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The Wide Dynamic Range Vegetation Index and its Potential Utility for Gap Analysis

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Introduction

In landscapes with moderate to high densities of green biomass, the widely used Normalized Difference Vegetation Index (NDVI) has long been known to exhibit reduced sensitivity to moderate-to-high vegetation density. This loss of sensitivity diminishes the utility of the NDVI to discriminate among land cover types or land cover quality. A straightforward modification of the NDVI, the Wide Dynamic Range Vegetation Index (WDRVI), was recently developed (Gitelson 2004) and has been shown to be effective in tracking spatio-temporal variation in diverse ecoregions throughout the conterminous United States (Viña et al. 2004). In this brief note, we illustrate the prevalence of reduced sensitivity of the NDVI, introduce the WDRVI, and illustrate the advantages of the WDVRI over the NDVI using Landsat ETM+ data that spans a range of canopy densities.

Limitations of the NDVI

The Normalized Difference Vegetation Index is calculated as the ratio of the difference between near infrared (ρ_{NIR}) and red (ρ_{red}) reflectance divided by their sum: ($\rho_{NIR}-\rho_{red}$) / ($\rho_{NIR}+\rho_{red}$). Values range from −1 to +1. The specific value of NDVI for a scene depends on the wavelengths used to represent ρ_{NIR} and ρ_{red}, the radiometric and spatial resolutions of the sensor, the illumination and atmospheric conditions, the sun-target-sensor geometry, and the distribution and types of objects within a scene. The proper biogeophysical interpretation of the NDVI is the fraction of absorbed photosynthetically active radiation (fAPAR). The NDVI loses sensitivity when the leaf area index (LAI) exceeds about 2. Reduction in its dynamic range means fewer distinct levels of NDVI are observable. When the LAI is much larger than 2, even a large change in the LAI may be undetectable using the NDVI. This has implications for land cover/land use change studies but land cover classification as well. A limited dynamic range may distort and obscure interesting spectral features that could aid classification.

During a significant portion of the temperate growing season, it is as if a green veil obscures changes across the vegetated land surface. We can visualize the duration and extent of the green veil using the biweekly composites of maximum NDVI as observed by the NOAA AVHRR sensors. Here we simply count the number of times during the growing season that a pixel exceeds a specific NDVI threshold associated with the transition to reduced sensitivity. In Figure 1, for example, there are some dark areas of the region that never experience reductions in NDVI sensitivity (e.g., lakes, reservoirs, badlands) and others that are in the zone throughout the growing season (e.g., coniferous forests, deciduous forests in eastern Kansas, integrated agribusiness complex near Garden City, KS). Note the distinct bright triangle in Nebraska south of the Platte River (see arrow); we will zoom into this area in an example below.

