Landsat 5 TM Level 1 Product - Radiometry Status

This document summarizes the radiometric differences that users of Landsat 5 Thematic Mapper imagery may observe over time for radiometrically corrected scenes (Level-1) generated by the NLAPS processing system. A brief discussion is provided on the origin of these potential differences, along with a partial listing by band of these differences at various times.

Landsat-5 TM Sensor

In general, the TM instrument has demonstrated very good radiometric stability throughout its operating life. Vicarious calibration measurements acquired throughout the instrument's lifetime have demonstrated stable detector response with respect to detector gain. The internal calibrator lamps, however, have been observed to significantly increase in brightness over time, and this becomes especially apparent after ~1988.

Landsat-5 TM Level-1 Processing system

The Landsat 5 TM was radiometrically calibrated prior to launch, and processing algorithms were developed that estimated detector gain based on the internal calibration lamp response. The procedure involved regression of lamp response against the pre-launch measured radiances for all eight lamp states.

NLAPS, the current Landsat 5 ground processing system, uses the same algorithms to obtain detector gain. This procedure no longer produces the desired calibration; the result is a short-term variation in the apparent gain of the instrument (resulting in radiometric differences in Level-1 products) as summarized in the table below from 1984 to 2002. However, between 2000 and 2002 additional problems have been observed, the first of which involves NLAPS using the pre-launch default database coefficients to perform radiometric calibration. Secondly, the pulse extraction window including the corrupted pulses ('light leaks') appears to have introduced additional uncertainties into the sensor gain estimates.

Quantitative and qualitative analysis were done with the lifetime gain model to obtain the percentage difference in radiance between the Level 1 NLAPS estimate and an estimate obtained from the raw data using a lifetime gain model. Percentage differences are listed for all bands by respective acquisition date in Table-1. The procedure adopted for this analysis is briefly discussed in the appendix of this document.

L-5 TM Radiometric Calibration Processing Modifications (May, 2003)

Given the observed differences in radiometric processing within NLAPS and an improved understanding of the behavior of the Landsat 5 TM instrument and its internal calibrator, modifications are being implemented to improve the radiometric calibration of

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the existing TM archive. The modified approach would involve discontinuing use of the internal calibrator for the reflective bands (with the exception of the thermal band), implementing instead a time-dependent calibration look-up table. The table, consisting of discrete band-averaged gain coefficients throughout the instrument's lifetime, has been created and will soon be implemented into NLAPS processing.

It is remarkable that the Landsat 5 TM has continued to perform so well for a period of time far exceeding its design life. We believe the implementation of these processing changes as well as additional calibrations will lead to a superior Landsat-5 TM data product that can be calibrated to an accuracy that will be comparable to that of Landsat-7 ETM+ and will therefore continue to provide the basis for long-term studies of the Earth's land surface.

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Table 1 Percentage differences listed for all bands by respective acquisition date.

(a) The first part of the table list the expected differences that were caused due to the procedure adopted for radiometric processing. (Summarized in appendix/figure2).
(b) The next part gives the differences that may have caused when users received the products that were calibrated using the pre-launch values. (appendix/table2)
(c) Large errors due to the pulse extraction window including the light leak. (appendix Figure3)

