4 Land-Use and Land-Cover Change

Strategic Research Questions

6.1 What tools or methods are needed to better characterize historic and current land-use and land-cover attributes and dynamics?

6.2 What are the primary drivers of land-use and land-cover change?

6.3 What will land-use and land-cover patterns and characteristics be 5 to 50 years into the future?

6.4 How do climate variability and change affect land use and land cover, and what are the potential feedbacks of changes in land use and land cover to climate?

6.5 What are the environmental, social, economic, and human health consequences of current and potential land-use and land-cover change over the next 5 to 50 years?

See Chapter 6 of the *Strategic Plan for the U.S. Climate Change Science Program* for detailed discussion of these research questions.

Land use and land cover are linked to climate and weather in complex ways. Key links between changes in land cover and climate include the exchange of greenhouse gases (such as water vapor, carbon dioxide, methane, and nitrous oxide) between the land surface and the atmosphere, the radiation (both solar and longwave) balance of the land surface, the exchange of sensible heat between the land surface and the atmosphere, and the roughness of the land surface and its uptake of momentum from the atmosphere.

Because of these strong links between land cover and climate, changes in land use and land cover can be important contributors to climate change and variability. Reconstructions of past land-cover changes and projections of possible future land-cover changes are needed to understand past climate changes and to project possible future climate changes. Land-cover characteristics are important inputs to climate models. In addition, changes in land use and land cover, especially when coupled with

climate variability and change, are likely to affect ecosystems and the many important goods and services they provide to society. The combination of climate and land-use change may have profound effects on the habitability of the Earth in more significant ways than either acting alone. While land-use change is often a driver of environmental and climatic changes, a changing climate can, in turn, affect land use and land cover. Climate variability alters land-use practices differently in different parts of the world, highlighting differences in regional and national vulnerability and resilience.

The interaction between land use and climate variability and change is poorly understood and will require the development of new models linking the geophysics of climate with the socioeconomic drivers of land use. Providing a scientific understanding of the process of land-use change, the impacts of different land-use decisions, and the ways that decisions are affected by a changing climate and increasing climate variability are priority areas for research. In addition to being a driver of Earth system processes affecting the climate, carbon cycle, and ecosystems, land-use and land-cover change is a global change in its own right, requiring its own research foundation.

Highlights of Recent Research

Highlights of recent research supported by CCSP participating agencies follow.

Projections of land-use and land-cover change. National projections of changes in land use and land cover were updated as part of a national renewable resources assessment, designed in part to support global climate change analyses. In this assessment, future climate was assumed to reflect current trends. Projected land-use changes include deforestation due to pressures to develop rural land as the human population expands—a larger area than that converted from other rural lands (e.g., agriculture) to forestry. More than 70 million acres of U.S. rural land are projected to be converted to urban and developed uses between the present and 2025. The majority of the 70 million acres is projected to come from forestland, thereby reducing the carbon storage potential of terrestrial ecosystems. Substantial shifting of agricultural and other lands to forest use is also projected, which would significantly reduce the net effect on total forest area. On remaining forestland, investment is projected to increase in certain areas, with a 14-million-acre increase in planted pine area in the South during the next 50 years. This investment is expected to result in a significant increase in sequestered carbon per acre for such treated lands. The amount of gross area changes in land uses and land covers is a multiple of net area changes, which is important for carbon accounting.

New Enhanced National Land Cover Database. The USGS, with significant support from EPA, NASA, NOAA, and USDA, is developing a new National Land Cover Database (NLCD). The 2001 NLCD, slated for completion in 2005, is being developed using circa-2001 Landsat 7 remote-sensing data. The 2001 NLCD will complement the recently completed 1992 NLCD, but will be enhanced through the generation of additional land-cover attributes and will have expanded geographic coverage (all 50 States). The new database includes significant advances over the 1992 data set. It includes land cover, percent tree cover, and percent impervious surface cover data layers. In a parallel effort between USGS and the USDA Forest Service, the same Landsat data and NLCD layers are being further interpreted into natural vegetation data layers. The collective set of NLCD land-cover data products is a crucial input to regional hydrology, climatology, biogeochemistry, and ecosystem functioning investigations (see Figure 15).

