Nile Basin Vegetation Response and Vulnerability to Climate Change

Armando Barreto[1*], Kamel Didan[1,2,3], Muluneh Yitayew[3]

[1] VIP Lab., ECE Dept., [2] Institute of the Environment, [3] ABE Dept., The University of Arizona,
*abarreto@email.arizona.edu

Introduction

The Nile Basin is one of the world's water resources hotspots that is home to over 310 million people in ten riparian countries representing one third of the total African population. The Basin has one of the most complex eco-hydrology in the world ranging from the highlands of Ethiopia and Equatorial Lake regions to the low desert in Sudan and Egypt. The basin, like all other basins of the world, is facing water resources challenges exacerbated by climate change and increased demand. Although hydrology and ecology are tightly intertwined, the focus was always on the hydrological services of the basin and little attention is devoted to the region's ecosystems.

With vulnerability to climate change, manifested with multiple droughts, floods, and an ever increased dependency on the river water, and the subsequent political discord, the region is in need for an integrated assessment of its eco-hydrology and ecosystems changes.

Objectives

Using a simple diagnostic approach the objectives of this work is to assess the response of the Nile Basin vegetation cover to the main climate drivers (Precipitation and Temperature) and to characterize and understand sensitivity of the vegetation cover to the potential impacts of climate change.

Data and Methods

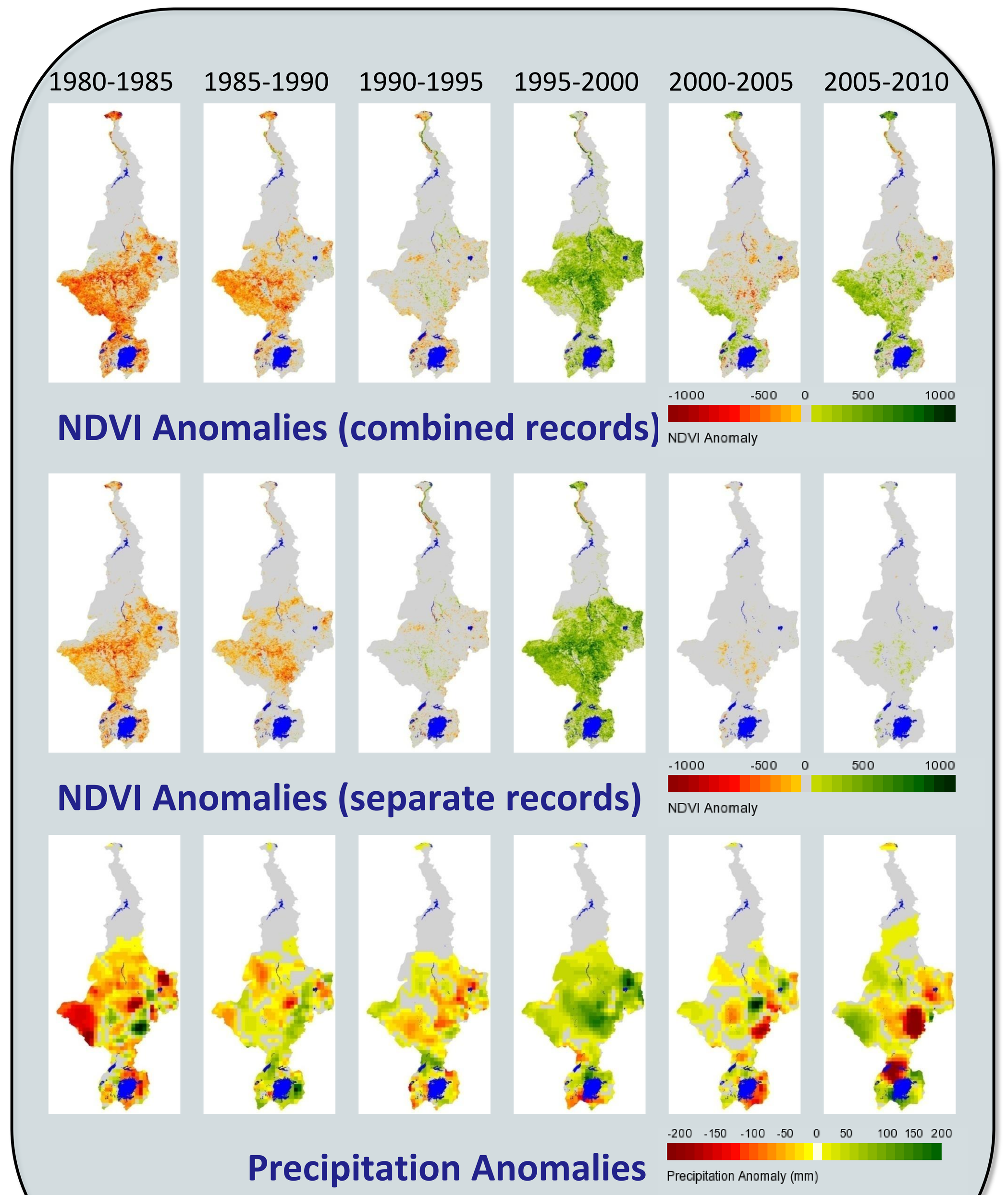
This work makes use of the newly generated seamless multi-sensor long-term data record about the land surface vegetation and phenology. The VIP dataset is a 30+year record of vegetation index and growing season compiled from AVHRR and MODIS sensors by the Vegetation Index and Phenology laboratory (vip.arizona.edu). Monthly composite of the VIP data was used in this analysis.

