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DEVELOPMENT OF TECHNIQUES FOR PRODUCING STATIC STRATA MAPS AND DEVELOPMENT OF PHOTOINTERPRETIVE METHODS BASED ON MULTITEMPORAL LANDSAT DATA

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16. Abstract

The Report documents the progress conducted in support of the Large Area Crop Inventory Experiment (LACIE). Research was conductedfor two tasks. These tasks include 1) evaluation of the UCB "static" stratification procedure and modification of that procedure if warranted, and 2) the development of alternative photointerpretive techniques to the present LACIE procedure for the identification and selection of training fields (areas).

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Quarterly Progress Report

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SECTION 1.0:

STATIC STRATIFICATION FOR SIGNATURE EXTENSION

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1.0 STATIC STRATIFICATION FOR SIGNATURE EXTENSION

1.1 OBJECTIVE

The objective of this task is to evaluate and if necessary improve the signature extension stratification maps developed by UCB in previous LACIE tasks. Specifically, the ability of the strata to group spectrally similar wheat subclasses is being evaluated. In addition, variables used to produce the strata maps are being analyzed with regard to their influence on spectral signature of wheat fields, and, if needed, new variables will be introduced to refine or otherwise alter the stratification process.

1.2 GENERAL APPROACH

The task, designed to evaluate the statistical significance of the static stratification and to provide information for its refinement, has been divided into two subtasks. These are (1) to evaluate through analysis of variance (ANOVA) the static stratification's ability to group spectrally similar areas in order to maximize signature extension success and (2) to determine the statistically significant signature controlling variables for use in refining the stratification procedure.

SUBTASK A: SPECTRAL GROUPING ANALYSIS

The purpose of this subtask is to determine if the static stratification does in fact isolate areas tending to have similar wheat signatures. This analysis is also intended to discover the extent to which individual strata can be grouped together and still provide for potentially successful signature extension.

The initial experimental procedure consisted of obtaining a systematic sample of wheat fields in each land use/soils/climatic stratum and then comparing, through analysis of variance, the differences in spectral signature for the corresponding fields within and between strata. Results from this analysis (reported in Thomas and Hay, 1977) suggested the need for a revised approach. Rather than compare differences in signature between individual wheat fields, a procedure that compared differences (1) in wheat spectral density functioning between strata and (2) between wheat spectral density functions and those for other crops appeared more appropriate.

This second approach is intended to more effectively identify potential classification accuracies, and therefore ensure signature extension success, within and between strata.

It is composed of four basic steps. The first, preprocessing, is intended to standardize segments to a common sun elevation and haze condition. This is accomplished by implementation of XSTAR haze correction procedures (Lambeck 1977) developed at ERIM. Preprocessing in this case is intended to provide a more stable measurement frame (Landsat or Tasselled Cap Space) and thereby increase the ease with which real spectral differences can be identified and evaluated.

The second step involves clustering via ISOCLAS (adapted from JSC) each preprocessed sample segment. ISOCLAS control parameters are patterned after those currently in use at JSC, adjusted when necessary to optimize clustering performance based other UCB LACIE experience. Thirdly, each resulting cluster, or combination of similar clusters, is then labelled as to cover type. This is accomplished by drawing a random sample of pixels for each segment to a pre-specified sample size for each cluster. An image analyst then references each pixel drawn to the corresponding ground data (JSC Blue-ray sheets) and labels the pixel as to cover type. When ground data is missing or questionable, the analyst interprets multidate PFC transparencies to identify the cover type.

Data for all labelled pixels in all clusters is summarized by land use/soil association/climatic stratum in each sample segment. The proportion of each cover type (e.g. wheat, alfalfa, corn, fallow, etc.) in each cluster is also determined from the pixel sample. Clusters are then assigned to cover type groups according to the dominant cover type in each. The range in spectral reflectance mean vectors (i.e. vectors containing the average response in each Landsat or Tasselled Cap band) for clusters belonging to a given cover type group is defined to represent the range of the spectral reflectance density function corresponding to that group. Multiple comparison tests (based on Scheffé 1959) are then applied to determine the statistical separability of each cluster belonging to wheat cover types relative to non-wheat clusters in the same as well as different signature extension strata. This comparison utilizes the spectral mean vectors and covariance matrices for the clusters as defined in the clustering step. Results are interpreted in terms of the degree of overlap between cover type spectral density functions. Strata are combined when their respective wheat spectral density functions have significant overlap and overlap with other cover types is minimal or is similar in both strata. In the limiting case, the stratification should give rise to distinctly different wheat spectral density functions between strata.

Two biophase periods have been initially selected in Kansas and North Dakota in which to apply the revised grouping analysis procedure just described. Date # 1 in both states represents a wheat emergence condition. The second date corresponds approximately to a jointing or advanced jointing condition for the wheat crop. These time periods were selected based on sensitivity analysis results reported in section 1.3 which suggested these biophase stages were most difficult to characterize by static stratification variables. This analysis is therefore considered conservative relative to the performance of the static stratification. Tables 1.1 and 1.2 list the sample segments employed for each date in each state. Available segments were limited to those having ground data to minimize incorrect interpretation of results.

Table 1.1: Kansas Sample Segments Currently in Use for Spectral Grouping Analysis

	Seg. ID	Date # 1	Date # 2
	1019	1-19-76	
	1020		5-7-76
	1035		5-6-76
	1041		5-6-76
	1154	1-18-76	
	1171		5-4-76
	1176		
	1851	1-19-76	
	1852		5-6-76
	1854		
	1855	1-14-76	5-6-76
	1857	1-20-76	
	1860		5-6-76
	1861	1-20-76	5-7-76
	1864	1-20-76	
	1880	1-18,19-76	5-6-76
	1882	1-18-76	
	1884		5-4-76
	1886		5-6-76
	1887	1-18-76	5-6-76
	1891	1-18-76	
TOTALS	21	12 (11 dif. segs.)	12

Table 1.2: North Dakota Sample Segments Currently in Use for Spectral Grouping Analysis

	Seg. ID	Date # 1	Date # 2
	1603	5-28-76	7-4-76
	1614		7-1-76
	1618	5-24,26-76	6-30-76
	1624	5-25-76	
	1633	5-26-76	6-30-76
	1642	5-24,25-76	6-30-76
	1645	5-24,25-76	6-29-76
	1647		7-4-76
	1648	5-28-76	
	1650	5-27,28-76	
	1651	5-28,29-76	
	1656		7-2-76
	1660	5-26-76	
	1662	5-24-76	
TOTALS	14	16 (11 dif. segs.)	8

SUBTASK B: SIGNATURE CONTROLLING FACTOR SENSITIVITY ANALYSIS

This subtask differs from the first in that the cause for signature variability is explored. The basic approach is to develop regression relationships relating spectral reflectance (dependent variable) to a set of static stratification, seasonal, and date-specific (predictor) variables. A list of these variables is given in Table 1.3. The importance of the static (long term, i.e. 30 year plus), seasonal, and date-specific variables is then expressed in terms of the percent of total Landsat band variance accounted for by each. Reflectance versus predictor variable regressions are established by biophase to identify the changing importance of the variables over time.

Two different methods of obtaining matched spectral response and predictor variable data have been developed in this study. The first, completed this past quarter, was applied to a subset of Kansas 1973-74 T&E segments (see Table 1.4). Briefly, the procedure consisted of first sun angle-correcting Landsat data for all segments via JSC tables (Lockheed 1976), generating a band 7/5 ratio for each pixel, and generating Landsat 1 Tasselled Cap spectral representation for each segment. A small ($\leq$ 15) systematic sample of wheat fields was drawn from each land use/soils stratum in each segment examined. Field-specific Landsat and Tasselled Cap band averages were then obtained for each field sampled using an interactive color display system. Values for static, seasonal, and date-specific variables were measured according to procedures listed in Table 1.3 and recorded by field along with the Landsat spectral data.

Once all data had been obtained and coded for each field sampled, regression relationships were established between each spectral band and list (Table 1.3) of signature predictor variables. Separate regression equations were obtained from Landsat bands 4, 5, and 7 and Tasselled Cap bands 1, 2, 3, and 4 by date. Landsat band 6 was not included due to noise problems and data storage/manipulation limitations present at the time.

The relative importance of each signature predictor variable listed in Table 1.3 is expressed two ways. Measure # 1 consisted of the percent of total spectral variance (by band) explained by the addition of a given predictor variable to the regression equation. Variables were added in the same order as listed in Table 1.3 using a stepwise regression technique. The order - static, seasonal, date-specific - was chosen to most effectively identify the percent spectral variance accounted for by the static stratification variables before application of a signature extension algorithm. The R^2 (multiple correlation coefficient squared) increments, representing the percent of variance added by variable, are highly dependent on this ordering.

The second measure of signature predictor variable importance did not depend on order of entry into the regression. A forward selection regression procedure was used to order variables and tabulate the R^2 increments. Using this technique, the predictor variable having the highest simple correlation with two spectral band in question is entered into the regression first. The next variable entered is the one having the highest partial correlation with the spectral band after the effect of the first variable entered is removed. The third variable entered has the next highest partial correlation with the spectral response variable among all remaining predictor variables with the effects of the first two

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Table 1.3: Signature Predictor Variables Used in the Kansas 1973-74 Wheat Spectral Sensitivity Analysis

Predictor Variable	Measurement Technique Used for Each Field Sampled
I. Static Stratification Variables (Obtained from Static Strata map)	
A. Cultivated area percent (CULTPCT)	Midpoint of cultivated area percent range for the land use class covering the wheat field.
B. Crop diversity (CDIVSITY)	Midpoint of the crop diversity class covering the wheat field. Crop diversity is coded in terms of three equal-sized classes together spanning a scale of zero (lowest) to ten (highest).
C. Soil available water holding capacity (AWC)	Average inches of water held per inch of soil at field capacity in the top 24 inches for the static strata soil association covering the wheat field. These values are obtained from information available in county soil survey publications.
D. Long term average growing season degree-days (LTGSDD)	Midpoint of growing season degree-day class covering the wheat field. Degree-day classes obtained from 30 year average data by automatic and manual interpolation of ground meteorological station data for the period April through June.
E. Long term average growing season precipitation (LTGSP)	Midpoint of growing season precipitation class covering the wheat field. Precipitation classes obtained from 30 year average data by automatic and manual interpretation of ground meteorological data for the period April through June.

II. Seasonal Variables
(Specific to 1973-74 Growing Season)

A. Growing season degree-days accumulated to Landsat pass date

(SUMGSDD)

Calculated from temperature dates supplied from nearest ground meteorological station having a physical/climatic setting most closely approximating the segment in which the wheat field falls. Growing season period: April through June.

B. Growing season precipitation accumulated to Landsat pass date

(SUMGSP)

Determined as in II. A. relative to precipitation data.

C. Average January 1974 temperature

(JANTEMP)

Determined from nearest meteorological station as in II.A.

D. Planting season (1973) degree-days accumulated to Landsat pass date

(SUMPSDD)

Determined as in II.A. but for the period September through November.

E. Planting season (1973) precipitation accumulated to Landsat pass date

(SUMPSP)

Determined as in II.A. relative to precipitation data in the period August through November.

III. Landsat Date-Specific Variables

A. Average bare soil albedo

(ALBDRY)

Average sum of Landsat band 4, 5, and 7 digital reflectance values for a sample of bare soil fields falling in the land use/soils stratum in which the wheat field falls.

B. Precipitation in the four days preceding Landsat pass date

(PPT4DA)

Determined as in II.A. relative to precipitation data.

C. 100 X Tangent of Landsat scan angle

(SCANANG)

Departure measured along scan line of segment relative to an imaginary base line perpendicular to the scan direction and pass through the Landsat full frame center point. Measurement made on full frame containing segment for appropriate pass date. The departure, reported in nautical miles, is defined as zero on the base line and increases

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	positively to the east and negatively to the west. Then $\tan(\text{scan angle}) = \frac{\text{departure (n.m.)}}{\text{mean sat. altitude (494 n.m.)}}$.
D. Average Slope* (SLOPE)	Use 1:250,000 topography sheets to calculate average slope for the land use/soils stratum covering the wheat field in question for the segment in question.
E. Landsat Band 7 to Band 5 ratio (RASF)	Obtain average (2x) band 7 to (1x) band 5 ratio for the wheat field.

*Footnote: Slope was fixed, not date-specific. Its placement in this position of predictor variable listing was for the purpose of determining the R^2 overlay between scan angle and slope.

Table 1.4: Number of Fields Sampled by Segment by Date for the Subset of Kansas 1973-74 Segments Used in the First Spectral Sensitivity Analysis

Segment	Date Set: No. 1 One of: 20, 23, 24 Oct. '73	No. 2 One of: 18, 20 April '74	No. 3 One of: 6, 9 May '74	No. 4 One of: 24, 26, 27 May '74	No. 5 14 June '74
1018		17		17	
1026		10		10	
1029	14	14		14	
1036	37 (Landsat only)		37	37	37 (Landsat only)
1045 North				22	
1065	10 (Landsat only)		10	10	10 (Landsat only)
1109	15	15	15		
TOTALS	76 (47 Landsat only)	56	62	110	47 (Landsat only)

variables entered removed, and so on. Average rank (order) and R^2 increment among all bands for a giben date provide the second measure of performance.

