Application of the Tasseled Cap Concept to Simulated Thematic Mapper Data

Measurements of agricultural crops and soils in the six reflective bands of the Thematic Mapper primarily occupy three dimensions—two which are equivalent to the MSS data plane, and a third which represents the contribution of the TM mid-infrared bands.

INTRODUCTION AND BACKGROUND

Considerable study of the spectral characteristics, correlations, and physical information carried in the Landsat Multispectral Scanner (MSS) bands has been undertaken over the life of the Landsat program. Numerous ratios, sums, differences, and linear combinations of the four MSS bands have been proposed. One set of linear combinations, called the Tasseled Cap Transformation (Kauth and Thomas, 1976), has gained particular attention. This transformation is based on the observation that, in agricultural regions, the correlations between the visible bands and between the near-infrared bands of the MSS cause vegetation and soil related information to fall primarily into a single plane. The Tasseled Cap Transformation rotates the data such that a “head-on” view of that plane is obtained, thus capturing the vast majority of MSS data variation in two dimensions. In addition, the features produced are directly correlated to physical characteristics of agricultural fields, and are thus readily interpretable.

With the successful launch of Landsat-4, which carries the Thematic Mapper (TM) as well as the Multispectral Scanner, new spectral bands are available for analysis. Table 1 describes the nominal band widths of the TM. Of particular interest are bands 1, 5, and 7, which measure reflected radiation in spectral regions unsampled by the MSS, and band 6, a thermal imaging band.

Abstract: Thematic Mapper signal counts in the six reflective bands (i.e., excluding the thermal band) are simulated using field and laboratory spectrometer measurements of a variety of crops, crop conditions, and soil types. The atmospheric model and prelaunch sensor characteristics comprise the other components of the simulation. The simulated data are found to occupy essentially three dimensions, two of which are equivalent to the MSS Tasseled Cap Greenness and Brightness features, and a third which is substantially influenced by the mid-infrared bands of the TM. This new dimension is primarily related to soil characteristics, including soil moisture. The nature and characteristics of each dimension are discussed, as are some of the expected information gains (over MSS data) resulting from the additional dimensionality of the data.

The utility of the Tasseled Cap Transformation in processing and analyzing MSS data, and the added complexity introduced to data from the TM as a result of the greater number and wider spectral dispersion of bands measured by that sensor, make a Tasseled-Cap-like transformation for TM data desirable.

Early simulation studies of the reflective Thematic Mapper bands (excluding band 6, the thermal
Table 1. Nominal Band Widths of the Thematic Mapper (50 Percent Response)

<table>
<thead>
<tr>
<th>Band</th>
<th>Wavelength (μm)</th>
<th>Low</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.45</td>
<td>0.52</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>0.52</td>
<td>0.60</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>0.63</td>
<td>0.69</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>0.76</td>
<td>0.90</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>1.55</td>
<td>1.75</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>10.4</td>
<td>12.5</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>2.08</td>
<td>2.35</td>
<td></td>
</tr>
</tbody>
</table>

band) have found correlations between sets of TM bands similar to those seen in the MSS bands, suggesting that, with MSS data, the effective dimensionality of TM data may be less than the total number of bands. Holmes (unpublished data, 1979) simulated top-of-atmosphere radiances using geologic as well as agricultural spectra, and predicted at least three significant dimensions. Based on the dispersion of the geologic data, Holmes also postulated the existence of a plane of soils, instead of the line of soils seen in MSS data. Badhwar and Henderson (1981), using exclusively agricultural spectra to simulate ground-level radiances (i.e., no atmospheric effects) predicted only two important information-bearing dimensions. They further characterized the two information-bearing dimensions as resembling Greenness and Brightness in the MSS Tasseled Cap Transformation, although the signs and magnitudes of their coefficients were not entirely consistent with those of the MSS Tasseled Cap Transformation.

