Annual Report for Period: 09/2006 - 08/2007
Submitted on: 06/20/2007
Principal Investigator: Olson, Jennifer M.
Award ID: 0308420
Organization: Michigan State University
Submitted By:

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: 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: Yes

Contribution to Project:

Coordinate activities in Tanzania and provide expertise in land use systems.

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.

Name: Maitima, Joseph

Worked for more than 160 Hours: No

Contribution to Project:

Coordinate activities in East Africa (especially Kenya) and provide expertise in ecology in Africa

Name: Mugisha, Sam

Worked for more than 160 Hours: Yes

Contribution to Project:

Coordinate activities in Uganda and provide expertise in land use systems.

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: 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: 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

Name: Hession, Sarah

Worked for more than 160 Hours: Yes

Contribution to Project:

Sarah is doing her dissertation on the application of spatial statistics to the analysis of climatic and vegetation data used in the project.

Name: Kostas, Alexandrias

Worked for more than 160 Hours: Yes

Contribution to Project:

PhD student

Name: Wilson, Sigismond

Worked for more than 160 Hours: Yes

Contribution to Project:

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

Lansing area schoolteachers, and at MSU the outreach staff of the African Studies Center and the Center for Advanced Study of International Development preparing classroom curriculum materials..

Goverment officials and university faculty in Kenya, Tanzania, and Uganda who participate in CLIP workshops.

Activities and Findings

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

Educational activities are also described in training and development section.

Findings:

Findings are described in the attached file in 'research activities.'

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, Washington-Ottombre, Torbick and Hession have in given conference presentations and participated in writing of research papers

Education Activities
We are working with grade school classroom teachers to develop curriculum materials reflecting Michigan standards in the Social Sciences - specifically people-environment interaction. To our knowledge, deploying a complete set of lessons plans that integrate learning objectives from the Life Science, Earth Science and Social Science (Geography) benchmarks of a state-approved curriculum has never been done with Google Earth. The advantages for teachers of this approach include 1) a paperless set of lessons that can be accessed via the WWW; 2) the engaging user interface of Google Earth itself, which is very appealing to students; and 3) access to high resolution images and maps that would be difficult or impossible to affordably provide to each student via other mechanisms. Our linkage with LATTICE ensures a cadre of classroom teachers who will adopt and critique our materials and, undoubtedly, innovate new ways to use our science outcomes to teach students.

Outreach Activities:

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

The project team is working with Lansing Area Teachers groups to prepare curriculum materials based on CLIP. The team has made presentations to this group.

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. 223, vol. 34 (2), (2007). Published,

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,

Conway, D., C. E. Hanson, R. Doherty, and A Persechinon., "GCM simulations of the Indian Ocean dipole influence on East African rainfall: Present and future", Geophysical Research Letters, p. doi:10.10, vol. 34, (2007). Published,

Ge, J. Qi, B. M. Lofgren, N. Moore, N. Torbick, and J. M. Olson., "Impacts of land use/cover classification accuracy on regional climate simulations.", Journal of Geophysical Research-Atmosphere, p. (D5), D05, vol. 112, (2007). Published,

Olson, J., G. Alagarswamy, J. Andresen, D. Campbell, J. Ge, M. Huebner, B. Lofgren, D. Lusch, N. Moore, B. Pijanowski, J. Qi, N. Torbick, J. Wang., "Integrating diverse methods to understand climate-land interactions at multiple spatial and temporal scales.", GeoForum, p. , vol. , (2007). Accepted,

Smucker, T., D. Campbell, J. Olson, and E. Wangui., "Contemporary challenges of participatory field research for land use change analyses: Examples from Kenya.", Field Methods, p. , vol. , (2007). Accepted,

Alexandridis K, Pijanowski B C., "Assessing multiagent parcelization performance in the MABEL simulation model using Monte Carlo replication experiments.", Environment and Planning B: Planning and Design., p. 223, vol. 34 (2), (2007). Published,

Pijanowski, Bryan C. and Amélie Y. Davis. ., "Error Propagation in Coupled Regional Land-Climate Models: 1. Quantifying Aggregate Spatial Errors from a Land Change Model to a Regional Atmospheric Model.", Earth Interactions, p. , vol. , ( ). Submitted,

Hanson, C. and Conway, D., "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,

Pijanowski, Bryan C. and Amélie Y. Davis. ., "Error Propagation in Coupled Regional Land-Climate Models: 1. Quantifying Aggregate Spatial Errors from a Land Change Model to a Regional Atmospheric Model.", Earth Interactions, p. , vol. , ( ). Submitted,

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Ge, J. Qi, B. M. Lofgren, N. Moore, N. Torbick, and J. M. Olson., "Impacts of land use/cover classification accuracy on regional climate simulations.", Journal of Geophysical Research-Atmosphere, p. D05107., vol. 112, (2007). Published,

Olson, J., G. Alagarswamy, J. Andresen, D. Campbell, J. Ge, M. Huebner, B. Lofgren, D. Lusch, N. Moore, B. Pijanowski, J. Qi, N. Torbick, J. Wang., "Integrating diverse methods to understand climate-land interactions at multiple spatial and temporal scales.", GeoForum, p. , vol. , (2007). Accepted,

Olson, J., G. Alagarswamy, J. Andresen, D. Campbell, J. Ge, M. Huebner, B. Lofgren, D. Lusch, N. Moore, B. Pijanowski, J. Qi, N. Torbick, J. Wang., "Integrating diverse methods to understand climate-land interactions at multiple spatial and temporal scales.", GeoForum, p. , vol. , (2007). Accepted,

Smucker, T., D. Campbell, J. Olson, and E. Wangui., "Contemporary challenges of participatory field research for land use change analyses: Examples from Kenya.", Fielod Methods, p. , vol. , (2007). Accepted,

Pijanowski, Bryan C. and Amélie Y. Davis. ., "Error Propagation in Coupled Regional Land-Climate Models: 1. Quantifying Aggregate Spatial Errors from a Land Change Model to a Regional Atmospheric Model.", Earth Interactions, p. , vol. , ( ). Submitted,

Alexandridis K, Pijanowski B C., "Assessing multiagent parcelization performance in the MABEL simulation model using Monte Carlo replication experiments.", Environment and Planning B: Planning and Design., p. 223, vol. 34(2), (2007). Published,

Books or Other One-time Publications

Ge, Jianjun., "Improving Regional Climate Modeling in East Africa Using Remote Sensing Products.", (2007). Thesis, Published
Bibliography: Michigan State University, Department of Geography

Hession, S. L., Shortridge, A. M., & Torbick, N. M.., "Categorical models for spatial data uncertainty.", (2006). Book, Published
Editor(s): Mário Caetano and Marco Painho
Collection: Proceedings of Accuracy 2006: pp. 386-395
Bibliography: ISBN 972-8867-27-1.

Web/Internet Site

URL(s):
clip.msu.edu
Description:

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:

Statistical Procedures:
Application of GeoSpatial techniques further the fields of statistics and spatial statistics in the following ways:
1. It uses globally available remotely sensed and climate data, allowing application to other regions;
2. It will further statistical methods capable of handling climatic data, which often violate the assumptions underlying standard regression techniques.

Regional Climate Modelling
For the first time, a separate lake model was incorporated into RAMS.
We incorporated 1-dimensional model of lake dynamics of Lake Victoria into RAMS; this was important because Lake Victoria is much warmer than typically represented in RAMS, due in part to shallowness and vertical thermodynamic transport in the lake. A 3-D model of the lake would be a further improvement but was deemed to computationally intensive for this work.

We revalidated RAMS in its new configuration and made some modifications to the Kain-Fritsch scheme in RAMS to more accurately parameterize the cloud depths and convective activity in tropical highlands, which is often poorly represented in RAMS due to a mid-latitudes bias of the model.

We have completed a resource (software program) for CCSM data conversion, and also incorporated CCSM sea surface temperature data into the RAMS model. This will be made freely available to the RAMS users' community.

We have made significant contribution to a methodology of coupling a RCM to crop-climate models. We successfully converted RAMS output for direct use in the CERES-MAIZE crop model, and also adapted RAMS data for statistical use in the Marksim weather generator. The contributions allow RAMS results to be compared to observed climatological data and GCM results at appropriate scalesùa key element of our integrative efforts in CLIP. The methodology will be written up and submitted to a journal for publication.

Finally, we have completed 3 sets of decadal runs û longer than any other study to our knowledgeùand compared the long-term trends and patterns.

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:

Ge, Jianjun completed his PhD in Geography under the aegis of the project and has taken an appointment at Oklahoma State University. Two other PhD students are writing their dissertations and 1 MA student is completing his thesis.

Contributions to Resources for Research and Education:

PAPER PRESENTATIONS:

Washington-Ottombre, C., B. Pijanowski, J. Olson and D. Campbell. 2007. Combining Role-Playing And LTM Simulations To Study Land-Use Drivers, Presented at the 2007 IASTED (International Association of Science and Technology for Development) Conference On Environmental Modelling And Simulation, Honolulu, Hawaii, August 20 û 22.

Hession, Sarah L., Ashton M. Shortridge, and 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. http://2006.spatial-accuracy.org/

Pijanowski, B. Land use change patterns around the world's Great Lakes. International Association of Great Lakes Researchers. May 6-9, 2006. Keynote.

Pijanowski, B. Challenges to modeling land use change at different scales: Adapting a complex systems approach to address uncertainty. Earth Systems Science Partnership Conference, Beijing, China. Nov 4-8, 2006. Paper. Special Session Hosted by the Global Land Project.

Ottombre-Washington, C., B. Pijanowski, K. Alexandridis, D. Campbell and J. Olson. Using participatory Bayesian Belief Networks, Role Playing Simulation and Agent-Based Models to Understand Land Use. Beijing, China. Nov 4-8, 2006. Poster.

Pijanowski, B. A. Davis, D. Ray, K. Robinson and Nathan Moore. Integrating land use and climate change models at regional scales: important scaling issues. Framing Land Use Dynamics II Conference, Utrecht, Netherlands, April 23-26, 2007. Paper.

Pijanowski, B. C. Washington-Ottombre and K. Alexandridis. Using role-playing games, multi-criteria evaluation, machine learning and agent-based models to understand climate-drive land use change. Framing Land Use Dynamics II Conference, Utrecht, Netherlands, April 23-26, 2007. Paper.

POSTERS PRESENTED

Hession, Sarah L., Nathan M. Torbick and Ashton M. Shortridge. 2006. Spatiotemporal Analysis of Precipitation in East Africa. Multivariate Methods in Environmetrics. Chicago, IL October 26-28, 2006.

Contributions Beyond Science and Engineering:

Our colleagues in Tanzania, Kenya and Uganda have regular contact with government officials and share CLIP findings. ILRI, Nairobi, has a mandate to share scientific findings with policy makers.

