

**Progress Report 2003:**  
**Landsat Radiometric Calibration: Towards a 20-Year Record of  
Calibrated Thematic Mapper Class Data for Carbon Cycle Studies**

**Principal Investigator: Brian Markham<sup>1</sup>,**

Landsat Calibration Scientist, Biospheric Sciences Branch – Code 923,  
Goddard Space Flight Center, Greenbelt, MD 20771  
Phone: 301-614-6608, FAX: 301-614-6695, EMAIL: [Brian.Markham@gsfc.nasa.gov](mailto:Brian.Markham@gsfc.nasa.gov)

**Co-Principal Investigator: Dr. John Barker<sup>1</sup>,**

Landsat Associate Project Scientist, Biospheric Sciences Branch – Code 923,  
Goddard Space Flight Center, Greenbelt, MD 20771  
Phone: 301-614-6610, FAX: 301-614-6695, EMAIL: [John.L.Barker@gsfc.nasa.gov](mailto:John.L.Barker@gsfc.nasa.gov)

**Co-Investigator: Dr. Dennis Helder**

Electrical Engineering Dept., South Dakota State University, Brookings, SD 57007  
Phone: 605-688-4994, FAX: 605-688-5880, EMAIL: [Dennis.Helder@sdstate.edu](mailto:Dennis.Helder@sdstate.edu)

**Co-Investigator: Frank Palluconi**

Jet Propulsion Laboratory, Mail Station 183-501,  
4800 Oak Grove Drive, Pasadena CA 91109  
Phone: 818-354-8362, FAX: 818-354-0966, EMAIL: [frank.d.palluconi@jpl.nasa.gov](mailto:frank.d.palluconi@jpl.nasa.gov)

**Co-Investigator: Dr. John Schott**

Center for Imaging Science, Rochester Institute of Technology,  
Rochester NY 14623  
Phone: 716-475-5170, FAX: 716-475-5988, EMAIL: [schott@cis.rit.edu](mailto:schott@cis.rit.edu)

**Co-Investigator: Dr. Kurt Thome**

Remote Sensing Group, University of Arizona, Tucson, AZ 85721  
Phone: 520-621-4535, FAX: 520-621-8292, EMAIL: [kurt.thome@opt-sci.arizona.edu](mailto:kurt.thome@opt-sci.arizona.edu)

**Co-Investigator: Pat Scaramuzza<sup>1</sup>**

Raytheon ITSS/EDC/SSB/IAS, EROS Data Center, Sioux Falls, SD 57198  
Phone 605-594-2647, FAX: 605-594-6529, EMAIL: [pscar@edcmail.cr.usgs.gov](mailto:pscar@edcmail.cr.usgs.gov)

**Co-Investigator: Dr. Philippe Teillet<sup>1</sup>**

Canada Centre for Remote Sensing, 588 Booth Street, Ottawa, Ontario K1A 0Y7 Canada  
Phone: 613-947-1251, FAX: 613-947-1385, EMAIL: [phil.teillet@ccrs.nrcan.gc.ca](mailto:phil.teillet@ccrs.nrcan.gc.ca)

