Application of a High Spectral Resolution Vegetation Index For Estimating Percent Cover, Leaf Area Index, and Evapotranspiration in Arid Environments

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Abstract

Airborne spectroradiometer data of arid land vegetation was acquired of three sites in the western USA. The data were used to generate values for a derivative green vegetation index (DGVI) which measures the amplitude of the chlorophyll red edge feature. DGVI values were found to be highly correlated to measures of percent cover, Leaf Area Index (LAI) and annual evapotranspiration (ET). The results indicate that high spectral resolution satellite remote sensing will be very useful for monitoring and characterizing arid land vegetation.

1. Introduction

Vegetation indices are mathematical transforms designed to assess the spectral contribution of vegetation to multispectral observations. The most widely used green vegetation indices are formed with data from discrete red and near infrared (NIR) bands. These vegetation indices operate by contrasting intense chlorophyll pigment absorptions in the red against the high reflectivity of plant materials in the NIR. The value of red versus NIR vegetation indices lies in the potential use of the vegetation index values to estimate vegetation parameters such as percent cover, transpiration rate, and Leaf Area Index.

It has been observed that variations in the spectral properties of background rock and soil materials can have adverse affects on vegetation indices, especially at low levels of vegetation cover. There are three main types of rock-soil affects on vegetation indices, listed here in their general order of prominence: 1) Albedo Affect: The brightness of the background materials can have a pronounced impact on the vegetation index values derived using ratio based formulas (Huete et al., 1985; Elvidge and Lyon, 1985), with bright backgrounds producing lower vegetation index values and dark backgrounds producing higher vegetation index values. The albedo affect on green vegetation indices can be demonstrated through simple linear mixing of pure vegetation and rock-soil spectra (Elvidge and Lyon, 1985). 2) Red-NIR Slope Affect: Variations in the slope from red to NIR reflectance in background materials (rock, soil, litter) can produce variations in vegetation index values (Elvidge and Lyon, 1985). Most background materials have slightly higher reflectance in NIR wavelengths than in the red region. This produces a positive slope from red to NIR. However, there are considerable variations in this red to NIR slope for different background materials. And 3) Non-Linear Mixing Affect: NIR light transmitted through plant canopies can be either absorbed or reflected by substrate materials. For plant canopies with bright backgrounds there can be a measurable enhancement of the NIR light reflecting from a plant canopy with a bright background relative to a dark background (Huete et al., 1985), creating a non-linear spectral mixing situation (Roberts et al. 1993). This third affect acts in an opposite sense to the first affect, raising vegetation index values slightly for plant canopies with bright backgrounds.

In analyzing the three adverse effects of background variations on vegetation indices, we have hypothesized that a green vegetation index derived from a continuous set of narrow bands across the chlorophyll red edge feature, would be capable of reducing the first two listed adverse background effects (albedo and red to NIR slope) on vegetation index performance. It is known that the albedo affect is induced by band ratioing. By making direct measurements of the amplitude of the chlorophyll red edge without the use of band ratios, the background albedo affect can be eliminated. The red to NIR slope affect should be minimized by restricting the red to NIR wavelength range to the chlorophyll red edge and the immediately adjacent bands.

Studies by Elvidge et al. (1993) revealed that the presence of trace quantities of green vegetation (~5% green cover) can be detected in high spectral resolution data from NASA's Airborne Visible-Infrared Imaging Spectrometer (AVIRIS). These results were based on the persistence of the chlorophyll red edge feature, from 0.7 to 0.75 um, at low levels of green vegetation cover. However, these results were obtained using tree covered plots with relatively uniform soil background. Elvidge and Chen (1995) developed a high spectral resolution green vegetation index, using first to measure the amplitude of the chlorophyll red edge (Figure 1). Elvidge and Chen successfully demonstrated the superiority of the narrow band vegetation index by analyzing reflectance spectra of a plant canopy with a variety of rock-soil backgrounds. By successively removing leaf material Elvidge and Chen (1995) demonstrated that the detection limits for green vegetation with high spectral resolution observations is in the range of 3-5 % green vegetation cover. Traditional vegetation indices have difficulty confirming the presence of vegetation with less than 10-20% green cover.

In this paper we present results obtained from airborne spectra indicating the potential use of high spectral resolution observations for the estimation and temporal tracking of green cover, evapotranspiration, and leaf area index in arid environments.

