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COMPARISON OF LANDSAT MSS, NIMBUS 7 CZCS, AND NOAA 6/7 AVHRR FEATURES FOR LAND USE ANALYSIS

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I. ABSTRACT

Spectral characteristics of the Coastal Zone Color Scanner (CZCS) on board Nimbus 7, the Advanced Very High Resolution Radiometer (AVHRR) on NOAA 6 and 7 and the Multispectral Scanner (MSS) on Landsat 1-3 are analyzed to comparatively assess their utility for land use analysis through remote sensing. The examination of simulated in-band radiances suggests that each sensor would respond to incident radiation reflected from a typical agricultural scene in a highly comparable manner, with most of the variation captured in two physically related variables. Several measures of green vegetation are examined and features are proposed for crop condition assessment with consideration of the course resolution characteristics of AVHRR and CZCS.

II. INTRODUCTION

The Landsat Multispectral Scanner has been shown to be a valuable tool for monitoring earth resources through remote sensing. The particular spectral, spatial and temporal characteristics of the instrument have been successfully exploited for crop identification (e.g., LACIE[1]) and crop condition asessment (e.g., AgRISTARS[2]). The critical importance of temporal coverage has been demonstrated for crop inventory applications.[3] Landsat 3 provides repeat coverage only every 18 days, and a few strategically placed days of poor viewing conditions can render a data set virtually useless. This has been a significant limitation in the application of the technology in areas of frequent cloud cover (e.g., Rio Grande do Sol, Brazil). The Coastal Zone Color Scanner on Nimbus 7 and the Advanced Very High Resolution Radiometer on NOAA 6 and 7 do not suffer from this same limitation with repeat cycles of 6 days and 1/2 day, respectively. Both CZCS and AVHRR systems have sensors in the visible and near infrared region, the regions utilized in MSS land use investigations. It is the objective of the study described in this paper to compare the response of these sensors to soil and vegetation targets in order to assess the feasibility of their use for the crop inventory and assessment applications. The analysis is currently limited to examining relative spectral attributes of the sensors, though spectral features are proposed that consider the course resolution characteristics of AVHRR and CZCS.

III. THE SENSORS

The four channel AVHRR on board NOAA 6 and NOAA 7 has two channels in the visible and near IR region. Channel 1 and 2 bandwidths are from 0.55-0.68 μm (50% points) and 0.71 to 0.98 μm, respectively. The two satellites are in near polar sun-synchronous orbits at 850 km altitude, with NOAA 6 orbiting south across the equator at 7:30, and NOAA 7 orbiting north across the equator at 14:30. The sensor IFOV is 1.4 milliradians, which translates to 1.1 km ground resolution at nadir. The field of view is $\pm 56^{\circ}$, yielding a swath width of 2250 km. With the satellites each completing 14.1 orbits/day, the wide swath gives an effective repeat coverage every 1/2 day.[4]

The Nimbus 7 CZCS is a six channel radiometer with an IFOV of 0.825 km at nadir. The bandwidths of the five visible and near IR channels are 0.43-0.45 μm, 0.51-0.53 μm, 0.54-0.56 μm, 0.66-0.68 μm, and 0.70-0.80 μm. Each of the first four channels has a separate gain which is normally determined by the sun elevation angle. However, these gains may be set by command to accomodate special conditions. The gain of channel 5 is fixed to give the same response over land targets as channel 6 of Landsat MSS. As the first four channels are designed for sensing water conditions, they may saturate over most land targets. Nimbus 7 follows a sun-synchronous, near polar orbit at 955 km, has a swath width of 1566 km, and provides repeat coverage of a given target every six days. Over flight occurs approximately at local noon.[5]

Landsat's MSS is a four channel sensor with bandwidth of 0.50-0.60 μm, 0.60-0.70 μm, 0.70-0.80 μm and 0.80-1.10 μm. These channels (labeled 4 through 7, respectively) have an IFOV of 80 m and a swath width of 185 km. Landsat's sun-synchronous, near polar orbit at 955 km gives repeat coverage every 18 days, occuring at approximately 9:30 local time.[6]

