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# AGRICULTURAL APPLICATIONS FOR THERMAL INFRARED MULTISPECTRAL SCANNER DATA

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## ABSTRACT

Remote sensing in agricultural research has traditionally been focused on the reflective portion of the spectrum. Recent advances in thermal infrared remote sensing are adding a new dimension to agricultural studies through digital image analysis. This paper will briefly discuss preliminary findings on the utility of the Thermal Infrared Multispectral Scanner (TIMS) for several agricultural applications in plant studies, soil studies, hydrologic and topographic concerns, inventory and monitoring of conservation and other man-induced agricultural practices, and cartographic feature extraction. Multiple sets of TIMS data were acquired over a highly agricultural test site in the Coastal Plain region of southeast Alabama. Data sets were acquired during the spring for maximum bare soil exposure, however, a large percentage of fields had maturing small grain crops or very young corn enabling studies of both vegetative and soil thermal responses. Both predawn and afternoon data sets were obtained to evaluate minimum/maximum diurnal effects on thermal response and each predawn-afternoon pair was collected at three spatial resolutions (5, 10, and 30 meters) to analyze the effect of cell size on data information content. Multiple-band digital thermal data of this type should prove quite useful in several agricultural and global process models.

## I. INTRODUCTION

Much of traditional remote sensing in agricultural research has been limited to the reflective portion of the spectrum. However, advances in thermal infrared remote sensing are adding a new dimension to image analysis. Terrestrial surfaces including soil, water, vegetation, and man-made materials exhibit different thermal spectral responses (Buettner, 1965).

Variations in moisture content, texture, bulk density and porosity are important in influencing remotely sensed soil thermal spectral responses (Meyers and Heilman, 1968). Of these, moisture content is one of the more important factors affecting temperature and emissivity in both soils and vegetation and clearly the means by which hydrologic features are identified. Blanchard, et al., (1974) found that most soils had emissivities of 0.7-0.9 compared to 1.0 for an ideal blackbody. Water bodies approach the emissivities of blackbodies while vegetation is often considered a "grey body" with emissivities near 0.95.

Knowledge of the factors influencing soil and plant thermal responses and the way they are manifested in remotely sensed data can be very instructive in understanding and monitoring a variety of agricultural conditions and processes. Models can be developed which can predict diurnal surface temperature changes (Kahle, 1977) monitor soil moisture conditions (Idso, et al., 1975) or plant canopy temperatures for stress (Myers, et al., 1970). Other procedures can utilize remotely sensed data to identify conservation practices (Pelletier, 1985) and study topographic features (Mahrt and Heald, 1981).

Agriculturally-related applications of data acquired with the Thermal Infrared Multispectral Scanner (TIMS), an airborne thermal sensor operated by NASA/NSTL, will be discussed in this paper. The 8.2-12.2μm range of the sensor is nominally covered by six bands (8.2-8.6 μm), (8.6-9.0μm), (9.0-9.4μm), (9.4-10.2 μm), (10.2-11.2μm), and (11.3-11.6μm). The sensor has an instantaneous field of view of 2.5 milliradians; a total field of view of 76°; and a ground resolvable temperature of approximately 0.2°C, depending on the band. In addition to the work conducted by Pelletier (1985) in identifying conservation practices a number of other vegetation studies have been conducted using the TIMS (Anderson, 1983; Anderson, 1984; and Sader, 1984) as well as archeological investigations (Sever, 1983). Kahle, et al. (1983) has also investigated the use of the TIMS sensor for geological applications and continues research in this area today. These geologic applications with the TIMS should prove very instructive in future soils research with this sensor.

## II. APPLICATIONS

Multiple applications exist for plant studies, soil studies, hydrologic and topographic concerns, inventory and monitoring of conservation and other man-induced agricultural practices, and cartographic feature extraction. This paper will discuss the utility of Thermal Infrared Multispectral Scanner data for several applications in agricultural landscapes. However, many of these applications may prove useful in other landscapes as well.

### A. SITE AND DATA DESCRIPTION

The research reported here are preliminary findings from the use of the TIMS over a test site in the Coastal Plain region of southeast Alabama. More than half the hectarage in this area is in row crops and pasture with corn, small grains, soybeans and peanuts representing the majority of the land planted to row crops. The predominating soil types belong to the Paleudult great group and are represented by the Dothan (Plinthic Paleudult), Orangeburg (Typic Paleudult), and Red Bay (Rhodic Palendult) series which are all deep, well-drained upland soils with sandy loam surfaces and sandy clay loam subsurface horizons and low in organic matter. The land is very subject to erosion and most fields have been terraced in recent decades.

