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Reducing Landsat MSS Scene Variability

Reflectance calculations were most effective overall for reducing interscene variability; however, band ratioing proved most useful on the bright targets.

Abstract: Landsat 1, 2, and 3 MSS data acquired for six different nonvegetated targets over a three-year period were used to determine which of five transformations was most useful for reducing between-scene variability. The following values were calculated from the MSS digital numbers (*dn*): (1) radiance; (2) reflectance; (3) reflectance corrected for changes in the Earth/sun distance; (4) normalized dn (normalizing equations proposed by ERIM researchers); and (5) band ratios. Results indicated that reflectance calculations were most effective overall for reducing interscene variability; ratios proved most useful on the bright targets.

Introduction

The spectral variability of a particular land-cover feature over time is a function of changes in the spectral response characteristics of the target and viewing conditions. In terms of land-cover assessment, the first factor may be considered useful information, the second, noise. Accounting for the latter without affecting the former is important in situations where multiple scenes are used to assess/monitor land cover. Studies which utilize multiple acquisition Landsat MSS data must be concerned with apparent scene changes which are due to the effects of changing sun angle, atmospheric conditions, or sensor differences. Correcting or removing scene noise should interest those involved with digital change detection and digital data base manipulations which include multitemporal or mosaicked MSS scenes.

The purpose of this study was to determine the utility of various published transformations for reducing scene variability. These included calculations of radiance and reflectance using linear models available in the Landsat Data Users Handbook (USGS, 1979), linear normalizing equations empirically derived by Environmental Research Institute of Michigan (ERIM) personnel, and band ratioing. In addition, climatological data were assessed to determine the utility of archived weather information for further reducing scene variability.

Landsat Digital Transformations

The Landsat MSS sensor response to radiance from an unchanging target is affected by factors which may be grouped into three generic categories:

> *Viewing Factors:* Sensor response varies due to changes in the sun-target-sensor geometry (Potter, 1974; Malila *et al.*, 1975; Kowalik *et al.*, 1982).
>
> *Atmospheric Factors:* Sensor response varies due to changes in the capability of the atmosphere to transmit and scatter radiation (Rogers and Peacock, 1973; Potter, 1974; Turner *et al.*, 1974; Hulstrom, 1974; Fraser, 1974; Fraser *et al.*, 1977; Dozier and Frew, 1981).
>
> *Systems Factors:* Spectral variability is a function of the instrument used to detect target radiance (Slater, 1979). Also, data preprocessing may be a source of variation (Grebowsky, personal communication).

Transformations which account for and remove variability associated with the viewing and systems factors were tested in order to determine which transforms were most effective. The MSS digital number (*dn*) responses acquired over unchanging targets over a period of three years were transformed using the following calculations in order to determine if scene variability could be significantly reduced.

Radiance: The radiance calculation attempts to

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account for response differences between satellites. Digital numbers were converted to radiance measures using transformations available in the Landsat Data Users Handbook (USGS, 1979).

$$\text{Radiance} = \frac{dn}{D_{max}}(L_{max} - L_{min}) + L_{min}$$

where dn = digital number (unitless);
D_{max} = the maximum digital number that can be recorded by the satellite: 127 for bands 4, 5, and 6; 63 for band 7 (unitless); and
L_{max}, L_{min} = the saturation and threshold radiance levels, respectively, for a given satellite and band; in milliwatts per square centimetre per steradian. These values are given in Table 1.

Reflectance (at the top of the atmosphere): Reflectance, a unitless number varying between 0 and 1.0, is a measure of the percentage of light reflected from a given target. Radiance measures were converted to reflectance measurements by accounting for the strength of the incoming solar radiation and the angle of incidence of radiation on the target at the time of the overpass (USGS, 1979). This reflectance measure assumes (1) that the target is lambertian, and (2) that the affects of the atmosphere on target response are lambertian.

$$\text{Reflectance} = \frac{\pi}{E \cdot \sin(a)}(\text{Radiance})$$

where E = the solar constant for a given band at the top of the atmosphere (in mW/sq cm)
band 4 = 17.70 band 6 = 12.37
band 5 = 15.15 band 7 = 24.91.
a = solar elevation, or 90-solar zenith angle (degrees).

Reflectance, Earth/Sun: The Earth is closest to the sun in early January each year, and farthest away in early July. This variation can alter the strength of the incoming solar radiation by as much as 6.7 percent.[1] The Earth/sun (*E/S*) distance variation was taken into account to correct the solar constant values. One astronomical unit (AU) = 1.496 × 10**11 metres, which is the nominal distance between the Earth and the sun.

$$\text{Reflectance, } E/S = AU^2 \cdot (\text{Reflectance})$$

where *AU* is the Earth/sun distance (in astronomical units, Nautical Almanac Office, 1975–1978).

