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MONITORING GLOBAL VEGETATION DYNAMICS USING THE NOAA/AVHRR

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I. ABSTRACT

NOAA/AVHRR satellite data have been shown to be useful for regional-scale monitoring of both spatial and temporal dynamics of vegetation, particularly when used in conjunction with climate data. In this investigation, the authors have examined AVHRR Normalized Difference (ND) greenness values along an east-west transect across Texas and evaluated the ND gradient relative to the environmental change in climate and actual vegetation.

II. INTRODUCTION

There have been numerous studies of global vegetation based on satellite data, mainly Landsat Multi-Spectral Scanner (MSS) imagery. Data extracted from these images is useful because the relatively narrow-scan (5° longitude) Landsats produce images of high resolution (80 m). However, ecological studies based on Landsat images seem to be destined to remain vulnerable to the data infrequency/cloud cover problem, especially in humid regions.

The meteorological satellites, conversely, scan 56° of longitude, providing less detail (resolution = 1.1 km) than Landsat but offering daily worldwide data collection. Very little ecological use has been made of the meteorological satellites, particularly the NOAA/AVHRR (National Oceanic and Atmospheric Administration/ Advanced Very High Resolution Radiometer). Gray and McCrary (1981a; 1981b) obtained a high correlation for vegetation greenness as measured by NOAA-6 AVHRR Large Area Coverage data sets and Landsat MSS data within identical target areas. They demonstrated that variations in the AVHRR responses provide useful information about vegetation response to moisture availability and thermal conditions. Horvath, Gray, and McCrary (1982) concluded that the metsat system is best suited for large-area analyses of surface features on a daily basis. Tucker (1984) has shown that real-time, continental-scale vegetation maps produced from AVHRR composited data can accurately reflect spatial distributions and seasonal-phenological greenness changes of major vegetation types. In this paper, we hope to further substantiate the use of AVHRR digital data for monitoring spatial-temporal dynamics of vegetation on a global scale.

III. METHODS

From our original study (Greegor and Norwine, 1981) we established an east-west transect extending approximately 1300 km (800 mi) across Texas at approximately 30° N. Beginning in humid southeastern Texas (93° W) the transect stretched westward into arid West Texas (106° W) through three distinct climatic types and four to five major vegetation regions. Both the climatic and vegetative stratifications result from a severe east-west moisture gradient (52 to 8 inches mean annual precipitation).

Satellite Data. NOAA/AVHRR data for five relatively cloud-free dates in 1980 were acquired and processed: 19 April, 28 April, 10 July, 8 October, and 9 October (representing three climatic seasons). Reflective Channels 1 and 2 data were obtained for five adjacent scanlines along the 1300 km transect. We recognize the degree of uncertainty present in AVHRR data as a function of an extreme scan angle. A pixel grid (5×5) was sampled at regular intervals (0.25° longitude) along the transect providing 50 samples per transect-date. A mean pixel value for each of the two channels was determined for each grid. These values were treated using the Landsat-derived normalized difference (ND) equation, which has been shown to be a satisfactory index of surface greenness (Rouse, et al. 1973; Deering et al., 1975). The ND values were generated for each of the 50 sites on the five dates in 1980.

Climate Data. Trenchard and Artley (1981a; 1981b) recently developed a new climatic variable whose simplicity and sensitivity seem to make it appropriate for biogeographical investigations. This hypothetic medium was originally termed the "sponge" but has been renamed the Hydrologic Factor (HF) by ourselves. HF can be calculated at any weather station where daily temperature extremes and precipitation are recorded. Because the weather stations rarely coincided with any of the 50 sample sites, it was necessary to select the nearest one, usually within a few kilometers. HF ranges between zero and 8 inches (capacity) (see Norwine and Greegor, 1983, for complete discussion).

Definitions of Additional Variables. From the preliminary phase of this research (see Norwine and Greegor, 1983) a good correlation was established between ND and HF which led to the already proposed vegetation-hydrologic factor index (I_{vh}) (Eq. 1).

$$I_{vh} = ND \times HF \qquad (1)$$

In this discussion, it is important to recognize that our data base for ND is represented by five dates in 1980. HF values, however, have been determined in the following manner: (a) HF--mean HF value for the three months in 1980 preceding the ND date; and, (b) HF_{sn}--mean HF seasonal (3 mo) normal (1941-1970) value. The basis for selecting the preceding three months assumes that climate averaged over a shorter or longer period would not correlate as closely with greenness. With this in mind, ND has been adjusted to provide a more accurate estimate under normal climatic conditions, the "expected" ND (Eq. 2).

