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THE THEMATIC MAPPER TASSELED CAP -- A PRELIMINARY FORMULATION

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I. ABSTRACT

A transformation is described which rotates Thematic Mapper data (excluding the thermal band) in a manner analogous to that used in the MSS Tasseled Cap Transformation, thus providing a direct view of the planes of data dispersion and a direct association of spectral features with physical scene characteristics. This TM Tasseled Cap Transformation includes MSS-equivalent Greenness and Brightness features, as well as at least one additional important feature. The new feature, tentatively termed "Wetness", offers promise of enhanced ability to assess soil conditions, monitor vegetative development, and delineate cover classes. Relationships between scene characteristics and spectral variation in the transformed data space are discussed based on both simulated and actual TM data.

II. INTRODUCTION

Although the Landsat Multispectral Scanner (MSS) detects reflected radiation in four spectral bands, experience with MSS data from agricultural regions has shown that on a given day, the vast majority of data variability is confined to a single plane in the four-dimensional space. Each pair of spectral bands provides a skewed view of that plane - none gives a direct or "head-on" view. The Tasseled Cap Transformation developed by Kauth and Thomas[1] serves to rotate the MSS data in a linear fashion such that a head-on view of the data plane is achieved. In addition, this transformation defines the plane by means of two features, termed Greenness and Brightness, which can be readily associated with physical properties of agricultural scenes. The reduction in data volume and ease of data interpretation afforded by the Tasseled Cap Transformation has resulted in its widespread acceptance.

Early studies of simulated data from the Thematic Mapper (TM) on-board Landsat-4 suggested that a similar transformation might be derived for this new sensor[2,3]. More recently, an extensive set of simulated Landsat-4 MSS and TM data has been utilized to derive an estimate of a Thematic Mapper Tasseled Cap Transformation, and to understand the data relationships in the domain defined by the six reflective TM bands (excluding the thermal band)[4].

This paper presents a preliminary version of the Tasseled Cap Transformation derived for actual TM data. The previously mentioned simulation work[4] serves as a base of reference from which the actual data transformation is derived and by which the physical factors influencing the observed dispersion of actual TM data may be understood.

III. MATERIALS AND METHODS

A. DATA

Simulated-Data. TM and MSS signal counts were simulated using actual field reflectance spectra[5], pre-launch sensor characteristics[6,7,8], and atmospheric model data[9]. Included were data for three crops and three growing seasons, as well as data for a wide variety of soils sampled from across the U.S.[10]. Over 1600 partially or fully vegetated spectra and over 600 soil spectra were used.

Actual-Data. Portions of three TM frames were analyzed. Table 1 provides descriptive information on these scenes. All three are predominantly agricultural, with lesser amounts of water, natural vegetation and urban areas. The portion of the North Carolina scene used covers a private agricultural experimental farm, with several crops grown in large contiguous fields and surrounded by forest and natural vegetation. This scene thus provides both a pure agricultural sample (the farm itself) and a diverse mix of cultivated and natural cover types.

Regions of interest were identified within the TM frames, and samples were selected from these regions (1-in-225 for the Arkansas/Tennessee and Iowa scenes, and 1-in-25 for the North Carolina scene). The resulting samples of approximately 12000-, 9000- and 13000-pixels for the three scenes respectively comprised the actual data sets on which analysis was carried out.

B. DERIVATION OF TRANSFORMATION

The simulated data transformation was based on a multi-dimensional rotation of the principal components (eigenvectors) derived from the covariance matrix associated with the six reflective TM bands. Rotation of the eigenvectors was necessitated by the complex nature of the data distribution, and in order to derive features which had both physical and statistical basis. These rotations were carried out in such a way that the orthogonality of the features was preserved. Reference 4 provides a more complete description of the process by which the simulated transformation was derived, and explains the limitations of principal components in the complex TM data space.

Analysis of the simulated data revealed that they were not uniformly or randomly dispersed through the six-dimensional space, but rather were concentrated in particular regions or planes (this subject will be more fully discussed in the next section). The coefficients derived for the simulated data were selected to align the observed planes of data concentration with the coordinate axes, much as does the MSS Tasseled Cap Transformation.

