An Integrated Analysis of Regional Land-Climate Interactions

A proposal submitted to the National Science Foundation, Biocomplexity Program: Coupled Natural and Human Systems

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PROJECT SUMMARY

The intensity and spatial reach of contemporary human alterations of the Earth's land surface are unprecedented. Land use and land cover change (LULCC) are among the most significant of these human influences. Many studies demonstrate the influence of LULCC on local and regional climate which, when aggregated, may significantly alter the global climate. Meanwhile, climate change is expected to significantly affect people and ecosystems due to warmer temperatures and altered precipitation patterns. While significant research has focused on global climate modeling and socioeconomic drivers of land use change, an integrated assessment of coupled human-climatic systems is required to address the question*: .What is the magnitude and nature of the interaction between land use and climate change at regional and local scales?*

An international multi-disciplinary team, including social, ecological, atmospheric and statistical scientists, proposes to address this question by exploring the linkages between two foci of global change research, LULCC, and climate change, which have had largely independent scientific paths. A major goal of global change science is to obtain a more reliable estimation of future climatic conditions. This goal increasingly requires higher resolution regional scale climate modeling that includes feedbacks between the land and atmosphere. This project is among the first to complete the loop of land use/climate/land use impacts assessment. Its contribution is in analysis of the linkages between components.how does land use change affect climate, and how will climate change affect land use? These linkages will be examined through characterizing and modeling agricultural systems, land use, the physical properties of land cover, and the regional climate. East Africa, with its variety of ecosystems, wide range of tropical climatic conditions, areas of rapid land use change, and a population vulnerable to climatic variability, will be the location of the research.

An NSF Biocomplexity Planning Grant enabled the team to develop an approach to conduct this analysis. Proof of concept activities validated the feasibility of the approach, which includes: detailed long-term case studies of LULCC; models to project LULCC from local to regional scales; analyses of time-series satellite imagery to translate the effects of LULCC on land surface characteristics conditions; net primary productivity simulations; a regional climate model integrating those land surface parameters; and finally feedback experiments identifying the effect of projected climate change on people.s use of the land including crops, pasture, forests and urban centers. Broader Impacts. The project will have an *educational impact* from schools to the scientific community including: A direct link to grade school education through inclusion of project findings as teaching material in Michigan State University (MSU) courses required of teacher education majors and in-service teachers. Large numbers of MSU undergraduates will also benefit from project findings included in general education courses taught by PIs. Graduate students will be trained and mentored in an interdisciplinary context through the project and its links to the new Environmental Science and Policy Program at MSU. Strenuous efforts to promote *participation of underrepresented groups* will be made through recruitment of students to participate in the project via disciplinary networks, and through project fellowships supported by new funds committed by MSU. Capacity building of young and mid-career African scientists and policy makers will be accomplished through formal and informal training.

The methods and analyses used in this integrated assessment of coupled land use-climatic systems in East Africa will *enhance scientific understanding* that, through *dissemination of results* in scientific and public forums, will inform studies in the tropics and in similar ecosystems. This will add to scientific knowledge on interactions and feedbacks between climate and land use/ land cover, and methodological contributions in complex system modeling. The results will *benefit society* by indicating possible impacts of climate variability upon people.s livelihood systems and land use. These will have critical implications for agricultural research and policy, conservation and land use planning in the region.

AN INTEGRATED ANALYSIS OF REGIONAL LAND-CLIMATE INTERACTIONS

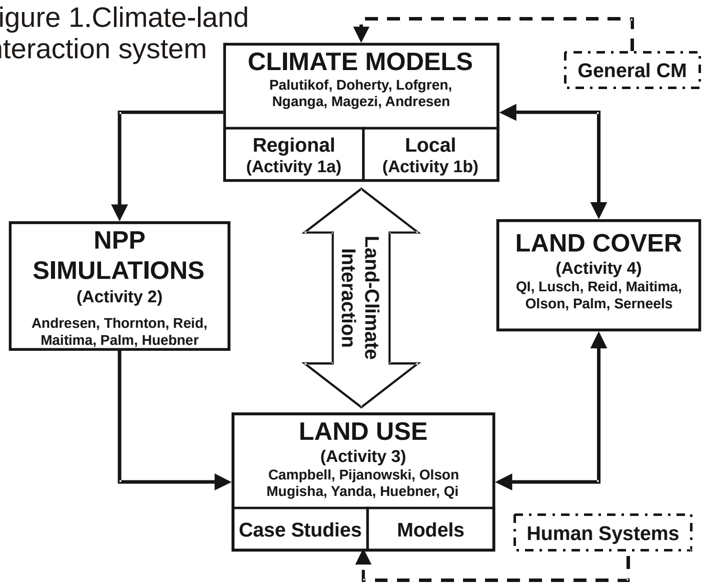
PROJECT DESCRIPTION

A central goal of global change science is to obtain more reliable assessments of likely future climatic conditions and to assess the impacts on society, such as poverty, food production, and the incidence of disease (McCarthy et al. 2001). Concern with issues such as rising sea levels, increased frequency and intensity of extreme climatic events, and variability in crop production is influencing policy discussions in vulnerable countries. In the future, these issues will be addressed by higher resolution modeling of climate change, analysis of feedbacks between the land and atmosphere, and appropriate tools for impact analysis. Recent research has suggested that climate changes associated with anthropogenic land cover changes (e.g., deforestation) at the regional level may be as significant as those associated with global scale forcing of increasing concentration of greenhouse gases (Pielke et al. 2002). As global change research moves from the global to the regional, and ultimately local, scale, a key integrating question that will be the focus of this proposed study is ***"What is the magnitude and nature of the interaction between land use and climate change at regional and local scales?"***

Many researchers agree that a complex relationship exists between climate and land use change through feedbacks at the land-atmosphere boundary (Betts 2000; Bonan 2001; Doherty et al. 2000; Levis et al. 1999). Changes in land cover may affect regional climate through altering of land surface characteristics such as surface roughness, albedo, and vegetation, all of which influence surface energy balance fluxes (Lofgren 1995, 1995). A change in the large-scale climate circulation due to enhanced greenhouse gases, for example, can bring about land use change, which can induce further regional climate change, particularly by intensifying droughts and promoting multi-year drought persistence (Nicholson 2000). However, the nature and relative magnitude of the interactions between climate change and land use change are largely unknown. Previous numerical modeling that investigated land surface-atmosphere feedbacks has failed to give satisfying results, in part because land use/cover has not been adequately defined and topographic features have not been incorporated into coarse-scale models (Nicholson 2001).

Social, political and economic pressures are responsible for substantial transformations of land globally (Desanker and Justice 2001; Houghton et al. 1999; Ramankutty and Foley 1999; Tilman et al. 2001). Understanding the proximate and underlying driving forces of land use change requires information about decision-making at the individual, household, farm or community levels, and of how these decisions are influenced by drivers at national and international scales (Geist and Lambin 2002; Turner 1999). Scaling up local information to a regional scale to define appropriate land surface parameters that inform regional climate models is at the forefront of environmental change research (Lambin et al. 1999; Lambin et al. 2001; Pielke et al. 1998; Schellnhuber and Sahagian 2002; Serneels 2001; Wilbanks and Kates 1999). Meanwhile, climate change is also becoming a driver of land use change, yet little research regarding the nature of climate drivers on land use change has been conducted.

Figure 1.Climate-land interaction system



This project team will conduct an integrated analysis of the linkages and feedbacks between land use, land cover and climate in East Africa represented by arrows in Figure 1. This conceptual framework was created by participants at a workshop in February of 2002 in Nairobi, Kenya who concluded that the dynamics within each box were well understood, but that the linkages and feedbacks in the system were poorly understood. Three tiers of knowledge are involved in the project: the component boxes are the best researched; the linkages have been studied at various levels of analysis; and the full system is at the scientific frontier.

