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JUNE 1983

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LAND COVER CHANGE MONITORING WITHIN THE EAST CENTRAL LOUISIANA STUDY SITE-- A CASE FOR LARGE AREA SURVEYS WITH LANDSAT MULTISPECTRAL SCANNER DATA

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16. ABSTRACT

This report documents results established for four digital procedures developed for characterizing the radiometric changes between multidate Landsat spectral data sets into meaningful measures of land cover/use dynamics. Each technique's performance was contrasted against digitized land use change maps, which were produced from contemporaneous, retrospective aerophoto coverage, in a cell by cell comparison over a one half by one degree area in east central Louisiana as a standard for comparison. This test site is characterized by massive clearing of the bottomland hardwood forests along the lower Mississippi River Valley alluvial plain for conversion to cropland and pasture.

The four techniques identify from 10.5 to 13.0 percent loss in area of forestland in a five year period which is supported by measurements made from concurrent aerophoto coverage for each date. However, they differ more by how accurately this amount of change is distributed, the need for ancillary ground truth, and amount of usable information that is extractable. All require some method of digitally co-registering the two data sets. All are capable of providing tabular statistics as well as map products. Two are capable of detecting changes and identifying their locations. The other two, in addition to this, provide information to qualify land cover conditions at each end of the study interval.

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1. INTRODUCTION

This report documents results accomplished at the NASA, National Space Technology Laboratories, Earth Resources Laboratory (NSTL/ERL) from the development and testing of an agricultural land use change monitoring capability as a part of the Land Cover Information Systems (LCIS) task of the AgRISTARS Domestic Crops and Land Cover (DCLC) project in cooperation with the U.S. Department of Agriculture, Statistical Reporting Service (SRS).

Change detection analyses using remotely sensed digital data have been applied to a variety of natural resource problems. They have been used in the monitoring of alteration in coastal[19, 26], forestland[5, 10, 15, 18], rangeland, desert[4, 20], and interior wetland[8] environments as well as the measurement of land use dynamics in both urban[9, 22, 23, 24] and natural settings[3, 6, 18, 26]. This information has been used to monitor for water quality changes in watersheds[14, 16] and for increases in strip-mined lands [1, 11].

The remote detection of locational changes in surface cover materials presupposes there are associated, measurable radiometric differences between successive dates corresponding to these changes on the ground. Geometric relationships preserved by imaging scanners make this possible. As a result, several methods have been devised to recognize and map these phenomena. Those tested have included: band ratioing[8, 9, 24], band subtraction (image differencing)[9, 18, 22], pre-classification differencing (delta data classification)[26], post classification comparison[5, 8, 10, 15, 23, 26], classification of multidate data[2, 26], and measurement of spectral change vectors[1, 5, 11, 15].

Other comparisons for change have been accomplished through conversion of the digital counts to absolute physical quantities that are then subtracted[20] and also by taking statistical measures of correlation, covariance, and/or percent-explained-variance by the first eigenvalue to compare between data sets[4]. One investigator used the Kolmogorov-Smirnoff (K-S) test to identify changes between dates[6], while yet another has correlated land use changes with information contained in the third principal component of a transformed, multi-date data set[3].

Numerous obstacles prevent the straightforward execution of these operations, and subsequent problems make evaluation difficult. Basically, any of these methods require spectral data sets to be precisely co-registered so that the radiometric response of corresponding ground areas can be compared. Positional inaccuracy adversely affects performance, although one method employing the K-S test reports that it is relatively independent of small misregistration errors[6]. Other problems include the influence of time-dependent variations of the extrinsic factors listed in Table 1. These factors variably combine to alter the radiometric fidelity of the recorded spectral response of a scene. This degrades technique performance by inducing the detection of untargeted factors. A few of these (e.g., clouds, cover material, and soil moisture changes) are locational by nature whereas other changes affect total coverage. Investigators have experimented with and applied various data modifications in attempts to negate or compensate for such factors. Generally a great deal must be assumed, and only the major influences are treated, usually by "standardizing" or equalizing the effects on each data set rather than "correcting" or removing it as a factor since no one has proven that the effects can be entirely subtracted.

Table 1. Considerations for Temporally Dependent Sources of Change in Reflectance Between Data Sets

Atmospheric Differences

- Clouds
- Haze
- Humidity
- Dust

Seasonal Differences

- Solar Illumination Angle
- Phenologic Stage

Surface Differences

- Soil Moisture
- Cover Materials

Sensors/Systems Differences

- Orbital Altitude
- Platform Attitude
- Differential System Deterioration Rates
- Sensor Calibration

Processing Differences

- Formatting
- Resampling Procedures
- Decompression Procedures

Astrophysical Differences

- Solar Flux
- Magnetospheric Interference
- Various Axial Motion Components
- Ecliptic Variations
- Eccentricities in Orbit

Geometric corrections for skew, rotation, scaling, etc., are regularly applied to rectify both data sets in early stages of preprocessing before co-registration[5, 6, 9, 12, 17, 18, 19, 20, 26]. Other investigators have tried to correct for aerosols (haze)[12] and other non-localized atmospheric effects[20] as well as clouds[3, 12]. Atmospheric correction models usually require additional measurements acquired concurrently with the spectral data; otherwise data sets are standardized to one another by the same factors that are inherently collected in the data[20]. If not for the unavailability of these concurrent atmospheric measurements and the expense and complexity of mathematically describing atmospheric interactions, the use of these models would be more prevalent. More frequently used are standardizations for effects of differences in solar illumination angle and of differences in sensor calibration[12, 20, 21, 25]. The effects of these factors can be eliminated, however, by selecting data collected on anniversary dates with the same sensor to avoid the major influences of seasonal and system differences. But there are no guarantees that such factors as phenologic conditions or soil moisture are as cyclical as sun angle effects and consequently have equal influences in each date. Also, data within these constraints of geographic and temporal coincidence may not be available. However, the data were available for this study, and overall scene characteristics of both data sets were very similar. The author achieved better results with this approach when testing the first two techniques described in Section 3 than with data sets standardized by either the ERIM-developed coefficients[12] or the Landsat User's Handbook[20, 21, 25] coefficients for both sun angle and sensor gain calibration.

