

SATELLITE OBSERVED SHIFTS IN SEASONALITY AND VEGETATION -RAINFALL RELATIONSHIPS IN THE SOUTHWEST USA

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ABSTRACT:

Water availability limits plant growth and production and its availability mediates the responsiveness of vegetation land cover to global changes. There is an urgent need to understand how dryland ecosystems will respond to increases in interannual precipitation variability with more frequent, extreme drought events and changes in temperature, as predicted by global climate models. Our goals in this study were to combine spatially distributed rainfall data with satellite-based measures of photosynthetic activity and productivity to derive and analyze precipitation use efficiency (PUE) dynamics across wet and dry years and across land cover types to assess differential rainfall-vegetation sensitivities. We addressed vegetation responses to rainfall using MODIS data, and precipitation data from PRISM datasets and TRMM satellite data, both spatially registered to MODIS data. PUEs were computed on a pixel basis using the relationship of PUE equal to the annual productivity divided by annual rainfall (MAP). We computed both climatologic and standard anomaly values based on MODIS vegetation indices (VIs). Our key conclusions are that vegetation patterns are strongly coupled to precipitation variability, but with distinct responses at alternative spatial and temporal scales. We found anomalies of PUE yielded highly sensitive and strong vegetation response patterns to drought, including land cover dependencies. We also assessed the impacts of land cover modifications on water availability, and found that, based on knowledge of a variable PUE, one can improve predictions of land cover responses to climatic changes.

1. INTRODUCTION

The Southwest U.S. is a cohesive region encompassing the Chihuahuan, Sonoran, and Mohave deserts, consisting of major biome types with highly diverse vegetation physiognomies that include desert scrub, grasslands, savanna, and riparian zones interspersed with montane forests. These dryland ecosystems are currently undergoing rapid land transformations causing significant shifts in the physiognomic makeup of the vegetation with consequences to surface hydrologic processes, water balance, and primary productivity (Breshears et al. 2005).

Water availability limits plant growth and production and its availability mediates the responsiveness of vegetation land cover to global changes. There is an urgent need to understand how these ecosystems will respond to increases in interannual precipitation variability with more frequent, extreme drought events and changes in temperature, as predicted by global climate models (Hickler et al. 2005). The goals of this study were to combine spatially distributed rainfall data with satellite-based measures of photosynthetic activity and productivity to derive and analyze precipitation use efficiency (PUE) dynamics across wet and dry years and across land cover types to assess differential sensitivities associated with land cover type (Huxman et al. 2004).

Key questions posed by this study include, (1) Can satellite remote sensing datasets be used to detect ecosystem changes and responses to drought; (2) What are the controls and drivers of biome seasonality; (3) What is the role of climate change and human impacts on seasonal biome shifts (start of and length of

growing season; disrupted seasonal cycles); (4) What are the resilience properties of biomes to climate variability; and (5) Are there thresholds to abrupt changes in seasonality?

2. METHODS

We analyzed the spatio-temporal vegetation responses, sensitivities, and seasonal shifts to precipitation patterns in the Southwest with time series satellite data, and assessed vegetation-hydrologic linkages through the analysis of PUE across continuous temporal-spatial scales. We addressed both local site and regional vegetation responses to rainfall using MODIS Vegetation Index data (MOD13A3 monthly 1km satellite time series data of vegetation photosynthetic activity) from 2000-2009 and precipitation data from PRISM datasets at 4km resolution and TRMM satellite data at 25km resolution, both spatially registered to MODIS data. The Southwest Regional GAP land cover data was utilized for local scale analysis of vegetation physiognomies. Precipitation use efficiency's (PUEs) were computed on a pixel basis using the relationship of PUE equal to the annual productivity divided by mean annual rainfall (MAP),

$$PUE = ANPP / MAP \quad (1)$$

Where ANPP is the annual net primary productivity, computed by integrating the MODIS VI values for individual years. We also derived seasonal PUE measures through integration at

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monthly timesteps. We computed both climatologic and standard anomaly values for MAP, PUE, and annual production based on MODIS vegetation indices (VIs). Regional analysis and local site analysis were made at the Walnut Gulch Experimental Watershed (WGEW) and Santa Rita Experimental Range (SRER), as depicted in Figure 1.

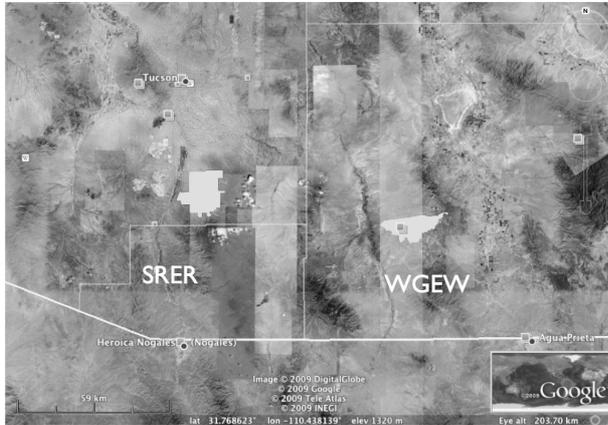


Figure 1. Regional and local site study area in southwest U.S. encompassing Arizona, New Mexico, and Mexico.

