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## 22 October 1982 - 21 January 1983

## Study on Radiometric Consistency of Landsat-4 Multispectral Scanner

Contract NAS5-27254

with

NASA Goddard Space Flight Center
Greenbelt Road
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# STUDY ON RADIOMETRIC CONSISTENCY OF LANDSAT-4 MULTISPECTRAL SCANNER

## 1. OBJECTIVES

The major objectives of this investigation are to address the following two topics, relative to characterization of Landsat-4 image data quality:

a. Detector calibration: The calibration of the six Landsat detectors in each band will be studied in order to determine the magnitude of any calibration differences that remain after ground processing and, if needed, to provide information that would support corrective techniques.

b. Satellite-to-satellite calibration: Calibration differences between Landsat-4 and previous Landsat satellites will be studied and, as needed, a method will be developed to adjust Landsat-4 multispectral scanner (MSS) signals, in all four spectral bands, to match the calibration of previous MSS sensors.

## 2. APPROACH

To address the first objective, two statistical analyses of sensor responses are being conducted. The first is a detector-by-detector calculation and analysis of signal means, variances, and amplitude histograms. The second is the calculation and analysis of characteristics of an along-track profile generated for each scene by averaging all pixels on each scan line.

To address the second objective, we have identified potential geographic locations and time periods for simultaneous coverage by Landsats 3 and 4 and will obtain, analyze, and compare the sensor responses from the overlap zones and identical subareas in paired frames of MSS data.

## 3. STATUS AND TECHNICAL PROGRESS

Computer-compatible tapes of radiometrically, but not geometrically, corrected Landsat-4 MSS data (Type "A" tapes) were ordered and received for two scenes. An initial analysis of the radiometric characteristics and consistency of that data was conducted. A preliminary analysis report was generated to support NASA's need to document the Landsat-4 MSS performance prior to turning control of the system to NOAA. A copy of that report is included as Appendix A; two other copies were earlier forwarded directly to Mr. William Alford, Code 902.1, for incorporation into his overall Landsat-4 MSS documentation report.

Also described in the preliminary report is the progress we've made in obtaining coincident coverage by Landsats 3 and 4 for use in satellite-to-satellite calibration.

William Malila and Daniel Rice attended the Second Landsat-4 Investigator's Workshop and presented material relative to our initial analysis results. We also are planning to present information at the Early Results Symposium in February.

## 3.1 Problems

The major problem has been the delay in getting both information that joint acquisitions by Landsats 3 and 4 have occurred and access to the computer-compatible tapes once identified. Mr. Ross Nelson, our NASA Science Representative, has been helpful in expediting this process at NASA/GSFC. We have ordered tapes and are hopeful that at least one pair of coincident Landsat-3 and Landsat-4 scenes will be received in time for analysis to be completed and results presented at the February symposium.

## 3.2 Accomplishments

(1) An initial analysis was completed and a preliminary report was generated (a copy is included as part of this report).

(2) Several preliminary findings were made relative to radiometric properties of the Landsat-4 MSS.

(3) Dates and locations for coincident coverages by Landsats 3 and 4 were identified and special arrangements were made for acquisition of data by both satellites.

(4) The Principal Investigator and Co-Investigator participated in the Second Landsat-4 Investigator's Workshop.

3.3 Significant Results

Based on our full-frame analysis of computer-compatible, Type "A" tapes of radiometrically (but not geometrically) corrected data for two diverse scenes, the following initial findings were made with regard to Landsat-4 MSS radiometric properties:

(1) The Landsat-4 MSS appears to produce data of overall good quality with dynamic ranges and target responses being qualitatively similar to those of previous MSS sensors.

(2) Banding due to between-detector differences appears to be well, but not fully, corrected; a residual rms error of about 0.3 counts was measured.

(3) Amplitude quantization effects observed are consistent with those expected in terms of detector differences and empty signal level bins. The look-up tables used in the radiometric preprocessing varied slowly with scan line number in blocks of 200 lines, as is advertised for the tracking of calibration signals.

(4) A low-level coherent-noise (diagonal striping) pattern was observed in all bands and quantified by Fourier analysis:

(a) The principle component of this noise was found to be at a highly consistent wavelength of 3.6 pixels along a scan line, corresponding to a 28 Khz frequency in the signal.

(b) The magnitude of this effect was found to be about 0.75 of a count in the worst band (Band 1) and about 0.25 counts in the best band (Band 4).

Preparations were made for establishing a relative radiometric calibration for MSS 4 data with respect to MSS 3 data:

(1) All time and place coincidences of Landsat-3 and -4 coverages in the contiguous United States were identified and tabulated for Dec. 1982 through Mar. 1983.

(2) Special arrangements were made for the acquisition of a subset of this coincident data.

(3) Imagery from one early coincident pair was examined visually. Development of this relative calibration will proceed when digital data become available.

## 3.4 Publications

Appendix A, Preliminary Report on Investigation of Radiometric Properties of Landsat-4 MSS, by W. A. Malila and D. P. Rice, 18 Jan 1983, was provided to NASA for inclusion in their Landsat-4 MSS documentation report to NOAA.

## 3.5 Recommendations

It is recommended that techniques for removing the coherent noise effects be investigated by NASA and/or Landsat-4 investigators and that our planned analyses be continued and completed as data become available.

## 3.6 Funds Expended

A total of approximately $38,000 was expended through 15 January 1983 on this contract.

## 3.7 Data Utility

The data appear to be of generally good quality and are qualitatively comparable to data from earlier Landsats. The radiometric defects we found in the data appear to be relatively minor. We understand that the 0 to 63 counts range of the Band 4 data on the tapes we examined has been expanded to 0 to 127 counts on data generated since mid October.

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# PRELIMINARY REPORT ON

# INVESTIGATION OF RADIOMETRIC PROPERTIES OF LANDSAT-4 MSS

W. A. Malila and D. P. Rice

Prepared Under

Contract NAS5-27254
(Landsat-4 Investigation AN-23)

For

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18 January 1983

## ABSTRACT

Two full frames of radiometrically corrected Landsat-4 MSS data were examined to determine a number of radiometric properties. It was found that Landsat-4 MSS produces data of good quality with dynamic ranges and target responses qualitatively similar to those of previous MSS sensors. Banding appears to be quite well corrected, with a residual rms error of about 0.3 digital counts being measured; the histogram equalization algorithm appears to be working as advertised. A low-level coherent noise effect was found in all bands, appearing in uniform areas as a diagonal striping pattern. The principle component of this noise was found by Fourier analysis to be a highly consistent wavelength of 3.6 pixels along a scan line (28 KHz). The magnitude of this effect ranged from about 0.75 of one count in the worst band (Band 1) to only about 0.25 counts in the best band (Band 4).

Preparations were made for establishing a relative radiometric calibration from MSS 4 data with respect to MSS 3. All time and place coincidences of Landsat 3 and 4 coverages in the contiguous United States were identified and tabulated for 12/82 - 3/83 and special arrangements were made for the acquisition of a subset of this coincident data. One set of coincident images was examined visually. Development of this relative calibration will proceed when digital data become available.

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# 1
# INTRODUCTION

## 1.1 BACKGROUND

The Landsat user community has been concerned about the continuity of Landsat multispectral scanner (MSS) data. Landsat-4 extends the decade of data availability afforded by the first three Landsat satellites. We believe that continuity should be thought of not only as being the continued availability of high quality Landsat MSS data, but also the consistent interpretability of signal amplitudes and spectral features extracted from MSS data. Hence, of interest are both the internal calibration between detectors within each spectral band, with related dynamic-range and signal-to-noise characteristics, and the radiometric calibration of the Landsat-4 MSS bands relative to the characteristics of the preceding Landsat sensors.

If detectors within a band are not perfectly calibrated with respect to each other (i.e., equalized), image banding results and extra variability or noise is introduced into the statistical descriptions (e.g., signatures) of signals from specific scene classes. Similarly, if the noise associated with each detector channel were to significantly exceed design specifications, the utility of the data collected by the system would be diminished. Also, reduced dynamic range could degrade data utility.

Furthermore, if the radiometric calibration of the Landsat-4 MSS bands were not to match well that of its predecessor or were to drift, algorithms, techniques, and procedures with fixed coefficients or thresholds developed for use with Landsat 1, 2, and 3 MSS scanners would have to be modified accordingly.

## 1.2 OBJECTIVES

The objectives of this investigation are to address the following two topics, relative to characterization of Landsat-4 image data quality:

a. Detector calibration: The calibration of the six Landsat detectors in each band will be studied in order to determine the magnitude of any calibration differences that remain after ground processing and, if needed, to provide information that would support corrective techniques.

b. Satellite-to-satellite calibration: Calibration differences between Landsat-4 and previous Landsat satellites will be studied and, as needed, a method will be developed to adjust Landsat-4 multispectral scanner (MSS) signals, in all four spectral bands, to match the calibration of previous MSS sensors.

In addition, we will examine the overall quality and characteristics of Landsat-4 MSS data and make recommendations where possible that could improve the data quality.

## 1.3 PURPOSE OF THIS PRELIMINARY REPORT

This report was prepared to provide NASA with a description of our preliminary findings at this point in time, in support of their need to document the Landsat-4 MSS system and its performance prior to turning over control of the system to NOAA. Due to delays in obtaining Landsat-4 MSS data, we have not been able to carry out our full intended analysis, but reportable progress and results have been achieved in several areas and are presented herein.

# 2
# APPROACH

An empirical approach involving several topics is being pursued to assess the quality of Landsat-4 MSS image data. Thus far, data from the two frames described in Section 3 have been obtained for analysis.

