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 land cover and climate include the exchange of greenhouse gases between the land surface and the atmosphere, the radiation balance (both solar and long-wave) 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 are 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 affect ecosystems, biodiversity, and the many important goods and services they provide to society, including carbon sequestration. One focus of FY 2006 land-use and land-cover change (LULCC) projects will be to provide large-scale biomass estimates and forest cover assessments for carbon models.

Determining the effects of land-use and land-cover change on the Earth system depends on an understanding of past land-use practices, current land-use and land-cover patterns, and projections of future land use and cover, as affected by human activities, population size and distribution, economic development, technology, and other factors. Land-use models and innovative methods for projecting land-use and land-cover patterns and characteristics into the future (5 to 50 years) will be a subject for a special overview workshop at the National Academy of Sciences.

The combination of climate and land-use change affects the Earth's environment in more significant ways than either acting alone. While land-use change is likely 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. In FY 2006, U.S. LULCC research will examine such regional heterogeneities both in the United States and internationally.

The interaction between land use and climate variability is poorly understood and will require the development of 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 climate, the carbon cycle, and ecosystems, land-use and land-cover change are global changes in their own right, requiring a separate research foundation. CCSP research in this area in FY 2006 will include a focus on improving multi-sector models for land-use change, and on improving models that relate climate change, population density, and land use and cover to regional water availability.

Highlights of Recent Research

Selected highlights of recent research supported by CCSP participating agencies follow.

Projecting Area Changes for Major Forest Types.[1] Modeling the dynamics of forest cover changes is part of the periodic national forest resource assessments by the USDA Forest Service and cooperators. One of the largest changes in U.S. forest type areas over the last half-century has involved pine forest types in the South. The area of planted pine has increased more than 10-fold since 1950, mostly on private lands. Baseline projections indicate a net increase of about 5.6 million ha (about 13.8 million acres), which is approximately a 52% increase in planted pine area in the South over the next 50 years. This forest investment is expected to result in a significant increase in sequestered carbon per acre. With increasing amounts of timber harvests arising from plantations, this will also affect carbon storage in wood products. U.S. forests elsewhere will also continue to change in structure and composition, as the area of timberland with trees older than 150 years on National Forest lands is projected to more than double by 2050. Many of those forests are in the Pacific Northwest and can lead to a notable increase in sequestered forest carbon.

Population, Land Use, and Climate Change Impacts on Regional and Local Water Supply and Demand.[12] Forest Service scientists assessed the effects of model-projected climate change scenarios coupled with potential changes in population, hydrology, and land use/land cover to examine future water supply and demand across the southern United States. Long-term average, maximum, and minimum water yield and demand were examined. Water yield reflects the combined influences of vegetation, soils, precipitation, temperature, and evaporation. The study found that current water yield exceeds water demand by more than 100 times during an average precipitation year in the region. However, some local areas are currently experiencing significant water shortages due to high population density, water demand, and/or periodic drought. Overall, the climate projections suggest that total water yield will increase in the region over the next 20 years. Local water shortages are projected to increase and expand in area during the next 20 years, with population change having the greatest impact on local water supply stress. Projected changes in climate and vegetative cover will have larger region-wide impacts on water yield, but relatively little impact on local changes in water supply stress compared to population change (see Figure 13).

Lowland Forest Loss in Protected Areas of Indonesian Borneo.[3] Analysis of lowland forest loss in protected areas of Indonesian Borneo (Kalimantan) demonstrates progress toward understanding how complex histories of land use, land cover, policy,

