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EVALUATION OF MULTIBAND, MULTITEMPORAL, AND TRANSFORMED LANDSAT MSS DATA FOR LAND COVER AREA ESTIMATION

E. R. Stoner
G. A. May
M. T. Kalcic

National Aeronautics and Space Administration
National Space Technology Laboratories
Earth Resources Laboratory
NSTL Station, MS 39529

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16. ABSTRACT

Various techniques for processing Landsat MSS data were investigated for the purpose of land cover area estimation. Sample segments of ground-verified land cover data collected in conjunction with the USDA/ESS June Enumerative Survey were merged with Landsat data and served as a focus for unsupervised spectral class development and accuracy assessment. Multitemporal data sets were created from single-date Landsat MSS acquisitions from a nominal scene covering an eleven-county area in north central Missouri. Analysis and processing were performed on the USDA/ESS EDITOR system and on the NASA/NSTL/ERL ELAS software.

Classification accuracies for the four land cover types predominant in the test site showed significant improvement in going from unitemporal to multitemporal data sets. Transformed Landsat data sets did not significantly improve classification accuracies. Land cover area estimates using regression estimators showed mixed results for different land covers. Misregistration of two Landsat data sets by as much as one and one half pixels did not significantly alter overall classification accuracies. Existing algorithms for scene-to-scene overlay proved adequate for multitemporal data analysis as long as statistical class development and accuracy assessment were restricted to field interior (non-border) pixels.

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Research Division

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I. INTRODUCTION

This paper describes efforts by the National Aeronautics and Space Administration/National Space Technology Laboratories, Earth Resources Laboratory (ERL), and the United States Department of Agriculture, Economics and Statistics Service (ESS), to investigate techniques of processing various Landsat data sets for the purposes of land cover classification and area estimation. A Missouri study site comprising a single Landsat scene was selected. Ground-gathered and Landsat data were synthesized and analyzed on both the ERL and ESS computer systems. This study was not designed to compare these two systems but rather to evaluate different analytical tasks and procedures and their effect on the results obtained from Landsat classifications.

The objectives of this study were to:

- Determine classification and estimation differences between unitemporal and multitemporal analysis.
- Determine classification and estimation differences using all multispectral scanner (MSS) bands, various subsets, and transformed MSS data.
- Evaluate land cover estimates derived from EDITOR regression methods.
- Evaluate the adequacy of June Enumerative Survey (JES) segment data for representing the spectral diversity of all land cover types.
- Evaluate the effect of misregistered multitemporal data in classification results.

Methods and results of the investigation are discussed in the following sections.

II. DATA SOURCES

The study site included 11 counties in north central Missouri. All ground and Landsat data used in the study were collected during the 1979 growing season.

A. Ground Data

Thirty-three ESS June Enumerative Survey sample segments were located throughout the 11-county area. The crop or land use was recorded for all land within each segment, typically 2.5 square kilometers in size. During June a trained enumerator delineated the land cover information for each segment on an aerial photograph. Segments from this JES sample were then registered to a base map and all field boundaries were digitized and transformed into latitude-longitude coordinates.

B. Landsat Data

Landsat MSS data over path 28/row 32 of the Worldwide Reference System were obtained for May 14, August 3, and September 17. Efficient utilization of Landsat data requires knowing the geographic location of each pixel within the scene. Landsat row-column coordinates were related to map latitude-longitude or UTM coordinates by scene-to-map registration. The major components of this map registration technique are discussed by Hanuschak, et al. (1979), and Joyce, et al. (1980). Results indicate the registration accuracy of an entire scene to be within one pixel for the 57 x 57-meter pixel size of P-format Landsat data.

To conduct multitemporal analysis, the Landsat images had to be registered to each other. Several different algorithms and procedures have been developed to perform scene-to-scene registration of Landsat images (Anuta, 1970, 1977; Joyce, et al., 1980). In each procedure one scene was selected as the base frame and a second scene was registered to this base. In this study the base frame was August 3. ESS techniques were used to register the May 14 scene to this base and NSTL/ERL procedures were used to register the May 14 and September 17 data to the base.