Climate data for the corresponding 30-year period was acquired from the Global Precipitation Climatology Centre (GPCC) data version 6.0 from 1970-2010 and the Global Historical Climatology Network-Monthly (GHCN-M) version 3.2.1 Temperature Anomalies from 1970-2012.

Additionally, combined Terra/Aqua yearly Land Cover products (MCD12C1) from 2001 to 2012 were used to assess change and further constrain the analysis.

The area of interest was defined by the basin boundaries minus all water bodies. When processing the data, we considered the full basin, then considered only the vegetated areas as defined by the MODIS LC data record. We further clustered the analysis by 500m elevation bins and by LC classes. The purpose was to isolate impacts and anomalies. Various long term time series were generated, along with anomalies per-pixel and averages. Spatial distribution and correlation with the climate drivers was also analyzed.

To assess the impact of residual across sensors and continuity biases we considered the full record (AVHRR+MODIS) and the AVHRR and MODIS separately.



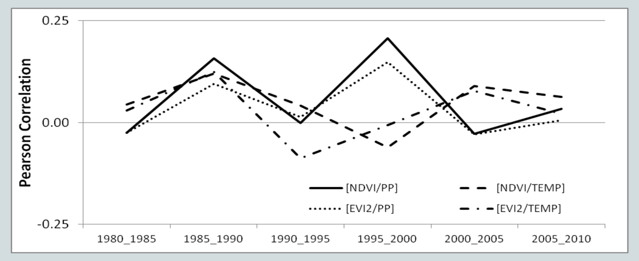
NDVI Anomalies (combined records)

NDVI Anomalies (separate records)

