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SPACE SCIENCES LABORATORY

ANALYSIS OF THE QUALITY OF IMAGE DATA ACQUIRED BY THE LANDSAT-4 THEMATIC MAPPER AND MULTISPECTRAL SCANNERS

Principal Investigator

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Space Sciences Laboratory
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Berkeley, CA 94720

Period of Performance

January 3, 1983 - August 13, 1984

Quarterly Status and Technical Progress Report #4
October 1, 1983 - December 31, 1983

UNIVERSITY OF CALIFORNIA, BERKELEY

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1.0 TECHNICAL PROGRESS REPORT

Our research during this quarter was focused on 1) the preparation and presentation of technical material for several meetings and documents; 2) the continuation of the geometric analysis of TM film products; and 3) the initial investigation of the quality of TM data acquired over our forestry study area and processed through the new Thematic Mapper Image Processing System (TIPS).

1.1 Preparation and Presentation of Technical Material

1.1.1 PECORA VIII Symposium

Based on the invitation to present our TM image quality research results at the PECORA VIII Symposium, a paper was prepared and presented during the symposium (October 5, 1983). The paper was compiled from previous reports and will be published in the proceedings of the Symposium during 1984.

1.1.2 Development of General Electric Brochure Material

At the request of Mr. David J. Wright, General Electric (Space Systems Division) we prepared narrative and illustrative material for the new Landsat-4 brochure being prepared by General Electric. Our early work illustrating the usefulness of TM Band 5 for discriminating crop types on single-date imagery is being highlighted in the agricultural section of the brochure. In addition to photographic illustrations, generalized graphs were prepared showing the relative spectral response for several cover types for each reflective TM band. A short narrative was drafted indicating the improved quality of the TM data and its usefulness in agricultural surveys.

1.1.3 Preparation of IEEE Geoscience and Remote Sensing Paper

At the invitation of Dr. Vincent V. Salomonson, serving as Volume Editor, we prepared a manuscript highlighting our results to date on the analysis of TM and MSS image quality focusing on one aspect, namely, the spectral variability of selected agricultural and forest cover types in California. The paper summarized our initial work within a small agricultural area in the San Joaquin Valley on the Landsat-4 scene acquired December 8, 1982, and within the NASA-Bucks Lake Forestry Study Site in the northern Sierra Nevada on the Landsat-4 scene acquired August 12, 1983. The early results from the forestry study site are included in this quarterly report in Section 1.3. The special issue of the IEEE Transactions on Geoscience and Remote Sensing highlighting early evaluations of Landsat-4 TM and MSS data is scheduled for April 1984.

1.1.4 Third Landsat-4 Investigator's Workshop

Material was prepared and presented at the Third Landsat-4 Investigator's Workshop on December 6-7 at NASA-Goddard Space Flight Center. The presentation was designed to highlight only the progress made to date since the last Investigator's Workshop. Since we had previously presented material at the Early Results Symposium, the ASP Annual Convention and the PECORA VIII Symposium, only those results recently obtained from the forestry study site were presented. Tabulated summary statistics and photographic images of both the TM data and color aerial oblique photographs taken simultaneously to the Landsat-4 overpass were presented. These data and selected color images presented at this workshop are reproduced in Section 1.3.

1.1.5 Presentation to Local Groups and Visitors

During this reporting period several presentations on our recent results were given at meetings of local professional organizations and to distinguished visitors of both the Department of Forestry and Resource Management and the Space Sciences Laboratory. Highlights of these presentations were the viewing of high quality photographic images created from both the TM and MSS digital data by the EROS Data Center, the IBM Palo Alto Scientific Center, and NASA-Goddard Space Flight Center. A detailed listing of these presentations is provided in Section 2.2.

1.2 Geometric Analysis of TM and MSS Film Products

1.2.1 Background

The geometric quality of the TM and MSS film products are being evaluated by making selective photo measurements such as scale, linear and area determinations; and by measuring the coordinates of known features on both the film products and map products, and then relating these paired observations using a standard linear least squares regression approach. The major emphasis of our work is to analyze the film products from Landsat-4 that are generally accessible to the user community. There were three types of Landsat-4 film products being generated at the EROS Data Center (EDC) and the Goddard Space Flight Center (GSFC): (1) standard multispectral scanner (MSS) film products, (2) "interim" Thematic Mapper (TM) analytical film products, and (3) LAS-Scrounge TM "engineering" film products. The standard MSS film products are generated at the EDC using the CCT-PM digital data with a Laser Beam Recorder (LBR) to produce master film copies for black-and-white and color composite reproduction. The "interim" TM analytical film products were generated at EDC using the return beam vidicon (RBV) image production system to make the first generation

working masters during the Scrounge environment and prior to the operational film generation under the TIPS environment. The LAS-Scrounge TM "engineering" film products were generated at GSFC for engineering purposes, archiving, and routing with CCT orders for LIDQA investigators.

The interim TM film products are being used for our analysis because they most closely represented those products that would be used by the user community and were the only film products available at the time of our investigation. Originally, these products were to be generated by the LAS-Scrounge during the pre-TIPS environment, but as the demand for these products increased, arrangements were made to have the EDC produce the products using the RBV image production system. Using the CCT-PT data, EDC produced the film masters using the LBR and the supporting computer system formerly dedicated to RBV film production. In order to adapt the TM data to this system, the resulting "interim" TM analytical film product represented only a sub-area of a full TM scene produced under operational conditions (Figure 1). The interim TM film product represents approximately 72 percent of the area of a full TM scene. The format is 5322 x 5322 pixels, centered on the full scene, with a resulting image of 20.2 x 20.2 cm covering a land surface area of approximately 2,300,590 ha. (5,684,760 ac.).

1.2.2 Approach

A seven step procedure is being used to evaluate t ᵔ geometric properties of the TM film products.

(1) Select the image product to be analyzed. A two times enlargement of interim Band 7 image T0318-007 (Path 044, Row 033) covering the southern Sacramento Valley on 1 February 1983 will be selected for this study. This particular scene is selected because (1) it was currently available, (2) with the exception of small portions of the image, it was cloud free, (3) this Band provided a sharp image of moderate contrast, and (4) the area covered represented a wide range of land use and elevational zones. The major limitation of using this image was that due to the low sun elevation at the time of image acquisition (26 degrees) many of the steep canyons in the wildland areas in the western and northern portions of the scene were deeply shadowed. We felt that this limitation was outweighed by the facts that (1) the image in its two time enlarged format was available, and (2) all the small water bodies were at the maximum water levels which would allow for better precision in selecting control points.