Special Requirements

Special reporting requirements: None
Change in Objectives or Scope: None
Animal, Human Subjects, Biohazards: None

Categories for which nothing is reported:

Activities and findings:

The major activities of the Climate-Land Interaction Project (CLIP) in this reporting period have been to elaborate the "loop" of interactions between regional climate and land use by assessing the linkages between the components of the loop. Key components (Figure 1) include local and regional land use change analyses and modeling; analyses of satellite imagery to translate the effects of land use change to land surface characteristics; simulations of the impact of land surface changes on the regional climate, modeling the impact of climate change on net primary productivity (NPP); and analyses of the effect of productivity changes on people and their use of the land (Olson et al 2007). The altered land use would then impact the climate in a feedback loop.

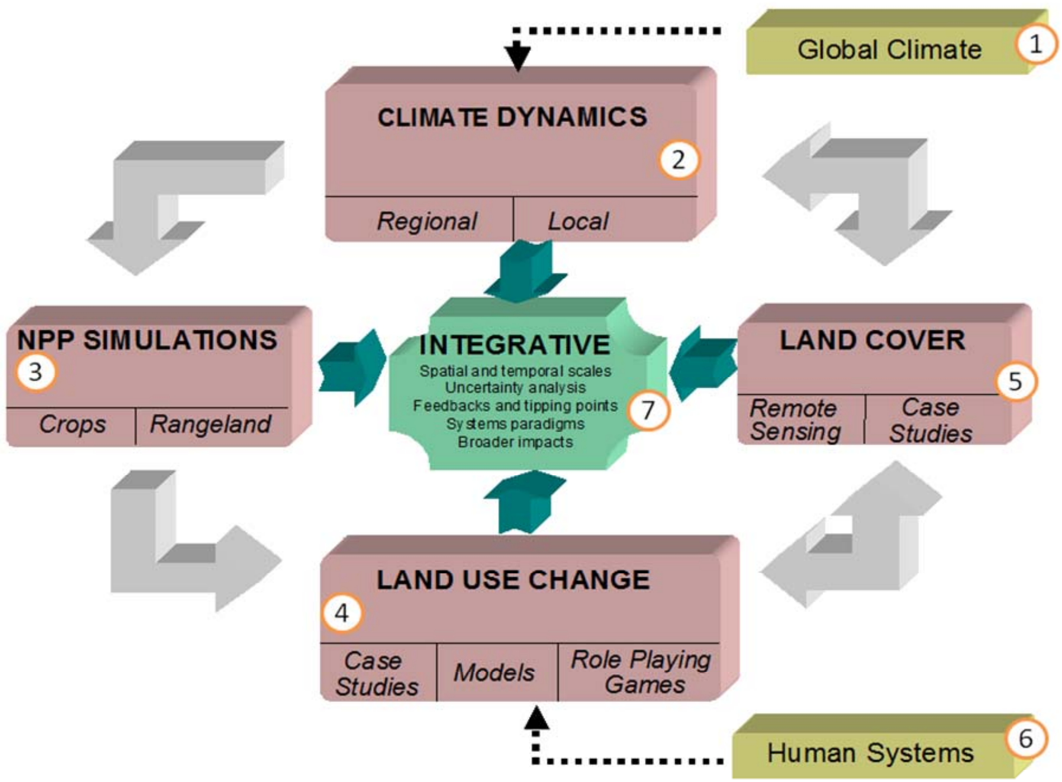


Figure 1. Conceptual Framework of the Project. Numbers are referred to in the text.

The activities during this reporting period have included 1) regional climate modeling to test the sensitivity of the climate to both perturbed (from greenhouse gases) climate and to land use change, 2) comparing General Circulation Model (GCM) simulation results for East Africa with those of the project's regional climate model; 3) analyzing historical climate and land cover data to assess temporal and spatial trends; 3) linking the NPP model to the regional climate model and to our historical baseline data to determine the effects of climate change on maize and bean yields, and 4) developing land use projections based on human population dynamics, crop-climate yield probabilities and other data and information.

During the next three months of this reporting period the project team will continue these activities as well as: 1) simulate the impact of projected climate scenarios upon the productivity and potential distribution of a variety of crops – maize, beans, sorghum, and millet – that are grown in the region; 2) expert system workshops in Kenya, Tanzania and Uganda where the results of the analyses of projected land use, rainfall and temperature, and crop productivity will be assessed by national experts, and likely agricultural and other land use adaptations to the effects of climate change will be discussed; 3) preparation of university- and grade school-level teaching resources including a visual presentation in a Google Earth environment and written resources developed specifically for grade school students.

A. The Regional Climate Responds to Land Use and Climate Change

A suite of regional climate simulations is providing information on whether, and if so how, land use and land cover change affects the regional climate. It is also providing information on projected climate to inform NPP models and thus identify the climate change impact on vegetative productivity. We are using version 4.4 of the Regional Atmospheric Modeling System (RAMS) that has explicit land surface variables. A significant effort was required in the first few years of the project to parameterize RAMS for East Africa's situation. Improvements were also made in the first few years to the model's generic vegetation and land surface characteristics using MODIS satellite imagery since East Africa has rainfall patterns and vegetation atypical of the areas used to inform RAMS. Newly developed MODIS Leaf Area Index (LAI) and Vegetation Fractional Cover (VFC) imageries were incorporated directly into RAMS.

Since the last report submitted to NSF, we have shrunk the size of the domain for our climate model and recalibrated parameterizations including for convection and cloud physics. There is some evidence that the boundary conditions extracted from NCAR's Community Climate System Model (CCSM)) simulations are excessively wet in the boundary layer; this wetness is propagated into the RAMS domain and results broadly in more rainfall throughout the domain than is observed by the Tropical Rainfall Measuring Mission (TRMM) satellite image estimates for the historical period. There remain some problems in the model's convective parameterizations over complex terrain, and this typically results in highly excessive rainfall in areas with steep slopes. Basic comparisons of rainfall data against long-term TRMM trends show that these areas are largely limited to areas near Lake Turkana, east of the Ruwenzori Mountains, and east of Mount Elgon. Simulated land surface temperature (LST) compares reasonably well against long-term distributions of MODIS-derived LST products, typically falling within 4 degrees of the MODIS LST averages. The dominant error in simulated LST appears to be strongly correlated to albedo errors; this is currently under investigation. In general, the modeled crop yields simulated with our calibrated RAMS model are very similar to those generated using our baseline historical climate data (WorldClim).

We have completed 3 decadal trials corresponding to Master Plan Experiments 1-3. The Master Plan simulations are:

CASE 1. Current, static land cover (2000) and current boundary conditions (2000-2009)
CASE 2. Current, static land cover (2000) and future boundary conditions (2050-2059)
CASE 3. Future, static land cover (2050) and current boundary conditions (2000-2009)
CASE 4. (*in* process) Future, static land cover (2050) and future boundary conditions (2050-2059)
CASE 5. First feedback scenario: like Case 1, but with an updated land cover that incorporates vegetative and human responses to the forecasted climate change;
CASE 6. Future meteorological conditions based on Case 5, with a projected LULC from socioeconomic factors alone

CASE 7. Closing the land-climate-land-climate loop: future meteorological boundary conditions and projected LULC based on the socioeconomic factors and people's land use responses to climate change.

Assessing differences between Case 1 and Case 2 will show the effects of land surface boundary condition changes alone; assessing differences between Case 1 and Case 3 will show the effects of LULC change alone. To identify the synergistic effects of altered boundary conditions and LULC together, a comparison will be made of Case 4 + Case 1 – Case 2 – Case 3. Experiment 4 is currently underway, and results from Experiments 1-3 have been relayed to the crop-climate modeling and land use teams.

This has resulted in:

1. *Analysis of projected climate change due to land use change in the next 50 years (Box 5 to 2 in Figure 1).*

Land cover projected to 2050 shows widespread expansion of agriculture in the savannas and woodlands of Kenya and Tanzania, and of southern Uganda. The expansion of agriculture is by far the dominant difference in the two landscapes. While much of this transformation involves expansion into marginal grasslands, the transformation to agriculture in areas of southwest Uganda and southern Tanzania replaces Miombo woodland, mixed forest, and other more complex land cover. These changes in cover thus result in different shifts in surface characteristics—e.g., transforming savanna to agriculture has higher albedo following harvest, but albedo is virtually unchanged during much of the maize growing season. By comparison, the transformation of darker Miombo woodland and other forested areas to agriculture involves a much brighter albedo and a very different seasonal phenology. These differences in the types of land cover being replaced result in different atmospheric responses to the arrival of agriculture, which we exhibit in the following figures. The dominant change in surface forcings is strongly related to albedo, and these forcings exert a strong influence on convective precipitation.

Changes in land cover in southwest Uganda result in wooded cover being replaced by cultivation, which results in generally drier soils and hotter daytime temperatures (Figure 2A). The loss of soil moisture diminished the moderating effect of humidity on daily temperature range, thus also lowering the dew points and decreasing the average minimum temperature (Figure 2B). A similar but smaller effect is also evident on the eastern edge of Lake Victoria. Changes in minimum temperature for much of Tanzania appear related to precipitation increases (Figure 3).

There are also large-scale consequences of agricultural expansion and the general brightening of the region's albedo. The effect of a brighter surface appears to have a broad effect on large-scale transport of moisture into the domain through a shallower boundary layer. This shallower boundary layer allows moisture into the highlands, but more rainfall preferentially falls on the Indian Ocean side of the domain, and less moisture is able to propagate inland to Uganda and the Lake Victoria region (Figure 3).

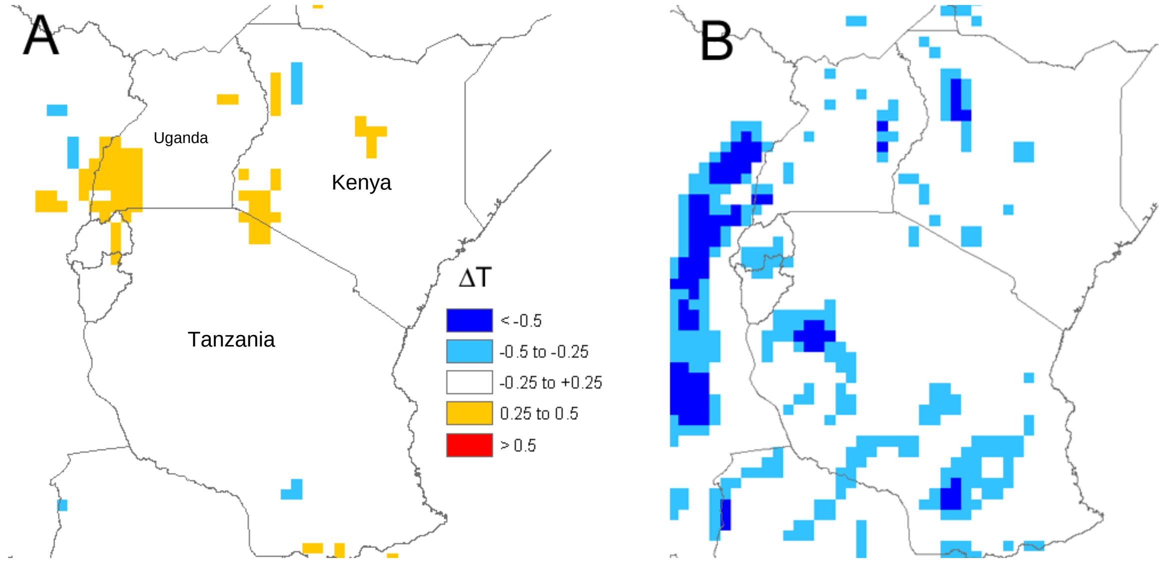


Figure 2. Temperature differences (degrees C; CASE 3 – CASE 1) due to projected changes in land cover only. (A) changes in annually-averaged daily maximum temperature; (B) changes in annually-averaged daily minimum temperature.