IV. EXPERIMENT DESIGN

Previous work has demonstrated the correlation between the difference in AVHRR channels 2 and 1 and the difference between MSS channels 7 and 5 (the Ashburn vegetation index).[7] Other studies have shown that most of the variation of MSS data for typical vegetation scenes lies within a plane called the Greenness-Brightness plane.[8] To investigate whether a comparable phenomenon could be attributable to CZCS or AVHRR scanners and to compare green measures, a simulated data set was constructed and used. The reflectivity in the visible and near IR region of various targets of interest was available through the Laboratory for Applications of Remote Sensing LARSPEC data base. Employing the nominal spectral response functions for each sensor along with the Turner radiation transfer model,[9] inherent inband radiances were computed by:

$$L_{i,j,k} = \frac{1}{\pi}\int_{\lambda_1}^{\lambda_2} E(\lambda)\rho_i(\lambda)R_{jk}(\lambda)d\lambda$$

where

- $L_{i,j,k}$ is the inherent radiance for target i and channel j of sensor k
- $E(\lambda)$ is the global incident solar irradiance
- $\rho(\lambda)$ is the global reflectivity of the target
- $R(\lambda)$ is the channel spectral response function

Transmissivity of the atmosphere, path radiance and sensor dynamic range and absolute signal calibration were not simulated at this time. However, global incident solar irradiance was modified according to solar time of sensor overpass for an August time of year. Differences in reflectivity due to bidirectional effects related to differing solar zenith angles was not available and remains a shortcoming of this simulation. CZCS band 1 (.43-.45 μm) was not simulated due to the unavailability of reflectance data.

For purposes of simulation, the scene was considered to consist of soils from throughout the continental U.S., wheat, corn and soybeans at all stages of development and in various stages of experimental control (e.g., nitrogen or moisture stress). This simulation does not represent a 'real' scene, however enables the simultaneous examination of variety of factors influencing the detection of radiation by remote sensors. In this paper only analysis of a subset of the entire data set including soil and wheat samples is presented. Over 500 soil reflectance samples (LARS soil experiment 78100701)[10] and close to 400 measurements of 30 wheat plots (experiment 79100806)[11] under experimental control for disease and nitrogen fertilization effects are included in this analysis.

V. THE TASSELED CAP TRANSFORMATION

The primary method of analysis carried out was based on the Tasseled Cap Transformation as a frame of reference for comparison of sensor response. The Tasseled Cap[12] is an invariant linear transformation of the four MSS band values which has been shown to capture the vast majority of the spectral variation of typical agricultural scenes in two dimensions. In addition, the derived features are essentially interpretable in terms of physical phenomenon. The first Tasseled Cap variable, called Brightness, corresponds to spectral variations in the MSS spectral domain that relate to soil Brightness or target albedo. The second variable, called Greenness, is aligned in the spectral direction of principle variation associated with the amount of green biomass present in the scene. Greenness is a measure of contrast between the infrared and visible channels. These two variables typically represent more than 95% of the total variability in an agricultural scene. The third variable, called Yellow, has been found to correspond to external effects like haze and sun angle as well as scene features like soil or rock color and water. Yellow is a contrast between the visible bands. The fourth variable, Nonsuch, is a measure of contrast between infrared bands and has been observed to contain little significant information.

In this analysis, tasseled cap-like features were computed for each sensor in a manner comparable to that employed in determining the Tasseled Cap for actual Landsat MSS. A principle component analysis of the soil data was carried out and the first principle component was chosen to be the direction of soil brightness. A greenness feature was derived by selecting a vigorous sample of green vegetation and determining a perpendicular from that target to the direction of soil brightness. For MSS and CZCS, yellow was established by determining an orthogonal component to greenness and brightness that emphasized contrast in the visible bands. Greenness and brightness were of primary concern in the analysis. Figure 1 illustrates the approach for AVHRR. The data scattered along channel 2 shall be referred to as the 'Green Arm' whereas that scattered in the direction of soils the 'Soil Arm'.

VI. RESULTS

Figures 2, 3 and 4 demonstrate the resulting greenness/brightness transformation for each sensor. The remarkably comparable visual appearance bears out in statistical analysis. For MSS, as expected, 98.5% of the scene variation was found to reside in the principle plane. This transformation was of course simply a rotation of the two AVHRR bands. Ninety-five percent of the variation of CZCS response in channels 2 to 5 is represented in the greenness/brightness plane, with a yellow feature explaining the remainder. More significantly, both greenness and brightness measures were strongly related when compared between sensors. A linear relationship was sufficient to achieve a R^2 greater than .99 in all cases. Figure 5 illustrates the strong relationship between MSS greenness and AVHRR greenness. These findings indicate that each sensor on the whole can be expected to respond to incident radiation from vegetated scenes in a comparable fashion. This suggests, at least conceptually, a ready transferability of technology developed for MSS to AVHRR and CZCS, with appropriate recalibration.

A number of green measures are routinely employed in land use analysis. Three are compared here for AVHRR: greenness, EVI (Environmental Vegetative Index), and greenness ratio. EVI is calculated by simply differencing the two AVHRR bands (in this case normalized in scale). The greenness ratio is the quotient of the second and first bands (again normalized). Figures 3, 6 and 7 illustrate the three features respectively. EVI is equivalent to greenness, as they are both simple differences. The greenness ratio disperses data along the green arm, with targets significantly differing in brightness assigned similar green ratio values.