(2) Grid the image into nine equal area blocks. The TM image will be gridded to ensure that the control points will be evenly distributed throughout the image, and that they will represent all elevation zones and land use patterns present in the image (Figure 2).
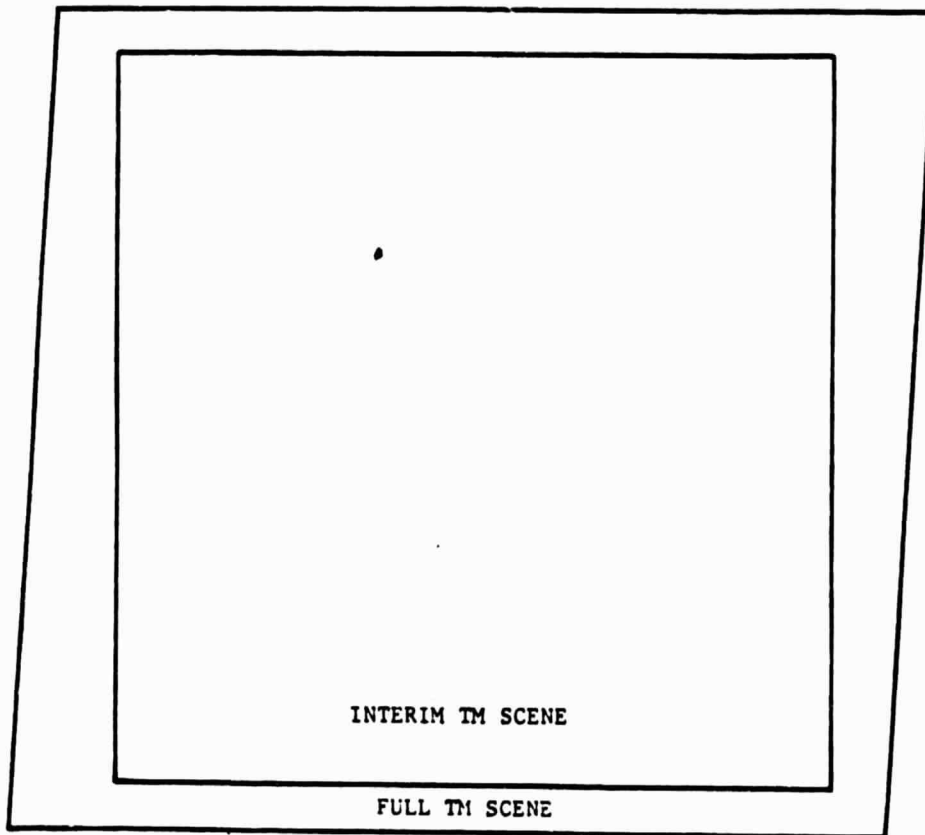
Figure 1. Spatial relationship between the TM full
scene film product and the interim TM film
product. The interim product is shown at
reduced scale to illustrate the 72% re-
duction in ground area coverage.

Scene T0318-007, Path 044, Row 033, 01 February 83

Figure 2. Schematic of the gridded TM scene. The scene
was gridded into nine equal area blocks to
ensure that the control points would be evenly
distributed throughout the image. For each
block, 40-50 control points were selected.

(3) Select control points. The control points selected to represent those natural and cultural features that can be located reliably on both the TM image and on United States Geological Survey 7 1/2' quadrangle maps. I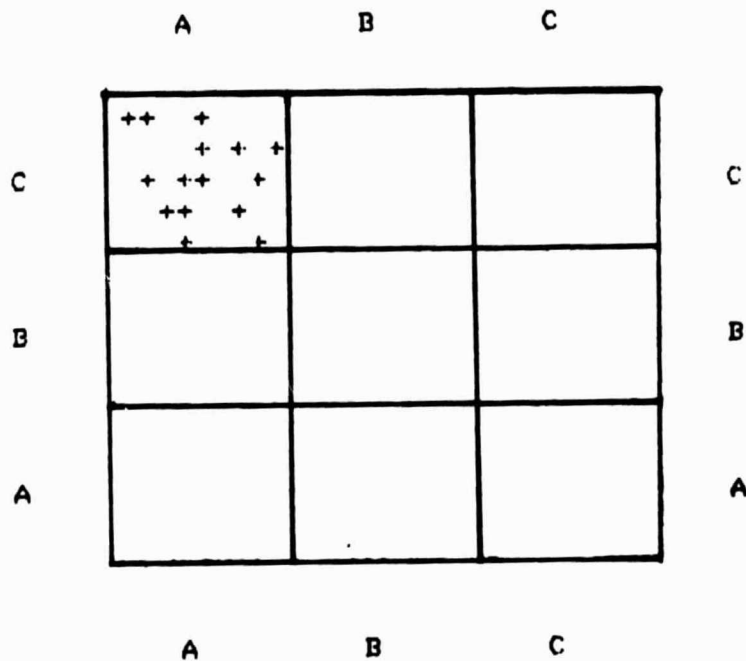n the agricultural areas, these features will be predominantly field intersections or irrigation ditches; in the urban areas they will be predominately major road intersection or airfield runways; in the wildland areas they will be water bodies, stream courses, and converging points of ridges and canyons. Each control point will be pin pricked on the image with a corresponding annotation made on the map sheet with a .30mm pen. Approximately 40 to 50 control points will be selected for each block on the TM image, and they will be located on 144 map sheets that represent the area of the image.

(4) Measure image and map coordinates for control. The x and y coordinates of the image control points will be measured to the nearest 0.001 inch (25.4×10^{-6} m.). The corresponding UTM east and north map coordinates will be scaled off the map sheets to the nearest 10 meters ground distance.

(5) Check for image and map coordinate errors. In order to check for digitizing and map scaling errors, a first order regression between map and image coordinates will be performed using the program developed by Daniel (1971). For those coordinate pairs for which the residuals are excessive, the digitized and map coordinates will be verified, and changed where appropriate.

(6) Develop regression between image and map coordinates. Using the odd numbered control points, first and second order regressions will be developed between the image and map coordinates.

(7) Evaluate the geometric properties of the image. Using the regression developed in (6) the map coordinates of the even numbered control points (test points) will be predicted using the corresponding digitized image coordinates. The residuals, summarized by blocks, will be plotted; and an analysis of variance (ANOVA) will be performed on the residuals using the nine blocks as treatments. In addition, first and second order regressions between the image and map test points will be developed and the resulting coefficients will be compared with those calculated in (6).

