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# THE ROLE OF SPATIAL, SPECTRAL AND RADIOMETRIC RESOLUTION ON INFORMATION CONTENT

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ABSTRACT

A factorial experiment was conducted to quantitatively assess the influences of sensor spatial, spectral and radiometric resolution on information content, defined in terms of spectral separability and classification accuracy of training fields. This study necessitated the systematic spatial, spectral and radiometric degradation of high resolution aircraft scanner data varying between approximate Thematic Mapper and Multispectral scanner specifications. Five flightlines were selected to include agriculture, rangeland, forest, water and urban land cover types of varying complexity.

Two approaches were taken in evaluating the changes in information content due to changes in spatial, spectral and radiometric resolution. In both approaches a supervised set of training statistics was generated for each data set. Each simulated data set was classified using a Gaussian maximum likelihood classifier and the classification accuracies were thoroughly investigated. In addition, average pairwise class separabilities were computed through Transformed Divergence which was the primary separability measure used for evaluation.

Results show that lower spatial resolution and higher radiometric resolution yielded higher classification accuracies on all flightlines tested. The differences in classification accuracies for the spectral characteristics were indeterminate: higher spectral resolution resulted in higher accuracies in 70% of the cases considered.

## I. INTRODUCTION

As electronic technology advances, constantly giving birth to more powerful scientific tools, remote sensing researchers are provided with data characterized by a dynamic set of basic qualities. For over a decade, users of remotely sensed data have become intimately familar with the characteristics of the Landsat series Multispectral Scanner (MSS) data. Although data continues to be collected with these scanners, as well as various satellite, aircraft and field instruments, it is expected that the Thematic Mapper (TM) aboard Landsat 4 will provide a new generation of remotely sensed data. An understanding of the effects of improved spatial, spectral and radiometric resolution is required both by users of TM data and by those developing new data analysis techniques and designing new sensor systems for monitoring earth resources. The following factorial experiment was designed to provide a quantitative assessment of the influence of these three factors on differences in information content between TM and MSS data.

Information content is not easily quantitatively defined. An analyst who visually observes higher spatial resolution data will almost definately say that he sees more information than in a lower spatial resolution data set, yet a satisfactory quantitative measure has not yet been defined. Various attempts have been made to measure information content. A popular approach has been classification accuracy because classification procedures are widely used to extract information from remotely sensed digital data.

Classification accuracy alone has not proven to be a sufficient measure of information content when trying to compare TM and MSS data. Work by Markham and Townshend, (1981); and Clark and Bryant, (1977); has shown a general trend for greater classification accuracy with coarser spatial resolution data, contrary to the obvious increase in structure and detail apparent through visual interpretation of the data. Although such anomolous results have been explained, (Wiersma and Landgrebe, 1978; Markham and Townshend, 1981; and Townshend, 1980) incorrect conclusions should not be drawn. The authors believe that lower classification accuracy does not imply lower information content.

Realizing the difficulty in quantitatively defining information content, this study undertook the problem by the addition of another quantitative measure to support any conclusions to be drawn from accuracy results. In this analysis, information content is evaluated in terms of spectral separability as well as classification accuracy of training fields using a standard per pixel classifier. Although these two measures are generally related, they differ in significant aspects; separability considers classes pairwise, accuracy considers all classes at once. It was expected that in cases where higher spatial resolution might lead to lower classification accuracy (urban environments), spectral separability might be higher and the discrepancy attributed to improper image analysis techniques.

The present study does not seek to determine classification accuracy per se, but to use this measure to test for the effects of spatial, spectral and radiometric resolutions as they are varied singly and in combination. Accuracy assessment was based only on training fields, although such analysis techniques are known to lead to inflated accuracy estimates. Random test fields are normally required for valid estimates of accuracy, however reliance on training fields alone avoids statistical sampling problems because complete enumeration is possible. Although the training field accuracies may be artificially high, the effects of varying the three resolutions are valid.

