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RDS RESEARCH AND DATA SYSTEMS, INC.
10300 GREENBELT ROAD, SUITE 206, LANHAM, MARYLAND 20706 (301) 390-6100

An Analysis of New Techniques for Radiometric Correction of LANDSAT-4 Thematic Mapper Images

An Analysis of New Techniques for Radiometric Correction of LANDSAT-4 Thematic Mapper Images

Prepared For

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Prepared By

John Kogut
Eliane Larduinat
Maureen Fitzgerald

Research and Data Systems, Inc.
10300 Greenbelt Rd.
Lanham, MD 20706

One of the primary objectives of this task is to investigate the utility of new methods for generating TM RLUTS which will improve the quality of the resultant images. Toward that end, various techniques for reducing detector to detector striping, and forward and reverse scan banding which were observed in early TM images were investigated. These investigations for the most part centered upon understanding the behavior of the TM calibration procedure, and in particular how the data taken when the detectors viewed the TM calibration lamps and shutter could be used to improve the operational algorithms for computing detector gains and biases.

The contents of the TM CCT-ADDS tape were changed for data processed after April 27, 1983 to take into account the new collection window for the calibration data. For all tapes received after that date the shutter and calibration data are formatted as follows:

A raw video scan contains scene data, data from when the detectors see the shutter, data from the shutter when the DC restore circuits are working, more shutter data, data from when the detectors view the calibration lamps, and then more shutter data. The amount of each type of data for forward and reverse scans is arranged as follows:

Forward (odd numbered) scans

148 Pixels of lamp data (CAL)
24 Pixels of shutter data before DC restore (B)
28 Pixels of shutter data after DC restore (A)

Reverse (even numbered) scans

148 Pixels of lamp data (CAL)
24 Pixels of shutter data after DC restore (A)
28 Pixels of shutter data before DC restore (B)

Figure 1 shows a schematic of this data format.

The calibration file contains 32000 byte physical records, with each physical record containing 844 byte quad records. Each quad record contains a 4 byte field and 4 records at 210 bytes each. The residual bytes in the physical record are filled with a hex value of 4E.

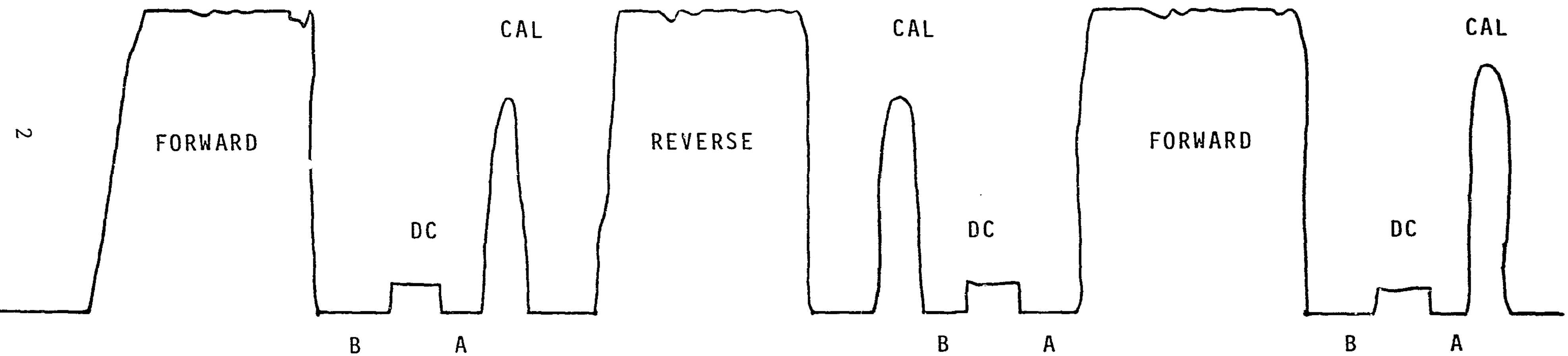


FIGURE 1 - DATA COLLECTION FORMAT FOR THE CCT-ADDS

Several scenes with data in this format have been analyzed in order to evaluate the utility of the radiometric corrections operationally applied to the image data, and to investigate several techniques for reducing striping in the images.

January 6, 1983; Terrebonne Bay, LA Scene (W022040)

Band 1

Analysis of the Calibration Data

Printer plots of the TM shutter data were produced and detector statistics were compiled and plotted. These statistics included various combinations of the average shutter counts for each scan before (SB) and after (SA) DC restore for forward (ODD) and reverse (EVEN) scans.

The main conclusions of this analysis were:

1. The absolute value of the average shutter counts before and after DC restore seem to be correlated with the brightness of the image for that band.

2. For detectors 4 and 12 both SA and SB averages appear to be locked into states about +1 and -1 count above and below the scene average. This effect is also observed to a lesser extent (0.5 count) for detectors 8 and 10. This observation is consistent with those reported by others (1).

3. The average value for detector 1 is consistently higher than for the rest of the detectors, and SA is consistently larger than SB.

Appendix A gives details of this analysis.

Intrusions of the image into the calibration data were observed for detectors 15 and 16, and to a lesser degree for detector 14. They occurred at the beginning of the calibration window for forward scans and at the end for reverse scans. They were generally limited to less than 10 observation points. When data which contained these intrusions was used in subsequent analyses, the image intrusion data was screened out.

Radiometric Correction Analysis

A number of mehods for decreasing image striping were investigated and applied to this scene, including:

- All detector gains set equal to 1.0 and scan dependent biases
- Scan dependent gains and biases
- Prelaunch gains, and scan dependent biases

The technique which produced the best results is described below.