1.2.3 Results to Date

At this time, the first five steps of this procedure have been completed. A summary of this work is given in Table 1. A total of 476 control points have been selected. Of these, 238 have been designated as "test points". These points are currently being

Table 1. Summary of Control Point Selection for Scene T0318-007 (Path 044, Row 033), 01 February 1983

BLOCK	CLOUD COVER (%)	ELEVATION RANGE OF POINTS (FEET)	NUMBER OF REGRESSION POINTS	NUMBER OF TEST POINTS	GEOGRAPHIC DESCRIPTION	PREDOMINANT LAND USE*
AA	10	14-2080	27	27	Napa Valley; Coast Range	3, 1, 4
AB	50	5-384	17	17	Coast Range, Sacramento Valley	1, 3, 4
AC	5	0-391	22	22	Sacramento Valley; Sierra Nevada foothills	1, 3, 4
BA	15	43-1960	30	30	Coast Range; Sacramento Valley	3, 1
BB	0	20-199	27	27	Sacramento Valley	1
BC	0	20-2000	27	27	Sacramento Valley; Sierra Nevada foothills	3, 1, 4
CA	0	54-1540	33	33	Coast Range; Sacramento Valley	1, 3
CB	0	48-1384	26	26	Sacramento Valley; Sierra Nevada foothills	1, 3
CC	0	200-3540	29	29	Sierra Nevada foothills and mountains	2, 3
			238	238		

*LAND USE CODE (from: Durrenberger and Johnson, 1976)

    1   Cropland and pasture - irrigated or unirrigated

    2   Forest and woodland - grazed or ungrazed

    3   Open shrub woodland - grazed

    4   Urban

tested and edited for digitizing and scaling errors. This process
and the final evaluation will be completed during the next re-
porting period (June - March 1984).

1.2.4 Literature Cited

Daniel, Cuthbert and Fred S. Wood. 1971. Fitting equations to
    data. Wiley-Interscience, New York.

Durrenberger, Robert W. and Robert B. Johnson. 1976. California -
    patterns on the land. Fifth edition. Mayfield Publishing
    Company.

1.3 Early Evaluation of TM and MSS Data for Selected Forest Cover Types

1.3.1 Background

The objectives for this phase of our research are to: (1)
develop a basic understanding of the TM data of forested environ-
ments with regard to spectral characteristics and variability,
spatial resolution, and radiometric sensitivity, and (2) determine
the extent to which major forest cover types can be detected and
identified on TM digital and image products.

Our forestry study site is located in Plumas County, approxi-
mately 265km northeast of San Francisco. The area contains a
diversity of forest cover types ranging from stands of red and
white fir (*Abies magnifica* and *A. concolor*, respectively) to stands
of mixed conifer dominated by Ponderosa Pine (*Pinus ponderosa*),
Douglas-fir (*Pseudotsuga menziesii*), and/or Sugar Pine (*Pinus lam-
bertiana*). Several other cover types are also prevalent and include
low density Jeffrey Pine (*P. jeffreyi*) stands on soils derived from
ultramafic parent material; hardwood stands; dense shrub fields; wet
and dry meadows; bare soil; granitic rock outcrops; and large water
bodies.

1.3.2 Approach

The first Landsat-4 scene for this site was acquired on 12 August
1983 (#84039218143, WRS Path 44, Row 32). The TM data were trans-
mitted to GSFC via the Tracking and Data Relay Satellite System (TDRSS)
and the TDRSS receiving station at White Sands, New Mexico. The TM
data were processed by the Thematic Mapper Image Processing System
(TIPS) at GSFC as a "P" tape. The simultaneously acquired MSS data
were purchased from the EDC as a "P" tape (CCT-PM). These data were
received at U.C. Berkeley on October 14, 1983, on 6250 bpi density
tapes.

Large-scale (1:4,300-1:13,000) color and color infrared oblique
aerial photography was acquired over the study site using a dual 35mm
camera system operated from a light aircraft. The purpose of acquiring

this photography was to document the environmental conditions prevalent at the time of the overpass. These photos are used in conjunction with available ground data to document forest canopy, non-forest cover, and understory conditions. The aerial photography was acquired within one hour of the Landsat-4 overpass on August 12, 1983 from 1200-1300 P.D.T. Ground cover conditions were documented based on interpretation of these photographs, the field data sheets from an intensive field study conducted in the area during August 1982, and this investigator's knowledge of forest conditions and management practices in the area.

Based on the available ground data and aerial photography for this site, the TM and corresponding MSS digital data were extracted from the full scene CCT's. A 1200 x 1200 pixel block area (1,440,000 pixels) was extracted from the CCT-PT using the IBM image processing system at the Palo Alto Scientific Center with assistance of Mr. Ralph Bernstein and Mr. Jeff Lotspiech. The corresponding area was extracted from the CCT-PM; and both data sets were written to separate disk files for analysis.

Forest stands of known cover type and condition were located in the digital data set, annotated, and statistics calculated for each stand. Both radiance numbers (RN), or counts, extracted from these sample fields and spectral radiance values were used for statistical analysis, plots, and image generation. Spectral radiance for each spectral band was calculated based on the following relationship [1]:

$$L_i = \frac{RN_i - \hat{O}_i}{\hat{G}_i}$$

where,

L_i = Spectral radiance, $mWcm^{-2}\text{-}sr^{-1}\text{-}\mu m^{-1}$, for TM Band i

RN_i = Radiance number, in counts, for TM Band i

$\hat{O}_i$ = Average Offset, in counts, for TM Band i

$\hat{G}_i$ = Average Gain, in counts/$mWcm^{-2}\text{-}sr^{-1}\mu m^{-1}$, for TM Band i

i = Spectral Band Index

The pre-launch band offset and band gain values were used in the equation [2]. The summary statistics for the forestry study site are presented in radiance numbers and spectral radiance; forest stand statistics and plots are in radiance numbers only.