C. Synthesis of Ground and Landsat Data

In order to simultaneously use the ground and Landsat data during computer analysis, the exact location of the field and segment boundaries within the Landsat data had to be determined. The first step of this procedure was to produce a gray scale map of a window containing the predicted area of the segment. Using the digitized segment files, plots of the segment ground data were made at the same scale as the gray scale maps. Each plot was overlaid on the gray scale map and shifted until the field boundaries best fit the field patterns of the map. The new coordinates of the segment were recorded in a computer file containing the precision registration of segment ground data to Landsat data.

For every Landsat pixel falling within a segment there is a corresponding ground cover data point. This registration technique permits the identification of boundary pixels which can be eliminated from consideration during training and classification. Further details of these techniques are discussed by Ozga and Donovan, 1977.

III. DATA PROCESSING

Analysis and processing were performed on both USDA/ESS and NASA/NSTL/ERL facilities. The ESS EDITOR system (Ozga and Donovan, 1977) was used for photo and map digitization, scene-to-scene registration, Landsat analysis of sample segments and full scenes, and calculation of regression estimates of land cover types. These processes were executed by using purchased computer time on a PDP-10 in Cambridge, Mass., and the Illiac IV computer in Sunnyvale, Calif.

The Earth Resources Laboratory Applications Software (ELAS) was used at NASA/NSTL to perform scene-to-scene registration, analyze segment and full scene data for the various land cover types, and for examining misregistration effects. ELAS is a comprehensive operating subsystem, written principally in FORTRAN language, for processing and analyzing digital imagery data. A Perkin-Elmer 3242 computer was used for all analyses.

All processing was done using a four-category data set. The numbers of pure field interior pixels for each category contained within the 33 segments were: corn, 1,098; soybeans, 2,138; dense woodland, 559; and hay/permanent pasture, 3,580 (Table 1). Training statistics were derived from, and accuracy testing was performed on, the same set of pixels in a method known as resubstitution.

IV. EVALUATION OF CLASSIFICATION PERFORMANCE USING UNITEMPORAL, MULTITEMPORAL, AND TRANSFORMED LANDSAT DATA SETS

A. EDITOR Analysis

Training statistics were developed by clustering the field interior Landsat pixels within the 33 segments for each of the four categories. The iterative clustering algorithm was set up according to the parameters given in Table 2. The May four-channel, August four-channel and May/August eight-channel data sets were clustered using these parameters. Treating

TABLE 1. NUMBER OF SAMPLE FIELDS BY COVER TYPE FOR 33 JES SEGMENTS FROM NORTH CENTRAL MISSOURI

Cover Type Category	Number of Fields	Mean Field Size (ha)	Total Pixels	Non-Border Pixels	Percent Non-Border Pixels
Corn	51	10.3	1,515	1,098	67.9
Soybeans	117	9.1	3,277	2,138	65.2
Hay/Permanent Pasture	134	11.5	4,751	3,580	75.4
Dense Woodland	35	10.0	1,076	559	52.0

TABLE 2. CLUSTER PARAMETERS FOR EDITOR ANALYSIS

Cover Type Category	Cluster Distance	Initial No. of Clusters	Final No. of Clusters
Corn	0.75	16	13
Soybeans	0.75	16	13
Dense Woodland	0.75	8	6
Hay/Permanent Pasture	0.75	16	13

Percent Convergence = 97

each data set the same ensured that major differences in clustering and classification results were due mainly to differences between the three data sets.

Training statistics obtained for each of the four categories, using all 33 segments, were input to a maximum likelihood classification algorithm on the Illiac IV. The same default parameters were used to classify each of the three data sets. The percent correct classification (PCC), commission errors, and a breakdown of computer time are given in Table 3. A one-way analysis of variance, with arcsin $\sqrt{p}$ transformation and Newman-Keuls Range Test (Steel and Torrie, 1960) was conducted to determine differences in the classification results. At the 10% level, the overall PCC of the May/August data set was significantly greater than the overall PCC's of either the May or August unitemporal sets. The computer time required to process eight channels of data was slightly less than twice the time for processing a single four-channel data set.

