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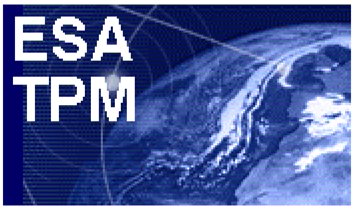

LANDSAT PRODUCT RADIOMETRIC CALIBRATION

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Purpose of this document

This document aims at explaining to end-users radiometric calibration procedures currently used for processing of ESA TM/ETM+ data before dissemination.
After more than 20 years of service, the L5 TM continues to operate well. Nevertheless, the instrument has aged, its characteristics have changed and actual ESA calibration procedure does not take into account such evolutions. To overcome this issue, following proposition from USGS, ESA is planning to make new calibration procedures on board ground segment.
This document is dedicated to explain basic concept of this new calibration procedure and give some references to go further.
Last section details procedure for an offline product recalibration. In doing so, user will be able to improve himself the absolute radiometric accuracy of its product.

Radiometry processing - current configuration

The section is an update of the [RD-1] document part dealing with "radiometry processing".
ESA/TM processing software includes the both following types of calibration: pre-flight calibration and in-flight calibration (for all channels except channel 6).
This section aims at shortly describing procedure for a pre-flight and in-flight calibration of products for better exposing at the end the operational configuration of TM/ETM+ ESA chain.

In-flight calibration

In-flight calibration is a procedure to compute absolute gains. This method is based on data results from the Internal Calibration (IC) system, which is part of the instrument. It enables a monitoring of the sensor's degradation and allowing an adjustment of the calibration parameters. The procedure is based on regression of lamps responses against the measured radiances for all eight-lamp states; ([000], [001], [010], [100], [011], [101], [111])

Figure here below depicts the detector responses to following events:

- Image data ending
- Shutter data obscuration – Dark current
- Shutter flag – Calibration pulse

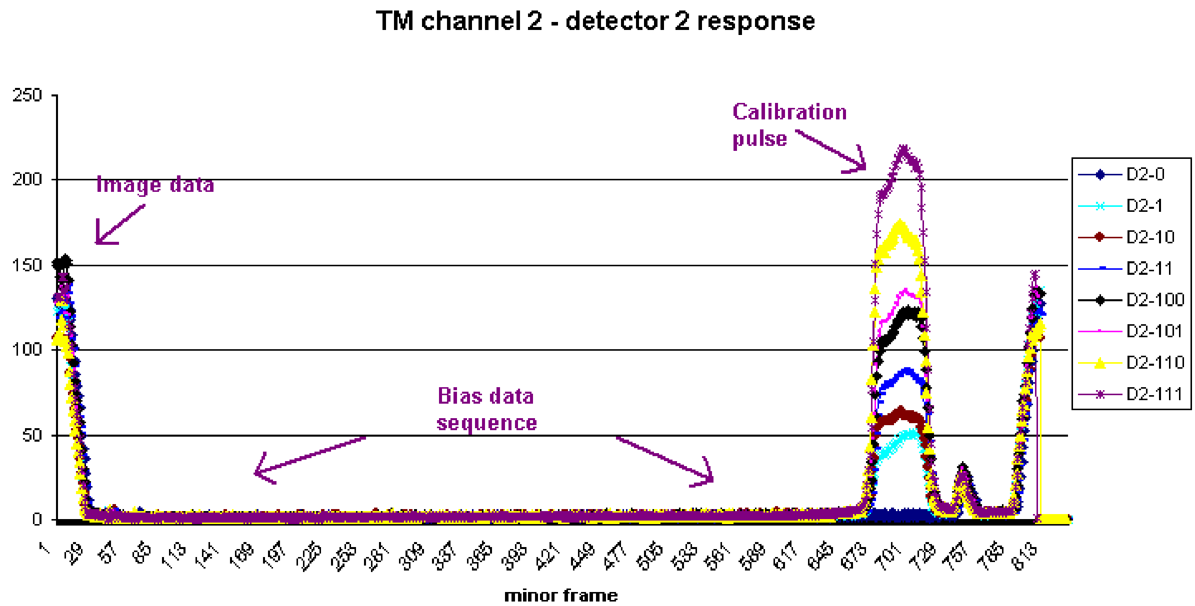

fig. 1 - Example of forward calibration data, one plot for one lamp state.

