Revised Landsat-5 Thematic Mapper Radiometric Calibration

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***Abstract*—Effective April 2, 2007, the radiometric calibration of Landsat-5 (L5) Thematic Mapper (TM) data that are processed and distributed by the U.S. Geological Survey (USGS) Center for Earth Resources Observation and Science (EROS) will be updated. The lifetime gain model that was implemented on May 5, 2003, for the reflective bands (1–5, 7) will be replaced by a new lifetime radiometric-calibration curve that is derived from the instrument's response to pseudoinvariant desert sites and from cross calibration with the Landsat-7 (L7) Enhanced TM Plus (ETM+). Although this calibration update applies to all archived and future L5 TM data, the principal improvements in the calibration are for the data acquired during the first eight years of the mission (1984–1991), where the changes in the instrument-gain values are as much as 15%. The radiometric scaling coefficients for bands 1 and 2 for approximately the first eight years of the mission have also been changed. Users will need to apply these new coefficients to convert the calibrated data product digital numbers to radiance. The scaling coefficients for the other bands have not changed.**

***Index Terms*—Bias, calibration, characterization, gain, Landsat-5 (L5), Libya, lookup table (LUT), National Land Archive Production System (NLAPS), offset, radiance, reflectance, relative spectral response (RSR), spectral bands, Thematic Mapper (TM).**

I. Introduction

LANDSAT-5 (L5) was launched on March 1, 1984, with the Thematic Mapper (TM) Earth-imaging sensor onboard. The satellite and sensor continue to operate today, after more than 23 years of service. The TM has seven spectral bands: six 30-m reflective bands and one 120-m thermal band. TM bands have center wavelengths of approximately 0.49, 0.56, 0.66, 0.83, 1.67, 11.5, and 2.24 μm, respectively. The raw and calibrated data products are quantized to eight bits.

The TM incorporates an internal calibrator (IC) with lamps for the reflective bands, a blackbody source for the thermal band, and a temperature-monitored shutter for all the bands. The IC is located behind the primary instrument telescope. The calibrator is synchronized with the scan mirror such that the detectors view the calibration sources during each scan mirror turnaround (when no scene data are being taken).

The operations of the satellite and its ground processing system have evolved over the years [1]. The U.S. Geological Survey (USGS) has operated L5 since 2001 and currently processes TM data through the National Land Archive Production System (NLAPS). Most users order the fully processed (Level 1G) data products, to which both radiometric and geometric corrections have been applied. An exponential-decay model was implemented in 2003 [2] to represent the radiometric response or gain of each reflective band as a function of time since launch. The exponential model and coefficients are used to generate a day-specific band-average lookup table (LUT) [3] of detector gains for use in processing. After the application of the LUT gains, the data are rescaled to a fixed radiance range (referred to as the postcalibration dynamic range) represented by LMIN (radiance corresponding to "zero" DN) and LMAX (radiance corresponding to "255" DN). The thermal-band gain is calculated based on the responses to the IC shutter and blackbody, and image data are similarly rescaled to a fixed radiance range. Note that the Landsat-7 (L7) Enhanced TM Plus (ETM+) products are scaled to an LMIN value of "one" DN, and the "zero" DN is reserved for the fill data.

II. Radiometric Calibration Procedure

Data continuity requires consistency in the interpretation of image data acquired by different sensors. Calculation of radiance is the fundamental step in putting data from multiple sensors and platforms onto a common radiometric scale. The following is a partial list of variables used for radiometric calibration.

Q	Raw quantized voltage or response [DN].
G	Detector gain or reponsivity $[\mathrm{DN}/(\mathrm{W}/(\mathrm{m}^2 \cdot \mathrm{sr} \cdot \mu\mathrm{m})]$.
B	Detector bias or background response [DN].
L_λ	Spectral radiance at the sensor's aperture $[\mathrm{W}/(\mathrm{m}^2 \cdot \mathrm{sr} \cdot \mu\mathrm{m})]$.
Q_{cal}	Quantized calibrated pixel value [DN].
$Q_{\mathrm{cal\,min}}$	Minimum quantized calibrated pixel value $(\mathrm{DN} = 0)$ corresponding to LMIN_λ.
$Q_{\mathrm{cal\,max}}$	Maximum quantized calibrated pixel value $(\mathrm{DN} = 255)$ corresponding to LMAX_λ.
LMIN_λ	Spectral radiance that is scaled to $Q_{\mathrm{cal\,min}}$ $[\mathrm{W}/(\mathrm{m}^2 \cdot \mathrm{sr} \cdot \mu\mathrm{m})]$.
LMAX_λ	Spectral radiance that is scaled to $Q_{\mathrm{cal\,max}}$ $[\mathrm{W}/(\mathrm{m}^2 \cdot \mathrm{sr} \cdot \mu\mathrm{m})]$.

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G_{rescale} Band-specific rescaling gain factor $[(\text{W}/(\text{m}^2 \cdot \text{sr} \cdot \mu\text{m}))/\text{DN}]$.

