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An Evaluation of Simulated Thematic Mapper Data and Landsat MSS Data for Discriminating Suburban and Regional Land Use and Land Cover

Analysis of simulated Landsat Thematic Mapper data in comparison to Landsat MSS data at the fringe of Denver, Colorado indicated improved land-use and land-cover mapping capabilities for TM.

Abstract: *Aircraft scanner data simulating the Landsat Thematic Mapper (TM) along with Landsat Multispectral Scanner (MSS) were evaluated for their use in discriminating among suburban and regional land use and land cover. The rapidly urbanizing area east of Denver, Colorado was selected as a test site.*

Results indicates spectral bands from each of the major spectral regions—visible, near infrared, middle infrared, and thermal infrared—each provided unique spectral information for use in discriminating the Level I and Level II classes. There was significant redundancy between bands within spectral regions to warrant an exclusion of a band, when reducing costs is desired. Analysis of the Level I urban class and Level II urban classes indicated the visible bands provided improved spectral discriminations. At the higher 30-m spatial resolution of the TMS system the overall discrimination for many classes such as commercial/industrial, rangeland, irrigated sod, irrigated alfalfa, and irrigated pasture was improved over MSS primarily as a result of the added spectral bands (TMS 1: 0.45 to 0.52 μm; TMS 5: 1.55 to 1.75 μm; TMS 6: 2.08 to 2.35 μm; and TMS 7: 10.4 to 12.5 μm). However, for more spectrally heterogeneous classes such as residential the higher resolution of TMS resulted in increased within-class variability, yielding more spectral class overlap.

Introduction

Several investigators have evaluated the utility of Landsat Multispectral Scanner (MSS) data to map urban land cover (e.g., Carter and Jackson, 1976; Friedman, 1980; Erb, 1974) and to monitor urban land-cover change (e.g., Todd, 1977; Toll *et al.*, 1980; Angelici *et al.*, 1976; Jensen and Toll, 1982). Other researchers have used Landsat MSS data to estimate various urban parameters such as measuring population levels (e.g., Lo and Welch, 1977; Ogroski, 1975). New remote sensing capabilities will be available for urban studies through the use of data obtained by the Landsat-4 Thematic Mapper (TM). The TM, a primary sensor payload on Landsat-4 and -5, offers improvements in spectral, spatial, and radiometric characteristics in comparison to the MSS. Specific areas of improvement include a higher spatial resolution (30 m for TM versus 79 m for MSS), additional channels (seven for TM versus four for MSS) with newly defined spectral locations, and increased radiometric sensitivity. See Salomonson *et al.*, (1980), Engel (1980), Engel (1983), and Irons (1983) for a further discussion of the Landsat TM.

The primary emphasis of this effort is to study the characteristics of the Landsat Thematic Mapper through analysis of aircraft collected Thematic Mapper Simulator (TMS) data. As a reference base, TMS data were compared with Landsat MSS data. A

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suburban and rural land area test site was selected in the expanding urban sprawl of eastern Denver, Colorado. This area consists of a broad selection of suburban and regional land use and land cover, including various stages of urban development. Suburban and outlying areas are particularly important regions for land-use planning, resource management, residential and commercial development, transportation planning, etc.

DATA TYPES AND STUDY AREA

The TMS NS-001 multispectral scanner was developed by NASA/Johnson Space Center for the purpose of providing an aircraft scanner with the same spectral channels as those for the Landsat TM (Richard *et al.*, 1978). The NS-001 multispectral scanner was mounted on a NASA C-130 aircraft and flown over the eastern fringe of Denver, Colorado on 20 June 1979 at approximately 1 P.M. local time. Two flight lines were flown in a north-south direction, each approximately 46 km (25 nautical miles) in length. Because the angular instantaneous field-of-view of the NS-001 is 2.5 milliradians and the flight was flown at 3.047-km (10,000-feet) altitude, the spatial dimension of the pixels is approximately 7.5 m (25 feet) on a side at nadir. The look angle of the scanner is ±50°. A Landsat-2 MSS Computer Compatible Tape (CCT) providing coverage of the study area was compared to the Landsat TM simulation. The overpass of the satellite was on 18 June 1979, with an acquisition time of approximately 10:35 A.M. local time. The 8.62×10^{-5} milliradian instantaneous field-of-view with a 916-km (569-mile) altitude of the Landsat MSS yields a 79-m (259-feet) pixel width. The look angle of the Landsat MSS is approximately ±5.78°. An image subset consisting of 650 lines with each line containing 250 pixels was extracted for analysis. A comparison of the Landsat TM and Landsat MSS data is provided in Table 1.

Figure 1 depicts the study area location. The study area occurs in the eastern fringe of Denver, Colorado, an area undergoing rapid urbanization. The area includes a wide range of land use and land cover, including rangeland, construction sites, and residential. A two level land-use and land-cover classification scheme was developed (Table 2). Black-and-white photography (1:20,000), obtained in conjunction with NS-001 data, was interpreted in order to identify the land-use and land-cover classes. Color infrared photography (1:20,000 on 15 July 1980) along with field verification was used to further improve on the photointerpretation. Fields less than four hectares (10 acres) in arca were not included in the interpretation because of problems with locating the fields on the sensor data. The test site occurs in a semi-arid environment with much of the suburban land being watered. Irrigated agriculture occurs along the flood plain to the south of Cherry Creek Reservoir. Rangeland and dryland agriculture such as winter wheat comprise most of the rural lands. In the suburban area there are many sites contributing to a different spectral signature. The wide spread construction activity yielded two transitional classes. The newly constructed residential neighborhoods had little sod or tree cover. Further, there were many areas with cleared lands prior to construction. See Jensen and Toll (1982) for a detailed discussion on detecting residential construction activity using Landsat MSS data.

