Annual Report for Period: 09/2005 - 09/2006 **Submitted on:** 11/01/2006

Principal Investigator: Campbell, David J. **Award ID:** 0308420

Organization: Michigan State University

Title:

BE/CNH: An Integrated Analysis of Regional Land-Climate Interactions

Project Participants

Senior Personnel

Name: Campbell, David

Worked for more than 160 Hours: Yes

Contribution to Project:

Campbell has been involved in administering the grant at the university level. This has involved negotiating space and equipment issues, and overseeing the budget. 2) The land use component of the project.

Name: Pijanowski, Bryan

Worked for more than 160 Hours: Yes

Contribution to Project:

Dr. Pijanowski is leading the land use/cover change modeling activities which are being coordinated with other PIs on the land use/cover change group (principally Drs. Campbell and Olson).

Name: Olson, Jennifer

Worked for more than 160 Hours: Yes

Contribution to Project:

Dr. Olson has led the land use component of the research, and has coordinated the integration of the components of the project. This has included 1) collecting and preparing a variety of data and information concerning land use change, and socioeconomic and environmental variables at the case study and the East Africa regional level; (2) designing and supervising specific studies affecting future land use (urbanization, deforestation related to fuelwood harvesting), and 3) coordinating particularly with the remote sensing and the land use modeling component of the project on, for example, issues of temporal & spatial data comparability. She has also acted as a project manager for much of the project activities, such as coordinating people and research components in the US, UK and East Africa, organizing meetings, hiring personnel, purchasing equipment, etc.

Name: Qi, Jiaguo

Worked for more than 160 Hours: Yes

Contribution to Project:

Dr. Qi has continued the focus established previously. He continues the land cover dynamics analysis over East Africa. He and his students analyzed three currently available land covers (IGBP, Africover, and GLC200)to study which land cover product is best fit for the regional climate model (RAMS). He also worked on the comparison of these three classification systems and tried to merge classes that make sense to the RAMS model.
In addition to these analysis, he worked with his students to derive other surface parameters that RAMS model requires. They include albedo, LAI, fPAR, and surface temperature derived from current satellite images. These data have been organized and transformed to the format that is ready to use for RAMS model. Working with Lijian Yang and his students, Dr. Qi also analyzed the phenological characterisitcs of the LAI and fPAR variables required by the RAMS model. The results from this activity should be a better phenological parameterization derived from the data, to replace assumed parameterization by the current RAMS model. Also, Dr. Qi worked with his students Jianjun Ge, on RAMS model re-paramerization and tested which biophysical parametes (LAI, fPAR, albedo, and geospatial changes of land cover types) are RAMS model most sensitive to. The results from this analysis will help prioretize the tasks when parameterizing the RAMS model.

Name: Andresen, Jeffrey

Worked for more than 160 Hours: Yes

Contribution to Project:

Andresen has been involved with 1) The agroclimatic modeling portion of the project. He participated in the design and set up of two cropping system simulations considered in the project, maize and natural vegetation/rangeland pasture. Major activities thus far have included selection of the simulation models to be used in the project, collection of daily climate, soil profile, and agronomic data from East Africa, early validation of the selected models, and preparation of software needed to stochastically generate sequences of representative daily climate data for use in the models. 2) The regional climate modeling portion of the project. He assisted with the set up new parallel processor computational facilities at MSU and in initial validation of the regional climate models (surface parameterization). 3) The recruitment and hire of two post doctoral (research associate) positions associated with the regional climate modeling and the agroclimatic simulation portions of the project

Name: Huebner, Marianne

Worked for more than 160 Hours: Yes

Contribution to Project:

Dr. Huebner (Department of Statistics) produced estimates for the temporal dynamics of the medians of LAI using different algorithms (Monte Carlo, robust, Levenberg-Marquardt) and assessed the goodness of fit. She led regular discussions about research design and also on the functions for land cover variables used by RAMS, the study area and land cover types to be considered, and the available data and statistical methods that can be used to analyze these data. She also worked with graduate students to produce exploratory statistical analysis to study the temporal and spatial distribution of LAI for various land cover types.

Name: Lusch, David

Worked for more than 160 Hours: Yes

Contribution to Project:

Dr. Lusch has worked on the land cover analyses. A major task has been the selection and quality assessment of different land cover schemes, such as Africover. Dr. Lusch conducted an aerial survey in Kenya over two study sites taking digital video images that permit comparison between land covers on the ground and those reported in the classification schemes.

Name: Yang, Lijian

Worked for more than 160 Hours: No

Contribution to Project:

Dr. Yang supervised the graduate students in Statistics in the production of confidence bands for preliminary data to evaluate the fit of the trigonometric curve for LAI in one land cover type used by RAMS. These procedures will now be available for assessment of the structure of a variety of land cover variables.

Name: Wilson, Sigismond

Worked for more than 160 Hours: No

Contribution to Project:

Mr. Wilson (new PhD student in Geography, MSU) has started a study on migration trends and the political ecology of those trends in East Africa.

Name: Lofgren, Brent

Worked for more than 160 Hours: Yes

Contribution to Project:

Dr. Lofgren, NOAA GLERL Labs, Ann Arbor, has been involved in coordinating the efforts of those involved in the climate work for CLIP. He played a primary role in setting up the 8-node cluster and setting up RAMS to run on that system, and has supervised and done extensive consulting with Nathan Moore in running and testing RAMS in the African domain, and helped to provide guidance in coordinating the input and feedback of land cover data for RAMS.

Name: Conway, Declan

Worked for more than 160 Hours: Yes

Contribution to Project:

Dr. Declan Conway, Climatic Research Unit, University of East Anglia. Drs. Conway and Hansen (below)have collected and disseminated to team members historical rainfall and temperature data for East Africa. They have conducted trend analysis of monthly rainfall examining inter-annual and seasonal variability.

Name: Misana, Salome

Worked for more than 160 Hours: No

Contribution to Project:

Dr.Misana (Assoc Professor, University of Dar es Salaam): completed a case study of land use change and driving forces in Tanzania and participated in a cross-site regional comparison of land use change in East Africa (funded mostly under another project). She also assisted with and participated as an expert in the Tanzanian land use expert systems workshop.

Name: Yanda, Pius

Worked for more than 160 Hours: No

Contribution to Project:

Dr. Pius Yanda (Assoc Professor, University of Dar es Salaam): has collected and made available data and information from Tanzania, including meteorological and GIS data (land cover, etc.). He also prepared and coordinated the Tanzanian land use expert systems workshop (identified and invited the experts, etc.) and wrote a report of workshop results.

Name: Mugisha, Samuel

Worked for more than 160 Hours: No

Contribution to Project:

Samuel Mugisha (Geographer, Makerere University): completed three case studies of land use change and driving forces in Uganda and participated in a cross-site regional comparison of land use change in East Africa (funded mostly under another project). He also prepared and coordinated the Ugandan land use expert systems workshop (identified and invited the experts, etc.) and digitized the resultant land use change 'zones'.

Name: Thornton, Philip

Worked for more than 160 Hours: No

Contribution to Project:

Dr. Thornton of ILRI has organized the establishment of the soils and meteorological database for paramaterizing the crop- and rangeland-climate models for East Africa, and has been conducting initial runs of the models. The research associate in this area who has been hired and will begin work in the next year will build this on.

Name: Kim, Dong-Yun

Worked for more than 160 Hours: No

Contribution to Project:

Dr Kim has conducted trends analysis of historical precipitation data to identify changes in length and severity of droughts.

Post-doc

Name: Moore, Nathan

Worked for more than 160 Hours: Yes

Contribution to Project:

Dr. Moore has been engaged in calibration and validation of the atmospheric model The code has been modified to permit the use of an alternative, more accuate land cover database (Africover). The model has been calibrated via several numerical parameterizations to produce atmospheric conditions in close agreement with observed measurements-- temperature, relative humidity, and so on. At this point the validation is heavily dependent on quality and availability of observations. We have found that observations are extremely sparse in both space and time, and that some gridded datasets offer significantly different respresentations of some variables (see attached figure; scales are different, but maxima/minima are not consistent). Time series of domain-averaged quantities should improve model-to-observation correspondence, at the expense of higher spatial resolution.

Name: Hansen, Clair

Worked for more than 160 Hours: No

Contribution to Project:

Dr Hansen, Climatic Research Unit, University of East Anglia. Drs. Hansen and Conway (above) have collected and disseminated to team members historical rainfall and temperature data for East Africa. They have conducted trend analysis of monthly rainfall examining inter-annual and seasonal variability.

Name: Alagarswamy, Gopal

Worked for more than 160 Hours: Yes

Contribution to Project:

Gopal is running the crop-climate simulations.

Name: Ray, Deepak

Worked for more than 160 Hours: Yes

Contribution to Project:

Land use modelling and input to regional climate models.

Graduate Student

Name: Goodwin, Michael

Worked for more than 160 Hours: Yes

Contribution to Project:

Mr. Goodwin (M.A. student, Geography Department, MSU) has conducted a study of urbanization trends in East Africa. He has collected and collated census and other demographic data for Kenya, Uganda and Tanzania, and has written a report summarizing trends and their driving forces. He has also started a report on tree cutting due to fuelwood collection in the region. Supported with funds from NSF and from FLAS Language Fellowship.

Name: Wang, Jing

Worked for more than 160 Hours: Yes

Contribution to Project:

From the Department of Statistics (MSU),with Lan Xue examined relationships between a number of variables that represent land surface characteristics. These include procedures to analyze the dependence structure of one variable (e.g., LAI - leaf area index) on a large number of other variables, and formulated procedures for the construction of confidence band (error bar) around the regression curve that relates one variable to another.

Name: Xue, Lan

Worked for more than 160 Hours: Yes

Contribution to Project:

From the Department of Statistics (MSU),with Jing Wang examined relationships between a number of variables that represent land surface characteristics. These include procedures to analyze the dependence structure of one variable (e.g., LAI - leaf area index) on a large number of other variables, and formulated procedures for the construction of confidence band (error bar) around the regression curve that relates one variable to another.

Name: Mitchell, Marian

Worked for more than 160 Hours: No

Contribution to Project:

(PhD student, Geography Department, MSU): Ms. Mitchell has conducted several tasks, including a broad literature review and complication of knowledge elicitation methods (for the expert systems workshops), and some GIS data preparation.

Name: Alexandridis, Konstantinos

Worked for more than 160 Hours: Yes

Contribution to Project:

Mr. Alexandridis (PhD student, Purdue University) is coordinating the agent-based model development with Mr. Pithadia and Dr. Pijanowski. He is also leading the development of three peer-reviewed papers on the agent based simulation model. He is also conducting research on how role playing simulation and agent based models can be interfaced.

Name: Wilson, Sigismond

Worked for more than 160 Hours: Yes

Contribution to Project:

Working on issues of urbanization and conflict resolution.

Name: Davis, Amelie

Worked for more than 160 Hours: Yes

Contribution to Project:

Working on demographic projections for East Africa to be linked to the land use models

Undergraduate Student

Technician, Programmer

Name: Pithadia, Snehal

Worked for more than 160 Hours: Yes

Contribution to Project:

Mr. Pithadia (Research Technician, Purdue University)) is working on developing GIS layers for input to the neural network model as well as recoding the model so that it can be used with a mid-scale multi-criteria evaluation component. Male, East Indian, citizen of India.

Other Participant

Research Experience for Undergraduates

Organizational Partners

NOAA Great Lakes Environmental Research Lab

glerl IS providing one-quarter of Brent Lofgren's time, support for some of his travel. Graduate Assistant Jianjun Ge spent time working on RAMS with Lofgren at the NOAA lab in Boulder Colorado.

FAO

Provided land cover data - Africover

USGS EROS Data Center

Provided SRTM data

NASA

Provided MODIS data

University of Dar Es Salaam

Institute for Resource Assessment (IRA) provided meteorological data

Makerere University, Uganda

MUIENR provided meteorological data

International Livestock Research Institute

Administration of CLIP contracts by ILRI continued during the year 2005. By December 2005, all payments had been made. These contracts covered two participants in Uganda and two in Tanzania. These contracts had been running since 2003 the first year of CLIP activities and covered activities reported in last year's annual report. New contracts to cover activities in the current year have been made.

Activities under these new contracts will include:
1. Writing a report on adaptation to climate change in Uganda, Kenya and Tanzania. Which involves collecting existing literature, reflecting on model results, conducting interviews as necessary, and writing the report
2. Liaison with government meteorological services, including assisting in collecting meteorological data as needed;
3. Providing expertise in local and regional weather and climate conditions;
4. Assistance with interpretation and analysis of the regional climate modeling results.
5. Participation in project meetings and workshops,
6. Contributing to the writing of papers and reports.

During the year whose activities are covered in this report, ILRI undertook collection of long term maize yield data from East Africa (Uganda, Tanzania and Kenyan) and visited a number of research stations in the three countries. Data collected has now been presented to the modeling teams in MSU and UK to be incorporated in crop yield models.

Over the year IRLI has undertaken research on the effects of climate change on the composition and distribution of livestock feed resources in Kenya under the CLIP project. The aim of this research is to assess how climate change will affect availability and quality of livestock feed resources especially in the vast pastoral areas where livelihoods depend almost entirely on livestock. The grazing systems in these pastoral areas are characterized by nomadic movements of people and cattle in search of pastures whose presence and grazing quality is determined by the amount of rainfall and length of growing season. These areas have experienced recurrent droughts over the last few decades resulting in major changes livestock herds partly due to availability of feed resources. We have analyzed the distribution of grass species according to 12 major eco-regions in Kenya and characterized their affinities to climatic factors like the length of growing seasons, rainfall patterns and their usefulness as fodder plants.

This work will continue to 2007 and will link up with models being generated on scenarios of vegetation and land cover.

Other Collaborators or Contacts

Activities and Findings

Research and Education Activities: (See PDF version submitted by PI at the end of the report)

Conference Papers

Ge, J., J. Qi, N. Moore and N. Torbick, Quantifying the recent trend of major mountain glaciers using long term AVHRR imagery, Earth System Science Partnership (ESSP) Open Science Conference, Beijing, China, 9-12 November 2006, abstract submitted.
Ge, J., J. Qi, N. Moore and N. Torbick, Comparison of land surface temperature from Moderate-Resolution Imaging Spectroradiometer (MODIS) and Regional Climate Modeling System (RAMS) in East Africa, AAG, Chicago, IL, USA, 7-11 March 2006.
Ge, J., N. Moore, J. Andresen, N. Torbick and J. Qi, Simulating land surface temperature using Regional Atmospheric Modeling System (RAMS) in East Africa (5-P-362), 1st iLEAPS Science Conference, Boulder, CO, USA, 21-26 January 2006.
Ge, J., J. Qi and N. Torbick, Biophysical evaluation of five land covers for land-climate interaction modeling in East Africa, IEEE International Geoscience and Remote Sensing Symposium, Seoul, South Korea, 25-29 July 2005.
Moore,N., B. Lofgren, J. Andresen, B. Pijanowski, J. Olson. 2005. 'Projected Changes in Precipitation Variability and Distribution Due to Land Cover Change in East Africa' Paper presented at the American Geophysical Union fall 2005 meeting, San Francisco, December 6-9 2005.
Moore, N., B. Lofgren, N. Torbick, J. Wang, and J. Andresen, 2006, Modeling changes in energy budget variability and distribution due to land cover parameterization in East Africa. 1st iLEAPS Science Conference, Boulder, CO, 21-26 January 2006.
Olson, J. 2006. 'A multi-scale analysis of three land use systems in the East African savanna.' Paper presented at the NSF Conference on Interdisciplinary Science, Dar es Salaam, May 2006.
Olson, J. and rest of CLIP team. 2006. 'Linking Social Processes to Regional Climate Change,' Paper presented at the Association of American Geographers Annual Meeting, Chicago, IL, March 8, 2006.
Olson, J. 2006. 'A multi-scale analysis of the linkages between human and biophysical processes in East Africa.' Paper presented at the 2006 Annual Meeting of AAAS, St. Louis, MO, Feb. 20, 2006.
Olson, J. N. Moore, B. Pijanowski. 2006. 'Land Use/ Cover Change Impacts on Climate at a Regional Scale: Addressing the human/environment interface in East Africa.' Paper presented at the 6th Open Meeting of the Human Dimensions of Global Environmental Change Research Community (IHDP), University of Bonn, Bonn, Germany, 9-13 October 2005.
Torbick, N., et al. 2006. Land use land cover assessment and parameterization for climate-land interaction modeling. Association of American Geographers Annual Meeting, Chicago, Illinois, USA March 8.
Torbick, N., Lusch, D., Olson, J., Ge, J., Qi, J. 2005. Evaluation of land use land cover for climate û land modeling using videography. Proceedings at the 25th International Geoscience and Remote Sensing Symposium, IEEE, July 25-29th 2005, Seoul, Korea.
Torbick, N. Hession, S., Ge, J., Shortridge, A. 2006. Spatiotemporal interpolation of NDVI and precipitation. American Society for Photogrammetry and Remote Sensing. Reno, Nevada, May 1-5.
Qi, J., Ge, J. Torbick, N. Moore, N. 2005. Land Cover Impacts on Climate Simulations. International Geoscience and Remote Sensing Symposium. Proceedings at the 25th International Geoscience and Remote Sensing Symposium, IEEE, July 25-29th 2005, Seoul, Korea. Seoul, Korea.
Sarah L. Hession, Ashton M. Shortridge, Nathan M. Torbick. 2006. Categorical models for spatial uncertainty. Seventh International Symposium on Spatial Accuracy Assessment in Natural Resources and Environmental Sciences. Lisbon, Portugal. July 5-7.
website

PROJECT WEBSITE
http://clip.msu.edu

RAMS Simulations
We have successfully completed a continuous decade (actually 12 straight years) of RAMS simulations using our regionally-specific phenology

splines.
To our knowledge a simulation with RAMS has never been run this long.
We have tested the differences between regionally-specific phenology and the default RAMS phenology; this comparison will be published in the coming year. We have also tested the effects of our regionally-specific land cover (CLIPcover) compared to the default OGE cover; we expect to publish these results as well in the coming year.

