MONITORING LAND USE AND DEGRADATION USING SATELLITE AND AIRBORNE DATA

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1. Introduction

In July 1990 AVIRIS and AIRSAR data were collected over the Manix Basin Area of the Mojave Desert to study land degradation in an arid area where center-pivot irrigation had been in use. The Manix Basin is located NE of Barstow, California, along Interstate-15 at 34°57'N 116°35'W. This region was covered by a series of lakes during the Late Pleistocene and Early Holocene. Beginning in the 1960's, areas were cleared of the native creosote bush-dominated plant community to be used for agricultural purposes. Starting in 1972 fields have been abandoned due to the increased cost of electricity needed to pump the irrigation water, with some fields abandoned as recently as 1988 and 1992. These circumstances provide a time series of abandoned fields which provide the possibility of studying the processes which act on agricultural fields in arid regions when they are abandoned. Ray et al. (1992) reported that polarimetric SAR (AIRSAR) could detect that the concentric circular planting furrows plowed on these fields persist for a few years after abandonment and then disappear over time and that wind ripples which form on these fields over time due to wind erosion can be detected with polarimetric radar. Ray et al. (1993) used Landsat Thematic Mapper (TM) bandpasses to generate NDVI images of the Manix Basin which showed that the fields abandoned for only a few years had higher NDVI's than the undisturbed desert while the fields abandoned for longer time had NDVI levels lower than that of the undisturbed desert. The purpose of this study is to use a fusion of a time series of satellite data with airborne data to provide a context for the airborne data. The satellite data time series will additionally help to validate the observation and analysis of time-dependent processes observed in the single AVIRIS image of fields abandoned for different periods of time.

2. Methods

Fourteen Landstat Multispectral Scanner (MSS) images of the Manix Basin Area covering the years 1973–75 and 1978–1988 were acquired from the EROS Data Center. Images acquired between the end of May and mid-August were selected in order that the images would be compatible with the AVIRIS data (July 1990) in terms of the season when the data were acquired. For the years prior to 1979, only a few images acquired each year are available in digital form, so some of the images are not totally satisfactory in terms of data quality, cloud cover, and areal coverage. Additionally, an image collected by the Russian Resource satellite in January 1991

was acquired through the generosity of Arnold Selivonov of the Institute of Space Devices.

The MSS images consist of four bands (0.5–0.6 μm, 0.6–0.7 μm, 0.7–0.8 μm, and 0.8–1.1 μm) with a nominal resolution of 79 m by 57 m for pre-1979 images and 57 m by 57 m for the post-1978 images. The Russian Resource data consist of three bands (0.5–0.6 μm, 0.6–0.7 μm, and 0.8–0.9 μm) with a nominal resolution of 30 m by 30 m; however, the pixels appear to cover a slightly larger area than Landsat TM pixels, yielding a pixel spacing of approximately 32 m by 32 m for the Resource data. AVIRIS data consist of 224 bands between .4 μm and 2.5 μm with .01 μm-wide bands all with a nominal resolution of 20 m by 20 m.

It was necessary to co-register all fourteen images to remove image distortions due to changes in the spacecraft attitude and to match the pixel spacings. The co-registration was performed on 1001-sample by 801-line subimages which contain the region of interest. The Russian Resource data were also co-registered with the MSS data. The AVIRIS data were resampled spectrally using the MSS bandpasses and then co-registered with the satellite data. A video of the co-registered imagery has been produced with the aid of the JPL digital animation laboratory.

Instead of the standard NDVI we have chosen to use the infrared percentage vegetation index (IPVI) developed by Crippen (1990) in which the subtraction of the red radiance (reflectance) is recognized as irrelevant and is eliminated, yielding: $IR/(IR + Red)$. IPVI is related to NDVI by:

$$IPVI = \frac{1}{2}(NDVI + 1)$$

IPVI ranges from 0 to 1, never taking on negative values, as can NDVI. It is also quicker to calculate than NDVI.

3. Preliminary Results

Even without the removal of the relative biases between the images and instruments and the atmospheric offset corrections, the IPVI trends seen on the abandoned fields in the AVIRIS data seem to be confirmed with the combined MSS/AVIRIS/RESOURCE data set. In figure 1a we see a plot of IPVI of three abandoned fields in the northernmost part of the study area; the IPVI has been normalized by dividing the values from the abandoned fields by the average IPVI for a large region of the undisturbed desert. This normalization (NIPVI) was performed in an attempt to remove biases which may be due to annual variability in rainfall and other growth parameters. Another important factor may be the harvesting schedule of the alfalfa, which is not considered in these examples but merits attention in the future. This set of fields was not covered by either the 1975 MSS image or the July 1990 AVIRIS data.

