Potential for Semiarid Community Type Differentiation via Exploitation of the Directional Signal : Tests with AVHRR Data

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Abstract - Community-level vegetation type differentiation is regarded as an important application of remote sensing in monitoring the health of semiarid environments and yet it has proved difficult to discriminate more than two or three community types with confidence when using coarse spatial resolution data from off-nadir scanning sensors such as the AVHRR, even when multi-temporal datasets are used. Attempts to relate vegetation phenology to community type using AVHRR data have produced mixed results and large classification errors have been attributed to subpixel scale topographic and soil background variations, lack of in-flight calibration, inaccurate reflectance retrieval and poor registration. While these are important factors, anisotropy in surface reflectance as a result of the bidirectional reflectance distribution function (BRDF) also causes severe perturbations in the signal and yet this is rarely accounted for adequately. Recent years have seen a wider acknowledgement of this fundamental aspect of optical remote sensing, although it is usually approached as a problem. The extent of the improvement in community type differentiation may be considerable when a BRDF model is used to separate isotropic and anisotropic components. Here this potential is tested using data from the AVHRR over semi-arid regions.

INTRODUCTION

Degradation of semi-arid grasslands is often assessed in terms of the distributions of community types since it is generally agreed that sustained climatic or anthropogenic disturbance leads to encroachment of shrubs and annuals into grass and perennial-dominated ecosystems [1]. Community type differentiation with remote sensing provides a method for estimating these distributions over large areas, although attempts to map community types using AVHRR composites have produced mixed results [2], owing in part to BRDF-induced fluctuations [3]. Important differentiating features which are measurable remotely include vegetation phenology, location in multispectral space and the directional signal - a result of differing proportions and arrangements of illuminated and shaded soil, green leaves, brown leaves and woody material in the sensor's field-of-view, as well as differences in their optical properties. Multiangular data have shown potential in classification of agricultural targets [4]; here the AVHRR directional signal is tested in community type differentiation over discontinuous but statistically-homogeneous semiarid canopies.

METHOD

A linear, semiempirical BRDF model composed of isotropic, LiSparseMODIS geometric-optical and RossThin volume scattering kernels was inverted against multidate AVHRR HRPT / LAC datasets as described in [5, 6]. The data were derived from 21 orbits over a 17-day period for Inner Mongolia (IMAR) [5] and 17 orbits over a 25-day period for New Mexico (NM) [6] at the peak of the growing season and the end of dry season, respectively. Five datasets were constructed for the IMAR and NM experiments: visible (VIS) and near-infrared (NIR) surface reflectance estimates, uncorrected for BRDF effects ("uncorrected"); isotropic reflectance modeled with nadir viewing and sun at zenith ("Iso"); anisotropic parameters ("Aniso"); both parameters ("Iso+Aniso"); and maximum-NDVI-value composited VIS and NIR reflectance from PM orbits ("MVC_PM"). Ten and 17 training sites >2km in extent were defined for the Inner Mongolia and New Mexico study regions, respectively, with each representative of a recognized community or cover type. The sites are located in Xilingol League, Inner Mongolia Autonomous Region, P. R. China [5], on the Jornada Experimental Range, New Mexico, USA [7] and the Sevilleta National Wildlife Refuge, New Mexico, USA [8] (Table 1). The potential for community type differentiation is assessed via transformed divergence (TD; a measure of separability in the range 0-2000) and by signature distributions.

RESULTS

In both IMAR and NM experiments the uncorrected AVHRR signatures provided very poor separability as a result of the lack of adjustment for directional perturbations (Table 2). In both experiments the MVC_PM signatures provided better clustering and a corresponding increase in separability, although many class pairs remain confused and some IMAR signatures show multiple clusters in VIS:NIR space as a result of preferential selection of off-nadir samples (Fig. 1). In both experiments the isotropic signatures provided separabilities which are comparable or superior to those provided by the MVC_PM dataset (Figs. 4, 5). In both experiments the anisotropic parameter values allow better discrimination between community types than uncorrected or composited data and in the NM experiment also provided better separability than the isotropic signatures (Figs. 3, 4, 5, 6). The isotropic + anisotropic signatures provided equal or

Table 1. Community and cover types with worst-case Transformed Divergence ratios (across all class pairs).

