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Fourth Type II Quarterly Status and Technical Report

STUDY ON SPECTRAL/RADIOMETRIC CHARACTERISTICS OF THE THEMATIC MAPPER FOR LAND USE APPLICATIONS

21 June 1983 — 20 September 1983

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16. Abstract

Progress during ERIM's fourth quarter of effort under the Landsat-4 Image Data Quality Assessment program for the Thematic Mapper is described.

Our previous characterization of scan-related low-frequency noise was extended and refined through detailed analysis of shutter calibration data on CCT-ADDS tapes and, for the first time to our knowledge, detailed analysis of reflective-band data from nighttime acquisitions. A recommended correction procedure was identified that uses calibration shutter data both as a diagnostic and to obtain correction values.

Through comparison of coincident TM and MSS data, illustrations of the added information content of TM data for agricultural applications were developed. The capability of improved spatial resolution to better define boundaries and to resolve spatial details is shown. Spectral analysis of Tasseled-Cap Transformations of TM and MSS data shows high correlation between Greenness features, greater signal range for TM, and indications that a subset of TM bands could accurately simulate MSS data, if required.

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Fourth Quarterly Report

STUDY ON SPECTRAL/RADIOMETRIC CHARACTERISTICS
OF THE THEMATIC MAPPER FOR LAND USE APPLICATIONS

1. OBJECTIVE

The objective of this investigation is to quantify the performance of the TM as manifested by the quality of its image data, in order to suggest improvements in data production and to assess the effects of the data quality on its utility for land resources applications. Three categories of this analysis are: a) radiometric effects, b) spatial effects and c) geometric effects, with emphasis on radiometric effects.

2. TASKS

Four tasks have been established to address the above objective. The first three are to study radiometric performance, spatial performance and geometric performance, respectively, while the fourth is to study spectral characteristics. In keeping with the identified objective, the radiometric performance study is the major task.

3. STATUS AND TECHNICAL PROGRESS

During this fourth quarterly reporting period, work was continued on our study of the radiometric performance of TM. A more complete characterization of scan-related noise in TM reflective-band data was achieved through analyses of both calibration shutter data from CCT-ADDS tapes and non-thermal data from night scenes. A new approach to diagnosis and correction is suggested, as a conclusion to our study. In addition, a separate study (responsive to the second and fourth tasks) was conducted of the spatial and spectral characteristics of TM data, as compared to MSS data, from an agricultural scene. The increased information content of TM data was clearly demonstrated. Also, a technical presentation was made at an SPSE-ASP conference, an invitation to present at the Pecora VIII Symposium was accepted, and three candidate color examples for inclusion in Volume II of the Early Results Symposium Proceedings were forwarded to GSFC.

3.1 PROBLEMS

None.

3.2 ACCOMPLISHMENTS

Accomplishments were achieved in two major areas, described in Sections 3.2.1 and 3.2.2.

3.2.1 RADIOMETRIC ANALYSIS OF SCAN-RELATED LOW-FREQUENCY NOISE

Introduction

In past reports, we have described a very low-frequency noise which we discovered in TM data. It is related to mirror sweeps, that is, step changes in detector outputs occur at irregular times between changes in mirror sweep directions. The magnitude of this effect varies from detector to detector within any given band, but the step changes are correlated between detectors.

A major difficulty in quantifying and understanding this scan-related low-frequency noise lies in the fact that it is of small magnitude (<2.5 digital counts) relative to the radiometric variation present in the scene. Previously, we analyzed averages of scene values along entire scan lines to detect and quantify the effect, but scene content introduced some variability. The calibration shutter data which are present on the CCT-ADDS data tapes present a new opportunity to view a stable, homogeneous "scene". In these data, the only signal variation will be due to noise, either random or systematic. We also explored the use of nighttime data from the non-thermal detectors and use of signals from a "dead" detector.

Last quarter we presented a method of partially compensating for low-frequency noise in Band 1 by looking at the difference between the scan-line-mean signal of a noisy detector and that of an adjacent detector. This approach was based on two assumptions which at best are only partially correct: 1) the adjacent detector is not noisy and 2) the scene observed by the two detectors is identical.

A correction procedure was described, based on computing this difference for Detectors 4 and 3 of Band 1 to determine which of two distinct states the system was in and then applying a fixed subtractive correction to Detectors 4, 8, 10 and 12 in Band 1. Although this procedure is effective, it has several drawbacks. These include: 1) a requirement to process some of the scene data (Detectors 3 and 4 of Band 1) one additional time, 2) application of fixed subtractive factors, and 3) correcting only those detectors explicitly designated as noisy.

Analysis of Calibration Shutter Data (from CCT-ADDS) as a Diagnostic

In looking for low-frequency (below scan frequency) noise effects, all the pixel values for a given detector and scan are averaged, which reduces the effects of high frequency random noise. For the shutter data found on CCT-ADDS tapes, this involves 24-28 pixels. Figures 1(a) through 1(f) illustrate the mean digital count values returned from the shutter for each detector and for each scan in Scene 40049-16262. (The spacing between detector traces on Figure 1 is 2.2 digital counts.) The data are taken from observations of the shutter after the DC restore procedure has been performed. The systematic low-frequency noise is clearly seen in these plots, as is the fact that it is not limited to the previously identified Detectors 4, 8, 10 and 12 in Band 1 and Detector 7 in Band 7. It is also clear that the noise takes on two basic forms: that examplified by Band 1 Detector 4 (Form #1) and a higher frequency noise apparent in Band 7 Detector 7 (Form #2). Most of the detectors in the reflective bands have low-frequency noise characterized by one or both of these two forms. Thus, we see that calibration shutter data can be used equally as well as scene data averages for diagnosis of low-frequency noise states and perhaps better, due to no variations in scene content.

Analysis of Nighttime Non-Thermal Data to Characterize the Noise

Although the shutter data provide valuable insight into the characteristics of the very low-frequency noise, random effects still show through. To further reduce the effects of random higher-frequency events, averaging over larger numbers of pixels was desirable. The data collected during nighttime over-passes provides such an opportunity, with the reflective bands effectively viewing a "shutter" more than 6000 pixels long (vs. the 24-28 pixels of actual shutter data). Figures 2(a) through 2(f) illustrate the scan-line mean signal returned by each of the detectors in Bands 1-5 and 7 for the August, GA scene. The data appear exceptionally clean with respect to random effects, and dramatically display the two forms of low-frequency noise mentioned above.

A study of these plots yielded several observations, some subtle and some not so subtle.

(1) Essentially all detectors in the reflective bands are affected.

(2) Most detectors exhibit a combination of Form #1 and Form #2 noise.

(3) A very slight scan direction effect is noticeable, primarily in Band 1 where reverse scan means are lower than forward scan means by less than 0.1 digital counts.

(4) Each form of the noise is present in two phase relationships relative to the base detectors (defined as Band 1 Detector 4 for Form #1 and Band 7 Detector 7 for Form #2).

(5) In general, for Form #2 noise, the odd numbered detectors are in phase with Band 7 Detector 7 and the even numbered detectors are 180° out of phase.

(6) For Form #1 noise, most detectors are in phase with Band 1 Detector 4. Exceptions, which are 180° out of phase, are: Band 2, Detector 3; Band 3, Detectors 8 and 9; Band 5, Detectors 3, 5, 8, 9, 10, 13, 14 and 15; and Band 7, Detectors 3, 9, 13 and 15.

(7) The Form #2 noise has a stable period of four scans (two forward/reverse scan cycles).

(8) In most cases, the peak-to-peak magnitude of the noise is less than one digital count of signal level, but for Band 1 Detector 4 it is approximately 2.1 counts.

(9) The "dead" detector, Detector 3 of Band 5, displays both Form #1 and Form #2 noise.

Some additional observations regarding the low frequency noise are based on scenes other than the Augusta scene used to produce Figure 2.

(10) The four-scan period seen for Form #2 noise on Day 161 (Augusta night) is not present in earlier scenes which have been analyzed (covering days 37-145). In these earlier scenes, Form #2 noise does have a higher frequency than does Form #1, but it is not strictly periodic as seen for Day 161. The Grand Bahamas scene, 40182-15125, (Day 182) again displays the four-scan period, with one minor "glitch". On Scan 355 (out of 374 for the scene), the phase of the noise changes by 180°, continuing with a four-scan period.

(11) The magnitude of Form #1 noise in Band 1, Detectors 4, 8, 10 and 12 is unchanged in all scenes we have observed, with the exception of Scene 40182-15125. In this scene, the peak-to-peak variation is greatly reduced, to less than 0.5 count.

(12) A final observation which could perhaps provide someone insight into the radiometric correction procedure is that substantial variability was found among detectors for the Buffalo night scene (40037-02243). For instance, in Band 4, Detector 16 had a scene-wide

mean signal of approximately 173, while the neighboring Detector 15 had a mean of 1.2, and so on. Most detectors had near zero values, as would be expected. We had received only the CCT-AT for this scene and these data proved to be of no use for analysis of low-frequency noise without first undoing the radiometric correction process, because the reflective bands were over stretched, and possibly the zero level was overfilled for many detectors.

The source(s) of low-frequency noise have not been determined by this analysis, but these observations are put forward with the hope that they will assist other investigators who may be searching for the underlying cause(s) of the noise.

Furthermore, although the specific low-frequency noise source(s) have not been determined, we believe we have characterized the noise sufficiently to develop empirical methods for substantially reducing effects of this noise in scene data.

Analysis of "Dead" Detector Data as an Alternative Diagnostic

Another method considered for diagnosing noise states involved examination of the "dead" detector (Band 5, Detector 3). In the initial scene examined (40049-16262), the scan-line-mean signal of this detector occupied four distinct, although closely spaced, states which corresponded to the high and low states of Form #1 and Form #2 noise. Thus, values from this detector could potentially serve as an indicator of which state the noise was in, and an appropriate corrective factor could be applied to all the noisy detectors for that scan. Further examination, however, demonstrated that although "dead", Band 5 Detector 3 did in fact respond to scene content. The signal response due to scene content overshadowed the response due to low-frequency noise in most cases, eliminating the ability of this detector to uniquely define the system noise state.

Recommended Correction Procedure

The shutter data on the CCT-AD S provide a simple, efficient and effective means of correcting for low-frequency noise effects. Since these shutter data are affected in the same manner as the scene data, the recommended correction procedure (for each channel) is to compute the mean signal value of the shutter after DC restore and then subtract this value from every pixel value in that scan. Since this subtractive value will most likely be non-integer, incorporation of this offset would best be accomplished in the computation of the Radiometric Look-Up Table (RLUT), so as to eliminate an additional rounding/truncation step. This would, however, require an update of that table for each mirror sweep (every 16 scan lines).

An example of the potential effectiveness of this correction procedure is illustrated by a comparison of Figures 3 and 4. Figures 3(a) and 3(b) are plots of scan-line-means for Bands 1 and 7, respectively, for scene 40049-16262. The scene content is apparent, as is the effect of low-frequency noise. As discussed previously, Figures 1(a) and 1(f) are similar plots, but of the shutter data. Figures 4(a) and 4(b) then are the result of subtracting the shutter data (Figure 1) from the raw data (Figure 3). Form #1 noise appears to be entirely eliminated and Form #2 noise greatly reduced. It is recommended that this procedure be seriously considered by NASA for incorporation into the standard ratiometric correction procedure for Landsat-4 TM data. Since the computation method used in this example was applied to the scan averages and therefore did not represent any added quantization effects that may result from a modified RLUT and pixel-by-pixel corrections, the recommended next step would be for NASA to analyze more recent data and, if warranted, implement a full correction procedure, test it on a trial basis on a number of scenes (including those we have analyzed) and carefully compare the new images and their statistics with those from the existing procedure. We have no plans to pursue this matter further unless requested to do so by NASA.

3.2.2 SPATIAL AND SPECTRAL COMPARISON OF COINCIDENT TM AND MSS DATA

Coincident TM and MSS data collected on 24 September 1982 over an agricultural holding in eastern North Carolina were analyzed and compared. Details of this study are presented in Appendix A.

The site features large square-mile blocks that are subdivided into 16 narrow (100-m-wide) strip fields separated by 3-m-wide drainage ditches. The MSS image appeared to be an out-of-focus version of the TM image. The drainage patterns were evident in TM data, but not in MSS data, and roads and field boundaries were much less jagged in TM. Appendix A presents example scan line traces across several fields and a spectral step function to graphically illustrate the advantages of the improved spatial resolution of TM in resolving edges and fine features. The greater within-field variation found with TM indicates both a greater information-gathering potential and a possible need to modify some classification approaches that have come to be conventional for the processing of MSS data.

Spectral features were generated using the Tasseled Cap Transformations of MSS and TM. Both raw band values and the Tasseled-Cap features from the two sensors were compared using a subset of fields in the scene. High correlations were found between the MSS bands and their most similar TM counterparts. Greenness measures were found to be essentially identical for the two sensors (except for greater dynamic range with TM), while some differences were found between Brightness measures (due to contributions from additional bands in TM). Indications are that a subset of TM Bands could be used to accurately simulate MSS data if needed for some application. The added dimensionality of TM data has been the subject of other studies at ERIM.

These analyses were neither exhaustive nor strictly quantitative. Nevertheless, they provide clear and understandable examples of several key improvements in land remote sensing offered by the Landsat Thematic Mapper.

3.3 SIGNIFICANT RESULTS

Our previous characterization of scan-related low-frequency noise was extended and refined through detailed analysis of shutter calibration data on CCT-ADDS tapes and, for the first time to our knowledge, analysis of reflective-band data from nighttime acquisitions. A recommended correction procedure was identified that uses calibration shutter data both as a diagnostic and to obtain correction values. Unless other circumstances arise, we plan no further study under this contract of these artifacts in Landsat-4 TM data.

Through comparison of coincident TM and MSS data, illustrations of the added information content of TM data for agricultural applications were developed. The capability of improved spatial resolution to better define boundaries and to resolve spatial details was shown. Spectral analysis of Tasseled-Cap Transformations of TM and MSS data showed high correlations between Greenness features, greater signal range for TM, and indications that a subset of TM bands could accurately simulate MSS data, if required.

3.4 PUBLICATIONS AND PRESENTATIONS

Michael Metzler attended the joint SPSE/ASP conference on Techniques for Extraction of Information from Remotely Sensed Images, 16-19 August 1983, at Rochester, New York. There he presented a paper authored by himself and William Malila, entitled "Radiometric Characterization of Thematic Mapper Full Frame Imagery".

In response to an invitation by organizers of the Pecora VIII Symposium to be held in Sioux Falls, SD, on October 4-7, 1983, an abstract was submitted and accepted for the session on Landsat 4 results. Entitled "Radiometric Analyses of Landsat-4 Digital Image Data", by William Malila, Daniel Rice and Michael Metzler, the paper will be presented by W. Malila.

3.5 RECOMMENDATIONS

As discussed in Section 3.2.1, it is recommended that NASA examine more recent data and, if warranted, implement and test on a trial basis a correction procedure for scan-related low-frequency noise, based on the procedure defined herein.

3.6 FUNDS EXPENDED

A total of approximately $32,000 was expended during the three months June through August 1983. The cumulative spending through August represents approximately 44% of the total contract award and 63% of the funds allocated. Expenditures during the period 1-20 September 1983 are not included in these percentages.

