

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

Principal Investigator: Brian Markham,

Landsat Calibration Scientist¹, 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

Co-Principal Investigator: Dr. John Barker,

Landsat Associate Project Scientist¹, 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

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

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

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

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

Co-Investigator: Pat Scaramuzza¹

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

Co-Investigator: Dr. Philippe Teillet¹

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

¹ 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. Complete reconstruction of Landsat-5 TM radiometric calibration history
 1. Reflective bands
 2. Thermal band
 - ii. Provide recommendations to ground processing systems
- (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. Develop prototype atmospheric correction methodology for Landsat-5/7 TM/ETM+ data based on NCEP atmospheric profiles and the MODTRAN-4 atmospheric model.

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

Landsat-5 calibration history reconstruction

This year:

Reflective bands:

1. Complete merged internal calibrator, vicarious, cross calibration analyses
2. New vicarious acquisitions about 2/year

Thermal band:

1. Reexamination of historical thermal band calibration data
2. Perform wintertime Great Lakes scenes analyses
3. Perform recent Lake Tahoe analyses (circa 2/year)

Submission of Recommendations to ground processing systems

Next 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 (both thermal and reflective)

Landsat-4 TM calibration history reconstruction

This year:

None

Next year:

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

Completion of internal calibrator record reconstruction

Submission of recommendations to ground processing systems

Thermal Band Atmospheric Correction

This year:

Develop prototype atmospheric correction methodology for Landsat-5 TM and Landsat-7 ETM+ data based on NCEP atmospheric profiles and the MODTRAN-4 atmospheric model

Next 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 6 large site (Railroad Valley, Ivanpah Playa) vicarious calibrations were successfully acquired; 4 dates have been reduced to provide ETM+ reflective band calibrations (see UAz report). Data for 3 Brookings, SD vicarious calibrations were successfully acquired; data to be reduced in future as required: **Note:** The SDSU effort has been refocused on completing Landsat-5 historical record, particularly the outgassing correction, as this has been their historical strength. Also, their primary atmospheric simulation expert, Dr. Steve Schiller, has left the program. UAz has been assisting SDSU in processing recent vicarious data collects. Data for 4 RIT L7 ETM+ thermal band vicarious calibrations were acquired during the period; only the 2001 data set has been processed to date. (see RIT report). Data for 7 JPL L7 ETM+ thermal band vicarious calibrations were acquired; data have been processed through 2001 date (see JPL report). **Note:** The data acquired but not processed are expected to be processed by the next twice-yearly calibration meeting, currently scheduled for December 2002. Landsat calibration workshops were held at GSFC on 11/14-11/15 2001 and at RIT on 5/29-5/30/2002. 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.

Landsat-5 calibration history reconstruction

Many of the reflective band analyses were performed prior to initiation of this study. This included the band average calibration history presented as a time dependent equation. On going studies during this period primarily emphasized the outgassing correction for the Short Wave Infrared bands (5 and 7) on TM (see Helder report for details). A formulation is now present that allows determination of the band average gain at any point since launch for any of the reflective bands. Thermal band analyses for Landsat-5 TM have occurred in three areas; (1) reexamination of the thermal band data acquired during the tandem Landsat-5 and Landsat-7 period during June 1-3, 1999, (2) analysis of a number of wintertime great lakes imagery with water temperatures near 0° C and (3) vicarious calibration of recent Landsat-5 TM data using the Lake Tahoe buoy/raft datasets. The combined results show that the data currently operationally processed at EDC using the NLAPS software provides data calibrated to within about 1° C. This is encouraging given historic reports of discrepancies of up to 8° C in Landsat-5 TM retrieved temperatures. Data processed in 1987 as part of the FIFE experiment showed TM temperatures off by about 8° C; these same data processed with the current NLAPS system show the data to be within about 1° C. Several analyses continue on Landsat-5 TM data to document the relative detector-to-detector variations in gain over time in the reflective and thermal channels and to reexamine the formulation of the gain equations as some bands appear to have a continuing degradation not adequately captured by the equations. The current recommendations for historical calibration of Landsat-5 TM data have been presented to EDC. Implementing the recommendations involves a significant change to the processing system; costs are being determined.

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 is in development 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 a distribution 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 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. The prototype for this suite of tools has been developed, though it has not been tested in this form. 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.

NARRATIVE

The first 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 nearly complete; equations for calibrating data at any point since launch have been developed. Recommendations on implementation of this calibration have been presented to EDC. A prototype thermal band atmospheric correction method has been developed. In the second year vicarious calibrations will continue for Landsat-7 ETM+ and Landsat-5 TM, refinements to the Landsat-5 calibration equations will be evaluated and the Landsat-4 TM calibration record will be analyzed. The atmospheric correction methodology will be made generally available to Landsat data users via a web interface.

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.**
- **Landsat-5 TM data as currently processed by the NLAPS system at EDC has uncertainties up to 15-20 %range in the reflective and about 2% in the thermal band.**
- **Algorithms have been provided to 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 accurate at about the 2% level with the current EDC processing system, which is significantly better than has been reported elsewhere**
- **A new radiometric calibration methodology for Landsat-5 TM data has been developed and presented to EDC.**

PEER-REVIEWED PUBLICATIONS

J. A. Barsi, J. R. Schott, F. D. Palluconi, D. L. Helder, S.J. Hook, B. L. Markham, G. Chander, E. M. O'Donnell, "Landsat TM and ETM+ Thermal Band Calibration", Canadian Journal of Remote Sensing, in press.