Systematic and Random Variations in Thematic Mapper Digital Radiance Data

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ABSTRACT: We report studies of the systematic and random variations in digital radiance data obtained by the Landsat-4 and Landsat-5 Thematic Mappers over an agricultural crop area which was apparently uniform and cloud-free. Systematic variations appeared to be time-dependent and bandpass-dependent. The predominant effect seemed to be random variations, which appeared to be in keeping with those expected from prior investigations. It is suggested that uncorrected variations will provide a limitation on the nonphotointerpretative analysis of images.

INTRODUCTION

RADIANCE RECORDED by any remote sensing instrument will contain noise which will consist of both systematic and random variations. Systematic variations may be due to sun-target-sensor geometry (e.g., Duggin, 1985; Kirchner and Schnetzler, 1981) atmospheric conditions (e.g., Dave, 1978) and the interaction of the spectral characteristics of the sensor with those of upwelling radiance (e.g., Slater, 1979; Duggin, 1985; Markham and Barker, 1985). Random variations in the data may be caused by variations in the nature and in the heterogeneity of the ground cover (e.g., Daughtry *et al.*, 1981; Duggin, 1978, 1983, 1985), by variations in atmospheric transmission, and by the interaction of these variations with the sensing device (e.g., Duggin, 1985). In addition, systematic and random errors can arise from the sensor itself.

It is important to be aware of the extent of random and systematic errors in recorded radiance data across ostensibly uniform ground areas in order to assess the impact on quantitative image analysis procedures for both the single date and the multidate cases. It has been shown that random variations in irradiance and in reflectance characteristics (caused, for example, by variations in the nature and in the heterogeneity of ground cover) can cause variations in the discriminability of vegetation stress (Duggin, 1983) and that random variations in unresolved (sub-pixel-sized) cloud can affect discriminability of agricultural targets (Duggin *et al.*, 1984). Duggin and Schoch (1984) and Wardley (1984) showed that the impact of random variations in irradiance, ground reflectance, and atmospheric transmittance on target discriminability can be angle-dependent. Systematic variations in radiance due to scan angle have been observed by many workers in, for example, even Multispectral Scanner (MSS) data with a scan angle range of 11.56° (Kaneko and Engvall, 1977) and in Advanced Very High Resolution Radiometer (AVHRR) data which has a much larger scan angular range of ±55° (e.g., Duggin and Saunders, 1984; Duggin and Piwinski, 1984). The cause of the angular dependence of spectral radiance (and therefore of discriminability) is the systematic variation in the reflectance properties of ground cover with illumination and with viewing angles (e.g., Bauer *et al.*, 1979; Kollenkark *et al.*, 1982; Smith, 1983). In the case of emitted radiance, there is a dependence of emissivity on view angles (e.g., Kimes *et al.*, 1980; Kimes and Kirchner, 1983; Kimes, 1983). Atmospheric scattering and transmission also vary with viewing and with illumination angles (e.g., Turner, 1978; Dave, 1978). The combination of these systematic variations in factors controlling radiance levels gives rise to upwelling radiance which varies with viewing geometry in a target-dependent manner (e.g., Kirchner and Schnetzler, 1981; Duggin, 1985). There is the possibility that systematic effects may be corrected for if they are properly understood.

It was our intention in this study to examine the systematic and the random variations in digital radiance data recorded in each band by the Thematic Mapper (TM) over crop areas which were ostensibly

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uniform and which were free from visible cloud. The Thematic Mappers on Landsat-4 and Landsat-5 have narrower bandpasses and a wider range of wavebands than the MSS or the AVHRR, and so findings for the MSS and for the AVHRR cannot automatically be assumed to apply to the TM, even though the scan angle range for the AVHRR can be restricted to that of the TM. For example, the superior spatial resolution of the TM (30 m IFOV as compared to 83 m IFOV for the Landsat-4 and Landsat-5 MSS and 1 km for the AVHRR) will increase the random variation between radiance values recorded from individual pixels located in apparently uniform areas.