PHYSICAL CONFIGURATION

| | |
|---|---|
| INSTANTANEOUS FIELD OF VIEW (IFOV) | 1.25 mrad |
| PIXELS/SCAN LINE | 716 |
| SCAN ANGLE | 42.5° |
| SWATH WIDTH | 8 nm |
| RESOLUTION (FROM 19,800 km) | 25 meters |

CHANNEL CONFIGURATION

| | | | |
|---|---|---|---|
| CHANNEL 1 | .38-.42 μm | CHANNEL 7 | .65-.69 μm |
| CHANNEL 2 | .42-.45 μm | CHANNEL 8 | .70-.79 μm |
| CHANNEL 3 | .45-.50 μm | CHANNEL 9 | .80-.89 μm |
| CHANNEL 4 | .50-.55 μm | CHANNEL 10 | .90-1.10 μm |
| CHANNEL 5 | .55-.60 μm | CHANNEL 11 | 2.05-2.35 μm |
| CHANNEL 6 | .60-.65 μm | CHANNEL 12 | 2.05-2.35 μm (HIGH GAIN) |

Figure 1. Sensor specifications of the Daedalus multispectral scanner flown over the Central Valley, Ca. July 31,1981.

| FLIGHT-LINE | TOTAL # OF POLYGONS | INFORMATION CLASSES | # OF PIXELS (25 m) |
|---|---|---|---|
| MN | 32 | INDUSTRIAL/COMMERCIAL: LITTLE/NO VEG. | 12,118 |
| | | INDUSTRIAL/COMMERCIAL: MODERATE VEG. | 2685 |
| | | MOBILE HOME PARKS | 3199 |
| | | RESIDENTIAL: LITTLE/NO VEG. | 2907 |
| | | RESIDENTIAL: MODERATE VEG. | 13,690 |
| | | RESIDENTIAL: HEAVY VEG. | 8779 |
| KL | 42 | MIXED FOREST | 3257 |
| | | DECIDUOUS FOREST | 1075 |
| | | CONIFEROUS FOREST | 4879 |
| | | DECIDUOUS FOREST WITH BRUSH | 830 |
| | | DECIDUOUS FOREST WITH GRASS | 2418 |
| | | PERENNIAL GRASSES | 395 |
| | | INLAND LAKES | 3101 |
| IJ | 14 | DECIDUOUS FOREST | 1346 |
| | | CONIFEROUS FOREST | 393 |
| | | DECIDUOUS FOREST WITH BRUSH | 902 |
| | | DECIDUOUS FOREST WITH GRASS | 1607 |
| | | PERENNIAL GRASSES | 731 |
| OP | 82 | ALFALFA | 2842 |
| | | CORN | 238 |
| | | COTTON | 8242 |
| | | FALLOW | 1074 |
| | | NATURAL VEGETATION | 4313 |
| | | STUBBLE | 1184 |
| | | MATURE VINEYARDS | 18,678 |
| | | YOUNG VINEYARDS | 1442 |
| EF | 34 | ALMONDS | 6343 |
| | | COTTON | 23,819 |
| | | FALLOW | 11,358 |
| | | TOMATOES | 932 |
| | | BRUSH/SHRUB | 3870 |

Figure 2. Information classes by flightline.

## II. PROCEDURES

### A. DATA ACQUISITION

Digital data used in this experiment were collected by a Daedalus (DEI-1260) multispectral scanner (DMS) aboard a U2 high altitude aircraft at 19.8 km on July 31,1981. Figure 1 lists sensor specifications including spectral waveband regions, note the unfortunate lack of data in the regions of TM channels 5 and 6. Flightlines extended over Fresno County in California's Central Valley and portions of the western Sierra Nevada. Five flightlines were selected to include a variety of land cover types representative of western ecozones. The land cover types delineated within each flightline are listed in figure 2. Two flightlines of agricultural areas were needed for crop diversity (Flightlines OP and EF). Other flightlines included an urban environment near the city of Fresno, CA (MN), water and rangeland areas in the foothills and a forested area near Bass Lake in the Sierra Nevada (KL and IJ).