The overarching research question of the project is: ***"What is the magnitude and nature of the interaction between land use and climate change at regional and local scales?"*** The sub-research questions addressing the components and linkages, include:

1. *Global to regional links:* Is global climate change discernibly affecting regional climate, and if so, how? What are the current and near term climate variability trends, such as the frequency and intensity of droughts, floods and El Nino Southern Oscillation (ENSO) events, and how are they influenced by large-scale climate phenomena?
2. *Regional climate to productivity:* Does the composition and distribution of natural and agro-ecosystems change with past and future climate change? How might the spatial and temporal dynamics of natural and agro-ecosytems affect net primary productivity (NPP)?
3. *Productivity to use:* How will changes in natural and agricultural productivity affect land use practices and patterns? What aspects of climate change are most likely to affect individual and community decisions regarding their land use? How will different livelihood systems respond?
4. *Use to cover:*What intensity of land use change significantly affects land cover?
5. *Cover to climate:* How sensitive is regional climate to alterations of land cover? What degree of conversion of land cover, such as from bush to crops or forest to crops, is required to alter biophysical parameters that link to regional climate? What spatial extent of land cover change is required before the climate is affected?

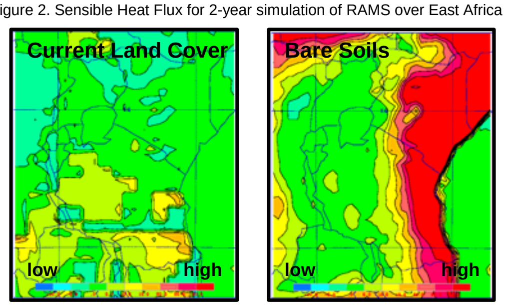
After addressing these questions, we will integrate our models to study the complex feedbacks between land and climate through a series of experiments comparing and contrasting different coupled systems. Our comparisons will address broad system-wide questions such as: the nature of feedbacks; temporal and spatial dynamics, types of driving forces that affect the system; nature of perturbations, and the presence of tipping points.

CURRENT RESEARCH

Our current research adds to knowledge of regional climate and land use dynamics. During the NSF Planning Grant work, we developed dynamic models of land use, land cover, climate change NPP for East Africa which will serve as a foundation for our proposed work that will explicitly couple these systems. The models and their interpretation are based on existing site and regional-level research in climate, ecology, land use/cover and socioeconomics conducted by team members (bold font in this proposal section) and others.

The region has a substantial body of reliable meteorological observations, many extending back to the early 20th Century, which have been systematically archived. Recent analyses have shed light on patterns and trends (Hulme 1992; Kanonya and **Nganga 1995**; Mutai et al. 1998; Ogalla 1988, 1989; **Doherty** et al. 2000). Changes in lake levels indicate large fluctuations in past climate (**Mworia**-Maitima 1991), and current trends suggest the glacier on Mt. Kilimanjaro may disappear by 2020 (Thompson et al. 2002). Analyses have established links between sea surface temperatures and large lakes (Manoudou and Nicholson 1998; **Mworia-Maitima 1997, 1999; Semazzi** 1996, Sun et al. 1999) with the regional climate. Majugu (1984) established a link between mesoscale and synoptic scale atmospheric features with precipitation patterns in the region (Majugu 1984). The El Nino Southern Oscillation (ENSO) frequently leads to major shifts of normal atmospheric circulation patterns across the region, resulting in abnormal wetness (El Nino) or dryness (La Nina) during the region's short rainy season (Camberlin et al. 2001; Mukabana and Pielke 1996) which in turn may lead to changes in biomass production (Anyamba et al. 2002). During the past 50 years, while total rainfall in most areas has not changed, there has been a marked decrease in the frequency but an increase in the intensity of rainfall events, and a change in the intensity and duration of ENSO periods (Camberlin et al. 2001; Mukabana and Pielke 1996). Meanwhile, general circulation models (GCMs) project that under an enhanced greenhouse climate, East Africa will become warmer than at present with possible decreases in

Figure 2. Sensible Heat Flux for 2-year simulation of RAMS over East Africa

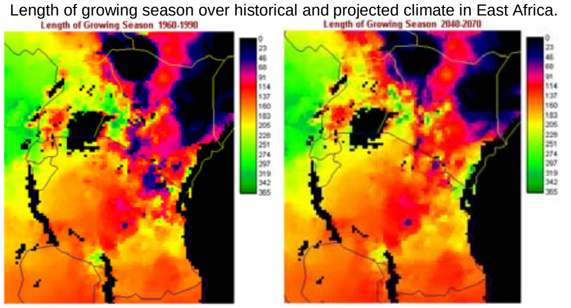


summer precipitation (Giorgi 2001, Hulme 1998).

Previous regional climate modeling studies have led to revealing scientific discoveries, but their results lack direct applicability to the current project. In many cases, scenarios were simplified to test land-climate feedbacks (Dickinson and Henderson-Sellers 1988; Eltahir and Bras 1993; **Lofgren 1995a, 1995b**; Nobre et al. 1991; Xue and Shukla 1993, 1996). Thus, they simulated the atmospheric response to arbitrary, exaggerated changes in land surface characteristics to demonstrate feedback effects between the surface and atmosphere (e.g., deforestation of the entire Amazon or Congo Basins). Another factor is the coarse spatial resolution of GCMs (typically 100's of km) which cannot effectively take isolated topographic features into account, such as East Africa's 5,895 meter high Mount Kilimanjaro. More recently, models with finer grid spacing have been applied to scenarios of land use change in other parts of the tropics (**Semazzi** and Song **2001**; Wang et al. 2000), while others have looked at fine-scale simulation of Eastern Africa, including topography and water bodies (Mukabana and Pielke 1996; Sun et al. 1999). However, little attention has been paid to the coupling of land use and climate in East Africa. A special consideration for climate simulation in a tropical (vs. extratropical) setting is the overwhelming importance of convective precipitation in the tropics, which is potentially sensitive to the land cover parameters. Under the NSF Planning Grant, **Lofgren** completed several executions of the Regional Atmospheric Modeling System (RAMS) for East Africa at 40x40km resolution. He parameterized the model using Michigan State University (MSU), International Livestock Research Institute (ILRI 2002) and (Dickinson and Henderson-Sellers 1988)derived databases and demonstrated that land cover changes significantly affect the energy balance at the land-atmosphere boundary (Figure 2).

The long-term relationship between climate and vegetation in the region has been examined by **Mworia-Maitima** and colleagues' research, who show a clear relationship between plant species composition and climate (**Mworia-Maitima 1991, 1999**) and land use change and carbon sequestration (**Palm et al. 2002**). The distribution of C3:C4 grasses, for example, follow an altitudinal cline due to temperatures and rainfall (Livingstone and Clayton 1980). Climate change is expected to alter the distribution of these grasses, affecting grazing patterns of domestic animals and wildlife. For example, the progressive growth of bush that is often related to increases in rainfall is probably responsible for the degradation of pasture. This degradation has resulted in conflicts over resource use between communities and ethnic groups (Oba et al. 2000). Another source of inter-seasonal variability is ENSO, which may have profound impacts on NPP through its link with regional precipitation patterns (Anyamba et al. 2002; Phillips and McIntyre 2000).

Figure 3.
Length of growing season over historical and projected climate in East Africa.



