

Remotely Sensed Vegetation Phenology of Sky Islands in the Madrean Archipelago

W.J.D. van Leeuwen^{a,b,*}, M.A. El Vilaly^a

^a School of Natural Resources and the Environment, ^b School of Geography and Regional Development,
University of Arizona, Tucson, AZ 85721, USA – (leeuw, abdsalam)@email.arizona.edu

Abstract – The goal of this work is to develop an assessment of changes in landscape scale phenology (Timing of biological events such as green-up and flowering) for vegetation along elevation gradients for mountain sky islands in the drylands of the Southwest US and Northern Mexico. The main goal is to better understand the variability in climate and vegetation green-up relationships as they vary seasonally and interannually and along the elevation and latitudinal gradients. Land surface phenological time series derived from the MODIS Normalized Difference Vegetation Index data from 2000 to 2010 were processed to characterize the interannual and seasonal variability among different sky islands in the Madrean Archipelago. Representative mountains among the sky islands and elevation clines showed unique recurring and interannual phenological trajectories and spatial patterns related to seasonality, drought, and some wildfire events. The start of the season was generally earlier for the higher elevations, while seasonal productivity generally increased with elevation.

Keywords: Environment, Climate, Ecosystem, Geography, land cover, MODIS

1. INTRODUCTION

Sky Islands in the Southwestern USA have elevation gradients along which temperatures decrease and precipitation increase from the desert floor to the mountain top. Mid domain effects have been observed to result in higher vegetation biodiversity and productivity at intermediate elevation which could be related to decreasing area and edge effects characteristic for isolated mountains in the Madrean Archipelago. These sky islands are also exposed to extreme and complex climatic variations and disturbances such as drought and wildfires, which result in distinctive patterns of vegetation response. As a result, many vegetation communities on these sky islands are impacted by invasive species, variation in species ranges and changes in biodiversity. One means of evaluating and monitoring these sky islands could be based on vegetation phenology [1]. Satellite time series of spectral vegetation index data can be used to observe and describe the seasonal and inter-annual variability and change in vegetation growth patterns in response to environmental variables such as soils, soil moisture, precipitation and temperature. Our main objectives are to: 1) evaluate long term remotely sensed vegetation index time series data for monitoring and characterizing vegetation phenology and response for a range of Sky Islands, 2) examine the start of the season change and variability for a range of sky islands, and 3) examine seasonal productivity change and variability in response to elevation. The proposed research framework is based on the integration of contextual GIS, land cover, climate and elevation data with remote sensing time series data.

2. DATA and METHODS

2.1 Study Sites

The region between the Rocky Mountains and Sierra Madres is comprised of relatively low elevation drylands with well distributed mountain ranges that make up the Madrean Archipelago. For instance, the Rincon Mountains are in the Sonoran desert represented by cacti and shrubland at 800m and gradual vegetation changes with alpine forest at an elevation of about 2500m (Figure 1). Many sky islands have elevation ranges between 500m to ~3000m corresponding to eco-zones with low to high vegetation cover (Figure 1), and vegetation types such as desert scrub, mesquite, grassland, mixed oak, juniper and pine forests. Elevation data are based on The Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Model (GDEM) with a spatial resolution of 30 m; <http://www.gdem.aster.ersdac.or.jp/feature.jsp>.

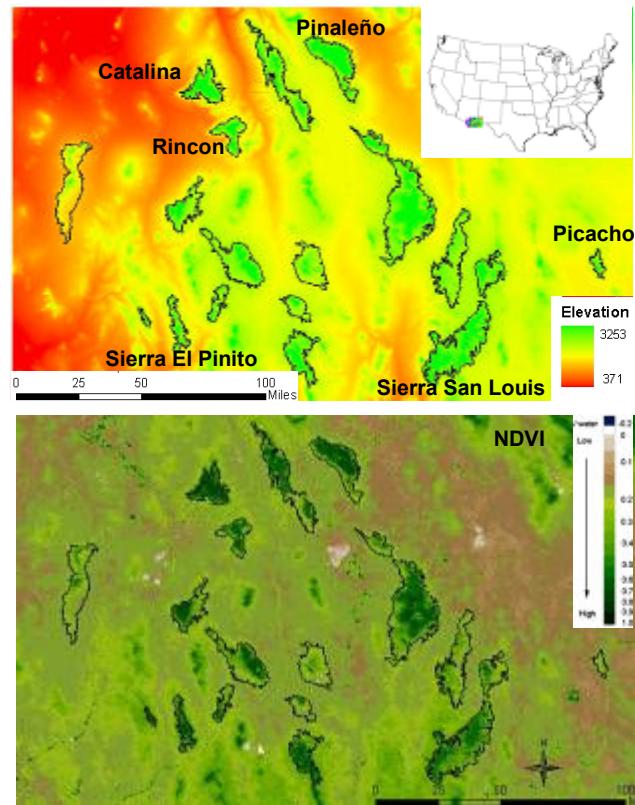


Figure 1. Elevation (top) and NDVI (bottom) image (2002) of the study area and the sky islands (black polygons) illustrate the elevation and vegetation differences between the mountain ranges and desert landscape.

