Effects of Land-Use on Climate and Water Resources:
Application of a Land Surface Model for Land-Use Management

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Progress Report
Year 1 (5/1/00-4/30/01)

Statement of Work
YEAR 2 (5/1/01-4/30/02)

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Project Summary

The goal of this work is to use remote sensing land cover and leaf area index data to initialize a model of biogeophysical, biogeochemical, and hydrologic land-atmosphere interactions to assess the impact of natural land cover change and human land-use change (LCLUC) on climate and water resources. The work supports the development of the Community Land Model for the Community Climate System Model (CCSM). This model is being developed in coordination with the CCSM Land and Biogeochemistry Working Groups from the NCAR LSM, BATS, and other terrestrial models. The land model is being developed in four key areas: biogeophysical processes regulating the exchanges of energy, moisture, and momentum; biogeochemical processes such as carbon and dust; routing of runoff downstream into rivers; and vegetation dynamics.

Principal accomplishments during the first year are:

1. Development of a global 20-year atmospheric dataset at 3-hour resolution to allow model development uncoupled from an atmospheric model. This dataset allows us to develop and test new model parameterizations in a global context prior to coupling to a climate model.
2. Development of ½° datasets of plant functional types and their individual monthly leaf area index. The land model was re-coded to represent vegetation as patches of co-existing plant functional types (PFTs) within a grid cell rather than as discrete biomes. This allows the model to interface better with dynamic global vegetation models (DVGMs), which represent vegetation as PFTs and change the abundance and geographic distribution of PFTs over time.
3. The surface biogeophysics were updated to include new parameterizations of soil temperature and water, snow processes, runoff generation, and surface energy exchange. These significantly improve the simulation when coupled to a climate model.

Work during the second year includes:

1. Documenting the effects of the new surface biogeophysics on climate.
2. Implementing a dynamic global vegetation model to provide an integrated terrestrial model for climate studies.
3. Further development, testing, and application of the dust emission scheme.

Key Words

Research Field: biogeochemistry models, ecosystem modeling, SVAT models
Geographic Area/Biome: global, North America
Remote Sensing: AVHRR, Pathfinder, MODIS
Methods/Scales: global scale

Project Goals and Methods

This project addresses the following relevant NASA ESE scientific questions:

1. What are the consequences of land use and land cover change?

The work does not use social science (0%). The themes covered by the project include:

1. The effect of LCLUC on climate: 50%
2. The effect of LCLUC on water resources: 25%
3. The effect of LCLUC on carbon storage: 25%

The principal goals for the first year of the project were to:

1. Develop a global atmospheric dataset to force the model uncoupled to an atmospheric model;
2. Develop a global dataset of plant functional types (PFTs) and their leaf area index (LAI); and
3. To update the biogeophysical processes in the model.

First Year Progress and Second Year Work

This work resulted in:

1. New findings: -
2. New potential: Community Land Model for the Community Climate System Model
3. New products: 20-year global atmospheric forcing dataset; global PFT dataset; monthly global LAI dataset

A 20-year dataset of temperature, humidity, wind speed, precipitation, and radiation for the period 1979-1998 was developed at 3-hour resolution from the NCEP re-analyses and supplementary observational data. This dataset has a T62 spatial resolution (approximately 1.875° longitude by 1.915° latitude). Instantaneous temperature, wind speed, specific humidity, and surface pressure at 6-hour resolution were extracted from the reanalyses and linearly interpolated to 3-hour resolution. Infrared radiation emitted by the atmosphere was calculated from air temperature and water vapor. Precipitation, which was averaged over the 6-hour interval, was applied uniformly to the two corresponding 3-hour intervals. Precipitation rates were scaled to the observed monthly precipitation totals. Surface solar radiation was obtained from top of the atmosphere solar radiation scaled to match a 1984-1990 climatology of monthly surface solar radiation from the International Satellite Cloud Climatology Project.

A ½° dataset of the fractional cover of 15 PFTs were defined based on available 1-km land cover data and climate rules. The 7 primary PFTs are needleleaf evergreen or deciduous tree, broadleaf evergreen or deciduous tree, shrub, grass, and crop. One-half degree maps of the abundance of each primary PFT (Figure 1) were derived from the 1-km IGBP DISCover dataset of natural and anthropogenic land cover and the 1-km University of Maryland tree cover dataset of evergreen, deciduous, broadleaf, and needleleaf tree cover. Temperature and precipitation data were then used to derive physiological variants of these PFTs.