Land-Use/Land-Cover Change in the Amazon Region. The Amazon Basin contains the largest intact tropical forest biome in the world. It is a region undergoing

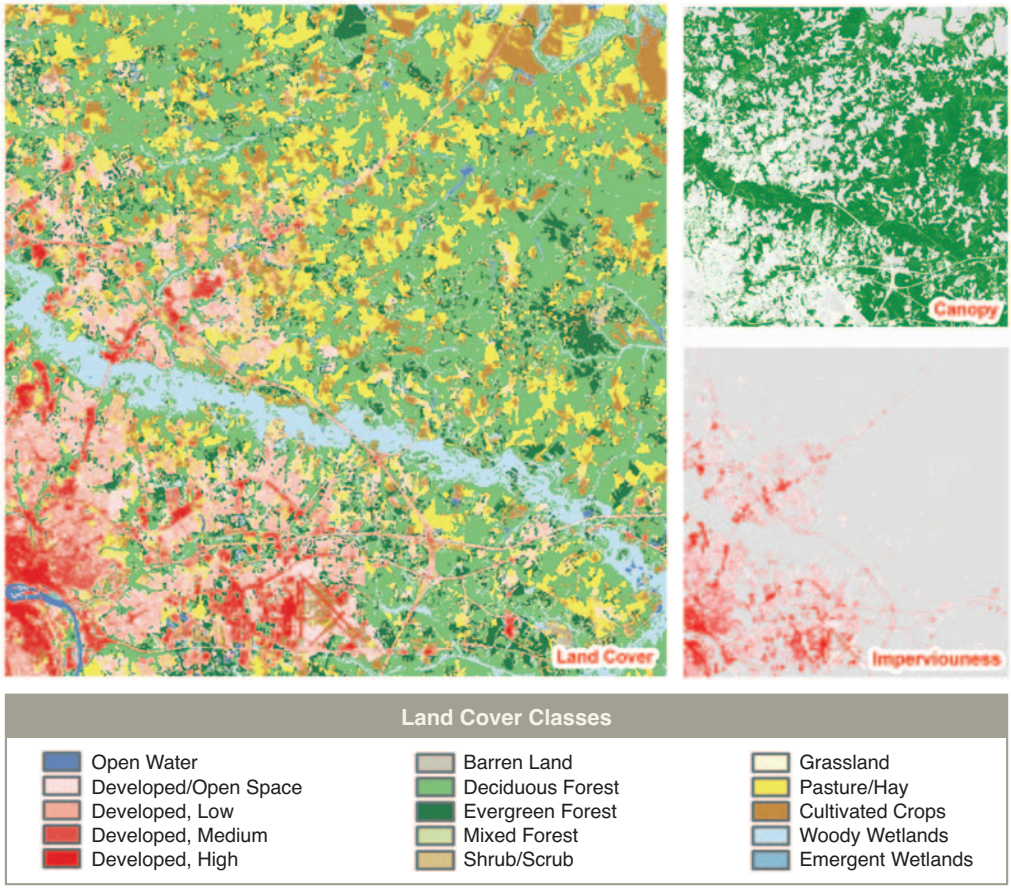


Figure 15: The development of the 2001 National Land Cover Database (NLCD) is underway and data sets are being released to researchers as they are completed. This Richmond, Virginia, example illustrates the data layers being produced. The map of land cover categories depicts the complex matrix of developed and natural lands on the fringe of Richmond. The map is used for assessments of consequences of land-cover patterns for ecosystem goods and services and climate variability. The 2001 NLCD also includes maps of canopy density, which are important for biogeochemistry studies, and surface imperviousness, which is needed for studies of hydrological processes and investigations of urban heat island issues. *Credit: USGS.*

