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EVALUATING THE RADIANCE TRANSFORMATION FOR NORMALIZING LANDSAT DATA

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ABSTRACT

With the current interest in the use of remotely sensed data for earth resources monitoring and georeferenced data base applications, the Eastern Regional Remote Sensing Applications Center (ERRSAC) is examining techniques which improve the comparability of Landsat multispectral scanner (MSS) data acquired on different dates. Of special concern is the variation of statistical data describing spectral signatures associated with land cover types in the categorization of Landsat data. The image categorizations are typically performed using the digital unitless counts read directly from the computer compatible tape. The resulting classification maps from two dates for the same area may be similar, but the statistical data derived from each date are varied. This study emphasizes one of the many possible scene-dependent factors, namely, the sensor gain and offset corrections.

One technique under study to normalize Landsat MSS data is the conversion of digital brightness counts to relative radiance values measured in energy units (mW/cm^2 sr). The statistical data of signatures from 23 land cover classifications derived from all three Landsats were compared before and after the radiance normalization. Significant convergence occurred among these data sets for mean spectral values and the variances associated with each of seven major land cover types for MSS bands 4, 5, and 7. Overall, the variance attributed to the sensor component was reduced from 5.39 to 2.69 percent with the largest decrease occurring in band 4 (14.4 percent to 3.7 percent).

I. INTRODUCTION

A major resource management objective for the next decade will focus on the assessment of land cover change and associated surface biomass from satellites on a global basis. The assessment of surface changes in cover (or biomass) requires that the spectral variances for the cover types from different data sets be small relative to the interscene variance. For the simplest case of change assessment, the comparison of radiance measured for one cover type from anniversary date scenes for the same location, the estimated error on the apparent change of a particular cover type equals the sum of the variances for both dates. Since the probability of constant sensor calibration (i.e., same sensor and/or calibration settings) over time is small, the problem of accounting for sensor differences is critical to the development of a regional monitoring capability.

The derivation of meaningful surface reflectance information from Landsat MSS data has been examined by many investigators.[2,6,7] A known source of variance in data collected from the three Landsat MSS sensors to date is related to the gain and offset calibration settings.[3,8] These sensors can be actually treated as 5 different sensors, since both Landsats 2 and 3 were each recalibrated once in orbit. The sensors, for our purposes, can be designated as: Landsat 1 (L1); Landsat 2A (L2A) for data acquired between January 22, 1975 and July 16, 1975; Landsat 2B (L2B) for data acquired after July 16, 1975; Landsat 3A (L3A) for data acquired between March 5, 1978 and May 31, 1978; and Landsat 3B (L3B) for data acquired after May 31, 1978.

This study is the first in a series of investigations on the usefulness of transforming the digital count values read from the computer compatible tapes (B values) to Radiance (R values), which express the measured reflectance in energy units of relative radiance (mW/cm^2 sr) using the appropriate gain and offset information[3,8] for each sensor and band (Table 1) and the relationship[4] (for each band):

$$R = \frac{B\,(R_{max} - R_{min})}{B_{max}} + R_{min}$$

where R = Relative Radiance, R max = Maximum Sensor Radiance (Table 1 value), R min = Minimum Sensor Radiance (Table 1 value), B = MSS Digital Count, B max = Maximum MSS Digital Count.

The completed land cover classification results from 23 ERRSAC projects, especially the statistical information describing the MSS spectral signature classes (N = 747) and their interpreted Level I[1] land cover assignments, constituted the data source for this study. These results represent MSS data from April to September for 4 of the 5 possible MSS calibration settings between 1973 and 1980 (no results were available for L2A) for test areas from Virginia north to Vermont, and west to Minnesota. In each of these projects, the spectral classes were partitioned into land use/ land cover categories using interpretive techniques and ground truth.

These results were stored in a special data base where they were cross-referenced by a number of variables. The three variables examined here are (a) Level I land use/land cover categories (C, n = 7) for urban, agriculture, rangeland, forest, water, wetlands, and barren; (b) MSS sensor (S, n = 4) for Landsat 1, Landsat 2B, Landsat 3A, and Landsat 3B; and (c) the 4 MSS bands.

II. APPROACH

The 23 data sets were first sorted according to the MSS sensor used for acquisition. The spectral signatures from each sensor set, expressed in B values were converted to R values. A statistical analysis was performed, based on statistical parameters for both the B values and the transformed R values for the spectral data from each land cover category. Of interest here are the comparison of a Univariate Analysis of Variance (ANOVA) for cover type, sensor, and interaction of cover type with sensor; and a paired comparison for sample variance and means between sensors for cover type. The F-test was used for determination of statistically significant differences in variance between pairs; the t-test was used to test significant differences in sample means. The error probability of rejecting the null hypotheses when it is actually true was selected to be $\leq .05$ in all cases.