The first step was to compute and analyze signal statistics on a detector-by-detector basis for the six detectors in each of the four spectral bands on the "A" tapes. Means, variances, and histograms of signal amplitudes were computed for the entire frame, for four 600-line segments and twelve subsegments, and for several diverse scene classes. Within-band means and variances were compared to search for evidence of detector "banding" effects. Histograms were examined to compare the quantization patterns (a result of radiometric look-up tables) found in the signal amplitudes, both for the entire scene and for the image subsegments. Digital display maps were produced from these scenes and examined visually for banding effects. The detector-based statistics and Variable X vs. Variable Y scatter plots also were examined qualitatively for dynamic range and other characteristics, relative to our experience with previous Landsats.

Another approach used for detecting banding effects was the Fast Fourier Transform (FFT) technique. FFT's were computed of a down-track profile for each band for each frame; these profiles were obtained by averaging all pixels in each scan line. Spatial frequencies at integer wavelengths (e.g., six scan lines) that are more pronounced than others at nearby frequencies can be indicative of bandings and give a quantitative measure of its magnitude.

FFT's also were computed for sections of individual scan lines at selected locations down the frame. These results provided a mechanism for detecting and quantifying coherent noise effects in the image data, both amplitude and phase as well as between-band comparisons. This type of noise produces a pattern on images that appears as light diagonal stripes.

The final topic addressed was satellite-to-satellite calibration. Landsat Path-Row locations and dates within the contiguous 48 states were identified where simultaneous coverage is possible by the Landsat 3 and Landsat 4 scanners. This possibility exists because of the 16-day and 18-day repeat-coverage cycles of Landsat 4 and Landsat 3, respectively. Arrangements were made to have the Landsat 3 tape recorder turned on during those frames to acquire such data for subsequent analysis. The availability of simultaneous coverage will eliminate several confounding effects from the analysis of relative radiometric calibration between these systems.

# 3
# DESCRIPTION OF DATA SET

As noted above, two Landsat-4 frames have been obtained to date from the EROS Data Center and used for the analyses reported herein. They are different from each other both geographically and by the content of their scenes. One is near the East Coast of the U.S. and includes the border between North and South Carolina. The other is near the West Coast, covering the Imperial Valley of California adjacent to the border with Mexico. From the specific parameters given in Table 1, it can be seen that both were acquired in late September, 1982.

The Carolina scene is made up primarily of forests and pasture, with some agricultural fields. The California scene is more diverse and contains a highly productive agricultural area, a large inland lake (Salton Sea), desert or semi-desert areas, and some mountains.

TABLE 1. DESCRIPTION OF DATA SET

| Geographic Location | Landsat-4 Path/Row | Date of Acquisition | Frame ID |
|---|---|---|---|
| S. Carolina (N. Carolina) | 17/36 | 29 Sep 82 | 40075-15271 |
| California (Imperial Valley) | 39/37 | 23 Sep 82 | 40069-17433 |

# 4
# INITIAL ANALYSIS RESULTS

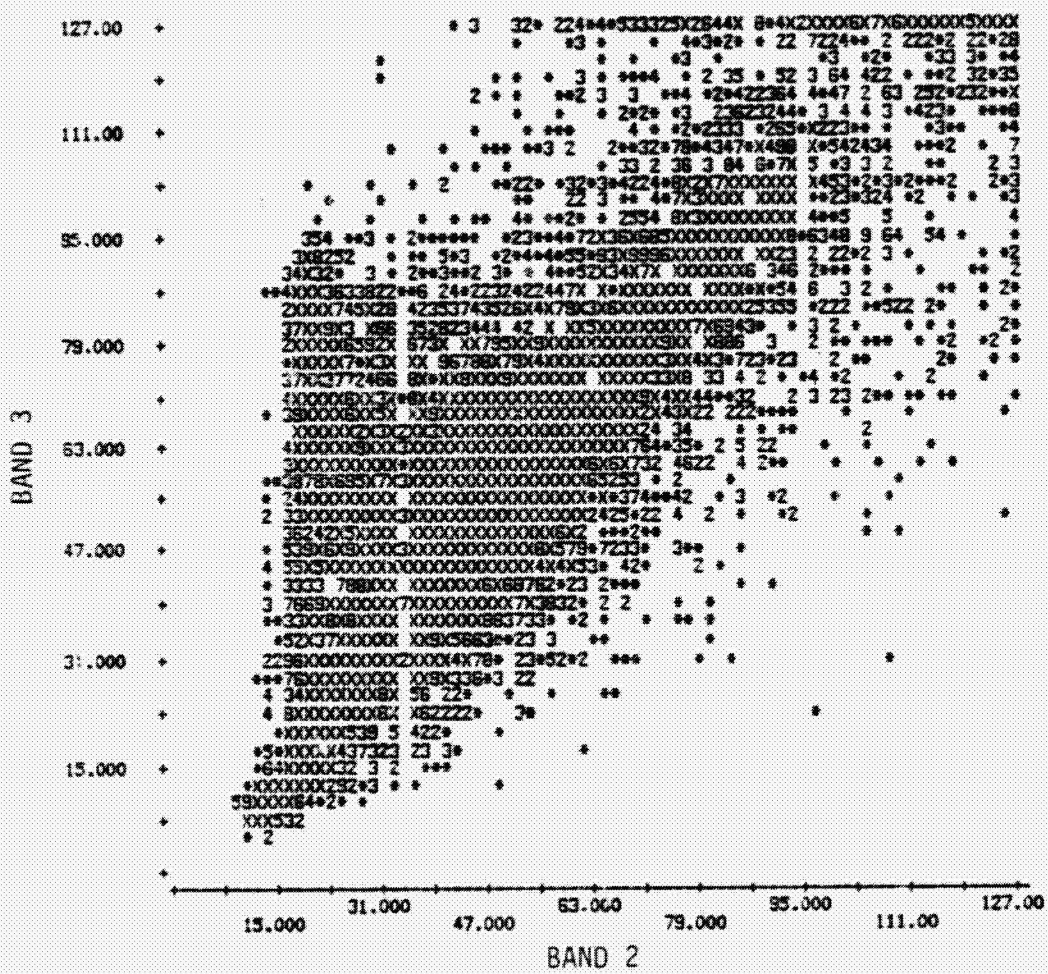
This section presents the initial results of our analysis, as of 18 Jan 83. After a qualitative comparison of Landsat-4 MSS image data to that from previous Landsat multispectral scanners, we present quantitative analyses of detector-to-detector calibration differences and their effects, amplitude quantization effects, and coherent noise effects. Progress on our satellite-to-satellite calibration effort is also presented in detail.

## 4.1 QUALITATIVE COMPARISON OF SCENE RESPONSES TO THOSE FROM PREVIOUS LANDSATS

### General Comments on Radiometric Behavior

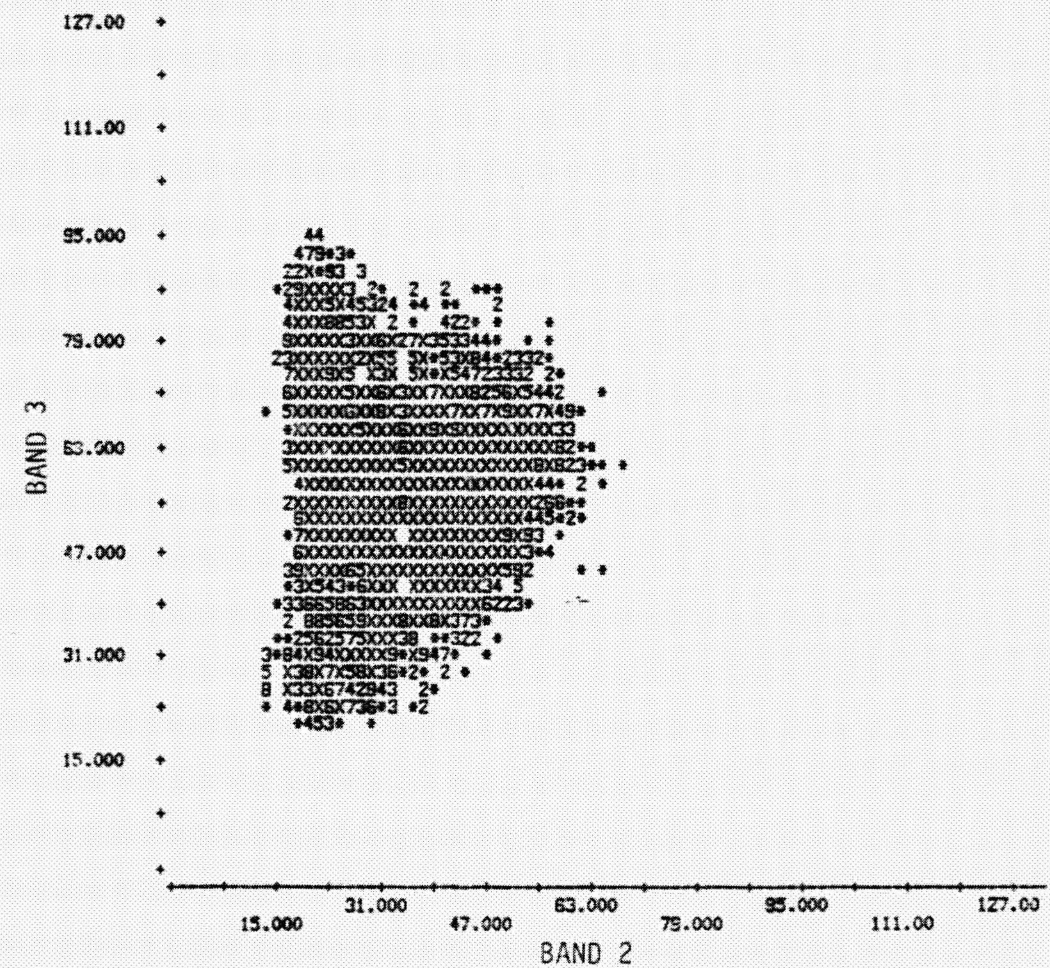
One scene (Imperial Valley) showed excellent quality with target responses and dynamic range similar to other Landsats, a very favorable result. A second scene (South Carolina) was radiometrically different in that this scene had a much narrower range of signals, although much of this narrowness may be attributed to scene content or atmospheric effects.

