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Seasonal Vegetation Differences from ERTS Imagery*

Digitized densitometer readings from ERTS MSS imagery were employed to determine seasonal vegetation differences.

Abstract: *Knowledge of the times when crop and forest vegetation experience seasonally related changes in development is important in understanding growth and yield relationships. This article describes how densitometry of* Earth Resources Technology Satellite (ERTS-1) *multispectral scanner* (MSS) *imagery can be used to identify such phenological events. Adjustments for instrument calibration, aperture size, gray-scale differences between overpasses, and normalization of changing solar elevation are considered in detail. Seasonal vegetation differences can be identified by densitometry of band 5 (0.6-0.7 micrometers) and band 7 (0.8-1.1 micrometers)* MSS *imagery. Band-to-band ratios of the densities depicted the changes more graphically than the individual band readings.*

Introduction

The timing of events associated with seasonal plant development, such as crop planting and harvest times, has been of interest to vegetation managers for centuries.[6] Since the launch of the *Earth Resources Technology Satellite (ERTS-1)* several researchers have been developing methods of using the multispectral scanner's (*MSS*) outputs to identify such phenological events.[3,5] *ERTS* data giving regional repetative coverage offers substantial cost savings over conventional ground-based surveys.

This article describes work undertaken to find if forest and crop phenological events can be assessed through densitometry of *MSS* positive transparencies. Previous research has indicated the possible success of this approach. Visual interpretations of tonal differences on the imagery have been related qualitatively to seasonal albedo changes.[2] Wiegend, *et al.* working on a crop productivity project found that individual *ERTS-1* band densities and ratios formed from these densities were indicative of vegetation status.[7]

The *MSS* transparencies have been designed for possible densitometry evaluation. However, the *ERTS Data User's Handbook* cautions that only macro-densitometry work should be undertaken.[1] Modulation transfer and chemical adjacency effects are cited as problems in working with densitometer apertures less than 3.0 millimeters in size. Simplifying a complex situation, densitometry of a small area within a transparency can be unreliable or misleading where there are large differences in density between adjacent image areas.[4] In effect, the apparent density of a small area (at image scale) which is adjacent to an area of greatly different albedo will have an image density which is partially in-

* This research was supported in part under NASA contract No. NAS5-21781 and by State Agricultural Experiment Stations Regional Project NE-69.

fluenced by the adjoining area's density. For example, if a small area on the ground has a very low reflectance (high image density) and is adjoining a large area of relatively higher reflectance, the resulting small area image density will be less than it should be as indicated by the amount of reflectance received from the small area by the *MSS*. However, it is often desirable and necessary to work with ground sites smaller than 3.0 millimeters at image scale. On the 9-inch *ERTS* transparencies this aperture encompasses an area of more than 700 hectares.

The objectives of the research involve the evaluation of densitometry methods to identify seasonal changes on a relatively small area from *ERTS-1 MSS* transparency images. A study of the validity of using less-than-recommended aperture sizes and techniques for making instrument calibrations, solar elevation normalizations, and adjustments to densitometered values between overpasses are considered. The use of band ratios is also examined.

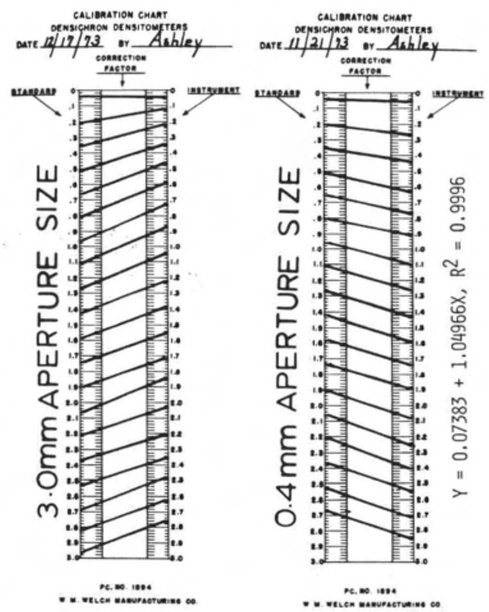

FIG. 2. Calibration charts for two Aperture sizes and the regression for the smaller diameter.

