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5089-3 (1144)

January 26, 1984

1.   Introduction

TITLE: CCRS Proposal for Evaluating LANDSAT-4 MSS and TM Data

Investigation Number: LANDSAT-4, F-2

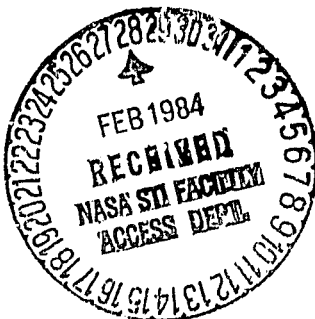Authors: Dr. W.M. Strome, (PI)
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Organization: Canada Centre for Remote Sensing (CCRS)

Type of Report: Second Progress Report

Reporting Date: September 3, 1983 to January 2, 1984

II. Technique

The following LANDSAT-4 imagery was used in the study: 3 MSS scenes and 4 TM scenes.

Sensor	Path/Row	Identification	Date	Data Type
MSS	16/24	Mistassini, Que.	21/06/83	raw
MSS	16/28	Ottawa, Ont.	24/10/82	geocoded
MSS	16/28	Ottawa, Ont.	07/07/83	geocoded
TM	48/26	Vancouver Is., B.C.	27/12/82	raw
TM	48/27	Vancouver Is., B.C.	27/12/82	raw
TM	42/36	Oxnard, California	15/11/82	raw
TM	33/37	White Sands, NM	03/01/83	raw

The above MSS and TM imagery was acquired at the Prince Albert Satellite Station. Most data, except for the MSS scenes of Ottawa, were in the uncorrected and raw form.

III. Accomplishments

The objectives of the Canadian proposal are:

(1)   to quantify the LANDSAT-4 sensors and system performance for the purpose of updating the radiometric and geometric correction algorithms for MSS and for developing and evaluating new correction algorithms to be used for TM data processing;

(2)   to compare and access the degree to which LANDSAT-4 MSS data can be integrated with MSS imagery acquired from earlier LANDSAT missions;

(3)   to apply image analysis and information extraction techniques for specific user applications such as forestry or agriculture.

During the reporting period the accomplishments toward these objectives have been:

(1)   measurement of interband registration errors in raw LANDSAT-4 MSS data, (Reference 3).

(2)   measurement of multitemporal registration errors between two LANDSAT-4 MSS geocoded products and measurement of registration errors between one LANDSAT-2 and two LANDSAT-4 MSS geocoded products, (Reference 4).

(3)   development of a revised algorithm for radiometric calibration of TM data, (Reference 1, 2).

(4)   production of a geocoded TM image.

(5)   investigation and comparison of algorithms for the replacement of the failed detector data.

IV. Significant Results

Detailed observations of background reference levels have shown that line-dependent variations in raw TM image data and in the associated calibration data can be measured and corrected by applying a simple offset correction on a line-by-line basis.

V. Publications

The following papers were prepared:

(1)   Revised Radiometric Calibration Techniques for LANDSAT-4 Thematic Mapper Data by J. Murphy, T. Butlin, P. Duff, A. Fitzgerald, Third LANDSAT-4 Workshop, December 6-7, 1983, NASA Goddard Space Flight Center.

(2)   Revised Radiometric Calibration Techniques for LANDSAT-4 Thematic Mapper Data (extended paper) by J. Murphy, T. Butlin, P. Duff, A. Fitzgerald, IEEE Transactions on Geoscience and Remote Sensing, (to be published).

VI. Problems

TM application studies based on the Lac St. Jean (14/26) and the Sorel (14/28) scenes acquired on October 10, 1982 have been delayed because the data could not be processed on the NASA facility due to the absence of telemetry. The data will be transcribed at the Prince Albert station once the NASA Martin Marietta high density tape recorder has been returned and installed at the station. The shipping of the recorder to Prince Albert is two months behind schedule.

VII. Future Sensor Recommendations

At the Third LANDSAT-4 Workshop it was suggested that Principle Investigators could include in their quarterly report their recommendations concerning the development of future visible and infrared sensors. A copy of a report produced by the RADARSAT Project Office and presenting an assessment of the requirements for a visible and infrared sensor has been included.

Reference 1.

REVISED RADIOMETRIC CALIBRATION TECHNIQUE
FOR LANDSAT-4 THEMATIC MAPPER DATA
BY THE CANADA CENTRE FOR REMOTE SENSING

AUTHORS: J. MURPHY, T. BUTLIN, P. DUFF, A. FITZGERALD

KEYWORDS: Remote Sensing, Landsat-4, Thematic Mapper, Radiometric Calibration

INTRODUCTION

A technique for the radiometric correction of LANDSAT-4 Thematic Mapper (TM) data was proposed by the Canada Centre for Remote Sensing (CCRS) in 1982, and two reports defining the method and discussing preliminary results were presented by CCRS at the LANDSAT-4 Scientific Characterization Early Results Symposium. Subsequent detailed observations of raw image data, raw radiometric calibration data and background measurements extracted from the raw data stream on High Density Tape have highlighted in the proposed method, major shortcomings, which if left uncorrected, can cause severe radiometric striping in the output product. Results presented here correlate measurements of the DC background with variations in both image data and calibration samples. The effect on both raw data and the correction required using the earlier proposed technique is explained, and the correction required for these factors as a function of individual scan line number for each detector is described. It is shown how the revised technique can be incorporated into an operational environment.

RADIOMETRIC CORRECTION OVERVIEW

The radiometric correction method has three separate steps.

1) For a reference detector in each spectral band, the corrections required to place the data from this detector on an absolute scale are calculated, using in-flight calibration data.

ii) The relative differences between all other detectors in each band and the reference detector are calculated, using the means and standard deviations of the raw data values, which are derived from the raw data histograms. In order to ensure that the histograms correspond only to pixels with radiance values for which the response of each detector is linear, all those pixels which saturate any one detector within a band are removed from the histogram of each detector within that band.

iii) Absolute and relative correction are combined, to give absolute gains and offsets for all detectors of all bands.

RAW DATA OBSERVATIONS
CALIBRATION DATA EXTRACTION

The absolute calibration procedure using in-flight calibration data relies on extracting and averaging calibration pulses from within the raw data stream, for each scan line in turn. The internal calibrator steps through eight unique calibration states, with approximately 40 consecutive scans at each level, as shown in Figure 1. An average digital number (DN) for each of the eight states (after ignoring overshoot, warm-up time and cool-down time), is then combined with the corresponding prelaunch DN and radiance level.

CALIBRATION DATA VARIABILITY

Detailed observations of averaged calibration pulse values within the stable area of each calibration state have shown variations of magnitudes from one to four DN from line to line for the same detector, which are uncorrelated with scan direction. Moreover, it has been observed that for many detectors, the averaged calibration pulse values are quantized into either the high or low extremes of the range of variability, rather than being randomly distributed throughout the range. This is exemplified in Figure 4 for detector 6 of band 1.

IMAGE DATA VARIABILITY

Using a scene (Path 48, Row 28, November 11, 1982) consisting of only a large water body with nominally very small scene content variability from scan line to scan line, an estimate of the variation of detector response within one spectral band and from swath to swath was obtained. This was achieved by selecting a strip 100 pixels wide by 320 swaths long, and by plotting the average of each of these 100 pixels as a function of scan line number. Detailed observations have shown, in addition to the 16-line periodicity, due to differences in absolute calibration of each of the 16 detectors, variations of magnitudes from one to four DN for those lines corresponding to particular detectors. As is the case with the calibration data, the variations are uncorrelated with scan direction, and show the same quantization effects. This is exemplified in Figure 3, Plot 1, for detector 4 of band 1. (This detector has been chosen for illustrative purposes only. At least seven other detectors in the reflective bands have shown similar quantization effects, and many others have shown random variations of approximately 2 DN).

BACKGROUND LEVEL OBSERVATIONS

In order to define the procedure for extracting calibration pulse averages and for estimating DC reference levels, the raw data stream from the end of one scan line to the start of the next scan line was investigated in detail. Sample plots were marked up with the nominal locations of calibration pulse centre, and with three nominal regions characterizing the background level, one before DC restore (BDC), one during DC restore (DDC), and one after DC restore (ADC). Observations of the BDC values revealed very close correlation with the observed image data background level for the scan line immediately preceding the background level measurement. This is exemplified for detector 4 of band 1 in Figure 1, Plot 2.

A similar high correlation was observed between the appropriate DC (ADC for forward scans, and BDC for reverse scans) measurement for the calibration pulses. This is exemplified for detector 4 of band 1 in Figure 4.

However, there was no correlation between ADC of the previous line and the observed image data background-level at the start of the next line. Plots of BDC, DDC and ADC as a function of line number show that there is little change in DC level during this entire region. The example shown in Figure 2 for detector 4 of band 1 indicates the change in DC level for each scan line independently, by connecting with straight lines the BDC, DDC and ADC measurements appropriate to that line. The discontinuity between the background level measurement

TM CAL FILE   LAMP SEQUENCE BY SMITH NO.