The radiance numbers for the entire 1200 x 1200 pixel block area were input to a standard statistical program to compute means, variances, coefficients of variation (CV), minimum and maximum values, skewness, kurtosis, and covariance and correlation matrices for the

TM and MSS data. These summary statistics provide an overview of the frequency distributions by band of the TM spectral data, and will be used at a later time to optimize color mapping tables to produce various image products for interpretation. The coefficient of variation (CV), expressed as a percent, is used to represent the relative variation about the mean, and is calculated using the mean and variance ([std. dev./mean] x 100). This relative measure allows for an easy comparison of spectral band means and their associated variability which may exhibit a wide range of values. Tests for normality which represent the degree of symmetry and peakedness of frequency distributions are skewness and kurtosis, respectively. The skewness is the third product moment about the mean; symmetrical, normal frequency distributions have skewness of zero. Large positive values of skewness indicate data non-normality in which an increasing magnitude of the mean is accompanied by a corresponding increase in variance. Kurtosis is the fourth product moment about the mean; all data distributions have values of kurtosis greater than -2 and normal distributions have a kurtosis value of zero. Though both covariance and correlation values were calculated, only the correlation matrix is presented. The values of the covariance matrix are difficult to interpret for evaluating the relationship between spectral bands. The product moment correlation coefficient (r) is calculated from the band variances, and provides a standard form for evaluating these interband relationships. For the radiance numbers extracted from individual forest stands, only means, variances, and CV's were calculated. For each TM and MSS spectral band of this site, both black-and white and color composite images were produced to visually represent the digital data and to illustrate the spectral variability of selected forest cover types.

1.3.3 Results and Discussion

The summary statistics for the forestry study site are shown in Tables 2 and 3. The statistics in Table 2 include the band means, variances, CV's minimum and maximum values, and skewness and kurtosis for the frequency distribution of the 1,440,000 pixels per band. TM Bands 5 and 7 are the most variable bands and can be considered normally distributed as is the least variable band, TM6. TM Bands 1 and 2 exhibit lower variability but cannot be considered normally distributed due to the high values of skewness and kurtosis. No transformations were performed to normalize the data or stabilize the variance. Bands 1, 5, and 6 contain saturated pixels due to (1) the high albedo of granitic rock outcrops (Band 1); (2) high albedo of dry, bare soil on both level terrain and south facing slopes (Band 5); and (3) the high radiant temperature of the granitic rocks and bare soil (Band 6). The interband correlations in Table 3 show the familiar high positive correlation between TM Bands 1, 2 and 3; and low correlation between Band 4 and Bands 1, 2, 3, 5 and 7. Both the short-wave bands in the summer forested scene show high positive correlations with the thermal band. This is directly related to the close association between the radiant temperature response of forest cover types, and their relative moisture status. Generally speaking, the

TABLE 2. Summary statistics for the forestry study site.

TM Band		$\bar{x}$	s	CV	Min	Max	Skewness (γ_1)	Kurtosis (γ_2)
1	RN:	66.1	8.1	12.3	41	255	3.1	25.0
	L:	4.1	0.5		2.5	16.1		
2	RN:	23.7	5.2	21.9	11	166	2.5	16.8
	L:	2.8	0.5		1.3	20.6		
3	RN:	23.2	8.2	35.3	7	214	2.4	10.5
	L:	2.2	0.8		0.7	20.2		
4	RN:	64.1	16.1	25.1	0	172	0.2	1.9
	L:	5.8	1.4		-0.06*	15.8		
5	RN:	46.7	22.5	48.2	0	255	1.1	1.5
	L:	0.6	0.2		-0.03*	3.2		
7	RN:	18.0	11.7	65.0	0	164	1.5	3.1
	L:	0.1	0.06		-0.02*	1.1		
6	RN:	190.1	15.1	7.9	139	255	1.1	1.6

*noise

RN = Radiance number, counts
L = Spectral radiance, $mWcm^{-2}-sr^{-1}-um^{-1}$
n = 1,440,000 pixels

TABLE 3. Correlation matrix for the seven TM bands for the forestry study site.

BAND	1	2	3	4	5	7	6
1	1.00	0.94	0.96	0.15	0.74	0.84	0.30
2		1.00	0.96	0.24	0.80	0.87	0.77
3			1.00	..18	0.81	0.90	0.81
4				..00	0.43	0.18	0.06
5					1.00	0.93	0.85
7						1.00	0.97
6							1.00

n = ..0,000 pixels

-11-

low reflective properties in TM5 and 7 of vegetative canopies are directly related to actively growing vegetation under relatively high moisture conditions. As canopy moisture content increases, there is more absorption of the short-wave radiation by the canopy and a correspondingly lower radiant temperature of the canopy due to dissipation of heat energy through evapotranspiration. Conversely, conditions in a forested environment which have highly reflective properties in TM5 and 7 (granitic rock outcrops; dry, bare, coarse-textured soil) also have high radiant temperatures due to low moisture conditions.

Individual forest cover type statistics are shown in Table 4 and plotted in Figure 3. Table 4 contains the band means and coefficients of variation (standard deviation/mean x 100) for individual vegetated and non-vegetated cover types for the seven TM bands. As both sensors were operating simultaneously during this overpass, band means and CV's of three of the four MSS bands which most closely correspond to the relevant TM bands are also included in Table 4. Though portions of both MSS 3 (0.70-0.81 um) and MSS 4 (0.81-1.02 um) fall within portions of TM 4 (0.78-0.90 um), MSS 4 was selected so as to avoid that highly variable region of vegetation response curve between 0.70-0.80 um where the spectral reflectance of vegetation goes from a minimum at 0.645 um (peak chlorophyll absorption) to a maximum at 0.880 um (peak infrared reflectance). Based on field plot data and synoptic surveys conducted in this area for several years, areas of known cover type conditions were located in the spectral data and extracted from the disk files for statistical analysis. For this phase of our investigation, only homogeneous stands of vegetation and other cover types, all of variable areal extent, were selected for statistical analysis. Future analysis will include field data in which specific forest stand parameters (basal area, average stand height, age, diameter breast height, timber site) have been measured for 130 plots of variable size within the Meadow Valley 7½' topographic quadrangle.