Findings: (See PDF version submitted by PI at the end of the report)

Training and Development:

Drs. Olson, Moore and Andresen have used East African land use change, and climate information in geography classes at MSU, and in General Education classes.

Graduate students Ge, Torbick, Hession and Goodwin have all participated in conference presentations and in writing of research papers (see listing).

Outreach Activities:

Team members have made presentations at public forums, including with policy makers, and campus-wide groups, as well as at professional meetings (see Other Specific Products)._ Graduate students and post-doctoral fellows have been actively involved.

Journal Publications

Alexandridis, K., and B. Pijanowski., "Assessing multi-agent parcelization performance in the MABEL simulation model using Monte Carlo replication experiments.", Environment and Planning B., p. , vol. , ( ). Accepted

Alexandridis, K. T., and B. C. Pijanowski., "Simulating sequential decision making processes of base action actions in a Multi Agent Based Economic Landscape Model.", Ecological Economics., p. , vol. , ( ). Submitted

Zhen Lei, Bryan Pijanowski and Jennifer Olson., "Distributed Modeling Architecture of a Multi-Agent-Based Behavioral Economic Landscape (MABEL) Model.", Simulation, p. 503, vol. 81, (2005). Published

Campbell, David, David Lusch, Thomas Smucker, Edna Wangui., "Multiple Methods in the Analysis of Driving Forces of Land Use and land Cover Change: A Case Study from SE Kajiado District Kenya.", Human Ecology, p. , vol. 33, (2005). Accepted

Xue, L. and Yang, L., "Estimation of semiparametric additive coefficient model.", Journal of Statistical Planning and Inference, p. , vol. , ( ). Accepted

Xue, L. and Yang, L., "Additive coefficient modeling via polynomial spline.", Statistica Sinica, p. , vol. , ( ). Accepted

Ge, J., Qi, J., Torbick, N., Olson, J., Lusch, D. 2005., "Biophysical evaluation of four land covers for land-climate interaction modeling in East Africa.", Remote Sensing of Environment., p. , vol. , ( ). Submitted

Hanson , Clair E. and Declan Conway, "?A cross-scales analysis of rainfall variability in East Africa; from decadal scale to daily scale and from regional scale to station scale??", Climate Research, p. , vol. , ( ). Submitted

Hanson , Clair E. and Declan Conway, "?Simulating East African Rainfall using a Stochastic Weather Generator and Coupled Global Climate Models. Part 1: Model Calibration and Validation?", Climate Research, p. , vol. , ( ). Submitted

Pontius, Robert Gilmore Jr., ... Bryan Pijanowski, Snehal Pithadia, et al., "State of the art of dynamic land-change modeling as measured by quantitative validation.", Annals of American Association of Geographers, p. , vol. , ( ). Submitted

Torbick, N., Lusch, D., Olson, J., Ge, J., Qi, J. 2005., "An Assessment of Africover and GLC2000 using general agreement and airborne videography", International Journal of Remote Sensing, p. , vol. , ( ). Submitted

Torbick, N., Qi, J., Lusch, D., Olson, Moore, N., J., Ge., "Developing land use/land cover and parameterization for climate and land modeling in East Africa.", International Journal of Remote Sensing., p. , vol. , ( ). Submitted

Wang, J. and Yang, L. (, "Polynomial spline confidence bands for regression curves.", Annals of Statistics, p. , vol. , ( ). Submitted

Yang, L., Park, B. U., Xue, L. and Härdle, W., "Estimation and testing for varying coefficients in additive models with marginal integration.", Journal of the American Statistical Association, p. , vol. , ( ). Submitted

Wang, J. and Yang, L., "Polynomial spline confidence bands for regression curves.", Annals of Statistics, p. , vol. , ( ). Submitted

Books or Other One-time Publications

Web/Internet Site

Other Specific Products

Product Type:

website

Product Description:

PROJECT WEBSITE

http://clip.msu.edu

A dedicated site with a link to the CLIP home site has been set up at: http://www.uea.ac.uk/dev/climate/impacts_8.htm

Sharing Information:

Online

Contributions

Contributions within Discipline:

We have successfully completed a continuous decade (actually 12 straight years) of RAMS simulations using our regionally-specific phenology splines. To our knowledge a simulation with RAMS has never been run this long. We have tested the differences between regionally-specific phenology and the default RAMS phenology; this comparison will be published in the coming year. We have also tested the effects of our regionally-specific land cover (CLIPcover) compared to the default OGE cover; we expect to publish these results as well in the coming year.

Data passed from LTM to RAMS in decadal increments has been achieved as part of Coupled System #3. We also have proof-of-concept for passing RAMS data to the CERES-MAIZE model successfully, thus completing all inputs and outputs to and from the climate segment of our loop.

Advances in GeoScience concerning use of globally-available spatial data sets for climate change science have been reported to the international science community via journal articles and presentations at professional meetings.

Contributions to Other Disciplines:

This is a multidisciplinary project and team members have made presentations at meetings of their individual disciplines (see Other Specific Products).

Contributions to Human Resource Development:

Jing Wang completed her PhD in Probability and Statistics under the aegis of the project. Two other PhD students are writing their dissertations and 1 MA student is completing his thesis.

Contributions to Resources for Research and Education:

Contributions Beyond Science and Engineering:

Policy-makers and others (eg NGO's) who have participated at meetings at which project results have been presented, have reported that they have used the experience in their work in East African institutions.

Special Requirements

Special reporting requirements: None

Change in Objectives or Scope: None

Unobligated funds: less than 20 percent of current funds

Animal, Human Subjects, Biohazards: None

Categories for which nothing is reported:

Any Book

Any Web/Internet Site

Contributions: To Any Resources for Research and Education

Land Use Land Cover Change Findings

Assessments

Assessments have been carried out on several available LULC products for East Africa. Products (and administering agencies) evaluated include:

- ***Africover***, United Nations Food and Agricultural Organization
- ***Global Land Cover for the year 2000*** (GLC2000), Joint Research Centre's Global Vegetation Monitoring Unit as part of the Millennium Ecosystem Assessment
- ***MODIS LAI, fPAR, EVI, Clouds, and Surface Temperature***, NASA and the MODIS Land Product Team
- ***Global Land Cover Characterization/Olson Global Ecosystem***, USGS, University of Nebraska-Lincoln, Joint Research Centre
- ***Land-Ecosystem Atmosphere Feedback*** (LEAF) model, RAMS characterization data

Methodologies included both traditional assessment metrics as well as creation of a new biophysical evaluator. The traditional metrics included two primary techniques. The first technique compared levels of agreement/disagreement of land categories between products in the form of contingency, or confusion, tables. The tables indicate particular class trends, overall accuracies, omission and commission errors, and misclassification patterns across the study region. Results show a range of class level agreement (0.3%-92%) and moderate overall general agreement (41%). Example Figure RS1 and Table RS1 illustrate classification patterns and a confusion table for Africover and GLC2000.

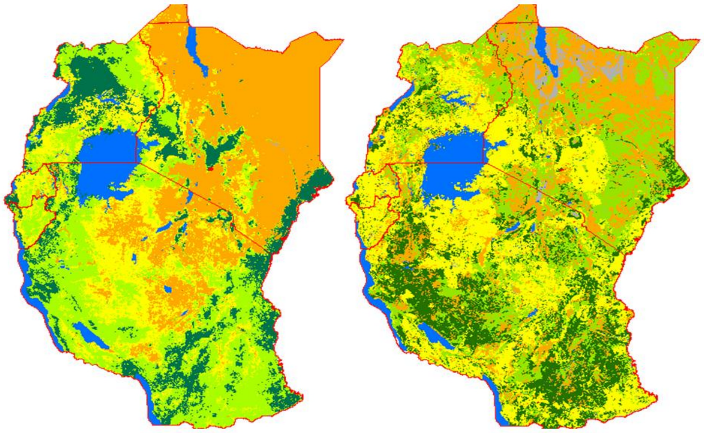


Figure RS1. GLC2000 (left) and Africover (right) aggregated into same classification scheme. *Forest*:dark green, *woodland/shrubland*:light green, *grassland*:orange, *agriculture*:yellow, *barren*:grey, *water*:blue, and *urban*:red.

Table RS1. General agreement between Africover and GLC2000 in East Africa study area.

		GLC2000							
Africover		1	2	3	4	5	6	7	row total
forest	1	**4264900**	10558200	975500	3255200	900	81100	5800	19141600

woodland/shrubland	2	3413500	**7414300**	14458500	7950100	4600	48400	1300	33290700
grassland	3	1770400	7385300	**25741900**	9186200	63300	350700	1300	44499100
agriculture	4	10581000	21437300	10115600	**24947300**	10800	338300	32600	67462900
barren	5	108100	241300	4017400	296400	**15900**	163800	900	4843800
water	6	233300	202800	303500	491100	25500	**11868100**	1500	13125800
urban	7	82100	177600	100500	227800	300	29300	**75100**	692700
column total		20453300	47416800	55712900	46354100	121300	12879700	118500	**74327500**

The second traditional assessment technique included generating fine scale (resolution) data for evaluating products over selected ecological gradients and case studies sites. Approximately five hours of oblique video imagery was recorded over two transects (combined length of about 900 km) that covered notable ecological gradients associated with Mt. Kenya in the north and Mt. Kilimanjaro in the south. A Cessna U206C aircraft was flown at an altitude of 1000 meters above ground level as indicated by the radar altimeter. A GPS unit (Garmin GPS V) fitted with a high gain, low-battery-draw external antenna (Mighty Mouse II) internally recorded the flight tract and placed geographic coordinates and heading information on each video frame using a GPS video overlay unit (SeaViewer Sea-Trak). The digital video data was used as a reference source to assess land product accuracies and land surface biophysical characteristics.

In summary the video assessment techniques found *agricultural* land uses generated substantial errors and disagreement in the remote sensing LULC products. Agricultural land parcels typically exhibit ranging attributes and characteristics. The spatial distribution of crops, leaf type and phenology, management intensity gradients, and cover density commonly vary widely from location to location. Although difficult to capture in a LULC product, this is the reality of land surface conditions in the region. The digital video data showed natural land categories in this region, such as *tree-savanna, shrubland*, or *grassland*, all to exhibit large amounts of biophysical variation as well. In the selected flight lines is not uncommon in this region for a relatively small agricultural parcel to be surrounded by other land types. These small agricultural fields were not identified well in land products that used coarse imagery. Products that had initial classifications schemes emphasizing land use categories, specifically agricultural characteristics, tended to have higher accuracies. A manuscript has been submitted to International Journal of Remote Sensing for publication consideration that summarized these findings.

Due to the limitations of traditional assessment metrics a new evaluation measure was developed. The new statistic, termed ***Q***, was designed to evaluate land products based on biophysical characteristics of the land surface at different scales. The method spatially aggregates within-class Leaf Area Index (LAI) variation over any time period. For our CLIP project we used a two year time span to capture phenological dynamics.

A smaller mean ***Q*** value for a LULC product indicates the more consistent biophysical structure within a class and the more precise for climate modeling. The evaluation executed for CLIP was conducted at three different spatial scales corresponding to

30×30, 50×50 and 100×100 km quadrats. Based on ***Q values***, we found that GLC2000 is significantly lower than LEAF which is the default land characterization in RAMS. For the evaluation in East Africa using two year LAI the statistic ranks MODIS IGBP better than Africover, which ranks better than OGE. In theory, the **Q** statistic can be adjusted to use any remote sensing product for any time period on any scale.

RS Phenology:

Within the RAMS model, vegetation phenology was modeled as a function of latitude and longitude of a simple sine and cosine functions. While in reality, vegetation phenology varies with location weather conditions and local elevations. Depending on the precipitation pattern, vegetation may have different seasonality even though they are at the same latitude. To capture seasonality for each land cover type at each geographic location, spline techniques were applied to a four-year record of leaf area index (LAI) derived from MODIS products. The spline technique generated a set of coefficients for each geographic location (the RAMS simulation grid cell) that can be read into the RAMS model for improved modeling. The spline curves showed a significant deviation from those since or cosine curves that otherwise would have been used in the RAMS model. Because of better and more accurate representation of the vegetation phenology of the region, the regional climate simulation is expected to have better representations of the climate conditions of the study area. (See below of improved simulation).

LULC-RS Product Simulations

The impact of LULC product choice needs to be assessed in order to evaluate the importance the role land surface parameters play in climate-land modeling. Further, human land use land cover changes can be assessed by simulating multiple land use and land covers incorporating change aspects. Each of the different products has different land surface parameters modeling radiation absorption, exchanges of sensible and latent heat between land and atmosphere, storage of energy, and physical surface characteristics. Short run simulations of the LULC products in RAMS were carried out to examine climate model parameterization capabilities and impacts of artificial LULC changes. An example of a specific objective under the product simulations was to compare land surface temperature simulations among LULCs.

The products were used for a 5 month time span in 2003 using RAMS version 4.4. All of the simulations were performed on a nested grid configuration. The outer grid has 34 × 40 points at 80km intervals, while the inner grid has 62 × 62 points at 20km intervals. Both grids extended over 32 vertical levels, with the lowest atmosphere level located at 50m above ground level. A 60 second time step was employed for the outer domain, and 20 second time step for the inner domain. Initial grid lateral boundary conditions were provided by the NCEP-NCAR global reanalysis dataset. The Kain-Fritsch scheme was used to parameterize on the model grids. The surface energy budget is represented by LEAF-2, which represents land surface biophysical characteristics within RAMS and partitions net radiation into sensible, latent, and soil heat fluxes.

The inner domain temperature from RAMS using OGE (Fig RS2a) was compared with MODIS land surface temperature (LST) product (MOD11C2) (Fig RS2b). Fig. RS2 qualitatively illustrates similar spatial patterns. MODIS LST maps the temperatures of soil and vegetation on the land surface at 0.05 degree pixel size. RAMS produces a couple of surface temperature variables. The cell averaged vegetation temperature generated from RAMS was used to compare results. Observation time for MODIS LST at this location is approximately 8:30 UTC, while RAMS vegetation temperature was calculated for 9:00 UTC. Both temperatures are averaged over a five month period: Feb to Jun in 2003. The differences in generated parameters between simulation results and validation products make direct comparisons challenging. Thus examining their spatial patterns is more appropriate. Overall, RAMS vegetation temperature has captured the general spatial pattern displayed by MODIS LST. Temperatures near the eastern edge and western edge are higher than that in the center of the study region. However, MODIS temperature at three locations (north and southeast of Lake Victoria and southwest portion of the study area) are much higher than the corresponding RAMS temperature. In these three places the major land cover types are open grassland and croplands, vegetation density is relatively low. RAMS vegetation temperature in these locations possibly underestimates the reality.

RAMS temperature results in the inner domain from the simulations were compared to study the effects of different land cover products on the regional climate simulations. For this comparison, screen surface temperature (2m above surface) was used. First, five month screen temperatures at 9:00 UTC were averaged for each of land product simulations. Then averaged screen temperature from the first simulation (OGE) was used to subtract that from the second (GLC2000) and the third (MODIS) simulations. Two difference maps between land cover products generated surface temperatures over the study area are illustrated in Fig. RS3. Figure RS3a is the difference between OGE and GLC2000 (TGLC-TOGE) and Figure RS3b is the difference between OGE and MODIS (TMOD-TOGE). For Figure RS3a, the maximum, minimum, and mean differences are 5.9, -9.7 and -0.06 Fahrenheit degrees respectively. In the western portion of the study area higher temperatures are produced by OGE. For Figure RS3b, the maximum, minimum and mean differences are 3.4, -11.3 and -1.1 Fahrenheit degrees respectively. In Fig. RS3 the southwestern portion of the study area OGE has higher temperatures present.

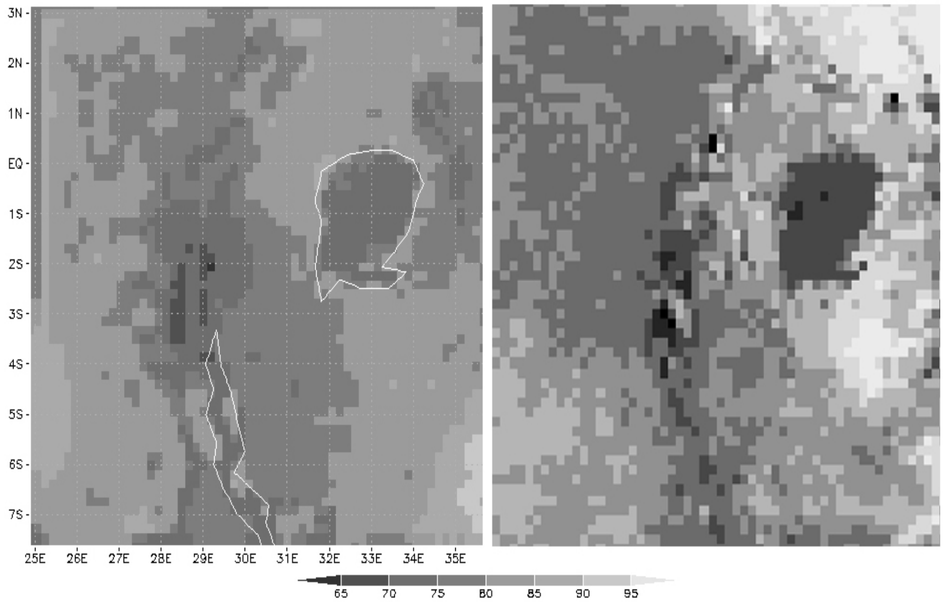


Figure RS2: Five month (Feb – Jun) averaged vegetation temperature (a) and five month averaged MODIS land surface temperature (b). The units are Fahrenheit degrees.