Data sets were acquired during the spring (early May) for maximum bare soil exposure, however, a large percentage of fields had maturing grain crops or very young corn enabling studies of vegetative thermal responses as well as soil response. Both predawn and afternoon data sets (afternoon first and the following morning) were obtained to evaluate minimum/maximum diurnal effects on thermal response. Each predawn-afternoon pair was collected at three spatial resolutions (5, 10, and 30 meters) to analyze the effect of cell size on data information content. All data were processed with the Earth Resources Laboratory Applications Software (ELAS), (Junkin, et al., 1980).

### B. PLANT STUDIES

During the heat of the day water bodies in thermal imagery will generally appear as the coolest (darkest) features in the scene (Figure 1). Thermal response will increase next with dense forested canopies, peak-season rowcrops and pasture areas while soil response can be quite high but more variable within a field due to factors discussed later. During the night (actually just predawn) the water bodies in the thermal imagery will generally appear as the warmest (brightest) features in the scene followed closely, in this case, by paved asphalt roads (Figure 2). The rest of the scene, however, displays considerably less contrast than the daytime image yet the feature/thermal response relationships continue to appear reversed. These relationships are caused by differences in thermal inertia such that water bodies exhibit a very high thermal inertia while soils have a much lower thermal inertia and vegetation and mixed classes between vegetation and soil will experience intermediate phases of thermal inertia (Pratt and Ellyett, 1979; Price, 1977).

Crop/plant vigor and canopy density can often be inferred from thermal data with assistance from training samples. Mature crops ready for harvest and diseased plants or those under water stress are more susceptible to extremes in temperature caused by diurnal fluctuations than healthy, vigorously growing plants. When night and day thermal images are overlaid, a large difference in thermal response can be used to differentiate mature or stressed plants from healthy vegetation of the same type which have small differences in temperature. In some cases these thermal response differences are indicative of different crop/plant types and may be valuable for classification purposes. This relationship is illustrated by the fields near position A in Figures 1 and 2. Other observations indicate that low density vegetation levels (e.g., very young crops), though they may still appear as bare soil within the reflective portion of the spectrum, can often be determined from TIMS data (example of adjacent fields near position B in Figures 1 and 2).

## C. SOIL STUDIES

In order to understand thermal properties of soils one must understand those factors that affect soil temperature; (1) those that influence the amount of heat available at the soil surface and (2) those that influence the dissipation of the available heat (Hanks and Ashcroft, 1980). Soil color and soil mulch, which are largely dependent upon mineralogy and organic matter content, are the major factors that influence the amount of heat received by the soil surface, while water content and bulk density are those primary factors responsible for heat dissipation within the soil.

While porosities often vary from 30 percent for fallow soil to near 60 percent for freshly tilled soil (Chudnovski, 1962), Moga (1962) observed that heat conduction drastically decreased when porosity increased above 30 percent. Such changes in porosity plus moisture content could be responsible for the greater variability in temperature over a bare field than a vegetated one as observed by Millard et al., (1981). This kind of variation was reported to be as large as $6^{o}$C in studies conducted in California by Hatfield et al., (1982). Position C on Figures 1 and 2 illustrate two bare soil fields - the one on the bottom more recently plowed (higher moisture content and higher porosity) than the field on the top.

While the relative effective radiant temperature relationships for vegetated areas within a band remain near constant between bands the thermal spectral response from soil may vary. Mineralogy can in certain cases be responsible for significant variation between bands. Erosion gullies comprised of high quartz content sandy materials exhibit low thermal response in bands 1 and 3 due to the reststrahlen band while having a high response in band 5 (Figures 4 and 5 - position a). Sand textured material in eroded fields illustrate the same relationship (Figures 4 and 5 - position b).

The relationships between channel 3 (band 3) and channel 5 (band 5) in Figure 4 (Day) are illustrated by a scattergram in Figure 6. Vegetation stretches along the A axis, bare soil clusters near C and low density level vegetated fields cluster near B. As the season progresses B and C population nodes would subside and trend nearer to A. Figure 7 illustrates the same relationship between channel 3 and channel 5 of the night set in a population scattergram. In this scattergram, however, vegetation and soils fall closely together at A while the water stands out at B.