A second method of obtaining the matched spectral response and predictor variable data will be utilized with 1976 Kansas and North Dakota LACIE segments. This procedure will differ from the first in the following respects. Spectral data will be obtained from a systematic or random sample of pixels labelled as wheat in the spectral grouping analysis described in Subtask A. This implies, also, all preprocessing and clustering steps discussed in that analysis. A more refined set of static, seasonal, and date-specific variables will be evaluated for signature response correlation. These signature controlling variables will be selected based on the results of the first analysis.

1.3 RESULTS LAST QUARTER

SUBTASK A: SPECTRAL GROUPING ANALYSIS

Work in progress.

SUBTASK B: SIGNATURE CONTROLLING FACTOR SENSITIVITY ANALYSIS

Ordered Regression

Results from analysis of the subset (Table 1.4) of the 1973-74 Kansas Test & Evaluation Lacie segments are presented in this section. Discussion will focus on results for the first measure of signature predictor variable importance, namely percent of total spectral variance (by band) explained by addition of a given predictor variable to the regression equation. The reason for this emphasis is that the ordered entry of variables - static, then seasonal, and then date-specific - should most efficiently identify the potential signature variance control to be gained with static and seasonal stratification prior to date-specific signature extension.

Tables 1.5 and 1.6 summarize the incremental proportion of wheat spectral variance (equivalent to R^2 values) accounted for by entering static, seasonal, and date-specific variables in the order listed in Table 1.3. A similar pattern of R^2 through the crop year 1973-74 is evident in both the Landsat and Tasselled Cap spectral measurement spaces. This temporal pattern for the static variables consists of a relatively low R^2 on Date # 1 (emergence), a high R^2 in Date # 2 (jointing minus), a drop in R^2 on date # 3 (jointing plus), another R^2 peak at date # 4 (turning minus), and drop in R^2 on the last date. Seasonal variables accounted for little variance (after the effects of long term or static variables were removed) in wheat spectral response over the year. Date-specific variables peaked in performance on date # 3.

Tables 1.7 and 1.8 list R^2 values resulting when the seasonal variables are not included in the ordered (stepwise) regression procedure. In this case, most of the variance formerly attributable to seasonal variables is now accounted for by date-specific variables. The temporal pattern of R^2 values appears similar to that described in Tables 1.5 and 1.6.

TABLE 1.5: KANSAS (CROP YEAR 1973 - 74)

SPECTRAL SENSITIVITY ANALYSIS SUMMARY

(TOTAL R^2 AVERAGED OVER L4, L5, L7 BY GROUP)

GROUP*	DATE # 1 (EMERGENCE) OCT. 20, 23, 24	DATE # 2 (JOINTING -) APRIL 18, 20	DATE # 3 (JOINTING +) MAY 6, 9	DATE # 4 (TURNING -) MAY 24, 26, 27	DATE # 5 (TURNING +) JUNE 14
I. STATIC VARIABLES	.375	.875	.292	.541	.303
II. SEASONAL VARIABLES	.146	.006	.013	.096	.104
III. REAL-TIME (SCENE-SPECIFIC) VARIABLES	.154	.077	.322	.136	.091
IV. ALL GROUPS COMBINED	.674	.961	.656	.774	.498

*ALL GROUPS INCLUDED IN REGRESSION

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TABLE 1.6:

KANSAS (CROP YEAR 1973 - 74)

SPECTRAL SENSITIVITY ANALYSIS SUMMARY

(TOTAL R^2 AVERAGED OVER TC1, TC2 BY GROUP)

GROUP*	DATE # 1 OCT. 20, 23, 24	DATE # 2 APRIL 18, 20	DATE # 3 MAY 6, 9	DATE # 4 MAY 24, 26, 27	DATE # 5 JUNE 14
I. STATIC VARIABLES	.422	.743	.241	.582	
II. SEASONAL VARIABLES		.019	.047	.086	
III. REAL-TIME (SCENE-SPECIFIC) VARIABLES	.195	.125	.274	.157	
IV. ALL GROUPS COMBINED	.617	.881	.562	.825	

*ALL GROUPS INCLUDED IN REGRESSION

TABLE 1.7: **KANSAS (CROP YEAR 1973 - 74)**

SPECTRAL SENSITIVITY ANALYSIS SUMMARY

(TOTAL R^2 AVERAGED OVER L4, L5, L7 BY GROUP)

GROUP*	DATE # 1 OCT. 20, 23, 24	DATE # 2 APRIL 18, 20	DATE # 3 MAY 6, 9	DATE # 4 MAY 24, 26, 27	DATE # 5 JUNE 14
I. STATIC VARIABLES	.375	.882	.292	.541	.303
II. REAL-TIME (SCENE-DEPENDENT) VARIABLES	.295	.073	.365	.238	.198
III. GROUPS I AND 2 COMBINED	.674	.961	.656	.779	.498

*SEASONAL VARIABLES EXCLUDED FROM REGRESSION

TABLE 1.8: **KANSAS** (CROP YEAR 1973 - 74)

SPECTRAL SENSITIVITY ANALYSIS SUMMARY

(TOTAL R^2 AVERAGED OVER TC1, TC2 BY GROUP)

GROUP*	DATE # 1 OCT. 20, 23, 24	DATE # 2 APRIL 18, 20	DATE # 3 MAY 6, 9	DATE # 4 MAY 24, 26, 27	DATE # 5 JUNE 14
I. STATIC VARIABLES	.422	.743	.241	.582	
II. REAL-TIME (SCENE-DEPENDENT) VARIABLES	.195	.139	.321	.241	
III. GROUPS 1 AND 2 COMBINED	.617	.881	.563	.823	

*SEASONAL VARIABELS EXCLUDED FROM REGRESSION

An explanation for the bimodal R^2 temporal pattern obtained in this analysis must be developed by relating wheat canopy development to the signature predictor variables used in the regressions. Detailed canopy development information over broad areas was not available; however, knowledge of general wheat development patterns for Kansas, known physiological relationships, as well as interpretation of full frame Landsat CIR transparencies, and review of variable-specific sensitivity analysis results (Table 1.9 - 1.18) suggest the following hypothesis for the R^2 pattern.

At emergence (date # 1), the wheat "canopy" will be composed of isolated shoots; consequently spectral signature will be dominated by soil surface reflectance. Soil reflectance will in turn be a function of surface horizon texture and moisture content. Reference to Tables 1.9 and 1.10 confirms the importance of soil reflectance generally (dry soil albedo for bare soil) and texture (strongly related to soil available water holding capacity) in accounting for variance in spectral response. These same tables did not show the soil surface wetting measure (precipitation in the four days previous to Landsat pass date - i.e. Four-day precipitation) as important since no precipitation occurred in this period.

The degree to which soil dominates reflectance will be a function of cultural practices and crop development. Favorable Fall growth environments will favor shoot development and reduce soil spectral influence. 1973 planting season degree-days, one measure of growth environment, was shown to be one of the most important factors (Table 1.9) accounting for variance in Landsat bands. Cultural practices including planting date, seeding density, planting pattern, variety mix, and irrigation/fertilization application will also affect the percent coverage of soil by wheat and degree of additional coverage at pass date due to canopy development. These cultural practice factors were poorly represented in this analysis. Only a very general measure, cultivated land percent, was included. This cultivation practice variable was found significant. At present, we ascribe the relatively low average total R^2 for Date # 1 to a lack of these cultural practice variables -- variables particularly important in determining soil dominance of wheat signature in this biophase.

Results in Tables 1.11 and 1.12 show long term (30 year average) growing season degree-days, cultivated land percent, and soil water holding capacity account for most of the wheat spectral variance on the second date (jointing minus). Apparently, the degree of wheat canopy development could, at this biostage in this crop year, be expressed largely as a function of climate and soil type. In fact, an average of 87.5 percent of the variance in wheat field mean spectral response in Landsat bands and 74.3 percent in the first two Tasselled Cap bands was accounted for by the static stratification variables as a whole. This situation represents most closely that originally hypothesized for signature extension stratification.

TABLE 1.9: KANSAS (CROP YEAR 1973 - 74)

SPECTRAL SENSITIVITY ANALYSIS (R^2 VALUES)

DATE: OCTOBER 20, 23, 24
NO. OF SEGMENTS: 4
TOTAL NO. OF FIELDS: 76

	L4	L5	L7
1. CULTIVATED PCT.	.124	.160	.058
2. CROP DIVERSITY	.015		.112
3. WATER HOLDING CAP.	.076	.091	.114
4. L.T. GROW. SEASON DEG.-DAYS	.056	.071	.196
5. L.T. GROW. SEASON PRECIP.	.02		.008
	(.274)	(.322)	(.529)
6. GROW. SEASON DEG.-DAYS			
7. GROW. SEASON PRECIP.			
8. JANUARY TEMP.			
9. PLANT. SEASON DEG.-DAYS	.196	.223	.011
10. PLANT. SEASON PRECIP.			
	(.196)	(.223)	(.011)
11. DRY SOIL ALBEDO	.105	.095	.027
12. FOUR-DAY PRECIP.			
13. SCAN ANGLE			
14. AVG. SLOPE			
15. 7/5 RATIO	.027	.036	.177
	(.132)	(.131)	(.199)
TOTAL	.602	.675	.744

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TABLE 1.10: KANSAS (CROP YEAR 1973 - 74)

SPECTRAL SENSITIVITY ANALYSIS (R^2 VALUES)

DATE: OCTOBER 20, 23, 24
NO. OF SEGMENTS: 2
TOTAL NO. OF FIELDS: 29

	TC1	TC2	TC3	TC4
1. CULTIVATED PCT.	.175	.548	.034	.002
2. CROP DIVERSITY				
3. WATER HOLDING CAP.	.122	0	.115	.073
4. L.T. GROW. SEASON DEG.-DAYS				
5. L.T. GROW. SEASON PRECIP.				
	(.297)	(.548)	(.149)	(.075)
6. GROW. SEASON DEG.-DAYS				
7. GROW. SEASON PRECIP.				
8. JANUARY TEMP.				
9. PLANT. SEASON DEG.-DAYS				
10. PLANT. SEASON PRECIP.				
11. DRY SOIL ALBEDO				
12. FOUR-DAY PRECIP.				
13. SCAN ANGLE				
14. AVG. SLOPE				
15. 7/5 RATIO	0	.390	.372	.251
	(.000)	(.390)	(.372)	(.251)
TOTAL	.297	.938	.522	.325

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TABLE 1.11: KANSAS (CROP YEAR 1973 - 74)

SPECTRAL SENSITIVITY ANALYSIS (R^2 VALUES)

DATE: APRIL 18, 20
NO. OF SEGMENTS: 4
TOTAL NO. OF FIELDS: 56

	L4	L5	L7
1. CULTIVATED PCT.	.287	.250	.153
2. CROP DIVERSITY			
3. WATER HOLDING CAP.	.221	.226	.241
4. L.T. GROW. SEASON DEG.-DAYS	.296	.251	.410
5. L.T. GROW. SEASON PRECIP.	.141	.096	.055
	(.946)	(.820)	(.859)
6. GROW. SEASON DEG.-DAYS	.009	.010	
7. GROW. SEASON PRECIP.			
8. JANUARY TEMP.			
9. PLANT. SEASON DEG.-DAYS			
10. PLANT. SEASON PRECIP.			
	(.009)	(.010)	
11. DRY SOIL ALBEDO			.003
12. FOUR-DAY PRECIP.			
13. SCAN ANGLE			
14. AVG. SLOPE			
15. 7/5 RATIO	.025	.109	.101
	(.025)	(.109)	(.104)
TOTAL	.980	.940	.963

TABLE 1.12: KANSAS (CROP YEAR 1973 - 74)

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SPECTRAL SENSITIVITY ANALYSIS (R^2 VALUES)

DATE: APRIL 18, 20
NO. OF SEGMENTS: 4
TOTAL NO. OF FIELDS: 56

	TC1	TC2	TC3	TC4
1. CULTIVATED PCT.	.110	.323	.001	.234
2. CROP DIVERSITY				
3. WATER HOLDING CAP.	.316	.121	.344	.226
4. L.T. GROW. SEASON DEG.-DAYS	.337	.080	.846	.373
5. L.T. GROW. SEASON PRECIP.	.015	.184	.036	.129
	(.778)	(.708)	(.867)	(.962)
6. GROW. SEASON DEG.-DAYS	.001	.027	.002	.006
7. GROW. SEASON PRECIP.				
8. JANUARY TEMP.				
9. PLANT. SEASON DEG.-DAYS				
10. PLANT. SEASON PRECIP.				
	(.001)	(.027)	(.002)	(.006)
11. DRY SOIL ALBEDO	.005	.005	.005	
12. FOUR-DAY PRECIP.				
13. SCAN ANGLE				
14. AVG. SLOPE				
15. 7/5 RATIO	.024	.216	.048	.019
	(.029)	(.221)	(.053)	(.019)
TOTAL	.808	.955	.923	.987

However, by date # 3 (jointing plus) the static variables no longer account for a high percentage of the spectral variance (Tables 1.13 and 1.14). The band 7 to band 5 ratio, a date-specific variable, is dominant. Only crop diversity, and to a lesser extent long term growing season precipitation, cultivated land percent, soil water holding capacity, and 1974 growing season degree-days account for any more than neglible amounts of variance in wheat field mean response. At this time of year, the wheat canopy covered close to 100 percent of the soil surface in most western and central portions of Kansas. Canopy near infrared reflectance (band 7 in this case) was at its peak or close to either side of the peak in most sample segments. A similar though reverse pattern (trough instead of peak) existed for chlorophyll-related depression of reflectance in band 5. As a consequence, the average wheat spectral response curves appeared very flat when viewed over different climatic, land use, and soil association strata. This is not to imply that differences do not exist. On this date segments 1036 and 1065 (Southwest Crop Reporting District) have very similar Landsat band 7 to band 5 ratios, a measure used in this study as an indicator of crop development stage (maturity). Segment 1109 is, on the other hand, tracking spectrally behind 1036 and 1065 with a higher 7 to 5 ratio. Thus differences are present, but not as pronounced as on dates # 2 and # 4.