Another standardization based on the same theory as the regression modeling technique described in Section 3.4 was also tested. Attempts were made to model no change areas between dates in order to relate second-date spectral response as a function of the first date's response. This relationship was then extended to the entire second-date scene to describe it in the same terms as the first, which serves to equalize the extrinsic effects mentioned before. The transformation using the model coefficients worked well in the forested areas where the manual sample selection was adequate. A suitable sample of other types of unchanged areas of the scene was absent, and the model could not sufficiently describe these areas. This data set-dependent approach to standardization hypothetically enables scenes, regardless of differences, to be related under equivalent terms.

In addition to the problems of registration, extrinsic factor effects, and acceptable digital data selection, a control area is essential to establish performance levels and to verify results when operating in an experimental mode. This inexorably creates the need for ground data coincidental in time and space with the necessarily retrospective study interval to be used as a standard for comparison. Therefore definition of a control area dictates common areal coverage at two points in time from two different data sources. This restriction has prevented many investigators from having adequately substantive proof of performance from their results. Most often they do not satisfy all these criteria because the data are simply non-existent, or they are more interested in the success of the application. Usually aircraft photography has been the only reliable, alternative data source for large area surveys of this nature on successive dates, but even then coverage has been

spatially limited and irregularly collected. In spite of this, aerophotography has been used successfully to map land cover and land use change[13, 16] and previously has been the only other feasible recourse until the advent of this technology. The control area, with its attendant data requirements, is necessary only for the experimental process. It is not required for the routine application of these methods.

Schemes for detecting surface changes take two basically different directions in approaching their performance objectives. One, a technique is used to examine or sample the entire pixel population as an undifferentiated set. As a result it may identify anything from relative measures based solely upon the radiometric count difference of matched resolvable elements at two points in time[4], or the technique may be able to locate and quantify specific types of change areas which indicate conditions at each time frame[2, 10]. Two, a technique may operate on a specified subset or stratum of cells where the changes known to be occurring are the subject of study such as in a particular ecosystem or habitat, with all other pixels being eliminated from analysis. This simplifies the procedure, and less confusion develops at the outcome because of the reduced number of data points to analyze. This allows the detection operations to address more subtle differences than could be recognized otherwise where these differences might be masked by greater spectral differences, which may not be of concern for a particular application, occurring in the general pixel population. Of course a means of differentiating the population is required prior to operating on the correct subset. The choice of schemes is dependent upon the objectives of the analyst for the specific purpose to be undertaken and potential for its best results.

The methods that were developed and tested here were intended to express these changes in terms of the naturally vegetated landscape which underwent a change of conditions associated with agricultural production. Thus a survey of the whole population of data cells was taken as in the first option mentioned. The objectives of technique execution were to detect and to locate changed pixel areas as well as to describe conditions at each date capable of characterizing the changes present with the least amount of ground truth. This does not mean that other methods or approaches will not provide these same informational components: detection, location, and identification. It was also desirable that they be flexible enough to provide maps as well as tabular accounts of specific change types that would affect agricultural productivity estimation.

2. STUDY SITE AND DATA

2.1 Study Site Description

The test site covers an area from 91.5° to 92° W. longitude and from 31° to 32° N. latitude on the fertile alluvial plains of the lower Mississippi River in east central Louisiana. This area is further characterized by minimal relief, poor drainage, and fertile, shallow, undeveloped, organic-rich soils complexly distributed by the fluvial processes at work in this region. Extensive mixed-bottomland hardwood forests of oak, gum, and cypress once dominated the landscape. Rapid clearing for agricultural production of crops and livestock has left less than a quarter of these forests standing[2]. Table 2 shows the deforestation rates for parishes that are a part of this

Table 2. Past and Predicted Acreages of Bottomland Hardwoods in Those Parishes Partly or Wholly Contained in Study Area.

Parish	Total Acreage in Parish	*Total Acreage in Parish That Originally Produced Bottomland Hardwoods	Acreage Remaining in Bottomland Hardwoods			Average Bottomland Forest Clearing in Acreage per Year 1962-1968	Bottomland Acreage Remaining in 1985 Based on 1962-1968 Average Annual Clearing Rate
			1961	1964	1968		
Avoyelles	528,600	500,474	303,300	290,700	241,480	8,831	91,353
Caldwell	552,500	114,691	114,800	109,800	97,800	2,427	56,541
Catahoula	467,200	362,632	280.200	262,200	138,200	20,284	0
Concordia	453,800	447,815	337,600	313,600	266,600	10,143	94,169
Franklin	411,500	406,290	137,000	126,00	101,000	5,143	13,569
Tensas	398,700	393,592	256,100	230,100	195,100	8,714	46,962

*Lytle, S.A. and M.B. Sturgis, 1962, General Soil Areas and Associated Soil Series Group of Louisiana, LSU Agricultural Experimental Station, Baton Rouge, Louisiana.

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study area. The magnitude and type of land cover change occurring within this area played a significant role in its selection as an exploratory site for technique development and testing.

2.2 Landsat MSS Data

Landsat MSS data sets collected October 10, 1974, and October 2, 1979, were obtained covering the frame defined by path and row coordinates 25/38 of the Worldwide Reference System for Landsats 1, 2, and 3. Fall data sets were used as this is the driest time of the year for this locale. It had been hypothesized from previous study[10] that forest and agricultural land cover conditions in this season would offer enhanced spectral separability by minimizing the problem of spectral overlap partly caused by the excessive surface wetness that prevails most of the year.

The 1974 data set is in the pre-EDIPS X format for CCT's (57m by 79m resolution cell, geometrically uncorrected) while the 1979 data set is in the EDIPS P format of partially corrected, 57m X 57m resolution cells. A technique for overlaying Landsat data with Seasat data described by Wu[27] was used to co-register and merge these differing data format types into a single 8 channel, multidate source file. Registration was accomplished to within one pixel (57m RMS) of the base set.