DATA PROCESSING

The Landsat Thematic Mapper simulator (TMS) data obtained for the study area have three major limitations: (1) the data are uncalibrated; (2) there are spectral and geometric changes in the pixel data attributed to the ±50° scan angle; and (3) the 7.5-m spatial resolution of the data does not correspond to the 30-m spatial resolution of the Landsat TM. These limitations, and methods used to compensate or correct them, are discussed below.

DATA CALIBRATION

An examination of the calibration data showed that there was insufficient laboratory data to implement valid data calibration procedures (Forman,

TABLE 1. SIMULATED THEMATIC MAPPER, LANDSAT THEMATIC MAPPER, AND LANDSAT MSS INSTRUMENTATION

Band Description	NS-001 TM Simulator (Micrometres)	Landsat TM (Micrometres)	Landsat MSS (Micrometres)
Spectral Band 1	0.45-0.52	0.45-0.52	0.5-0.6
Spectral Band 2	0.52-0.60	0.52-0.60	0.6-0.7
Spectral Band 3	0.63-0.69	0.63-0.69	0.7-0.8
Spectral Band 4	0.76-0.90	0.76-0.90	0.8-1.1
Spectral Band 5	1.55-1.75	1.55-1.75	
Spectral Band 6*	2.08-2.35	10.40-12.50	
Spectral Band 7*	10.40-12.50	2.08-2.35	
Ground IFOV (nadir)	7.5 m	30 m	79 m
Quantization Levels	256	256	64

* On Landsat-4 TM, bands 6 and 7 designations are switched.

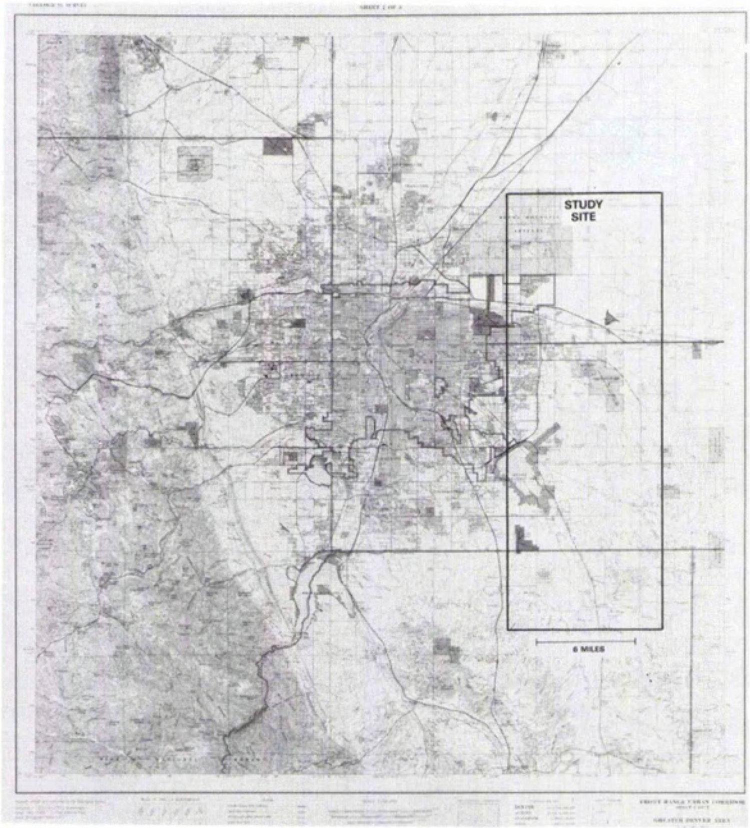

FIG. 1. Study site is located east of Denver, Colorado.

1980). However, the calibration data that were part of the data stream provided a means for assessing the instrument stability and data channel noise. This was accomplished by computing and plotting the averages and standard deviations of calibration data acquired at one second intervals during the back-scan portion of the scanner sweep. During the back-scan a calibration lamp and two thermal bodies are observed for all spectral channels of the NS-001. An examination of plots for all channels indicated there was little variation ($\mu_\epsilon < 0.01\%$). Hence, lack of calibration data for assessment between bands was not considered a significant problem.

SCAN ANGLE

In order to reduce the effects caused by changing view angle, only the central 400 pixels for each scan line of 700 pixels were used. The maximum scan angle was thereby reduced to ±28.6°, with a maximum across scan line pixel width of 9.9 m. A pixel at the nadir was 7.5 m in width. No corrections were applied to compensate for any residual scan angle effects.