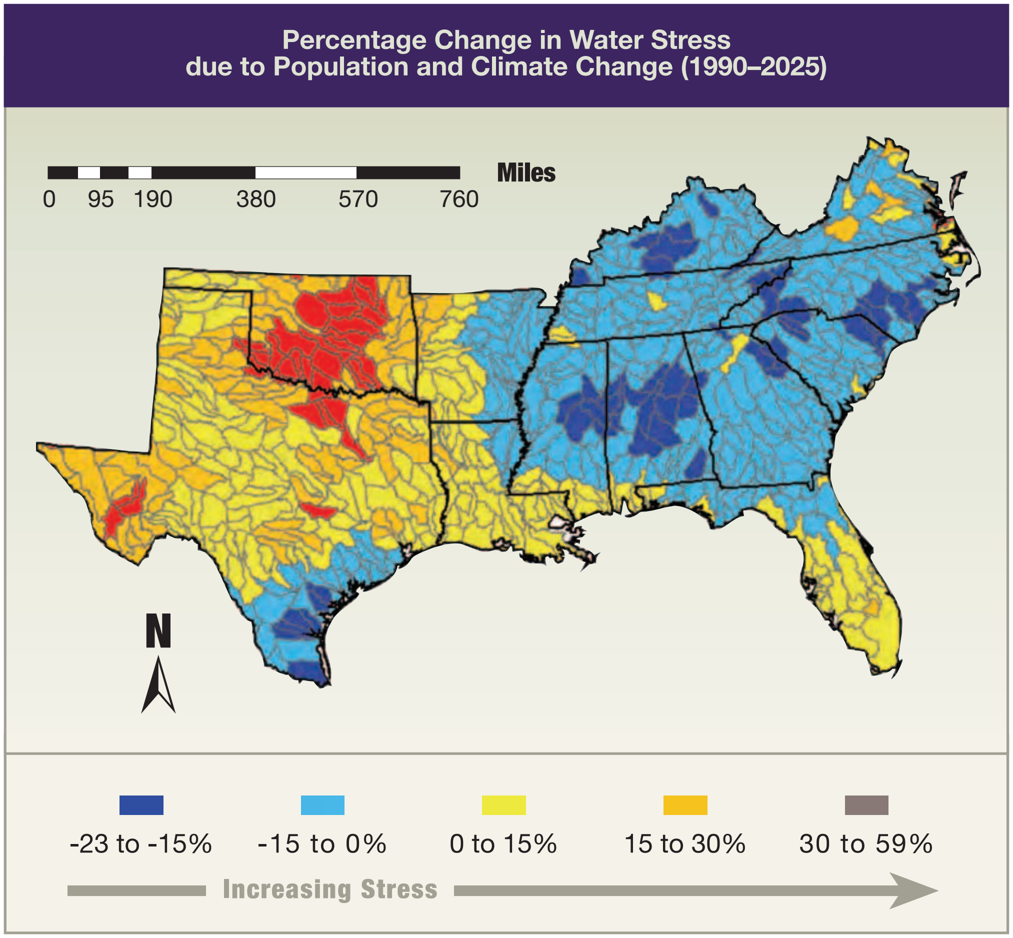


Figure 13: Percentage Change in Water Stress. Projection of effects of changes in population and climate on changes in water stress between 1990 and 2025. This projection used the Hadley 2 Climate Model with sulfates included to project precipitation and air temperature out to 2025; U.S. census demographic projections to 2025; and 1992 Multi-Resolution Land Characteristics (MRLC) vegetation data. *Credit: S. McNulty, USDA/Forest Service.*

and sudden economic change can result in rapid change in land cover. These findings will contribute to improved ecosystem modeling. Satellite remote sensing of land-cover change between 1985 and 2001 reveals rapid and pervasive deforestation of lowland forests within protected areas: a 56% loss (>29,000 km^2) was documented across Kalimantan. Socioeconomic and political drivers of these land-use changes were examined for the period 1970 to 2002. The collapse of logging concession timber stocks through overexploitation, coupled with high demand for timber by wood-based industries and policies that promote oil palm plantations, drive both illegal logging and forest clearing. In combination, these land-use changes result in lowland forest fragmentation and loss of wildlife habitat (see Figure 14).

Results of this research are being applied to verify forest inventories, update estimates of tropical carbon emissions dynamics, and assess effects on biodiversity. In Indonesia, these products are being used by nongovernmental organizations, multilateral donors, and governmental agencies to increase transparency, accountability, and management in remote frontier areas with the aim of reducing illegal logging.