2.3 Aerophotographic Data

Conventional, high altitude, color IR photography was available for retrospective ground coverage contiguously defining the test site. Aero-

photographic missions had previously acquired these data October 4, 1974, at 1:120,000 scale and October 24, 1979, at 1:60,000. This closely coincided with the endpoints of the 5-year interval between Landsat overpasses when the spectral digital data were acquired. (See Table 3.)

The two sets of photography were analyzed for changes in land cover distributions. Changed areas were delineated and rectified upon a common base using the eight USGS 15' series of topographic maps that comprise the study area. Digital land use change maps were produced using an X-Y digitizer to define the polygonal boundaries in the UTM coordinate system. Next this polygonal information was converted into a raster data file with each data cell representing either a change or no change area. This sequence is illustrated for a 15' subset of the area in Paragraph 4.1.

Table 3. Data Acquisition Dates for Data Types Used in This Investigation

DATA SOURCE	DATE ACQUIRED	
	TIME 1	TIME 2
LANDSAT MSS	October 10, 1974	October 2, 1979
FALSE COLOR IR AEROPHOTOGRAPHY	October 4, 1974	October 24, 1979

2.4 Map Information for USDA/SRS Areal Unit Analysis

Prior to sampling and estimating the crops, livestock, farm labor, etc., for a geographic area, SRS personnel stratify land uses and agricultural land

use intensities through aerophotographic interpretation. These land use strata are further subdivided into what is the basic SRS geographic analysis area or frame unit. Each frame unit is a similarly homogeneous part of the stratum it represents. It corresponds to a specific polygonal area of the land surface bounded by permanent, recognizable map features.

Strata maps (the area sampling frames) for Catahoula and Concordia Parishes were obtained, and the frame unit boundaries were digitized. Superimposing these areal reference units with information produced by one of the change detection processes gives land use change statistics, as well as land use proportions at both dates, for each frame unit. Also, the geographic location and extent can be mapped on peripheral devices and used effectively to update the stratification. (See Figure 1.) Here the same boundaries are used, and frame units only are redefined, which prevents reconstructing the entire frame by present means.

3. CHANGE MONITORING TECHNIQUES

3.1 Post-Classification Comparison

This approach is one of the most widely used. It involves making independent land cover classifications for both points in time, usually through automated spectral pattern recognition techniques. These are reduced to common descriptive categories and then compared for areas of each category that have changed during the period covered.

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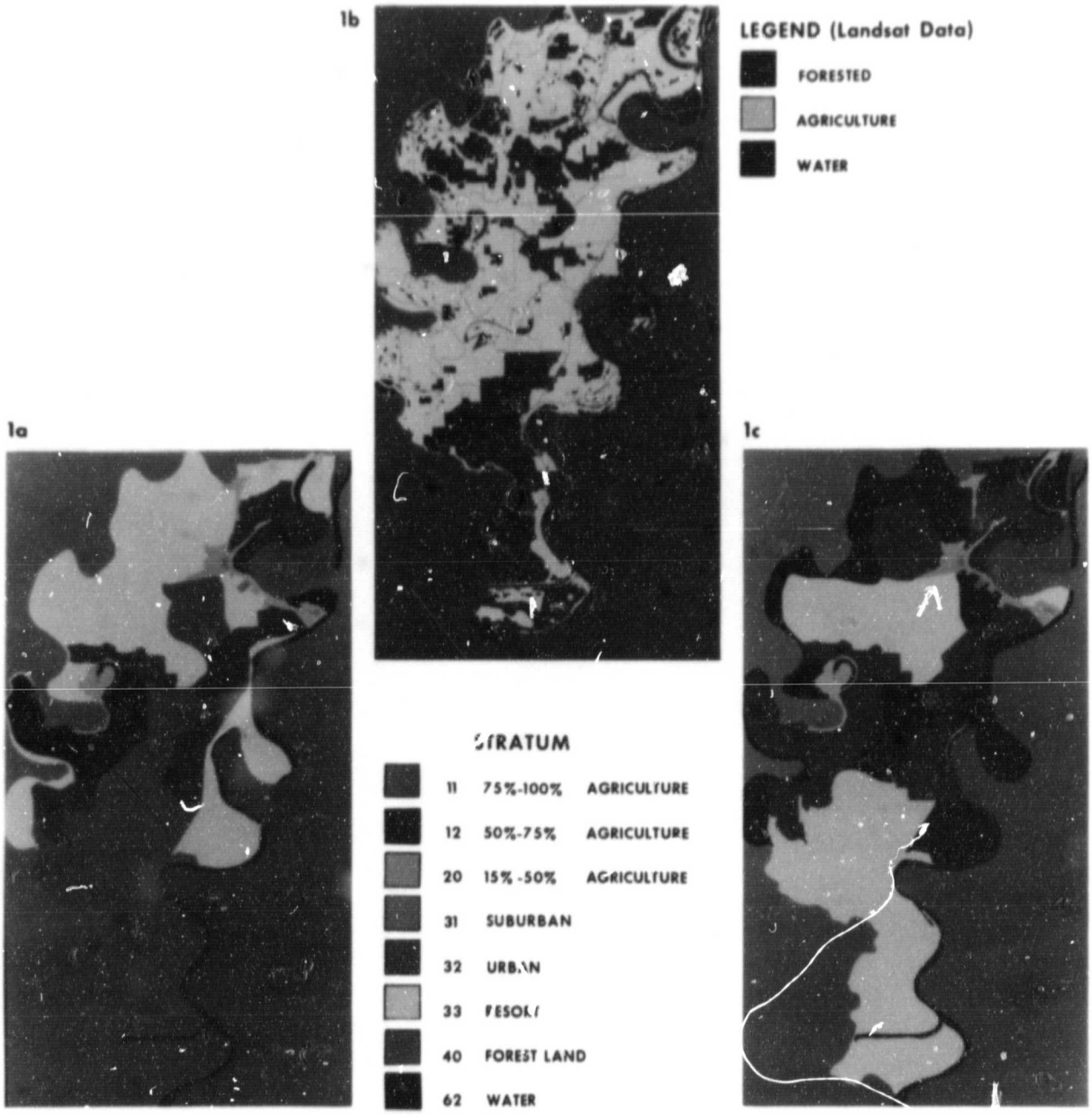