	Percentage % difference observed in the Gain					
	BAND					
Date	**1**	**2**	**3**	**4**	**5**	**7**
01-Mar-84	0.01	0.06	0.04	0.03	0.00	0.00
1-Jan-85	-0.26	-1.08	-0.76	-0.66	-0.07	-0.04
1-Jan-86	-0.59	-2.48	-1.76	-1.52	-0.17	-0.10
1-Jan-87	-0.94	-3.84	-2.75	-2.37	-0.26	-0.15
1-Jan-88	-1.27	-5.17	-3.72	-3.20	-0.36	-0.20
1-Jan-89	-1.61	-6.46	-4.67	-4.01	-0.45	-0.26
1-Jan-90	-1.94	-7.71	-5.59	-4.81	-0.54	-0.31
1-Jan-91	-2.26	-8.93	-6.49	-5.59	-0.64	-0.36
1-Jan-92	-2.59	-10.11	-7.38	-6.36	-0.73	-0.42
1-Jan-93	-2.91	-11.27	-8.25	-7.12	-0.82	-0.47
1-Jan-94	-3.23	-12.39	-9.10	-7.87	-0.92	-0.52
1-Jan-95	-3.55	-13.48	-9.94	-8.60	-1.01	-0.57
1-Jan-96	-3.86	-14.55	-10.76	-9.32	-1.10	-0.63
1-Jan-97	-4.18	-15.59	-11.56	-10.04	-1.20	-0.68
1-Jan-98	-4.49	-16.61	-12.36	-10.74	-1.29	-0.73
1-Jan-99	-4.80	-17.60	-13.13	-11.43	-1.38	-0.79
1-Jan-00	-5.11	-18.57	-13.90	-12.10	-1.47	-0.84
1-Jan-01	-5.41	-19.52	-14.65	-12.77	-1.56	-0.89
1-Jan-02	-5.72	-20.44	-15.39	-13.43	-1.66	-0.94
1-Jan-03	-6.02	-21.35	-16.11	-14.08	-1.75	-1.00
NLAPS performing abs. Calibration using Pre-Launch values						
BM (2002)	-20.00	-17.00	-11.00	0.00	0.88	-1.70
Observed % difference Range (IC Pulse Corrupted due to light leak)						
BM/SM (2002)	-26.03	-17.36	-3.58	0.22	3.02	0.60
	-19.00	-24.57	-16.29	-6.69	-1.93	-2.89

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Appendix

(Supporting Figures/Document)

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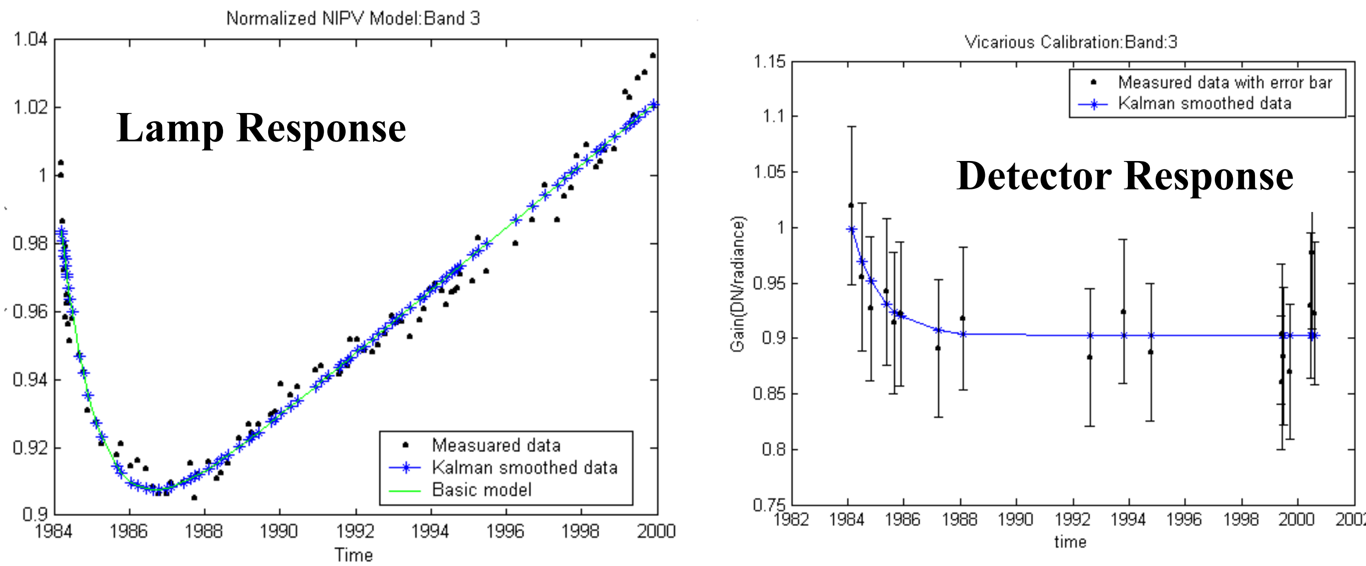


Figure 1 Normalized NPV and the detector (Gain response) in units of DN/radiance

Lamp/Detector Response
- An exponential decrease in **detector response** most apparent from launch to early 1988.
- A linear increase in **lamp response** most apparent from mid 1988 to the present.
- A non-existent (very small change) in **detector response** from mid 1988 to the present.