3.7 DATA RECEIPTS

Raw data tapes (CCT-BT) were received during this quarter for the following scenes:

Grand Bahamas	40182-15125
Death Valley	40124-17495
New Orleans	40062-15591
Augusta, GA (night)	40161-02481
Bluff, Utah	40176-17252

Radiometrically, but not geometrically, corrected data (CCT-AT) were received for one scene:

Bluff, Utah	40176-17252

Fully corrected data (CCT-PT) were also received for this scene.

ADDS data (CCT-ADDS) were received for five scenes:

NC Iowa	40049-16262
NE Arkansas	40037-16031
Morehead, NC	40070-15084
Buffalo, NY (night)	40037-02243
Grand Bahamas	40182-15125

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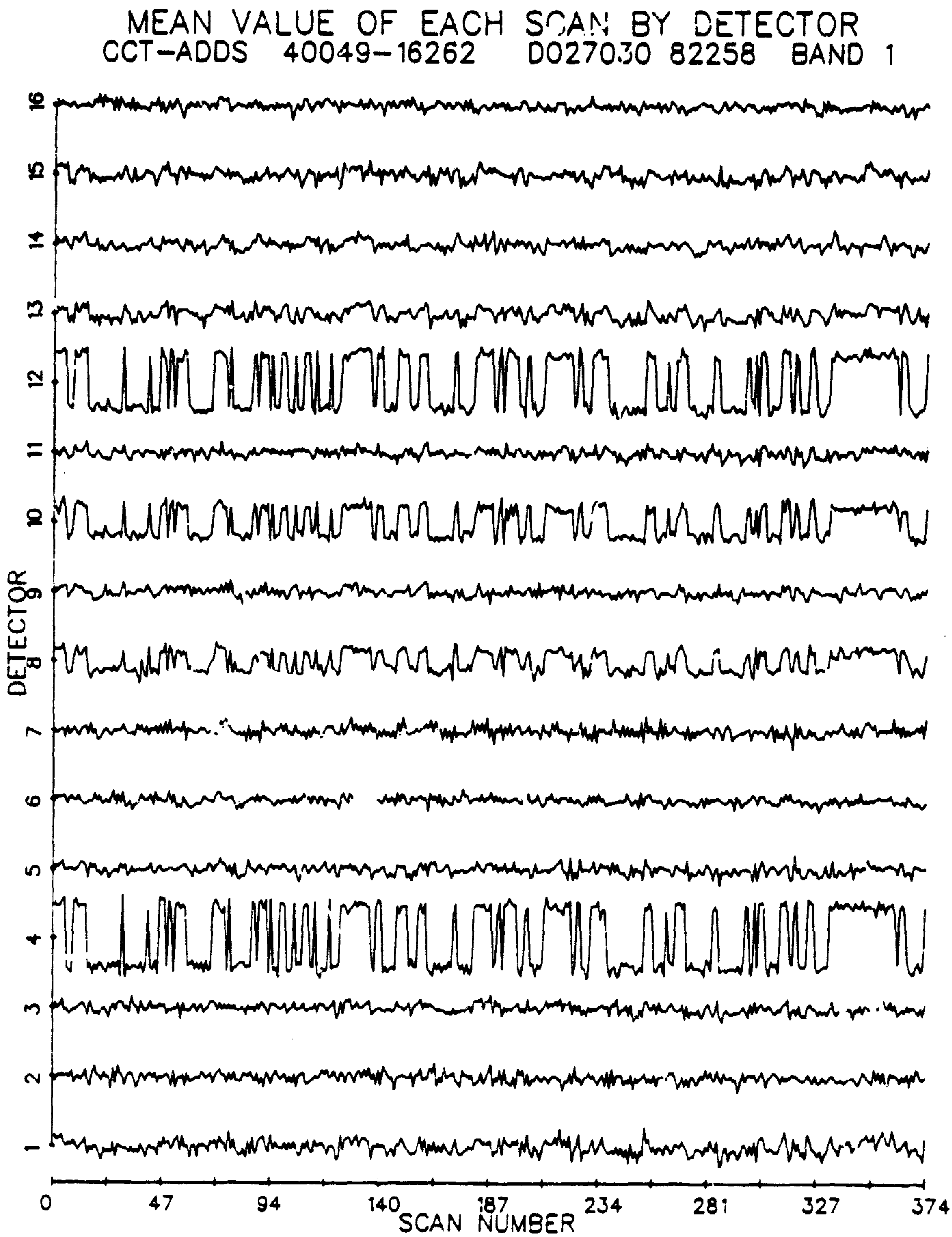

FIGURE 1(a). SCAN AVERAGES (BY DETECTOR) OF CALIBRATION SHUTTER DATA, BAND 1

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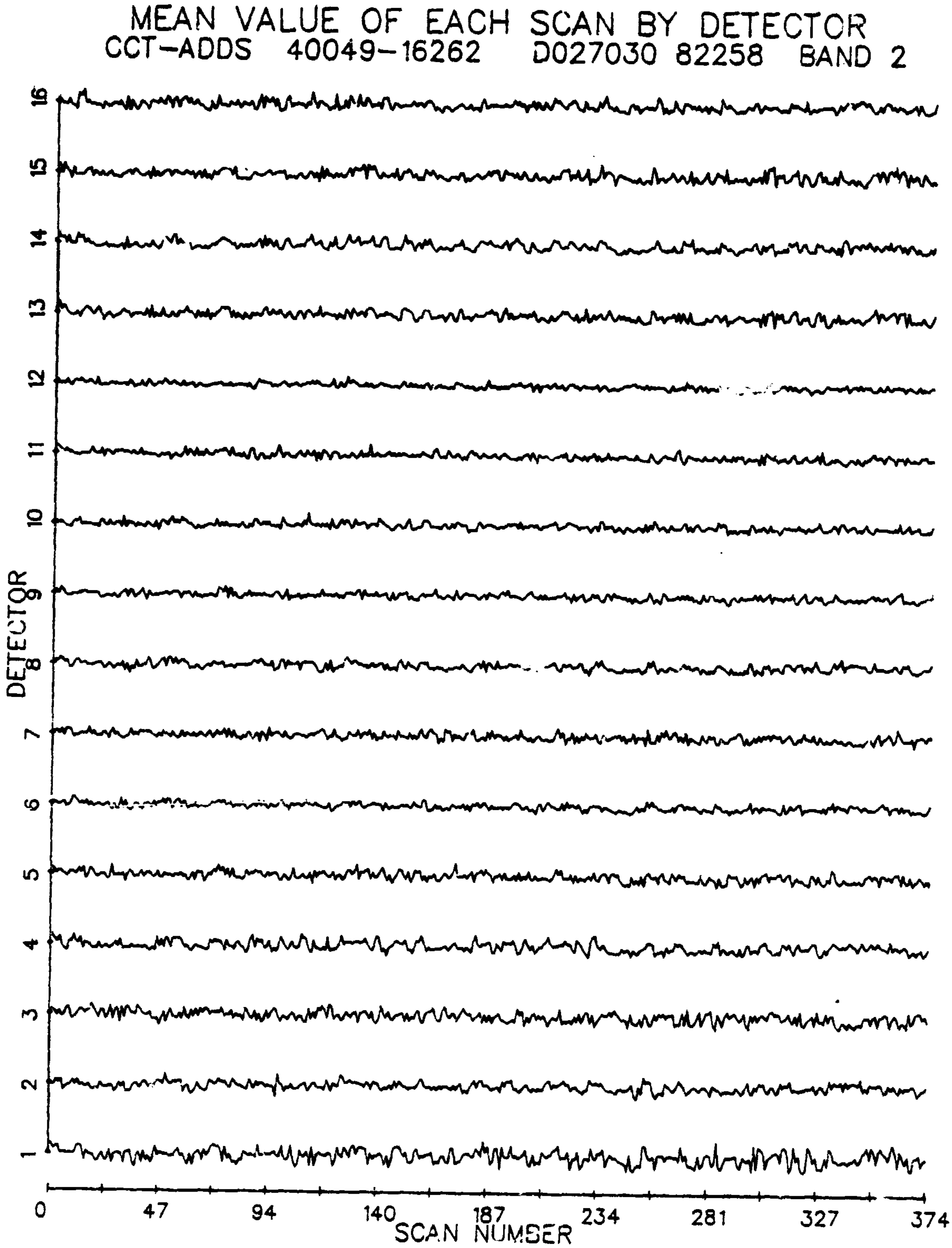

FIGURE 1(b) SCAN AVERAGES (BY DETECTOR) OF CALIBRATION SHUTTER DATA, BAND 2

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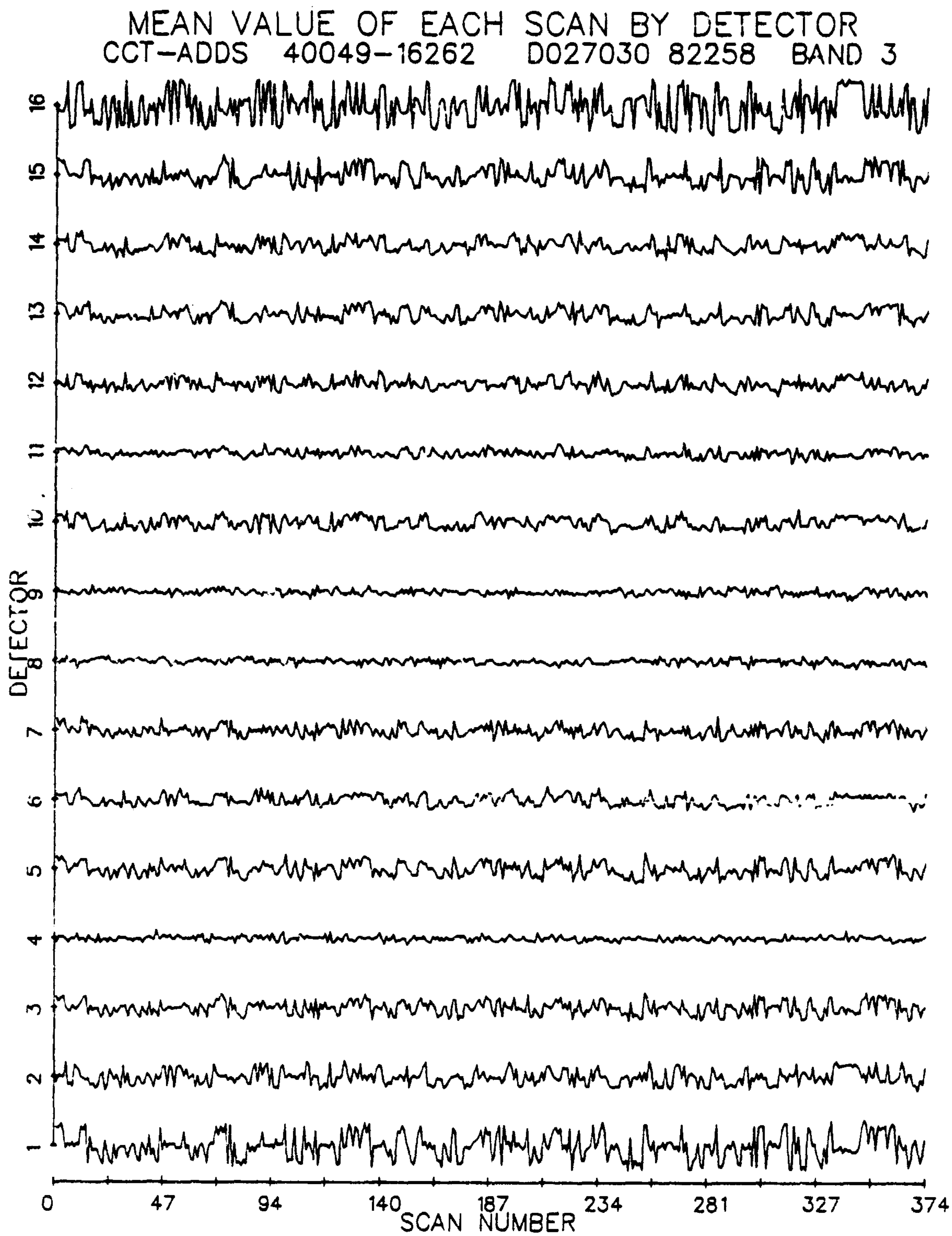

FIGURE 1(c). SCAN AVERAGES (BY DETECTOR) OF CALIBRATION SHUTTER DATA, BAND 3

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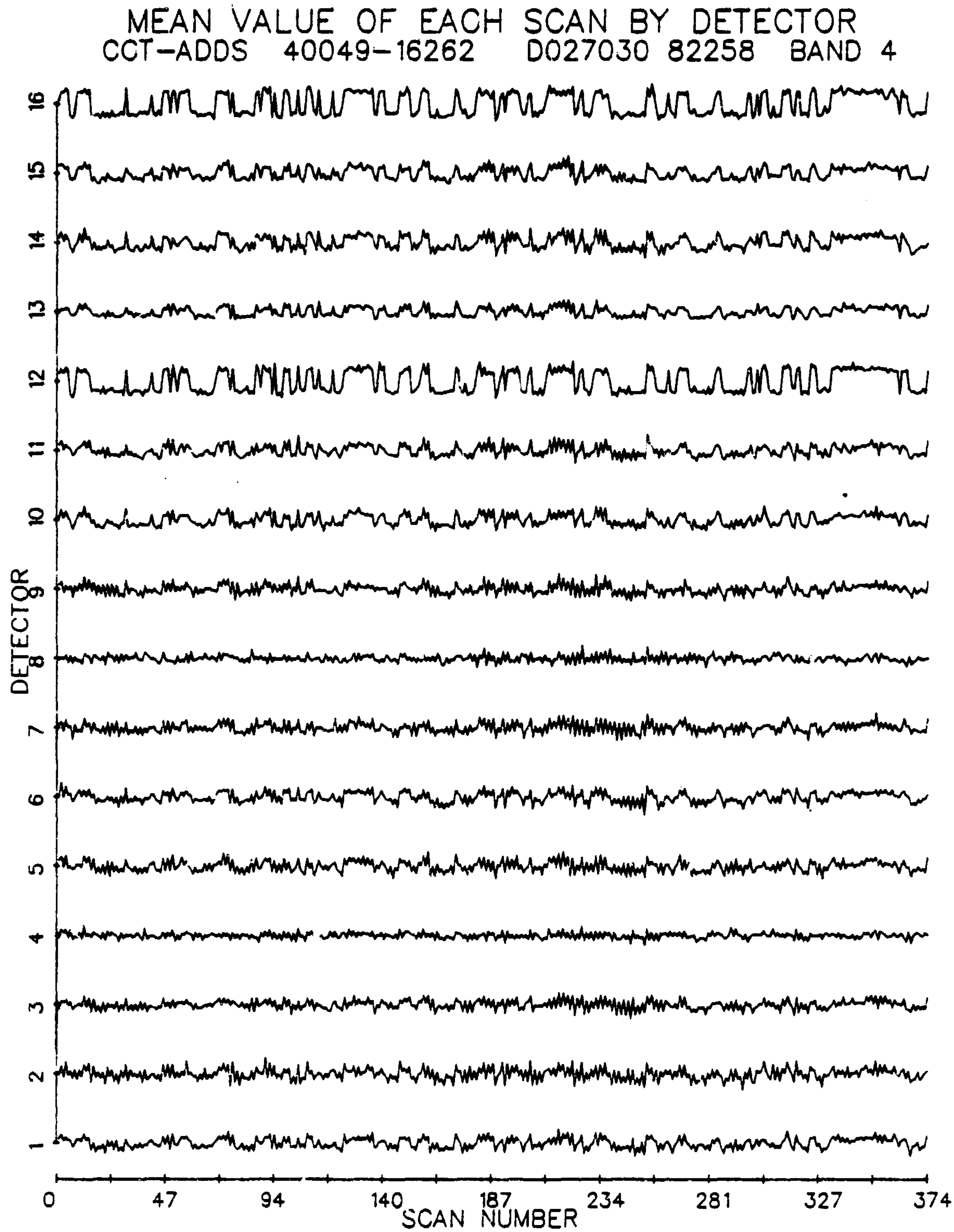