BAND: 1, DET: 4, No. SWATHS: 324, COUNT: 31 (CAL)

	0	1	2	3	4	5	6	7
AVERAGE:	2.59	42.65	61.93	102.36	101.14	129.95	159.62	209.25
STD.DEV:	0.55	0.93	1.21	1.22	1.11	1.04	0.95	1.20

FIGURE 1
Representative Calibration Lamp State Sequence
for Detector 4 of band 1.

immediately prior to the start of scan line N (ADC from scan line N-1) and the background level measurement immediately after scan line N (BDC for scan line N) is clearly evident.

DEFICIENCIES IN THE EARLIER PROPOSED TECHNIQUE

The effects on TM data radiometrically corrected using the earlier proposed technique will be three-fold. Firstly, the variations in calibration samples will decrease the accuracy of the absolute calibration of the reference detector. Secondly, the random variations in background reference level within a scene for some detectors means that the detector response cannot be characterized by a fixed, scene-dependent, gain and offset. Relative gains and offsets calculated from raw data histograms will therefore be inaccurate. Thirdly, the application of a fixed gain and offset over an entire scene will not remove the observed background variations of up to 4 DN which occur randomly from line to line throughout the scene.

REVISED OPERATIONAL PROCEDURE

Revisions to the earlier proposed technique are therefore required.

i) The in-flight calibration data will be accumulated for the reference detector, but the relevant line-by-line background level measurement (corresponding to BDC or ADC) will be subtracted before including it in the calibration state average.

ii) The sums and sums of squares of the raw data will be accumulated for a full scene. However, histograms will be accumulated a swath at a time, such that any saturated values can be removed. A background level, corresponding to BDC, will be subtracted from the truncated histogram before the sums and sums of squares are accumulated.

iii) The absolute and relative correction parameters will be combined to yield scene-dependent absolute gains and offsets for all detectors.

iv) The data will be calibrated line by line, by applying offsets and gains to each pixel in turn. However, the scene-dependent offset must first be modified by the line-dependent offset, corresponding to BDC, before being subtracted from the raw data value.

If pixel-dependent corrections are required, these will be calculated and applied before modifying each pixel in the line by the scene-dependent gain.

All these operations can be conveniently performed in floating-point notation before geometric correction and conversion to the final 8-bit form.

CONCLUSION

Detailed observations of background reference levels have shown that line-dependent variations in raw TM image data and in the associated calibration data can be measured and corrected within an operational environment, by applying simple offset corrections on a line-by-line basis. The radiometric calibration procedure defined by CCRS has been revised accordingly.
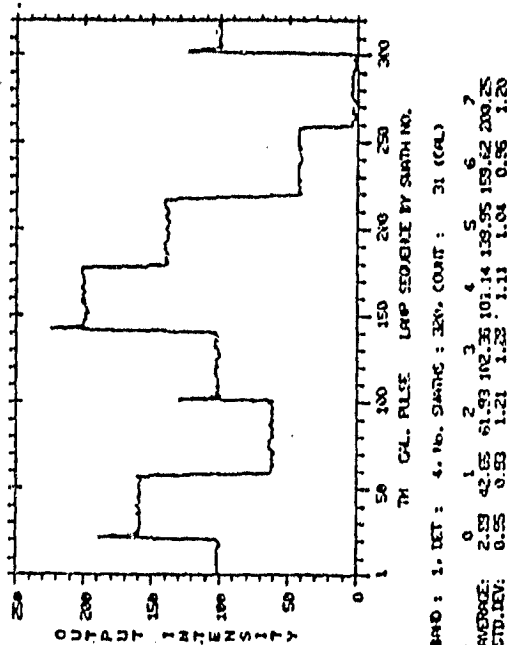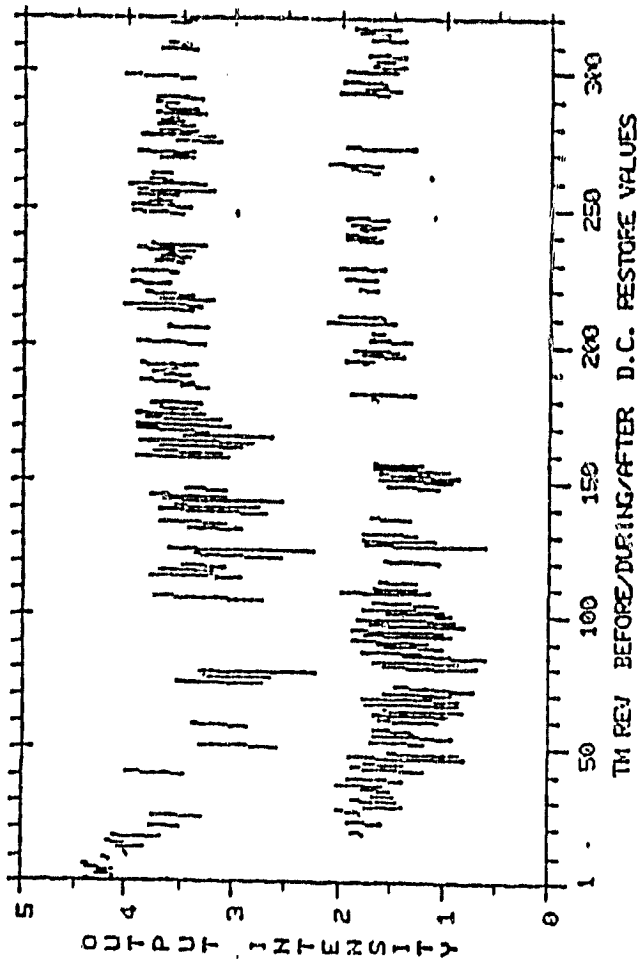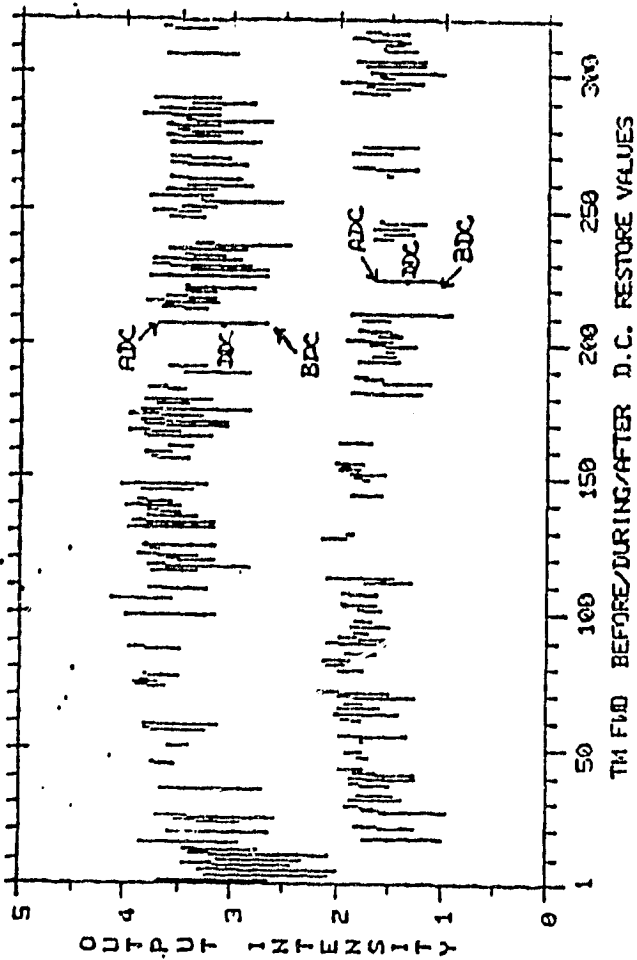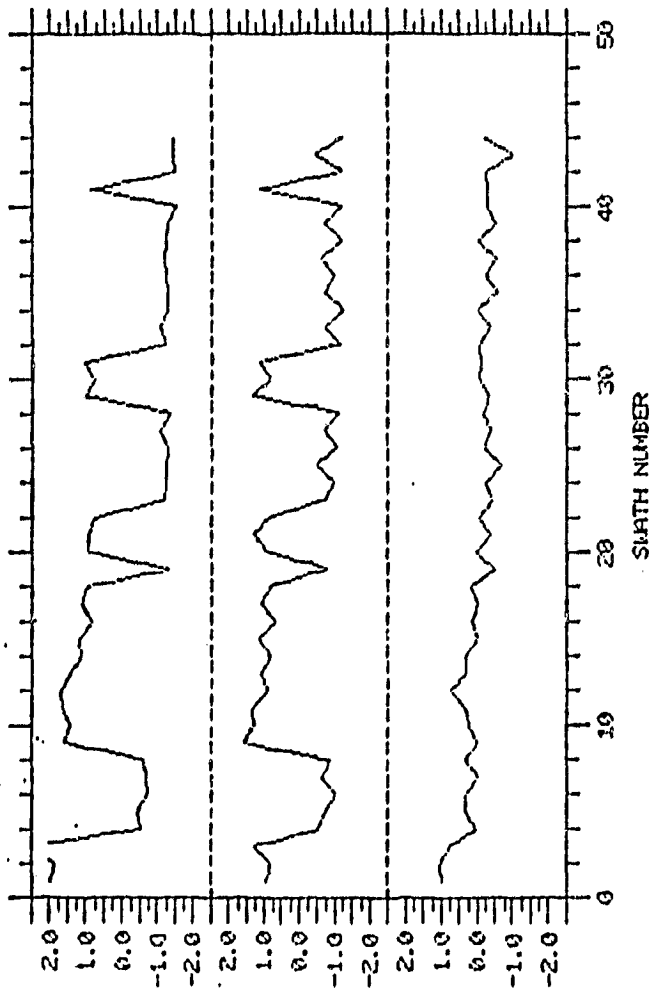
FIGURE 2

Plots of BDC, DDC and ADC as a function of line number
for Detector 4 of band 1.