The work reported here was undertaken to more fully investigate the applicability of the Tasseled Cap Transformation approach to TM data. It extends the previous work of Holmes and Badhwar and Henderson by (1) using a more extensive data set of crop and soil spectra, (2) including simulation of actual signal counts using pre-launch absolute calibration and detector response data, (3) using a more sophisticated and precise atmospheric model, (4) verifying the simulation with actual TM data, and (5) going beyond principal components analysis to a more thorough evaluation of the dispersion of data in the six-dimensional space defined by the reflective TM bands.

Materials and Methods
Simulation of TM Signal Counts

The base data for the simulation are spectra collected by the Laboratory for Applications of Remote Sensing (LARS) at Purdue University as part of a vegetation remote sensing research program at the NASA Johnson Space Center (Biehl et al., 1982). These include measurements of field plots of crops at the Purdue Agronomy Farm and laboratory measurements of soil samples (Stoner and Baumgardner, 1980). The field spectra include bare soil plots and partially- or fully-vegetated plots of corn, soybeans, and winter wheat collected in 1978, 1979, and 1980. Spectral measurements were taken at intervals throughout the growing seasons of these crops, and various types of agronomic information (e.g., percent cover; proportions of green, yellow, and brown leaves; stage of development) were recorded concurrently. Data were included from experiments in which planting dates, nitrogen fertilization levels, plant populations, and other such factors were varied through a range typical of those found in the U.S. Corn Belt.

The laboratory-measured soil spectra were collected under controlled conditions at 0.1 bar moisture tension, and represent samples of soils from across the U.S. as well as a few from Brazil and other countries. Spectra of 294 soil series are included in this data set. A range of descriptive information accompanies the spectral measurements, including particle size distribution, organic matter content, mineralogy, and parent material.

Both field and laboratory spectra were collected using an Exotech Model 20C spectroradiometer. Reflectance factors were computed by comparison to a barium sulfate standard. In total, 1642 spectra of vegetated plots and 636 spectra of soils were used.

Data from the Dave atmospheric model (Dave, 1978) were employed, along with pre-launch composite detector response functions obtained from the NASA Goddard Space Flight Center (Markham and Barker, 1982; Barker, 1983), to compute top-of-atmosphere radiances for the six reflective TM bands. Dave’s Model 3, a clear atmosphere, was used with nadir view and a 45-degree solar zenith angle. Spectra were assumed to derive from infinitely large fields (i.e., background reflectance was equal to target reflectance), thus avoiding the confounding influence of radiation reflected from neighboring fields entering into the field of view by means of atmospheric scattering.

Pre-launch absolute calibration data, also obtained from the NASA Goddard Space Flight Center (Barker, unpublished data, 1982), were used to convert top-of-atmosphere radiances to sensor signal counts. Table 2 shows the gains and offsets used. It should be emphasized that the pre-launch tests of the TM board lamp calibration is use actual TM data. Thus, some di simulated and real calibration

The resulting simulated situation and compared to TM data collected on 22 Aug and Tennessee (see Figure were generally similar except wider range of vegetative c through senescent) and prese in the simulation resulted in that of the real data, which w vegetation. All bands of the displaced lower in signal cc. A combination of sun a tions in atmospheric condit versus internal calibration are for the observed offset. Over pears to support the viability.

Analysis Methods

Principal components analysis to evaluate data dimensional essentially planar distributor principal components can also plane into which the data ar both simulated and real MSS c ical components will define the Tasseled Cap plane, and ide features essentially equi Cap features Greenness and I Crist, 1984).

However, while principal can provide insight into the with more than two dimension
spectra include bare soil vegetated plots of corn, collected in 1975, 1979, and 1982. The studies were taken at
•oing seasons of these agronomic observations of green, yellow, and development were re-
grade vegetation, nitrogen fertilizers, and other such fac-
range typical of those.

Soil spectra were collected at 0.1 bar moist samples of soils from
W from Brazil and other il series are included in the database.

tative information acquisition, including soil and water.