III. RESULTS

The ANOVA (Table 2) was performed to test the effect of the B→R conversion over all sensors examined, where the null hypotheses were: Ho_1: $\sigma^2_c = 0$; Ho_2: $\sigma^2_s = 0$; and Ho_3: $\sigma^2_{cxs} = 0$ (Table 3). Ho_2 was accepted for both B and R for Band 6; however, for Bands 4, 5, and 7, the Ho_2 was rejected for B but accepted for R. This represents a statistically significant reduction in the sensor component of the interaction term as B→R for Bands 4 (a reduction in variance from 14.4 to 3.7 percent) and 7 (a reduction in variance from 4.7 to 2.3 percent). Overall, the percent variance of the sensor component was reduced from 5.39 to 2.69. Ho_1 and Ho_3 were rejected for both B and R in all bands, indicating that the variance due to cover type was significantly different from the variance due to either the interaction of cover type with sensor, or the variance due to other error sources.

The interaction of cover with sensor was examined more closely for Bands 4 and 7. Refer to Table 4 for the Band 4 summary statistics. For both bands, the B→R transformation converged three of the sensor band means for most cover types (L2B, L3A, and L3B for Band 4; L1, L2B and L3B for Band 7). At the same time, these three means together moved further, in general, from the fourth sensor values (L1 for Band 4; L3A for Band 7), although the net effect was a reduction in variance among sensors for most cover types as B→R.

Using the t test to determine significant differences between pairs of sample means with unequal variances, only 6 of the possible 42 pairs (6 sensor pairs, 7 land cover types) demonstrated equal population means for B in Band 4, whereas the number rose to 13 for R as shown in Table 5. For Band 7, 5 pairs had equal means for B and 12 for R. All categories showed convergence as B→R, except urban and barren in Band 4; all categories except wetlands in Band 7. For Bands 4 and 7 together, the land covers which showed the greatest convergence of means were agriculture, forest and wetlands; for cover type means from sensor pairs, the greatest convergence was demonstrated for L2B and L3B. The data set tested did not show significant differences for Band 5.

IV. DISCUSSION/CONCLUSIONS

For our data base, which consisted of multisource, multisite, and multidate MSS data, the B→R conversion significantly reduced the among sensor variance for Bands 4, 5, and 7 and produced a significant covergence of means in Bands 4 and 7 for most cover types. This observed reduction in variance is especially noteworthy given the intrinsic variety of the data compared. Data sets imaging the same area and analyzed using similar procedures might show a more substantial initial reduction. Of special interest here is the improvement shown in the agriculture category (Table 5). While the B→R conversion is valuable, more work is needed before it can be incorporated into standard spectral analysis procedures.

Reduction in the observed spectral variance is necessary, regardless of the source, before valid measures of cover type change can be obtained. Our data show a variance contribution from other sources (the error term in ANOVA) among the bands between 34 and 47 percent, whereas cover type contributed 44 to 55 percent to the total variance, among the bands. This large additional variance is not unexpected, given that the data base accessed a variety of sites, dates, latitudes, atmospheric conditions, seasonal growth stage, etc. Work is continuing, on the basis of this study, to produce comparable data from the various MSS sensors. Other sources of variance captured in the unaccounted variance error, such as solar elevation and land cover versus use category assignment, are also under investigation.

V. ACKNOWLEDGMENT

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TABLE 1. Landsats 1, 2, and 3 Sensor Response, Gain, and Offset Data Used in Radiance Calculations

MSS Band	Wavelength (μm)	Brightness Value (Digital Count) Minimum	Maximum	Radiance (mW/cm^2 sr) Minimum	Maximum
Landsat 1					
4	0.5–0.6	0	127	0	2.48
5	0.6–0.7	0	127	0	2.00
6	0.7–0.8	0	127	0	1.76
7	0.8–1.1	0	63	0	4.00
Landsat 2 (January 22, 1975 to July 16, 1975)					
4	0.5–0.6	0	127	0.10	2.10
5	0.6–0.7	0	127	0.07	1.56
6	0.7–0.8	0	127	0.07	1.40
7	0.8–1.1	0	63	0.14	4.15
Landsat 2 (after July 16, 1975)					
4	0.5–0.6	0	127	0.08	2.63
5	0.6–0.7	0	127	0.06	1.76
6	0.7–0.8	0	127	0.06	1.52
7	0.8–1.1	0	63	0.11	3.91
Landsat 3 (March 5, 1978 to May 31, 1978)					
4	0.5–0.6	0	127	0.04	2.20
5	0.6–0.7	0	127	0.03	1.75
6	0.7–0.8	0	127	0.03	1.45
7	0.8–1.1	0	63	0.03	4.41
Landsat 3 (after May 31, 1978)					
4	0.5–0.6	0	127	0.04	2.59
5	0.6–0.7	0	127	0.03	1.79
6	0.7–0.8	0	127	0.03	1.49
7	0.8–1.1	0	63	0.03	3.83