The Kauth Thomas transformation (Kauth, et al., 1978) was applied to the May four-channel and August four-channel data sets. The brightness and greenness components from these two transformed sets were combined to give a new four-channel data set. A second multitemporal data set was obtained by combining channels 5 and 7 from the May and August raw data.

These two data sets were clustered using the parameters given in Table 2. The classifications were obtained using the default parameters for the EDITOR algorithm. The results are given in Table 4; for comparison purposes, Table 4 also shows the eight-channel results reported in Table 3.

TABLE 3. EDITOR CLASSIFICATION RESULTS OF MAY AND AUGUST SINGLE-DATE AND MAY/AUGUST OVERLAID DATA SETS

Cover Type Category	May 4-Channel	Aug 4-Channel	May/Aug 8-Channel
Corn			
PCC	53.4	64.1	74.7
Commission Errors	63.1	58.9	24.9
Soybean			
PCC	51.3	62.8	76.8
Commission Errors	38.4	28.2	23.9
Hay/Permanent Pasture			
PCC	68.1	65.2	76.4
Commission Errors	23.1	28.4	21.1
Dense Woodland			
PCC	48.4	35.3	56.7
Commission Errors	66.2	65.1	49.3
Overall			
PCC	58.6	61.2	74.2
Commission Errors	41.4	39.6	26.3
Computer Time (seconds)			
Cluster (PDP-10)	620	677	1,131
Classify (Illiac IV)	2	3	6
Total	622	680	1,137

TABLE 4. EDITOR CLASSIFICATION RESULTS OF THE MAY/AUGUST EIGHT-CHANNEL, MAY AND AUGUST B,G/B,G*, AND MAY AND AUGUST 5,7/5,7** DATA SETS

Cover Type Category	May/August 8-channels	May & Aug B,G/B,G	May & Aug 5,7/5,7
Corn			
PCC	74.7	73.3	70.9
Commission Errors	24.9	31.8	36.5
Soybean			
PCC	76.8	75.1	71.0
Commission Errors	23.9	27.5	27.4
Hay/Permanent Pasture			
PCC	76.4	73.9	73.8
Commission Errors	21.1	20.2	20.9
Dense Woodland			
PCC	56.7	54.6	54.8
Commission Errors	49.3	51.0	54.1
Overall			
PCC	74.2	72.2	70.6
Commission Errors	26.3	28.4	29.5
Computer Time (seconds)			
Cluster (PDP-10)	1,131	641	560
Classify (Illiac IV)	6	6	3
Total	1,137	702***	563

*Brightness and greenness components of the Kauth Thomas transformation.
**Bands 5 and 7.
***55 seconds for transforming.

A one-way analysis of variance with arcsin $\sqrt{p}$ transformation and Newman-Keuls Range Test was performed at the 10% level. The overall PCC's of each data set did not differ significantly from each other. However, from an operational.standpoint, the classification performance should be compared to the cost of production. As shown in Table 4, a 2% increase was obtained using all eight channels rather than the four-channel transformed data. This small improvement in classification required 62% more CPU time. If this proves to be typical, individual users should determine the trade-offs between accuracy and costs.

B. ELAS Analysis

The same 33 JES segments were analyzed using ELAS. The within class cluster (WCCL) program was used with default parameters for developing spectral class means and covariance matrices for each land cover category. WCCL is an unsupervised procedure which collects training statistics on a point-by-point basis within previously defined classes (in this case, JES land cover categories). It uses a discard method to delete statistics made from four or fewer pixels that do not meet certain scaled distance criteria.

Training statistics developed by WCCL are used as input to a maximum likelihood classification program, WMAX. A pixel-by-pixel tally of the maximum likelihood classification with corresponding JES land cover identification provided the basis for calculation of percent correct classification and commission error for each Landsat data set. As mentioned previously, training statistics and accuracy tabulations were developed on the same set of field interior (non-border) pixels.