ERIM Transformations: The ERIM transforms correct for satellite differences and correct for sun angle by normalizing to a 39 degree solar zenith angle. The satellite responses are corrected to Landsat 2 data processed prior to 16 July 1975, which correspond to preprocessing steps implemented for all LACIE (Large Area Crop Inventory Experiment) segments.

$$\text{ERIM} = \left(\frac{\cos(39)}{\cos(\theta)}\right) \cdot (m \cdot dn + b)$$

where m, b = linear coefficients (Table 2).
dn = Landsat MSS digital number.
θ = solar zenith angle.

The ERIM calculation results in a unitless digital number value corrected to a nominal sun angle.

Ratios: Ratioing has been used to reduce the effects of solar zenith angle (Crane, 1971; Vincent, 1972, 1973) and topography (Holben and Justice, 1980; Justice *et al.*, 1981) on sensor response. Adjacent band ratios and a common vegetation index were tested to determine how well such calculations removed scene variability. The ratios tested were:

band 4/band 5 band 6/band 7
band 5/band 6 band 7/band 5

The effects of changes in atmospheric conditions on Landsat MSS response have been documented by numerous authors. Potter (1974), Turner *et al.* (1974), and Fraser *et al.* (1977) have documented the effects of changing atmospheric conditions on the ability to accurately classify MSS data. Atmospheric differences which affect MSS sensor response (thereby affecting recognition capability) are a function of changes in particulate concentrations (Fraser, 1974), aerosol concentrations (Fraser *et al.*, 1977), and aerosol and water vapor content (Dozier and Frew, 1981). The effects of changing atmospheric haze levels on target response can be appreciable. Rogers and Peacock (1973) calculated that over 50 percent of the MSS signal in bands 4, 6, and 7 was attributable to atmospheric path radiance for a dark water target.

Numerous factors are available in weather records which may explain interscene variability. Three variables are found which may be related to haze level. Two, relative humidity and precipitable water, describe water content characteristics of the surface and atmospheric column, respectively.[2] Although no historical descriptors of particulate or aerosol concentrations could be found, horizontal visibility measurements were used to characterize atmospheric transparency.[3] Cloud cover adjacent to the target may also affect sensor response. Clouds in the vicinity of a target may decrease satellite response to that target due to the resampling filter

[1] Difference in light intensity between 3 January and 3 July: 3 January, AU = 0.9833, 3 July, AU = 1.0167. Intensity Difference = $(1/.9833^2 - 1/1.0167^2)*100.0$ = 6.7%

[2] Precipitable water is the amount of rain which would be generated from the atmosphere if all the moisture condensed and fell.

[3] Turner *et al.* (1974) and Malila *et al.* (1975) express reservations concerning the use of horizontal visibility to describe atmospheric conditions. Visibility, however, was considered *in lieu* of an alternative.

TABLE 1. LINEAR COEFFICIENTS USED TO CALCULATE RADIANCE VALUES FROM LANDSAT MSS DIGITAL NUMBER RESPONSES (FROM LANDSAT DATA USERS HANDBOOK, USGS (1979) OR ROBINOVE (1982)). THE UNITS ARE MILLIWATTS PER SQUARE CENTIMETRE PER STERADIAN.

	Landsat 1		Landsat 2*		Landsat 2*		Landsat 3†		Landsat 3†	
band	L_{min}	L_{max}	L_{min}	L_{max}	L_{min}	L_{max}	L_{min}	L_{max}	L_{min}	L_{max}
4	0	2.48	0.10	2.10	0.08	2.63	0.04	2.20	0.04	2.59
5	0	2.00	0.07	1.56	0.06	1.76	0.03	1.75	0.03	1.79
6	0	1.76	0.07	1.40	0.06	1.52	0.03	1.45	0.03	1.49
7	0	4.00	0.14	4.15	0.11	3.91	0.03	4.41	0.03	3.83

* Landsat 2 coefficients listed for data processed before (first two columns) and after 16 July 1975.
† Landsat 3 coefficients listed for data processed before (first two columns) and after 1 June 1978.

used in preprocessing the MSS data (Grebowsky, personal communication). Conversely, clouds near the target may, through reflection, increase the amount of light falling on the target and/or may increase atmospheric path radiance over the target. Rainfall may also affect target response because soil, rock, and sand targets darken with increasing moisture content. These atmospheric factors were investigated to determine their impacts on scene variability.

PROCEDURE

A data base was compiled consisting of (1) MSS responses for six targets in the southwestern United States imaged by Landsats 1, 2, and 3 from 1975 to 1978, and (2) meteorological and astronomical information for each overpass date. The response data had been compiled by Goddard personnel to assess the quality of the MSS radiometric corrections. The six targets were chosen for the stability of their reflectance characteristics over time. Three of the targets were located in the MSS scenes which included Alamagordo, New Mexico and Holloman Air Force Base (path 35, row 37, see Figure 1). Two of the targets were located on dark basaltic lava flows northwest of the White Sands National Monument. The third target was the white gypsum sand within the Monument boundary. A 24 by 24 pixel matrix (576 pixels) was imaged for each target as often as atmospheric conditions and satellite operations permitted. The remaining three targets were located at the northern end of the Gulf of California (path 41, row 38, see Figure 2). Two of the three targets were quartz sand north and west of the Gulf of California. The third target included deep water in the Gulf south of the mouth of the Colorado River. A 48 by 48 pixel matrix (2304 pixels) was imaged on each target on a given overpass. The mean target spectral responses (one mean response per target for a particular day) were used in all subsequent analyses. Figure 3 spectrally describes each of the six non-vegetated targets.