* Corresponding author.

2.2 MODIS Time Series Data

Long term MODIS (Moderate Resolution Imaging Spectroradiometer; 2000-2010; 250m; 16-day composites; 23 observation/year; MOD13) [2] time series of the Normalized Difference Vegetation Index (NDVI) data were used to characterize vegetation dynamics, interannual trajectories and derived phenological characteristics for the sky islands [3].

2.3 Climate Data

Climate data used in this research were extracted from the PRISM (Parameter-elevation Regressions on Independent Slopes Model [4]) dataset, at 4 km spatial and monthly temporal resolution. The mountains often have at least twice as much rainfall in the summer as the low elevation desert areas (Figure 2).

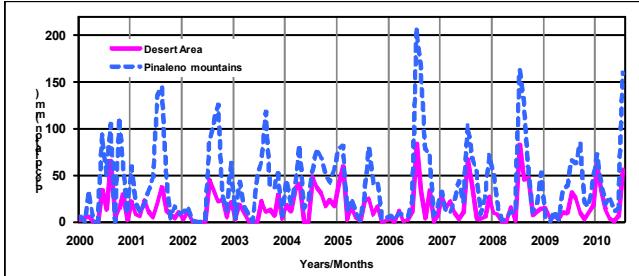


Figure 2: Seasonal and interannual precipitation trajectories for a low elevation desert and the Pinaleño mountains from 2000 to 2010.

2.4 Deriving Land Surface Phenological Variables

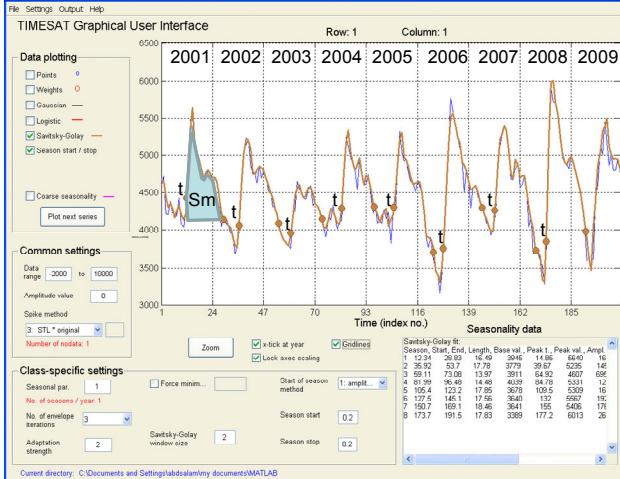


Figure 3. Example of a sky-island based interannual NDVI trajectory (blue line) and phenological metrics (brown dots) that are derived annually from MODIS NDVI time series with Timesat using the Savitzky-Golay filter and a moving polynomial regression technique (brown line): Timing (t) of Start, Greenness Integration (Small Integral - Sm).

using the Savitzky-Golay filter and a moving polynomial regression technique (brown line): Timing (t) of Start, Greenness Integration (Small Integral - Sm).

We used time series analysis software (Timesat) [5] to extract pheno-metrics: start of the season, and an integrated metric related to seasonal productivity. The derivation of these phenological metrics minimizes atmospheric noise in the NDVI time series data using the Savitzky-Golay filter and local polynomial fits of a moving NDVI composite interval (7 observations). An example of

the land surface phenological metrics that can be derived from the NDVI time series observations is shown in Figure 3. The start of the season (SOS) is derived based on the increase of 20% relative to the amplitude of the NDVI during a growing season. The small integral (Sm; Figure 3) is a proxy for seasonal productivity and is based on the integration on the NDVI values between the start and end of season.

2.4 Elevation and phenology analysis

The phenological metrics will be derived for the study area after which the relationship between elevation and phenological metrics are initially characterized examined for individual sky islands using a simple linear regression approach without accounting for the number of samples for each elevation level.

3. RESULTS AND DISCUSSION

A limited number of examples are presented in this short research manuscript and are the preliminary results of this ongoing project.