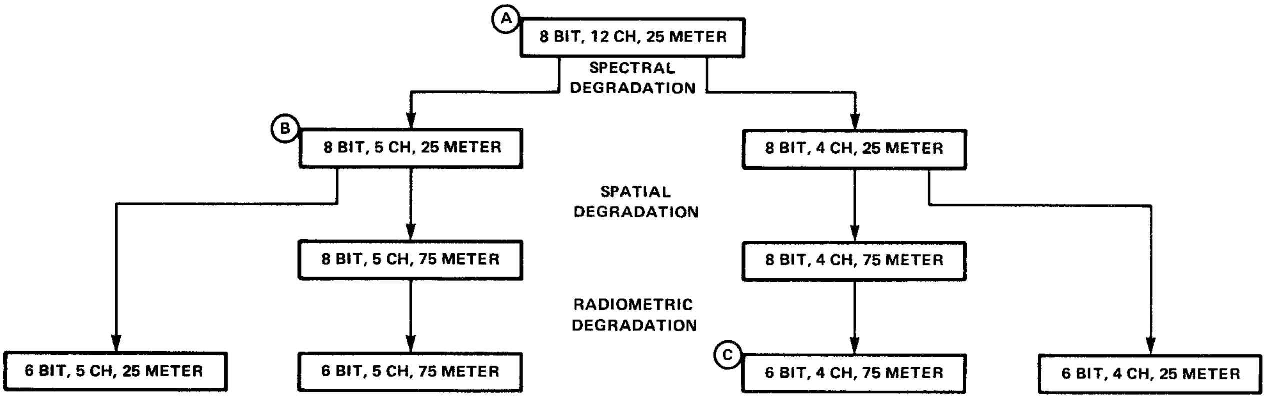


Figure 3. A systematic generation of eight simulated data sets per flightline is created by varying spectral, spatial and radiometric characteristics between approximate TM amd MSS values: A) original Daedalus scanner data, B) closest approximation to TM data, C) closest approximation to MSS data. Future references to these data sets will be abbreviated as A) 8b12c25m, B) 8b5c25m, C) 6b4c75m, etc.

B. DEGRADATIONS

The intent of this study was to provide a quantitative assessment of the influence of the three resolution factors (spectral, spatial, radiometric) at two levels (≃MSS, ≃TM) each. To achieve this goal, the systematic generation of spatially, spectrally and radiometrically degraded data varying between approximate TM and MSS specifications was necessary. This series of degradations resulted in the generation of eight simulated data sets per flightline for each of the five flightlines, yielding a total of forty data sets. Figure 3 illustrates this sequence starting with the original data and systematicaly degrading one factor at a time.

Spatial degradation transformed the data from 25 meter (≃TM) to 75 meter (≃MSS) resolution using a simple 3x3 super pixel averaging method. Spectral degradations of the 12 channel DMS data were performed to create 5 channel (≃TM) and 4 channel (≃MSS) data sets. The 5 channel data sets were created by selecting the 5 Daedalus channels most closely approximating TM channels. Specifically, TM 1,2,3,4 and 7 were approximated by Daedalus channels 3,5,7,9 and 12. The four channel data sets were created by averaging adjacent Daedalus channels after adjusting for differences in gains and offsets; Daedalus channels 4 and 5 were used to simulate MSS 4, Daedalus channels 6 and 7 to simulate MSS 5, Daedalus channel 8 to simulate MSS 6, and Daedalus channels 9 and 10 to simulate MSS 7. Radiometric degradation proportionally reduced the dynamic range of the 8 bit data (≃TM) to 6 bit data (≃MSS) by the fourth root of the dynamic range (Latty, 1982).

C. GROUND REFERENCE DATA

Ground reference data for the five flightline segments were gathered in August 1981 and July 1982. The field efforts were concentrated in southern Fresno County and the Bass Lake area in the Sierra. The field methods used in 1981 consisted of verifying land cover and agricultural crop types along several road transects southeast of Fresno. This information was used to update California Department of Water Resources crop type maps compiled in 1979 on USGS 7 1/2 minute base maps. The 1982 ground data collection was restricted to rangeland and forestry cover types which had changed very little since 1981. This field work consisted of three days of land cover verification of sites previously delineated on aerial photography.

Two high altitude U2 photo missions (June 1980 and July 1982) and a low altitude 35mm color slide reconnaissance flight over Fresno County (August 1981) were conducted to support this project. High altitude color infrared photography was recorded by the camera system onboard the U2 aircraft at a scale of 1:33,000. To aid the analyst while delineating urban, forestry and rangeland training sites both the high and low altitude photography were photo interpreted.

