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LANDSAT IMAGE DIFFERENCING AS AN AUTOMATED LAND COVER CHANGE DETECTION TECHNIQUE (INTERIM REPORT)

Prepared For

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
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GODDARD SPACE FLIGHT CENTER

By

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Under

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ABSTRACT

Image differencing has been investigated as a technique for use with Landsat digital data to delineate areas of land cover change in an urban environment. Landsat data collected in April 1973 and April 1975 for Austin, Texas, were geometrically corrected and precisely registered to United States Geological Survey (USGS) 7.5-minute quadrangle maps. At each pixel location reflectance values for the corresponding bands were subtracted to produce four difference images. Areas of major reflectance differences are isolated by thresholding each of the difference images. The resulting images are combined to obtain an image data set of total change. These areas of reflectance differences were found, in general, to correspond to areas of land cover change. Information on areas of land cover change was incorporated into a procedure to mask out all nonchange areas and perform an unsupervised classification only for data in the change areas. This procedure identified three broad categories: (1) areas of high reflectance (construction or extractive), (2) changes in agricultural areas, and (3) areas of confusion between agricultural and other areas. Efforts are underway to include 1977 Landsat data and to rigorously evaluate the results of the image differencing technique and the unsupervised classification.

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SECTION 1 - BACKGROUND

In 1975 a joint research project between Goddard Space Flight Center (GSFC) and the Bureau of the Census began. The program is to examine the utility of Landsat remotely sensed data for monitoring land cover/land use activity around major urbanized areas in the United States. Early work in the project has shown that major land cover classes in the urban fringe (transition zone between urban and rural populations) can be identified from satellite data (Reference 1).

Land cover change is a key element in the urbanized area boundary delineation program conducted by the Census Bureau. The frequent, synoptic nature of Landsat data makes it well suited for the detection of land cover change. In an extension of the earlier work on this project, a technique for the delineation of areas that have undergone major changes in spectral reflectance (indicating changes in land cover) has been developed.

This document reports progress to date in the development of one approach for monitoring land cover change and also describes objectives of future research.

SECTION 2 - ANALYSIS TECHNIQUE

The fundamental operation in automated change detection is the subtraction of one digital image from another. The differencing operation is carried out by subtracting the reflectance value for a point in one image from the reflectance value for the same location in the second image. Landsat I or II multispectral scanner (MSS) output consists of four bands or digital images. Thus, to difference all of the Landsat MSS data in a scene requires four operations per pixel location--one for each of the four MSS bands.

The subtraction of one digital image from the other results in an image in which positive and negative values represent areas of change and zero values indicate areas that remained unchanged. When applied to Landsat data with a data range of 0 to 127, the potential range of difference values is -127 to +127. In the Small Interactive Image Processing System/Video Image Communication and Retrieval System (SMIPS/VICAR) system (Reference 2), all results are stored as positive values scaled from 0 to 255 by the addition of a constant. This operation can be expressed mathematically as

$$\Delta X_{ijk} = X(1)_{ijk} - X(2)_{ijk} + C \qquad (2\text{-}1)$$

where ΔX = change image

$X(1)$ = image at time 1

$X(2)$ = image at time 2

C = a constant

$i = 1 \ldots n$ number of lines

$j = 1 \ldots n$ number of columns

$k = 1 \ldots n$ number of bands

When applied to Landsat data, this results in four different images that can be subsequently analyzed using standard image processing techniques.

For this project areas of change were identified for each of the four MSS bands and these results combined to obtain an image representing total change. Change areas for each band of the difference image were determined by identifying those pixels with intensity values above or below calculated threshold levels (i.e., density slicing the image). Pixels in the difference image with reflectances above the high threshold represent areas that have increased in reflectance from time 1 to time 2 (high reflectance change), whereas pixels with values below the lower threshold represent areas that have decreased in reflectance from time 1 to time 2 (low reflectance change). Pixels with reflectances that fall between the threshold values are considered to have remained unchanged. This procedure results in a series of images depicting areas of change for each band which can then be combined to obtain an image showing all areas of change.

This process makes two assumptions: (1) changes in land cover/land use will result in corresponding changes in reflectance values, and (2) these reflectance changes will be of sufficient magnitude to distinguish them from the normal variation of features within the images.

SECTION 3 - STUDY SITE

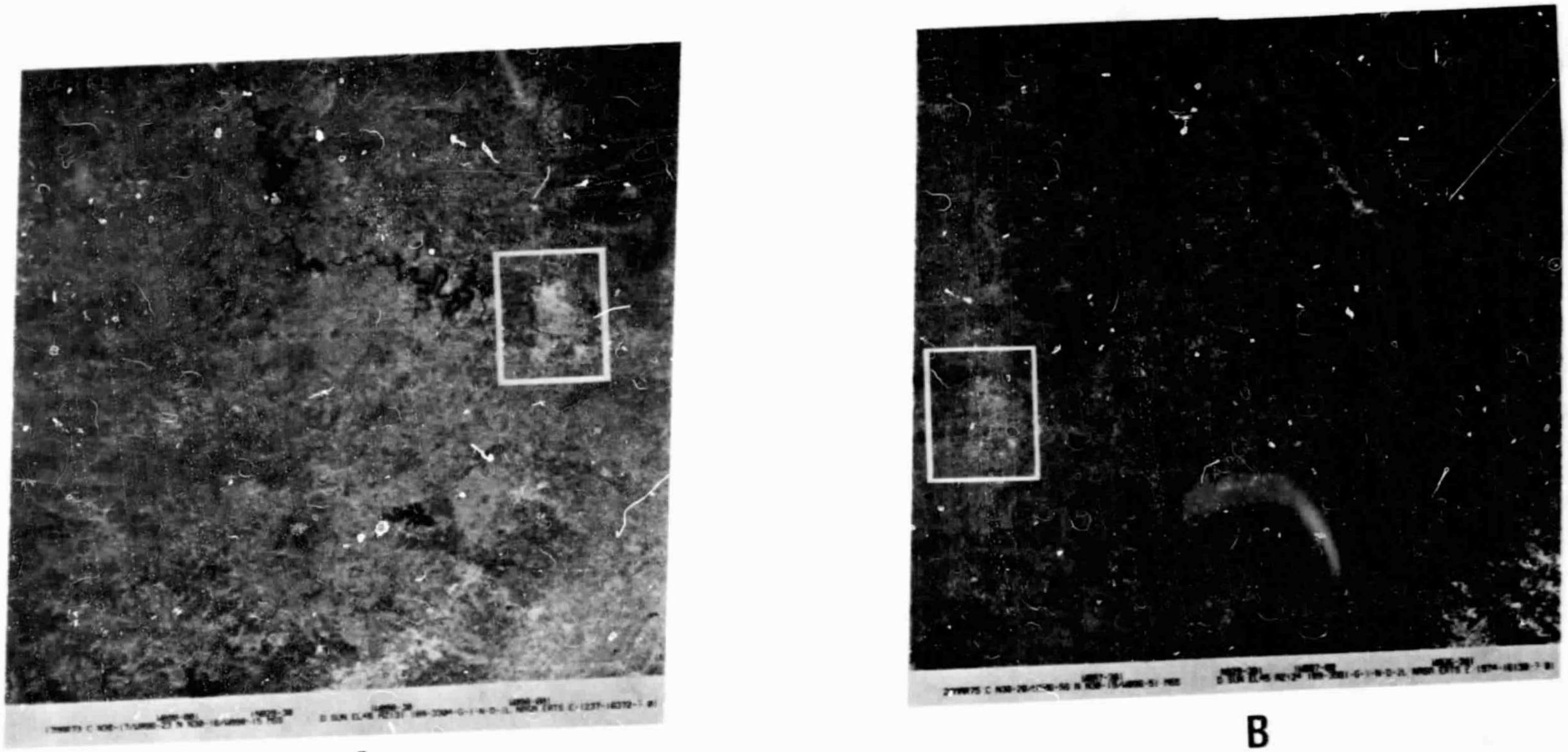
The test site for this study is an area of approximately 1200 square kilometers encompassing Austin, Texas, and its environs. This area was chosen because the Census Bureau conducted pretests there for the 1980 census at the start of this work. The Bureau intended to compare pretest results with satellite data products. As part of that earlier work, 1973 and 1975 images were registered to United States Geological Survey (USGS) topographic maps. The availability of registered images and the interest of the Bureau of the Census led to the use of Austin as the site for image differencing/change detection experimentation. To date, however, results of the census pretest have not been made available.