TM CALIBRATION AND D.C. RESTORE VARIATION

NEXT >

SWATH NUMBER

BAND DET No.SWATHS   COUNTS
1   4   300   31 (CAL), 23 (D.C.)

FIGURE 4

Variations in averaged calibration pulse values as a function of
scan line number for detector 4 of band 1.
Plot 1 shows changes in averaged calibration pulse values
(CALSAM) represented as a deviation from the mean value for the
320 scans.
appropriate calibration state average.
Plot 2 shows changes in DC reference level using ADC for forward
scans and BDC for reverse scans.
Plot 3 shows changes in CALSAM after SDC (or ADC) has been
subtracted.

TM IMAGE MEAN AND D.C. RESTORE VARIATION

SWATH NUMBER

BAND DET SWATHS PIXELS MEANS
1   4   1 to 45   2500 to 2599   38.79 (Image)   2.45 (D.C.)

FIGURE 3

Variations in image data background level as a function of scan
line number for detector 4 of band 1.
Plot 1 shows changes in raw image data background level (RAW)
represented as a deviation from the mean value averaged over all
320 scans.
Plot 2 shows changes in DC reference level before DC restore
(BDC).
Plot 3 shows changes in RAW after BDC has been subtracted.

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REVISED RADIOMETRIC CALIBRATION TECHNIQUE
FOR LANDSAT-4 THEMATIC MAPPER DATA

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Keywords: Remote Sensing, LANDSAT-4, Thematic Mapper, Radiometric
           Calibration

ABSTRACT

A technique for the radiometric correction of LANDSAT-4 Thematic Mapper
(TM) data was proposed by the Canada Centre for Remote Sensing (CCRS) in
1982, and two reports defining the method and discussing preliminary
results were presented by CCRS at the LANDSAT-4 Scientific
Characterization Early Results Symposium (References 1 and 2). Subsequent
detailed observations of raw image data, raw radiometric calibration data
and background measurements extracted from the raw data stream on High
Density Tape have highlighted in the proposed method, major shortcomings,
which if left uncorrected, can cause severe radiometric striping in the
output product. Observations presented here show that there are random
fluctuations in the background level for spectral band 1 of magnitudes
ranging from 2 to 3.5 digital numbers (DN), depending on detector number.
Similar variability is observed in all the other reflective bands, but
with smaller magnitude in the range 0.5 to 2.5 DN. More significantly, it
is shown how measurements of the DC background level can be correlated
with variations in both image data background and calibration samples.
The effect on both raw data and on data corrected using the earlier
proposed technique is explained, and the correction required for these
factors as a function of individual scan line number for each detector is
described. It is shown how the revised technique, which includes
corrections for a line-dependent offset in addition to the scene-dependent
gain and offset, can be incorporated into an operational environment.

RADIOMETRIC CORRECTION OVERVIEW

The TM sensor array consists of 100 detectors in 7 spectral bands. There are 16 detectors for each of bands 1 through 5 and 7 (the reflective bands), and 4 for band 6 (the thermal band), arranged so that each scan results in 16 different image lines for the reflective bands and 4 lower resolution lines for the thermal band. The procedure chosen by CCRS for the radiometric calibration of LANDSAT-4 TM data is based on the method used by CCRS for LANDSAT Multispectral Scanner (MSS) data, and may be divided into three stages.

a) A reference detector is chosen for each spectral band, and the corrections required to place the data from this detector on an absolute scale are calculated, using in-flight calibration data, pre-launch calibration data and the maximum and minimum radiance values associa*** with the response of the band.

b) The relative differences between all other detectors in each band and the reference detector are calculated, using the means and standard deviations of the raw data values as calculated from the sums and the sums of the squares of the scene data values. These, in turn, are usually calculated from the histograms of the raw data values. In order to ensure that the histograms correspond only to pixels with radiance values for which the response of each detector is linear, all those pixels which saturate any one detector within a band are removed from the histogram of each detector within that band. The procedure is repeated for each band in turn.

c) Finally, the absolute calibration of the reference detector for each band is combined with the relative calibration of the other detectors within the same band to provide an absolute calibration of all one hundred detectors.

RESIDUAL RADIOMETRIC STRIPING ESTIMATION

A simple method of assessing the radiometric striping in TM images due to differences in absolute calibration of the individual detectors within a band consists of selecting arbitrary subscenes, and for each band plotting as a function of the line (or detector) number the radiometric intensity values averaged over a fixed number of pixels. In such profiles, the residual striping appears as a repetitive pattern with a period of sixteen lines which is added to the scene content. Because the scene data is averaged over a number of pixels, (for example 100 pixels), variations from line to line due to scene content tend to be small and gradual, particularly over uniform areas such as large water bodies. It is convenient to subject these profiles to Fourier analysis to provide a quantitative estimate of the nature of the residual striping. The procedure can also be used on the data from each detector individually to detect variations on a line by line basis.

EARLY ASSESSMENT OF RADIOMETRIC CORRECTION

Three test scenes were corrected using the procedure outlined above and were subjected to residual radiometric striping analysis. It was immediately apparent that the relative corrections within each band were inadequate. Moreover, the striping profiles from several individual detectors showed random variations from line to line of magnitudes varying up to four digital numbers (DN).

An in-depth investigation into the background data relating both to calibration samples and to the image data was then initiated.

RAW DATA OBSERVATIONS
CALIBRATION DATA EXTRACTION

All the one hundred detectors are exposed to calibration radiance levels during a portion of each scan as shown in Figures 1a and 1b for forward and reverse scans respectively. These figures show the sequence of events for a typical detector during the period that scene radiance is obscured, following transmission of scene data for the scan. A period of background level (DC) restoration precedes the calibration pulse for the forward scan and follows it for the reverse scan. For bands 1 through 5 and 7, the internal calibrator steps through eight unique calibration states, with approximately 40 consecutive scans at each level, as shown in Figure 2. (For the thermal band 6, the calibration level is essentially constant. Band 6 calibration is not discussed here.) The absolute calibration procedure using in-flight calibration data relies on extracting and averaging the calibration pulses from within the raw data stream, for each detector, for each scan line in turn and an average digital number (DN) for each of the eight states (after ignoring overshoot, warm-up time and cool-down time), is then combined with the corresponding prelaunch DN and radiance level.

CALIBRATION DATA VARIABILITY

Detailed observations of averaged calibration pulse values within the stable area of each calibration state have shown variations of magnitudes from one to four DN from line to line for the same detector, which are uncorrelated with scan direction. Moreover, it has been observed that for many detectors, the averaged calibration pulse values are quantized into either the high or low extremes of the range of variability, rather than being randomly distributed throughout the range. This is exemplified in Figure 3 for detector 4 of band 1, where the top plot shows the deviation from the mean value for the appropriate calibration state average. Large deviations are expected only when the calibration state changes, every 40th scan, as exhibited in Figure 4 Plot 1 for band 7, detector 13.

IMAGE DATA VARIABILITY

Using a scene (Path 48, Row 28, November 11, 1982) consisting of only a large water body with nominally very small scene content variability from scan line to scan line, an estimate of the variation of detector response both within one spectral band and from swath to swath was obtained. This was achieved by selecting a strip 100 pixels wide by 320 swaths long, and by plotting the average of each of these 100 pixels as a function of scan line number. Figure 5 is a plot for all 11 swaths for all detectors of band 1 and clearly shows the 16 line periodicity which arises from differences between the 16 detectors in the array. However, detailed observations have shown, in addition to the 16-line periodicity, variations of magnitudes from one to four DN for those lines corresponding to particular detectors. As is the case with the calibration data, the variations are uncorrelated with scan direction, and show the same quantization effects. This is exemplified in Figure 6, Plot 1, for detector 4 of band 1, whereas Figure 7 Plot, 1 shows detector 5 of the same band to be essentially free from this effect.

BACKGROUND LEVEL OBSERVATIONS

In order to define the procedure for extracting calibration pulse averages and for estimating DC reference levels, the raw data stream from the end of one scan line to the start of the next scan line was investigated in detail, using data specially extracted by the CCRS Thematic Mapper Transcription System (TMTS) (Reference 3). In support of this investigation, TMTS was also able to transmit to a moving window display (MWDP) the entire scan from the start of scene data, including the shutter obscuration period following scene data and part of the following scan of the opposite direction, by averaging the data for one detector in blocks of 16 pixels, and displaying this data for one detector only in each pair of scans. By viewing this display for those detectors which exhibited banding it was found that the banding was continuous through the scene data and the following obscuration, but that discontinuities occurred before the start of the following scan. Figure 8 shows this for band 7 detector 7 where forward sweeps of Vancouver are followed by reverse sweeps. Thus DC background values extracted from a particular scan could be used to correct the scene data for that scan only and have little relation to the following one.