Five multiband, multitemporal, and transformed Landsat data sets were analyzed using the above procedure. Classification results for these data sets are given in Table 5. Computer times were not compared for ELAS classifications. A one-way analysis of variance, followed by a Newman-Keuls test of significance at the 10% level, was performed on the overall percent correct classifications, which were transformed to $\arcsin\sqrt{p}$ in order to ensure normal distribution, independent means and variances, and homogeneous variances. The August single-date data set had the lowest overall PCC, while the three-date data set had the highest. However, the above test revealed that the overall PCC for the three-date data set was not significantly different from the overall PCC for the August/September data set. The overall PCC's of all other data sets were significantly different from each other. It should be noted that the May scene was not of high quality and had considerable haze.

The August/September four-channel Kauth transformed data set did not show an improvement over the four-channel (5,7/5,7) data set for the same dates. Even though the percent correct classifications for corn and dense woodland were higher for the Kauth transformed data, the PCC's for soybeans and hay/permanent pasture (which had the largest numbers of field interior pixels) dropped in comparison with the data set made up only of bands 5 and 7 for the two dates. The August/September (5,7/5,7) data set, based on its good classification of corn and soybeans, was chosen for testing subsequent data processing procedures.

V. EVALUATION OF LAND COVER ESTIMATES

A. EDITOR Regression Estimates

The classification results shown in Table 4 were used to obtain segment level regression estimates for each category using the ESS regression

TABLE 5. ELAS CLASSIFICATION RESULTS FOR FIVE MULTIBAND, MULTITEMPORAL, AND TRANSFORMED LANDSAT DATA SETS FROM ANALYSIS OF 33 JES SEGMENTS FROM NORTH CENTRAL MISSOURI

	August 2 Channels (5,7)			May/Aug 4 Channels (5,7/5,7)			Aug/Sept 4 Channels (5,7/5,7)			May/Aug/Sept 6 Channels (5,7/5,7/5,7)			Aug/Sept 4 Channels (B,G/B,G)**		
Cover Type Category	Spectral Classes	PCC*	Commission Errors	Spectral Classes	PCC*	Commission Errors	Spectral Classes	PCC*	Commission Errors	Spectral Classes	PCC*	Commission Errors	Spectral Classes	PCC*	Commission Errors
Corn	5	59.1	62.1	10	74.8	22.0	8	78.0	20.9	12	76.5	13.7	5	81.0	25.6
Soybeans	7	56.4	29.7	21	81.5	24.2	16	84.9	16.7	15	82.5	14.1	11	77.4	26.4
Hay/ Permanent Pasture	13	71.4	29.3	24	79.9	15.2	24	85.5	14.5	21	88.7	17.6	11	71.9	28.1
Dense Woodland	2	30.0	49.8	3	58.9	48.2	4	60.3	30.4	3	63.7	29.6	2	71.4	52.2
Overall	27	62.1	37.9	58	78.0	22.0	52	82.3	17.7	51	83.1	16.9	29	74.8	25.2

*Percent Correct Classification

**Brightness and greenness components of the Kauth Thomas transformation methodology (Craig, et al.,1978). Table 6 contains the R^2 and coefficient of variation (C.V.) values of these estimates. A test for significant differences is included in the table.

All of the corn estimates were significantly different from each other. The May/August (5,7/5,7) corn estimate differed from all eight-channel and B,G/B,G estimates at the 1% confidence level. These differences are supported by the variability in the corn estimate C.V.'s.

B. ELAS Large Area Spectral Class Definition

The August/September (5,7/5,7) data set was used to derive homogeneous spectral classes for the entire 15,120 km^2, 11-county area. Spectral class training statistics were developed using the ELAS program SRCH, which is an unsupervised procedure for collecting training statistics from homogeneous fields by passing a 3 by 3 pixel window through the data (Joyce, et al., 1980). For this data set, 7.5% of the total pixels available in the study site were selected by SRCH for development of 54 spectral class statistics.