The analysis was performed on several scenes at different growth stages. We considered agricultural areas. We wished to see if there were seasonal effects upon both random and systematic variations in digital radiance data recorded in the Thematic Mapper bandpasses.

ANALYSIS

In this analysis, we were constrained by data availability; the data which we hoped to obtain at various stages over agricultural regions including one in Iowa (path 27, row 31 on the World Reference System (WRS)) were not available at all of the growth stages requested. Some acquisitions were cloudy, and unforeseen circumstances prevented the acquisition of other scenes in time to perform the analysis for this report.

The images which we discuss in this report are restricted to one region and are listed in the following table. In each case, we used radiometrically corrected P-type Computer Compatible Tape (CCT) data (NASA, 1983) for WRS path 27, row 31, which covers a corn/soybean area in Iowa. In August 1982, only 4-band data were available. In the following table, sun azimuth and elevation are shown. However, when considering the view azimuth angle it should be recalled that the track of the spacecraft is approximately 10° from N, so that radiance is recorded from a linear swath defined by movement of the mirror, which goes from approximately 100° from N (when the scanner mirror looks east) to 280° from N (when the scanner mirror looks west).

Date	Image Number	Sun Elevation (degrees)	Sun Azimuth (degrees)
2 Aug. 1982	4001716261	54	126
21 Oct. 1982	4009716273	33	151
15 Aug. 1984	5016716293	52	130

Firstly, in each case, the data were screened using the Landsat Assessment System for cloud and for uniformity. That is, to ensure that the scene did indeed consist entirely of crop areas for those regions examined. Only the roads between fields were not vegetated for the areas studied.

In the first analysis, a mask was generated. Three swaths were used across the full image: each was 300 lines deep and started at lines 500, 1900, and 5000. Slices which were 16 pixels wide were taken in these swaths. The slices had starting pixel numbers 300 (bottom two swaths), 500, 1000, 2000, 3000, 4000, 5000, 6000, 6500, 6700 (top two swaths). The offset is related to the Earth rotation correction of the Landsat image. In this manner, a nonbiased analysis was performed by analyzing all of the pixels in each slice over an apparently uniform, cloud-free agricultural region. Training within these regions on areas which appeared uniform on the image was not performed in this analysis, as it was considered that this would have resulted in bias deriving from unsubstantiated, a priori assumptions as to the nature of the target. The mean digital counts for each slice were calculated for each bandpass. The digital counts were used since we were interested in variations within images and considered that errors due to offset would not seriously affect other estimates of coefficients of variation (standard deviation divided by the mean; CV) in radiance, except to alter the CV by about 15 percent in the case of TM band 6 (Barker, 1984; Barker *et al.*, 1984). At the same time, the variance and the coefficient of variation were calculated for each slice.

Figure 1 shows the mean digital radiance values for the 2 August 1982 image for path 27, row 31. Only four bands were available for analysis for this image. The mean radiance values are shown as a function of scan angle (starting pixel value for the slice) and of mean scan line for the swath from which the slices were taken. In this and in all subsequent figures, the northernmost swath (lower mean line number) is closest to the viewer, west is to the left (lowest pixel number) and east is to the right (highest pixel number). There was no attempt to register images in this investigation.

It is seen that there is a significant systematic variation with scan angle before harvest, with a superimposed random variation of about 5 percent. The systematic variation is over 10 percent between the edges and the center of the image and is apparently close to symmetric about nadir for TM band 1 of the preharvest image. The effect becomes more pronounced in band 2 and is almost 25 percent in band 3. There is a strongly asymmetric 30 percent change across the image for TM band 4 of the same image. There appears to be a general decrease in mean pixel radiance from south (mean scan line 5150) to north (mean scan line 650) in this image, coupled with some change in the apparent scan angle dependence. Also shown are the coefficients of variation (CVs) for the pixel radiance values contained within each slice of each single-band image. The CVs are also plotted as a function of pixel and mean scan line for the slices considered in the mask

