Land and Land-use Change in the Climate Sensitive High Plains:
An Automated Approach with Landsat

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Introduction

The High Plains is an economically important and climatologically sensitive region of the United States and Canada. The High Plains contain 100,000 sq km of Holocene sand dunes and sand sheets that are currently stabilized by natural vegetation. Droughts and the larger threat of global warming are climate phenomena that could cause depletion of natural vegetation and make this region susceptible to sand dune reactivation.

The original proposal was directed toward the use of Landsat TM data to establish the state and ongoing changes of the surface in the 1.2 million sq. km, semi-arid High Plains region of the central US. A key objective was to develop a model to predict the reactivation of the 100,000 sq. km of Holocene dunes found on the High Plains during an extended drought.

At least one Landsat 5 image per year for 1985, 1988 and 1996 was obtained for 32 scenes on the High Plains to coincide with wet and dry years. Additional Landsat 7 data were acquired for 1999 and 2000 primarily for Colorado and Nebraska. As luck would have it, there was no severe drought during the study period 1985-2000.

Attention was focused on developing methods for mapping dry vs. green vegetation on sparsely vegetated rangelands in sandy soils, since these were the areas most susceptible to surface reactivation during a drought. This study was the focus of a 2000 master's thesis by Amanda Warner entitled "Quantifying Fractional Ground Cover on the Climate Sensitive High Plains Using AVIRIS and Landsat TM Data" as well as a paper entitled "Quantifying BRDF Effects in comparing Landsat 7 and AVIRIS Near Simultaneous Acquisitions in Studies of High Plains Vegetation Cover" by Goetz et al. This paper was submitted to Remote Sensing of Environment and is in review.

The modeling aspects are covered in a 2002 master's thesis by Ethan Gutmann entitled "Mapping the Potential for Eolian Surface Activity in Grasslands of the High Plains using Landsat Images"

A series of studies on irrigation practices and land cover modeling revealed by time series analysis of Landsat images were reported in meetings using posters. In 2001 the titles were: "High Plains Aquifer: Estimated Usable Lifetime and Potential Land-Use Change", "Identification of Irrigated Lands: The Utility of a High Resolution Thermal Band" and "Potential for Surface Change in Grasslands in the Climate Sensitive High Plains". In 2000 the title was: "Decadal Change in Irrigation Practices in the High Plains", in 1999 "Land and Land-use Change in the Climate Sensitive High Plains", In 1998 "A Multiyear Calibration of Landsat TM". The complete posters are available at: http://cires.colorado.edu/cses/all_posters.html .

Conclusions

In the area of sparse vegetation cover, the thesis addressed how fractional vegetation cover can be mapped with the Landsat instruments using linear spectral mixture analysis and to what accuracy. The method discussed in this thesis made use of a high spatial and spectral resolution sensor called AVIRIS (Airborne Visible and Infrared Imaging Spectrometer) and field measurements to test vegetation mapping in three Landsat 7 sub-scenes.

Near-simultaneous over flights of two different sensors provide an excellent means of comparing results and removing some unknowns. The high correlation between all the AVIRIS scenes used and the corresponding areas in the Landsat 7 images indicate that Landsat data can be unmixed to show fractions of soil, NPV and green vegetation and be related to the AVIRIS data when the appropriate endmembers are used. Unmixing with Landsat endmembers alone does correlate well with the AVIRIS results but with the fractions having a relatively larger margin of error.

In the area of BRDF analysis, BRDF effects caused by AVIRIS scan angle can be derived for Landsat bands by normalizing the AVIRIS data with Landsat 7 values since the AVIRIS swath width only subtends 0.8° in the Landsat data. Landsat data can be used to normalize reflectance data in individual AVIRIS images making it possible to account for the BRDF of scenes that are heterogeneous, where column averaging to obtain the BRDF is not applicable.

In the area of modeling there are five major conclusions produced in the Gutmann thesis.

1. Physics based modeling potential

This goal of this study was to develop and analyze a model for potential sand transport in the High Plains of North America. This study has illustrated an attempt to bring together the necessary components to run a simple, physics based model to estimate future sand transport across the High Plains. This study has shown that better modeling of future vegetation is a subject that needs substantial work, and has suggested several methods by which this modeling might be improved: a more detailed incorporation of the spatial variability in vegetation and soil type, higher temporal resolution satellite measurements and model estimates, and incorporation of recent rainfall data when estimating vegetation cover from NDVI. In addition, further improvements could be made to the model as a whole with a better understanding of the effects of vegetation on sand transport and by integrating sand transport over several years of wind data.