FIGURE 1(d). SCAN AVERAGES (BY DETECTOR) OF CALIBRATION SHUTTER DATA, BAND 4

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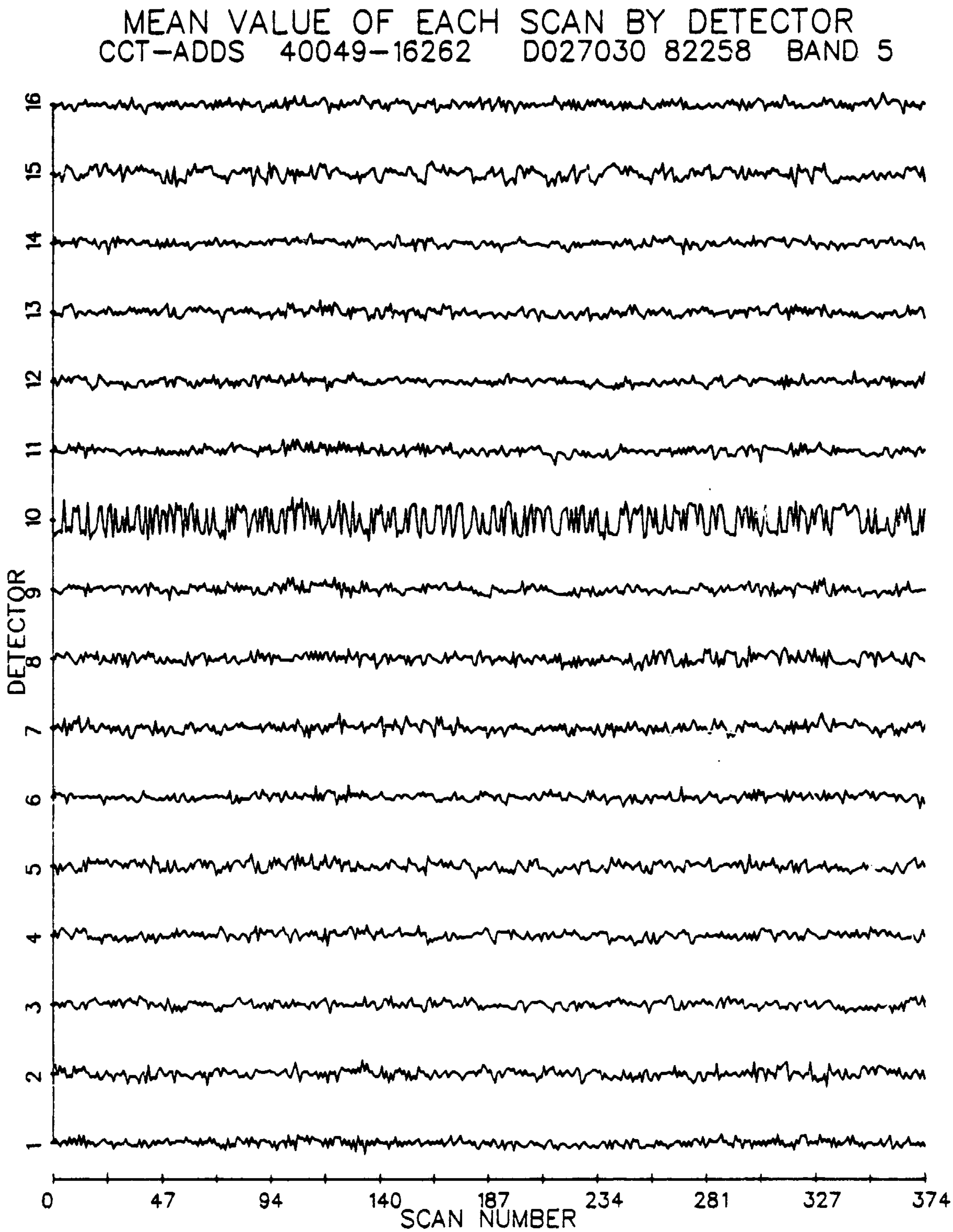

FIGURE 1(e). SCAN AVERAGES (BY DETECTOR) OF CALIBRATION SHUTTER DATA, BAND 5

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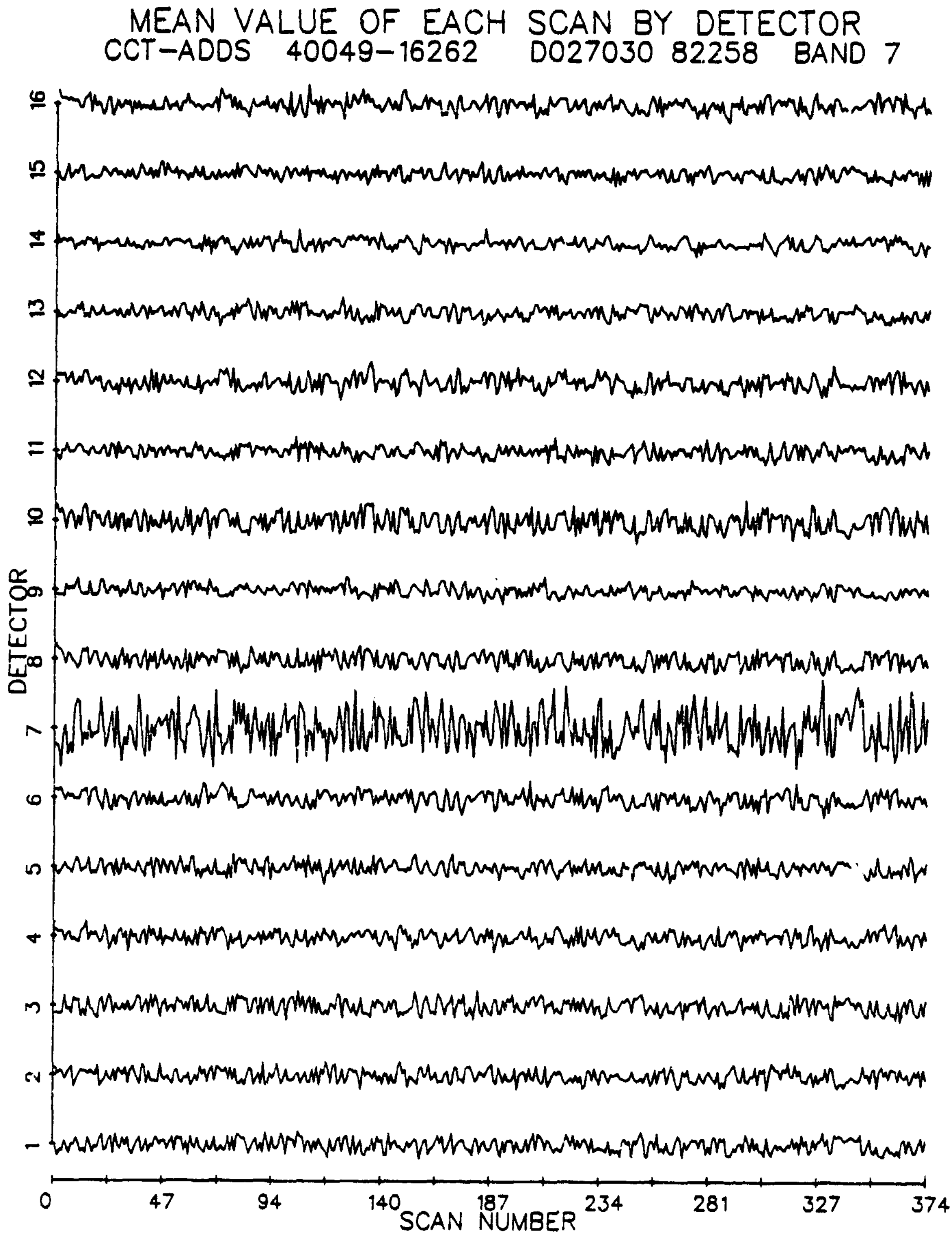

