Annual Report for Period: 09/2004 - 09/2005
Submitted on: 10/20/2005
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 1) administering the grant at the university level. This has involved hiring of post-doctoral staff, negotiating space and equipment issues, and overseeing the budget. 2) The land use component of the project. He designed the Role Play Simulation exercise and implemented it in Kenya. The 'roles' of herders, farmers, and administrators were played by senior personnel in a variety of Kenyan government agencies invited by Dr Mwangi of the National Environment Management Authority. He conducted a fieldwork in Kenya to update information on changes in land use patterns and dynamics.

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. 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 the approach and conducting land use expert systems workshops in Kenya, Uganda and Tanzania, 3) designing and supervising specific studies affecting future land use (urbanization, deforestation related to fuelwood harvesting), and 4) 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:
This past year, Dr. Qi focused on 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.

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: Yes

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.

Name: Ford, Tavares

Worked for more than 160 Hours: Yes

Contribution to Project:

Tavares Ford is working with Brent Lofgren at GLERL Labs on the RAMS simulations. He is an expert in RAMS programming and applications, and in hardware management.

Other Participant

Research Experience for Undergraduates

Organizational Partners

NOAA Great Lakes Environmental Research Lab

glerl IS providing one-quarter of Brent Lofgren's time, and a portion of Tavares Ford's time, to conduct research on this project.

FAO

Provided land cover data - Africover

USGS EROS Data Center

Provided SRTM data

NASA

Provided MODIS data

Various

Participants in the Land Use Expert Systems Workshops came from a variety of ministries and government agencies in Kenya, Uganda and Tanzania, and from the University of Nairobi, Makerere University, the University of Dar es Salaam, the Global Environment Facility, and the U.S. National Science Foundation.

University of Dar Es Salaam

Institute for Resource Assessment (IRA) provided meteorological data

Makerere University, Uganda

MUIENR provided meteorological data

Other Collaborators or Contacts

Activities and Findings

Research and Education Activities:

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.

LULC - Remote Sensing Activities
The LULC - remote sensing components of CLIP encompass a variety of themes including dataset generation, LULC assessment, model validation and parameterization, land surface trend analysis, and remote sensing science development.

Land Use Change Activities
WE have focussed upon developing the land use modelling procedures. This has included using information fromm case study analysis, role play simulations and expert systems studies to parametirize the models.

CROP-CLIMATE (NPP) ACTIVITIES
1. Weather data for crop modeling: Daily weather data (rainfall, maximum and minimum temperatures, and solar radiation) are necessary inputs for the
crop simulation modeling, which is being used to quantify agronomic productivity potential across the East Africa project domain. Given incomplete spatial and temporal coverage of individual climatological recording stations across the study area, a decision was made to utilize a gridded weather data base with complete spatial and temporal coverage over the entire domain. Two potentially suitable databases were identified, the 1957-2002 ERA40 1-degree resolution global database from the European Centre for Medium-Range Weather Forecasting and the 0.5-degree resolution TS2.1 database (1901-2002) from the Climate Research Unit of University of East Anglia. In an evaluation of both gridded weather data sets with daily observed data from 11 sites across the region, the CRU TS2.1 set was found to more closely match the observed data, and is being used to synthetically generate 101-year sequences of daily weather data for the NPP simulations for all 0.5 degree grids within the CLIP spatial domain. All daily synthetic weather data will be generated with the MARKSIM technique (Jones and Thornton, 2000), which has been used successfully in tropical climates.

2. Soil Profile data: Detailed soils data are also a necessary input variable for the crop simulation modeling activities. For our regional simulations, representative soil profile data for each 0.5 degree grid box in the project domain were assembled. The data are based primarily on the 1:1,000,000 FAO soils map of the world (FAO, 1995). The WISE soils database was utilized to identify representative soils for each grid box from the FAO series (Batjes & Bridges, 1994). The crop simulations will be run with each individual soil type and the results weighted by the relative preponderance of each soil type within each grid to give an estimate of simulated yield for that grid. Concerning the conversion of the WISE soils database to DSSAT format (required for the crop simulations), the databases were finalised and a paper written up for publication. A short-term consultant examined statistically the soil profiles in the WISE database, with the aim of defining the key parameters for each soil type that vary widely across sites, and that may be expected to have substantial impact on the variables (such as water holding capacity) to which DSSAT crop models are sensitive. Information was assembled on the ranges and distributions of key variables for each soil type in the soil profile database. More work is required on defining a set of profiles for each soil type that consists of a median or average profile, and profiles corresponding to low and high values of the key variables identified.