3. RESULTS

3.1 Productivity and precipitation anomaly relationships

The relationship of productivity anomalies with precipitation anomalies is plotted in Figure 2. For the 10 years of data analyzed, there were significant deviations in both precipitation and productivity, as measured with the MODIS NDVI, with standardized anomalies exceeding ± 1 standard deviation (Fig. 2). For the case of negative precipitation standard anomalies, NDVI (and productivity) values mostly exhibited negative anomalies. Peak productivity was achieved in wet years in which precipitation values were nearly at 1 standard deviation positive anomalies (Fig. 2). However, in wetter years where precipitation anomalies were in excess of 1 and 2 standard deviations, productivity values decreased again toward average conditions (i.e., zero NDVI anomalies). Figure 2 indicates that there existed optimal rainfall conditions for vegetation growth over this period with both excess and deficiency conditions resulting in depressed vegetation production.

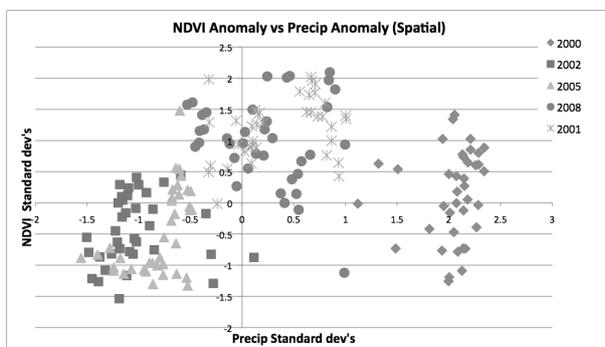


Figure 2. Relationship of productivity anomalies (with NDVI) and precipitation anomalies.

3.2 Relationship of PUE with MAP

The relationship of PUE and MAP is plotted in Figure 3. The driest years resulted in the highest PUE values, particularly when precipitation values were under 300mm per year. MAP levels that exceeded 300mm and approached levels of 600mm, resulted in no change in PUE values. This indicates the ratio of productivity to rainfall (ANPP/ MAP) remains fairly constant with a constant increase in vegetation productivity with increase in rainfall. Only in the driest years was there more productivity relative to the amount of rainfall received.

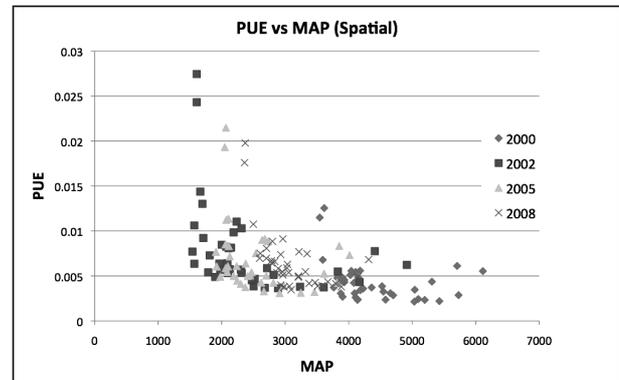


Figure 2. Precipitation use efficiency (PUE) plotted against mean annual precipitation (MAP) for 4 climatic variable years.

In accordance with the results shown in Figure 2, the highest MAP levels resulted in depressed productivity which when ratioed by the higher MAP, resulted in the very low PUE values. Although the lowest MAP levels also resulted in depressed productivity, the loss of vegetation growth was of lower magnitude than the lower rainfall amounts, resulting in a net increase in PUE.

3.3 Relationship of PUE and precipitation anomalies

In Figure 4, the relationship of PUE anomalies with precipitation anomalies is shown to be highly linear with a strong negative relationship. The driest years exhibited the highest PUE results, i.e., vegetation productivity was most efficient as rainfall anomalies became increasingly negative. The wettest years produced the lowest PUE results, indicating that vegetation growth was least efficient with increasing positive rainfall departures from normal. All 10 years of data yielded the same trend, with only 5 years shown in Figure 4 for clarity purposes.

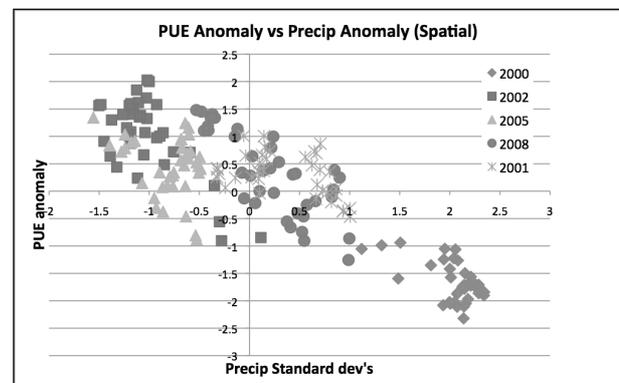


Figure 4. Relationship of anomalies in PUE with anomalies in rainfall.

4. CONCLUSIONS

We addressed vegetation responses to rainfall using MODIS data, and precipitation data from PRISM datasets and TRMM satellite data, both spatially registered to MODIS data. PUEs were computed on a pixel basis using the relationship of PUE equal to the annual productivity divided by annual rainfall (MAP).

Our key conclusions are that dryland vegetation patterns and responses to drought and rainfall conditions are clearly coupled to precipitation variability. Although water availability limited plant growth and production, we found precipitation use efficiencies became higher as the vegetation became more efficient in its use of water for growth. We found PUE anomalies clearly yielded highly sensitive and strong vegetation response patterns to drought.

There is an urgent need to understand how dryland ecosystems will respond to increases in interannual precipitation variability with more frequent, extreme drought events and changes in temperature, as predicted by global climate models. We found that with knowledge of a variable PUE, one can improve predictions of land cover responses to climatic changes. Future work is aimed at achieving a better understanding of precipitation effects on ecosystem processes and the time lags generated by vegetational constraints to climate changes. There is also a need to further explore the impacts of land cover modifications on water availability.

5. REFERENCES

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