Climatological and astronomical data associated with each acquisition were collected from various sources. The solar zenith angle was calculated using the declination and equation of time available in the Nautical Almanac (Nautical Almanac Office, 1975–1978) for a particular day. The Earth/sun distance was also available in the Nautical Almanac. Climatological data were collected from various meteorological archives. Relative humidity was calculated using temperature and dewpoint readings from weather stations closest to the targets. The Yuma, Arizona station is approximately 100 kilometres north northwest of the Baja study sites; Holloman Air Force Base is approximately 25 kilometres east of the White Sands National Monument. Cloud cover, horizontal visibility, and precipitation estimates were also available from these stations through the National Climatic Center (NCC), Ashe-

TABLE 2. ERIM LINEAR COEFFICIENTS USED TO CORRECT ALL LANDSAT DATA TO THAT LANDSAT 2 DATA PROCESSED PRIOR TO 16 JULY 1975.

	Landsat 1		Landsat 2*		Landsat 3†	
band	*m*	*b*	*m*	*b*	*m*	*b*
4	1.04	−5.79	1.275	−1.445	1.1371	0
5	1.00	1.19	1.141	−2.712	1.1725	0
6	1.09	−2.91	1.098	−2.950	1.2470	0
7	0.82	3.01	0.948	0.446	1.1260	0

* From Kauth *et al.* (1978).
† From Holmes *et al.* (1979).
Note: Landsat 3 to 4 equations are available in Rice and Malila (1983).

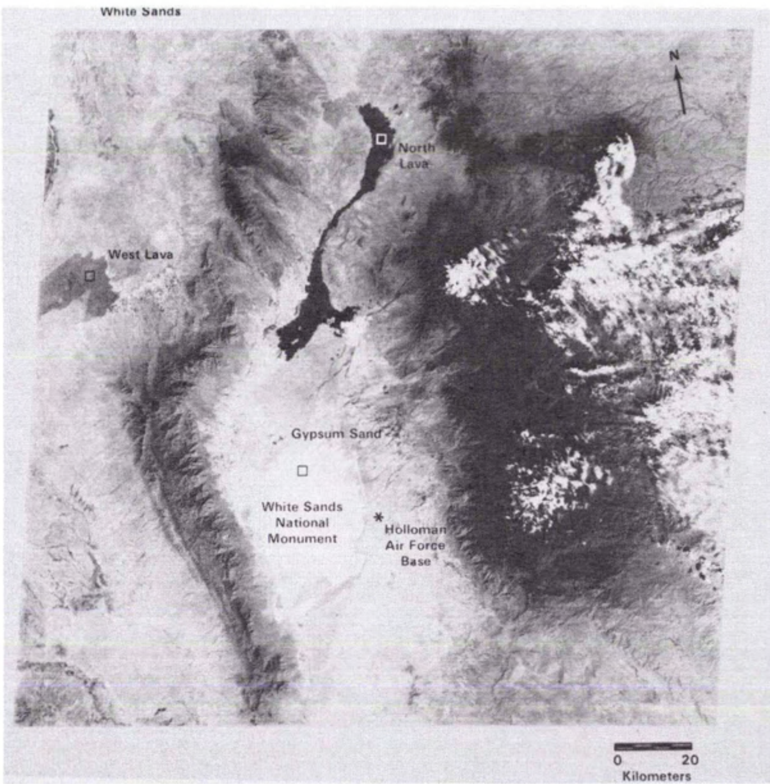

FIG. 1. MSS band 5 photo of the White Sands study area (path 35, row 37) with the three sites outlined: North Lava (top), West Lava (left), and Gypsum Sand.