Sample plots of the obscuration period data were marked up with the nominal locations of calibration pulse centre, and with three nominal regions characterizing the background level, one before DC restore (BDC), one during DC restore (DDC), and one after DC restore (ADC), as exemplified in Figures 1a and 1b. Observations of the BDC values confirmed very close correlation with the observed image data background level for the scan line immediately preceding the background level measurement. This is exemplified for detector 4 of band 1 in Figure 6 Plot 2, and Plot 3 shows the resulting small variations after BDC has been subtracted from the raw data. However, there was no evident correlation between ADC of the previous line and the observed image data background level at the start of the next scan line.

Figure 7 shows the case for band 1 detector 5, which exhibits no banding and is followed by a DC value which is also relatively invariant. The resulting difference plots for these two adjacent detectors are essentially the same.

A similar high correlation was observed between the appropriate DC (ADC for forward scans, and BDC for reverse scans) measurement for the calibration pulses. This is exemplified for detector 4 of band 1 in Figure 3.

Plots of BDC, DDC and ADC as a function of line number show that there is little change in DC level during this entire region. The example shown in Figure 9 for detector 4 of band 1 indicates the change in DC level, for each scan line independently, by connecting with straight lines the BDC, DDC and ADC measurements appropriate to that line. However, the changes which do occur during the DC restore region are always positive, indicating that there is a small background level 'droop' during the sweep. The two distinct quantization levels are again evident, and DC restore apparently does not result in changes between the two levels.

SUMMARY OF BACKGROUND LEVEL VARIATIONS

The background level variability was studied in detail, paying particular attention to the quantization effect. Table 1 is a summary, as extracted from 320 swaths of the test scene, for all detectors of both the range of DC values (BDC, DDC and ADC) and the number of discrete levels. The quantization effect is evident in all detectors of all bands, but this is often partially obscured by large fluctuations at each level which can sometimes be almost as large as the level spacing. Band 1 is most affected, with all detectors having a range of at least 2 DN. In particular, the discrete levels for detectors 4, 8, 10 and 12 are clearly defined, being spaced by 2 DN for detectors 4 and 12, with additional fluctuations bringing the total spread to almost 4 DN. In band 2, detector 1 has four clearly defined levels with a total spread of less than 1.5 DN, whereas the other detectors are little affected with a range of 0.5 DN. In band 3, both detectors 16 and 1 have four levels with a total spread of 2 DN. It was observed that most detectors of band 4 suffered a 'bottoming' effect at 2 DN, such that very few excursions of BDC, DDC or ADC below 2 DN were found. Figure 10 shows this effect for band 4, detector 16. In each of bands 5 and 7, all but one detector exhibited a total range less than 1 DN. However, detector 7 of band 7 stands out as having large random fluctuations of 2.5 DN. It has also been observed that, regardless of the magnitude of the difference between the quantization levels, transitions from high to low levels (or from low to high levels) occur at the same scan line number for all detectors of all bands. From this summary, it can be seen that the raw data for all bands will exhibit a banding effect ranging from 1 DN in the best case (band 5) to 4 DN in the worst case (band 1).

DEFICIENCIES IN THE EARLIER PROPOSED TECHNIQUE

The accuracy of the radiometric calibration of TM data will be reduced if no corrections are made as a function of line number. There are three major impacts, affecting both the absolute calibration data and the relative corrections.

Firstly, the random variations in calibration sample averages within each state will decrease the accuracy of the absolute calibration of the reference detectors.

Secondly, the overall scene histogram for those detectors affected by background level fluctuations will have a larger standard deviation than, and possibly a different mean value from, those detectors which exhibit small changes in background level. Relative gains and offsets calculated from the raw data histograms will therefore be inaccurate.

Finally, the application of a fixed gain and offset over an entire scene will not remove the observed background variations of up to four DN, which occur randomly from line to line throughout the scene.

REVISED OPERATIONAL PROCEDURE

Revisions to the earlier proposed technique to account for background levels which vary randomly as a function of line number but which are constant within a line can be quite simply incorporated into existing procedures.

Firstly, the calibration pulse average for each line must have the relevant background level measurement subtracted from it. For forward scans, ADC must be used, and for reverse scans, BDC is the appropriate value. The modified calibration samples can then be included in the state average, in the usual way.

Secondly, the histograms for each detector of each band must be accumulated one line at a time for each direction independently, and must be truncated to remove all those pixels which saturate any one detector within the band. The line-dependent background level must then be subtracted from the truncated histogram, and must also be saved for later use when correcting the raw data. These histograms, which have been truncated to remove saturation effects and which have been shifted to account for background level variations, can then be incorporated into the accumulation of the sums and sums of squares of the raw data for the entire scene. The scene-dependent relative gains and offsets can then be computed. (Any systematic variations which are a function of pixel position within the scan line are assumed to have a negligible effect on the overall scene statistics, in comparison to the line-dependent background variations. Therefore, when accumulating histograms as required to derive the scene-dependent gains and offsets, no correction for pixel location effects will be included, other than the separate accumulation of forward and reverse histograms to account for the fundamental difference due to direction-dependency.) The final phase of calculating absolute scene-dependent gains and offsets is to combine the absolute calibration of the reference detector with the relative calibration of the remaining detectors within the same band.

Finally, the raw data must be corrected, taking account of corrections which are a function of scene, of line and of pixel position within the line. This is conveniently effected by first subtracting an offset from each raw data value and then dividing it by the scene-dependent gain. The offset includes a scene-dependent component derived from the absolute and relative calibrations, and the line-dependent component extracted from the background data. If pixel-dependent corrections are required, they can be included in the offset correction. All these operations can be conveniently performed in floating-point notation before geometric correction and conversion to the final 8-bit form, in order to retain the maximum accuracy.

CONCLUSION

Detailed observations of background reference levels have shown that line-dependent variations in raw TM image data and in the associated calibration data can be measured and corrected within an operational environment, by applying simple offset corrections on a line-by-line basis. The radiometric calibration procedure defined by CCRS has been revised accordingly.

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LIST OF ILLUSTRATIONS

BAND	DETECTOR	RANGE	NUMBER OF DISCRETE LEVELS
1	4	3.5 DN	2
	8,10,12	~ 3 DN	2
2	REST	~ 2 DN	2
	1	1.2 DN	4
	REST	~ 0.5 DN	2
3	16	2.0 DN	4
	1	1.8 DN	3
	REST	~ 1 DN	2 or 3
4[1]	16	1.0 DN	2
	REST	< 1 DN	2
5	10	1.0 DN	2
	REST	< 0.5 DN	2
7	7[2]	2.5 DN	2
	REST	< 0.5 DN	2

1. Lowest level is 2.0 DN

2. This detector is noisy

TABLE 1.   SUMMARY OF BACKGROUND LEVEL VARIABILITY
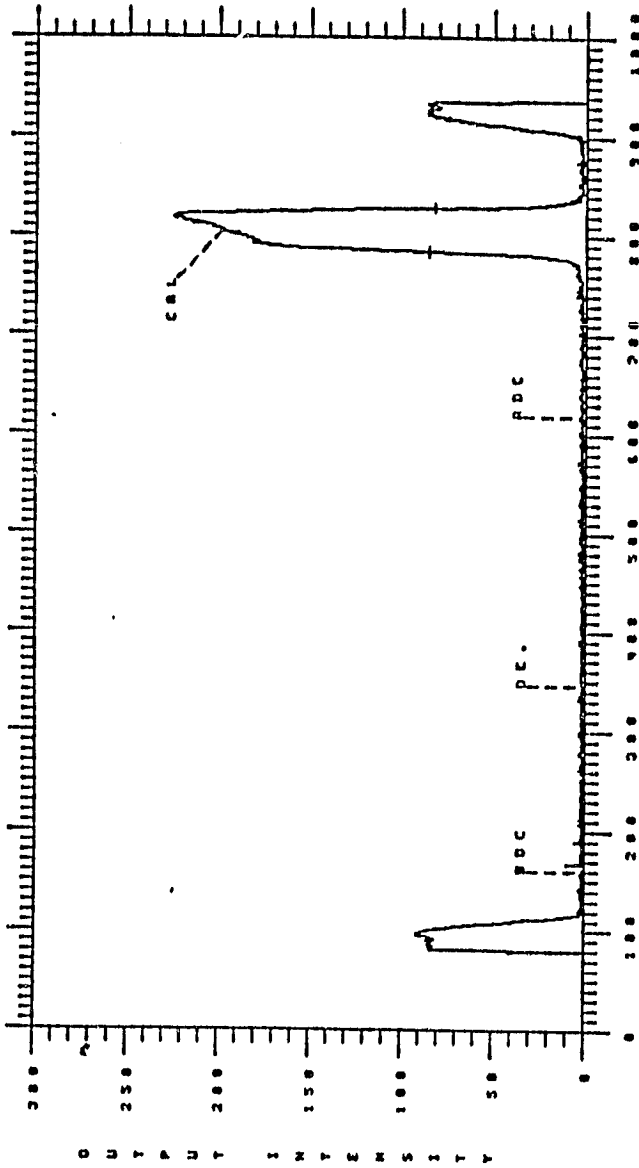
Figure 1A Forward Scan data during obscuration
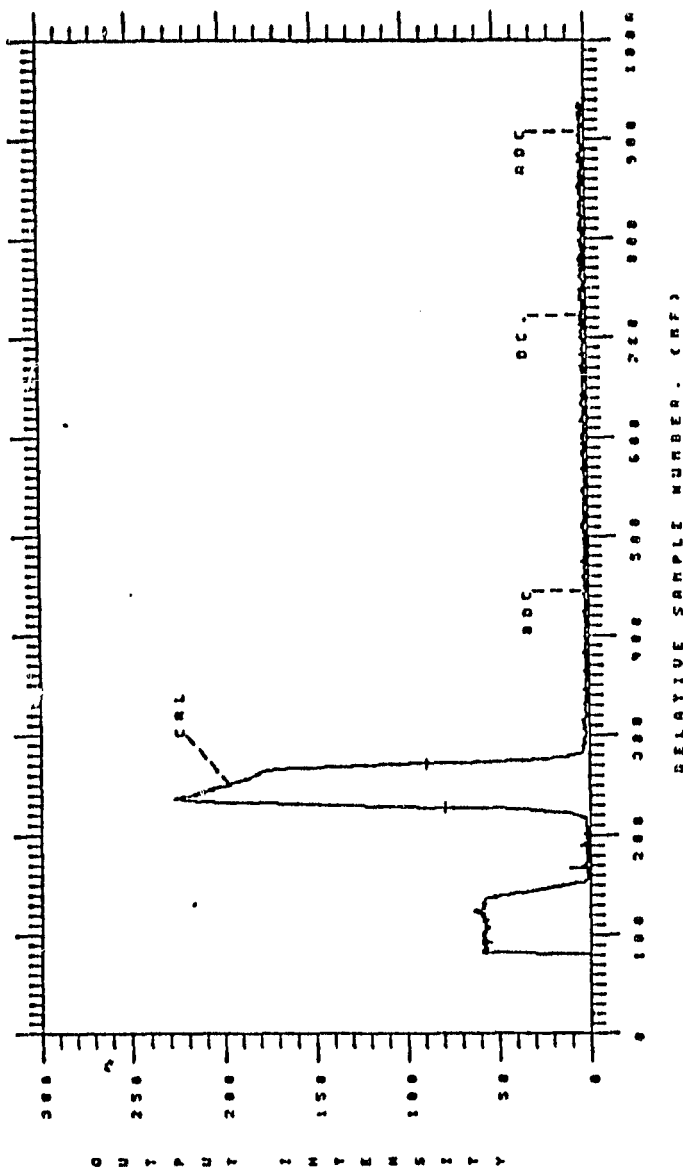
980