FIGURE (1c) SHOWS HOW LANDSAT MSS DERIVED LAND USES WITHIN USDA/SRS POLYGONAL GROUND REFERENCE DATA (1b), WERE USED TO UPDATE THE LAND USE INTENSITIES OF THE AREA SAMPLING FRAME (1a) FOR CONCORDIA PARISH, LA

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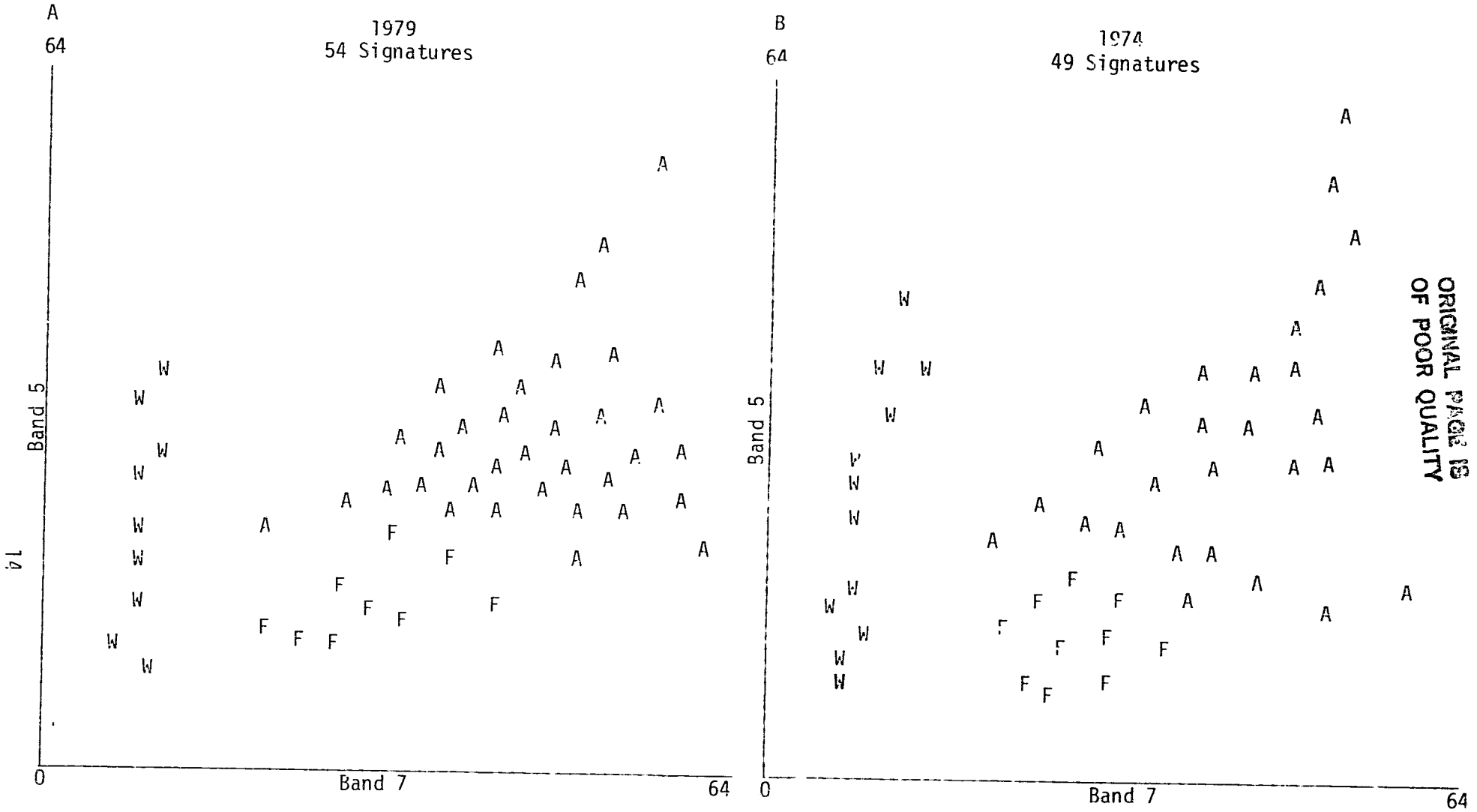
Figure 1. Update of USDA/SRS Frame Units for Concordia Parish

In this case an unsupervised clustering technique that passes a user-defined window through the data to find spectrally homogeneous areas was used[10]. These are reduced into statistically defined spectral groupings or signatures which provide the decision boundaries for mapping all data cells into classes based upon probability densities via a maximum likelihood algorithm. The 1974 data set produced 49 spectral classes, and the 1979 data set produced 54 such groups. Through interpretive examination both sets were reduced into the three major surface covers that exist at this site: cropland, forestland, and water. With both time periods commonly represented by this classification scheme, they were numerically recoded in order to be digitally compared for detecting the desired changes. Figure 2 graphically depicts the assignment of each spectral signature to one of the three major surface covers and the position of the means of each signature on a plot of a visible and infrared band.

3.2 Spectral Change Pattern Analysis

This method uses the same pattern recognition technique in 3.1 as the primary data reduction method; however, rather than operating on individual dates, the co-registered, composite, multidate file or subsets of corresponding channels in each date are used as the source for statistical signature development. In this manner, as in the sense of multiseasonal classifications, the added information from another date defines classes whose spectra have changed in a distinct pattern in addition to those groups that have the same spectral response in both dates. In this way these composite signatures can be temporally sliced to indicate the spectral response at each date because



Plots relate position of spectral group means in digital count values in two MSS bands for each date with land cover assignments: F = forests, A = agriculture, W = water.