Because of change in lamp characteristics, in-flight calibration procedure is not operational any more. Accordingly, the whole of TM products, acquired since launch, are generated following a pre-flight calibration procedure.

Pre-flight calibration

ESA TM/ETM+ sys-corrected products are currently calibrated according to a pre-flight method; pre-launch instrument detector gains, stored on the form of look up tables, are used for the mapping of raw detector count into calibrated count.

Detector bias estimate

Detector bias ($Bias$) is computed by averaging 500 values belonging to the bias data sequence (depicted in fig. 1). Detector bias is expressed in count.

For a given scan mirror direction, bias data and calibration pulse data sequences of one detector response are stored into the CEOS calibration file data record. Imagery and calibration file data records may be matched on basis of the time code value.

Detector dark current data or bias data sequence belongs to the shutter region. This latter occurs during the calibration phase (obscuration of focal plane by a shutter flag) before or after the calibration pulse according to scan mirror direction (respectively forward or reverse). Dark current is not affected by calibration lamp sensitivity loss; this is the reason why it can be used as absolute reference point.

One can note that detectors bias estimate inherits from methods used for in-flight calibration procedure.

Detector gain

Detector gain is a pre-flight one, and comes from look up tables hard stored inside a fixed Calibration Parameter File (CPF).

An example of the CPF part dealing with detector gain to be applied on band 2 is illustrated just here after:

```
GROUP = DETECTOR_GAINS
GROUP = DETECTOR_GAINS_LOW
    ………..
    B2L_Prelaunch(96.0744,95.7134,95.6122,95.6488,95.7841,95.3500,95.5780,96.5793,95.2780,96.0402,
    96.2585,96.6037,96.0341,95.6476,96.4902,94.8695)
………
END_GROUP = DETECTOR_GAINS_LOW
END_GROUP = DETECTOR_GAINS
```

Pre-flight detector gain values are listed in document [RD-2] (table C-7a) and are expressed in : Counts per mW/(cm².str) unit.

Spectral detector gain per band is computed multiplying detector gain by corresponding bandwidth (expressed in micrometers units) and dividing by 10. Detector gain ($Gain$) or detector response value is then expressed in Counts per W/(m².str.µm) unit.

Calibration procedure steps

This part details radiometry processing steps from raw detector count until calibrated digital number and correspondence with radiance value.

Through detector bias estimate and implementation of a line-by-line subtraction, TM/ETM+ processor performed a scan correlated shift correction.

The mapping of raw detector count into calibrated count, involved implementation of a detector equalization method. Because, dynamic ranges and response differs significantly among the detector and in order to reduce these differences, all detectors of all bands are equalized for a given calibrated count.

So that, all counts is referring to a same radiance. Detector equalization procedure is performed through the use of detector LUT (CPF)..

Conversion from raw uncalibrated detector count to calibrated count is applied for the sixteen detectors of reflective bands and is proceed according to following steps:

- Detector bias estimated on line by line bias,
- Conversion of raw detector count coded onto 8 bytes (0,255) into at sensor radiance value, $L*$ expressed in W/(m².str.µm).unit;

$$L* = (Q_{raw} - Bias)/Gain \quad \text{(eq 1)}$$

- Conversion of radiance value into calibrated count;

$$Q_{cal} = L* \frac{Q_{max} - Q_{min}}{L_{max} - L_{min}} - L_{min} * \frac{Q_{max} - Q_{min}}{L_{max} - L_{min}},$$

$Q_{min} = 0$, $Q_{max} = 255$, respectively minimum and maximum calibrated count.

L_{min}, L_{max} are minimum and maximum spectral radiance band limit, expressed in W/(m².str.µm).unit;

$$Q_{cal} = L * \frac{255}{L_{max} - L_{min}} - L_{min} * \frac{255}{L_{max} - L_{min}} \quad \text{(eq 2)}$$

Using (1) and (2), un-calibrated detector count can be converted into calibrated count (Q_{cal}), and value is now independent from the detector.
From calibrated products, in order to convert calibrated count to at sensor radiance value, the bands specific rescaling factor $G_{resc} = \frac{L_{max} - L_{min}}{255}$ bias $B_{resc} = L_{min}$ are used (eq 3).
These values (G_{resc}, B_{resc}) are usually embedded within product format and expressed in W/(m².str.µm)/Count unit;

- in radiometric ancillary record of leader file for CEOS format,
- in the header file for FAST, GeoTiff formats.