DATA SOURCES

Density measurements on *MSS* band 5 (red) and band 7 (near-infrared) 9-inch positive transparencies and ground observation photography of forest-agricultural sites across the eastern United States from August 1972 to November 1973 provided the data base for this study. A Welch Densichron spot densitometer was used to make the density readings (Figure 1). Measurements on the imaged forest-crop areas and the transparencies fifteen-step gray-scale wedge were recorded for all cloud-free coverage.

Ground observation photography was taken as close as possible to the date of each *ERTS-1* overpass. These Ektachrome-X color slides were obtained with a tripod-mounted camera oriented to cover the same scene over the different dates. The slides documented the condition of each site's vegetation and provided correlation and comparison data for the *MSS* density measurements. Photography was not taken after deciduous forest leaf-fall was completed in early winter until a few weeks before leafgrowth was expected to begin in the spring.

FIG. 1. Densitometry of *ERTS* imagery.

DENSITOMETERED DATA ADJUSTMENTS

Several adjustments and standardizations were made to the measuring equipment and resulting densitometer readings. Calibration of the densitometer was undertaken first so that the different *MSS* gray-scale and imagery readings would represent standardized, comparable quantities. The amount of adjustment to the Densichron's readings was found by comparing instrument readings with known densities on a Kodak calibration step wedge. Whereas this change is often made by graphical solution, a simple linear regression equation was developed to apply the correction for the large amount of data in this project. The inverse solution of this equation predicted the standardized readings (Figure 2).

The aperture size which could be used most effectively to assess vegetation differences was then examined. Some of the sites in this study were of less than 20 hectares in area and an aperture size of 0.4-millimeter diameter was required to measure these. The minimum size recommended by the *User's Handbook* was 3.0 millimeters. However, the authors felt that since the forest, crop, and surrounding area generally did not contrast greatly, it would be possible to obtain reliable density readings using an aperture size comparable to the project's smaller sites, a little less than ½ millimeter. As a test of this hypothesis, calibrated readings from bands 5 and 7 imagery of four aperture openings ranging from 0.4 to 3.0 millimeters, were compared by using an analysis of variance to find if there were significant differences in readings between the aperture sizes.

Standardization of *MSS* imagery grayscales between different imagery dates was also considered. Processing differences or other factors could introduce inequalities in densities at the same wedge positions. This possibility was studied by graphically plotting the 15-wedge mid-point densities of one date against another for several transparencies. The relationship appeared to be linear with varying slopes between different dates. With this in mind, simple linear regressions were developed and tested to see how well the differences in gray-scales between dates could be adjusted back to the density at the same position on the gray-scales of a selected base date (Figure 3).

Solar elevation normalization was the last correction considered for the density measurements. This adjustment was necessary to compensate for differences in solar elevation between different dates. Such differences would inherently give albedo changes even

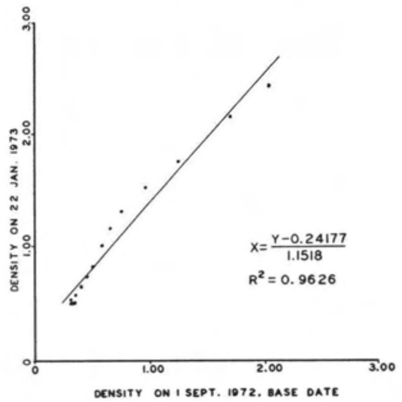

FIG. 3. Example of data plot and base date standardization equations derived from this data.

if forest or crop conditions had not changed. One can see this by noting the general darkening which occurs on the imagery as solar elevation decreases. The densities were normalized by applying a sine function to the solar elevations. This should have resulted in objects with similar reflectance having the same densities between overpasses.