The seasonal course of leaf area index (LAI) for each PFT present in a grid cell was derived from 1-km AVHRR red and near infrared reflectances (channel 1 and 2) for April 1992 to March 1993. First, a 'pure PFT' Normalized Difference Vegetation Index (NDVI) temporal profile was derived for each 200-km by 200-km grid cell. The 'pure PFT' NDVI was derived from the 1-km AVHRR reflectances and the abundance of the 7 primary PFTs (needleleaf evergreen tree, needleleaf deciduous tree, broadleaf evergreen tree, broadleaf deciduous tree, shrub, grass, crop) and bare ground for each 1-km pixel. For each PFT present in a 200-km grid cell, the 'pure PFT' NDVI was extracted by averaging the NDVI over 1-km pixels in which the abundance of the PFT was greater than 60%. Then NDVI profiles were converted to LAI using an approximation of the NDVI-LAI relationships of *Myneni et al.* [1997]. Finally, the 200-km LAI product was interpolated to a 0.5° by 0.5°grid (e.g., Figures 2, 3).

Significant improvements have been made in the parameterization of soil temperature and water, snow processes, runoff generation, and surface energy exchange. The basis for these improvements is detailed comparison of the NCAR LSM, BATS and other models with numerous flux measurements made at tower sites located in various ecosystems and environments. These comparisons were conducted as part of this project and by the CCSM Land Working Group. A merging of the NCAR LSM and the Common Land Model was found to retain much of the desirable features of both models and forms the biogeophysical package for the CCSM Land Model – the Community Land Model.

When the new Community Land Model is coupled to the NCAR Community Climate Model, significant improvements are seen in the simulated surface climate. Surface air temperature is cooler during January over much of the Northern Hemisphere, reducing a warm bias in the CCM-LSM coupling. Summer temperatures are warmer, reducing a cold bias. The new land model has a much more pronounced seasonality to runoff, consistent with observations, than the NCAR LSM.

The background work accomplished in the first year provides the foundation for the scientific studies in the second year. This second year's work will focus on three tasks:

1. Document the differences in climate due to the new biogeophysical packages. The parameterization of surface biogeophysics provides the physical feedbacks between land and atmosphere and the links to other processes such as dust entrainment, carbon fluxes, and vegetation dynamics. Preliminary climate model simulations show marked differences between the NCAR LSM and the new Community Land Model. These differences will be documented in a series of climate model experiments to better understand the two models.
2. Implement a dynamic global vegetation model. The use of PFTs is motivated by a desire to change vegetation over time in response to climate change. Ecologists have long developed dynamic global vegetation models (DGVMs) which simulate vegetation dynamics and the terrestrial carbon cycle. These models typically are developed independent of climate models and have proved difficult to couple with climate models except through asynchronous coupling techniques. We have begun to explore the coupling of a DGVM into the Community Land Model to provide an integrated terrestrial model for use with the CCSM. Preliminary results are promising and we expect to make substantial progress during the next year.
3. Further refine and test the dust emissions scheme. In collaboration with Dr. Charles Zender (UC-Irvine), we are implementing his dust emissions scheme to simulate the radiative effects of dust on climate. We have been working with prototype code and expect to finalize this parameterization during the next year.

Conclusions

Work during year 1 lead to significant developments in the Community Land Model for use with the Community Climate System Model. The global 20-year atmospheric dataset allows for rapid, offline development of the model uncoupled to an atmospheric model. The development of global PFT and LAI datasets allows the model to be implemented in a manner consistent with the development of biogeochemical and vegetation dynamics models by the ecological modeling community. Updating the surface biogeophysics provides a significant improvement to the simulated climate.

Publications

Bonan, G.B, Levis, S., Kergoat, L., and Oleson, K.W. Landscapes as patches of plant functional types: an integrating concept for climate and ecosystem models. Global Biogeochemical Cycles, submitted.