Status

Initially, CPF was designed for ETM+, since Landsat 7 launch, an update version of CPF is issued on monthly basis and used as input of the processing chain.
Due to TM instrument aging, nominal sensor degradation is causing a lost of the product radiometric accuracy. Accordingly; product calibration method consisting in using pre-flight procedure is not reliable anymore; old calibration gains cannot be used anymore for computing calibrated count.
To overcome detector degradation issue, solution relies on the use of a detector gain computed on basis of a lifetime gain model [RD-3]. The detector gain should be stored in the monthly CPF.
Next section is focusing on basis procedure for calibration based on lifetime Look Up Table.

Improvements: Towards a definitive L5 TM Calibration

USGS will release the L5 TM CPF by mid-2006 and a format document is now available [RD-4].
However, the ESA Landsat processor shall be tested in order to evaluate the change needed to incorporate this new CPF.
If the result of the validation is positive, product calibrated using the lifetime LUT will be disseminated to end-user.
Purpose of this section is two folds; to shortly explain how new calibration procedure (LUT calibration method) works on processor side and to present to user community the USGS standard formula for offline product correction.
Because TM/ETM+ processing chain will be updated next Year (2007), in the mean time, offline recalibration is is less efficient but remains well suited for improving calibration accuracy of about 10 %.

LUT calibration method

This method requires as input an absolute gain value, strongly related to the spectral band, and a set of relative gains that are related to detectors belong to this band.

Absolute gain model

Absolute gain values (G_{LUT}) are band average gains and are derived from a lifetime gain model. As pre-flight gain values, absolute gain values are expressed in Counts per W/(m².str.µm) unit.

Relative gain model

Relative gain values (G_{rel}) are derived from a lifetime gain model. For one detector of one reflective band is attributed a relative gain value. The unit of relative gain is 1 and $G_{rel} = A_1.t + A_2$ with A_1, A_2 coefficients provided in [RD-5]. Detector gain (absolute) value is getting multiplying absolute band average gain by detector relative gain.

LUT calibration steps

As for pre-flight calibration; objective is to convert uncalibrated detector raw count into calibrated count. This approach differs significantly from the last one because:

- It uses values derived from lifetime model, so that, relative calibration process occurs conjointly with absolute calibration,
- No conversion to at sensor radiance is performed,

LUT calibration procedures and formulas used are detailed just hereafter.
For demonstration purpose, let us remind formula for getting at sensor radiance value either from uncalibrated raw detector count (Q_{raw}) (eq 1) and fromcalibrated count (Q_{cal}) (4) using rescaling factors (3)

$L^*=(Q_{raw}-Bias)/Gain$ (eq 1)

$L^*=Q_{cal}.G_{res}+B_{resc}$ (eq 4)

Equality between (eq 1) and (eq 4) gives:

$$Q_{cal}.G_{res}+B_{resc}=(Q_{raw}-Bias)/Gain$$

Formula for computing Q_{cal} from Q_{raw} is the following one:

$Q_{cal}=(Q_{raw}-b)/a$ where $a=Gain.G_{resc}$ and $b=Bias+Gain.B_{resc}$

$a=G_{rel}.G_{LUT}.G_{resc}$ and $b=Bias+G_{rel}.G_{LUT}.B_{resc}$

The chart just here after (fig. 2) illustrates L5 TM calibration procedures. Relative and absolute calibration procedures are explained.

This method should be implemented on processor side. It cannot be applied on TM level 1 product already disseminated. Hereafter, the method for an offline recalibration of level 1 product is highlighted.