In addition to the importance of relative thermal response changes for soils study is the determination of absolute temperature values. The knowledge of absolute temperature (possible with atmospheric correction of the thermal data) can be useful in determining planting date. Absolute temperature values obtained from digital thermal data are also useful in studies of evapotranspiration.

## D. HYDROLOGIC AND TOPOGRAPHIC CONCERNS

Near-surface soil moisture patterns and true hydrologic features, on a large scale, can also be identified with thermal data. The presence of water in the soil tends to stabilize the temperature gradient causing moist soil to appear cooler than surrounding areas in the day and warmer during the night. With this source of digital data alone and in situ measurements, or in addition to reflective digital data, hydrologic modelling takes on a new dimension. Figure 8 illustrates 30 meter resolution afternoon data of the entire test site. This image shows a good overview of the drainage network at this scale, whereas larger scale analysis and finer resolution as illustrated in Figure 1 will show smaller moisture patterns. Figure 9 illustrates 30 meter resolution predawn data of the test site. In this image, water bodies become a dominant feature, appearing quite bright. Notice the water within the river channel in the upper left plus the warming influence of the soil moisture immediately adjacent to the channel. The medium-toned areas in the body of the image are generally vegetated fields, though moisture patterns are also noticeable.

Topography can also have an effect on thermal response. South facing slopes will appear warmer than North facing ones and hills will be more susceptible to climatic effects than valleys. In Figure 9 the sharp drop in elevation along the major stream networks allowed cool air to settle in them since this area experienced a fairly calm, unclouded night just prior to the acquisition of this data.

## E. CONSERVATION PRACTICE INVENTORY

Many conservation and agricultural practices appear strikingly in thermal data. Terraces are quite evident due to a moisture differential in the soil (and subsequent temperature gradient), therefore altering spectral response either directly from the bare soil itself, or indirectly through a moisture stress effect on the vegetated canopy. Figure 1 illustrates several terraced fields with the warm (bright) areas being the crests of terraces since they are drier than the adjacent troughs). In Figure 2 the wetter troughs appear warmer.

Other features important in conservation practice inventories are grassed waterways and field drainage ditches which, due to accumulation of soil moisture, are also easily identified in thermal data. Erosional gullies, as mentioned before, can often be identified in thermal data when their mineral composition is significantly different from the surrounding area.

### F. CARTOGRAPHIC FEATURE EXTRACTION

Through a series of data enhancement techniques, including principal component analysis and high-pass band filtering, many cartographic features can be enhanced and extracted. In addition to the terraces, grassed waterways, field drainage ditches and erosional gullies noted above, field hedgerows can often be identified (Figure 10). Roads can be classified and delineated from soil more easily with thermal data than with reflective data due to the highly emissive thermal properties associated with the increased bulk density of asphalt road material. Streams and open water bodies are as easily delineated.

The feature extraction output derived from such filtering procedures has great potential use in agricultural models developed for field-scale analysis. In the Universal Soil Loss Equation (USLE), for example, man-induced topographic changes such as drainage ditches, terraces, and the slightly elevated areas along fence rows must be considered along with natural topography if they alter the runoff direction by changing slope length. Other uses of extracted hydrologic features could prove quite useful in area-wide hydrology studies.

### G. SPATIAL RESOLUTION

As with reflective data, as resolution cell size increases the information content decreases. Figure 11 illustrates a 10 meter afternoon image acquired with the TIMS while Figure 12 illustrates a 30 meter afternoon image acquired over the same area just minutes earlier. Most all the features discernible in the 5 meter data are maintained in the 10 meter data, though the data has lost some definition. The 30 meter data maintains basic field outlines and tone but has lost all definition of terraces, gullies, and other agricultural features which generally have spacings less than 30 m. The only suggestion of such features now exists in the fact that the fields containing them exhibit higher spectral variability than the surrounding bare soil or dense forest vegetation. Scattergrams from 30 meter data also lack the well-defined characteristic population nodes exhibited as in Figures 3 and 6 (from 5 meter data) due to the increased amount of mixed or border pixels.

## III. SUMMARY

While much of traditional remote sensing in agricultural research has been limited to the visible and reflective IR, advances in thermal infrared remote sensing are adding a new dimension to image analysis. While a number of broad-band thermal infrared sensors have been developed and utilized in the past the Thermal Infrared Multispectral Scanner (TIMS) allows for narrow-band analysis in the range of 8.2-11.6 μm at spatial resolutions down to 5 meters in cell size. Due to the presence of multiple bands, emissivities of land surfaces may be calculated. While the thermal response of many surfaces (e.g., vegetation) change only relatively between bands, important soil properties can be determined through analysis of band-to-band differences.

