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 affect the global climate system through biogeophysical, biogeochemical, and energy exchange processes. Variations in these processes due to land-use and land-cover change in turn affect local, regional, and global climate patterns. Key processes include uptake and release of greenhouse gases by the terrestrial biosphere through photosynthesis, respiration, and evapotranspiration; the release of aerosols and particulates from surface land-cover perturbations; variations in the exchange of sensible heat between the surface and atmosphere due to land-cover changes; variations in absorption and reflectance of radiation as land-cover changes affect surface reflectance; and surface roughness effects on atmospheric momentum that are land-cover dependent. Human activity can and does alter many of these processes and attributes, but weather and climate, as well as geological and other natural processes, are also important.

For example, land-cover changes such as deforestation and forest fires alter ecosystems and release carbon dioxide, methane, carbon monoxide, and aerosols to the atmosphere. They also change the reflectivity of the land surface which in turn determines how much of the sun's energy is absorbed and thus available as heat, while vegetation transpiration and surface hydrology determine how this energy is partitioned into latent and sensible heat fluxes. At the same time, vegetation and urban structure determine surface roughness and thus air momentum and heat transport.

Land-use and land-cover change studies also provide critical inputs to large-scale vegetation biomass and forest cover assessments that are key components of the carbon cycle. Future land-use and land-cover change goals include very accurate biomass estimates to refine knowledge of carbon storage in vegetation, understanding regional land-use changes that affect biomass, and quantifying linkages and feedbacks between land-use and land-cover change, climate change forcings, climate change, and other related human and environmental components.

Research that examines historic, current, and future land-use and land-cover change, their drivers, feedbacks to climate, and environmental, social, economic, and human health consequences is therefore of utmost importance and often requires interagency and intergovernmental cooperation. One example of a multi-agency effort is the Congo Basin Forest Partnership, which focuses on conserving the second largest tropical rainforest in the world in equatorial Africa. Satellite data are used to map forest extent, determine habitat fragmentation, and enforce conservation laws, and thus minimize greenhouse gas emissions from deforestation. Another example was the North America Land Cover Summit held in September 2006, which explored and encouraged collaboration among institutions and government agencies to advance the development and application of land-cover information in Mexico, the United States, and Canada.[1]

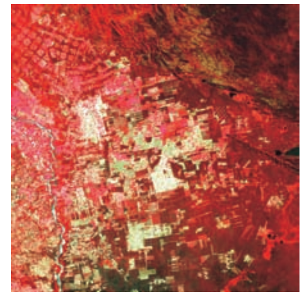
Highlights of Recent Research

Selected highlights of recent research into land-use and land-cover change issues supported by CCSP-participating agencies follow.

Land-Use and Land-Cover Change Drivers Vary by Region and Geopolitical Events.[2,3] As part of a national assessment of U.S. land-cover change, the USGS recently completed and web-published an analysis of land-cover and land-use change rates for 20 U.S. ecoregions that span 1,650,930 km^2 of the eastern United States. Land-cover extent and changes through time were assessed for ten land-cover types through five time periods: 1973, 1980, 1986, 1992, and 2000. Major findings of this study showed that eastern U.S. land change was connected primarily to timber harvesting and urban growth, together with a decline in agricultural activity. The observed changes were complex and ecoregion specific. The southern United States is thought to be the largest sink for carbon in the conterminous United States. In a long-term assessment of change, researchers reconstructed an annual land cover of the southern United States from 1860 to 2003 with a spatial resolution of 8 km. The pattern of land-cover change in the southern United States was primarily driven by the change in cropland, including cropland expansion and forest regrowth on abandoned cropland. The net flux of carbon due to land-use change in this region was estimated to be zero from 1980 to 2003; but, from 1860 to 1980, land-use and land-cover change was estimated to have resulted in a net release of 9.4 GtC across the southern United States.

Changes in Eastern Europe due to Socioeconomic and Political Factors following the Breakdown of the Soviet Union.[4] A comparison of land cover in the Polish, Slovak, and Ukrainian Carpathian Mountains in 2000 from Landsat images showed marked differences in forest cover, dominant forest species, and agricultural fragmentation. These differences can largely be explained by socialist forest management. Post-socialist land-cover change was greatest in Ukraine, where there was high agricultural fragmentation and widespread early-successional shrublands indicating extensive land abandonment. The abundance and pattern of arable land and grassland was attributed to land tenure in socialist times and economic transition since 1990. These results suggest that broad-scale socioeconomic and political factors are of major significance for land-cover patterns in Eastern Europe.