Spectra were collected 0C spectroradiometer, computed by comparison.
In total, 1642 spectra of soils were

ospheric model (Dave, g with pre-launch corrections obtained from
light Center (Markham 1983), to compute top-of
he six reflectance Tm clear atmosphere, was
5 degree solar zenith de to derive from in-
ground reflectance was thus avoiding the con-
ilation reflected from into the field of view by
rivation data, also ob-
Space Flight Center (1982), were used to con-
ances to sensor signal ains and offsets used. It

Principal components analysis is frequently used to evaluate data dimensionality. In the case of an essentially planar distribution of data, the first two principal components can also be used to define the plane into which the data are dispersed. Thus, in both simulated and real MSS data, the first two principal components will define a plane very similar to the Tasseled Cap plane, and can be rotated to provide features essentially equivalent to the Tasseled Cap features Greenness and Brightness (Ince, 1981; Crist, 1984).

However, while principal components analysis can provide insight into the dimensionality of data with more than two dimensions, it may fail to define the actual planes into which the data are dispersed. This phenomenon is illustrated in Figure 2. In this case, data are distributed into two perpendicular planes. Assuming that the data are equally dispersed throughout the planes, the principal components will be defined as shown: one component parallel to the line of intersection of the two planes, a second forming a right triangle, of which it is the hypotenuse, with the edges of the two planes, and a third dividing that right triangle into two equal right triangles (reflections of each other). Variations in the dimensions of and data density in the two planes will change these results to a degree, but as long as the basic relationship of two (or more) planes exists, principal components will not necessarily provide definition of those planes.

Accordingly, principal components analysis (based on the covariance matrix) was used only to provide a starting point for analysis of TM data dispersion. These components were then rotated, two or three at a time, in a linear fashion which preserved the orthogonality of the six components. By the process of applying various rotations, the data relationships in the TM data space were discovered and defined.

Once the TM data space was understood in spectral terms, the descriptive information collected, along with the spectral data by LARS, was used to associate the variations of TM data in the defined feature space with the physical characteristics of the crop canopy or soil.

FIGURE 1

The data in Figures 4 through 8 and 11 represent samples taken from the entire simulated data set. The particular samples plotted in each figure were selected using a technique designed to highlight the

<table>
<thead>
<tr>
<th>Offset</th>
<th>0.82</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>0.81</td>
</tr>
<tr>
<td>5</td>
<td>-0.04</td>
</tr>
<tr>
<td>4</td>
<td>0.69</td>
</tr>
<tr>
<td>1</td>
<td>2.64</td>
</tr>
<tr>
<td>7</td>
<td>3.16</td>
</tr>
</tbody>
</table>

Fig. 1. Comparison of simulated and actual TM data (actual data from AGRISTARS segment 9653, 22 August 1982). Simulated data distributions are shown using dashed lines.
distribution of the data while smoothing out differences in density over the range of the data distribution. This sampling was necessitated by the limitations of pen plotting devices, which have difficulty plotting extremely dense data.

The technique involves definition of spectral bins in the two dimensions defined by the features plotted in each figure. Each data point is considered in turn, and assigned to the appropriate bin. The first data point which falls in a particular bin is plotted, while subsequent data points which fall in the same bin are ignored. All figures in this paper were made using three-count bins.

PLANE OF VEGETATION

Table 3 provides the coefficients used to transform the simulated TM signal counts into this feature space. The coefficients of the first two components are, for the TM bands which sample the same spectral regions as the MSS bands (TM bands 2, 3, and 4), comparable to those which define MSS Greenness and Brightness. These two components, which define the plane of vegetation in the TM data, are displayed in Figure 4. Again, a strong resemblance to the MSS Greenness-Brightness plane is apparent. Although Badhwar and Henderson (1981) reached a similar conclusion, their coefficients differed in sign and/or magnitude for at least some of the TM bands as compared to the MSS bands, because they used only the eigenvectors produced by principal components analysis. With rotations applied, we find that a Greenness-Brightness plane does exist in TM data, with coefficients which are entirely consistent with MSS Tasseled Cap coefficients. Greenness describes the contrast between the near-infrared and the visible bands, with the mid-infrared bands essentially cancelling one another. Brightness is a partial sum of all bands. In another paper (Crist and Ciccone, 1984) we show that this TM Greenness is virtually identical to MSS Greenness, while the Brightness features are slightly different. For the most part, however, the plane of vegetation in TM data is equivalent to the MSS data plane.