Figure 1

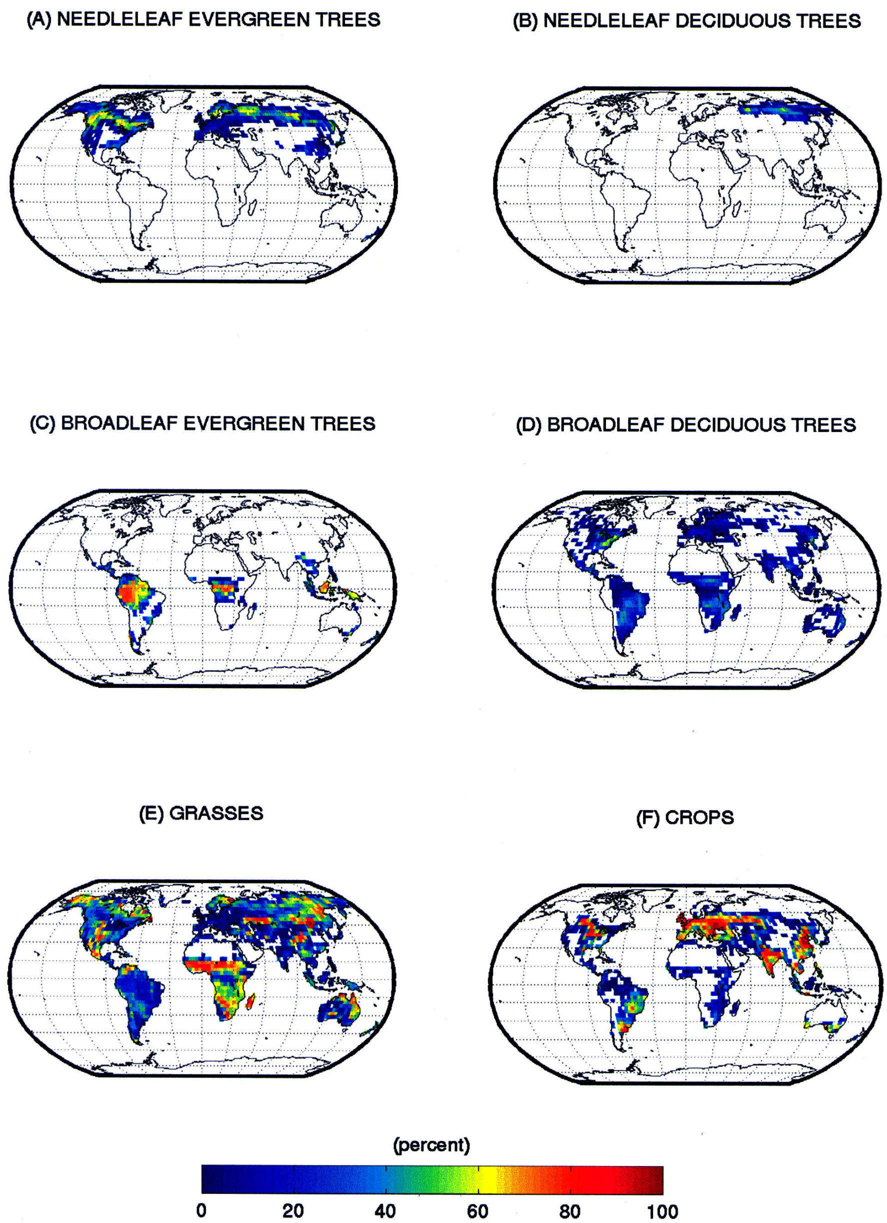
(A) NEEDLELEAF EVERGREEN TREES
(B) NEEDLELEAF DECIDUOUS TREES
(C) BROADLEAF EVERGREEN TREES
(D) BROADLEAF DECIDUOUS TREES
(E) GRASSES
(F) CROPS
(percent)
0
20
40
60
80
100