Figure 1b Reverse Scan data during obscuration
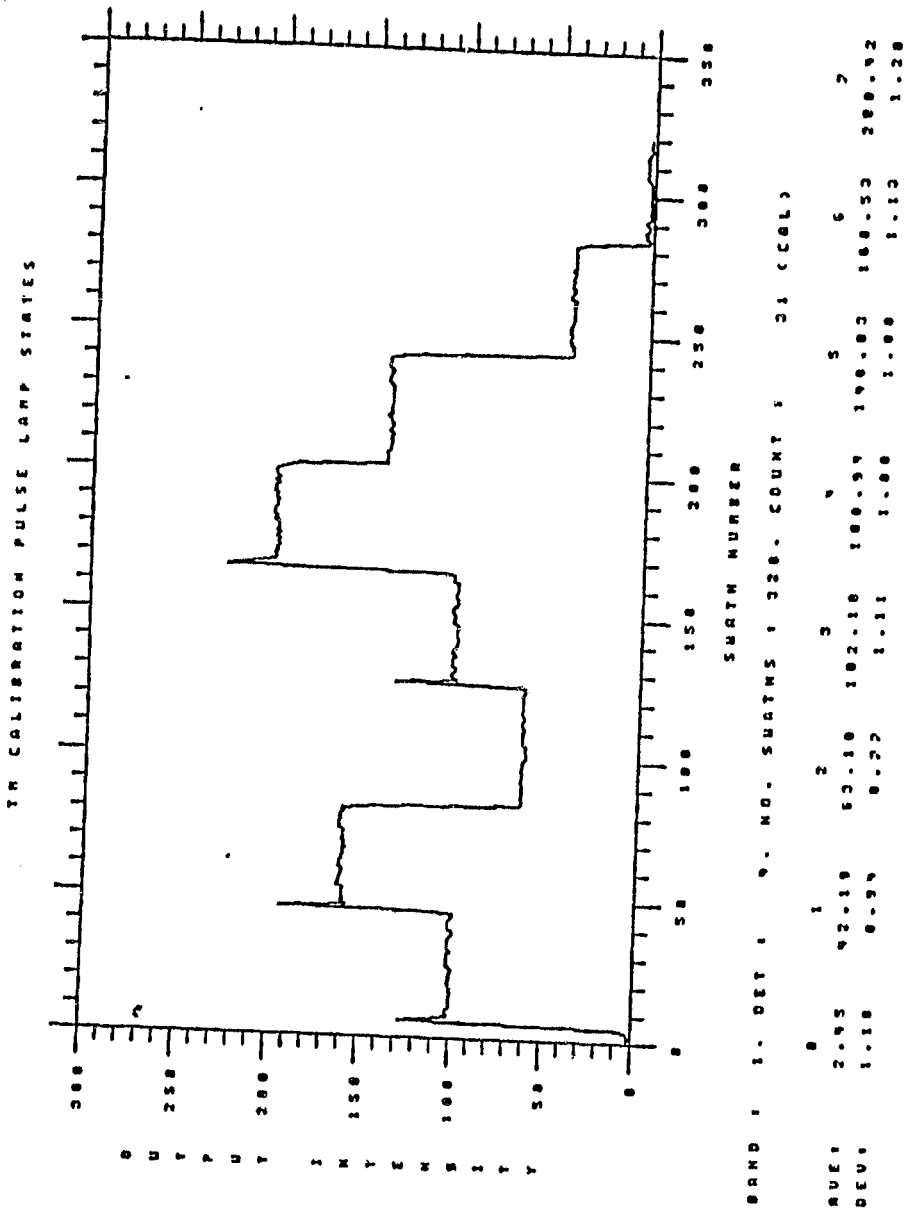
Figure 2   Representative calibration lamp state sequence for band 1, detector 4
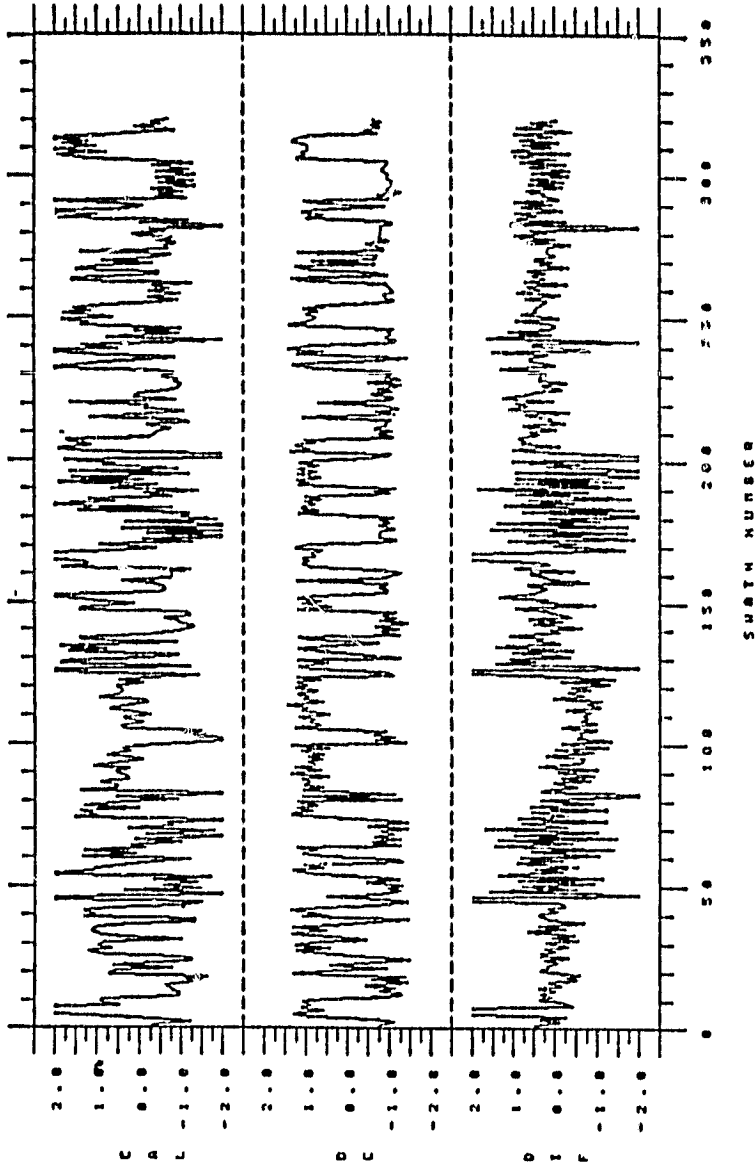
Figure 3   Calibration and DC Restore variation for
band 1, detector 4

Variations in averaged calibration pulse values as a function of
scan line number for detector 4 of band 1.
Plot 1 shows changes in averaged calibration pulse values
(CALSAM) represented as a deviation from the mean value for the
appropriate calibration state average.
Plot 2 shows changes in DC reference level using ADC for forward
scans and BDC for reverse scans.
Plot 3 shows changes in CALSAM after BDC (or ADC) has been
subtracted.