A look at these responses and the dynamic range of the Imperial Valley scene can be taken by using the scatterplots of Figure 1 (Band 3 vs. Band 2). This figure comes in five parts, the first part representing a sample of a large diverse area of the scene, and the remaining parts representing four general ground classes. In Figure 1(a), the principle classes in the scene are all represented, and so the overall dynamic range is apparent. The four target types displayed in Parts (b)-(e) illustrate that:



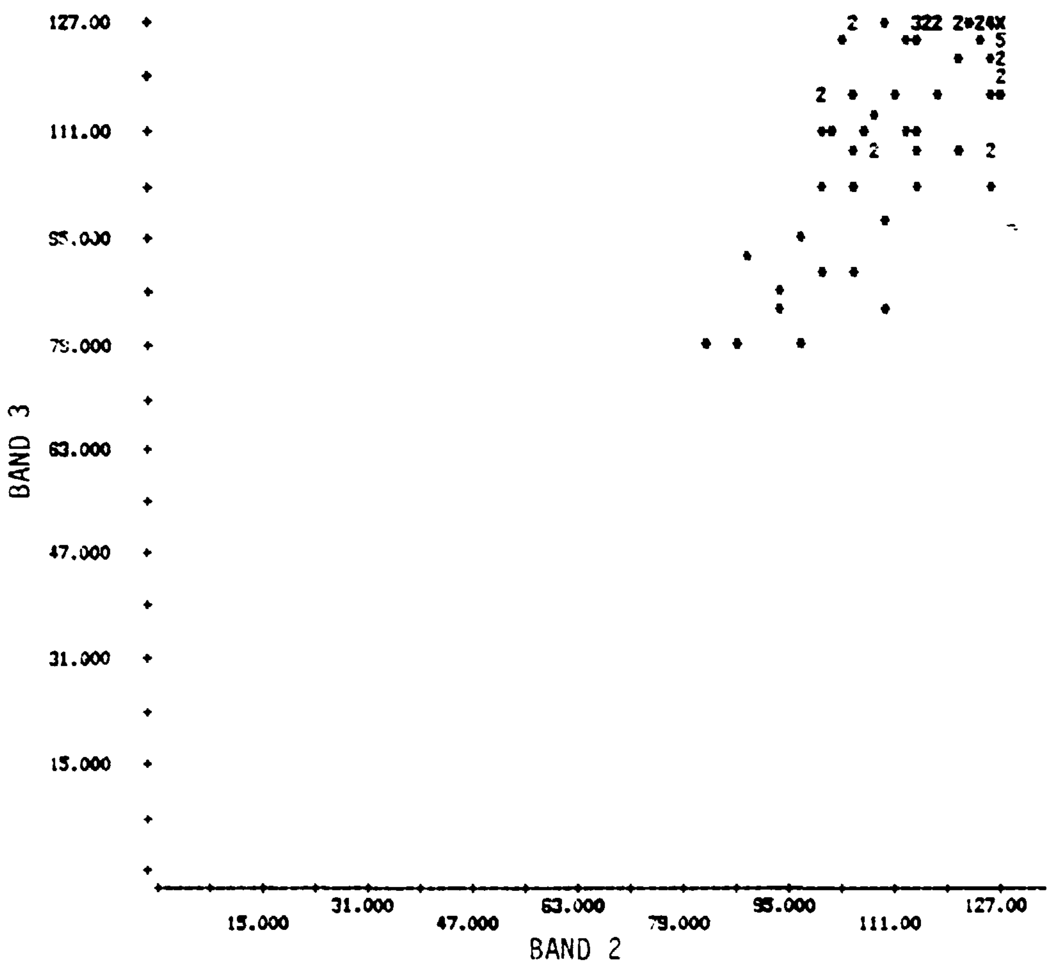

(a) Comprehensive Sample of the Scene

FIGURE 1. LANDSAT 4 MSS BAND 3 VS. BAND 2 SCATTERPLOTS OF SELECTED REGIONS IN THE IMPERIAL VALLEY SCENE



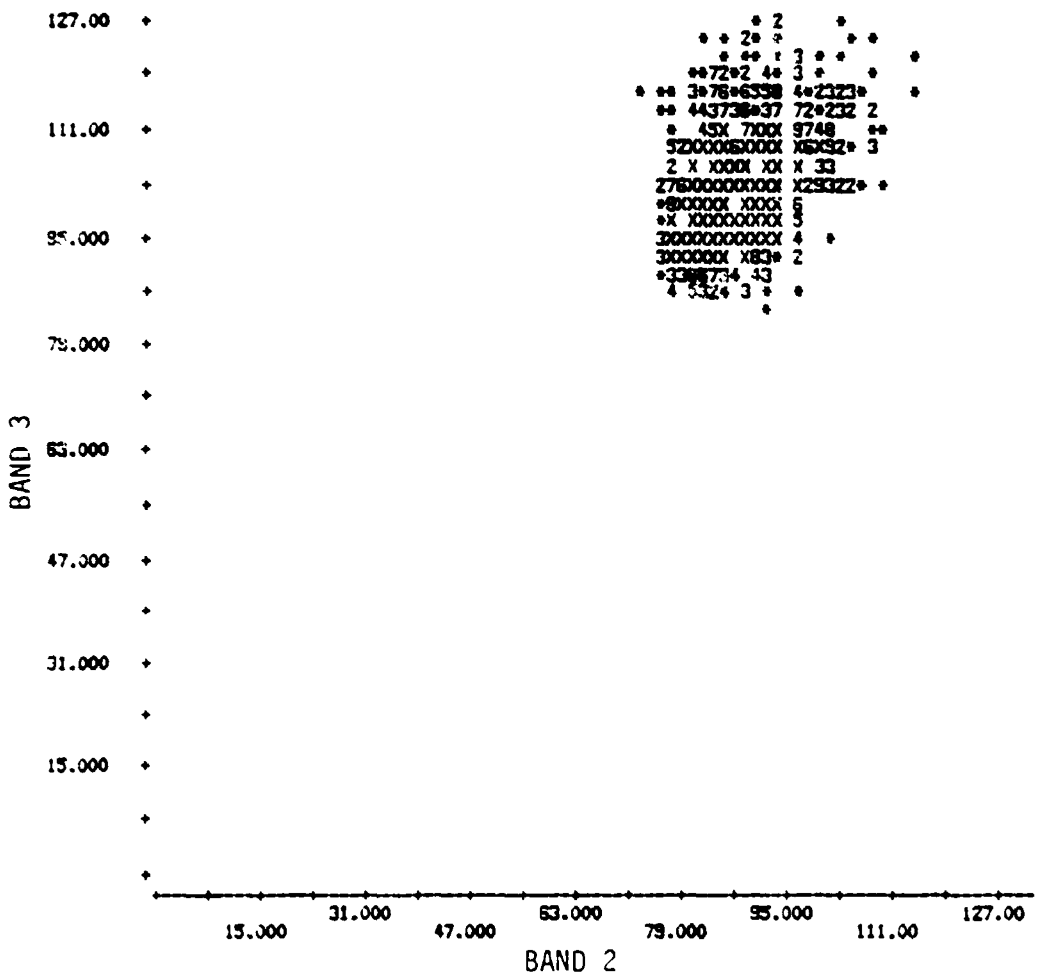

(b) Agricultural Region

FIGURE 1. LANDSAT 4 MSS BAND 3 VS. BAND 2 SCATTERPLOTS OF SELECTED REGIONS IN THE IMPERIAL VALLEY SCENE (Cont'd)



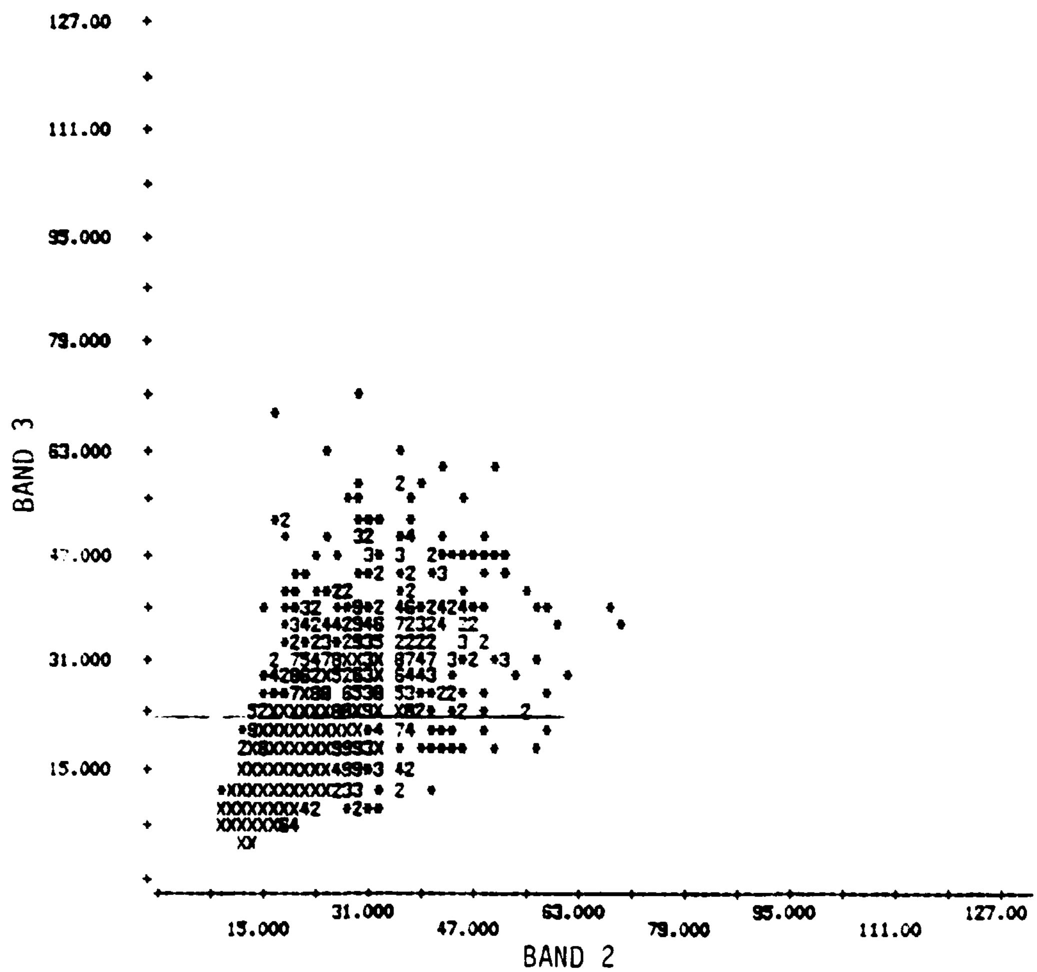

(c) Clouds

FIGURE 1. LANDSAT 4 MSS BAND 3 VS. BAND 2 SCATTERPLOTS OF SELECTED REGIONS IN THE IMPERIAL VALLEY SCENE (Cont'd)