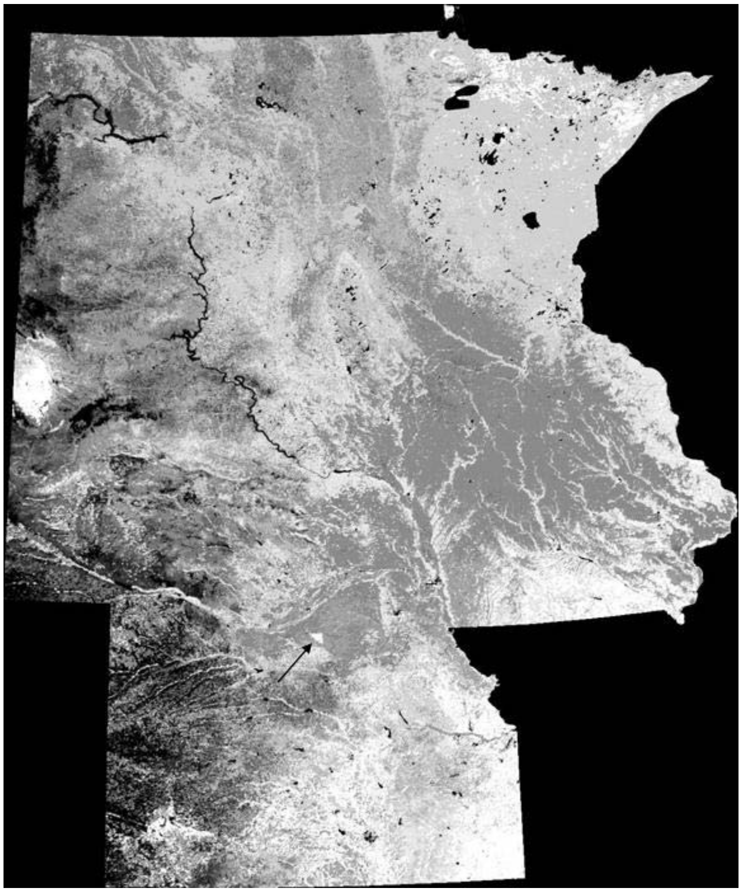


Figure 1. Persistence of reduced NDVI sensitivity over the GAP Great Plains region (ND, SD, NE, KS, MN, IA) using AVHRR composites from 2000. Brighter pixels spent more time during the 15 biweekly compositing periods of the growing season in the zone of reduced NDVI sensitivity.

Lifting the green veil with the WDRVI

Gitelson (2004) introduced the WDRVI as a way to enhance the dynamic range of the NDVI by applying a weighting parameter α to the near infrared reflectance:

$$\text{WDRVI} = (\alpha * \rho_{\text{NIR}} - \rho_{\text{red}}) \,/\, (\alpha * \rho_{\text{NIR}} + \rho_{\text{red}}). \qquad [1]$$

If α equals 1, then the WDRVI is equivalent to the NDVI. If α equals ($\rho_{\text{red}} / \rho_{\text{NIR}}$), then the WDRVI equals zero. Think of α as a tuning knob that adjusts the gain on the index. Selection of the coefficient for the α parameter requires some forethought, so we will illustrate the effect of different coefficient values on the WDRVI.

Example with Landsat 7 data

We have chosen a small piece of an ETM+ scene acquired on August 4, 2001 (Path 29, Row 32) with a nominal spatial resolution of 28.5 m. Figure 2 shows the NDVI calculated from sensor reflectances without any atmospheric correction. For this same image, we also calculated the

WDRVI at different levels of α (0.20, 0.10, 0.05) that had been used by Gitelson (2004). We also calculated a coefficient value adjusted to scene characteristics using the heuristic:

$$\alpha_{est} = 2 * (\text{average } \rho_{red}) / (\text{maximum } \rho_{NIR}) \qquad [2]$$