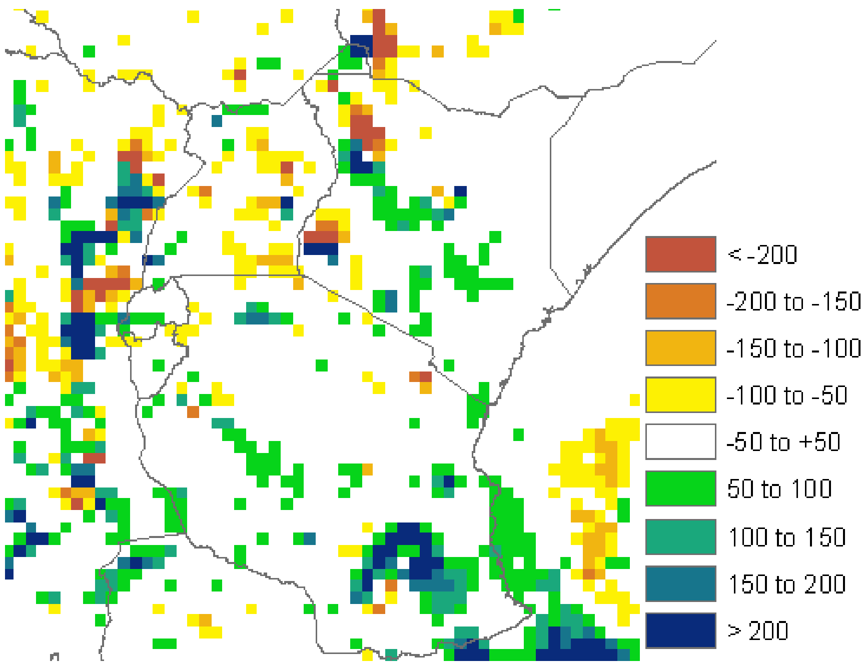


Figure 3. Changes in ten-year accumulated precipitation (mm) from 2000-2009 to 2049-2050 due to changes in land cover only. A future landscape with expanded agriculture shows the possibility of important rainfall declines in Uganda but with enhanced rainfall in the highlands of Kenya, and Tanzania, particularly in the Eastern Arc Mountains near Iringa.

2. *Analysis of projected regional climate change due to global climate change in the next 50 years (Box 1 to 2 in Figure 1).*

Generally, many GCMs predict a warmer, wetter East Africa by mid-century. CCSM under SRES Scenario A1B also predicts warmer and wetter patterns, particularly in the highland areas, and this pattern is propagated into the model interior of RAMS. Hence, our simulations show a warmer, wetter pattern as well. The improved topography and resolution of land cover characteristics drastically improves the regional simulations; patterns of highland and coastal precipitation are much closer to observations in the RAMS results. Figure 5 shows that both maximum (A) and minimum (B) daily average temperatures show increases due to perturbed climate, and the difference patterns are related to both rainfall and CCSM boundary forcings. Generally speaking, areas that see increases in precipitation (Figure 6) also see a narrowing of their daily temperature range (lower maxima and higher minima—e.g. northern Kenya). Areas that see no large precipitation differences simply get slightly warmer, and areas that see precipitation declines witness expanded daily temperature ranges. In some cases, the temperature increases are so hot as to close stomata and thus halt transpiration, which further reduces regional humidity and leads to higher temperatures in the vicinity of the rainfall declines.

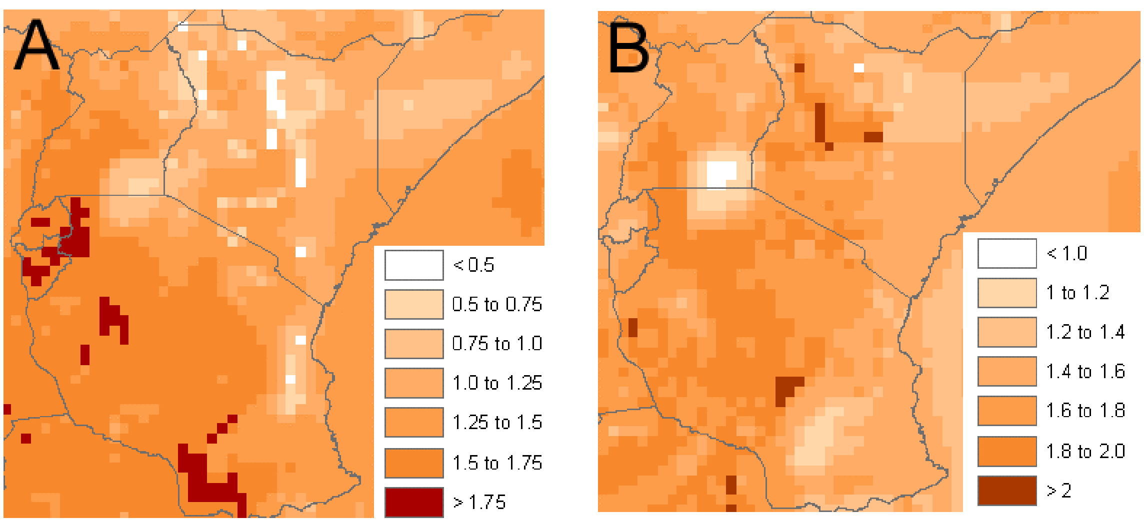


Figure 5. Temperature differences (degrees C; CASE 2 – CASE 1) due to projected changes in climate only. (A) changes in annually-averaged daily maximum temperature; (B) changes in annually-averaged daily minimum temperature.

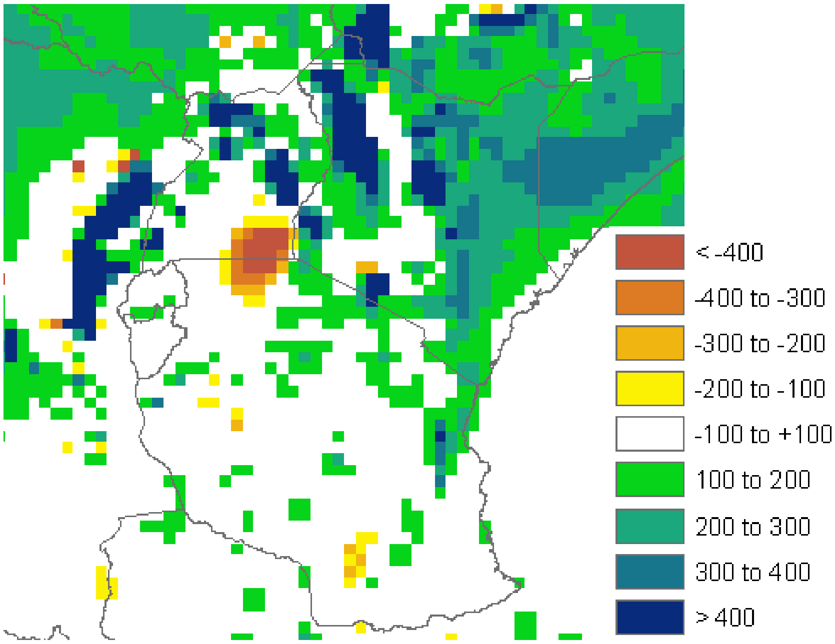


Figure 6. Changes in ten-year accumulated precipitation (mm) from 2000-2009 to 2049-2050 due to global climate change only. Echoing the general warmer and wetter trend of CCSM projections, our simulations indicate warmer and wetter conditions, particularly in the highland areas.

Kenya in CASE 2 (current land cover, future climate) witnesses a broad increase in precipitation almost everywhere, but most dramatically in its arid northern provinces. Some of these heaviest rainfall differences are connected to model parameterization of convection, but the overall pattern of increased rainfall is directly attributable to the extra moisture from the GCM boundary conditions. There are also increases in precipitation along the Congo border exceeding a rate of 40mm/year. Precipitation changes are not as dramatic in most of Tanzania, and areas around Lake Victoria show a pronounced decline likely due to warmer temperatures aloft and thus a more stable atmosphere over the lake. Precipitation declines in Uganda under CASE 3 (future land cover, current climate) are opposite in sign and in different areas than the CASE 2 precipitation increases for Uganda; this indicates that the upland and lowland areas of Uganda—key agricultural regions—may experience dramatically different climate regimes in the near future. Areas around Mount Kilimanjaro show no appreciable changes, and the Iringa area in southern Tanzania actually shows more of an impact from land cover change than from climate change. The team will soon have results of simulations of the combination of land cover change and climate change on the region.

Comparing General Circulation Models (GCMs) for the East African Region to assess uncertainty levels (Box 1 and 7, in Figure 1).

It is now standard in climate change science to present the simulation results of a suite of GCMs to reduce uncertainty levels. This is especially important for regional scale analyses, where GCMs can vary significantly. It is important that GCMs realistically simulate East African rainfall variability across time and space, in order to provide confidence in their projections of future rainfall in this region. It is also essential that influences on rainfall behavior on interannual timescales are adequately modeled by GCMs. Six coupled GCMs were assessed in terms of their ability to simulate observed characteristics of East African rainfall, the Indian Ocean dipole and their temporal correlation (Conway et al. 2007). Model results were then used to analyze the future behavior of rainfall and the Dipole Mode Index (DMI). All models simulate reasonably well the spatial distribution and variability of annual and seasonal rainfall over the 1961–1990 period. Model simulation of observed DMI characteristics is less consistent with observations, however, five models reproduce similar correlations to those observed between the DMI and East African short rains (SON). In the future, there are no clear inter-model patterns of rainfall or DMI behavior. In this sample of models four (two) out of six simulate modest increases (decreases) in annual rainfall by the 2080s. For SON, three of the six models indicate a trend towards increasingly positive phase of the DMI, two indicate a decrease and one shows no substantial change. Our results demonstrate that with this sample of models no clear signal emerges in the future behavior of SON DMI and East African rainfall. We find that models simulate differing responses in Indian Ocean SST patterns to greenhouse gas forcing with varying consequences for future DMI behavior. This uncertainty is compounded by instability in the association between the DMI and East African rainfall and its likely interaction with changes in other influences that have not been considered.