While the same planar structure was apparent in the actual TM data, application of the simulated data coefficients to these data resulted in sightly skewed presentations of the data planes. This result was not unexpected, since one would expect some differences between the simulated and actual data. A series of relatively small rotations about one or more of the feature axes was thus applied to restore the intended alignment of the data planes with the TM Tasseled Cap coordinates.

Because of its greater purity with respect to cover type, the North Carolina agricultural area was primarily used to determine the required adjustments to the transformation, while the other two scenes were used to verify those adjustments. The transformation presented in this paper achieved the desired result for all three scenes, and is thus expected to be applicable for other TM scenes as well.

IV. RESULTS AND DISCUSSION

The basic relationships of crop and soil data in the six-band TM data space are illustrated in Figure 1. The "Plane of Vegetation" is occupied primarily by samples of full vegetative cover. Figure 2 shows the dispersion of agricultural data from the North Carolina scene in this plane. The obvious similarity in shape to the MSS Tasseled Cap is borne out by comparison of the simulated MSS and TM data, which shows a very high (>.99) correlation between TM and MSS Greenness (contrasts between the visible and near-infrared bands), and a moderately high (.77) correlation between Brightness features (weighted sums of all bands) derived for the two sensors[11]. Thus the "Plane of Vegetation" can be treated as equivalent to the MSS plane of data dispersion (Tasseled Cap Plane). However, it should be noted that while Brightness in the MSS Tasseled Cap was defined as the axis of principal soil variation, the same is not true, as we shall see later, in TM Tasseled Cap space. Here, the Brightness direction primarily defines, along with Greenness, the Plane of Vegetation, and is oriented for that purpose.

Kauth and Thomas[1] described a "plane of soils" in the MSS Tasseled Cap space, defined by Brightness and Yellowness (primarily a contrast between the green and red bands). However, in MSS data virtually all the variation normally encountered in soils is confined to the Brightness direction, leading to the more common reference to the "soil line" in MSS data.

In TM Tasseled Cap space, a distinct "Plane of Soils" can be seen, defined not by Yellowness but by a third TM Tasseled Cap feature which is a contrast between the sum of the two longer infrared TM bands (bands 5 and 7, 1.55 to 1.75 μm and 2.08 to 2.35 μm respectively) and the sum of the visible and near-infrared bands (bands 1 through 4). This feature, has been shown to respond to soil physical properties, and particularly to soil moisture status[4]. Soil effects in the Plane of Soils will be further discussed later in the paper. Like Brightness, the Third feature direction is primarily oriented to define the Plane of Soils, rather than to respond to particular physical scene characteristics. However, as we shall see later, associations of such characteristics with this feature can be made.

The zone between the two planes, termed the "Transition Zone", is occupied by samples of partial vegetative cover, where both plant materials and soil background are visible to the sensor. Thus for cultivated crops, data in this region can be considered to be "in transition" between the Plane of Soils and the Plane of Vegetation. Figure 3 shows the Transition Zone as it appears in the North Carolina Ag. Farm Scene.

In the MSS Tasseled Cap plane, crop development was expressed primarily as a progression from the soil line toward the green arm and then back toward the soil line (Figure 4). Viewing the TM Plane of Vegetation head-on results in a similar expression of crop development, but in the entire TM Tasseled Cap space, crop development is a distinctly three-dimensional event. A field now begins somewhere on the Plane of Soils depending on soil characteristics and conditions, migrates toward the Plane of Vegetation (and particularly the green arm in that plane) as vegetation begins to occupy a greater proportion of the field of view of the sensor, reaches the Plane of Vegetation around the time of full canopy closure, moves downward in the Plane of Vegetation (toward the Plane of Soils) with the onset of senescence, and finally returns to a point on or near the Plane of Soils (Figure 5). Any movement along the green arm such as might be associated with addition of vegetated material after canopy closure has occurred, is expressed as movement within the Plane of Vegetation; the green arm is located entirely within this plane.

