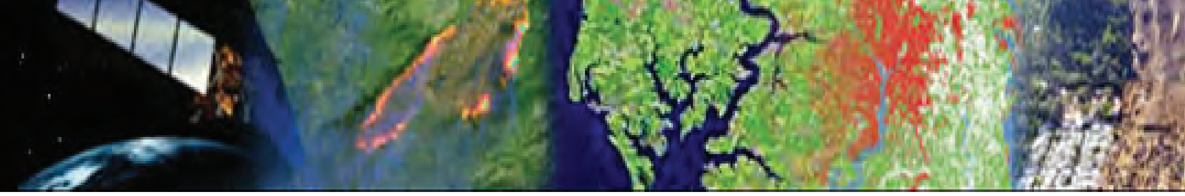

USGS
science for a changing world

# Geographic Analysis and Monitoring Program

*In 1913, Miami, Florida, was a small settlement along the banks of the Miami River. Today, the city and its surrounding landscape have been utterly transformed. Buildings stand where woodlands once grew. Networks of streets and highways have replaced wetlands. The city's population has burgeoned from a few thousand to nearly 400,000 (fig. 1). In 2000, Miami and its neighboring municipalities ranked as the Nation's 6th largest metropolitan area, having grown over 23 percent from 1990 to 2000.*

*How significant are such changes to the landscape? What impact do they have on natural ecosystems, climate, resources, and human health? How do changes in one location affect other parts of a region, an entire country, or the rest of the world? How do landscape change and human-induced factors, such as population growth, interact to influence the risk and vulnerability of communities to hazard events? What can we learn from past land-surface changes that will enable us to better predict and handle changes in the future?*

*The U.S. Geological Survey's (USGS's) Geographic and Analysis Monitoring (GAM) Program answers these and other vital questions about land-surface change.*


**Figure 1.** These two photographs of the same location in Miami, taken in 1913 and 1997, exemplify how dramatically urban expansion can alter the landscape, ecosystems, and the human environment over time. (Photos courtesy of Historical Museum of Southern Florida, left; South Florida Water Management District, right.)

## A Changing Planet

The surface of the Earth is changing rapidly, at local, regional, national, and global scales, with significant repercussions for people, the economy, and the environment. Some changes have natural causes, such as wildland fires or hurricanes, while other changes on the land, such as resource extraction, agricultural practices, and urban growth, are human-induced processes. There are other types of changes that are a combination of natural and human-induced factors; landslides and floods, for example, are fundamentally natural processes that are often intensified or accelerated by human land use practices. Whatever their cause, land-surface changes can have profound environmental and economic impacts.

Changes in land use and land cover are also important contributors to climate change because the land and the atmosphere are intricately linked through the exchange of gases, the radiation balance of the land surface, wind behavior, and many other factors. At the same time, some changes in the land surface can impartially record the impacts of climate change.

Cumulatively, land-surface changes at the local level have the potential to impact global climate and threaten the sustainability of natural systems worldwide. They can also affect human health and the health of ecosystems, influence vulnerability to floods and fires, interfere with biogeochemical cycles, and threaten biodiversity.

## Focus of GAM Research

The goal of the GAM Program is to contribute to an understanding of the Nation's urgent environmental, natural resource, and economic challenges. The program assesses the Earth's land cover at a range of spatial and temporal scales to better understand the causes and consequences of land cover change.

Land cover—the biophysical pattern of natural vegetation, agriculture, and urban areas—is the product of both natural processes and human influences. While human modification of land cover is an inevitable aspect of modern society, human-induced changes in land cover have important implications for both society and the environment. Land cover provides an indication of the availability and quality of natural resources, as well as a historical record of resource use. Consequently, comprehensive information about land cover is essential in a wide variety of investigations, such as assessing climate change, evaluating ecosystem status and health, understanding spatial patterns of biodiversity, and informing land use planning and land-management policy.