Figure 2. Plots of Spectral Group Means

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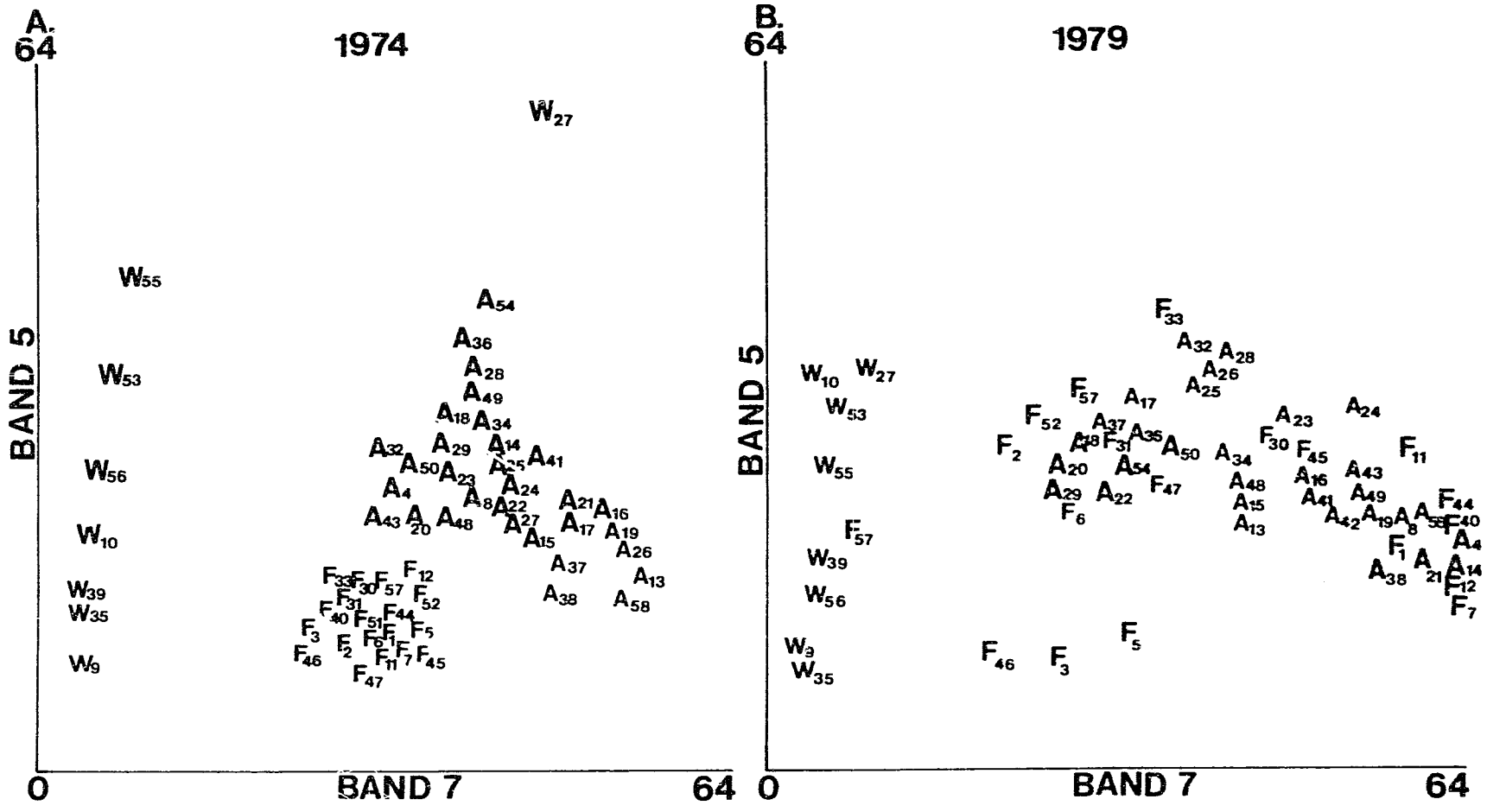
the same spectral class represents both dates, unlike the previous technique in which each date had signatures developed separately. Thus after mapping the data into these statistically defined categories, areas of change and no change can be identified by their signature migration along with conditions indicative of the surface cover at each point in time.

In this investigation, the full eight channels of data, a six-channel subset (bands 4, 5, 7 of both dates) and a four-channel subset (bands 5 and 7 for both dates), were tested and developed sets of 56, 52, and 58 training statistics, respectively. The results from the three data sets differ by only 0.3%, with the four-channel data set giving the most accurate results. Whether this is because of the high correlation between MSS bands providing essentially most of the information in two channels or of the optimization of the classifier for four channels is not certain. Figure 3 graphically shows the assignment and position of each of the 58 spectral group means in two bands for both dates of the four-channel data set. Note here that the same class occurs for each date whereas before (3.1) the classes between dates have no relationship other than they represent corresponding types of surface materials.

3.3 Radiance Vector Shift

This method uses an algorithm that looks at two channels of information from each date independently and then compares for differences between data sets in terms of standard deviation and an angle of relative, directional shift[17]. The algorithm works by finding all the pairwise occurrences from



Plots show relation of composite signature means to land cover assignments in each date. Each signature, designated by numerals, applies to both dates. Previous land cover assignment symbol is retained in second date to show changes between the three major land covers. F = Forests, A = Agriculture, W = Water

Figure 3. Plots of Composite Signature Means

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the two channels that have been selected from the first data set within the second, and it computes a distance from these corresponding pixel locations in standard deviations for that set of specific pixels. It then takes an angular measure relative to the first point, to the position of the second point which is described by its values in the two channels. It was believed in the design of this particular algorithm this second channel of information would have descriptive value to the type of change, but as is, this directional component is not relatable through any common reference frame such as the origin of the two axes describing the Euclidean space that the values occupy. That is, a number of possible land covers could have the same value for the bidirectional shift as well as equivalent measures of magnitude and be entirely different types of changes at both beginning and end. Another shortcoming to this algorithm's treatment of spectral change vector analysis is the averaging of the co-occurrence values in the comparison data set. Because of this, identity of the values resulting from that specific change is lost.

A continuous range of change values is output where zero represents no change. A threshold is decided upon based upon ground data since there is no outstanding data feature to delineate the change/no change boundary. Usually this is gradational; the boundary may cover a range of five values or more. This condition leads to commission and/or omission errors wherever the threshold is set. In this case the ground truth was used to obtain the value producing the best results.

