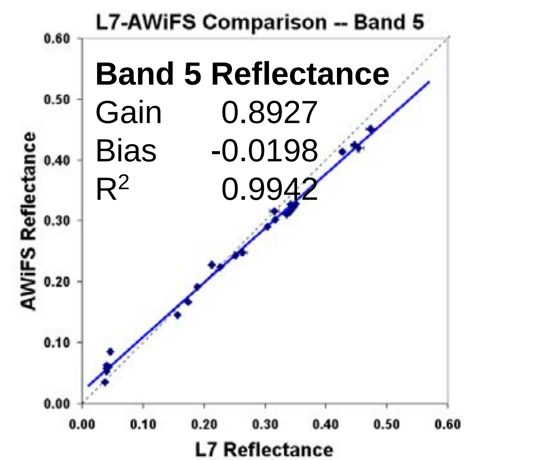


IRS-P6 AWiFS / ETM+ reflectance comparison plots (Mesa, AZ)

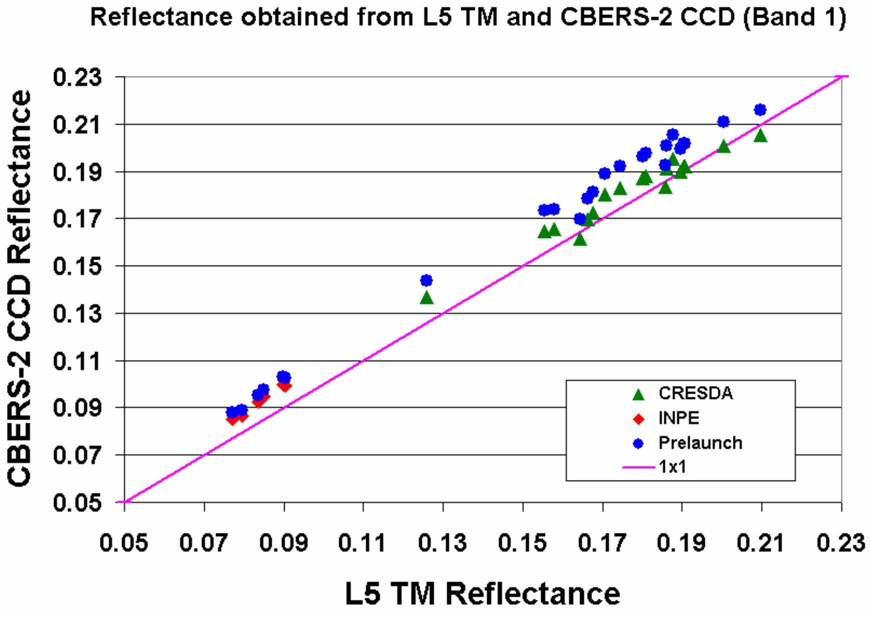


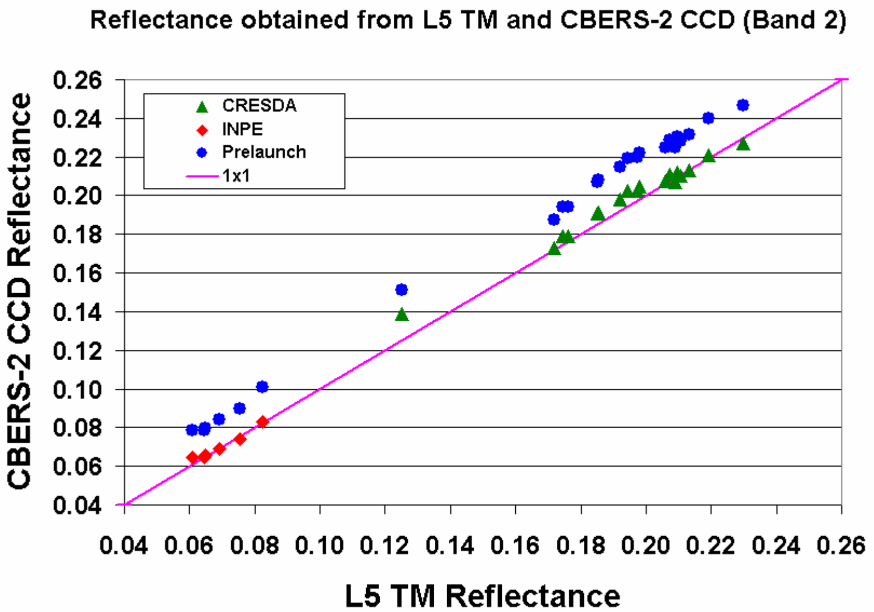


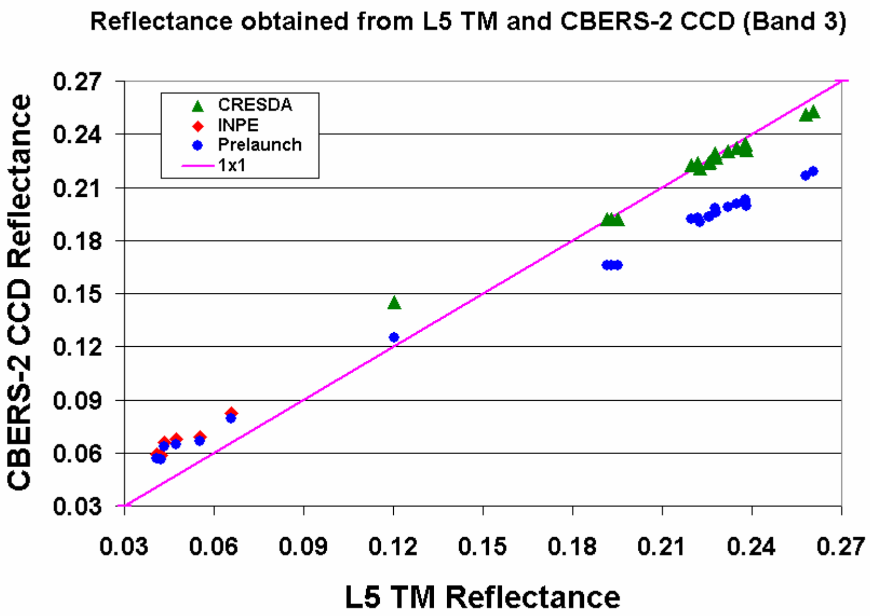


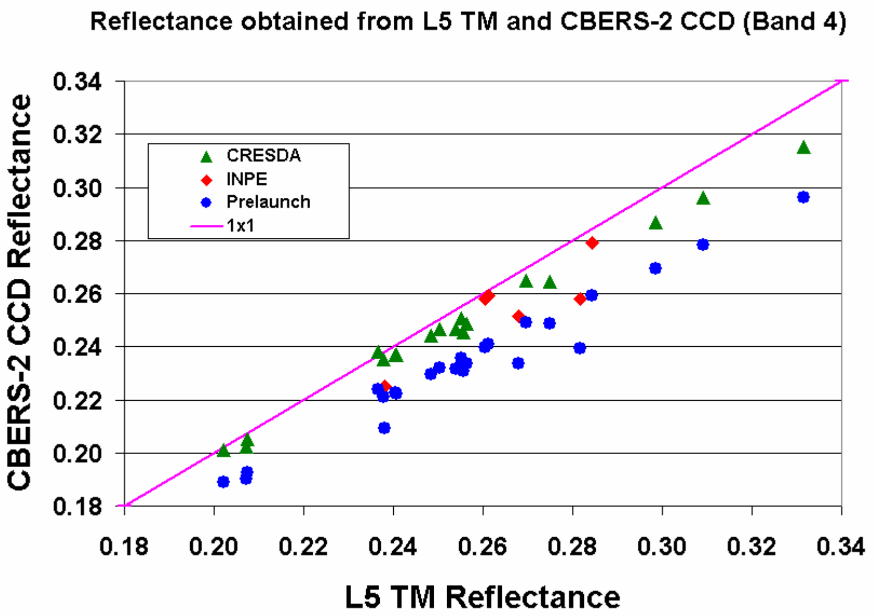


CBERS-2 CCD /L5 TM reflectance comparison