Figures 6 and 7 show the locations of other cover classes in the Plane of Vegetation and the Transition Zone, as observed in the actual data sub-scenes. Relationships in Figure 6, the Plane of Vegetation, are again consistent with those in the MSS Tasseled Cap Plane (e.g., the "badge of trees"[1]). In the view provided by Figure 7, water and forest/natural vegetation cover types are shown to project in front of the Plane of Vegetation (when that plane is viewed head-on as in Figure 6), while roads and manmade structures tend to occupy a position well behind the Plane of Vegetation (same viewing arrangement). Such deviation from the Plane of Vegetation is one example of information unavailable from the MSS but now accessible with the TM.

Figure 8 shows the dispersion of simulated TM soils data in the Plane of Soils. Since the bare soil and sand classes both represent multiple observations over time of a few homogeneous plots, variation within these groups such as that seen in Figure 8 must be the result of changes in soil conditions rather than of differences in intrinsic soil properties. One condition likely to show such temporal variation is moisture status. A similar pattern of variation is seen in the lab soils group when comparing samples of a given series which vary only or primarily in terms of moisture content.[4]

The dispersion of actual TM data in the Plane of Soils, as illustrated in Figure 9, resembles that of the simulated data. Although lack of detailed ground information makes thorough comparison impossible, the inclusion of other cover types identifiable in the real data sets does provide insight into the expression of scene characteristics in the Plane of Soils. In addition to actual soils data, concrete and other such manmade materials can be taken to represent extremely dry materials. Similarly, one can treat turbid water as an extremely wet soil, and clear water as the ultimately wet material. The location of these classes, along with the simulated soils data, gives rise to a clear direction of principal moisture variation, as depicted in Figure 10. Just as the addition of green vegetated matter causes increases in both Greenness and Brightness, so changes in moisture status cause changes in both the Third feature and Brightness. The relationship of the Third TM Tasseled Cap feature to moisture status is thus analogous to the relationship of Greenness to the presence of green vegetated matter, suggesting the proposition that this Third feature be called "Wetness."

The lesser features of the transformation are illustrated using the simulated data, in Figure 11. It appears that significant agricultural information may be contained even in the Fourth feature of the transformation, particularly with respect to soils which are responsible for the dispersion at the lowest Greenness levels in Figure 11a. However, while physical scene characteristics can clearly be associated with the first three features, the lesser three features of the TM Tasseled Cap Transformation as presented are driven entirely by statistical considerations. Further studies may determine that the features as defined can be associated with particular physical characteristics, or that redefinition of these lesser features is necessary in order to allow such association.

Table 2 presents the coefficients for this preliminary formulation of the Thematic Mapper Tasseled Cap Transformation. The coefficients for the first three features are offered in confidence that they will be applicable to a variety of scenes and will provide a useful frame of reference for TM data understanding. The lesser three features are offered for completeness, and with a similar level of confidence that further research will indicate desirable revisions in their formulation. However, as indicated in Figure 12, the relative variation associated with these three features is minimal compared to that contained in the first three features. Thus while important information for particular applications may reside in the "residual" data space of the lesser three components, the vast majority of information in the TM reflective data domain is captured in Greenness, Brightness, and the Third feature or "Wetness."

V. SUMMARY AND CONCLUSIONS

Analysis of both real and simulated TM data reveals that, in addition to the Tasseled Cap plane observed in MSS data, at least one additional important dimension is added in the space defined by the six reflective TM Bands. This additional dimension provides for easier delineation of classes such as trees/natural vegetation, and affords the opportunity to extract more comprehensive soils-related information. In addition, the expansion of crop development from a two-dimensional to a three-dimensional event is likely to make available more detailed information regarding crop condition and the mix of components in the sensor field of view.

This study demonstrates the increase in information content afforded by the Thematic Mapper, and provides a preliminary means by which the data may be understood. However, the increased information content is accompanied by a greater overall complexity, and full understanding of the information available in the Thematic Mapper, and the best means by which that information may be extracted, are subjects for further investigation.

As more data from the TM become available, representing a broader range of cover classes and conditions as well as multitemporal observations of a single scene and accompanied by detailed ground truth information, the coefficients presented in this paper, and our understanding of the interpretation of the associated features, may be modified. The transformation presented here is thus intended to be a starting point, representing our initial level of understanding, from which future research can proceed.