B. Remote Sensing Data for Improved Land Cover Characterization

In prior reports, we discussed how the land surface parameters that are imported into RAMS were improved using global and regional land cover datasets, and especially remote sensing data. In this reporting period, we conducted uncertainty analyses of land cover data imported into RAMS, and analyzed historical trends in vegetation data from satellite imagery to assess the effects of recent climate change.

Testing Uncertainty Levels in Land Cover Schemes

We evaluated land cover classification schemes in East Africa and the uncertainties associated with this land cover classification scheme (Hession et al. 2007). These data are categorical and require specific geostatistical methods for analysis. Accuracy measures for remotely sensed land-cover data are often limited to use of the kappa statistic, a summary statistic that does not represent spatial autocorrelation. Instead, we used two different spatially explicit methods to evaluate the accuracy of Global Land Cover 2000 (GLC2000) for a study area including parts of Kenya and Tanzania (simple indicator kriging with varying local means and indicator cokriging) against available ground truthed land use data. Both methods rely on accuracy data (a confusion matrix) to inform predictions. As shown on Figure 7, accuracies are generally low. User's accuracies for forest, wood-shrubland, and other are 11%,18%, and 11% respectively. Also, 87% of cells classed as forest and 72% of the cells classed as wood-shrubland by GLC2000 were identified as agriculture in the reference data. While 55% of reference samples were identified as agriculture only 9% of GLC2000 samples were identified as agriculture.

GLC Class		1	2	3	4	5	Row Sum	User
Forest	1	**10**	2	0	78	0	90	0.11
Wood-shrubland	2	7	**17**	0	65	1	90	0.18
Grassland	3	0	29	**59**	30	2	120	0.49
Agriculture	4	1	8	2	**19**	0	30	0.63
Other	5	0	6	9	1	2	18	0.11
Column Sum		18	62	70	193	5	**30%**	
Producer		0.55	0.27	0.84	0.10	0.40		

Figure 7. Confusion/error matrix for Kenya/Tanzania study site.

The rather low accuracies translate into simulated land cover maps that are somewhat different from the original GLC2000 classification. A paper illustrating the propagation of land cover classification uncertainties in the CLIP domain is in the works.

The application of these methods is relatively new in remote sensing, and a thorough review of the underlying assumptions and the practical use of these methods related to adherence to assumptions has not been completed. We are currently evaluating the underlying assumptions of these methods, which include stationarity of the confusion matrix across the study area. We are evaluating statistical methods that will be useful in comparing and identifying differences between confusion matrices for subregions of the study area. These methods also allow for the simulation of alternate land cover maps based on the observed level of accuracy for propagation of uncertainty in the land cover product. The results of these analyses will be useful for propagation of uncertainty in the larger CLIP project.

Assessing the sensitivity of the regional climate model to land cover classification accuracy to assess uncertainty levels (Box 5 to 2, and 7, in Figure 1).

The uncertainty originating from the land surface and its propagation need to be examined to improve the representation of the land surface in climate models. Accurate representation of the land surface in regional climate models is becoming increasingly crucial as numerous studies are simulating the influences of human modification of the Earth's surface on regional and global climate. The advantages of remote sensing data to monitor the land surface have been recognized for decades. The climate modeling community, however, has yet to fully utilize this technique, especially the recently developed remote sensing products which have been proven to be very suitable for global change studies. We conducted analyses to improve the representation of the land surface and to test the impact of land cover classification accuracy on regional climate modeling in East Africa (Ge 2007).

Several global and regional land cover datasets from different sources now exist. A statistical measure "Q" was developed to evaluate the land cover classification specifically for the purpose of climate modeling. In terms of this Q measure, GLC2000 was ranked the best among four land cover datasets. Newly developed MODIS Leaf Area Index (LAI) and Vegetation Fractional Cover (VFC) imageries were incorporated directly into RAMS, and the default land cover dataset was updated by GLC2000. The impact of the improved land cover parameters was examined by comparing the model simulated land surface temperature (LST) and precipitation with MODIS LST and precipitation from the Tropical Rainfall Measuring Mission (TRMM) satellite. This study finds that the incorporation of MODIS LAI and VFC greatly improves the spatial and temporal characteristics of LST. The precipitation, however, is less sensitive to the improved land surface conditions.

This analysis found that land cover classification accuracy under (worse than) 80% has a significant impact on simulated precipitation, especially when the land surface has an important effect on the overlying atmosphere. As the accuracy worsens, the effect of the errors becomes stronger. In the remote sensing community, an 85% overall accuracy has been suggested as a guideline of classification quality control. This study shows that this accuracy target can satisfy the requirement of climate modeling in the East Africa region. In reality, however, the classification accuracy is often much lower in the historically reconstructed and future projected land cover datasets that are usually used in climate modeling studies.

Trends in historical vegetative productivity in relation to climate change and human induced land use change (Box 5 responding to 2 and 4).

An analysis has been conducted of changing vegetation amounts and vigor (productivity) across the East Africa project domain from 1982 to 2003 using satellite image data. Trends in vegetative productivity would reflect climate change as the vegetation responds to altered rainfall and temperature, and changing human land management such as large scale deforestation. This analysis will provide an indication of when, where and how climate has been changing over the past 25 years that can be compared with the projected changes in future climate. The historical response of vegetation to climate change also informs our simulations of future vegetation characteristics for the feedback loop analysis.

The data analyzed is the Normalized Difference Vegetation Index (NDVI) derived from AVHRR satellite imagery from 1981 to 2003 prepared by Global Inventory Modeling and Mapping Studies (GIMMS). The NDVI analysis results are being compared against meteorological station data, CRU TS 2.1 gridded climate surface data, and supplemental land use data and information. The NDVI data was aggregated to a 18 km grid to match that of the CRU data to permit vegetation/ climate spatio-temporal modeling.

An important aspect of the analysis is the comparison of statistical approaches to measure temporal trends in productivity—linear regression (the method usually employed in analyzing NDVI), isotonic regression and others. Isotonic regression analysis does not require an assumption of independence or non-colinearity of data, an assumption that is not met in time series data such as NDVI, so the isotonic regression results are more robust. Isotonic regression also identifies when a significant change in the event being studied occurs, reflecting a long term, systemic change such as a tipping point in the system.

Figure 8 shows maps of statistically significant changes in vegetation productivity from 1981 to 2003. Most of the domain has had either no change or an increase in productivity. Although the general spatial patterns are similar, the isotonic regression determination of significant change shown on the left appears to be more conservative or discriminating than the linear regression results. The isotonic results show less land as having significantly declining productivity in particular.

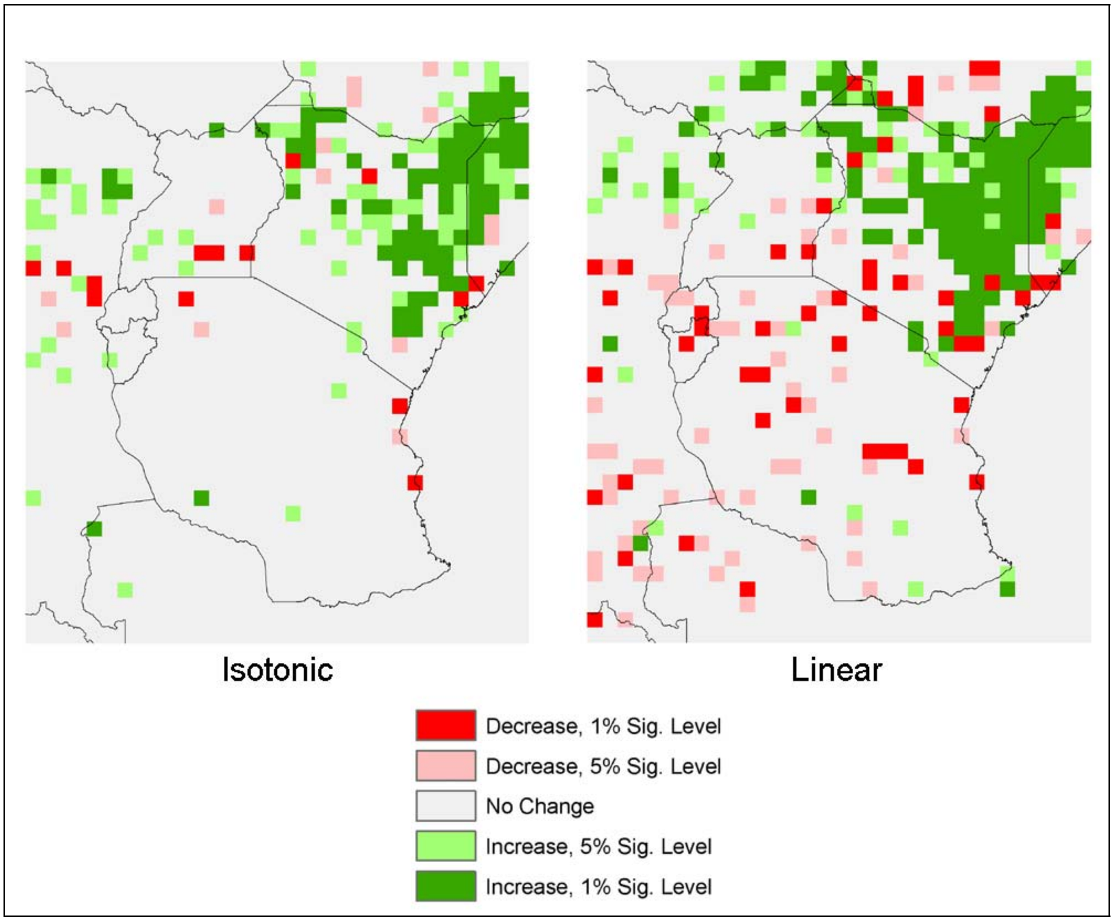


Figure 8. Significant Changes in Vegetation Amounts (NDVI) from 1981 to 2003 using Isotonic and Linear Regression.