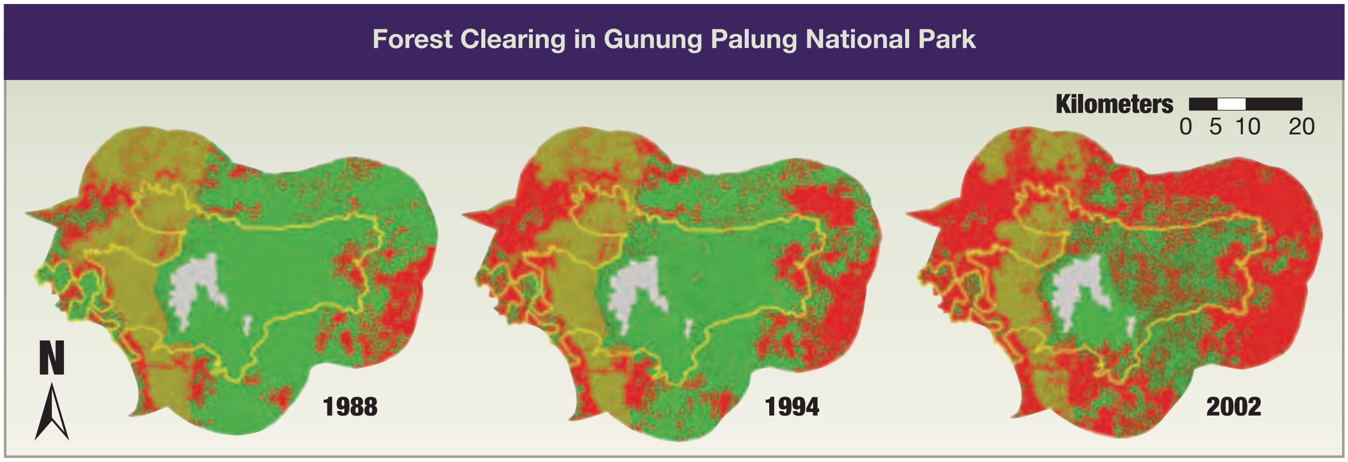


Figure 14: Forest Clearing in Gunung Palung National Park, 1988–2002. Cumulative forest loss within the Gunung Palung National Park boundary (yellow line), Indonesia, and its surrounding 10-km buffer. Forest and non-forest classifications are based on Landsat Thematic Mapper time series. Lowland (green) and peat (olive) forests were converted to non-forest (red), first predominantly in the buffer and later within the park. Grey areas are montane forest and excluded from the analyses.
Credit: S.N. Trigg, University of Maryland (from Curran et al.*, 2004).*

Simulating Urban Development in the Baltimore-Washington, D.C., Area.[2,7,11] Using an existing urban model, scientists simulated patterns of urban development in the Baltimore-Washington, D.C., area. Empirical calibration of the model using Landsat Thematic Mapper image maps of past change between 1986 and 2000 provided calibration of the model using fine-scale data, and refined model projections of future change. The data set also enabled an extensive sensitivity analysis of the model. To serve regional planning needs, the multi-agency Chesapeake Bay Program is now supporting the creation of 30-year projections for the entire Bay watershed that will inform vulnerability assessments and decision support. These scenarios range from one that assumes a continuation of current growth trends and environmental protection policies, to one that assumes stronger environmental protection on open lands and greater use of mass transit. This research is at the forefront of urban modeling, creating fine-scale projections over large areas, using methods grounded in urban theory and economics, and incorporating satellite remote-sensing products (see Figure 15).