SPATIAL RESOLUTION

To reduce the 7.5-m spatial resolution to that of the Landsat TM, a spatial filter was applied to the TMS data. The use of a straight averaging procedure results in data obtained by enlarging the scanner aperture, reducing the sampling rate, and increasing the ground speed of the sensor (Sadowski and Sarno, 1976). Because this is not a realistic change, it was decided to use a digital filter as specified by Sadowski and Sarno. The filter estimated the overall modulation transfer function when doubling the flying altitude of an airborne multispectral scanner. This procedure considered the properties of a typical multispectral scanner system in addition to atmospheric changes. The filter was used in two sequences to degrade the TMS data at 7.5 m to 30 m. Because the procedure reduced the variation from system noise, Gaussian noise based on sensor noise levels was added back into the data after filtering. To be compatible with the other channels, the thermal infrared channel, TMS 7, was also degraded to 30 m rather than to the 120 m that is obtained by the Landsat-4 TM.

METHODOLOGY

To evaluate the Landsat TM simulator (TMS) data and Landsat MSS data, three analysis techniques

TABLE 2. CLASSIFICATION CATEGORIES AT LEVELS I AND II FOR DENVER, COLORADO (adapted from Anderson *et al.*, 1976)

1. Urban
    - 1.1 Residential with Landscaping (Single Family House)
    - 1.2 Residential with No Landscaping (Single Family Houses)
    - 1.3 Apartments and Townhouses (Multi-family Dwelling)
    - 1.4 Commercial and Industrial Complexes
    - 1.5 Transitional Areas Prior to Construction (Cleared Land)
2. Agriculture
    - 2.1 Irrigated Sod
    - 2.2 Irrigated Alfalfa
    - 2.3 Irrigated Pasture
    - 2.4 Winter Wheat
3. Rangeland
    - 3.1 Herbaceous Rangeland
4. Water
    - 4.1 Reservoirs

were employed. First, through implementing a stepwise analysis procedure, the order of entry of spectral bands used to calculate the classifications was examined. Second, results from a per pixel maximum likelihood classifier were compared with reference data, and outputs were displayed in contingency tables along with accuracy figures. Last, a measure of transformed divergence was computed for various spectral band groupings in order to assess optimum waveband combinations. Assessment of the channels entered in a stepwise procedure yields information on optimum channels for overall cover classification. In addition, analysis of classification results at each step (or band entered) yields information on the optimum number of bands input for classification. Classification analysis provides substantive information on comparisons between sensor channels, MSS and simulated TM sensor systems, and hierarachial cover classifications. Transformed divergence averages provide an indirect measure of classification accuracy and were more efficient to implement in a multichannel analysis in comparison to classification analysis. Of the three analysis techniques, classification analysis is considered the most useful. The order of channel entry is based on F-statistics. The F-statistics are more sensitive to error due to departures from normality than are the discriminant functions in classification analysis. In addition, although channel entry analysis provides results indicative of an overall classification, it does not readily provide detailed information for specific classes. Further, dependence between bands significantly affects the order of channel entry. Transformed divergence is based on differences between two class covariance matrices. This measure often yields an indirect approximation of classification performance. Classification analysis, on the other hand, yields information on both omission and commission error in addition to indicating specific class confusions.

An evaluation of all the pixels in the TMS and MSS data sets was infeasible because of expenses associated with processing costs and analyst time. In addition, Craig (1979) and Cambell (1981) report that using contiguous pixels tends to bias the calculated statistics due to spatial autocorrelation. For these reasons, a sampling scheme was implemented in order to estimate spectral class characteristics.

SAMPLING SCHEME

A sample of 100 noncontiguous pixels was selected for each class from the unregistered Landsat MSS and TM simulator data sets. The TM simulator and Landsat MSS data were not registered to one another in order to prevent digital count changes during data resampling. Having 100 observations for each class approximated the minimum number of observations required for drawing inferences about the sample populations. To reduce possible problems associated with mixed class pixels, those pixels near class boundaries were not selected. The unregistered data sets were output on a CRT screen, and a cursor was manipulated in order to implement an aligned-systematic sampling technique (Cochran, 1977) of 100 noncontiguous pixels for each class. The total number of pixels was estimated by class, and this number was divided by 100 to provide an estimate of the grid spacing between sample pixels. Pixels were selected in a triangular network in which pixels lie at vertices of equilateral triangles.

CHANNEL ENTRY ANALYSIS

The order of the channels used to calculated the classification functions is entered (or deleted) based on the ratio of the within-group or class dispersion to the total class dispersion. The ratio of these variables is called the Wilks' Λ-criterion. Values range from 0 to 1 with smaller values indicating increasing separation between groups. The corresponding F-statistic is used to test the significance of the change in Λ when adding a band. The variable or band with the largest F-to-enter statistic is entered. Various entry (and deletion) rules may be described. Lachenbruch (1975) warned that only the first three to five variables are all that should be safely entered. Any additional variables may be noise. In addition, if the bands are more correlated, then the F-statistics become more distorted.

CLASSIFICATION ANALYSIS

A per pixel Gaussian maximum likelihood classifier was implemented. A "jackknife" procedure was employed in the classification procedure in which pixels to be classified are not used to define classification functions. According to Davis (1973) and

Swain (1978), discriminant functions are not affected by moderate departures from normality. Histograms were examined for all classes and channels, however, to ensure that there were no substantial departures from normality. The classes were in part chosen for spectral normality. Results of the classification are output into a contingency table with class confusions and classification accuracies.