The one large scale change appears to be that of increasing productivity across the northern part of the domain, especially in Northeast Kenya and in western Somalia. Northwest Kenya, southern Sudan and parts of northern Democratic Republic of the Congo may also be experiencing increasing productivity. The increase across northern Kenya and western Somalia is occurring in arid and semi-arid zones, so although the increase may be statistically significant, the actual rise in production is relatively small. Production had been gradually increasing from 1981, but the isotonic regression analysis indicates that a major change in the system occurred in the mid-1990s with a jump in vegetative productivity during an El-Nino event and then a continuation of this higher vegetative growth. The extent of land in Northeast Kenya under desert-like conditions shrunk and appears to have been replaced by sparse grassland conditions, and some of the area that had been under sparse grassland appears to have been replaced by grassland savanna conditions. Northwest Kenya, in contrast, appears to have remained under near desert-like conditions despite some increase in vegetation. We are now examining metrological station data and meteorological data to determine the climatic reasons for the increase in vegetation.

The trend of increasing productivity in the northern section of the CLIP domain may continue in the future. The climate model simulations of future (perturbed) climate show that rainfall is expected to increase in this area (Figure 6). Because of this, the CLIP team decided to conduct crop-climate simulations of maize, beans and more drought resistant sorghum and millet in the northeastern section of the domain, despite it being too dry to support crops under current conditions, to test whether this area may be able to produce crops in the future.

Unlike the areas with increasing productivity, the areas with decreasing productivity are small and scattered, and some appear to be associated with the impact of human activity. The linear regression analysis indicates more area under declining productivity, especially in Tanzania, compared to the isotonic regression analysis which indicates only a few isolated spots of declining productivity. Those that show up in the isotonic regression are areas impacted by human-induced land use change. The Tanzanian and Uganda capital cities and coastal zones along Lake Victoria and the Indian Ocean appear, for example, as do several sites in Eastern Congo probably related to deforestation including following the in-migration of Rwandan refugees. The declining productivity in Tanzania that shows up in the linear regression analysis may be due to climate change (higher temperatures, little change in rainfall) and/ or to land use change. This will be further examined with supplemental data.

C. Net Primary Productivity (NPP) responds to Future Climate Change (Box 2 to 3 in Figure 1)

The impact of altered precipitation and temperature due to future climate change on NPP is also being examined. One of the most dynamic elements of NPP is in the agricultural system as changes in crop productivity impact humans and their land use decisions. We are therefore investigating the interrelationship between the productivity of representative staple food crops and climate variability and change across the CLIP domain over two time frames: i) historical (1901-2002) and ii) projected future (present-2050).

Since the last reporting period, we have simulated historical maize production in the CLIP domain using CRU TS 2.1 climate data with 0.5 degree grid resolution (58Km). Analyzing the model output, we found the use of low resolution climate surfaces derived from spatially interpolated data such as CRU TS 2.1 resulted in a reduction of ability to capture real environmental variability, especially in areas with strong climatic gradients such as East Africa. In an attempt to obtain higher resolution climate data for future simulations of net primary productivity (NPP), we aggregated the data from the WorldClim (Hijmans et al. 2005) data set to 18 km spatial resolution to be consistent with the statistically downscaled high resolution RAMS CLIP data which will be used to simulate NPP at future time periods. The new triage at 18 Km resolution has 24943 combinations of soils in 6840 pixels within the CLIP domain as against 653 pixels at 0.5 degree grid resolution (59Km).

Simulation of maize production in the CLIP domain at the 18km resolution under a variety of differing combinations of input soils data and agronomic assumptions (e.g. planting date, irrigation) with the WorldClim reference climate data set (based on the period 1951-2000) is presented in Figure 9. The spatial distribution of 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. Future climate conditions for the NPP simulations will be obtained from the output of *both* GCMs and the regional climate model. Given the uncertainty associated with the future projections and the results of our study comparing GCMs for East Africa, we are considering output from three separate GCMs: CCSM3 (Collins et al., 2006), HadCM3 (Johns et al., 2003), and ECHAM4 (Roeckner, 1999).

We also initiated simulation of maize yields in the future time period using daily weather data derived form the RAMS regional climate model embedded within CCSM global climate model for the period 2000-2059. Results of simulated maize yield reported here are for the two decades, 2000-2009 (Case 1) and 2050-2059 (Case 2). In these simulations we used the 2000 land cover for both climate simulations and boundary conditions of 2000-2009 and 2050-2059. Mean simulated maize yields for the two decades are given in Figure 10. The spatial distribution of maize yields in both the periods is similar to the historical maize yield simulated using the WorldClim as shown in Figure 9. In order to visualize the climate change effects, the yield differences between 2050 and 2000 are shown in Figure 11. Differences between the two decades suggest that the maize yield increases in the 2050s are possible in highland areas of Kenya, Tanzania, Rwanda and Burundi probably due to increases in minimum temperature. On the other hand, overall reductions in maize yields were found in the cattle corridor of Uganda, and in northeastern and southern Tanzania. Biophysical reasons for the differences associated with the climate change are being examined in greater detail.

Currently the land use potential in the northeastern Kenya is under seasonal grazing due to scanty rainfall. Our studies have shown an increase in NDVI in northeastern Kenya during 1980 to 2000 (described above). The Regional Climate Model predicts an increase in precipitation during the future time period in this region leading to a possibility to support a short or very short cropping season. Using crop simulation models we are now investigating the feasibility to grow early maturing sorghum and millet that can withstand drought in the northern Kenya (not included in figures below). This could potentially lead to significant alterations in land use systems in this area.

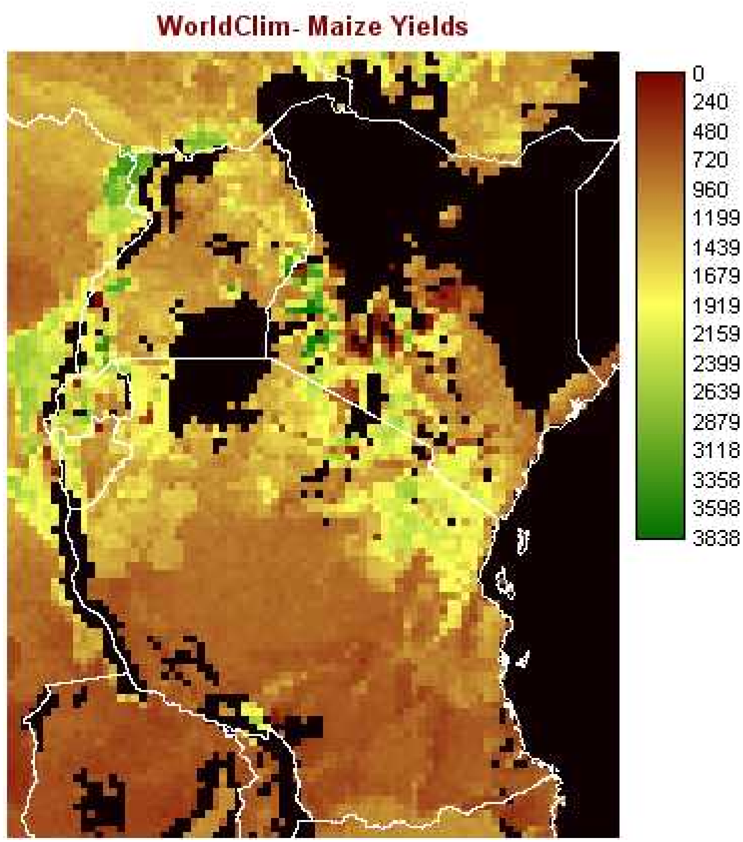


Figure 9. Simulated rain-fed maize yields (kg/ha) in CLIP domain under current conditions using WorldClim climate data.

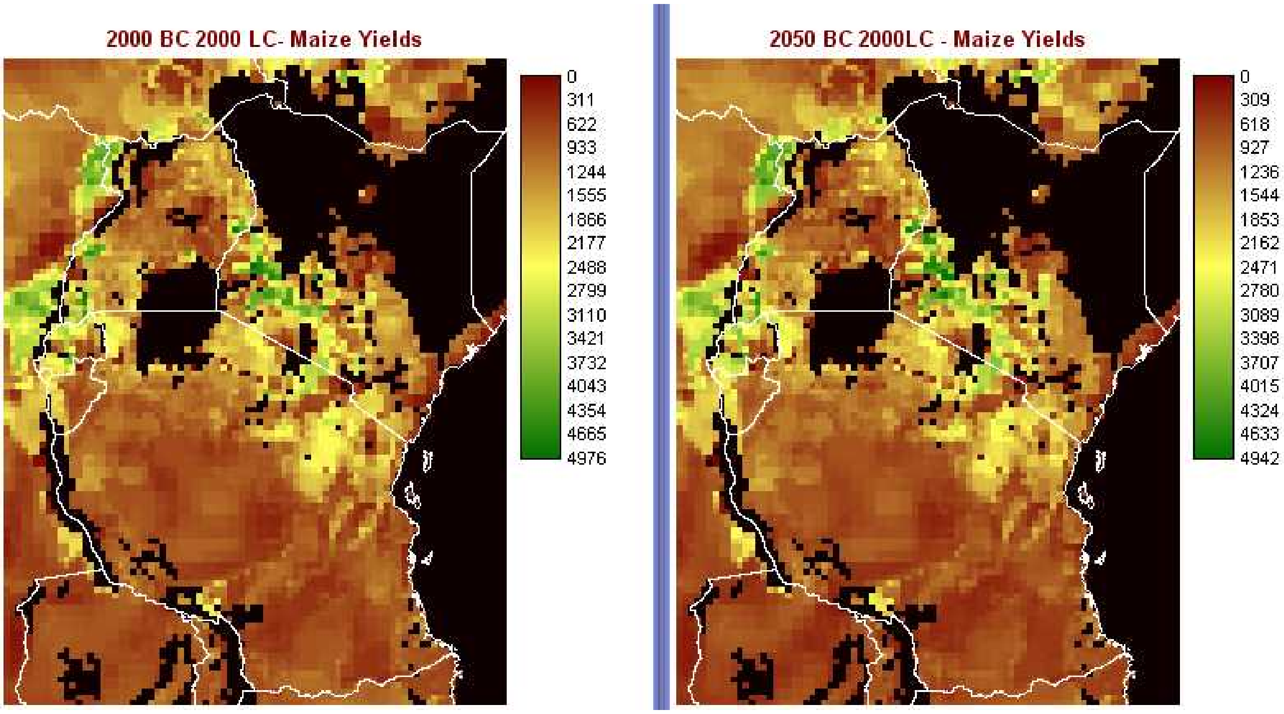


Figure 10. Simulated rain-fed maize yields (kg/ha) using RAMs simulated weather data. Left panel shows the yields for the period 2000-2009 and the right panel shows the yields for 2050-2059 due to global climate change.