Impervious Surface Area Grid of the United States.[6] The construction and maintenance of impervious surfaces (buildings, roads, parking lots, roofs, etc.) constitutes a major human alteration of the land surface, changing the local hydrology, climate, and carbon cycling. The United States is adding impervious surface area at a rapid pace. Population is increasing at a rate of 3 million people per year. Annual U.S. public and private sector construction spending is greater than $480 billion. This includes more than one million new single-family homes and more than 10,000 miles of new roads per year. Given these trends, impervious surface area is likely to become a more prominent environmental and growth management issue in the coming years. However, few areas have mapped impervious surface area, due in part to the technical challenges and cost constraints of using high spatial resolution (e.g., 1-m) data for direct mapping of constructed surfaces. As an alternative, existing national coverage data sources have been used to model the percent cover of impervious surface area on a 1-km grid for the conterminous United States. The data sources included satellite-observed nighttime lights, three classes of Landsat-derived urban land cover, and U.S. Census Bureau road vectors. The results indicate that total impervious surface area of

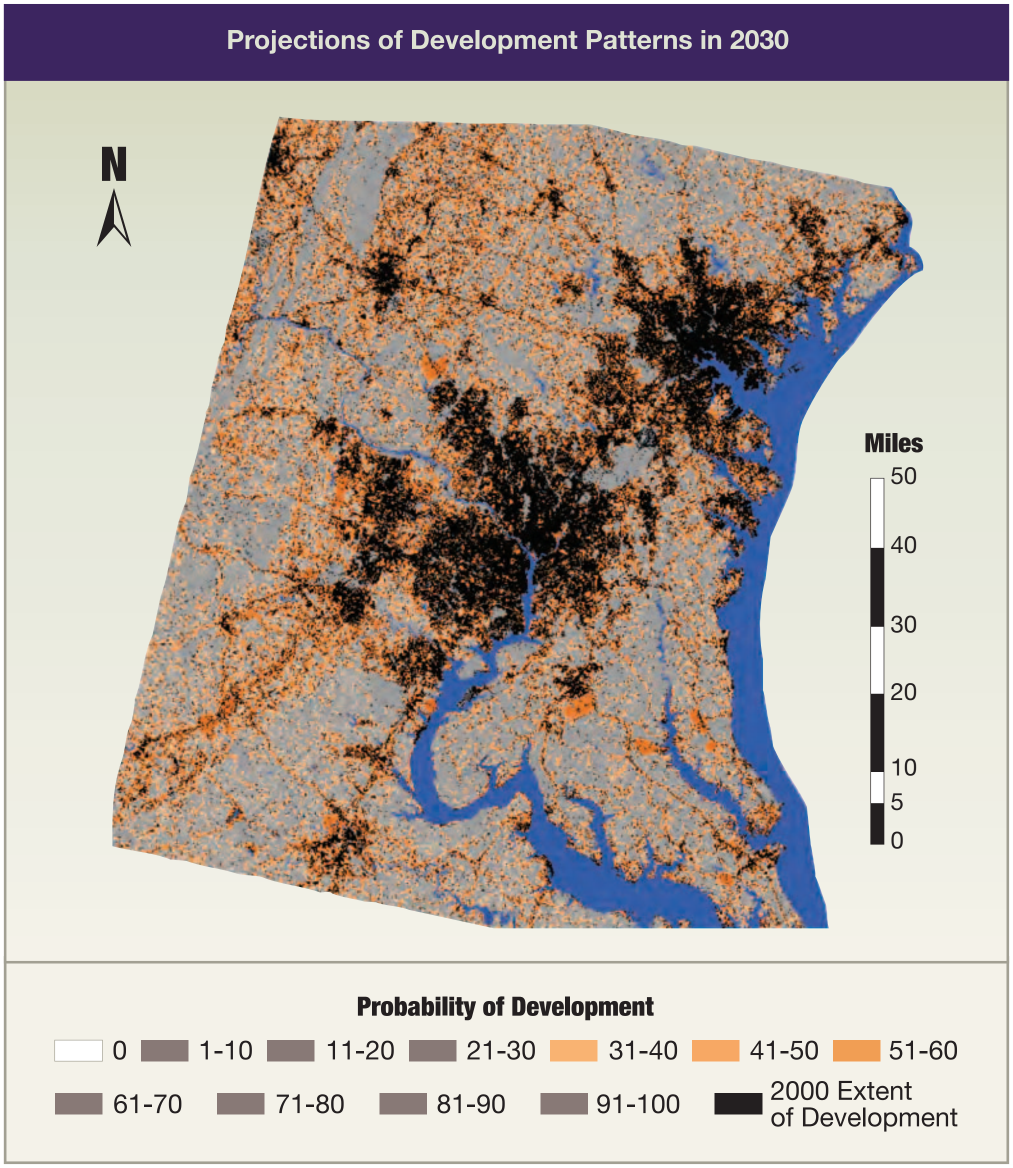


Figure 15: Percentage of Development Patterns in 2030. Using a cell-based urban model (SLEUTH), projections of development patterns in 2030 were created assuming three different policy scenarios (current trends, managed growth, and low growth). SLEUTH was calibrated using Landsat-derived