$$ND_e = HF_{sn}/HF \times ND \qquad (2)$$

IV. RESULTS AND DISCUSSION

Vegetation Spatial Dynamics. One of our intentions has been to assess the validity of the preliminary results (Norwine and Greegor, 1983). The expanded sampling corroborates our initial results that: (a) both ND and HF are a function of longitude; (b) ND is a function of HF; (c) ND is a function of vegetation amount; and, therefore, (d) I_{vh} is a function of longitude and vegetation amount and permits the recognition and classification of the major vegetation regions on the transect (Table 1; Fig. 1). Tucker, et al. (1984) noted a definite north to south ND gradient in the African Sahel from 1981 AVHRR data, which corresponded closely to the precipitation gradient.

Table 1. Pearsonian r values for the variables, ND, HF (1980 season), and HF_{sn} (seasonal normal) as a function of longitude for five dates in 1980.

	19 APR	28 APR	10 JUL	8 OCT	9 OCT	MEAN
ND	.87	.87	.91	.76	.81	.84
HF	.90	.90	.97	.42	.43	.72
HF_{sn}	.94	.93	.98	.85	.85	.91

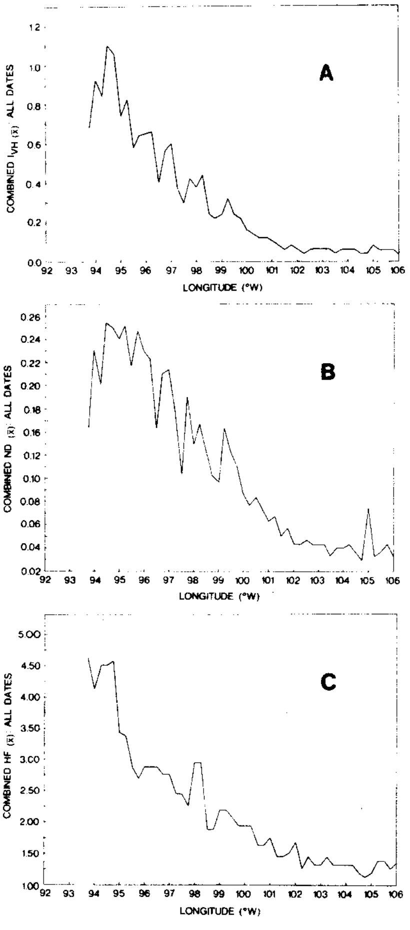

Figure 1. 1980 mean values for (A) I_{vh}, (B) ND, and (C) HF plotted against longitude.

When ND was combined with HF as I_{vh} (Fig 1a), the curve smoothed considerably. When annual (12 month mean) normal HF values were substituted for 1980 HF values in the I_{vh} equation, and a log transformation performed, linearity (against longitude) improved dramatically ($r = 0.97$; Fig 2). From the transformed values, we could tentatively conclude that I_{vh} values >6.5 are high productivity coastal and forest communities; values <3.6 would be low productivity desert, and anything in between would be transitional savannas and woodlands.

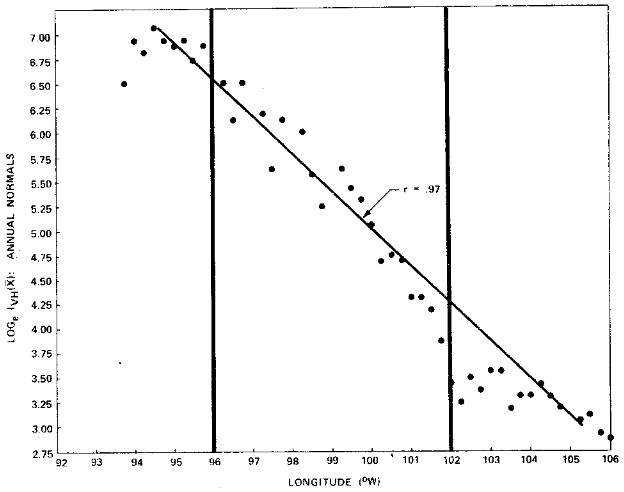

Figure 2. The $\log_e$ transformation values for I_{vh}, using the annual (12 month mean) normal values of HF in the I_{vh} equation (see Eq. 1). The vertical divisions at 96° and 102° are the approximate major vegetation breaks on the transect (see text).

The mean ND and HF values for 1980 were plotted against each other and cluster analysis done which resulted in excellent agreement between the clusters and alleged vegetation along the transect (Fig 3; Table 2). It must be noted that the number of classes, five, was selected a priori to suite the number of major vegetation groups encountered on the transect.