FIGURE 1(f). SCAN AVERAGES (BY DETECTOR) OF CALIBRATION SHUTTER DATA, BAND 7

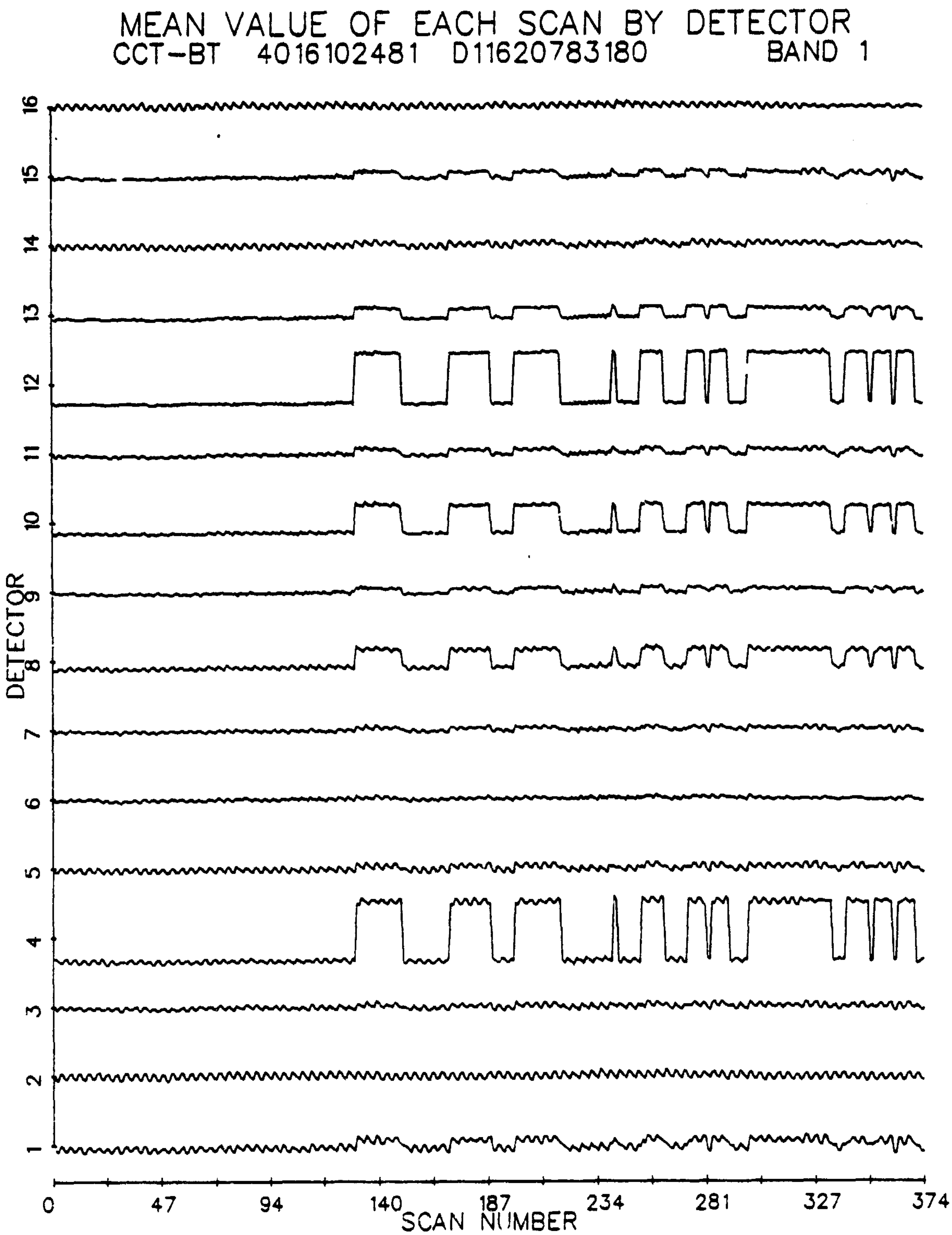

FIGURE 2(a). SCAN AVERAGES (BY DETECTOR) OF NIGHTTIME SCENE DATA, BAND 1

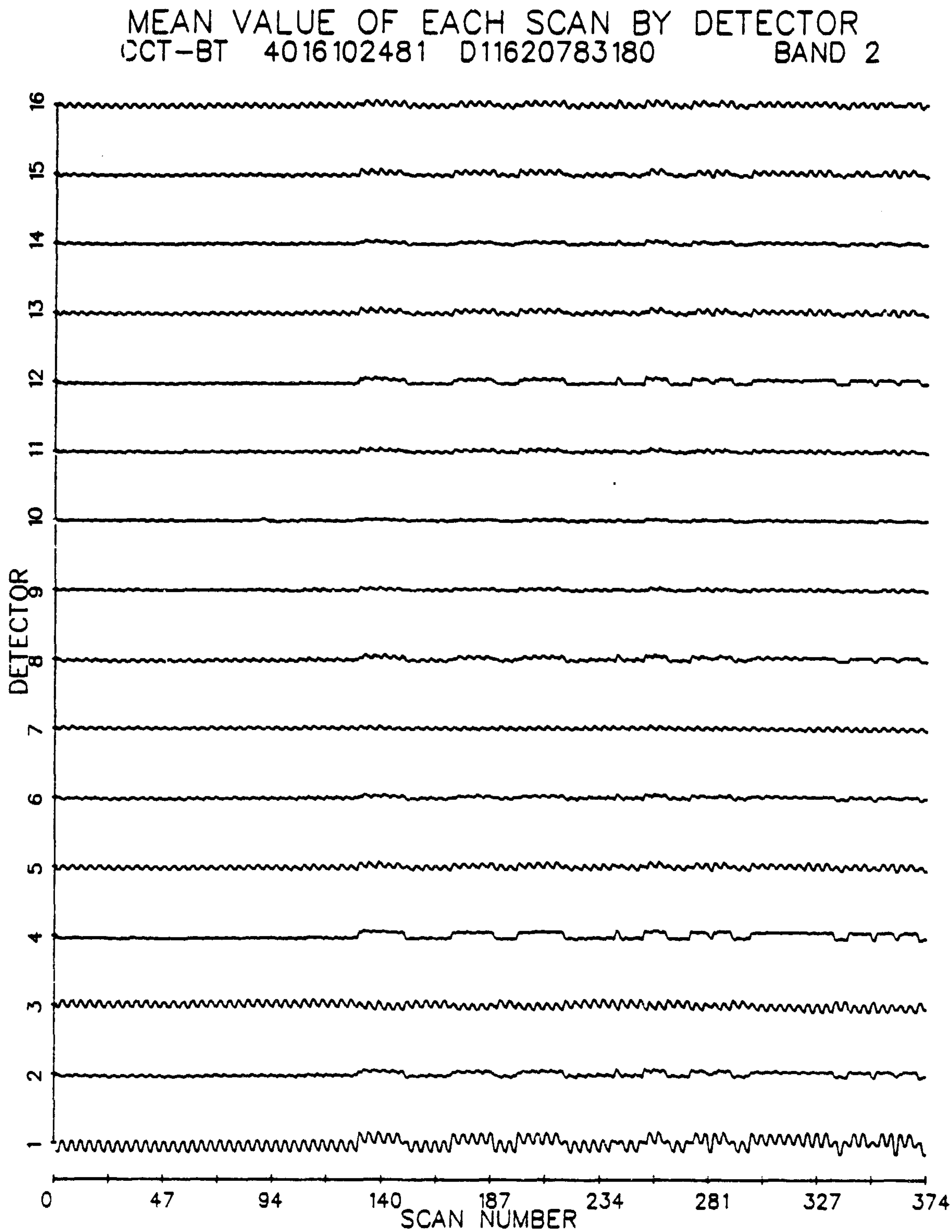

FIGURE 2(b). SCAN AVERAGES (BY DETECTOR) OF NIGHTTIME SCENE DATA, BAND 2

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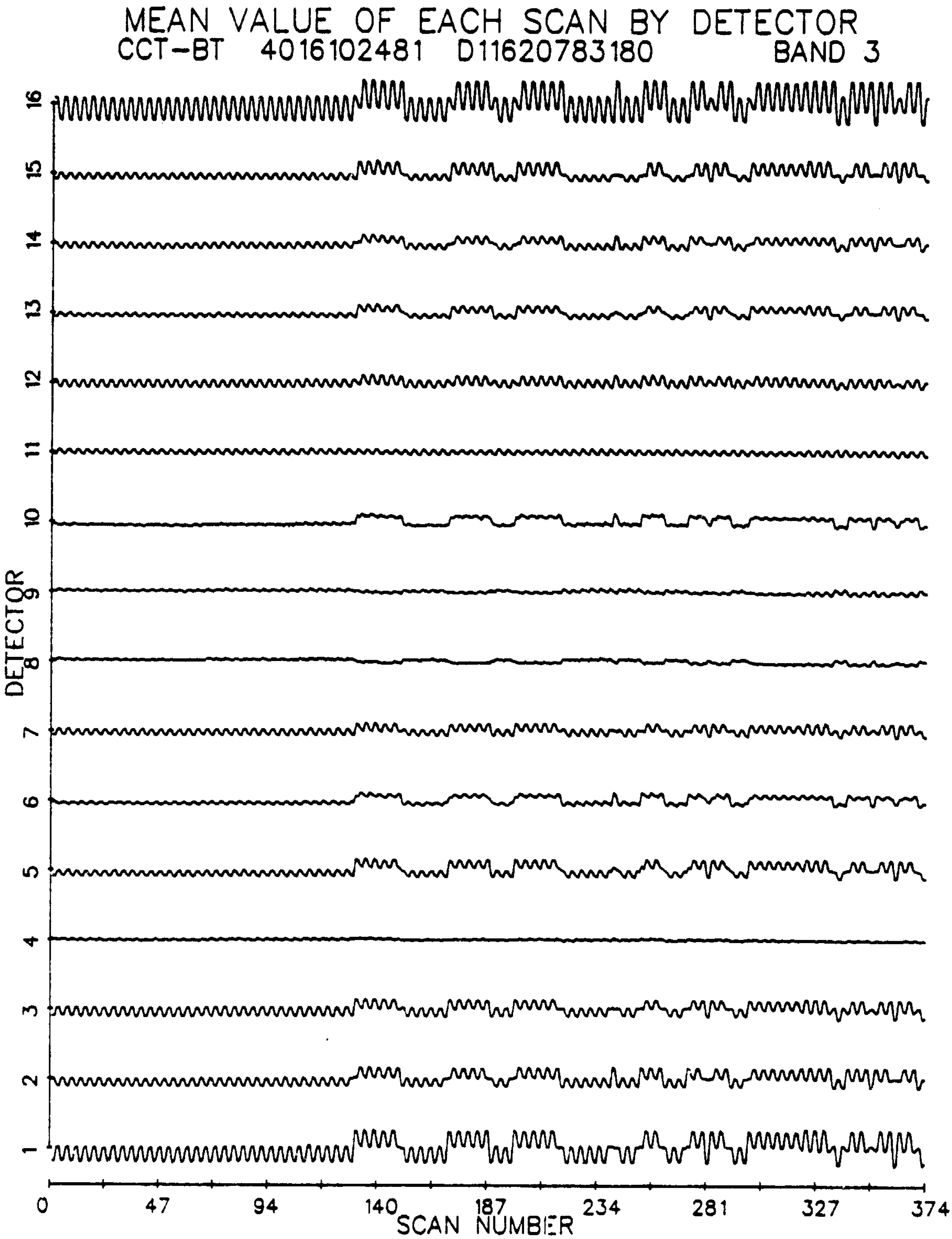

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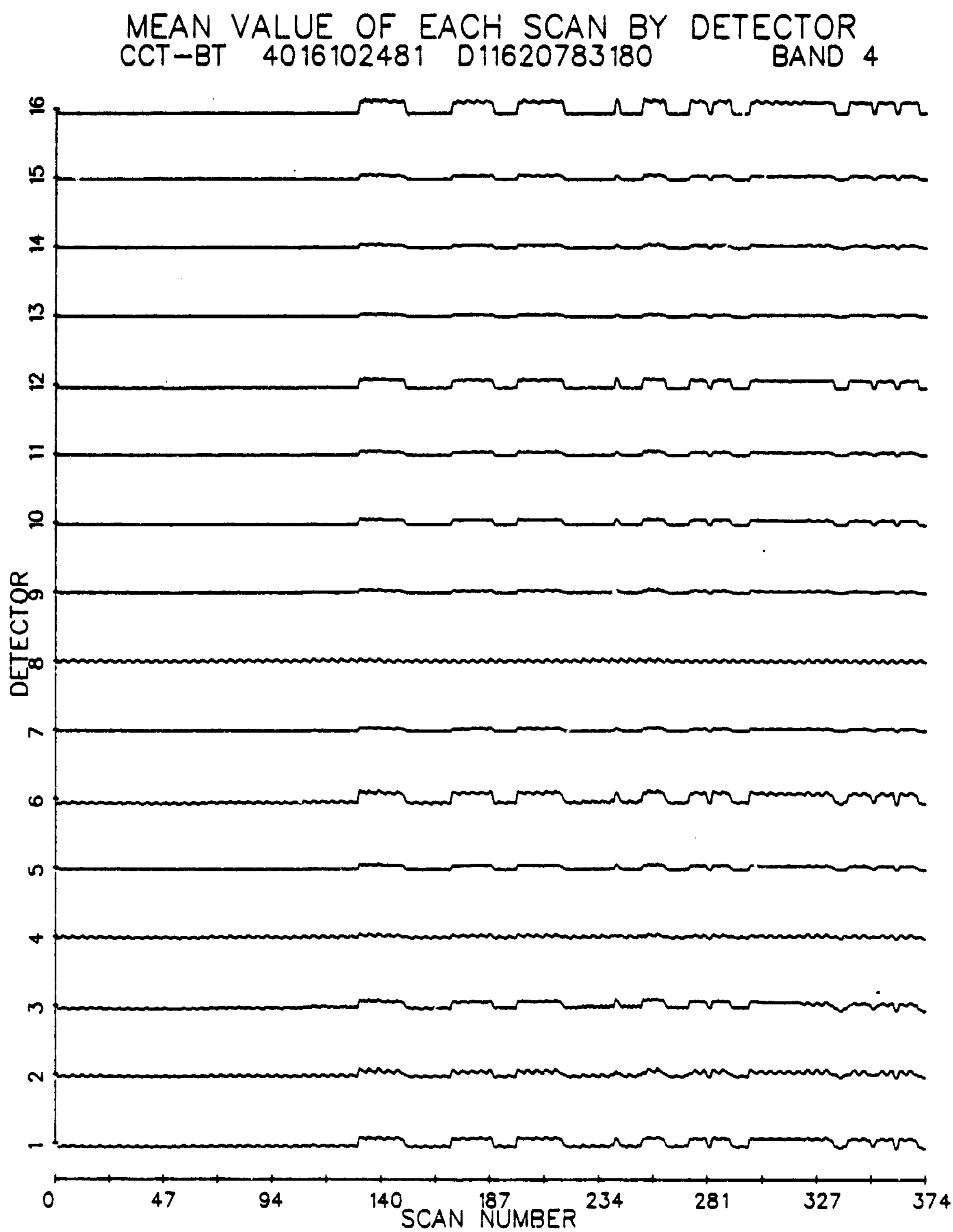

FIGURE 2(d). SCAN AVERAGES (BY DETECTOR) OF NIGHTTIME SCENE DATA, BAND 4

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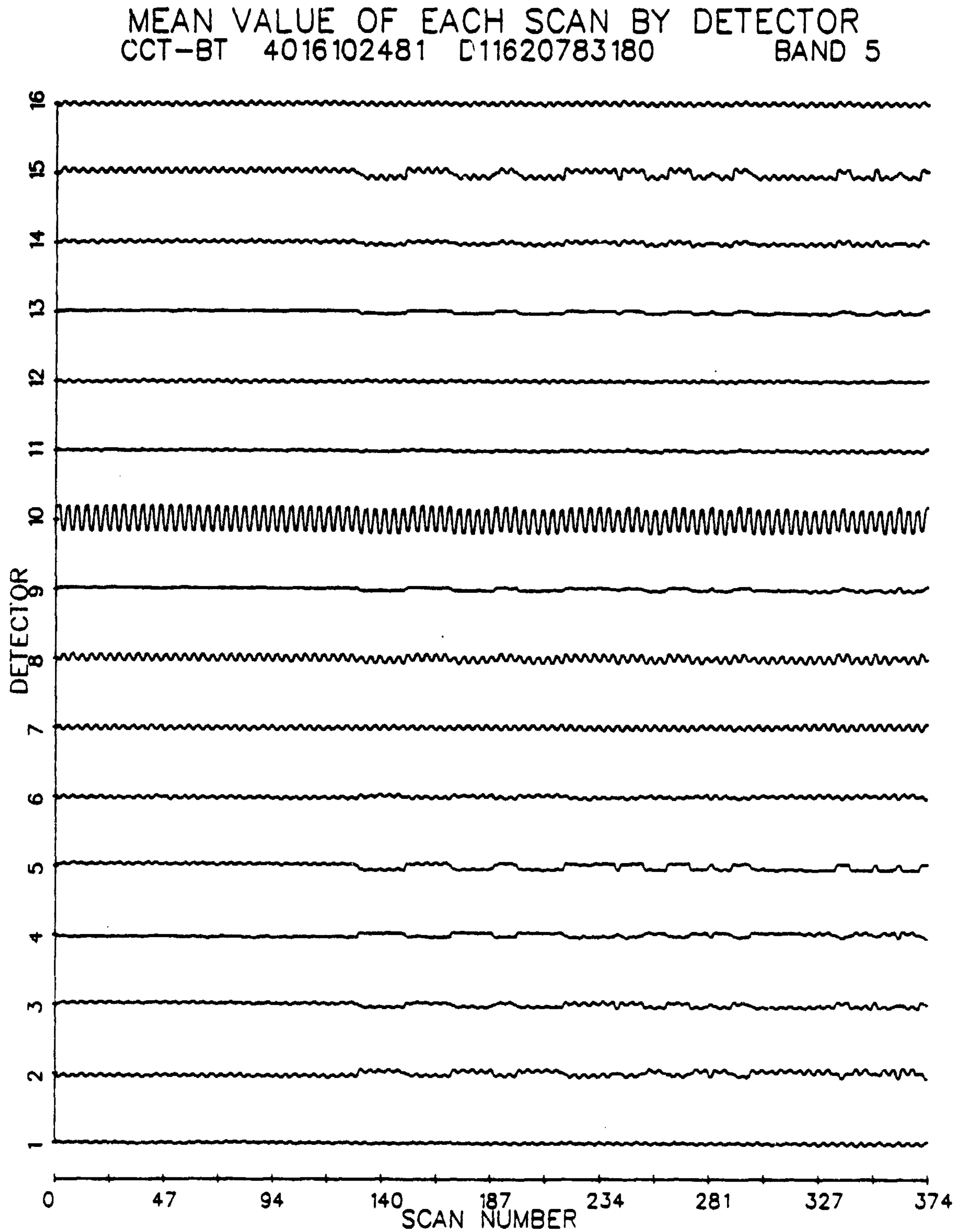