Vegetation differences were depicted by plotting individual adjusted band densities and band-to-band ratios over time. These plots were compared with ground observation photography to make the assessment of change. The ratios were calculated as:

$$R\ 5\text{-}7 = \frac{\textit{density band } 5 - \textit{density band } 7}{\textit{density band } 5 + \textit{density band } 7}$$

This ratio, unlike the individual band density readings, would cancel density influencing, multiplicative effects such as solar elevation differences between overpasses.

Results of Data Adjustment Procedures

Several data adjustment procedures had to be evaluated before the seasonal vegetation change study could be undertaken. The selection of an aperture size which could be used to make meaningful density readings was the first of these. An analysis of variance of several measurements from four forested sites over two dates for band 5 and 7 imagery, using four replications for each of the apertures, indicated there was no significant difference at the 5 per cent level in density readings for any of the sizes. The aperture diameters examined were 0.4, 1.0, 2.0, and 3.0 millimeters. The 0.4-millimeter aperture was selected to make all of the study measurements because it allowed measurement of the project's smaller sites.

The performance of regression adjustments for instrument calibration and base date standardization was also examined. The equation approach for making these adjustments was used because of the ease with which it could be incorporated into computer programs to handle the project's large volume of data. Three calibrations of the instrument were found necessary over the course of the study. The coefficient of determinations (r^2) was greater than 0.99 for all three. The base date standardization equations also performed well. The r^2 values were always greater than 0.80 and more than two-thirds were greater than 0.97.

Normalization to a common solar elevation was carried out as the final adjustment to the densitometered data. The readings were corrected for a 45 degree angle through the function:

$$normalized\ density = \frac{sine\ \gamma\,(x)}{0.71}$$

where x = imagery density reading corrected for all except solar elevation

γ = solar elevation angle for that imagery

Figure 4 summarizes the data flow of adjustments to the base densitometer readings. Initially, a simple linear calibration equation was derived from instrument and calibration wedge data. Next, the date of the first cloud-free coverage was selected as a base date. Simple linear regressions were then developed between calibrated density readings of gray-scale wedge mid-points for this date and all others, and these equations were used to standardize all of the site readings to comparable base date levels, after which the normalizing sine function was applied. Thus, sequentially, the site vegetation densities were measured, calibrated, standardized, and normalized for solar elevation differences. Table 1 illustrates the step-by-step results for a forest site.

Results of Vegetation Change Studies

The adjusted densities and band-to-band ratios were well correlated with seasonal vegetation changes. Figure 5 graphically illustrates the relationship between seasonal progression (green wave) and recession (brown wave) of forest vegetation at the Vermont test site, together with the band 5 and 7 densities and ratios. Figure 6 demonstrates a similar relationship for cotton growing near College Station, Texas. Ground observation slides were interpreted to obtain the appropriate annotation for vegetation condition at each overpass (Figure 7).

Band 5 solar-normalized densities generally increased (i.e., reflectance decreased) as forest leaf development progressed, and decreased with vegetation recession. These results were expected because red reflectance would decrease when soil and red-reflecting forest litter were covered by the developing forest canopy. Chlorophyll absorption of red wavelengths by the leaves would further this reduction. The band 7 corrected densities demonstrated that near-infrared densities

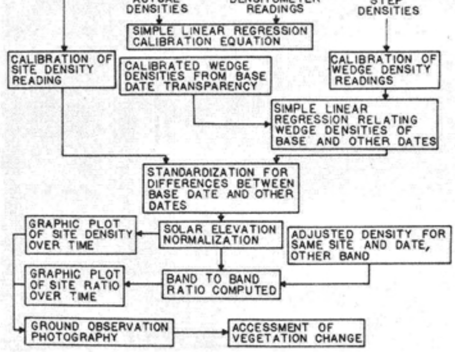

Fig. 4. Data flow for the densitometry study of vegetation change.