## D. TRAINING SITE DELINEATION

Training site delineation was performed using the Interactive Digital Image Manipulation System (IDIMS) on an HP-3000 minicomputer. The information classes used in this study were Level II and Level III land cover categories similar to those of Anderson et al., 1976. Training sites were delineated using the 25 meter data displayed on a color monitor. The training site polygons were delineated only once per flightline. Multiple polygons were delineated for most classes. To define training site polygons for the 75 meter data each 25 meter polygon file was converted to image format and spatially degraded to 75 meter resolution using the degradation routine previously mentioned. Any super pixels containing pixels from outside the original training field polygons were eliminated, thus ensuring purity of the 75 meter polygons. The size of the training sites was an important consideration when delineating fields because the spatial degradation of the 25 meter polygons resulted in a dramatic decrease in the number of pixels per polygon.

## E. DATA ANALYSIS

The data analysis procedures employed in this study are basically MSS analysis techniques. Although it was expected that MSS techniques should readily apply to TM data, this expectaton may be questioned after witnessing the results of this experiment.

In developing this study, the intent was to simulate a modified supervised classification (Swain and Davis, 1978) for each of the degraded data sets with multiple clusters for each information category. In an effort to minimize analyst influence, histograms for each training area for each of the 40 data sets were examined and the number of multispectral modes apparent in the data were estimated. (To reduce analyst bias one analyst completed this task since an experiment among five experienced analysts revealed high variability due to individual interpretations. Limiting this work to one analyst at least eliminated the possibility of increasing the variance between data sets due to analyst bias. All data sets were treated equally by the analyst.) The number of clusters requested in the spectral clustering algorithm for a given information category was set at the number of histogram modes plus two, except when an insufficient number of points were present to support the request. Thus, the variability in the data itself was used to define the number of clusters. This approach was an effort to improve on earlier studies (i.e. Markham and Townshend, 1981) which often used only one cluster per information class. Multiple clusters per information class seemed appropriate when increased detail in the image was obvious. After establishing the number of clusters to request, other parameters were kept constant between data sets. The spectral clustering algorithm used was the LARSYS/EDITOR version (Swain, 1973) installed on a CRAY-1S computer. One hundred percent convergence was requested, no cluster merging was permitted, and the minimum number of pixels per spectral class was set at 100 for 25 meter data and 16 for 75 meter data. Clusters with less than this minimum number of pixels were deleted.

Statistical editing of the clusters was not incorporated in this study because it was felt that such editing could compromise the very effects under investigation. Separability measures were calculated, however, as one of the two means of evaluating information content. Transformed Divergence (Dt) was the primary separability measure used. Jeffries-Matusita and Swain-Fu distances were compared to Transformed Divergence for two of the five flightlines (OP and MN). It was found that the trends between the eight data sets for each of these two flightlines were the same, regardless of the separability measure used. This comparison resulted in the choice of calculating only Transformed Divergence for the remaining flightlines, as no new information was gained through the other measures.

Cluster statistics were grouped by information class, and within each flightline, all combinations of information class separabilities were averaged for each data set (see figure 4). To generate these pairwise class separabilities, feature combination evaluation software, written and installed on a SEL 32/77 minicomputer (Card and Angelici, 1983) was utilized. No further quantitative analysis was performed on these separability measures. However the separability relationships between the eight data sets per flightline were examined.

## F. CLASSIFICATION AND ACCURACY ASSESSMENT

Changes in information content due to varying spatial, spectral and radiometric resolutions were also evaluated by computation of classification accuracy for each training site. The spectral clusters generated by software installed on the CRAY-1S computer were merged into a composite statistics file independently for each of the 40 data sets. As previously mentioned, no editing was performed on the