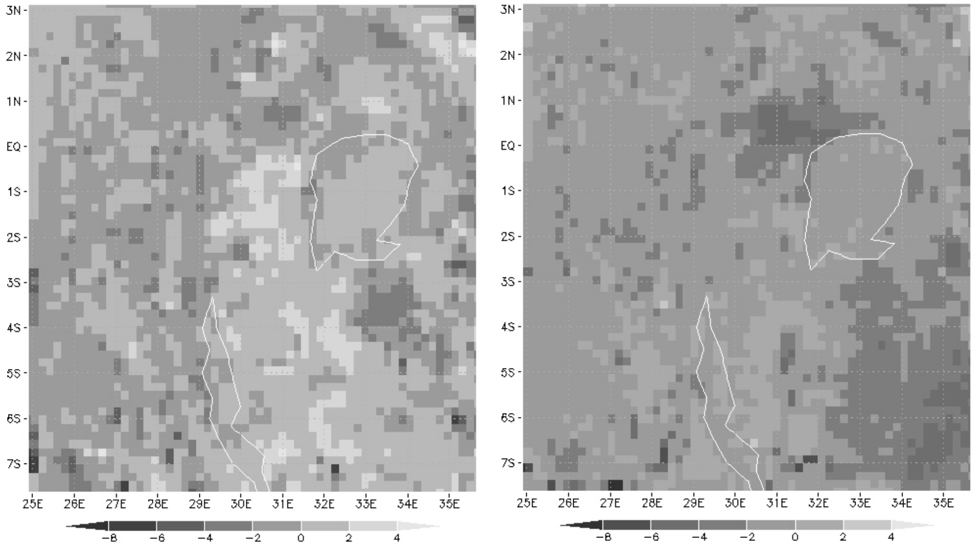


Figure 3: Five monthly (Feb – Jun) averaged difference of screen (2m) temperature between simulations using OGE and GLC2000 (a) and between simulations using OGE and MODIS IGBP(b). The units are Fahrenheit degrees.

Dataset Generation and Project Connections

A large effort has been to integrate remotely sensed products with other various activities CLIP is undertaking. Working closely with other subgroups, specialized datasets have been developed to parameterize models operating in CLIP to East Africa conditions. A variety of products from the NASA Earth Observing System, Landsat, SPOT, MODIS, TRMM/TMI, aerial flights, and others have been processed, developed, organized, and integrated. These include Leaf Area Index, Land Surface Temperature, Albedo, Land Use Land Cover Change, Fractional Cover, Precipitation, Enhanced Vegetation Index, Net Primary Production, and others. All of which have been developed at a range of spatial and temporal scales. These dataset and specialized hybrids will improve analysis and model simulations for many of the CLIP activities.

Land cover variability:
Model simulations have been performed with the LPJ (Lund-Potsdam-Jena) dynamic vegetation model over East Africa to investigate 20th century land cover variability. The model has been driven by CRU05 monthly gridded climate dataset at 0.5° by 0.5° resolution for the entire East African domain for the period 1901-2002. Annual output of land-cover types, vegetation and soil carbon and hydrology have been produced.

A comparison of land-cover types and carbon fluxes between 1901 and 2002 has been performed. A decline in C4 grass as the dominant plant type has been simulated as a result of wetter conditions in model year 2002 compared to 1901. Since the 1920s there has been and substantial increase in vegetation and soil carbon and NPP for the entire regions. Carbon fluxes due to fire are highly variable over the 100-year period.
Future work will examine a) land cover and carbon trends over the 20th century and b) land cover and carbon variations due to wet and dry conditions associated with El Niño Southern Oscillation (ENSO) and Indian Ocean Dipole (IOD) events in the 20th century for different climatic regions within East Africa. This work will be performed in collaboration with colleagues Clair Hansen and Declan Conway at the University of East Anglia, UK.

Sensitivity to climate:
Further simulations have been performed to test LPJ model sensitivity to the underlying climate and its spatial and temporal resolution. Simulations were performed using a) daily and b) monthly station climate data from 10 East African stations (courtesy of P. Thornton). Simulations varied with weather station varying between 7-40 years. Annual vegetation, soil and hydrology output has been archived.
Analysis of these simulations will enable an evaluation of:
a) Vegetation model sensitivity to the spatial scale of the input climate data: gridded vs. station data
b) Vegetation model sensitivity to the temporal scale of the input climate data: monthly vs. daily climate data.
Preliminary analysis suggests strong sensitivity of carbon (vegetation and soil) fluxes to both the spatial and temporal scale of the driving climate data.

This work will be written up for publication in peer-reviewed journals in 2006.

Land Use

1)

The data collected in the initial phases of the project has been used in conjunction with remotely sensed imagery and additional field verification in the preparation of a land cover map that provides a more region specific portrayal of land cover than pre-existing coverages (see discussion above).

2)

The analyses of land use change processes and patterns have been continued and specific attention has been paid to the political ecology of three important processes – migration, urbanization and fuelwood/deforestation, (around 90% of urban populations use charcoal made from native tree species for all their cooking). The outcomes of the variety of land use studies have been applied in the parameterization of the land use change models and are one basis for assessment of model performance (see below).

3)

Two versions of LTM output for the region have been developed to date (Sept 2005). Both version produce rain fed crop expansion from current to 2040 at five year time steps. Data from the UN Population Projection Forecasts (2004 revision) were used to determine future amounts of rainfed crop use. An urban change model is also under development.

The CLIP LTM version has required developing new approaches to modeling in areas where land use change data do not exist. First, we have developed an LTM potential version of the model that allows the neural network to learn about the current location of a use based on spatial input drivers (e.g., elevation, meteorological information like rainfall, temperature, etc). Previous versions of the model worked solely on change maps. Second, calibration tools that are used to judge model performance (Kappa, receiver operator characteristic curves) needed to rewritten so that inputs to these tools work on one time map rather than on two maps that produce a change map.

Recent work has also shown that the number of training cycles greatly influences model performance based on accuracy of location, probability distribution and the shapes of resulting uses in the landscape (Pijanowski et al., 2005). We have now found that most simulations in East Africa take around 250,000 cycles to produce reasonable output. Areas in the United States require 40,000-60,000 cycles to produce adequate results (e.g., Kappas > 0.6).

One of the more interesting results of the LTM modeling has been the discovery that rain-fed agricultural potential modeling produces adequate results at fairly coarse cell-size resolutions of 1km. Modeling of urban spatial location and pattern performed very poorly (Kappas near 0.0) for all major urban centers in the region (Nairobi, Dar es Saalam and Kampala). A model for Nairobi composed of 90m cells parameterized using the same spatial drivers (e.g., distance to road, distance from town center) produced reliable model output (Kappas > 0.68). Thus, a tipping point of model accuracy exists somewhere between 90m and 1km where resolution size begins to degrade model accuracy. These are exciting results as it indicates that there are significant scale issues that need to be addressed in modeling different land uses, especially at large regional scales such as East Africa.

We have also been able to produce a set of LTM outputs that randomly assign locations of change but produce maps in the amount of rainfed agriculture anticipated from our forecast "demand" model based on the UN Population forecasts. We intend to use these to determine whether a random model has any impact on regional climate-land interactions compared to a spatially explicit model of land use change.

We intend to use the expert system maps generated from the 2004 local workshops to compare these projections. We will likely need to develop a set of qualitative and quantitative metrics to characterize these differences. We also intend to use the Likert scale weights provided by the experts to create another set of projections that can be used as part of a larger collection of "ensemble of model runs" that can be summarized conceptually for use in decision making and comparing different scenarios. We have outlined a "future space" concept that allows us to quantify a set of model ensemble run. Many of our routines have in the past been conducted by hand either in the GIS or using the neural net software. We have now automated over two dozen steps in the GIS, statistical packages and using the neural network batch routines. This increases our ability to select the best model from a large neural net simulation entailing hundreds of thousands to millions of cycles and to examine model performance behavior across these simulations.

As part of a related study, Pijanowski and his group have embarked on a spatially-explicit population model that would help us to examine how large shifts in gender spatial distribution, effects of conflict, changes in fertility transitions, etc. would affect land use change at large scales. The model is being developed for the study area, and other areas around the world (e.g., Nepal, Costa Rica). We have begun to interact with scholars in this field, including Waldorf at Purdue and Sweeny at UC Santa Barbara.

4) Our Role Play Simulation (RPS) is being written up for submission to the Journal of Artificial Simulation of Social Systems (JASSS). We argue that the RPS exercise helps us to: (1) prioritize spatial drivers for inputs to a reduced form land use change model, such as our the neural net based LTM; (2) understand human behavior as it relates to the parameterization and testing of our agent based model, MABEL; (3) investigate important factors that are difficult to model, such as wildlife-human conflict, and determine it's role in developing social models. Future work will focus on how we can use the RPS to parameterize a MABEL-type agent based model to test our understanding of how biophysical and socioeconomic factors influence human behavior and social interaction.

5) Advancements in an agent-based model (MABEL) that simulates land-bidding-land division behavior using Bayesian Belief Networks and GIS have been made so that the model uses the highly irregularly shaped land use/parcels in our case study regions. A set of spatial metrics and temporal agent-goals were applied to the case study regions in East Africa and compared to regions in the United States. Two papers have been published

on this aspect of the model. One of these papers (Alexandridis and Pijanowski in press) explored how a Monte Carlo approach can be used to examine the behavior of the model using a stochastic approach to model parameterization and the other (Lei et al, 2005) describes how tools are integrated to simulation agent behavior in a spatial context. A third paper has been submitted to Ecological Economics that outlines the core MABEL model and showcases some of the model components (e.g., Bayesian Belief Networks, land-bidding and agent-agent interaction)

6) The Land Transformation Model (LTM) has been subjected to a battery of performance tests using several large regions in the United States. We have recent published on paper in the International Journal of Geographic Information Science that describes how we use a scaleable window metric, Kappa statistic, shape metrics (e.g., FRAGSTATS) and transition independent statistics (e.g., receiver operator characteristic) to judge model performance. We found that neural networks perform well in most situations, improve performance when training is extensive (e.g., over 60,000 cycles) and when locations used to train the model have had considerable about of change (e.g., > 25%). We have now developed code that calculates these metrics for a variety of training cycles storing them in a format for large scale analysis (i.e., so that we may compare thousands to millions of different LTM models generated by the neural network). New metrics are also being developed (Bayesian classifiers) that quantify how well the model predicts the distribution of patch sizes across the landscape. A draft of a paper has been completed, with a German scientist as co-author, that examines how well the model performs in landscapes where the amount of change varies considerable as well as the degree of fragmentation. In brief, we found that the LTM model performed well at very large training cycles (~500,000) for patch size distributions that were very small and very large; the model did not perform well on mid-size patches of urban use.

7) The Land Transformation Model (LTM) has now been compared to seven other well known land use change models (Pontius et al., in review) in a recent IGBP LUCC study. Results show that the LTM performs well in areas with highly fragmented land uses but does not do as well as other models (e.g., CLUE) in terms of transferability. The authors (Pijanowski is a co-author) argue that more intermodel comparisons are needed that place each of the models on “equal ground” as each were developed for specific purposes and applied to different areas of the world.

Climate Downscaling Findings

This has resulted in:

1. Century to decadal scales for East Africa: Comparison between two gridded rainfall products shows that despite efforts to ensure spatial and temporal homogeneity, the GPCC grid series do not differ noticeably from the CRU TS 2.1 grid series over East Africa. This is likely to be a consequence of low density of stations that meet both datasets’ quality control criteria in the East African region so that their grid series are based

on similar station networks. The CRU gridded product indicates that over the 1901-2002 period the East African region has experienced different trends in annual rainfall. The spatial behaviour of annual linear trends for four timeslices show that at the beginning of the 20th Century the western part of the region experienced increasing rainfall, this shifted to the north during the 1931-60 period, was isolated to the regions of highest topography during the 1961-90 period and covered the eastern half of the region during the last 12 years of the record.

2. Sub-regional: Local scale analyses of annual, seasonal and daily rainfall characteristics in three sub-regions of East Africa show that it is difficult to generalise about temporal variability in these areas of diverse terrain. Between the sub-regions there are some similarities, e.g., the seasonal regimes are similar in Kenya/Tanzania and Uganda along with some differences, e.g., interannual variability; SW Tanzania shows a stronger drying trend than the Kenya/Tanzania and Uganda sites. There is also considerable temporal variation within the sub-regions despite the fact that most of the stations in each sub-region also lie within regions of temporal coherence identified by regionalisation methods.
3. Station and grid-box scale interannual variability: SW Tanzania shows a slight drying trend in annual rainfall with the exception of Mbeya across the full station record. This trend is replicated by the GPCC data (1951-2000) and is also found in both data sets for the overlap period. The Ugandan stations show decreasing rainfall in the most northern locations and increases in the most southern stations whilst GPCC shows decreases across the Ugandan region. The overlap period for both data sets indicates a general decrease in rainfall with the exception of Lyantonde. Kenya/Tanzania shows a mixed pattern of increasing and decreasing annual rainfall, unrelated to location. A reduction in the length of overlap period between the station and GPCC data results in the majority of the stations showing a positive trend. Comparison between the GPCC and station data shows that in general the GPCC grid boxes replicate the trends identified by the station data for the overlap period but are not of equal magnitude.
4. Daily time scales: Analyses based on wet and dry day frequencies in Uganda and SW Tanzania reveal decreases in the number of wet days and increases in the number of dry days over the record whilst for the Kenya/Tanzanian sub-region the number of wet and dry days per year tends to be relatively consistent through time. There is no consistent trend in the wet day amount or the frequency of heavy rainfall days across the three sub-regions, possibly a result of a lack of overlapping data and incomplete series.
5. Cross-Scales analysis: In nearly all cases trends in rainfall are highly sensitive to the period over which they are calculated because there are few examples of long duration sustained trend in any rainfall statistics. Thus, no clear, systematic signal emerges across temporal scales. It is well known that for this reason, seasonal climate forecasts need to be tailored

to particular location specific predictor relationships and that these may be subject to interdecadal variability. This spatial and temporal heterogeneity highlights the difficulty of generalising the interactions between climate and, biophysical and socio-economic systems in the region.

Climate Modelling

Upon completion of validation (see above), we focused our research activities on comparing the default Olson Global Ecosystem (OGE) land cover with a new land cover hybrid, which we call CLIPcover. The first stage of this comparison was to replace the spatial distribution of OGE land cover classes with the CLIPcover distribution. The phenological and temporal variability of these land cover classes was not altered at this point. After 1 month of simulations using both land cover schemes, the RMS differences in accumulated precipitation compared to TRMM estimates are statistically indistinct. Spatially, modeled rainfall reproduced the ITCZ cloud cover but generated much more precipitation at higher elevations. The levels of increased precipitation appear to be related to changes in albedo and shifts in large-scale transport of moisture (Figure M1). Albedo is not well-correlated with precipitation in the southernmost part of the domain and in the Lake Victoria region. These anomalies may be related to differences in upper boundary layer winds and lake temperature respectively, but this is still under investigation.