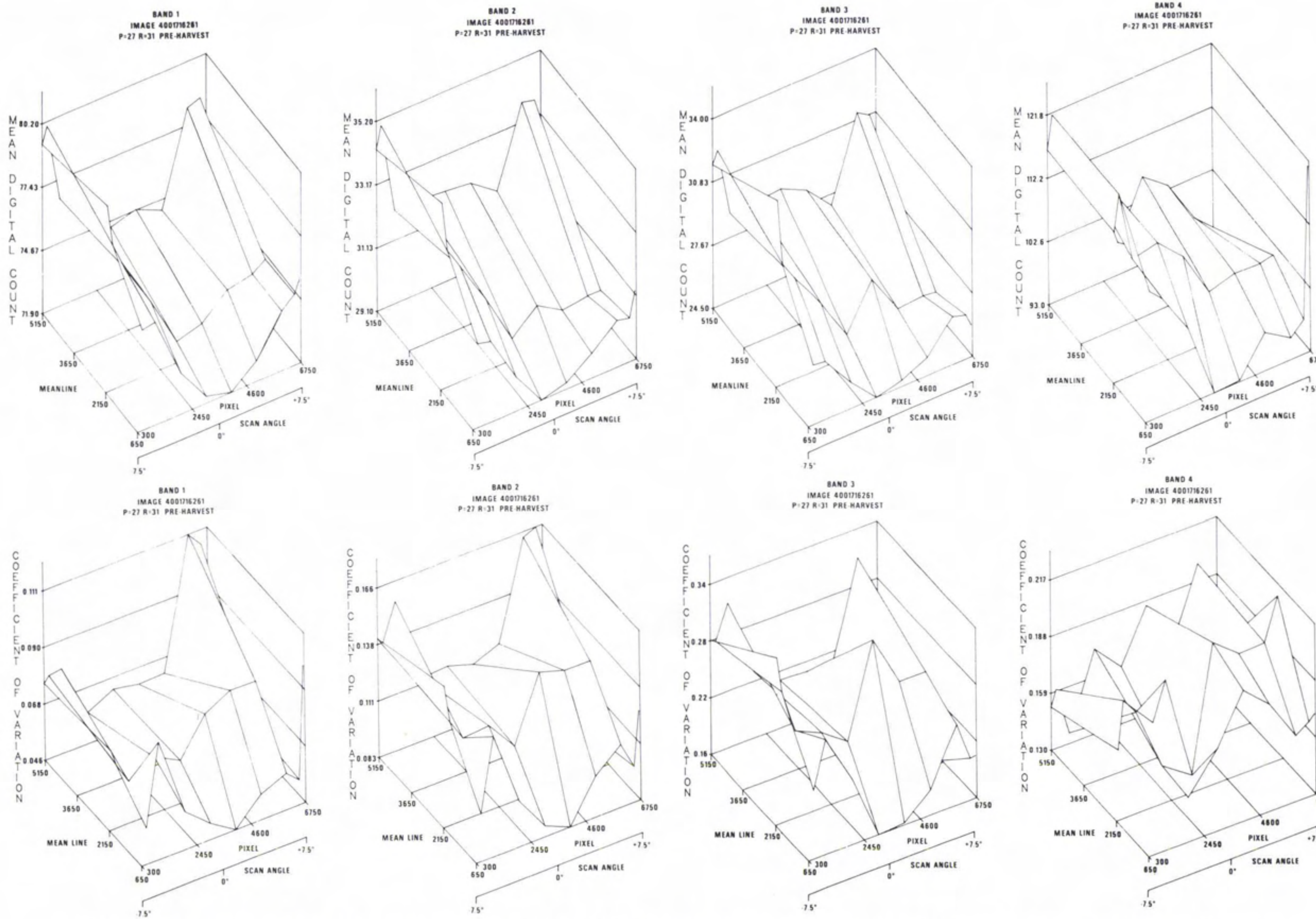

FIG. 1. The means and coefficients of variation of digital radiance data for rectangular 4800-pixel sample areas (slices) described in the text, plotted as a function of scan angle (pixel) and of mean scan line for the preharvest image no. 4001716261, path 27, row 31, 2 August 1982. Only four bands of data were available.