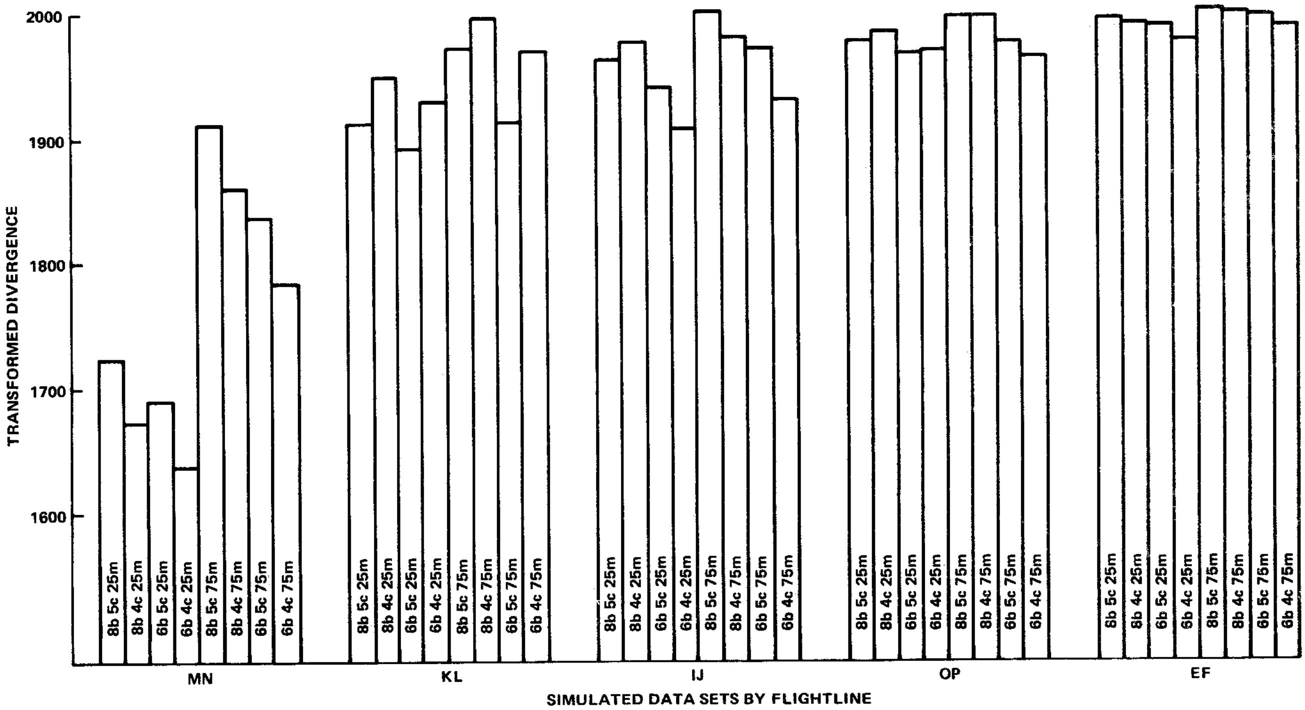


Figure 4. Transformed Divergence averaged for all class combinations for each of the 40 data sets. Data arrangement allows for visual comparison between 25 and 75 meter data, 8 and 6 bit data, 5 and 4 channel data, or any combination of the 3 characteristics for each flightline.