Austin is located in central Texas between the Coastal Plain and the Edwards Plateau. Its terrain varies from level, open farmland and fields in the east to tree-covered hills in the west. The Austin central business district (CBD) is surrounded by commercial, industrial, and high-density residential development. Further from the center city--primarily to the north, east, and south--lie low-density residential development and agricultural areas. In addition, a limited number of estates and trailer parks are mixed into this diverse landscape.

SECTION 4 - DATA

Subsets of Landsat data collected on March 17, 1973 (Figure 4-1(A)), and March 24, 1975 (Figure 4-1(B)), were used as the principal input for this study. Near-anniversary data sets were selected to minimize phenological and seasonal variations. Each subimage was geometrically corrected and precisely registered to USGS 7-1/2-minute quadrangle maps and resampled to 60-meter-square picture elements (Figures 4-2(A) and (B)) using the Digital Image Rectification System (DIRS) implemented at GSFC (Reference 3). The SMIPS/VICAR system available at GSFC was used for all subsequent processing and analysis.

Supporting data for the study included USGS topographic maps (photo-revised in 1973), low-altitude black and white photography taken in 1973 and 1974, a few frames of low-altitude black and white photography taken in 1975, and 1977 high-altitude black and white imagery.



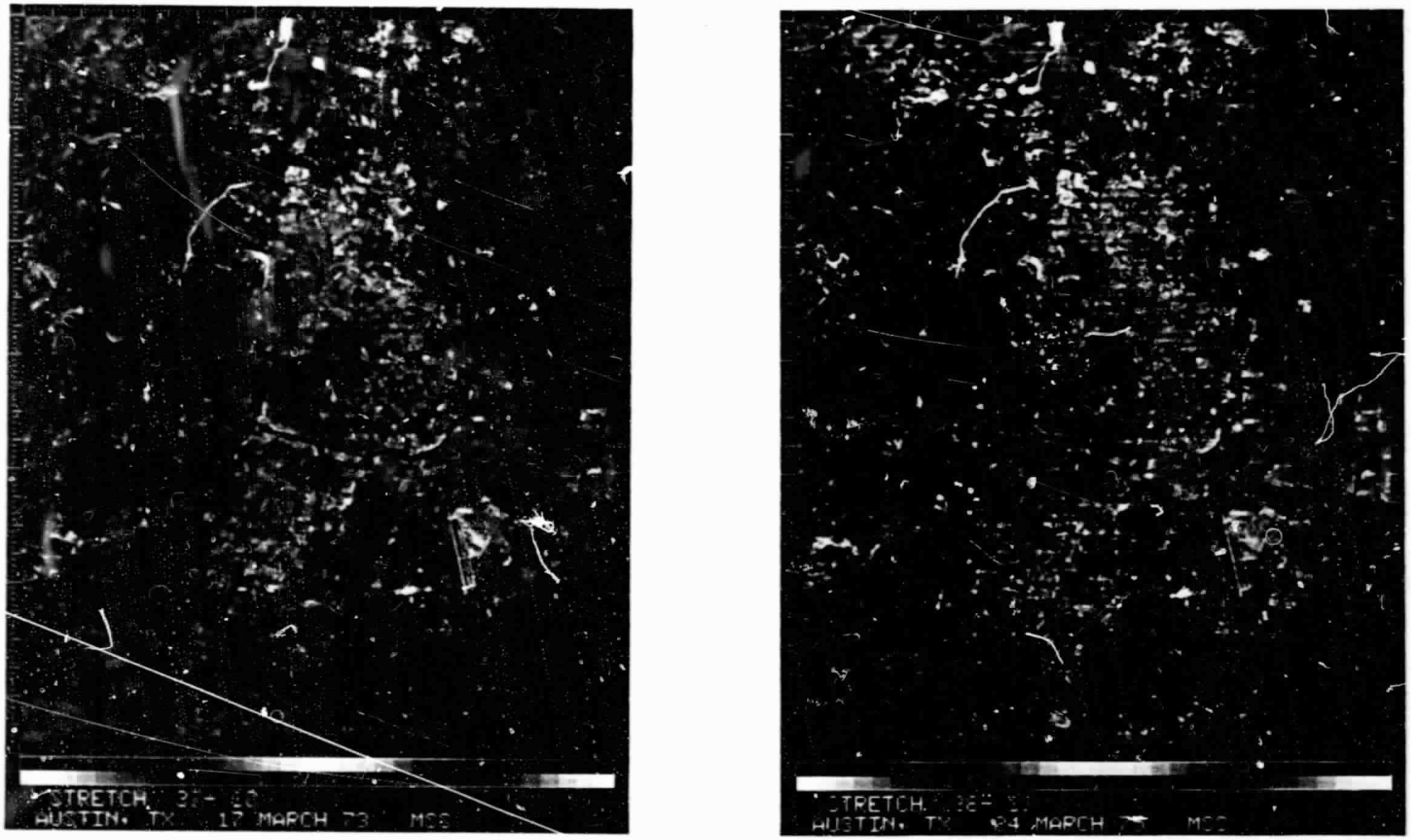
A

MARCH 17, 1973

B

MARCH 24, 1975

Figure 4-1. Landsat Scenes 1237-16372 and 1974-16130. The Austin, Texas, study site is indicated by the white boxes.