(a) Internal calibrator analysis results through 1999 for the solar-reflective bands indicate that the Landsat-5 TM lifetime radiometric response follows an exponential plus linear model. The exponential part seemed to reach an asymptotic limit in 1987, and is considered to be a “true change” in response (likely due to outgassing from the spectral filters during the first few years after launch).

(b) The subsequent linear increase is considered to be a change in the IC system response (likely due to changes in lamp characteristics) rather than a true change in instrument response. For example, the IC lamps may be contaminated in the region where the photodiode in the lamp radiance control system is viewing the lamps, potentially causing a reduction in measured radiance at the photodiode that would drive an increase in overall lamp brightness. The exact source of this change has not yet been verified, however.

(c) Vicarious calibration results suggest a relatively constant response since 1988. However, the linear increase as seen in the lamp response was not observed in the vicarious calibration methods. Once the linear term was removed from the IC model there seems to be good agreement between the IC and the vicarious results.

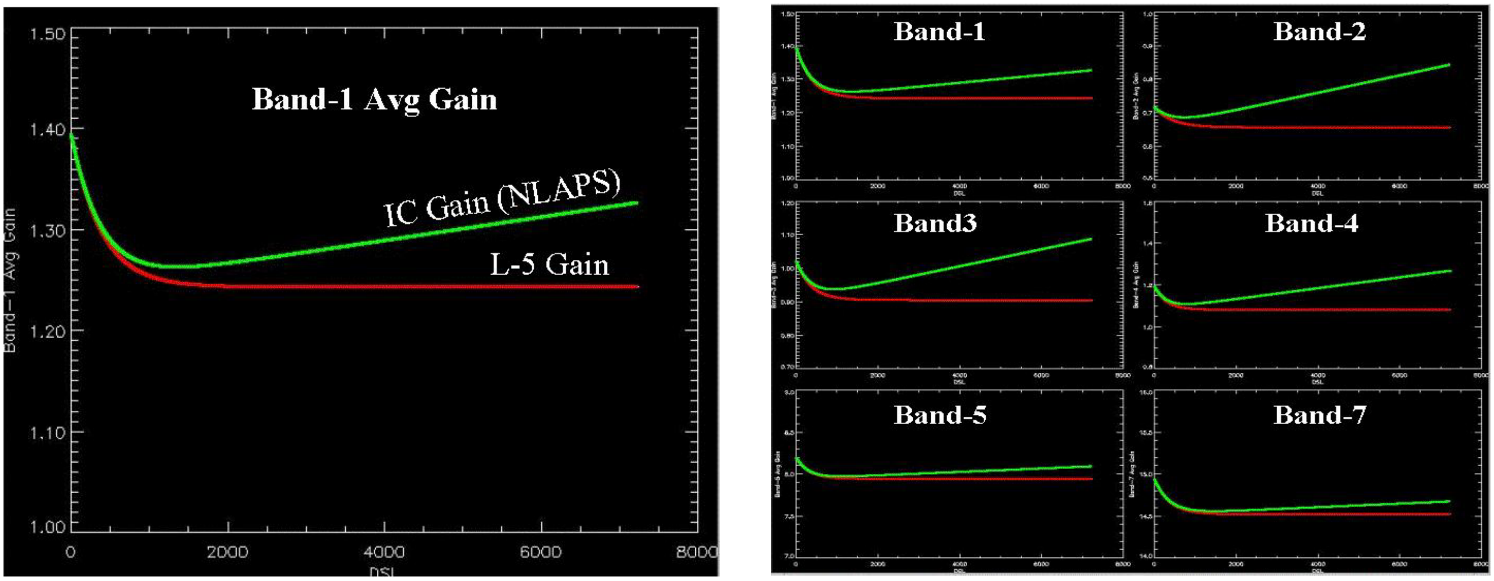


Figure 2 L-5 sensor gain over the instrument lifetime, and the apparent IC gain used by NLAPS for radiometric processing of all TM archive data.