The within-cluster mean distance (Table 2) was slight in clusters one, two, four, and five but significantly larger in cluster three. While the least variation was in cluster four, the sample size was small ($n = 2$). This corroborates our earlier findings (Norwine and Greegor, 1983) that desert scrub (1), shrubland (2), and mixed pine-hardwood forest (4) exhibited the greater greenness consistency of the types represented. The savanna (3) and coastal prairie (5), because of agricultural practices, are more heterogeneous.

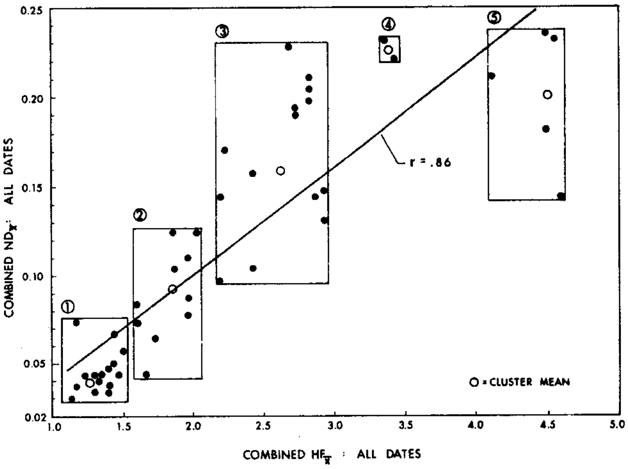

Figure 3. Mean ND values for five sample dates in 1980 plotted as a function of mean seasonal 1980 HF values. Enclosures 1-5 represent the results of cluster analysis and are numbered west to east on the transect (see Table 2).

Table 2. Results of a cluster analysis of two variables, $ND_{\bar{x}}$ and $HF_{\bar{x}}$ values from five sample dates in 1980.

Cluster		Mean		Mean Distance[1]		
No.	Sites	ND	HF	Within	Between	Vegetation[2]
1(W)	32-50	.04	1.32	.021	0.288	TPDS(34-50)
2	22-31	.09	1.83	.046	0.762	EPS (19-33)
3	8-21	.16	2.64	.143	0.648	SP (9-18)
4	6-7	.23	3.40	.004	1.174	MPHF(6-8)
5(E)	1-5	.20	4.47	.063		CP (1-5)

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[1] Both within and between cluster mean values taken to three decimal places to avoid zero entries.

[2] Derived from Gould (1975) vegetation map of Texas: TPDS - Trans-Pecos Desert Scrub; EPS - Edwards Plateau Shrubland; SP - Savanna Prairie; MPHF - Mixed Pine-Hardwood Forest; and CP - Coastal Prairie.

Clustering of the variables, $ND_{\bar{x}}$ and $HF_{\bar{x}}$, produced good separation of all five classes. Between-cluster mean distances remained high in all pairs except clusters one and two. Discriminating desert scrub (1) from shrubland (2) might pose some problems were it not for the significant within-cluster difference between the two. Comparing the cluster classification with the alleged vegetation stratification, only six of the 50 sites were misclassified.

Vegetation Temporal Dynamics. As mentioned earlier, HF was based on the mean value of the three months prior to the ND date. Because the 1980 summer (July - September) was atypical (e.g. Hurricane Allen), it yielded an array of HF values of low correlation with both longitude and ND (Tables 1; 3). The HF seasonal normal (HF_{sn}) mean values for summer produced a dramatic increase in correlation against longitude but still not as high as April and July which suggests that the Texas summer climate is the least predictable, and furthermore, expresses the smallest east-west gradient of the three seasons.

Table 3. Pearsonian r and regression slope (b) values when ND was plotted against HF for the five 1980 sampling dates.

	19 APR	28 APR	10 JUL	8 OCT	9 OCT
r	.89	.80	.89	.28	.40
b	.06	.06	.04	.02	.04

When the ND was plotted against HF for each 1980 sampling date we found it instructive to look at both the Pearsonian r values and the slopes (b) of the regressions (Table 3). A good correlation between ND and HF would render combinations of the two (e.g. I_{vh}, ND_e; see Eqs. 1, 2) more useful for vegetation analysis. On the other hand, poor ND-HF correlation from a gradient that had previously provided good correlation, should not be ignored. In the particular case of October 1980, the ND correlation with longitude did not drop significantly from April or July, but HF against longitude did (see Table 1). This suggests that the atypical 1980 summer weather can explain the poor ND-HF correlation. The slope of the regression (b) is, of course, indicative of the steepness of the gradient. The April gradient was steeper than July and October. It would be expected that the greenness differences across Texas would be more dramatic in April than July or October.