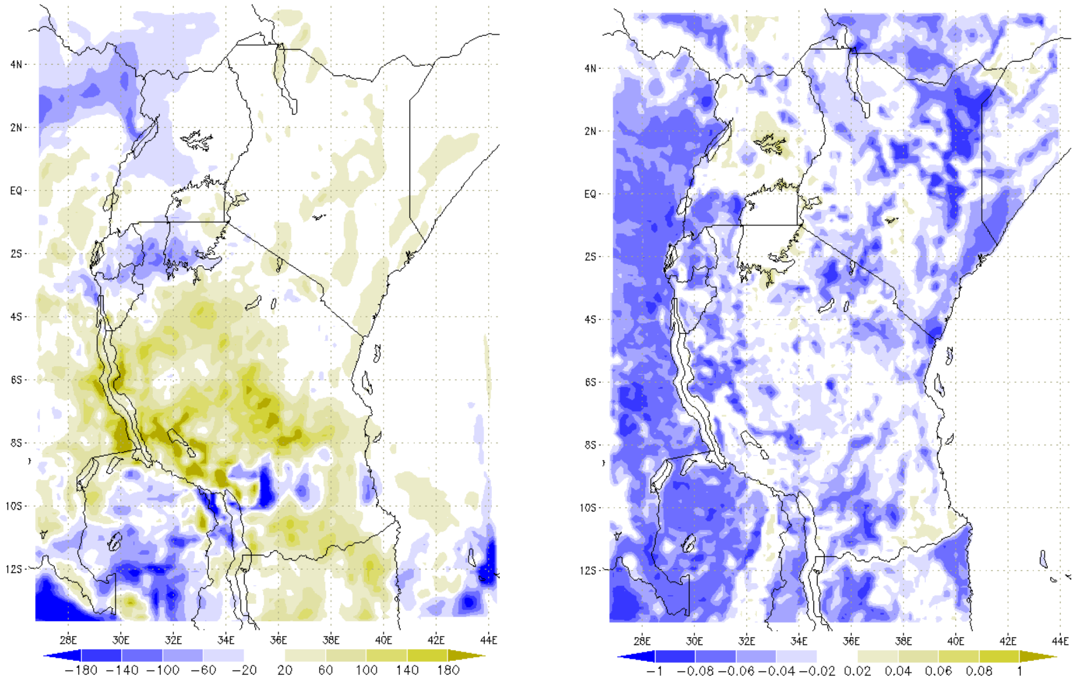
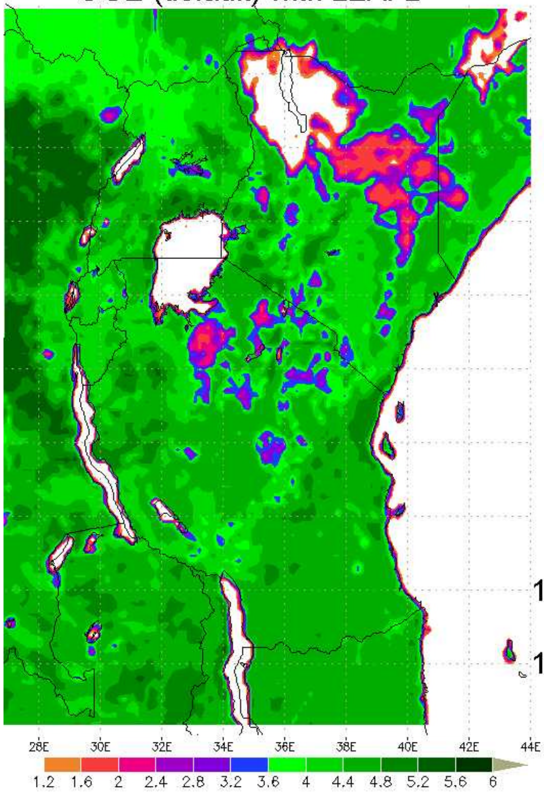
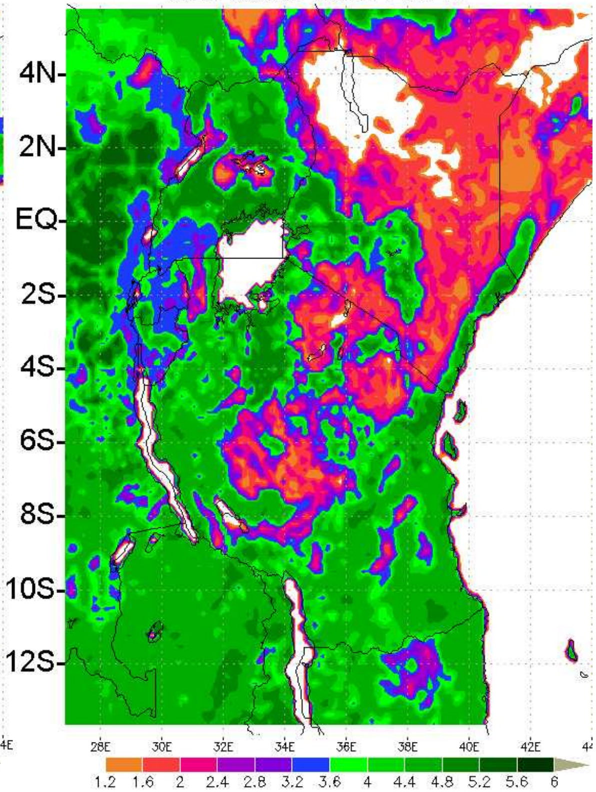


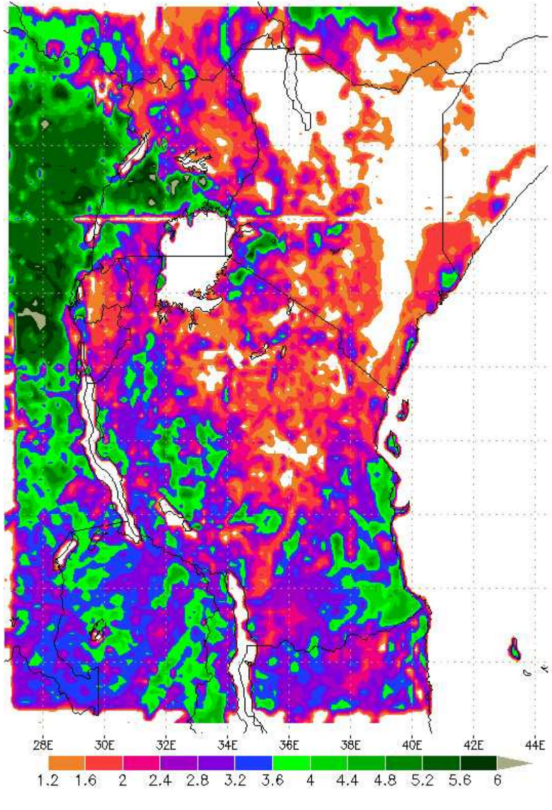
Figure M1.
Simulated accumulated precipitation Simulated albedo difference, difference
(mm), March 8-31, 2000 March 8-31, 2000
(CLIPcover minus OGE cover) (CLIPcover minus OGE cover)

Integration with Land Cover

In most atmospheric models, land cover phenology is represented simply as a function on latitude and Julian day; this is the case with RAMS. However, east Africa is unique among equatorial regions in its low LAI, lack of dense rainforests, and bimodal rainfall pattern. This sharp departure from typical phenology necessitated an improved representation of land cover and a more accurate depiction of vegetation properties—namely, LAI and fractional cover— over time. The LAI splines constructed by Lijian Yang and Jing Wang clearly capture the bimodal character of east African vegetation, particularly for maize farming, and these splines have been incorporated into RAMS. We anticipate reproducing this spline approximation for fractional cover as well in RAMS. Figure M2 shows the changes in LAI resulting from the change to CLIPcover, followed by the addition of the LAI spline function. The MODIS image for that same date is given for comparison. Errors in classification still exist, particularly in the southern parts of the domain, but the overall representation lf LAI in the model is improved.


OGE (default) with LEAF2


CLIPcover with LEAF2


CLIPcover with LAI spline function

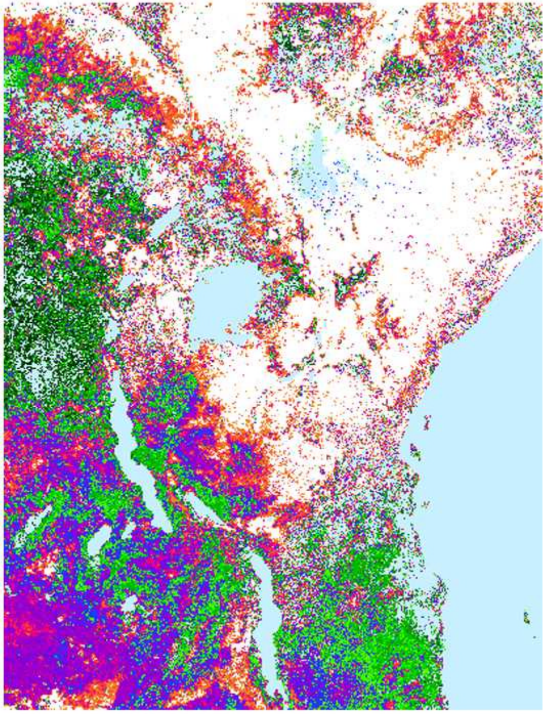

MODIS LAI for 8 May 2000

Figure M2. LAI for east Africa using OGE cover, CLIPcover, and CLIPCover plus LAI spline approximation. MODIS imagery for the same date is provided for comparison. Pale blue in the MODIS image represents water or cloud cover.

Activities and findings:

Research and Education Activities:

The major activities of the project in this reporting period have been to develop a region-appropriate representation of every component of the research framework: climate, crop-climate, land use, land cover and regional climate modeling. This goal has been accomplished together with initial assessment of issues of uncertainty as they apply to model development and application.

Land Use-Land Cover Activities

Over the past year, the Land Cover group continued working on the analysis of the land use and land cover and the linkages to regional climate. Several key areas that the LC group focused on include:

a. Parameterization of regional climate models with remote sensing products. Improved land use and land cover data (Torbick et al., 2005, Torbick et al., 2006), pixelized vegetation phenology information from remote sensing observations (Wang et al. 2006), spatial distribution of albedo, total leaf area index, and total fractional vegetation cover (Ge et al., 2006) were derived from long term satellite observations were parameterized into the most current version of regional climate modeling system (RAMS), adjusted for East Africa geographic domain. The purpose was to improve the parameterization of the RAMS model for more accurate simulation of the regional climate condition under various land use and land cover change scenarios, thus reducing the model uncertainty in simulating the regional climate.
b. Quantification of LULC uncertainties derived from remotely sensed images and analysis of the error propagation to regional climate model (RAMS). Two major conclusions were reached in this analysis. The first one is that there exist significant inconsistencies among the current land use and land cover products, used in regional climate models, that would result in significant uncertainties in regional climate model simulations (Qi et al., 2005). The second conclusion we reached was that there is a threshold of land use and land cover accuracy (80%). When uncertainty or errors in LULC reaches more than 20% regional climate model simulations may not be reliable (Ge et al., 2006).
c. Analysis of sensitivity of regional climate change to land degradation. Although many studies suggest that land use and cover change can result in changes in regional climate, quantification of the magnitude of change required to result in significant change in climate simulation has not been done. Furthermore, past studies focused on the impacts of categorical changes in land use and land cover, little has been done to quantify subtle changes in land surface attributes such as degradation. An example is the degradation of grassland that does not result in land use conversion (Grassland remain grassland but total fractional vegetative cover has been significantly reduced due to overgrazing, for example). Preliminary test indicate that this non-categorical changes can result in significant differences in regional climate model simulations (Ge et al., 2006).
d. Changes in land use and land cover, including reduction in vegetation cover and retreating of snow covers in high altitude mountains, are assumed to be caused by

both regional climate change and human impacts. However, little research has been done or has been successful in discerning the two drivers. Using a long term satellite observation records, a study carried out by the LC group suggested that the two driving forces can be separated by examining the changes in green vegetation indicator, NDVI, at different elevations (Torbick et al., 2006), thus providing a feasible approach to discern the two driving forces.

Land Use

I. Case Study Sites and Regional CLIPcover Assessment

We have taken the land use/cover data for each of the case study sites (see Figure 1) and compared the land use/cover classes to that of CLIPcover. We used the cross tabulation function (TABULATEAREA) between the case study sites contained in a grid format and registered to the 1km CLIPcover database. We also calculated total area in each class for the study sites and compared the total area for each class in CLIPcover.

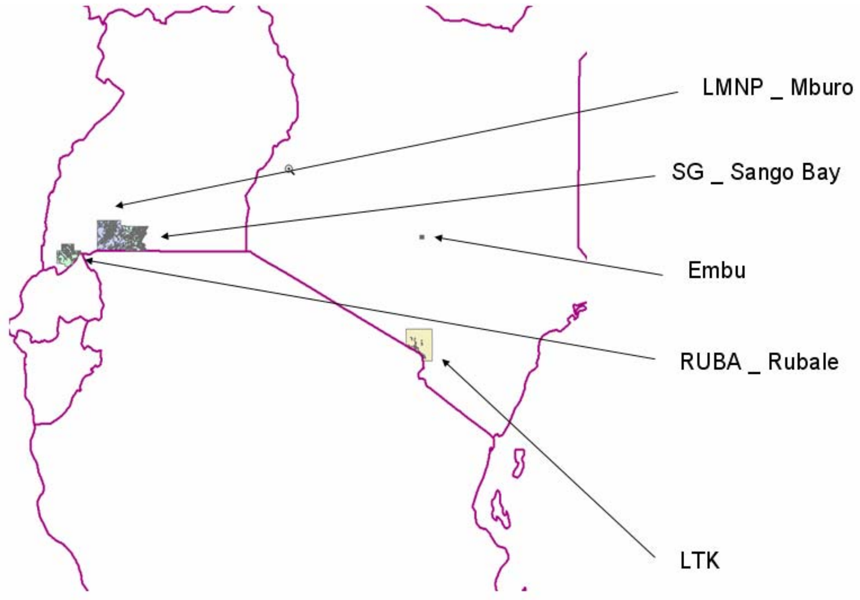
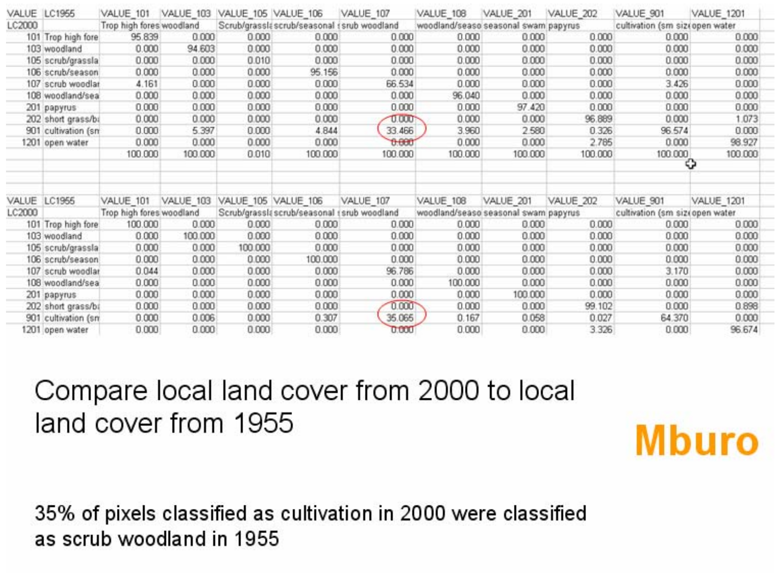


Figure 1. Location of the study sites conducted in our land use/cover map agreement analysis.

Figure 2 shows an example cross tabulation table for the cast study site Mburo, Uganda. The cross tabulation was performed on both the 1955 and 1995 land use/cover data and the CLIPcover for 2000 (labeled at LC2000). This particular table, adjusted to percent total area, shows that over one third of the scrub/woodland in the case study site database is cultivated in the regional CLIPcover.



VALUE	LC1955	VALUE_101	VALUE_103	VALUE_105	VALUE_106	VALUE_107	VALUE_108	VALUE_201	VALUE_202	VALUE_901	VALUE_1201
LC2000		Trop high fores	woodland	Scrub/grassla	scrub/seasonal	srub woodland	woodland/seaso	seasonal swam	papyrus	cultivation (sm siz	open water
101	Trop high fore	95.839	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
103	woodland	0.000	94.603	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
105	scrub/grassla	0.000	0.000	0.010	0.000	0.000	0.000	0.000	0.000	0.000	0.000
106	scrub/season	0.000	0.000	0.000	95.156	0.000	0.000	0.000	0.000	0.000	0.000
107	scrub woodlar	4.161	0.000	0.000	0.000	66.534	0.000	0.000	0.000	3.426	0.000
108	woodland/sea	0.000	0.000	0.000	0.000	0.000	96.040	0.000	0.000	0.000	0.000
201	papyrus	0.000	0.000	0.000	0.000	0.000	0.000	97.420	0.000	0.000	0.000
202	short grass/b	0.000	0.000	0.000	0.000	0.000	0.000	0.000	96.889	0.000	1.073
901	cultivation (sn	0.000	5.397	0.000	4.844	33.466	3.960	2.580	0.326	96.574	0.000
1201	open water	0.000	0.000	0.000	0.000	0.000	0.000	0.000	2.785	0.000	98.927
		100.000	100.000	0.010	100.000	100.000	100.000	100.000	100.000	100.000	100.000

VALUE	LC1955	VALUE_101	VALUE_103	VALUE_105	VALUE_106	VALUE_107	VALUE_108	VALUE_201	VALUE_202	VALUE_901	VALUE_1201
LC2000		Trop high fores	woodland	Scrub/grassla	scrub/seasonal	srub woodland	woodland/seaso	seasonal swam	papyrus	cultivation (sm siz	open water
101	Trop high fore	100.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
103	woodland	0.000	100.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
105	scrub/grassla	0.000	0.000	100.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
106	scrub/season	0.000	0.000	0.000	100.000	0.000	0.000	0.000	0.000	0.000	0.000
107	scrub woodlar	0.044	0.000	0.000	0.000	96.786	0.000	0.000	0.000	3.170	0.000
108	woodland/sea	0.000	0.000	0.000	0.000	0.000	100.000	0.000	0.000	0.000	0.000
201	papyrus	0.000	0.000	0.000	0.000	0.000	0.000	100.000	0.000	0.000	0.000
202	short grass/b	0.000	0.000	0.000	0.000	0.000	0.000	0.000	99.102	0.000	0.898
901	cultivation (sn	0.000	0.006	0.000	0.307	35.065	0.167	0.058	0.027	64.370	0.000
1201	open water	0.000	0.000	0.000	0.000	0.000	0.000	0.000	3.326	0.000	96.674

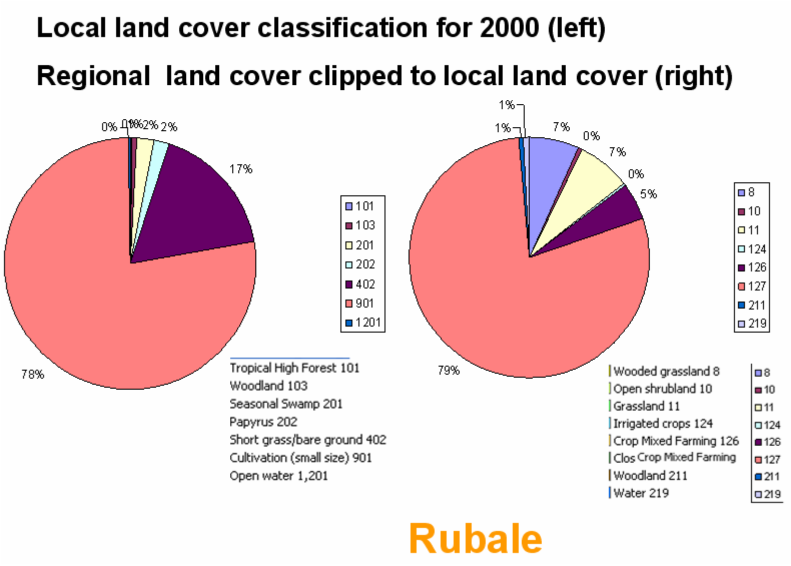
Compare local land cover from 2000 to local land cover from 1955

Mburo

35% of pixels classified as cultivation in 2000 were classified as scrub woodland in 1955

Figure 2. A cross tabulation of land use/covers in the case study and CLIPcover databases.