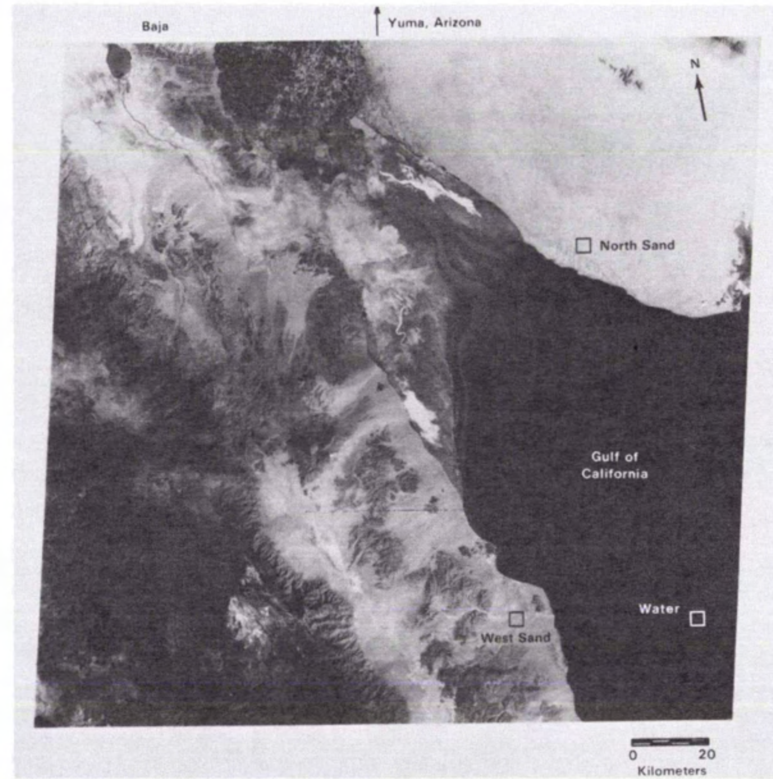

FIG. 2. MSS band 5 photo of the Baja (Gulf of California) study area (path 41, row 38) with the three sites outlined: North Sand (top), West Sand (left), and Water.

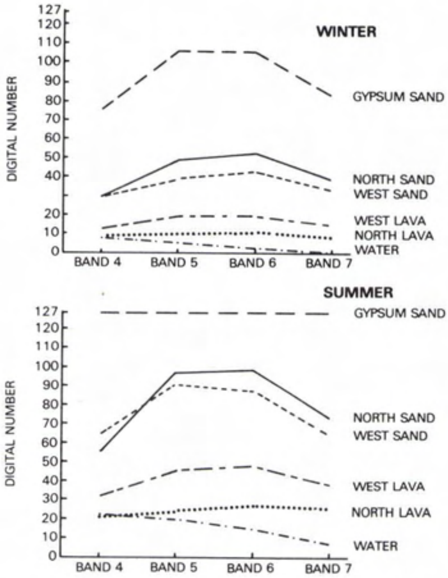

FIG. 3. The spectral characteristics of the six targets, winter (mid-December) and summer (mid-June), as sensed by the Landsat 2 MSS.

ville, North Carolina. Precipitable water was interpolated from Composite Index Moisture Charts (NOAA, 1979; also available from the NCC).

Having acquired the astronomical and climatological data, and having calculated the necessary transformations, the information listed in Table 3 was available for each acquisition. The number of acquisitions available in the data base for each target is listed in Table 4.

The data in column 1 of Table 3 were analyzed to determine which data transformation most effectively reduced scene variability. Coefficients of variation (standard deviation/mean) were compared so that scaling differences between the transformations could not affect the comparision. The transformation which most consistently produced the lowest coefficient of variation for the six targets would be the most effective preprocessing step for correcting between-scene variation.

TABLE 3. MISSION PARAMETERS AND CLIMATOLOGICAL DATA

date and calendar day	relative humidity (percent)
satellite (MSS 1,2,3)	precipitable water (inches)
solar zenith angle	horizontal visibility (miles)
sun/Earth distance (astronomical units)	cumulative rainfall (inches) for the 6 days, 3 days, 1 day, and 10 hours prior to MSS acquisition
digital number, bands 4–7	cloud cover (percent) estimated from satellite photos
radiance, bands 4–7	cloud cover (percent) estimated from ground station
reflectance, bands 4–7	
reflectance, Earth/sun distance, bands 4–7	
ERIM digital number, bands 4–7	
4/5,5/6,6/7,7/5 ratios	

The effects of changes in atmospheric conditions were analyzed by regressing climatological data (column 2, Table 3) against that transformed data which exhibited the lowest coefficients of variation for all study areas. Preliminary studies had indicated only weak linear relationships or random relationships between weather data and corrected MSS digital data. Hence, multiple linear regression techniques were used to assess the importance of the meteorological data.

RESULTS

Figure 4 illustrates the magnitude of yearly scene variability and also illustrates the effects of the different transformations on target response for one of the six targets. The mean and variance of the data acquired in a given band on a particular study site over a three year period were calculated for each transformation. Coefficients of variation (CV) were calculated for each band/study site/transformation combination. The results of those CV calculations are given in Figure 5. The lower the CV, the better is the correction in terms of reduction of between-scene variability.

TABLE 4. THE NUMBER OF ACQUISITIONS LISTED IN THE DATA BASE FOR EACH STUDY SITE, BY SATELLITE AND BAND.

