SATELLITE MEASUREMENTS OF ALBEDO AND RADIANT TEMPERATURE FROM SEMI-DESERT GRASSLAND ALONG THE ARIZONA/SONORA BORDER

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Abstract. Along the international border separating the U.S. (Arizona) and Mexico (Sonora), differences in the grazing intensity of domestic livestock are commonly presumed to have created a large difference in vegetation cover between the two countries. This vegetation difference is reportedly responsible for an extensive albedo and temperature discontinuity that may be affecting regional climate. In this study, we used Landsat Thematic Mapper data to examine trans-border differences in these two biophysical parameters. Albedo and radiant temperature estimates were computed for 25 km-long (east-west) transects through semi-desert grassland on each side of the border at two different times of year. Only small average trans-border differences in these parameters were found, and in some cases average albedo and temperature data were essentially equal on each side of the border. In addition, we found significant spatial heterogeneity in conditions on both sides of the border. These results suggest that, based on a small sample, it may be difficult to assess whether there are significant differences in biophysical properties of semi-arid grassland between Arizona and Mexico in the vicinity of the border. We conclude that more extensive spatial and temporal sampling is critical in assessing any possible trans-border differences in average terrain conditions that might affect climate, and that this data must be coupled with more extensive meteorological data to assess whether a difference in climate also exists.

1. Introduction

Across the Arizona/Mexico border, differences in grazing intensity are commonly presumed to have led to substantial differences in the amount of grass cover. The Mexican side of the border is thought to be more heavily grazed than the U.S. side (Balling et al., 1998; Couzin, 1999). This condition, in turn, is thought to be responsible for higher albedo and temperature on the Mexican side of the border, which may be affecting regional climate. Balling (1988) analyzed long-term climate records, from meteorological stations in both Arizona and Mexico, for a large portion of the Sonoran Desert. He found that summertime maximum temperatures of the Mexican stations were nearly 2.5 °C higher than the Arizona stations, after accounting for latitude and elevation, and suggested this difference was due to overgrazing of the Mexican rangeland.

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In this study, we used Landsat Thematic Mapper (TM) data to estimate albedo and radiant temperature for 25 km-long east-west transects through a semi-desert grassland on each side of the Arizona/Sonora border. We measured these biophysical parameters at two times during 1998, when the grasses were mainly senescent (late May) and mainly green (late August).

2. Background

Bahre and Bradbury (1978) sampled landscape conditions along the Arizona/Mexico border, finding that the Arizona side had, on average, more grass cover and lower surface albedo. The nominal reason for greater vegetation cover on the U.S. side was that overgrazing of the landscape in Arizona was reduced or stopped following the enactment of the Taylor Grazing Act in 1934, which controlled the number of livestock allowed to graze on federal lands. However, Bahre and Bradbury (1978) also noted that uncontrolled grazing continued on patent and state lands in Arizona. They found areas of low grass cover on the Arizona side on private land and on U.S. Forest Service land that had been heavily grazed. Conversely, some areas in Mexico had high grass cover where they were undergrazed because they lacked water development for cattle or were protected. Thus, the Mexican land was not found to be more overgrazed than the Arizona land in all areas. Nevertheless, the notion of an extensive, sharp, ubiquitous difference due to overgrazing in Mexico has come to have some acceptance. Couzin (1999) reports that crossing the border anywhere in Arizona will reveal this difference.

Several investigators have found that a decrease in vegetation cover leads to an increase in mid-day terrain albedo and radiant temperature (Jackson and Idso, 1975; Wendler and Eaton, 1983; Vukovich et al., 1987). Other investigators (Bryant et al. 1990; J. M. Michalek et al., submitted to *Int. J. Rem. Sens.*) that used study sites located directly along the Arizona/Sonora border also found significant differences in vegetation cover, albedo and surface temperature in small field plots. In most of the reported cases, vegetation cover was higher in Arizona, and mid-day albedo and radiant temperature were higher in Mexico. However, these measurements from small field plots may not accurately represent these biophysical parameters along a larger portion of the Arizona/Sonora border region. Some of the existing measurements were made from locations in Arizona that are known to have restrictions on grazing intensity, which could create a bias.

This study attempts to provide a more representative sample of semiarid grassland conditions on each side of the Arizona/Sonora border in southeastern Arizona by examining a relatively large geographic area (compared to small field plots used in previous studies) with similar site conditions.

