

Understanding and predicting the impact of climate variability and climate change on land use and land cover change via socio-economic institutions in Southern Africa

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Research Question: "How does climate variability and climate change influence land use and land-cover change as it works through socio-economic institutions?"

- We develop temporally and spatially multiscale understanding of the relationships between land-cover and land-use change (LCLUC) and climatic shifts in three watersheds in four southern African nations.
- Hypothesis: **Socio-economic institutions are the main instruments of human adaptation to climate variability and change, and that the observable outcomes of institutional adaptations are seen in the spatial and material expression of LCLUC.**
- This study will test the resilience of the socio-ecological systems of southern Africa, enhance the use of remote sensing, and provide models for climate scenario planning.

Research Objectives and Proposed Methods

Objective 1: Develop an understanding of past climate, past climate variability and the main drivers of climate change for this region, across the last 80 years.

Objective 2: Determine the spatial and temporal characteristics of land cover change as it correlates with climate variability across the past 40 years, the past decade and the next 20 years under different scenarios of climate change (IPCC 2007).

Objective 3: Develop understanding of land-use history and land-use change across the region and then develop linkages between spatial and temporal characteristics of land use as it relates to climate variability.

Objective 4: Use results of the previous three research objectives to test future scenarios using the SAVANNA and QnD object oriented models with Global Sensitivity and Uncertainty methods.

- Create a virtual, experimental laboratory with SAVANNA and QnD wherein we can explore climate variability, potential scenarios of climate change and potential political and economic adjustments of the coupled-natural human system, and conduct a formal reliability analysis of the modeling system.
- Linkage and Analysis of Models: Explore the model

Expected Outcomes and Work Products

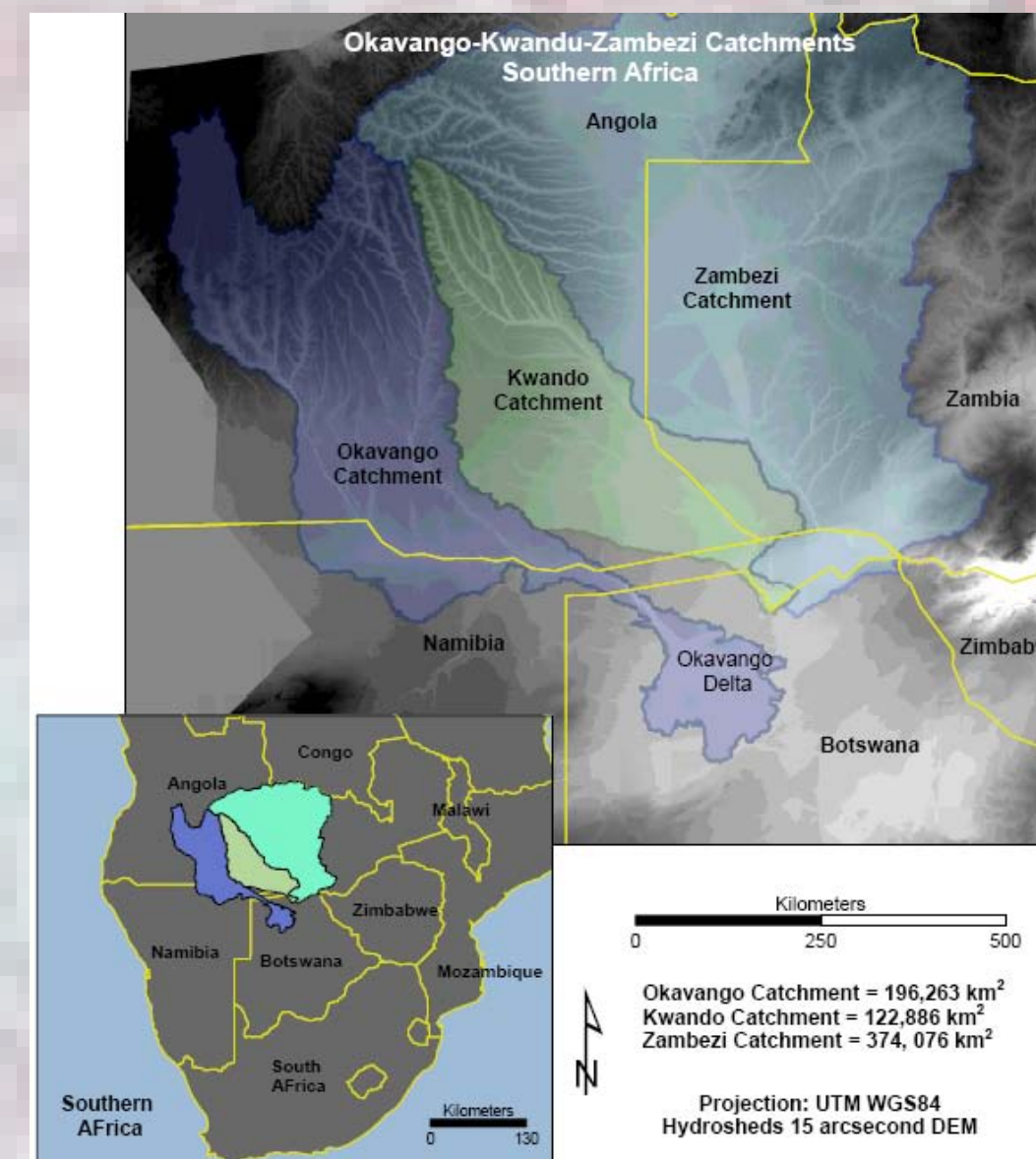
- Projections of LCLUC in response to both current climate and climate availability and impending climate change, for selected areas of intensive socio-economic and ecological research in southern Africa.
- Comparisons among multiple existing models of LCLUC in the southern African context.
- Evaluations of the projections by novel methods of interactions with stakeholders, with the potential for feedbacks from the stakeholders to the system.
- Empirical data sets of biophysical and socio-economic variables relating to landscape dynamics in the four countries.
- Empirical models (e.g. logistic regression) that relate both physical (e.g., deforestation, water quality, land-cover change) and social variables (e.g., migration patterns, income inequality, land-use-change, differential cultural practices) to LCLUC, economic growth, and environmental change;
- Cross-boundary comparisons between countries regarding the local and regional landscape dynamics.