(d) Sand Dunes

FIGURE 1. LANDSAT 4 MSS BAND 3 VS. BAND 2 SCATTERPLOTS OF SELECTED REGIONS IN THE IMPERIAL VALLEY SCENE (Cont'd)




(e) Water

FIGURE 1. LANDSAT 4 MSS BAND 3 VS. BAND 2 SCATTERPLOTS OF SELECTED REGIONS IN THE IMPERIAL VALLEY SCENE (Concluded)

1. Agricultural data fills out a roughly triangular "Tasseled Cap" shape that occurs, and is well documented, for all previous Landsat MSS data for vegetated areas.
2. Water is represented by low signals in all bands.
3. Sand is bright in all bands.
4. Clouds are so bright as to cause signal saturation at Level 127 in both bands.

These observations are normal for all MSS data, and provide evidence that Landsat 4 MSS data are roughly comparable to previous Landsat MSS's.

## 4.2 DETECTOR-TO-DETECTOR DIFFERENCES

Since the data used in this analysis are from "A" tapes, they are presumed to be radiometrically corrected. The correction carried out at GSFC consists of adjustments to detector gains and biases according to calibration source level, alignment of histogram means and variances, and data decompression functions for Bands 1-3 (on the two tapes we've examined, MSS Band 4 has not been decompressed). The resulting set of corrections (for each detector in each band) is determined independently for each block of 600 scan lines (one quarter of a Landsat 4 MSS scene) and is separately interpolated to each block of 200 scan lines. What follows is a determination of the magnitude of any banding effects present in the data after the above radiometric corrections were applied.

In order to determine the presence of possible residual banding effects, photographic images and line-printer maps of the data were examined. Banding effects were rarely noted, except in areas of nearly uniform radiance such as water bodies. Figure 2 shows an area of high reflectance near Imperial Valley, California, in which a banding effect can be noted.

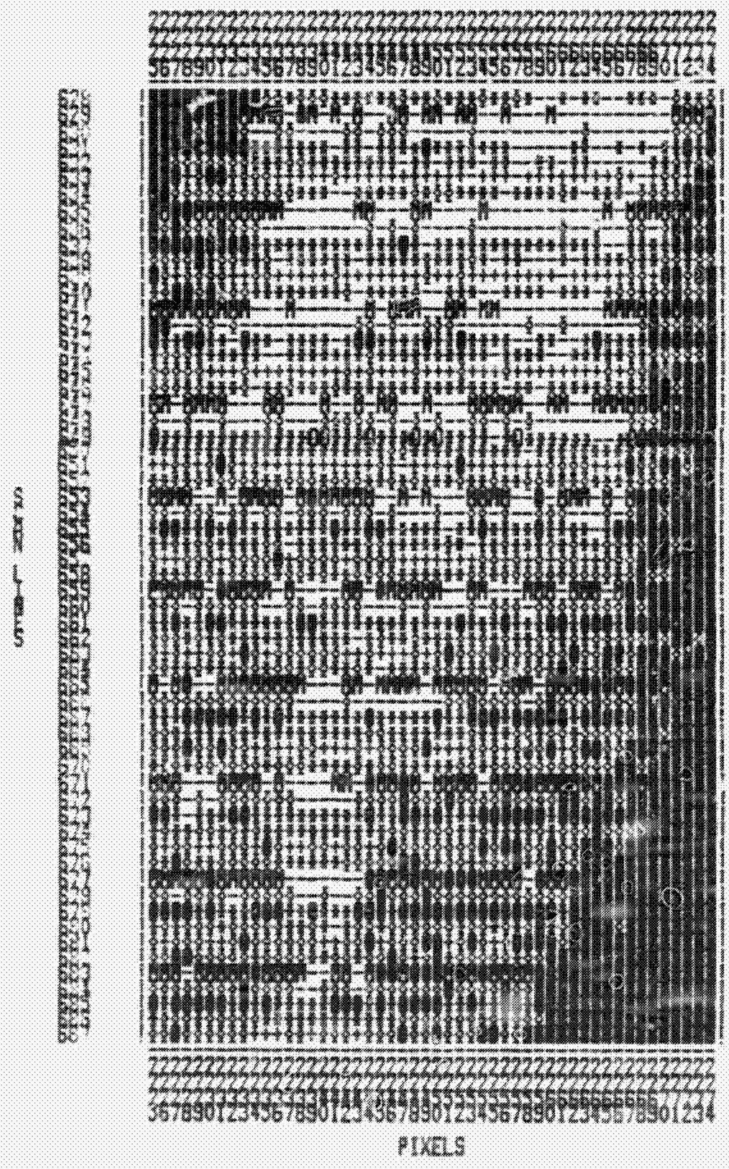


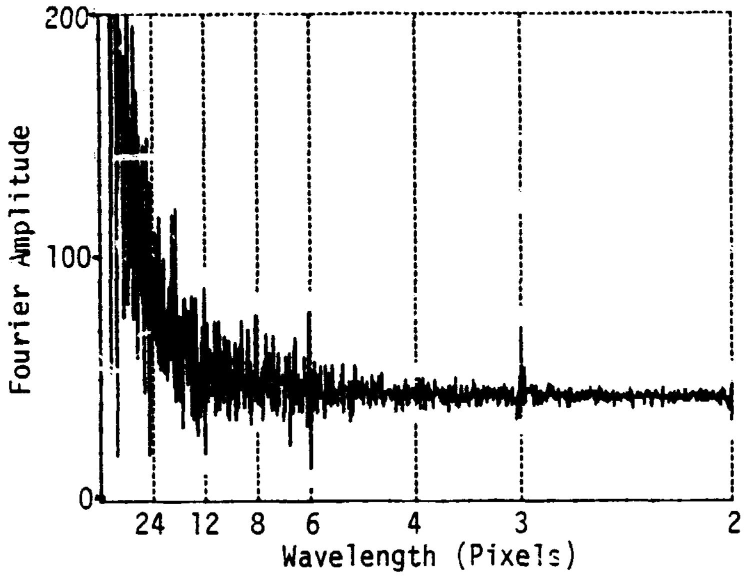
FIGURE 2. EXAMPLE OF THE DETECTOR BANDING EFFECT
(Bright Shallow Valley)

After band averages were computed for each scan line in two Landsat frames, fast Fourier transforms were computed for each band in each frame, and were examined for the presence of a response to a wavelength of 6 pixels (and its harmonics at 3 and 2), as shown in Figure 3, which contains examples of the transforms. A disturbance in the general pattern of scene information is apparent at and near the wavelengths 6, 3, and 2 pixels (or scan lines) in these plots. Generally there are slight positive and/or negative responses near these wavelengths, indicating that the banding is generally but not always well corrected, and that the correction interacts slightly with scene information that is near these wavelengths. In the worst case, Band 4 of the South Carolina Frame P17/R36, the average deviation from the mean of the six detectors based on the Fourier transforms is 0.27 of one count (with a measurement error of approximately 0.05 due to the scene information). The occasional amplitude reductions (down-going spikes) imply that expected scene information near the banding wavelengths was partially eliminated by the correction algorithm. In passing, we additionally note that the Imperial Valley scene appears to contain more information at spatial wavelengths of 8 to 12 pixels and longer, representing the greater variety of scenic content in this frame.

To further quantify the banding error, and to examine any scene-dependence of the error, detector means were computed for five regions representing different types of scene context. As presented in Table 2, these means show a rather low level of banding error, also generally less than 0.3 counts. The magnitude of these errors does not seem to be target-dependent, nor does any detector seem to be off in a consistent direction (although Detector 5 of Band 2 tended to take on extreme values in four of five cases).