2. Spatial resolution

Landsat scale spatial resolution is required to study sand dunes in the High Plains. Small, localized dune fields such as those in Eastern Colorado effectively disappear with larger (≥500m) pixel sizes. Dune crests may be the only areas that stand out. If these areas were averaged together with surrounding, vegetated areas by low spatial resolution satellite imagery, the true instability of these dunes would not be captured. In addition it is not possible to map land use with enough accuracy using lower spatial resolution imagery because even large pivot irrigation systems are too small to detect. However, it may be possible to incorporate high temporal, low spatial resolution with the high spatial resolution data from Landsat to further improve the model.

3. Temporal Resolution

The benefit of increasing satellite temporal resolution is unclear. The simple test performed here showed no relationship between the number of images used and the correlation coefficient when regressing Century and NDVI values. It is possible that extremely high frequency imagery, such as bi-weekly MODIS data would be a substantial benefit to the model, but it is clear that simply collecting twice as many Landsat images does not substantially improve the results of the present model.

4. Areas of instability

This model has also mapped areas of potentially higher instability, though the present map is not suitable for planning purposes. At the moment careful interpretation of the output is required because of the poor correlation between NDVI and Century values. Some regions of apparent instability may only appear that way due to recent weather conditions or local soil color. It appears that the largest areas at risk are in the Nebraska Sand Hills, and portions of Eastern Colorado and Western Texas. Further areas at high risk are spread out across the High Plains and generally highly localized. This model does not map areas that are currently farmed, thus large areas may be at risk that are not shown in this model. In addition this model only maps areas of potential sand transport. Dust, which has important implications for human health and well being, is not mapped by the present model.

5. Future Work

One of the major results of this thesis is the understanding of our current limitations in this field, and the suggestion of possible methods of improvement. There are many holes in our current understanding and in the available data that need to be filled before an accurate assessment of dune stability can be made. The area that needs the most work is the prediction of future vegetation cover. In addition, a better method of incorporating a time series of wind measurements and a denser network of weather stations would be beneficial. The prediction of future vegetation could probably be improved with a more accurate model of vegetation response to climate, and a higher temporal resolution sequence of satellite and model estimates. One of the first improvements that need to be investigated is the inclusion of high temporal resolution MODIS data. Though this would mean decreasing the spatial resolution of the model, but the increased ability to estimate the relationship between climate and vegetation would substantially out weigh this loss.

A better estimate of wind speed over time should be used. The current model only includes an index of wind speed. Winds may be highly seasonal in nature, so an estimate for each month should be used. Work needs to be done to determine the best wind index for this type of study, and what the effects of seasonal variation are.

In the studies of irrigated lands we made the following findings:

1. Within the High Plains, the number of irrigation pivots doubled between 1985 and 1996. Significant numbers were also abandoned and the reasons varied by county as explained by the county agents. A major problem is the depletion of the High Plains Aquifer, which extends from South Dakota into Texas.

2. With use of USGS water depletion statistics, we showed that in the next 50 years over 4,500 pivots in sandy soil would be abandoned raising the question whether the soil could be stabilized before new blowouts and dune fields would be established.

3. The thermal infrared band 6, in conjunction with NDVI, based on bands 3 and 4 of the ETM+ can be used to map irrigated lands. By melding the NDVI, thresholded at 0.5, and temperatures surrounding the cooler peak of the histogram it was possible to obtain an r^2 correlation coefficient between Landsat data and the agricultural statistics on a county basis.

References

Goetz, A. F. H., K. B. Heidebrecht, E. D. Gutmann. A. S. Warner, E. L. Johnson and L. R. Lestak, 2002, Quantifying BRDF effects in comparing Landsat 7 and AVIRIS near simultaneous acquisitions for studies of High Plains, *Remote Sensing of Environment*, in review.

Gutmann, E. D., 2001, Mapping the Potential for Eolian Surface Activity in Grasslands of the High Plains using Landsat Images, MS thesis, University of Colorado, Boulder

Warner, A. S., 2000, Quantifying Fractional Ground Cover on the Climate Sensitive High Plains Using AVIRIS and Landsat TM Data, MS thesis, University of Colorado, Boulder.

Goetz, A.F.H., E. Johnson, and E.D. Gutmann, 2002, Mapping of irrigated lands with the Landsat TM thermal band. In progress.

Goetz, A.F.H., L. Lestak, and E. Johnson, 2002, Potential for soil deflation related to the High Plains Aquifer irrigation lifetimes. In progress.