Part 1: Spatial and temporal variability of precipitation within the Okavango-Kwando-Zambezi catchment of southern Africa

Figure 1. Study Area

The Okavango, Kwando, and upper Zambezi (OKZ) catchments. 683,000 km² in tropical and sub-tropical Zambia, Angola, Namibia, and Botswana

Precipitation is a fundamental factor in earth-atmosphere feedbacks and is especially important in dryland areas where human populations rank very low in human well-being and development indicators (MEA, Drylands). Southern Africa is one of the most sensitive areas to precipitation variability and a large degree of uncertainty exists about future rainfall projections and its effect on land-cover dynamics (Flato 2001).



CLIMATE RESEARCH QUESTIONS

- What are the spatial and temporal inter-annual precipitation patterns within the regional catchment area of southern Africa?
- Is there a difference in precipitation input across the three basins?
- Do wet and dry years correspond in the upper and lower catchment areas for each sub-basin?
- What is the relationship between ENSO and rainfall variability in the OKZ catchment?

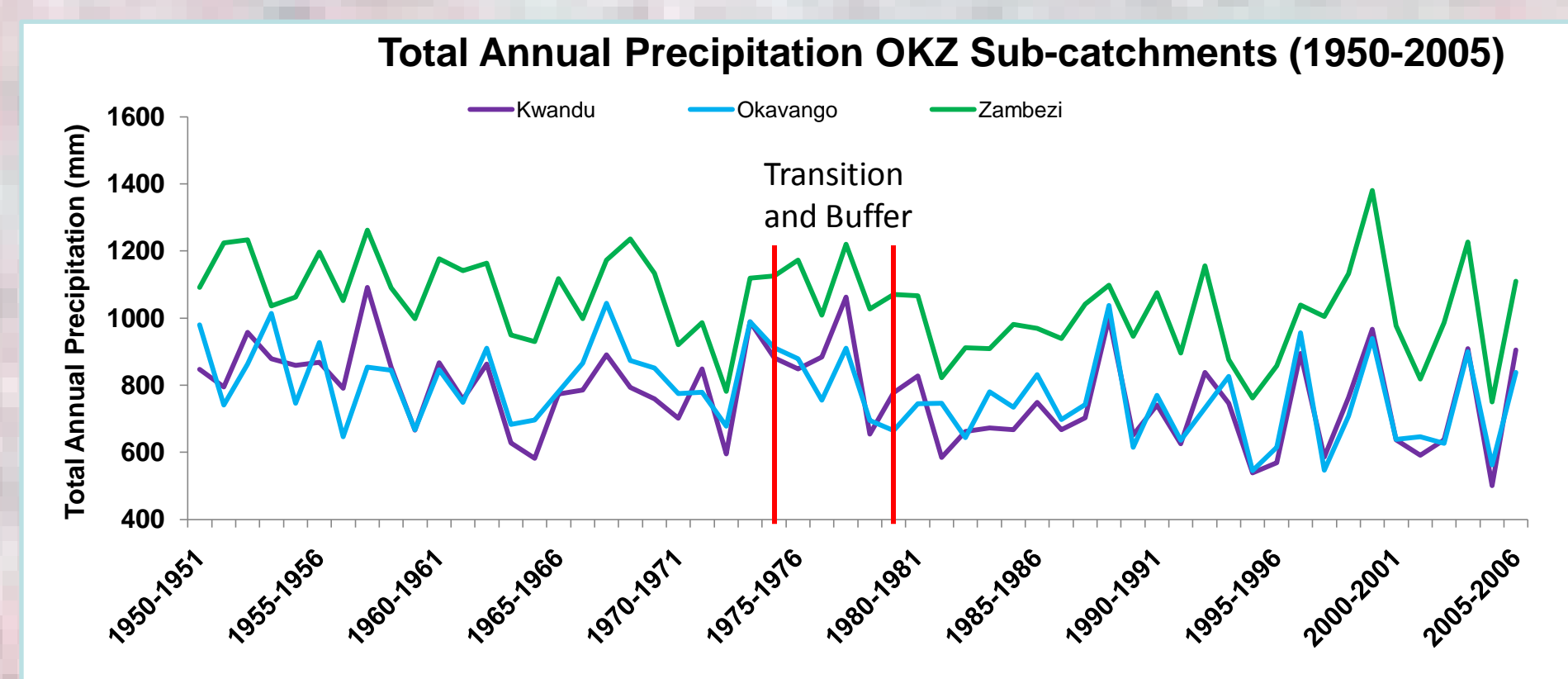


Figure 2 (right) Median rainfall from 1950-1975 and 1980-2005 respectively.