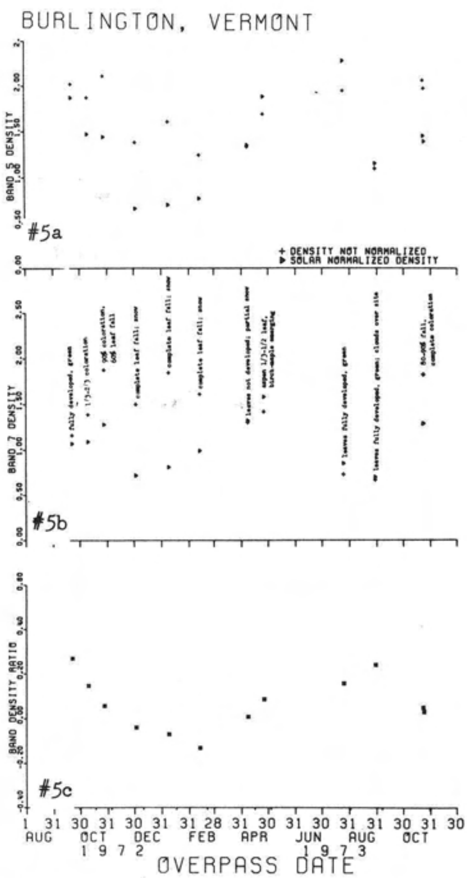

Fig. 5. Individual band density and ratio plots for the Burlington, Vermont forest site. 5a. Band 5 densities. 5b. Band 7 densities. 5c. ratio of band 5 and 7 densities.

TABLE 1. DATA ADJUSTMENT SUMMARY WORK SHEET FOR THE BURLINGTON, VERMONT FOREST SITE.

Date	Band	Instrument Density	$X = \frac{y-007383}{1.04767}$ Calibrated Density	$r^2 = 0.999$ Base Date Standardization Equation	Standard Density	Solar Radiation Correction α	sine	Normalized Density	Base Date 10/10/72 Band Density Ratio
9/12/72	5	1.92	1.81	$X = \frac{y+0.3205}{1.0550}$	2.02	41°	0.6560	1.87	0.27
	7	0.89	0.80	$X = \frac{y+0.3257}{0.9715}$	1.16	″	″	1.07	
10/10/72	5	1.98	1.87	——	1.87	34°	0.5592	1.47	0.15
	7	1.49	1.39	——	1.39			1.09	
10/27/72	5	1.99	1.88	$X = \frac{y+0.2514}{1.0120}$	2.11	29°	0.4848	1.44	0.06
	7	1.74	1.63	$\frac{y+0.1721}{0.9567}$	1.88			1.28	
12/2/72 snow	5	1.40	1.30	$X = \frac{y+0.1369}{1.0418}$	1.38	20°	0.3420	0.66	−0.04
clouds	7	1.51	1.41	$X = \frac{y+0.0971}{1.0032}$	1.50			0.72	
1/8/73 snow	5	1.72	1.61	$X = \frac{y+0.0861}{1.0565}$	1.61	18°	0.3090	0.70	−0.07
	7	1.90	1.79	$X = \frac{y+0.0247}{0.9826}$	1.85			0.81	
2/12/73 snow	5	1.34	1.24	$X = \frac{y-0.0679}{0.9419}$	1.24	26°	0.4384	0.77	−0.13
	7	1.60	1.50	$X = \frac{y-0.0729}{0.8887}$	1.61			0.99	
4/7/73 snow	5	1.27	1.17	$X = \frac{y+0.2539}{1.0688}$	1.33	46°	0.7193	1.35	0.01
	7	1.20	1.10	$X = \frac{y+0.2465}{1.0394}$	1.30			1.32	
4/25/73 cloud	5	1.98	1.87	$X = \frac{y-0.4023}{0.8685}$	1.69	52°	0.7880	1.88	0.09
shaded	7	1.74	1.63	$X = \frac{y-0.4779}{0.8140}$	1.42			1.58	

decreased (reflectance increased) as foliage developed and started increasing with the fall brown wave (Figure 5b).

The densities adjusted for everything except solar normalization also have been plotted in Figure 5 for comparative purposes. The same general correlations are evident; however, from the differences between the normalized and non-normalized measurements it is apparent that image density is in part determined by solar elevation, particularly at low angles.