VII. DISCUSSION

The comparability of AVHRR, MSS and CZCS, illustrated by this analysis through simulation of a vegetated scene, points to promise for the joint or interchangeable application of these sensors while using common features for monitoring land conditions. The application of AVHRR and CZCS sensors for land use analysis is certainly desirable on the basis of both repetitive coverage and data volume. However, certain key limitations in this simulation must be kept in mind. Certain parameters of observation have not, as of this writing, been modeled, particularly bi-directional reflectance, atmospheric conditions and absolute sensor calibration and dynamic range. Any one of these may introduce non-linearities in the perceived linear relationship among sensor spectral features, especially the automatic gain control employed in CZCS. Saturation over land targets has been detected as a problem for CZCS, whose primary application is hydrological exploration.

A most significant difference is the effect of disparate resolution sizes of the sensors. CZCS and AVHRR with 825m and 1100m resolution respectively do not favorably compare to MSS at 79m resolution. Certainly the application of CZCS and AVHRR for crop identification would be ill-advised. However, the potential of these sensors for assessment of overall crop condition on a large area basis may exceed that of Landsat due to favorable temporal and data volume attributes. The simulation analysis suggests a methodology to this end that would enable the use of common features between sensors for condition assessment.

Examining Figures 2-4, note that the density of measurements along the soil arm and green arm would be a comparable feature among sensors. Figure 8 illustrates a method of decoupling Greenness and Brightness so that the axes represented relate strictly to the presence or absence of green vegetation or soil. These features referred to as soil (s) and vegetation (v) are derived as follows:

$$v = ||(b,g)||\sin\theta_F = ||\overline{p}||\sin\theta_F$$

$$s = ||\overline{p}||\cos\theta_F$$

where

$$\theta_F = 90 * \frac{\theta_I}{\Delta\theta}$$

$$\theta_I = \text{Arccos}\,\frac{\overline{p}\cdot\overline{u}}{||\overline{p}||}$$

$$\Delta\theta = \text{Arccos}\,(\overline{u}\cdot\overline{v})$$

for

$\bar{p}$ the greenness/brightness vector

$\bar{u}$ a unit vector in the direction of the soil arm

$\bar{v}$ a unit vector in the direction of the green arm

It is suggested that the stratification of this feature space into zones, as illustrated in Figure 8, and computing multitemporal features of scene density and magnitude by zone would apply to large area assessment of crop condition and determination of cultural events like crop emergence or harvest.

VIII. CONCLUSIONS

AVHRR, MSS and CZCS, three operative civilian remote sensing systems with spectral responses in the visible and infrared regions of the energy spectrum, are found to respond comparably to incident radiation from typical agricultural targets simulated using field reflectance measurements. Most of the signal variation of the three sensors is found to reside in two dimensions whose key axes, greenness and brightness, related to green biomass and albedo, in a highly correlated fashion between sensors. It is conjectured that there is potential for the joint or interchangeable application of these sensors, using common features, for crop condition assessment or the detection of agronomic cultural events. The multitemporal stratification of the data from each sensor according to two features that decouple spectral response to soil related and green vegetation related phenomena is proposed. Future work to further investigate, evaluate and apply the use of such features derived separately or jointly from AVHRR, CZCS and MSS sensors is recommended.

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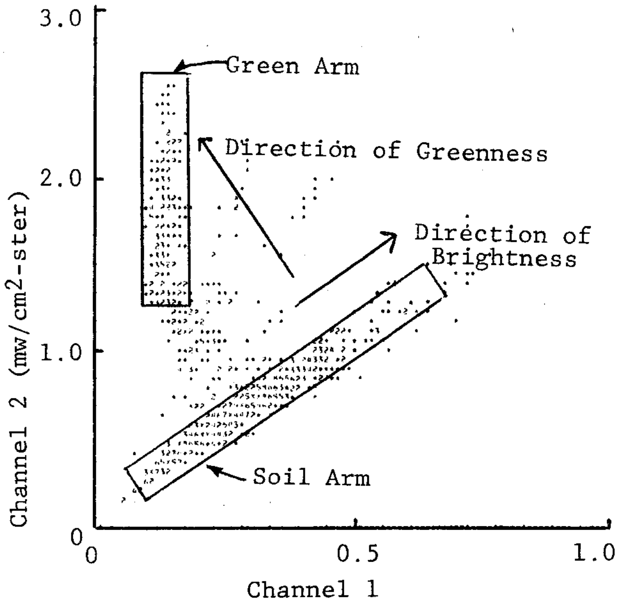