092
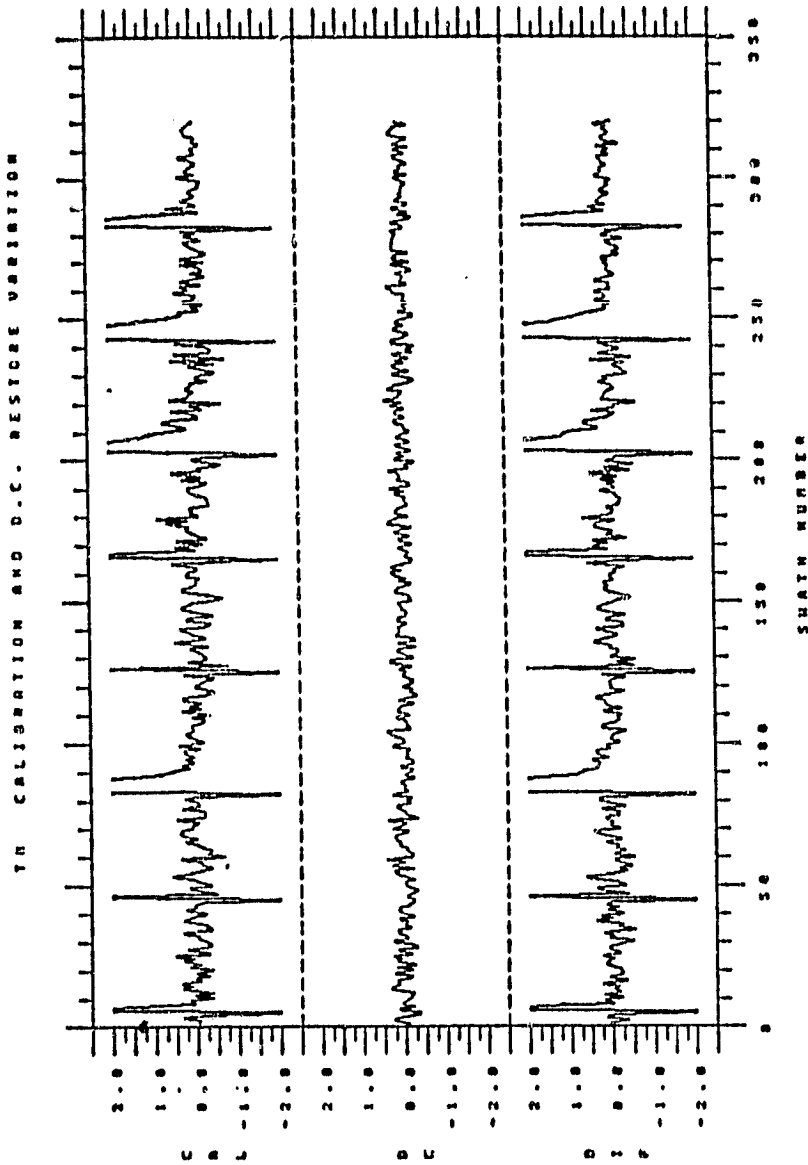
Figure 4   Calibration and DC Restore variation for
band 7, detector 13
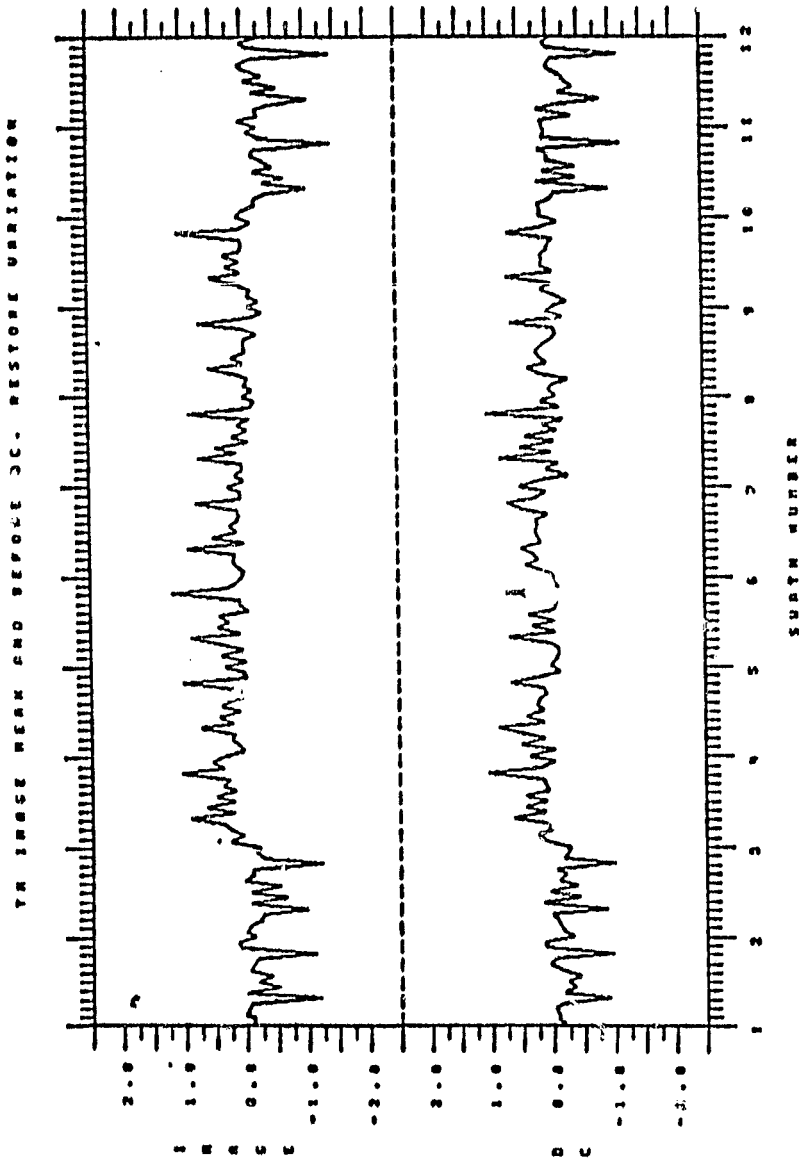
Figure 5   Image mean variation for all detectors of band 1

Figure 6   Image mean and DC Restore variation for band 1, detector 4

Variations in image data background level as a function of scan
line number for detector 4 of band 1.
Plot 1 shows changes in raw image data background level (RAW)
represented as a deviation from the mean value averaged over all
320 scans.
Plot 2 shows changes in DC reference level before DC restore
(BDC).
Plot 3 shows changes in RAW after BDC has been subtracted.