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## V. BIOGRAPHICAL SKETCHES

Ramona E. Pelletier was born in Fitchburg, MA. She received the B.S. and M.S. degrees in Agronomy and Soil Science from Auburn University. She has been employed in the Earth Sciences Division of the NASA/NSTL/Earth Resources Laboratory since January 1982 and has been a Principal Investigator for a number of soils and agriculturally related remote sensing projects including those under the joint program for Agriculture and Resource Inventory Surveys Through Aerospace Remote Sensing (AgRISTARS). Her recent work has focused on the investigation of soil properties through remote sensing and modelling.

Michael C. Ochoa was born in Los Angeles, CA in 1960. He received the B.S. degree in soil science from Auburn University in 1983. He is presently working towards the M.S. degree in soil science through a co-operative arrangement between Auburn University and the NASA/NSTL/Earth Resources Laboratory where he is primarily involved in developing techniques to use Thermal Infrared Multispectral Scanner (TIMS) data in agricultural research with special emphasis on soils.

Benjamin F. Hajek received the B.S. degree in Agronomy from Texas A&M and the M.S. and Ph.D. degrees from Auburn University in soil science. He worked as a soil scientist at the Soil Survey Laboratory in Beltsville, MD; was manager of a soil science unit with Battelle Memorial Institute in Richland, WA; and is currently professor of soils in the Agronomy and Soils Dept. at Auburn University. He has worked in the areas of soil classification, genesis, mineralogy and the characteristics and productivity of eroded soils; and is currently investigating surface soil properties that influence the thermal response of soils.

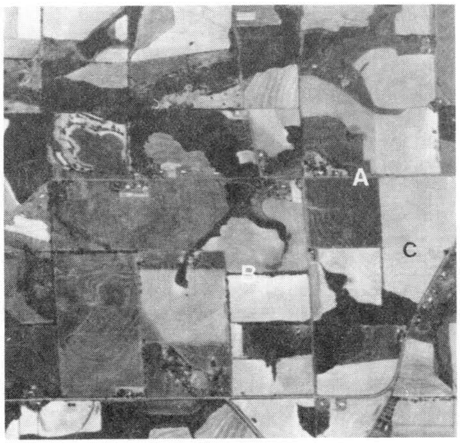

Figure 1. Raw band 5(10.2-11.2 μm), 5 meter - afternoon TIMS data.

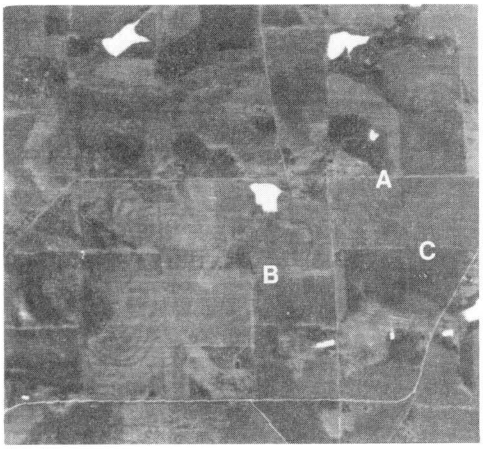

Figure 2. Raw band 5(10.2-11.2μm), 5 meter - predawn TIMS data.

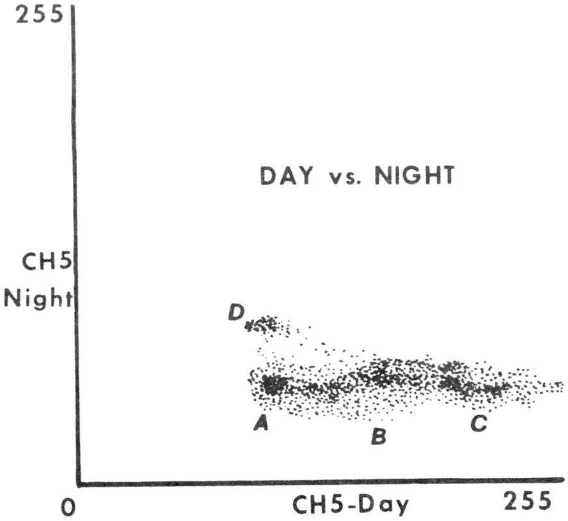

Figure 3. Scattergram of raw thermal response values for channel 5 (10.2-11.2 μm) 5 meter day vs. night TIMS data.