The entire study site was classified using a maximum likelihood classification program, MAXL. A pixel-by-pixel comparison of classification assignments with JES segment class identification allowed for labeling of the spectral classes as to their predominant cover type. Thus, the 54 training classes were combined into 7 land cover types. Certain cover types, such as water, were not represented in the JES segment data, while other cover types, such as hay and pasture, possessed more spectral variability than existed in the JES fields (Table 7). These spectral classes were labeled based on expected seasonal reflectance characteristics of water

TABLE 6. EDITOR SEGMENT LEVEL REGRESSION ESTIMATES USING SEVERAL MULTITEMPORAL DATA SETS

DATA SET	CORN R^2	CORN C.V.	SOYBEAN R^2	SOYBEAN C.V.	HAY/ PERMANENT PASTURE R^2	HAY/ PERMANENT PASTURE C.V.	DENSE WOODLAND R^2	DENSE WOODLAND C.V.
All 8	0.93	5.46%	0.84	6.12%	0.71	7.97%	0.60	15.32%
Kauth B,G/B,G	0.88	7.05%	0.84	6.26%	0.74	7.60%	0.62	14.83%
May/August 5,7/5,7	0.79	9.10%	0.80	6.86%	0.73	7.68%	0.54	16.32%
All 8 vs. Kauth	*		***		***		***	
All 8 vs. 5,7/5,7	**		***		***		***	
Kauth B,G/B,G vs. 5,7/5,7	**		***		***		*	

Test Hypothesis: $R_1^2 = R_2^2$

* = Significant at 0.05 level.
** = Significant at 0.01 level.
*** = Not significant.

TABLE 7. ELAS CLASSIFICATION RESULTS FOR ANALYSIS OF AUGUST/SEPTEMBER FOUR-CHANNEL (5,7/5,7) DATA SET USING SRCH-DERIVED STATISTICS

Cover Type Category	Spectral Classes	Mode of Spectral Class Definition	PCC
Corn	5	JES Data	69.6
Soybeans	18	JES Data	87.8
Hay/ Permanent Pasture	21	18 Classes-JES Data 3 Classes-VIS/IR* Plots	72.0
Dense Woodland	2	JES Data	65.3
Winter Wheat	2	JES Data	Not Tested
Waste	1	JES Data	Not Tested
Water	5	VIS/IR Plots	Excluded from JES Sample Frame
Overall	54	--	75.7

*Visible/infrared

and hay as displayed on plots of Landsat MSS band 5 vs. band 7 response. These results point to the possibility of under-representation of the spectral diversity among the land cover types of a large geographic area when segment data from only slightly more than 0.2% of the area are used for spectral class definition. It should be noted that the JES sample was 0.6%, but several segments were not included because of cloud cover.

Reduced classification accuracy of this whole-scene classification, as compared with the results of analysis of only the segments themselves, can be attributed to the existence of "mixed" classes developed by the SRCH approach. Mixed classes represent cases of spectral similarity among different land cover types. In the SRCH procedure, each spectral class was defined to represent just one land cover type even for those situations in which a portion of the JES segment pixels assigned to that spectral class belonged to other land cover types.

VI. EVALUATION OF MISREGISTRATION BETWEEN DATA SETS

Concern over the possible deleterious effects of pixel misregistration on classification accuracy of multitemporal data sets led to a study of intentional registration offsets on the August/September four-channel (5,7/5,7) data set. These two Landsat scenes had been registered using a manual seed point location procedure followed by computer-guided control point selection (Joyce, et al., 1980) to achieve a root mean square (RMS) error of 49 meters for the overlaid data sets. Intentionally misregistered data sets were produced by adding 20 meters (about 1/3 pixel) and then 30 meters (about 1/2 pixel) to the element (column) coordinate of the control point location for the scene being overlaid. These offsets were chosen because the RMS error resulting from computer assisted scene-to-scene overlay procedures seldom exceeds the dimensions of one and one-half pixels for good quality Landsat MSS data.