TABLE 3. LANDSAT MSS CORRELATION MATRIX

Channel	1	2	3	4
1 MSS 1	1.00			
2 MSS 2	0.97	1.00		
3 MSS 3	0.46	0.44	1.00	
4 MSS 4	−0.06	−0.11	0.81	1.00

TRANSFORMED DIVERGENCE ANALYSIS

Divergence is a measure of the statistical separability between groups or classes. For two normal density functions, divergence statistics increase with an increased separation between means and a decreased variance. Divergence is a pairwise distance measure between classes. Thus, given a set of Landsat TM simulator of MSS channels for any two classes, the channels which yield the largest divergence indicate the optimum channels for classification. Swain (1978) reports that to estimate the divergence for more than two classes it is reasonable to average the pairwise divergence statistics. There are two terms associated with transformed divergence. The first term consists of the contribution from differences in the covariance matrices between classes. The second term is a normalized distance between class means. Because divergence is a measure of the separability, divergence may be considered an indirect measurement of classification accuracy. Swain (1978) provides a further discussion of transformed divergence.

RESULTS AND DISCUSSION

Results from processed aircraft TM simulator and Landsat-2 MSS data were assessed in order to estimate Landsat-4 TM and MSS spectral cover class discrimination capabilities. In order to clarify the presentation of results, a brief discussion of the logic used when conducting the analysis is given next. Initially, the order of entry of channels used to calculate the discriminant functions was examined. The order of entry of bands was in part dependent on the bands previously entered and thus yielded information on the set of optimum bands for classification. Results from the classification and transformed divergence analyses yielded information on spectral class discrimination capability using various spectral bands and band combinations. Transformed divergence averages were examined for each set of possible waveband combinations using both two bands (i.e., a total of 21 TMS and 6 MSS channel combinations) and three bands (i.e., a total of 35 TMS and 4 MSS channel combinations). All other assessments were based on classification accuracies from the classification analysis. Single band analyses provided an assessment of the spectral discrimination capabilities of the major spectral regions: visible, near infrared, middle infrared, and thermal infrared. Results from single channel classifications were obtained through separately inputting each spectral band (MSS and TMS) into the classification analysis. Contingency tables derived from the classification of the seven TMS bands and four MSS channels yielded information on sources of confusion between classes and provided for comparisons between TMS and MSS. All results were based on the spectral values of 100 pixels sampled for each Level II class. Level I results were derived through combining processed Level II data.

CHANNEL CORRELATION

For many applications, redundant or highly correlated bands may be removed while minimizing information loss. Tables 3 and 4 give correlations between bands for Landsat MSS and TM simulator data, respectively. One hundred randomly selected pixels were chosen from each system for input. As expected, the visible bands, MSS 1 and MSS 2 (Table 3), and TMS 1, TMS 2, and TMS 3 (Table 4), are highly intercorrelated (0.95 r^2 or greater). Further, the near infrared bands, MSS 3 and MSS 4 (Table 3), are correlated to one another (0.81 r^2). The middle infrared bands, TMS 5 and TMS 6, are highly intracorrelated and both are highly correlated (0.72 r^2 or

TABLE 4. LANDSAT TM SIMULATOR CORRELATION MATRIX

Channel	1	2	3	4	5	6	7
1 TMS 1	1.00						
2 TMS 2	0.95	1.00					
3 TMS 3	0.97	0.97	1.00				
4 TMS 4	0.12	0.17	0.15	1.00			
5 TMS 5	0.78	0.73	0.82	0.30	1.00		
6 TMS 6	0.87	0.84	0.90	0.11	0.93	1.00	
7 TMS 7	0.63	0.60	0.60	−0.21	0.72	0.74	1.00

greater) with the other TMS bands, with the exception of TMS 4 (Table 4). The low correlation of the near infrared band, TMS 4, with all of the other bands indicates it provides unique spectral information. In general, the major spectral regions (visible, near infrared, middle infrared, and thermal infrared) all appear to have different information between spectral regions but have similar information within spectral regions.

CHANNEL ENTRY ANALYSIS

Table 5 lists the bands as they were entered into the classification analysis using Level II data. For both the TM simulator and Landsat MSS data sets, the first channel entered was a visible channel (TMS 3 and MSS 2, respectively) followed by a near infrared channel (TMS 4 and MSS 3, respectively). The next channel entered for the TMS data was the thermal infrared channel, TMS 7. The primary trend of the channels selected for entry is to represent channels from the major spectral regions (visible, near infrared, middle infrared, and thermal infrared for TM, and visible and near infrared for MSS). These major spectral regions have unique spectral properties that contribute to the discrimination of urban area cover types. For example, to discriminate among the wide range of cover types in the urban fringe zone (i.e., various levels of perviousness, vegetative cover and density, cover type mixtures, etc.), it is useful to have spectral information covering a wide range of phenomena. Analysis of spectral plots indicated trends such as the vegetative type discrimination of TMS 3 (0.63 to 0.69 μm), the vegetative density discrimination of TMS 4 (0.76 to 0.90 μm), the moisture content discrimination of TMS 5 (1.55 to 1.75 μm), and the cultural versus natural target discrimination of TMS 7 (10.4 to 12.5 μm).