3.1 Sky Island Vegetation Dynamics

Land surface vegetation times series NDVI data for Sierra San Luis show that each year has different phenological trajectories (Figure 3). The NDVI trajectories show the impact of a year with low precipitation in 2002 and a relatively wet year in 2007, resulting in higher NDVI values for the latter. The NDVI trajectories of the sky islands regions are very different and can be used to examine the impacts of drought, wildfire and seasonality (Figure 4). There were two wildfires in the Santa Catalina Mountains in 2002 and 2003 respectively. The NDVI values dropped significantly due to drought and fires during those years, but show an increasing trend after the fire indicating some recovery and increased vegetation cover. The interannual differences in NDVI response among the sky islands can be large (Figure 4). The most eastern sky island (El Picacho) generally has the least vegetation cover and largest interannual differences compared to the other sky islands

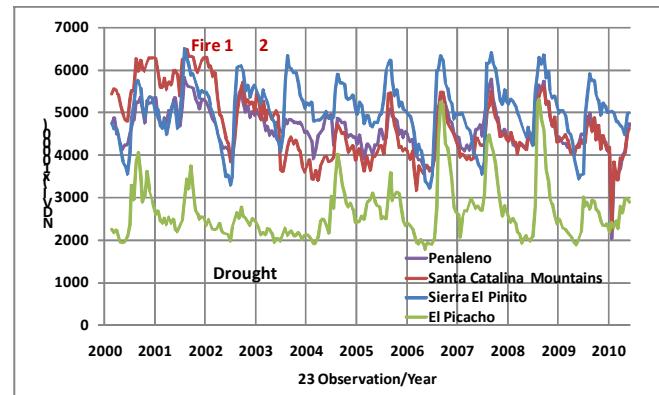


Figure 4. Interannual NDVI trajectories for representative sky islands. The impact of the strongest drought years can be seen for all sky islands while the fires on the Santa Catalina Mountains show an additional decrease in NDVI.

3.2 Selected Phenological Dynamics

Elevation, SOS and vegetation productivity do not always show the same spatial distribution and patterns (Figure 5). We believe that some of these patterns could be related to aspect and temporal and spatial variability in rainfall and vegetation types.

The start of the growing season for most sky islands is generally earlier for higher elevations than for lower elevations (Figure 5 and 6). This pattern is consistent for most years, although for some years the start of the season is similar for all elevation levels. It should be noted that the sky island elevation ranges are different for the two that are shown in Figure 5; 1500-3200m vs. 1500 - 2200m. Both plant water availability and temperature conditions will determine the Start of the Season [3]. Since the upper elevations tend to get more rain in the winter than the lower elevations, we believe that water limitations at the lower elevations will postpone the start of the season unless the lower elevations receive adequate winter rainfall for winter annuals to grow in the spring.

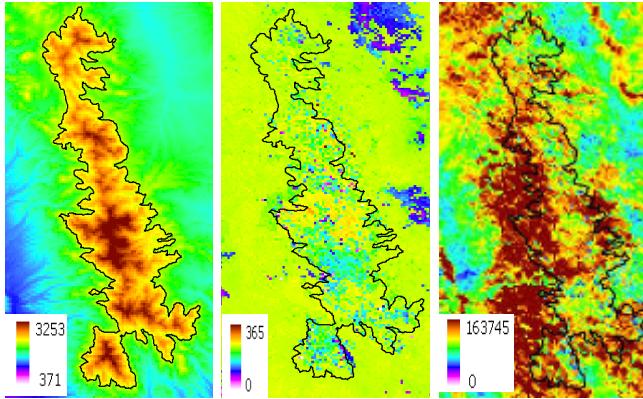


Figure 5. Example of the spatial patterns of elevation (m; left), SOS (DOY; middle) and small integral (\sum NDVI; right) for Sierra El Pinito during 2007.

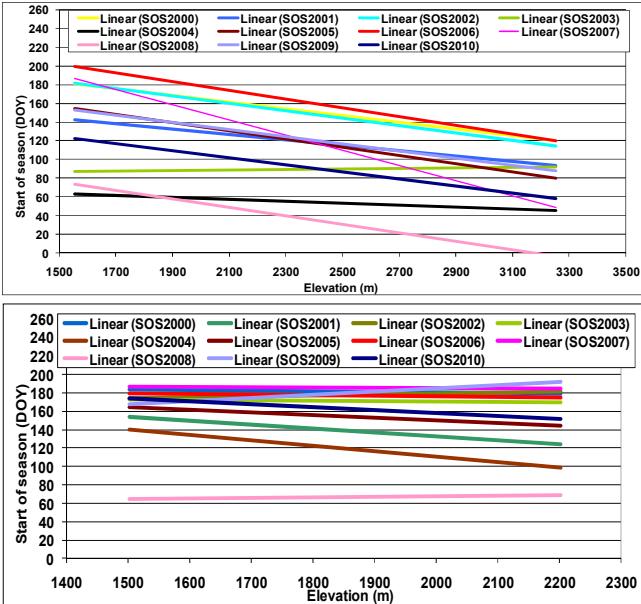


Figure 6. Example of the interannual trends in the SOS as a function of elevation for 2000-2010 for two sky islands: The Pinaleño Mountains (top) and the Sierra El Pinito (bottom).