	Bands											
	Landsat 1				Landsat 2				Landsat 3			
Target	4	5	6	7	4	5	6	7	4	5	6	7
Baja[1]												
N.S.	11	16	16	16	42	42	42	42	5	5	5	5
W.S.	15	20	20	20	39	39	39	39	6	6	6	6
Wat.	16	21	21	21	36	36	36	36	6	6	6	6
White Sands[2]												
N.L.	16	21	21	21	36	36	36	36	3	3	3	3
W.L.	18	22	22	22	31	31	31	31	3	3	3	3
G.S.	17	22	22	22	35	35	35	35	3	3	3	3

[1] Each observation consists of the mean spectral response of 2304 pixels.
[2] Each observation consists of the mean spectral response of 576 pixels.

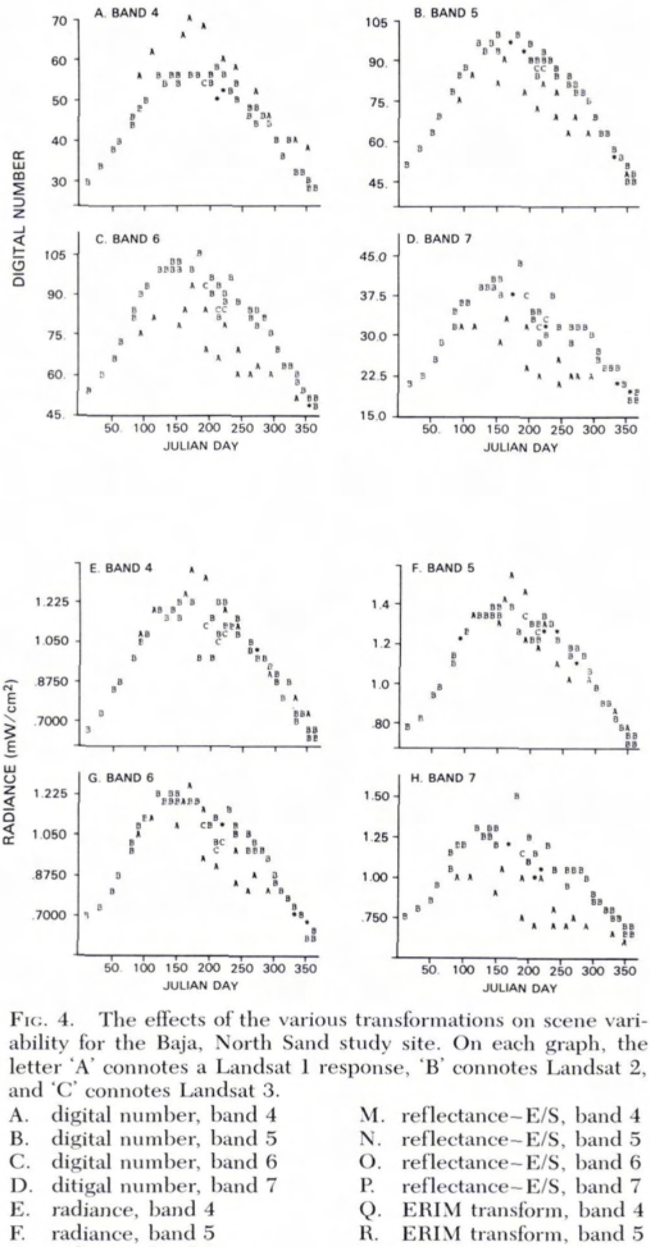

FIG. 4. The effects of the various transformations on scene variability for the Baja, North Sand study site. On each graph, the letter 'A' connotes a Landsat 1 response, 'B' connotes Landsat 2, and 'C' connotes Landsat 3.

A. digital number, band 4
B. digital number, band 5
C. digital number, band 6
D. ditigal number, band 7
E. radiance, band 4
F. radiance, band 5
G. radiance, band 6
H. radiance, band 7
I. reflectance, band 4
J. reflectance, band 5
K. reflectance, band 6
L. reflectance, band 7
M. reflectance–E/S, band 4
N. reflectance–E/S, band 5
O. reflectance–E/S, band 6
P. reflectance–E/S, band 7
Q. ERIM transform, band 4
R. ERIM transform, band 5
S. ERIM transform, band 6
T. ERIM transform, band 7
U. ratio, 4/5
V. ratio, 5/6
W. ratio, 6/7
X. ratio, 7/5.

The results indicate that much of the variance reduction over dark targets may be attributed to the radiance calculation which takes into account differences between sensor configurations. The radiance transformation proves to have less of an effect and the reflectance calculations a more pronounced effect as target brightness increases. In other words, differences between satellites are relatively more pronounced on darker targets; sun angle effects quickly become the primary source of variation as