The spectral differences, or variance, on date # 3 that were explained by static stratification variables can be given the following interpretation. As just mentioned, the largest spectral differences occurred between segment 1036 and 1065. Physically, 1109 differs from the former two by having denser texture soils with higher water holding capacities. This characteristic, when combined with higher growing season rainfall, leads to delay in crop maturation relative to 1036 and 1065 - - a situation confirmed by the spectral data. In addition, the climatic environment in 1109 is sufficiently different from 1036 and 1065 such that one would suspect that different varieties of wheat more appropriate to the humid environment would be planted. This may manifest itself in wheat varieties with delayed maturation behavior. All three factors - growing season, precipitation, crop diversity, and available water holding capacity were found to account for variance in the analysis on date # 3.

The majority of the explained variance in the Landsat bands and in the Tasselled Cap band 2 was attributed to the Landsat band 7 to band 5 ratio. Importance of this date-specific variable relative to static stratification variables supports the conclusion that local growth environment variations rather than major differences in climate and soils dominate on third date. One further relationship should be noted for date # 3. At this time segment 1109 was behind 1036 and 1065 in 1974 accumulated growing season degree-days, a situation favoring later wheat maturation in 1109. This seasonal degree-day variable was identified as accounting for a small amount of variance, particularly in Landsat band 7 and Tasselled Cap band 1.

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TABLE 1.13: KANSAS (CROP YEAR 1973 - 74)

SPECTRAL SENSITIVITY ANALYSIS (R^2 VALUES)

DATE: MAY 6, 9
NO. OF SEGMENTS: 3
TOTAL NO. OF FIELDS: 62

	L4	L5	L7
1. CULTIVATED PCT.	.086	.143	.001
2. CROP DIVERSITY	.151	.129	.023
3. WATER HOLDING CAP.	.073	.105	.039
4. L.T. GROW. SEASON DEG.-DAYS			
5. L.T. GROW. SEASON PRECIP.	.004	.011	.110
	(.314)	(.388)	(.173)
6. GROW. SEASON DEG.-DAYS	.025	.013	.091
7. GROW. SEASON PRECIP.			
8. JANUARY TEMP.			
9. PLANT. SEASON DEG.-DAYS			
10. PLANT. SEASON PRECIP.			
	(.025)	(.013)	(.091)
11. DRY SOIL ALBEDO	.001		.002
12. FOUR-DAY PRECIP.			
13. SCAN ANGLE			
14. AVG. SLOPE			
15. 7/5 RATIO	.342	.364	.257
	(.343)	(.364)	(.259)
TOTAL	.681	.766	.522

TABLE 1.14: KANSAS (CROP YEAR 1973 - 74)

SPECTRAL SENSITIVITY ANALYSIS (R^2 VALUES)

DATE: MAY 6, 9
NO. OF SEGMENTS: 3
TOTAL NO. OF FIELDS: 62

	TC1	TC2	TC3	TC4
1. CULTIVATED PCT.	.030	.101	.453	.017
2. CROP DIVERSITY	.150	.047	.006	.031
3. WATER HOLDING CAP.	.082	.023	.498	
4. L.T. GROW. SEASON DEG.-DAYS				
5. L.T. GROW. SEASON PRECIP.	.006	.044	.007	
	(.267)	(.215)	(.964)	(.048)
6. GROW. SEASON DEG.-DAYS	.094		.005	.026
7. GROW. SEASON PRECIP.				
8. JANUARY TEMP.				
9. PLANT. SEASON DEG.-DAYS				
10. PLANT. SEASON PRECIP.				
	(.094)		(.005)	(.26)
11. DRY SOIL ALBEDO		.002		
12. FOUR-DAY PRECIP.				
13. SCAN ANGLE				
14. AVG. SLOPE				
15. 7/5 RATIO	.080	.465	.001	.038
	(.080)	(.467)	(.001)	(.038)
TOTAL	.442	.682	.670	.111

By date # 4 (turning minus) the static variables have reasserted their influence. Differences in soil water holding capacity combined with precipitation input (long term and seasonal precipitation) have apparently (see Tables 1.15 and 1.16) differentially stressed the wheat crop. This stress when combined with differing energy input (long term growing season degree-days) explained approximately one third to one half of the total spectral variance in all Landsat and Tasselled Cap bands. Most of the remaining explained variance on date # 4 was associated with the Landsat band 7 to band 5 ratio. As such, this variable represented date-specific and location-specific crop maturity influences (natural and management practice related) accounted for by static or seasonal variables.

Usefulness of results from date # 5 (turning plus) are limited by the fact that two segments with available data, 1036 and 1065, fall in the same climatic stratum. Three variables account for most of the explained variance (see Table 1.17); in order of importance these are crop diversity, Landsat band 7 to 5 ratio, and 1974 growing season degree-days accumulated to the date in question. Banding on band 6 prevented generation of Tasselled Cap spectral values.

Much of the explained difference can probably be attributed to the larger seasonal degree-day input into segment 1036 relative to 1065, and also to date specific (indicated by 7/5 ratio) natural or cropping practice influences at the field level. The importance of crop diversity indicated in Table 1.17 may be an artifact of the limited data set for this date. No physical explanation cat at present be given for the importance of this variable.

Table 1.18 summarizes the average R^2 (proportion of total spectral variance) values over all five dates for Landsat bands 5 and 7 and for the two most important Tasselled Cap bands 1 and 2. Landsat band 4 results were very similar to those for band 5 and were thus omitted. The grand average column on the right side of Table 1.18 indicates that cultivated area percent, soil available water holding capacity, long term growing season degree-days, and Landsat band 7 to band 5 ratio were the most important signature predictor variables. Especially note worthy is the fact that the band 7 to 5 ratio, in spite of being the last entered in the regression equations, accounted for the largest amount of spectral variances in all but the first Tasselled Cap band.

Given the entry of variables in the order listed in Table 1.18, we can roughly express the results averaged over all dates as follows. Cultivated area percent, soil available water holding capacity, and long term growing season degree-days each account for 1/8 of the total spectral variance. Crop diversity and long term growing season precipitation each explain about 1/16 of the variation. Landsat band 7 to 5 ratio accounts for approximately 3/16 of the variance, while the remaining variables together explain another 1/16. Altogether, an average of approximately 3/4 of the total spectral variance was explained by variables in the regression equations.

TABLE 1.15: KANSAS (CROP YEAR 1973 - 74)

SPECTRAL SENSITIVITY ANALYSIS (R^2 VALUES)

DATE: MAY 24, 26, 27
NO. OF SEGMENTS: 6
TOTAL NO. OF FIELDS: 110

	L4	L5	L7
1. CULTIVATED PCT.	.011	.008	.072
2. CROP DIVERSITY	.012	.042	.078
3. WATER HOLDING CAP.	.158	.209	.003
4. L.T. GROW. SEASON DEG.-DAYS	.312	.296	.086
5. L.T. GROW. SEASON PRECIP.	.018	.032	.280
	(.511)	(.588)	(.524)
6. GROW. SEASON DEG.-DAYS	.010	.011	.008
7. GROW. SEASON PRECIP.	.053	.064	.001
8. JANUARY TEMP.			
9. PLANT. SEASON DEG.-DAYS	.005	.004	.057
10. PLANT. SEASON PRECIP.	.008	.010	.058
	(.076)	(.089)	(.124)
11. DRY SOIL ALBEDO			
12. FOUR-DAY PRECIP.			
13. SCAN ANGLE			
14. AVG. SLOPE			
15. 7/5 RATIO	.168	.152	.088
	(.168)	(.152)	(.088)
TOTAL	.755	.829	.737

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TABLE 1.16: KANSAS (CROP YEAR 1973 - 74)

SPECTRAL SENSITIVITY ANALYSIS (R^2 VALUES)

DATE: MAY 24, 26, 27
NO. OF SEGMENTS: 6
TOTAL NO. OF FIELDS: 110

	TC1	TC2	TC3	TC4
1. CULTIVATED PCT.	.032	.018	.032	.037
2. CROP DIVERSITY	.004	.130	.008	.066
3. WATER HOLDING CAP.	.132	.162	.083	.164
4. L.T. GROW. SEASON DEG.-DAYS	.352	.034	.165	.049
5. L.T. GROW. SEASON PRECIP.	.002	.298	.057	.223
	(.522)	(.642)	(.345)	(.539)
6. GROW. SEASON DEG.-DAYS	.001		.009	.001
7. GROW. SEASON PRECIP.	.075	.024	.102	.067
8. JANUARY TEMP.				
9. PLANT. SEASON DEG.-DAYS	.020	.014	.018	.023
10. PLANT. SEASON PRECIP.	.033	.005	.048	
	(.129)	(.043)	(.177)	(.091)
11. DRY SOIL ALBEDO				
12. FOUR-DAY PRECIP.				
13. SCAN ANGLE				
14. AVG. SLOPE				
15. 7/5 RATIO	.048	.266		.169
	(.048)	(.266)		(.169)
TOTAL	.700	.950	.522	.799

TABLE 1.17: KANSAS (CROP YEAR 1973 - 74)

SPECTRAL SENSITIVITY ANALYSIS (R^2 VALUES)

DATE: JUNE 14
NO. OF SEGMENTS: 2
TOTAL NO. OF FIELDS: 47

	L4	L5	L7
1. CULTIVATED PCT.	.001		.010
2. CROP DIVERSITY	.275	.312	.223
3. WATER HOLDING CAP.	.012	.010	.064
4. L.T. GROW. SEASON DEG.-DAYS			
5. L.T. GROW. SEASON PRECIP.			
	(.288)	(.322)	(.298)
6. GROW. SEASON DEG.-DAYS	.100	.095	.118
7. GROW. SEASON PRECIP.			
8. JANUARY TEMP.			
9. PLANT. SEASON DEG.-DAYS			
10. PLANT. SEASON PRECIP.			
	(.100)	(.095)	(.118)
11. DRY SOIL ALBEDO			
12. FOUR-DAY PRECIP.			
13. SCAN ANGLE			
14. AVG. SLOPE			
15. 7/5 RATIO	.111	.158	.003
	(.111)	(.158)	(.003)
TOTAL	.500	.574	.419

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Table 1.18: Summary of Ordered Contributions to R^2 by Band Averaged Over Dates

	Band: L5	L7	TC1	TC2	Row Average
I. Static Variables					
1. CULTPCT	.111	.059	.087	.227	.121
2. CDIVSITY	.097	.089	.038	.044	.067
3. AWC	.128	.099	.163	.074	.116
4. LTGSDD	.124	.139	.172	.029	.116
5. LTGSP	.028	.091	.006	.131	.064
II. 1973-74 Season-Specific Variables					
6. SUMGSDD	.026	.043	.024	.007	.025
7. SUMGSP	.013		.019	.006	.010
8. JANTEMP					
9. SUMPSDD	.045	.014	.005	.004	.017
10. SUMPSP	.002	.012	.008	.001	.006
III. Date-Specific Variables					
11. ALBDRY	.019		.001	.002	.005
12. PPT4DA					
13. SCANANG					
14. SLOPE*					
15. RASF	.164	.125	.038	.334	.165

*Fixed: Not date-specific but placed here for purpose of determining the R^2 overlap between scan angle and slope effects.

Examining the spectral predictor variable importance by band, the following relationships were evident. Landsat bands 5 and 7 and Tasselled Cap bands 1 and 2 are again used as the most important measures of spectral response. On the average, cultivated area percent, soil available water holding capacity, and long term growing season degree-days were the static variables consistantly accounting for significant amounts of spectral variance in band 5. Much of the remaining explained variability in band 5 was accounted for by the band 7 to band 5 ratio. Long term growing season degree-days dominated explained variance in Landsat band 7 on dates 1 and 2, while long term growing season precipitation is the most significant static variable on dates 3 and 4. Landsat band 7 to band 5 ratio is consistantly important over dates 1 to 4 and dominates on dates 3 and 4. Date # 5 is excluded from this analysis due to the low number of segments and poor distribution between climatic and soil types.