Methodology

For a given region of N pixels in a TM raw image let:

$$r_{de} = \frac{1}{N} \sum \left[\frac{M_{i,j,d} - B_{j,d}}{G_d} \Bigg/ \frac{G_e}{M_{i,j,e} - B_{j,e}} \right] \quad (1)$$

Where

$M_{i,j,d}$ = The digital value for pixel i, scan j, detector d.

$B_{j,d}$ = The bias for scan j, detector d.

G_d = The scan independent gain for detector d.

If we rewrite (1) as

$$r_{de} = \frac{G_e}{G_d \; N} \sum \left[\frac{M_{i,j,d} - B_{j,d}}{M_{i,j,e} - B_{j,e}} \right] \quad (2)$$

which is the ratio of the true gains for any two detectors d and e, then we can assume that :

$$r_{d,e} = 1 \quad (3)$$

If we define the gain for detector 9 as being 1.0 then

$$G_d = \frac{1}{N}\sum\left[\frac{M_{i,j,d} - B_{j,d}}{M_{i,j,9} - B_{j,9}}\right] \qquad (4)$$

the quantity

$$\frac{1}{N}\sum\left[\frac{M_{i,j,d} - B_{j,d}}{M_{i,j,9} - B_{j,9}}\right]$$

is the average value over the homogeneous region of the ratio of detector d to detector 9 for an image corrected with the biases $B_{j,d}$, and constant gains equal to 1.00 for all detectors. The biases for each detector are computed for each scan in the scene from the shutter data before and after DC restore.

Algorithm for Radiometric Correction

1. The raw TM image is corrected using a constant gain equal to 1.0, and scan dependent biases which for scan j and detector d is:

$$B_{j,d} = \frac{1}{2}\left(SA_{j-1,d} + SB_{j,d}\right) \qquad (5)$$

2. Using the DCOPY program, an image is made for each detector in a homogeneous test region. The ratio of each detector to detector 9 is computed using the DIVPIC program. The average detector ratio over the test region is computed using program LIST. These average ratios are then taken as the gain for each detector.

3. New support files are produced using the scene dependent gains and the scan dependent biases.

4. The RADCOR program is used to produce a radiometrically corrected image from the raw images and the gains and biases computed above.

The Band 1 part of Figure 2 shows the average detector data numbers for a homogeneous water window of this scene when the gains and biases are computed using this method. As can be seen, the difference among all detectors is less than 0.25 counts.

Band 6

Several methods of performing radiometric correction to minimize striping were investigated for Band 6. All the methods involved determining differences in the Band 6 geometric correction factors (β_d) by analyzing homogeneous regions of nighttime thermal TM scenes. The method which produced the best results is given below.

Methodology

Differences in gain between detectors were attributed to different geometrical scaling factors (β_d) for each detector. In order to evaluate β_d for each detector the gain and bias for Band 6 are given as:

$$G_{j,d} = \beta_d \frac{N2-N1}{255} FBB_{j,d} \qquad (6)$$

$$B_{j,d} = CS_{j,d} - \left(0.9NS - 0.19\right) FBB_{j,d} + N1\, \beta_1\, FBB_{j,d} \qquad (7)$$

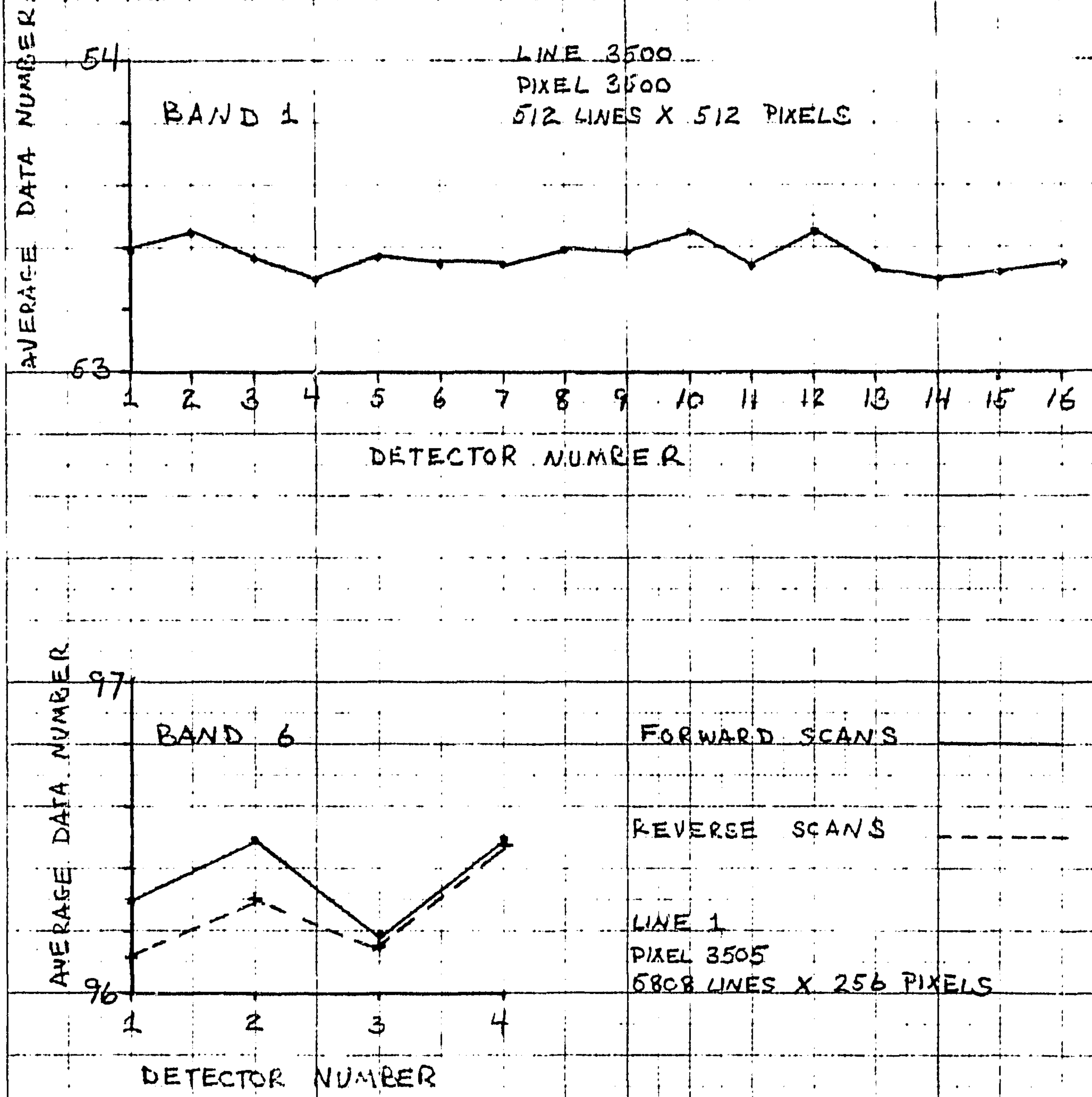
Where:

$FBB_{j,d}$ = Internal gain for scan j, detector d

$CS_{j,d}$ = Shutter counts for scan j, detector d

FIGURE 2 - AVERAGE DATA NUMBER VALUES FOR HOMOGENEOUS WATER WINDOWS

JANUARY 6, 1983 TERREBONNE BAY, LA SCENE



N1, N2 = Spectral radiances at the limits of the detector's response

If $M_{i,j,d}$ is the digital value for pixel i, scan j, and detector d for the raw image, then :

$$DN_{i,j,d} = \frac{M_{i,j,d} - B_{j,d}}{G_{j,d}} \quad (8)$$

$$DN_{i,j,d} = \frac{1}{\beta_d} \frac{255}{N2 - N1} \left[\frac{M_{i,j,d} - CS_{j,d}}{FBB_{j,d}} + \left(0.9NS - 0.19\right) \right] - \frac{255\,N1}{N2 - N1} \quad (9)$$

If we assume that $FBB_{j,d}$ is scene dependent and equal to the average over the entire scene, and that CS is essentially constant, then over a large region R of the image the average counts measured by all detectors will be roughly equal, that is:

$$\langle DN_{i,j,d} \rangle = \langle DN_{i,j,e} \rangle \quad (10)$$

over the large region of interest.

Then:

$$\langle DN_{i,j,d} \rangle = \frac{1}{\beta_d} \frac{255}{N2-N1} \left[\frac{1}{K} \sum \frac{M_{i,j,d} - CS_{j,d}}{FBB_{j,d}} + 0.9NS - 0.19 \right] - \frac{255}{N2-N1} \quad (11)$$

and

$$\frac{\beta_d}{\beta_e} = \left[\frac{\dfrac{\langle M_{i,j,d} \rangle - CS_d}{FBB_d} + 0.9NS - 0.19}{\dfrac{\langle M_{i,j,e} \rangle - CS_e}{FBB_e} + 0.9NS - 0.19} \right] \quad (12)$$

The β coefficients are calculated as follows:

Detector 2 is taken as the standard and its β value is set to 0.725

The average shutter count (CS_d) and internal gain (FBB_d) are computed for each detector over the entire scene.

The average digital value measured by each detector $\langle M_{i,j,d} \rangle$ over a large region of the scene (256 x 5632 pixels) is computed for the raw image using programs DCOPY, DIVPIC, and LIST.

Using this technique the β values for this image were found to be:

DET	β
1	0.713135
2	0.725000
3	0.714003
4	0.722340

The radiometric corrections to the image were made as follows:

The average internal gain FBB_d for each detector was calculated as the average over all scans of $FBB_{j,d}$.

$$FBB_{j,d} = (CB - CS)_{j,d} / (NB - NS) \tag{13}$$

Where

EVEN SCANS $$(CB - CS)_{j,d} = \frac{1}{2}\left(CB_{j-1,d} - SA_{j-1,d} + CB_{j,d} - SB_{j,d}\right) \tag{14}$$

ODD SCANS $$(CB - CS)_{j,d} = \frac{1}{2}\left[(CB - CS)_{j-1,d} + (CB - CS)_{j+1,d}\right] \tag{15}$$

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The gains and biases for each detector are calculated from:

$$G_d = \left(\frac{N2 - N1}{255}\right) \beta_d \, FBB_d \qquad (16)$$

$$B_{j,d} = CS_{j,d} - KC_j + N1 \, \beta_d \, FBB_{j,d} \qquad (17)$$

where:

$$CS_{j,d} = \frac{1}{2}\left(SA_{j-1,d} + SB_{j,d}\right) \qquad (18)$$

$$KC_j = (0.9NS - 0.19) \, FBB_{j,d} \qquad (19)$$

The average digital values measured by each detector were calculated for the large test region of the image using the gains and biases computed this way and are given in the Band 6 part of Figure 2.

Differences between the average detector values for forward and reverse scans which are observed here, and which appear greater in other scenes are the subject of further investigation.

January 14, 1983 <u>Grand Bahamas Scene (W014042)</u>

The procedure used for Band 1 in the Terrebonne Bay Scene was tested for all the reflective bands for this scene. It worked well for Bands 1 through 4, but for Bands 5 and 7 the digital counts in the scene are small (of the order of 5 counts with many zeros) so that the DIVPIC program could not be used to compute the gains for these bands. For bands 5 and 7 then, the detector biases were computed as in the other reflective bands. But the gains were calculated using data taken when the detectors viewed the calibration lamps.

Using this method the gain for any detector is given as

$$G_d = \frac{\sum_{\ell=1}^{7} SIG_{d,\ell} / L_\ell}{\sum_{\ell=1}^{7} LEV_{d,\ell}} \qquad (20)$$

where:

$SIG_{d,\ell}$ = The sum over all scans in calibration lamp level of the average calibration peak count minus the bias for that scan.