maps of the built environment that documented development patterns between 1986 and 2000. This data set provided a baseline that the calibrated model used to extrapolate patterns into the future. Following business-as-usual patterns of low density and dispersed development, this model projects that the amount of developed land could increase 123%, putting at least 1,300 km^2 of forests and 1,537 km^2 of agricultural lands at risk. *Credit: C. Jantz and S. Goetz, The Woods Hole Research Center.*

the 48 states (and D.C.) is 112,610 (±12,725) km^2, which is slightly smaller than Ohio (116,534 km^2; see Figure 16).

Modeling Global Change Impacts on Wildfire Cycles.[8] A Geographic Information System (GIS) model (FCS-1) has been developed to enable research on how the combined impacts of climate, fire, and human activities influence the nature, distribution, and intensity of fire risk at scales relevant to management concerns and needs. FCS-1 was developed with the recognition that strategic land management requires an understanding of fire behavior and community needs over time. The model incorporates traditional fire science with the human dimension of landscape management in order to identify assets (e.g., property and recreation opportunities) at risk in case of fire. A study utilizing this model emphasized evaluation sessions involving both experts and community members. The evaluation sessions provided valuable opportunities to improve scientific understanding of (a) the ways in which models like FCS-1 might be employed in strategic planning activities to address fire risk problems, and (b) the levels of confidence held by decisionmakers, scientists, and