Thornton and colleagues have used several ecological (e.g., RANGEMOD) and agricultural (e.g., CERES-MAIZE) models to examine the dynamics of NPP using historical and GCM projected climate **(**Jones and **Thornton 2002; Thornton** and Jones **1998)**. Their findings (Figure 3) suggest that future climate will dramatically affect agricultural production across space and time; for example, the length of the growing season in East Africa will increase in some areas and decrease in others primarily as a result of altered precipitation amounts and timing. **Andresen's (Andresen et al. 2001; Andresen et al. 2000)** work on crop production and future climate change in the US Great Lakes region has received considerable attention by US federal agencies (e.g., EPA, USDA) and national media (e.g., CNN). His model results projected increased yields for many

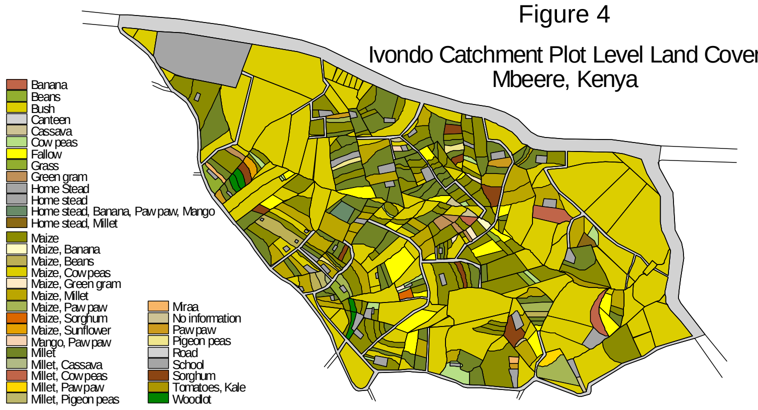


Figure 4
Ivondo Catchment Plot Level Land Cover
Mbeere, Kenya

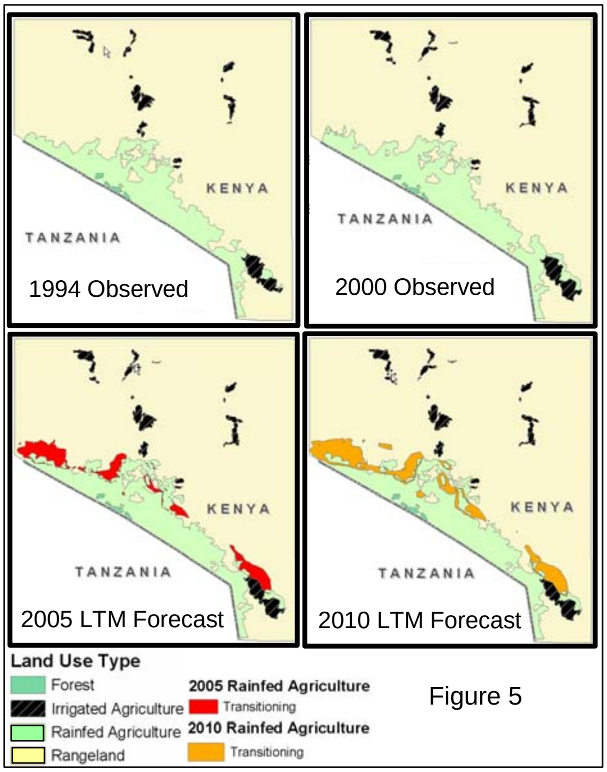
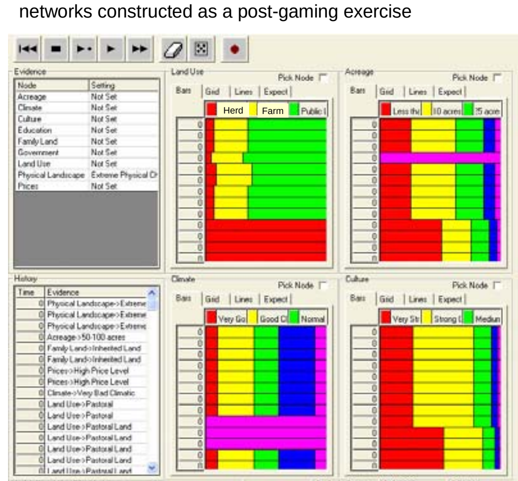


Figure 5

regional crops (e.g., soybeans, wheat).

Changes in productivity will have profound impacts on the people of East Africa , who are largely dependent on rainfed cropping and pasture (approximately 80% of the population are agriculturalists). People's livelihoods and the natural ecosystems, already undergoing rapid change, will have to respond to increased temperatures, climatic variability and frequency of droughts and floods (McCarthy et al. 2001). Agriculture and other human/environment issues have been the focus of spatial database development (**ILRI 2002**) including LULCC analyses. Several LULCC site studies (e.g., Figure 4) with long-term data and information are being analyzed in the Land Use Change, Impacts and Dynamics (LUCID) project being coordinated by **Olson** and **Mworia-Maitima**, and that includes many other members of this project (GEF 2000). The sites include ecological/elevation gradients (e.g., Mts. Kilimanjaro and Kenya) where the vegetation is strongly influenced by orographic rainfall and the interaction of climate and land use is readily studied. Rapid land use changes are being driven by a variety of processes and events including human population growth and migration, intensification of commercial agriculture, a transformation of land tenure from communal to individual ownership, and control of livestock diseases (**Butt and Olson 2002; Campbell et al. 2000; Mugisha 2002; Olson 1998; Reid et al. 2000; Reid et al. 2001**; Smucker 2002**; Yanda 2001**). . The result is rapid land use/cover changes including deforestation and conversion of grassland to cropland. This can be illustrated by a brief caricature of contemporary conditions in southern Kajiado District, Kenya. In response to a variety of factors, including decadal climate variability and drought, herders in the savanna area are diversifying their land use to include crop production (**Campbell 1986**; **Campbell 1999**). This implies a more sedentary livelihood and reduction of grazing pressure over wide areas of the savanna. One possible outcome is that the land cover will change from grass-bush dominant to bush-tree dominant. Such a change in land cover could alter a number of physical characteristics of the land-atmosphere boundary layer such as energy and water balance. Were this to happen with sufficient intensity over a large enough area it could contribute to changes in local and regional climate. Thus a complex relationship exists between climate change and land use change through feedbacks between vegetation and the atmosphereAdditional land cover analyses include the National Biomass Project in Uganda (NBS 1996), the AFRICOVER project (Latham 2001), the University of Dar es Salaam's land cover interpretation of northern and western Tanzania (**Yanda** and Shishira **2001**), and Colorado State University/ILRI's Savanna project (Galvin et al. 2001), and Serneels and Lambin's Maasai Mara analyses (Serneels and Lambin 2001).

Figure 6. Simulation of land use change using belief networks constructed as a post-gaming exercise



Over the last year, the team has made substantial progress to integrate tools and data to characterize land use and climate change interactions. Pijanowski's **GIS and Artificial Neural Network based Land Transformation Model (LTM)** (Pijanowski et al. 2002; Pijanowski et al. 2000) **was used to explore the interaction of spatial drivers of**

Figure 7. Vegetation biomass derived from Landsat ETM+. Legend: cyan=conservation area; red=roads; blue= watershed boundaries.

land use change using Campbell's **30 year land use data from Loitokitok, Kenya and Olson's 50 year data from Embu/Mbeere, Kenya**. **Pilot LTM versions (Figure** 5**) performed as well as applications in the US .** Campbell **and** Palutikof's **role playing simulation of land use conflict, developed for East Africa pastoralist/farmer land use decision making** (Campbell and Palutikof 1978)**, was updated and validated for better parameterizing and interpreting land use change modeling. Post-game debriefing of participants diagrammed their decision making processes. Figure** 6 **illustrates how making the region hotter and drier would shift preferences from farming to herding** (Alexandidris et al. in review,)**. Qi** has established approaches using remote sensing to analyze arid grassland systems, climate (**Qi et al. 1995**) and biophysical parameters including leaf area index **(Qi et al. 1995; Qi et al. 2000)**, fractional vegetation cover and forage biomass (**Qi et al. 2000**). His work in the Southwestern US (**Qi and** Wallace **2002**) has shown that management practices significantly alter NPP of grassland systems. He uses Landsat ETM+ to develop online interactive maps that show ranchers the effect of grazing on plant production (Figure 7). An area not grazed for over 35 years is visible in this September 2001 scene.