Atmospheric haze, clouds, and ground-snow cover altered expected densities and ratios. These resulted in decreased densities (increased reflectance) in both bands 5 and 7. The August, January, and February Vermont data illustrate the effect of cloud and snow (Figure 5).

Seasonal vegetation differences were most easily studied by using the band ratios. Figure 5c shows the rhythmic cycle of these changes over the project's forest sites. The ratio increased with foliage development and decreased with senescence or crop harvest. Typical ratios for forest vegetation were 0.25 to 0.50, full leaf development, all green; 0.10 to 0.25, some intermediate stage of leaf development or coloration; and below 0.10, complete leaf fall. A study of ratios for specific crops has not been completed at this time. However, a limited analysis of cotton, sorghum, and wheat at the North Carolina and College Station, Texas sites indicated that crops also have typical ratios associated with their seasonal development.

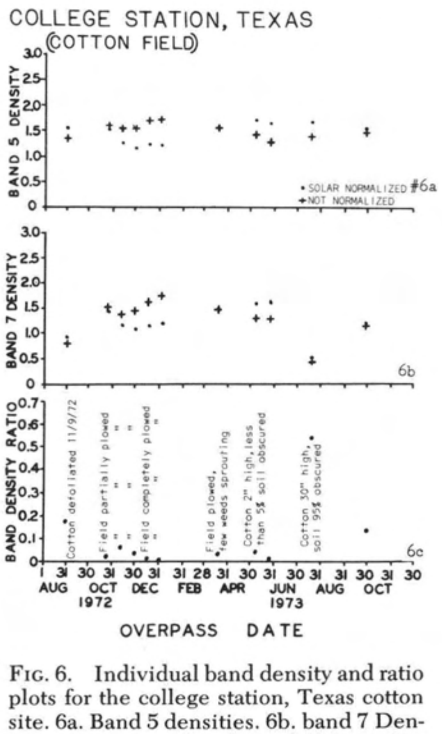

FIG. 6. Individual band density and ratio plots for the college station, Texas cotton site. 6a. Band 5 densities. 6b. band 7 Densities. 6c. ratio of band 5 and 7 densities.

The ratios and the individual band densities are affected by atmospheric conditions as shown by the fact that even after normalization, the ratios for a given stage of vegetation development change between overpasses. The difference in a ratio resulting from atmospheric haze or clouds can be 0.2 or greater. An example of this inconsistency comes from data on our southern Indiana forest site where the densities for fully developed oak forest changed from 0.32 to 0.20 between one-day overlapping orbit coverage. Significant haze was noted on the day whose data gave the lower ratio.

Conclusions

Density measurements on *ERTS-1* transparencies can be used to identify seasonal vegetation differences. Several adjustments must be made to the density readings to correct for instrument calibration, differences in processing, and changes in solar elevation between different sets of imagery. A small-diameter densitometer aperture (0.4 millimeter) gave reliable density readings.

Further study is needed on the influence of solar elevation and atmospheric differences on *MSS* imagery. Whereas the band ratio does partially adjust for solar elevation and atmospheric differences, it does not completely compensate for the problem. Incident solar-radiation measurements by wavelengths or bands at the time of over-pass possibly could provide a basis to adjust for this situation.

The band 5 and 7 ratio represented seasonal vegetation differences better than plots of the individual band densities. The ratio increased with foliage development and decreased with senesence.

Although not done for this project, the densitometry and data-adjustment procedures could be automated. The regression and solar-normalization corrections would be derived and applied by inputing the gray-scale and site-density readings, along with the solar elevation from the transparencies, into a system of computer programs. Using this approach, it should be possible to assess seasonal vegetation changes over large areas at relatively little expense.

FIG. 7. Example of ground observation photography from the Vermont forest site. 7a. Leaves emerging, April 26, 1973. 7b. green, fully developed, September 21, 1972. 7c. One-third to two-thirds coloration, October 10, 1972. 7d. Complete leaf fall, snow, April 8, 1973.

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