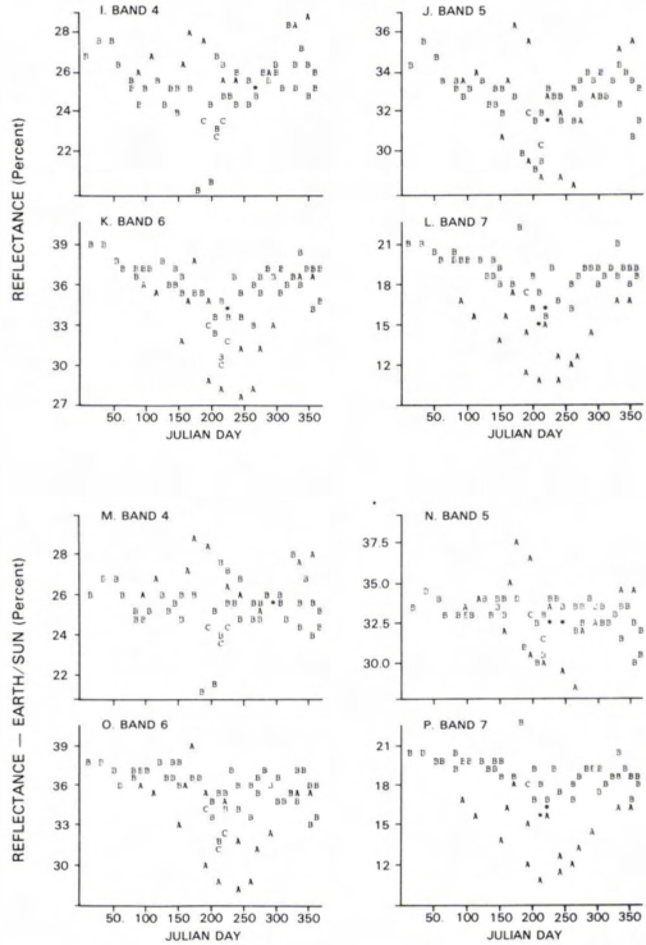

FIG. 4. (Continued)

target brightness increases. Regardless of the target brightness, the Earth/sun distance correction offers little in terms of the reduction of interscene variability.

In terms of CVs, the ERIM transformations were slightly less effective than the reflectance transformations. Both take into account satellite differences and sun angle corrections. The use of one or the other makes little difference except over dark targets, in which case the reflectance transformation produces consistently lower CVs. Because both light and dark targets would be present in any given scene, and because the reflectance transformation produces a value understandable in physical terms (Robinove, 1982), the reflectance transformation appears to be more useful.

Ratioing did as well or better than the other transforms in terms of reducing scene variability, except over dark targets. Kriegler *et al.* (1969) explain that ratioing is an effective variance reduction technique only if additive effects such as the effects of sensor differences and atmospheric path radiance changes are small compared to multiplicative effects such as changes in sun angle. The additive effects are relatively large over dark targets, hence ratioing proves least effective. Those ratios which include the infrared responses in the denominator recorded very high CVs due to extremely low digital readings. These low divisors inflated the variance, thereby driving up the CV estimates. The only other abnormally high ratio CV (Baja, West Sand, 6/7 ratio) could be traced to an anomalous near-zero digital response in band 7. The results suggest that ratioing may, of the approaches considered, be the best method of reducing between-scene variability. This finding, however, must be qualified. Ratios, on the average, perform as well or better than the other corrections; such calculations, however, are subject

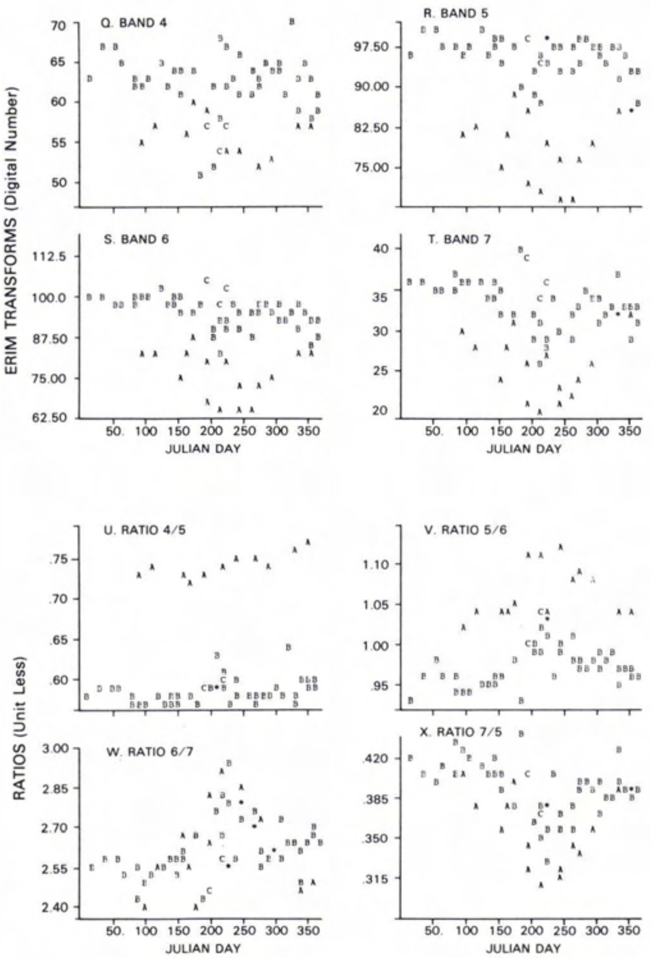

FIG. 4. (Continued)

to anomalous responses. If the low response is in the divisor, the situation is exacerbated, and very large transformed data values may result if the sensor is malfunctioning or the targets are dark. Second, ratioing, unlike the other transforms, has the potential for removing scene information along with scene noise. If ratioing is used to reduce between-scene variability, select a ratio that will not remove pertinent spectral information. The 7/5 ratio, as an example, may prove to be the most productive ratio for vegetation analyses (Tucker, 1979). Adjacent band ratioing may be more useful for geological applications.