For each of the years from 2000-2010 the vegetation productivity generally increased with elevation for the Pinaleño Mountains (Figure 6). 2010 was one of the wetter years and resulted in the highest productivity. For Sierra El Pinito, vegetation productivity

generally decreased or was similar with elevation (Figure 6). The interannual variability in vegetation productivity for both sky islands is large. The magnitude and range (~10000-40000) of the vegetation productivity is generally the same for both sky islands at the higher elevation range (2200m; Figure 7), while the productivity range at the lower elevation range for the Pinaleño Mountains is lower (~0-20000) than for Sierra El Pinito (~10000-40000). The latitudinal gradient in temperature and precipitation could contribute to these differences.

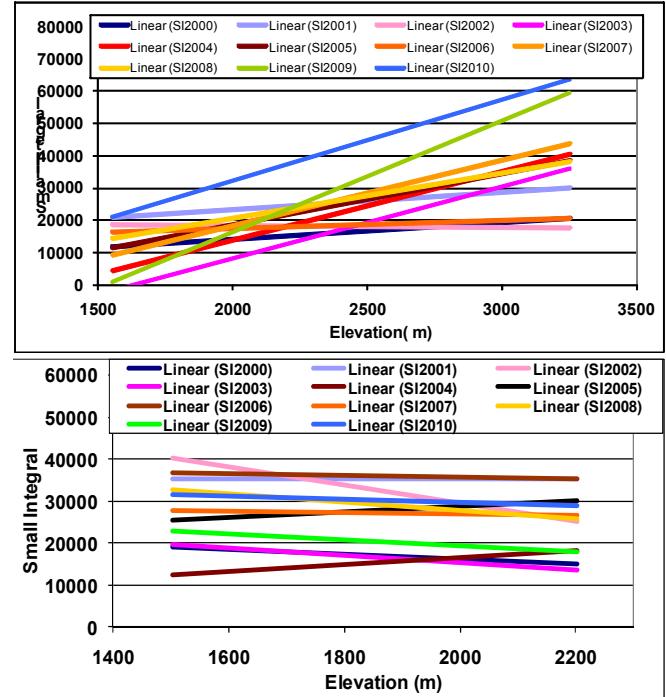


Figure 7. Inter-annual variability of vegetation productivity changes as a function of elevation for two sky islands: The Pinaleño Mountains (top) and the Sierra El Pinito (bottom).

4. CONCLUSIONS

Satellite derived land surface vegetation phenological data (SOS and vegetation productivity) for each of the sky islands showed a range of trends with elevation, and interannual variability in response to temperature and precipitation metrics. The mid-domain effect often observed represented by increased biodiversity at intermediate elevation ranges was not clearly observed for vegetation productivity or the start of the season.

The spatio-temporal phenological characterization utilizing MODIS time series data show distinctive vegetation response patterns and trajectories that provide a means to monitor the sky islands and provide a better understanding of landscape response to disturbance (e.g. wildfire), climate (e.g. drought) and human activities (e.g. forest restoration) that can better inform conservation and management practices.

Future research will involve a more in-depth analysis of the phenological characteristics of the sky islands between the Colorado Rockies and the Sierra Madres to determine their response and resilience to environmental variability. We would like to explore if other variables like vegetation type, climate, topography and aspect will further elucidate the vegetation

responses along the elevation gradients represented by the Madrean sky islands.

ACKNOWLEDGEMENTS

The authors would like to thank the Arizona Remote Sensing Center for providing the data and computing facilities to conduct this research. Partial support was provided by NASA MEaSUREs CA# NNX08AT05A.

REFERENCES

1. Reed, B.C., et al., *Measuring Phenological Variability from Satellite Imagery*. Journal of Vegetation Science, 1994. **5**(5): p. 703-714.
2. Justice, C.O., et al., *The Moderate Resolution Imaging Spectroradiometer (MODIS): Land remote sensing for global change research*. Ieee Transactions on Geoscience and Remote Sensing, 1998. **36**(4): p. 1228-1249.
3. van Leeuwen, W.J.D., et al., *Phenological Characterization of Desert Sky Island Vegetation Communities with Remotely Sensed and Climate Time Series Data*. Remote Sensing, 2010. **2**(2): p. 388-415.
4. "PRISM Climate Group, O.S.U., <http://prism.oregonstate.edu>, created 4 Feb 2004."
5. Jönsson, P. and L. Eklundh, *TIMESAT--a program for analyzing time-series of satellite sensor data*. Computers & Geosciences, 2004. **30**(8): p. 833-845.