Climate and Human Impacts on Water Resources in Africa

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Abstract: The availability of fresh water is one of the most critical environmental issues of our time [Postel *et al.*, 1996]. This is particularly true in Africa where large portions of the continent are arid or semi-arid and the precipitation is highly variable. Additionally, large changes in land cover/land use and water management practices have taken place during the last 50 years including: removal of water from river systems for irrigation and consumption, degradation of forage land by over-grazing, deforestation, replacing natural ecosystems with mono-cultures, and construction of dams. The relatively large population and delicate ecosystems therefore, depend on water resources that vary greatly due to climate fluctuations and human induced changes. With increasing population and development pressures on existing water supplies in Africa the vulnerability of the populations dependent upon these resources will likely continue to grow. Therefore, it is crucial that we improve our understanding of the variability of terrestrial hydrologic systems in Africa, and how human activities may affect those resources.

Changes to the surface water resources in Africa result from complex interactions between a number of different factors including: natural climate variability, land use/land cover changes, and changes to water management practices. Quantifying the importance of these factors and providing information for timely response to resource variability will require a combination of diverse scientific tools applied in a flexible framework. We feel that those tools are now beginning to become available: 1) satellite data is of sufficient length and accuracy to quantify land use and land cover, and monitor water resources; 2) ecosystem and hydrology models can now accurately and explicitly model regional water resources, such as river discharge, lake level, and lake area; and 3) our understanding of the response of humans to resource variability in Africa has matured to include flexible community based solutions.

We feel that now is the time to explore the combination of these tools for water resource assessment in Africa. In this study we will assemble a combination of researchers with expertise in the development and application of each of these tools. Our goal is to simultaneously quantify the relative impacts of the three major determinants of the observed changes in terrestrial hydrology in Africa since 1950: (1) climate variability, (2) land use/land cover change, and (3) water management practices.

We will concentrate our efforts in four regions in semi-arid and arid Africa: (1) the Niger River and its interior delta, (2) the Lake Chad/Chari River system in north-central Africa, (3) the Sudd marshlands of the Nile, and (4) the Okavango River and its interior delta in southern Africa. We have chosen these four regions because:

- *water resources are limited and highly variable*
- *population and development pressures are already large and increasing*
- *land use and land cover changes have been significant*
- *current or suggested future water management schemes are large in relation to the water resources and have international implications*

KEYWORDS
Research Fields: Anthropogenic Effects, Land Cover Classification, Ecosystem modeling
Geographic Areas: Sahel, Southern Africa
Remote Sensing: AVHRR, MODIS, Radars
Methods/Scales: Regional scale, Time series analysis, Integrated assessments

Our research directly addresses **NASA-ESE scientific questions; a**) what are the changes in land cover and/or land use (monitoring/mapping activities) --by merging satellite and census data to quantify how land cover and land use have changed over the last 50 years and **c**) what are the consequences of LCLUC --by quantifying the impact of LCLUC on the water resources of Africa. **Proportion of social science** – 25%, **water** – 100%

Our research team aims to improve our understanding of the terrestrial water resources (e.g. river discharge, surface water level, and inundated area) of the arid and semi-arid regions of Africa. Our project will link satellite- and census-derived land cover and land use history, satellite observations of surface water level and area, comprehensive regional ecosystem and hydrology models, and ground based observations. Over a three-year period, we will focus on the following **specific objectives**:

- *Quantify land use and land cover history.*
- *Quantify state of water resources through satellite and ground based data.*
- *Quantify the impact of climate variability and human impacts on water resources since 1950 using numerical models.*
- *Investigate applications of our numerical modeling and satellite tools for assessment of near-term water resources.*

Goals and accomplishments for year 1
Overall Project Accomplishments: Hired post-doctoral fellow Kaiyuan Li in May of 2002.

Land use/land Cover- goal: Collect archival data on land use history from national governments and international organizations tallying land cover types. Spatialize census data by merging with satellite data. **Accomplishments:** Not yet complete; are collecting sub-national level census data with help of an undergraduate student hourly and collaborations with the United Nations Food and Agricultural Organization, the International Food Policy Research Institute, and Dr. Babatunde Agbola, University of Ibadan, Nigeria. **Issues:** 1992 croplands data set (based on merging satellite data and national level census data) does not compare favorably with FEWS data

- Are compiling sub-national level data to improve data set

Satellite Observation of Water Level and Area- goal: Identify locations on rivers, lakes and wetlands for satellite observation, collect existing data sets of water area and height. **Accomplishments:** 1) Sites have been located for each region, imagery is being collected for Sudd marshlands 1994-present, archive of TOPEX/POSEIDON (T/P) data for the 4 study regions is continuing and on schedule (will be terminated with satellite re-classification scheduled for mid-to-late 2002), and are ingesting ERS-2 altimeter data for period 1995-present.
Issues:
1) Due to the launch of its follow-on mission, Jason-1 in December, 2001, it is expected that T/P will either be i) switched off, or ii) transferred to a differing orbit during mid-to late- 2002.