The reflectance transformation without the Earth/sun correction consistently produced the smallest coefficient of variation for a given band and target. Ratioing reduced scene variability to a greater degree; however, problems with very large outliers (a result of very low or anomalous responses) and the possible loss of informational content reduce this applicability of this transformation technique.

One should note that the reflectance transformation is not always effective. Those transformations which correct for sun angle (i.e., reflectance and ERIM transformations) add to between-scene variation if the sensor is consistently saturated (see Figure 5, gypsum sand, bands 5 and 6). The sun angle correction exacerbates the situation if the target is very bright. Figure 6 illustrates the effects of the correction on the responses from a target which saturates the scanner for over half the year.

It is evident from Figure 4 that none of the transforms adequately account for sensor differences in all bands. The reflectance and ERIM corrections, which reduce scene variation, do not equate the Landsat 1 and 2 sensor responses. An analysis of the data indicated that the more recent the Landsat 1 data, the less effective the corrections were for all sites. This relationship is most apparent in the two

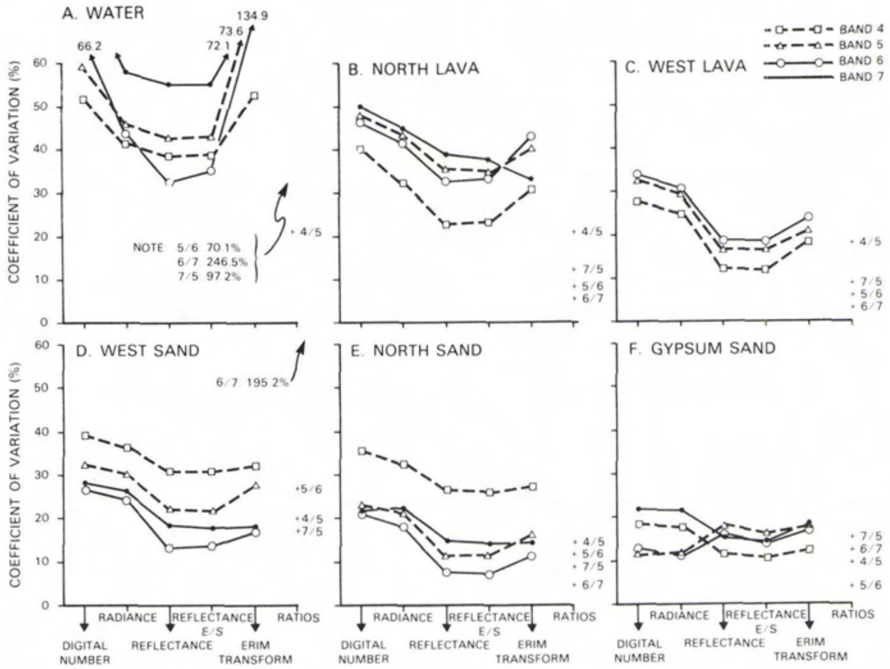

FIG. 5. The coefficient of variation (in percent) calculated for each transformation, by band, for each study area. Graphs A–F progress from the darkest target (Water) to the lightest target (Gypsum Sand).

infrared bands, less so in bands 4 and 5. Landsat 1 degradation (relative to Landsat 2 MSS responses) is readily apparent in 1977, five years after launch.[4]

The net result of the analysis is that the reflectance transformation is the most consistently useful transformation for reducing between-scene variability, regardless of target brightness. These transformed data were used to assess the utility of climatological data for further explaining between-scene variability.

The reflectance data were regressed with the climatological data for each band and target. Landsat 1 MSS reflectance values were adjusted to remove the temporal variation unique to this sensor. Equations in Nelson (1985) were used to remove the noise. Results showed that none of the atmospheric variables consistently explained significant variation. On bright targets (north sand and gypsum sand) precipitable water explained significant variation in bands 6 and 7 at the 99 percent level of confidence. In these cases, regression coefficients were negative, suggesting a decrease in the apparent reflectance with increasing atmospheric water concentrations. The inclusion of the atmospheric variables did not prove to be consistently useful for reducing interscene variation.