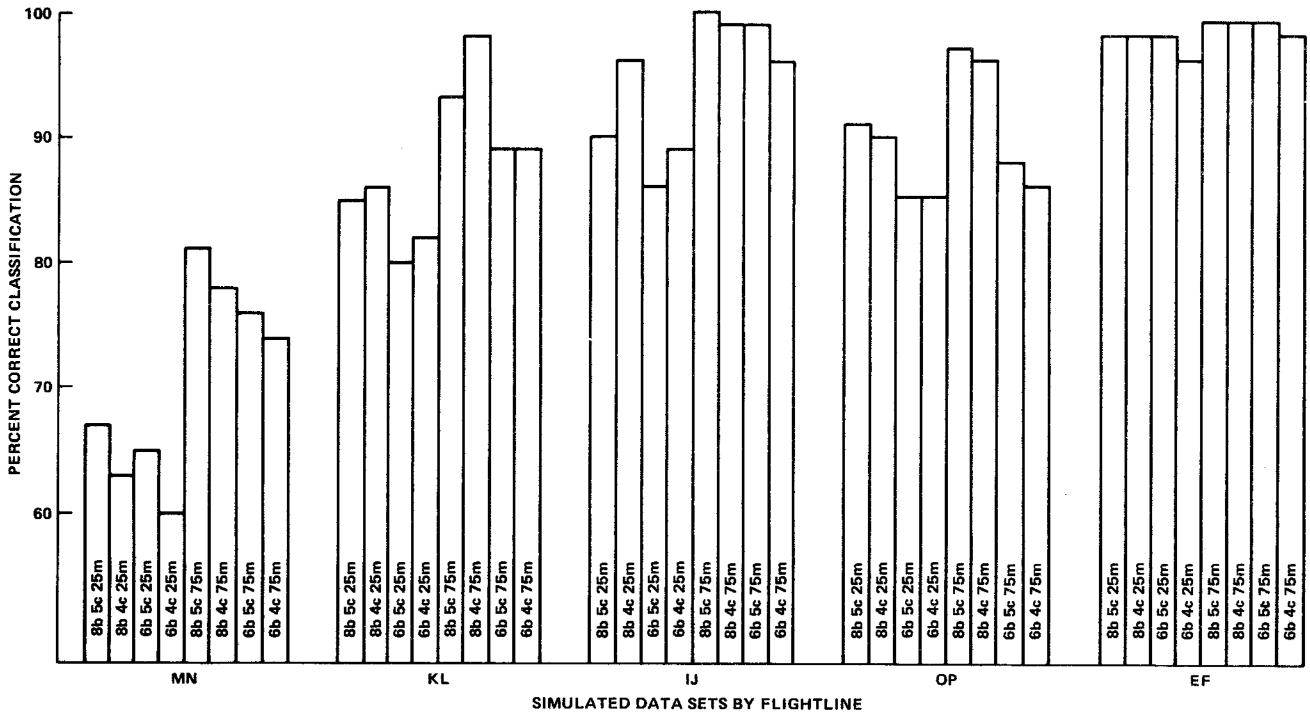


Figure 5. Percent Correct Classification for each of the 40 data sets.

cluster statistics other than deleting clusters with too few pixels. A maximum likelihood classification was then performed for each of the 40 data sets, utilizing the independent statistics files. After the data were classified, pixel summaries for each training site were calculated using a counting algorithm available in the EDITOR software package which uses a registered polygon mask image overlaid on the classified data. This procedure tallies the class assignments of pixels within the polygons, and generates a classification error matrix. Within each data set, accuracy was determined for each information class, as well as overall accuracy (calculated as total number of pixels correctly classified divided by total number of pixels in the training sites). Figure 5 shows the overall accuracies for each of the 40 data sets.

## III. RESULTS

The overall classification accuracies for each data set within each flightline (as displayed in figure 5) show that every low spatial resolution data set (75 meter) has a higher classification accuracy than the corresponding high spatial resolution data set (25 meter). For example, the 8 bit, 5 channel, 75 meter data has higher accuracy than the 8 bit, 5 channel, 25 meter data. The same is true for 8 bit, 4 channel, 75 meter data compared to 8 bit, 4 channel, 25 meter data and so on for the similar 6 bit combinations where spectral and radiometric resolutions were held constant. These comparisons hold true for all flightlines. Although the differences in classification accuracies due to radiometric factors are not as pronounced as those due to spatial factors, figure 5 displays that the accuracies for data with 8 bit digitization are always greater than data with 6 bit digitization for all flightlines (including flightline EF where accuracy differences are very small and the accuracies are close to 100%). 8 bit, 5 channel, 25 meter data exhibited higher classification accuracies than the 6 bit, 5 channel, 25 meter data and so on for all combinations where only the radiometric resolution changes. Comparisons of the 5 ≃TM channels and the 4 ≃MSS channel data show an ambiguous trend. The 5 channel data always have higher accuracies in flightlines MN, OP, EF and in the 75 meter IJ data, but the reverse is true for flightline KL and for the 25 meter IJ data.