Land-Cover Change Detection using MODIS Data for Non-Agricultural Areas of the U.S. East Coast.[5] Moderate Resolution Imaging Spectroradiometer (MODIS) 250 m data are used to form the Normalized Difference Vegetation Index (NDVI), a measure of the photosynthetic capacity of vegetation. Composite NDVI data sets were used to provide automated detection of vegetation change and alarm capability on a 1-year time step for the Albemarle-Pamlico Estuary System region of the U.S. east coast. Vegetation change detection accuracy was assessed for 2002 at 88% with a reasonable balance between change commission errors (22%) and change omission errors (28%). Annual change detection rates across the Albemarle-Pamlico Estuary System over the 2002 to 2005 study period were estimated at 0.7% per annum and varied from 0.4% in 2003 to 0.9% in 2004. Extended regional variations were also readily apparent ranging from 1.6 to 0.1% per annum for the tidal water and mountain ecological zones, respectively. This research included the application of an automated protocol to first filter the MODIS vegetation index data to remove unreliable data values and then estimate the missing data values using a statistical technique to provide high-quality uninterrupted data to support the change detection analysis. The methods and results detailed apply only to non-agricultural areas.



Development and Verification of Improved Methods for Remote Assessment of Land-Use Variables Linked to Climate Forcings in Brazil.[6] Brazil has become a major producer in world soybean markets, with about 10 million hectares currently planted. Cultivation of this crop is rapidly expanding into two Brazilian ecological zones: the savannah or cerrado, and the forested Amazonian region. The climatic consequences of converting forested Amazonian areas into cropland are significant due to their vastly different storage capacities for carbon. There is a need for accurate updated information on the newly expanded agricultural areas in Brazil and the current total production in order to predict contributions to climate forcings from these regions. A method for assessing crop area and retrieving crop condition parameters that can be used to assess crop yields was developed using data from the MODIS instrument onboard the Terra satellite.

Development and Verification of Improved Methods for Remote Assessment of Land-Use Variables Linked to Climate Forcings in the Mid-West United States.[7] Crop type, yield, and land management affect the balance of greenhouse gas fluxes from land cover in the mid-western United States. The magnitude of surface changes such as tillage intensity affects residue cover and thus the moisture and radiation energy balances at the land surface through changes in evaporation and reflectance. However, these distinctions are difficult to assess across landscapes. Agricultural Research Service scientists working in Iowa have developed a method using Landsat Thematic Mapper and EO-1 Hyperion imaging spectrometer data to classify tillage intensity in cropland.

Development and Verification of Improved Methods for Remote Assessment of Land-Use Variables Linked to Climate Forcings in Central America.[8] A methodology has been developed for observing changes in tropical forest cover for large areas using data with high temporal frequency from coarse-resolution satellite imagery. Proportional forest cover change is estimated from multi-spectral, multi-temporal MODIS data that are transformed to optimize the spectral detection of vegetation changes. This methodology has been applied using MODIS data in Central America. Landsat data are also used to record higher detail changes of forest cover in Central America. This work describes the distinct patterns of change from year to year due to land-cover changes resulting from forest clearing, regeneration, and changes in climate. It was found that the ability to detect forest cover change patterns using this methodology was relatively independent of the spatial resolution of the data. Associated model simulations indicated the best metrics for detecting tropical forest clearing and regeneration are the shortwave infrared information from the MODIS data at 500-m resolution. Errors were found to range from 7 to 11% across the time periods of analysis.

Regional Climate Change due to Agricultural and Urban Development in California.[9] In the western United States, large changes in land cover and land use have occurred

over the past century with rapidly expanding urbanization along the Pacific coast, and extensive agricultural development inland. A regional climate model was used by researchers to quantify the differences in surface energy fluxes and atmospheric circulation associated with land-cover changes between approximately 1990 and the present. They showed that irrigated agriculture in California lowered mean and maximum surface air temperatures, while conversion of natural vegetation to urban areas increased ground temperatures. This land-use change pattern resulted in changes in the spatial patterns of air pressure and energy balance causing reduced westerly breezes and increased inland breezes. Overall, conversion of natural vegetation to irrigated agriculture has had a larger effect on California's climate than urban growth up until now, but future projections of increased conversion of irrigated land to urban/suburban development could alter this balance.