An example analysis for land use/cover class quantity is shown in Figure 3 below for Rubale. In this particular case, the amount of cropland in both agrees well.



Local land cover classification for 2000 (left)

Regional land cover clipped to local land cover (right)

Rubale

Figure 3. An example land use/cover quantity analysis that examines the area occupied in each land use/cover class in the case study and CLIPcover databases.

This analysis serves several purposes. First, as we scale up from the case study sites to the region, we need to know how well the data match between scales and across the case study sites. Second, models developed at the smaller case study site need to be compared against the regional model and a cross walk of land cover types might be necessary to test model goodness of fit. Finally, methods developed between spatial scales could be applied to broader uncertainty analysis conducted project wide.

II. LTM Outcome Assessment

We have developed version 2 of our LTM model during the last year. This version has the following characteristics:

1. 12 drivers of rainfed agriculture (distance to big cities over 1m, distance to national parks, distance to surface water, distance to roads in three categories (A, B and C), distance to major cities (50K-1m), distance to towns (less than 50K), distance to permanent streams, slope, topography (concave to convex), and annual precipitation)
2. CLIPcover in 34 categories of land use/cover in 1km raster grid file
3. Urban expansion that is proportional to population increases, but only projected for increases in urban areas
4. Agricultural expansion that is proportional to population increases in both urban and rural areas
5. Climate inputs from a 0.5 x 0.5 30 year meteorological database for the continent of Africa; we used average annual precipitation
6. No input from a crop production or CERES-Maize yield/NPP estimates
7. No input from any soils databases

The model was configured differently than in the past (Pijanowski et al., 2002, 2005); the output for our model was not the presence or absence of change from two time periods but rather the presence or absence of rainfed agriculture. As such, we refer to this type of LTM parameterization as a potential version of the model (as opposed to a change version). Figure 4 shows the projections of agriculture in 5 year time steps from current (2000) to 2050.

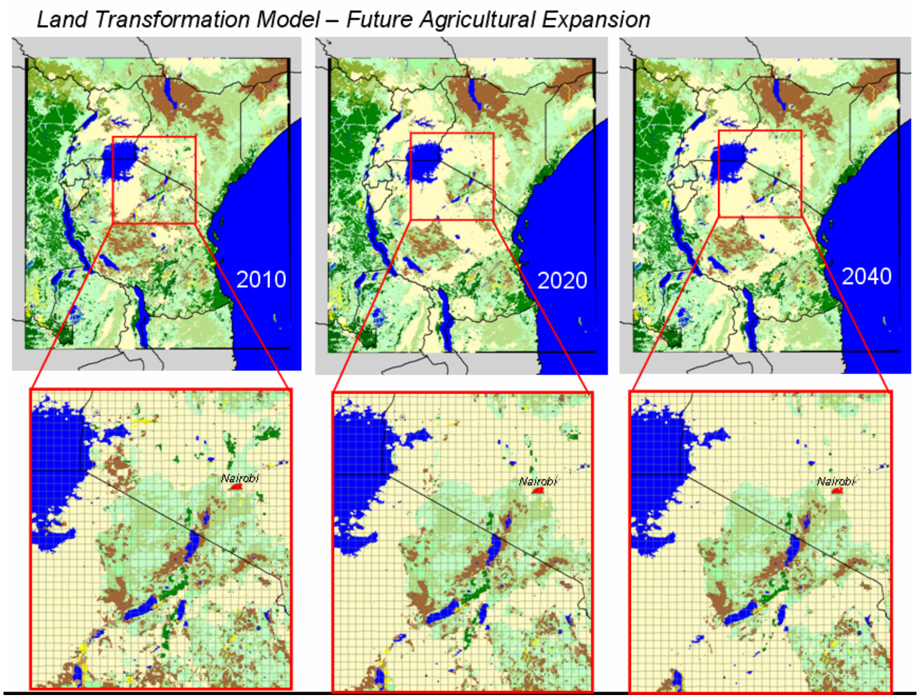


Figure 4. LTM results for agricultural expansion from 2000 to 2050; shown are 2010, 2020 and 2040.

We also explored three different ways to expand urban into the future. This included the use of a neural network potential version, an MCE version where weights were assigned on the basis of pair-wise rankings following Voogd (1983) and a simple gravity model. For the MCE (Figure 5), we have concentrated our work on a small area representing Nairobi and surrounding towns. Here, expert judgment is used to assign the weights, such as distance to previous urban, distance to roads, to create a spatial probability map of change.

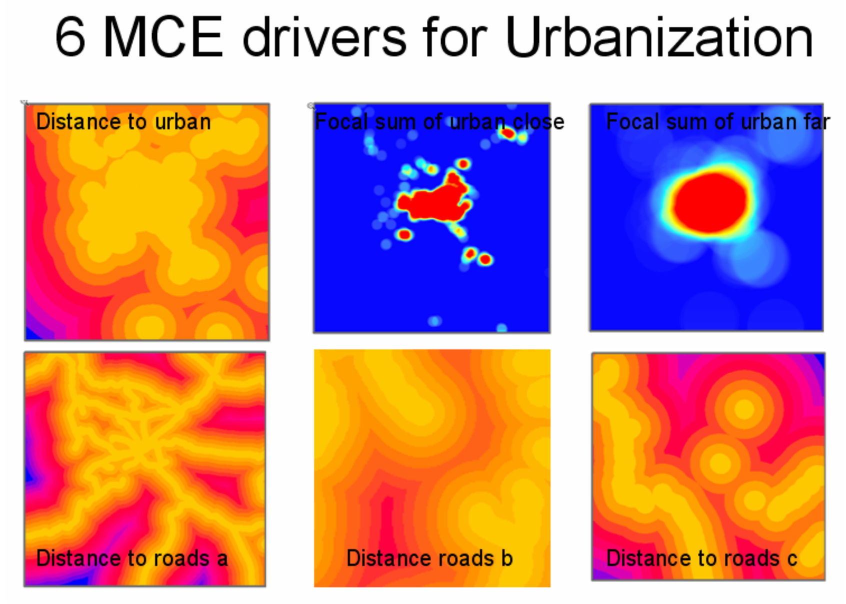


Figure 5. Spatial drivers for the Nairobi MCE urbanization model.

Our current MCE urban expansion model uses the following drivers: distance to previous urban, focal sum of urban (small neighborhood), focalsum of urban (large neighborhood), and distance to roads in three classes (A, B and C) see Figure 6.

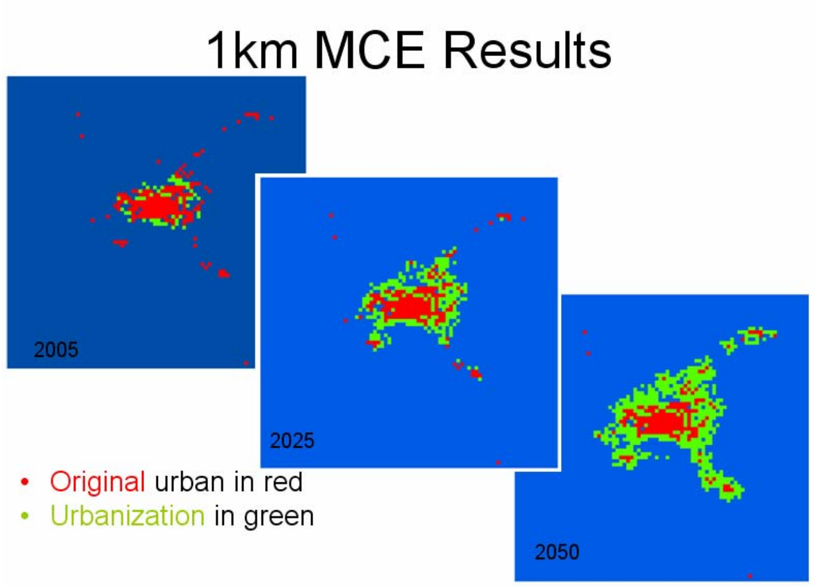
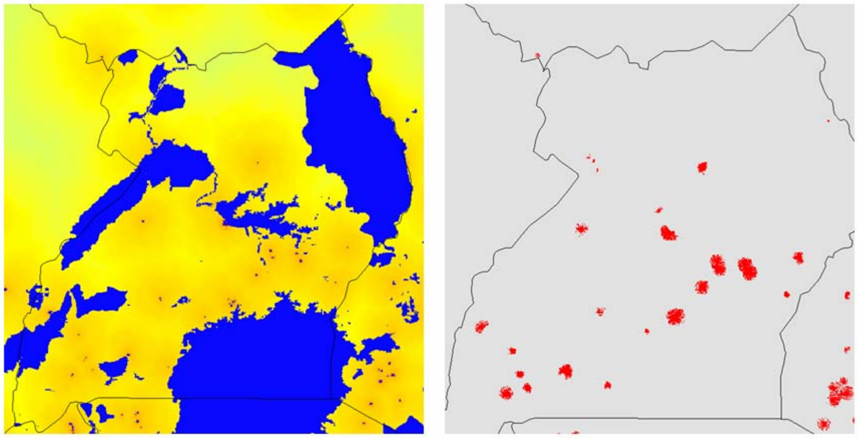


Figure 6. MCE results for urban expansion around Nairobi.

We are currently exploring other methods to expand urban as well as determine whether a high degree of accuracy of spatial pattern of expansion is necessary for inputs into the RAMS simulation. We have used the MCE model developed for Nairobi and expanded it to the entire region at 5 year time steps. Figure 7 shows the results of applying the MCE model to all of Uganda (year 2050 shown).



Probability map of urban change in Uganda based on MCE with a randomization effect (left)

The more orange the more probable to become urban

Map of urban expansion in 2050 (right)

Figure 7. The urban expansion MCE model for 2050 for Uganda.

We have also examined what current land use/covers the 2050 LTM projections of ag and urban expansion will replace. This analysis was done at the regional and country scale. One example analysis is provided for Kenya in Figure 8.

Kenya LULC Change 2000-2050

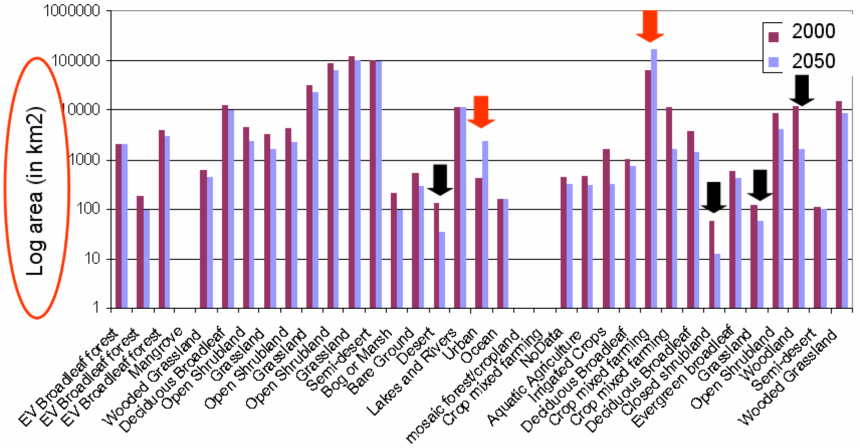


Figure 8. Land use/cover amounts for current (CLIPcover) and LTM 2050 projections.

Figure 8 shows that as urban and agriculture expand (red arrows) some other classes, such as woodlands and evergreen broadleaf, will be lost. These are expected transitions. Some transitions, however, need further assessment; for example, the loss of desert (like to either agricultural or urban expansion) is a bit troublesome although this represents a very small proportion of change across the entire region.

III. LTM to RAMS uncertainty analysis

1. Uncertainty Bin Analysis

We have developed a neural net outcome uncertainty metric, ψ, for the presence/absence of a land use/cover class that is scaled to each climate box. This metric is being developed to help us ascertain the amount of variability in quality of output from the 1km LTM that is passed to the 36km climate grids in RAMS. We used the GIS derived inputs to train on the presence/absence of rainfed agriculture (Figure 9) in the region. The neural network weights from the training exercise were then applied to the inputs during the testing exercise to estimate the probability of occurrence for rainfed agriculture, which we call outcome probabilities. Figure 9 shows the distribution of the outcome probabilities as they range from 0-1.0 (they are scaled to integer values of 0-10,000 in the GIS). Values near 1.0 reflect that the neural net has assigned a high certainty to that location that it should be in the rainfed agriculture class. Values near 0 are locations that are most unlikely to have rainfed agriculture based on the inputs. On the other hand, values near the center of the probability distribution contain locations that the neural network does not have a high degree of certainty that the cells fall in either binary category. Our uncertainty metric, ψ, is calculated as the sum of the proportion (note: we use percentages and proportions interchangeably here) of cells in the upper and lower probability bins (we call these two as high certainty bins) subtracted by the proportion of cells in the middle probability bins (i.e., the uncertainty bin). We sum the proportions of cells in upper, lower and middle outcome probability bins in increments of 0.05 such that:

$$\Psi_{i,j} = U_{i,i} + L_{i,j} - M_{i,j}$$

Where U, L and M are the proportion of cells in the *i* climate grid box in the upper, lower and middle outcome probabilities, respectively, in bins of size *j*. We calculated $\Psi_{i,j}$ for probability bins in 0.05 increments so that for the case of $j = 0.05$, the proportion of cells in the *i* climate box with values 0.95-1.0 and 0.0-0.5 are summed, divided by the total number of cells in the climate grid (note: there are slight variations of the size of the climate grid across the region due to use of a non equal area projection used by RAMS) and then subtracted from the proportion of cells in the climate box that fall in the middle range of 0.45-0.55. Figure 9 provides an illustration of the outcome probabilities for one LTM simulation where U, L and M outcome probabilities bins are shown. $\Psi_{i,j}$ can range from +100% to -100% where +100% represents a climate grid that contains cells only in the U and L bins; -100% represent climate grids that have cell values in the middle only.

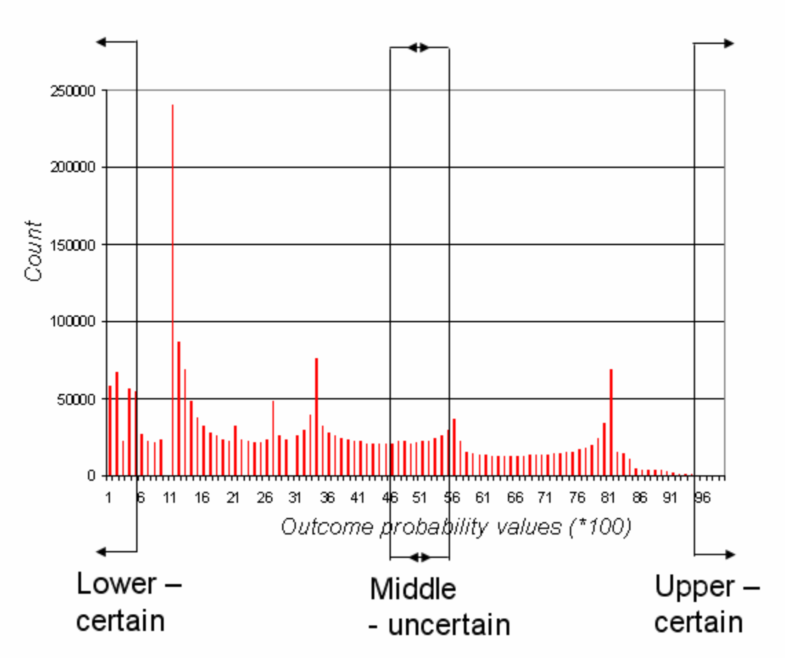


Figure 9. An example LTM outcome probability distribution also showing U, L and M boundaries.

Figure 10 contains outcome uncertainty maps for climate grids in 5% increments from 5% to 25%. Figure XF displays a map of outcome probabilities for the original 1km LTM grid, values from this map were used in the calculation of $\Psi_{i,j}$ for maps A-E. In these maps, climate grid boxes that are green have the greatest number of cells in the uncertainty bin; those that are red have the most number of cells in the high certainty bins. Figure XA shows a map for *j*=5%. Note that the green areas are located on the periphery of current rainfed agriculture areas, and locations of red are generally areas that are currently desert or contain rainfall that is very unlikely to support any crops. As we move to *j*=10%, we see more red colored climate grids because more cells are placed in these larger certainty bins. Once the 25% bin is reached, all cells from the outcome probability map for each climate grid are placed in either the uncertainty or certainty bin (i.e., when *j*= 0.25, then U=75-100%; L=0-25%; M=25-75%).