Soil available water holding capacity and long term growing season degree-days are the most important variables in explaining Tasselled Cap band 1 variance on dates 2 and 4. Cultivated area percent was also important earlier in the growing season (dates 1 and 2). Crop diversity was significant on date 3 as well as on date 5. In the case of Tasselled Cap band 2, the Landsat band 7 to band 5 ratio was consistently an important predictor variable. This result supports the hypothesis that the 7 to 5 ratio is strongly correlated to the Kauth green band. Even after the effects due to all other variables were removed, the Landsat 7 to band 5 ratio still accounted for 46.5 percent of the total variance in Tasselled Cap band 2 on date # 3. This time of year corresponded approximately to the spectral wheat calendar peak for the 7 to 5 ratio in western and central Kansas. Cultivated area percent was also important in explaining variability in Tasselled Cap band 2 on dates 1 through 3. On date # 4, crop diversity, soil water holding capacity, and long term growing season precipitation joined the Landsat band 7 to band 5 ratio in accounting for spectral variance in the second Tasselled Cap band.

Regression Without Prior Ordering

A second regression analysis was performed to determine the most significant signature predictor variables when no order of entry was specified in advance. For this purpose, a forward selection procedure was applied to the data used in the previous ordered regression analysis.

The product of this second analysis was a ranking of signature predictor variables from first entered (into the regression) to last along with the increment in spectral variance explained (R^2 increment). Results were developed from separate regressions by band by date. A summary of the three most important variables at the top of each list is given in Table 1.19.

The list together with corresponding R^2 increment and F-statistic data were then used to rank the signature predictor variables in terms of relative importance, highest to lowest. For the 15 predictor variables defined in Table 1.3 and also listed in Table 1.18, the following rankings resulted:

1. Landsat band 7 to band 5 ratio (RASF)
2. average bare soil albedo (ALBDRY), accumulated precipitation for the four days previous to pass date (PPT4DA), Landsat scan angle (SCANANG), and slope percent (SLOPE)

Table 1.19: Summary of Three Most Important Signature Predictor Variables by Band and by Date Using Forward Regression (No Initial Order of Predictor Variable Entry Specified). Increment to R^2 Shown in Parenthesis.

Date No.	L4	L5	L7	TC1	TC2	TC3	TC4
1.	ALBDRY (.445)	ALBDRY (.479)	ALBDRY (.382)	SLOPE (.175)	RASF (.925)	RASF (.106)	RASF (.117)
	RASF (.051)	RASF (.088)	RASF (.287)	AWC (.122)	SUMPSDD (.012)	SLOPE (.315)	ALBDRY (.145)
	CULTPCT (.028)	CULTPCT (.041)	CULTPCT (.022)		AWC (.001)	AWC (.101)	AWC (.064)
2.	PPT4DA (.954)	PPT4DA (.826)	PPT4DA (.816)	LTGSDD (.730)	PPT4DA (.659)	LTGSDD (.800)	PPT4DA (.964)
	RASF (.021)	RASF (.083)	RASF (.144)	RASF (.056)	RASF (.296)	RASF (.098)	RASF (.023)
	LTGSDD (.004)	LTGSDD (.030)	AWC (.002)	SCANANG (.012)	JANTEMP (.0004)	SUMGSP (.015)	AWC (.0003)
3.	RASF (.567)	RASF (.672)	SLOPE (.223)	SLOPE (.279)	RASF (.670)	SUMGSP (.967)	CDIVSITY (.046)
	SLOPE (.080)	SLOPE (.063)	RASF (.253)	RASF (.132)	AWC (.008)	CDIVSITY (.002)	RASF (.032)
	CDIVSITY (.008)	CULTPCT (.009)	SUMGSDD (.502)	CDIVSITY (.010)	CDIVSITY (.002)	RASF (.001)	SUMGSDD (.029)
4.	RASF (.526)	RASF (.631)	RASF (.228)	LTGSDD (.455)	RASF (.904)	JANTEMP (.387)	RASF (.733)
	LTGSP (.133)	LTGSP (.124)	LTGSP (.340)	SUMGSP (.062)	LTGSP (.034)	SUMPSP (.053)	SLOPE (.027)
	CDIVISTY (.047)	SCANANG (.029)	SUMPSBD (.054)	ALBDRY (.075)	SUMPSDD (.005)	SUMPSP (.068)	SUMPSDD (.013)

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3. long term growing season degree-days and precipitation (LTGSDD and LTGSP)
4. cultivated area percent (CULTPCT), crop diversity index (CDIVSITY), and soil available water holding capacity (AWC)
5. 1974 growing season degree-days and precipitation accumulated to the Landsat pass date (SUMGSDD and SUMGSP), average January 1974 temperature (JANTEMP), and Fall 1973 planting season degree-days and precipitation (SUMPSDD and SUMPSR)

Brief comments regarding these rankings follow:

1. RASF was clearly the most important variable. It ranked on the top of the list for 11 of the 28 regressions under consideration; in 13 more regressions it ranked second. Roughly speaking, RASF explained approximately half of the spectral variance accounted for by predictor variables. Its dominance is largely due to the fact that it was a scene and band dependent variable varying by pixel. All other variables, varied only by segment or stratum within segment.

2. ALBDRY, PPT4DA, and SCANANG represent the remainder of the date-specific variables examined in this study. Together with SLOPE, these variables as a group exhibited erratic ranking behavior. However, all but SCANANG came out on top in at least one regression. They all tended to be very highly correlated with each other and with several members of groups 3 and 5. SCANANG seemed to be the least important. Their appearance, even at the top of a list, seemed highly dependent on the presence or absence in the list of other variables with which they were highly correlated.

3. The static variables LTGSDD and LTGSP exhibited behavior similar to group 2, except they gave a high negative correlation ($r = -.9$) for date 4, which contained 6 of the 7 segments. They each came out on top in at least one regression. LTGSDD appeared slightly more important, and together they were slightly less important than group 2.

4. CULTPCT, CDIVSITY, and AWC were consistently of medium importance. These variables tended to be highly correlated with each other and only moderately correlated with other variables.

5. The seasonal variables as a group generally received lower rankings. Notable exceptions to this trend occurred in band TC 3 on dates 4 and 5. Interestingly, these variables did somewhat better in Tasselled Cap as opposed to Landsat spectral space.

SECTION 2.0:

DEVELOPMENT OF PHOTOINTERPRETATION METHODS BASED ON MULTITEMPORAL LANDSAT DATA

2.0 DEVELOPMENT OF PHOTOINTERPRETATION METHODS BASED ON MULTITEMPORAL LANDSAT DATA

2.1 SUMMARY TASK DESCRIPTION

The objective of Task II is to develop photointerpretive methods for utilizing multitemporal Landsat data which are improvements to the current Lacie methods. In order to accomplish this objective, Task II has been approached through three subtasks. These subtasks are: (1) Subtask A - Familiarization with JSC/LACIE Photointerpretation Procedures, (2) Subtask B - the Development of Multitemporal Interpretation Procedures whereby individual temporal images and temporal spectral data are analysed by means of a decision logic for the identification of wheat, and (3) Subtask C - the Development and Evaluation of Methods for Reducing Multitemporal Data to a single image set of multitemporally combined/enhanced images and/or a numeric representation of the spectral data.

2.2 SUBTASK A: FAMILIARIZATION WITH JSC/LACIE PHOTOINTERPRETATION PROCEDURES

Objective

The objective of this subtask is to familiarize UCB with JSC/LACIE photointerpretation procedures. In addition to an initial familiarization effort with current LACIE procedures, a continuing effort is maintained to remain current on all implemented and proposed photointerpretation procedure modifications. This subtask is vital to efficient and effective performance upon the other two subtasks within Task II.

Approach

An initial familiarization visit to JSC was made in August 1976. During this visit CAMS Operations personnel provided tutorial sessions and over-the-shoulder-look interpretation sessions for the RSRP personnel. In addition to reviewing CAMS procedure documents as they become available, UCB will maintain contact with CAMS Operations personnel and will request additional interactive sessions as needed to remain current on any modifications to the JSC/LACIE photointerpretation procedures.

Progress Last Quarter

A member of the RSRP staff (C.M. Hay) spent three weeks (28 March 1977 to 15 April 1977) at JSC aiding in the development of the LIST method. This provided an excellent opportunity for contact with LACIE operational analysts and a better appreciation of the analyst's interpretation environment problems was acquired. Also an update of progress of new interpretation procedures (Small Fields Procedure and Procedure 1) was gained. Contacts such as these with the operational environment of LACIE are the most efficient method for UCB personnel to stay current with JSC/LACIE photointerpretation procedures.

During this quarter the special PFC Alternative Product Evaluation was concluded. This secondary study provided the RSRP an opportunity to compare the usefulness of current and potential future interpretation products to the analysts. As a result of this study an increased awareness of the significance of data distortion as occurs when Landsat spectral data is mapped to display or image production was gained and subsequently will benefit the other two subtasks of this task. The results of the PFC Alternative Product Evaluation are presented in Appendix A.

Work To Be Accomplished Next Quarter

Procedure 1 is scheduled for implementation within the next quarter at JSC. After implementation has occurred, UCB plans a visit to JSC for a briefing from operational analysts and other JSC personnel on Procedure 1 as actually implemented. Problems pertaining to analyst labeling that may be associated with Procedure 1 will be reviewed at this time.

2.3 SUBTASK B: DEVELOPMENT OF MULTITEMPORAL INTERPRETATION PROCEDURES, AND SUBTASK C: DEVELOPMENT OF IMAGE REPRESENTATION TECHNIQUES FOR COMPRESSED MULTITEMPORAL DATA.

Background

In order to develop products and procedures that can potentially increase the labeling accuracy of analysts working with Landsat data such as in LACIE, it is first necessary to understand the components of the labeling process. The labeling process can be considered to consist of two main components (1) feature detection and (2) feature identification. Feature detection is defined to be the action of discrimination, based on spectral, spacial and temporal characteristics, a unique entity observable within the Landsat multitemporal spectral data. Feature identification is defined to be the action of assigning a name (eg. wheat, non-wheat) to the detected feature. Correct feature identification can not properly proceed unless feature detection has first occurred. Feature detection, however, does not insure feature identification. Errors in labeling can thus occur due to (1) failure to detect a feature of interest, and (2) failure to correctly identify a detected feature.

Errors Due to Failure to Detect a Feature of Interest

In multitemporal analysis of Landsat (low resolution) data for crop identification, the characteristics that the analyst seeks to detect are (1) the presence or absence of a vegetation canopy within specific biophases, (2) the relative condition or stage of development (quality of presence) of a vegetation canopy within specific biophases, and (3) the spacial distribution (local field size and shape, and overall proportion of similar fields in the segment) of a given spectral/vegetation canopy type. Of these three characteristics, the first is the most important for wheat detection and identification. Determination of the other two characteristics is necessary when significant overlap between wheat and confusion conditions exists or when acquisitions are missing or of poor quality. If a vegetation canopy can not be detected within a critical wheat biophase the probability of ultimately identifying the feature as wheat is lowered. Thus if the standard PFC Product 1 fails to represent a vegetation canopy in a manner normally expected by the analyst, there is a danger of mislabeling due to failure to detect the presence of vegetation on a given acquisition. Product 1 tends to inadequately represent low density vegetation canopies. Many, though not all, of these low canopy situations are detectable upon examination of the actual numeric spectral data. Thus auxiliary products which are designed to more clearly indicate the presence of low density canopies or other difficult canopy states should aid in increasing labeling accuracies where errors are due to non-detection.

In assessing the quality of the vegetation canopy, the numeric spectral data allows the analyst to differentiate more finely between stages of canopy development or condition than does the standard Product 1. This capability may be useful in discriminating wheat from close confusion crops. Auxiliary products that allow the analyst to evaluate the actual numeric spectral data improve detection and measurement of canopy presence or absence as well as canopy condition.

Products currently being investigated and refined as auxiliary aids to the analyst are listed in Table 2.1. The numeric spectral data products are meant to give the analyst a precise measure of condition and help him calibrate the standard images with which he is working. The image display products are meant to give the analyst a convenient representation of the spacial distribution of a given condition.

Errors Due to Incorrect Identification of a Detected Feature

While the standard image and auxiliary products allow the analyst to detect a feature, it is actually ancillary data from outside a specific set of Landsat spectral data that allows the analyst to identify a detected feature. The analyst must make correlations between a given spectral-temporal response pattern and the ancillary data about ground conditions. An analyst's ability to do this is dependent upon his educational background, his experience with the environment that he must analyze, the quality of training, the definitiveness of data correlations that have been given to him as guidelines, and the quality of his own analytical thought processes. At present, the analyst has very little data with which to make the needed spectral to ground correlations. Landsat data has not been available for a period sufficient to develop all the necessary correlations. The analyst, therefore, must develop these correlations (or more appropriately inferences to possible correlations) for himself from the ancillary data and spectral data given to him. Until the necessary spectral to ground condition correlations can be determined and definitively presented to the analyst the identification process will continue to be heavily dependent on the skills and experience of the individual analyst.

TABLE 2.1: DATA TO BE EVALUATED FOR THE DEVELOPMENT OF PRODUCTS FOR IMPROVED FEATURE DETECTION

- NUMERIC SPECTRAL DATA
  - SPECTRAL MEANS, STANDARD DEVIATION AND COVARIANCE
  - 7/5 FIELD/PIXEL-SPECIFIC RATIOS
  - KAUTH GREEN NUMBERS AND BRIGHTNESS NUMBERS
- IMAGE DISPLAY
  - CLUSTER MAPS
  - PRINCIPAL COMPONENTS REPRESENTATION
  - KAUTH ROTATED DATA
  - TEXAS A & M UNIVERSITY DATA REDUCTION TECHNIQUE
  - 7/5 RATIO
  - MULTITEMPORAL COMBINATIONS OF ABOVE

The ancillary data currently considered to be the most valuable to the analyst in aiding him to develop the needed correlations are listed in Table 2.2. This ancillary data should not only contain mean values and descriptions of average normal conditions but also should include variability information about the data. The variability data should include temporal variability (year to year) as well as spacial variability if at all possible.