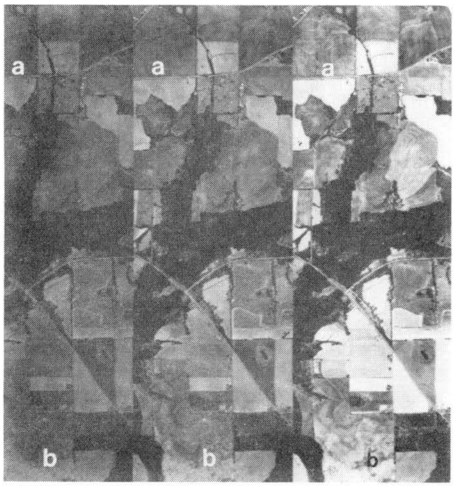

Figure 4. Raw bands 1(8.2-8.6µm), 3(9.0-9.4µm), and 5(10.2-11.2µm), 5 meter - afternoon TIMS data.

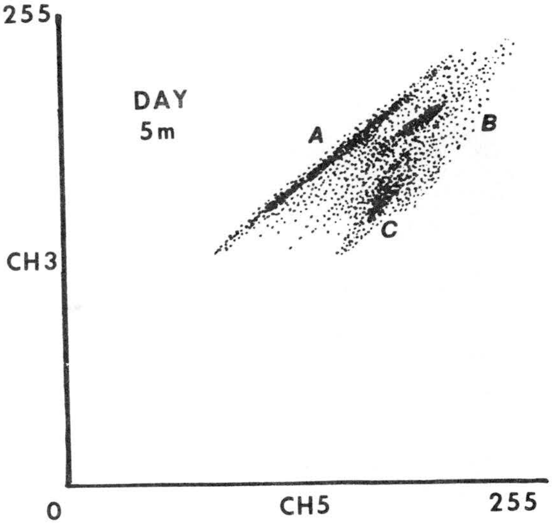

Figure 6. Scattergram of raw thermal response values for Channel 5(10.2-11.2 µm) vs. Channel 3(9.0-9.4µm), 5 meter - day TIMS data.

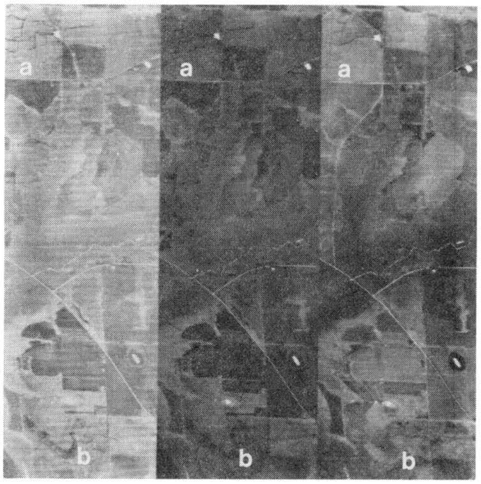

Figure 5. Raw bands 1(8.2-8.6µm), 3(9.0-9.4µm), and 5(10.2-11.2µm), 5 meter - predawn TIMS data.

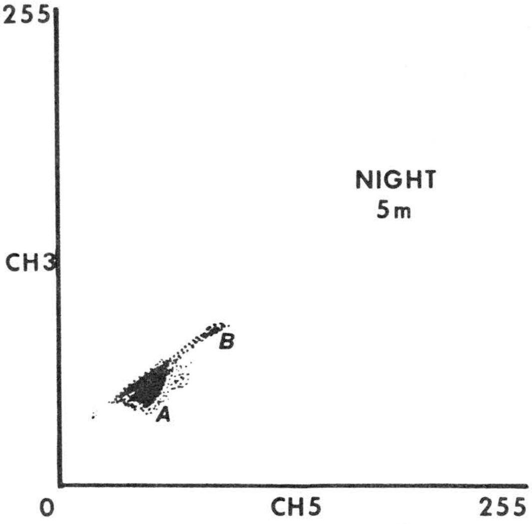

Figure 7. Scattergram of raw thermal response values for channel 5(10.2-11.2 µm) vs. channel 3(9.0-9.4µm), 5 meter - night TIMS data.