$LEV_{d,\ell}$ = The expected digital count for lamp state and detector ℓ, d.

L_ℓ = The number of scans in lamp state ℓ.

For Band 6 the procedure was identical as that used for the Terrebonne Bay Scene, including using the same β coefficients.

The gains which were calculated for all bands for this scene are given in Table I.

TABLE I

COMPUTED GAIN FOR THE GRAND BAHAMAS SCENE

GAINS FOR THE REFLECTIVE BANDS

DET	BAND 1	BAND 2	BAND 3	BAND 4	BAND 5	BAND 7
1	1.005	0.983	0.987	0.990	0.925	0.946
2	1.015	0.993	1.002	0.994	0.933	0.969
3	1.020	0.990	0.988	0.984	1.000	0.951
4	1.021	1.128	0.996	0.989	0.921	0.962
5	1.012	1.015	0.999	0.962	0.914	0.935
6	1.005	1.005	0.996	1.010	0.936	0.963
7	0.995	0.998	0.994	0.985	0.934	0.965
8	1.006	0.994	0.974	0.937	0.940	0.947
9	1.000	1.000	1.000	1.000	0.930	0.951
10	1.011	0.992	0.999	1.033	0.923	0.961
11	1.005	0.996	0.983	1.007	0.940	0.950
12	1.011	0.985	1.001	0.949	0.950	0.965
13	1.011	1.005	0.990	0.967	0.929	0.954
14	1.013	1.003	0.984	0.951	0.937	0.948
15	1.023	1.010	0.991	0.932	0.924	0.944
16	1.026	0.989	0.985	0.978	0.950	0.975

Band 6 Geometrical Scaling Factor β and Average Internal Gain FBB

DET	β	FBB
1	0.7131	284.940
2	0.7250	292.346
3	0.7140	280.984
4	0.7223	296.132

New support files for all seven TM bands were produced for this scene using the procedures outlined above for the reflective and thermal bands. The resulting support files were applied to the B data for this image by replacing the operational SCROUNGE procedure TMHIST, RLUT, and RADIOM programs with the RADCOR program. This new procedure for producing a radiometrically correct image was called PSEUDO-SCROUNGE.

Although the gains for this scene were computed from the image data using the DIVPIC program, Table II shows that they are very close to the gains calculated for the Terrebonne Bay Scene. The maximum difference between the two sets of gains is about 0.5% which translates into a difference of less than 1 count for image pixel values of 200. The fact that the difference between Band 1 gains computed independently for the two scenes were small indicates that it will be possible to apply one set of gains to subsequent scenes and not have to recompute new gains for each new scene.

The radiometrically corrected images for all bands were analyzed for the Grand Bahamas Scene and the preliminary conclusions were as follows:

1. Detector to detector striping was generally reduced for bands 1,2,4, and 6.

2. The detector striping in Band 3 was reduced overall, however a crosshatching pattern with pixel values about 2 counts higher than neighboring detectors was observed for detector 1.

3. Computing the gains for Bands 5 and 7 using the method outlined above resulted in a more striped final image. Because of this, it was decided that for future PSEUDO SCROUNGE runs the detector gains and offsets which are computed by TIPS will be used for Bands 5 and 7.

An anomalous scan to scan banding which occurred near large bright targets was observed in Bands 1,2,3,and 4 for this scene. It appeared that after the detectors had viewed a large cloud, the brightness for the subsequent pixels in the scan was lower than for the corresponding pixels in the scans before and after. Several regions of the radiometrically corrected image were examined in detail and the general pattern which was observed is shown in Figure 3. In addition, the following features of this phenomenon were observed:

TABLE II

COMPARISON OF THE GAINS FOR BAND 1 CALCULATED INDEPENDENTLY FOR THE TERREBONNE BAY AND GRAND BAHAMAS SCENES

DET	TERREBONNE BAY	GRAND BAHAMAS	% DIFFERENCE
1	1.00846	1.00473	0.37
2	1.01838	1.01492	0.34
3	1.02318	1.02029	0.28
4	1.01529	1.02080	0.54
5	1.01425	1.01192	0.23
6	1.00759	1.00499	0.26
7	0.99696	0.99502	0.19
8	1.00754	1.00625	0.13
9	1.00000	1.00000	0.00
10	1.01127	1.01098	0.03
11	1.00677	1.00503	0.17
12	1.00791	1.01089	0.29
13	1.01210	1.01072	0.14
14	1.01495	1.01330	0.16
15	1.02584	1.02265	0.31
16	1.02745	1.02654	0.09

1. The difference in pixel values between a bright scan and the following dark scan is of usually between 2 to 4 counts.

2. The lower pixel brightness is discernable for up to about 1000 pixels after the bright target region has last been viewed.

3. Data taken during the period when the detectors view the TM shutter seem to be affected by the presence of bright targets, with the noisiest areas of the shutter data corresponding to portions of the image which contain large bright targets such as clouds.

These observations indicate that this striping is caused by the detectors becoming saturated when they view a bright cloud, and depress the DC restore level. This reduces the bias for scans containing a bright cloud, and striping occurs.