These data from the six reflective bands are graphically displayed in Figure 3. For each band, the mean radiance number (in counts), +1 standard deviation about the mean, is plotted for each cover type sampled. A major cover type discrimination one would like to make when stratifying forest cover types is between true fir stands of lower economic value and mixed conifer stands of higher economic value. By reviewing the spectral statistics, there is no apparent spectral difference between these two major cover types. The only band in which we see some difference is in the thermal band (TM6). This results from the higher topographic position that true fir occupies. The resulting lower radiant temperature of the true fir canopy allows the spectral differentiation between the two types using TM6. Another discrimination of importance is between mixed conifer stands and stands dominated by hardwood species, namely Black Oak (*Quercus kelloggii*), which is an indicator of high timber site (highly productive). Statistics from a mixed stand dominated by Black Oak is plotted under "Hardwood". From the statistical data, a major dif-

TABLE 4. TM and MSS spectral statistics for the forestry study site. Values tabulated are average radiance numbers ($\bar{x}$) and coefficients of variation (CV) calculated from the digital data.

| SPECTRAL BAND	TRUE FIR		MIXED CONIFER		HARDWOOD		SHRUB		MEADOW		BARE SOIL		ROCK		WATER	
	$\bar{x}$	CV	$\bar{x}$	CV	$\bar{x}$	CV	$\bar{x}$	CV	$\bar{x}$	CV	$\bar{x}$	CV	$\bar{x}$	CV	$\bar{x}$	CV
TM1	63.5	9.3	61.6	3.1	60.0	1.7	65.8	5.1	75.1	10.5	87.6	3.1	99.3	11.4	58.3	3.9
TM2	22.2	14.4	20.0	4.8	20.3	2.8	25.7	8.2	30.6	14.6	38.5	5.7	41.8	14.3	16.4	8.4
MSS1	15.0	13.3	13.4	9.6	14.3	4.0	16.8	10.0	20.7	13.5	25.3	7.7	29.0	10.3	11.4	8.7
TM3	20.7	19.8	17.5	9.2	17.3	6.7	23.8	14.4	33.0	24.8	53.9	9.8	47.7	8.1	12.4	15.0
MSS2	13.1	20.9	10.3	15.5	11.0	20.0	14.8	15.7	21.8	24.1	36.9	11.8	33.5	12.5	6.4	20.9
TM4	57.2	14.9	56.2	6.8	73.3	11.0	103.7	11.1	82.4	15.7	67.9	6.3	58.6	6.4	9.5	48.7
MSS4	35.6	12.2	34.9	5.4	45.7	9.8	67.0	10.6	54.7	14.4	46.7	8.0	38.1	9.3	3.3	45.9
TM5	31.2	52.1	27.0	21.5	33.7	29.8	55.7	16.3	87.8	19.4	138.2	7.2	90.6	13.0	3.4	198.7
TM7	11.8	69.6	8.6	33.7	9.0	38.5	17.5	28.9	34.5	27.9	71.1	11.4	54.4	17.7	1.7	184.2
TM6	168.3	7.1	179.4	3.2	175.3	2.6	188.7	3.2	210.5	3.4	252.9	1.7	200.9	2.4	173.4	1.1

-13-
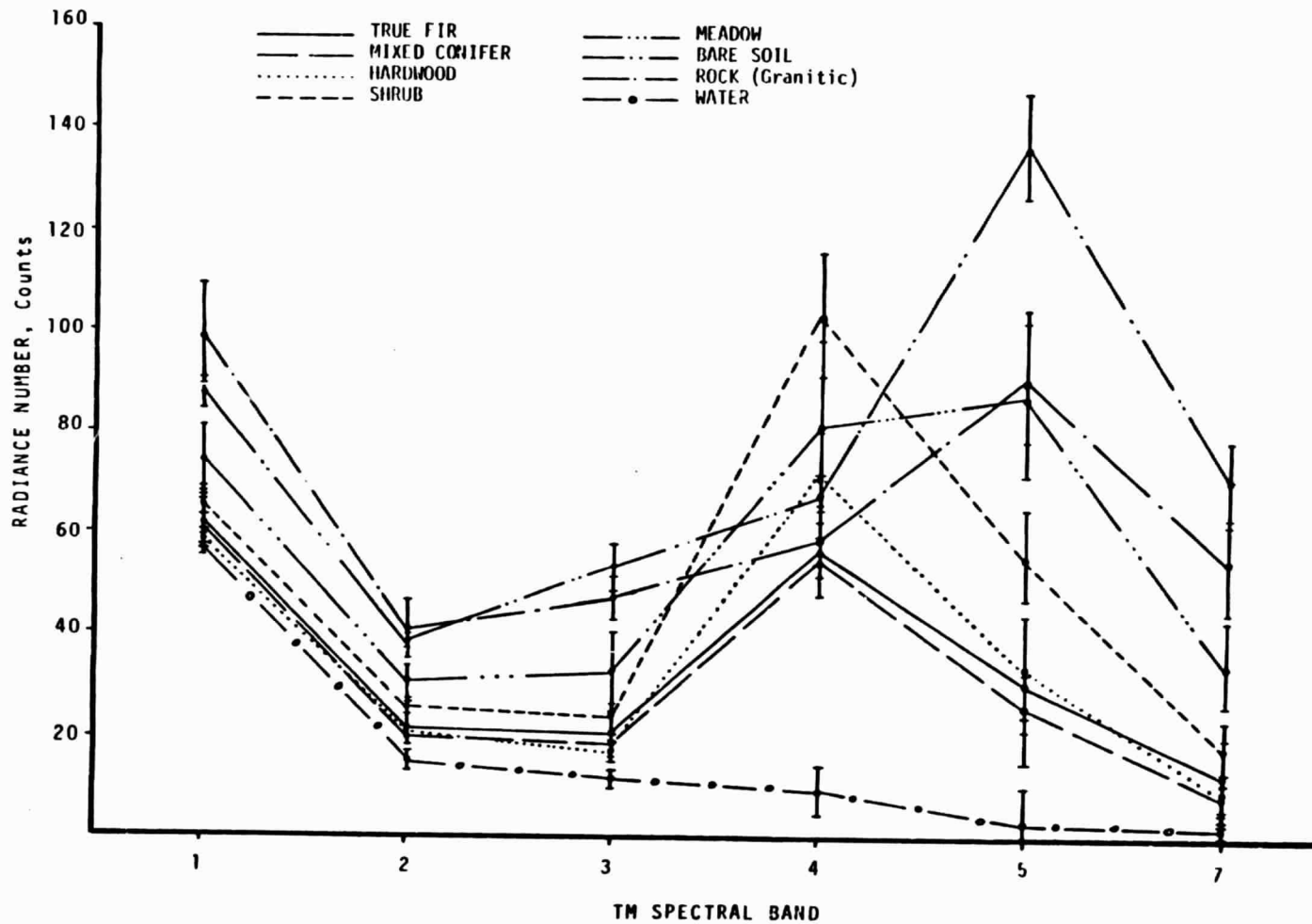
Figure 3. Plot of RN values (± 1 s.d.) for each of the reflective TM bands for several forest cover types.

ference in spectral response is seen in TM 4, as one would expect. This is also evident when viewing the TM image products where an increasing percentage of hardwood species within a mixed conifer stand is reflected in increasing light red tones on the image distinguishing these cover types from the "pure" conifer stands having a dark red tone. Discrimination of trees from shrubs and herbaceous vegetation is quite obvious by examining both the spectral plots and film products. Differentiation between wet and dry meadows can be accomplished using both TM 4 and TM 5 due to the differences in high photographic infrared reflectance (TM 4) and low shortwave infrared reflectance (TM 5) resulting from dense herbaceous growth under high canopy moisture conditions in the wet meadows. Dry, bare soil and rock outcrops exhibit the highest TM 5 and TM radiance with some areas on south facing slopes causing pixel saturation (RN: 255) on both bands. Deep and relatively clear water bodies in this area are spectrally behaving as one would expect with increasing absorption of solar radiation as wavelength increases.