superimposed on the image. There is approximately a 50 percent variation in CV about nadir for bands 1 through 3, with a superimposed random variation in the CV and a systematic decreasing trend toward the north portion of the image (decreasing mean scan line). Band 4 (the reflected infrared region) shows mainly random variation with a slight monotonically increasing trend in CV from west to east. It is noteworthy that the CV is generally less than 10 percent for band 1 and 15 percent for band 2 but rises to nearly 30 percent for band 3 (whose digital values are lower than bands 1 or 2), falling back to less than approximately 17 percent in band 4. There does appear to be a general trend for the CV to decrease from south to north.

The same region (path 27, row 31) was viewed again after harvest (21 October 1982). A color infrared rendition of this image on the interactive computer screen suggested that this area was mostly stubble. The mean digital counts for bands 3, 4, 5, and 6 are shown in Figure 2 as a function of the same variables as for Figure 1. Bands 1 and 2 showed behavior similar to band 3, and the behavior of band 7 was similar to that of band 5. The mean digital counts appear to show a general trend decreasing approximately 10 percent from west to east in the image. The reverse is the case in band 6, the thermal infrared channel. There appears to be a slight decreasing trend in radiance values from south to north in the image, and the noise (random variation) in digital radiance values appears to be approximately ±10 percent. The digital values are lower after harvest except in band 3. The coefficients of variation for this image are shown as a function of pixel and mean scan line in Figure 2. They are all slightly higher than in the case of the preharvest image for the first four bands, are around 20 percent in band 5, 30 percent in band 7, but less than 5 percent in band 6. However, there is an apparently anomalous increase in CV at the far east side of the image, which was not readily explicable from image data of the slices examined on the interactive computer screen. The most obvious possibility would be a greater heterogeneity in ground cover at the eastern edge of the scene. For this image, an examination of the scene and of the analyzed slices in a false color rendition on the interactive computer screen suggested that patches of vigorous vegetation existed in what appeared to be stubble or soil areas. The distribution of these scene elements might have, for some reason, been more heterogeneous toward the extreme east of the image.

The same area (path 27, row 31) was examined using a later (Landsat-5) acquisition obtained on 15 August 1984 (image number 5016716293). For this image, in order to avoid slight, localized cumulus cloud it was necessary to start the three swaths at lines 2072, 3900 and 4900. Mean digital radiance values are shown for bands 3, 4, 5, and 6 for the test areas (slices) as a function of pixel and of mean scan line in Figure 3. Again bands 1 and 2 behaved similarly to band 3 and band 7 behaved similarly to band 5. Bands 1 to 4 show weaker systematic trends than the 2 August 1982 image of the same area. Random variation appears generally to be of the order ±5 percent in digital radiance values, while there is no obvious symmetry in the systematic component of variations in bands 1 to 3. Band 4 shows approximately a 20 percent decrease in radiance for the southern portion of the image, but no such trend in the middle or for the northern region. The dependence on mean scan line seems pronounced only for bands 5 to 7. Band 6 does show the same general increase to the east as for the October 1982 image, analyzed in Figure 2.

The coefficients of variation of the pixel radiance values for bands 3, 4, 5, and 6 are shown in Figure 3 for the windowed areas (slices) described by the overlay mask, plotted as a function of pixel and of mean line. The CVs were found to be below 0.08 for band 1 and generally below 0.10 for band 2, with a random variation of up to 30 percent and with only a slight systematic decreasing trend to the northeast. In band 3, the CV is 0.25 at the west edge of the image, falling to 0.15 or less toward the east. The decrease is more pronounced in the north of the image than is the case in the south. In band 4, the CV is generally less than 0.18, with a random variation of up to ±20 percent and a slight decrease from west to east in the south of the image. The situation is similar in band 5. The thermal infrared (IR) band, TM band 6, shows CV values less than 0.04, which exhibit a general decrease in trend from west to east in the south of the image and a general decrease from south to north, which is more pronounced in the east of the image. Band 7 has higher CV values (up to 0.40). There is a decrease from west to east and a slight decreasing trend from south to north. However, while the thermal IR band (band 6) shows the northeast region of the image to exhibit the lowest variance, bands 4, 5, and 7 (reflected-to mid-IR) show high variance. This may indicate a higher heterogeneity in growth stage in this region.