Based on the evidence presented above, it appears that banding is rather well corrected, although there is perhaps more effect on the

Band 1, Imperial Valley 39/37




Band 2, Imperial Valley 39/37

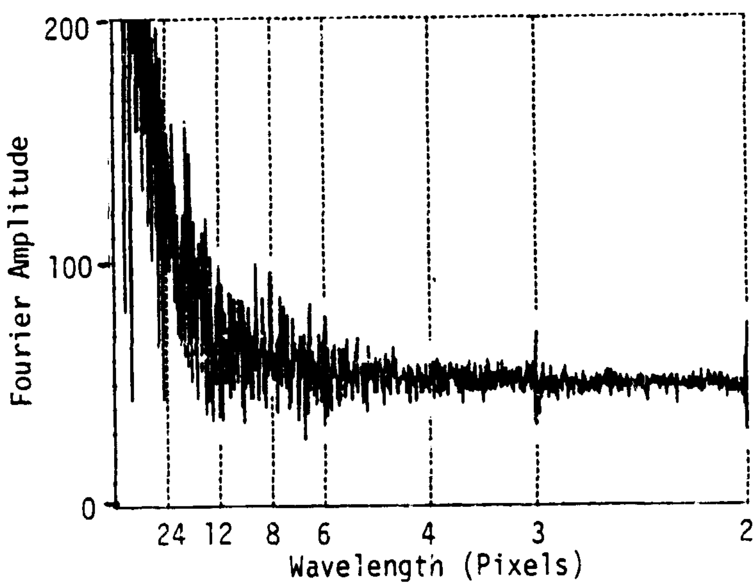
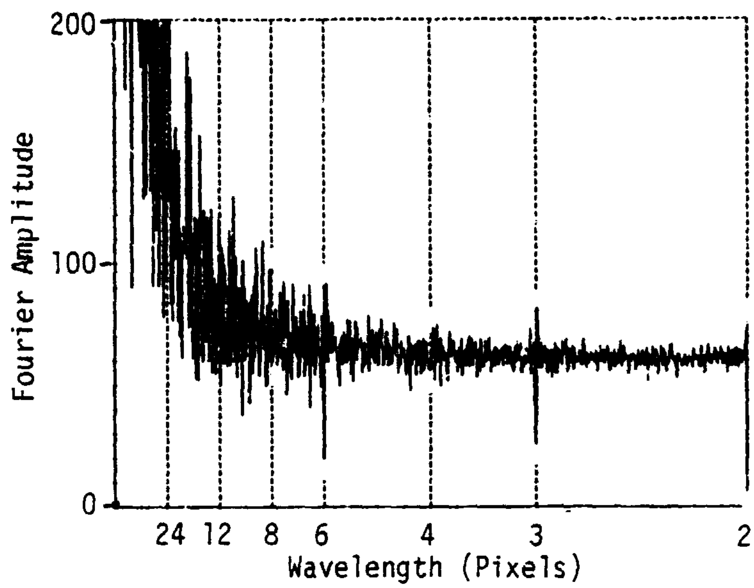



FIGURE 3. DOWN-TRACK FOURIER TRANSFORMS OF SCAN LINE MEAN VALUES, SHOWING BANDING EFFECTS AFTER RADIOMETRIC CORRECTIONS

Band 3, Imperial Valley 39/37




Band 4, Imperial Valley 39/37

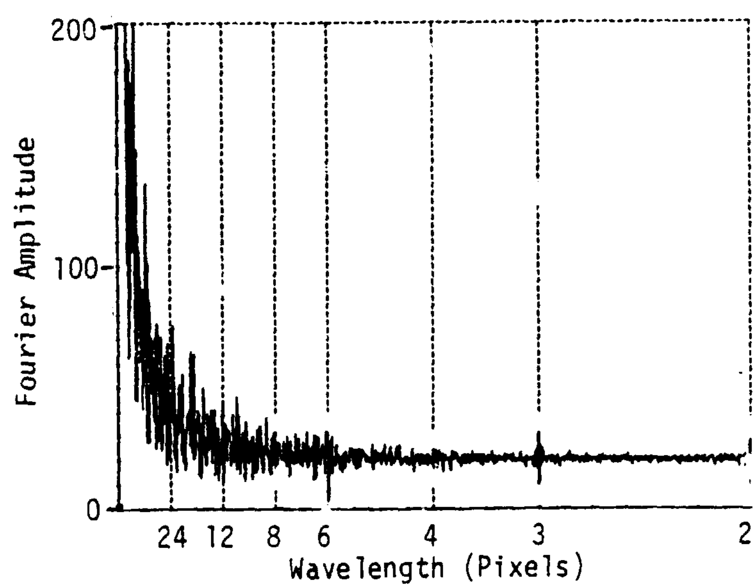
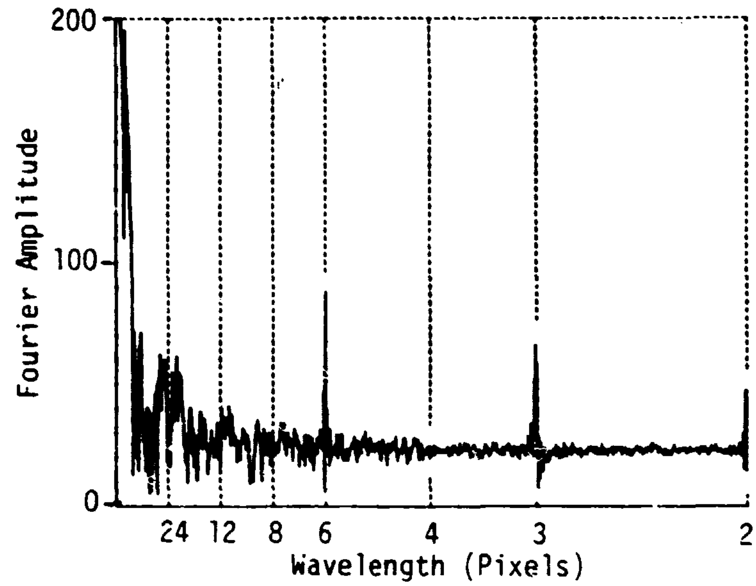



FIGURE 3. DOWN-TRACK FOURIER TRANSFORMS OF SCAN LINE MEAN VALUES, SHOWING BANDING EFFECTS AFTER RADIOMETRIC CORRECTIONS (Cont'd)

Band 1, South Carolina 17/36




Band 2, South Carolina 17/36

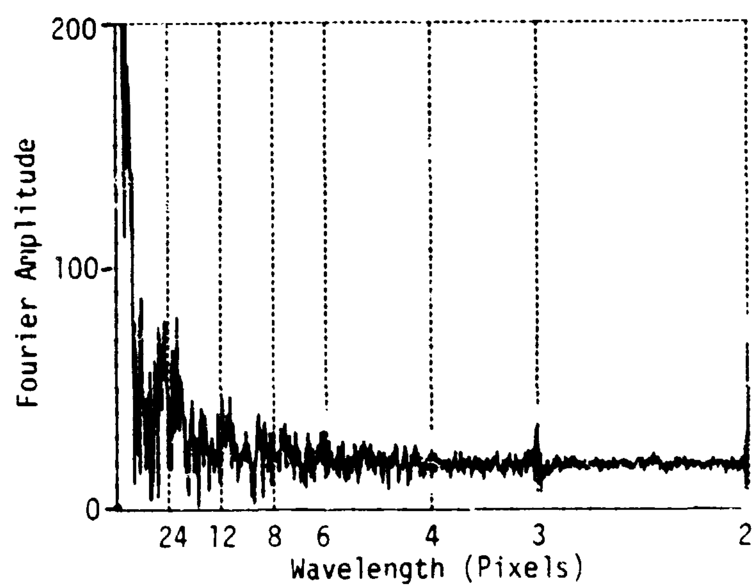
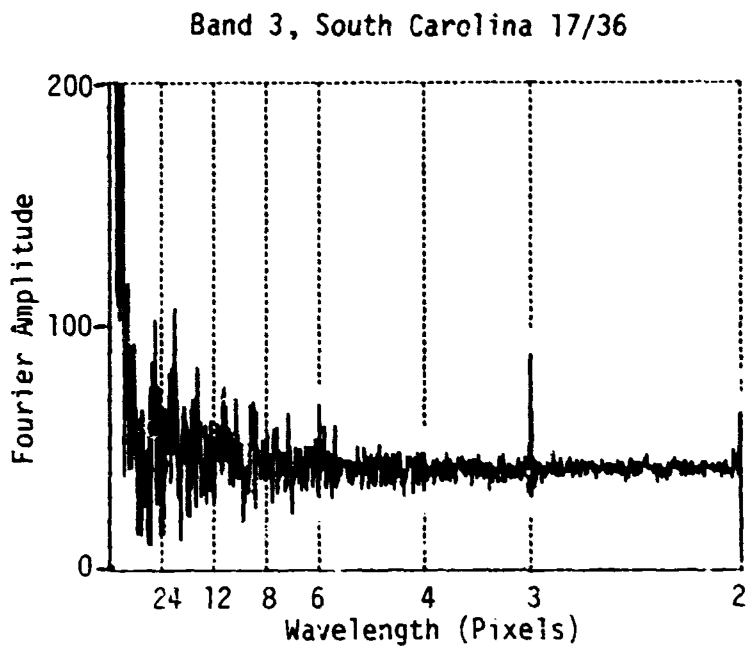



FIGURE 3. DOWN-TRACK FOURIER TRANSFORMS OF SCAN LINE MEAN VALUES, SHOWING BANDING EFFECTS AFTER RADIOMETRIC CORRECTIONS (Cont'd)



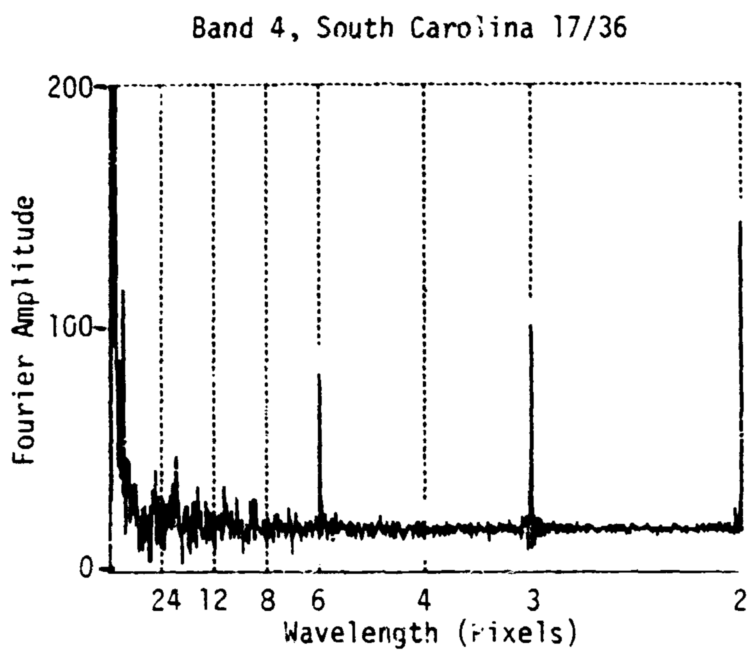




FIGURE 3. DOWN-TRACK FOURIER TRANSFORMS OF SCAN LINE MEAN VALUES, SHOWING BANDING EFFECTS AFTER RADIOMETRIC CORRECTIONS (Concluded)