---

<sup>1</sup> Participating, though not funded by this study

## ABSTRACT

Three types of activities are being conducted within this investigation: (1) maintaining the radiometric calibration of the Landsat-7 ETM+ sensor by incorporating redundant vicarious calibration efforts; (2) reconstructing the Landsat-4, 5 TM radiometric calibration records based on a combination of on-board, vicarious, and cross calibration with Landsat-7 methods and (3) improving the usability of the single band of Landsat TM/ETM+ thermal data by developing an atmospheric correction routine based on generally available atmospheric data. The Landsat-7 ETM+ calibration effort involves four vicarious calibration investigations: two for the reflective spectral bands of the ETM+ (by Helder and Thome), and two for the thermal band (by Palluconi and Schott). Each of these investigations predicts the radiance at the sensor aperture using a combination of ground- and/or aircraft-based reflectance, radiance or temperature measurements, coupled with measured and/or modeled atmospheric parameters. These results are then compared with the radiance predicted by the operational data processing system at the EROS Data Center (EDC). On-going investigations at NASA Goddard and EDC that are funded outside of this study will examine the behavior of the ETM+ instrument relative to its on-board calibration systems. These vicarious and on-board calibration results are brought together per the radiometric calibration plan for Landsat-7 to provide the updated calibration results for the operational Landsat-7 data processing system. For the reconstruction of the Landsat-4/5 TM radiometric calibration records, a subset of the proposed investigators are: (1) analyzing the radiometric calibration record of the Landsat-4/5 TM's relative to their internal calibrators; and (2) analyzing historical Landsat-4/5 TM data of ground targets for which there is correlative data, or for cases where the ground data can be well estimated. Additional investigations are refining the cross calibration of the Landsat-5 TM to the Landsat-7 ETM+ based on near simultaneous data sets that were acquired early in the life of Landsat-7. The overall objective of the study is to provide a definitive 20+ year (1982 to end of Landsat-7 mission life) calibration record for the TM class of instruments. The goal is to understand the calibration of the reflective bands to  $\pm 2\%$  for the Landsat-7 ETM+, and  $\pm 5\%$  for the earlier Landsat TM's. For the thermal band, band 6, the goal is to achieve an uncertainty of  $\pm 1\%$  for the Landsat-7 ETM+ instrument, and  $\pm 2\%$  for Landsat-5 TM.

### KEYWORDS:

Research Fields: Calibration; Product Validation

Geographic Area/Biome: Global

Remote Sensing: Landsat, VIS, Near-IR, SWIR, Thermal IR

Methods/Scales: In-situ data, Time Series Analysis

## QUESTIONS

- 1) This investigation best fits under question a) what are the changes in land cover and/or land use (monitoring/mapping activities). Although the investigation is not considering land use or land cover change, it is developing techniques and parameters by which a Landsat data set can be generated that is devoid of sensor degradation effects and therefore more readily useable for detecting land use/land cover changes.
- 2) Proportion of social science: 0%.
- 3) Proportion of themes: Calibration: 90%. Atmospheric Correction: 10%.

## GOALS

- (1) Maintaining the radiometric calibration of the Landsat-7 ETM+ sensor by incorporating redundant vicarious calibration efforts;
  - a. This year:
    - i. Conduct at least 6 vicarious calibrations of the reflective and thermal bands of the ETM+ with redundant calibrations during summer months.
    - ii. Conduct thermal band vicarious calibrations across a sufficient range of temperatures to decipher gain versus bias variations
    - iii. Conduct twice yearly calibration workshops to compare/integrate vicarious calibration results with on-board calibration measurements.
- (2) Reconstructing the Landsat-4, 5 TM radiometric calibration records based on a combination of on-board, vicarious, and cross calibration with Landsat-7 methods
  - a. This year
    - i. Support implementation of the revised Landsat-5 TM reflective band calibration recommendations
    - ii. Independently evaluate the trends in calibration based on “invariant” sites
    - iii. Evaluate the impact of the varying instrument temperature due to duty cycle variations on the L5 TM thermal band calibration
    - iv. Initiate evaluation of the L4 TM historical reflective band calibration
- (3) Improving the usability of the single band of Landsat TM/ETM+ thermal data by developing an atmospheric correction routine based on generally available atmospheric data.
  - a. This year
    - i. Provide users a thermal band atmospheric correction routine for recent Landsat-5 and Landsat-7 thermal band data
    - ii. Validate the performance of the atmospheric correction routine
- (4) Documenting the results of the calibration efforts in peer-reviewed journals.
  - a. This year
    - i. Initiate special journal issue on Landsat performance

## **TIMELINE**

### **Landsat-7 vicarious calibration (every year):**

U Arizona Reflective band: Vicarious Calibrations: Bimonthly to Quarterly (year round)

SDSU Reflective band calibrations: 2/year April-October

RIT Thermal band calibrations: once in May (thermal bar), 2 additional times per year

JPL/ 4/year Lake Tahoe; Hot sites – Salton Sea, etc 2/ year

**Next year:** Evaluate impact of SLC-off instrument temperature change on L7 ETM+ thermal band calibration

### **Landsat-5 calibration history reconstruction**

#### **This year:**

Assist EDC in implementation of calibration recommendations

Independently reevaluate trends in calibration based on “stable” uniform sites

Update formulation of equations as required.