3.4 Regression Model

This method involves the development of a mathematical model through a stepwise regression procedure between each date that relates the second date (T_2) spectral response for individual ground cells to those for the first date (T_1) for each corresponding channel of information. The model values predicted for T_2, as described by its best fit with T_1, are subtracted from the actual T_2 data to produce a digital file of residual errors for all pixel locations. Areas of land cover change coincide with the more anomalous values derived from the predictive model. A critical value is determined for the residual error values, and pixels assigned a change/no change status accordingly. In all trials between corresponding bands in each date, the relationship was best described by a cubic equation in the form:

$$Y_{ijk} = A_0 + A_1X_{ijk} + A_2X^2_{ijk} + A_3X^3_{ijk} + E_{ijk}$$

where:

Y_{ijk} = band k value at row i and column j in second date (T_2),

X_{ijk} = band k value at row i and column j in first date (T_1),

A_0 = constant offset,

A_1, A_2, A_3 = multiplicative factor for first, second and third order regression coefficients, and

E_{ijk} = Y observed - Y predicted, residual error that represents change to some degree beyond predicted fit between dates for the ground area imaged at row i and column j in band k.

The basic precept here is that if there were no change, $E_{ijk} = 0$. This would be the case if an area could be imaged twice in short succession before any measureable changes could take place or if this relationship was established

for a duplicated data set: $Y_{ijk} = X_{ijk}$ (or $T_2 = T_1$). But as the interval between successively collected data increases, this relationship evolves to express whatever changed conditions present can be mathematically described -- in this case, a cubic expression.

Earlier trials did not deliver the expected results. Sampling of corresponding cells between dates had depended upon a coarse, regular interval of point selection, because of program limitiations and study area size, and proved to be inadequate to describe the desired relationship. After reconsideration, it was decided that to properly describe T_2 response as a function of T_1, the model should express the relationship between dates in terms of no change. In other words, the samples used to develop the model should be selected from areas with absolutely no location-specific surface changes. In this way: (1) the many environmental difference factors influencing every cell could be taken into consideration and be expressed by the model as a constant offset, and (2) the calculated, predicted values of the model would reflect no surface changes so that (3) in computing the residual errors between the model's predicted value and those actually observed, highly anomalous values would occur in areas of change. Unfortunately, only forested areas of no change could be stratified for model building and did not represent the entirety of land covers within the scene. The manual or supervised procedure of sample selection for defining the model was unable to locate enough acceptably unchanged examples of other representative land covers to successfully describe them through the stepwise regression analysis. Of the major land covers characterizing this area, no agricultural samples could be used--even though there were large areas of agriculture in both dates--because

of the continual changes in surface conditions brought about by their intensive human use. Even the large areas of water in this area were rejected, because they also varied extremely between dates. With no other type of samples but forest to develop the relation between dates, the model did not perform well under these other condtions. However, within forested areas, the method worked reasonably well. There was very little error or noise, and with experience the various residual error levels could be associated with specific types of change.

In expressing the locational, no-change relationship between dates, this method might also work well as a data-specific standardization between any data sets from which the model was developed. This idea was not fully tested because of the same sampling problem.

4. EVALUATION OF RESULTS

4.1 Verification Procedure

For verification of detected changes of land use between 1974 and 1979, the digital ground data mapped from the coincident aerophoto coverage was formatted into a multichannel, georeferenced data file. Every $57m^2$ cell within polygon boundaries representing the photointerpreted land use change was encoded with the value "1". All areas of no land use change were assigned a zero value. This exercise served to provide complete, contiguous data representation for an area of eight 15' series quadrangle maps with a digital land use change map to serve as a comparison standard for method performance.

Each individual change detection technique's digital output was also registered into the data base as "0's" or "1's". This was accomplished after registering the Landsat data to the UTM coordinate system[7] so that equivalent points on the ground could be compared.

Criteria for photointerpretation employed the use of a minimum ten percent crown closure to distinguish forests from non-forests. Only change areas larger than ten acres were delineated during photointerpretation. In order to maintain as much label definition consistency and compatibility between data sources as possible, Landsat-derived data products were further subjected to a spatial classifier recognizing only change parcels larger than ten contiguous acres, effectively eliminating anything less from the comparison. Each technique's output was then added cell-by-cell to that of the doubled ground data value to produce an "error source map" and/or accuracy statistics. This operation is better described by CH0 = CH1 + (CH2 *2)

where: CH0 = result of operation for comparison

CH1 = MSS-derived change data

CH2 = ground reference data

for each equivalent ground resolution cell. The possible outcome of this operation is a 0, 1, 2, or 3 for each cell where (0) zero represents agreement between both data sources that no change has occurred for that cell, (1) one indicates commission error on the part of the computer-identified change technique, (2) two indicates omission error, and (3) three indicates there was mutual agreement to that data cell having undergone changes. Statistical information from this procedure for the four techniques tested is shown in Table 4, and an "error source" map is shown in Figure 4.

Table 4. Accuracy Tabulation of Verification Procedure Results

COMPUTER-ASSISTED TECHNIQUE	COINCIDENCE OF LANDSAT-DERIVED AND AEROPHOTO-DERIVED LAND COVER CHANGES									
	AGREEMENT						DISAGREEMENT			
	NO CHANGE		CHANGE		TOTAL AGREEMENT		COMMISSION ERROR		OMISSION ERROR	
	Area Sq mi.	%	Area Sq mi.	%	Area Sq mi.	%	Area Sq mi.	%	Area Sq mi.	%
POST-CLASSIFICATION COMPARISON	1744.0	85.8	184.9	9.1	1928.9	94.9	80.3	3.9	23.0	1.1
SPECTRAL CHANGE PATTERN ANALYSIS	1768.1	87.0	185.5	9.1	1953.6	96.1	56.2	2.8	22.4	1.1
RADIANCE VECTOR SHIFT	1722.2	84.7	153.6	7.6	1875.8	92.3	102.1	5.0	54.3	2.7
REGRESSION MODEL	1746.6	86.0	67.1	3.3	1813.7	89.3	72.0	3.5	146.5	7.2