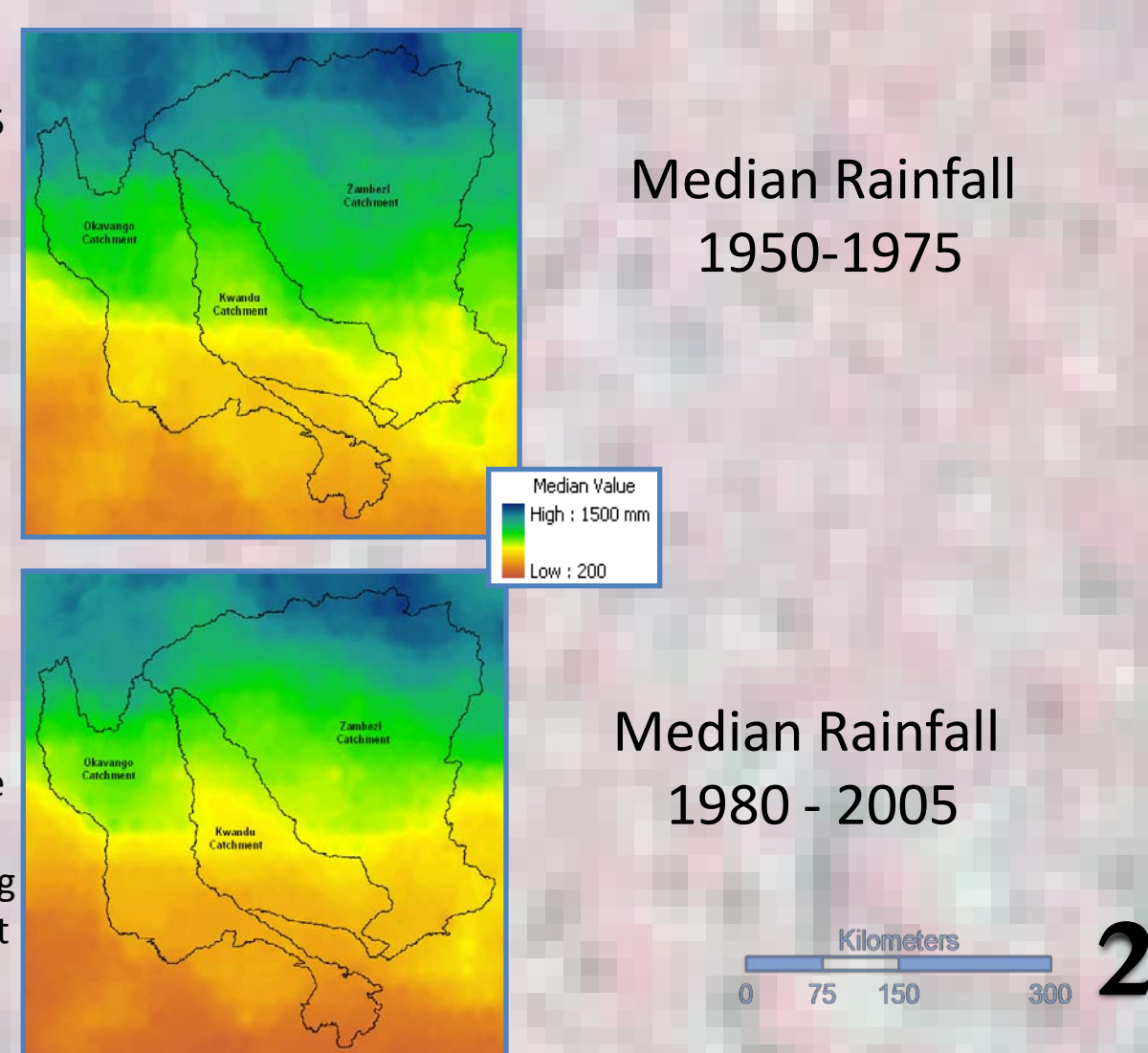


Figure 3 (below) Image differencing between the two periods of interest with an identified buffer zone separating the two times with a global shift in climate patterns in the 1970s