3. NPP simulation: Attention was given to designing a system for running thousands of different simulations sequentially within the study region. Information on the farming systems in key areas, together with weather data, soil profiles and information on local varieties and cropping calendars, will form the basis for running baseline simulations to replicate current production levels and practices for the case study sites. These baseline runs will be carried out using a similar system of model drivers, data pre-processors and results post-processors, as that of Jones and Thornton(2002). Crop and pasture model input data were assembled from CD archives, consisting of historical field trial, soils and weather data from Kenya, Uganda and Tanzania. Initial analyses with individual climate station data were carried out with the CERES-Maize model to determine sensitivity of maize yields to the highly variable soil types found across the region. The results indicated strong sensitivity of maize yield to soil water holding capacity. Other initial crop modeling work concerned the potential for double cropping across the region, as precipitation totals in many areas allows the production of secondary crops. For example, at Embu, Kenya between 1926 and 1955, an average of 318 mm of precipitation fell after the harvest of maize crop, providing an opportunity to grow a second dry bean crop. Simulation results at this location indicated that an additional mean yield of 277 kg/ha of dry bean besides the primary maize crop mean yield of 2830 kg/ha can be obtained using this double cropping strategy.

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 û 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.

REGIONAL CLIMATE MODELING:
A series of sensitivity tests were undertaken to optimize specific parameters in the RAMS model. These include cloud condensation nuclei (CCN) concentration, CCN shape parameter, convective updating frequency, convective trigger velocity, radiation scheme, radiation update frequency, and initial soil moisture conditions.

Our primary research activities have been to conclude the validation and to develop precipitation comparisons of the model to observations. Following this, our activities have centered on incorporating an accurate representation of LAI and fractional cover, based on satellite-derived quantities, and evaluating the model's response to this improved parameterization.

Atmospheric observations in East Africa are scarce. Validation of the model was conducted based on comparisons with radiosonde data where available, and with remotely-sensed data if applicable. Since the CLIP project places emphasis on integration of many parts, we have emphasized validation of the model against precipitation and temperature. These two variables will be relayed to a crop model, so it is imperative that RAMS output be validated against precipitation and temperature at a minimum. These variables are governed in large part by the radiation budget at the surface, so accurate spatial, temporal, and phenological representations of the surface are vital to accuracy.

Statistical Analyses
The statistical analyses have been exploring 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.

The data involved in predicting future climate change or future land use change span long time scales (years or decades). There is a lack of replication in the measurements, and thus accuracy of the data cannot be estimated in many situations. Carefully planned experiments help to use resources efficiently to answer the prioritized research questions. Issues that affect the design of climate simulations are a clear problem definition, logistic factors, and methods to analyze the data and confirmation of the results. The choice of the experimental set-up impacts the inherent variation in the estimation of the effects. Many climate studies have not carefully considered the choices for problem definition, method of design and analysis and its impact on the results. Such issues are discussed in a paper being prepared for publication.

From May 2004 to August 2005, Ph. D. students Wang, J. and Xue, L. had been partially supported by Graduate Fellowship of the CLIP. They, together with their Ph. D. advisor, senior personnel Yang, L., had performed statistical analysis for CLIP as well as carried out research in mathematical statistics. Their works led to the following papers and conference/workshop presentations. Currently, Wang, J. continues to work on the phenological analysis, under the guidance of Yang and Qi. Xue, L. has graduated and taken up appointment as assistant professor at the Department of Statistics, Oregon State University.

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

Training and Development:

Dr. Olson used East African land use change information in geography classes at MSU. MSU and Purdue University graduate students (N= 9) learned methods and topics related to land use change modeling approaches that blend traditional quantitative methods and knowledge elicitation techniques form the social sciences.

Mr. Alexandridis, a PhD student studying under Dr. Pijanowski, has given several presentations at national scientific meetings (Agent 2004 at Argonne National Laboratory) and has given a lecture on agent based modeling approaches to a graduate student course. He has been awarded a prestigious Purdue Research Foundation doctoral completion fellowship for the 2005-2006 academic year. Four other new graduate students at Purdue have now learned to use the LTM and spatial model performance tools: Amelie David (PhD student), Deepak Ray (postdoctoral student), Ritayan Mitra (PhD student) and Jonah Duckles (MS student). In addition, two visiting scientists from Europe, one from Germany (Dr. Daniel Muller) and one from Moldova (Mr. Sergui Beladeva) have been training in the use of the LTM and one paper with Dr. Muller has been developed comparing how well the model captures spatial development patterns in the Upper Midwest of the US and in Albania, one of Dr. Muller's study areas.