A

MARCH 17, 1973

B

MARCH 24, 1975

Figure 4-2. Enhanced Pictures of the Geometrically Corrected and Registered Portions of Landsat Scenes 1237-16372 and 1974-16130

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SECTION 5 - RESULTS AND DISCUSSION

For this study a difference image was produced by subtracting 1973 pixel values from the corresponding elements in the 1975 image and adding a constant of 128. Thus, Equation (2-1) becomes

$$\Delta X_{ijk} = X(1975)_{ijk} - X(1973)_{ijk} + 128$$

The four resulting difference images are the basis of all further analysis.

5.1 DIFFERENCE DATA STATISTICS

Differencing procedure results are illustrated by histograms of MSS 7 for the 1973, 1975, and difference data sets (Figure 5-1). The histogram of the differenced data (Figure 5-1(C)) is centered near 128 with a much tighter standard deviation than the histograms of the raw data. The histograms of all four difference images (Figure 5-2) are tightly clustered near 128. The means and standard deviations for each of these images and their raw data counterparts are presented in Table 5-1. Mean values near 128 are expected for the difference data sets because most areas have remained unchanged during the 2-year period.

Table 5-1. Means and Standard Deviations of 1973, 1975, and Differenced Images

MSS BAND	1973		1975		DIFFERENCE	
	MEAN	STANDARD DEVIATION	MEAN	STANDARD DEVIATION	MEAN	STANDARD DEVIATION
4	60.8	11.3	61.7	11.1	128.8	6.7
5	51.4	15.3	53.1	15.2	127.6	9.3
6	71.4	16.2	75.5	16.4	132.2	10.1
7	76.5	17.6	78.7	18.2	130.7	11.9

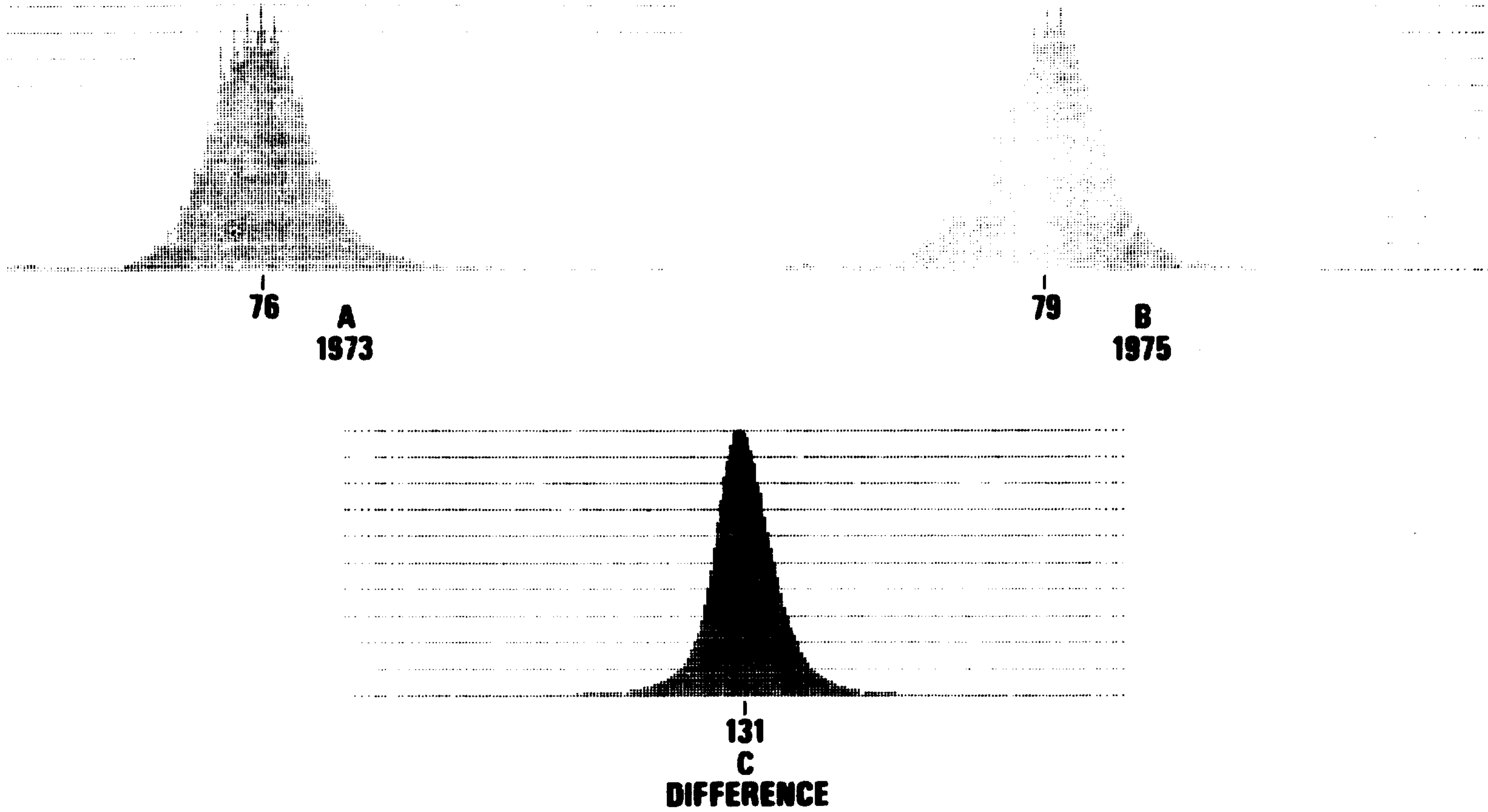


Figure 5-1. Histograms of MSS 7 for 1973, 1975, and the Difference Data Set, With Mean Values Shown for Each Distribution