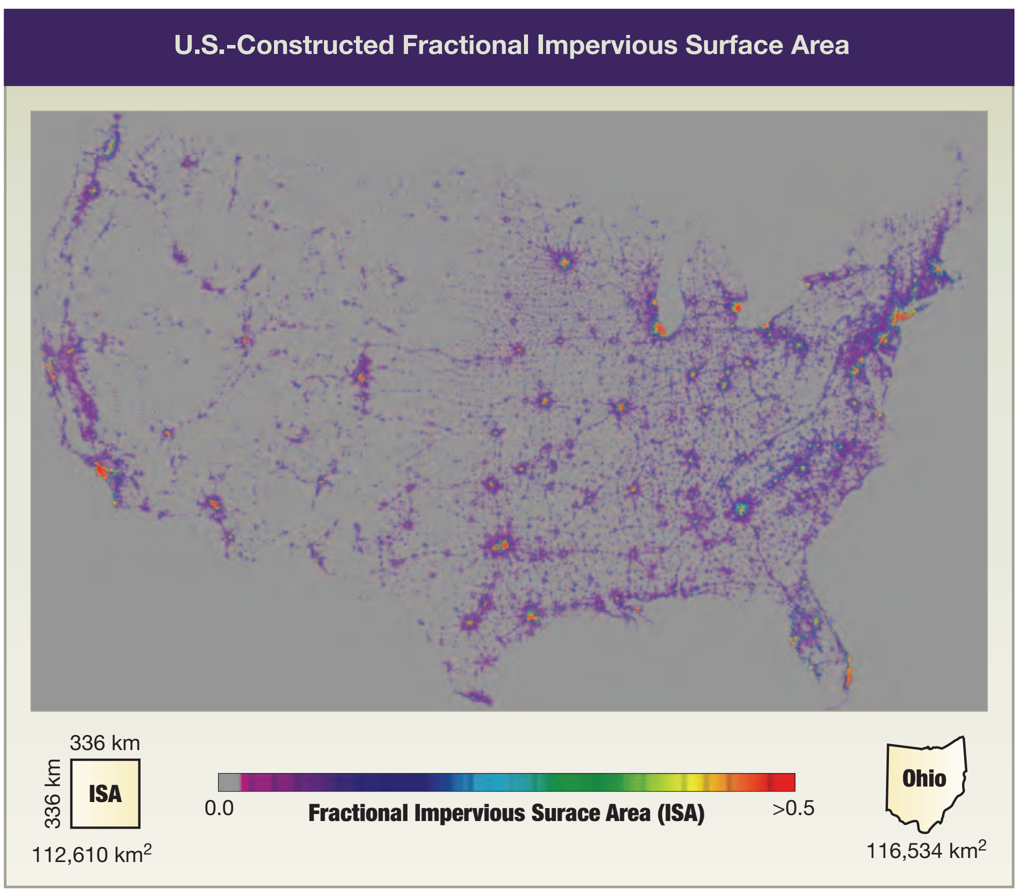


Figure 16: **Fractional Impervious Surface Area**. The U.S.-constructed impervious surface area (ISA) in 2000 was nearly the size of Ohio. Population is increasing at a rate of 3 million people per year. Annual U.S. public and private sector construction spending is greater than US$480 billion. This includes more than a million new single-family homes and more than 10,000 miles of new roads per year. *Credit: C.D. Elvidge, NOAA/National Geophysical Data Center*.

community members in the various types of scientific information contained in the model.

Establishing the Effects of the Soviet Union's Collapse on the Onset of Spring across Kazakhstan.[4,5,10] Agricultural policies in centrally planned economies of the Soviet Union left enduring legacies of land-surface transformations across eastern Europe and northern Eurasia. The collectivization efforts of the 1930s and 1950s reorganized the land-patch dynamics of cultivated landscapes. The collapse of the economic and political institutions of the Soviet Union at the beginning of the 1990s led to widespread agricultural de-intensification, land abandonment, loss of livestock, and decreased grazing pressure. Mixed into the record of satellite observations of the vegetated land surface are multiple sources of variation: seasonality, interannual climatic variation, changes in observing sensors, and human activity, including land-use/land-cover change. Methods were developed to differentiate the influences of human activities from the other sources of variation at a spatial scale appropriate to link with mesoscale meteorological models. The research focused on Kazakhstan, the ninth