Only the exponential decrease observed in the net pulse value (NPV) and gain model represents a real change in the TM's gain response. The observed linear increase in the NPV model is a "false" effect – consistent with the understanding that the gain response does not increase over time. However, the sensor gain calculated using the IC follows the false effect and introduces error in the radiometric calibration accuracy.

- NLAPS uses IC data to perform absolute calibration.
- The integrated pulse value (IPV) and the shutter value (SV) is extracted for all the lamp states from the calibration file.
- Calculating "Absolute Gain" coefficients involves using the pre-launch linear regression coefficients based on the radiance values measured from each calibration lamp during pre-launch calibration.
- Due to the above procedure we would expect variation in "Absolute Gain" when the calibration pulse height (IPV) values change. Since the bias information and the pre-launch lamp radiance have remained constant throughout the instruments lifetime.
- This would suggest the "IC gain" will follow the lamp response. For example, the "Absolute Gain" will increase as the "IPV" increases.

Thus, in estimating the "differences" that can be expected from the level-1 product the linear trend was added to the lifetime gain curve.

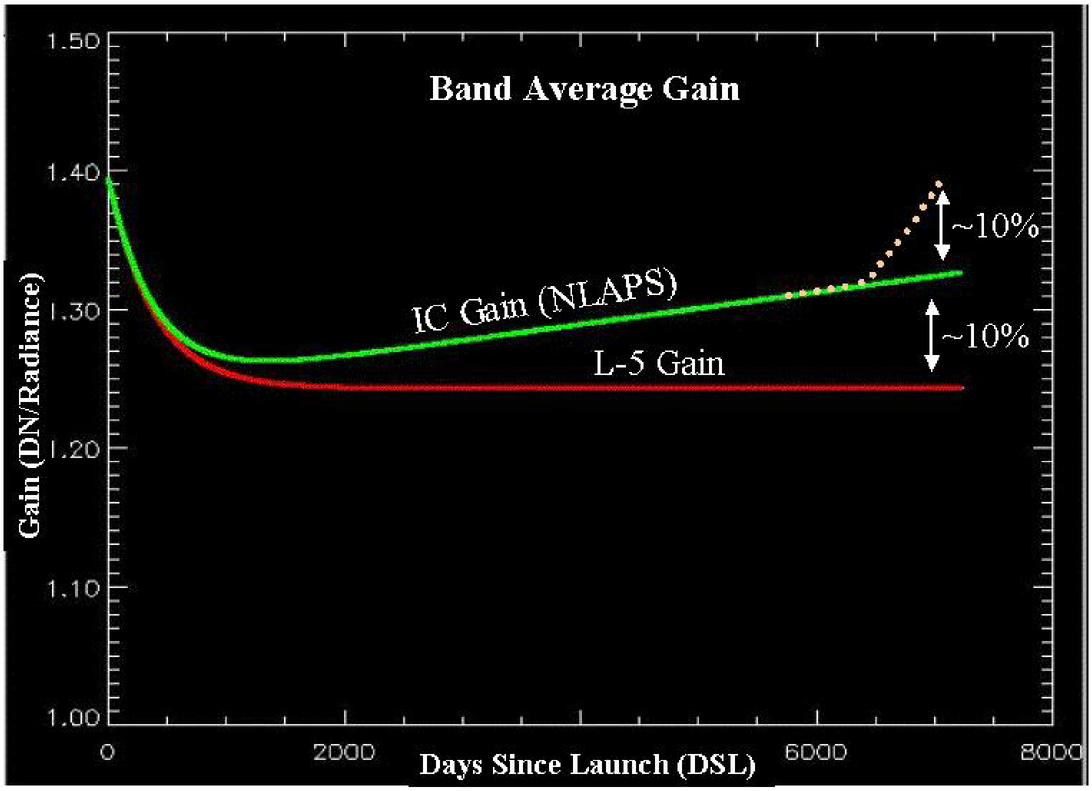
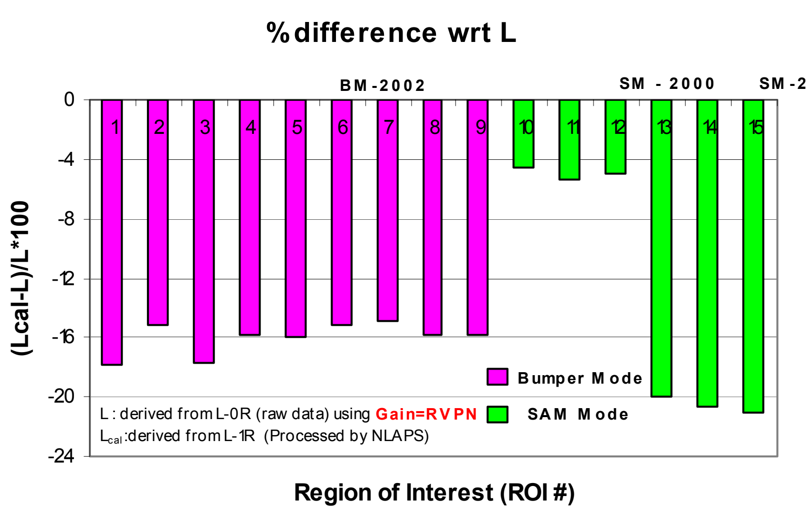