The solid line in figure 1a represents the farthest upwind of the set of three fields (referred to as field 9), the dotted line is the field which is farthest downwind (field 11), and the dashed line is the field between them (field 10). The location of the fields with respect to the wind direction is important, because an abandoned field may be a potential source of aeolian sediment which may affect areas downwind of the field. In 1978 both fields 10 and 11 appear to be in cultivation. The fields were likely taken out of cultivation in 1979, but the substantially lower NIPVI for that year might alternatively be due to poorer production on these fields. Interviews with local residents and water well records indicate that irrigation on these fields stopped in 1980. After 1978, both fields show a strong, nearly-exponential decline in NIPVI, with field 11, which is downwind, declining more sharply than field 10. In 1981, cultivation on field 9 seems to begin; the NIPVI curve for field 10, which is immediately downwind, shows an inflection as the drop in plant cover seems to slow. In 1982 the cultivation on field 9 is either suspended for the year, or a strong downturn in productivity occurs, and the NIPVI levels on both fields 10

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continue to drop. Cultivation resumes or productivity increases on field 9 in 1983, which correlates with a halt in the decay of NIPVI values on field 10 and an increase on field 11. In 1984 field 9 is abandoned and NIPVI values for it drop dramatically, which is coupled with a fairly steep drop in NIPVI values for fields 10 and 11. Between 1985 and 1991 the highest NIPVI values are generally associated with the most upwind field and the lowest with the most downwind field, and by 1991 all three fields have NIPVI levels very similar to those of the background desert. Interestingly, water well records suggest that irrigation on field 9 was halted in 1980 which seems to be inconsistent with the high vegetation levels in 1981–1983. This land is owned by St. Anthony's Monastery, and one of the monks stated that the field was last irrigated in 1982, which is more compatible with the IPVI data.

Figure 1b shows NIPVI curves for two other fields in the study area. These fields were covered by the 1990 AVIRIS data, but not by the 1975 MSS data. The solid line is the curve for field 6a which is the upwind field in this pair, and the dotted line is for field 6b which is the downwind field. Both fields seem to be active in 1978, but in 1979 field 6a is abandoned and a substantive drop in NIPVI occurs to levels which are still higher than for the desert. In 1981, both fields are in active cultivation. Field 6b is abandoned in 1982 and NIPVI sharply drops while field 6a remains in cultivation. It is interesting to note that the 1982 NIPVI values for field 6b are higher than those for field 6a in 1979. Field 6a is abandoned in 1983 and NIPVI on both fields come to similar levels which are slightly higher than those of the desert. The NIPVI values for these fields remain about the same with the field 6b values typically lower than those for field 6a. In 1990, a sharp drop in NIPVI occurs for field 6b while field 6a drops only slightly. The 1990 AVIRIS data show what appears to be a very large area of blown sand extending up to 2 kilometers downwind of field 6b. The NIPVI value for field 6b in 1991 has increased significantly to just below that for field 6a. The downwind sandblow seems to be less extensive in the 1991 Resource image. Interviews with the local people give 1983 or 1984 as the date of final abandonment, and there was mention that irrigation on one of the fields had stopped in 1978 or 1979. The dates inferred from the imagery seem to agree with these statements.

The data presented in figure 1 show that a time sequence of remote sensing data incorporating both airborne and satellite borne data can be used to observe and potentially quantify changes in land cover due to changes in land use. These changes are both direct, as in the case of the vegetation level dropping steeply when cultivation stops, and indirect, as in the cases illustrated above where downwind fields lose less vegetation and, in some cases, gain vegetation when they are protected by an upwind field, and lose more vegetation when an abandoned field is immediately upwind. This more substantive loss in vegetation on the downwind fields is probably due to the fact that sand eroding from the upwind field abrades, damages, and buries plants on the downwind field. Ray et al. (1992, 1993) mention extensive wind ripples on several of these fields as evidence of substantial wind erosion, and there were observations of sand drifting off of field 11 made in early December 1990. NDVI data presented in Ray et al. (1993) also show that, in two pairs of upwind/downwind fields, the downwind field was less well vegetated than the upwind field. Ray et al. (1993) also mention "plumes" of lower NDVI values extending downwind of several abandoned fields.