These spectral relationships between major cover types are illustrated in Figure 4. Four additive color composites of various TM and MSS spectral bands provide a good indication of the relative improvements of TM data over MSS in terms of both spatial and spectral resolution. A stereo-pair of small format (35mm), low altitude color oblique aerial photography taken coincident with the Landsat-4 overpass is also shown in Figure 4. The composites cover a ground area of approximately 5200 ha (52 km^2) and are reproduced here at a scale of approximately 1:65,000. Each composite was imaged directly from the digital data using a color graphics camera. Three spectral bands were individually displayed on a high resolution black-and-white monitor and projected through color filters onto a single frame of 35mm Ektachrome (ASA 200) color film. Color internegatives were then generated for making multiple copies of the prints. The top left image (4b) is a composite of MSS bands 1, 2, and 4; the bottom left image (4c) is TM 2, 3, and 5; and the bottom right image (4d) is TM 3, 4, and 6; all projected through blue, green, and red filters, respectively. The area coverage of the low oblique aerial photography is annotated on each composite. Five major forest cover type conditions are annotated on the overlay for the upper left TM composite only. These cover type conditions include: (A) bare soil which results from clearing forest vegetation for expanding a ponderosa pine plantation; (B) high density mixed conifer (>70% crown closure) including a variable species mix of Ponderosa pine, Sugar pine, White fir, and Incense cedar; (C) low density conifer (Jeffrey pine < 20% crown closure) on soil with low fertility. (D) wet (high water table) and dry meadows at/or shortly after peak forage production, (E) broadleaf riparian forest vegetation (>90% crown closure) including cottonwood, willow, and big leaf maple.

The improvement in the spatial resolution of the TM sensor over the MSS sensor can be seen by comparing the top two composites in Figure 4 (a,b). The same surface area is represented on both composites. Significant detail on the TM image which cannot be consistently identified on the MSS image include the location of road and stream networks, area and shape of small forest clearings,

definition of vegetation boundaries, and discrimination of small homogeneous vegetation units within a matrix of complex cover types. With the clear definition of major unpaved forest roads and discrimination of significant topographical features and small stream networks on the TM imagery, these image products are more suited for field navigation than are the MSS film products. A composite which includes TM 5 (4c) would be best for road and stream network delineation because the contrast between a dry road surface and moist vegetation surface and between a stream coarse and adjacent features is higher on this band than on a composite containing TM 4 without TM 5 (4a).

The improvement in spectral resolution of the TM sensor over the MSS sensor and the improvements which can be expected by using various TM spectral band combinations for stratifying major forest conditions can be seen in Figure 4. By comparing the forest cover type conditions annotated on the overlay with their appearance on the other image types, several significant results are evident. Image composites which contain TM Band 5 in combination with two other visible bands (i.e. TM 2, 3) are inferior than those which contain TM 4 for the discrimination of important highly infrared reflective (TM 4) cover types (shrubs, hardwoods, meadows). This is evident by examining the detail in Figure 4a (TM 2, 3, 4) in which a variety of these cover types of varying areal extent are easily discriminated due to the bright red tones. By examining the same detail in Figure 4c (TM 2, 3, 5) these cover types are not as evident. This includes the riparian forest area at "E", a network of small wet meadows near the upper left center portion of the image, and the dense shrub field in the upper right center of the image. This results from the high level of absorption of the solar radiation in this band (1.57-1.78 um) by vegetation having a high leaf water content. The optimum combination of reflective TM bands for discriminating most forest cover types would be either a TM 2, 4, 5 or TM 3, 4, 5 where both the reflective and absorptive properties of diverse cover types could be exploited.

The discrimination of thermal differences of forested cover types is important for assessing regional soil and plant moisture conditions and for mapping those sites suitable for reforestation programs. The data being acquired by the broad thermal infrared band, TM 6 (10.42-11.66 um), is the highest quality data both spatially and spectrally, ever acquired by an earth-orbiting land remote sensing satellite. The TM 6 data have added a new dimension to the characterization of forest resources on image products. This is evident on the composite shown in Figure 4d. This composite includes two reflective bands (TM 3, 4) and the thermal band (TM 6). Though the coarser ground resolution (120m vs. 30m) prohibits the discrimination of small features of interest (small forest clearings, water bodies), the large scale radiant temperature differences between major forest cover types is obvious. In this composite, those cover types which are highly infrared reflective in TM 4 and also have a high moisture status (low radiant temperature) are shown in tones of

light green (wet meadows, riparian forests, dense shrub fields).
At the other extreme, those cover types with relatively low in-
frared reflectance in TM 4 and also have a low moisture status
(high radiant temperature) are shown in tones of light red, or
pink (bare soil, dry meadows, low density coniferous forest). In-
termediated cover types, such as high density conifer forest on
northerly aspects, are shown in darker green tones. By combining
the thermal band of low spatial resolution with the reflective
bands of high spatial resolution, a unique and useful image product
is produced. This "thermal" composite should include TM 4 as one
of the reflective bands and not TM 5. Due to the high positive
correlation between TM 5 and TM 6 (Table 3.) resulting from the
radiant temperature response and the moisture relationships of
diverse cover types, the composite containing both TM 5 and TM 6
would be redundant and provide less information about forest cover
conditions than would a composite containing the TM 4 band. Again,
the most useful composite would be one containing both TM 4 and TM 5,
or both TM 4 and TM 6 with the addition of a visible band (TM 1, 2, 3).