ACKNOWLEDGEMENTS

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Table 1. Description of Thematic Mapper Data Sets

Scene Name	Scene #	Date	Sub-scene Lines	Sub-scene Points
Arkansas/Tennessee	40037-16031	22 Aug '82	1-1600	2975-4775
Iowa	40049-16262	03 Sep '82	1-965	1990-4235
North Carolina	40070-15084	24 Sep '82	1755-2225	3125-3810

Table 2. Thematic Mapper Tasseled Cap Preliminary Coefficients

	TM Band					
Feature	1	2	3	4	5	7
Brightness	.3037	.2793	.4743	.5585	.5082	.1863
Greenness	-.2848	-.2435	-.5436	.7243	.0840	-.1800
Third	.1509	.1973	.3279	.3406	-.7112	-.4572
Fourth	-.8242	.0849	.4392	-.0580	.2012	-.2768
Fifth	-.3280	.0549	.1075	.1855	-.4357	.8085
Sixth	.1084	-.9022	.4120	.0573	-.0251	.0238

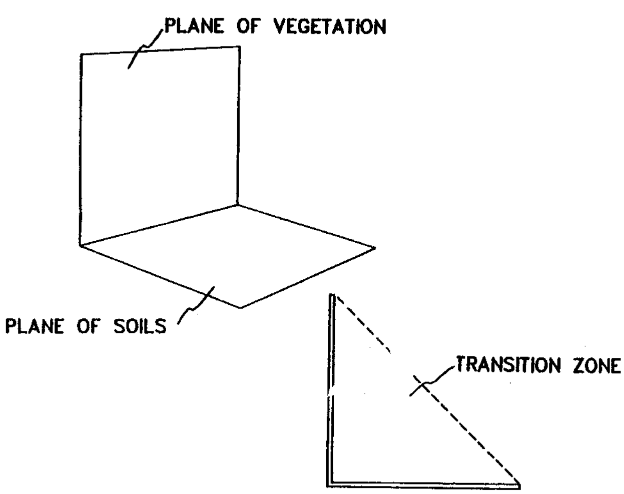


Figure 1. Dimensional Relationships in Six-Band Thematic Mapper Data.