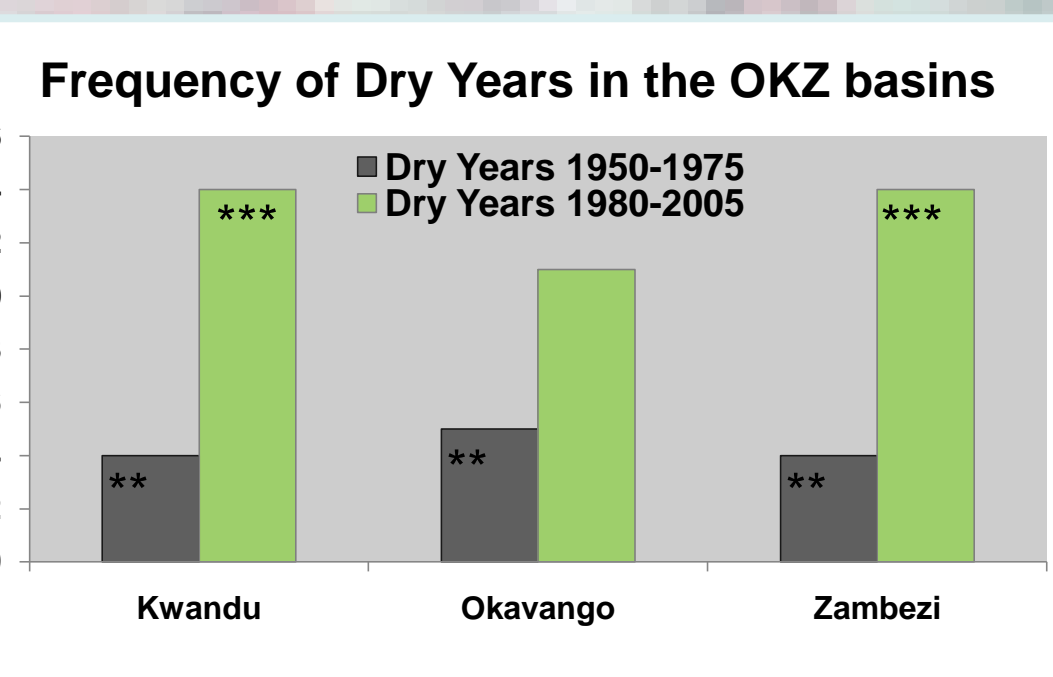
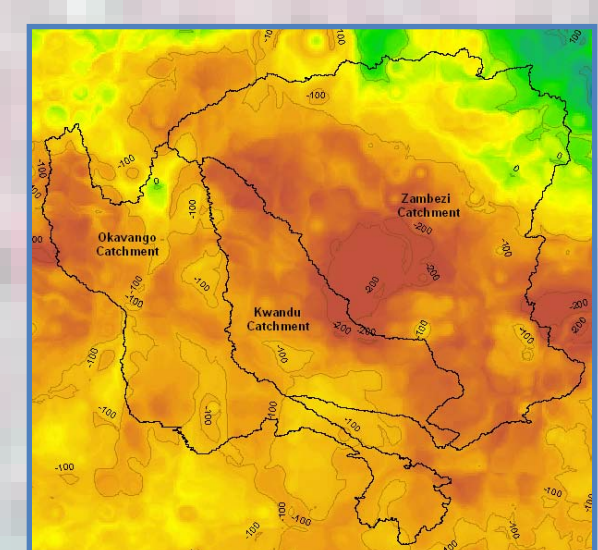
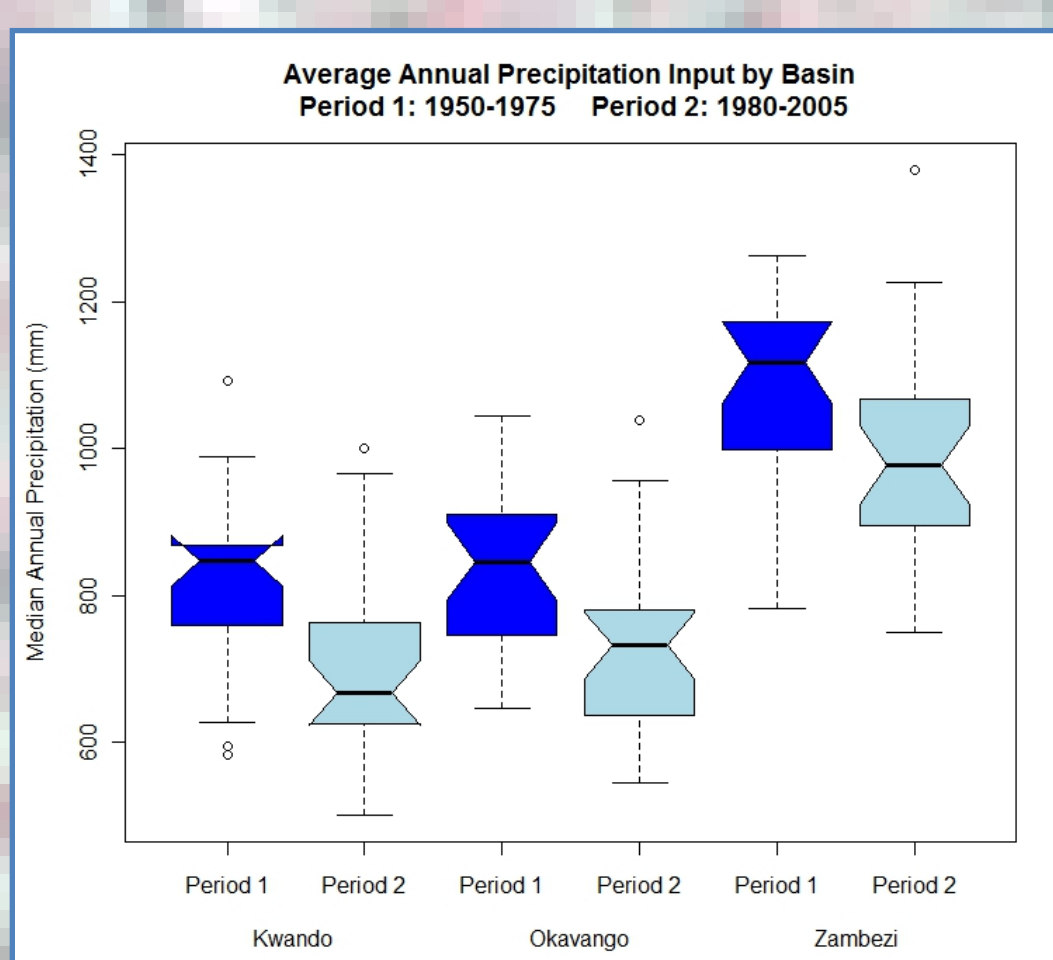


Figure 4 (top) Indicates total median annual precipitation input has seen a uniform decrease across all three sub-catchments from 1950-1975 to 1980-2005

Figure 5 (bottom). Indicates the increase in number of dry years across the three sub-catchments based on the years that fall in the lowest tercile (< 33%) of each sub-catchment time series

- Increase in dry years across all three sub-catchments
- Average annual decrease in precipitation input across all three sub-catchments



Chi-Square results indicate precipitation input within catchments operates similarly across the upper and lower regions (exception: P1: 1950-1975 of the Kwando).