TABLE 2. DETECTOR AVERAGES FOR FIVE AREAS IN ONE LANDSAT 4 FRAME (Imperial Valley, California)

| | | Landsat MSS Band | | | | |
|---|---|---|---|---|---|---|
| Detector | | 1 | 2 | 3 | 4 | |
| 1 | | 23.01 | 21.08 | 36.80 | 14.44 | |
| 2 | | 23.29 | 21.00 | 36.91 | 14.41 | |
| 3 | | 22.94 | 21.10 | 36.94 | 14.53 | |
| 4 | | 23.23 | 21.04 | 37.31 | 14.62 | Highlands |
| 5 | | 23.25 | 20.97 | 37.18 | 14.43 | |
| 6 | | 23.31 | 21.03 | 37.15 | 14.70 | |
| | σ = | .16 | .05 | .19 | .12 | |
| 1 | | 33.08 | 35.51 | 53.86 | 19.03 | |
| 2 | | 33.38 | 35.78 | 54.18 | 19.09 | |
| 3 | | 33.41 | 36.06 | 54.32 | 18.99 | |
| 4 | | 33.32 | 36.10 | 54.22 | 18.80 | Agricultural |
| 5 | | 33.31 | 35.86 | 53.60 | 18.81 | |
| 6 | | 33.08 | 35.69 | 53.75 | 18.91 | |
| | σ = | .15 | .22 | .29 | .12 | |
| 1 | | 62.23 | 76.10 | 84.14 | 25.73 | |
| 2 | | 62.11 | 76.76 | 84.25 | 25.62 | |
| 3 | | 62.10 | 76.08 | 84.54 | 25.84 | |
| 4 | | 61.42 | 76.01 | 84.04 | 25.89 | Sands |
| 5 | | 61.78 | 75.88 | 83.81 | 25.84 | |
| 6 | | 61.99 | 76.23 | 83.88 | 25.63 | |
| | σ = | .30 | .31 | .27 | .12 | |
| 1 | | 20.79 | 13.65 | 10.09 | 2.43 | |
| 2 | | 21.02 | 13.69 | 9.88 | 2.35 | |
| 3 | | 20.64 | 13.70 | 9.91 | 2.21 | |
| 4 | | 20.73 | 13.52 | 9.59 | 2.27 | Water |
| 5 | | 20.26 | 13.37 | 9.84 | 2.07 | |
| 6 | | 20.81 | 13.90 | 10.22 | 2.30 | |
| | σ = | .25 | .18 | .22 | .12 | |
| 1 | | 51.62 | 61.55 | 69.43 | 22.10 | |
| 2 | | 51.77 | 61.82 | 69.17 | 22.27 | |
| 3 | | 51.58 | 61.58 | 69.30 | 22.44 | |
| 4 | | 52.16 | 61.68 | 69.52 | 22.53 | Bright Shallow Valley |
| 5 | | 51.28 | 62.07 | 69.31 | 21.97 | |
| 6 | | 51.67 | 61.79 | 69.56 | 22.05 | |
| | σ = | .29 | .19 | .15 | .22 | |

scene content (q.v. the Fourier transforms) than necessary. The residual banding could be due in part to the integer quantization of the independently rescaled detector signals, which is the subject of the next section.

## 4.3 AMPLITUDE QUANTIZATION EFFECTS IN DETECTOR SIGNALS

Since the radiometric preprocessing described in the previous section includes a decompression in Bands 1-3, an offset and scaling, and a conversion to integers, a histogram of preprocessed data in these bands for each detector will necessarily contain empty bins intermixed with populated bins. In addition, the bin pattern will differ from one detector to another because of the slight differences in scaling due to the detector calibration adjustment. This is expected and observed, as shown in Table 3. Furthermore, the spacing of populated bins increases with bin level for Bands 1-3, which is proper for the decompression taking place.

The consistency of this pattern throughout the Landsat frame and between two Landsat frames was examined. It was found that the pattern was quite different between the two frames examined, and that a gradual change of pattern occurred from one block of 200 scan lines to the next in each frame. Both observations are consistent with the advertised behavior of Landsat MSS in which the radiometric transformation tracks minor changes in calibration source response.

Detector saturation has been noted in this data set for cloud pixels. This occurred in both Landsat frames analyzed, and in both cases Bands 1-3 saturated at count level 127, and Band 4 saturated at count level 63. By examining areas of increasingly bright clouds, it was found that saturation occurred most often in Band 3, next in Bands 2 and 1, and least often in Band 4. Band 2 seemed to saturate slightly more often on clouds than did Band 1.

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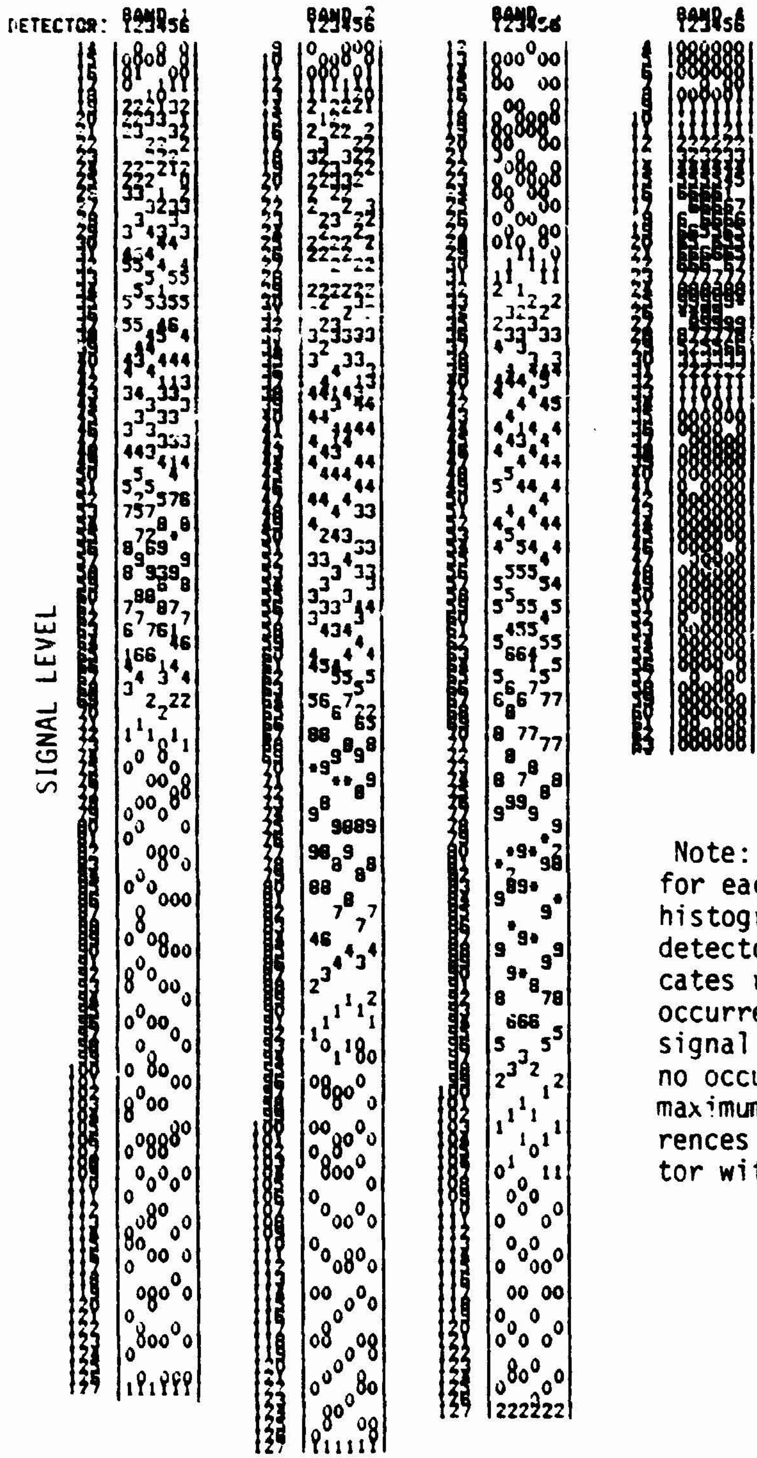
TABLE 3. EXAMPLE OF QUANTIZATION EFFECTS




Note: Each of six columns for each band represents one histogram for a specific detector. Each digit indicates relative number of occurrences at a specific signal level (blank means no occurrences, * means maximum number of occurrences found for any detector within each band).

One of the brightest non-cloud areas in the Imperial Valley frame (possibly desert sand) was examined for possible saturation. No saturation was found at the existing sun elevation angle, which was 47°. The band nearest to saturation (Band 3) had a maximum signal level of 107, so that saturation at count level 127 would be likely to occur on an identical target if the sun angle were increased to 61° or above.

A very small number of pixels in a large area of sand dunes were found to be saturated in Band 3. This could support the above observation in that these pixels could be on a slope facing the sun, thus representing the equivalent of a larger sun elevation angle.

## 4.4 PRESENCE OF DIAGONAL STRIPING (COHERENT NOISE) IN LANDSAT-4 MSS

A careful examination of imagery from MSS-4 revealed a diagonal striping pattern, particularly in areas of nearly uniform radiance. One such area is a water body presented in Figure 4. This noise is attributed to a coherent noise source in the system.