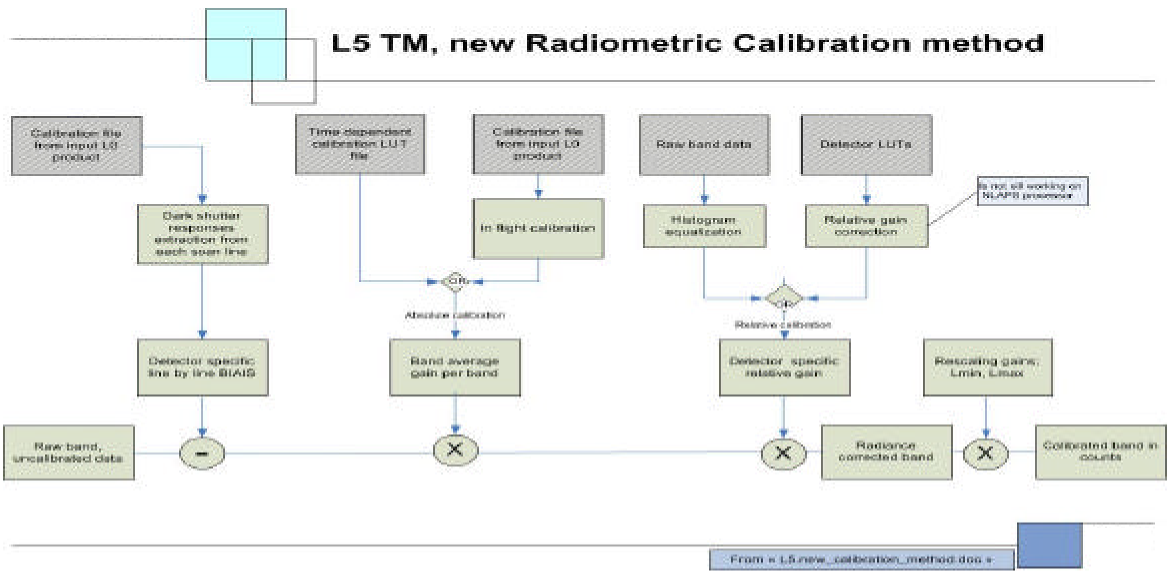

fig. 2 - Calibration procedure summary for TM reflective bands.

Product recalibration procedure

Recalibration procedure shall be applied to level 1 products (Sys corrected or geo referenced).

Lifetime model

Firstly, for the offline recalibration end-user has to compute lifetime gain (eq 5), which depends on the time since launch (in decimal years) and on spectral bands parameters such as listed in (table 1). Method is explained in [RD-6], hereafter we propose a summary of the method adapted to ESA products.

$$G_{LUT.} = a_0 \exp(-a_1(t - t_0)) + a_2 \quad \text{(eq 5)}$$

where,
t time in decimal years, *where,*
t time in decimal years
(for instance for a scene of 13/09/2004, DOY =255, then t= 2004 + DOY/365, t=2004.6986)
t0 = 1984,21; represents "time zero", the acquisition date of the first calibration pulse data measurements.
a0 and **a2** spectral bands coefficients in W/(m².st.µm) unit
a1 is dimensionless

band	a0	a1	a2
1	0.1457	0.9551	1.243
2	0.05865	0.8360	0.6561
3	0.1119	1.002	0.9050
4	0.1077	1.277	1.0820
5	0.2630	1.093	8.209
6	0.5027	0.9795	14.7

table 1 – Coefficients for computing lifetime gain model.

Table 2 lists the pre-launch band gain ($Gain_{band}$) for each TM spectral band. Pre-launch band gain is computed in averaging on detector gains ($Gain$) belonging to the corresponding spectral band.

band	Pre-launch Gain
1	1,555
2	0,786
3	1,02
4	1,082
5	7,875
6	14,77

table 2 -Pre-launch Gain

LUT gain and pre-launch band gains are used for computing the rescaled gain: $G_{res\_lut} = \dfrac{Gain_{band}}{G_{LUT.}}$

Conversion of calibrated count to radiance value

Calibrated count (Q_{cal}) or product band pixel value need to be converted into radiance value using old rescaling gain (G_{res_old}) and offset coefficients (B_{resc}) embedded within product format.

$$L^* = Q_{cal} . G_{res\_old} + B_{resc}$$

Computation of corrected radiance value

The re-calibrated radiance $L_{new}*$ is computed as follow:

$$L_{new}* = L \ * G_{res\_lut}$$

Conclusions

USGS results let us think that LUT calibration method applied to ESA processing chain will improved significantly radiometric calibration accuracy of product.
This document has clarified radiometry calibration methods routinely used for processing of ESA TM/ETM+ products. It highlights the new calibration procedure, which is a part of ESA plans for improvement of TM product quality.
However, subsequent works are now required for validating and implementing the method on our side. Processor update will more likely occur for next Year (2007).
In the mean time, before new method is operational, document is proposing a USGS method, for making user able to re-calibrate level1 product. In doing so, the improvement of radiometric accuracy using this method is significant but remains less efficient than if a new calibration procedure was implemented on the processor.

Acknowledgment

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Reference

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