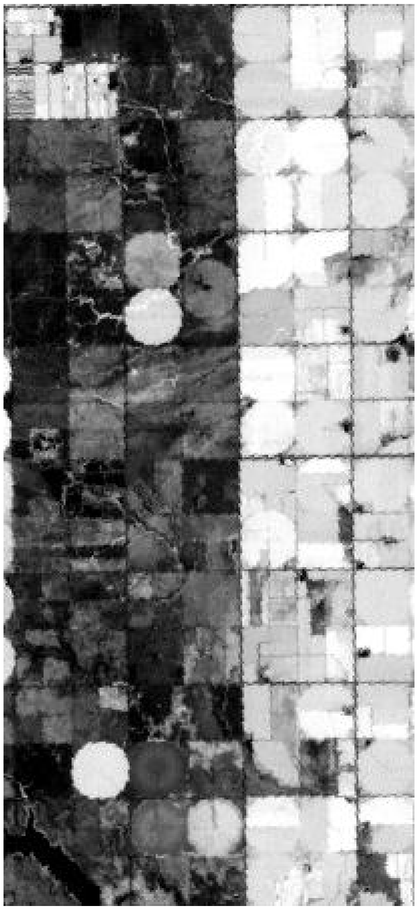
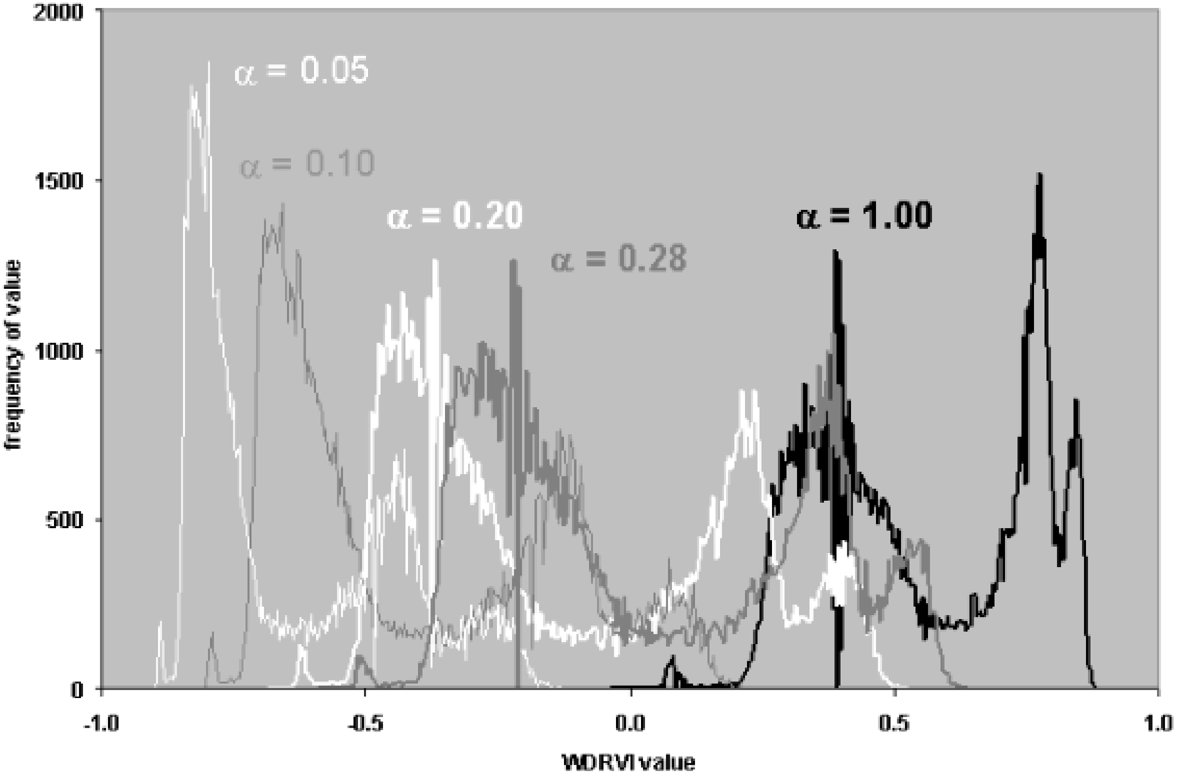


Figure 2. NDVI calculated from a Landsat ETM+ image (P29, R32) acquired August 4, 2001. Location is at the edge of a research farm near Hastings, NE. Brighter tones indicate higher fAPAR. Circles are quarter-section (160 acre; 65 ha) fields irrigated by center pivot.

Our scene had an average red reflectance of 7.7% and maximum near infrared reflectance of 54.9%, thus the α_{est} equaled 0.28. Figure 3 shows the histograms that result from calculating the WDRVI with different α values, and Table 1 provides a statistical summary of these distributions.


α = 0.05
α = 0.10
α = 0.20
α = 0.28
α = 1.00
2000
1500
1000
500
0
frequency of value
-1.0
-0.5
0.0
0.5
1.0
WDRVI value