New vicarious acquisitions about 2/year (thermal and reflective)

#### **Next year:**

Evaluate temperature sensitivity of thermal band calibration using a set of Lake Tahoe measurements across the maximum range of instrument temperatures

### **Landsat-4 TM calibration history reconstruction**

#### **This year:**

Review of data availability for historical analyses (vicarious, cross cal, etc)

Initiate internal calibrator record reconstruction

#### **Next year:**

Complete Landsat-4 TM internal calibrator analyses, cross calibration analyses and submission of recommendations to ground processing systems

### **Thermal Band Atmospheric Correction**

#### **This year:**

Implement operational web accessible thermal band atmospheric correction method for Landsat-5 TM and Landsat-7 ETM+ data accessing readily available atmospheric data

## ACCOMPLISHMENTS/GAPS/ISSUES

### **Landsat-7 vicarious calibration:**

Data for 9 large site (Railroad Valley, Ivanpah Playa) vicarious calibrations were successfully acquired; 8 dates have been reduced to provide ETM+ reflective band calibrations (see UAz report). Data for 2 Brookings, SD vicarious calibrations were successfully acquired; data to be reduced in future. SDSU acquisitions from 2002 have been processed. **Note:** SDSU has a new field data acquisition and atmospheric scientist, Dr. Dave Aaron, who has replaced Dr. Steve Schiller. Data for 7 RIT L7 ETM+ thermal band vicarious calibrations were acquired during the period; only the 2001 and 2002 data set has been processed to date. (see RIT report). Data for 6 JPL L7 ETM+ thermal band vicarious calibrations were acquired; data have been processed through 2002 date. **Note:** The data acquired but not processed are expected to be processed by the next twice-yearly calibration meeting, currently scheduled for December 2003. Landsat calibration workshops were held at UAz on 12/11 –12/12/ 2002 and at SDSU on 6/10-6/11/2003. All results showed continued stability of the ETM+ calibration, i.e., no discernible change in calibration since launch and continued calibration uncertainty at ~5% in the reflective bands and ~1% in the thermal band. Biases exist between the vicarious methods and the operational reflective band calibration and seem to vary with the ground calibration site being used. The impact of the Scan Line Corrector (SLC) failure, which results in lower operating temperature of the SLC, on the thermal band calibration, is yet to be assessed.

### **Landsat-5 calibration history reconstruction**

The team's recommendations on the Landsat-5 TM reflective band calibration history, resulting in part from this effort, were implemented by the USGS EROS Data Center ground processing system (NLAPS) in May 2003. This should greatly improve the accuracy and consistency of the L5 TM data. An independent verification of the lifetime L5 trends has been attempted using an "invariant" site approach. This produced results that are inconsistent with the implemented calibration for the late 1980's to early 1990's portion of the calibration history. Additional sites will be attempted using foreign ground station archives. This period in the lifetime of the instrument may be difficult to conclusively resolve as no vicarious calibration efforts were funded at the time. Analyses have been completed on the stability of the individual detector relative gains, i.e., their gains relative to the band average. An implementation of a lifetime relative gain history is being recommended to EDC to replace the scene-by-scene destripping that currently occurs in operational processing. An additional two Landsat-5 TM vicarious calibration acquisitions were performed by SDSU and 1 by UAz. Thermal band analyses for Landsat-5 TM have occurred in two areas; (1) additional Landsat-5 TM vicarious calibration data collections and (2) the identification and acquisition of historical data sets that can be used in conjunction with buoy or ship data to assess the historical Landsat-5 TM thermal band calibration

**Thermal Band Atmospheric Correction:**

Atmospheric correction for a single thermal band requires an understanding of the atmosphere through which the radiance passed and the capability to model the effects of that atmosphere. Too often, users do not have access to the tools or data they need to determine the atmospheric correction parameters. A web-interface tool has been developed to provide users with the atmospheric correction parameters for a specified date, location and time. The Atmospheric Correction Parameter Calculator makes use of modeled atmospheric profiles provided by the National Centers for Environmental Prediction (NCEP) known as "NCEP 6-hourly 1 degree GDAS Final Run meteorological data". Through a suite of tools, the appropriate atmospheric profile is retrieved from the archive, averaged in time and space for the specified point, and input into MODTRAN-4. MODTRAN-4 models the effects of the given atmosphere, outputting spectral transmission and upwelling and downwelling radiance (among other parameters). The transmission is averaged and the upwelling and downwelling radiances are integrated, both over the ETM+ bandpass. These three parameters are emailed to the user, along with all the data used to derive the parameters. The tool is available at [http://tightrope.gsfc.nasa.gov/atm\\_corr/atm\\_corr.html](http://tightrope.gsfc.nasa.gov/atm_corr/atm_corr.html). This same correction method is used by both RIT and JPL in their vicarious calibration work; JPL even uses the NCEP atmospheric profile for some cases. This technique has been shown to be capable of predicting surface brightness temperatures to within 0.5K.