Table 1. Linkages and Feedbacks between Project Activities (linkages indicated in italics)

ACTIVITY	INPUTS	OUTCOMES
1a. Regional Climate Projections Parameterize RAMS and LEAF regional climate models for E. Africa	- GCMs - Topography - Current land cover	Regional scale climate change scenarios: (a) current land cover as a control run, (b) two extreme land cover changes
1b. Local Level Climate Analysis - Analyses of historical data - Validate RCM output with observations - Downscaling from global to regional and local scales for high resolution scenarios	- GCMs - Historical meteorological records for East Africa	Historical climate analyses including trends and variability, & their relationship to ENSO; Scenarios at high spatial & temporal resolutions; Present and future daily weather series for NPP simulations
2. Ecosystem productivity simulations Agricultural/ecosystem modeling using DSSAT, RANGEMOD, BIOME3 models	↳ *Present and future climatic conditions for vegetation* - Soils characteristics	Productivity under historical and projected climate conditions; maps of areas particularly vulnerable to climate change
3. Land Use/Cover Projections - Identify LULCC patterns& drivers from case studies and role-playing simulations - Model& up-scale to region w/ LTM/MABEL - Add climate change as driver - Convert land use to cover classes	↳ *How climate change will affect distribution of land uses* - Long-term case studies identify pattterns, driving forces & their surrogate variables - Regional data bases	Scenarios of regional land use change assuming no climate change (control runs), and scenarios that include the impact of climate change on land use Scenarios of land cover based on projected land use
4. Land Cover Parameters Specify current and projected land surface parameters using imagery, algorithms, field validation & learning sites from Activity 3	↳ *Maps of projected land cover* - Satellite imagery - Biophysical & socioeconomic data	Regional distribution of land surface parameters (albedo, LAI, etc.) varying seasonally (past, current & future scenarios)
5. Response of the RCM Conduct experiments with land cover scenarios, testing the RCM's sensitivity to types and magnitudes of land cover changes	↳ *Revised land surface parameters*	Regional climate simulations that incorporating altered land surface. These feed the next iteration of NPP simulations& land use change analyses
6. Integrated Analysis of Climate-Land Feedbacks Conduct experiments with linked models of climate-land use-land cover change	↳ *Outputs and interpretations of Activities 1-5*	An integrated analysis that compares and contrasts different coupled climate-land systems and their implications for livelihoods, science and policy

THE PROPOSED WORK

Our proposed work will occur over four years and focus on the coupling themes illustrated on the systems diagram (Figure 1) and summarized on Table 1 above. Six research activities, detailed below, will answer our research questions aimed at the linkages of the climate-land feedback system. These activities will permit us to address the overarching question: ***"What is the magnitude and nature of the interaction between land use and climate change at regional and local scales?"***

Activity 1a. Regional Climate Model Simulations under Different Future Land Covers

Land use change has the potential to modify climate, primarily at local to regional scales, and perhaps also at the global scale (Pielke et al. 2002). Whether the magnitude of the impact of land use change will rival that of enhanced atmospheric concentrations of greenhouse gases is still highly uncertain, and is likely to be highly dependent on location.

We propose to utilize a RCM adjusted for various conditions to more effectively examine land/climate interaction in a tropical setting, through use of realistic land use change scenarios and sensitivity studies. The model simulation, centered over the Lake Victoria area, would have an inner domain with 40x40 km grid spacing covering the countries of Kenya, Tanzania, Uganda, Rwanda, Burundi, the easternmost extreme of Democratic Republic of Congo, and the southernmost extremes of Sudan and Ethiopia. The outer domain, at 120x120km grid, covers much of Africa and the Indian Ocean.

The RCM being used in the study is based on RAMS (Pielke et al. 1992). Lofgren has refined the version under the name Coupled Hydrosphere-Atmosphere Research Model (CHARM) to enhance its utility for simulations over long time periods, and will refine it further to better represent convective rainfall (Lofgren 2000, 2002). RAMS and CHARM include a parameterization of the exchange of water, energy, and momentum between the land surface and the atmosphere, a scheme known as the Land Ecosystem-Atmosphere Feedback model (LEAF) (Lee et al. 1993). In LEAF, parameters are organized by vegetation class and given calibration data, can be expanded to include additional land cover types and seasonal variations in parameters. LEAF uses a tiling approach in which the land cover within a grid square is specified as a fraction of land cover classes.

Two sets of CHARM simulations will be conducted. Initially, we will incorporate current land cover for a control run from Activity 4 as well as two dissimilar, prescribed future land covers that represent possible "extreme" land cover change scenarios. The extreme land cover changes will be used as tests of regional climate sensitivity to the physical characteristics and spatial extent of such changes. Subsequent testing will consider scenarios that rely on more realistic land surface characterization and land use/cover forecasts (Activities 3 and 4). We will use the land use change analyses from Activities 3 and 4 to: a) determine the fractional coverage of each land cover type and surface water in each grid-cell; and b) introduce seasonality of vegetation and associated physical surface characteristics.

Expected Result: A comparison will be made of CHARM model simulations using different land cover. The model will subsequently be run with an iterative land/climate/land feedback scenario (Activity 6). Initial runs will allow development of hypotheses on the impact of land cover change on regional climate. The sensitivity of the regional climate will be tested using likely land use change scenarios developed by Activities 3 and 4, and improved land surface parameters derived from Activity 2.

Activity 1b. Local Level Historical and Future Climate Analyses

High quality observations of daily and monthly climate for exist for East Africa since the early 20th Century. We will analyze these data to look for current trends and to assess the influence of large-scale phenomena such as ENSO and the Indian Ocean dipole. Extreme value analysis using Generalized Extreme Value and Pareto Distributions (Palutikof et al. 1999) will characterize the occurrence of extremes over the historical record, and inform explorations of influences of climate on historical land use. Understanding the relationship between historical variability and ENSO-type phenomena is essential to the study of future climate changes, since these phenomena will themselves be affected by climate change, thus inducing indirect changes in the climate of regions (Mason 2001).

The historical data sets permit: i) validation of the RCM output, and ii) development of statistical downscaling models to generate regional and local scenarios of future climate change with high spatial and temporal resolutions. GCMs provide information on future climate changes but lack accuracy at high spatial and temporal resolutions (Palutikof et al. 1997). Their results may be downscaled, either using RCMs (Activity 1a) or by building statistical models which relate large-scale features of the atmospheric circulation, which are well-modelled by GCMs, to the local phenomena required by impact studies

(Winkler et al. 1997). The literature on statistical downscaling in low latitudes is small. We anticipate that methods based on weather generators (Huth et al. 2001; Wilby et al. 2002) with parameterizations appropriate to the region, and/or deterministic transfer functions will be appropriate, (Hellstrom et al. 2000; Winkler et al. 1997) rather than techniques based on circulation weather typing, which work well in high latitudes (Conway and Jones 1998; Wilby 1998). Non-linear relationships between large-scale circulation and surface climate will be explored using neural networks (Trigo and Palutikof 1999).

Climate model output from a number of modeling institutions will be collected. These should include the National Center for Atmospheric Research (NCAR), the Community Climate System Model CCSM2.0 (Blackmon et al. 2001; Meehl et al. 2000), the Second Generation Canadian Climate Centre model (Flato et al. 2000) and the Third Generation Hadley Centre HadCM3 (Gordon et al. 2000). Where possible, this will include output based on:

(i) different greenhouse gas emissions scenarios; typically the high emissions A2 and moderate emissions B2 scenarios of the Special Report on Emissions Scenarios (SRES), and at some centers the very high emissions A1FI (Nakicenovic and Swart 2000), and

(ii) different ensemble members (i.e., with different starting conditions, such that the natural variability in the climate may be expected to evolve in different ways).

Although large amounts of data will be involved, it is only by taking this approach that uncertainty in the future projections of climate change can be characterized.

The output of the downscaling activities will be used to: i) analyze the range of uncertainty in the climate projections by examining, for example, how the moments of the distributions of temperature and precipitation (mean, variance, skewness) evolve throughout the simulations, which typically extend from 1860 to 2100, and how this evolution is affected by factors such as natural variability, emissions forcing, and model type; ii) validate the output of GCMs to assess the confidence which can be placed in their future simulations of climate change. This validation will include an examination of how well the different GCMs reproduce the relationship between large-scale ENSO and Indian-dipole events and East African rainfall that is seen in the observations; and iii) construct statistical downscaling models to generate the high spatial and temporal resolution predictions of future climate change required by the project.

Expect result: Results of these activities will include: 1) historical documentation of trends and the occurrence of extremes (droughts and floods); 2) analysis of the role of large-scale drivers of climate variability in East Africa; 3) uncertainty analysis of model predictions of future climate change for the East African region; and 4) downscaled scenarios of future climate change for use in the crop and rangeland/climate models.