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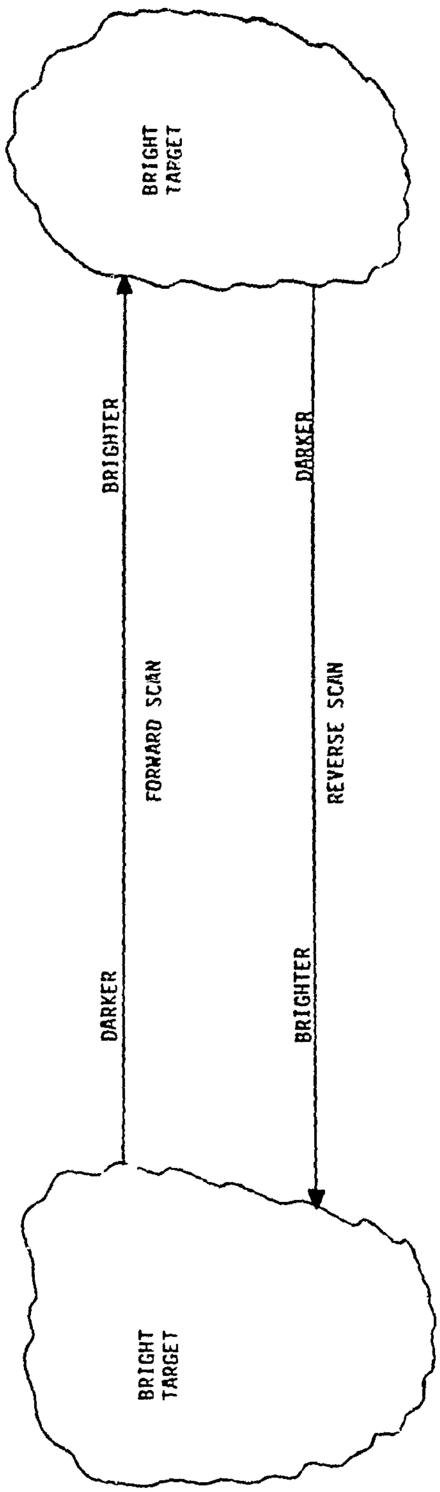


FIGURE 3 - BRIGHT TARGET SCAN TO SCAN BANDING

References

1. Study of Spectral/Radiometric Characteristics of the Thematic Mapper for Land Use Applications, W.A. Malila, and M.D. Metzler, ERIM Report NO. 164000-3-T, June 30, 1983.

APPENDIX A

ANALYSIS OF THE NEW SHUTTER DATA FOR SEVERAL TM SCENES

Statistics for various combinations of TM shutter or background data from the new collection window are computed by the BACH software. Twelve seperate parameters are computed for each detector and scan in a TM scene, as well as scene statistics for each detector. The shutter average, S, is computed as the mean of the 16 points before (SB) or the 16 points after (SA) the DC restore window. Different combinations of odd (forward) scan, SOB, SOA; and even (reverse) scan SEB, SEA shutter data averages were combined to form the shutter data parameters.

Printer plots of the 12 shutter data parameters are produced from BACH and give every parameter for each scan, or scan pair. In addition BACH computes, for every detector and every parameter, the scene average, standard deviation, the minimum and maximum, and where they accurred, and the parameter range.

<u>January 6, 1983 TERREBONNE BAY, LA SCENE</u> (W022040)

Shutter data for TM Band 1 and Band 6 for the January 6, 1983 Terrebonne Bay, LA scene were analyzed using BACH.

<u>Band 1</u>

Inspection of the printer plots of the 12 shutter data parameters for this scene indicated the following:

- o The values of SOB, SOA, SEA; and the SB, SA sequence seem to show variations as a function of scan which follow the brightness of the image data for this scene.
- o For a number of scans in the scene the shutter counts for detectors 4 and 12 are about 2 counts higher than the average for the rest of the scene. The same pattern of this "noise" is also seen for detectors 8 and 10, but the magnitude is only about 0.5 counts.

Figures A-1 and A-2 show the average of each of the shutter parameters for each detector for this scene. The X axis in each graph is detector number and the Y axis is average counts. These plots show that for Band 1:

- o Detector 1 is consistently about 0.5 counts higher than the other detectors.

