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. Our project links 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. 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%

Goals and accomplishments for year 2 July 2002-June 2003

Land use/land Cover- goals *Quantify land use and land cover history in our four regions of interest***.** **This period:** Fuse archival and satellite data to produce regional land use and land cover maps. **Accomplishments:** Have analyzed the various sources of land cover data in the Sahel for the quality of cropland distribution. Have compiled sub-national census data on harvested crop area for major crops, for many nations in the Sahel. **Issues:** We find that none of the available moderate-resolution satellite (AVHRR, MODIS) based land cover classifications are able to capture the spatial distribution of croplands in the Sahel.

- Solution 1--Have used population density as a proxy to model croplands with some success but this may not be best long-term solution because of "circularity".
- Solution 2--We have begun collaboration with Mark Friedl at Boston University (MODIS Science Team) to try to directly calibrate MODIS data against cropland census data to derive cropland distribution.

Satellite Observation of Water Level and Area- goals *Quantify state of water resources through satellite data.* **This period:** Identify locations on rivers, lakes and wetlands for satellite observation, collect existing data sets of water area and height from 1992 to present. **Accomplishments:** 1) Final ingestion of the TOPEX/POSEIDON GDR data. There is now a 10-year dataset on-line, spanning September, 1992 to August, 2002. 2) Initial evaluation of Jason-1 altimetry (T/P follow-on mission).
Issues: 1) T/P has been moved to another orbit track. There are no viable targets in the Lake Chad basin in the new orbit track. Tracks are still to be checked for the Sudd, Okavango and Niger internal delta. 2) We have found a serious problem regarding Jason-1; a new extra routine in the processing of its raw data, rejects radar echoes (and subsequent height values) if not over calm inland water (rivers, wetlands, and calm lakes).

- Solution --This finding has been reported to the French ground-processing teams, and in due course will be reported to the USA PO.DAAC and NASA/HQ as it seriously affects several NASA funded projects and a USDA-sponsored applications program. However, currently, the problem is *unsolvable*.

Modeling impacts on water resources- goals *Quantify the impact of climate variability and human impacts on water resources since 1950 using numerical models.* **This period:** Set-up and tune models for all African locations, complete initial model runs to evaluate climate impact. **Accomplishments:** 1) Completed major improvements to ecosystem model. 2) Completed tuning of ecosystem model for semi-arid Africa. 3) Developed new hydrology model. 4) Completed initial model simulations for Chad and Niger basins. **Issues:** Ecosystem model (IBIS) needed unanticipated improvements to better simulate the water budget of semi-arid Africa well

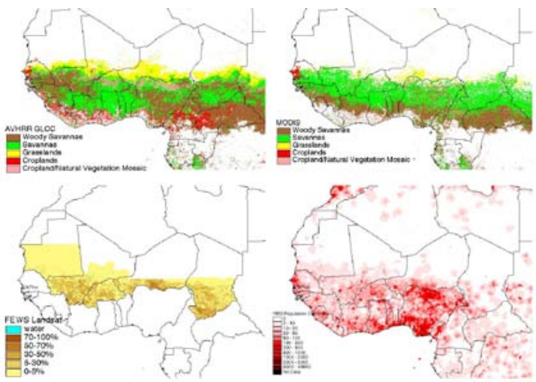
- Solution --Developed new algorithms to represent soil water infiltration, root depth profile, and variable root water uptake. Now probably most complete large-scale land-surface model available.

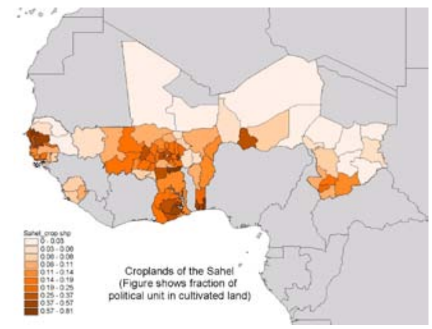
Assessment of near-term water resources- goals *Use numerical models and satellite tools to assessment near-term water resources.* **This Period:** Use satellite altimetry to quantify Lake Chad basin water resources. **Accomplishments:** Developed techniques to accurately estimate mean monthly river discharge and predict (39 days in advance) the monthly water height of Lake Chad from T/P altimetry for period 1992-2002. Results are far more successful that we had initially anticipated.

Progress

Our work in year two of our project has been centered on completing our satellite altimetry data to the end of the T/P record, developing land cover data sets, refining and running our ecosystem models, and developing techniques to derive accurate estimates of water resources from satellite altimetry. The T/P satellite altimetry data is now stored through August 2002 and is being used for the Lake Chad basin. **Next steps** are to: 1) evaluate the available locations in the Sudd, Niger, and Okavango records. 2) Explore and validate the ERS-1 & ERS-2 altimeter data. It is a more complex dataset from which to derive altimetric height and a number of options are being explored to best “retrack” (i.e. gain the most accurate height) the radar waveforms.