TRANSMISSION ZONE

Rotating the data 90 degrees about the y or Greenness axis (right hand rule), we obtain a view of the edges of both planes, and a data distribution as illustrated in Figure 5. In this figure, Greenness is still on the y-axis, but the x-axis now defines a Third Component, with the Brightness axis perpendicular to the page. Figure 6 shows a sample of the data from Figure 5, in the same projection. Only fully vegetated plots (full or nearly full canopy closure) and bare soils are shown here, with the result that the definition of the two planes is readily apparent. In contrast, Figure 5 highlights the transition zone occupied by partially vegetated plots.

The location of the brown (senescent) vegetation samples in Figure 6 suggests that the spectral path followed by the plots in the time period from max-
at the angle between libration dependent factors applied a angle might not be ration of the data into and, as will be discussed in terms of the variation in the planes though in a somewhat

Table 3. TM Feature Space Transformation Coefficients—First Three Features

<table>
<thead>
<tr>
<th>Feature</th>
<th>Band 1</th>
<th>Band 2</th>
<th>Band 3</th>
<th>Band 4</th>
<th>Band 5</th>
<th>Band 7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brightness</td>
<td>0.33183</td>
<td>0.33121</td>
<td>0.55177</td>
<td>0.42514</td>
<td>0.48057</td>
<td>0.25252</td>
</tr>
<tr>
<td>Greenness</td>
<td>-0.24717</td>
<td>-0.16283</td>
<td>-0.40639</td>
<td>0.85468</td>
<td>0.95493</td>
<td>-0.11749</td>
</tr>
<tr>
<td>Third</td>
<td>0.13929</td>
<td>0.22490</td>
<td>0.46339</td>
<td>0.25178</td>
<td>-0.70133</td>
<td>-0.45732</td>
</tr>
</tbody>
</table>

...mant vestigial development (high Greenness) to maturity is primarily, or at least first, down the plane of vegetation rather than back through the transition zone. Stratification of the data in Figure 5 by percent cover with 100 percent green or brown leaves leads to the same conclusion: the transition zone is populated largely by samples that are "greening up," whereas samples of senescent vegetation remain, for the most part, in the plane of vegetation until they have reached a relatively low level of closure, and a very low Greenness. Once these samples begin to migrate back toward their starting point in the plane of soils, their Greenness values are so low that the movement appears to take place almost entirely within the plane of soils.

PLANE OF SOILS

In Figure 7, the plane of soils is viewed head-on, by means of a -90-degree rotation about the x- or Brightness axis in Figure 4 (again by the right hand rule). Now Greenness is perpendicular to the page, and Brightness and the Third Component are on the x- and y-axes, respectively. The same projection, with only soils data plotted, is shown in Figure 8.

While detailed understanding of the soil characteristics expressed in variation within the plane of soils is the object of current research, several pieces of evidence suggest that soil moisture content is at least one important factor determining the Third Component value of bare soil targets.

First, because analysis of reflectance spectra has shown middle-infrared reflectance to be most sensitive to soil moisture (Stoner and Baumgardner, 1980), one could logically assume that the Third Component of the TM Tasseled Cap, which contrasts middle-infrared reflectance with visible and near-infrared reflectance, would show a degree of moisture sensitivity.