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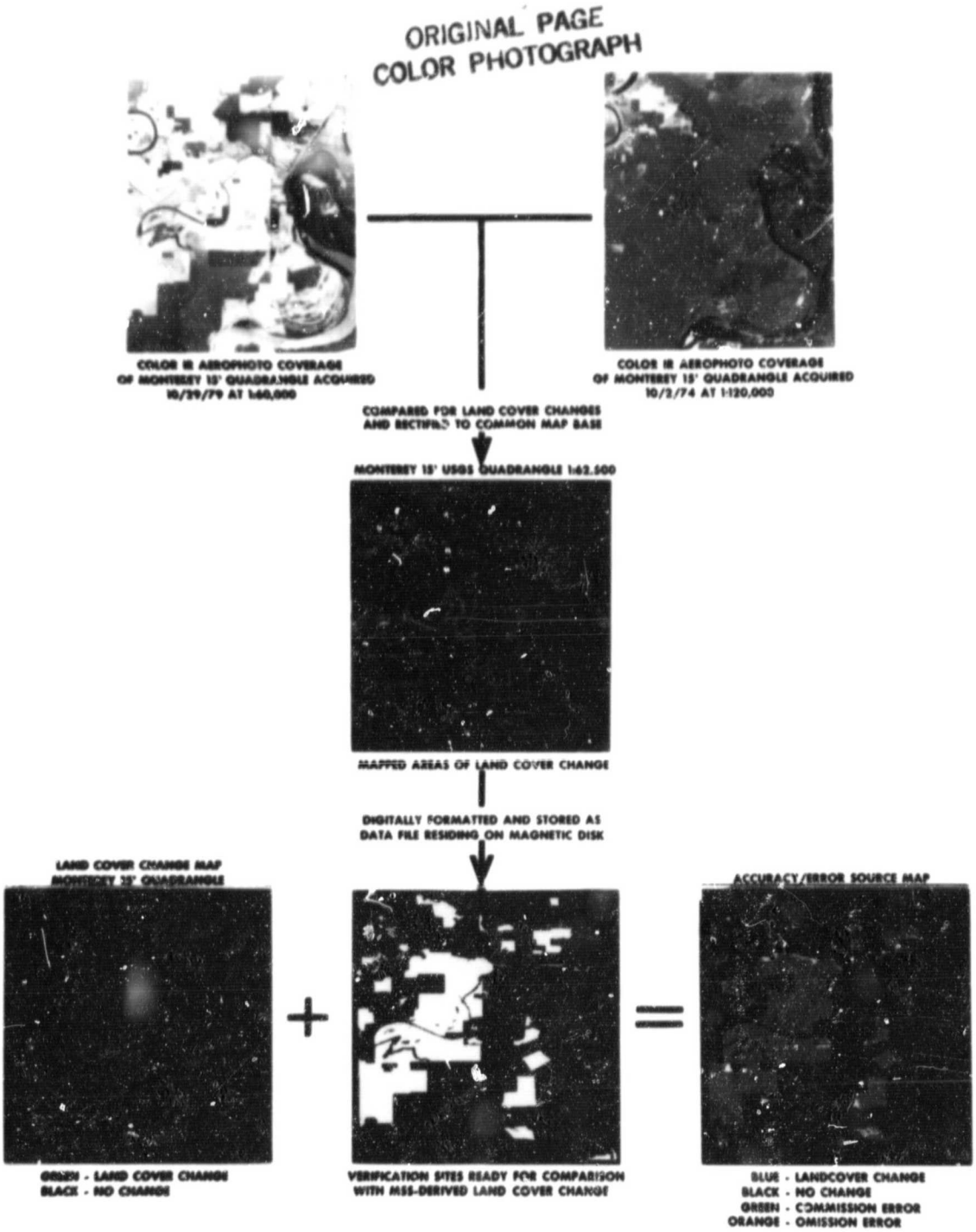

ACCURACY EVALUATION

DATA SOURCE ARGUMENT		FREQUENCY	PERCENT	AREA
ERROR	COMMISSION	4705	2.1	5.5
	OMISSION	2784	1.3	3.5
AGREEMENT	CHANGE	30,564	18.5	48.4
	NO CHANGE	162,875	78.1	304.3
	TOTAL	200,888	96.6 % CORRECT	361.7 SQ. MILES

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Figure 4. Accuracy Verification Procedure Between Landsat-Derived and Aerophoto-Derived Land Cover Change

Using the error-source map generated from this procedure, the corresponding locations of the commission and omission errors can be examined in the photography and a descriptive determination of their cause can be identified, whereas the numerical procedure alone only classifies the errors in one of these two ways. With this ability, the first examination revealed that many of the larger areas of commission error were locations of actual change that had been overlooked during the photointerpretation. The data in these were locations updated to correct these errors in the ground truth. After further reexamination of this information in its spatial context, the remaining errors were attributed to the following factors:

1. Non-simultaneous acquisition of Landsat and aerophotographic data as in the case of sizable random, locational errors of omission;
2. Several types of misregistration of the ground data to a common map base such as:
   (a) photo-to-map transfer of land use change delineations,
   (b) imprecise digitizing of these locations,
   (c) conversion of this polygonal data to a raster data file, as in small, contiguous errors of both commission and omission in boundary locations;
3. Misregistration between data types such as:
   (a) band-to-band registration in individual spectral data sets,
   (b) scene-to-scene registration between spectral data sets,
   (c) scene-to-map registration for a georeferenced data set which resulted in more scattered, but patterned, errors of both types in many physical boundary locations;

4. Human error in ground data set development such as:

   (a) incomplete identification of all change sites between sets of photography that could not be corrected and

   (b) misinterpretation of land use change which resulted in small discrete errors of both types;

5. Discordant labeling criteria between data types--This factor caused either commission or omission errors depending on the circumstance. For instance, a computer-assisted, satellite-detected spectral change may consistently occur at a forest density break of 40 percent crown closure, whereas manual mapping criteria may stipulate a 10, 15, or 20 percent break before it is recognized as a change to another category. Other problems of this nature included surface areas covered by high water and the range of surface conditions associated with cultivated areas.