A Fourier transform analysis of this noise pattern was carried out on selected scan lines distributed throughout two Landsat frames. It was found that the noise consisted of a dominant wavelength of 3.6 pixels along scan, and was present in all bands, but particularly Bands 1-3. The wavelength was highly consistent throughout each Landsat frame, but was slightly different (3.57 compared to 3.59) for the two frames. In one frame (South Carolina), two other wavelengths appeared somewhat consistently and with significant strength, namely the wavelengths 2.02 and 4.63 pixels, but these and other smaller peaks were not analyzed in depth. The frequency corresponding to the observed dominant wavelength is approximately 28 KHz.

Figure 5 is a Fourier transform that illustrates peaks at the principle and two secondary wavelengths, along with a number of additional peaks that are minor or inconsistent. The magnitude of the

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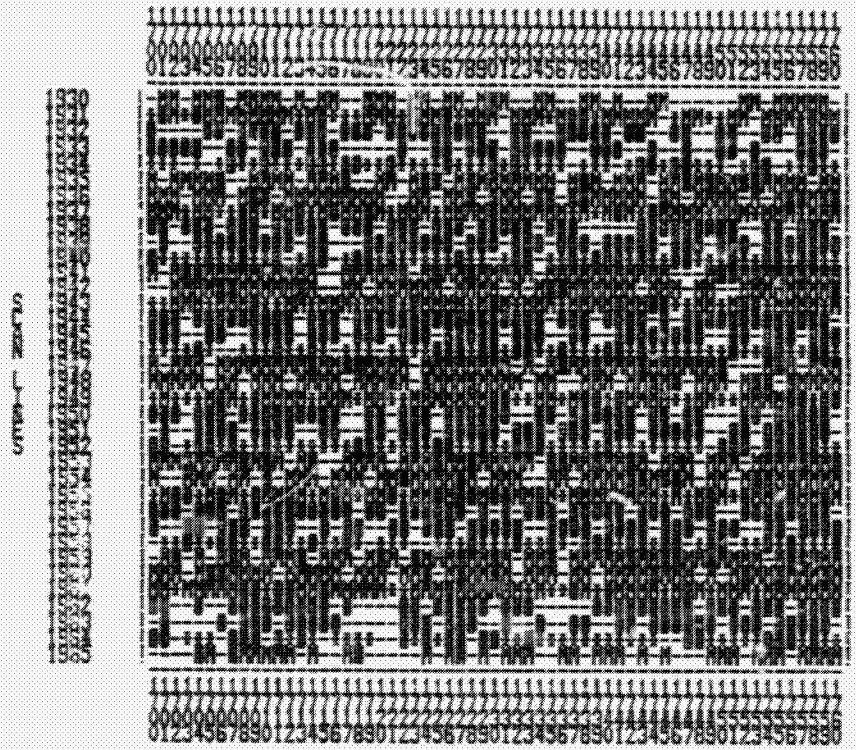
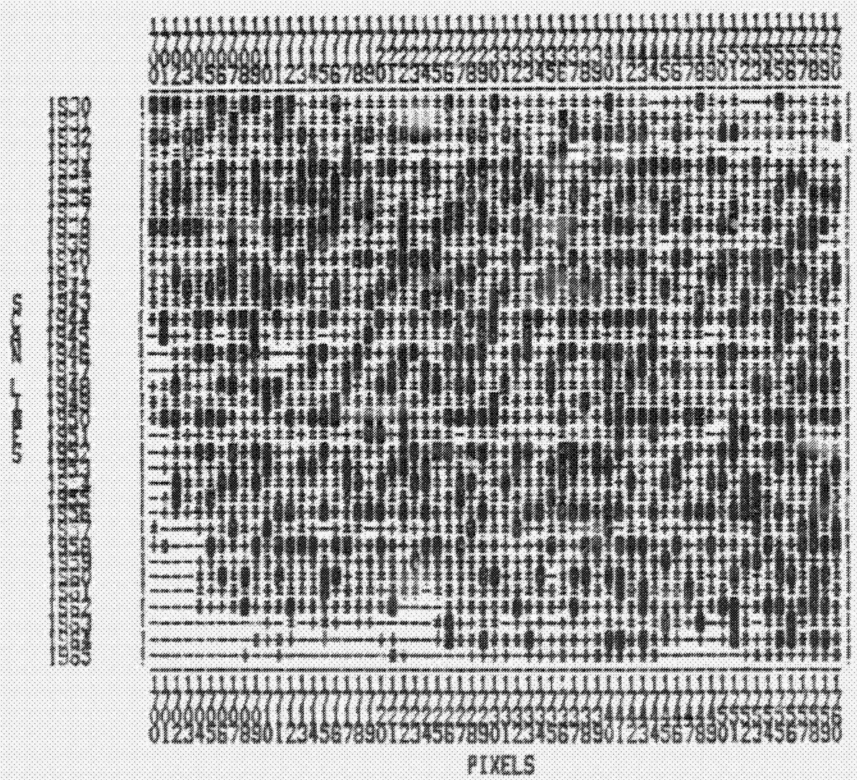
OF POOR QUALITY






(a) Band 1




(b) Band 3

FIGURE 4. EXAMPLE OF DIAGONAL STRIPING (COHERENT NOISE)
IN SOUTH CAROLINA SCENE, WATER AREA

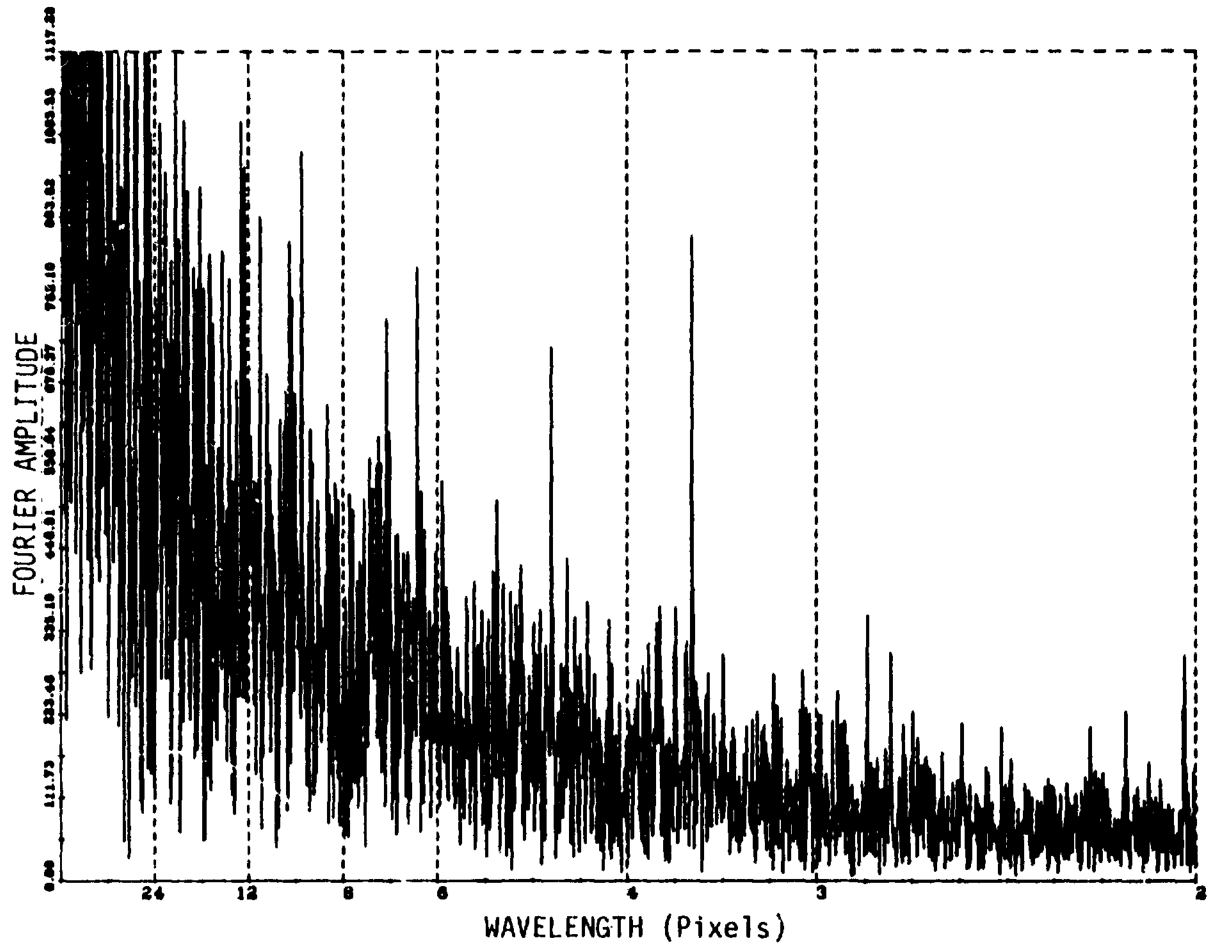



FIGURE 5. ALONG SCAN FOURIER TRANSFORM SHOWING COHERENT NOISE PEAK AT WAVELENGTH 3.6 (South Carolina, Scan Line 2117, Band 3)

sine-wave component at the primary peak was computed and tabulated along with a determination of wavelength for each scan line considered. This information, presented in Table 4, shows that the magnitude of the noise did not exceed one count in the worst band (Band 1), and demonstrates how consistent the wavelength remained throughout a full frame. Also, the fact that the same frequency was measured in all bands means that the noise is correlated between bands and could add rather than average out in linear combinations of band variables; our investigation comparing band-to-band correlations and phases is incomplete at this time.

## 4.5 SATELLITE-TO-SATELLITE CALIBRATION

Due to the differing repeat cycles of Landsats 3 and 4, simultaneous coverage possibilities exist every 144 days. The pattern of their paths is such that spatial coincidences (or near coincidences) of their frame centers occur in temporal coincidence along tracks spanning the East Coast and the Western U.S., as shown in Figure 6. In the Central U.S., the spatial coincidences occur one day apart in time. The tracks of spatially coincident coverage do not align with the ground track of either satellite, and in fact are oriented more easterly than the satellite tracks.