- For this project, the T/P data archive will be classed as complete.

2) The NOAA AVHRR images are obtained from the on-line Satellite Active Archive. Unfortunately the new World Wide Web archive system can be very slow due to network traffic.

- Currently looking at ways to refine the search process.

3) ERS altimeter datastreams are vastly larger than T/P and exist on 700 cumbersome exabytes.

- We are looking into the purchase of an exabyte autostacker to speed up the ingestion process.

Modeling impacts on water resources- goal: Set-up and tune models for all African locations.
Accomplishments: Not yet accomplished. Begun initial evaluation of ecosystem model performance for Lake Chad basin

Progress

Our work in year one of our project has been centered on hiring staff, developing the land use data set and compilation of time-transient satellite data of water area and height. We hired a post-doctoral fellow in May of 2002 (Kaiyuan Li) and two undergraduate student hourly workers. The postdoctoral fellow has begun evaluation of our ecosystem and hydrology models with emphasis on improving the efficiency of the models (particularly the hydrology model) and has begun initial simulations for the Lake Chad basin to test the quality of our climate data and model performance.

In year one we have evaluated the quality of our existing croplands data set (Ramankutty and Foley, 1998, 1999, developed by merging land cover classification at 1 km resolution based on AVHRR with cropland census data) against the Famine Early Warning System (FEWS) network data set of "cultivation use intensity" (CUI; based on higher resolution Landsat data) for Western Sahel and Southern Africa. Our initial comparison shows that our data set is poor in the Sahel (Figure 1). In Southern Africa, the intensity of cultivation is well captured, but the precise spatial distribution is not. Thus, we need to improve our representation of cultivated areas for the present day.

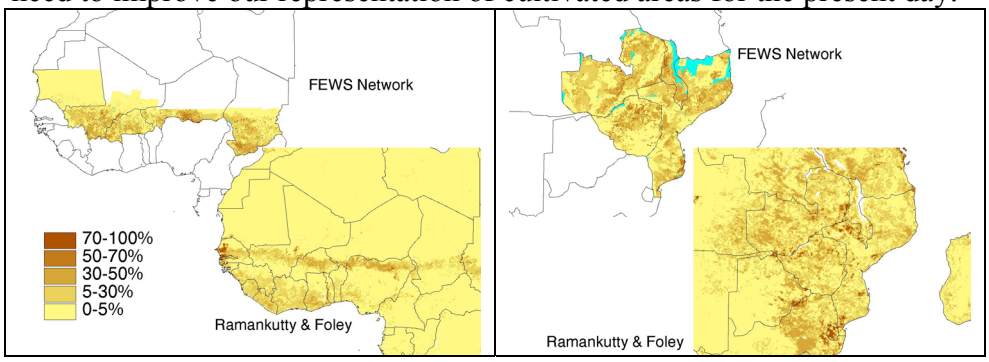


Figure 1: Comparison of contemporary croplands data set from Ramankutty and Foley (1998) and the FEWS network.

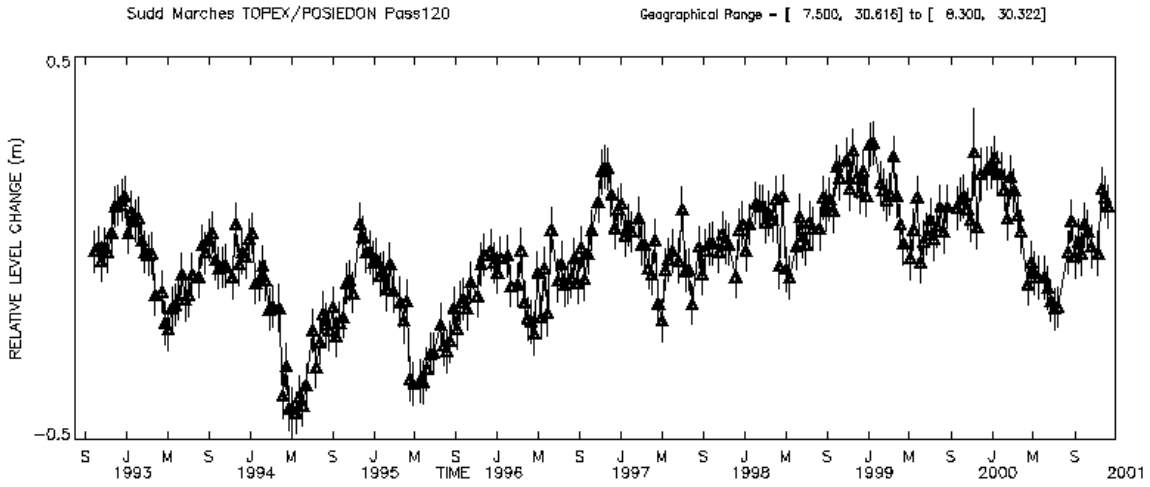
As a first step in improving our land use/cover data we have started compiling agricultural census data for the African nations that comprise our four basins from the latest census, and from previous censuses. To help with this, we have hired an undergraduate student hourly (with funds leveraged from other sources as well, including our collaboration with the International Food Policy Research Institute (IFPRI)). We are compiling subnational (one administrative unit below the nation) data on harvested area for the major crops in the region, livestock numbers (to get an indication of pasture area), and extent of agricultural area (cropland, pasture). So far, we have collected data for the following countries: Chad, Mali, Burkina Faso, Guinea, Nigeria, and Sudan.