In Table 8, classification results for the misregistered data sets are compared with results for the data set with no offset. Overall classification results for the three data sets are not significantly different at the 10% level after transformation of PCC's to arcsin $\sqrt{p}$. Even with a 30-meter offset, which caused a noticeable misregistration of ground features when observed on a digital display device, the overall classification accuracy dropped only 2%. These results confirm the observations of Cicone, et al. (1976), who found that the effect of misregistration is not a significant factor of concern in the recognition of field interior pixels which remain field interior after misregistration. The lack of significant differences in overall classification accuracies between registered and misregistered data sets does not reflect the very real differences arising from reduced availability of pure non-border pixels and errors in proportion estimation of data sets containing an inflated number of mixture pixels. The problem of reduced availability of non-border pixels is crucial for cover types which, because of their field size or shape, already have low percentages of field interior pixels, as is the case with fields of dense woodland shown in Table 1. The percent correct classification for dense woodland dropped more than any other cover type in the misregistered data sets, while dense woodland also had the smallest percentage of non-border pixels.

TABLE 8. ELAS CLASSIFICATION RESULTS FOR ANALYSIS OF AUGUST/SEPTEMBER FOUR-CHANNEL (5,7/5,7) DATA SET WITH MISREGISTRATION BETWEEN DATES

Cover Type Category	No Offset*		20-m Offset		30-m Offset	
	PCC	Commission Errors	PCC	Commission Errors	PCC	Commission Errors
Corn	78.0	20.9	76.3	24.7	76.7	25.7
Soybeans	84.9	16.7	84.2	17.7	82.8	16.8
Hay/ Permanent Pasture	85.5	14.5	83.1	15.3	83.9	16.6
Dense Woodland	60.3	30.4	61.2	39.4	56.9	38.2
Overall	82.3	17.7	80.8	19.2	80.4	19.6

*Scene-to-scene registration achieved by use of ELAS overlay technique, resulting in 49-m RMS error for 57 x 57-m pixel size.

VII. SUMMARY

Multiband, multitemporal, and transformed Landsat MSS data sets were analyzed using pattern recognition procedures employed by the USDA Economics and Statistics Service and by the NASA/NSTL Earth Resources Laboratory for the purpose of land cover area estimation. The analyses had in common the use of field-verified land cover data for training and accuracy testing in the form of 33 June Enumerative Survey segments, typically 2.5 km^2 in size. Corn, soybeans, hay/permanent pasture, and dense woodland predominate in the landscape of the 11-county north central Missouri test area and were the four land cover types studied.

Multitemporal data sets gave significantly higher classification accuracies than any single-date Landsat data set for data processing procedures used by both ESS and ERL. The use of only Landsat MSS bands 5 and 7 in multitemporal analysis showed no significant difference in overall classification accuracy from analysis using bands 4 and 6 in addition to bands 5 and 7. Transformed data sets also failed to significantly improve classification accuracies, but rather served as a means of reducing data from four to two channels per date, thus decreasing processing time.

Segment level land cover regression estimates were obtained using the JES data as the dependent variable and Landsat classified results as the independent variable. It was found that the use of all eight channels for the May/August data set resulted in significantly higher correlation coefficient values for corn than use of four-channel Kauth transformed data or four-channel band 5,7/5,7 data. Other cover types did not show significant differences between data sets.

ELAS analysis results indicated that the spectral diversity among the land cover types was under-represented by the 0.2% sample. A follow-on study using wall-to-wall field verification data is planned to further define an adequate sampling scheme for total land cover mapping.

Misregistration of two Landsat data sets by as much as 79 meters (about one and one-half pixels) did not significantly alter overall classification accuracies. Even though a noticeable offset could be observed in the position of ground features when viewed on a digital display device, the "effective purity" of field interior pixels apparently was maintained. Existing algorithms for scene-to-scene overlay are adequate for multitemporal data analysis as long as statistical class development and accuracy assessment are restricted to non-border pixels.

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