FIGURE 2(e). SCAN AVERAGES (BY DETECTOR) OF NIGHTTIME SCENE DATA, BAND 5

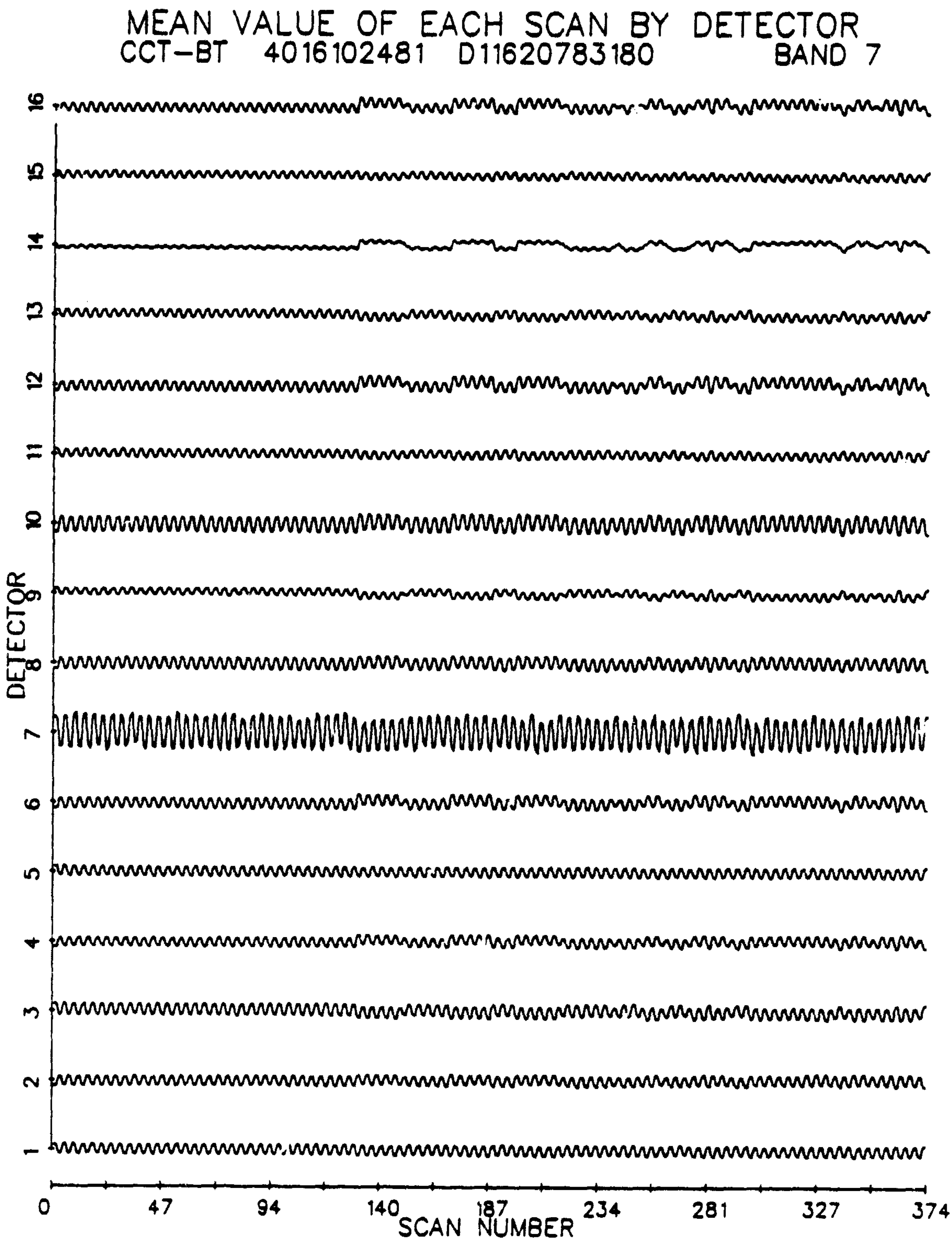

FIGURE 2(f). SCAN AVERAGES (BY DETECTOR) OF NIGHTTIME SCENE DATA, BAND 7

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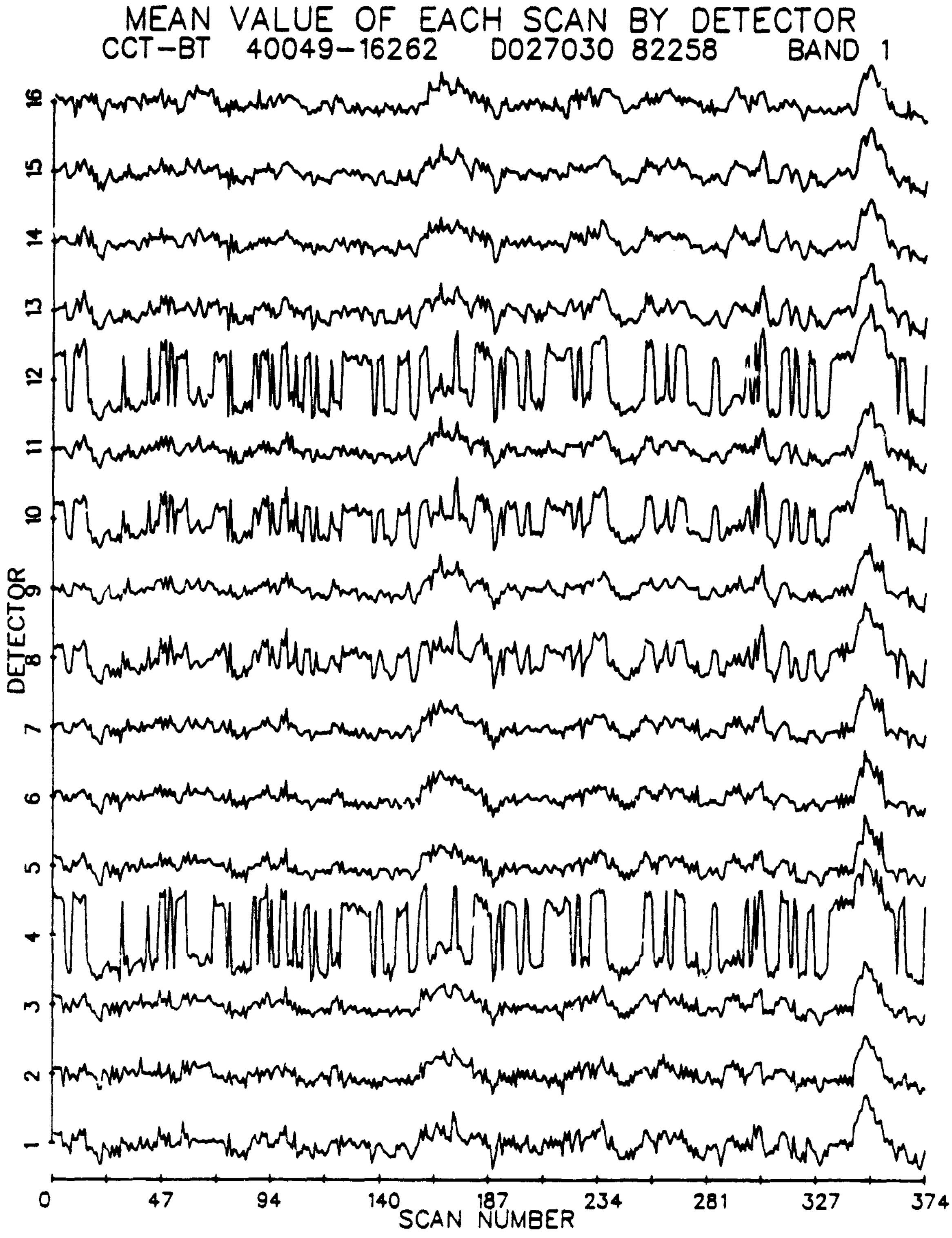

FIGURE 3(a). SCAN AVERAGES OF SCENE DATA, BEFORE CORRECTION, BAND 1

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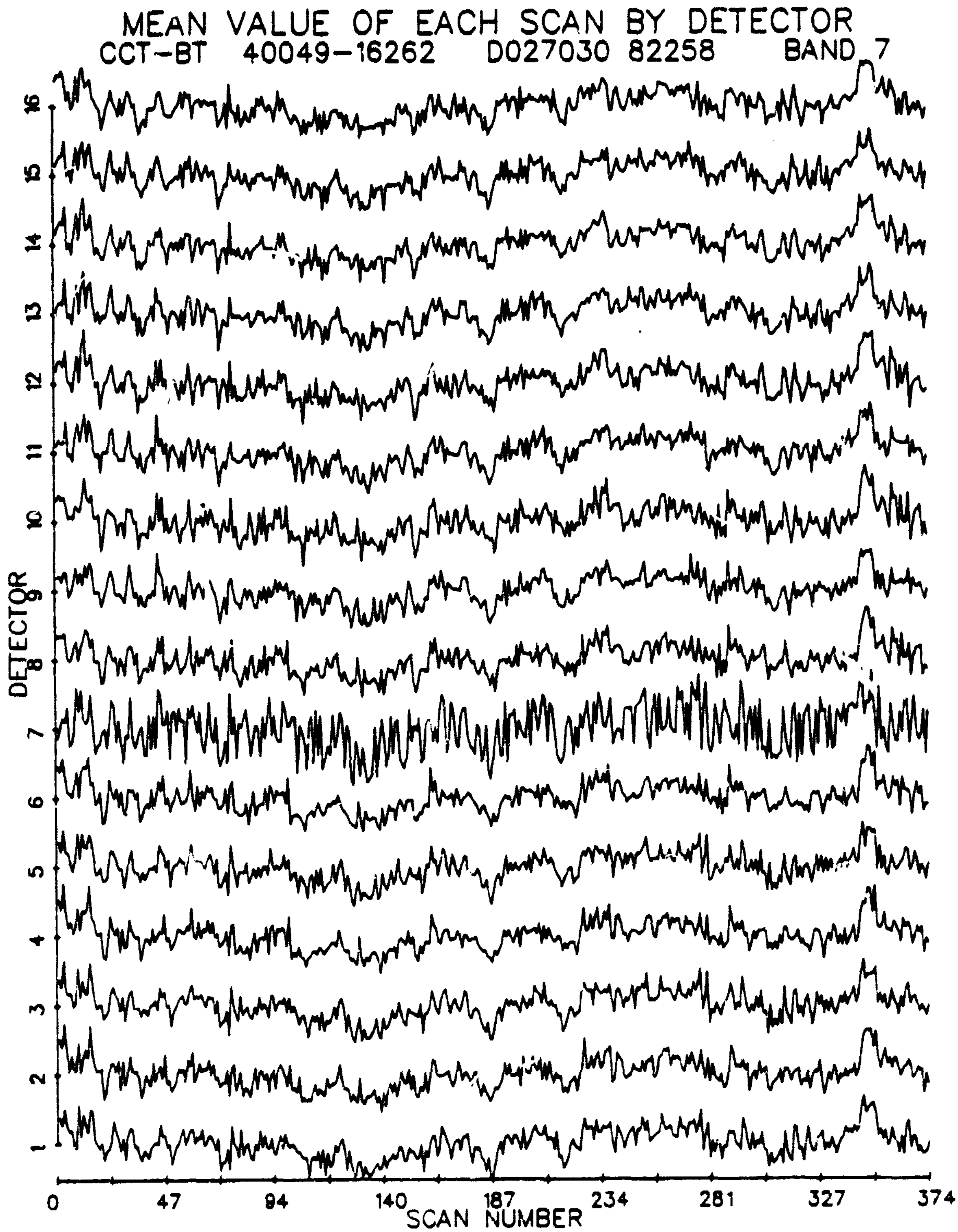

FIGURE 3(b). SCAN AVERAGES OF SCENE DATA. BEFORE CORRECTION, BAND 7

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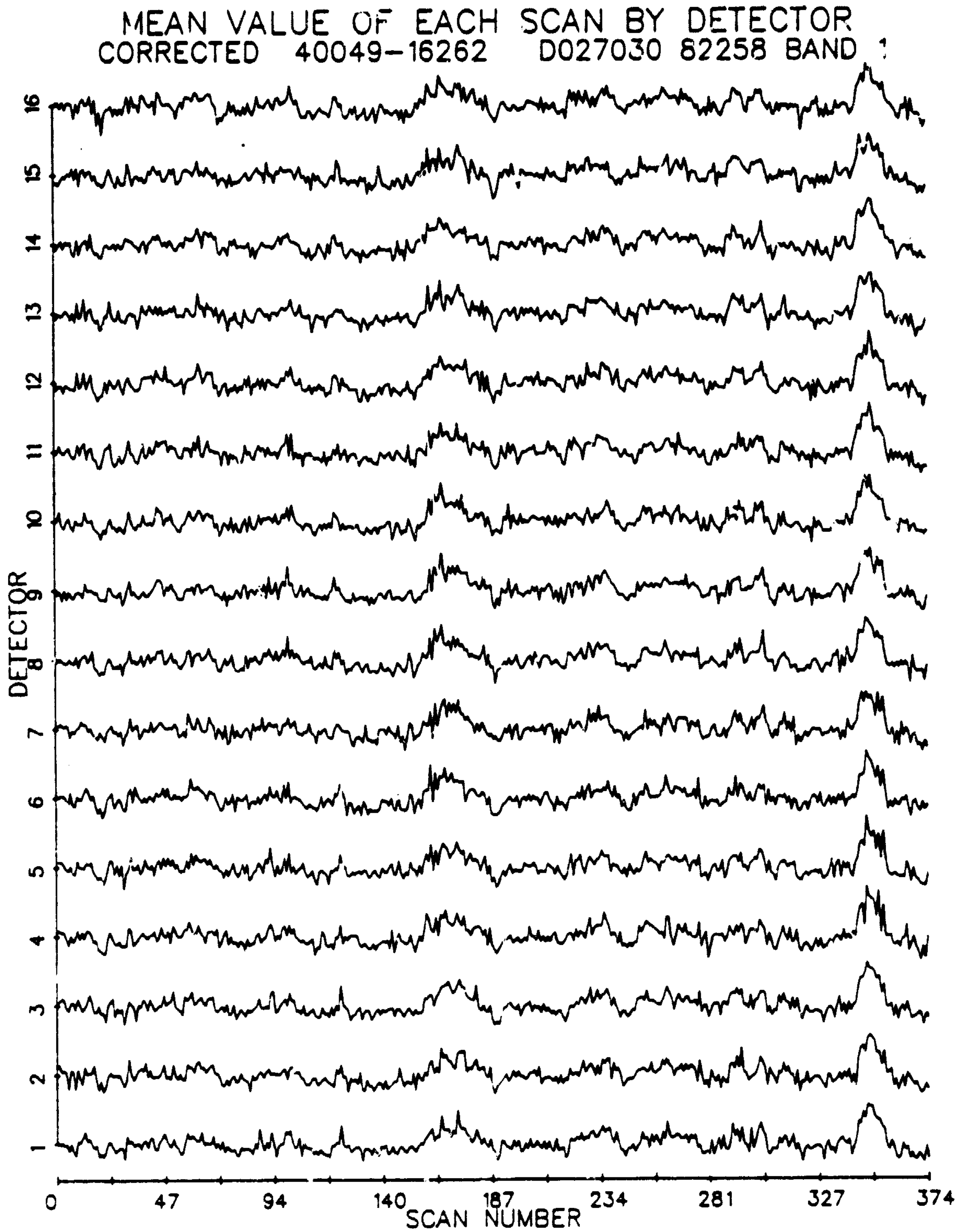


FIGURE 4( ). SCAN AVERAGES OF SCENE DATA, AFTER CORRECTION, BAND 1
(by subtraction of calibration shutter averages)

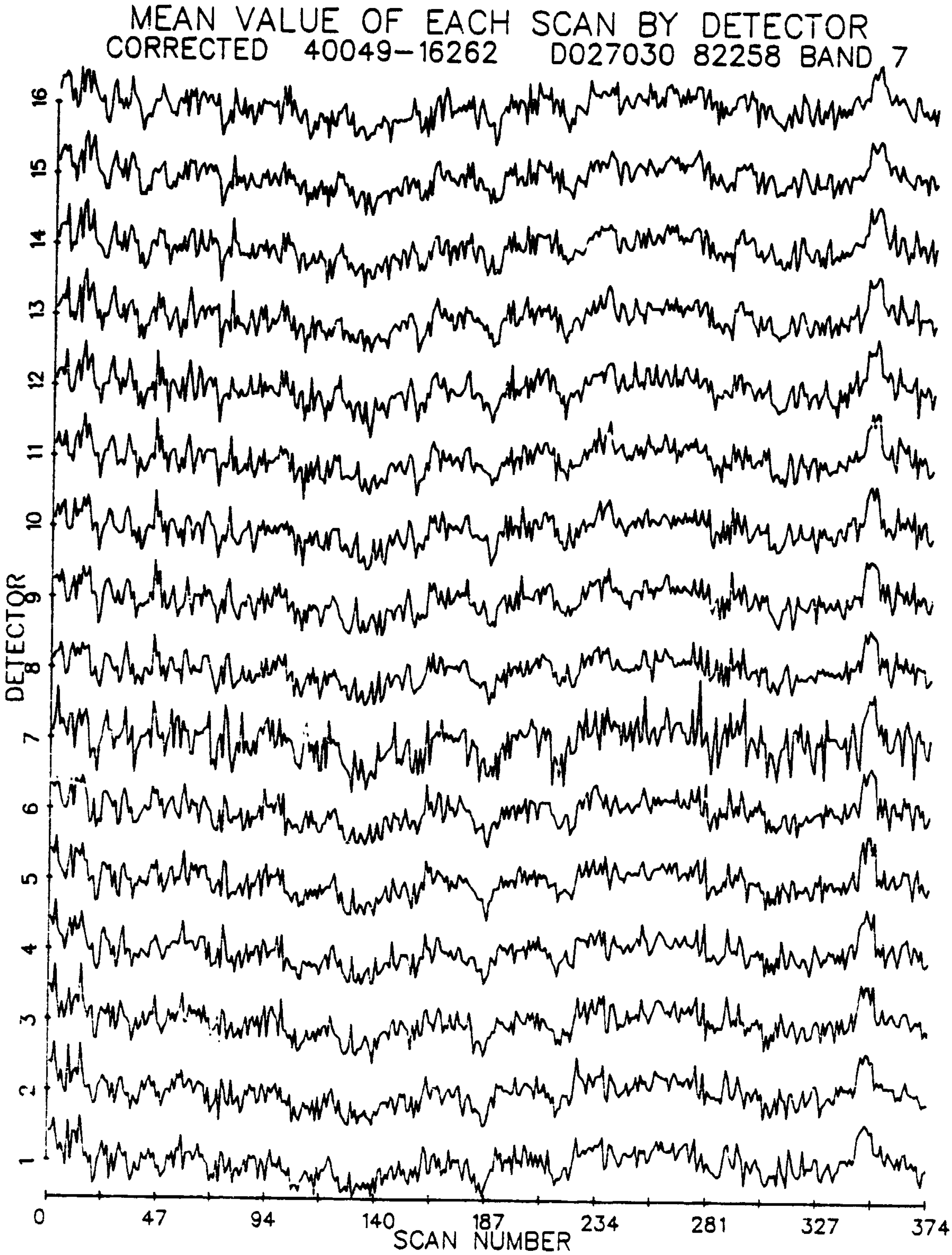


FIGURE 4(b). SCAN AVERAGES OF SCENE DATA, AFTER CORRECTION, BAND 7
(by subtraction of calibration shutter averages)

COMPARISON OF COINCIDENT LANDSAT-4 MSS AND TM DATA

Eric P. Crist

I. INTRODUCTION

Objective. The overall objective of this study was to compare particular characteristics of data collected by the MSS and TM sensors on board Landsat-4. Of particular interest were the effects of increased spatial resolution, enhanced signal-to-noise ratio, and finer quantization of the TM as compared to the MSS.

