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THE EQUIVALENCE OF THREE TECHNIQUES FOR ESTIMATING GROUND REFLECTANCE FROM LANDSAT DIGITAL COUNT DATA

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16. Abstract

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ABSTRACT

The equivalence of three separate investigations that related Landsat digital count (DC) data to ground measured reflectance (R) was demonstrated. One investigator related DC data to the cosZ, where Z is the solar zenith angle, for surfaces of constant R. The second investigator corrected the DC data to the solar zenith angle of 39 degrees before relating to surface R. Both of these investigators used Landsat 1 and 2 data from overpass dates 1972 through 1977. A third investigator calculated the relation between DC and R based on atmospheric radiative transfer theory. The equation coefficients obtained from these three investigators for all four Landsat MSS bands were shown to be equivalent although differences in ground reflectance measurement procedures have created coefficient variations among the three investigations. These relations should be useful for testing atmospheric radiative transfer theory.

INTRODUCTION

Three recent studies have demonstrated the repetitive radiometric accuracy of the Landsat multispectcral scanners (MSS) as applied to the fundamental problem of estimating ground reflectance (Kowalik et al., 1982; Richardson, 1982; and Jackson et al., 1982). The first two studies evolved simple linear equations that related gound reflectances (R), measured with hand-held radiometers, with Landsat digital count (DC) data. These data were obtained from arid locations, to minimize atmospheric and solar zenithy angle (Z) effects, for all four Landsat MSS bands in the 0.5 to 1.1 um range. Jackson's et al. (1982) approach was based on atmospheric radiative transfer theory. The objective for this paper was to demonstrate that these three different procedures produced equivalent relations between DC and R data.

EXPERIMENTAL PROCEDURE

Kowalik et al. (1982) related DC data to the cosZ for surfaces of constant reflectance over several Landsat sample dates. He obtained DC data from 10 computer compatible tapes (CCT) containing Landsat data for 12 small sites of constant ground reflectance in the Walker Lake area of Western Nevada. He used two Exotech Model 100 ERTS Radiometers to measure the corresponding ground reflectance for Landsat 1 and 2 overpass dates in 1972, 1973, and 1977.

Richardson (1982) corrected all DC data to a reference solar zenith angle of 39 degrees and to the LANDSAT 22 January 1975 to 15 July 1975 calibration period and then related the corrected DC data to surface R. Richardson obtained DC and ground reflectance data from seven published sources from Landsat 1 and 2 overpass dates in 1972, 1973, 1975, 1976, and 1977; providing 82 observations altogether.

Jackson et al. (1982) obtained relations between radiance at the top of the atmosphere and ground reflectance using atmospheric radiative theory developed by Herman and Browning (1975).

The equation coefficients obtained from these published sources comprised the basic data for this study. Equivalency was demonstrated by algebraically rearranging Kowalik's and Jackson's original equations obtained for each of the four Landsat bands to compare with Richardson's original equations by using the ratios of the slopes of each of the four equations from all approaches.

RESULTS AND DISCUSSION

The albebraic results obtained from rearranging Kowalik's original equations is shown for Landsat MSS band 7(0.8 to 1.1 um range). Kowalik's original relation is:

$$R7 = 2.41 + 0.315*2*DC7/\cos Z; \quad (1)$$

notice that Kowalik doubled the DC values in band 7. Richardson obtained corrected DCc values as follows:

$$DCc = DC*\cos 39/\cos Z, \quad (2)$$

so that

$$DC = DCc*\cos Z/\cos 39. \quad (3)$$

Thus, multiplying the slope in (1) by 2 and substituting (3) into (1) yields

$$R7 = 2.41 + 0.630*DCc7/\cos 39. \quad (4)$$

Equation (4) is further simplified since cos39 equals to 0.777 so that Kowalik's et al. (1982) origiral equation (1) reduces to

$$R7 = 2.41 + 0.811*DCc7 \quad (5)$$

that compares to Richardson's (1982) original equation,

$$R7 = -0.49 + 1.22*DCc7. \qquad (6)$$

This same procedure was used to transform Kowalik's original equations for Landsat MSS bands 4, 5, and 6, as shown in Table 1, for comparison to Richardson's equations. The ratio of Richardson's to Kowalik's slope values (R/K) are shown in Table 1. These ratios show that Richardson's and Kowalik's slope coefficients differ by 21%, 11%, and 13% in Landsat MSS bands 4, 5, and 6, respectively. There is a 50% difference in band 7. Thus, Richardson's slope coefficients are greater in all four bands than Kowalik's.