**Documentation**

An arrangement has been made to document the results of the Landsat radiometric and geometric performance in a special issue of the IEEE Transactions On Geoscience and Remote Sensing. This issue is currently scheduled for December 2004.

## NARRATIVE

The second year of the study has been completed. The Landsat-7 vicarious calibrations contributed significantly to maintaining confidence in the Landsat-7 calibration. Landsat-7 ETM+ radiometric calibration continues to be stable and accurate within 5% in the reflective band and ~1% in the thermal band. The reconstruction of the Landsat-5 TM radiometric calibration record is complete; equations for calibrating data at any point since launch have been developed and revised processing has been implemented by EDC. Uncertainties remain in the mid-life calibration of the L5 TM, circa 1988 – 1993. Additional analyses next year will attempt to resolve these uncertainties. The L5 TM thermal band calibrations, though generally accurate to about  $\pm 2\%$ , show some dependency on instrument temperatures. Also, times have been identified where the thermal calibration of the Landsat-5 TM is off by 5% or more. This occurs when the ground processing software does not use the on board calibrator and applies a default gain of “1” and bias of “0”, resulting in uncalibrated data being distributed. These will be explored further in the third year. Additionally, vicarious calibrations will continue for both Landsat-5 and Landsat-7 instruments in the next year and the Landsat-4 TM reflective band calibration record will be finalized.

## MOST SIGNIFICANT RESULTS

- **Landsat-7 ETM+ radiometric calibration of data processed by EDC is accurate to 5% in the reflective bands and 1% in the thermal band.**
- **Algorithms have been implemented by EDC to improve the reflective band calibration of Landsat-5 TM data to be consistent with Landsat-7 ETM+ data with uncertainties in the 5-10% range.**

## CONCLUSIONS

- **Vicarious calibration results provided by this study continue to show accurate radiometric calibration of the Landsat-7 ETM+ data.**
- **Landsat-5 TM thermal data calibration has been shown to be generally accurate at about the 2% level with the current EDC processing system, which is significantly better than has been reported elsewhere. Some instrument temperature sensitivity is apparent and cases of failed calibration have been identified.**
- **A new radiometric calibration methodology for Landsat-5 TM data has been implemented by EDC.**

## PEER-REVIEWED PUBLICATIONS

1) Barsi, J.A., J.R. Schott, F.D. Palluconi, D.L. Helder, S.J. Hook, B.L. Markham, G. Chander and E.M. O'Donnell, Landsat TM and ETM+ thermal band calibration, Canadian Journal of Remote Sensing, 29: 141-153, 2003.

2) Chander, G. and B. L. Markham, Revised Landsat 5 TM radiometric calibration procedures and post-calibration dynamic ranges, IEEE Trans. on Geoscience and Remote Sensing, Letters, in press

3) Thome, K.J., Biggar, S.F., W. T. Wisniewski, Cross-comparison of EO-1 sensors and other Earth Resources Sensors to Landsat-7 ETM+ Using Railroad Valley Playa, IEEE Trans. On Geoscience and Remote Sensing, 41: 1180-1188, 2003.

4) Biggar, S.F., Thome, K. J., and W. T. Wisniewski, Vicarious radiometric calibration of EO-1 sensors by reference to high-reflectance ground targets, IEEE Trans. On Geoscience and Remote Sensing, 41: 1174-1179, 2003.

5) Bryant, R., Moran, M. S., McElroy, S. A., Holifield, C. D., Thome, K. J., Miura, T. and S. F. Biggar, Data continuity of Earth Observing 1 (EO-1) Advanced Land Imager (ALI) and Landsat TM and ETM+, IEEE Trans. On Geoscience and Remote Sensing, 41: 1204-1213, 2003.