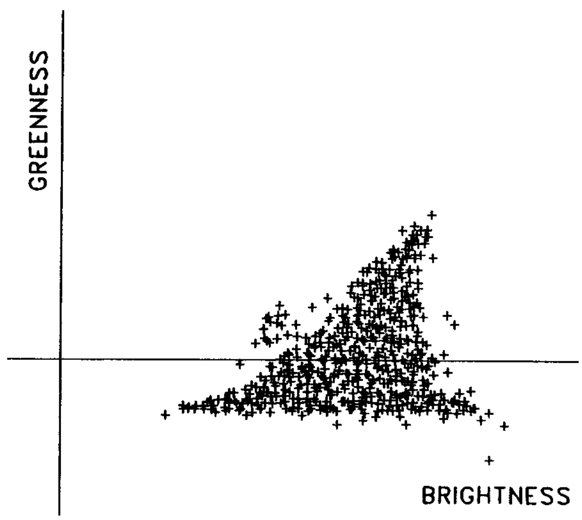


Figure 2. TM Tasseled Cap Plane of Vegetation - North Carolina Ag. Farm Data

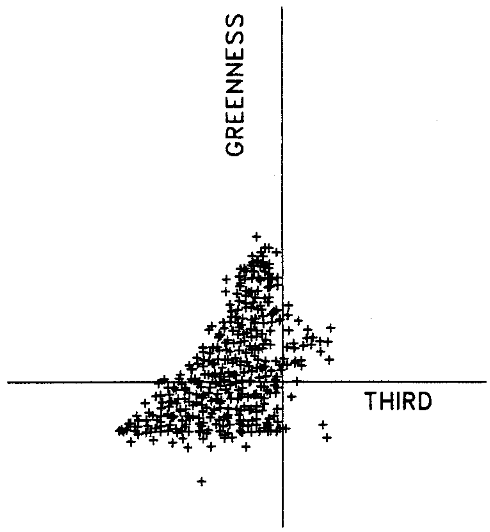


Figure 3. TM Tasseled Cap Transition Zone - North Carolina Ag. Farm Data

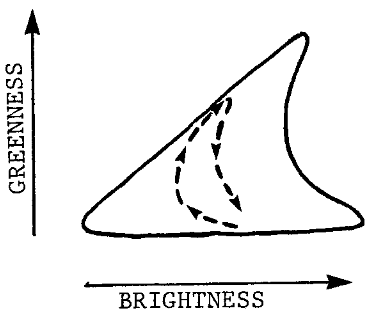


Figure 4. Crop Development in Tasseled Cap Greenness/Brightness (Plane of Vegetation).

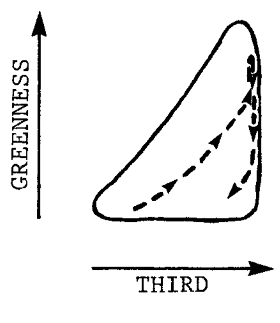


Figure 5. Crop Development in Tasseled Cap Greenness/Third (Transition Zone).

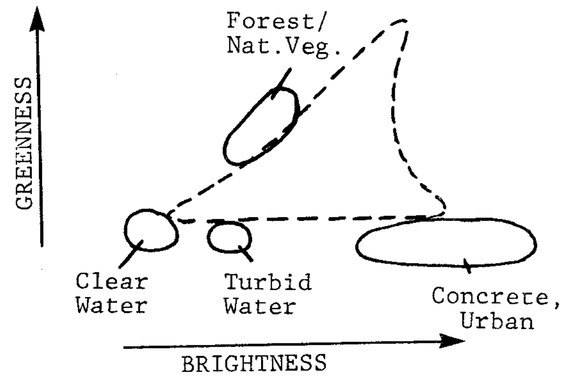


Figure 6. Location of Other Cover Classes in Plane of Vegetation

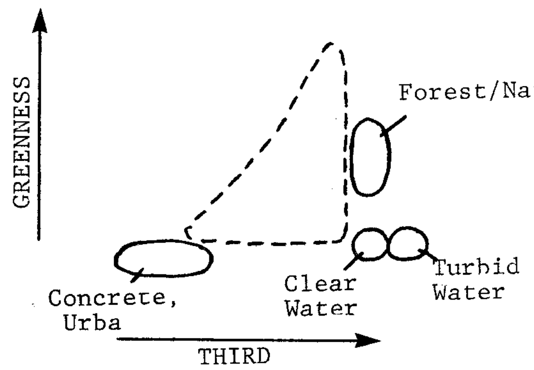


Figure 7. Location of Other Cover Classes in Transition Zone View.

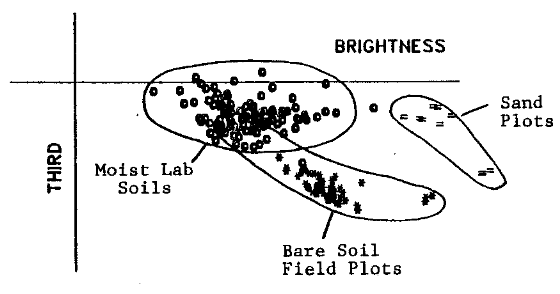


Figure 8. TM Tasseled Cap Plane of Soils - Simulated Data (Soils Only)