Catchment	Median	n	Chi-Sq Value	DF	Probability	Fisher's Value
Okavango	- Median	n				
	P1: 1950-1975	25	3.59	1	*	0.087
	P2: 1980-2005	25	3.59	1	*	0.087
Total: 1950-2005	55	8.04	1	***		
Kwando	- Median	n				
	P1: 1950-1975	25	0.44	1		0.671
	P2: 1980-2005	25	10.00	1	***	0.00365
Total: 1950-2005	55	8.04	1	***		
Zambezi	- Median	n				
	P1: 1950-1975	25	11.99	1	****	0.00217
	P2: 1980-2005	25	20.30	1	****	0.00004
Total: 1950-2005	55	36.87	1	****		

Summary

- Distinct differences across catchments both spatially and temporally.
- Increased frequency of dry years in the second period (1980-2005)
- Little evidence of an association between wet and dry years in the upper and lower catchments of each basin
- Two most western catchments (Kwando and Okavango) more similar in magnitude and pattern across space and time
- Suggests more influence from ENSO on precipitation dynamics in Kwando and Okavango than the Zambezi

Part 2: Linking climate to landscape: Vegetation response to precipitation variability

- Potential impacts of climate variability on vegetation structure and composition depend on understanding how inter- and intra-annual precipitation affects seasonal vegetation dynamics.
- Water is the major limiting resource in semi-arid and arid ecosystems, and vegetation species respond to the timing, frequency, and intensity of rainfall in different ways.
- We study the response of photosynthetic activity to intra-annual precipitation variability in the regional OKZ catchment at a monthly time-step from 2000-2009.

Hypothesis: Precipitation in the seven months prior to the dry season regulates vegetation productivity at the start of the dry season.

Tested by geographically weighted regression (Fotheringham, et al. 2002) of monthly rainfall estimates on remotely-sensed estimates of vegetation productivity.

1. Data Acquisition

Tropical Rainfall Monitoring Mission 3B43 dataset (TRMM) and monthly vegetation responses using the MODIS 13A1 16-day composite normalized difference vegetation index (NDVI) product as a proxy for vegetation productivity. Data were acquired at a monthly time step and layer-stacked for the years 2000 to 2009 (Figure 4).

2. Data Summary

The highest cross correlation between NDVI and precipitation is measured at a one month lag (Figure 5).

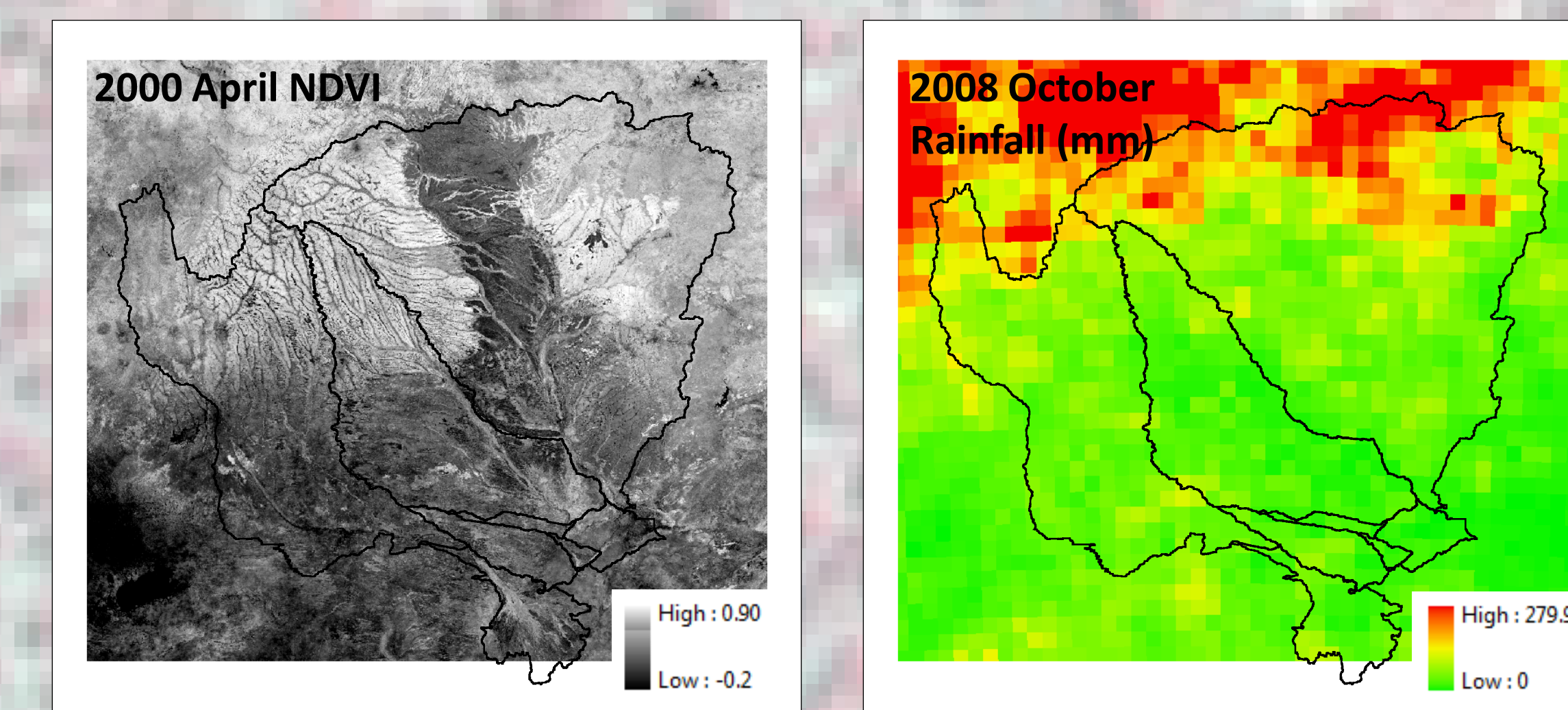


Figure 6. Samples of individual layers from the layer stacked datasets. Monthly NDVI was acquired from the MODIS 13A1 16-day composite, 500 m datasets as close to mid-month as possible. TRMM 3B43 monthly rainfall estimates (rainfall in mm was converted from average daily rate) are "best" estimates using gauge stations modeled with satellite-based measures.