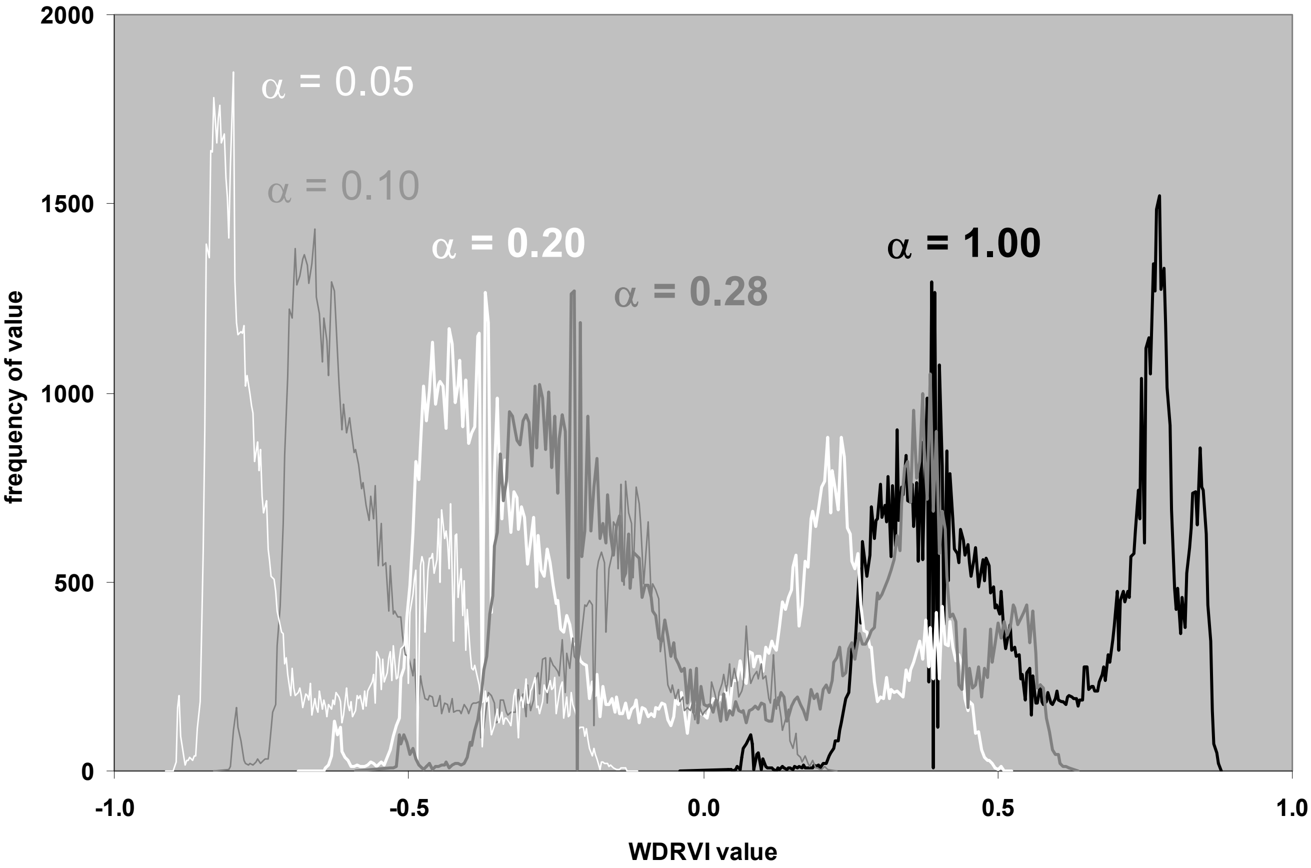


Figure 3. Histograms of WDRVI obtained for different values of α.

Table 1. Summary statistics for WDRVI calculated with various values for α.

Coefficient Value	Mean	Maximum	Minimum	Range	Change in Range over the NDVI
α = 1.00	0.553	0.883	−0.040	0.923	--
α = 0.28	0.037	0.635	−0.589	1.224	+33%
α = 0.20	−0.115	0.524	−0.688	1.212	+31%
α = 0.10	−0.406	0.231	−0.831	1.062	+15%
α = 0.05	−0.636	−0.110	−0.912	0.802	-13%

Discussion

It can be seen that the shape of the distributions changes significantly with change in α; in particular, the two modes at high NDVI values spread out as α decreases (Figure 3). However, the cost of enhanced dynamic range at the high end is some loss of sensitivity at the low end. Notice the contraction of the small mode at the low end as α decreases (Figure 3). Attenuation of the near infrared reflectance can increase the dynamic range of the WDRVI over the NDVI: α =

0.20 yields more than 30% increase in dynamic range (Table 1). Notice that $\alpha_{est} = 0.28$ gives a slight improvement in dynamic range over $\alpha = 0.20$, but tuning the coefficient value to particular scene characteristics could impair scene mosaicking and temporal comparisons. We suggest that since $\alpha = 0.20$ has been shown to be effective with proximal sensors (Gitelson 2004) as well as with AVHRR (Viña et al. 2004) and Landsat ETM+ (this note) imagery in the absence of atmospheric correction, it is a good initial value from which to explore the potential of the WDRVI in revealing more variation in settings with moderate to high green LAI.

Conclusions

1. The WDRVI offers a simple way to enhance dynamic range that is limited by the NDVI under conditions of moderate to high biomass (LAI > 2).
2. Tuning the weighting parameter α to different values changes histogram shape.
3. A coefficient value of 0.20 for α appears to be generally effective.
4. For low biomass settings (LAI < 1), the NDVI still works best for distinguishing vegetation.

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