1995121589

USE OF AIRSAR TO IDENTIFY WOODY SHRUB INVASION AND OTHER INDICATORS OF DESERTIFICATION IN THE JORNADA LTER

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1. INTRODUCTION

The replacement of semidesert grassland by woody shrubland is a widespread form of desertification. This change in physiognomy and species composition tends to sharply reduce the productivity of the land for grazing by domestic livestock, increase soil erosion and reduce soil fertility, and greatly alter many other aspects of ecosystem structure and functioning (Schlesinger *et al.*, 1990).

Remote sensing methods are needed to assess and monitor shrubland encroachment. Detection of woody shrubs at low density would provide a particularly useful baseline on which to access changes, because an initially low shrub density often tends to increase even after cessation of the disturbance (e.g., overgrazing, drought, or fire suppression) responsible for triggering the initial stages of the invasion (Grover and Musick, 1990). Limited success has been achieved using optical remote sensing. In contrast to other forms of desertification, biomass does not consistently decrease with a shift from grassland to shrubland. Estimation of green vegetation amount (e.g., by NDVI) is thus of limited utility, unless the shrubs and herbaceous plants differ consistently in phenology and the area can be viewed during a season when only one of these is green (Musick, 1984).

The objective of this study was to determine if the potential sensitivity of active microwave remote sensing to vegetation structure could be used to assess the degree of shrub invasion of grassland. Polarimetric Airborne Synthetic Aperture Radar (AIRSAR) data were acquired for a semiarid site containing varied mixtures of shrubs and herbaceous vegetation and compared with ground observations of vegetation type and other land-surface characteristics. In this preliminary report we examine the response of radar backscatter intensity to shrub density. The response of other multipolarization parameters will be examined in future work.

2. METHODS

2.1 Study Site

The study site is located in the southern Jornada del Muerto plain in south-central New Mexico. The area includes the study site of the Jornada Long-Term Ecological Research (LTER) Project. Also included in the area are private and BLM-managed grazing land and two long-established range management research facilities (USDA/ARS Jornada Experimental Range and New Mexico State University College Ranch). The U.S. Geological Survey maintains an instrumented test site for studies of climatic conditions and wind erosion on the Experiment Range.

The terrain covered by the data sets has low relief. A wide variety of soils are represented, with surface soil texture ranging from sandy and loamy on uplands to silty and clayey in swales and depressions. Gravelly soils are also common on alluvial fans at the eastern margin of the plain, but were not sampled in this study.

Grassland occupied >90% of the area in the mid-19th century, but shrubland encroachment has now reduced grassland area to less than 25% (Buffington and Herbel, 1965). Some adjacent pastures differing in grazing history exhibit sharply defined boundaries between shrubland and herbaceous vegetation, and distinct shrub-free patches surrounded by shrubland have been created by herbicide treatment and mechanical removal of shrubs. Mesquite (*Prosopis juliflora*) is the most abundant woody shrub; others include *Acacia* spp., tarbush (*Flourensia cernua*), and creosotebush (*Larrea tridentata*). Another common invader of grasslands is broom snakeweed (*Gutierrezia sarothrae*), a perennial subshrub. This species is woody only at the base of the stems (Pieper and McDaniel, 1989) and is thus not considered a woody shrub.

Multifrequency, fully polarimetric, SAR data were acquired at X-band (3-cm wavelength), L-band (24 cm), and P-band (68 cm) on August 1, 1990, by NASA's Airborne Synthetic Aperture Radar (AIRSAR) platform (DC-8) during the summer growing season. Rainfall during the previous month was greater than normal, and both herbaceous plants and shrubs were in leaf and green. During the week before the overflight, most rain gauges on the Jornada Experimental Range recorded from 6 mm to more than 12 mm of rain, and rain fell over much of the area on the day of the overflight (R. P. Gibbens, pers. comm.). Soil moisture content can thus be assumed to have been relatively high, although spatially variable.