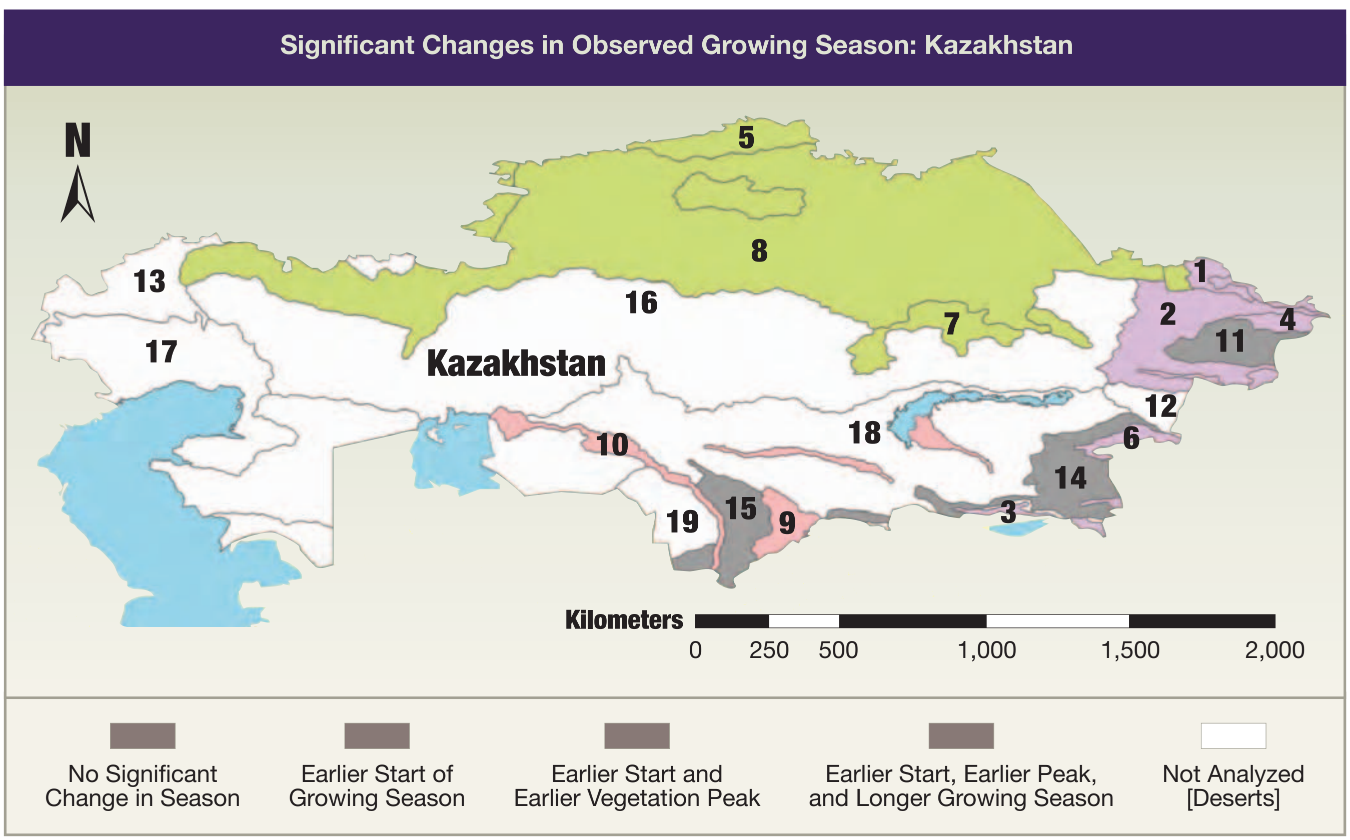


Figure 17: **Significant Changes in Observed Growing Season: Kazakhstan**. Significant changes in growing season have been detected in many of the 19 ecoregions across Kazakhstan. *Credit: G. Henebry, University of Nebraska-Lincoln*.

largest country in the world in land area, spanning both semi-arid to arid regions dominated by dryland agriculture and grazing, providing an excellent example of post-Soviet land-use/land-cover change. Of the nineteen ecoregions in Kazakhstan, twelve exhibit strong spring seasonality. Nine of those twelve have shown significant changes in growing season vegetation dynamics when comparing the 1980s under the Soviet regime with the late 1990s (see Figure 17). These change analysis methodologies are transferable to other regions dominated by temperate vegetation.

Synthesis of Land-Cover and Land-Use Research.[9] A synthesis of work carried out under the auspices of NASA's Land-Cover and Land-Use Change Program over the past 8 years was published in 2004. This program involves hundreds of scientists who have worked to understand human impacts on land cover, which is one of the most important forces changing our planet. The work reported in the volume and accompanying CD spans the natural and the social sciences, and describes the application of state-of-the-art techniques for understanding the Earth. These techniques include satellite remote sensing, geographic information systems, modeling, and advanced computing. The volume includes detailed case studies, regional analyses, and globally scaled mapping efforts.

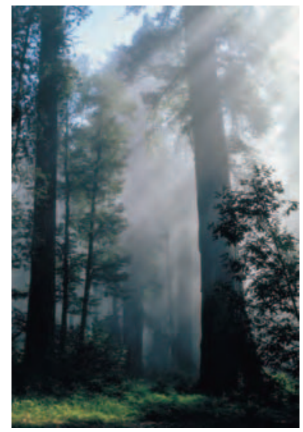
Highlights of FY 2006 Plans

CCSP will support research to identify, quantify, and understand fundamental processes of land-use and land-cover change and their consequences. One avenue for support of this work is an interagency solicitation that will result in delivery of the near-term (2-year) products addressing aspects of the LULCC science questions outlined in Chapter 6 of the *CCSP Strategic Plan* including detection and monitoring of LULCC processes; LULCC drivers and environmental impacts; and LULCC and climate variability and change interactions. A sampling of other key research plans for FY 2006 is provided below.