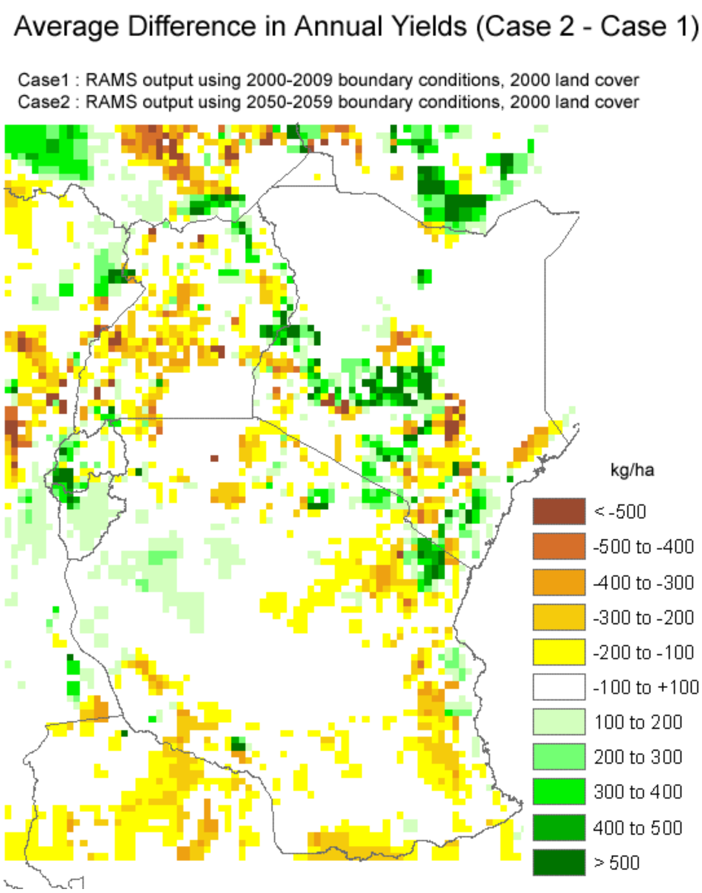


Figure 11. Average differences in maize yield between 2050 and 2000 due to global climate change.

D. Land Use Change affecting Land Surface Conditions and thus Climate, and Climate Change Impacting People and their Land Use Decisions (Box 4 and surrounding boxes in Figure 1)

Human activities at the local and community scales cumulatively change the distribution of land uses at the regional level. Modeling human activity and land use change at the regional level to effectively interact with the climate, land cover, and NPP models requires tools and methods that identify complex drivers of change operating at different scales, accommodate large amounts of data, incorporate the various spatial interactions inherent in land use change analysis, and that address data quality issues common in developing regions. The project employs a GIS and artificial neural network based model, called the Land Transformation Model (LTM) (Pijanowski et al. 2002; Pijanowski et al., 2005), and multiple datasets including dynamic human population, crop yield probabilities from the NPP modeling described above, and other data and information, to project scenarios of future land use that will demarcate future conditions at the land-atmosphere boundary. Uncertainty analyses of the land use change modeling results have also been conducted.

1. Land Transformation Model Forecasts – Estimation of Error Propagation to Climate Model to Assess Uncertainty (Box 4 and 7 in Figure 1)

The team has recently completed the analysis of error propagation that may originate from a land use change model as it impacts land surface properties used as input to a regional climate model, such as RAMS. We used the stable LTM "prediction map" for the location of rainfed agriculture based on lengths of different training cycles and compared this map to the project's land cover classification CLIPcover (described in prior reports) containing the original, observed rainfed agriculture. This analysis has initiated a series of investigations into quantifying the potential error propagation from land use/cover to the regional atmospheric model. Several new techniques and metrics were developed that included a statistical analysis of the performance of the neural net based model across different climate grid resolutions that are nested across the current grid boxes at 36km (Figure 12). The tools necessary to develop this analysis were coded and the analysis completed in December 2006.

A paper was written and submitted to the journal *Earth Interactions* in April 2007 with a student working on the project. The findings of this paper include: (1) the overall goodness of fit of the model to the observed data was judged to be very good to excellent using the receiver operating characteristics curve (AURC = 0.83), an unbiased measure of model performance; (2) error from the land use change model is likely to be clumped and that high quantity errors (over prediction/under prediction) are spatially aggregated; (3) that the greatest amount of error from the land use change model is located along the edges of large, homogenous patches of rainfed agriculture and in areas that are very heterogeneous; and (4) errors do not necessarily "cancel out" at larger scales (i.e., larger climate grid boxes).

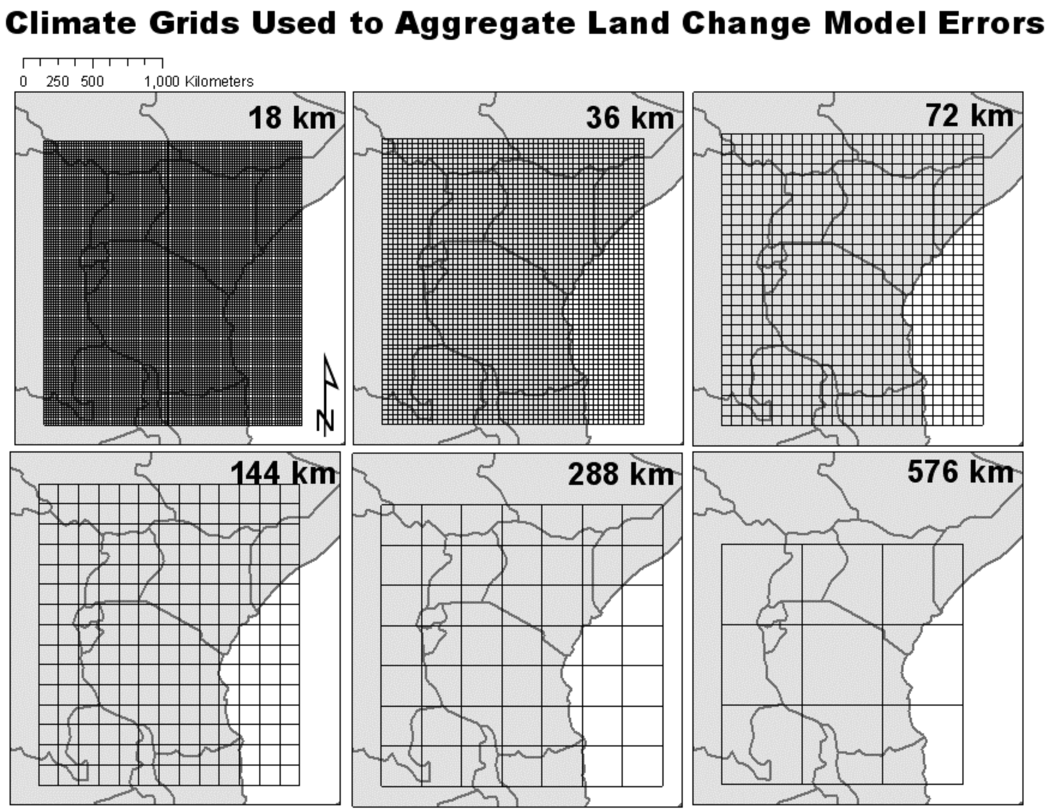


Figure 12. Map illustrating the nested climate grids used to quantify change use change model errors into a regional atmospheric model.

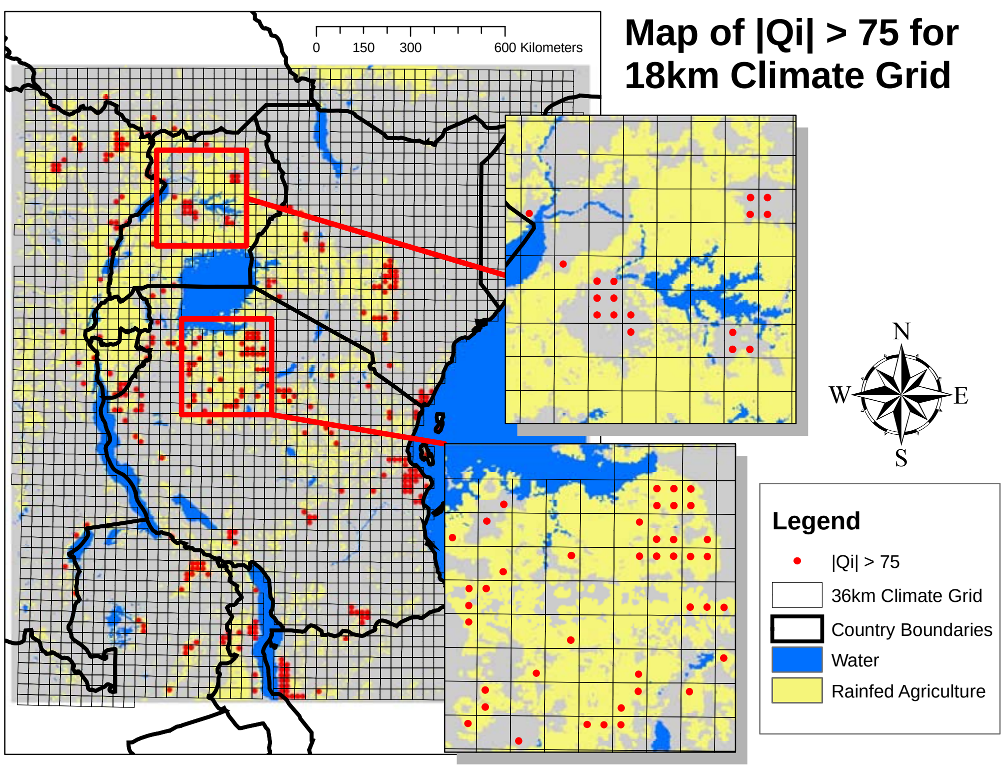
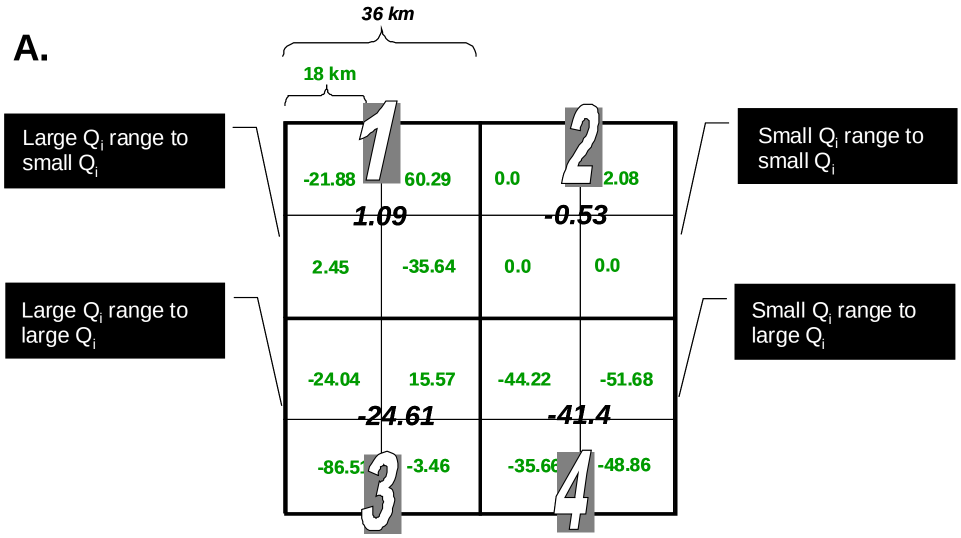


Figure 13. Locations of large quantity errors from the land use change model. Note that with the inset maps, high quantity errors are located along edges and in areas of complex patches of rainfed agriculture.