362

TM IMAGE MEAN AND BEFORE DC. RESTORE VARIATION

SWATH NUMBER
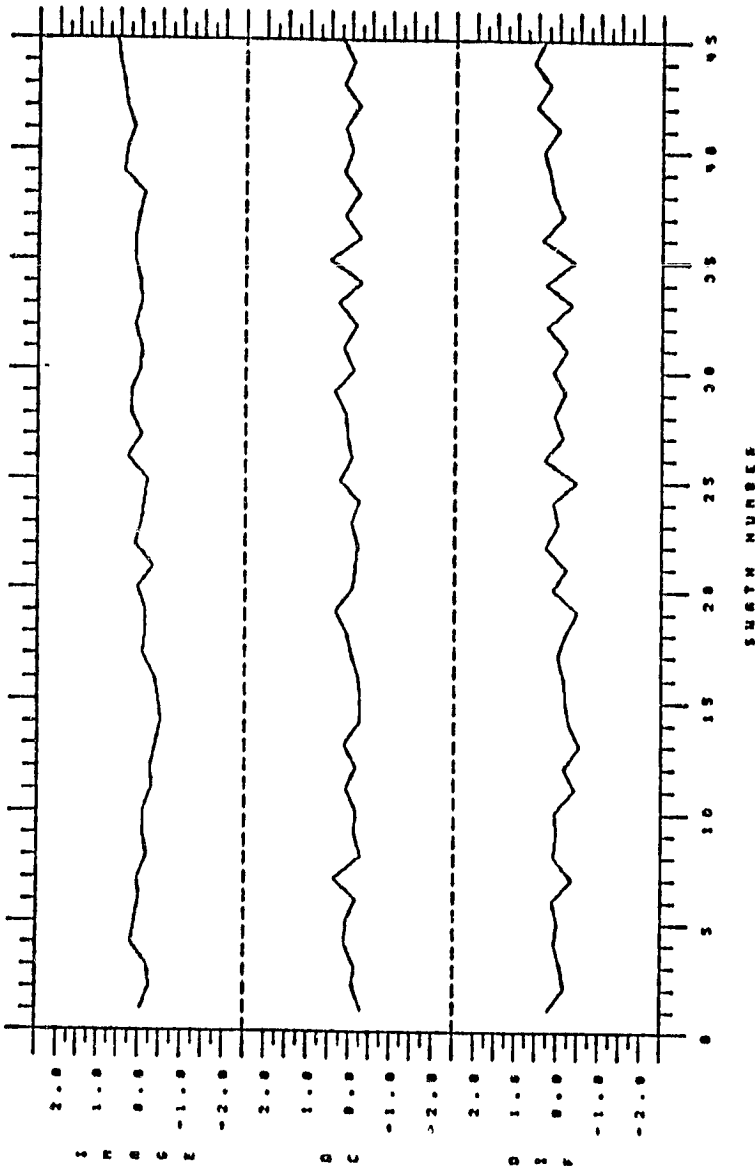
Figure 7   Image mean and DC Restore variation for band 1, detector 5
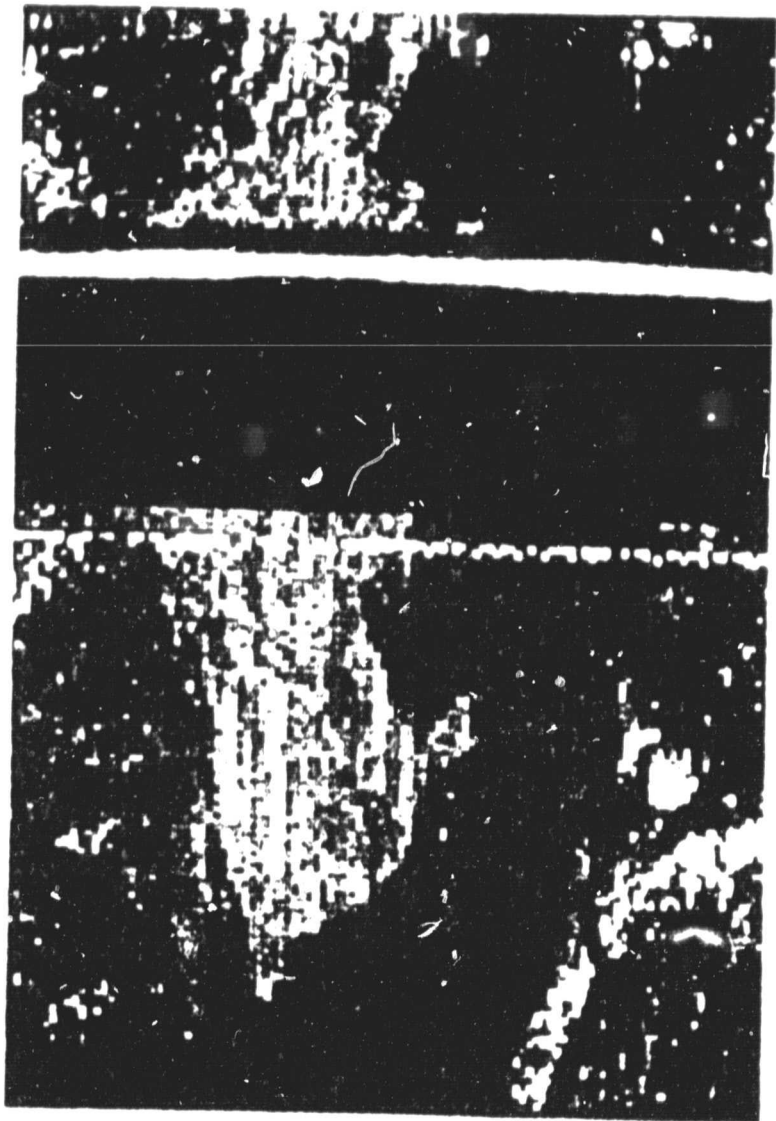
Figure 8   Display of band 7 detector 7 through the obscuration region

695
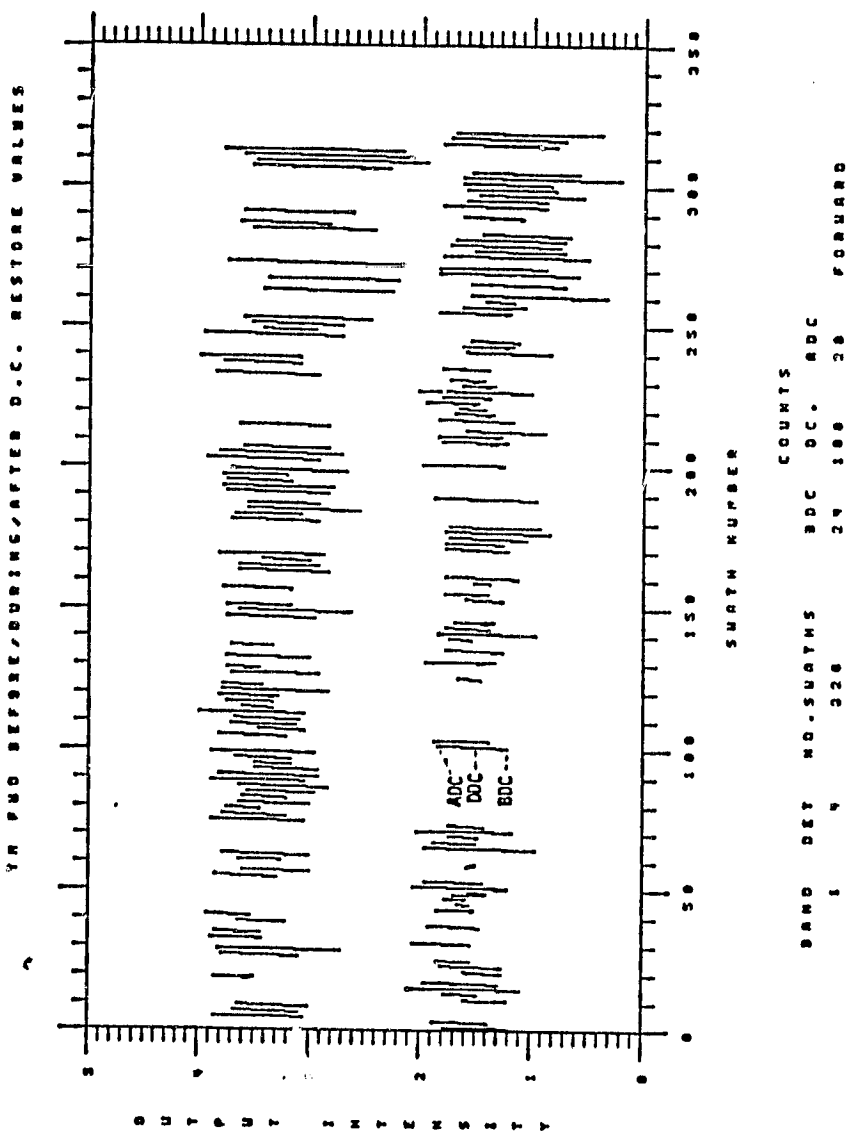

Figure 9   Plots of BDC, DDC and ADC as a function of
line number for band 1, detector 4