To make the role of spatial, spectral and radiometric characteristics more precise, the classification accuracy data were modeled as a three factor experimental design with each factor (spatial, spectral and radiometric characteristic) having two levels (≃TM and ≃MSS). For this analysis the classification accuracies were averaged over all factors except the factor being examined. To account for the differences in sample size (Scheffe, 1959) for the two spatial resolutions (25 and 75 meter) it was necessary to weight the averages. For example, to test for differences due to the radiometric characteristic (6 or 8 bit digitization), classification accuracies for all data sets having 6 bit digitization in a given flightline were weighted and averaged and compared to a similar weighted average for all 8 bit data. In figure 6, the weighted average accuracy for 6 bit data in flightline MN is 0.6848 versus 0.7225 for 8 bit data. Figure 6 also shows the weighted average accuracy for each level (≃TM and ≃MSS) of each of the other characteristics (spatial and spectral) for flightline MN, and complete results for flightlines KL, IJ, OP and EF. Note that for each flightline the MSS spatial characteristic yields higher overall average accuracies. This confirms in a more quantitative way the results interpreted from visual analysis of figure 5. Similarly, the TM radiometric characteristic yields higher accuracies in every flightline, a result which also confirms the earlier interpretation. The fact that in both cases the results are consistent across all flightlines and that these flightlines represent a wide variety of land cover types, lends credence that these results are correct

**OVERALL ACCURACIES AVERAGED BY CHARACTERISTIC**

| FLIGHTLINE | | | MN | | KL | | IJ | | OP | | EF | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CHARACTERISTIC | MSS | TM | MSS | TM | MSS | TM | MSS | TM | MSS | TM | MSS | TM |
| SPATIAL | 75 m | 25 m | 0.7719 | 0.6354 | 0.9231 | 0.8328 | 0.9853 | 0.9052 | 0.9196 | 0.8751 | 0.9859 | 0.9752 |
| RADIOMETRIC | 6 BIT | 8 BIT | 0.6848 | 0.7225 | 0.8511 | 0.9048 | 0.8471 | 0.9642 | 0.8599 | 0.9349 | 0.9749 | 0.9862 |
| SPECTRAL | 4 CH | 5 CH | 0.6874 | 0.7199 | 0.8880 | 0.8679 | 0.9531 | 0.9373 | 0.8926 | 0.9021 | 0.9775 | 0.9836 |

Figure 6. Overall accuracies averaged for each of the 4 data sets sharing one common characteristic.

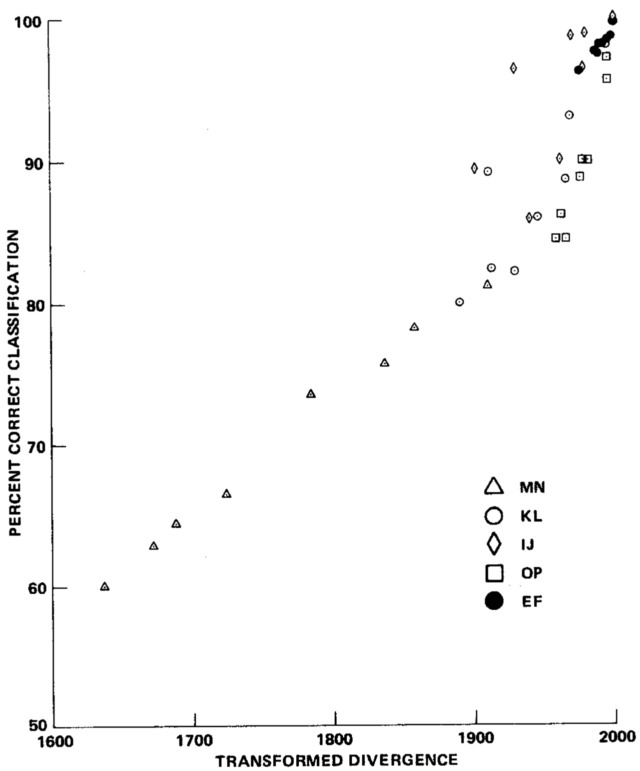


Figure 7. Percent Correct Classification vs. Transformed Divergence for each of the 40 data sets.

for all of the data and techniques used in this factorial experiment. On the other hand, although the results in figure 6 for the spectral characteristics confirm the earlier interpretation (that the TM spectral characteristic is better in some flightlines and worse in others) the results do not indicate that any generalities can be inferred. Since both flightlines that showed a preference for the MSS spectral characteristic (KL and IJ) represent forest/brush/grassland cover types, there is a suggestion that the preference may depend on cover type. The differences in overall accuracy in this case is small and any such suggestion is weak. Although each flightline represents a broad strata, i.e. urban, agriculture, forest/range etc., future work will include a more in depth study of accuracy by more detailed information classes. The possibility that cover type affects accuracy along with the three factors studied is recognized.