Figure 1. AVHRR Channel 2 vs. Channel 1

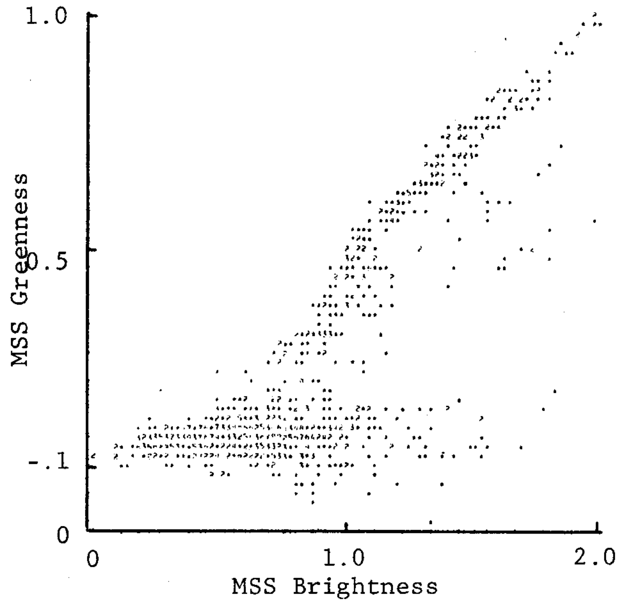

Figure 2. MSS Tasseled Cap Features

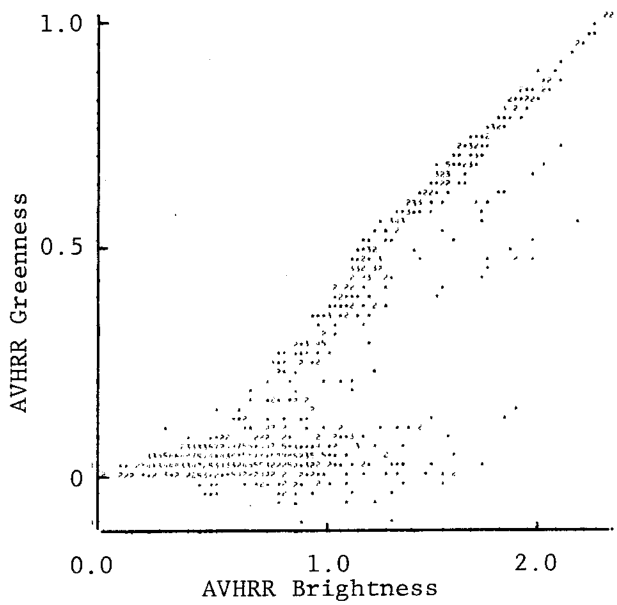

Figure 3. AVHRR Tasseled Cap Features

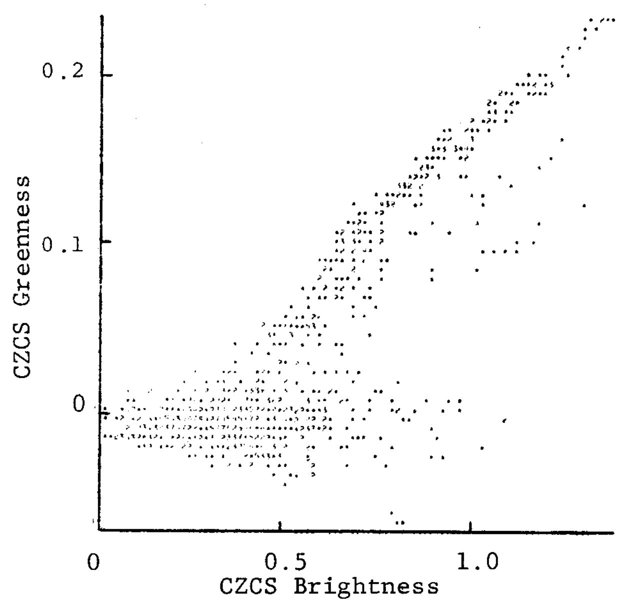

Figure 4. CZCS Tasseled Cap Features

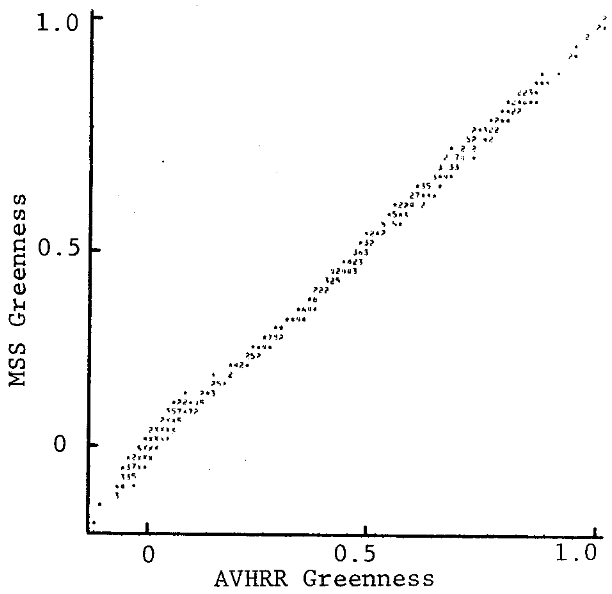