We have continued to collect time-series satellite altimetry of our regions of interest. TOPEX/POSEIDON (T/P) data for the 4 study regions continues to be ingested and archived to enable the update of currently derived time series of stage variations (e.g. Fig.1). The ERS altimeter data offers greater spatial coverage of the 4 study regions, although at a much poorer temporal resolution. All software for the ingestion and extraction of ERS data was completed in late 2001, and ingestion of the raw formatted data has begun. We have also instigated a project with a summer undergraduate student Michael Beckley. His main task is the retrieval of AVHRR imagery for the 4 study regions. So far, work has focused on the Sudd Wetlands. It is hoped that images from the ASAR (radar) and MERIS (visible, infrared, 300m resolution) instruments onboard the recently launched ENVISAT satellite can be utilized to complement and in part, validate some of the resulting AVHRR-derived (1km resolution) areal extents of Lake Chad. C. Birkett has been granted a limited image allocation from both instruments, and initial discussions have begun with another Lake Chad expert, Dr. Janet Nichol, as to how to best exploit

this limited resource given the opportunity of multiple frequency's, polarization states, spatial and temporal sampling. Our next steps are to; 1) determine ERS and T/P ground-track position locations over study regions and examine altimetric data, and 2) deduce time series of stage variations and where possible validate with any ground-based gauge data.

Conclusions

In conclusion, the first year of our research has been fruitful. We have hired a post-doctoral fellow to focus on the numerical modeling component of the project. His progress has been exemplary. As a result of his rapid comprehension of our modeling tools we are currently in the initial stages of evaluating the simulated water balance of the Lake Chad basin. Our evaluation of the our existing land cover/use data found problems with the quality but we have been able to collaborate with other researchers to begin development of a higher resolution data set of historical land use in Africa. It is anticipated that this data set will be the most complete data set of its type when completed. Our satellite data collection is also going well. The TOPEX/POSIEDON data provides a continuous record of water height for the period 1993 to 2001. Despite the anticipated decommissioning of this satellite in the coming year we believe that we have an excellent record of water resources where ground based observations are often not available or discontinuous (for example, see figure below for Sudd marshlands on the White Nile). We will be expanding this dataset to include numerous other locations in northern and southern Africa for the same time period.



One unanticipated and positive outcome of our first year of research on this project has been the extreme interest in collaboration generated. Numerous agencies and individuals have contacted us to offer data and support for our satellite and land use/cover data collection efforts. Currently, the following collaborators are actively working with us:

- Niger basin, Babatunde Agbola, University of Ibadan, Nigeria. Dr. Agbola has been appointed to work on land use and land cover change in Nigeria's Niger Delta region. We have decided to work together in our historical land cover data set for the Niger basin.
- Subnational census data for Africa, FAO and IFPRI. Our center, the Food and Agriculture Organization (FAO) (Contact person: Hubert George) and the International Food Policy Research Institute (IFPRI) (Contact person: Stanley Wood) are collaborating on a project to compile subnational agricultural census data for the developing nations. FAO and IFPRI already have extensive subnational census data for Africa compiled from the latest censuses, which they are willing to share with us. Thus, our main efforts will henceforth be focused on historical data collection.
- Co-ordination with the START regional network in Africa. START (contact person: Hassan Virji) is helping us identify scientists in Africa with common interests, and also have offered to help fund doctoral students if their research matches our interests. We have already identified a student who is reconstructing a historical data set of land use/cover for the Okavanga basin.

We anticipate that the coming year will provide rapid advancement towards our goals of quantifying the impacts of climate variability and land use/cover changes on the water resources in semi-arid Africa.