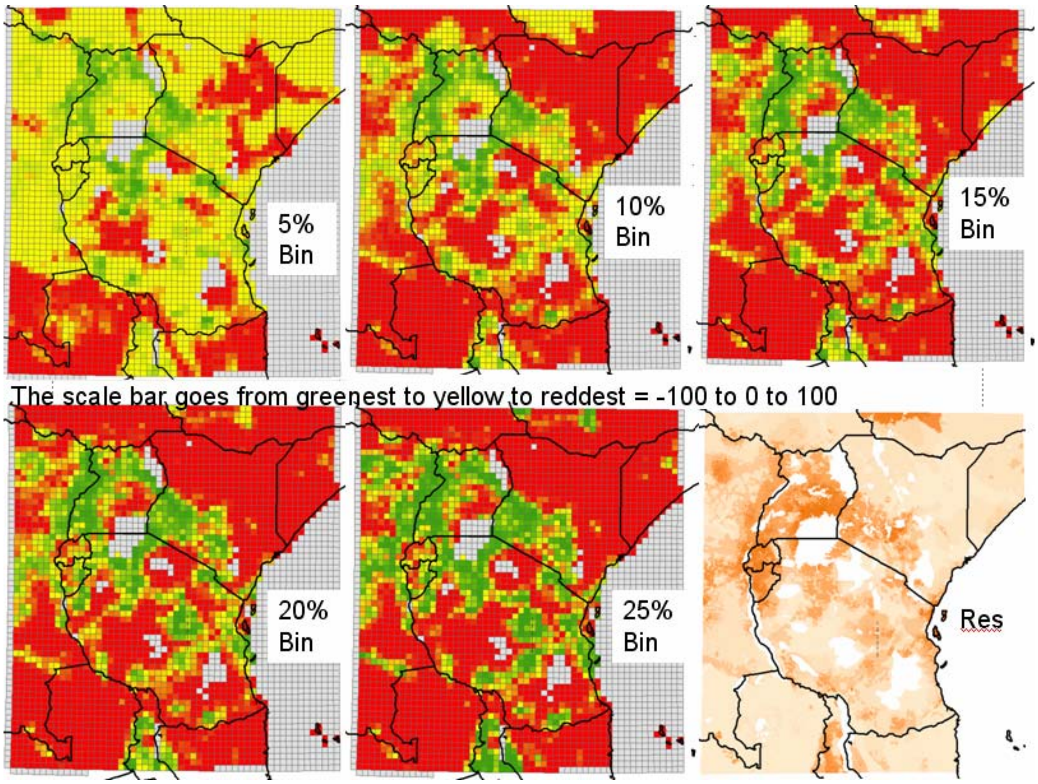


Figure 10. Uncertainty $\Psi_{i,j}$ values for each RAMS climate grid.

2. Omission/Co-mission errors and Scaleable Window Analysis

Following earlier work by Pijanowski (2002, 2005, in press), we compared how well the predicted current rainfed map from the LTM simulation the model fit to CLIPcover rainfed agriculture. We used the GIS to create a raster map, which we call a 01234 grid, with the following codes:

0 = LTM did not predict rainfed ag/CLIPcover assignment was not rainfed ag (correct assignment)
1= LTM predicted rainfed ag/CLIP cover assignment was not rainfed ag (co-mission error)
2 = LTM did no predict rainfed ag/CLIPcover assignment was rainfed ag (omission error)
3 = LTM predicted rainfed ag/CLIPcover assignment was rainfed ag (correct assignment)
4 = areas where rainfed ag cannot go (e.g., current urban and open water)

In previous work, Pijanowski (2002, 2005) used the ratio of the number of 3s in the raster map divided by original number of cells contained in the map for the category (e.g., rainfed) of interest as a metrics of model goodness of fit. This metric is expressed as a percentage and is referred to as the Percent Correct Metric or PCM. We also used a scaleable window technique similar to Costanza and Sklar (1992) and Pontius (2005) where a stepwise square window size is used to combine pairs of omission and commission errors occurring within the same window into correct cells. The proportion of 3s then increases with increasing window size. Certain window size thresholds are examined across simulations; such as the windows size where the proportion of correct cells surpasses incorrect cells (see Pijanowski 2005). Here, we were interested in the proportion correct within the climate grid size of 36km. Note from the Figure 11 below that there is a slight increase in model goodness of fit between the 1km and 36km results (63% versus 73% respectively).

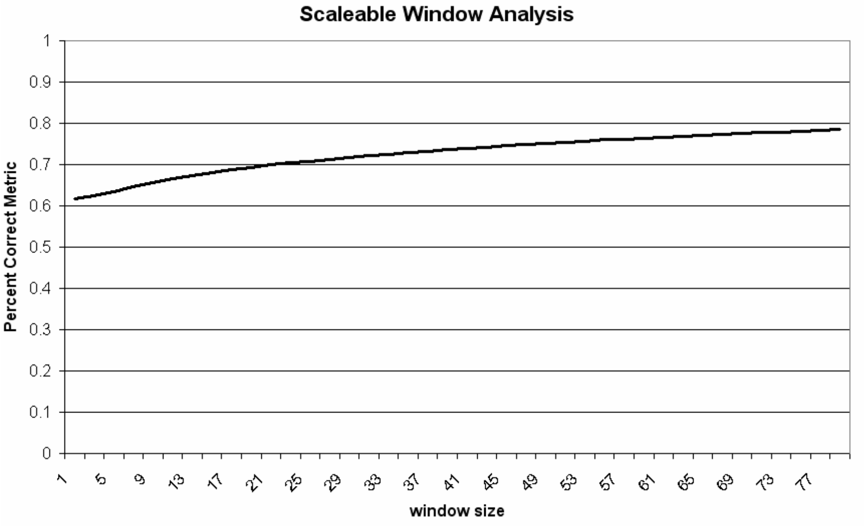


Figure11. The PCMs across scaleable window sizes form the analysis of the 01234 maps.

3. Driver Sensitivity Analysis Across Spatial Scales

We also ran reduced variable neural network models following the procedure of Pijanowski (2002) to determine the effects of individual drivers on the outcome. Separate 01234 grids were then used to calculate PCMs for each window size. The PCM for each reduced variable model (12 models of 11 variables) were then subtracted from the value of the PCM for the full variable model (12 drivers) at each window size. This plot is given in Figure 12. Note that on the y-axis, the value of 0.0 represents a condition that there no difference in the full and the reduced variable model; positive values represent the proportional increase in model goodness of fit by keeping that one variable; a negative value represents a condition that the variable of interest reduces overall model goodness of fit. The x-axis is the window size; the size of the RAMS climate box is indicated with the horizontal bar at 36km.

Note (Figure 12) that nearly all variables (i.e., drivers) contribute toward a better fit model. Roads of category C (i.e., rural roads) have the greatest influence, followed by distance to small towns (i.e., market centers). Also note that distance to town is also very sensitive to scale, the ΔPCM rises quickly and plateaus around 15km. Interestingly, precipitation hampers the model goodness of fit; the ΔPCM is negative for all window sizes. Precipitation for this particular simulation was from a coarse 0.5 degree database of 30 year precipitation averages. It is possible that the coarseness of the data introduced errors in the training of the data as 0.5 degree represents about a 60km pixel and our rainfed agriculture presence/absence map was presented to the neural net using 1km pixels.

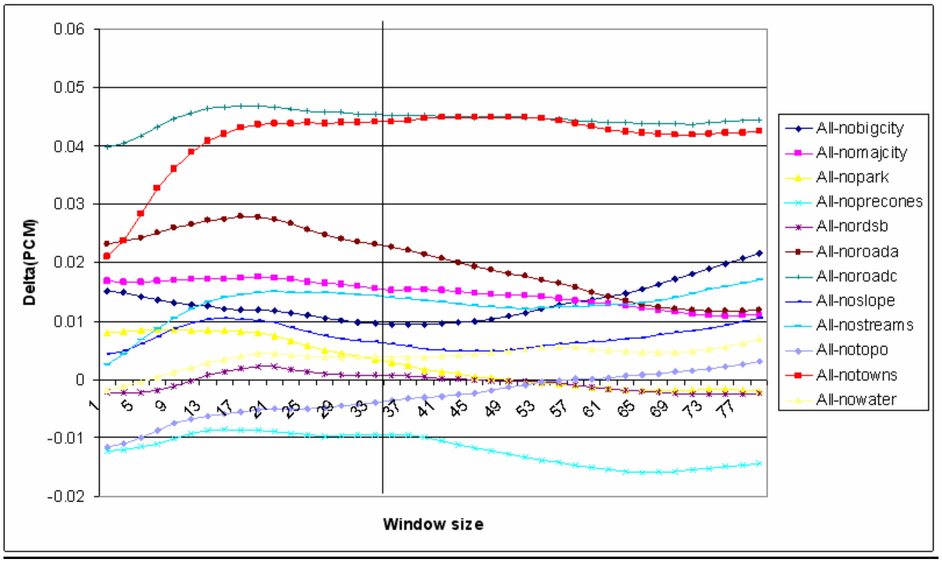


Figure 12. Drop-one-out and scaleable window analysis for the LTM rainfed simulations.

4. Neural Network Training Cycles

One unique feature of neural networks is their ability to learn from patterns in data. They use a delta function to adjust weights that are passed through a nonlinear function called an activation function that fits inputs (drivers) to outputs (the presence/absence of rainfed agriculture). The weights, initially assigned to random values, are adjusted during the simulation, each pass through the data is called a cycle. Pijanowski (in press) has shown that the neural networks improve their overall fit to the data during the course of the simulation and that following metrics such as the PCM model goodness of fit is useful to determining when to stop training. We examined each of the above metrics (PCM, scaleable window size) combined with the reduced variable analysis. We have started to visualize these complex metrics using 3D plots in R and Matlab (Figure 13). Note that PCM increases from about 0.63 during the start of the simulation to around 0.80 after 250,000 cycles (note: this simulation takes about 8 weeks). There is a greater increase in model goodness of fit early on in the training than, viz., later.

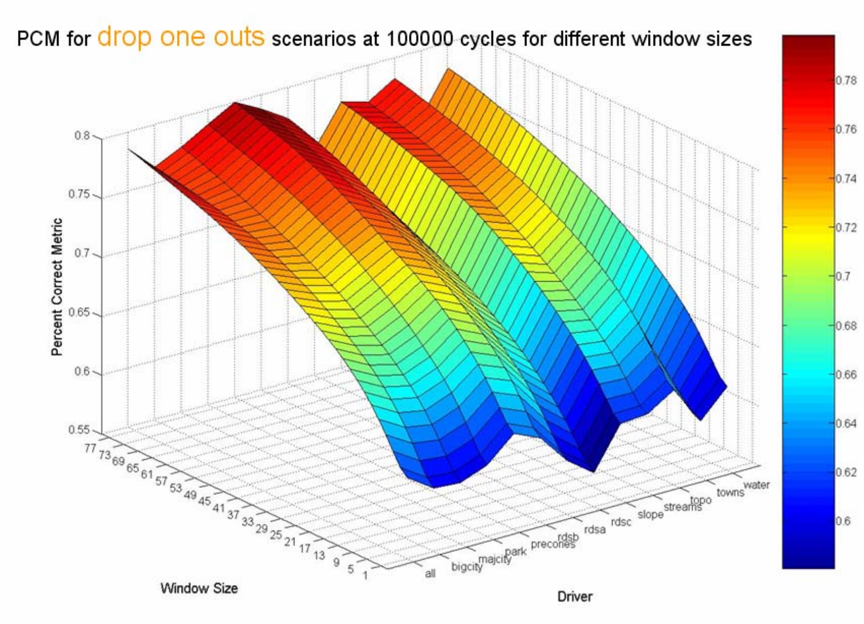


Figure 13. Visualization of the PCM across window sizes and across reduced variable LTM simulations.

5. Hierarchical Quantity and Location Error Assessment

A final uncertainty analysis examining the error associated with LTM-RAMS coupling that has been started involves the development of a metric that calculates the quantity error associated with LTM projections to RAMS. To illustrate how this metric works, one needs to consider that for any climate grid cell, the LTM will select the number of agriculture cells that should transition from another alterative land cover class. In some cases, the LTM will predict more or less cells to be in the agriculture class compared to CLIPcover. The quantity error can be assessed as another PCM, which we call PCMq, but not of the type of location (see Pontius 2005 for the importance of quantity and location errors).

Figure 14 shows a grid of our hierarchical boxes that we will calculate PCMq across the boxes. We plan to summarize PCMq across the box sizes using a mean and coefficient of variation.

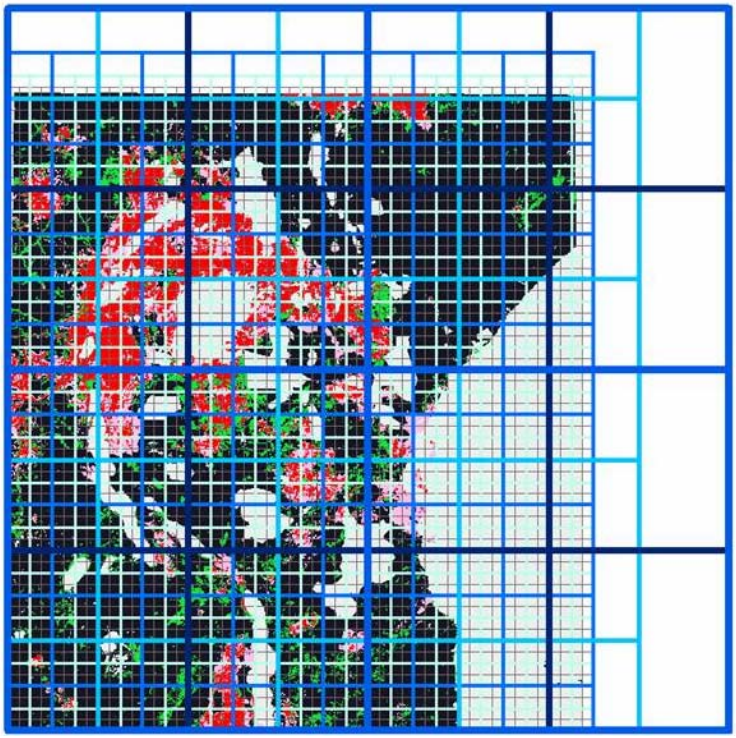


Figure 14. The polygon grid hierarchy scaling for use in the PCMq analysis for grid boxes of size 3km to 1044km. Boxes outside the modeling domain are excluded.

IV. CERES-Maize to CLIPcover/LTM Coupling

We have begun to take preliminary CERES-Maize output and examine how the crop simulations will be used as eventually input to the LTM. Our plan is to use maize yields for the six different cumulative probability cutoff points as separate inputs to the neural net based LTM. A set of separate CERES Maize simulations with optimal conditions (i.e., no limitations from soil and climate) were run to estimate the maximum possible yield that could be obtained in the future given technology enhancements. These simulations produced values that allowed us to normalize the CERES-Maize yield estimates so that values of 0.0 through 1.0 would always be obtained. These values will be hard coded in the LTM as we begin to process the data for input for version 3.

Prior to input into the LTM however, the point based CERES-Maize simulations that are run at 18km spacing (see Figure 16) need to be converted to a 1km grid and registered to the LTM modeling raster map. We have investigated several interpolation methods (spline, idw, polynomial interpolation) and we have currently decided to use a local polynomial interpolation method (Figure 17).

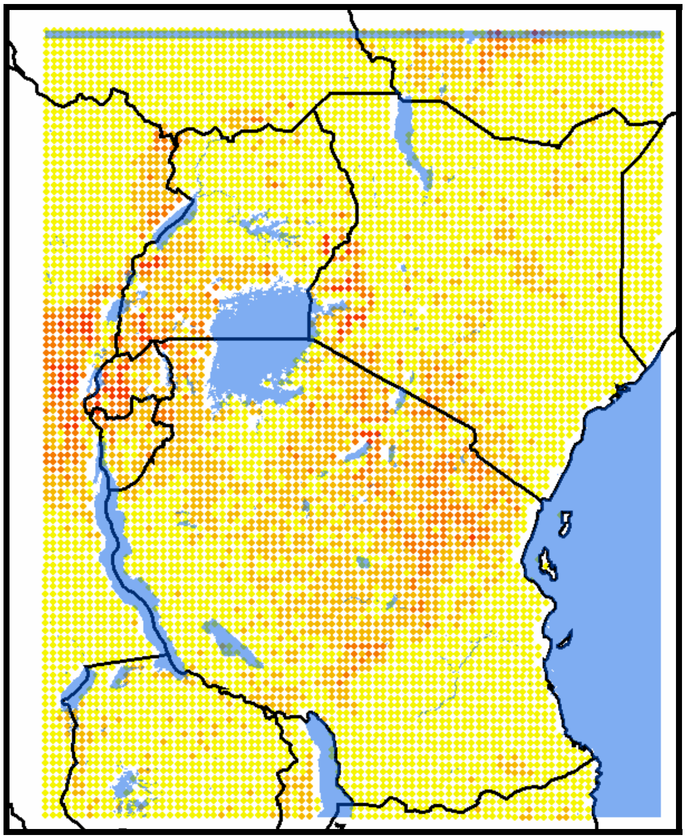


Figure 16. The locations of CERES-Maize simulations (N=7710). Colors represent relative yield potential (red = high; yellow = low).