3. Study Area and Method

Our study area is a 25 km-long (east-west) strip of land located along the Arizona/Sonora border, approximately 120 km southeast of Tucson, Arizona. This area is a semi-desert grassland dominated by perennial grasses with some shrubs/small trees. This particular portion of the international border is known to include land with variable grazing intensity both across the Arizona/Sonora border, as well as along the Arizona side. Only a small portion of this land (on the Arizona side) is restricted from grazing. The area is similar within narrow, adjacent (east-west) transects on each side of the international border with respect to several parameters (slope, aspect, soil type) that can affect albedo and temperature measurements. This study area was selected because it was a relatively large area of semiarid grassland for which other unwanted scene elements were not believed to be significant including: substantial elevation changes; significant changes in land cover; and the presence of irrigated agricultural land and/or urban areas.

Vegetation cover was observed along the length of this transect. In some locations vegetation cover was higher on the U.S. side of the border and in other locations vegetation cover was higher on the Mexico side. Objective field measurements were made at sample plots on both sides of the border (Michalek et al., in review). These measurements showed that, near solar noon, the areas with higher vegetation cover had lower albedo and radiant temperature. Landsat estimates of landscape albedo and radiant temperature were obtained from Landsat TM data collected on 26 May 1998 (when grasses were largely senescent) and 30 August 1998 (when grasses were largely green). These Landsat collection times are representative of the seasonal variability of perennial grasses (B. Alberti, 1998, pers. comm.).

Temperature estimates were obtained by converting Landsat TM band 6 digital numbers (DN) to radiant temperature using the system's nominal calibration information (see EOSAT Landsat Technical Notes, 1986).

Landsat TM albedo estimates were obtained from the following procedure. The reflective wavelength bands (TM 1-5, and 7) were first converted from DN values to reflectance values. This was done by using within-scene secondary calibration targets that were located during a field visit. We determined spectral reflectance for those targets deemed suitable on inspection, and that were temporally stable. Refelectance was measured by using either field radiometers and/or by obtaining samples of the materials for subsequent measurement of reflectance in the laboratory with a Beckman spectrophotometer. For each Landsat spectral band, a regression relationship was determined between reflectance (dependent variable) and DN values (independent variable). The regression relationships were applied to the 6 reflective Landsat TM bands to obtain reflectance-calibrated data. Nominal values of percent solar spectral irradiance were used to weight the TM spectral band reflectances. These irradiance-weighted reflectance values were then summed to produce Landsat TM solar albedo estimates. Our procedure for estimating albedo is comparable to that used by Toll et al. (1987) with AVHRR data.

TABLE I

Average albedo and radiant temperature from 25 km (east–west) transects near the Arizona/Sonora border for 26 May, and 30 August 1998 Landsat TM data

Transect location	Transect width (north–south) (m)	26 May 1998		30 August 1998	
		Albedo (%)	Temp. (°C)	Albedo (%)	Temp. (°C)
Arizona	100	19.62	37.44	18.29	36.21
Mexico	100	21.43	37.43	19.99	36.63
Arizona	2000	20.67	37.53	19.25	35.82
Mexico	2000	20.68	37.19	19.41	36.34

In order to assess whether there were trans-border differences in average albedo and radiant temperature, we extracted Landsat TM albedo and temperature information from paired transects in this semiarid grassland. Two sets of 25 km-long transects were considered with different north-south widths of 100 m and 2 km. The 100 m wide transects were centered 150 m north and 150 m south of the border. The 2 km wide transects were centered 1.1 km north and south of the border. The transects were positioned in this way to avoid the land immediately adjacent to the border, because this area is not representative of the surrounding vegetation conditions due to access roads and vehicle traffic. The western end points for all transects were located approximately 2 km west of the Coronado National Memorial's southeastern boundary.

4. Results

Figure 1 shows May 1998 Landsat TM images (albedo and radiant temperature) of the study area. Table I shows the albedo and temperature data extracted from the 25 km long transects of May and August 1998 Landsat data. Generally, we found the variability within a given transect to be greater than the difference between the average values of equivalent transects on each side of the border.

For the May TM data, 100 m $\times$ 25 km transects show the average albedo is higher on the Mexican side of the border by approximately 1.8%, and the average radiant temperature is practically identical on each side of the border. For the wider 2 km $\times$ 25 km transects, the average albedo is nearly identical on each side of the border, and the radiant temperature is slightly *higher* (by $< 0.5\,°$C) in Arizona.