6. Spectral similarity between certain surface materials and consequent co-classification--Small examples of various misclassifications were found that included confusion between burned over areas and wet areas, between some types of agriculture and forested sloughs, brakes, and wetlands, and within highly complex boundary areas where many land cover types occur within a single resolution cell and produce integrated spectra.

Most of these errors (1, 2, 4, and 5) could be eliminated in routine applications where the verification exercise is unnecessary.

4.2 Summary Conclusions

Computer generated classifications of Landsat multispectral (MSS) data can be used to measure forestland to agricultural land use changes accurately

when the proper data are selected and land parcels being converted are ten acres or larger. With these stipulations, the accuracy obtainable is at least equivalent to what can be obtained through aerophotographic measures of changed land use. Results showed that approximately 10.5% to 13% of the entire half degree by one degree study area had changed from forestland to agricultural use in the five-year period. However, in some areas where land use changes were more concentrated, data from certain 15' quadrangles indicated up to 20% of this land use change within their boundaries. Several blocks of land as large as four square miles incurred 100% clearing and replacement by agricultural use.

The methods reported here work without extensive efforts to standardize various extrinsic effects on each data set. All techniques require accurate digital co-registration of the data sets. The two methods involving maximum likelihood classifications as the primary data reduction tool provide all the information requirements discussed in Section 1 with the least ground truth. These methods also more accurately depict the geographic distribution of the changes identified. This is paramount in applications where this spatial detail is necessary. Even though all techniques' performance results vary from 89% to 96% correct and appear adequate, there is a marked difference in the images each technique's accuracy produces. (See Figure 5.) The added dimension of this additional information suggests that many applications would be unusable without at least a 95% accuracy by this method of accuracy measurement.

The post-classification comparison (PCC) and spectral change pattern analysis (SCPA) techniques obtained the same scores for accurately identified

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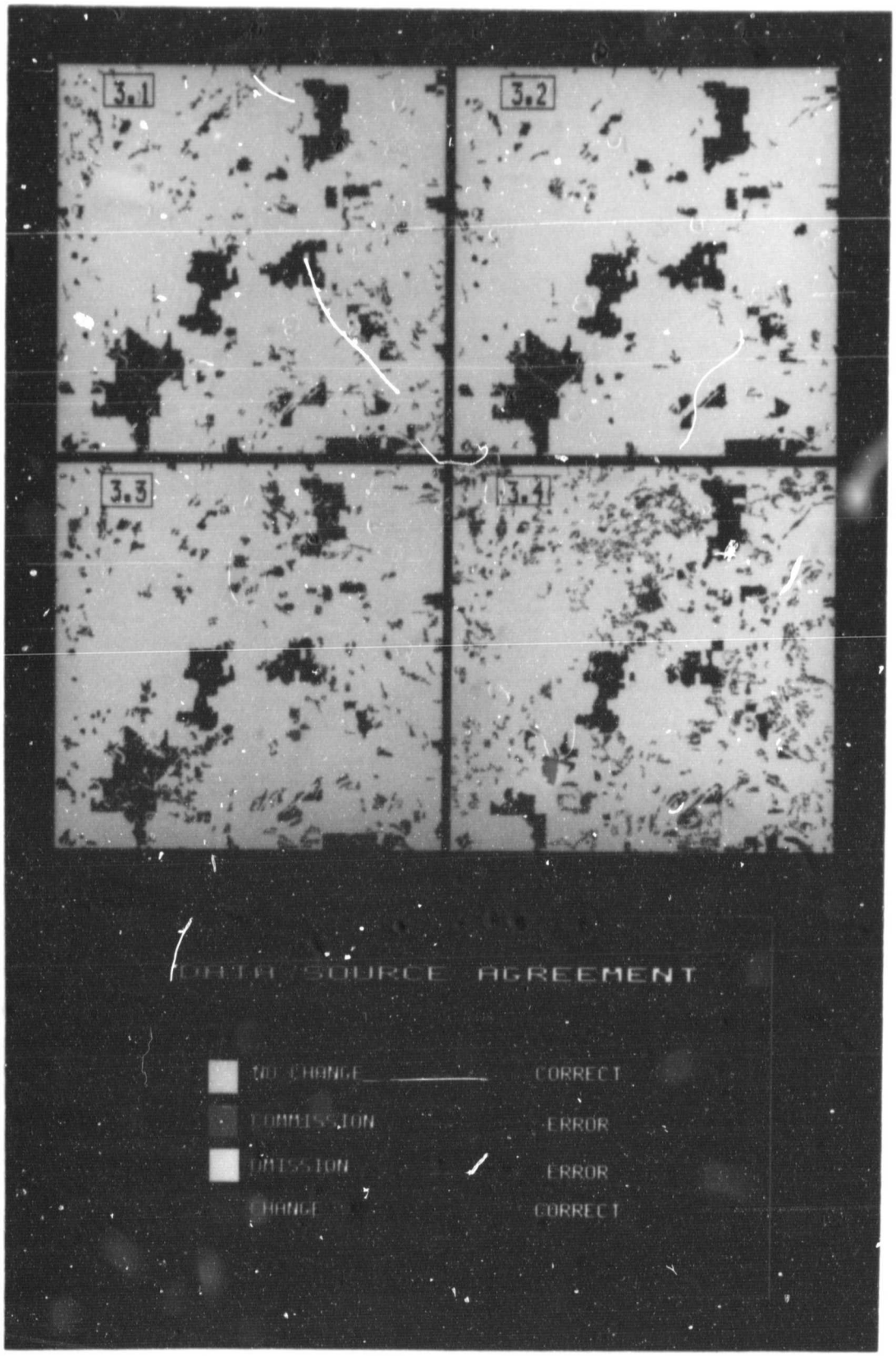

Figure 5. Results of Comparison of the Four Techniques with Ground Truth Data Sets

change and equal amounts of omission error because of similarities in the data reduction techniques used in each; however, the SCPA technique was more sensitive to decreases in forest cover density despite scoring less commission errors and despite user-supplied labels on spectral groups in the PCC technique that eliminated differing labeling criteria. Reasons for this will be explored as these methods are tested in test areas in Kansas and Arizona.

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