The analysis on the August 1982 image, when compared to that performed on the August 1984 image suggests that the systematic variations across an image depend on time. This may be related to the substantial nonuniform changes with Julian date in both the level and angular dependence of radiance recorded over the crop areas of the United States Great Plains by the AVHRR, as reported, for instance, by Duggin and Piwinski (1984). Atmospheric changes and variations at ground level can occur between image acquisitions. For example, some cloud was observed on the August 1984 image, while none was observed for the August 1982 image, suggesting that the atmospheric moisture content on the two dates was different.

Factors contributing to radiance changes across

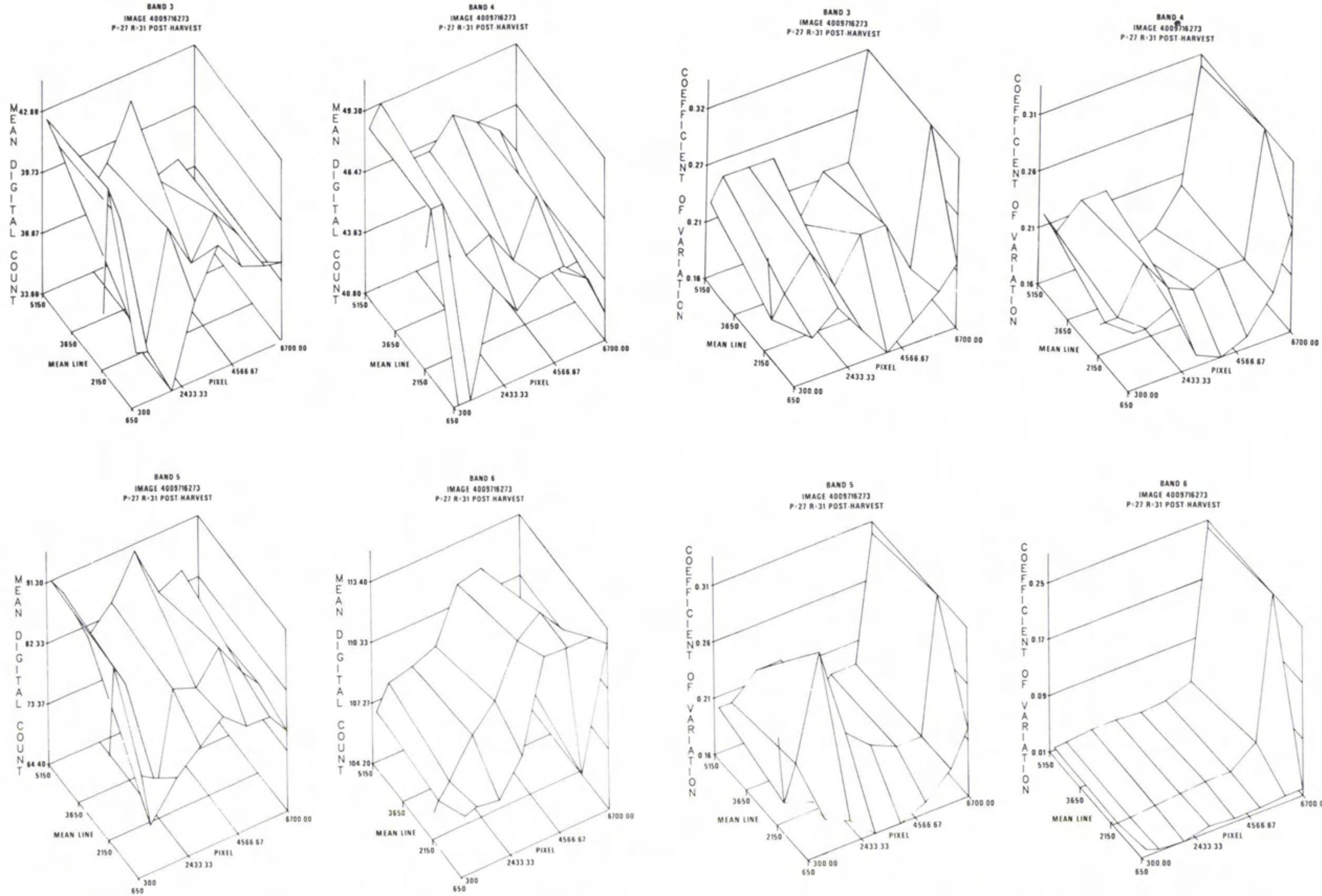

FIG. 2. The mean digital radiance values and coefficients of variation for bands 3, 4, 5, and 6 for the rectangular 4800-pixel sample slices of the mask described in the text, plotted as a function of scan angle (pixel) and of mean scan Line for the postharvest image no. 4009716273, path 27, row 31, 21 October 1982.