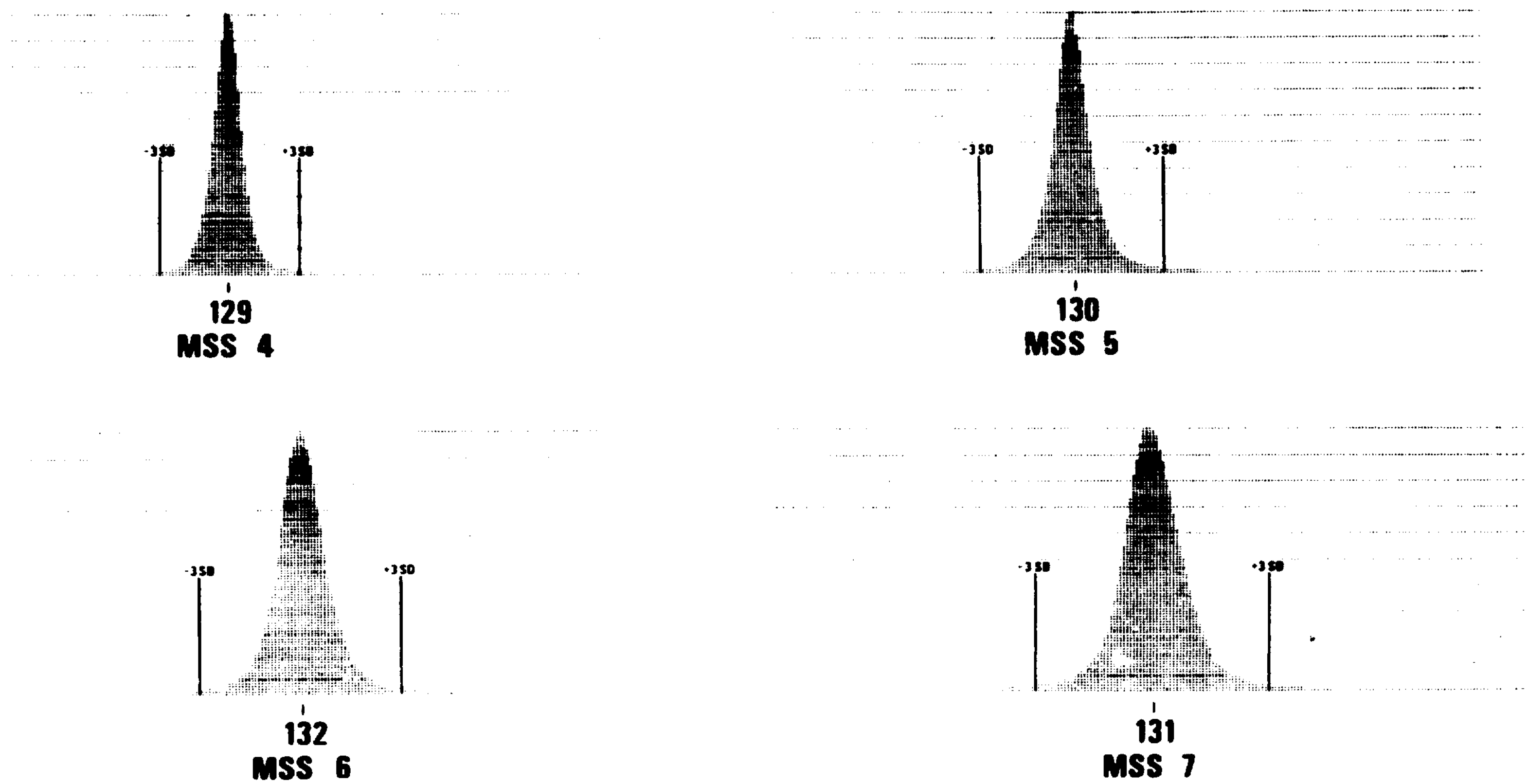


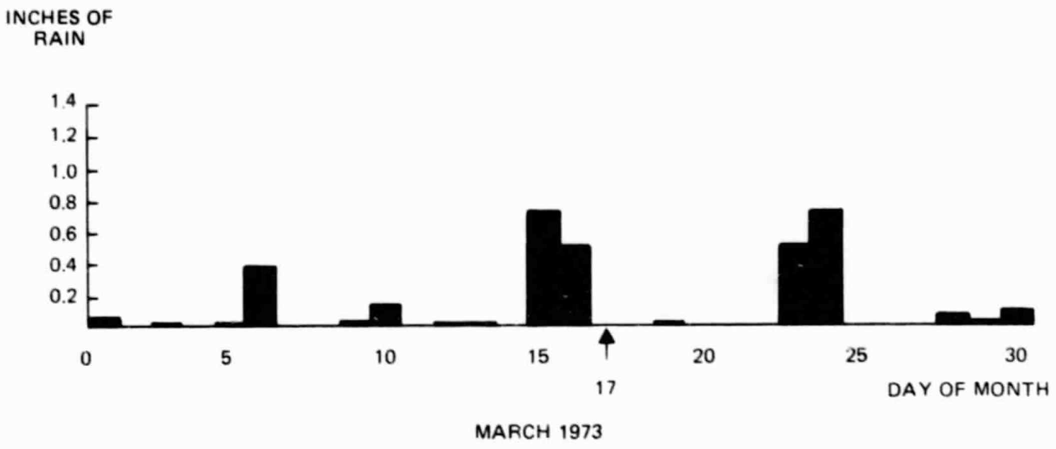
Figure 5-2. Histograms of the Four Difference Data Sets, With Mean Values Shown

Mean values and standard deviations for MSS-6 and MSS-7 difference data are higher and broader, respectively, than the means or standard deviations in MSS-4 and MSS-5 difference images. This suggests that an overall shift in radiance has occurred for these spectral bands. Indeed, rainfall data for March 1973 and March 1975 (Figure 5-3) show a cumulative rainfall of 1.2 inches for the 2 days prior to the March 17, 1973, image, whereas no appreciable rainfall was recorded for the 10 days prior to the March 24, 1975, image. Such a difference in ground moisture would contribute to the reflectance difference between the images, particularly for MSS 6 and MSS 7, because both bare soil and healthy vegetation decrease their reflectance of infrared radiation as their moisture content increases. Impervious areas, like the CBD, would not exhibit such changes. Given the difference in rainfall, responses for MSS 6 and MSS 7 for 1973 would be expected to be more varied and on the average lower than the values for 1975. Indeed, the mean values and standard deviations for MSS 6 and MSS 7 of the difference image (1975-1973) are higher and broader than MSS 4 and MSS 5 of the same product.

5.2 DIFFERENCE THRESHOLD

A direct display of the difference data produces a flat, low-contrast picture that is difficult to interpret (Figure 5-4). The intensity of an area in the image indicates the magnitude of the reflectance difference between the two dates for that location. Areas that have experienced major change appear light (increased reflectance) and dark (decreased reflectance) in the image. These light and dark areas correspond to the data located in the tails of the difference data histograms. The pixel locations corresponding to these differences can be selectively displayed by density slicing each of the difference images.

In this experiment the threshold values for the density slice were set at three standard deviations above and below the mean difference value (Table 5-2). Initially, threshold values of plus and minus two standard deviations were selected, but this appeared to overestimate the probable amount of change.