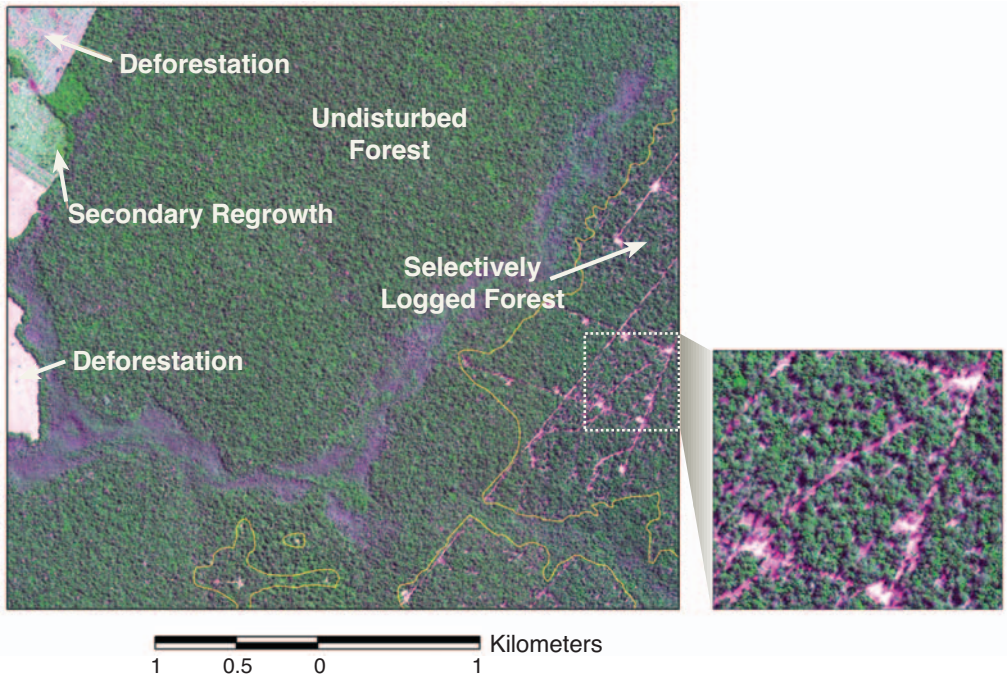


Figure 16:
Remotely sensed image identifying areas of undisturbed forest, selectively logged forest, deforestation (clear cut), and secondary regrowth. The image of Amazon forest degradation was acquired by the Space Imaging Ikonos satellite over Mato Grosso, Brazil (11o°34'S and 54°39'W), on 13 June 2000. It was band-sharpened to 1-m resolution and the display is color composite (3,4,1). *Credit: David Skole, Michigan State University.*

rapid transformation via land-use and land-cover change, with potentially profound effects on climate change, the hydrologic cycle, and ecosystem structure and biodiversity. Research underway has been utilizing the assets of Earth Observing System satellites and associated data and information systems to measure and assess these changes.

Findings to date confirm that forest degradation from fragmentation and logging has become an important disturbance in addition to deforestation. The area under selective logging is now 10-fold higher than it was in 1992. While not a significant disturbance prior to 1999, as some reports that did not use Earth observations had suggested, logging now represents roughly 30-40% of the total annual disturbance in Amazonian forests. This trend toward degradation as an important form of ecosystem disturbance is also being seen in other parts of the tropics, such as Southeast Asia, and presents new methodological and observation challenges. Future research will focus on refining the use of continuous field measurements of forest density, using the vastly improved detection capabilities of instruments aboard the Landsat and Terra satellites. Additional work is underway to extend the work in the Amazon to a prototype global monitoring system in support of the United Nations Tropical Forest Assessment.

Assessment of Global Forest Extent. Through the use of global measurements obtained by the Terra satellite, data products have been derived assessing the extent of forests and other properties of the Earth's land cover. The data provide consistent estimates of the extent of tree cover, independent of varying definitions of "forest."