TABLE 2. Analysis of Variance: Estimated Mean Squares for Cover Type and Sensors, by Band for Brightness and Radiance Values

Components of Variance	df	B4	B5	B6	B7	% of Total Variance, B
Cover (C)	6	2550.48	7359.35	7019.39	9752.48	47.57
Sensor (S)	3	1402.21	109.52	680.62	1942.63	5.39
C*S	17	191.76	524.39	512.95	552.86	6.46
Error	746	37.93	94.42	140.76	181.44	40.58
Components of Variance	**df**	**R4**	**R5**	**R6**	**R7**	**% of Total Variance, R**
Cover (C)	6	0.927	1.459	0.993	9.580	48.94
Sensor (S)	3	0.159	0.019	0.176	1.084	2.69
C*S	17	0.071	0.098	0.073	0.538	6.56
Error	746	0.015	0.019	0.020	0.169	41.81

TABLE 3. Analysis of Variance: Testing Hypotheses
R = H_o is Rejected A = H_o is Accepted

Hypothesis Tested	B4	B5	B6	B7	R4	R5	R6	R7
Ho_1: $\sigma^2_{cover} = 0$	R	R	R	R	R	R	R	R
Ho_2: $\sigma^2_{sensor} = 0$	R	R	A	R	A	A	A	A
Ho_3: $\sigma^2_{C*S} = 0$	R	R	R	R	R	R	R	R

TABLE 4. The 23 Project Sample Means and Variances for the Seven Cover Types, by Sensor, for Band 4

B Values

Land Cover Type	L1 $\bar{X}$	L1 s^2	L2B $\bar{X}$	L2B s^2	L3A $\bar{X}$	L3A s^2	L3B $\bar{X}$	L3B s^2
Urban	38.51	12.65	32.23	20.42	30.82	14.06	29.31	42.23
Agriculture	35.62	35.32	25.23	32.69	39.44	3.38	27.60	91.16
Rangeland	34.76	3.12	20.91	20.09	26.00	1.01	22.01	15.17
Forest	28.55	3.87	18.96	5.13	24.26	23.03	16.71	15.74
Water	29.38	47.30	19.60	21.75	26.16	27.47	20.02	42.46
Wetland	26.43	7.86	20.70	11.57	no data		22.75	4.55
Barren	42.16	188.89	27.92	18.24	46.38	106.66	41.63	161.81

R Values

Land Cover Type	L1 $\bar{X}$	L1 s^2	L2B $\bar{X}$	L2B s^2	L3A $\bar{X}$	L3A s^2	L3B $\bar{X}$	L3B s^2
Urban	.752	.0048	.727	.0082	.564	.0041	.628	.0170
Agriculture	.696	.0135	.587	.0132	.711	.001	.594	.0368
Rangeland	.679	.0012	.500	.0081	.482	.0003	.482	.0061
Forest	.557	.0015	.459	.0021	.453	.0067	.376	.0063
Water	.574	.0180	.474	.0088	.485	.0079	.442	.017
Wetland	.516	.003	.496	.0047	no data		.497	.0018
Barren	.823	.0721	.641	.0073	.829	.0308	.876	.065

TABLE 5. The results of the statistical test for equal means between populations (H_o: $\mu_1 = \mu_2$) for Band 4. A = H_o accepted; R = H_o rejected; X = no data.

Sensor Pairs (B Values)

Land Cover Type	L1:L2B	L1:L3A	L1:L3B	L2B:L3A	L2B:L3B	L3A:L3B
Urban	R	R	R	A	R	A
Agriculture	R	R	R	R	R	R
Rangeland	R	R	R	R	A	R
Forest	R	R	R	R	R	R
Water	R	R	R	R	A	R
Wetland	R	X	R	X	A	X
Barren	R	R	A	R	R	R

Sensor Pairs (R Values)

Land Cover Type	L1:L2B	L1:L3A	L1:L3B	L2B:L3A	L2B:L3B	L3A:L3B
Urban	A	R	R	R	R	R
Agriculture	R	A	A	R	A	R
Rangeland	R	R	R	A	A	A
Forest	R	R	R	A	R	R
Water	R	R	R	A	A	R
Wetland	A	X	A	X	A	X
Barren	R	A	A	R	R	R

VII. BIBLIOGRAPHY

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