Two of the three parallel flightlines barely overlapped and covered an area approximately 30 km along-track by 22 km across-track. The area covered by the third flightline was centered over the other two lines. Sites covered by the third flightline could thus be viewed at contrasting incidence angles.

2.2 Ground Truth

Field observations were made August 17-27, 1993. Changes in shrub density since the 1990 overflight were assumed to be slight. This assumption is based on 15 years of field experience in the area by the senior author, including repeated quantitative measurement of vegetation. In addition, several sites previously sampled and photographed in 1981-82 (Warren and Hutchinson, 1984) were revisited in 1993 and found to have changed little in shrub density.

Fifty-nine sites were visited in the field and delineated as polygons on black-and-white prints of the imagery. Sites were selected to be relatively homogeneous in vegetation and radar signature. Sites were photographed and visual estimates of vegetation composition and soil properties were recorded.

The sites were classified primarily according to percentage of ground area covered by woody shrub canopies (Table 1).

Table 1. Woody Shrub Cover Classes

Class	Woody Shrub Cover %
1	<1
2	1-5
3	5-25
4	>25

The density and composition of herbaceous vegetation varied widely at the lower shrub densities. Class 1 included sites ranging from bare ground to the densest grassland sites, which were in swales that receive extra moisture from runoff. The major woody shrub species on most sites was mesquite, but some sites were dominated by other shrub species.

An additional class (Class Y) was defined after preliminary analyses indicated that sites with a relatively high density of soaptree yucca (*Yucca elata*) had a distinctive radar signature. Stems of this species are unbranched to sparsely branched, 10-15 cm in diameter, 0.5-3.0 m tall, fibrous and high in water content. A conical to nearly spherical spray of narrow, fibrous leaves is borne at the apex of each stem. Understory vegetation of sites in Class Y varied widely, from grassland to dense shrubs.

2.3 AIRSAR Data Calibration and Processing

The multifrequency and fully polarimetric SAR data used in this study were processed at JPL using SAR processor version 2.40. Four 6-foot high aluminum corner reflectors provided by JPL were deployed with an inclination angle of 10 degrees on a smooth (radar dark) playa surface within the Jornada site. These reflectors were imaged during two of the three flightlines. The reflector responses were analyzed using MacSigma0 calibration software provided by the Jet Propulsion Laboratory (Norikane and Freeman, 1993). Calibration correction factors for radar backscatter and phase angles for all three SAR frequencies were computed using the corner reflector analysis software available as part of MacSigma0.

Radar backscatter intensity values for each of the fifty-nine visited sites mentioned above were computed for each SAR frequency and polarization after applying the correction factors derived using the corner reflectors. Some of the field sites were imaged during more than one of the three AIRSAR passes.

3. RESULTS AND DISCUSSION

We first sought a means of eliminating or minimizing the influence of incidence angle on backscattering power intensity. A preliminary examination indicated that variation in σ^0 (backscattering coefficient) with incidence angle for a given site or for sites of a given class was negligible for cross-polarized backscatter at incidence angles $>48°$. Backscattering coefficients for cross-polarized C, L and P band were examined for the 46 sites meeting this incidence angle criterion.

L-HV (horizontal transmit, vertical receive polarization) data provided the greatest separability of shrub density classes (Fig. 1). Backscattering coefficients increased with shrub cover, and appeared to be especially sensitive at low levels of shrub cover (e.g., in discriminating between Classes 1 and 2). P-HV backscatter also increased with shrub cover, but with more overlap between classes. Overlap was even greater in C-HV data (not shown).

Yucca-dominated sites (Class Y) had high backscatter in both L-HV and P-HV data, and could be confused with shrub-dominated sites if either L-HV or P-HV were used alone. However, yucca sites could be distinguished from non-yucca sites using these data in combination, because yucca sites had higher P-HV backscatter than non-yucca sites with similar L-HV backscatter.