Western Wildfires, Land-Cover Disturbance and Response to Climate Warming.[10,11] Wildfire intensity and duration can have a large effect on forest recovery. Scientists from Scripps Institute of Oceanography, the University of California Merced, the USGS, and the University of Arizona compiled a comprehensive database of large wildfires in the western United States since 1970 and compared it with land surface data and hydroclimatic data to show that marked and sudden increases in large wildfire activity in the mid-1980s—including higher frequencies, longer seasons, and longer duration of the fires—were strongly associated with increased spring and summer temperatures and earlier snowmelt. Recent studies in ponderosa pine-dominated forests of northern Arizona have found that intense stand-replacing wildfire converts forests to grasslands and shrublands and converts the land from a CO_2 sink to a source, even 10 years after burning, creating a positive feedback to increasing temperatures. Work emerging from CCSP is contributing to the Joint Fire Science Program, which is attempting to improve understanding of climate controls of wildfire (see Figure 6).

Coconino National Forest, Northern Arizona

Figure 6: Coconino National Forest, Northern Arizona. This photo shows Coconino National Forest 10 years after an intense stand-replacing wildfire. The wildfire converted the site from a dense forest of ponderosa pine to a grassland in which trees have not regenerated. Such a conversion from forest to grass- or shrub-land is common in ponderosa pine forests of the southwestern United States following intense wildfire. The instrument tower measures ecosystem CO_2 flux for comparison with unburned forest. This site was a CO_2 sink 10 years ago, but is now a CO_2 source due to decomposition of organic matter in the soil offsetting photosynthesis by the low leaf area of the grassland. *Credit: M. Montes-Helu, Northern Arizona University.*

National Land Cover Database Available for Use in Climate Models and Assessments.[12] The USGS, on behalf of the interagency Multi-Resolution Land Characteristics Consortium (MRLC), has made available the National Land Cover Database (NLCD 2001) products for the conterminous United States. These products are available for download from the MRLC web site at <www.mrlc.gov>. NLCD 2001 products include 21 classes of land cover, percent tree canopy, and percent urban imperviousness at 30-m resolution derived from Landsat imagery. NLCD 2001 will support a wide variety of users, institutional sectors, and local- to national-scale applications with this updated land-cover data. This baseline data set is essential in determining the effects of land-cover change on climate as well as the effects of climate change on land cover.

Deforestation Dynamics Assessed in Brazilian Amazon.[13,14] There has been considerable international attention on the Brazilian Amazon Basin because of the alarming rate of destruction of this high-biodiversity biome and because it is a major terrestrial buffer against rising atmospheric CO_2, a primary driver of global warming. Land-cover change from pristine forests to other uses accounts for most of Brazil's carbon emissions. Investigators combined deforestation maps, field surveys, and satellite-based information

on vegetation phenology to characterize the fate of large (>25 hectare) clearings as cropland, cattle pasture, or regrowing forest in the years after initial clearing in Mato Grosso, the state with the highest deforestation rate and soybean production since 2001. Cropland deforestation averaged twice the size of pasture clearings, and more than 90% of the conversion to cropland occurred the first year after deforestation. Economics appears to be a major driver of this change as the area deforested for cropland per year was directly related to the mean annual soybean price. Large-scale logging is relatively new in this region, and impacts of selective logging alone have been estimated to increase the annual carbon release from deforestation in the Amazon by 4 to 7%, thus adding to the CO_2 concentration of the atmosphere. Remote-sensing techniques were applied to identify and map areas of selective logging in the tropical upland or terra firme forests of the Brazilian Amazon in 1992, 1996, and 1999. The research results indicate that selective logging is rapidly increasing in both intensity and area. By 1992, at least 6,000 km^2 of forest had been logged, and the area affected expanded by an additional 10,000 km^2 from 1992 to 1996 and 26,000 km^2 from 1996 to 1999. Selective logging within protected areas increased more than two-fold between 1992 and 1996, and more than five-fold between 1996 and 1999 in that region (see Figure 7).