Figure 3 The window used to extract the pulse included 'light leak' from the shutter, further increasing the uncertainties in the sensor gain calculations. The IC pulses were corrupted due to the light leak problem. The extraction window used for extracting the pulse location included the bumps from the light leak and further corrupted the estimates from the IC.

Figure 4 SAM-2000 data set shows an expected radiometric error of –6%, However the SAM/Bumper-2002 data show a –18 to 26% differences and shown in the below plot.



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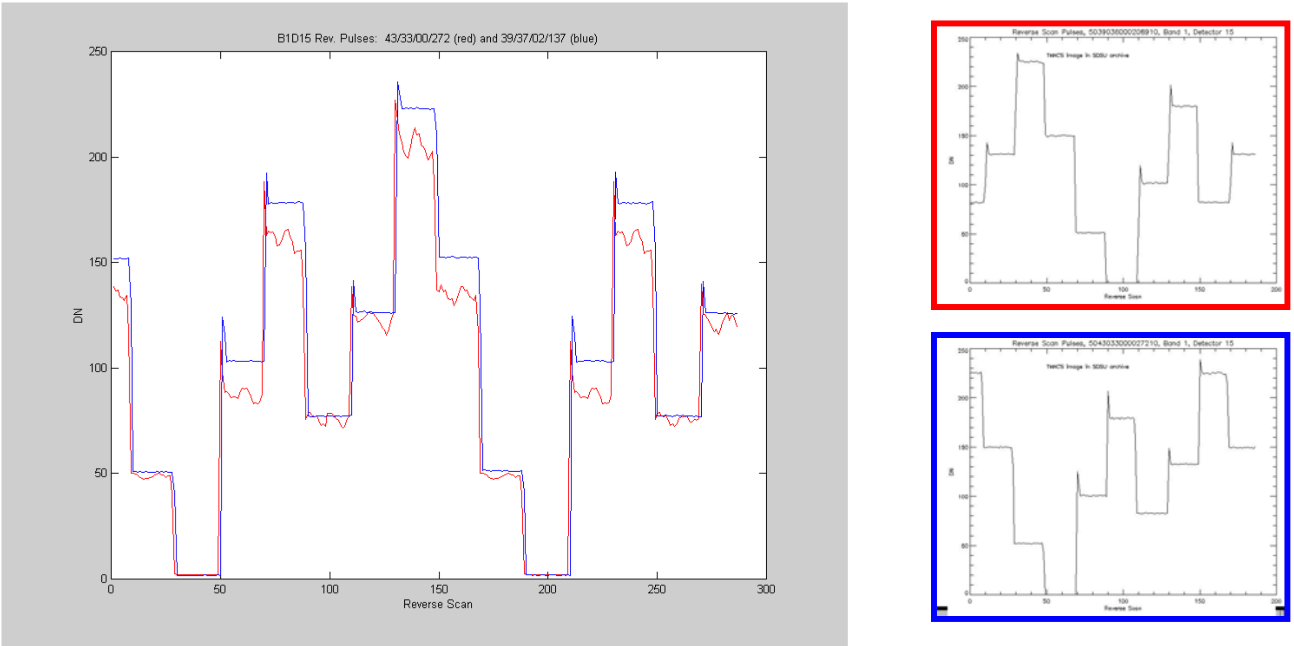