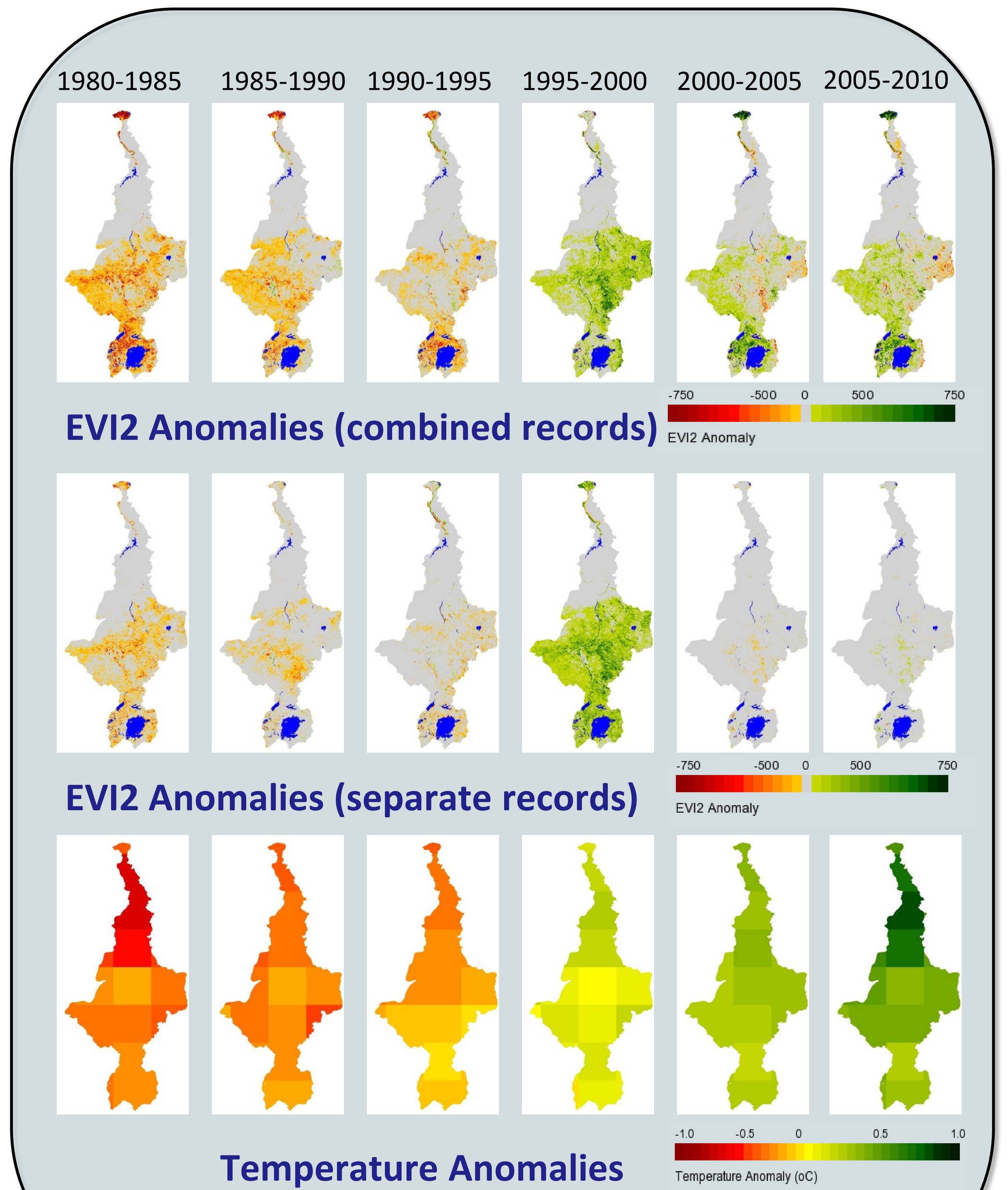
Precipitation Anomalies

To elucidate the impact of biases due to across sensor differences and/or due to the continuity, we used the full (VIP) AVHRR+MODIS records (top row) and single AVHRR/MODIS records (middle row). Both a bias and a difference in the anomalies between the two VIs are visible. However, the general spatial and temporal trends persisted consistently.

PERIOD	[NDVI/PP]	[NDVI/TEMP]	[EVI2/PP]	[EVI2/TEMP]
1980_1985	-0.025	0.045	-0.025	0.030
1985_1990	0.158	0.121	0.095	0.125
1990_1995	-0.001	0.041	0.014	-0.088
1995_2000	0.208	-0.061	0.148	-0.006
2000_2005	-0.028	0.090	-0.028	0.078
2005_2010	0.034	0.063	0.006	0.022