The results might be explained by the greater sensitivity of longer wavelengths to larger canopy structural components (Ulaby *et al.*, 1986). P band appeared to be most sensitive to yucca, which has uniformly large-diameter stems (10-15 cm). L band appeared to be most sensitive to woody shrubs, which are intermediate in mean canopy element diameter between herbaceous vegetation (<1 cm) and yucca. Application of microwave backscattering models specifically developed for discontinuous canopies (e.g., Wang *et al.*, 1993) might reveal alternative explanations of the observed results.

4. REFERENCES

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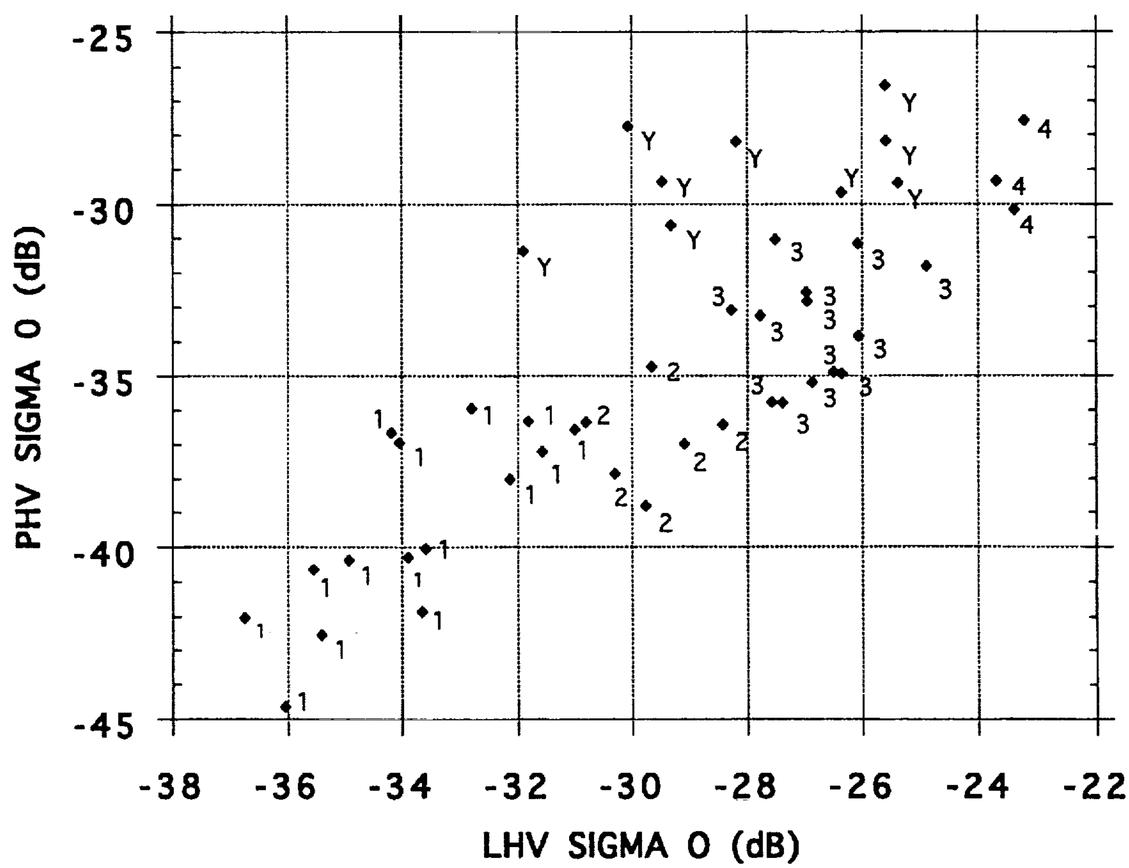

Figure 1. Backscattering coefficients (σ^0) in cross-polarized L and P bands for field sites. Y = yucca sites, 1-4 = woody shrub density classes as given in Table 1.