The trends in average separabilities displayed in figure 4 are remarkably similar to the trends displayed by classification accuracy. In figure 5, only two cases show an obvious reversal of trends: 6 bit, 5 channel, 25 meter data vs. 6 bit, 4 channel, 25 meter data in flightline IJ and 8 bit, 5 channel, 25 meter data vs. 8 bit, 4 channel 25 meter data in flightline OP. It was anticipated that averaged spectral separabilities could provide another perspective in the evaluation of the different characteristics of TM and MSS, particularly in the urban flightline (MN) where we anticipated that classification accuracy might be poorest. Given the method used for averaging separability, it is apparent that no new information can be derived from separability for our present purposes. Whether or not more detailed treatment of the separabilities (i.e. by information class rather than by flightline) can reveal new information awaits further analysis.

For each of the 40 data sets, overall averaged separability was plotted against overall classification accuracy and displayed in figure 7. The result is similar to a graph published by Boyd (1973); The only difference being that little scatter is evident except at high accuracies where it may not be significant.

## IV. CONCLUSIONS

At 75 meter spatial resolution, classification accuracy and interclass spectral separability were consistently higher for all of the flightlines studied than was the higher spatial resolution data. Also, 8 bit radiometric sensitivity produced a higher accuracy and spectral separability for all flightlines when compared to the 6 bit data sets. Results from the comparison of the 5 channel simulated TM spectral resolution data and the 4 channel simulated MSS resolution data were inconclusive. Although all differences noted in classification accuracy were readily apparent, some flightlines showed higher accuracies for the 5 channel data while other flightlines showed higher accuracies for the 4 channel data. The result that lower spatial resolution should yield higher classification accuracies in an urban environment (i.e. flightline MN) was anticipated and, in fact, it occasioned the attempt to utilize another measure for the comparison of TM and MSS characteristics, namely spectral separability, which might show an improvement for higher spatial resolution. This did not prove to be the case. The result that lower spatial resolution yielded significantly higher accuracies for all the flightlines was not fully anticipated. Landgrebe et al. (1977) indicated that for the pure pixel case classification accuracy tended to increase only slightly with decreasing spatial resolution. The case can be made (Clark and Bryant, 1977), that the pure pixel accuracies obtained at higher resolution are sufficient since they are generally above 85%, with the major exception of flightline MN (urban).

It is well to remember that the purpose of the present work was not to measure the classification accuracy of the various data sets but to use relative classification accuracies to test the significance of the spectral, spatial and radiometric differences between TM and MSS. On this basis, the radiometric characteristics of TM are a distinct improvement, the spectral characteristics of TM are indeterminate with respect to MSS, and the spatial characteristics of TM are a distinct detriment based on traditional MSS classification techniques.

Although MSS spectral character could be simulated well by the Daedalus scanner used in this experiment, the simulation of the TM spectral characteristics would be highly improved by the addition of the TM channels 5 and 6 to the data set. Full simulation of the TM channels may yield a more conclusive comparison of the spectral characteristic of TM vs MSS data.

The significance of the result that TM spatial resolution is a detriment with respect to the present analysis is extremely important, but should not be misunderstood. The authors feel that higher spatial resolution yields higher information, the problem is that traditional analysis methods do not take advantage of the detail and structure inherent in the data. Future work will concentrate on which aspects of the analysis should be improved to fully utilize data from scanners with improved resolution capabilities. The per-pixel maximum likelihood classifier employed in this study seems to be a likely candidate on which to concentrate new methods of analysis in order to gain improvement in the classification accuracy of high spatial resolution data. In particular, incorporation of the spatial structure by use of texture measures or contextual classifiers would seem appropriate.

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