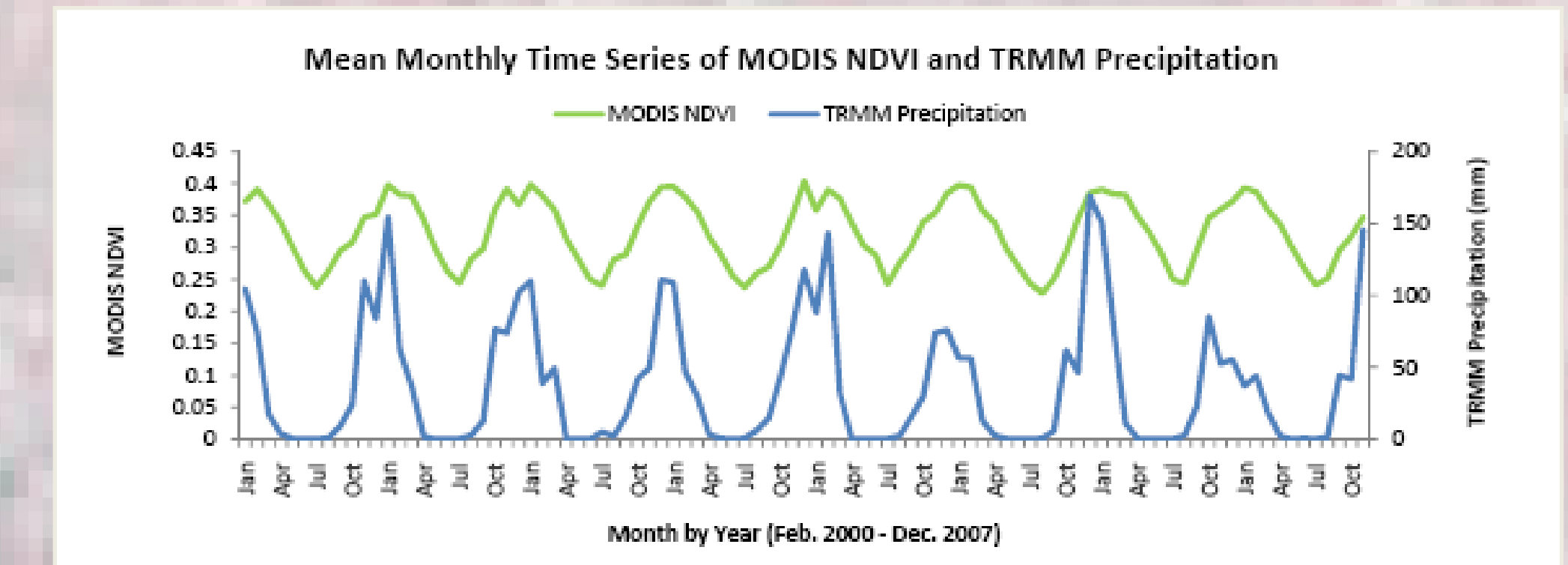


Figure 7. Average monthly time series from the layer-stacked NDVI and TRMM precipitation estimates showing the seasonal patterns in both datasets.