Figure 5. Relationship Between MSS and AVHRR Greenness

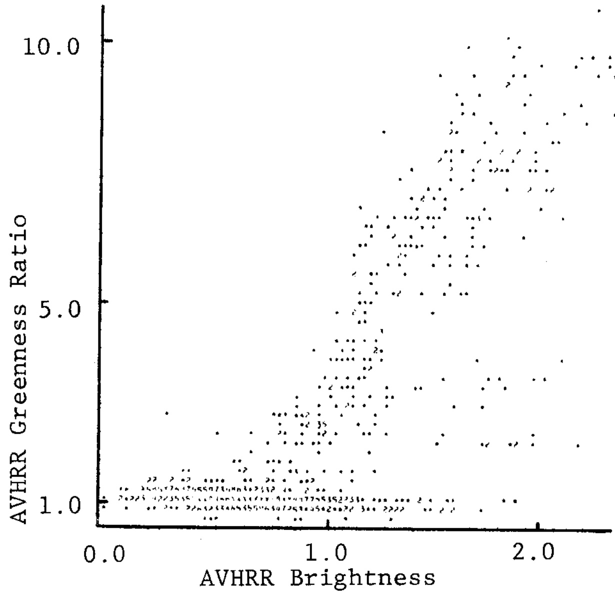

Figure 6. AVHRR Greenness Ratio vs. Brightness

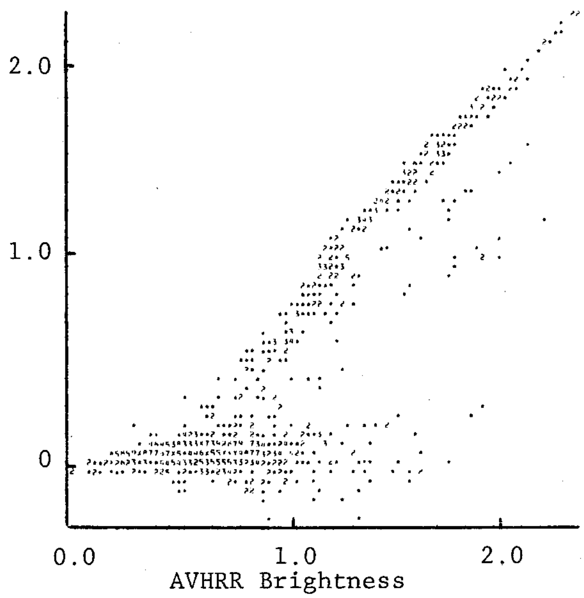

Figure 7. AVHRR EVI vs. Brightness

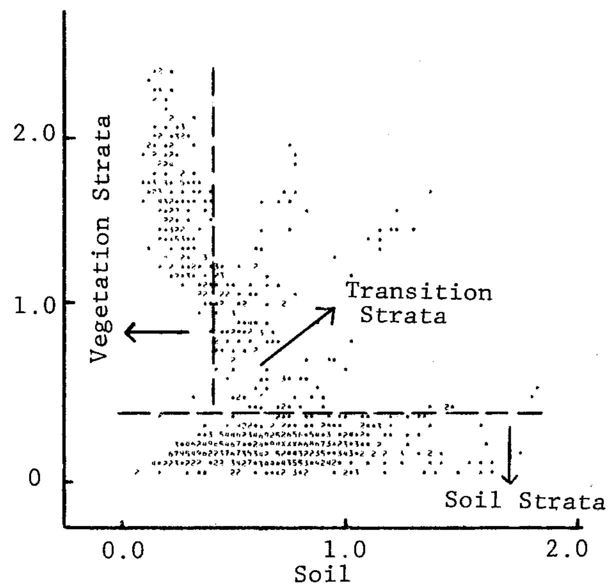

Figure 8. AVHRR Vegetation vs. Soil Derived Features

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