Activity 2. Ecosystem Productivity Under Present and Altered Climates

Results from recent GCM simulations from a number of models suggest that future climate in East Africa will become warmer, with possible decreases in summer precipitation (Giorgi, 2001, Hulme 1998, Rosenzweig 1998). Regardless of uncertainties pertaining to future precipitation, a warmer climate (with associated increases in potential evapotranspiration) would likely result in considerable new pressures on the soil, water resources, livelihoods and natural systems of the region. The impact on a vulnerable human population may be severe because of the close dependence on rainfed crops and pasture. The projected changes in climate could contribute to changes in land use and land cover. Regions where certain crop species or natural vegetation currently thrive may become marginal and in certain regions species may exceed their tolerance limits with warmer and drier climates (Jones and Thornton 2002).

*Activity 2.1. Develop Net Primary Productivity Simulation Models for East Africa.*We propose an investigation of the interrelationships between water, natural vegetation, agriculture, and climate in this region over two time frames: 1) historical and 2) future as projected by the RCMs in Activity 1b. The PIs will utilize deterministic crop, rangeland, and natural systems simulation models to estimate the effects of projected climate change on land cover and NPP of natural and agricultural systems. Models included in this Activity will be CERES-Maize (Tsuji et al. 1994), RANGEMOD (Berry and Hanson 1991), and BIOME3 (Haxeltine and Prentice 1996), representing a typical agricultural production system, a livestock rangeland grazing system, and natural vegetation, respectively. The CERES-MAIZE and RANGEMOD models have already been adapted for tropical conditions in the East African region, but their application to climate change conditions in the tropics is recent . These plot-level simulation models will allow an examination of the system's sensitivity to soil characteristics, which are directly associated with plant productivity through altered water holding capacities and potential fertility. Time series of model output water balance and other bioclimatological variables will be analyzed following the methodology of Andresen *et al.*(2001) to isolate the influences of climate and technology. In contrast, the BIOME3 simulation is a global-scale model that simulates competition between the dominant plant functional types and natural vegetation types or biomes for given climatic and soil conditions. This model will be used to simulate dominant historical and future vegetation types in East Africa under current climatic and soil conditions. For the future time frames, CO_2 enrichment will be accounted for in the model simulations with future SRES emission scenarios (Activity 1b). The models will be validated with observed data from: 1) local and regional agricultural statistics, and 2) in selected areas with remotely-sensed data from Activity 4.

Activity 2.2. Spatial-temporal analysis of NPP model simulations and integration with land use change models. Integration of projected climate scenarios and NPP models is an essential part of our efforts to accurately portray the natural and agricultural biomass production across the region, especially in areas of high topographical variability. This Activity is challenging because of the dissimilar spatial scales involved; plot or point-level data from the agricultural simulation models, and 0.5° degree resolution in the BIOME3 natural ecosystem simulations. The outputs from all simulations will feed into the land use activities on vulnerability and adaptation as they relate to the biophysical drivers of land use change. Specifically, key output variables (e.g. crop yield) will be used to create probability density functions which can in turn be utilized in probabilistic simulations of LULCC in Activity 3. The agricultural output will be spatially integrated to the community level (Jones and Thornton 2002), while the ecosystem model output should be compatible on a spatial scale with the outcome in land cover dynamics with remote sensing (Activity 4).

Expected Result: Results will include 1) historical and projected future series of vegetation types, bioproductivity and bioclimatological variables pertaining to NPP; 2) analysis of the role of climate in two representative agricultural production systems in the form of probability distributions that can be used as input in land use change simulations; and 3) uncertainty analysis of simulated bioproductivity (including food production) predictions given future climate changes for East African.

Activity 3. Land Use/Land Cover Change Projections

We will generate a set of plausible LULCC scenarios for East Africa. Results will be an assessment, through the historical interpretation of land use change (LUC), of scenarios that will be projected as land surface properties required by the RCM.

Much research has sought to identify common LUC patterns and their driving forces in tropical areas by comparing sites across the globe (Geoghegan et al. 1998; Liverman 1994; Moran et al. 1994). The comparisons have identified characteristic driving forces, but their relative importance varies as broader “root” drivers are mediated by “proximate” drivers, and as slow processes are interrupted or accelerated by sudden shocks (Geist and Lambin 2001; Lambin 1997; Lambin et al. 2001; Skole et al. 2000; Turner 2001; Walker and Steffen 1997). Although a theory of LUC is not on the horizon, a generally accepted approach to identifying the drivers to predict future LUC is evolving (Lambin et al. 1999; Serneels et al. 2001) that uses a combination of 1) spatial modeling of surrogate variables of driving forces, 2) agent-based modeling, and 3) qualitative analysis identifying drivers and their surrogate variables, and interpreting model results. We include three components, all tested during proof of concept activities, in a bottom-up approach to derive regional LUC projections.

Activity 3.1. Estimates of extreme land cover change scenarios. The land use team will use current land cover maps, and population and biophysical data to develop two “extreme” land cover scenarios using GIS and expert judgment to be used for the initial RCM simulations.

Activity 3.2. Identification of drivers of LUC from case studies. Identification and analysis of the driving forces of LUC and the possible response of the population to climate change is informed by results from long-term field research and GIS analyses that we have been conducting for up to 25 years, now being coordinated in the LUCID project (GEF 2000). The length of the studies has permitted examination of how people have responded to periods of normal, and above and below normal, periods of rainfall (Campbell 1984, 1968, 1999), and varying policy, political stability, economic and demographic conditions (Butt and Olson 2002; Campbell and Olson 1991; Mugisha 2002; Mugisha and Huising 2002; Olson 1998; Reid et al. 2000; Smucker 2002; Yanda 2001).

Activity 3.3. Model land use scenarios using spatial databases. The spatial modeling of these sites is being conducted using the LTM (Pijanowski et al., 2001a; Pijanowski et al. 2001b; Pijanowski et al.

2002) which follows in the tradition of spatial allocation models. However, the tool uses contemporary methods to assess variables associated with historical LUC . The model uses neural nets which train on data to numerically solve spatial interactions between surrogates of LUC drivers; these neural nets can then effectively generalize across datasets and spatial regions to scale-up from site results to a larger region. Spatial data for the scaling-up includes regional land cover (Latham 2001) and other variables (ILRI 2002). Once the initial LTM is established, we will introduce information from the RCM and the NPP simulations to determine the impact of climate change on land use. The introduction of climate change effects represents an innovation in LUC modeling.

*Activity 3.4. Represent the decisions of agents in changing land use***.** The Multi-Agent Based Economic Landscape (MABEL) model which simulates the economics of land transitions (Axelrod 1997; Box 2002; Gimblett 2002; Sallach and Macal 2001) will integrate the economic utility for land uses of individuals and groups. The model is parcel based to factor in the trade of portions of parcels. Once the model is initiated, it updates each agent's utility values in a Bayesian fashion. Extensions to MABEL will include organizational and other institutional rule agents such as land tenure regulations, cultural traditions, social hierarchies and marketing networks for horticultural crops.

Activity 3.5. Capture decision making as it responds to external driving forces. An approach to improve the parameterization of MABEL is role-playing simulation, often employed to assess how people make decisions in situations of tension, competition, or conflict (Green 2002). The team will build on an existing simulation (Campbell and Palutikof 1978; Schoemaker 1998) and conduct new simulations to identify the objectives and strategies of groups (e.g., farmers, pastoralists and conservationists) in their competition over land (Campbell 1981; Campbell et al. 2000). The results will include an assessment of initial conditions, identification of drivers of change and land use maps. This linking of role-playing and agent-based modeling is a recent innovation (Barreteau et al. 2001). Two simulations will be conducted, the first to analyze current drivers of LUC, and the second to identify the impact of climate change on communities and their land use decisions.