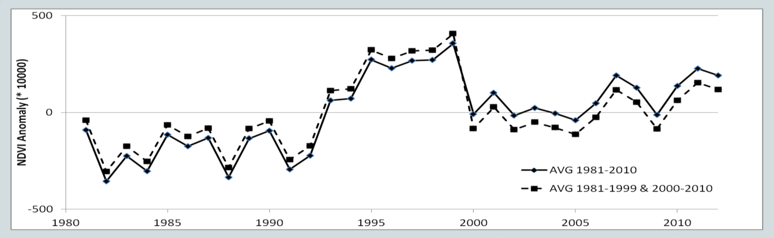
The global correlation between the VIs and climate drivers anomalies was very complex, with T and P switching roles. The VI correlation with P and T was positive and significant in the late 80'ies. In the early 90'ies the drivers started to recover leading to insignificant correlations. Starting late 90'ies a divergence develops, where VI anomalies remained positively and strongly correlated with P, while the correlation with T anomaly became insignificant. As T continues to rise and P continues to recover the VI anomalies correlation switched direction, where P impact became insignificant while T started to correlate positively with the VI anomaly. Temperature started to play a more prominent role in Land cover change. In the late 2010 things seem to be going once again to a normal state. This points to the complex relation between vegetation and drivers



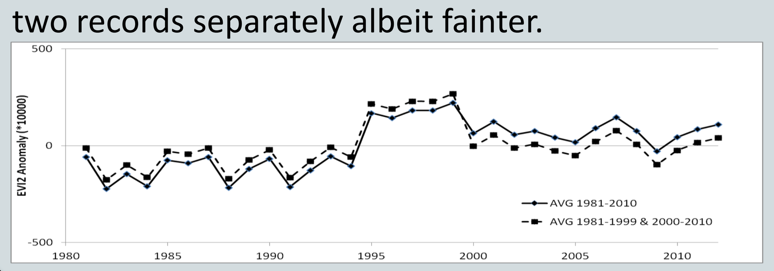
EVI2 Anomalies (combined records)

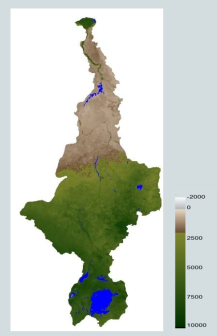
EVI2 Anomalies (separate records)

Temperature Anomalies

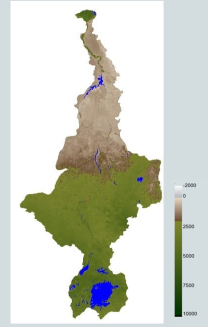


Long term NDVI Anomaly shows the impact of climate extremes, especially droughts (80ies). A strong positive anomaly (recovery) in late 90's corresponding to a positive precipitation anomaly develops. This positive anomaly continued till now. EVI2 follow a very similar pattern. The same patterns for both VIs persist when looking at the two records separately albeit fainter.