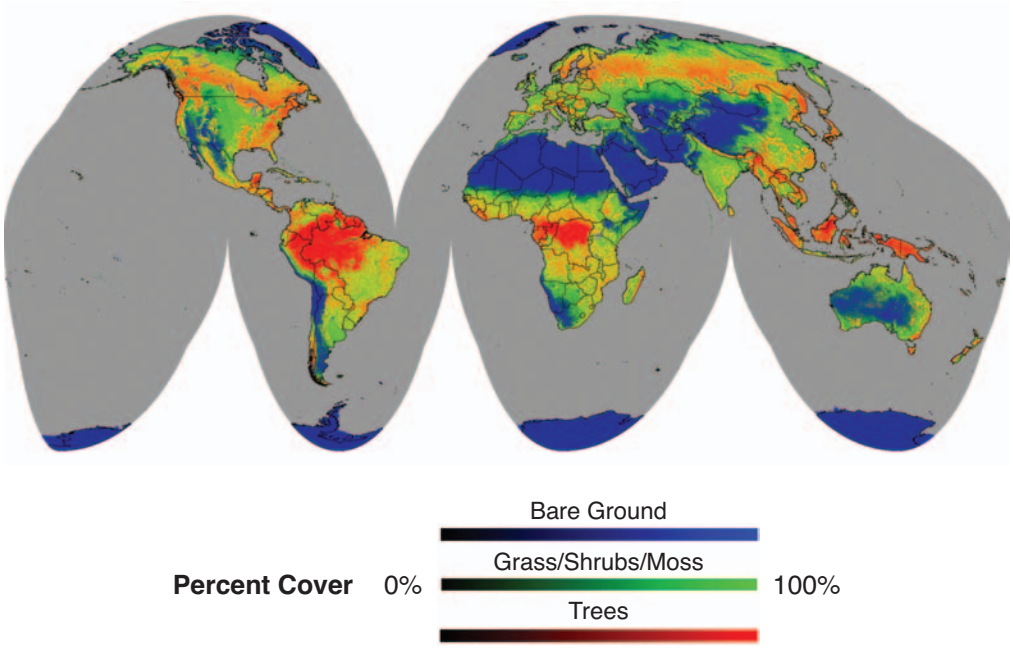


Figure 17: Global land-cover estimates of percentage tree cover, herbaceous cover, and bare ground within each 500-m by 500-m grid cell, derived from data acquired in 2001 by the Moderate-Resolution Imaging Spectroradiometer (MODIS) sensor onboard the Terra satellite platform. *Credit: R. DeFries, M. Hansen, and J. Townshend, University of Maryland-College Park.*

This is an improvement on previously produced assessments based on Landsat data. The freely available data set provides inputs to a range of terrestrial models and provides a baseline against which future changes in forest cover can be assessed (see Figure 17).

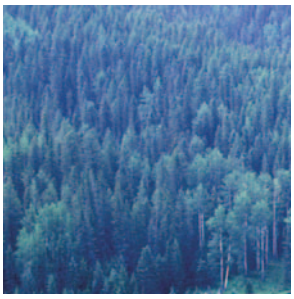
Highlights of Plans for FY 2004 and FY 2005

The CCSP will support research to identify, quantify, and understand fundamental processes of land-use and land-cover change and their consequences. Key research plans for FY 2004 and FY 2005 follow.

The extent of global agricultural land cover and land use. With the advent of remotely sensed data, researchers are now able to map global land cover consistently from space. However, remotely sensed data do not yet have the ability to distinguish between the various characteristics of agricultural land use. While they are able to distinguish croplands from other land cover, they are as yet unable to distinguish between different crops, identify irrigated land, or the amount of fertilizer applied. Such information is available only from ground-based sources, such as census data and land surveys. A combination of satellite-based land-cover data and ground-based agricultural census data will be used to derive global, spatially explicit data sets of agricultural land cover (croplands, pastures, and natural ecosystems) and land-use practices (cropping systems, irrigation, and fertilization). These data sets will be

critically important for the study of the ecosystem consequences of global agricultural land-cover change, including the trade-offs between various ecosystem goods and services.

These activities will address Question 6.1 (fourth and fifth of the milestones, products, and payoffs) of the CCSP Strategic Plan.