Outreach Activities:

The land cover variability work will be discussed in a guest lecture by Ruth Doherty to ecology undergraduates at the University of Edinburgh studying atmosphere-land-cover interactions in October 2005.
Dr. Pijanowski has given several presentations at public forums and non-technical groups in the last year that summarize the main approaches and early results of the project. Dr. Pijanowski has also given a presentation to the graduate program at Alabama A&M University, an HBI.

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:

The use of case study findings, role play simulation and expert systems information to parameterize the land use models,LTM and MABEL, is innovative and will make a contribution to the scientific and engineering fields.

The development of specific parameters to reflect the East African climatic and land-atmosphere boundary conditions in the Regional Climate Model provides a significant advance over the 'generic' use of the regional model.

Contributions to Other Disciplines:

Contributions to Human Resource Development:

Contributions to Resources for Research and Education:

Contributions Beyond Science and Engineering:

The scientists and government officials who participated in the role play simulation and in the expert systems activity 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 Other Disciplines

Contributions: To Any Human Resource Development

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.

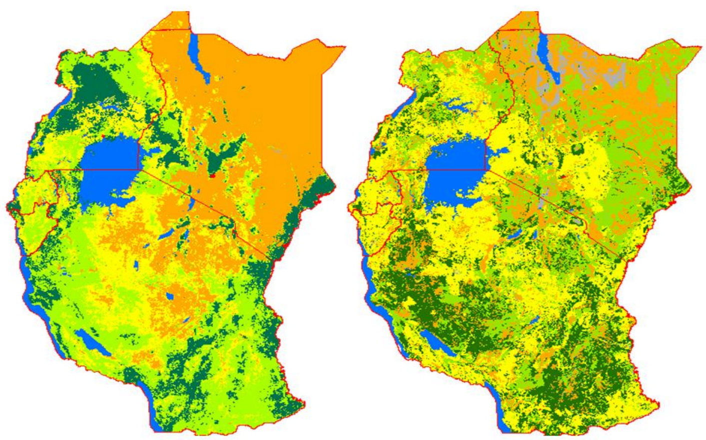

Figure RS1. GLC2000 (left) and Africover (right) aggregated into same classification scheme. *Forest*:dark green*, woodland/shrubland*:light green, *grassland*:orange*, agriculture*:yellow*, barren*:grey*, water*:blue*,* and *urban*:red.

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.

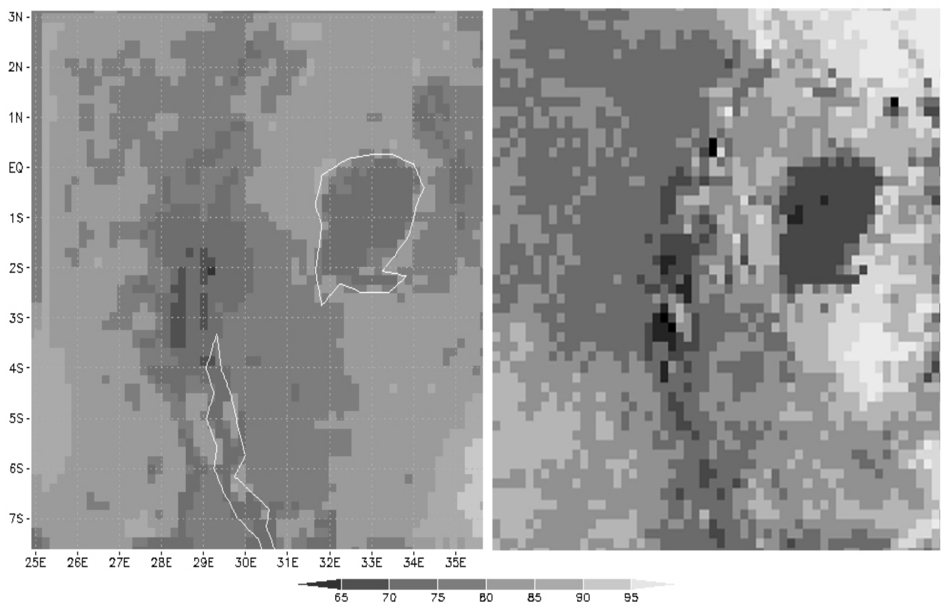

Figure RS2: Five month (Feb – Jun) averaged vegetation temperature (a) and five month averaged MODIS land surface temperature (b). The units are Fahrenheit degrees.