Highlights of Plans for FY 2008

Urgent land-use and land-cover change priority research questions include understanding historic, current, and potential future land-use and land-cover change patterns, dynamics, and drivers; understanding the mutual effects and feedbacks between climate variability and land use/land cover; and forecasting environmental, social, economic, and human health consequences. All of these land-use and land-cover change priority issues directly influence climate by affecting atmospheric trace gas composition and surface reflectance, and are thus critical to other CCSP research elements. While both *in situ* and satellite observations are essential, two satellite sensors are especially critical: MODIS (including its next generation moderate-resolution successor the Visible/Infrared Imager/Radiometer Suite) and Landsat. Without these satellite observations, the current pace of discovery and innovation in global land-use and land-cover change climate research would not be possible. Thus, an overall priority for this research element is to ensure continuity and improvements in land-use and land-cover observations, to compare and validate the different types of observations, and to coordinate activities for analysis and synthesis of their implications and projections, as follows:

- Improve quantification of the forces bringing about changes in the Earth's climate and related systems.
- Explore the uses and identify the limits of evolving knowledge to manage risks and opportunities related to climate variability and change.

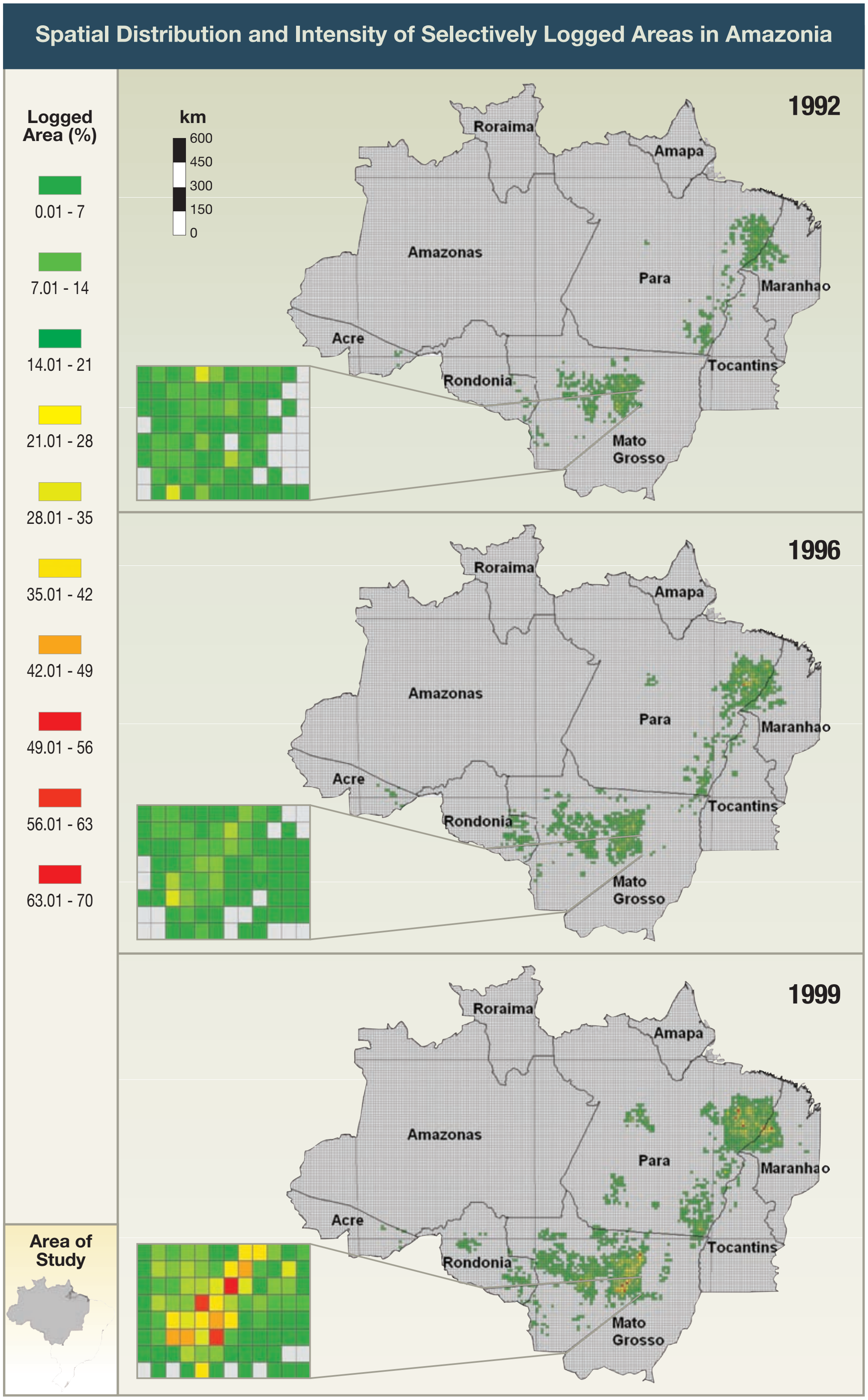


Figure 7: Spatial Distribution and Intensity of Selectively Logged Areas in the Amazon Basin. Spatial distribution and intensity of selectively logged areas summarized into 25 by 25 km grid cells in 1992, 1996, and 1999 for the Amazon Basin of Brazil. *Credit: E.A.T. Matricardi, D.L. Skole, and W.H. Chomentowski, Michigan State University; M.A. Cochrane, South Dakota State University; and M. Pedlowski, Universidade Estadual do Norte Fluminense Darcy Ribeiro, Brazil (reproduced from the* **International Journal of Remote Sensing** *with permission from the publisher Taylor & Francis Group).*

- Improve knowledge of the Earth's past and present climate and environment, including its natural variability, and improve understanding of the causes of observed variability and change.

Development of Land-Use Change Models. Developing future land-use and land-cover change scenarios and understanding drivers and feedbacks are necessary to assess impacts on the environment. A tool to generate future LULCC scenarios consistent with IPCC emissions scenarios is being developed, and will be used to assess the environmental impacts of climate and land-use change regionally and nationally. This will improve projections of climate and global change and contribute to understanding of possible management risks and opportunities related to climate change. It also contributes directly to understanding the feedbacks between climate change, conservation policies, and land-use and land-cover decisions.