969

Figure 9   Plots of BDC, DDC and ADC as a function of
line number for band 1, detector 4
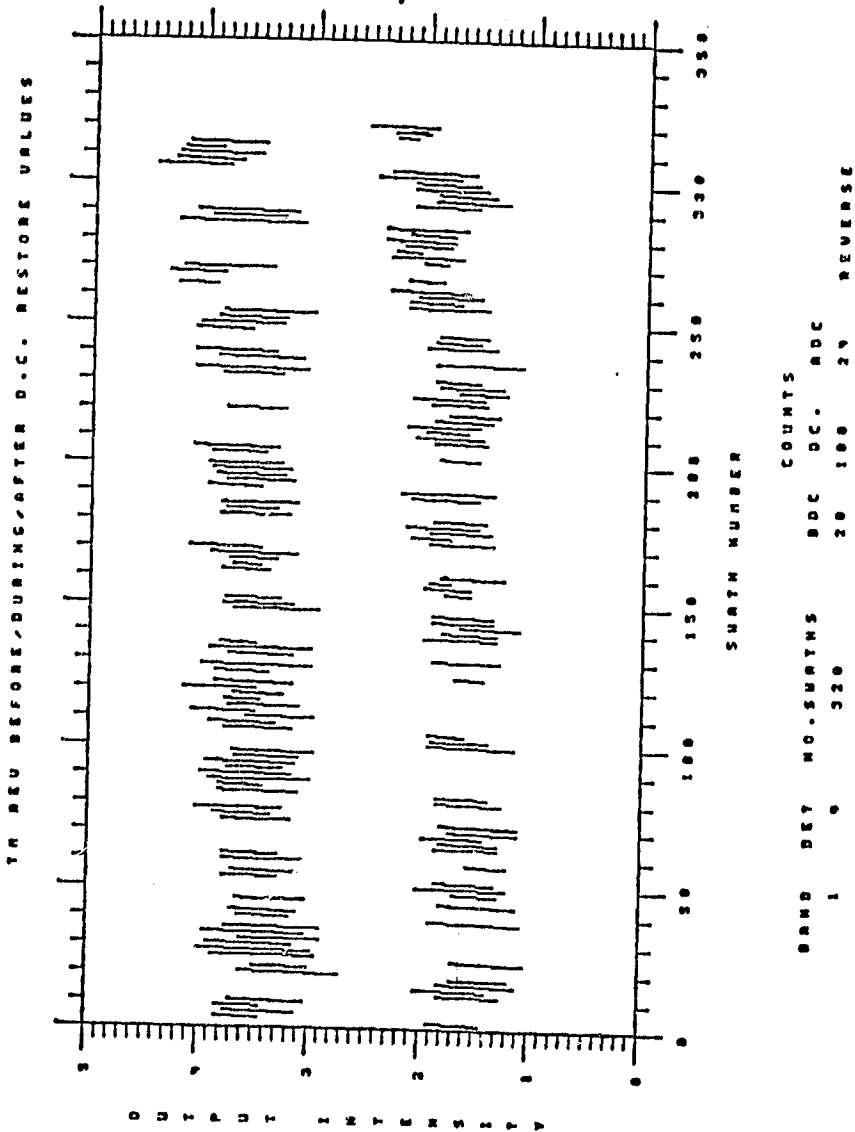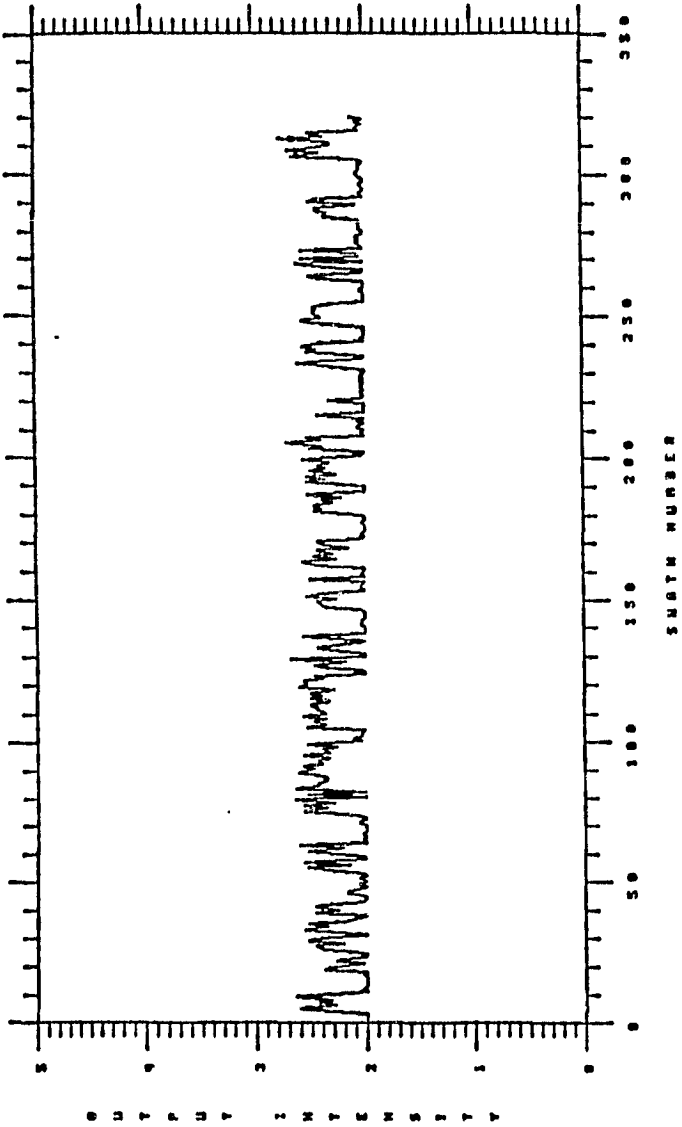
Figure 10 Plot of ADC for forward sweeps and BDC for reverse sweeps, for band 4, detector 16

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LANDSAT-4 MSS INTERBAND REGISTRATION

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Interband registration on raw LANDSAT-4 MSS data has been measured in the four MSS bands of the Mistassini scene (path-row 16-24, June 21, 1983). Statistical comparison between line-pixel locations of uniformly distributed ground control points in the four different bands permitted quantitative measures of the offset over the entire scene. The statistical distribution of the offset measures has also permitted to evaluate the standard error on the mean values, giving confidence on their precision.

In order to achieve precise offset measures, two different methods have been used to localize the control points. These are the manual GCP (Ground Control Point) extraction done on the CCRS Digital Image Correction System and the digital band-to-band correlation adapted from a digital stereographic correlation algorithm. The correlation matrix has been set to 13 lines by 13 pixels and different tests have been made on the correlation peak in order to prevent false correspondence.

The following table summarizes the results obtained from both methods. All band misregistrations are relative to band 1. Units are given in nominal interpixel and interline spacing of 57 m by 82.7 m. The pixel misregistration values are compared to the published figures (NASA).

TABLE 1. Interband line-pixel misregistration

BAND "N" RELATIVE TO BAND 1	LINE MISREGISTRATION	$(L \pm \sigma_L)$
	MANUAL GCP'S (SAMPLE SIZE)	DIGITAL CORRELATION (SS)
BAND 2 - BAND 1	0.10 ± 0.03 (98)	– – –
BAND 3 - BAND 1	0.10 ± 0.03 (98)	0.15 ± 0.01 (1681)
BAND 4 - BAND 1	0.10 ± 0.03 (98)	– – –

	PIXEL MISREGISTRATION	$(P \pm \sigma_P)$	
	MANUAL GCP'S (SS)	DIGITAL CORRELATION (SS)	POST LAUNCH OFFSET (NASA REV 7)
BAND 2 - BAND 1	1.91 ± 0.05 (98)	1.92 ± 0.01 (412)	1.95007
BAND 3 - BAND 1	3.97 ± 0.04 (98)	4.01 ± 0.01 (2648)	3.89084
BAND 4 - BAND 1	5.77 ± 0.04 (98)	5.74 ± 0.01 (1966)	5.84091

From these results, the following conclusions can be made.

- There is an agreement within 1σ between results obtained from the two line-pixel localization techniques. In all cases the digital correlation method gave the best offset measure due to the large sample size.

- There is a possible line misregistration of 0.10 pixel between band 1 and the other bands. There is no line misregistration between bands 2, 3 and 4.

- There is a divergence of 0.12 pixel (band 3) and -0.10 pixel (band 4) between the experimental pixel misregistration results and the published figures (NASA). No significant divergence has been found for band 2.

REFERENCE

NASA Goddard Space Flight Center, LANDSAT-4, To Ground Station Interface Description, Revision 7, August 1983, Page B-2.

LANDSAT-MSS MULTITEMPORAL REGISTRATION

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The multitemporal registration of LANDSAT-4 MSS products has been tested for two different geocoded subscenes acquired October 24, 1982 and July 7, 1983. They have also been compared with LANDSAT-2 MSS geocoded data acquired August 17, 1981. The geocoded subscenes correspond to the Ottawa area as DICS (CCRS Digital Image Correction System) products being geometrically corrected and resampled to 50 metre square pixels projected on the UTM grid. The subscenes extend over four 1: 50 000 scale National Topographic system maps. Each image is identified as:

    L4A:LANDSAT-4 MSS, path-row 16-28   Oct. 24, 1982

    L4B:LANDSAT-4 MSS, path-row 16-28   July 07, 1983

    L2: LANDSAT-2 MSS, path-row 17-28   Aug. 17, 1981

Statistical comparison between line-pixel locations of uniformly distributed ground control points in the three geocoded products permitted quantitative measure of the offset over the sub-scene. The statistical distribution of the offset measures has also permitted to evaluate the standard error on the mean values, giving confidence on their precision.

In order to achieve precise offset measures, two different methods have been used to localize the control points. These are the manual GCP (Ground Control Point) extraction done on the CCRS Digital Image Correction System and the digital band-to-band correlation adapted from a digital sterographic correlation algorithm. The correlation matrix has been set to 13 lines by 13 pixels and different tests have been made on the correlation peak in order to prevent false correspondence. Bands 2 and 4 have been used for the manual GCP extraction and band 4 only for the digital correlation.

The following table summarizes the results obtained from both methods. Units are given in resampled 50 metre square pixels.

TABLE 1. Multitemporal line-pixel misregistration

LANDSAT N RELATIVE TO LANDSAT M	LINE MISREGISTRATION $(L \pm \sigma_L)$	
	MANUAL GCP'S (SAMPLE SIZE)	DIGITAL CORRELATION (SS)
L4A - L4B	-0.17 ± 0.16 (21)	- - -
L4A - L2	-0.21 ± 0.13 (21)	- - -
L4B - L2	-0.04 ± 0.15 (21)	-0.38 ± 0.03 (393)

	PIXEL MISREGISTRATION $(P \pm \sigma_P)$	
	MANUAL GCP'S (SS)	DIGITAL CORRELATION (SS)
L4A - L4B	-0.89 ± 0.15 (21)	-0.75 ± 0.05 (625)
L4A - L2	-0.41 ± 0.22 (21)	-0.23 ± 0.05 (817)
L4B - L2	+0.46 ± 0.17 (21)	+0.52 ± 0.02 (1092)

From these results, the following conclusions can be made.

- There is an agreement within 2 σ between results obtained from the two line-pixel localization techniques. In all cases the digital correlation method gave the best offset measure due to the large sample size.

- There is a line misregistration of -0.38 pixel between LANDSAT-4B and LANDSAT-2 geocoded products.

- There is a significant pixel misregistration

  - of -0.75 pixel between LANDSAT-4A and 4B geocoded products
  - of -0.23 pixel between LANDSAT-4A and 2 geocoded products
  - of 0.52 pixel between LANDSAT-4B and 2 geocoded products

These line and pixel misregistrations are mainly due to local residual offsets as the geometric correction model is adjusted not only to the geocoded product area but to the entire LANDSAT scene.