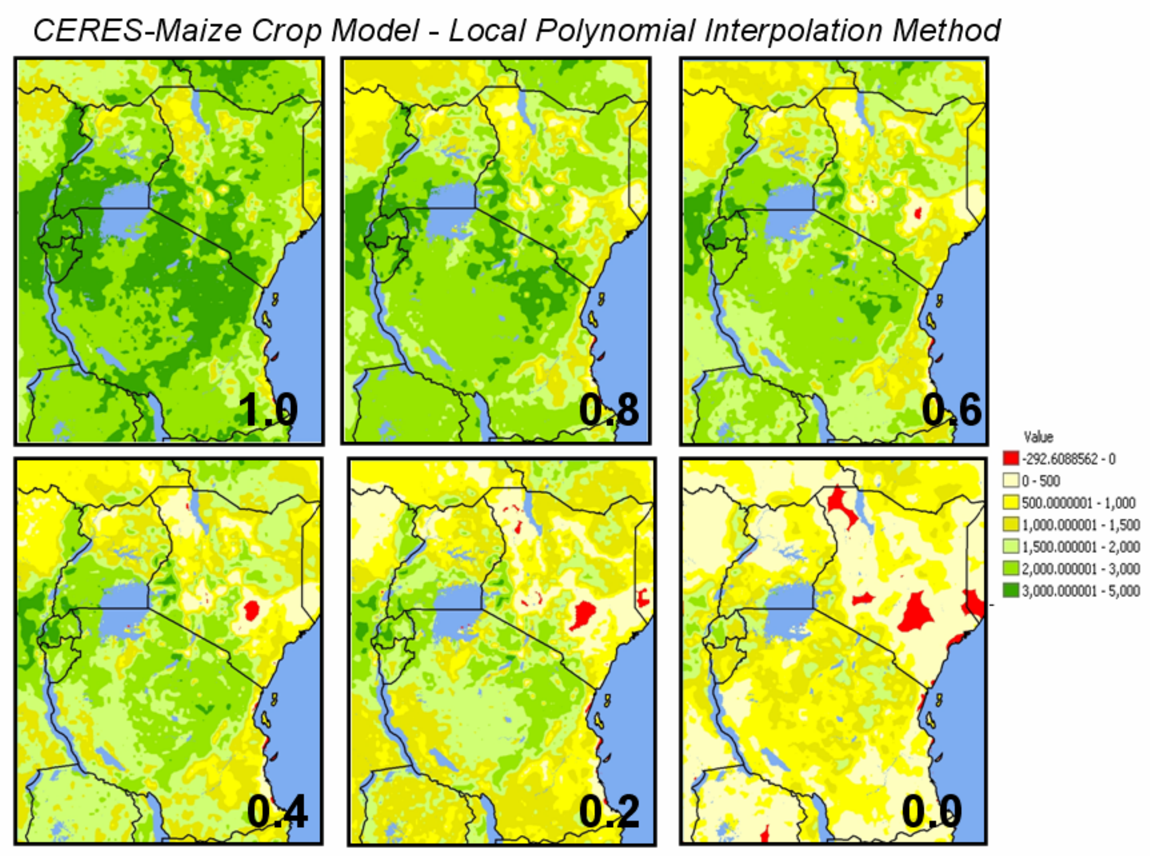
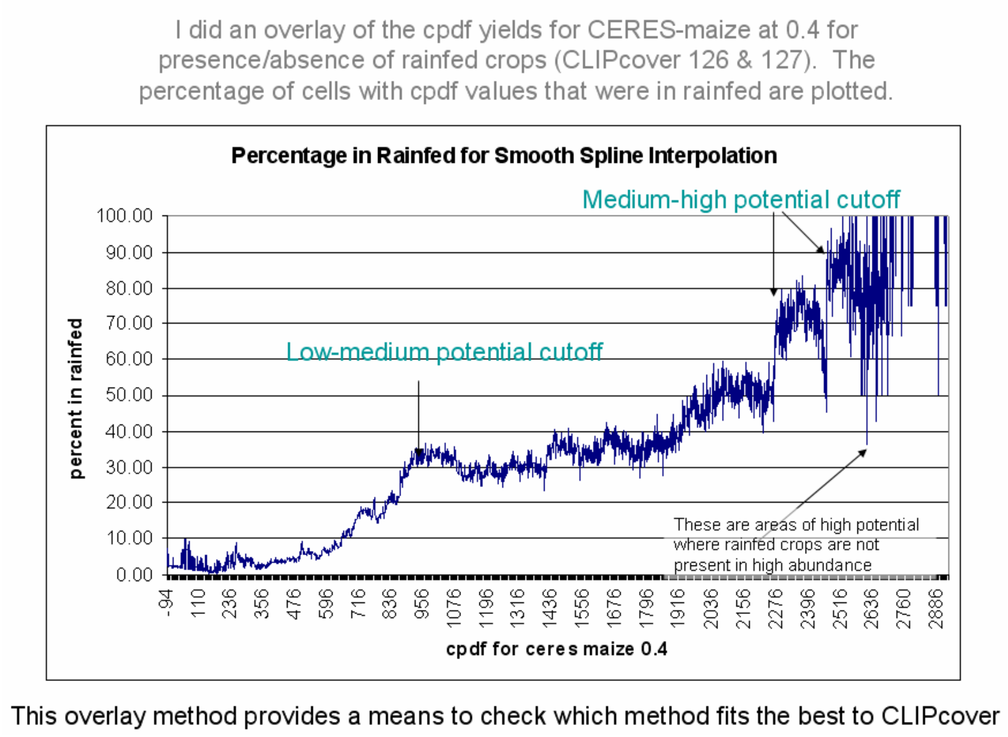


Figure 17. CERES-Maize yields interpolated using a LPI method in ArcGIS 9.1 geospatial analyst. Shown are the cdpf cutoffs for different probability thresholds.

Values in red represent negative (not possible) yields which will be converted to 0.0 using the GIS prior to input to the LTM.

A method to determine how well the CERES-Maize yields match with the presence and absence of rainfed crops was developed in the last year as well. An example analysis of this overlay is shown in Figure 18 below. Note that most cells that contain high CERES-Maize yields (i.e., greater than 2100) are represented as rainfed agriculture in CLIPcover. In contrast, areas with low yield estimates are rarely (less than 5% occurrences in CLIPcover) rainfed agriculture.


I did an overlay of the cpdf yields for CERES-maize at 0.4 for presence/absence of rainfed crops (CLIPcover 126 & 127). The percentage of cells with cpdf values that were in rainfed are plotted.

This overlay method provides a means to check which method fits the best to CLIPcover

Figure 18. Rainfed presence/absence and CERES-Maize yield overlay method.

V. Role Playing Simulation

Two major activities have focused on the RPS. First, we conducted another RPS at Purdue University (April 2006) as part of a PhD trial simulation for a new graduate student of Dr. Pijanowski. The RPS was a redesigned simulation that allowed the researchers to follow the simulation on a gridded sheet representing the same map as the original Campbell and Palutikof (1978) simulation. We also captured decisions at each time step and allowed players to make economic transactions using fake money. The results of this simulation are being written up.

Our second activity focused on synthesizing the June 2004 RPS held in Kenya. We currently have a draft paper for publication that describes the results of this RPS. In order to reach this stage, we had to digitize all of the maps (8) produced by the RPS participants and then conduct a GIS analysis of the outcomes. We used the GIS to create overlays of the two scenarios (land use adjudication without a park and one with the introduction of a park around the limited natural resource, a lake). In the paper, we present the argument that RPS can help support the development and testing of spatially explicit models of two types: reduced form and structural models (Figure 19).

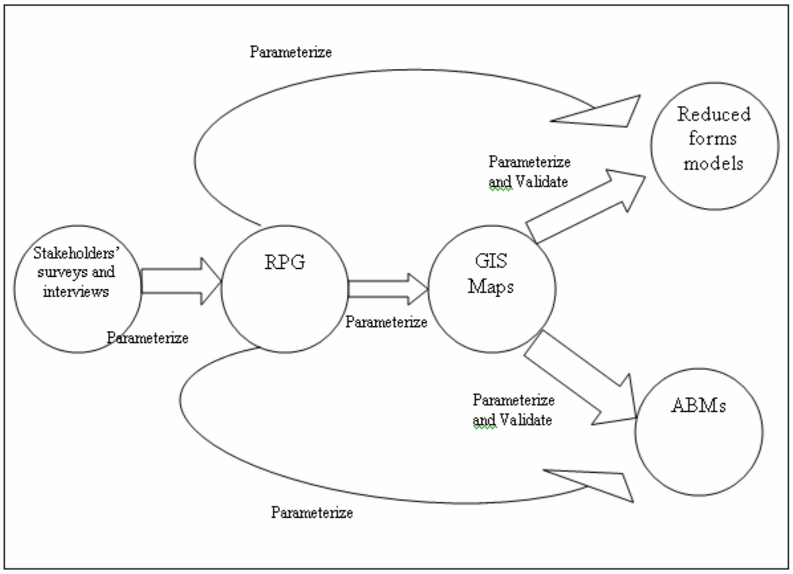


Figure 19. How RPS can help support the development and validation of quantitative land change models.

To develop the maps for use in modeling, we took the original RPS maps shown in Figure 20 (Figure 6 from the draft paper) and digitized main features and land use boundaries drawn by the participants (see the GIS version in Figure 21). All digitized maps have been placed into ArcGIS.

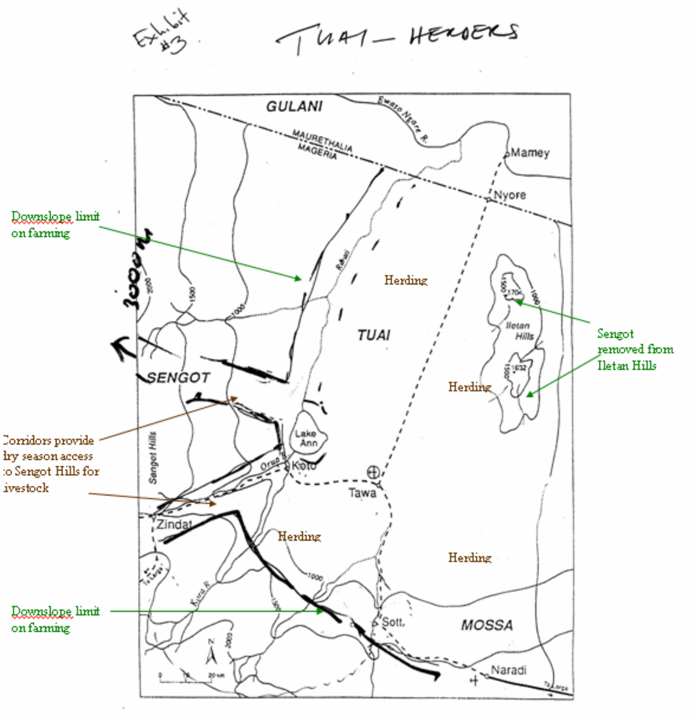


Figure 6: Tuai Herders' Proposed Land Allocation

Figure 20. The hand drawn map for the Tuai herders prior to the introduction of the wildlife park.

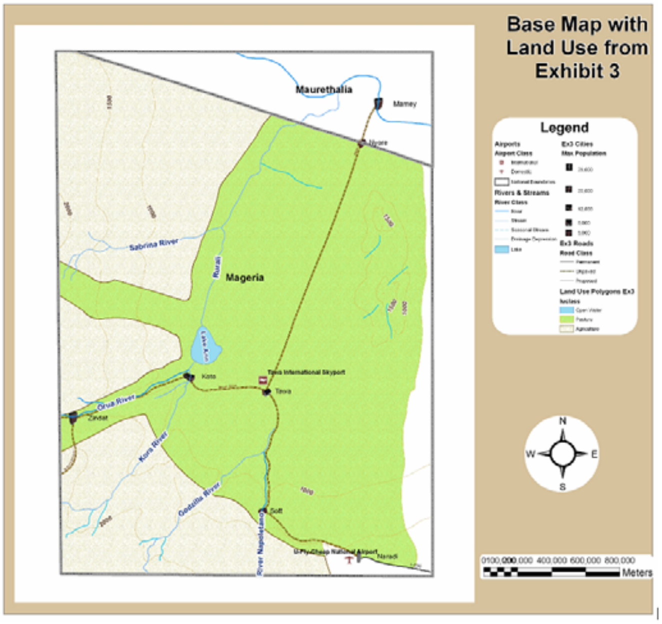


Figure 21. GIS map of the Tuai herder land area selected by the group participants.

Present-day and future vegetation modelling:

A number of model simulations have been performed with the LPJ (Lund-Potsdam-Jena) dynamic vegetation model:

1) Simulations testing LPJ model sensitivity to the underlying climate and its spatial and temporal resolution. Simulations were performed using a) daily and b) monthly station climate data from 10 East African stations (courtesy of P. Thornton).
2) 20th and 21st century simulations using 19 realisations from 9 state-of-the –art GCM performed in support of the latest IPCC 4th assessment.

Annual output of land-cover types, vegetation and soil carbon and hydrology have been produced.

Simulations in 1) above has been used to examine model sensitivity to climate inputs: Simulation length varied with weather station varying between 7-40 years. Analysis of these simulations will enable an evaluation of:
a) Vegetation model sensitivity to the spatial scale of the input climate data: gridded vs. station data

b) Vegetation model sensitivity to the temporal scale of the input climate data: monthly vs. daily climate data.
Analysis has shown that:

- Simulated NPP was generally less variable for the coarser spatial scale CRU gridded dataset
- Simulated NPP, vegetation and soil carbon was often higher using coarser spatial scale CRU dataset
- NPP, and soil and vegetation carbon was always higher for simulations that used the lower temporal resolution data: aggregated monthly station values as oppose to daily station data
- Different climate datasets often produced different dominant PFTs

The basis of these results are lower monthly minimum temperatures and higher monthly maximum temperatures and greater number of dry days obtained from the daily station data values, suggesting that more extreme temperatures and greater water stress periods experienced by vegetation yields lower productivity of NPP and soil and vegetation carbon.

Simulations in 2) have just been completed. We have discovered a large variation in predictions of vegetation and soil carbon with GCM simulations. Further work will analyze these results in more regional detail, as well as fitting a Bayesian model of uncertainty to the results. Then these results will be written up for publication in a high impact journal. A number of climate impacts groups have expressed interest in this work, and most recently (sept 25-26th) I hosted a workshop on probabilistic climate impacts assessment.

Climate variability in East Africa:

We have assessed the link between East African rainfall, and two large-scale climate phenomena: the Indian Ocean Dipole and the Southern Oscillation Index. In observations and in 6 different

CROP-CLIMATE (NPP) ACTIVITIES
NPP part for NSF annual report 2006.

Spatial analysis of NPP simulations

Spatial modeling of changes in net primary productivity (NPP), the vegetative response to climate change, is being conducted as part of the climate-to-land section of CLIP. One of the most dynamic elements of NPP is in the agricultural system as climate change affects the biophysical characteristics of crops, and as changes in agricultural productivity impact humans and their land use decisions. We investigated the interrelationship between the productivity of a representative staple food crop, maize, and climate variability and change across the CLIP domain for historical (1901-2002). The deterministic crop simulation model CERES-Maize from the DSSAT V. 4.0 model series (Hoogenboom et al. 2004) was used to simulate maize production. The CRU TS 2.1 climate data set extending from 1901 to 2002 for grids covering the CLIP domain surface at 0.5 degree resolution (Mitchell et al. 2003) provided raw monthly temperature and precipitation data, which were in turn used as input to MARKSIM software to stochastically generate daily weather data series (Jones and Thornton, 2000). Future crop simulations (2001-2050) will be carried out with daily climate data from the RAMS regional climate model embedded within the CCSM global climate model. Representative soils data were obtained from the Food and Agriculture Organization digital 1:5,000,000 soil map of the world (FAO, 1974). Agricultural suitability for maize production of all soils in each grid box across the CLIP domain was determined based on FAO soil unit ratings (FAO, 1978). For each soil found to be suitable, we assembled a file of representative physical soil profile characteristics based on the International Soils Reference and Information Centre's World Inventory of Soil Emission Potentials (WISE) data base (Batjes and Bridges, 1994). East African agricultural management information was obtained during field surveys and in literature reviews.

Historical maize production in the CLIP domain was simulated under a variety of differing combinations of input soils data and agronomic assumptions (e.g. planting date, irrigation) in order to determine the relative importance of climate in the production system. For example, simulated maize yields for each pixel in the CLIP window using appropriate planting dates and FAO soils for the 1901-1930 time frame are given in Figure xx. The relatively higher simulated maize yields in western Kenya, western sections of Uganda-Burundi-Rwanda and the 'Hills' region in southern Tanzania are in close agreement with current regional production patterns. Overall, soil type and associated water holding capacity across the CLIP domain were found to be of relatively greater importance in determining potential crop productivity than is the case in mid-latitude production areas. Based on analytical methods suggested by Andresen et al. (2001), time series outputs from the simulation studies was used to produce cumulative probability distributions (CPD) of crop yield and water balance components. These CPDs will in turn become inputs in the land use change model and will provide information on how climate change will affect household decisions on crop choice and land use. Complementary analyses of the impact of climate change on natural ecosystems are being conducted using the Lund Potsdam Jena (LPJ) vegetation model. The results of these analyses will also be incorporated into the land use model.

Use of low resolution spatially interpolated climate surfaces such as the CRU TS 2.1 climate data set (0.5 degree resolution) is likely to cause partial loss in the capability to capture environmental variability especially in areas with strong climatic gradients such as in East Africa. Therefore, we have identified a global gridded high resolution climate data known as WorlClim data (at a 30 arc s resolution often referred to as 1–Km spatial resolution; Hijmans et al. 2005). We aggregated the WorldClim data to 18 km resolution to match with the statistically downscaled high resolution RAMS CLIP data which will be used to simulate NPP at future time period. The new triage at 18 Km resolution has 7710 pixels in the CLIP domain as against 653 pixels at 0.5 degree resolution. Simulation of maize production in the CLIP domain at higher spatial resolution under a variety of differing combinations of input soils data and agronomic assumptions (e.g. planting date, irrigation) are in progress.