2.3.1 SUBTASK B: DEVELOPMENT OF MULTITEMPORAL INTERPRETATION PROCEDURES

Objective

The purpose of this subtask is to develop improved multitemporal interpretation procedures which will increase AI labeling accuracies relative to current LACIE interpretation procedures. Specifically procedures which allow the analyst to utilize both standard multitemporal image presentations and preprocessed spectral data presentations are being explored.

Approach

This subtask builds upon Landsat image interpretation procedures developed in a previous UCB-LACIE task (see Hay and Thomas, 1976) and endeavors to incorporate the use of more detailed spectral information (such as products being developed in Subtask C) along with the analysis of the standard image products. The time has come for more frequent usage of the detailed spectral information actually contained in Landsat data. Standard image products such as Product 1 do not allow for the refined feature discrimination that is possible with Landsat data. This is not to say that standard image products such as Product 1 are unnecessary; they are vital. What is now needed, however, is the incorporation of more refined spectral data into the analysis procedures along with standard image products.

A fair amount of additional information is available in the actual Landsat spectral data. However, formats for effective presentation of this data and methods of incorporating it into the analysis procedure need to be developed. Subtask C is addressing the development of effective presentation formats.

Subtask B addresses the development of methods and guidelines for the integration of more refined spectral data into the analysis procedure. A problem in developing these guidelines is the lack of sufficient correlation of Landsat spectral responses to given ground conditions. Spectral response-to-ground condition relationships are just now beginning to be established. As yet, the results are meager and inconclusive. This should not stop the use of more refined spectral data by the analysts however. Some general guidelines can be developed now for the analysts and refined later as more definitive results from data correlation studies become available.

TABLE 2.2: ANCILLARY DATA MOST NECESSARY FOR FEATURE IDENTIFICATION

- DATA FOR ALL CROP MADE AVAILABLE TO AI
  - CROP CALENDARS
  - CROP HISTORICAL PROPORTIONS
  - CROPPING PRACTICES
- METEOROLOGICAL DATA AFFECTING CROP DEVELOPMENT AND/OR SPECTRAL RESPONSE OF CROP
  - RECENT PRECIPITATION
  - POTENTIAL YIELD
  - EPISODAL EVENTS DATA
- SPECTRAL RESPONSE CORRELATED TO CROP DEVELOPMENT STAGES

Procedures are being explored that make use of vegetation indication measures such as the band 7 to band 5 ratio or Tasselled Cap green and brightness numbers. Information about the temporal pattern of the 7/5 ratio, green numbers, and brightness numbers for wheat and other crops as well as thresholds for the presence of vegetation can be utilized by the analysts. This task seeks to develop procedures and guidelines for the effective incorporation of this data into the analysis procedure.

Another aspect of the labeling procedure being explored in this subtask is that of sampling within the segment. The development of procedures for better data usage and more effective sampling are being pursued in full recognition of the development of Procedure 1 and with the view that any procedures developed would, theoretically, be compatible with the philosophy behind Procedure 1.

All procedure modifications will be evaluated against the JSC/LACIE field interpretation procedures (the control treatment). Evaluation criteria for the procedure modifications include(1) ability to improve labeling performance, (2) ability to improve segment wheat estimate, (3) ability to decrease effort expended and increase throughput rate, and (4) the repeatability of the results. These evaluation criteria are summarized in Table 2.3.

Table 2.3

Subtask B: Development of Multitemporal Interpretation Procedures

Evaluation Criteria

Analyst Identification Accuracy

Wheat Estimate for the Segment

Effort Expended/Throughput Rate

Repeatability of Results

Progress Last Quarter

Ground data for the 1975-1976 Kansas and North Dakota segments was received, catalogued, and filed. Ten (10) segments (5 from Kansas and 5 from North Dakota) from the 1976 data set that will be used for procedure evaluation were processed this quarter by the JSC/LACIE fields procedure.

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JSC/LACIE interpretation procedures are documented in NASA/LEC (1976) and are summarized below.

On the PFC transparencies:

1. Define spectral subclasses by analysis of the full segment.
2. Select training fields from within spectrally homogeneous areas to represent all subclasses defined in Step 1.
3. Identify all spectral subclasses as wheat or non-wheat using multi-temporal interpretation procedures.
4. Select five test fields which have not been selected as training areas.
5. Digitize and verify training and test field coordinates using a coordinatograph and the LARS terminal.
6. Submit segment for batch classification processing.
7. Evaluate the classification results using class map and performance matrix for training and test areas.
8. If necessary, modify training and submit for reclassification.

To simulate the JSC/LACIE control procedures, UCB analysts employed the following procedure.

UCB - simulation of JSC/LACIE procedures:

1. On the PFC transparencies, define subclasses according to JSC procedures.
2. Select training fields according to JSC procedures.
3. Identify as wheat or non-wheat all subclasses using JSC procedures.
4. Systematically select fifty test areas throughout the segment. (It is UCB's view that the five test areas as required by JSC procedures are insufficient for an adequate evaluation of the classification results.)
5. Extract training and test field coordinates using the UCB-Remedys color monitor display system. A coordinatograph as used at JSC is not available at UCB.
6. Submit the training deck to the supervised classifier (CALSCAN) for processing.
7. Evaluate the classification results using the class map and performance matrix for training and test areas.

Results for the fields procedure, which will be used as the control treatment for later comparison with alternative procedures, are presented in Table 2.4. These results include analyst labeling accuracies and proportion estimates, as well as accuracies and proportion estimates for CALSCAN* runs using Ai labeled fields as training (JSC fields procedure).

TABLE 2.4: Interpretation Accuracies Using JSC/LACIE Phase II Fields Procedures (Control)

Segment #	% Correct Wheat or Small Grains	% Commission[4] for Wheat or Small Grains	% Correct Non-Wheat or Non-Small Grains	% Commission Non-Wheat or Non-Small Grains	Total % Correct	Wheat Prop. Estimate	True Wheat Prop.
			ANALYST				
KANSAS (Winter Wheat):							
1019	94.6	1.4	99.3	2.9	97.6	34.1	35.6
1020	100.0	2.9	98.6	0.0	99.0	32.5	31.6
1035[2]	56.4	8.3	98.8	9.2	90.9	11.5	18.8
1035[3]	72.4	12.5	98.9	4.3	94.7	11.5	13.9
1041	70.7	25.6	94.0	7.1	89.4	18.8	20.0
1183	66.7	0.0	100.0	5.3	95.7	9.6	14.4
NORTH DAKOTA (Small Grains):							
1618	94.7	3.1	94.8	8.8	94.7	61.7	63.2
1624	93.2	9.9	86.8	9.1	90.4	52.4	56.3
1633	91.2	6.7	94.8	6.7	93.2	42.8	43.8
1645	94.2	.7	98.6	10.2	95.6	62.2	65.6
1662	73.3	15.4	89.7	18.6	82.6	34.3	43.1
			SUPERVISED CLASSIFIER (CALSCAN)[1]				
KANSAS (Winter Wheat):							% Threshold
1019	90.4	14.3	91.9	5.3	91.3	37.5	.20
1020	80.3	5.4	97.9	2.1	92.3	26.0	.20
1035[2]	52.8	38.7	91.7	11.3	84.0	17.4	.44
1035[3]	73.1	38.7	92.3	4.7	89.5	17.4	.44
1041	78.6	43.1	83.6	6.6	82.5	31.7	1.00
1183	53.3	30.4	96.1	7.5	90.0	13.4	.14
NORTH DAKOTA (Small Grains):							
1618	90.9	13.0	75.0	18.2	85.3	66.9	4.10
1624	84.6	22.6	68.1	22.5	77.4	61.5	.62
1633	73.3	22.3	83.8	19.5	79.3	40.6	.30
1645	83.8	9.5	83.5	26.5	83.7	61.8	.28
1662	73.9	27.2	70.5	24.0	72.1	53.4	.85

1. CALSCAN is UCB's adaptation of LARSYS A
2. Total wheat (i.e. wheat harvested & wheat abandoned)
3. Wheat harvested only
4. % Commission = # incorrectly called wheat/total # called wheat x 100

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Work was begun this quarter on the development of a procedure whereby the analyst uses output from multitemporal clustering to produce a stratification of the data into wheat probability strata. This procedure, called the Delta Function Stratification (DFS) Procedure, requires the AI to analyze Landsat band 7 to band 5 cluster mean ratios from each acquisition date included in each multitemporal cluster mean vector. Based on the analysis the analyst then (1) groups the clusters according to the probability that a given multitemporal cluster is wheat and (2) defines a display function for the clustered data which will allow visual grouping of the above grouped clusters. Visual grouping of similar clusters within the display product facilitates the usefulness of clustered data to the analyst in the interpretation process. The AI can more quickly analyze the data and relationships within the data will be more apparent.

By stratifying the segment into wheat presence probability strata, a separate estimate of mean and variance can be produced for each stratum thus potentially allowing more precise estimates for wheat to be made at the segment level.

Initially the Delta Function Stratification Procedure is being developed using a full season's set of acquisitions (i.e. at harvest procedure). However, once developed for an at harvest mode, continuing work will deal with application of the procedure to the production of mid and/or early season estimates.

Basically the procedure is as follows:

1.) The analyst selects for a given segment a set of 2 to 4 acquisitions which he has determined to be both necessary and sufficient for the identification of wheat.
2.) The multitemporal data is then clustered using the following procedure.
    a.) Five 20 point by 20 line seed areas distributed throughout the segment* are clustered** for 10 iterations using a STDMAX = 4.0, MAXCLS = 50, and NMIN = 30.
    b.) Punched output statistics from the seed run are input into a second clustering run on the full segment for an additional 10 iterations at a STDMAX = 4.0, MAXCLS = 60, and NMIN = 30. This equates to a total of 20 iterations for the segment.
    c.) Punched output statistics and a display map on tape are acquired from the second clustering run.

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*The upper left corner of the five 20 point x 2 line seed areas are: a.) 1,1; b.) 1,97; c.) 88,48; d.) 176,1; 3.) 176,97.

**Clustering algorithm ISOCLAS - UCB's adaptation of JSC ISOCLS.

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3.) The stat deck from the second clustering run is input to a program called CLODER. CLODER computes 2 times the ratio of the bad 7 to band 5 means for each cluster for each acquisition date submitted to the multitemporal clustering algorithm.

4.) The analyst then selects a cluster ordering reference acquisition date. This acquisition is the one on which the analyst determines that wheat is most discriminable from most other conditions/crop types present in the segment.

5.) Clusters are then ordered according to the 2 x band 7 to band 5 ratio of the cluster means. The highest ratio is listed first, and the lowest listed last. The higher ratios correspond to the clusters which represent actively metabolizing green vegetation.

6.) After the multitemporal clusters have been ordered by the 7/5 ratios on the reference date, the ratio of 2 x band 7 to band 5 means for all other acquisitions that were processed are recorded in proper temporal order along side the reference date ratio for each cluster.

7.) The difference or delta between the ratios for each pair of adjacent acquisitions is then computed (See Table 2.5).

8.) By knowing the temporal (biostage) function of the 7/5 ratio for wheat (see Figure 2.1) and all other major crops grown within a region, the analyst can then analyze the deltas between each processed acquisition and assign each cluster to a probability of wheat stratum. Three main strata are currently being used in the procedure. An option is available to the analyst to determine 2 substrata for each stratum making six the maximum possible number of substrata.

The three main strata are:

a.) High probability wheat/small grains stratum: probability ≥ 50 % that the cluster is wheat/small grains.

b.) Medium probability wheat/small grains stratum: ≥ 25 % to < 50 % probability that the cluster is wheat/small grains. This stratum seems to contain primarily pasture, alfalfa, and range clusters in winter wheat areas.

c.) Low probability wheat/small grains stratum: < 25 % probability that a cluster is wheat/small grains. This stratum in a winter wheat area usually contains summer crops such as corn or sorghum or fallow conditions.

9.) Once the clusters are assigned to strata the analyst then defines the display function for the clusters. This function is defined so that clusters within the same stratum or substratum will visually group together when displayed. This is necessary so that the analyst can efficiently analyze the spacial distribution of related clusters. Visual grouping can be accomplished in two ways: (1) by assigning the same color code to all clusters

Table 2.5:

Two times the band 7 to band 5 ratio of the cluster means has been calculated for each date (6May76 & 8July76) processed by the multitemporal clustering algorithm. Clusters are ordered (listed) by their 7/5 ratio on the 6May76 date. On this date wheat and alfalfa are expected to have the most significant vegetation canopies (higher ratios) and fallow, corn and sorghum are expected to have ratios below 1.1 (no vegetation canopy). The analyst has assigned each cluster to a probability of presence of wheat stratum based on analysis of the 7/5 ratios for the two dates and the change (delta) in the ratios between the two dates.