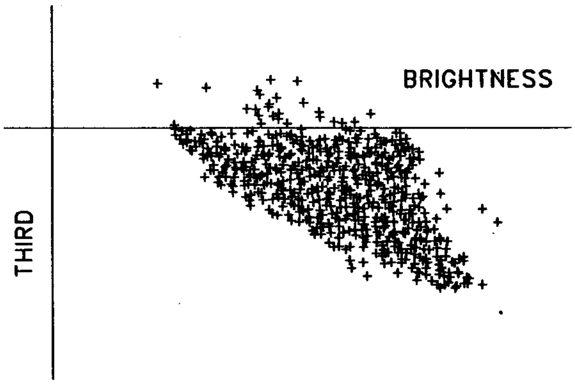
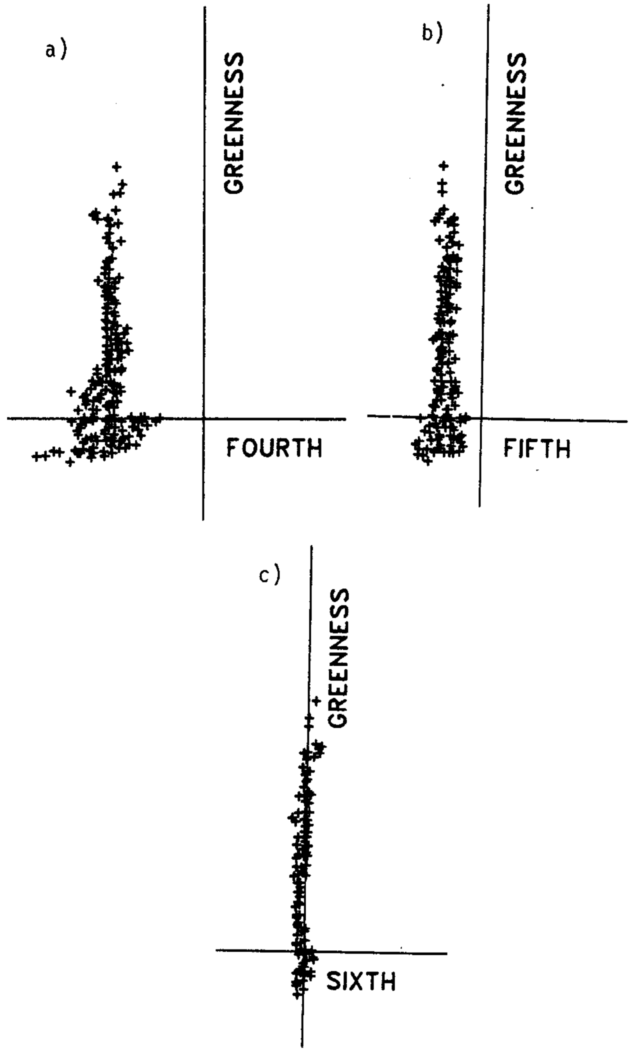


Figure 9. TM Tasseled Cap Plane of Soils - North Carolina Ag. Farm Data



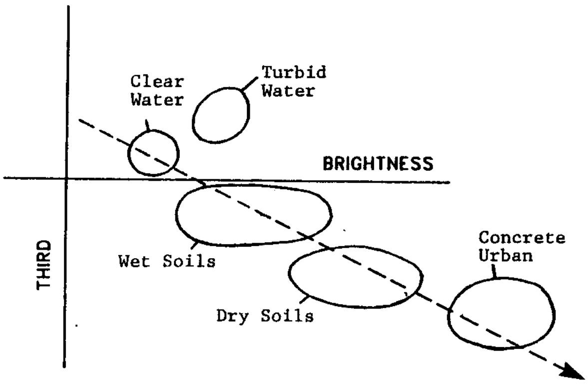


Figure 10. Approximate Direction of Moisture Variation in the Plane of Soils (arrow points in direction of less moisture).

Figure 11. TM Tasseled Cap Lesser Features Simulated Data.

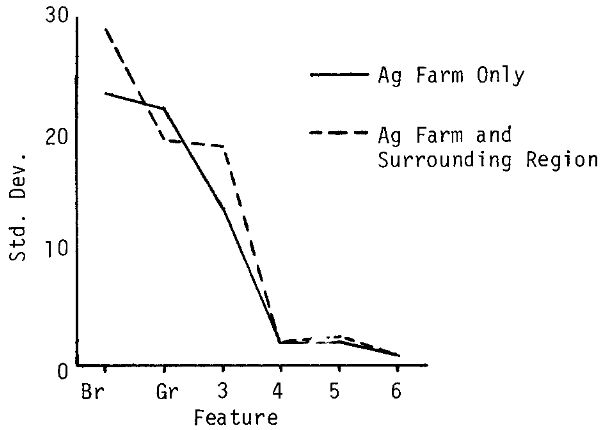


Figure 12. Relative Variation Associated with each TM Tasseled Cap Feature - North Carolina Scene

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