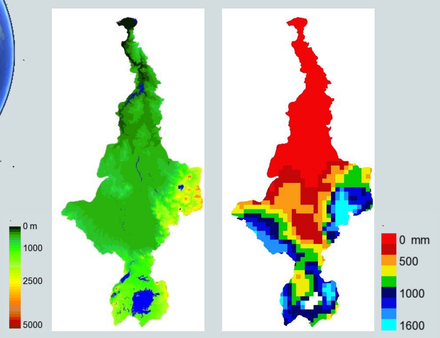




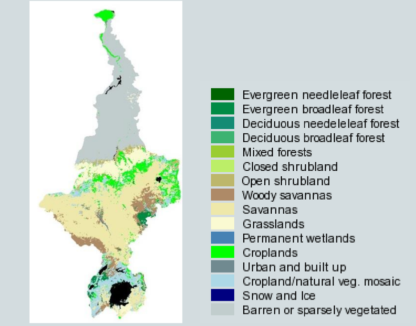
NDVI



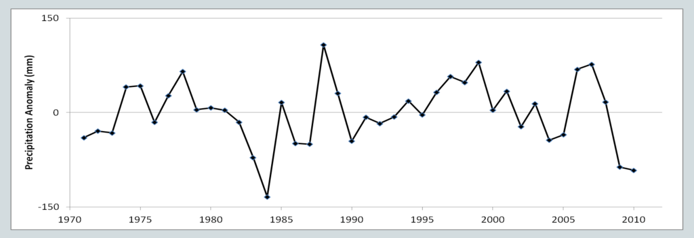
EVI2



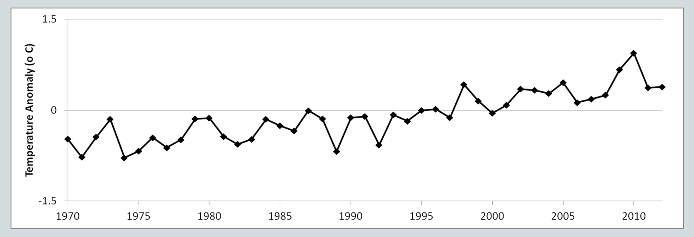
ELEVATION PRECIPITATION



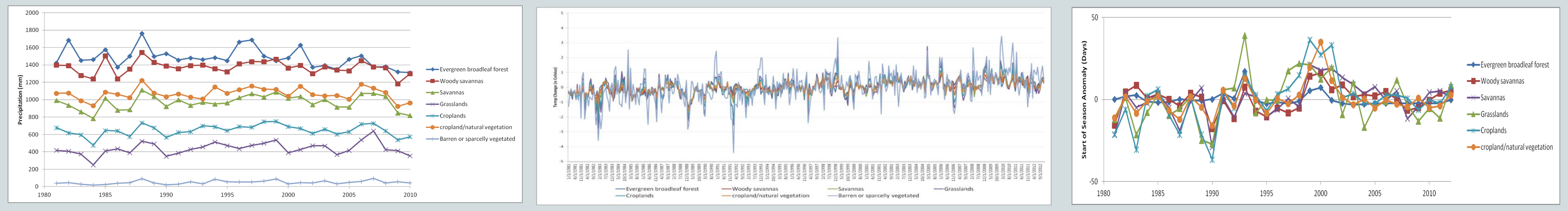
MODIS LAND COVER



Precipitation Anomalies shows the strong droughts of the 80'ies and a sustain wet period in the 90's. Temperature Anomalies shows a steady increasing trend. Except for the 90ies, this increase in temperature is associated with a wet period at lower elevation and dry period at higher elevation.