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

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

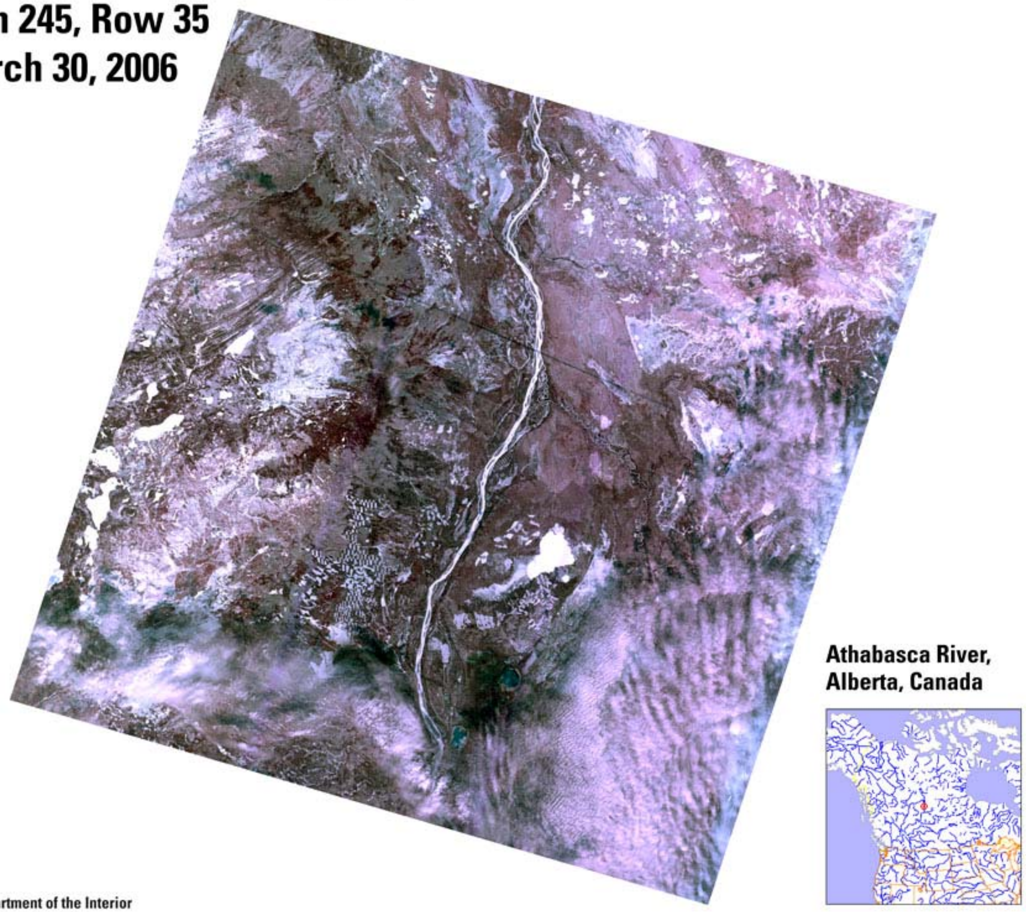
NASA/USGS technical group with Dr. Camara, the director of INPE, Brazil

USGS Deputy Director and NASA Program Executive with INPE Director

USGS
science for a changing world