4. Future Work

Crippen (1988) demonstrated the importance of atmospheric corrections for the analysis of band ratio images. The NDVI image calculated from the MSS-subsampled AVIRIS radiance data has a substantially different appearance as compared to the NDVI image calculated from the MSS-subsampled AVIRIS data corrected to apparent reflectance using the empirical line calibration technique described by Conel et al. (1987). It is apparent from an examination of the co-

registered MSS data that there are substantial differences in the instrument gains between the periods 1973–1978 and 1979–1988 which need to be removed in order to properly analyze the time sequence of data. The relative gains and offsets will be determined based on the assumption that there was little change in the spectral characteristics of alluvial fan deposits. IPVI images based on the uncorrected MSS data indicated that vegetation levels on these deposits were extremely low, which is also borne out by the IPVI values from the AVIRIS data. Crippen (1987) described a technique for calculating the atmospheric offset corrections for satellite data called the Regression-Intersection Method (RIM). Once the relative corrections between each image and the image selected as a reference have been applied, it is only necessary to apply RIM to one of the MSS images. The Russian Resource image will be corrected by directly using RIM. Other methods of correcting the data will be explored. The corrected data will be assembled into a video with sequences showing the corrected and uncorrected IPVI. The extension of these techniques into other areas where such sequences of data can be assembled is also anticipated.

5. References

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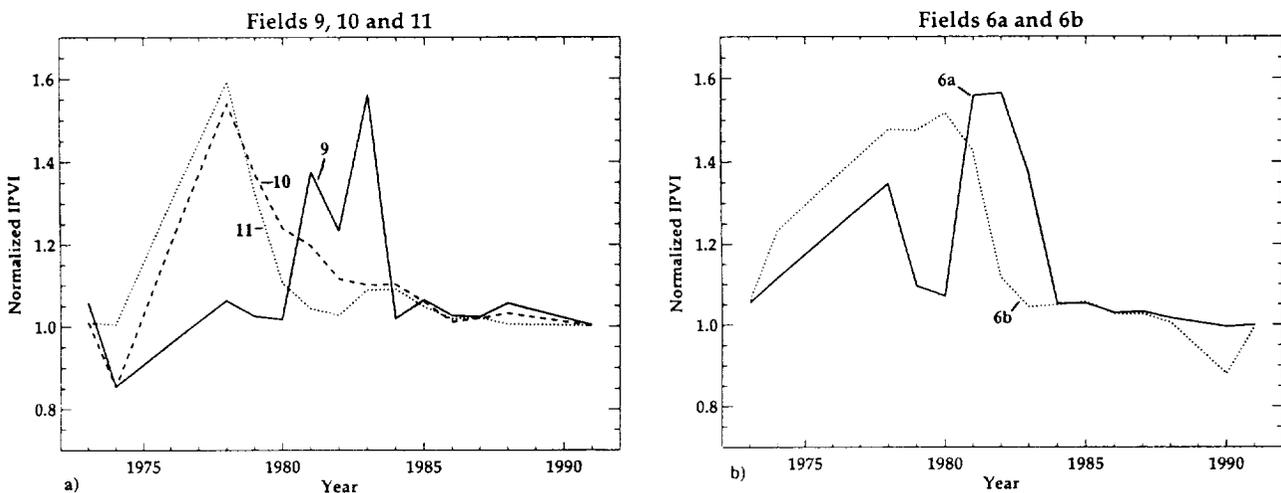
Figure 1: Plots of the normalized infrared percentage vegetation index (NIPVI) over time. Undisturbed desert values would fall along the line NIPVI= 1.0. This normalization is an attempt to minimize seasonal and rainfall variations which affect the entire region. No data from 1975, 1976 or 1977 are available for these fields. High values of NIPVI (NIPVI > 1.3) are believed to correspond to active cultivation. Note how NIPVI values relate to the position of the field relative to the wind. a) Field 9 (solid line) is farthest upwind, field 11 (dotted line) is farthest downwind, and field 10 (dashed line) is immediately between them. Note that no remote sensing data from 1990 are available for these fields. b) Field 6a (solid line) is upwind and field 6b (dotted line) is immediately downwind.

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