FIGURE A-1 - BAND 1 AVERAGE SHUTTER PARAMETERS JAN 6, 1983 TERREBONNE BAY SCENE

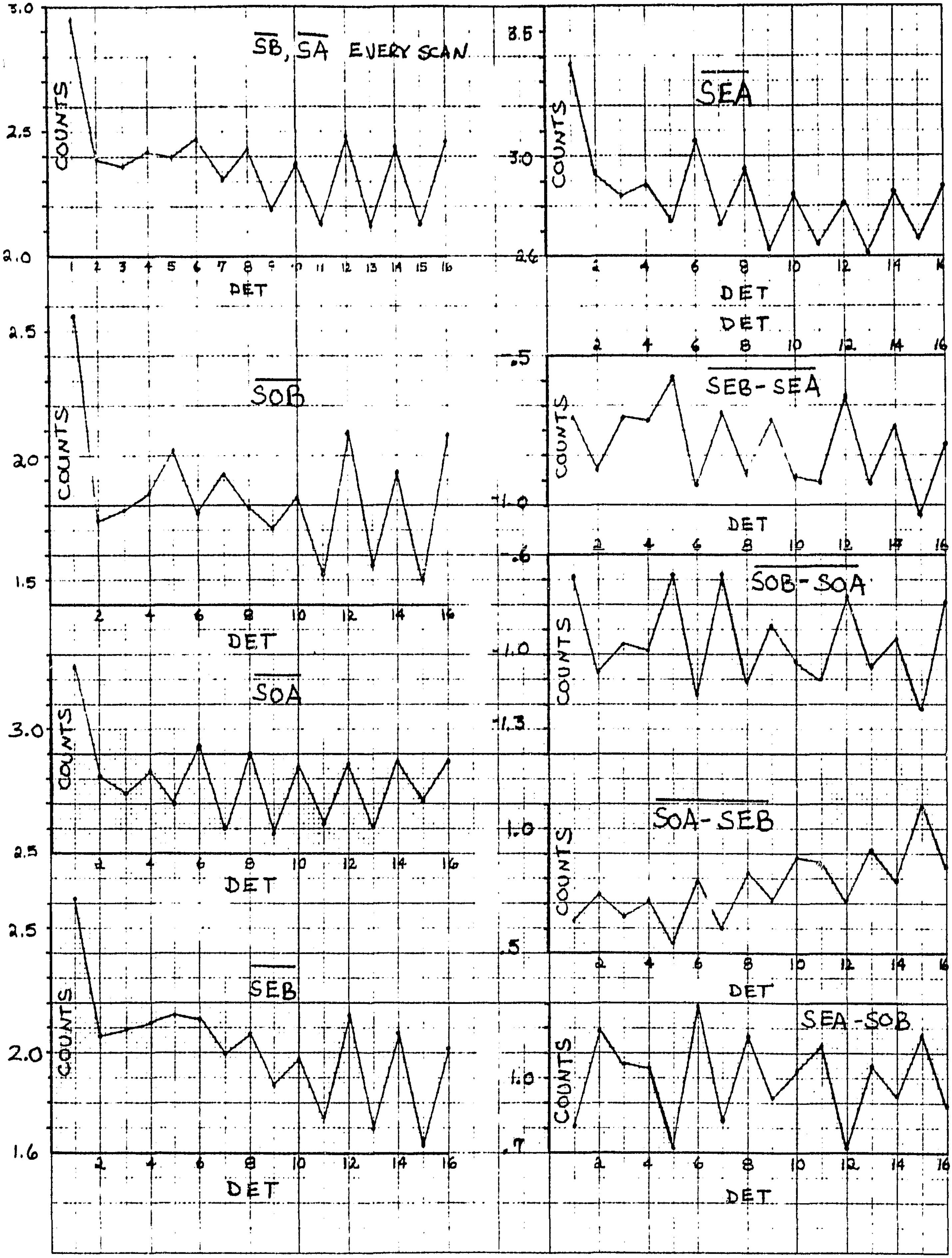
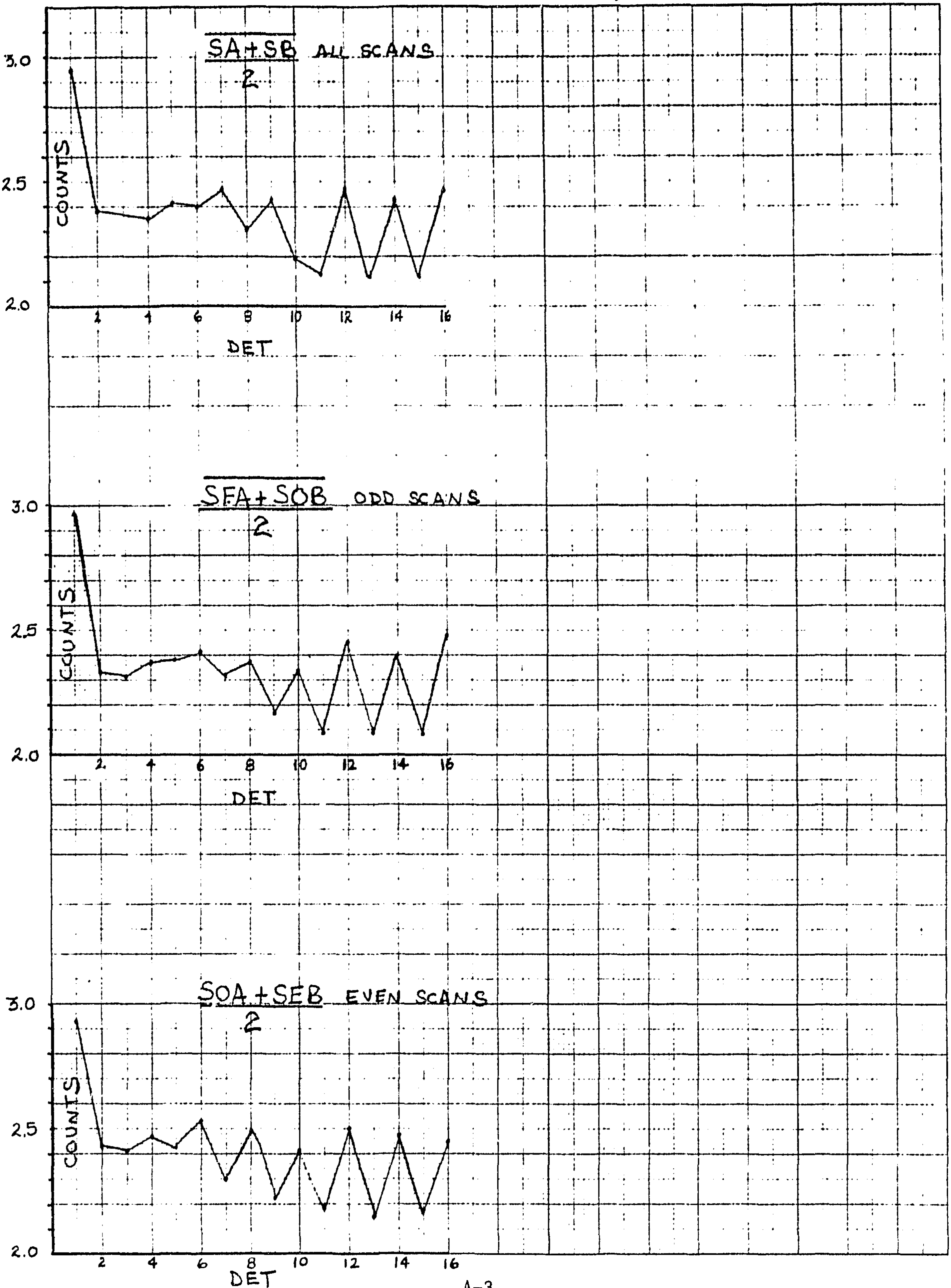


FIGURE A-2 - BAND 1 AVERAGE SHUTTER PARAMETERS JAN 6, 1983 TERREBONNE BAY SCENE



- Systematic differences in shutter counts between odd and even detectors are visible. The difference between odd and even detectors appears to become greater with increasing detector number.