Figure 5 IC pulse data extracted from 2000 and 2002 scene showing all the eight lamp states provided by MDA. There seems to a large variation between the pulse heights in these two years and the pulse (in red) does not seem to behave uniformly.

However, when the same pulses were extracted (right hand side) there does not seem to be any significant variation. Pulse has the same magnitude and shape indicating that nothing significant changed within the TM instrument.

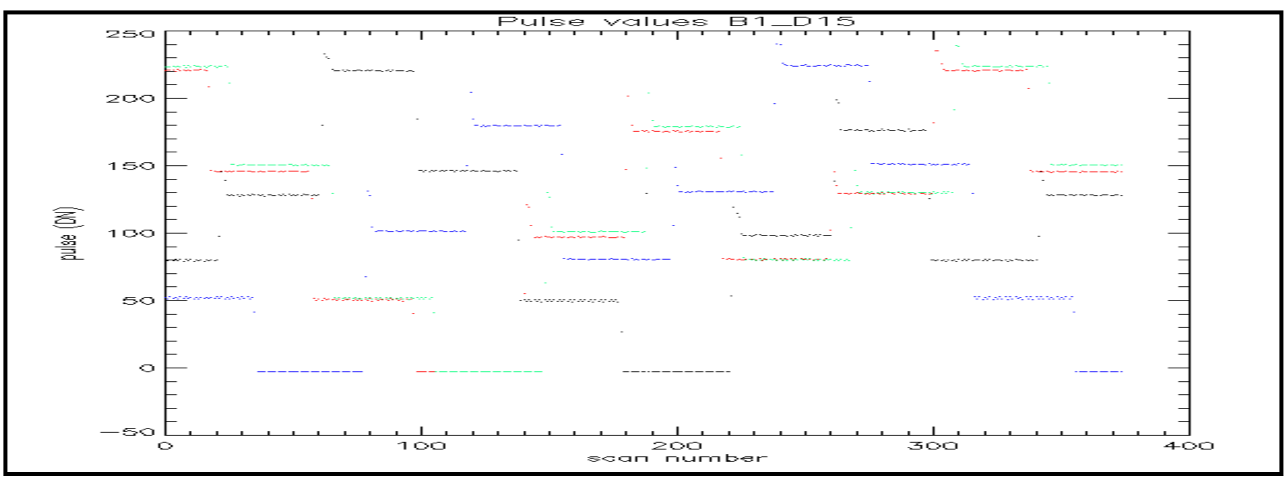

Figure 6 Internal calibration pulses for four different scenes from 2000 and 2002 showing all eight lamp states. The pulse heights seem to be very consistent with each other indicating that the pulse heights have not changed drastically with these two years.

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Landsat-5 Gain/Bias Coefficients

Table 1: Landsat-5 Pre-Launch Gain/Bias Coefficients

Band	Prelaunch Gain	Prelaunch Bias
1	1.555	1.8331
2	0.786	1.6896
3	1.02	1.8850
4	1.082	2.2373
5	7.875	3.2893
7	14.77	3.2117

Table 2: RVPN (Xcal) are the updated gain coefficients obtained using vicarious calibration. These gain coefficients were used for converting DN to radiance units for the raw data. Comparison of tandem-based (RVPN Xcal) and pre-launch gain coefficients for Landsat-5 TM for the RVPN test site in June 1999.
*Railroad Valley Playa in Nevada (RPVN)

Band	RVPN (Xcal)	Prelaunch	% Diff re Prelaunch
1	1.243	1.555	-20%
2	0.6561	0.786	-17%
3	0.905	1.02	-11%
4	1.082	1.082	0%
5	7.944	7.875	0.88%
7	14.52	14.77	-1.70%