A new enhanced map of forest biomass for all Russian territory. Researchers will develop a map of the forest biomass of all Russia based on Landsat satellite and 500-m- and 250-m resolution Terra MODIS satellite products, through a combination of classification and modeling and use of Russian forest inventory data of both high and low spatial resolution. This map will be an improvement over existing products, as no current maps of the forest biomass of Russia exist. The only current data are based exclusively on Russian forest inventory data of unknown and unverifiable quality and with little spatial detail. After a reliable methodology is developed and tested, this product could be reproduced on a repeated basis allowing the assessment of changes of forest carbon stocks over time.

These activities will address Question 6.1 of the CCSP Strategic Plan.

A database of land-cover change in Alaska from 1950–2001. A database of land-cover change in Alaska from 1950 through 2001 will be developed. The database is tied to a circa-1991 satellite-based land-cover classification of vegetation in Alaska. Spatial resolution will be 1 km and temporal resolution will be annual. The database will describe forest stand-age at 1-km resolution, a measure that will be most reliable for areas that have burned since 1950. Successional changes in vegetation will be defined by: 1) the occurrence of fires from 1950 to 2001, 2) an empirical model that defines vegetation transitions, and 3) rules that resolve inconsistencies between the 1991 land cover and the successional trajectories of the model. This product can be used to define how successional vegetation changes affect water and energy exchange in regional climate models, how changes in stand-age and vegetation affect carbon dynamics, and for testing process-based ecosystem models of historical land-cover changes in response to fire in the Alaska region.

These activities will address Question 6.2 of the CCSP Strategic Plan.

Projecting land-use change and its effects on forest. Societal demands for land in residential, commercial, and industrial uses are expected to continue to increase with growing populations and rising incomes. Research will continue to develop and evaluate methods for analyzing associated implications for wildlife habitat, timber supplies, carbon sequestration for climate change mitigation, biodiversity, and other ecological and economic impacts. Spatial econometric studies will be conducted of forest-cover changes, with expanded use of ecological and economic theories to guide model development and enhance robustness of projected changes.

These activities will address Question 6.3 of the CCSP Strategic Plan.

Integrated regional climate study with a focus on land-use and land-cover change and associated changes in hydrological cycles in the southeastern United States. A study focused on the southeastern United States will examine the effects of changes in land use/cover, cloud-precipitation process, and terrestrial ecosystem processes on variability in surface latent heat flux (evaporation and transpiration), and hence the regional hydrological cycle. Both drought and non-drought conditions will be studied. The study will use a sophisticated atmosphere-ecological modeling system and remotely sensed satellite data and products. For regional climate simulations, a number of remotely sensed data sets will be utilized, with climate-related variables including soil moisture, cloudiness, and cloud-free optical depth. In addition, the study will explore the advantage of using derived surface latent heat (and surface CO_2) flux maps for an improved characterization of the regional land-atmosphere interactions, including the water cycle associated with land use/cover. After carrying out the analysis in the southeastern United States, this approach and product can be readily expanded for a global-tropical application.

These activities will address Question 6.4 (first, second, and third of the milestones, products, and payoffs) of the CCSP Strategic Plan.

Report on impacts of urbanization on ecological services in a semi-arid region of the United States. The Edwards Aquifer is the primary water supply for the city of San Antonio, Texas, one of the ten fastest growing U.S. metropolitan areas. Ongoing research has focused on determination of the impacts of past land-use and land-cover change on regional ecological services—including water resources, vegetation for carbon sequestration, and refugia for wildlife habitat—and evaluation of public policy instruments to enhance these services in the future. This research relies on a strong multidisciplinary approach, using satellite images, modeling, and geospatial analysis tools. In FY 2004, the ongoing analysis is being expanded over the entire aquifer recharge region. The outcome of this research will be a comprehensive understanding of the effects of urbanization on ecological services in a semi-arid region, a determination of the effectiveness of policies to enhance ecological services, and decision support for optimizing ecological services through policies that appropriately manage land-use and land-cover change.

These activities will address Question 6.5 of the CCSP Strategic Plan.