- The droop over forward scans (SEA - SOB) averages to about 1 count, and droop over reverse scans SOA - SEB averages to about 0 8 count. Scan to scan droop over reverse scans appears to increase with detector number, but this may be related to the detectors viewing the calibration lamps between the time SOA and SEB are measured.

- For both odd and even scans the average of the shutter counts after the DC restore region, SA, is greater than the average before, SB. For even scans the mean difference is about 0.8 counts, and for odd scans the mean difference is about 0.9 counts.

Band 6

Inspection of the printer plots of the shutter parameters show that there is a variation in the shutter parameters that is smaller than that in Band 1, but which is also a function of the scan number in the scene; and which may reflect the image data in the scene. Figures A-3 and A-4 show the plots of the detector averages of the shutter parameters for Band 6. These plots indicate:

- o The difference between the shutter values for detector 1 and the average of the other 3 detectors is usually considerably greater than the differences among detector 2, 3, and 4. That is, detector 1 seems to be behaving differently from the other three.

- o Scan to scan droop for forward scans averages to about -0.01 counts, but the droop for detector 1 is to +0.02 counts and the average for detector 2, 3, and 4 is -0.02 counts. The mean droop for reverse scans is -0.12 counts.

- o For even scans the difference is shutter counts before and after the DC restore period is about 0.11 counts for even scans. For odd scans this average difference is +0.18 counts. The average difference for detectors 2, 3, and 4 is +0.29 counts while the difference for detector 1 is negative.

FIGURE A-3 - BAND 6 AVERAGE SHUTTER PARAMETERS JAN 6, 1983 TERREBONNE BAY SCENE

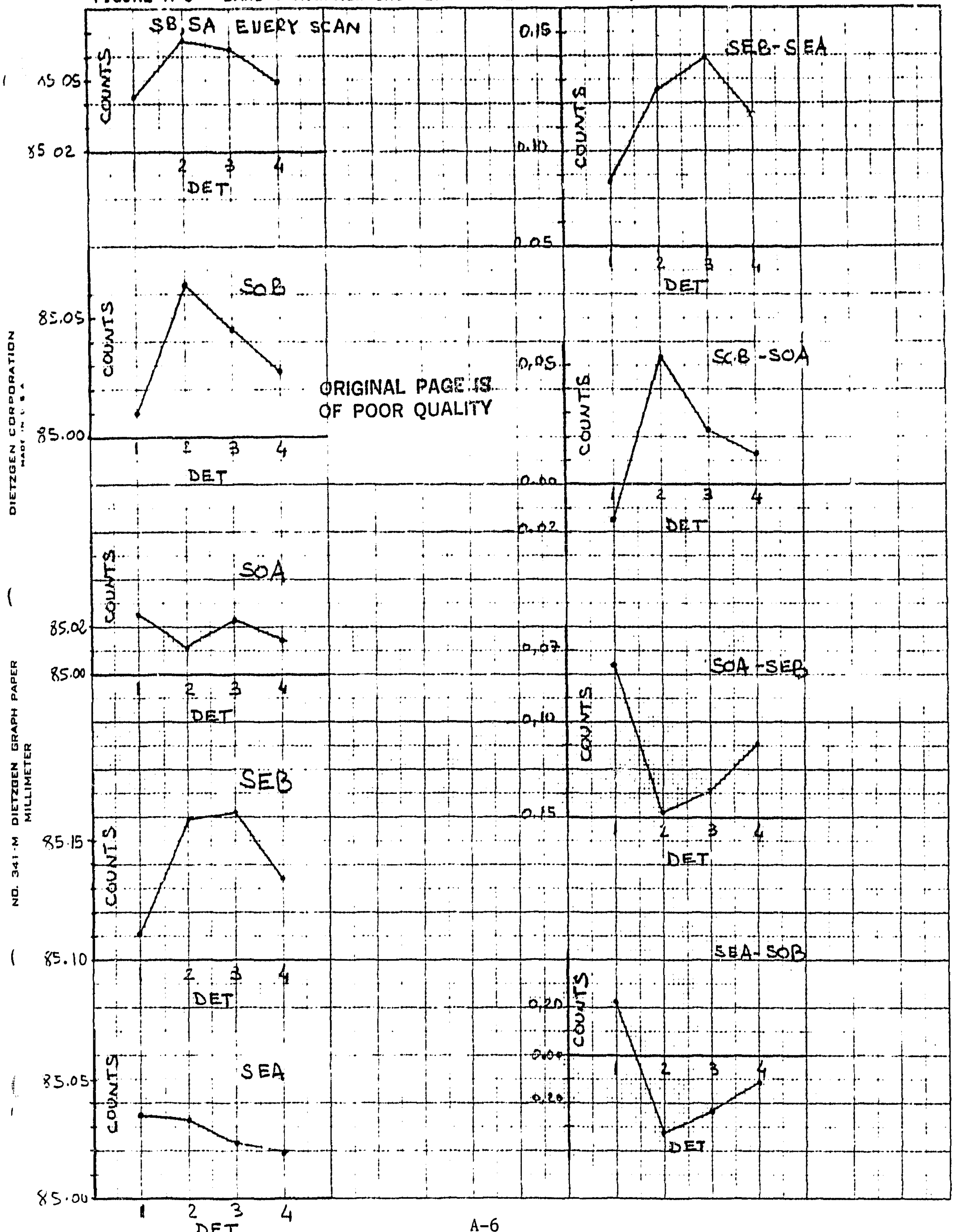
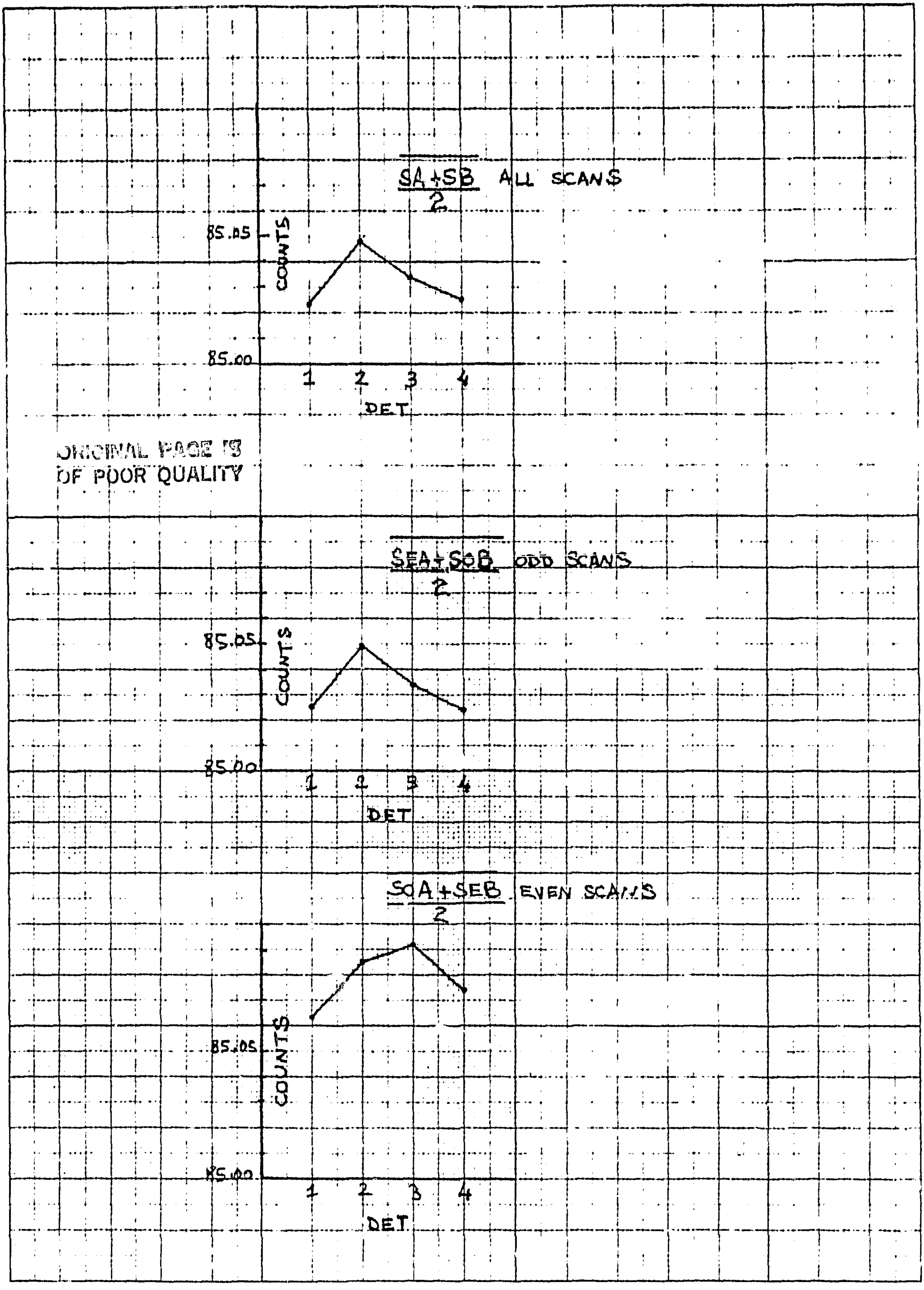