Data and Site Description. A portion of Scene #4007015084 (Path 14, Row 36), collected on 24 September 1982, was used in this analysis. This scene, which covers part of the North Carolina coastal area, includes a private agricultural holding called the Open Grounds Farm, which served as the primary study site. The Open Grounds Farm consists of about 44,000 acres of recently cleared land, divided into square mile blocks. At the time of satellite overpass, fields of soybeans, corn, and fescue at various stages of development were present. In close proximity to the farm are areas of water and natural vegetation/forest, resulting in a high degree of cover type diversity in a relatively small area.

Within each block, a series of ditches, approximately 3 meters wide, provide drainage. These ditches divide each square mile block into 16 strip fields. Two-lane improved gravel roads separate the blocks. The soils are mostly organic types, and allow little surface water penetration. In most cases, fields within a block were planted to the same crop at about the same time, but blocks were planted at a variety of times. An unusual amount (approximately 7.5-inches) of rain had fallen just prior to the overpass date.

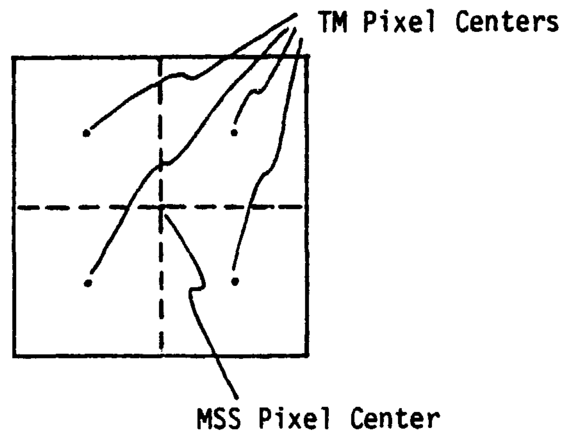
II. APPROACH

Selection of Analogous Regions. Line printer grey maps were produced for TM Band 3 and MSS Band 2 covering approximately the same geographic area. Field corners and other readily-identifiable features were then located on both maps, and fractional line and point values were estimated. A total of ten points, spread over the entire farm area, were used. Linear regression was then used to determine the relationship between the two coordinate systems. The actual adjustment factors applied also took into account the geometric constraints of the two systems, as shown in Figure 1. TM pixels, identified by their centers, must correspond to 0.25 or 0.75 of the line and point center of the overlaying MSS pixel (assuming both have gone through geometric correction processing, as was the case in this analysis). Similarly, MSS pixel centers must correspond to 0.5 of the line and point center of overlaying TM pixels.

Tasseled Cap Feature Generation. The Brightness and Greenness features of the Tasseled Cap transformations of MSS (Kauth and Thomas, 1976) and TM (Crist, 1983) data were selected for this analysis since they are essentially equivalent between sensors (Crist and Cicone, 1983). The TM transformation, as provided in Table 1, was applied directly to the TM data. Since Tasseled Cap coefficients for Landsat-4 MSS have not yet been determined, Tasseled Cap-equivalent features were derived through rotation of the principal data plane. The resulting transformation coefficients are presented in Table 2.

Feature Comparison. Raw band and Tasseled Cap features of the two sensors were compared using a subset of fields in the scene. This sample set is the same as that used to compare within-field variability, and is described in greater detail in the corresponding section.

Two comparisons were made for each band or feature pair. First, actual TM signal values were plotted against signal values for the MSS



MSS pixel center is 1/2 way between TM pixel centers

TM pixel centers are 1/4 or 3/4 way between MSS pixel centers

MSS pixels are 57 m-square and TM pixels are 28.5 m-square, in geometrically corrected Landsat-4 data

Figure 1. MSS/TM Pixel Geometric Relationships (Assuming perfect registration)

Table 1. Transformation Coefficients for TM Tasseled Cap Features (Crist, 1983)

	TM Band					
Feature	1	2	3	4	5	7
Brightness	.304	.279	.474	.559	.508	.186
Greenness	-.285	-.244	-.544	.724	.084	-.180

Table 2. Transformation Coefficients for MSS Tasseled Cap-Equivalent* Features

Feature	MSS Band 1	2	3	4
Brightness	.306	.475	.769	.298
Greenness	-.367	-.729	.462	.348

*Definitive Tasseled Cap transformation coefficients for Landsat-4 MSS have not yet been derived.

pixel within whose boundaries the TM pixel fell. Thus each MSS pixel was represented four times. Second, actual MSS signal values were plotted against the average signal from the four TM pixels corresponding to the same ground area as the MSS pixel.

Geometric Resolution Comparison. Five sample areas were identified which included at least one clear transition between cover types or conditions. The five regions are illustrated in Figure 2, and briefly described in Table 3. Equivalent MSS and TM regions were determined using the equations previously mentioned, and described in more detail in Section III. Greenness and/or Brightness values were then plotted against line and point number to provide a three-dimensional representation of the data surface. These plots were then compared for the two sensors, and conclusions were drawn based on the comparisons.

Within-Field Variation Comparison. Nine fields were selected for use in comparing the within-field feature variability with the two sensors. Included were samples ranging from substantial to little or no apparent variation (based on TM imagery). Figure 3 and Table 4 provide additional information on the sample set. Histograms of Greenness (for vegetated fields) or Brightness (for bare fields) and basic distribution statistics were used in the comparison.

Image Analysis. In addition to the more quantitative evaluations already described, a qualitative comparison of the two sensors was made using color composite images of the Open Grounds Farm area. Overall image quality or sharpness, and ability to distinguish particular features or boundaries were the primary emphases in this evaluation.

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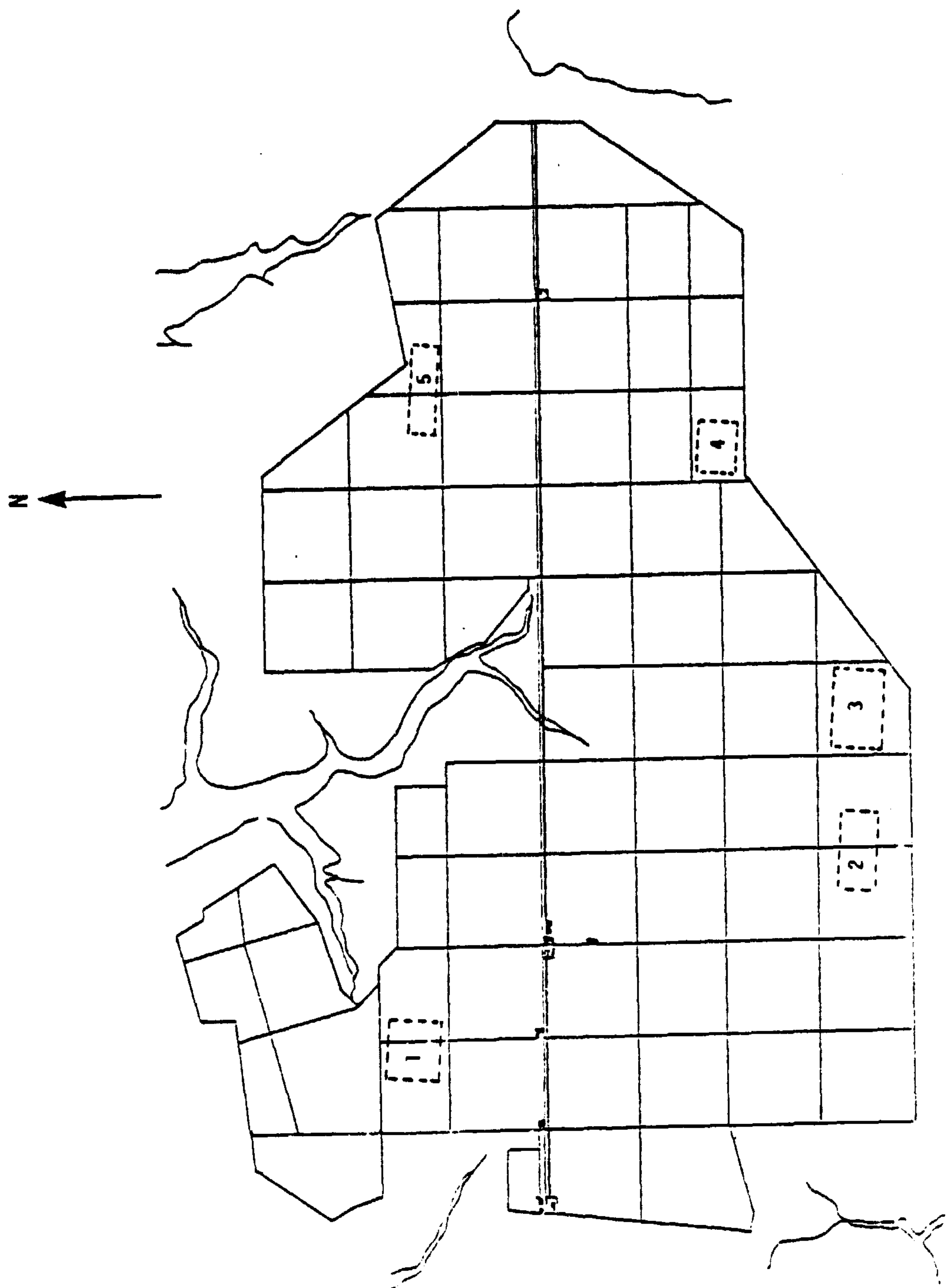

Figure 2. Approximate Regions Used for Comparison of Geometric Resolution

Table 3. Description of Test Regions for Comparison of Geometric Resolution

Note: Description is of fields or field conditions from left (West) to right (East) of specified area.

Region	Description (Based on TM Imagery/Ground Truth)
1	Green field - road - Brown field
2	Green field - road - Green field
3	Field beginning senescence - Field more fully senescent
4	8 to 9 sets of light/dark strips (corn stubble/ditch)
5	Partially-senescent field - road - green field - less green field

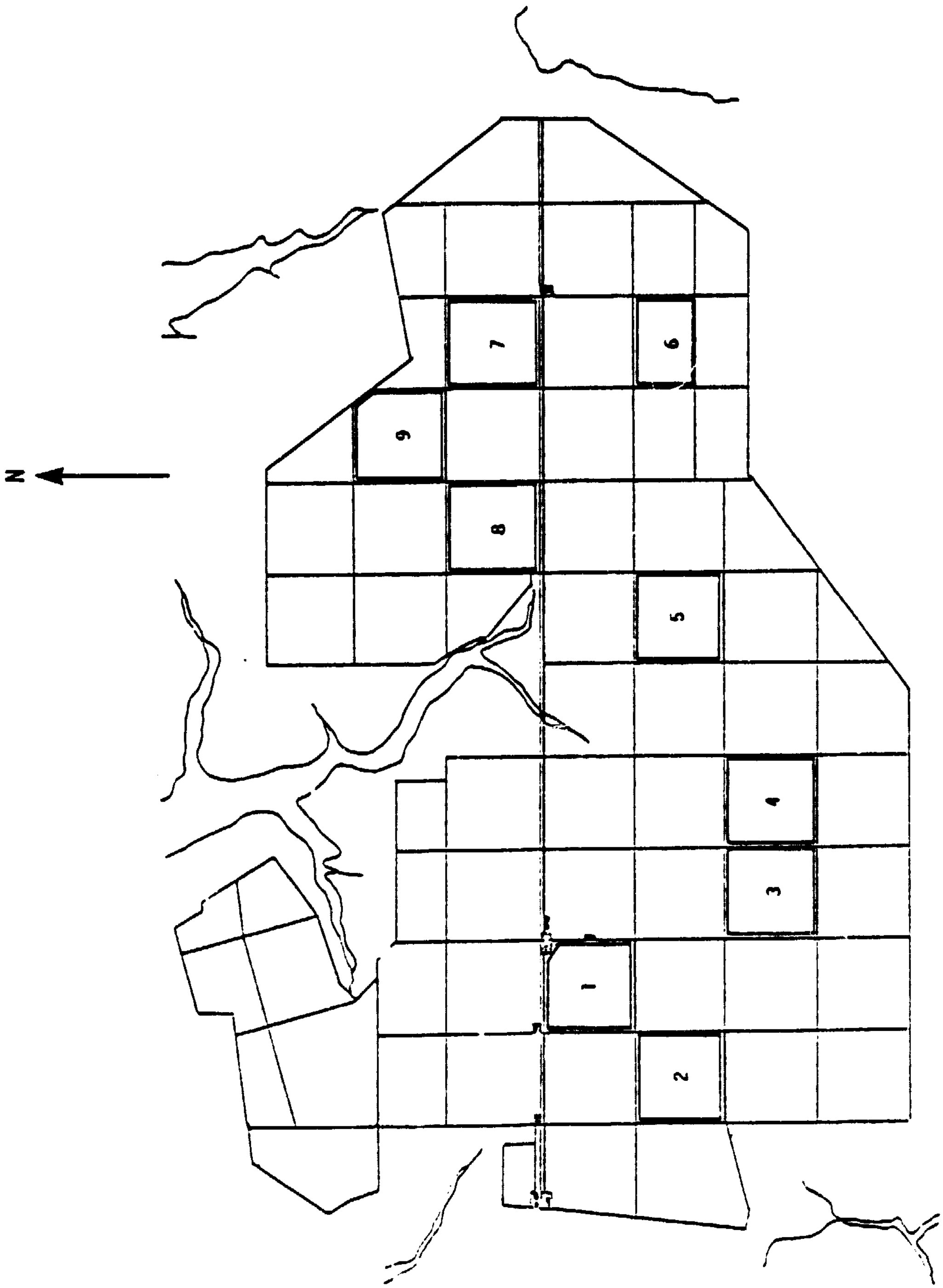

Figure 3. Approximate Regions Used for Comparison of Within-Field Variation

Table 4. Description of Test Regions for Within-Field Variation Comparison

Region	Description (Based on TM Imagery/Ground Truth)
1	Poor growth pasture, little apparent green vegetation, some variation but not extreme
2	Dense, lush green vegetation - little apparent variation
3	Green, but somewhat more variation than #2
4	Pasture, little apparent green vegetation, moderate variation - clear N-S striping
5	Crop residue/bare soil, some vertical (N-S) striping
6	Crop residue/bare soil, pronounced N-S striping
7	Moderately green vegetation, some variation
8	Little apparent green vegetation, marked N-S striping
9	Senescent vegetation, little apparent variation

III. RESULTS AND DISCUSSION

Feature Comparison. The band and feature relationships revealed in this analysis were comparable to those found in previous simulation analyses (Crist and Cicone, 1983), taking into account that: 1) the registration of the real data was imperfect, and 2) neither averaging the TM pixels nor duplicating the MSS pixels provided a truly equivalent MSS/TM data set. As would be expected, correlations were higher when TM pixels were averaged than when MSS pixels were duplicated. TM pixel averaging more closely approximates the MSS signal production, while MSS pixel duplication ignores any variation within the 57-meter MSS pixel, and thus is a poor approximation of TM signal production. Accordingly, the results presented in this section are based on TM pixel averaging.