CONCLUSIONS

The following conclusions were drawn from the results of this study:

- The reflectance calculation reduced between-scene variability most consistently. This correction is detrimental only in circumstances where very bright targets which saturate the sensor for a majority of the year are imaged. In these cases, a sun angle correction adds to the target response variability.
- The radiance correction and the ERIM correction account for differences between sensors. The utility of these corrections proved to be a function of the age of the Landsat 1 MSS . On all study sites, there appeared to be a marked degradation in the strength of the sensor response in the Landsat 1 infrared bands. This phenomenon was also noted (less strongly) in Landsat 1 MSS bands 4 and 5. These results indicate that time should be considered as an independent variable when calibrating the Landsat 1 MSS to any other sensor.
- Ratios were subject to large outliers as a result of divisions by very low, near-zero digital responses. As a result, for darker targets, ratios proved to be least effective due to the inflated variances. Ratios also make no allowances for satellite differences because the effects of the sensor vary from band to band (Robinove, 1982). Finally, ratios, unlike the

[4] Nelson (1985) subsequently modeled this decline in Landsat 1 sensitivity. His work suggests that the transmissive quality of the Landsat 1 MSS optical path has changed with time.

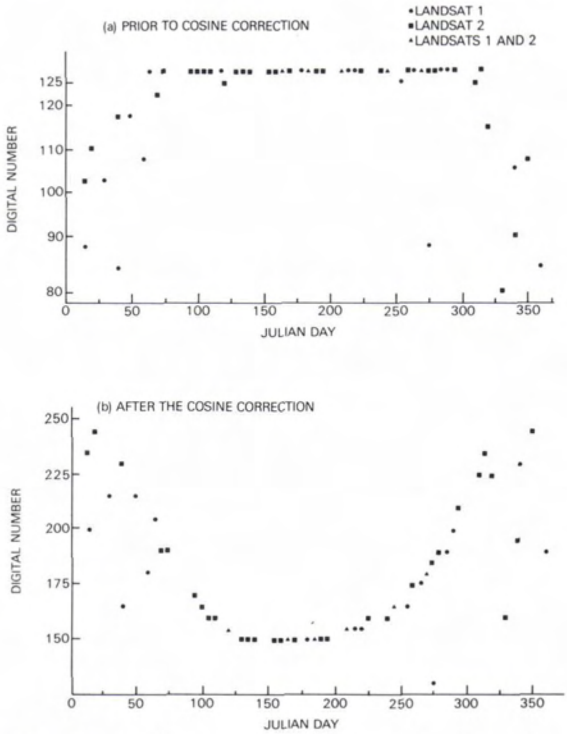

FIG. 6. Band response (digital number) versus time (calendar day) for Gypsum Sand, band 5, before (a) and after (b) the cosine correction.

other transformations, reduce scene information along with scene noise if inappropriate ratios are selected for a particular land-cover classification problem. Ratios would be the most effective method of reducing between-scene variability if the scenes do not contain dark targets (e.g., water).

- The ERIM transforms correct for satellite differences and sun angle. These corrections result in a transformation which is less effective than the reflectance correction available in the Landsat Data Users Handbook.
- Although annual changes in the Earth/sun distance may account for a change in the solar constant of 6.7 percent, such a correction is in the noise level and proves to be of no practical utility. Systems and atmospheric noise are as large as changes that might be imparted to the data by the changing Earth/sun distance. Therefore, until response variability due to satellite discrepancies and atmospheric changes are accounted for, corrections for the Earth/sun distance are of little use.
- Atmospheric factors commonly available in the meteorological archives proved to be of no practical utility for correcting arid target response variation. Relative humidity, precipitable water, rainfall, horizontal visibility, and other gross climatological estimates accounted for no significant consistent variation in the data. The lack of significance of the atmospheric variables is mitigated by two factors. First, some of the atmospheric measures were obtained far from the actual test sites, others were regional estimates of quantities which might vary with locality. On-site measures of the atmosphere at the time of the overpass would provide a more accurate assessment. Second, the six test sites are located in the arid southwestern U.S. and Mexico. Atmospheric factors may prove significant in more humid areas where variables such as precipitable water, rainfall, and relative humidity have greater seasonal ranges.
- Of the five transformations tested for reducing interscene variations, two proved most effective. Their effectiveness is target dependent. Ratios would be best used to account for target response variations over bright targets, such as arid rock/soil areas. The darker responses of vegetations, wetlands, and water would indicate that the reflectance transformation might best serve water-rich areas.

Appreciable, unexplained target variation remains. The results of this study indicate that a significant portion of that unexplained variation still lies with differences between the MSS sensors. Large differences are noted in satellite responses even after the reflectance or ERIM corrections are employed. The discrepancies exist because the reflectance and ERIM corrections assume that differences between satellites are time-invariant. These results suggest the opposite (i.e., these results suggest that sensor response to a given target may vary systematically over time). The remainder of the unexplained target variations may be attributed to changes in the atmosphere. Atmospheric effects can only be acertained empirically, and they rely on repeated on-site measurements of the atmosphere at the time of the overpass.

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