FIGURE A-4 - BAND 6 AVERAGE SHUTTER PARAMETERS JAN 6, 1983 TERREBONNE BAY SCENE



Scene Shutter Data Analysis

Plots of the average shutter data before (SB) and after (SA) the DC restore period for each TM scan were produced and evaluated for three scenes for which the new images have not yet been produced. These are images of San Francisco, Norman, AR ; and the Atlantic off Virginia. A brief description of the preliminary analysis of this data for the reflective bands follows:

Band 1:

The shutter counts for detectors 4 and 12 appear to be locked into two separate states about 2 counts apart for both SB and SA. This effect was observed previously for the Terrebonne Bay Scene, but was not present in the Grand Bahamas Scene. The same effect is observed in detectors 8 and 10 but the states are about 1 count apart. Detector 1 is higher on average than the other detectors by about 0.5 count, and SA is consistantly about 1 count higher than SB for all detectors. Also, even numbered detectors generally have a higher average count than odd numbered detectors.

Band 2:

Detector 1 is noisier and measures an average shutter count value about 0.6 counts higher than the rest of the detectors for both SB and SA, The value of SA is about 0.25 counts higher than both SB and SA. The value of SA is about 0.25 counts higher than SB for all detectors, and even detectors are generally higher than odd detectors for both SB and SA.

Band 3:

Detectors 16 is the noisiest for both SB and SA, and detector 1 measures the highest shutter counts about 0.5 counts above the rest of the detectors. SA is about 0.25 counts higher than SB for all detectors, and even detectors measure higher than the rest of the detectors.

Band 4:

SA is higher than SB by about a quarter count for all detectors, and even detectors are higher than odd for both SB and SA. Detector 1 measures the highest shutter values, between 0.25 and 0.5 counts higher than the rest of the detectors.

Band 5:

The average values for SA and SB are practically identical except that in detectors 1,2,15, and 16 SA is slightly higher than SB. Detector 10 shows the most noise.

Band 7:

SA and SB are practically identical except for detectors 1 and 16, where SA is slightly higher than SB. Detector 7 is the noisiest for both SB and SA.