B.

36km box ID	36km Qi	18km Qi	18km Qi	18km Qi	18km Qi
1	1.09	-21.88	60.29	2.45	-35.64
2	-0.53	0.0	-2.08	0.0	0.0
3	-24.61	-24.04	15.57	-86.51	-3.46
4	-41.4	-44.22	51.68	35.66	48.86

C.

Aggregate Qi value at larger grid box		Range of Qi at smaller grid box	
		Small	Large
	Small	25%	25%
	Large	25%	25%

Figure 14. Cross-scaling error analysis. This figure illustrates how quantity errors may or may not cancel out at larger scales. The results of the cross scaling analysis are given in the next figure.

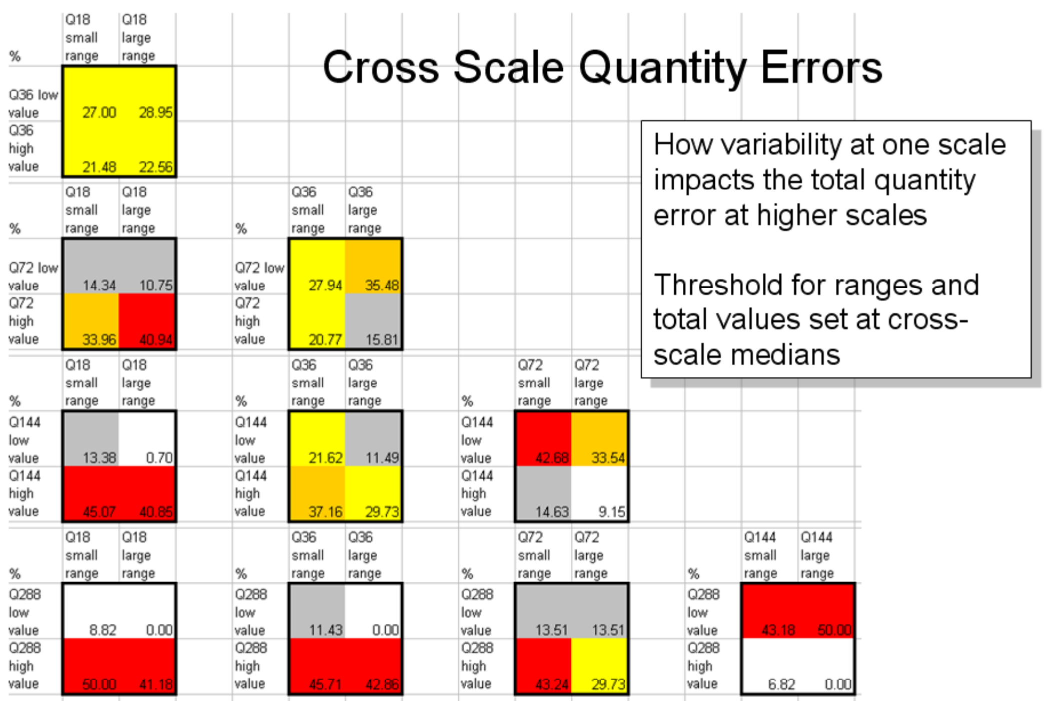


Figure 15. Cross scale quantity errors. This figure shows that (in red) errors can cancel out cross scales but they do not cancel out at smaller (18 through 72km) scales (i.e., climate grid boxes).

We also concluded that the coarse nature of the original climate data used for parameterization of the model is likely leading to poor model results along rainfed agriculture patches. It is unlikely that model performance in complex patches will improve unless other drivers are identified.

In submitting our paper to *Earth Interactions*, an online journal that publishes many papers on climate change and land use change, the editor responded enthusiastically to Dr. Pijanowski's inquiry about the possibility of a series of papers on this topic. Future papers that are in the works include: (1) the impact of land use change model errors on RAMS surface temperature; (2) the introduction of crop production models into the coupled land use-land cover-climate error propagation; (3) model ensemble variability for 2040 LTM projections based on the 6 different neural net cycle parameterizations.

Entirely new methods not currently used in either land use or climate change research were developed. These include: (1) the use of a true simple statistic to quantify binary confusion matrix errors and correct predictions; (2) the use of spatial clustering techniques to quantify the spatial nature of quantity errors; (3) a cross-correlation of the possible controlling factors for model performance, including the amount of edge in each climate box, the number of patches of rainfed agriculture, and proportion of the climate grid occupied by rainfed agriculture.

2. Analysis of Role Play Game Simulations (Boxes 4 and 6 in Figure 1).

We have conducted several analyses of the Kenya June 2004 Role Play Game (RPG) simulations that set up a situation of land use competition between Kenyans playing farmers and herders in a mythical location similar to many East African communities. We assessed how RPGs can inform and frame agent-based and reduced form (i.e., LTM) models (Figure 16). We conducted several analyses of the RPG and two land use change models developed from the RPG simulations that include: map comparisons (Figure 17) using a GIS from three different actors of the game: pastoralists, agriculturalists and the District Commissioner. We also used the information from the 2004 expert systems land use workshops and the RPGs to construct two reduced form models to determine how well they could predict the maps generated from the RPGs. We used a multi-criteria evaluation (MCE) procedure that employs simple GIS based maps of distance to road, slope, etc. to predict the occurrence of pasture and croplands. These drivers were then used in an LTM simulation to compare a machine learning tool versus an expert system developed MCE model (Tables 1 and 2). We also employed the "drop one out" approach that can estimate driver weights and are in the process of analyzing these results. A draft of these results were submitted for publication in the MODSIM conference in August 2007 (paper accepted) and a more detailed paper has been developed that will be submitted to JASSS in August of 2007 after our African colleagues have had a chance to review the manuscript. The paper focuses on how different methods can be used to inform our understanding of land use/cover change and what principles are needed to understand how these methods need to be integrated.

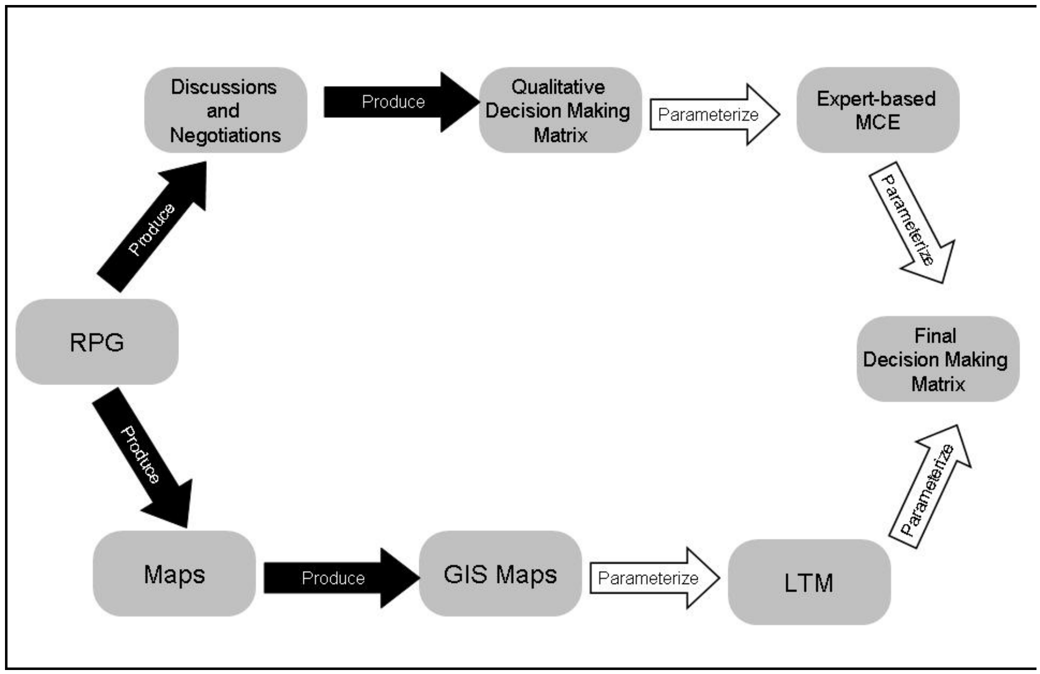


Figure 16. Information flow from the qualitative and quantitative methods used with the role playing simulations.

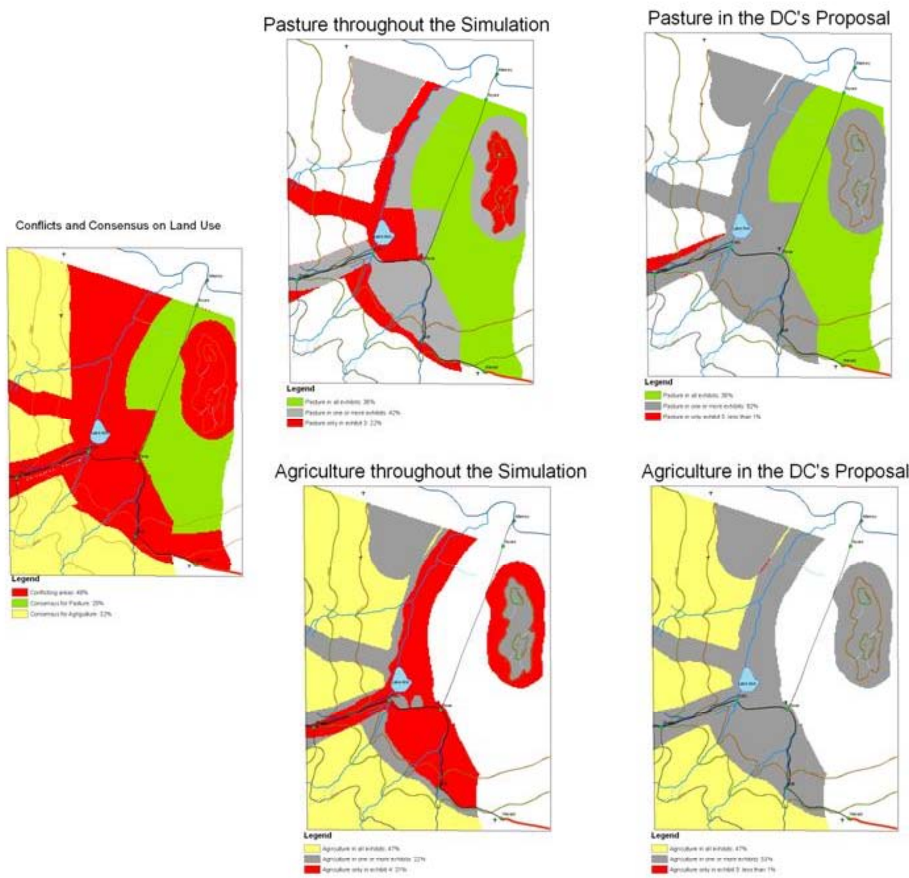


Figure 17: Comparison of the maps produced during the role-playing game

SIMULATIONS	% Correct with the LTM	% Correct with the MCE
Predicting Pasture, Sim 1	**88**	**52.17**
Predicting Agriculture	**99.06**	**22.41**
Predicting Pasture, Sim 2	**92.86**	**4.58**
Predicting Agriculture, Sim 2	**93.21**	**38.24**
Predicting Protected Area	**75.17**	**13.72**