Examination of the change in Wilks' Λ and classification accuracy at each step of channel entry in Table 5 also indicates the necessary number of channels to discriminate among Level II classes. The smaller the Wilks' Λ, the greater is the spectral separation between classes. Typically, the amount of change in Wilks' Λ and classification accuracy decreases with each step or channel entered. Evaluation of classification accuracy for TMS indicates a large increase in accuracy with the addition of a second channel (15.9 percent change) and reduction of increases until after a fifth channel is added. Entry of channels TMS 1 and TMS 6 at steps 6 and 7 added little to no additional spectral discrimination information. No improvement in classification accuracy at the last two steps is primarily attributed to the high correlation of TMS 1 with TMS 2 and TMS 3, and TMS 6 with TMS 5. Analysis of MSS data indicates that, after the addition of a near infrared channel to the visible channel at step 2, only a small amount of spectral information is added in the subsequent two steps.

SINGLE CHANNEL ANALYSIS

Analysis of results for the Landsat MSS and TM simulator classifications are given in Figures 2 and 3, respectively. In order to study the spectral discrimination capabilities for the MSS and TM sensor bands, initially only one band was evaluated at a time. The data are given by class and the channels are plotted according to classification accuracy. In addition, the overall classification accuracy is also plotted.

As indicated in Figures 2 and 3, the importance of bands for discrimination of categories depends on the classification level. At Level I land-cover classification there is a different set of phenomena in measurement space than at Level II. For example, for Level II classification it is required to discriminate between residential and apartments/townhouses, whereas in Level I the categories are combined. It is of significance that for Level II classification using Landsat TM simulator data the middle infrared band, TMS 5, is ranked first (Figure 3). This is primarily attributed to both the low error of confusion between apartments/townhouses and the other urban classes and also between the alfalfa and water classes. The visible channel, TMS 3, is ranked second at both levels of classification. However, for Level I classification the visible channel, TMS 2, is

TABLE 5. CHANNEL ENTRY STEPWISE DISCRIMINANT ANALYSIS

	TMS			MSS		
Step	Channel Entered	Wilks' Λ	Overall Classification Accuracy (%)	Channel Entered	Wilks' Λ	Overall Classification Accuracy (%)
1	3	0.1358	37.8	2	0.1198	43.1
2	4	0.0236	53.7	3	0.0176	57.0
3	7	0.0049	59.2	1	0.0112	61.1
4	2	0.0025	64.0	4	0.0087	64.6
5	5	0.0016	70.3			
6	1	0.0012	70.5			
7	6	0.0009	70.4			

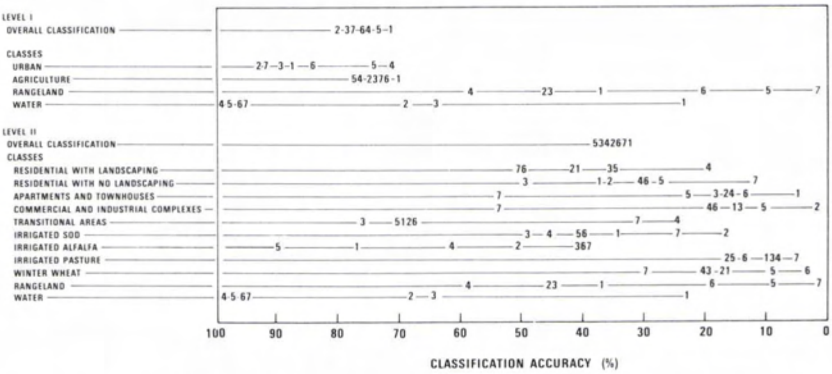

FIG. 2. Single band Landsat TM simulator classification accuracy assessment.

ranked first. For the MSS evaluation, MSS 2 provides the highest overall classification accuracy at both classification levels (Figure 3).

A more detailed description of TM simulator and Landsat MSS bands may be obtained by examining the band ranking in Figures 2 and 3 for each class. Typically, the use of the visible bands for both TM simulator (TMS 1, TMS 2, and TMS 3) and Landsat MSS (MSS 1 and MSS 2) provides the best discrimination for the urban Level I and II class(es). This is primarily a result of the higher classification accuracies for the residential and transitional classes. MSS 4 and TMS 7 assist in the higher classification accuracy for the commercial and industrial complex class as a result of the reduced spectral confusion with the two residential classes. The thermal band, TMS 7, is ranked as the highest accuracy for the apartment and townhouse class due to its capability to discriminate from residential cover. It is important to note that TMS data were obtained at a different time of day when scheduled for the TM (1:00 for TMS versus 9:30 for TM) and TMS 7 is at a different spatial resolution (30 m for TMS 7 versus 120 m for TM 7). The coarse 120-m spatial resolution of TM 7 results in a high proportion of class boundaries and correspondingly confounds spectral class discriminations. Further, the thermal characteristics of surface materials rapidly change with the time of day. Hence, the classes discriminated at 1:00 P.M. local time may not be discriminated at 9:30 local time. A mixture of channels best discriminate the agriculture cover, whereas rangeland is best discriminated by the near infrared channels, TMS 4 and MSS 3.

Landsat MSS data generally provide higher classification accuracies for the residential cover in comparison to the TM simulator data. This is primarily attributed to the spatial complexity of residential cover, which is more averaged at the Landsat MSS resolution of 79 m than the Landsat TM sioulation of 30 m. Townshend (1980) reports that an elarged field-of-view for heterogeneous classes tends to reduce the variation in scene noise and, therefore, tends to increase the classification accuracy. For the less heterogeneous classes, such as the agriculture classes, the Landsat TM simulator data provided higher classification accuracies.