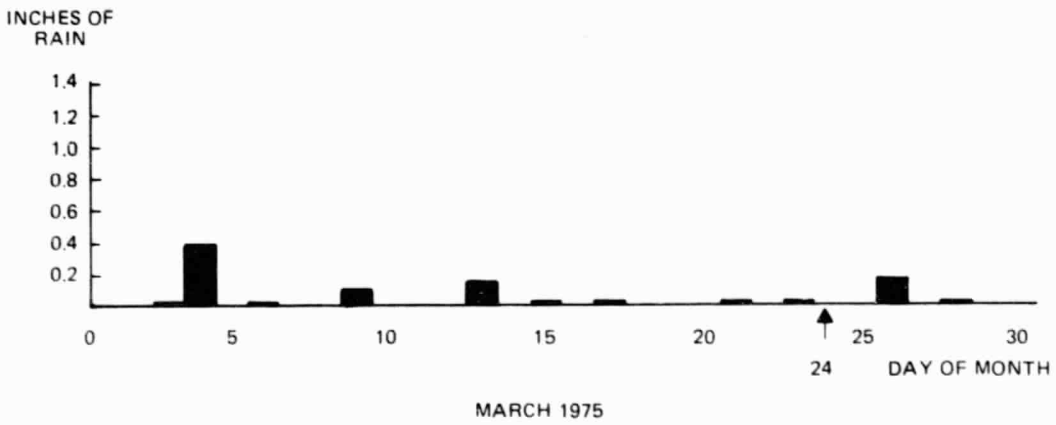


Figure 5-3. Daily Rainfall Data for Austin, Texas, During March 1973 and March 1975

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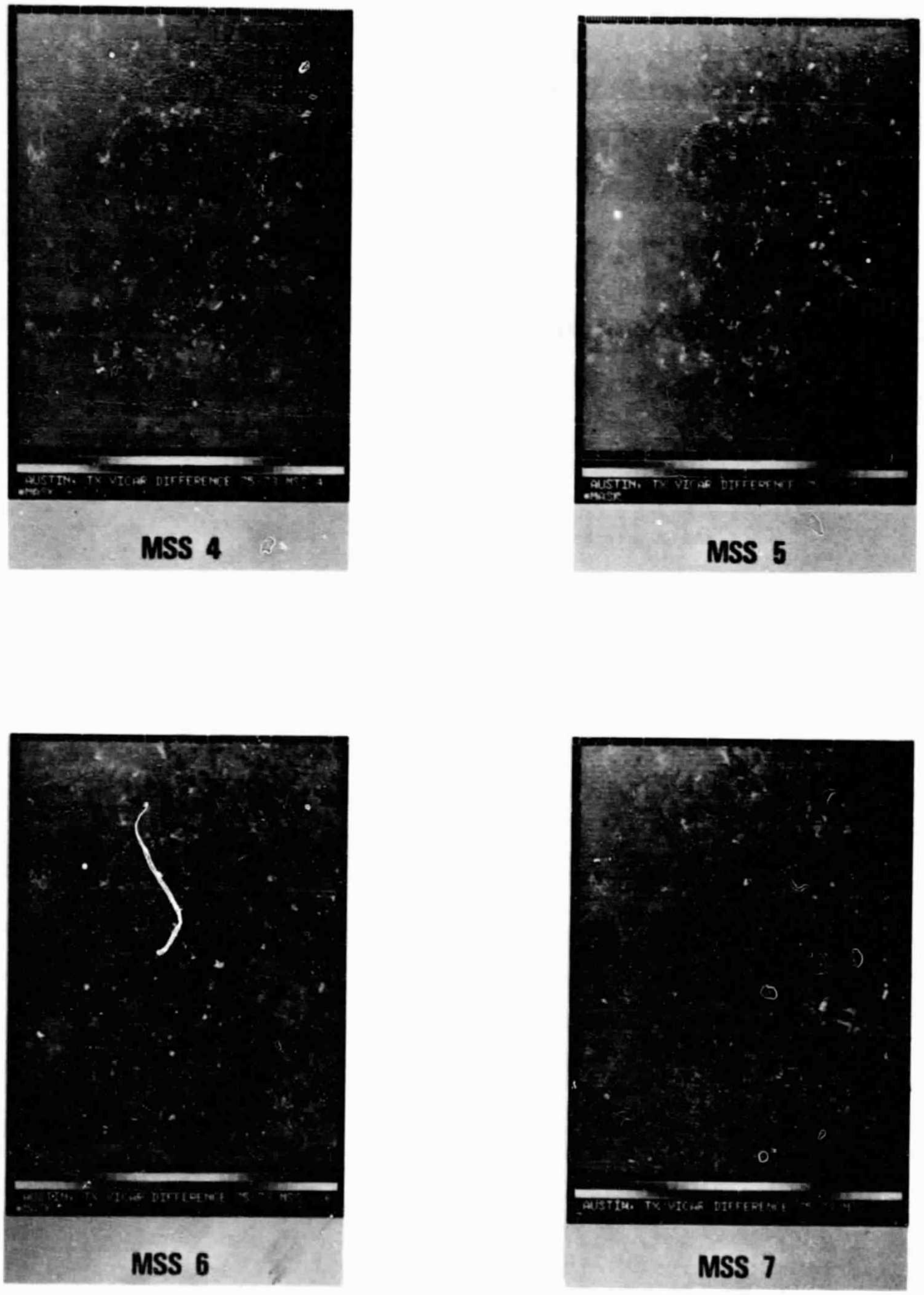


Figure 5-4. 1975-1973 Difference Images by Band

Table 5-2. Threshold Values for Density Slice

DIFFERENCED MSS BAND	3 STANDARD DEVIATIONS	-3 STANDARD DEVIATIONS (LOW THRESHOLD)	+3 STANDARD DEVIATIONS (HIGH THRESHOLD)
4	20.1	108	149
5	27.9	101	157
6	30.3	101	162
7	35.7	95	166

Picture elements with differences less than, or greater than, the threshold value are displayed in Figure 5-5. The top row of images (Figures 5(A) through (D)) shows those pixels that have decreased in reflectance from 1973 to 1975, for each of the MSS bands. The bottom row of images (Figures 5-5(E) through (H)) displays those pixels that have increased in reflectance. The areas delineated in these images correspond to all locations that had a variation in measured reflectance greater than the noise threshold of three standard deviations. These images were combined to generate a series of data sets that depict areas of decreased reflectance (low change), increased reflectance (high change), and decreased and increased reflectance (total change) (Figure 5-6).