Table 1: Summary of the performance of the LTM and the MCE

	Qualitative Decision Matrix	LTM	MCE
Resource System	**X**	**X**	**X**
Resource Units	**X**	**X**	**X**
Governance System	**X**		
Users	**X**		
Outcomes and Interactions	**X**		

Table 2: Summary of the performance of the various methods used in this work

3. First coded version of Watu Model Completed.

A simple demographic model that can be coupled to the LTM has been coded and we have developed a draft paper for publication that outlines the structure of this model. A PhD student has worked with a demographer and Dr. Pijanowski to develop the model. It is hoped that it can provide a means to address "what if" questions related to changes in fertility, gender based migration and age-specific population factors.

4. Expert System Workshops on Adaptation to Climate Change

Adoption of effective adaptation strategies will be a significant issue in response to impacts of projected climate change. Such strategies will be developed at the local, national levels, and global levels through experimentation and assessment of opportunities and constraints within the environmental and socio-economic-political systems. The CLIP project will conduct activities to identify possible responses to impacts of climate change. The land use implications of these responses will inform the land use change model, which will link to and affect the regional climate model leading to a feedback loop of climate impacts land use which then impacts climate.

In July and August 2007 team members from the US and Kenya, Tanzania and Uganda will host Adaptation Workshops in each of the three East African countries. Participants who are experts in agriculture, economic planning and environmental change will be invited from government agencies, academe, and NGOs. The workshops are designed to assess the scenarios projected by the climate, NPP-climate, and land use change models (Figures above), and to discuss anticipated implications, responses and adaptations at national and local levels. In keeping with the Political Ecology conceptual framework of this project, discussion address the implications of the model results within the experts' assessment of the future socio-economic, political, demographic, and policy context.

The agenda of the Adaptation Workshops will include: 1) participants will critique land use change model projections based on their expertise, 2) discussion of maps of projected climatic change (temperature and rainfall) from the regional climate model, and anticipated impact of climate change on forage and crop productivity for maize and beans, sorghum and millet, and projected distribution of these crops and livestock; 3) identification of key drivers of change including but not limited to climate and land use change projections. Policy, socio-economic, demographic and other processes will be identified and assessed in terms of relative importance of individual drivers, and 4) anticipated adaptations in rural livelihood systems and national policy in response to the climate change.

The products of these workshops will include 1) discussions on likely adaptations in and future configurations of rural systems; 2) identification of socio-economic and environmental policy options; and 3) input to the parameterization of new LTM simulations as the land use is altered due to climate change. The information on responses to climate and NPP change will be used to re-run the LTM and derive a second iteration of land use whose land cover parameters will be used in the second iteration of RAMS (Case 7). This represents a feedback to a second iteration of climate-land interaction, thus closing the loop of land use→climate→land use→climate.

E. Educational Activities

Over the past year, our broader impacts team has been developing several no-cost teaching resources that are based on the *Google Earth* user interface. These digital materials present a set of specific scenarios that engage student inquiries and that integrate learning objectives from the Life Science, Earth Science and Social Science (Geography) benchmarks of the *Michigan Curriculum Framework* (Michigan Department of Education). We are focusing on two case study areas that display steep environmental gradients (from alpine to savanna biomes) and increasing human population pressures: the southeast slope of Mt. Kenya and the northern slope of Mt. Kilimanjaro. The specific instructional materials (low-altitude, oblique airphotos; ground photos; maps and charts; and some text) have been compiled from both the previous LUCID (*Land Use Change, Impacts and Dynamics*) project (funded by UNEP-GEF and other donors) as well as the *Climate Land Interaction Project* (CLIP).

To ensure maximum educational impact, this project linked with the LATTICE group at MSU (http://www.latticeworld.org/). Developed in 1995 as an international education partnership, LATTICE (Linking All Types of Teachers to International Cross-Cultural Education) links six mid-Michigan school districts with international graduate students and scholars at Michigan State University. LATTICE concentrates on adult learning and promotes practical links to K-12 classrooms, with an overall mission of assuring a global perspective in K-12 classrooms. The team presented at the LATTICE session held January 11, 2007 in Haslett, Michigan. Our presentation was very well received, as the following responses to the after-meeting survey demonstrate:

- "Their Google Earth presentation was awesome!"
- "The Google Earth presentation was GREAT! I was blown away and amazed …"
- "This was a fascinating session. It helped to hear actual lessons and teaching that went on. I thought Dr. Lusch was great at explaining technology to those of us who aren't too good at it."

Lusch and Campbell from CLIP, along with Margaret Holtschlag (Vera Rayla Elementary School, Haslett, MI) and Judy Olson (Geography Dept., MSU) will be presenting a one-hour session entitled "Teaching Integrated Life Science, Earth Science and Social Science (Geography) Benchmarks Using *Google Earth* – An East African Example" at the Regional meeting of the National Science Teachers Association in Detroit, MI on October 20, 2007. This will be the official debut of the CLIP *Google Earth* teaching materials.

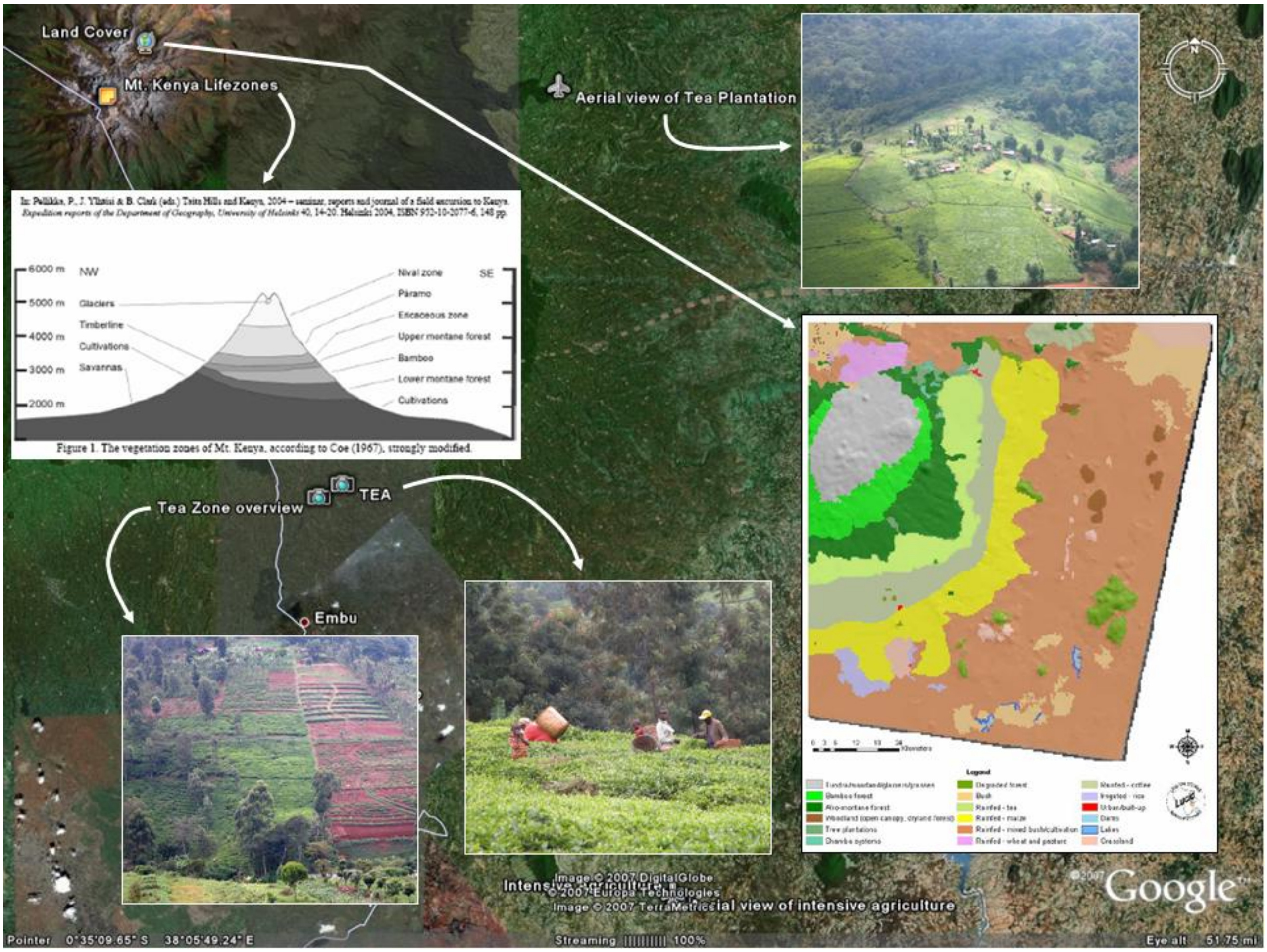


Figure 17. Educational materials developed using GoogleEarth

As background material for this activity Campbell and Sheba Moraa Onchiri, a Kenyan graduate student in the MSU College of Education, are preparing a text on Kenya modeled upon the format of the "Around The World" Series of the American Geographical Society.

Summary

Analyzing the interactions between climate and land over time and space has thus provided conceptual and methodological challenges. At the methodological level, it has required that datasets, models and other analytical techniques be adapted or that new techniques developed to improve coupling and to better represent the biocomplex system of East Africa. At the conceptual level research designs from the biophysical and human sciences have had to be integrated into a common analytical framework. This required a willingness among the team members to learn each others' scientific traditions and language, and appreciate and respect different analytical and methodological approaches. The CLIP research design calls for "conversations" among different analytical models in which the outputs of one activity serve as inputs to another. Challenges inherent in such analyses include datasets and models operating at different spatial and temporal scales, and processes and driving forces of change represented by vastly different types of quantitative and qualitative information.

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