MULTICHANNEL ANALYSIS

Results from transformed divergence were as-

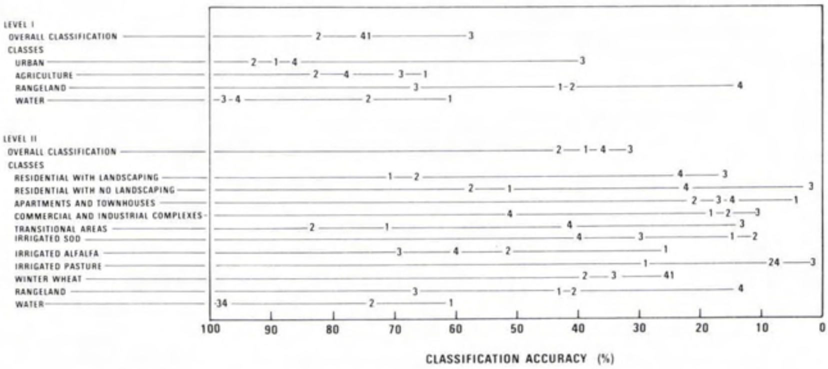

FIG. 3. Single based Landsat MSS classification accuracy assessment.

sessed in order to explore the land cover discriminating capability of Landsat MSS and TM simulator data when using subsets of two and three channel groupings. Transformed divergence provides a measure of the dissimilarity between two density functions. An overall transformed divergence was obtained by averaging the divergences between each of the class pairs (55 class pairs of 11 classes). Through determining the classification accuracy for ten sets of channels with low to high divergences, it was estimated there was frequently a change in overall classification accuracy of approximately 1 to 5 percent with a change in divergence of around 50 (1–2000 scale).

Transformed divergence statistics are summarized for Level II classification in Table 6. Typically, a combination of a visible and a near infrared band provides the highest divergence for a two-band Landsat MSS evaluation. Usually MSS 3 and MSS 4 have higher divergence values than the visible bands MSS 1 and MSS 2. This may be attributed to the visible bands having a higher correlation to one another than do the near infrared chanels. Hence, more information could be extracted from using two near infrared bands rather than two visible bands. Examining Table 6 indicates that there is little dissimilarity among the four possible sets of band combinations when using three Landsat MSS bands. For a two-band Thematic Mapper simulator analysis, a combination of a visible channel with one of the infrared channels yields the highest divergence (Table 6). The only exception is the high value for the pair of visible bands, TMS 2 and TMS 3.

As seen in Table 7 for Level I classification, a combination of MSS 1 and a near infrared band, MSS 3 or MSS 4, provides the highest divergence for a two-channel Landsat MSS evaluation. unlike the situation encountered for Level II classification, MSS 1 contributes to a higher divergence than does MSS 2. Conversely, MSS 4 contributes to a higher divergence than does MSS 3. This is also evident in the three-channel evaluation. Another trend apparent in both the two-channel and three-channel evaluation is that the two near infrared channels, when grouped together, contribute to higher divergences than do the two visible channels.

Results given in Table 7 for a two-channel Landsat TM simulator analysis indicate that the highest divergence arises when TMS 4 is combined with a visible band or the thermal infrared band. This is partially attributed to TMS 4 having relatively low correlations with the other bands. In addition, TMS 4 (0.76 to 0.90 μm) provides important land versus water and vegetative density discrimination capabilities. Typically, the best channel combinations are from two of the four spectral regions: visible, near infrared, middle infrared, and thermal infrared. The results of this analysis compare to results obtained from Hoffer *et al.* (1975) and Dottavio and Williams (1982), which showed that optimum separation of

TABLE 6. CHANNEL RANKING OF PAIRWISE DIVERGENCE STATISTICS FOR LEVEL II CLASSIFICATION

All Possible Set of Channel Combinations (two channels entered)		All Possible Set of Channel Combinations (three channels entered)	
MSS		*MSS*	
Channels	*Divergence*	*Channels*	*Divergence*
2,4 2,3	1577-1617	1,2,3	
		1,3,4	
3,4	1512	1,2,4	1671-1695
		2,3,4	
1,2	1440		
TMS		*TMS*	
Channels	*Divergence*	*Channels*	*Divergence*
1,5 3,5 2,5 2,3	1560-1599	2,3,5 2,3,6 2,3,4	
1,7 3,7		2,3,7 1,5,7 2,4,5	1727-1759
		3,4,5 3,5,6 1,2,5	
		1,4,5 2,5,7	
3,4 3,6 1,4 2,4	1516-1551	3,4,6 1,3,5 1,4,7	
1,6 2,6 2,7		3,5,7 3,4,7 1,3,6	
		2,4,6 2,4,7 1,2,6	1681-1718
1,2 4,5 4,7 1,3	1474-1496	1,5,6 1,2,3 1,4,6	
5,7 4,6		2,6,7 1,6,7 2,5,6	
		3,6,7	
6,7	1448	1,2,7 1,2,4 1,3,4	
		4,5,7 1,3,7 5,6,7	1638-1677
5,6	1336	4,5,6 4,6,7	