1.3.4

Spectral data were simultaneously acquired by the Thematic Mapper
(TM) and Multispectral Scanner (MSS) aboard the Landsat-4 spacecraft
on August 12, 1983 (Path 44) during an operational TDRSS test. The
data received from TDRSS were processed through the Thematic Mapper
Image Processing System (TIPS) at NASA-Goddard Space Flight Center.
A systematic analysis of both image and numeric data for a forestry
study site in the northern Sierra Nevada, California, has yielded
the following significant results:

(1) TM Bands 1, 5, and 6 contain saturated pixels (RN = 255)
for areas of high albedo and high radiant temperature (bare
soil, rock outcrops).

(2) TM Bands 5, 7, and 6 show high positive interband correla-
tion due to the close association between the absorption of solar
radiation in the 1.57-1.78 um and 2.10-2.35 um wavelength bands
by vegetation and the low radiant temperature of the same vege-
tation due to the cooling effects of evapotranspiration.

(3) The TM reflective bands (TM 1-5, 7) do not permit a clear
discrimination between true fir and mixed conifer stands on
spectral reflectance characteristics alone. Use of both the
thermal band (TM 6) and elevational gradients will improve this
important discrimination.

(4) The high spectral, spatial, and radiometric resolution of
the reflective TM bands permit the discrimination of forest
stands with increasing densities of Black Oak, an indicator
of highly productive forest sites.

(5) The improved spatial resolution of the TM sensor over that of the MSS allows for improved discrimination of road and stream networks, area and shape of small forest clearings, significant vegetation boundaries, and small homogeneous vegetation units within a matrix of complex cover types.

(6) Color image composites which include TM 5 are best suited for discriminating these small forest features essential for both navigation and mapping purposes.

(7) Color image composites which include TM 5 with other visible bands (i.e. TM 2, 3) are inferior for discriminating important vegetation types which are highly reflective in the photographic infrared portion of the spectrum (TM 4, 0.78-0.90 um).

(8) The optimum combination of reflective TM bands for discriminating most forest cover types would be either TM 2, 4, 5 or TM 3, 4, 5 where both the reflective and absorptive properties of diverse cover types can be exploited.

(9) The thermal infrared band (TM 6) contains valuable information on the relative radiant temperature differences between major cover types. Image products combining the spectral qualities of both the thermal and reflective bands and the spatial qualities of the reflective bands provide an optimum multispectral approach for the stratification of major forest cover type conditions.

(10) Color image composites should not contain both TM 5 and TM 6 due to the high positive correlation between these bands in a forested environment. If spatial resolution must be maximized, a composite containing TM 5 instead of TM 6 is recommended.

In summary, the spectral, spatial, and radiometric quality of the TM data are excellent. Based on this early stage of research, we conclude that this high quality data are more than sufficient for meeting most of the inventory objectives of the renewable resource specialist. The TM data should prove extremely valuable for (1) estimating forest cover types and area proportions required for most inventory and sampling purposes; (2) updating land use survey maps, and (3) determining the size, shape, and location of individual forest clearings and water sources.

1.3.5 References

1. J. Dozier, "TM data processing and correction", Landsat Sensor Design and Operation Course Syllabus, Lect. 12, Santa Barbara Research Center and U.C. Santa Barbara Extension, p. 12-2, 1983.