5.3 PRELIMINARY EVALUATION

The areas delineated in this way may provide useful information for identifying certain types of land cover change. Preliminary comparisons indicate that areas which have decreased in reflectance (low reflectance change) are primarily vegetated or agricultural areas. Areas of increased reflectance, however, seem to include both agricultural areas and areas of construction activity. A comparison of the low-reflectance change image and high-reflectance change image shows that 407 pixels increased in reflectance in one or more bands and also decreased in reflectance in one or more of the remaining bands. A color display of the total change image (Figure 5-7) highlights these areas as white,

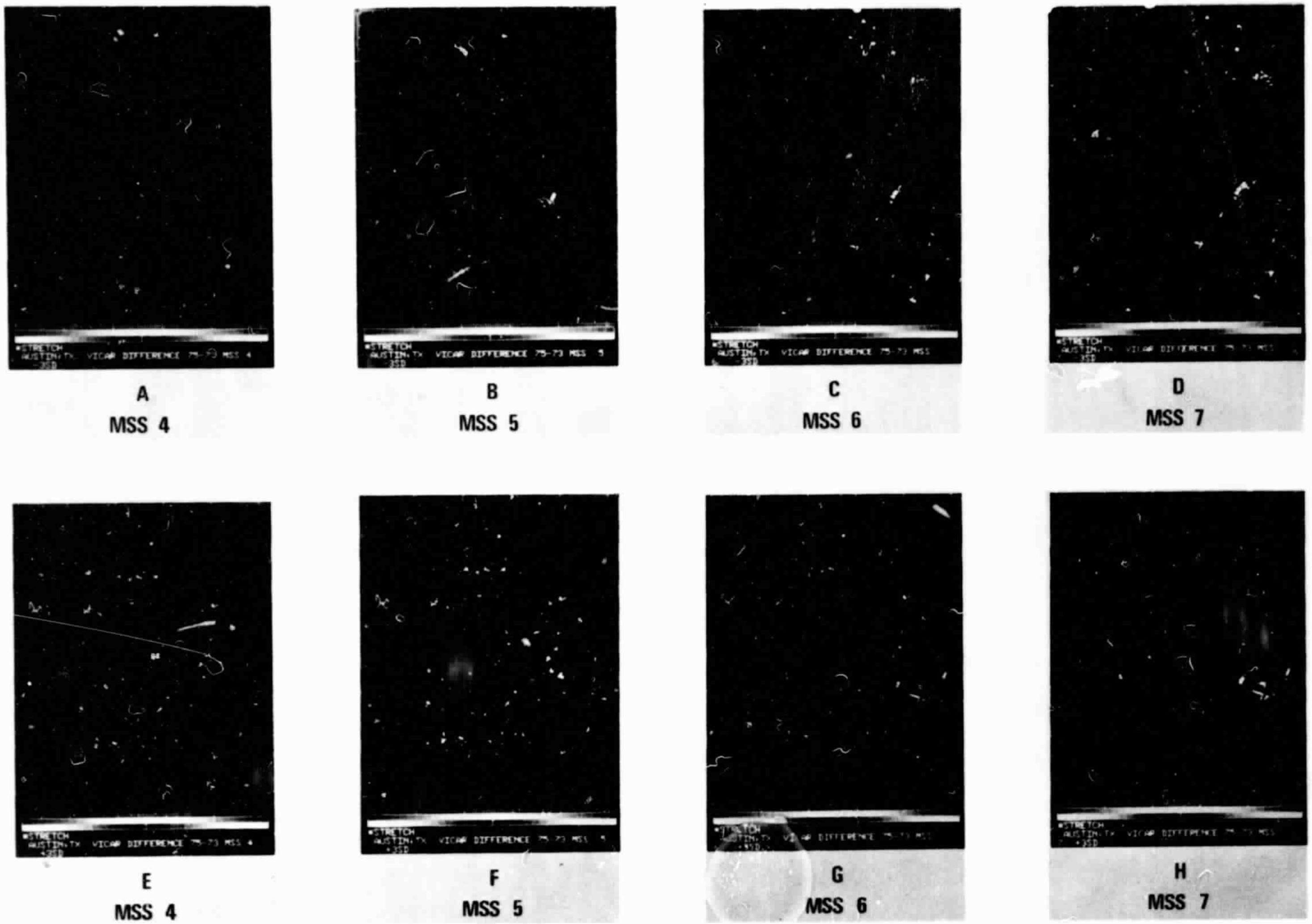
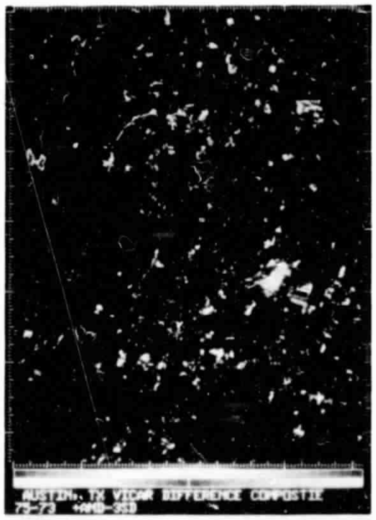


Figure 5-5. Areas of Reflectance Difference Greater Than Three Standard Deviations Above and Below Mean Values by Band