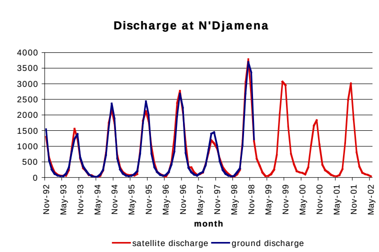
The land cover dataset development and evaluation has progressed well in year two. We have compiled crop harvested area at the sub-national level for many countries in the Sahel (this was aided by collaboration with the Food and Agriculture Organization) and derived a data set of cropland extent by calibrating the total harvested area against the national cropland area estimates from the FAOSTAT database (see figure at right). Additionally, we have compared the currently available land cover datasets (ours and other groups) and found that none adequately describes the spatial location of croplands in the Sahel in comparison to FEWS-Landsat derived data (see figure at left). Therefore we are pursuing two other sources of data on land cover. 1) We have developed a statistical model of land cover based on population and 2) we are also continuing to develop techniques to fuse census data with satellite data. **Next steps:** to continue to collaborate with Mark Friedl (MODIS Science Team at Boston University) to calibrate MODIS derived reflectances directly against cropland census data.





With the addition of our post-doctoral fellow in May 2002 our modeling component of the research has progressed rapidly. The available water resources of the semi-arid regions of Africa are particularly difficult to simulate because they represent a small portion of the total water budget (<10%). Therefore, in the last year we have improved our existing ecosystem model with the addition of numerous new algorithms, including: 1) a Green-Ampt function to improve realism of soil water infiltration, 2) variable rooting depth profile function to better represent deep roots in semi-arid climates, 3) variable root water uptake function to better represent the ability of plants to meet their water needs under variable soil moisture conditions, 4) functions to allow spatial variability of model moisture control parameters to better represent the response to spatial and temporal variability of climate. We have recently developed a surface water transport model, based on a cellular automata, that better represents lakes, wetlands, and rivers as continuous functions. Finally we have completed tuning of the models for the Sahel. Next steps are to prepare two manuscripts for submission to a peer-reviewed journal in Fall 2003, one detailing the new model developments and another the sensitivity of water resources to historical climate variability.

Finally, we have begun using satellite products to predict water resources. Using Topex/Poseidon altimetric data from an upstream



location calibrated with limited ground based data we are able to predict the discharge and lake water height in the Lake Chad Basin 10 and 39 days in advance of local observations respectively for the period 1992-2002 (figure at right). **Next Steps** are to: submit a manuscript to Water Resources Research and to test this procedure in the other basins of interest in Africa.

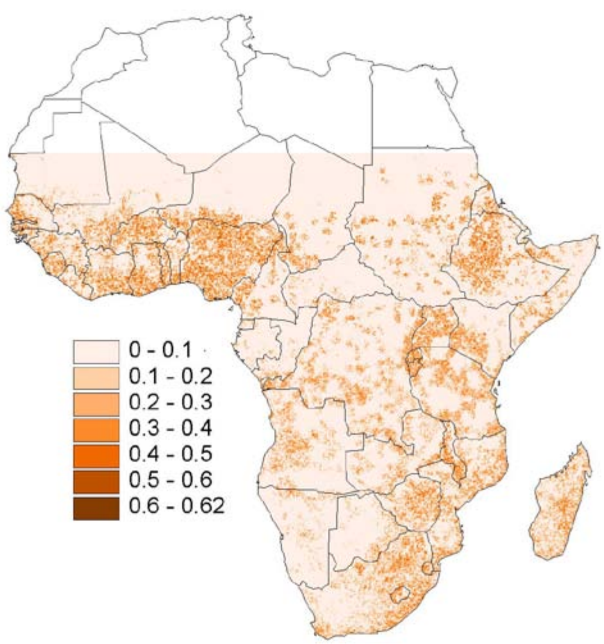
Conclusions

In conclusion, the second year of our research has been one of progress towards our goals. We have: 1) developed long time-series altimetric data for the Lake Chad basin. 2) Improved our understanding of the complexities of land cover detection in Africa, created new land cover products, and have developed collaborations to help improve current land cover products. 3) Made major improvements to our understanding and simulation of land-surface and soil water physics. 4) Applied satellite altimetry to predict water resources in the Lake Chad basin.

- **New findings 1)** We have documented that the Jason-1 data processing algorithm rejects radar echoes (and subsequent height values) over land. Therefore, no data will be available to the Earth System Science community on the height of rivers, wetlands, and calm lakes from this instrument. This problem is likely to seriously affect several NASA funded projects, in addition to ours, and a USDA-sponsored applications program. 2**)** Currently available land cover classification datasets based on moderate resolution imagery (AVHHR, MODIS) are inadequate to represent croplands in the Sahel.

- **New potential** We have shown that the river discharge and lake height in the Lake Chad system can be predicted up to 1-2 months in advance from satellite altimetry. This is the first time this has been shown and represents a potentially valuable tool in aiding water management decisions in the Lake Chad basin. We are testing the technique in other basins to determine its applicability elsewhere in Africa.

- **New products** We have developed a crop cover map based on population and crop statistics that may best represent the current status of crop cover in all of Africa (see figure below).



We have one publication that will be submitted to Water Resources Research by the end of July; Coe, MT, and CM Birkett, **Water Resources in the Lake Chad Basin: Prediction of River Discharge and Lake Height from Satellite Altimetry.** We anticipate two more peer reviewed publications this fall.