2. National Aeronautics and Space Administration, "Landsat-D Investigations Workshop", Proceedings, Goddard Space Flight Center, Greenbelt, MD, p. 2-51 and 2-53, May 1982.
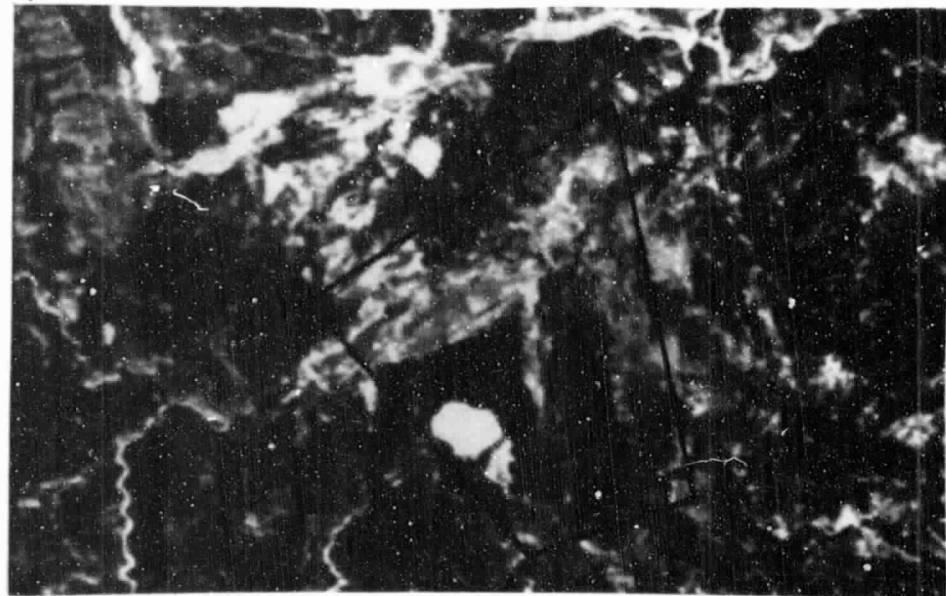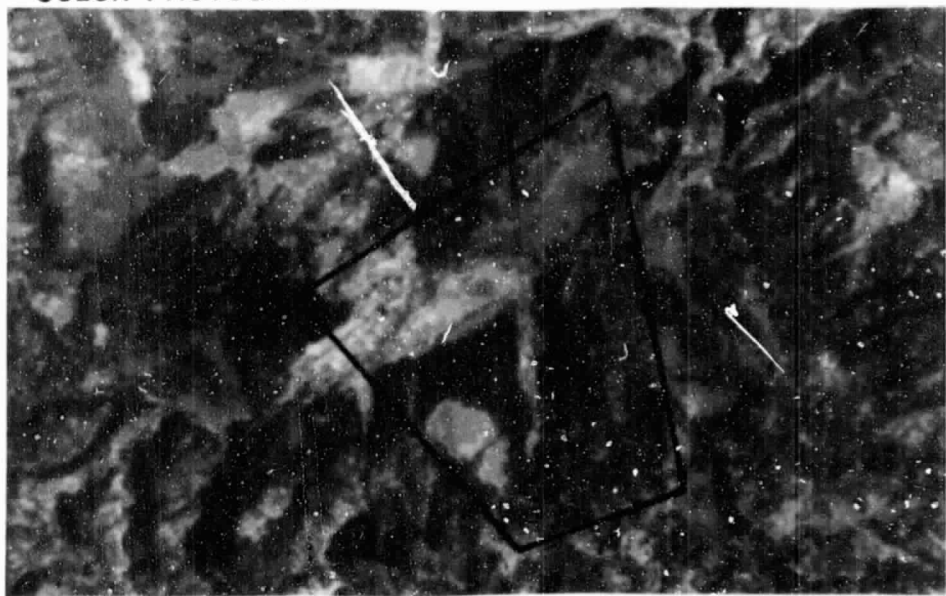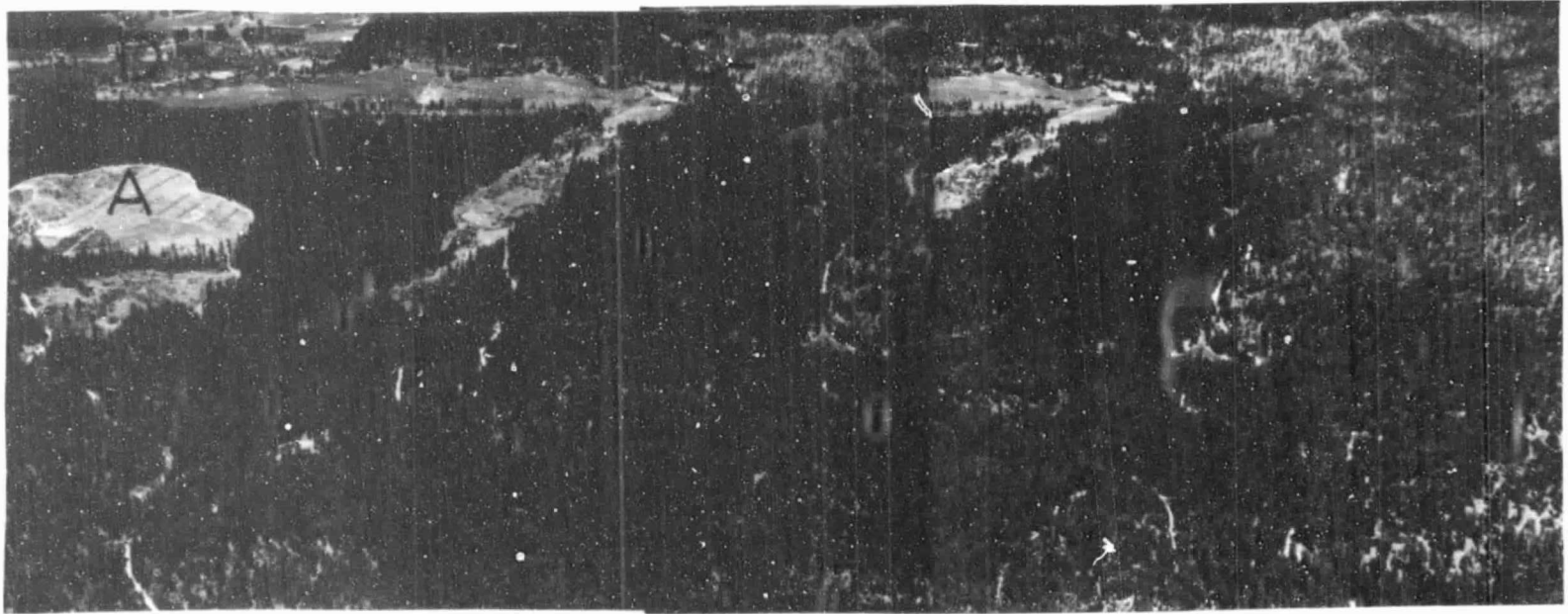
4a

4b

4c

4d

4e

Figure 4. Landsat-4 TM and MSS color (additive) composites and color aerial oblique photography
illustrating major forest cover type conditions. 4a: TM Bands 2,3,4; 4b: MSS Bands
1,2,4; 4c: TM 2,3,5; 4d: TM 3,4,6. The bottom image (4e) is a stereogram of a portion
of area covered by the composites using the low altitude (600m above the terrain) 35mm
color aerial oblique photography acquired coincident with the Landsat overpass on
August 12, 1983. The polygon on the composite overlay depicts the area covered by the
two oblique photographs. See the text for the cover type conditions annotated on the
overlay.

2.0 PUBLICATIONS AND PRESENTATIONS

2.1 Publications

DeGloria, S. D., A. S. Benson, and R. N. Colwell. 1983. Evaluation of Landsat-4 Image Quality for the Interpretation of Forest, Agricultural and Soil Resources - PECORA VIII Memorial Symposium Proceedings. Sioux Falls, South Dakota.

DeGloria, S. D. 1984. Spectral variability of TM and MSS data for selected agricultural and forest cover types. IEEE Trans. Geoscience and Remote Sensing (April 1984).

Preparation of material for the new General Electric Landsat-4 Brochure.

2.2 Presentations

PECORA VIII Memorial Symposium, Sioux Falls, South Dakota, October 4-7 (S. DeGloria)

California Map Society Meeting, November, San Francisco (A. Benson)

Remote Sensing Training Course, Mendocino National Forest, Willows, California, November 8-9 (A. Benson, K. Dummer, S. DeGloria)

Third Landsat-4 Investigator's Workshop, NASA-Goddard Space Flight Center, Greenbelt, Maryland, December 6-7 (S. DeGloria)

Community College Instructor's Workshop, Modesto, California, December 10 (B. Wood)

Distinguished Visitor's Seminars (S. DeGloria):

  Mr. Camino, Director General, Promotion of Agriculture for Spain

  Mr. Nedal, Director, Spanish Agricultural Research Service

  Mr. Tasias, Director, Spanish Agricultural Experimental Station at Tarragona

  Mr. Mathura D. Rajbhandari, Dean, Institute of Forestry, Hetauda, and Tribhuwan University, Tritureswor, Katmandu, Nepal

3.0 FUNDS EXPENDED TO DATE

The funds expended to December 31, 1983 under this contract are summarized in NASA Form 533M, "Monthly Contractor Financial Management Report", dated January 31, 1984.

4.0 PROBLEMS ENCOUNTERED TO DATE

Specific problem areas for this reporting period are discussed in the October, November and December monthly reports submitted to Mr. Darrel Williams, Code 923, NASA-Goddard Space Flight Center.