First CBERS-2 imagery downlinked to USGS EROS

Path 245, Row 35
March 30, 2006



Athabasca River, Alberta, Canada

U.S. Department of the Interior
U.S. Geological Survey

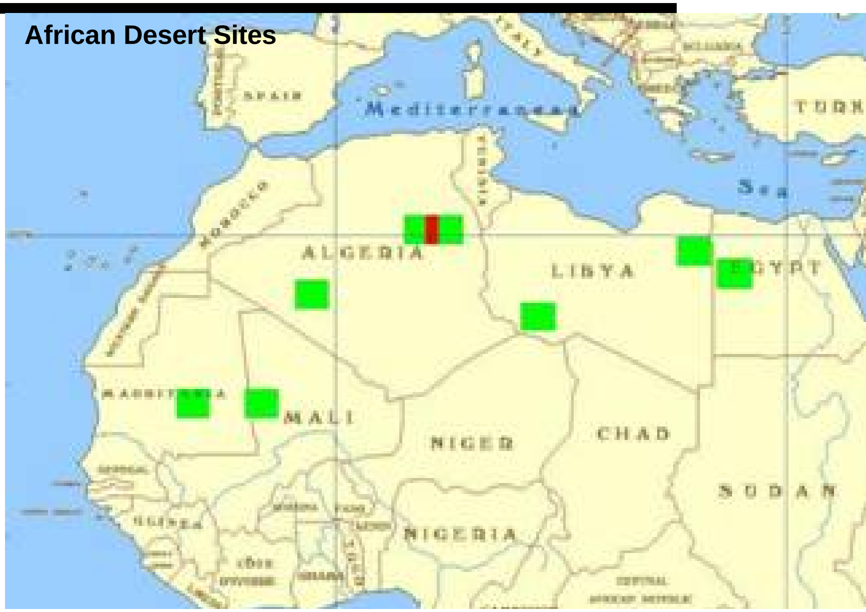
The first China-Brazil Earth Resources Satellite (CBERS-2) data downlink at USGS Center for EROS in support of the Landsat Data Gap Study