Figure 2

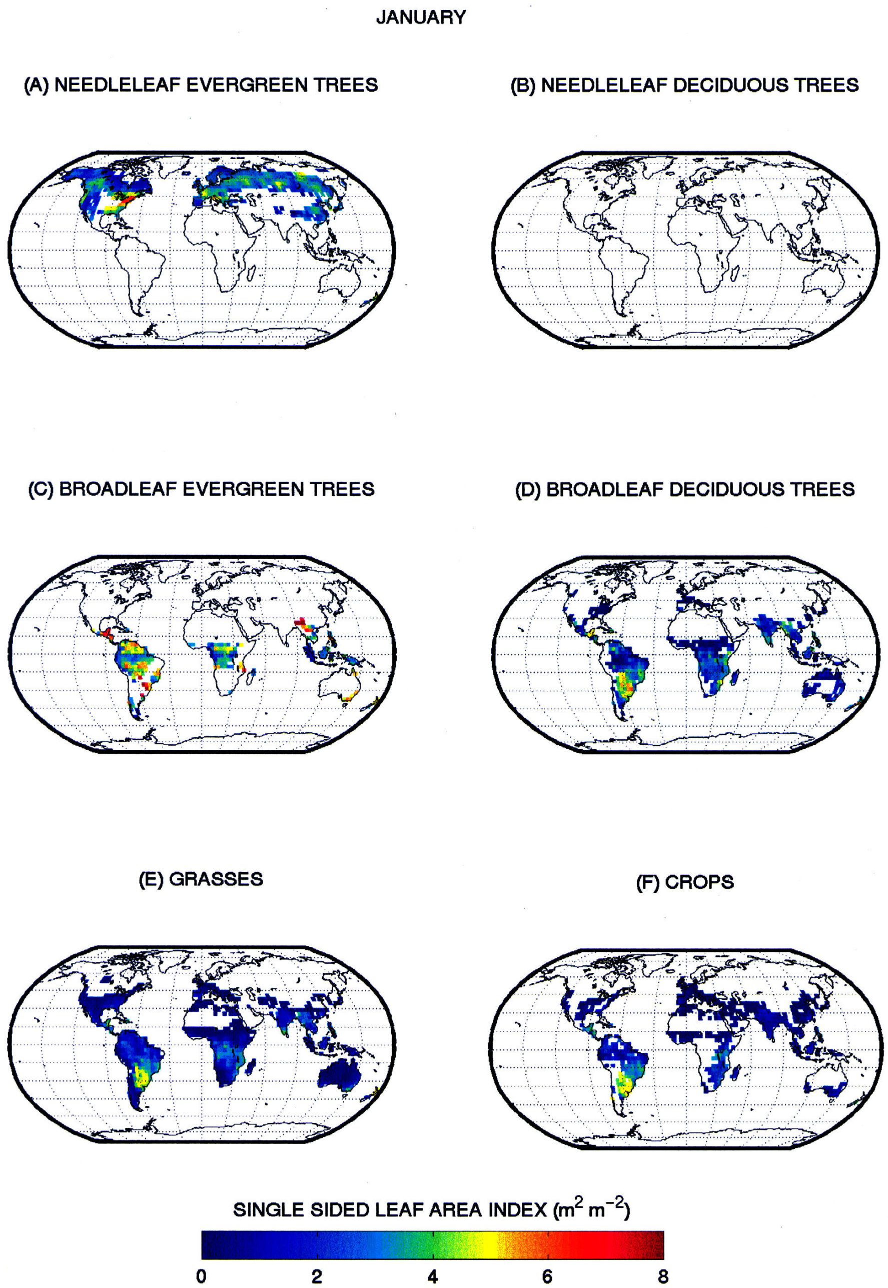
JANUARY
(A) NEEDLELEAF EVERGREEN TREES
(B) NEEDLELEAF DECIDUOUS TREES
(C) BROADLEAF EVERGREEN TREES
(D) BROADLEAF DECIDUOUS TREES
(E) GRASSES
(F) CROPS
SINGLE SIDED LEAF AREA INDEX (m2 m-2)
0
2
4
6
8