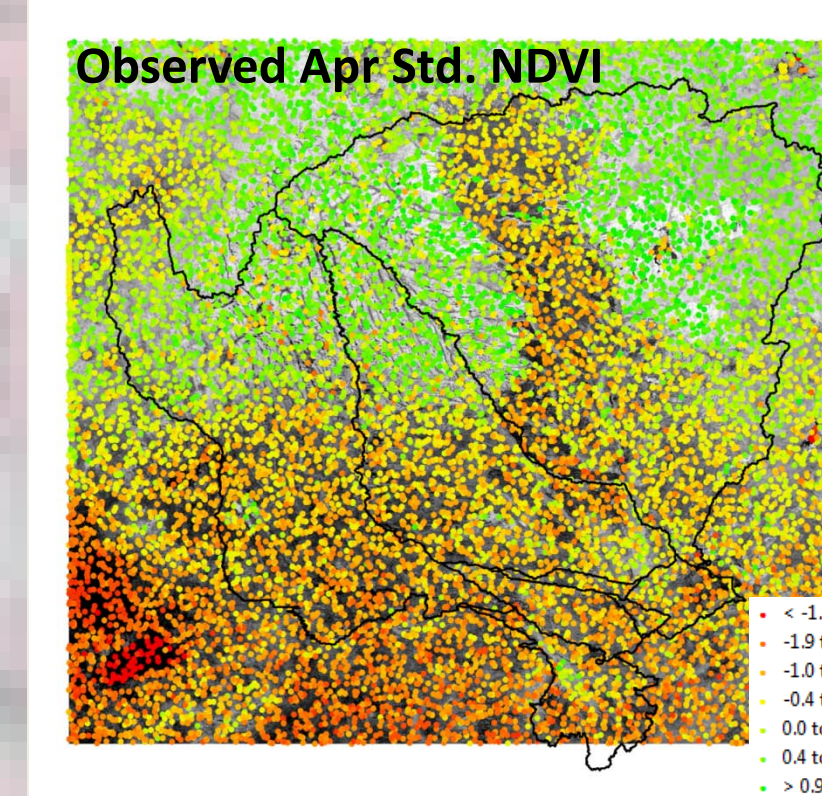


Figure 8. Random samples or dependent

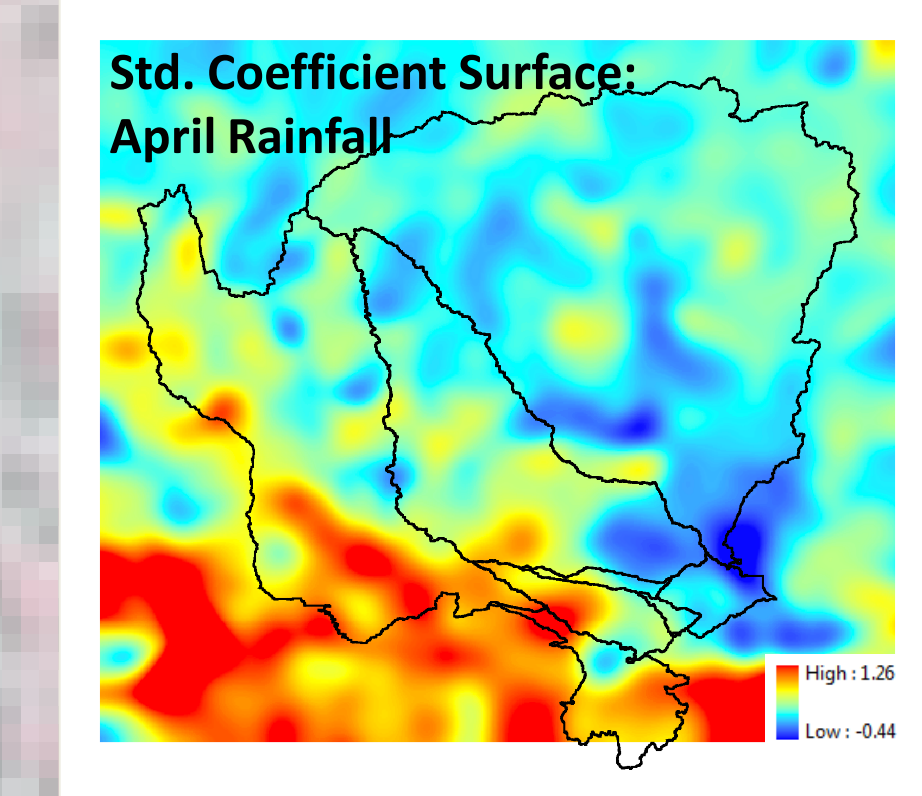


Figure 9. GWR regression estimates for each pixel location of the original 500 m MODIS NDVI layer stack.

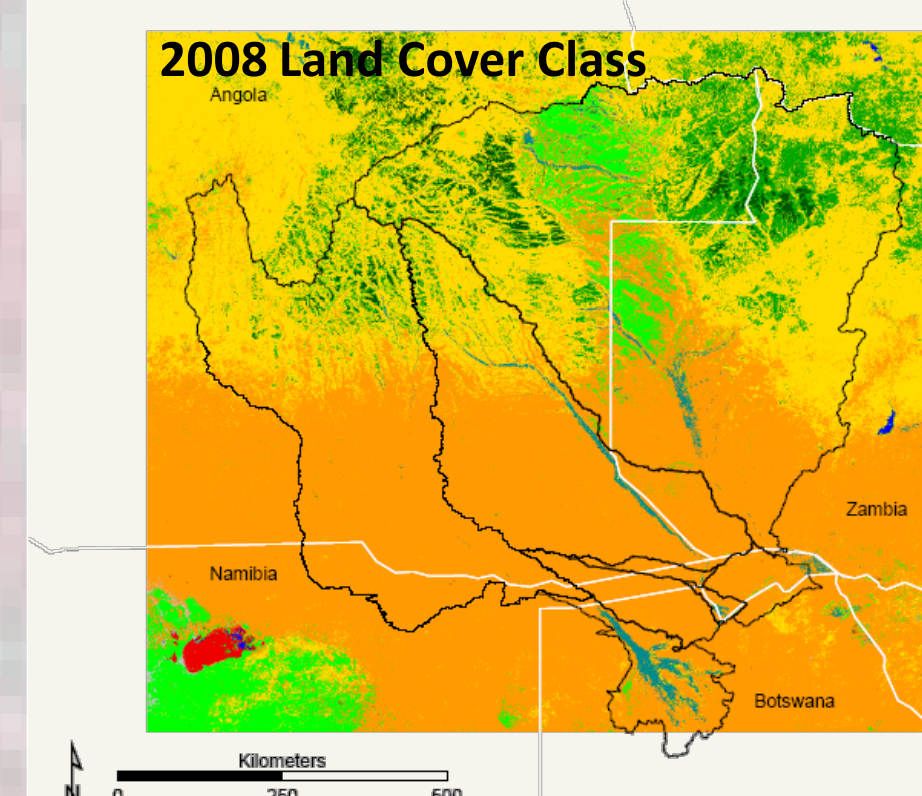
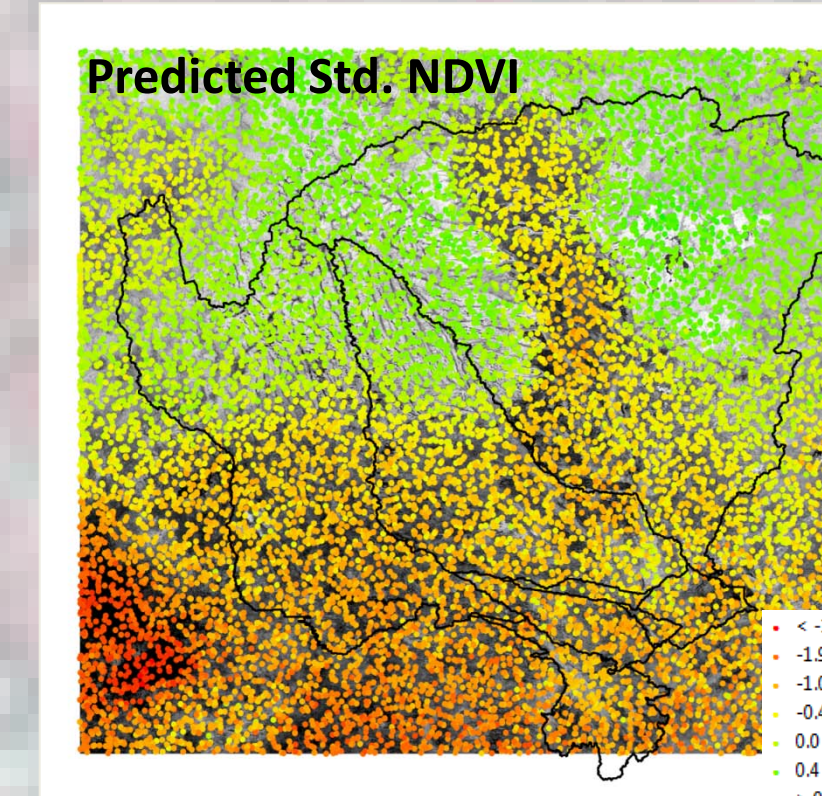