Second, the dispersion of the bare soil and sand plots in Figure 8 can be used to support this hypothesis. Because these data represent, in both cases, multiple observations over time from a fixed set of plots, one must conclude that the spectral variation observed is the expression of a variation in intrinsic soil properties (e.g., particle size distribution or mineralogy) but rather of variations in soil condition. One might reasonably expect that soil moisture content would vary over a period of several months. Thus, while other candidates may also be considered (surface crustging, for example), moisture content is, perhaps, the most likely.

Finally, evidence exists in the laboratory-measured soils data which points to moisture content as an important factor in determining Third Component values. Most of the soil series in this portion of the data set are represented by two samples. The

![Fig. 4](image1.png)  
**Fig. 4.** The plane of vegetation. TM Greenness and Brightness.

![Fig. 5](image2.png)  
**Fig. 5.** Side view of the planes in TM Feature Space. Greenness versus Third Component.
mechanism by which these samples were selected (Stoner and Baumgardner, 1980) allows for the possibility that some soil properties will vary between the two samples. By identifying those pairs of samples which have substantial differences in a particular characteristic and small differences in other characteristics, the impact of each soil property on spectral response can be considered essentially independently.

In Figure 9, vectors are plotted which show the magnitude and direction of change in spectral response within the plane of soils for ten soil series whose samples vary with respect to moisture content (defined as percent by weight of dry samples); Selection of the ten soil series was based on two sortings. First, all the series were sorted with respect to the relative change in moisture content between samples. Second, the 20 series with the largest relative change in moisture content were sorted based on the largest relative change in other properties expected to influence the middle-infrared versus visible and near-infrared contrast. The data in Figure 9 represent the ten series with the least variation in those other properties. A clear preference can be seen in the alignment of the vectors, a preference which is consistent with the previous discussion of the field plot data—increase in moisture content tend to be associated with lower Brightness values, and Third Component values nearer to zero.

Other soil properties, including the proportions of fine sand, medium sand, and clay, cation exchange capacity, iron oxide content, and organic matter content, were evaluated in the same way, but none were found or magnitude seen in Figure 9. The soil properties can appear to be a major in the plane of soil as is clear from its response attribute both Brightness and soil moisture is known Baumgardner, 1985 response is not unex tures appear to reflection is still being. Looking again at sand plots in Figure 1 of all the soil but a few of the Brightness of those Component value soil plots with v values. If in fact the dimension has inc condition classes Brightness alone Brightness are as status, but that more absolute is the case, then erable importance.

Complete and provided by this is achieved over wide range of Tn other direct correlated to par. Clearly, however information is the middle-infrared EXPLANATION OF FIG.

The reason thoroughly perpendicular least in part, by and soil spectra reflectance and with green vegetation is detected by tular structure of the lack of soil is not surprising values associate in a positive ab mid-infrared re ship is seen in many brown ve the near-zero Tgetated spectra of moisture-str
but none were found to show a preferential alignment or magnitude of change comparable to that seen in Figure 9. Thus, while the influence of other soil properties cannot be dismissed, soil moisture appears to be a major influence on spectral variation in the plane of soils.

As is clear from both Figures 8 and 9, the spectral response attributed to moisture content occurs in both Brightness and the Third Component. Because soil moisture is known to affect albedo (Stoner and Baumgardner, 1980), the correlation in spectral response is not unexpected. However, while both features appear to respond to moisture, new information is still being provided by the Third Component. Looking again at the field data from bare soil and sand plots in Figure 8, one can see that the Brightness of all the sand plots is higher than that of all but a few of the soil plots. More importantly, the Brightness of those sand plots with near-zero Third Component values is greater than that of the bare soil plots with very negative Third Component values. If in fact the response in the Third Component is the result of moisture status, then this new dimension has indeed allowed the discrimination of condition classes which are undetectable using Brightness alone. We conjecture that changes in Brightness are associated with changes in moisture status, but that the Third Component provides a more absolute measure of moisture condition. If this is the case, then the added information is of considerable importance.