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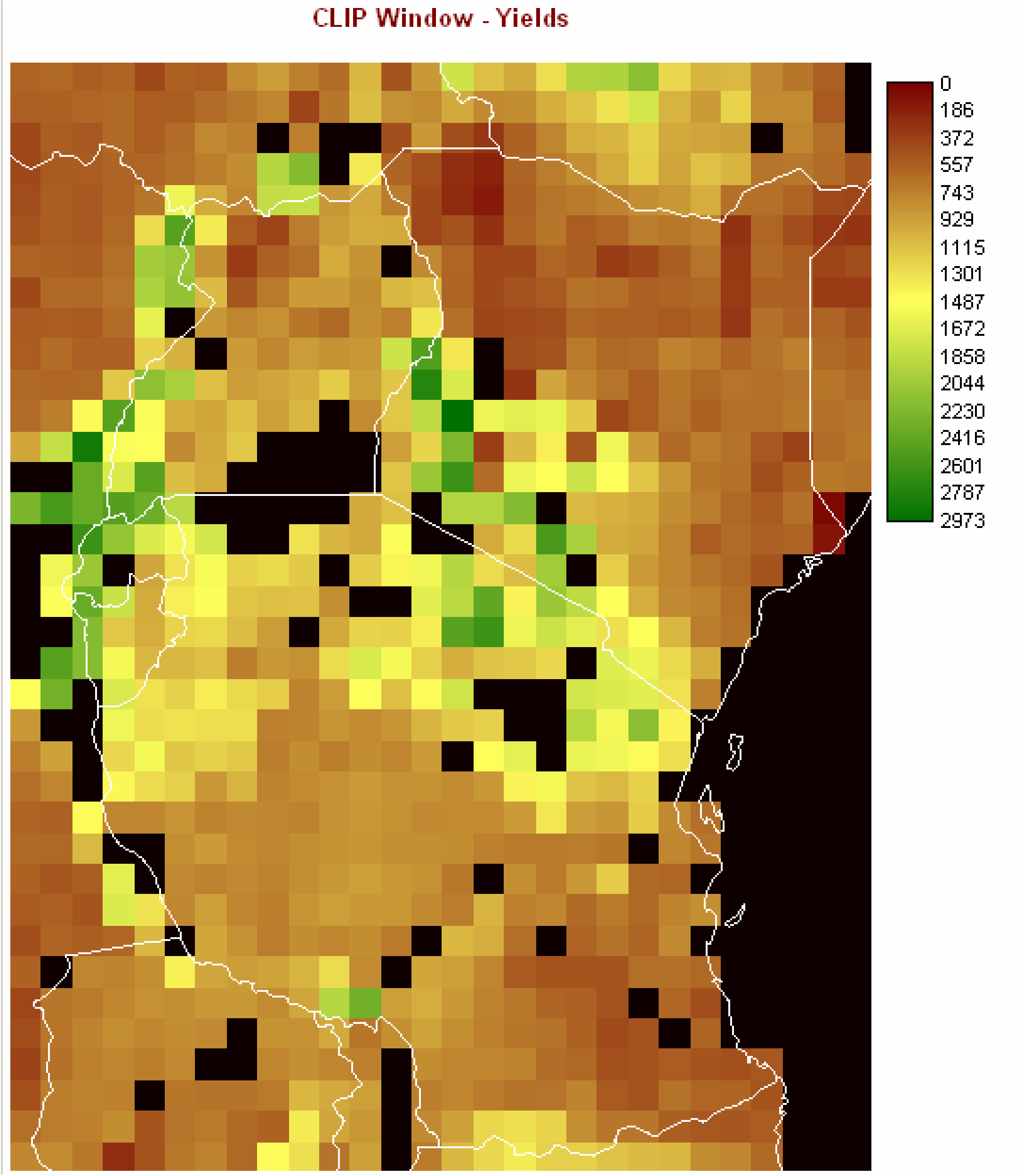

Figure 22. Simulated maize yields for the 1901-1930 time frame using stochastically generated daily weather data from CRU TS 2.1 climate data set and appropriate FAO soils (1974) and planting dates for each pixel(resolution 58 Km) in the CLIP domain.

CLIMATE DOWNSCALING

1 acquired and supplied ERA40 reanalysis data to CLIP (1deg. Resolution 4xdaily total column water and 2m temperature)
2 supplied CRU TS2.1 data to CLIP
3 downloaded monthly GCM data from the PCMDI site including ECHAM5, HadGEM1, HadCM3, CCCma, CSIRO Mk3.0, GFDL CM2.1 – temperature, sea surface temperature, mslp and precipitation
4 extraction of various regions to facilitate the construction of modelled SOI and Indian Ocean Dipole Index (Dipole Mode Index (DMI)) and comparison with precipitation variability
5 constructed DMI for the 6 GCMs (~1850-2100) for the control and future A2 scenario
6 acquired new GPCC VASClimO 0.5deg. gridded monthly precipitation climatology
7 evaluation of GPCC data ability to replicate trends in precipitation data over East Africa when compared to observed records (1951-2000)
8 GPCC data also compared to CRU 0.5deg. gridded climatology which has been identified in the literature as not being suitable for use in trend analyses. The GPCC data has been compared to the CRU climatology in order to assess whether the new data set is superior in terms of its ability to describe observed trends. One drawback of the GPCC data is its relatively short time span compared to the 100 years of the CRU gridded climatology
9 PCA of East African rainfall has been carried out for various time periods over the 20th Century.

This has resulted in:

1. Century to decadal scales for East Africa: Comparison between two gridded rainfall products shows that despite efforts to ensure spatial and temporal homogeneity, the GPCC grid series do not differ noticeably from the CRU TS 2.1 grid series over East Africa. This is likely to be a consequence of low density of stations that meet both datasets' quality control criteria in the East African region so that their grid series are based on similar station networks. The CRU gridded product indicates that over the 1901-2002 period the East African region has experienced different

trends in annual rainfall. The spatial behaviour of annual linear trends for four timeslices show that at the beginning of the 20th Century the western part of the region experienced increasing rainfall, this shifted to the north during the 1931-60 period, was isolated to the regions of highest topography during the 1961-90 period and covered the eastern half of the region during the last 12 years of the record.

2. Sub-regional: Local scale analyses of annual, seasonal and daily rainfall characteristics in three sub-regions of East Africa show that it is difficult to generalise about temporal variability in these areas of diverse terrain. Between the sub-regions there are some similarities, e.g., the seasonal regimes are similar in Kenya/Tanzania and Uganda along with some differences, e.g., interannual variability; SW Tanzania shows a stronger drying trend than the Kenya/Tanzania and Uganda sites. There is also considerable temporal variation within the sub-regions despite the fact that most of the stations in each sub-region also lie within regions of temporal coherence identified by regionalisation methods.
3. Station and grid-box scale interannual variability: SW Tanzania shows a slight drying trend in annual rainfall with the exception of Mbeya across the full station record. This trend is replicated by the GPCC data (1951-2000) and is also found in both data sets for the overlap period. The Ugandan stations show decreasing rainfall in the most northern locations and increases in the most southern stations whilst GPCC shows decreases across the Ugandan region. The overlap period for both data sets indicates a general decrease in rainfall with the exception of Lyantonde. Kenya/Tanzania shows a mixed pattern of increasing and decreasing annual rainfall, unrelated to location. A reduction in the length of overlap period between the station and GPCC data results in the majority of the stations showing a positive trend. Comparison between the GPCC and station data shows that in general the GPCC grid boxes replicate the trends identified by the station data for the overlap period but are not of equal magnitude.
4. Daily time scales: Analyses based on wet and dry day frequencies in Uganda and SW Tanzania reveal decreases in the number of wet days and increases in the number of dry days over the record whilst for the Kenya/Tanzanian sub-region the number of wet and dry days per year tends to be relatively consistent through time. There is no consistent trend in the wet day amount or the frequency of heavy rainfall days across the three sub-regions, possibly a result of a lack of overlapping data and incomplete series.
5. Cross-Scales analysis: In nearly all cases trends in rainfall are highly sensitive to the period over which they are calculated because there are few examples of long duration sustained trend in any rainfall statistics. Thus, no clear, systematic signal emerges across temporal scales. It is well known that for this reason, seasonal climate forecasts need to be tailored to particular location specific predictor relationships and that these may be subject to interdecadal variability. This spatial and temporal heterogeneity

highlights the difficulty of generalising the interactions between climate and, biophysical and socio-economic systems in the region.

EXAMINATION OF TEMPORAL AND SPATIAL TRENDS IN PRECIPITATION

This activity is examining temporal and spatial trends in the standardized precipitation index (SPI) over the study region in East Africa. Time series of a drought index were investigated for the period from 1963 up to 2002. Data from 19 stations were utilized. Missing data were substituted with gridded data (CRU) when appropriate. The Standardized Precipitation Index (SPI) is a versatile index calculated from precipitation data (McKee et al. 1993). It is a standardized score over a specific time scale such as 3, 6, or 12 months, relative for a particular site. Positive SPI values indicate greater than median precipitation, while negative values indicate less than median precipitation. We used clustering procedures, loess smoothing and spectral analysis to study the trends of wet and dry spells in East Africa, including the study of changes in variability across time and space.

STATISTICAL ANALYSES

Statistical analyses have continued to explore issues of uncertainty, replicability and assessment of regional patterns in the time series of LAI and albedo. These are essential to the parametization of "generic" regional climate models for the East Africa region.

REGIONAL CLIMATE MODELING:

The CLIP version of RAMS is tuned, and has been configured for four different computer systems. There are several simultaneous simulations currently running, including a comparison of climate under current conditions with those using 2050 land use conditions, but atmospheric boundary conditions corresponding to times near 2000. Extensive statistical analysis has been carried out using the current RAMS configuration. This includes histograms of variables by month, which is compared to observations of MODIS (for surface temperature) and TRMM (for precipitation). Some simple comparisons of RAMS simulations with observations are in progress for publication. In addition, some preliminary simulation differences driven with projected land cover datasets are illustrated in the accompanying figures.

We are currently adapting the model to run faster by adjusting the size of the domain and by adding sea surface temperatures that are specified to agree with input datasets corresponding to observations or the results of global simulations, as appropriate. We are also enhancing the capability of RAMS to output daily accumulated incident solar radiation, which is a relevant variable for input to the simulation of net primary productivity (NPP). This will accompany the more basic variables of daily high and low temperature and precipitation that have already been passed to the NPP models. Additionally, output from the Land Transformation Model (LTM) has been successfully ingested into RAMS. This combination of successful input and output from the relevant boxes in the feedback "loop" demonstrates the readiness of this component for execution as part of the loop. This has been accomplished in dry runs of all four of the basic coupled systems in Activity 6.

Submission of a set of papers is anticipated within a few months. The first two of these compare the simulation from RAMS using the land use dataset prepared especially for this project (CLIPcover) against the simulation using the Olson Global Ecosystem (OGE), the default land cover dataset for RAMS. The first will make the baseline comparison between these two options during a year with near average rainfall in the model domain. The second will assess how the ambient precipitation modulates this effect by doing the same comparison in years that were anomalously wet and dry. An additional third paper will assess the effect of empirical correction of annual cycle of land cover parameters, using cubic spline fits of leaf area index (LAI) and fractional vegetation cover (FC) to estimations from MODIS. This correction is motivated by the fact that the RAMS default formulation specifies an annual cycle of LAI and FC that are designed and calibrated for use in temperate latitudes. This means that the specified annual cycle of LAI and FC have both an incorrect trajectory of the annual cycle (the equatorial zone generally having two annual peaks in vegetation) and insufficient magnitude of intra-annual variation (Figures 23,24).

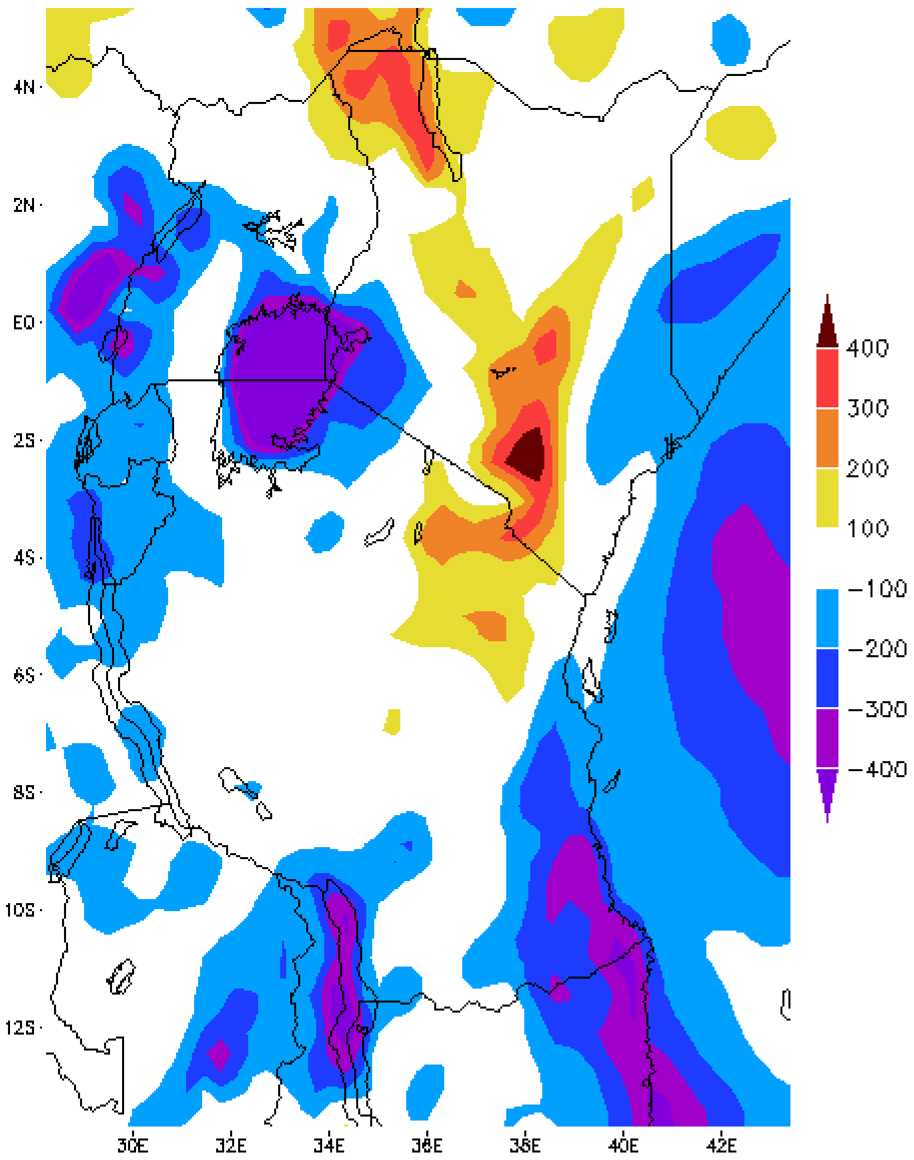

Figure 23. Accumulated precipitation difference (simulation using 2050 land cover minus that using 2000 land cover) for 1 January to 30 June, 2000. This period is selected to illustrate the larger precipitation difference; rainfall differences during the second half of the year are much smaller.

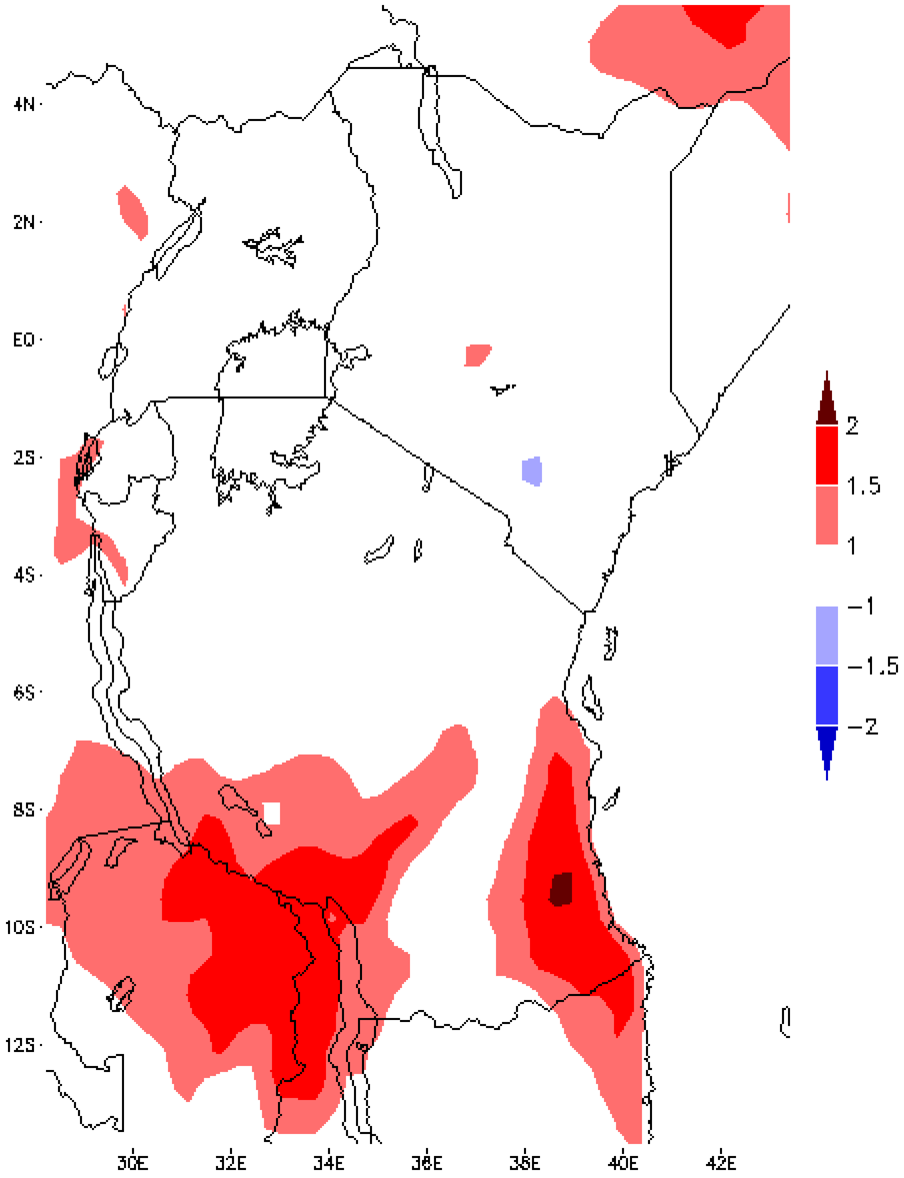

Figure 24. Near-surface air temperature difference (simulation using 2050 land cover minus that using 2000 land cover) for 1 January to 31 December, 2000.