Activity 3.6. Expert appraisal of model results. The results of Activities 3.1 to 3.5 will be scenarios of land use for 2010, 2020, 2030, 2040 and 2050. Project members and other experts of East Africa will provide an expert appraisal by critiquing the results based on their knowledge of the forces of change in the region (e.g., thresholds or tipping points of economic change that lead to LUC) and choose the most likely scenario. This group will similarly critique the results of the feedback experiments (Activity 6), the modeling of the impact of climate change on land use. Knowledge from the site studies of how people have responded to past climate variability will improve this process (Campbell 1999).

Expected Result**:** Socioeconomic and biophysical driving forces at different time periods and scales will be identified and analyzed. Maps of land use scenarios will be produced as inputs to Activity 4 which in turn informs the climate modeling (Activity 1a).

Activity 4. Land Cover Dynamics from Remotely Sensed Imagery

This activity will develop a suite of land cover products including continuous fields of land surface albedo, fractional vegetative cover (fvc), leaf area index (LAI), and fraction of absorbed photosynthetically active radiation (*f*PAR) at spatial resolutions ranging from 15m to 1000m using imagery from the TM/ETM+, AVHRR, MODIS and ASTER sensors. The following approaches will be used to derive these continuous fields:

Activity 4.1. Develop data sets of biophysical fields from remote sensing data. We will develop continuous fields of surface albedo, fractional vegetative cover (both green and senescent), LAI and *f*PAR. We plan to use AVHRR images dating prior to 2001 and MODIS imagery and its products for the remainder of the project to produce seasonal parameter characterization to improve model prediction (Foley et al. 2000). Algorithm development will include the modification of existing approaches developed for a rangeland environment in the Southwestern US , and those developed by MODIS team members (Huete et al. 1999; Knyazikhin et al. 1999; Strahler et al. 1999). Although these products have been validated with limited ground truthing, adjustments will be needed to better reflect East African land surface characteristics. These will include re-examination of cloud screening methods, standardized atmospheric correction, standardized data flow for directional and spectral normalization, albedo calculation, standardized methods for the evaluation of error bars, and a data-fusion algorithm that will merge data products of variable spatial resolutions. A nested-scale analysis using current AVHRR/MODIS/ASTER with ETM+ imagery will better capture the land-cover dynamics in semi-arid areas where vegetation signals are difficult to extract. The advantage of the nested-scale approach is that the imagery data will provide improved parameters over large areas and the data are compatible with both field-based observations and RCM simulations.

Activity 4.2. Product validation. Because the East African research sites have substantial field data available, validation of the land cover change map derived from satellite imagery analysis will use both existing and new data. Validation will use data documenting natural disturbances and human-induced land cover changes. The data will include site research findings, fine-spatial-resolution satellite data (IKONOS or QUICKBIRD), land use statistics, and meteorological statistics. Areas displaying a strong land cover change “signal” in the imagery will be examined by reference to the validation database. Similarly, important land cover change events documented in the validation database will be searched for in the land cover change map. A rigorous, quantitative validation of the map will be performed in this way, by computing a contingency table of joint occurrences of detection. The resulting validated map of changes will be used as input to the coupled climate and vegetation models (Activities 1a. and 2).

Activity 4.3. Linkages to climate models. Using these continuous fields of biophysical parameters for both model validation and as input to the climate models, we will test the sensitivity of the climate system to alterations of the land-surface. The use of remotely sensed biophysical parameters will improve our understanding of the spatial-temporal, two-way feedbacks between inter-annual climate fluctuations, vegetation activity, and land uses. The impact of the spatial heterogeneity of these parameters on the climate model predictions, when aggregated to the 40km cell size, will be assessed by studying the nested scales of the remotely-sensed data (from 30m to 1000m).

Activity 4.4. Linkages to land use models and case studies. Feedbacks from the land use modeling and case studies, in concert with the remotely sensed biophysical variables, may allow more temporally and spatially consistent land cover change detection and possible differentiation between natural and human-induced driving forces of change. Two approaches will be used: 1) project future land covers and land surface parameters using the LTM framework; and 2) link biophysical variables to land uses from case studies to extrapolate from local to regional scales.

Expected Result*:* Improved seasonal land surface parameters from remotely sensed imagery will be produced and validated for East African study sites. Maps of the past, current and projected distribution of land surface parameters including surface albedo, fractional vegetative cover (both senescent and green), LAI will be generated for input to the RCM (Activity 1a) and to the land use models (Activity 3).

Activity 5. Cross-Cutting Activities.

Uncertainty is inherent in systems research. It arises from the coupling of systems that operate at different spatial and temporal scales. As our models reflect only parts of a common greater whole, in which the parts interact, the level of uncertainty in understanding and predicting the larger system is great (Faucheux and Froger 1995).Uncertainty is also inherent within the structure of each model, and the data. This reflects the random or stochastic properties of a system and the lack of complete knowledge to understand events and processes (Morgan and Keith 1995; Morgan and Henrion 1998). A third uncertainty lies with the decision maker with regard to societal preferences or goals and the differences in outcomes between policy choices (NRC 2000).

*Activity 5.1. Addressing Uncertainty***.** The project will use a combination of quantitative and qualitative methods to assess and document the amount of uncertainty in our models and approaches. Quantitative methods may include: data mining and visualization, analysis of frequency distributions and time series of relevant climate variables, risk assessment of rare events with large impacts (e.g., floods and droughts), and correlation and regression analysis between inputs, Monte Carlo simulations, and outputs of coupled models. Qualitative analysis will entail a focus on discussions of known sources of error in data and model structure, and an examination of possible linguistic (Morgan and Henrion 1990) sources of uncertainty that relate to imprecision and bias in communication between disciplinary scientists. Our expert opinion approach (Activity 3.6) will allow us to combine quantitative model output with multiple interpretations of the same process by people knowledgeable about LULCC in East Africa.

Activity 5.2. Addressing Scale Issues. The importance of scale of analysis and of examining issues across scales has been addressed by both social scientists and biophysical scientists . The issue has been clearly stated in the context of ecology by Levin (1992) who wrote: “the problem of pattern and scale is the central problem in ecology....Applied challenges, such as the prediction of the ecological causes and consequences of global climate change, require the interfacing of phenomena that occur on very different scales of space, time, and ecological organization. Furthermore, there is no single natural scale at which ecological phenomena should be studied; systems generally show characteristic variability on a range of spatial, temporal and organizational scales.....The key to prediction and understanding lies in the elucidation of mechanisms underlying observed patterns" (Levin 1992).

To explore how theories can be used to provide a framework for analysis and synthesis across the project, portions of three workshops will be allocated to learn and explore inductive scientific theories. A presentation reviewing the theory and its empirical use in human and natural systems will be followed by a discussion on its potential use, strengths and limitations. A set of papers and/or books will serve as the foundation for discussion. Candidate frameworks include *Panarchy* (Gunderson and Holling 2001) which was developed to help understand how societies and natural systems change over time. Panarchy refers to the integration of system dynamics and scale; it extends the work of Allen and Starr (Allen and Starr 1982), O'Neill's (O'Neill et al. 1986) and Levin's (1992) versions of *hierarchy theory* by linking ecological, economic and institutional processes. It also considers learning, adaptation (in an evolutionary or organizational sense) and resilience. A second framework is *Political Ecology*, which addresses society/environment issues as outcomes of a process of interaction between and among societal and biophysical forces. It asserts the centrality of the land manager whose decisions are shaped by access to resources, social and economic status, and the opportunities and constraints defined by the national and international institutional and policy context. Addressing power and wealth differentials are central to the analytical approach (Blaikie and Brookfield 1987; Campbell and Olson 1991; Peet and Watts 1996; Zimmerer and Young 1998). The third framework is Landscape Ecology (Forman 1995; Golley 1987; Wu and Hobbs 2002), an interdisciplinary approach focusing on the relationship between pattern in landscapes and the processes that result from these patterns at multiple spatial and temporal scales.

Activity. 5.3 Project Workshops. Three workshops will be held during our study. The first, to be held in East Lansing, will serve as a project kickoff as well as establish a venue to address key integrative issues. The second workshop, held at the end of year 2 in Nairobi, will focus on the synthesis and coupling systems design issues (see Activity 6). The third workshop, held in year 4 in Nairobi, will focus on sharing of lessons learned from all investigators as well as provide a forum to communicate our results to key regional policy makers.