HIGH CHANGE

LOW CHANGE



TOTAL CHANGE

Figure 5-6. Composite Images of Change Areas

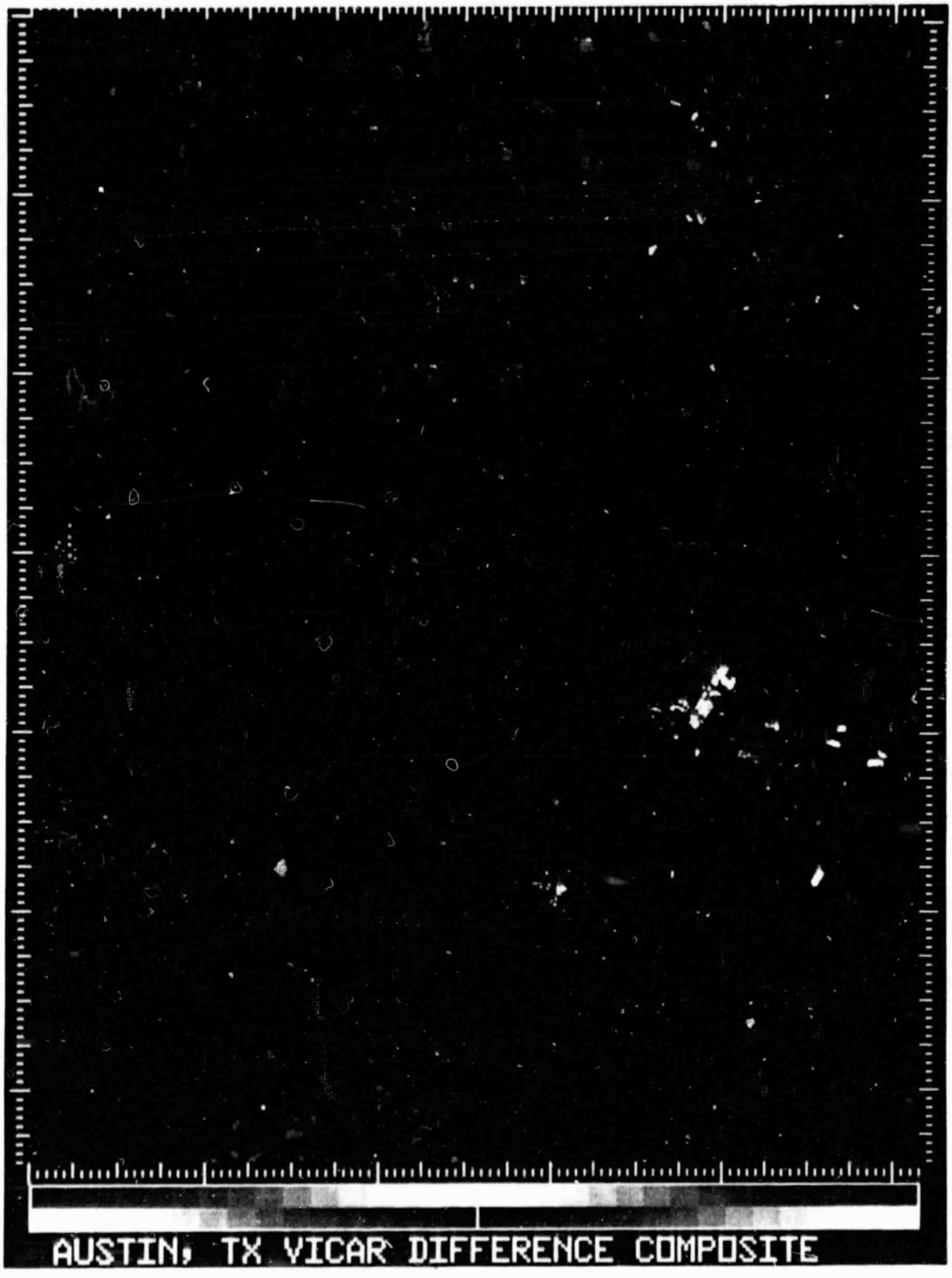


Figure 5-7. Total Change for the Scene. Low change is shown in red, high change in blue. Areas with both low and high change in various bands are shown in white.

with low change displayed in red and high change displayed in blue. Areas of both low and high reflectance change were, in fact, limited to agricultural areas and may be the result of a unique combination of agricultural practices and environmental conditions.

The image of total change was combined with a color enhancement of the raw data to produce an image that facilitates the evaluation of the change areas by providing a frame of reference for these areas (Figure 5-8). Preliminary comparisons of the change areas with supporting information are encouraging. Several major features have been correctly identified as change. Many of the change pixels are associated with agricultural areas, as typified by the agricultural areas adjacent to the river in the eastern portion of the image. Other major change areas are the result of construction activity, examples of which are freeway construction and probable residential building (butterfly shape) in the northwestern portion of the study area.

At present only general comparisons can be made regarding the accuracy of the change areas due to the lack of coincidental ground-truth information. These preliminary comparisons serve to demonstrate the application of such a procedure as a first-order estimate of land cover change. The principal advantage of this approach is that, given registered imagery, it is a computationally simple technique that can be accomplished with a minimum of analyst effort.

5.4 CHANGE AREA CLASSIFICATION

Thus far the procedure has identified areas of change within the image but has not provided specific information regarding the types of change that have occurred. Given the first-order estimate of land cover change, this information has been integrated into a procedure for classifying those change areas. The change data set can be used as a binary mask to extract the data for areas of change and thereby reduce the amount of data that must be processed by 97 percent.

Figure 5-8. Total Change Displayed Against a Background of the 1975 Data. Total change is shown in yellow.

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COLOR PHOTOGRAPH

Such a change area mask was applied to the 1975 data and to the difference data sets. The resulting data sets, consisting of response values for the areas of change and zero values elsewhere, were then analyzed using the SMIPS/VICAR version of the HINDU clustering algorithm. The option exists within the program to exclude specified values from the calculations. Utilizing this function to eliminate zero-valued pixels, processing was only carried out on the data for change areas. This approach has the advantage of substantially reducing the processing time. Further, the level of discrimination achieved by clustering can be expected to be more detailed for these areas than if all the data for the test site were processed. The initial classifications on both the 1975 data and the change area data are encouraging.

The clustering of the 1975 data in areas of change resulted in seven categories. Due to the lack of available ground truth, these results have not undergone detailed analysis. However, a preliminary evaluation grouped six of the categories into two general classes: high-reflectance change areas (primarily construction and extractive) (3213 points or 1.3 percent) and agricultural areas (3664 points or 1.4 percent). The seventh category combined both agricultural and nonagricultural areas (1473 points of 0.5 percent). These three general classes are shown in Figure 5-9. Results of the clustering of the difference data have not yet been evaluated.

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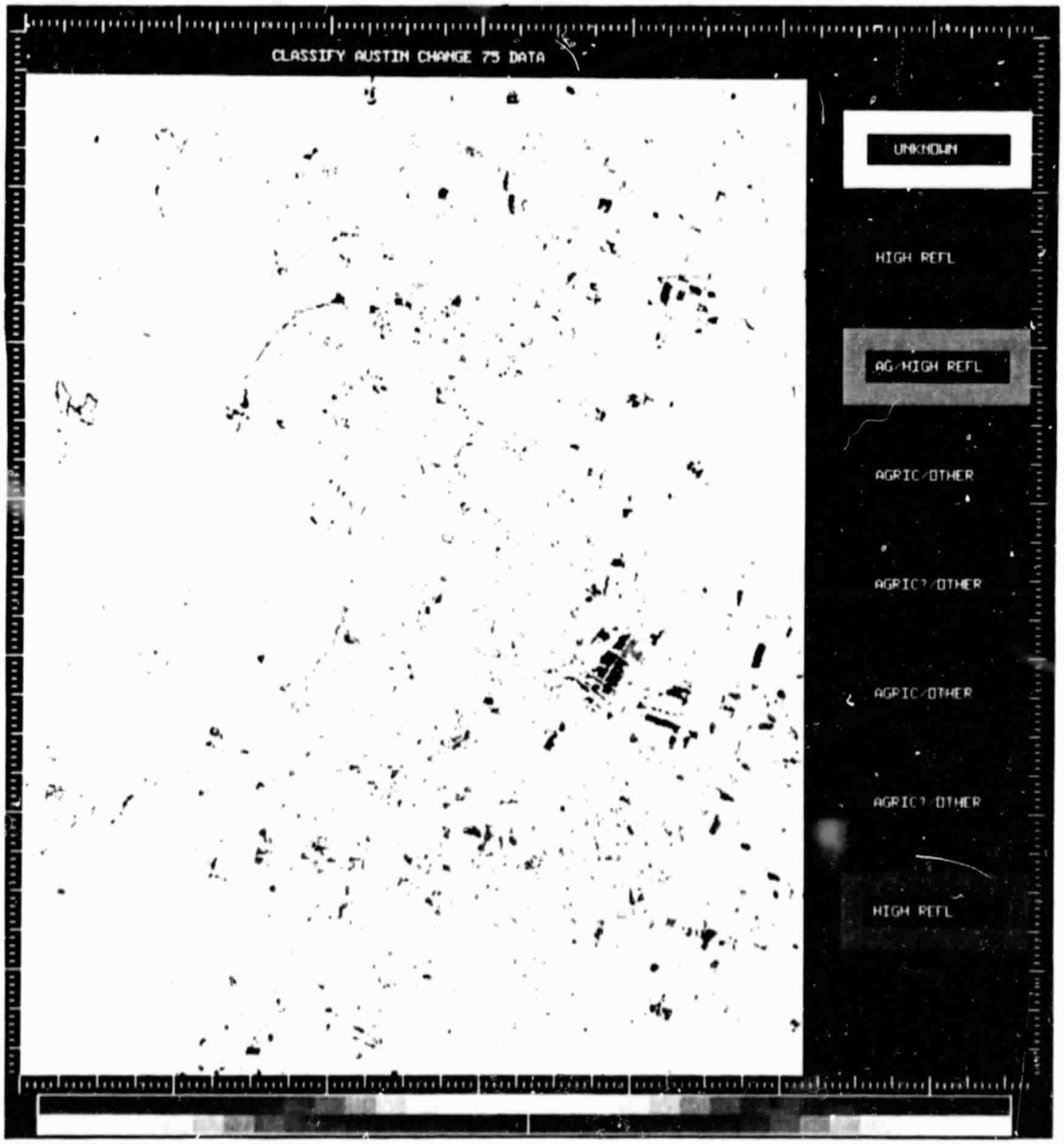