Figure 10. MODIS-derived L3 land cover type dataset for 2008.

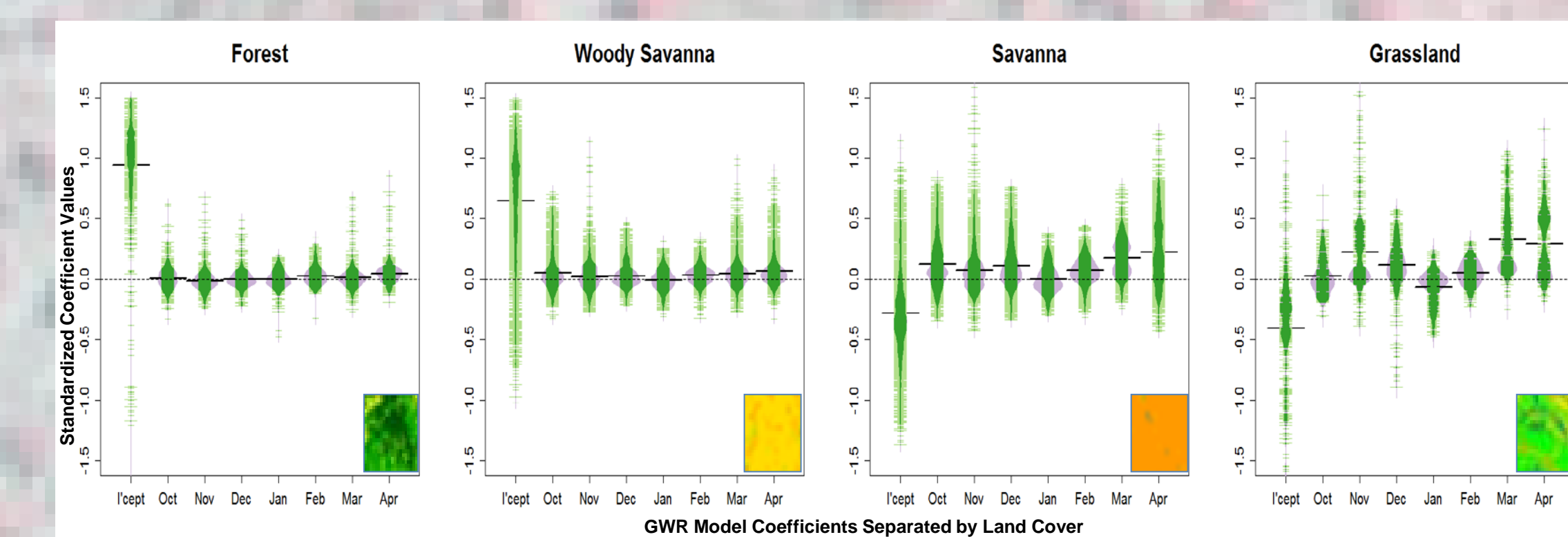


Figure 11. Using the land cover classes aggregated into forest, woody savanna, savanna and grassland, the coefficient surfaces were sampled for each point in the original random sample and plotted as bean plots. The effects of precipitation are far more marked as the proportion of grass to woody vegetation increases. Note that all coefficients are standardized.

Model Type	RSS	R ²	Adj. R ²	Δ AICc	Parameters Estimated	Bandwidth
Global OLS	12007.54	0.329	0.329	16646.95	8	N/A
GWR	3656.42	0.795	0.754	0.00	3015.40*	39,356 m*

Table 2. Global OLS model diagnostics compared to those of the GWR. GWR fits the data across the catchment much better as indicated by the delta AIC and increase in R². * The parameters estimated for GWR is the "effective number", an estimate based on the number of observations contributing to local model estimates. The bandwidth parameter (here fixed, in m) controls at what distance a Gaussian spatial weighting is applied (Fotheringham, 2002).

Conclusions and Future Directions

- GWR minimizes the effects of unmeasured, spatially-varying factors.
 - Intra-annual rainfall accounts for significant amounts of dry-season vegetation productivity in all vegetation types, but is of increasing importance for forests, woodlands, savannas, and grasslands, in order.
 - The next step will be to use a residual trends analysis to assess long-term vegetation responses to inter-annual changes in precipitation.
 - Our research contributes to climate-land studies, linking how vegetation types respond to precipitation variation at multiple spatial and temporal scales and is vital to understand shifting dynamics of dryland ecosystems.
- Vegetation responses differ by type, so sub-pixel analysis/ LMM are the next steps.**

Social science intensive fieldwork starting May 2010