Complete understanding of the new information provided by this new spectral dimension will only be achieved over time through experience with a wide range of T classification. Further analysis may show that other directions in the plane of soils are better correlated to particular conditions or conditions. Clearly, however, an important new source of soil information is made available through inclusion of the middle-infrared bands of the Thematic Mapper.

EXPLANATION OF PLANAR DISPERSION

The reason that the TM data primarily fall into two roughly perpendicular plane planes can be understood, at least in part, by examination of typical vegetation and soil spectra (Figure 10). The high near-infrared reflectance and low visible reflectance associated with green vegetation, the contrast between which is detected by Greenness, is a function of the cellular structure of the plant (Knipling, 1970). Thus, the lack of soil variation in the Greenness direction is not surprising. The high near-infrared reflectance values associated with green vegetation also result in a positive absolute difference between near- and mid-infrared reflection for these data. This relationship is seen in all green vegetation samples, and in many brown vegetation samples, and thus explains the near-zero Third Component values of most vegetated spectra. It should be noted that few spectra of moisture-stressed vegetation were available for analysis, and it is possible that such samples would deviate from the plane of vegetation in the direction of more negative Third Component values (larger difference between the mid-IR and other bands). Nevertheless, it appears that the high near-infrared reflectance of green vegetation is responsible both for the definition of the Greenness component and for the restriction of vegetation variation in the direction of the Third Component.

While differences in absolute calibration of some of the TM bands could, as mentioned earlier, alter the angular relationship between the planes of soil and vegetation, the calibration of the sensor has no effect on the independence of the physical factors which are responsible for the presence of planes of data dispersion in the TM Tasseled Cap space, nor on the physical factors causing variation in those planes. The loss of statistical independence would, however, require non-linear techniques to extract independent soil- or vegetation-related information.

LESSER COMPONENTS

The other components in the TM feature space are shown in Figure 11. It would appear that some information of interest may be present in the Fourth Component, particularly with respect to soils. As seen in Table 4, TM Band 1, which falls in the blue wavelength region unsampled by the MSS bands, plays an important role in this Fourth Component.
However, it is also apparent that soil variation in the component dimensions (Fig. 10) will also show up in the soil greenness values of vegetation and reduce the dynamic variable. However, in more complex relative to the first three.

The fifth and sixth components produced in the analysis show little variation, if any, in agricultural crops. However, that does not mean that these higher components are not important. The sixth component described here is primarily a soil moisture diagnostic. This component is sensitive to agricultural crops, and is sensitive to the presence or absence of moisture-stressed vegetation.

<table>
<thead>
<tr>
<th>Feature</th>
<th>Band 1</th>
<th>Band 2</th>
<th>Band 3</th>
<th>Band 4</th>
<th>Band 5</th>
<th>Band 7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fourth</td>
<td>-0.83104</td>
<td>0.07447</td>
<td>0.42144</td>
<td>-0.07579</td>
<td>0.23819</td>
<td>-0.25247</td>
</tr>
<tr>
<td>Fifth</td>
<td>-0.32530</td>
<td>0.05361</td>
<td>0.11485</td>
<td>0.11140</td>
<td>-0.46571</td>
<td>0.80549</td>
</tr>
<tr>
<td>Sixth</td>
<td>0.11381</td>
<td>-0.59714</td>
<td>0.42038</td>
<td>0.06866</td>
<td>-0.01629</td>
<td>0.02706</td>
</tr>
</tbody>
</table>

Summary

Simulating thematic maps of soils and crops at various stages primarily consistent with the MSS data and Brightness, and other features including moisture-stressed vegetation could not be considered as uniform atmosphere, crop and soil data is important, with a lesser fourth dimension.