Figure 5-9. Land Cover Classification of 1975 Data for Change Areas. Agriculture is shown in green, highly reflective areas in red, and confusion areas in yellow.

SECTION 6 - FUTURE WORK

The limited ground truth for 1975 precluded a rigorous evaluation of the accuracy of the procedure. Aerial photo coverage is available for 1977, as is a clear Landsat image for April 10, 1977. To test more thoroughly the previously described technique, it was decided to register the 1977 image to the earlier scenes and to repeat the change detection process using the 1973 and 1974 data sets. The 4-year time span of these images approximates the 5-year interval under which the Bureau of the Census will operate.

In addition to evaluating change over a 4-year period, the use of the 1977 data set provides an opportunity for a comparison of change over each 2-year period as a possible indicator of land cover change patterns.

6.1 SCENE REGISTRATION

Registration of the 1977 image to the earlier data set will be performed using a combination of DIRS and VICAR routines. This processing is nearly completed. Only the resampling of the 1977 image to conform with the 1973 data remains to be done.

DIRS was used to perform a first-order correction for major sources of distortion (Earth rotation skew, scanner over-sampling, mirror velocity, and so forth) and to resample the data for 60-meter-square pixels, the resolution of the 1973 and 1975 registered images. The first-order correction results in data sets that approximate the projection of the registered imagery.

The near-alignment of the data sets facilitates the identification of correlation points to be used for precise alignment of the images. Initially, 70 such points were selected. Two points were subsequently eliminated due to poor scene-to-scene correlation. The correlation values obtained from registration runs yielded a typical residual of 0.2 pixel between the tie points and the resampling grid surface. This value, combined with the use of 68 tie points for an area only 640 lines by 515 samples, suggests that the 1977 image will register very accurately to the 1973 data.

6.2 GROUND TRUTH

USGS 7-1/2-minute topographic maps, photo-revised in 1973, serve as the basis for comparison with the 1973 image. These maps are being updated using 1977 black and white aerial photography to provide a source of information concurrent with the 1977 Landsat data. Together these maps will provide additional land cover information that will provide a basis for evaluating the satellite-derived land cover change.

To facilitate the comparison of the photo-interpreted and the satellite-derived change areas, the photo-interpreted change information will be digitized using the television scanner input capabilities of the Atmospheric and Oceanographic Image Processing System (AOIPS) Hazeltine terminals. The resulting digital data will be corrected for scanner distortion, scaled, and registered with the satellite data.

6.3 DATA COMPARISON

The availability of registered satellite data and ground-truth information will permit an automated point-by-point comparison of the data results. This will make it possible to evaluate the results at each step in the differencing sequence (e.g., evaluation of change by band and evaluation of total change). The digitized ground truth will also make it possible to quickly evaluate the utility of the NDU clustering program to classify change areas. Such rigorous analysis of the various products is only practical when an automated technique such as this is employed.

SECTION 7 - SUMMARY

An efficient image differencing scheme for the detection of major changes in land cover has been demonstrated. The procedure subtracts the data value at a point from the data value for the same location in the second scene, then adds a constant to the difference. These results can be displayed in photographs using existing image processing systems, but their interpretation is not obvious. To facilitate identification of change areas, the difference images are density sliced at three standard deviations above and below their mean values. Pixels that show a variation greater than the threshold are taken to be areas of land cover change. The combination of threshold results for each band produces a total change image for the scene.

Besides providing a map of areas with substantial reflectance changes, the total change image can be used as a binary mask to extract raw reflectance data for change areas. This procedure reduces the amount of raw data for further analysis by approximately 97 percent. The reduction permits the HINDU clustering algorithm to rapidly process the scene. Such a classification of 1975 data revealed that most areas of high reflectance change are the result of construction activity. In the Census application these areas could be considered areas of residential development.

To test the image differencing technique further, a 1977 Landsat scene will be registered to the earlier data sets and used to analyze change in the study site over a 4-year period. This work has two primary benefits: (1) the 4-year time span more closely approximates the 5-year timeframe within which the Bureau of the Census will update its records, and (2) good ground truth is available for evaluating the results.

Using 7-1/2-minute quadrangle sheets (photo-revised in 1973) and 1977 aerial photos, it will be possible to derive ground-truth land-cover change information. This data will be digitized using a television scanner available on the

AOIPS Hazeltine terminals and then registered to the satellite data. Such a digitized ground-truth data base will permit extensive point-by-point evaluation of the Landsat-derived change areas and of the HINDU land cover classification.

The preliminary results are encouraging. They show that differencing Landsat images is an efficient technique to delineate areas of land cover change. Further, the information obtained from such a procedure can be easily integrated into an analysis and classification procedure to identify land cover change by type.

REFERENCES

1. National Aeronautics and Space Administration, Goddard Space Flight Center, Landsat Urban Area Delineation (Final Report), J. W. Christenson, J. B. Davis, V. J. Greeg, H. M. Lachowski, and R. L. McKinney, December 1977

2. --, X-933-76-14, User's Guide for Batch Operation of the SMIPS/VICAR Image Processing System, J. G. Moik, May 1976

3. --, Digital Image Rectification System Preliminary Documentation, P. Van Wie, M. Stein, E. Puccinelli, and E. Fields, November 1975