Land-Use Change Effects on Carbon Dynamics in Eastern Deciduous Forests of North America. Understanding the role of forests as potential carbon sinks is emerging as a national and global priority. In FY 2005, researchers began investigating the role of recent past, current, and future land-use change on carbon dynamics in eastern deciduous forests of North America. These forests may have played a major role in past carbon dioxide uptake due to regrowth following major cutting at the turn of the previous century. Current rates of timber harvest in eastern deciduous forests are high, so future land-use and -cover changes may again affect carbon cycling. New research will address the interactions between forest management and carbon sequestration. Research will continue through FY 2007 and the results will help State and national agencies manage forests in the context of future economic and climatic changes.

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

A New Enhanced Map of Forest Biomass for All Russian Territory. A map will be developed of the forest biomass of all Russia, based on Landsat satellite and 500m- and 250m-resolution Moderate-Resolution Imaging Spectroradiometer (MODIS) satellite products through a combination of classification and modeling and using 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 in forest carbon stocks over time.



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

Global Tropical Forest Assessment. A global tropical forest assessment will be conducted. The current rate of tropical forest loss and degradation is not well quantified. Previous efforts to measure deforestation in the tropics have had to rely on spot checks and sparse sampling. This study will utilize the global archive of more than 10,000 Landsat scenes that have been acquired since 2000. The study will measure, with fine spatial accuracy, deforestation and also logging, which has not been measured before. The results will be validated using a global archive of high-resolution IKONOS images acquired by NASA under the commercial Data Buy Program. The project is being developed within the framework of the Global Earth Observing System of Systems (GEOSS) initiative and in coordination with international programs, including the United Nations Food and Agriculture Organization, the United Nations Environment Programme, and the Global Observations of Forest and Land Cover Dynamics program.

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

A Basin-Scale Econometric Model for Projecting Future Amazonian Landscapes. A basin-scale econometric model will be developed for use in predicting land-cover change scenarios in the Amazon basin. This model will combine a regional-scale GIS with case studies to project land-cover change over large areas.

It will represent an improvement upon existing aggregate models for the Amazon, and will lead to enhanced projection of land-cover change based on observed historical deforestation in the basin. The empirical approach it employs will also facilitate the evaluation of confidence intervals for model coefficients and independent comparison of model projections.

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

Mitigation Plan for Landsat-7 Problem. Since 1972, Landsat satellites have collected data that have been invaluable for the quantitative study of land cover, land use, and land-cover change. The ground resolution of the Landsat satellites is ideally matched to study a wide range of surface phenomena. In addition, a variety of natural and human land-use changes, such as wildfires, deforestation, agricultural activity, glacier expansion/contraction, and urbanization represent alterations that also occur at spatial scales of tens of meters. Since June 2003, Landsat-7 data have been substantially degraded by a mechanical failure of the Landsat-7 instrument and there are no other satellite systems available to provide Landsat-type data globally at these spatial scales. While scientists are looking to use other U.S. and international satellite instruments to provide interim land-cover data, a recognized need exists to ensure the continuing availability of high-quality land-cover measurements into the future. The details of an observing strategy to meet this requirement are under discussion now within the U.S. Government. U.S. Government agencies affected by this include NASA, USGS, USDA, EPA, DOD, the Department of Homeland Security Federal Emergency Management Agency (FEMA), and NOAA. The proposed solution for the lack of Landsat-like data is to redirect agency resources to acquire global collections of data from Landsat-5, Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER), EO-1's Advanced Land Imager, and similar satellites now operated by foreign countries for the period 2005 to 2007. This effort will be organized by NASA and USGS, the two major users of Landsat data, with advice from and participation of other interested CCSP agencies.

These activities will address Questions 4.3, 4.4, and 4.5 of the CCSP Strategic Plan.

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