TABLE 7. CHANNEL RANKING OF PAIRWISE DIVERGENCE STATISTICS FOR LEVEL I CLASSIFICATION

All Possible Set of Channel Combinations (two channels entered)		All Possible Set of Channel Combinations (three channels entered)	
MSS		*MSS*	
Channels	*Divergence*	*Channels*	*Divergence*
1,3 1,4	1791-1820	1,3,4	1930
2,4 3,4	1630-1676		1762
2,3	1458		1698
1,2	1408		1448
TMS		*TMS*	
Channels	*Divergence*	*Channels*	*Divergence*
3,4 1,4 4,7 2,4	1872-1903	2,5,7 2,4,5 2,4,6	
		3,4,6 4,5,6 2,4,7	
2,7 1,7 3,6	1820-1837	3,4,7 1,4,7 1,4,5	1941-1979
		4,6,7 3,4,5 2,3,4	
5,6 2,6 5,6 2,3	1759-1781		
4,6 4,5		1,3,4 1,4,6 2,5,6	
		4,5,7 2,6,7 1,5,7	1896-1933
3,7 1,5 1,6 2,5	1712-1738	2,3,6 3,5,7 3,6,7	
1,3	1650	5,6,7 1,3,6 2,3,7	1814-1868
		1,3,7 1,2,4	
6,7	1523		
		3,5,6 2,3,5 1,6,7	1714-1755
3,5	1409	1,2,6 1,3,5	
1,2	1359	1,2,7 1,2,3	1628-1623
		1,2,5	1598
		1,5,6	1429

forest types was achieved by classifying multispectral data having at least one band from each of the major spectral regions.

Similarly, for a three-channel evaluation, TMS 4 also appears to contribute to higher divergence values for a Level I classification (Table 7). Overall, a combination of a visible channel and two infrared channels provides the highest divergence. The only exceptions are the infrared channel combinations of TMS 4, TMS 6, and TMS 7 and also TMS 4, TMS 5, and TMS 6.

With the exception of the two-channel Level II classification, combinations of the TM simulator channels provide higher divergences than do the Landsat MSS channels. This is partially attributed to the additional information contained in the TMS 5, TMS 6, and TMS 7 spectral regions that are not available on Landsat MSS. Improvements using TMS also

TABLE 8. LANDSAT TM SIMULATOR CLASSIFICATION—LEVEL I

CONTINGENCY TABLE

REFERENCE DATA Class	Percent Correct	1	2	3	4
1. Urban	95	476	6	18	0
2. Agriculture	96	4	382	14	0
3. Rangeland	80	4	16	80	0
4. Water	100	0	0	0	100
Commission Error (%)		2	5	29	0

Overall Classification Accuracy = 94%

TABLE 9. LANDSAT MSS CLASSIFICATION—LEVEL I

CONTINGENCY TABLE

REFERENCE DATA Class	Percent Correct	1	2	3	4
1. Urban	94	469	7	24	0
2. Agriculture	87	6	347	47	0
3. Rangeland	73	22	5	73	0
4. Water	99	1	0	0	99
Commission Error (%)		6	3	49	0

Overall Classification Accuracy = 90%

TABLE 10. LANDSAT TM SIMULATOR CLASSIFICATION—LEVEL II

CONTINGENCY TABLE

	Class	Percent Correct	1	2	3	4	5	6	7	8	9	10	11
REFERENCE DATA	1. Residential with Landscaping	61	61	0	3	21	0	0	0	0	3	12	0
	2. Residential with no Landscaping	63	6	63	0	12	19	0	0	0	0	0	0
	3. Apartments and Townhouses	56	32	2	56	6	3	1	0	0	0	0	0
	4. Commercial and Industrial Complexes	51	11	13	10	51	8	0	0	1	1	5	0
	5. Transitional Areas	79	0	18	2	0	79	0	0	0	0	1	0
	6. Irrigated Sod	89	0	0	0	0	0	89	9	1	1	0	0
	7. Irrigated Alfalfa	88	0	0	0	0	0	0	88	3	2	7	0
	8. Irrigated Pasture	46	0	0	0	0	0	4	36	46	8	6	0
	9. Winter Wheat	61	3	1	0	0	0	2	14	18	61	1	0
	10. Rangeland	80	1	0	0	1	2	0	0	4	12	80	0
	11. Water	100	0	0	0	0	0	0	0	0	0	0	100
	Commission Error (%)		46	35	21	44	29	7	40	37	31	29	0

Overall Classification Accuracy = 70.4%

may be due to spatial resolution, quantization level, or radiometric differences in comparison to MSS.

LANDSAT TM SIMULATOR VERSUS MSS CLASSIFICATION

Contingency tables are given in Tables 8 through 11 for a four-band Landsat MSS and a seven-band Landsat TM classification. This includes classification at Level I and Level II. Comparison of Tables 8 and 9 indicates significantly higher (0.05 significance level) overall accuracy at Level I classification for TM simulator data than for the Landsat MSS data. This is primarily from the increased confusion between agriculture and rangeland classes for the Landsat MSS classification. There are no significant ($\alpha = 0.05$) differences in accuracy between systems for either the urban or water classes.