We also obtained Landsat estimates of albedo and temperature from 25 km long transects with the 30 August 1998 scene, when grasses were green (Table I). For this Landsat scene, the 100 m $\times$ 25 km transects near the border show higher average albedo on the Mexican side by approximately 1.7%, and the average temperature is also slightly higher (by $< 0.5\,°$C). For the 2-km wide transects, albedo

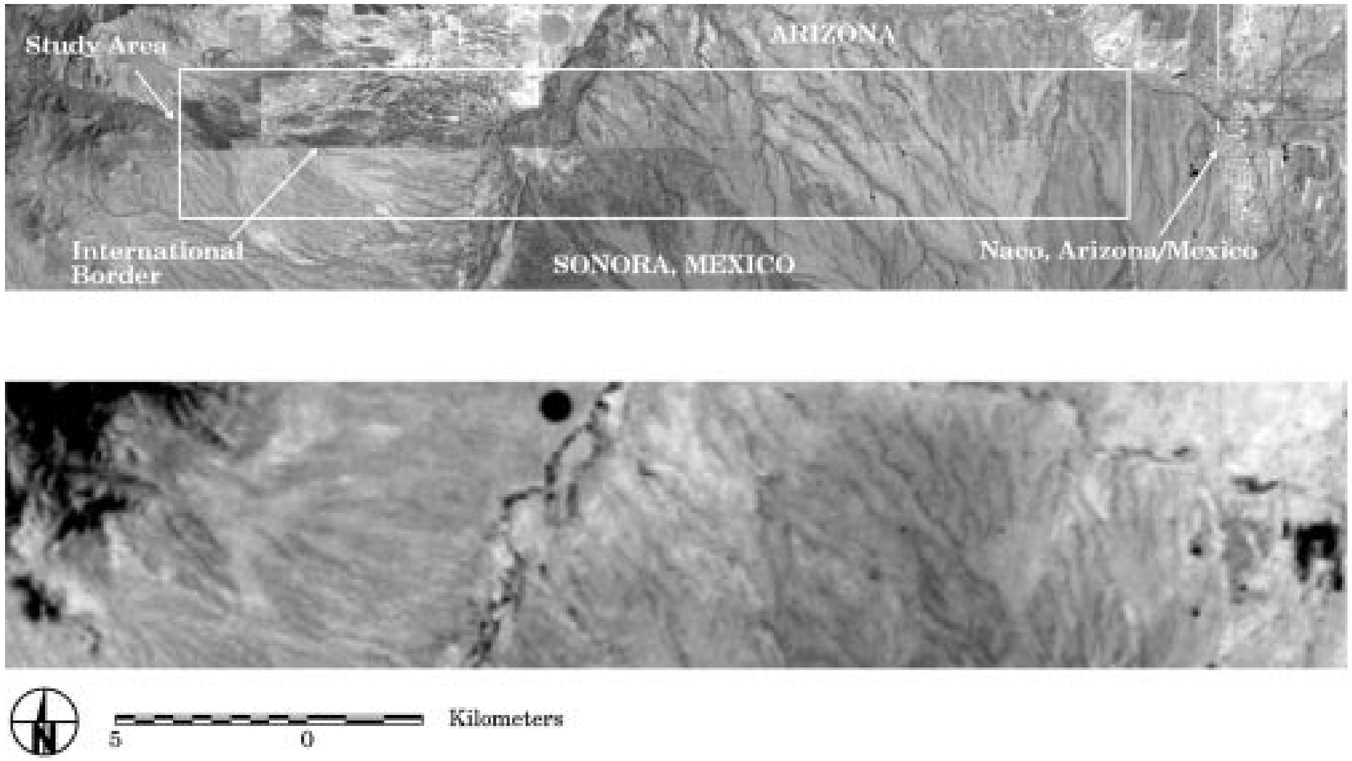

Figure 1. 26 May 1998 Landsat TM images of the Arizona/Sonora study site: (1) albedo image with nominal study area identification (top), and (2) radiant temperature image (bottom). For each image, darker pixels represent lower values and brighter pixels represent higher values.

is slightly higher on the Mexican landscape (by $< 0.2\%$) and so is temperature (by $\approx 0.5\,^{\circ}$C).

5. Discussion

The entire Arizona/Mexico border is not a flat, monotonic grassland extending for hundreds of kilometers. On the contrary, it is a spatially heterogeneous landscape with respect to eco-physical conditions. Spatial and temporal variation in vegetation cover, albedo and temperature over a large area can affect any potential impact of these parameters on regional climate. Therefore, this variability should be specifically considered when attempting to draw conclusions about regional conditions from samples of the landscape. In addition, the landscape conditions are not temporally static.

For assessing the effect of vegetation, albedo and radiant temperature on a regional phenomenon like climate, one must have an adequate (representative) sample of conditions encountered for all combinations of the relevant factors (e.g., vegetation type and amount, soil type, elevation, slope, aspect, and time of year). Meteorological data must also be representative of the same area. Maintaining control of eco-physical factors on each side of the border, or correcting for all of them, is critical for measurements of a dynamic, heterogeneous landscape, especially when cause-effect relationships are sought.