2. Methods

High spectral resolution reflectance spectra were acquired over arid land sites using an Analytical Spectral Devices - Personal Spectrometer (PS-2). This instrument acquires spectra in the 0.4 to 1.0 um region with 4 nm bandpasses (full width half maxima) with 1.4 nm sampling interval. The instrument head mounted in the bottom of the aircraft fuselage and was operated from inside the cockpit. The instrument calibrated to record reflectance spectra by acquiring measurements of a white calibration panel prior to takeoff. All spectra were completed within 20-30 minutes of takeoff under clear sky conditions. Airborne spectra were acquired from an altitude of approximately 60 meters above the ground surface. At this altitude the field of view of the sensor was ~ 27 meters in diameter.

Spectra were acquired at five sites in the Goshute Valley, Nevada; eleven sites in the Owens Valley, California; and eight sites along the Colorado River south of Blythe, California. From three to five spectra were acquired at each site. Figure 2 shows the three study sites on a map outline of the western USA.

The sites flown were selected based on the availability of ground truth data on the vegetation or rates of evapotranspiration. The sites in the Goshute Valley and Blythe each had an Bowen ratio meteorological station. The airborne spectral measurements were acquired of the vegetation surrounding the Bowen ration station towers. Date from the Bowen ratio stations provide estimates of the annual evapotranspiration in mm of water. Percent cover estimates for the Goshute Valley sites were made using a point count measurements in the field along randomly oriented line transects. Leaf point counts were used to estimate LAI along permanent transects flown in the Owens Valley. Percent cover estimates for the Blythe sites were made using gridded point counts made on the aerial photographs acquired at the time of the spectral data acquisition.

The DGVI calculation was performed by integrating the first derivative values obtained from the reflectance spectra from 680 to 754 nm. The first derivative value at 650 nm was subtracted from the each of the integrated values, providing a local baseline correction.

3. Results

Figure 3 shows sample reflectance spectra obtained from the airborne measurements. DGVI values were highly correlated to vegetation cover, ET and LAI. The relationship between DGVI and vegetation cover was found to be log-linear (Figure 4), as was the relationship between DGVI and LAI (Figure 5). DGVI values were linearly related to ET (Figure 6).

4. Conclusion

A growing body of research indicates that high spectral resolution remote sensing of the chlorophyll red-edge provides significant advantage over traditional broad band remote sensing for the detection and monitoring of the low levels of green vegetation present in arid lands. While such measurements are currently restricted to airborne or field surveys, satellite remote sensing with high spectral resolution is nearly a reality. In 1997 NASA will launch the first spaceborne imaging spectrometer designed for Earth observations (LEWIS). It is anticipated that there will a proliferation of such systems in the coming decades.

5. References

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Roberts, D.S., Smith, M.O., Adams, J.B., 1993, Green vegetation, nonphotosynthetic vegetation and soils in AVIRIS data. Remote Sensing of Environment, v. 44, p. 255-269.

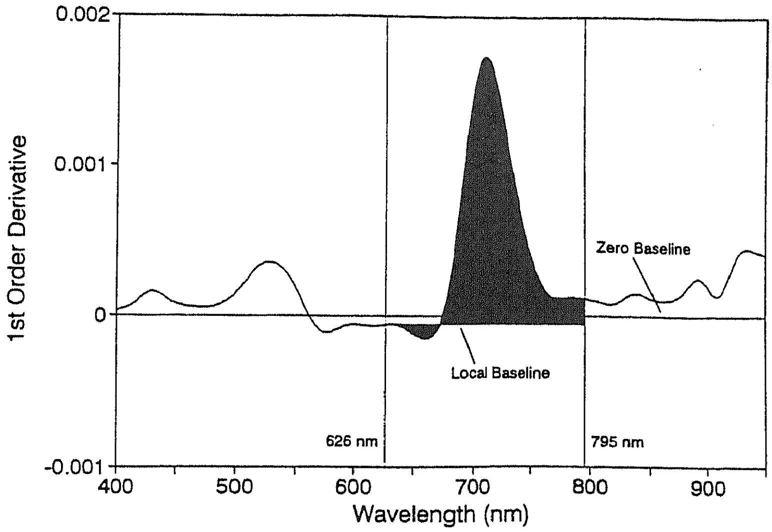

Figure 1. The Derivative Green Vegetation Index is calculated by integrating first derivative values across the chlorophyll red edge.