While most of the bands for this data set soils, the new dimer full canopy closure enhance the ability of vegetation and soil data. Thus, the potential for this process to draw inferences relies, in part, on the information offered by the increase in the geometric spe
However, it is also apparent that the axis of principal soil variation in the Greenness and Fourth Component dimensions (Figure 11a) is not parallel to the \( z \) axis (Fourth Component), indicating that any information relevant to soils in the Fourth Component will also show up in Greenness. Rotation of these two components to align the soil variation with the \( z \) axis, which would eliminate most of the variation in soil Greenness values, would also increase the variation of vegetation in the Fourth Component and reduce the dynamic range of the Greenness variable. However, in either case the total data variation relative to the first three components is small.

The fifth and sixth components, unrotated from those produced in the original principal components analysis, show little variation and are unlikely to carry much, if any, important information with respect to agricultural crops or soils. It is of interest to note, however, that other uses may be found for these higher components. The XSTAR haze normalization algorithm (Lambeck et al., 1978), which was developed for use with MSS data, utilizes the third component of the Tasseled Cap Transformation as a haze diagnostic. This component, termed Yellowness, is primarily a contrast between MSS Bands 4 and 5, and is sensitive to atmospheric scattering effects. The sixth component in the TM feature space described here is primarily a contrast between the equivalent TM bands (Bands 2 and 3), and thus may be of use in an XSTAR-like algorithm. Certainly, this study indicates that the amount of variability in this component associated with vegetation or soil characteristics is negligible.

**Summary and Conclusions**

Simulated Thematic Mapper data from a variety of soils and crops at a wide range of development stages primarily occupy three dimensions: two analogous to the MSS Tasseled Cap features Greenness and Brightness, and a third related primarily to soil features including moisture status. The behavior of moisture-stressed vegetation in the Third Component could not be assessed in this data set. With a uniform atmosphere, most of the variability of the crop and soil data is confined to these three dimensions, with a lesser amount of soil variation in a fourth dimension.

While most of the new information in the TM bands for this data set seems primarily related to soils, the new dimension will make achievement of full canopy closure easier to detect, and may also enhance the ability to estimate the relative mix of vegetation and soil in any particular picture element. Thus, the potential exists for improvement in our ability to assess the condition of vegetation and draw inferences related to that assessment. Certainly, more understanding is needed as to the gains in information, both direct and indirect, that are offered by the increased data dimensionality. In addition, geologic spectra should be evaluated with respect to their location in this TM feature space. Finally, of course, actual Thematic Mapper data must be evaluated, once data from a sufficient mix of field conditions, crop types, stages of development, and cover classes are available, in order to establish the similarities and differences in data dispersion as compared to these simulated data.

Clearly, however, a Tasseled-Cap-like transformation of Thematic Mapper data shows promise of being as valuable a tool as the Tasseled Cap Transformation has been for MSS, both in terms of data reduction and enhanced interpretability.

**Acknowledgments**

The authors wish to thank Mr. Larry Biehl and Dr. Marvin Bauer of LARS/Purdue University for their cooperation and assistance in obtaining the spectral data used in this work. Mr. Brian Markam of NASA/CSFC for providing TM detector response and calibration data and for assistance in obtaining other relevant information, and Dr. J. V. Dave, IBM, and Dr. David Pitts, NASA/JSC, for providing the atmospheric model data.

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**References**


FRONTIERS FOR GEOLOGICAL REMOTE SENSING FROM SPACE

Report of the Fourth Geosat Workshop

Sponsored by The Geosat Committee, Inc.

With Summaries and Recommendations For Future Geological Remote Sensing From Space

Flagstaff, Arizona
June 12-17, 1983

F. B. Henderson III and Barrett N. Rock

Editors

The Fourth Flagstaff Workshop dealt with current state-of-the-art developments in geological applications of satellite remote sensing techniques and their status in relation to the recommendations formulated at the original Geosat Flagstaff Workshop held in 1976. New information on the important emerging field of Geobotany was presented, as were current developments in advanced sensor systems. Also considered were questions of where the responsibility lies for future civil high-risk research and development for geological remote sensing applications as well as the proposal by the U.S. government to commercialize the earth observation and meteorological satellite programs.

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