H = high probability wheat stratum ($7/5_{6May} \geq 1.5$ and $7/5_{8July} \leq 1.1$)

Ma = medium probability wheat stratum1 ($7/5_{6May} \geq 2.5$ and $7/5_{8July} > 1.1$); most probably alfalfa

Mb = medium probability wheat stratum2 ($1.5 > 7/5_{6May} > 1.1$ and $7/5_{8July} > 1.1$); most probably alfalfa, pasture, range, urban

La = low probably wheat stratum1 ($7/5_{6May} \leq 1.1$ and $7/5_{8July} > 1.1$); most probably corn or sorghum

Lb = low probability wheat stratum2 ($7/5_{6May} \leq 1.1$ and $7/5_{8July} \leq 1.1$); most probably fallow

The resultant grouping of clusters into the five probability of presence of wheat strata for the segment is shown in Figure 2.2.

1035 FORD 6May76, 8July76 (47 Clusters)

STRATUM	CLUSTER	6May 7/5RATIO	Δ	8July 7/5RATIO	# Pixels	% Total
Ma	6	5.04	-3.55	1.31	72	0.3
Ma	3	4.76	- .33	4.43	128	0.5
H	22	1.89	- .92	.97	31	0.1
Ma	18	4.28	-1.91	2.32	83	0.3
H	48	4.07	-3.16	.91	62	0.2
Ma	39	3.78	-2.53	1.25	133	0.5
H	43	3.56	-2.60	.96	272	1.1
Ma	24	3.24	+ .72	3.96	65	0.2
H	26	3.02	-1.94	1.07	274	1.1
H	4	2.47	-1.52	.95	760	3.3
H	44	2.39	-1.58	.81	50	0.2
H	30	2.39	-1.31	1.08	85	0.3
Mb	28	2.26	- .88	1.38	432	1.8
Mb	23	1.97	- .67	1.30	119	0.5
Mb	45	1.91	+ .16	2.06	83	0.3
H	12	1.89	- .92	.97	934	4.0
H	17	1.82	- .85	.97	659	3.0
Mb	35	1.66	+ .95	2.61	173	0.7
H	16	1.66	- .64	1.02	684	2.9
H	40	1.56	- .47	1.09	100	0.4
Mb	32	1.55	+ .28	1.83	544	2.3
Mb	9	1.44	- .22	1.22	1834	7.3
Mb	5	1.33	- .11	1.72	2349	10.2
Mb	7	1.27	- .18	1.09	930	4.0
Mb	20	1.18	+ .10	1.28	953	4.1
Mb	42	1.16	+ .19	1.35	201	0.8
Mb	10	1.15	+ .18	1.33	529	2.3
Lb	13	1.12	- .21	.91	955	4.1
Lb	1	1.09	- .17	.92	310	1.3
Lb	29	1.08	- .12	.96	956	4.1
Lb	2	1.08	- .22	.86	1468	6.4
La	47	1.06	+ .17	1.23	56	0.2
Lb	15	1.05	+ .08	.97	659	3.0
Lb	11	1.03	+ .04	1.07	1102	4.8
Lb	41	1.03	+ .07	1.10	205	0.8
La	19	.99	+ .80	1.79	643	2.8
Lb	38	.98	- .10	.88	71	0.3
La	31	.98	+ .74	1.72	621	2.7
La	21	.96	+1.63	2.58	549	2.3
La	14	.95	+2.04	2.99	1167	5.0
La	8	.93	+2.11	3.04	1074	4.6
Lb	25	.89	0	.89	324	1.4
Lb	36	.88	- .33	.55	42	0.1
La	46	.86	+ .29	1.15	89	0.3
La	33	.83	+ .47	1.30	38	0.1
Lb	37	.83	- .01	.82	81	0.3
Lb	34	.82	+ .06	.88	29	0.1
Lb	27	.44	+ .08	.52	42	0.1

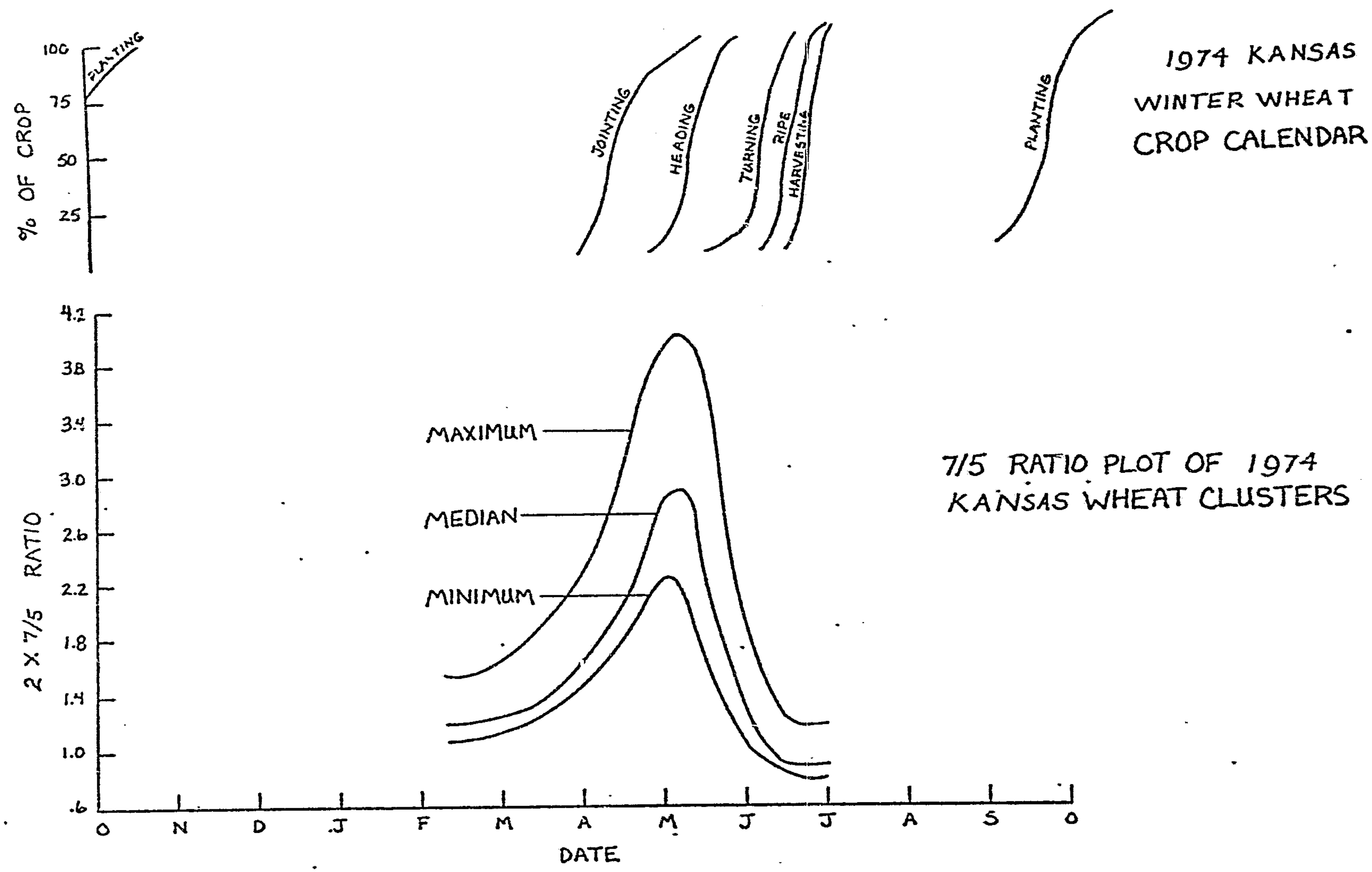

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Figure 2.1: Example of Band 7 to Band 5 Ratio of Winter Wheat Cluster Means through a Growing Season Compared to the Crop Calendar Plot

in the same substratum (this does not optimally allow for analysis of individual clusters) or (2) by assigning adjacent colors (e.g. red and orange, yellow and yellow green, blue green and blue) to adjacent clusters within a substratum as ordered by their 7/5 ratios on the reference date. Figure 2.2 illustrates display procedure 1 as described above and Figure 2.3 illustrates display procedure 2. In Figure 2.2 all the clusters belonging to one substratum have been individually displayed, clusters from the other substrata being displayed as a single color for that substratum only. This is due to a current limitation in the RSRP IGOR device whereby approximately 25 unique, visually separable colors are available. It is planned to remove this limitation during next quarter's effort by expanding the number of visually separable colors to between 60 and 100. At present, it is possible to work around the available color limitation by using multiple images and displaying individual clusters for a given substratum on each image.

Work To Be Pursued Next Quarter

The Delta Function Stratification Procedure will continue to be developed next quarter. An expanded number of segments will be processed and analyzed using this procedure to determine if it will be workable for the full variety of situations represented by LACIE sample segments. In addition, refinements to the quantitative test design will be considered as the Delta Function Stratification Procedure continues to develop.

2.3.2 SUBTASK C: DEVELOPMENT OF IMAGE REPRESENTATION TECHNIQUES FOR COMPRESSED MULTITEMPORAL DATA

Objective

The purpose of this subtask is to develop several alternative Landsat data reduction/compression spectral representations and to evaluate their role in multitemporal training procedures. These spectral representations function as additional sources of information to the analyst interpreter (AI). As such they should enable the analyst to better discriminate crop spectral density function components. If the spectrally discriminable classes can then be correlated to ancillary data (crop calendar data, historical agricultural statistical data, etc.) improved labeling should be possible.

Approach

Several multitemporal spectral representations developed from Landsat digital data will be presented to the image analyst. Three of these will receive major emphasis in quantitative testing. They include*: (1) Landsat band 7 to band 5 ratio multidate sequences, (2) Tasselled Cap (Kauth) green band multidate sequences, and (3) principal component representations of Tasselled Cap multidate sequences.

*All Landsat data will be first corrected to reference sun angle and haze condition using ERIM XSTAR procedure.

GROUND DATA

Stratum	% Wheat Harvested	% Wheat Abandoned	% Non-Wheat	# of Points*
H	75	4	21	28
Ma,b	7	0	94	84
La,b	5	8	87	97

*Sample of 209 grid points

Figure 2.2: Display Procedure 1 - Delta Function Stratification and Display Procedure was utilized to group the 47 multitemporal clusters into five wheat probability strata.

High probability wheat stratum (H), represented by red-violet areas, includes clusters $2x7/5_{May\ 6} \geq 1.5$ and $2x7/5_{July\ 8} \leq 1.1$.

Medium probability wheat stratum 1 (Ma), represented by red areas, includes clusters $2x7/5_{May\ 6} \geq 2.5$ and $2x7/5_{July\ 8} > 1.1$; most probably alfalfa.

Medium probability wheat stratum 2 (Mb), represented by blue areas, includes clusters $2.5 > 2x7/5_{May\ 6} > 1.1$ and $2x7/5_{July\ 8} > 1.1$; most probably alfalfa, pasture, range, or urban.

Low probability wheat stratum 1 (La), represented by green areas, includes clusters $2x7/5_{May\ 6} \leq 1.1$ and $2x7/5_{July\ 8} > 1.1$; most probably corn and sorghum.

Low probability wheat stratum 2 (Lb), represented by white and black areas, includes clusters $2x7/5_{May\ 6} \leq 1.1$ and $2x7/5_{July\ 8} \leq 1.1$; most probably fallow and water.

GROUND DATA

Stratum	% Wheat	% Barley	% Non Small Grains	# of Points*
Ha	71.2	20.3	8.5	118
Hb	38.1	23.8	38.1	21
Ma	29.6	3.7	66.7	27
Mb	25.0	0.0	75.0	8
La	12.1	0.0	87.9	32
Lb	0.0	0.0	100.0	3
				209

*Sample of 209 grid points

Figure 2.3: Display Procedure 2 - The Delta Function Stratification and Display Procedure was utilized to group 57 multitemporal clusters into six small grains probability strata.

Ha - high probability small grains substratum 1
Hb - high probability small grains substratum 2
Ma - medium probability small grains substratum 1
Mb - medium probability small grains substratum 2
La - low probability small grains substratum 1
Lb - low probability small grains substratum 2

Strata Ma, Mb, La, and Lb have been grouped into one color (brown) for display so that an adequate number of colors would be available for display of individual clusters within strata Ha and Hb. Warm colors are assigned to the clusters that have the higher 7/5 ratios progressively toward the cooler colors with decreasing 7/5 ratios. This allows visual grouping of similar clusters (similar 7/5 ratios) so that discrimination of landscape features is preserved thus aiding the analyst in his analysis of the data.

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Between date differences in Landsat 7/5 ratios or in Tasselled Cap green numbers will also be included as appropriate in (1) and (2) respectively.

Formats of image representation to the analyst will include hardcopy prints, color monitor display, and/or numerical representations. Color hardcopy is generated by the RSRP light emitting diode film annotator (IGOR). Television monitor display consists of single images (one or more bands) or simultaneous display of up to four separate images (each with one or more bands).