Even in the presence of the confounding influences mentioned above, high correlations were seen between the MSS bands and their most-similar TM counterparts. Table 5 provides the correlation matrix for the MSS and TM bands, while Figure 4 shows plots of the various band pairs.

The comparison of Tasseled Cap features reveals that the Greenness measures for the two sensors are essentially identical, while some difference exists between the Brightness measures. Table 6, and Figure 5, provide the comparisons. The degree of divergence in Brightness measures emphasizes the need for a more thorough evaluation and understanding of the relationship between TM and MSS Brightness.

Geometric Resolution Comparison. The results of this analysis clearly demonstrate the enhanced ability of the Thematic Mapper to respond to sharp changes or edges in a scene. Figures 6 through 8 show sample results for three test regions. Note that line numbers increase from bottom to top in these figures (i.e., reversed from actual data). In all three cases shown, though perhaps most vividly in Figure 7, a clear difference

Table 5. Correlation Matrix for MSS and TM (Averaged Pixels) Bands - All Nine Regions in Table 4.

TM 2	$\boxed{.909}$	.907	-.209	-.356
TM 3	.881	$\boxed{.975}$	-.455	-.574
TM 4	-.391	-.586	$\boxed{.972}$	$\boxed{.986}$
	MSS 1	MSS 2	MSS 3	MSS 4

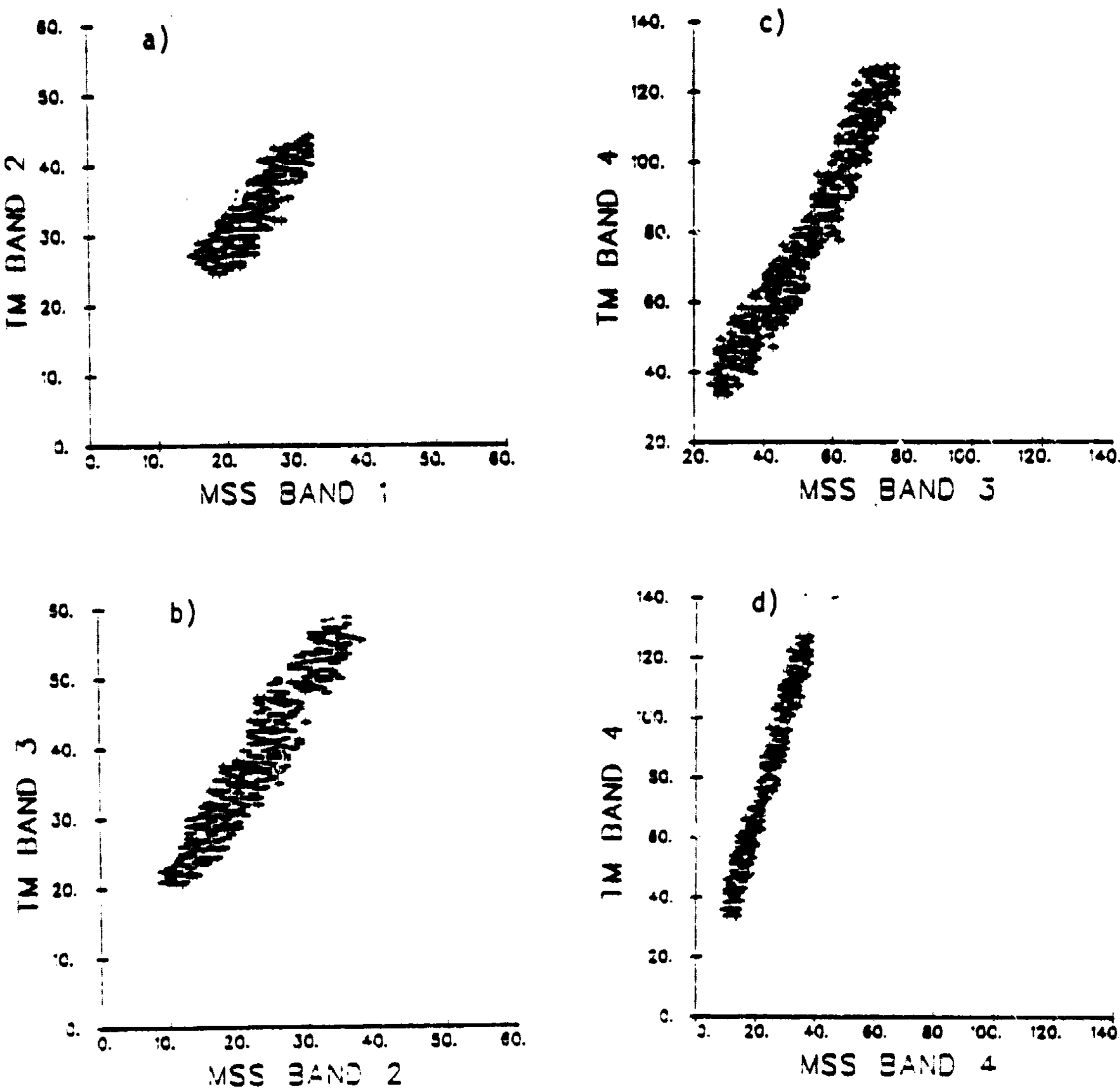

Figure 4. Comparison of Sensor Bands (TM Pixels Averaged to Correspond to MSS Pixels)

Table 6. Correlation Results for MSS and TM (Averaged Pixels) Tasseled Cap Features - All Nine Regions in Table 4.

TM Brightness/MSS Brightness	.747
TM Greenness/MSS Greenness	.990

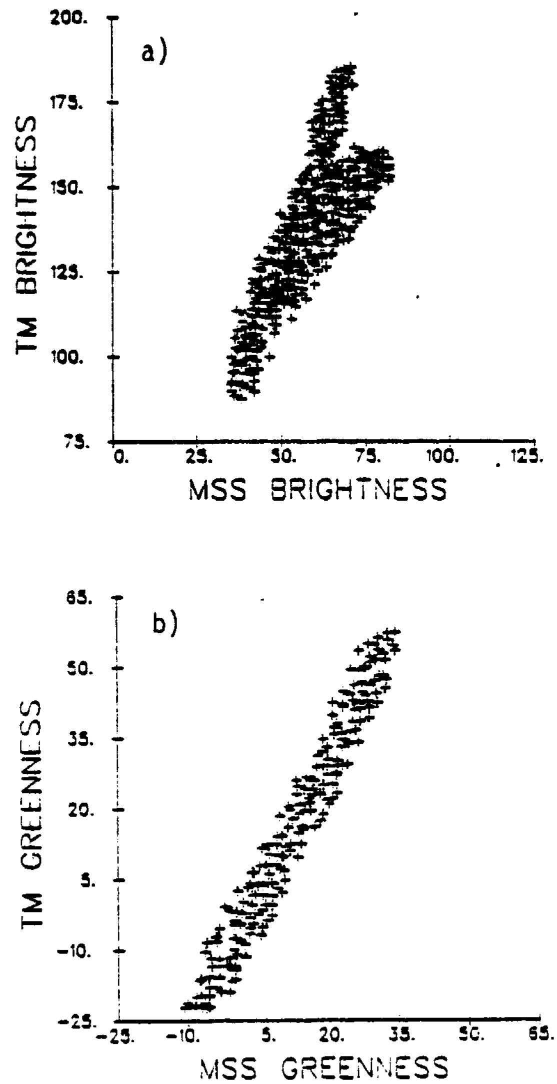

Figure 5. Comparison of Tasseled Cap Features (TM Pixels Averaged to Correspond to MSS PIxels)

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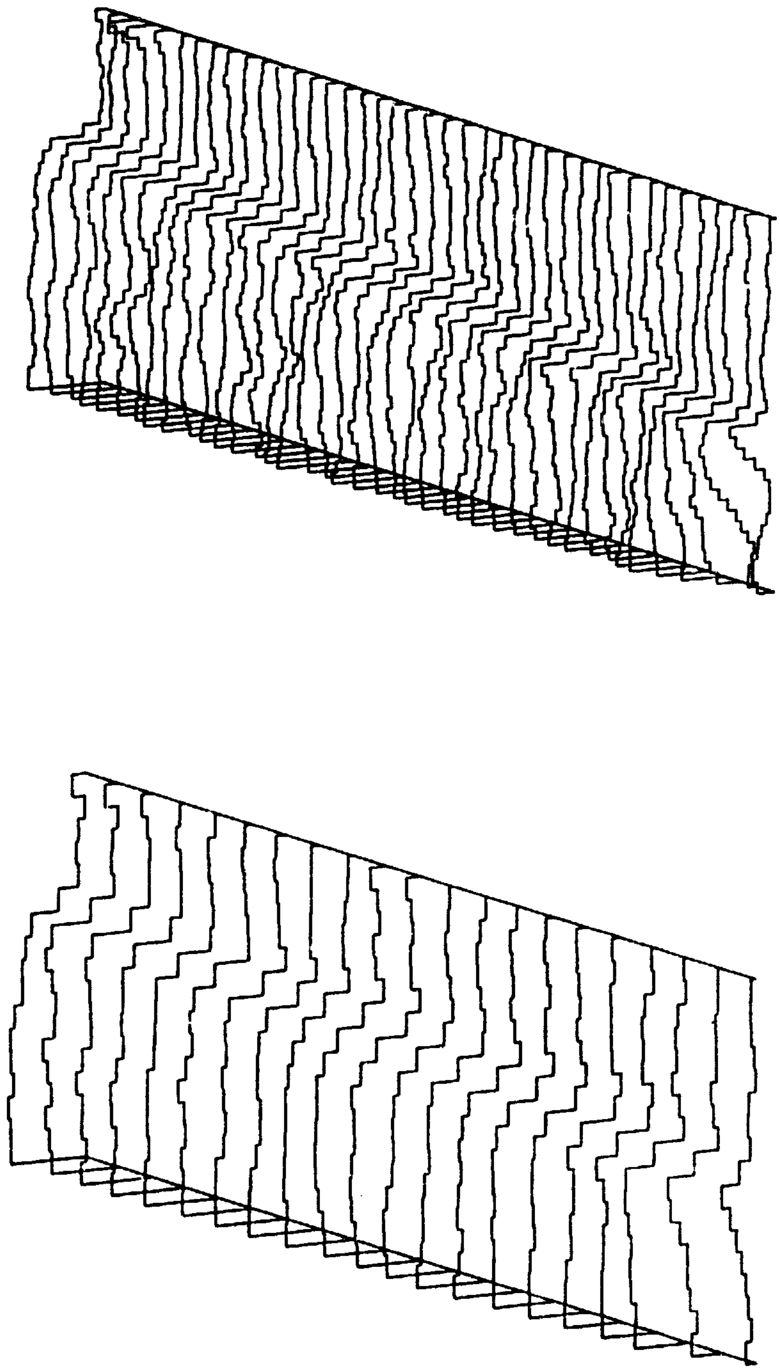
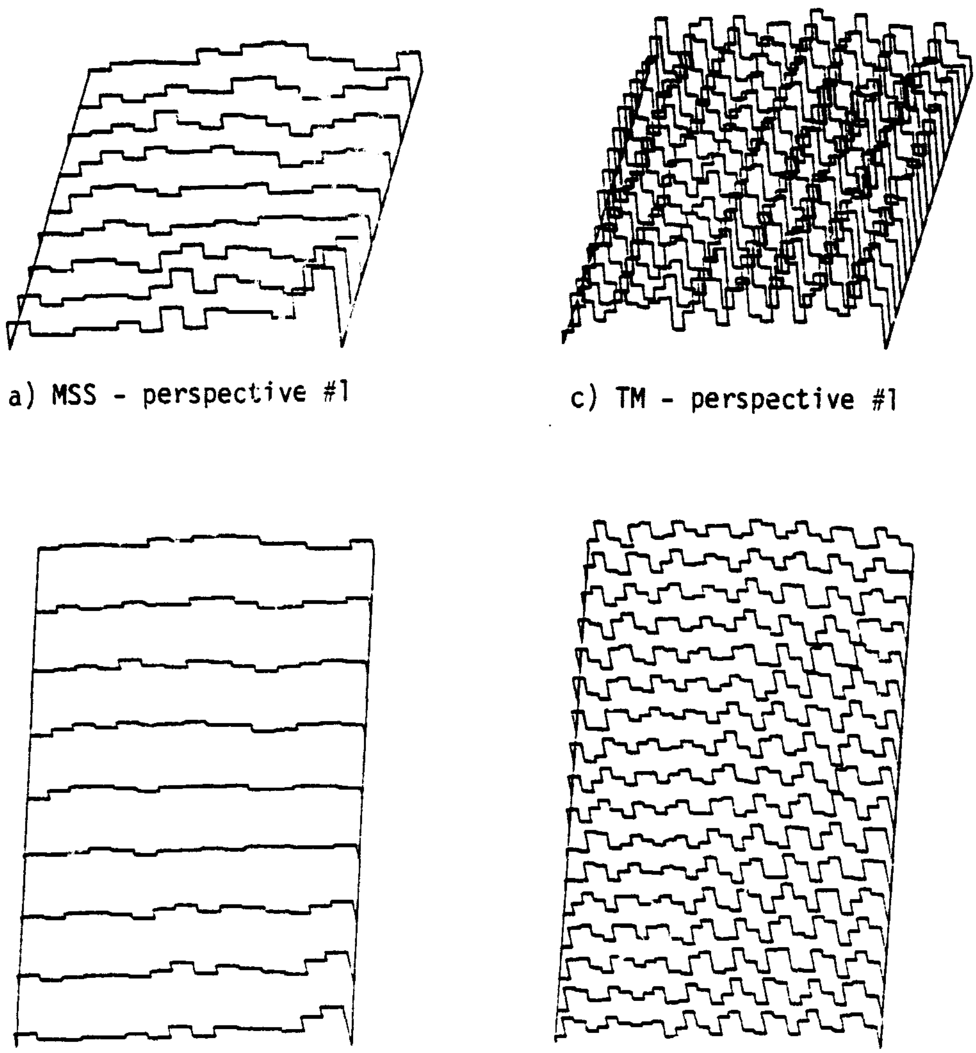