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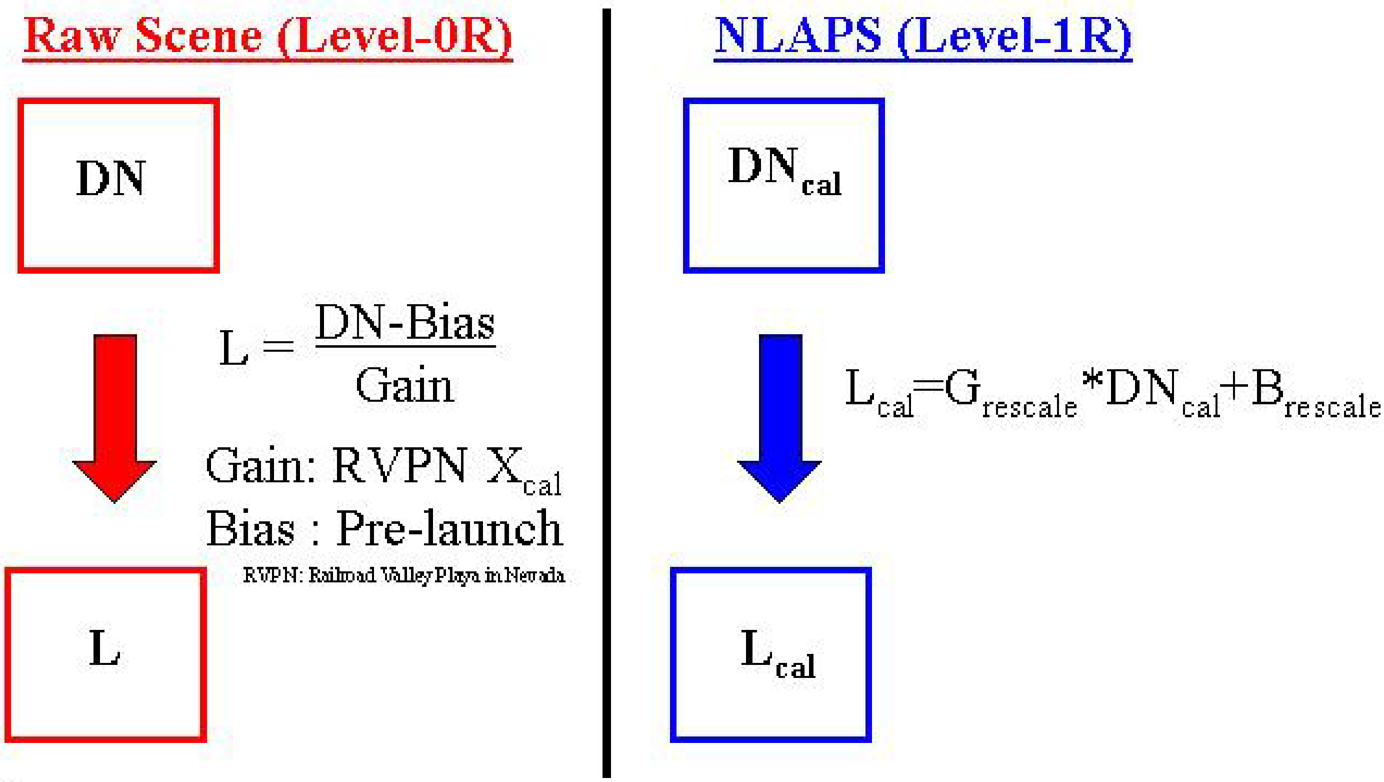
Procedure used for converting DN to Radiance (Level-0 and Level-1)