TABLE 11. LANDSAT MSS CLASSIFICATION—LEVEL II

CONTINGENCY TABLE

	Class	Percent Correct	1	2	3	4	5	6	7	8	9	10	11
REFERENCE DATA	1. Residential with Landscaping	70	70	0	13	8	0	0	0	0	0	9	0
	2. Residential with no Landscaping	68	2	68	4	16	9	0	0	0	0	1	0
	3. Apartments and Townhouses	55	29	4	55	6	0	0	0	0	1	5	0
	4. Commercial and Industrial Complexes	29	15	23	14	29	4	0	0	2	4	9	0
	5. Transitional Areas	87	0	13	0	0	87	0	0	0	0	0	0
	6. Irrigated Sod	72	2	0	0	0	0	72	7	3	16	0	0
	7. Irrigated Alfalfa	75	1	0	0	0	0	13	75	9	2	0	0
	8. Irrigated Pasture	22	0	0	0	0	0	31	4	22	4	39	0
	9. Winter Wheat	61	1	2	0	0	0	1	12	15	61	8	0
	10. Rangeland	73	16	2	1	3	0	0	0	0	5	73	0
	11. Water	99	0	1	0	0	0	0	0	0	0	0	99
	Commission Error (%)		49	40	37	53	13	38	23	57	34	49	0

Overall Classification Accuracy = 64.6%

At Level II classification, the Landsat TM simulator channels provides a significantly higher overall (0.05 significance level) accuracy (Table 10) than when using Landsat MSS channels alone (Table 11). This is primarily attributed to a difference in classification accuracy for the vegetative classes, agriculture and rangeland. Specifically, the change in classification accuracy is primarily a result of a difference in confusion between alfalfa, sod, and pasture and also between residential with landscaping and rangeland. For the two residential classes, the Landsat MSS channels provide higher classification accuracies. As mentioned previously, this is from the larger field-of-view of the Landsat MSS, which tends to average the response from the heterogeneous residential cover. The accuracy for the less heterogeneous industrial and commercial complex class increased when using the Landsat TM simulator bands.

SUMMARY AND CONCLUSIONS

There are several conclusions which may be drawn from this study.

- The visible channels for both the simulated TM (TMS 1, TMS 2, and TMS 3) and Landsat MSS (MSS 1 and MSS 2) provided the best single-band discriminations of the Level I and II urban classes. However, channels representing the major spectral regions (visible, near infrared, middle infrared, and thermal infrared) each provided important spectral information to further discriminate between the broad range of cover types occurring in the urban fringe zone.
- All seven simulated TM bands are not required for classification analysis. Five bands provided the same overall classification accuracy as seven bands. The two bands not used in the classification, TMS 1 and TMS 6, were highly correlated to other bands and provided little to no added spectral discrimination information for the classes evaluated. Analysis of Landsat MSS channels indicated an improvement in classification accuracy when using all four spectral channels. However, by far the largest increase in accuracy was when using one visible and one near infrared channel.
- Analysis of Landsat MSS channels provided higher classification accuracies in comparison to the simulated TM channels for the residential classes. This was primarily attributed to the urban area spatial complexity which is reduced through averaging of spectral response at the enlarged field of view of the Landsat MSS in comparison to the simulated Landsat TM. The within-field spatial complexity averaged by MSS relative to TMS reduced residential class scene variation and, hence, increased spectral class discriminations.
- For the less heterogeneous Level II classes, such as commercial and industrial, rangeland, irrigated sod, irrigated alfalfa, and irrigated pasture, the TM simulator provided higher classification accuracies in comparison to Landsat MSS. This is primarily attributed to the added spectral bands in the Landsat TM, providing additional spectral information.
- Effects from boundary or mixed class pixels as a function of spatial resolution were not evaluated in this study. Clearly, the proportion of mixed class pixels to the total pixels decreases with increased spatial resolution. Because mixed class pixels confounds discriminations, it is reasonable to assume that improved TM spatial resolution will increase classification performance. Therefore, there are two factors—added within-class variability and reduced boundary or mixed class pixels—working against one another. The extent of each factor is a function of within-class variability and class field size. Because these two factors vary from site to site and also with the level and type of classification scheme, results as a function of spatial resolution from various investigators will continue to be mixed.
- Analysis of the 30-m thermal infrared band, TMS 7, indicated enhanced information for the spectral discrimination of the Level I and Level II classes. Specifically, TMS 7 improved the classification performance of the urban categories. However, the thermal infrared band was at a 30-m spatial resolution at nadir and was flown at approximately 1:00 P.M. local time or near optimum time of day for temperature differences between materials. This is in contrast to the 120-m resolution and 9:30 a.m. overpass of the thermal infrared band on Landsat-4. The coarse 120 m spatial resolution of TM 7 frequently includes a higher proportion of class boundaries and correspondingly confounds the spectral class locations in measurement space.
- The set of optimum channels used for Level I analysis differed from those for Level II. At Level II classification there is a wide range of cover classes, typically resulting in numerous spectral differences. On the other hand, Level I consists of an aggregation of Level II classes, having different spectral locations and dispersions in measurement space.

In conclusion, many results were given of TMS data which may be characteristic of the capabilities of TM on Landsat-4. However, although factors such as spatial resolution simulation and spectral bands selection of TMS approximated TM, various differences between sensor systems such as radiometric sensitivity and geometric distortions may affect the capability of aircraft data to simulate satellite data. Conclusions given are based on land use/land cover in a rapidly urbanizing semi-arid area during the near peak of the vegetative growing season.

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