a) MSS

b) TM

Figure 6. Geometric Resolution Comparison - Test Region 1 - Greenness



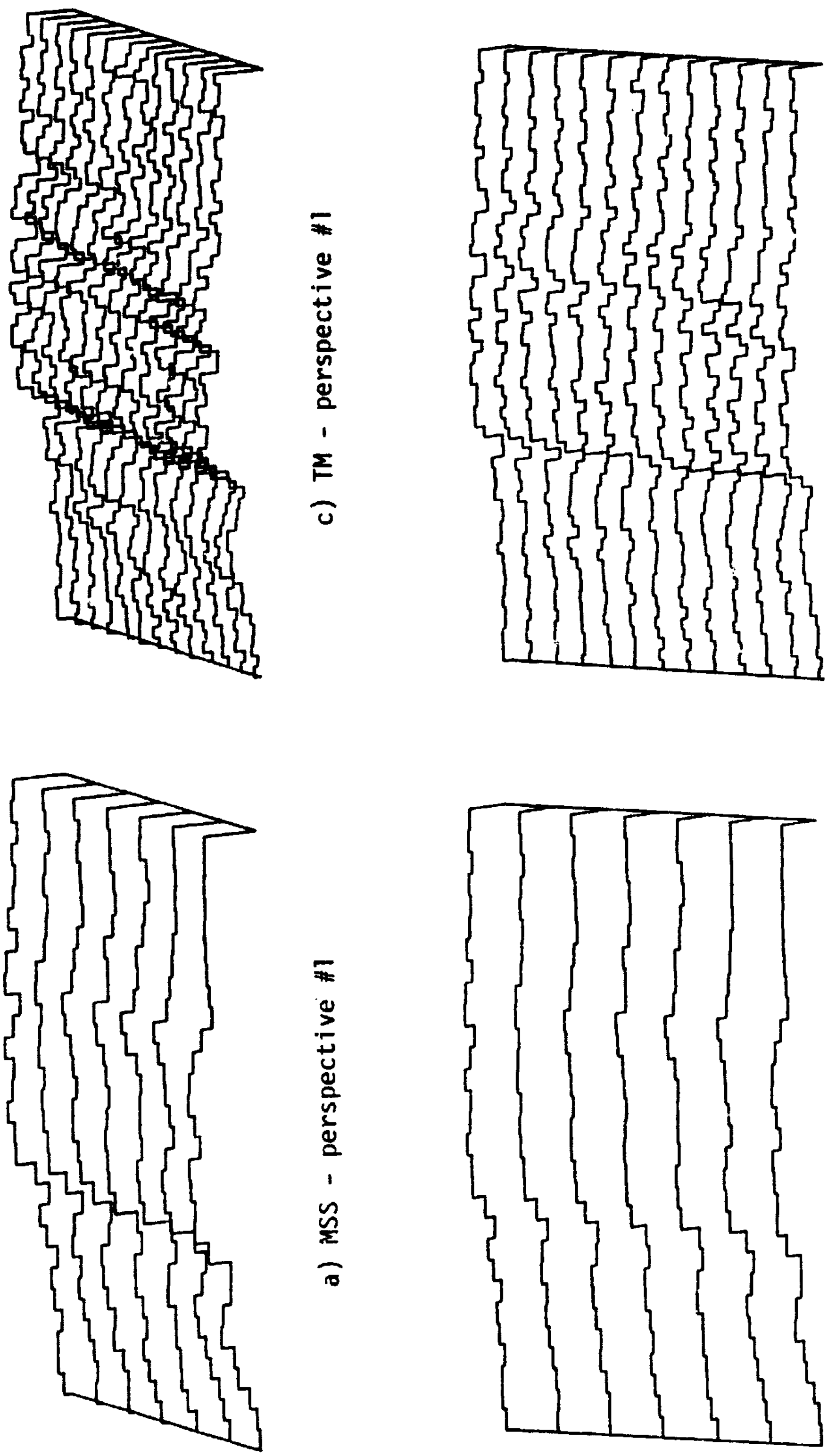
a) MSS - perspective #1

c) TM - perspective #1

b) MSS - perspective #2

d) TM - perspective #2

Figure 7. Geometric Resolution Comparison - Test Region 4 - Brightness



a) MSS - perspective #1

b) MSS - perspective #2

c) TM - perspective #1

d) TM - perspective #2

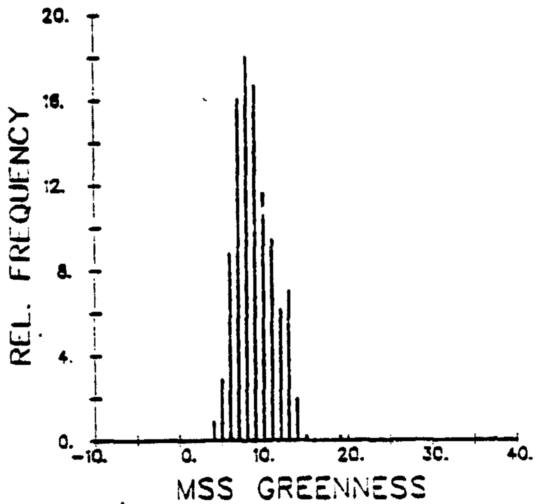
Figure 8. Geometric Resolution Comparison - Test Region 5 - Greenness

between sensors in ability to respond to spatial boundary conditions can be seen, with the higher resolution TM representing changes more sharply than the coarser resolution MSS.

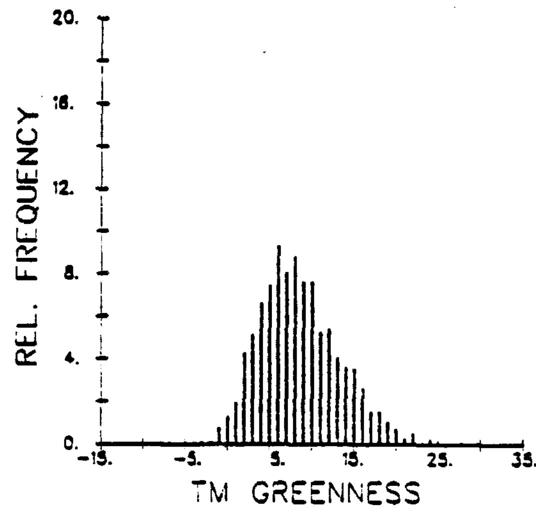
Within-Field Variation Comparison. The greater number of quantization levels of the TM (256 vs. 128) results in a far wider range of signal counts, and a higher standard deviation, for any given region or field. The first two histograms in Figures 9 and 10 show sample results for two test regions. In both cases the TM data are much more widely dispersed than are the MSS data.

In order to simulate MSS data with the same number of quantization levels as the TM data, the MSS histograms were replotted with stretched x-axes and compressed y-axes. This accomplishes graphically the result which would be obtained if each MSS data bin was divided into two bins, each containing half of the pixels from the original bin. The third histograms in Figures 9 and 10 show the result. Differences in the overall shapes of the second and third histograms (TM and stretched-MSS) in the two figures can thus be largely attributed to the improved spatial resolution of the TM, which allows it to respond to finer spatial variability.

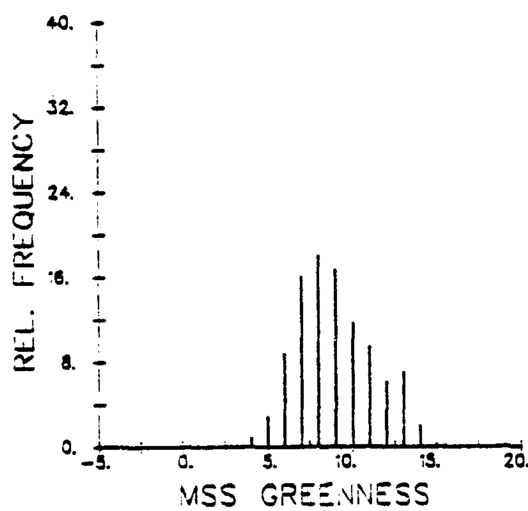
In those cases where less within-field variation was apparent overall, as for example the field depicted in Figure 9, the two sensors performed roughly comparably. This included most of the fully vegetated fields in the test set. Where substantial within-field variation was apparent, the effect of the TM's greater spatial resolution was clear (Figure 10, for example). In these instances, the TM data were more widely dispersed around a mean or mid-point than were the equivalent MSS data. This result was clear both in the histograms and in the statistical measures of data dispersion.



a) MSS



b) TM



c) MSS - scaled to compensate for quantization level difference

Figure 9. Within-Field Variation Comparison - Test Region 9

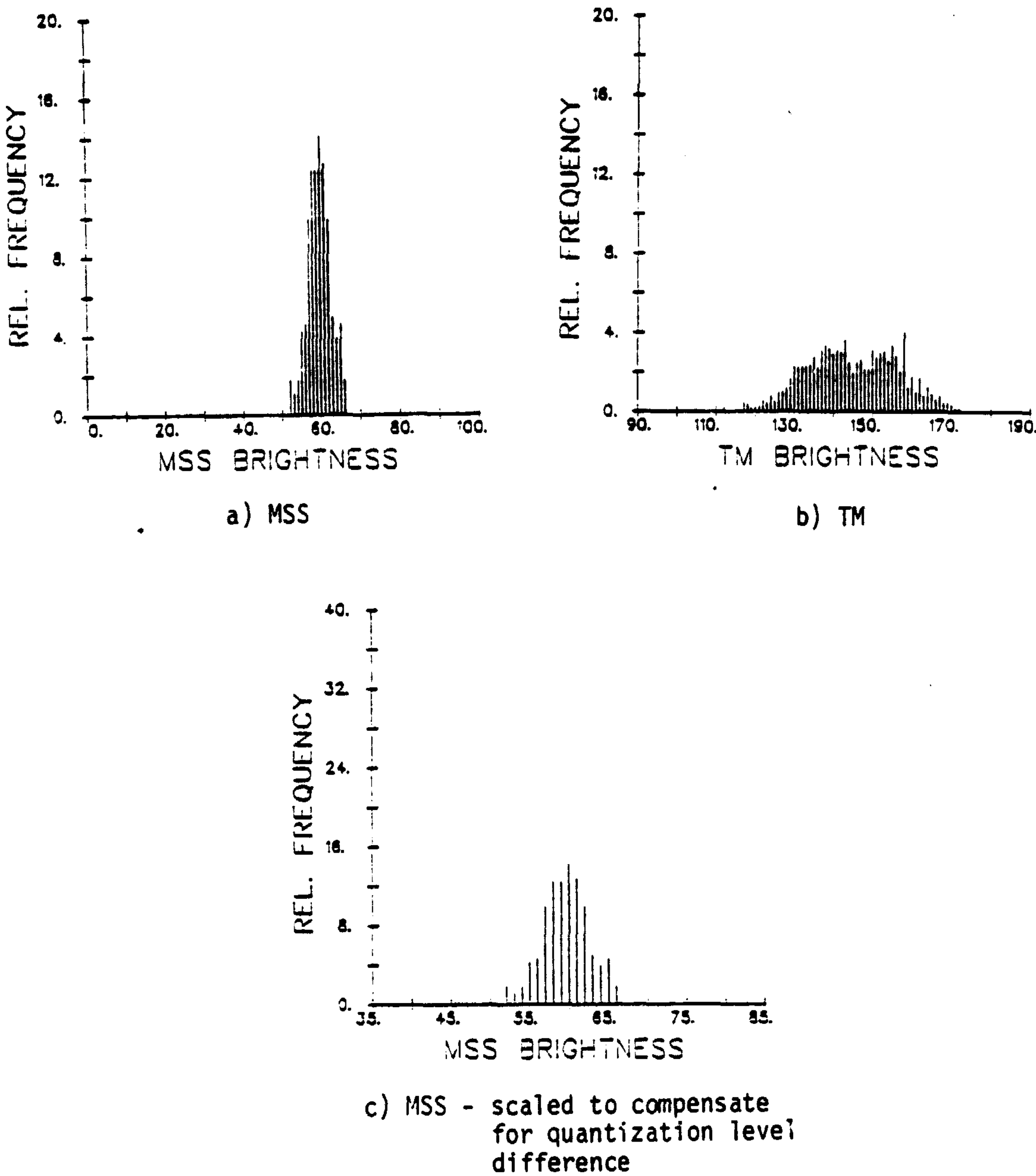


Figure 10. Within-Field Variation Comparison - Test Region 6

Image Analysis. The false color images derived from Bands 1, 2, and 4 of the MSS and Bands 2, 3, and 4 of the TM provided a quick, clear (though subjective) indication of many of the improvements embodied in the TM. The images have been submitted for inclusion in Volume 2 of the Proceedings of the Landsat-4 Early Results Symposium. The following summarizes the major observations:

1) A strong component of coherent noise was apparent in the MSS image, confounding to an extent the comparison of image characteristics. This noise has been seen in other data (e.g., Rice and Malila, 1983), and an electronic source has been identified by GSFC personnel.

2) Even with the noise, most gross features and some finer features were readily identifiable in the MSS image. Fields, most roads, rivers, etc. could all be easily recognized.

3) The contrast in terms of image sharpness and overall quality between the MSS and TM was striking. The impression was that of a focus adjustment, resulting in a transition from a blurry image (MSS) to a clear image (TM).

4) Roads, field boundaries, land/water boundaries, and other edges were noticeably jagged or stair-stepped in the MSS image, while for the most part, these features appeared smooth in the TM image. Under low-power magnification, roads in the TM image were detectably stair-stepped, but under the same magnification the jaggedness of these features in the MSS image was such that they were almost undetectable as linear features.

5) Some smaller roads, and the ditch pattern in the entire farm, were unresolved in the MSS image while appearing clearly in the TM image. The lack of fine detail of this type was unmistakable in the MSS image.

IV. SUMMARY AND CONCLUSIONS

The modest analyses reported here have provided graphic evidence of some of the improvements embodied in the Thematic Mapper as compared to the Multispectral Scanner. The image analysis and comparison of geometric resolution illustrate the benefits of increased TM spatial resolution in resolving edges and fine features. The greater within-field variation found with the TM when considerable within-field detail exists also illustrates the greater information-gathering capacity of the TM. Finally, the comparison of band and Tasseled Cap features illustrates some of the similarities between the sensors, indicating that a subset of TM bands could be used to simulate MSS data for applications where such data were needed.

While the improvements in the TM are clear, the effect of these improvements on traditional information extraction techniques is uncertain. For example, some traditional classification approaches, which use training samples to derive scene class statistics which are in turn used to identify unknown samples, may have difficulty handling the new information available in TM data. Classes which, with a coarser-resolution sensor, appeared homogeneous may now exhibit substantial variability (due, for example, to local variations in plant density, plant condition, or soil condition, or to the presence of small areas of a completely different cover type). The improvements embodied in the Thematic Mapper offer the <u>potential</u> for more accurate and comprehensive description of scene classes, but more sophisticated techniques may be required in order to realize these gains.

These analyses are neither exhaustive nor strictly quantitative. Nevertheless, they provide clear and understandable examples of a few of the key improvements in land remote sensing offered by Landsat-4's Thematic Mapper.

V. REFERENCES

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