All Landsat 3 and 4 coincidences in location and time have been identified for the Continental U.S. for the period from September 1982 thru March 1983. These are listed in Table 5. So far only one usable, nearly coincident data pair has been confirmed (24 September) and two coincidences in December are expected to become available. Coincidences on 12 January, 20 January and 15 February have been scheduled for acquisition.

TABLE 4. WAVELENGTH AND MAGNITUDE OF DIAGONAL STRIPING (COHERENT) NOISE

| Frame | Scan Line | Band | Wavelength (Pixels) | Magnitude |
|---|---|---|---|---|
| Carolina | 714 | 1 | 3.573 | .72 |
| | | 2 | 3.573 | .39 |
| | | 3 | 3.573 | .48 |
| | | 4 | 3.574 | .24 |
| | 1083 | 1 | 3.573 | .58 |
| | | 2 | 3.573 | .58 |
| | | 3 | 3.572 | .62 |
| | | 4 | 3.572 | .17 |
| | 1916 | 1 | 3.574 | .85 |
| | | 2 | 3.573 | .59 |
| | | 3 | 3.574 | .50 |
| | | 4 | 3.574 | .25 |
| Imperial Valley | 714 | 1 | 3.592 | .83 |
| | | 2 | 3.593 | .43 |
| | | 3 | 3.592 | .40 |
| | | 4 | 3.593 | .33 |
| | 1315 | 1 | 3.592 | .88 |
| | | 2 | 3.592 | .52 |
| | | 3 | 3.592 | .69 |
| | | 4 | 3.592 | .24 |
| | 1916 | 1 | 3.592 | .64 |
| | | 2 | 3.592 | .66 |
| | | 3 | 3.592 | .60 |
| | | 4 | 3.592 | .24 |
| | 2117 | 1 | 3.593 | .77 |
| | | 2 | 3.592 | .49 |
| | | 3 | 3.592 | .62 |
| | | 4 | 3.592 | .25 |
| Average Magnitude | | 1 | | .75 ± .11 |
| | | 2 | | .52 ± .09 |
| | | 3 | | .56 ± .10 |
| | | 4 | | .25 ± .05 |

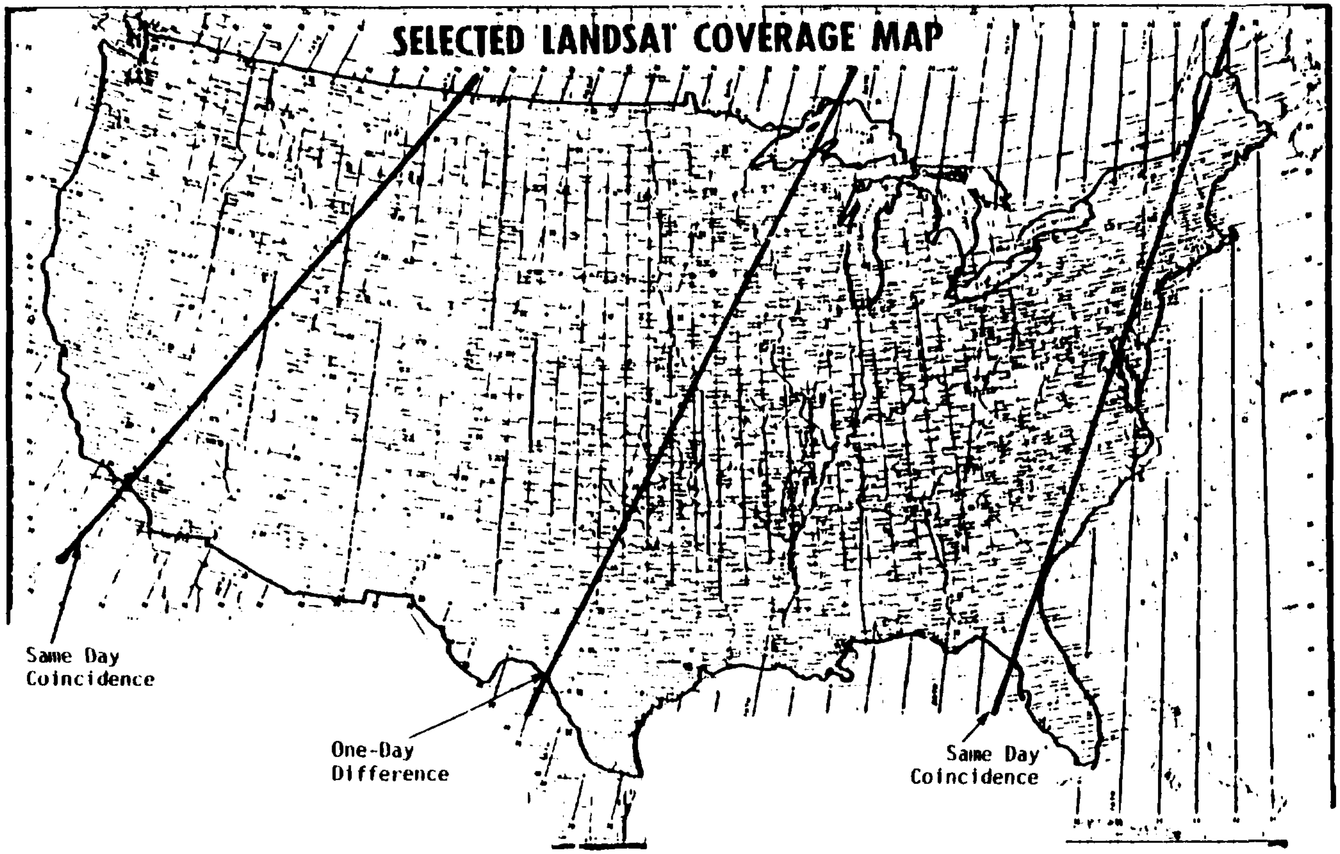



FIGURE 6. COINCIDENCES BETWEEN LANDSATS 3 AND 4 FOR LANDSATS 1-3

TABLE 5. COINCIDENT COVERAGES

| Date | Landsat 3 Path L3 | Landsat 4 Path L4 | Landsats 3 & 4 Row Range | Place |
|---|---|---|---|---|
| Sep 24, 1982 | 15 | 14 | 29-31 | East NY... Chesapeake Bay |
| Oct 2, 1982 | 41 | 38 | 27-31 | Northern Utah... Mid-Montana |
| Oct 15, 1982 | 18 | 17 | 37-40 | S. Carolina... Tampa Bay |
| Oct 23, 1982 | 44 | 41 | 35-36 | Los Angeles...NE |
| Nov 18, 1982 | 16 | 15 | 32-35 | Harrisburg VA... Raleigh NC |
| Nov 26, 1982 | 42 | 39 | 30-32 | Eastern Idaho |
| Dec 17, 1982 | 45 | 42 | 36 & South | Los Angeles & Southwest |
| Dec 22, 1982 | 14 | 13 | 25-31 | New England |
| Jan 12, 1983 | 17 | 16 | 34-37 | North & South Carolina, (Central Section) |
| Jan 20, 1983 | 43 | 40 | 32-35 | Eastern Nevada |
| Feb 15, 1983 | 15 | 14 | 29-34 | Eastern NY... Chesapeake Bay |
| Feb 23, 1983 | 41 | 38 | 27-31 | Northern Utah... Mid-Montana |
| Mar 8, 1983 | 18 | 17 | 37-40 | S. Carolina... Tampa Bay |
| Mar 16, 1983 | 44 | 41 | 35-36 | Los Angeles...NE |

Images of the 24 September matches have been received and examined. Our preliminary observations are that the image quality and appearance is much the same, except that Band 4 (MSS7) appears slightly darker on Landsat 4 and the coherent noise effect discussed in Section 4.5 is evident in Bands 1-3 only on Landsat 4.

Quantitative data from targets such as fields, water bodies, or uniform areas, will be extracted from each obtained coincident pair, and the target statistics will be used to determine a relative calibration of one satellite to the other.

# 5
# SUMMARY

Based on our full-frame analysis of computer-compatible, Type "A" tapes of radiometrically (but not geometrically) corrected data for two diverse scenes, the following initial findings were made with regard to Landsat-4 MSS radiometric properties:

(1) The Landsat-4 MSS appears to produce data of overall good quality with dynamic ranges and target responses being qualitatively similar to those of previous MSS sensors.

(2) Banding due to between-detector differences appears to be well, but not fully, corrected; a residual rms error of about 0.3 counts was measured.

(3) Amplitude quantization effects observed are consistent with those expected in terms of detector differences and empty signal level bins. The look-up tables used in the radiometric preprocessing varied slowly with scan line number in blocks of 200 lines, as is advertised for the tracking of calibration signals.

(4) A low-level coherent-noise (diagonal striping) pattern was observed in all bands and quantified by Fourier analysis:

(a) The principle component of this noise was found to be at a highly consistent wavelength of 3.6 pixels along a scan line, corresponding to a 28 Khz frequency in the signal.

(b) The magnitude of this effect was found to be about 0.75 of a count in the worst band (Band 1) and about 0.25 counts in the best band (Band 4).

Preparations were made for establishing a relative radiometric calibration for MSS 4 data with respect to MSS 3 data:

(1) All time and place coincidences of Landsat-3 and -4 coverages in the contiguous United States were identified and tabulated for Dec. 1982 through Mar. 1933.

(2) Special arrangements were made for the acquisition of a subset of this coincident data.

(3) Imagery from one early coincident pair was examined visually. Development of this relative calibration will proceed when digital data become available.

It is recommended that techniques for removing the coherent noise effects be investigated by NASA and/or Landsat-4 investigators and that our planned analyses be continued and completed as data become available.