DN to Radiance Conversion



Band:1

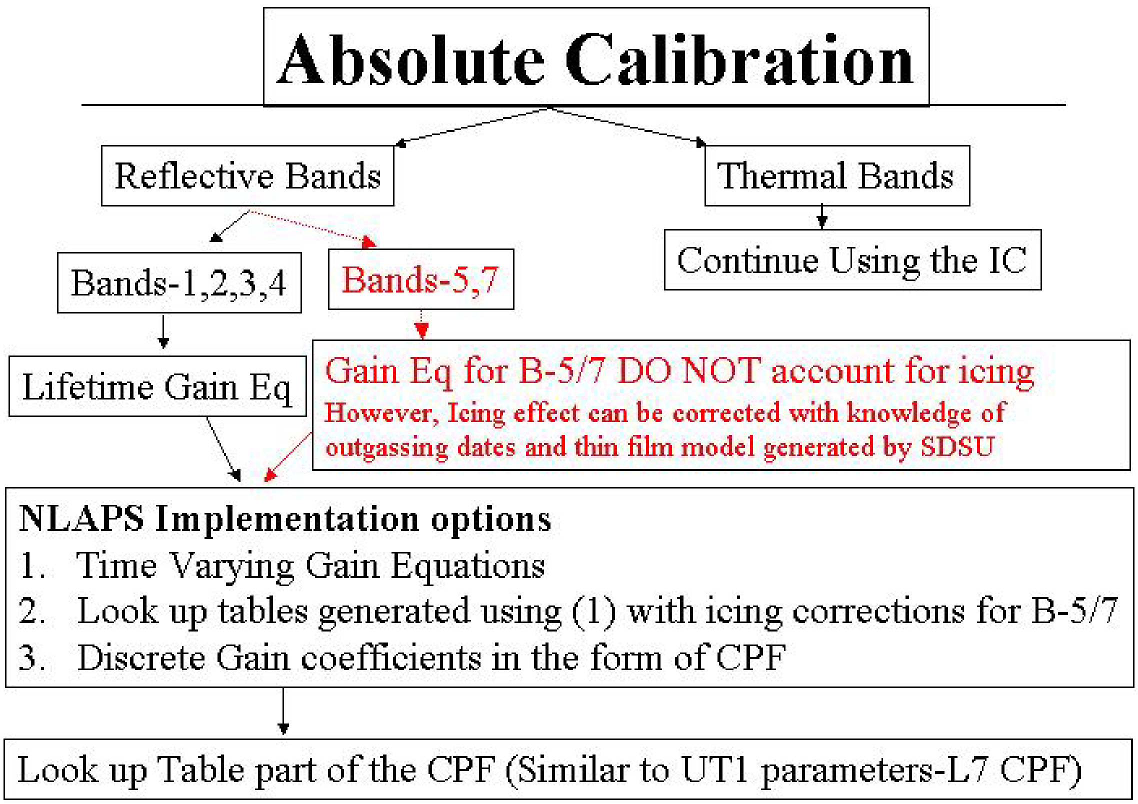
L=(DN-B)/G	RAW (L-0R)	
BIAS	1.8331	
GAIN	1.243	RVPN
GAIN	1.555	Pre-Launch

Band:1

L_{cal}=(DN*G)+B	NLAPS (L-1R)
BIAS	-1.52
GAIN	0.602431

L-5 TM Radiometric Calibration Processing (LPSO Recommendations)

1) Current Lmin and Lmax should continue to be used.
2) Perform Line-by-Line bias subtraction.
3) Memory Effect algorithm available from Dr. Helder (SDSU)
4) Relative Calibration- Use lifetime relative gain equations.
5) Absolute Calibration - Discontinue usage of the IC based approach for the TM reflective bands(except thermal band)



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References

[1] "Landsat to ground interface description," *Goddard space flight center Greenbelt Maryland June*, 1984.

[2] Dennis Helder, "Landsat-5 Radiometry", final report to NASA/*Goddard space flight center Greenbelt Maryland Feb-18*, 2002.

[3] Brian Markham, "L-5 TM Radiometric Calibration Processing " email dated 09/27/2002.

[4] SDSU IP Lab Home Page, http://iplab2out.sdstate.edu

[5] Teillet, P.M., Helder, D.L., Markham, B.L., Barker, J.L., Thome, K.J., Morfitt, R., Schott, J.R., Palluconi, F.D., "A Lifetime Radiometric Calibration Record for the Landsat Thematic Mapper" *Canadian Symposium on Remote Sensing,* August 2001

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