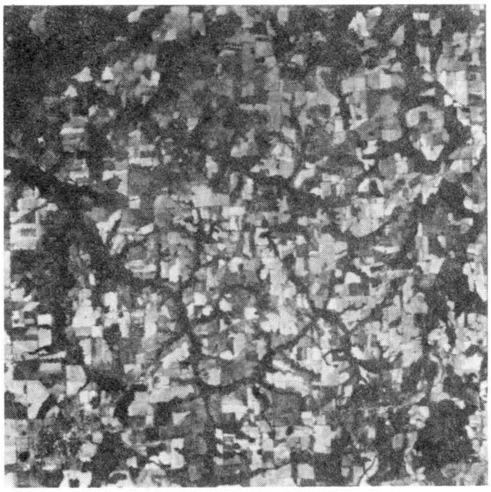

Figure 8. Raw band 5(10.2-11.2μm), 30 meter - afternoon TIMS data.

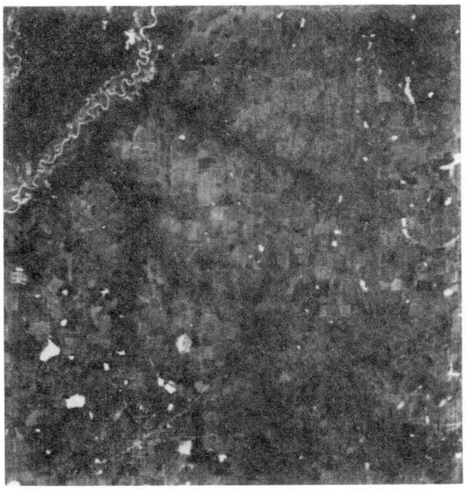

Figure 9. Raw band 5(10.2-11.2μm), 30 meter - predawn TIMS data.

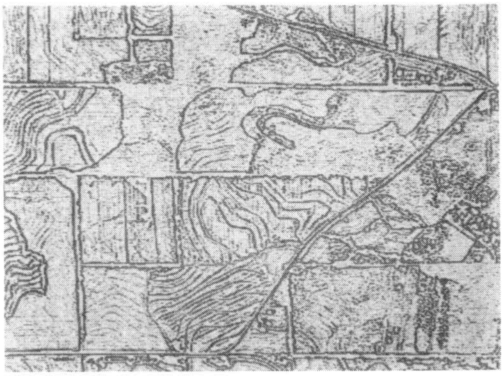

Figure 10. Linear feature extraction from high-pass band filtered 5m, afternoon TIMS data.

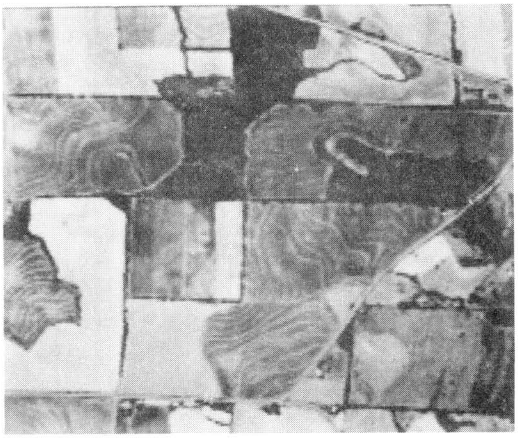

Figure 11. Raw band 5(10.2-11.2μm), 10 meter - afternoon TIMS data.

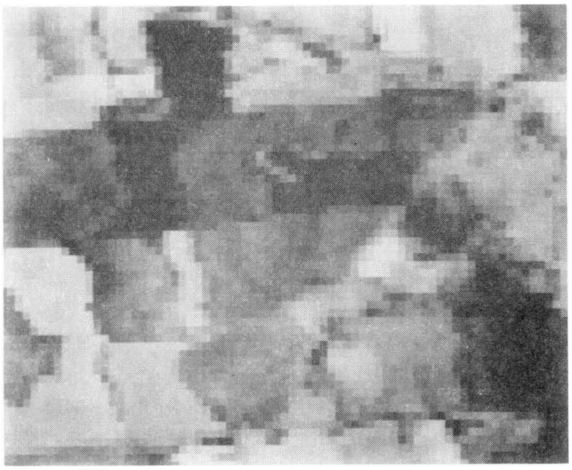

Figure 12. Raw band 5(10.2-11.2μm), 30 meter - afternoon TIMS data.