When ND was adjusted (Eq. 2) to ND_e to utilize the improved ND-HF correlation under normal (30 yr) climatic conditions (see HF_{sn}, Table 1), the ND_e gradient steepened dramatically for October (Fig 4). In theory, ND_e is designed to serve as an indicator of vegetation changes, e.g. desertification. Even after a climatically normal summer, the actual October ND would not be expected to achieve the ND_e values because the "greening" season is essentially over. It is our contention that acute vegetation responsiveness (i.e. greenness) to the 1980 summer climatic anomalies (e.g. Hurricane Allen, circa 19 August) had largely passed by October ND dates, yielding more "typical" ND values. Gray and McCrary (1981), using AVHRR data from southcentral Texas, did obtain a significant increase in their vegetation index, but within five days following Allen. Tucker, et. al. (1984) concluded from 1981 wet season AVHRR ND images of the Sahel that values were closely associated with previous precipitation events.

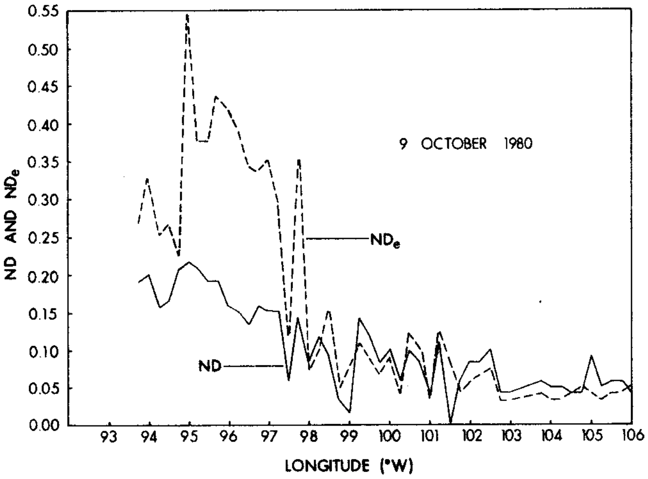

Figure 4. Normalized difference (ND) and expected normalized difference (ND_e) curves for 9 OCT 1980 sampling data.

When one is selecting satellite sampling dates for monitoring vegetation, it seems important to emphasize the climatically dependent (i.e. greenness response) and climatically predictable periods of the year (e.g. spring HF and July ND in Texas).

V. CONCLUSIONS

Gradient analysis has permitted us to better understand how satellite signatures respond along an environmental continuum relative to the climate and vegetation, in terms of both the spatial and the temporal relationships. This investigation demonstrated that NOAA/AVHRR satellite ND data and the HF variable are appropriate in large-area vegetation studies. It was found that satellite-measured levels of greenness closely correspond to observed vegetation and moisture gradients across Texas; that, in fact, greenness (ND) appeared to be largely a function of HF. A multivariate model (I_{vh}) combining the spectral and climatic indices permits stratification of the major vegetation types. An adjustment term (ND_e) was developed to correct ND values at any site for the effect of recent-season moisture variability (droughts, wet spells), thereby providing a measure of expected normal long-term greenness (useful because such a data base of ND "normals" does not exist).

Vegetation classification and change detection are expected to be relatively simple for the two vegetation extremes--closed canopy forests which tend to have high greenness and climate indices and low variance, and deserts, which generally have low index values and low variance. The problematic vegetation types are the more heterogeneous transitional areas such as woodlands and savannas, which tend to have considerable variation, making classification and change detection difficult. Presently, we are examining AVHRR gradients elsewhere in North America. A multi-temporal analysis may prove to be the best approach for identifying vegetation types that also exhibit significant seasonal spectral variation, e. g. grasslands.

It remains for this satellite-climate-vegetation gradient model to be tested against natural vegetation regions in other parts of the world. Following such studies, it is anticipated that ultimately such a model may be useful for global vegetation surveys and as a means of remote monitoring of eco-region dynamics (e. g. desertification), especially in underdeveloped areas where ground-truth data is limited.

VI. ACKNOWLEDGEMENTS

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VIII. BIOGRAPHICAL SKETCH

Dr. David H. Greegor, Jr., is an ecologist at Nebraska Wesleyan University and an Adjunct Professor at the UNL Remote Sensing Center in Lincoln. Over the past several years, he has been developing a model for global vegetation analysis using AVHRR satellite data. He is the author of papers published in ecology and remote sensing.

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