If we considered longer and wider transects on each side of the border than are reported in this paper, the possible reasons for any observed differences in albedo and temperature would be less clear than when we restrict our analysis to smaller areas known to be mainly relatively flat grassland subjected to variable grazing intensity. Longer or wider transects are more likely to cross portions of mountain ranges, irrigated agricultural land, or dry playas that may not exist, or may be less prevalent, on one side of the border. A significant portion of the Arizona/Mexico border runs through forested, mountainous areas that may not even be subjected to substantial grazing. Assessing ‘comparable’ conditions for a large section of the Arizona/Mexico border is fraught with spatial-temporal sampling complications (due to the inherent heterogeneity of the landscape) that can affect the interpretation of results. Demonstrating that any observed differences in albedo and temperature from extensive transects in this region is likely due to a single cause (e.g., trans-border differences in grazing intensity), seems to be a difficult task, at best.

Temporal variability is also a significant issue, since the amount of grass and its condition (green or senescent) varies temporally. Our two Landsat observations sample some of this variability. Antecedent precipitation can also affect results (see Bryant et al., 1990; Balling, 1989), but the paucity of meteorological data precluded us from evaluating this effect.

Just as grazing intensity, vegetation cover, albedo and radiant temperature are spatially variable, so are meteorological data. Meteorological station data need to be controlled not only for latitude and elevation, but also for other factors like local vegetation cover and albedo where the meteorological station is located. For example, meteorological data from a city are not likely to be representative of rangeland, and rangeland data are not likely to be representative of forest-land, regardless of their ‘condition’. Even if climate change is occurring along the Arizona/Mexico border, the current sampling density and location of available meteorological stations (approximately 1 per 4,500 km^2) may not be sufficient to precisely reveal a change that may be small and/or confined to either a narrow corridor very near the border or only the grazed rangeland valleys.

Additional important issues for assessing whether measured differences in albedo and radiant temperature found along the Arizona/Mexico border could be related to a change in regional climate are how different the relevant parameters are, and over what area the differences occur. Predictable long-term climate change requires a significant change in some important biophysical parameters over a fairly large area. As a point of reference, the temperature changes that occurred in the Sahel were reportedly associated with a four percent change in albedo (Sagan et al., 1979) over thousands of square kilometers (Otterman, 1974), although it is not clear whether this was due to overgrazing.

The magnitude of the albedo differences we observed along the Arizona/Sonora border are significantly smaller than four percent, over a much smaller area, and have significant spatial variability. Our observed radiant temperature differences were also small and did not show the same trend for different times of year and different transect widths. Overall, we found no compelling evidence in the satellite data that there currently is a sharp, consistent spatial discontinuity in albedo or radiant temperature along the 25 km of international border we examined, even in very narrow (100 m-wide) transects through grassland immediately adjacent to the border. The lack of necessary meteorological data prevented us from assessing any potential climate differences for this area.

6. Conclusions

Additional research in assessing the causative relationships between differences in vegetation cover (such as from overgrazing) and climate change is needed to understand under what circumstances changes in terrain characteristics may lead to climate change. Once the fundamental relationships are better understood, some understanding of the critical thresholds of change for relevant parameters (e.g., albedo and radiant temperature) that may be significant in affecting climate in a predictable way is needed. These thresholds are expected to be a function of the average amount of change in a parameter, the spatial extent of the change, and possibly the length of time over which the difference occurs. Spatial and temporal sampling issues need to be specifically considered in characterizing regional conditions and differences in conditions for heterogeneous environments. Further understanding will be achieved by examining changes in vegetation cover at locations where other contributing factors (vegetation type, soil type, slope, aspect, etc.) are either relatively constant over a large area (a 'region'), or can be controlled. An adequate sample of meteorological data must also be available. These studies will be most informative where the spatial extent of the terrain change is large, and the magnitude of the change is fairly consistent over its spatial extent.

In order to definitively answer the specific question of whether differential grazing intensity has lead to a regional climate difference across the international border between the U.S. and Mexico, additional studies are also needed. These studies should have several important characteristics including: (1) coverage of a much larger portion of the international border separating the U.S. and Mexico where grazing intensity is believed to have a significant effect on the landscape; (2) an experimental design that considers the spatial heterogeneity of the landscape in this region; (3) a more complete temporal sample of field and remote sensing measurements of important biophysical parameters; and (4) an adequate sample of meteorological data. The authors plan to conduct a more extensive study in the region that would include these important characteristics.

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