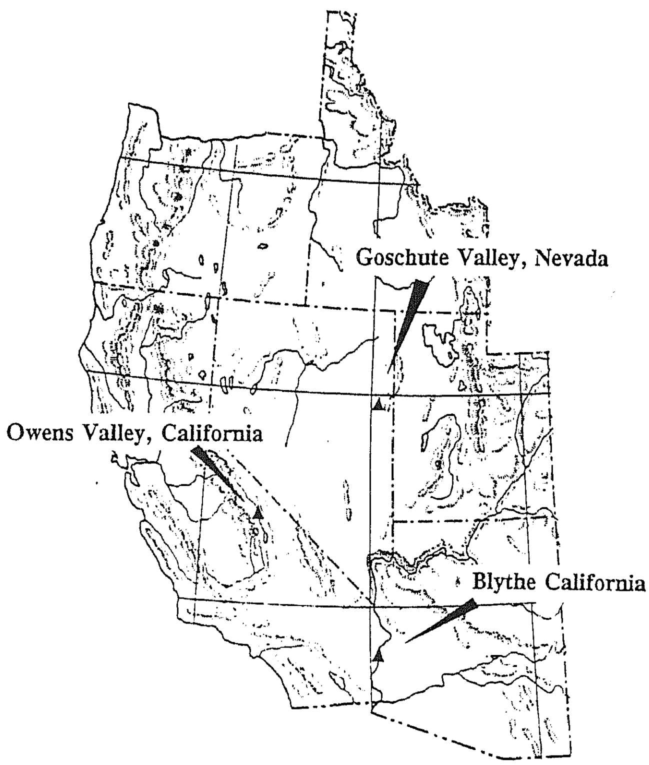

Figure 2. Sketch map of the western USA showing the three study sites.

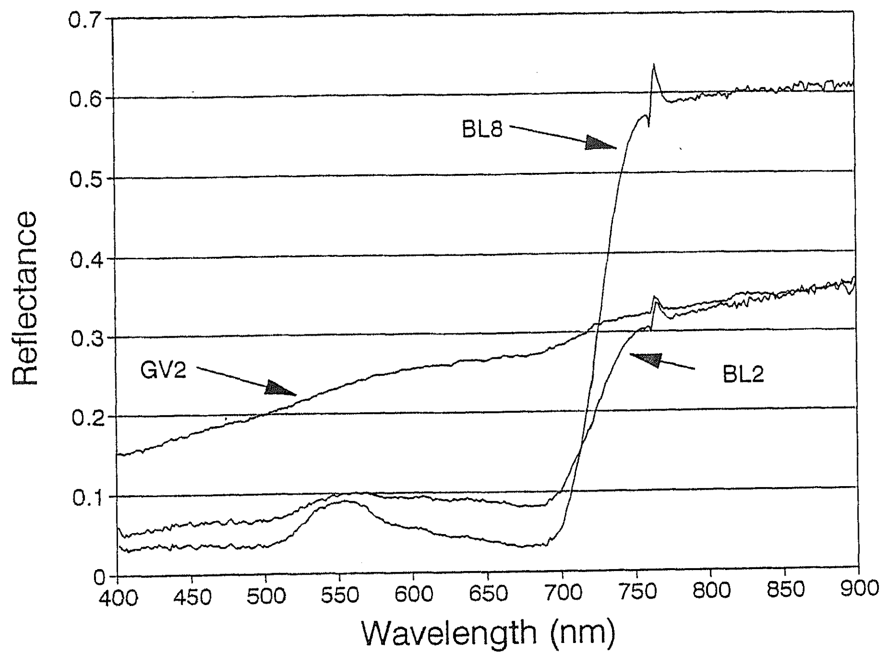

Figure 3. Sample reflectance spectra from the airborne measurements. BL8 = Uncut alfalfa crop at Blythe. BL2 = Salt cedar - mesquite area at Blythe. GV2 = Desertscrub in Goshute Valley.