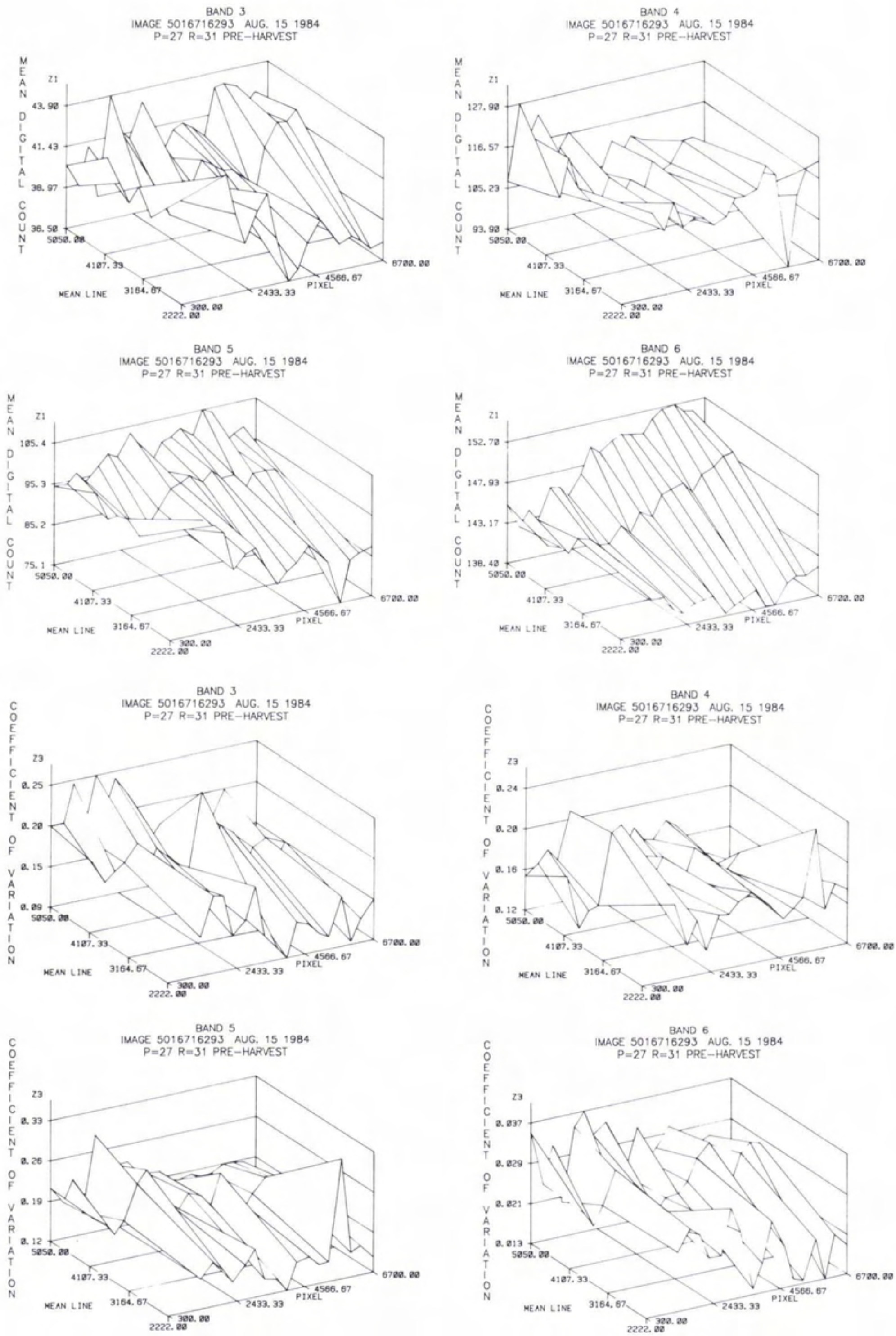

FIG. 3. The mean digital radiance values and coefficients of variation for bands 3, 4, 5, and 6 for the rectangular sample slices of the mask described in the text, plotted as a function of scan angle (pixel) and of mean scan line for the preharvest, 15 August 1984 Landsat-5 Thematic Mapper image no. 5016716293, path 27, row 31.

an image are atmospheric changes across the imaged area, together with atmospheric scattering anisotropy and hemispherical-conical spectral reflectance anisotropy which is dependent on sun-target-sensor geometry, as mentioned earlier. However, while these effects will be substantial for a large scan angle range, covering a large area, such as the AVHRR (±55°), one would expect these effects to be less for the TM, whose scan angle range is only ±7.7°.

It has been noted (Duggin, 1974, 1983) that the random variation to be expected in recorded radiance will arise partly from random variations in atmospheric transmission and partly from variations in irradiance: reported coefficients of variation are approximately 0.06 (Duggin, 1974, 1983). It has also been reported (Duggin, 1983) that ground reflectance measurements made at 80 m spacings in the MSS bandpasses show between 0.05 and 0.20 coefficient of variation. Systematic recorded radiance variation due to atmospheric scattering and bidirectional reflectance factors anisotropy might be expected to give rise to substantial scan angle dependence for large scan angle ranges (such as 55° for the AVHRR). However, random variations might be expected to predominate over systematic variations for the smaller scan angular range (±7.7°) for the Thematic Mapper. It is also interesting to note that the range of random variation before and after harvest in 1982 is not markedly different and that the same range of variation appears to apply to the August 1984 images.

CONCLUSIONS

This study cannot be considered exhaustive: indeed, it is still in progress as the multidate data continue to arrive. However, several conclusions are suggested by this work. While some systematic trends in radiance values with scan angle were observed prior to harvest over a crop area in 1982, the same pattern was not repeated two years later. It appeared that the random variation in mean digital values recorded from 4800 pixel sample areas at regular intervals across an image in three swaths generally exceeded the systematic variations for the three images studied, and that the coefficients of variation were within those which might be expected to occur from prior measurements. The coefficients of variation of the digital values from the 4800 pixel areas selected as regular intervals across an image showed some scan angle dependence but were more dependent upon bandpass than upon season or upon scan angle.

Random variations may affect image classification accuracy. Further, uncorrected systematic variations across and between images may impose restrictions on the level of classification accuracy which may reasonably be expected from automated classification of single date or multidate, multichannel digital Thematic Mapper data for the quantification and identification of terrestrial features in a nonphotointerpretive fashion. It is therefore important to understand the restrictions which such variations inherent in the digital radiance data may place upon analyses. To this end, further work is needed in which further empirical studies of digital radiance data are used to determine optimum regimes of data acquisition and analyses for selected feature identification and quantification.

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