Location -Community	Worst-Case TD Ratio Iso+Aniso/MCV_PM
Xilingol League, Inner Mongolia A.R.	
-*Stipa gobica* desert steppe (site A)	1.8
-*Caragana spp.* desert steppe (site B)	1.8
-Degraded *Stipa krylovii* typical steppe (site G)	1.0
-*Artemisia frigida /Carex spp.* typical steppe (site C)	1.0
-*Stipa grandis* typical steppe (site D)	1.0
-*Aneurolipideum chinense* haymaking (site E)	3.0
-*Stipa grandis* typical high steppe (high steppe)	4.3
-*Aneurolipideum chinense* typical steppe (site F)	3.1
-Saline soil flats (saline)	1.2
-Hun-Shan-Da-Ke dwarf elm on dunes (HSDK)	1.2
Jornada Experimental Range. New Mexico	
-Creosotebush with mesquite and tarbush	13.4
-*Bouteloua eriopoda* (upland black grama)	2.3
-*Sporobolus contractus* (upland dropseed)	1.6
-Mesquite (*Prosopis glandulosa*) on dunes	1.7
-Mixed shrubland	2.3
-Tarbush (*Flourensia cernua* DC) shrubland	13.4
-Grass-shrub transition	1.7
Sevilleta National Wildlife Refuge, New Mexico	
-Black grama / creosotebush mixture	5.2
-Barren or Sparsely Vegetated	1.9
-Black/Blue Grama (Chihuahuan / Plains grasslands)	1.7
-Blue / Hairy Grama Plains Grasslands	1.7
-Black Grama Chihuahuan Grasslands	2.1
-Creosotebush Shrubland -E side	na
-Creosotebush Shrubland -W side	7.5
-Great Basin Shrubland (4wing saltbush/Broom dalea)	2.0
-Black Grama / Galleta Transition Grasslands	7.5
-Great Basin Grasslands (Galleta/Indian Ricegrass)	1.2

superior worst-case performance than maximum-value compositing on NDVI, for all communities (Table 1) as well as superior overall performance (Fig. 2). In the IMAR experiment, the volume scattering parameter space provided most of the additional differentiating power with distributions along a gradient from saline soils to lush ungrazed *A. chinense* (not shown). In the NM experiment both anisotropic parameters furnished important discriminating information (Fig. 6).

CONCLUSIONS

Lack of precision in data used to construct multispectral or multitemporal signatures will inevitably translate into inaccuracy in classification. Even sophisticated classification methods (artificial neural networks, fuzzy classifiers) would not be able to make sense of the uncorrected data, while compositing on NDVI compromises data consistency. When BRDF effects are taken into account, distributions of community types in VIS : NIR space are far more reasonable.

Table 2. TD minima and means across all class pairs.

Experiment & Statistic	Datasets Uncorrected	MVC_PM	Iso+Aniso
NM min	18	150	1643
IMAR min	57	439	1342
NM mean	690	1759	1997
IMAR mean	876	1840	1976

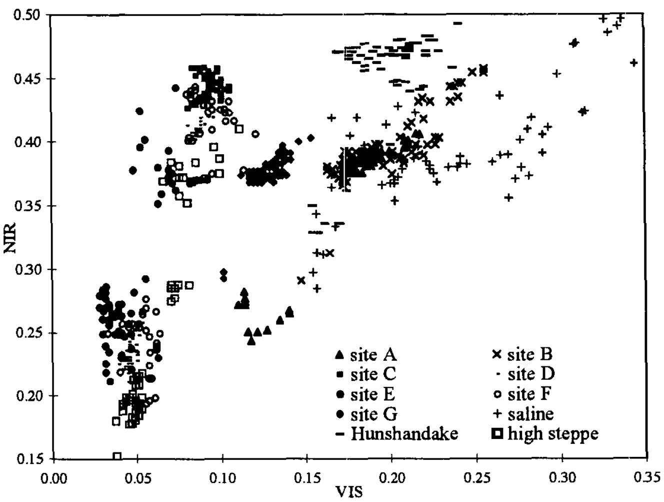

Figure 1. IMAR MVC_PM signatures (see Table 1).