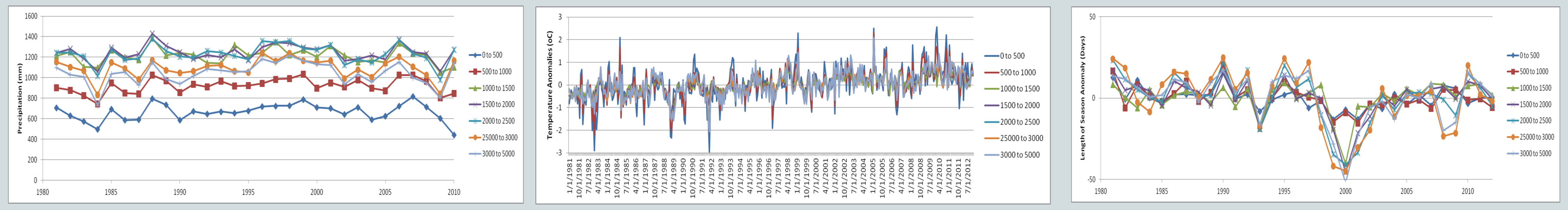


Analysis by Land Cover



Land Cover % per year	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Water	7.61	7.59	7.59	7.56	7.55	7.52	7.54	7.53	7.54	7.53	7.54	7.55
Evergreen needleleaf forest	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Evergreen broadleaf forest	9.59	9.44	9.54	9.37	9.40	9.21	9.28	9.27	9.30	9.27	9.32	9.39
Deciduous needleleaf forest	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Deciduous broadleaf forest	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.02	0.01	0.00
Mixed forest	0.06	0.02	0.01	0.02	0.03	0.04	0.04	0.02	0.02	0.02	0.02	0.04
Closed Shrubland	0.21	0.14	0.10	0.08	0.09	0.11	0.03	0.07	0.08	0.19	0.15	0.10
Open Shrublands	3.72	3.91	3.71	3.91	3.51	3.91	3.19	3.69	3.88	4.23	4.44	4.07
Woody savanas	6.46	6.65	6.37	6.56	6.37	6.36	6.41	6.39	6.34	6.56	6.69	7.27
Savanas	13.04	12.35	11.98	10.13	10.88	10.94	11.28	11.24	10.85	11.19	10.68	10.65
Grasslands	8.77	9.23	9.91	10.78	10.32	9.39	9.89	10.07	10.64	9.63	9.74	9.09
Permanent wetlands	0.09	0.14	0.16	0.18	0.18	0.21	0.23	0.24	0.21	0.22	0.19	0.23
Croplands	3.65	3.71	3.79	4.07	4.98	5.06	5.52	5.03	5.14	4.73	4.75	4.92
Urban and built up	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
Cropland/natural vegetation	5.85	5.95	6.07	6.78	5.97	6.31	5.74	5.67	5.59	5.83	5.93	5.87
Snow/ice	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Barren or sparsely vegetated	40.89	40.80	40.69	40.47	40.65	40.84	40.79	40.71	40.35	40.50	40.47	40.73

Analysis by Elevation



The clustered (LC and Elevation) precipitation and Temperature anomalies are consistent with the overall trends (steady Temp increase) and complex Precip. patterns that is Elevation dependent. This corresponds to a steady Land Surface Phenology metrics response considering the overall error (15-40days). The strong 2000 anomaly is most likely due to additional precipitation creating a 2nd season.

Results

Sensitivity of the basin's vegetation cover to climate was assessed using a simple diagnostic and correlation analysis approach. Over the last 30 years the basin experienced extreme climate events, in particular droughts (80'ies) and a noticeable and sustained recovery starting in the 90ies. While the temperature showed a steady increase, the precipitation showed widespread recovery (Wet period). This precipitation recovery (starting in the 90'ies) continued at lower elevation , whereas drier conditions started to show up at higher elevation. We looked at the associated changes in the vegetation index signal over the same period.

The overall response was complex owing to the complex climate regime (dry - wet, while increasingly hot), to topography, and the complex land cover of the region. Vegetation response was negative corresponding to the decrease in precipitation, until a strong and widespread recovery starting in the late 90'ies. The greening trend continued but started to break down with elevation as temperature started to play a more prominent role. The combined drier and hotter climate started to negatively impact high elevation vegetation. Over the same period we also observed an intensification of agriculture production corresponding to an increase in percent cover and productivity. These changes were mostly driven by changes in the precipitation regimes with initially little impact of the temperature. However, the temperature sustained increase started to have the stronger impact when associated with the slightly drier conditions.

Conclusions

Climate models project an eventual decrease in precipitation and continued increase in temperature for this region . These diagnostic results coupled with these climate change projection point to major negative impacts on the vegetation cover, productivity, and eventually their associated ecosystem services. These results suggest that the earlier changes will be experienced by the higher elevation areas.

References

Barreto A.M., Didan K. et al. A 30 year multi-satellite record of vegetation index and phenology (in prep).
Peterson, Thomas C. and Russell S. Vose, 1997: An Overview of the Global Historical Climatology Network Temperature Data Base, Bulletin of the American Meteorological Society, 78, 2837–2849.
Schneider, Udo; Becker, Andreas; Finger, Peter; Meyer-Christoffer, Anja; Rudolf, Bruno; Ziese, Markus (2011): GPCC Full Data Reanalysis Version 6.0 at 0.5°: Monthly Land-Surface Precipitation from Rain-Gauges built on GTS-based and Historic Data. DOI: 10.5676/DWD_GPCC/FD_M_V6_050

vegetation index & phenology Lab.
...Understanding a piece of the Earth system
http://measures.arizona.edu

Acknowledgements: This work was supported by NASA grants #NNX08AT05A and #NNX11AG56G (Kamel Didan, PI)