Activity 5.4 Focus Group Discussions. We will carry out a series of activities to examine issues of uncertainty and to standardize evaluation methods, such as model sensitivity and error assessment, across the project. During *first* workshop, the team will examine uncertainty across all aspects of the project. We will analyze distributions of variables paying particular attention to events that are likely to have large impacts on the system. Huebner and Pijanowski will develop a paper outlining methods and approaches to be followed and issues to address that relate to uncertainty, model parameterization and sensitive analysis. They will later develop a white paper outlining generic statistical methods to guide sensitivity analysis of paired-model executions, for example, correlation metrics between variables and predictors, regression techniques and categorical analysis. A risk assessment protocol to characterize the impact of extreme events will also be developed to address how shocks propagate through the system.

The *second workshop* will have one day devoted to examination of methods related to uncertainty in the linkages of models. The objective will be to integrate knowledge to create a holistic understanding of all types of uncertainty (Lubchenco 1998).

In the *last workshop,* we will assess the usefulness of different methods, tools and conceptual frameworks that we used to address our overarching question, ***"What is the magnitude and nature of the interaction between land use and climate change at regional and local scales?"*** For example, we will compare and contrast the land use change modeling approaches of Activity 3 to examine which approach provided the most useful information to scale up to the region, or what integrating approaches can be extended to other aspects of the study. The end product will be a paper that provides information on the interactions and the tools/approaches that are useful to understand the nature of land-climate interaction.

Activity 6. Exploring Climate-Land Feedbacks.

A culmination of the project efforts will be feedback experiments to determine the impact of climate change on land use, and land use change on climate. Once the RCMs, LUC models, and productivity simulations have been developed, the following coupled systems will be examined:

> *Coupled system #1*: Static land use, and dynamic climate. The climate model will be set to respond to an increase of atmospheric carbon dioxide. This system will serve as a reference for

analysis.
Coupled system #2: Static climate with dynamic land use. We would use the LULCC models and our land use forecasts will compared with coupled system #3 and #4.
Coupled system #3: Land use updated on decadal time steps and across two extreme and the most plausible scenarios. The climate and land use models would set to feedback on a decadal basis: the climate would respond to land cover changes over the previous decade, and the land use/cover would then respond to changing climatic conditions as interpreted through the local climate analysis and productivity simulations. The adjusted land cover would then be an input to the climate model, which would continue its execution. This feedback exchange will be over the decades 2010-2050.
Coupled system #4: Land cover updated seasonally and land use by annual time steps and across two extreme and the most plausible scenarios. This coupling is identical to #2 except land cover is updated seasonally and land use is updated with annual time steps.

The results from these experiments will be systematically compared across scenarios and across time steps, to examine spatial-temporal dynamics.

Members of the research team will meet on a biweekly basis to discuss recent research results. Early in the program, the group will develop a set of inductive research questions that will be explored as investigations progress. Candidate inductive research questions related to understanding the land-climate interactions at a regional scale include:

- Are the feedbacks between land use change and climate linear or non-linear? What interactions appear to have negative feedbacks? Positive feedbacks?
- Are there tipping points that cause one system to change state? What methods are useful to determine tipping points? What are general patterns characteristic of tipping points?
- What are the important spatial and temporal scales of interactions? To what degree does the climate response lag behind land use change, and vice versa? What are the important measures to consider when scaling up from case studies to the region?
- What are the key factors driving the dynamics? What components of the climate-land use system appear to be tightly coupled and which loosely coupled? Is there hidden order within complexity that can be understood and described?
- What is the nature of perturbations? How frequent are changes to the system introduced? Are the perturbations surprises or introduced with some level of predictability?

CONCLUSION

The severity of predicted impacts of climate change upon livelihoods requires that scientists investigate means of more accurately predicting climate change and portraying its consequences. Plausible regional assessments will contribute to this. At the regional scale scientists have gone beyond modeling of the global climate that relies on very generalized portrayals of land-atmosphere boundary conditions, to include characteristics such as topography and lakes.

This project will add to our understanding by integrating long-term case studies, application of the results of contemporary global climate models, a state of the art RCM, NPP simulations, and a variety of complementary LULCC models. It will provide the first comprehensive examination of the interactions between LUC and climate change in East Africa, and permit an assessment of the impact of climate change on the livelihood systems of the region.

The integration of a variety of data and information, and a suite of models, within a conceptual framework derived from ongoing debates in political ecology, landscape ecology and panarchy, permits this research to speak not only to coupled LULCC-Climate modeling in the tropics, but also to the broader scientific community addressing these issues.

MANAGEMENT PLAN

MSU is the lead institution, with Campbell (human-environment geographer, 15 years African experience) as project PI. ILRI is the coordinating institution in East Africa, with local project coordinators Olson (human-environment geographer, 20 years African experience) and Mworia-Maitima (Kenya, plant-climate ecologist). This institutional arrangement was successful during the Planning Grant activity and replicates that of the LUCID project. Each major activity has a Lead Scientist who directs research and supervises Research Assistants and Post-Doctoral Fellows. Activities consist of: *Linkages* *between Components* – Leads Olson and Pijanowski (landscape ecologist, 12 years experience with behavioral and land-climate models) and the entire team. Convene bi-monthly net-meetings to coordinate group and sub-group activities and discuss emerging results concerning linkages. Maintain existing web site for data and information sharing; *Land Use Case Studies* –Lead Olson, with Campbell, Yanda (Tanzania, land cover analyst), Mugisha (Uganda, GIS, LUC), Qi (10 years experience with remote sensing and GIS modeling of rangelands and productivity), and Research Assistant; *Land Use/Cover Modeling* – Lead Pijanowski, with Qi, Olson, Reid (range ecologist, 15 years African experience), Mworia-Maitima, Huebner (10 years experience as bioinformatics, mathematical ecology and epidemiology) and Research Assistant; *Land Cover Dynamics* –Lead Qi, with Lusch (remote sensing specialist), Palm (soil ecologist; 20 years tropical experience, 10 Africa), Mworia-Maitima, Reid, Palm and Research Assistant; *Net Primary Productivity* – Leads Andresen (agricultural climatologist, 10 years experience with crop-climate modeling) and Thornton (agricultural economist, crop-climate modeler, 10 years in Africa), with Reid, Palm, Mworia-Maitima and Post-Doctoral Fellow; *Regional Climate Modeling* – Lead Lofgren (10 years experience with regional climate models and hydrology-climate models), with Nganga (Kenya, climate change), Magezi (Uganda, climate change), Doherty (Africa climate change modeler) and Post-Doctoral Fellow; *Analyses Of Historical Climate Data; Statistical Downscaling* – Lead Palutikof (climate modeler, Co-Director of the Climatic Resesearch Unit, UK. 5 years at University of Nairobi), with Doherty, Andresen, Nganga and Post-Doctoral Fellow*; Uncertainty Analyses* – Lead Huebner, with Andresen, Pijanowski and Lofgren. A Board of Scientific Advisors, will consist of L. Berry, P. DeSanker and D. Ojima and other, will advise the project team. The Board will provide technical advice, liaise the project activities with the wider scientific community, and critically review project progress. The Board of Advisors and the entire project team will meet in Year 1 to establish the project, and in Year 2 to review progress and plan for integrating all models. In Year 4, a final workshop will be held to and policy experts will be invited to review the project.

BROADER IMPACT ACTIVITIES

We will actively integrate our research into education at the University level, actively engage stakeholders from important policy communities, and develop unique, highly effective web sites as part of our broader impact activities. We highly value these activities and applaud NSF's efforts to increase the potential benefits from scientific research.