An analysis of variance design will be used to quantitatively evaluate the effects of the three major spectral representation types (defined above) on AI labeling accuracy. To implement this design, a series of interpretation tests will be performed on 1976 LACIE blind sites in Kansas and North Dakota for which ground data is available. Analysts will be asked to first interpret the 209 grid intersections per segment using only the standard PFC film product and standard ancillary data. Next, segment grid intersections will be interpreted without standard products using only one of the three alternative spectral representations at a time. Each analyst will be randomly assigned one alternative product (multidate 7/5, multidate green number, or principal component of multidate green number) per segment to use for interpretation. Finally, alternative products will be combined with standard products and used to label the grid intersections for each segment. Analysts will interpret each segment once in this manner using the data combination containing the alternative spectral representation assigned to them previously.

The test performance measure is defined as the change in labeling accuracy obtained with the alternative spectral representations or with the combination of alternative and standard products <u>versus</u> use of the standard products alone. These labeling accuracy changes by segment by treatment are the observations entered into the analysis of variance. Thus the experiment is seen to consist of three treatment <u>groups</u>: (1) standard product versus standard product (the control treatment; expected differece equals zero), (2) alternative product versus standard product, and (3) combination of alternative and standard products versus standard product. Relative variation in accuracy differences between treatments (reported by segment) is expected to be less than corresponding variation in individual accuracy values. Consequently, the treatment-difference approach is expected to give the most powerful test for detecting labeling accuracy improvements due to alternative spectral aids at a given level of statistical significance.

Other spectral represenations will be evaluated qualitatively relative to potential labeling accuracy improvement by experienced image analysts. These additional spectral products include the Texas A & M multitemporal compression image as well as variations of the Landsat 7/5 ratio and Tasselled Cap space data.

Progress Last Quarter

Work this past quarter focused on (1) completion of major aspects of the experimental design described above, (2) implementation of the ERIM XSTAR sun angle and haze correction algorithms, and (3) development of interactive color monitor display software to rapidly create and manipulate spectral enhancements. In addition, two LACIE blind site segments were selected in Kansas (1035 and 1041) and two in North Dakota (1618 and 1633) for use in defining the specific data combinations and display formats for each of the three major spectral representations to be analyzed in the analysis of variance layout.

Next Quarter

A total of 17 test segments in Kansas and North Dakota will be interpreted by analysts using the standard PFC and ancillary data products. The resulting labeling accuracies will be used as the reference performance measure in the quantitative evaluation of the Landsat 7/5 ratio and green number spectral representations. Formats for presentation of spectral aid materials used will be finalized. All test segments will be preprocessed by XSTAR procedures before multidate spectral enhancements are generated. Interpretation using the resulting spectral enhancements will be initiated.

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APPENDIX A:

PFC ALTERNATIVE PRODUCT EVALUATION

APPENDIX A: PFC ALTERNATIVE PRODUCT EVALUATION

By: Andrew S. Benson

Introduction

Presently, the training data input to the CAMS are wheat and nonwheat subclasses which the AI's identify on a standard image type (Product 1) produced by the production film converter (PFC). There is evidence, however, that the parameters input to the PFC, viz., bias, gain, and spectral limits, may be producing a biased representation of the spectral data on the resulting imagery. It is conceivable that (1) indications of early canopy cover present in the spectral data would not be manifested in the imagery, (2) some of the wheat and nonwheat subclasses selected by the AI could have no correlation with spectral classes as seen by the classifier, and (3) adjoining segments from one Landsat frame would be produced using different parameters, thus producing varying representations of similar ground conditions.

In an attempt to improve the standard PFC image, three additional image types (hereafter referred to as Kraus, Hocutt, Kaneko) have been produced on the PFC using different formulae to compute the input parameters of gain and bias. These formulas plus the one used to compute Product 1 are given in Table A. 1. Of the four image types, Product 1 is the only one in which the spectral ranges for each band are computed independently of the others. With the Kaneko product, the spectral ranges for each band are computed separately based on the dispersion from the grand spectral mean for all bands. With Hocutt, one spectral range is computed for all bands based on the maximum dispersion exhibited by any of the three bands. With Kraus, the complete range of Landsat data are used to produce the image product.

In January 1977, personnel from RSRP began an additional secondary task at the request of JSC technical monitors which was designed to compare the usefulness of the current PFC image product with these alternative image products. The following paragraphs document the results of this study.

Objective

The primary objective of this study was to evaluate the relative usefulness of Product 1, Kaneko, Hocutt, and Kraus image products for detecting and identifying the presence of wheat. A secondary objective was to determine which of the three alternative products would be the best supplementary aid to Product 1 for the detection and identification of wheat during the early growing season when wheat canopy density is low.

Table A.1: Formulae Used to Compute Input Parameters to PFC Image Types*

	Product I	Kaneko	Hocutt	Kraus
PFC Gain	$A_I = \frac{256}{U_I - L_I}$	$A_I = \frac{256}{U_I - L_I}$	$A_0 = \frac{256}{U_0 - L_0}$	$A_0 = \frac{128}{P_0}$
PFC Bias	$B_I = (-1) L_I A_I$	$B_I = (-1) L_I A_I$	$B_0 = (-1) L_0 A_0$	None
	$U_I = P_I + 3S_I$	$U_I = P_0 + M_I$	$U_0 = \text{Max } (P_I + 3S_I)$	
	$L_I = P_I - 3S_I$	$L_I = P_0 - M_I$	$L_0 = \text{Min } (P_I - 3S_I)$	

$$M_I = \text{Max } [P_I + 3S_I - P_0, \; P_0 - P_I + 3S_I]$$

$$P_0 = \frac{P_1 + P_2 + P_3}{3}$$

* Internal document from LACIE Project Review Session, January 25-28, 1977, NASA Johnson Space Center, Houston, Texas.

Initially, the four PFC image products were ranked qualitatively for each date throughout the growing season using the following seven photographic image quality criteria:

1. Hue range (widest = 1, lowest = 4),
2. Overall image contrast range (highest = 1, lowest = 4),
3. Overall image density (lowest = 1, highest = 4),
4. Wheat signature intensity (highest = 1, lowest = 4),
5. Hue saturation (highest = 1, lowest = 4),
6. Ability to define field location -- feature specific contrast (best = 1, poorest = 4), and
7. Ability to represent spectral classes -- spectral data representation (best = 1, poorest = 4).

The first three criteria were applied to overall segment appearance, and the last four were applied to specific wheat and nonwheat fields for class evaluation within the segment.

A quantitative evaluation of all acquisition dates from each segment was as follows:

1. Histograms of the spectral data from bands 4, 5, and 7 for the entire segment were produced,
2. Statistics were computed for each band, viz., mean, standard deviation, and covariance matrix,
3. The spectral limits which applied to each image type as outlined in Table A.1 were computed,
4. From a sample of the wheat fields given in the ground data the average number of wheat pixels falling outside the spectral limits for each image type were determined, and
5. The spectral values of "anomalous appearing" pixels within wheat and nonwheat fields which were identified during the qualitative evaluation phase of the study were quantified.

Approach

In order to evaluate the relative merits of the standard PFC image products vs the three alternative image products, ground data, the four image products per date, and spectral data were examined for six Great Plains winter wheat segments and four spring wheat segments. A list of the segments and the acquisition dates available to the RSRP are given in Table A. 2.

Results

Qualitative Evaluation

The ranking of nine segments based on the photographic parameters is given in Table A.3. (Segment 1622 was excluded from this evaluation because no ground data were available). The performance index is based on the average ranking of each product by segment computed from all acquisition dates. The ranking index is based on the simple numerical ranking of the performance index for each segment.

As is clear from Table A.3, Product 1 was the best photographic product followed by Hocutt, Kaneko, and Kraus, respectively. This was to be expected because the procedure by which the gains and bias are calculated for Product 1 will maximize the contrast and brightness of an image. In comparison, for many of the acquisition dates, the alternative products were poorly exposed, had poor color balance, viz., a yellow or purple cast, and had a lower contrast.

The performance index ranking averaged for each image product is summarized by photographic parameters in Table A.4. Here again, the current product was ranked the highest overall and the highest for all photo parameters except one, viz., saturation of the wheat class.

A small number of anomalies occassionally appeared on Product 1 and Hocutt, which did not appear on the Kaneko and Kraus products. Inspection of the spectral data indicated that these anomalous pixels fell within the ranges defined for these two products and, therefore, were probably the result of system error. On the images that were inspected, these anomalous pixels were easily identified as such, so that in an operational system they should not confuse a skilled analyst. The cause of these anomalous pixels, however, should be determined.

Quantitative Evaluation

The extent of pixel compression for each segment in the lower and upper band range is given in Tables A.5a - A.5j and a summary of the average compression by segment is given in Table A.6. Again, as had to be expected from the formulae, the most compression occurred in Product 1, followed by Kaneko and Hocutt. All products, however, minimized the compression in the lower range which is desired to maximize the detection of wheat early in its development. The spectral data for a small sample of wheat fields taken throughout the growing season from a number of spring and winter wheat segments indicated that none of these data were compressed in either the lower or upper ranges. Finally, it must be recognized that even in the extreme cases, the percentage of points that are compressed by any image type is very low, and little data are lost, regardless of the method used to calculate image specifications.

Conclusions and Recommendations

Based on the qualitative and quantitative results of this limited study it has been concluded that the Product 1 is the best currently available photographic product to be used by the AI's. The image quality of Product 1 was consistently good while that of the alternative products varied considerably. (Much of this variability may have been due to improper film exposure or processing and not due to the manner in which the gains and biases were calculated. This could not be determined from the information made available to RSRP personnel). Maintaining consistent, good image quality is extremely important for an operational project such as LACIE which is dependent upon the processing of large volumes of AI data, so that analyst fatigue is minimized.

Of the three alternate products tested, Kraus is probably the most logical one to use as an ancillary image to Product 1. Although this conclusion is not supported by the results of this study, it is clear from the formulae used to calculate input parameters to the PFC that the Kraus product is the only one in which spectral compression of pixels is impossible. Therefore, on the Kraus product, all spectral data would be presented to the AI, thereby increasing the possibility of early detection of wheat.

It is recommended that the development of ancillary image products continue. This development, however, should have the objective of producing an image that emphasizes low density wheat only. It would not be necessary, therefore, to produce an image that represents the full range of vegetation within the segment since this would be an ancillary product that would be used in conjunction with Product 1. This need for reduced spectral range should increase the flexibility in the data manipulation to meet the desired objective.

Table A.2: The Segments and Their Acquisition Dates Used to Evaluate Four PFC Products

Segment	Location	Dates Available
1178	SE Kansas	22 Nov 75, 10 Dec 75, 27 Mar 76, 3 May 76, 20 May 76
1181	SE Kansas	11 Dec 75, 16 Jan 76, 22 Feb 76, 10 Mar 76, 3 May 76, 14 July 76
1232	SW Oklahoma	31 Dec 75, 23 Feb 76, 16 Apr 76, 22 May 76, 24 June 76
1521	SW Minnesota	23 May 76, 10 June 76, 21 Aug 76
1538	NE Montana	25 Apr 76, 13 May 76, 31 May 76, 18 June 76, 5 July 76, 23 July 76, 11 Aug 76
1574	E. Central Nebraska	7 Nov 75, 30 Dec 75, 18 Jan 76, 4 May 76, 9 June 76
1622	NE North Dakota	19 Apr 76, 7 May 76, 12 June 76, 30 June 76, 19 July 76, 6 Aug 76, 24 Aug 76, 10 Sept 76*
1681	NE South Dakota	6 May 76, 24 May 76, 10 June 76, 17 July 76, 4 Aug 76*
1851	NW Kansas	19 Jan 76, 6 Feb 76, 24 Feb 76, 13 Mar 76, 31 Mar 76, 6 May 76, 17 July 76
1865	SW Kansas	15 Dec 75, 7 Feb 76, 13 Mar 76, 18 Apr 76, 6 May 76

*No ground data available

Table A.3: Ranking of PFC Products Based on Photographic Parameters

SEGMENT	PRODUCT 1		KANEKO		KRAUS		HOCUTT	
	PERFORMANCE	RANK	PERFORMANCE	RANK	PERFORMANCE	RANK	PERFORMANCE	RANK
1181	1.2	1	2.8	3	4.0	4	2.1	2
1178	1.8	1	3.0	3	3.1	4	2.1	2
1232	1.3	1	3.1	3	3.5	4	2.2	2
1521	2.1	2.5	1.7	1	2.1	2.5	4.0	4
1538	1.5	1	2.7	3	3.3	4	2.5	2
1574	2.0	1	2.9	3.5	2.9	3.5	2.1	2
1851	1.5	1	2.5	3	4.0	4	2.0	2
1861	1.6	1	2.0	2	3.6	4	2.7	3
1865	1.6	1	3.0	3	3.7	4	1.8	2

Table A.4: The Performance Index/Ranking of All Segments Summarized by the Photographic Parameters Used for Qualitative Evaluation of Four PFC Image Types

Image Type	Wheat				Nonwheat				Overall			
	A	B	C	D	A	B	C	D	E	F	G	MEAN
Product 1	1.9/1	2.2/2	1.5/1	2.0/1	1.4/1	1.7/1	1.4/1	1.8/1	1.2/1	1.2/1	1.6/1	1.6/1
Kaneko	2.6/3	2.7/3	2.7/3	2.6/3	2.7/3	2.7/3	2.8/3	2.1/2.5	2.8/3	2.9/3	1.9/2	2.6/3
Kraus	3.2/4	3.2/4	3.4/4	3.1/4	3.5/4	3.4/4	3.5/4	3.3/4	3.5/4	3.5/4	3.3/4	3.4/4
Hocutt	2.2/2	1.9/1	2.4/2	2.4/2	2.4/2	2.1/2	2.3/2	2.1/2.5	2.5/2	2.4/2	3.2/3	2.4/2