The reasons for these differences in equation slopes are not clear. Both studies have used reflectance data from light and dark pumice sand located at Mono Lake, California. Richardson's reflectance data for this area was obtained by Ballew (1975) concurrently with the Landsat overpass time and are higher in all four bands than those reported by Kowalik (Table 2). This could mean that Kowalik's method of obtaining ground reflectance consistently yielded lower values than those reported by Ballew (1975). Kowalik used two radiometers; one viewed vertically upward to record the hemispherical irradiance and the other viewed downward to measure the surface radiance with a 15 degree FOV. The surface radiance was divided by the hemispherical irradiance to yield apertured reflectance. Ballew obtained bidirectional reflectance by referencing surface measured radiance to the measured radiance of Eastman white paint on aluminum. It may be that apertured reflectance will always be lower than bidirectional reflectance explaining Kowalik's lower slope values.

An example of the algebraic results obtained by rearranging Jackson's original equations is shown here for Landsat MSS band 7 (0.8 to 1.1 um range). Jackson's et al. (1982) original equation is:

$$F7 = 0.0015 + 0.2202*R7 + 0.00467*R7**2, \qquad (7)$$

where F7 is the ratio of radiance to irradiance at the top of a clear atmosphere detected by LANDSAT in MSS band 7 for a solar zenith angle of 45 degrees. (Units of 1/sr)

In general, the radiance (Li), at the top of the atmosphere, is related to DCi (Richardson et al., 1980) by using calibration coefficients (Ai and Bi) and solar constant values (Ei) for each Landsat MSS band as follows:

$$DCi = (Li - Bi)/Ai, \qquad (8)$$

where Li = FiEi and i = 4, 5, 6, and 7, for each Landsat MSS band. Thus, substituting equation (8) into equation (7), for i = 7, and neglecting the squared term in equation (7), yields:

$$DC7 = -1.61 + 0.868*R7. \qquad (9)$$

Equation (9) was multiplied by cos39/cos45=1.0991 to convert from a solar zenith angle of 45 degrees to 39 degrees and the resulting equation solved for R7:

$$R7 = 1.86 + 1.05\ DC7, \qquad (10)$$

that compares to Richardson's equation (6).

This same process was used to transform Jackson's original equations for Landsat MSS bands 4, 5, and 6, as shown in Table 1, for comparison to Richardson's equation. The ratio of Richardson's to Jackson's slope values (R/J) are also shown in Table 1. These ratios show that Richardson's and Jackson's slope values differ by 14%, 12%, 20%, and 16% for Landsat MSS bands 4, 5, 6, and 7, respectively. Thus, it appears that Richardson's slope values are higher than both Jackson's and Kowalik's. Jackson's and Kowalik's slope values (J/K) are in good agreement for bands 4, 5, and 6. There is a wide range of slope values for band 7 among all three investigators; possibly due to variation in atmospheric moisture that affects MSS band 7 more than the other MSS bands.

CONCLUSIONS

In conclusion, even though there were differences in equation slope values obtained for Kowalik's and Jackson's equations, as compared to Richardson's equation, it appears that the three approaches are probably equivalent. If ground reflectance measurements were comparable, in an absolute sense, then algebraically we should expect identical results from each approach. The radiometric accuracy of the Landsat MSS sensors are probably more repetitive than the various sources of ground reflectance measurements obtained from the three studies. Thus, it appears that the basic relations obtained by these studies are good approximations of the actual atmospheric transformations needed to convert Landsat DC to ground R for clear atmospheres. These relations, in their various algebraic forms, should be useful for testing atmospheric radiative transfer theory.

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Table 1 Comparison of Landsat equation a0 and a1 coefficients between Kowalik et al. (1982) and Richardson (1982). Slope ratios are computed by dividing Richardson a1 values by Kowalik a1 values (R/K), Richardson by Jackson (R/J), and Jackson by Kowalik (J/K).

Landsat Band um	Kowalik's Coefficients R=ao+a1*DCc		Jackson's Coefficients R=ao+a1*DCc		Richardson's Coefficients R=ao+a1*DCc		Slope Ratios		
	a0	a1	a0	a1	a0	a1	R/K	R/J	J/K
0.5-0.6	-2.94	0.394	-1.91	0.416	-5.90	0.476	1.21	1.14	1.05
0.6-0.7	-2.93	0.337	-0.11	0.334	-1.94	0.373	1.11	1.12	0.99
0.7-0.8	-0.76	0.363	1.41	0.334	-1.40	0.412	1.13	1.20	0.95
0.8-1.1	2.41	0.811	1.86	1.05	-0.49	1.220	1.50	1.16	1.29

Table 2 Comparison of mean ground reflectance values obtained of dark and light pumice sand areas located at Mono Lake, California, as measured by Ballew on clear summer days of July 26, and August 6, of 1974 and by Kowalik in 1977. Kowalik measured apertured reflectance while Ballew measured bidirectional reflectance.

Source		Mono Lake, California Pumice Sand Reflectance (%)			
		MSS4	MSS5	MSS6	MSS7 (%)
Kowalik	(Dark)	5.3	5.8	6.5	6.3
	(Light)	18.1	19.0	22.3	21.6
Ballew	(Dark)	7.6	8.3	8.4	8.0
	(Light)	21.9	23.8	24.2	24.3