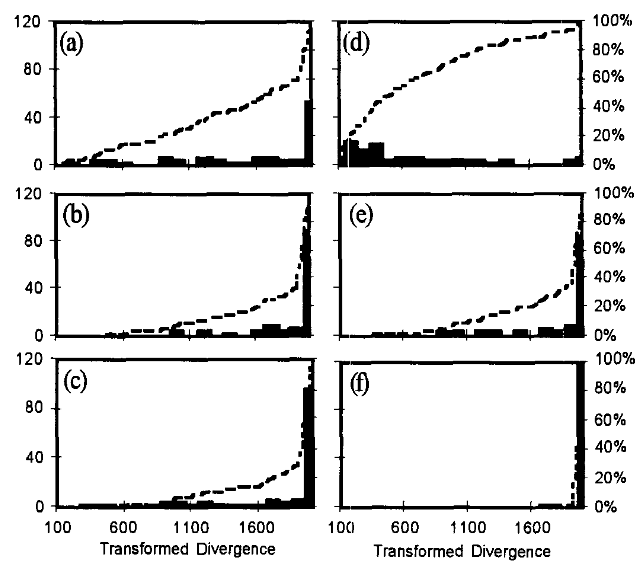

Figure 2. Transformed Divergence frequency distributions for (a, b, c) Inner Mongolia (d, e, f) New Mexico experiments: (a, d) uncorrected (b, e) MVC_PM (c, f) iso+anisotropic.

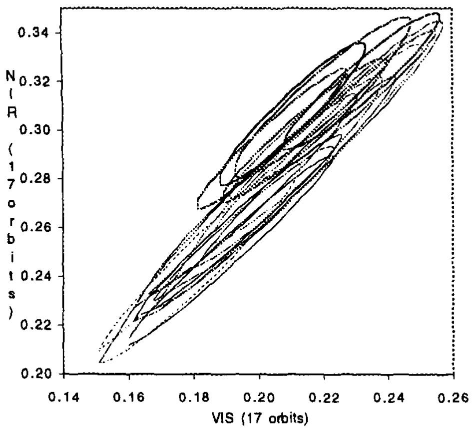

Figure 3. Ellipses (0.75 s.d.) from NM uncorrected AVHRR

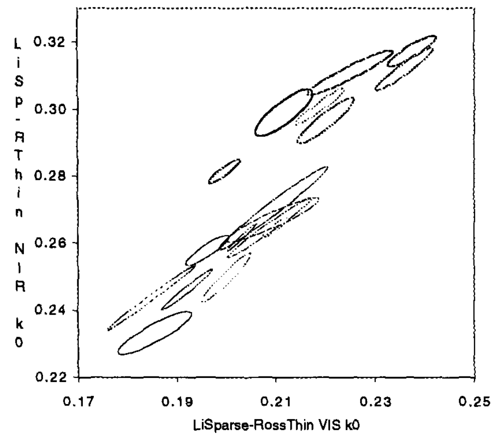

Fig. 5. Ellipses (0.75 s.d.) from NM isotropic reflectance (k0)

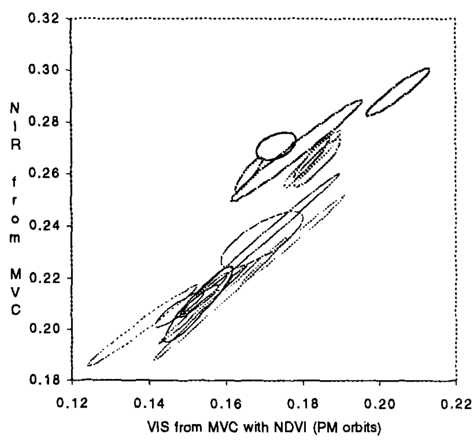

Figure 4. Ellipses (0.75 s.d.) from NM MVC_PM composite

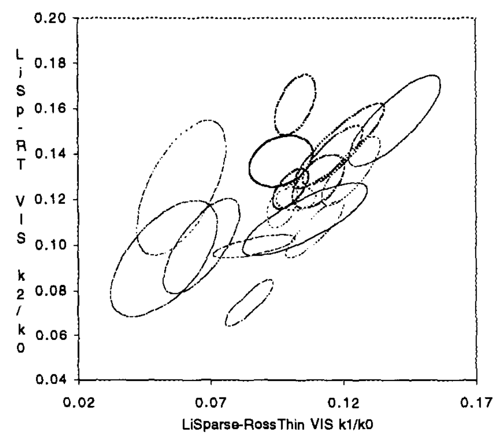

Figure 6. Ellipses (0.75 s.d.) from NM VIS anisotropy factors: k0, 1, 2 = isotropic, geometric, volume scattering.

The directional signal captured in the AVHRR-derived anisotropic BRDF model parameters shows extraordinary potential for community type differentiation and should be exploited where possible.

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