A Intensity
B Saturation
C Field location
D Training selection

(A–D: Wheat/Nonwheat)

E Hue range
F Contrast
G Density

(E–G: Overall)

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Table A.5a: Pixel Compression for Segment 1178 -- Lower Range (L) and Upper Range (U)

Date	PRODUCT I						KANEKO						HOCUTT					
	BAND 4		BAND 5		BAND 7		BAND 4		BAND 5		BAND 7		BAND 4		BAND 5		BAND 7	
	L	U	L	U	L	U	L	U	L	U	L	U	L	U	L	U	L	U
22 Nov 75	0	145	0	80	12	203	0	6	0	15	0	203	0	0	0	0	12	203
10 Dec 75	0	160	0	13	4	103	0	0	0	10	0	103	0	0	0	0	4	103
27 Mar 76	0	131	0	163	23	6	0	0	0	28	0	6	0	0	0	1	6	6
3 May 76	0	264	0	300	49	52	0	1	0	6	0	52	0	0	0	0	0	52
20 May 76	0	366	0	451	86	128	0	2	0	4	0	128	0	0	0	4	0	128
AVERAGE PER SEGMENT	0	213	0	201	35	98	0	2	0	13	0	98	0	0	0	1	4	98

Table A.5b: Pixel Compression for Segment 1181 -- Lower Range (L) and Upper Range (U)

Date	PRODUCT 1						KANEKO.						HOCUTT					
	BAND 4		BAND 5		BAND 7		BAND 4		BAND 5		BAND 7		BAND 4		BAND 5		BAND 7	
	L	U	L	U	L	U	L	U	L	U	L	U	L	U	L	U	L	U
10 Dec 75	7	253	0	70	8	128	7	3	0	70	1	128	0	1	0	1	8	128
16 Jan 76	1	170	0	39	3	14	1	1	0	39	0	14	0	0	0	1	3	14
22 Feb 76	0	30	0	30	19	91	0	4	0	30	0	91	0	0	0	6	2	91
10 Apr 76	0	22	0	17	0	57	0	1	0	17	0	57	0	0	0	13	0	57
31 May 76	0	93	0	81	58	163	0	2	0	1	0	163	0	0	0	0	0	163
14 July 76	0	199	0	206	168	257	0	160	0	148	0	257	0	127	0	143	0	257
AVERAGE PER SEGMENT	1	128	0	74	43	118	1	29	0	51	0	118	0	21	0	27	2	118

Table A.5c: Pixel Compression for Segment 1232 -- Lower Range (L) and Upper Range (U)

Date	PRODUCT 1						KANEKO						HOCUTT					
	BAND 4		BAND 5		BAND 7		BAND 4		BAND 5		BAND 7		BAND 4		BAND 5		BAND 7	
	L	U	L	U	L	U	L	U	L	U	L	U	L	U	L	U	L	U
31 Dec 75	0	356	0	274	0	78	0	29	0	189	0	78	0	0	0	38	0	78
23 Feb 76	0	298	0	323	43	39	0	2	0	323	0	39	0	0	0	42	22	39
16 Apr 76	0	190	0	301	64	136	0	17	0	182	0	136	0	3	0	155	8	136
22 May 76	17	149	0	87	146	42	17	25	0	87	44	42	0	11	0	87	25	17
24 June 76	0	340	0	160	57	20	0	2	0	160	20	20	0	0	0	160	8	1
AVERAGE PER SEGMENT	3	267	0	229	62	63	3	15	0	188	13	63	0	3	0	96	13	54

Table A.5d: Pixel Compression for Segment 1521 -- Lower Range (L) and Upper Range (U)

Date	PRODUCT 1						KANEKO						HOCUTT					
	BAND 4		BAND 5		BAND 7		BAND 4		BAND 5		BAND 7		BAND 4		BAND 5		BAND 7	
	L	U	L	U	L	U	L	U	L	U	L	U	L	U	L	U	L	U
23 May 76	101	102	0	141	0	107	101	6	0	9	0	107	0	0	0	0	0	107
10 June 76	43	192	0	203	191	32	43	3	0	1	191	32	1	0	0	0	191	32
21 Aug 76	0	62	0	70	12	4	0	10	0	49	12	4	0	0	0	4	12	4
AVERAGE PER SEGMENT	36	89	0	104	51	36	36	5	0	15	51	36	0	0	0	1	51	36

Table A.5e : Pixel Compression for Segment 1538 -- Lower Range (L) and Upper Range (U)

Date	PRODUCT 1						KANEKO						HOCUTT					
	BAND 4		BAND 5		BAND 7		BAND 4		BAND 5		BAND 7		BAND 4		BAND 5		BAND 7	
	L	U	L	U	L	U	L	U	L	U	L	U	L	U	L	U	L	U
24 Apr 76	2	36	6	22	35	68	2	0	0	22	35	18	2	0	0	22	26	0
13 May 76	9	18	7	34	21	31	9	0	0	34	21	11	8	0	7	34	21	0
31 May 76	0	46	0	21	6	47	0	3	0	7	0	47	0	0	0	1	0	47
18 June 76	0	24	0	6	97	43	0	6	0	1	0	43	0	0	0	6	0	0
5 July 76	0	8	0	1	34	39	0	0	0	0	6	39	0	0	0	1	0	0
23 July 76	2	92	0	12	29	18	2	4	0	12	12	18	0	0	0	12	1	0
11 Aug 76	0	3	0	0	25	77	0	1	0	0	25	77	0	0	0	0	3	0
AVERAGE PER SEGMENT	2	32	2	14	35	46	2	2	0	11	14	36	1	0	1	11	7	7

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Table A.5f : Pixel Compression for Segment 1574 -- Lower Range (L) and Upper Range (U)

Date	PRODUCT 1						KANEKO						HOCUTT					
	BAND 4		BAND 5		BAND 7		BAND 4		BAND 5		BAND 7		BAND 4		BAND 5		BAND 7	
	L	U	L	U	L	U	L	U	L	U	L	U	L	U	L	U	L	U
7 Nov 75	0	30	0	21	77	84	0	0	0	21	11	84	0	0	0	0	55	84
30 Dec 75	0	244	0	219	0	307	0	244	0	219	0	307	0	222	0	219	0	307
18 Jan 76	0	232	0	179	40	178	0	195	0	179	0	26	0	171	0	179	40	26
4 May 76	0	262	0	207	79	169	0	256	0	52	0	69	0	0	0	1	35	169
9 June 76	0	429	0	245	11	40	0	12	0	18	0	40	0	0	0	0	0	40
16 July 76	0	138	0	181	97	130	0	0	0	2	0	130	0	0	0	31	0	130
AVERAGE PER SEGMENT	0	223	0	175	51	151	0	118	0	82	2	109	0	66	0	72	22	126

Table A.5g : Pixel Compression for Segment 1622 -- Lower Range (L) and Upper Range (U)

Date	PRODUCT I						KANEKO						HOCUTT					
	BAND 4		BAND 5		BAND 7		BAND 4		BAND 5		BAND 7		BAND 4		BAND 5		BAND 7	
	L	U	L	U	L	U	L	U	L	U	L	U	L	U	L	U	L	U
19 Apr 76	0	179	0	127	0	259	0	179	0	127	0	73	0	2	0	127	0	259
7 May 76	32	102	77	45	271	114	2	45	4	45	271	58	0	9	0	26	271	114
12 June 76	121	107	21	215	0	142	121	18	21	4	0	142	0	0	0	0	0	142
30 June 76	0	252	0	213	28	35	0	134	0	126	0	35	0	38	0	53	0	35
19 July 76	1	154	0	119	25	0	1	21	0	5	0	0	0	0	0	0	25	0
6 Aug 76	0	832	0	711	35	0	0	4	0	488	0	0	0	0	0	4	0	0
24 Aug 76	0	185	0	120	37	18	0	1	0	120	3	18	0	1	0	27	19	18
10 Sep 76	2	14	0	13	147	6	2	2	0	4	0	6	0	0	0	0	147	6
AVERAGE PER SEGMENT	20	228	12	195	68	72	16	50	3	114	34	41	0	6	0	30	58	72

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Table A.5h: Pixel Compression for Segment 1681 -- Lower Range (L) and Upper Range (U)

Date	PRODUCT 1						KANEKO						HOCUTT					
	BAND 4		BAND 5		BAND 7		BAND 4		BAND 5		BAND 7		BAND 4		BAND 5		BAND 7	
	L	U	L	U	L	U	L	U	L	U	L	U	L	U	L	U	L	U
6 May 76	7	100	5	203	0	34	7	7	5	42	0	34	0	0	0	0	0	34
24 May 76	0	97	0	70	0	5	0	6	0	6	0	5	0	0	0	5	0	5
10 June 76	0	93	0	51	0	4	0	6	0	5	0	4	0	0	0	0	0	4
17 July 76	0	78	0	0	0	11	0	2	0	0	0	11	0	0	0	0	0	11
4 Aug 76	0	22	0	19	17	49	0	9	0	19	17	49	0	0	0	3	17	49
AVERAGE PER SEGMENT	1	78	1	69	3	21	1	6	1	14	3	21	0	0	0	2	3	21

Table A.5i : Pixel Compression for Segment 1851 -- Lower Range (L) and Upper Range (U)

Date	PRODUCT 1						KANEKO						HOCUTT					
	BAND 4		BAND 5		BAND 7		BAND 4		BAND 5		BAND 7		BAND 4		BAND 5		BAND 7	
	L	U	L	U	L	U	L	U	L	U	L	U	L	U	L	U	L	U
19 Jan 76	0	83	0	144	0	87	0	8	0	144	0	87	0	8	0	144	0	13
6 Feb 76	1	162	5	90	65	130	1	6	0	90	24	130	1	2	2	90	24	3
24 Feb 76	0	289	0	208	38	149	0	77	0	208	5	149	0	29	0	208	0	16
13 Mar 76	0	66	0	79	1	82	0	4	0	79	0	82	0	4	0	79	0	34
31 Mar 76	12	66	46	133	8	152	12	3	0	133	0	152	12	2	17	133	0	152
6 May 76	0	165	0	176	4	134	0	2	0	36	0	134	0	0	0	16	0	134
17 July 76	0	479	0	122	22	131	0	129	0	122	20	131	0	38	0	122	0	3
AVERAGE PER SEGMENT	2	187	7	136	20	124	2	33	0	116	7	124	2	12	3	113	3	51

Table A.5j : Pixel Compression for Segment 1865 -- Lower Range (L) and Upper Range (U)

Date	PRODUCT 1						KANEKO						HOCUTT					
	BAND 4		BAND 5		BAND 7		BAND 4		BAND 5		BAND 7		BAND 4		BAND 5		BAND 7	
	L	U	L	U	L	U	L	U	L	U	L	U	L	U	L	U	L	U
15 Dec 75	0	105	0	134	0	58	0	0	0	134	0	58	0	134	0	134	0	58
7 Feb 76	0	21	0	55	3	69	0	0	0	55	0	69	0	0	0	55	1	2
13 Mar 76	25	7	2	47	1	6	25	0	0	47	0	6	0	0	2	47	1	0
18 Apr 76	0	0	0	0	0	107	0	0	0	0	0	107	0	0	0	0	0	0
6 May 76	0	257	0	275	0	328	0	18	0	275	0	328	0	0	0	275	0	145
10 June 76	2	149	0	127	4	99	2	0	0	127	0	99	2	0	0	127	0	75
AVERAGE PER SEGMENT	5	90	0	106	1	111	5	3	0	106	0	111	0	22	0	106	0	47

Table A.6.: Summary of Average Pixel Compression -- Lower Range (L) and Upper Range (U) for All Segments

Date	PRODUCT 1						KANEKO						HOCUTT					
	BAND 4		BAND 5		BAND 7		BAND 4		BAND 5		BAND 7		BAND 4		BAND 5		BAND 7	
	L	U	L	U	L	U	L	U	L	U	L	U	L	U	L	U	L	U
1178	0	213	0	201	35	98	0	2	0	13	0	98	0	0	0	1	4	98
1181	1	128	0	74	43	118	1	29	0	51	0	118	0	21	0	27	2	118
1232	3	267	0	229	62	63	3	15	0	188	13	63	0	3	0	96	13	54
1521	36	89	0	104	51	36	36	5	0	15	51	36	1	0	0	1	51	36
1538	2	32	2	14	35	46	2	2	0	11	14	36	1	0	1	11	7	7
1574	0	223	0	175	51	151	0	118	0	82	2	109	0	66	0	72	22	126
1622	20	228	12	195	68	72	16	50	3	114	34	41	0	6	0	30	58	72
1681	1	78	1	69	3	21	1	6	1	14	3	21	0	0	0	2	3	21
1851	2	187	7	136	20	124	2	33	0	116	7	124	2	12	3	113	3	51
1865	5	90	0	106	1	111	5	3	0	106	0	111	0	22	0	106	0	47
AVERAGE FOR ALL SEGMENT	7	154	2	130	37	84	7	26	0	71	12	74	0	13	0	46	16	63

Total Pixels Per Segment = 22,932

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