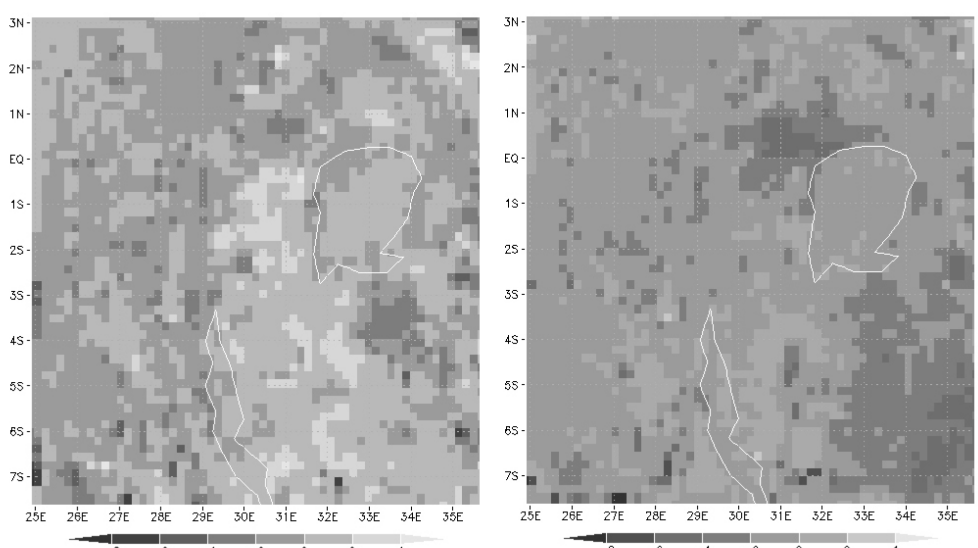

Figure 3: Five monthly (Feb – Jun) averaged difference of screen (2m) temperature between simulations using OGE and GLC2000 (a) and between simulations using OGE and MODIS IGBP(b). The units are Fahrenheit degrees.

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.

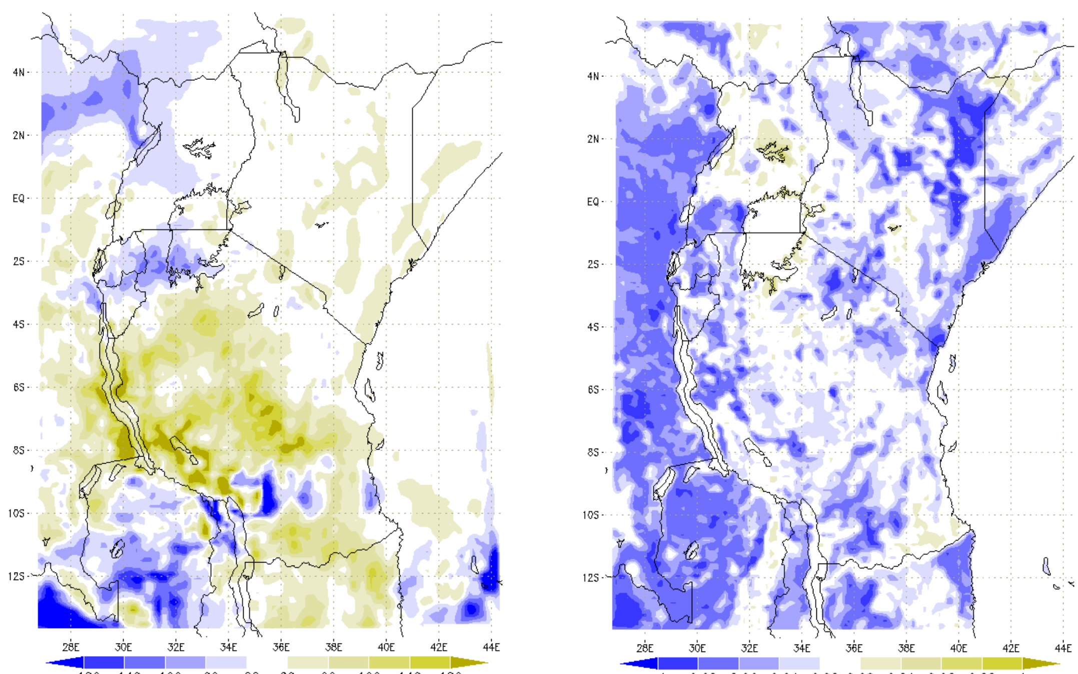

Figure M1.