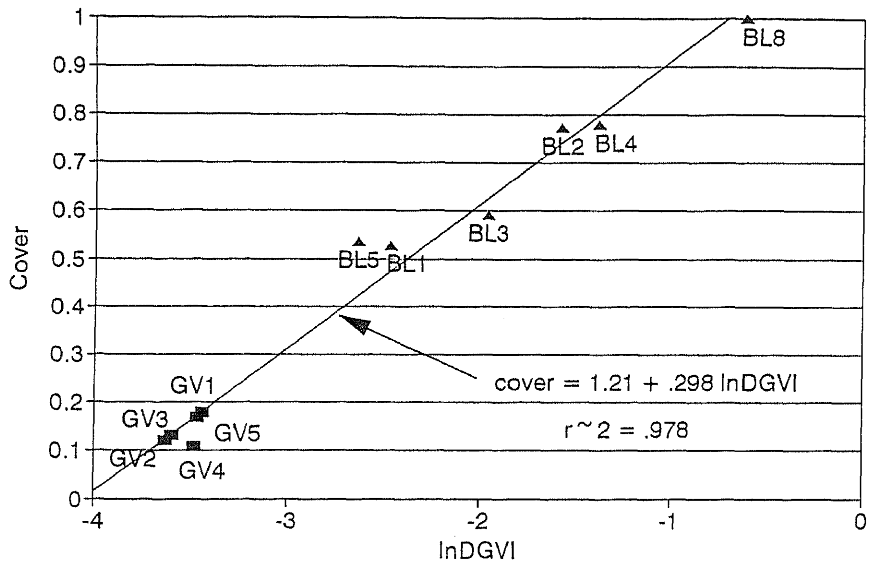

Figure 4. DGVI values versus cover for Goshute Valley and Blythe sites.

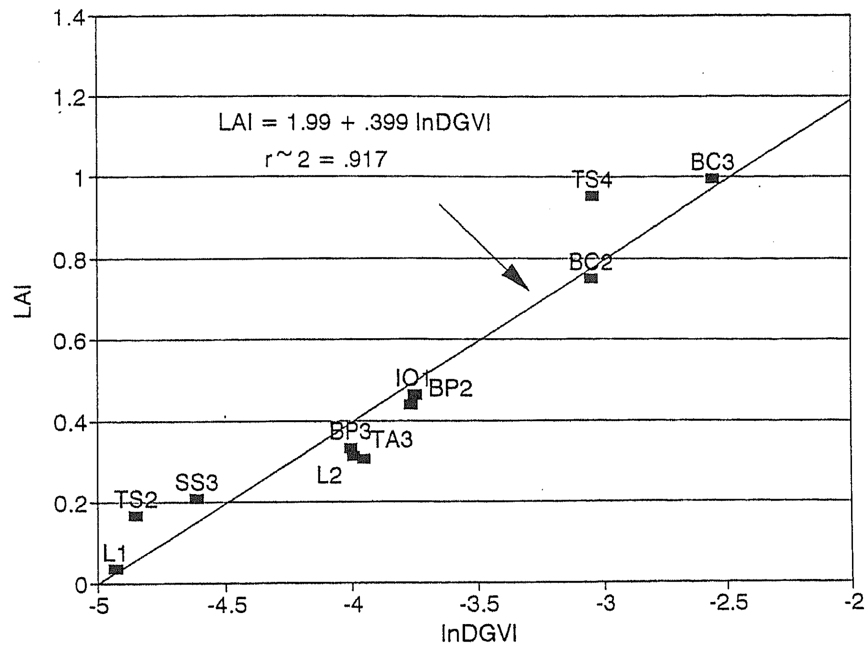

Figure 5. DGVI values versus Leaf Area Index (LAI) for eleven sites in the Owens Valley.

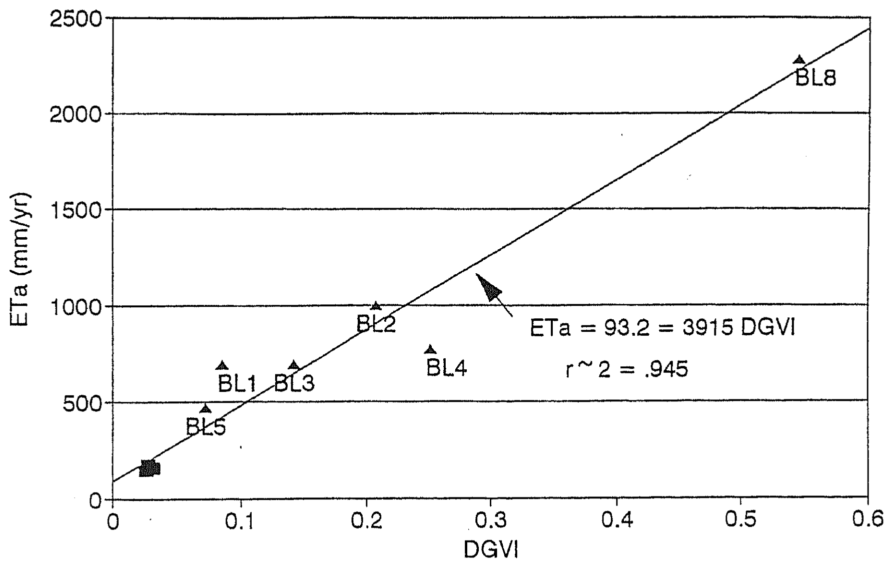

Figure 6. DGVI versus evapotranspiration (ET) for Goshute Valley and Blythe sites.