This activity will address CCSP Goals 3, 4, and 5 and Questions 6.1, 6.3, and 6.4 of the CCSP Strategic Plan.

Invasive Species Impacts on Land-Use and Land-Cover Change. Land use and climate change interact to influence the spread of alien or invasive species that in turn have ecological impacts that may result in climate forcings. The EPA, NASA, and USDA are coordinating solicitations to quantitatively investigate these interactions. In addition, a workshop is planned to study and determine future directions for research on interactions between land-use and land-cover change and the carbon cycle relating to climate change. These efforts help quantify climate change drivers and feedbacks, reduce uncertainties in projections of change, and improve understanding of sensitivities of natural and managed ecosystems.

This activity will address CCSP Goals 2, 3, and 4 and Questions 6.2, 6.4, and 6.5 of the CCSP Strategic Plan.

Prototype Land-Cover Mapping Activities. The National Land Cover Database effort in Alaska, Hawaii, and Puerto Rico will be finished by December 2007, marking completion of the first compilation of nationwide land cover ever produced at 30-m resolution. This will improve knowledge of Earth's present environment and its variability and form the baseline for quantifying change at high spatial resolution.

This activity will address CCSP Goal 1 and Question 6.1 of the CCSP Strategic Plan.

Landsat Data Continuity Mission. The importance of Landsat data continuity was a priority for FY 2007 and was emphasized in the FY 2007 edition of *Our Changing Planet*. Landsat Data Continuity Mission planning continues toward a proposed 2010 launch. In October 2006, NASA and USGS announced the selection and research objectives for the Landsat Science Team. The Science Team will recommend strategies for the effective use of archived data from Landsat sensors and investigate the requirements for future sensors to meet the needs of Landsat users, including the needs of policymakers at all levels of government. The team will cooperate with other Earth-observing missions, both nationally and internationally. This will improve quantification of drivers and atmospheric forcings of climate change, contribute to improved projections of this change, and provide improved understanding of the present environment, its variability, and how it is changing.

This activity will address CCSP Goals 1, 2, and 3 and Question 6.1 of the CCSP Strategic Plan.

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