Simulated accumulated precipitation (mm), March 8-31, 2000 (CLIPcover minus OGE cover)

Simulated albedo difference, difference March 8-31, 2000 (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.

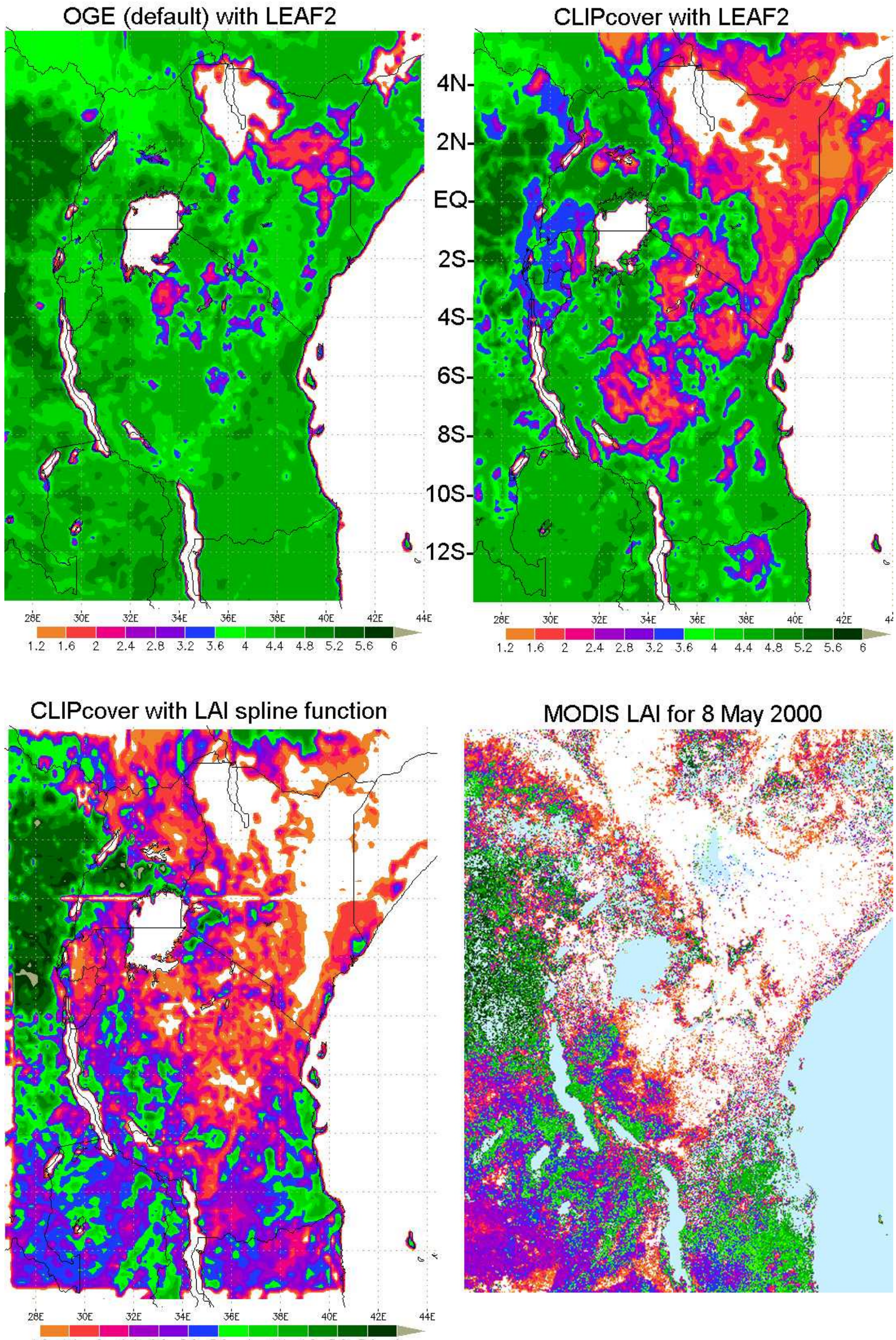
OGE (default) with LEAF2
CLIPcover with LEAF2
CLIPcover with LAI spline function
MODIS LAI for 8 May 2000
4N
2N
EQ
2S
4S
6S
8S
10S
12S
28E 30E 32E 34E 36E 38E 40E 42E 44E
1.2 1.6 2 2.4 2.8 3.2 3.6 4 4.4 4.8 5.2 5.6 6

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.