B_{rescale} Band-specific rescaling bias factor $[\text{W}/(\text{m}^2 \cdot \text{sr} \cdot \mu\text{m})]$.

A. Conversion to Radiance for L0Rp Products (Q-to- L_λ)

The pixel values in the raw data products (L0Rp) are represented as Q. The detectors exhibit linear response to the Earth's surface radiance. The response is quantized into 8-bit numbers that represent brightness values between 0 and 255 in the L0Rp. Instrument gains (G) and biases (B) are used to convert the raw data (Q) to at-sensor spectral radiance (L_λ). This process is given by the relationships

$$Q = G \times L_\lambda + B$$
$$L_\lambda = \frac{(Q - B)}{G}.$$

The G's are the band-average time-dependent gain coefficients generated from the lifetime gain models and stored in the LUT. The B's are the line-by-line biases that are based on the dark shutter responses acquired from each scan line. During processing, the band-average LUT gains are combined with the detector relative gains and the band rescaling gains to obtain a detector specific processing gain. Note that the G and B are only to be used on the L0Rp.

B. Conversion to Radiance for L1 Products (Q_{cal}-to- L_λ)

The pixel values in the Level 1 (L1) data are represented as Q_{cal}. During the radiometric calibration, pixel values (Q) from L0Rp image data are converted to units of absolute radiance using 32-bit floating-point calculations. The absolute-radiance values are then scaled to 8-bit values representing the calibrated digital numbers (Q_{cal}) before output to the distribution media. Conversion from Q_{cal} in L1 products back to L_λ requires knowledge of the original rescaling factors. This process is given by the following relationship:

$$L_\lambda = \left(\frac{\text{LMAX}_\lambda - \text{LMIN}_\lambda}{Q_{\text{cal max}} - Q_{\text{cal min}}}\right)(Q_{\text{cal}} - Q_{\text{cal min}}) + \text{LMIN}_\lambda$$

or

$$L_\lambda = \left(\frac{\text{LMAX}_\lambda - \text{LMIN}_\lambda}{255}\right) Q_{\text{cal}} + \text{LMIN}_\lambda$$

where

$$Q_{\text{cal max}} = 255$$
$$Q_{\text{cal min}} = 0$$

or

$$L_\lambda = G_{\text{rescale}} \times Q_{\text{cal}} + B_{\text{rescale}}$$

TABLE I
THIS MODEL IS USED IN LUT FORM (LUT07) TO REPRESENT THE BAND-AVERAGE GAIN OF THE TM BANDS. COEFFICIENTS a_0 AND a_2 ARE IN UNITS OF $\text{DN}/(\text{W}/\text{m}^2 \cdot \text{sr} \cdot \mu\text{m})$ AND THE a_1 COEFFICIENTS ARE 1/YEAR

L5 TM gain model fitting coefficients (LUT07)			
Band	**a_0**	**a_1**	**a_2**
1	0.2901	0.1399	1.209
2	0.1246	0.1045	0.6305
3	0.0839	0.2386	0.9028
4	0	0	1.082
5	0	0	8.209
7	0	0	14.695

where

$$G_{\text{rescale}} = \frac{\text{LMAX}_\lambda - \text{LMIN}_\lambda}{255}$$
$$B_{\text{rescale}} = \text{LMIN}_\lambda.$$

The LUT gains are used for converting the Q in the L0Rp to spectral radiance, while the rescaling gains (G_{rescale}) are used to convert the Q_{cal} in the L1 data to spectral radiance. The conversion from Q to Q_{cal} is performed during the L1-product generation; accordingly, users with L1 data do not apply the LUT gains for conversion to radiance.

V. CONCLUSION

An improved lifetime gain model, based on the instrument's detector response to pseudoinvariant desert-site data and cross calibration with the L7 ETM+, has been implemented for the absolute radiometric calibration of the L5 TM solar reflective bands. The modification in the calibration procedure has been implemented in NLAPS for all of the L5 TM products processed at the USGS EROS after April 2, 2007. This change will improve absolute calibration accuracy of data acquired during the early mission of the L5 TM sensor. The new lifetime gain model for the reflective bands (1–5, 7) is based on a lifetime radiometric-calibration curve that is derived from the instrument's response to desert sites and cross calibration with the ETM+. In this calibration update, only the LMAXs and the corresponding G_{rescale} values for bands 1 and 2 for approximately the first eight years of the mission have been changed. Users will need to apply new postcalibration dynamic ranges (G_{rescale} and B_{rescale}) to convert the newly processed calibrated data products to radiance. All data for the other bands and data for bands 1 and 2 from January 1, 1992, onward will continue to be scaled to the same LMINs and LMAXs as before. The revised postcalibration dynamic ranges are only applicable to the data processed after April 2, 2007, with the updated lifetime gain model (LUT07). The new LMAXs should not be applied to the data processed using IC gains. L4 TM sensor calibration will continue to use the postcalibration dynamic ranges as previously defined.