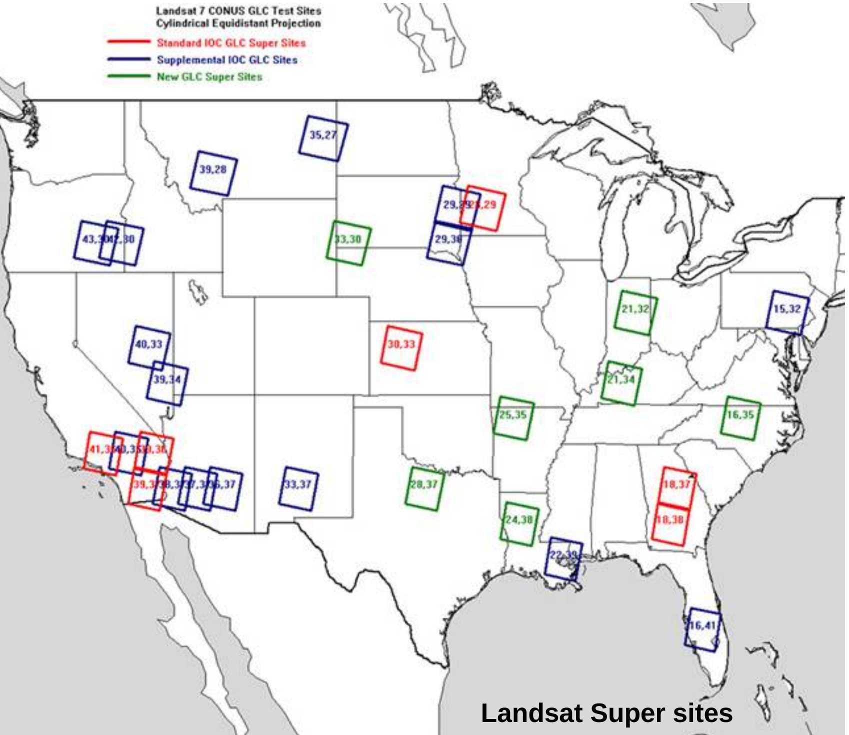
LDGST Summary

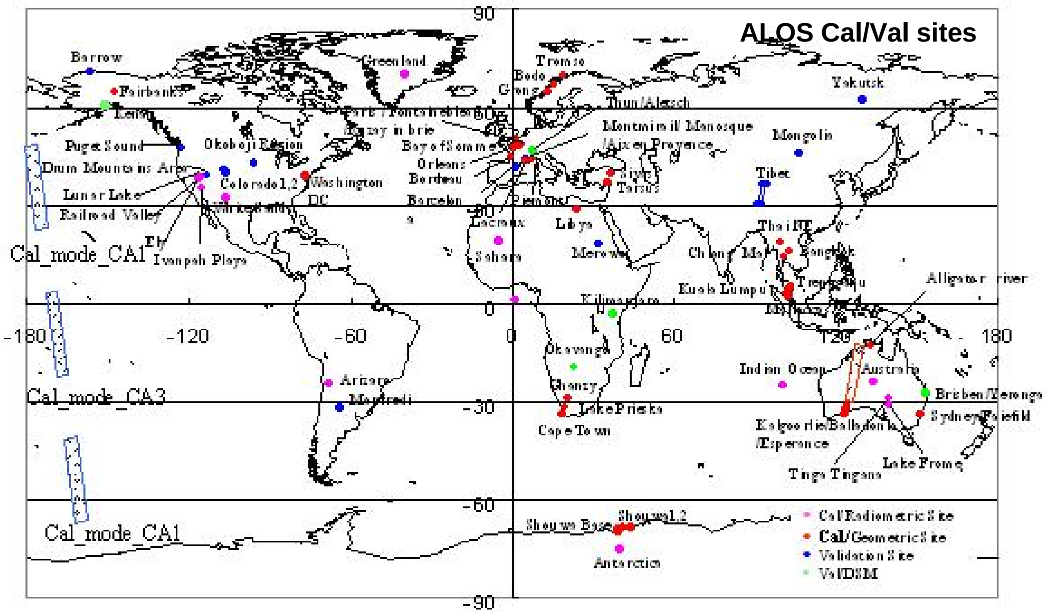
- **There is no substitute for Landsat**
  - Single source of systematic, global land observations
  - Alternate sources may <u>reduce the impact of a Landsat data gap</u>
- **We are characterizing multiple systems to understand which data sets may be compatible with the Landsat data record and can potentially supplement the Landsat data archive, <u>but no decisions have been made yet</u>**
- **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

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







On-going Cross-cal work at USGS

- **Cross-calibration of the L7 ETM+ and L5 TM sensor**
  - L7 ETM+/L5 TM and EO-1 ALI sensor
  - 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 Terra MODIS sensor
  - L5 TM and L4 TM sensor

USGS Recommendations

- **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**