Figure 3

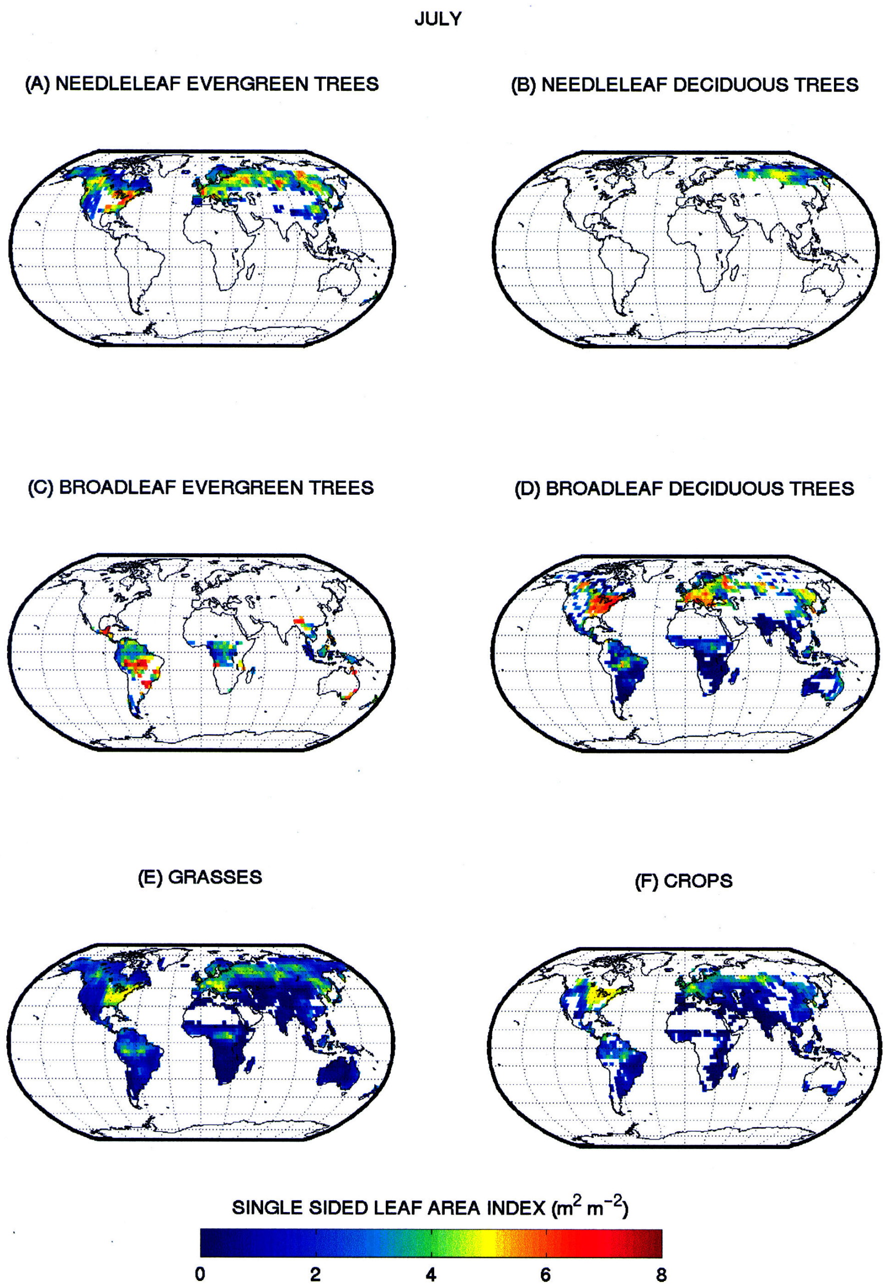
JULY
(A) NEEDLELEAF EVERGREEN TREES
(B) NEEDLELEAF DECIDUOUS TREES
(C) BROADLEAF EVERGREEN TREES
(D) BROADLEAF DECIDUOUS TREES
(E) GRASSES
(F) CROPS
SINGLE SIDED LEAF AREA INDEX (m^2 m^{-2})
0
2
4
6
8

Figure Legends

Figure 1. Distribution of needleleaf evergreen trees, needleleaf deciduous trees, broadleaf evergreen trees, broadleaf deciduous trees, grasses, and crops on a 3°×3° grid. Maps show the percent of the grid cell occupied by each plant type.

Figure 2. January satellite-derived leaf area index for needleleaf evergreen trees, needleleaf deciduous trees, broadleaf evergreen trees, broadleaf deciduous trees, grasses, and crops on a 3°×3° grid.

Figure 3. July satellite-derived leaf area index for needleleaf evergreen trees, needleleaf deciduous trees, broadleaf evergreen trees, broadleaf deciduous trees, grasses, and crops on a 3°×3° grid.