Develop Cooperative Learning Resources for Undergraduate Courses. A major undergraduate education focus will be to enhance our existing development of materials for large lecture classes using Cooperative Learning approaches. These include large, 200 to 500 student enrollment, integrated study, general education courses, *People and Environment* (250 students), *Introductory Biology: Ecology, Populations and Evolution* (400 students), *World Regional Geography* (200 students). These three courses are required of MSU's elementary and middle school teacher education majors. In-service teachers also heavily enroll in the web-versions of these courses. All PIs employ a variety of cooperative learning approaches in 300-500 student classes that have been shown to enhance the development of critical thinking skills by undergraduate students (NSF 1996). Cooperative Learning exercises will be developed using the following activities: one minute paper, five minute synthesis paper, fish bowl, interview, group discussion with group leaders, recorders and reporters, and concept diagrams. We intend to create a web site with the teaching resources and promote their use through announcements in various professional meetings and listserves (e.g., AGU, Ecological Society of America, and American Association of Geographers). Our curricular materials will also be available on the DLESE (Digitial Library of Earth Science Education; www.dlese.org) web site as well. We will also provide students with additional end of class surveys to gather information on the usefulness of the new materials.

Summer Study Abroad Course. MSU PIs and colleagues have developed a new five-week Overseas Study program "Society and Ecology in Kenya" that focuses upon students acquiring an understanding of the integration of societal and biophysical processes. It will be first offered in Summer 2003 and enroll between 15 and 20 students. The University of East Anglia also offers a course in East Africa that will potentially include findings of the project.

Graduate and Postdoctoral Education. The project seeks NSF funds for three doctoral students and three post-doctoral associates. Our graduate education activities will focus on interdisciplinary research methods and ethics. Using materials provided by the Indiana University's Pointer Center and guided by the National Academy of Sciences' report on *Responsible Science: Ensuring the Integrity of the*

Research Process (1990), we will develop a seminar on the project as well as those working on multidisciplinary projects, with the following research ethics foci: authorship in multi-author papers, human subjects research, gender, fraud and deception, and responsible data and project management.

Targeting Underrepresented Groups. The Graduate School at MSU has committed funds to support two graduate fellowships (see letter from Dean Klomparens) targeting underrepresented groups. The project will work with MSU's diversity recruitment program aimed at Histocially Black Colleges and Universities and other colleges with high enrollment of underrepresented groups, and through disciplinary networks to achieve this priority. PIs and MSU are committed to actively support these efforts. Students in the Kenya study abroad program are eligible for grants from the university focused explicitly on encouraging participation by students from underrepresented groups. The Colleges of Natural Science and Social Science at MSU have programs that target underrepresented groups (minorities and women) and provide them with unique opportunities in multidisciplinary research. Faculty members will give at least one talk to each of the following groups that have high impact on underrepresented groups: Charles Drew Enrichment Laboratory, and minority student organizations such as MSU Native American Indian Student Organization.

East Africa Policy Linkages. The project is committed to for capacity building for African scientists. East African team members will identify candidates for doctoral and post-doctoral positions. Possible funding sources include START (see letter from Professor Eric Odada), and foundations such as the Partnership to Strengthen African Universities involving collaboration between the Carnegie Corporation of New York and the Rockefeller, Ford, and MacArthur Foundations.

Enhance Scientific Understanding. The project design includes both a multidisciplinary approach, and a global perspective through participation of scientists from USA, Africa and Europe. The NSF Planning Grant supported a workshop and proof of concept activities. Discussions among scientists from different disciplines, trained in different scientific traditions, provided diverse perspectives on the nature and methods of science, and on analytical and methodological approaches as we addressed common research questions (Ewel 2001; Kinzig 2001). These learning will inform the US scientists and influence their future scientific activities. The methods and analyses used in this integrated assessment of coupled land use-climatic systems will provide an analysis of East African conditions that will allow comparisons with similar studies in the US and elsewhere, and thus add to the accumulation of scientific knowledge on regional climate modeling and its interactions and feedbacks with livelihood systems and their land use.

Dissemination of Results. The team members publish in scientific journals. They regularly advise national, state, and county agencies in the US, and some are advisors to international organizations including UNEP and the Global Environment Facility. The East African scientists are commonly involved in national policy discussions. A project web site will be constructed which will be informative and interactive. PIs have created interactive GIS web pages to allow users to place raster (grid based data from ESRI's ArcINFO GRID software) as well as vector (points, lines and polygons) layers on the web.

Benefits to Society. The findings will provide insights to the role of humans in contributing to climate change and to the likely impact of climate change on livelihoods and natural resources systems. The scenarios developed for East Africa will illustrate more generic themes of society-environment interaction under projected climate change. The results will indicate possible impacts of climate variability upon land use, including agriculture and land cover. These will have implications in the region, and through a comparative perspective in the USA, for policy and programs in conservation, agricultural research, and land use planning. The results of this project will contribute to a complementary project that will be led by East African institutions and involve many of our team. This project, in which UNEP/GEF has expressed interest, will include vulnerability analyses and mitigation strategies through field research and agro-economic modeling, and measurements and modeling of sequestered carbon.

RESULTS FROM PRIOR NSF SUPPORT

The Project Team received an NSF Planning Grant Proposal Number 0119821 "Climate and Land Use Change Processes in East Africa." for $66,982 with an effective date of 09/15/01-09/15/02. This funded a Workshop held in Nairobi, Kenya in February 2002, and a number of proof of concept activities. The *Workshop* brought together scientists from the US, East Africa, and the UK to assess the content and approach to analysis of each component of the project and the important questions represented in the linkages (Figure 1). Further, it was an important team-building exercise that generated commitment of participants to this proposed project, as reflected in the project team. *Proof of concept activities* included:

(1) regional climate modeling that demonstrated that the regional climate model output is sensitive to gross changes in land-atmosphere boundary parameters are such as albedo, surface roughness and evapotranspiration. The project will investigate what degree of changes in such parameters induced by LUC and by feedback from projected climate change; (2) crop-climate modeling that examined yield and phenological responses to climate variation; (3) identification of driving forces of LUC with an emphasis on the interplay between societal and biophysical forces over space and through time; (4) role-playing simulation – run with East African students—confirmed the complexity of interplay of drivers of LULCC from national to local scales and with strong attention to the temporal dimension. In this project role-playing by regional experts will permit evaluation of the driving forces underlying LUC, and will contribute directly to the parameterization of the agent-based model; (5) land use/land cover modeling that validated the LTM and MABEL models; and (6) assessment of the interactions and feedbacks between the concepts and models of these activities – this is the foundation of this proposal. The results of the workshop and of the proof of concept activities inform this proposal.

"From Pattern To Process In Land Use Change: Land Reform and Agricultural Intensification In Meru; Kenya." Dissertation support to Tom Smucker; number 9912067; dates: 5/00 to 10/01 Campbell PI; amount: $9,020. Smucker has completed his fieldwork and is currently writing up his dissertation, with anticipated completion in Spring 2003. He has made a number of conference presentations and two papers are in preparation for submission to journals. Smucker's field findings will contribute to the case study analysis of this proposed project. **(2)**

"Rural Livelihoods; Resettlement; And Land Use Change In South Africa." Dissertation support to Brent McCusker, number 9907061; dates: 8/99 to 1/01; Campbell PI. amount: $10,000. McCusker completed his dissertation in 2001, had a post-doctoral grant from NASA, and now a tenure track position at West Virginia University.

Thornton Co-PI and Reid Participant of "Biocomplexity, Spatial Scale and Fragmentation: Implications for Arid and Semi-Arid Ecosystems," DEB-0119618, $1.3 million, January 2002 to December 2006. Biological complexity in arid and semi-arid lands (ASALs) arises from spatially-linked ecological states and processes. Herbivores, humans and other agents integrate spatial units into complex ecosystems by moving among these units. Spatial complexity plays a central role in the structure and function of grazed ASAL ecosystems, but human land use tends to deplete spatial biocomplexity through ecosystem fragmentation. The goal of this research is to demonstrate the importance of complexity and the costs of fragmentation by linking ecological and socio-economic research. Project members are working in 21 ASAL ecosystems in Asia, Africa, Australia and North America. Part of this work involves assembling household models linked to ecosystem models and running scenario analyses. These household models can also be adapted to assess climate change impacts at the level of the agricultural system, thus this project's research complements the work proposed here.

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