The GAM Program conducts long-term studies of the land cover and disturbance histories of the United States and selected overseas areas in order to determine the reasons for and the impacts of land-surface change. GAM research activities seek to answer four fundamental questions:

1. What kinds of changes are occurring and why?
2. What are the impacts of these changes?
3. How do these impacts, in turn, further influence the land surface?
4. How can GAM research findings best be used for making decisions in resource use and allocation, as well as in reducing risk and vulnerability to natural hazards?

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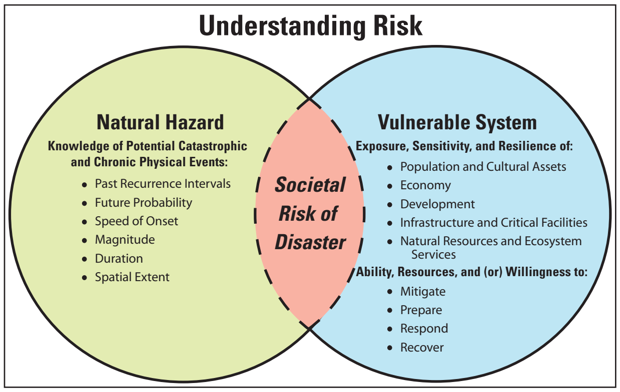


**Figure 2.** Diagram showing the combination of vulnerability and natural hazards to produce risk.

## The Range of GAM Science Investigations

The GAM Program is responsible for two continuing national projects: the National Land Cover Database (NLCD) and the Land Cover Status and Trends Reports. These long-term compilations of land cover conditions provide the foundation of USGS land-surface monitoring efforts, as well as those of numerous governmental and nongovernmental organizations. The results of these projects are necessary components of any regional or national environmental assessment.

Innovative applications of GAM research take place in many fields, including climatic and hydrologic variability, biogeochemical cycling, ecosystem health, natural hazards analyses (including disaster prediction, mitigation, and response), and wildfire science. These applications provide a basis for resource managers and the public to understand the dynamic nature of our landscape and to anticipate the consequences of the interplay between natural processes and human actions.

Analytical approaches to the geographic relationship of natural hazards and society (see fig. 2) enable GAM researchers to develop methods and processes, such as decision-support systems and economic models, that can facilitate the use of USGS science in public policy. By understanding the vulnerability and resilience of human and environmental systems in the context of place, geographic science can link assessments of potential hazards with the development of risk-reduction measures.

## GAM Science Highlights

### National Land Cover Database (NLCD)

Under the leadership of the USGS, the Federal interagency Multi-Resolution Land Characteristics Consortium develops the National Land Cover Database (NLCD 2001) for the Nation. Information contained in the massive database enables managers of public and private lands, urban planners, agricultural experts, and scientists with many different interests (for instance, climate change or invasive species) to identify critical characteristics of the land. Derived from Landsat satellite imagery, NLCD products include 21 classes of land cover, percent tree canopy, and degree of surface imperviousness in urban areas (fig. 3).

The national consistency of NLCD information makes possible the sweeping, contextual analysis of national land perspectives, such as the Heinz Center's *State of the Nation's Ecosystems* and the Environmental Protection Agency's *Draft Report on the Environment*.

### Land Cover Status and Trends

Understanding the impacts and feedbacks of land use and land cover change on environmental systems requires an understanding of the rates, patterns, and driving forces of past, present, and future land use and land cover change. As the first comprehensive national land cover change analysis ever conducted, the goals of the Land Cover Trends Project are to document and understand how, where, when, and why the Nation's land has changed, and thus provide a solid foundation of research for projecting future change and managing its consequences.

The objectives of the Land Cover Trends project are to (1) determine the amount, rates, and trends of contemporary land use and land cover change by ecoregion for the period 1973 to 2000 for the conterminous United States, (2) document the driving forces and consequences of change, and (3) synthesize individual ecoregion results into a national assessment of land use and land cover change.

In the eastern States, GAM scientists have found that most land cover change has been associated with forest harvesting and regrowth, agricultural abandonment, and development (fig. 4). Data from these

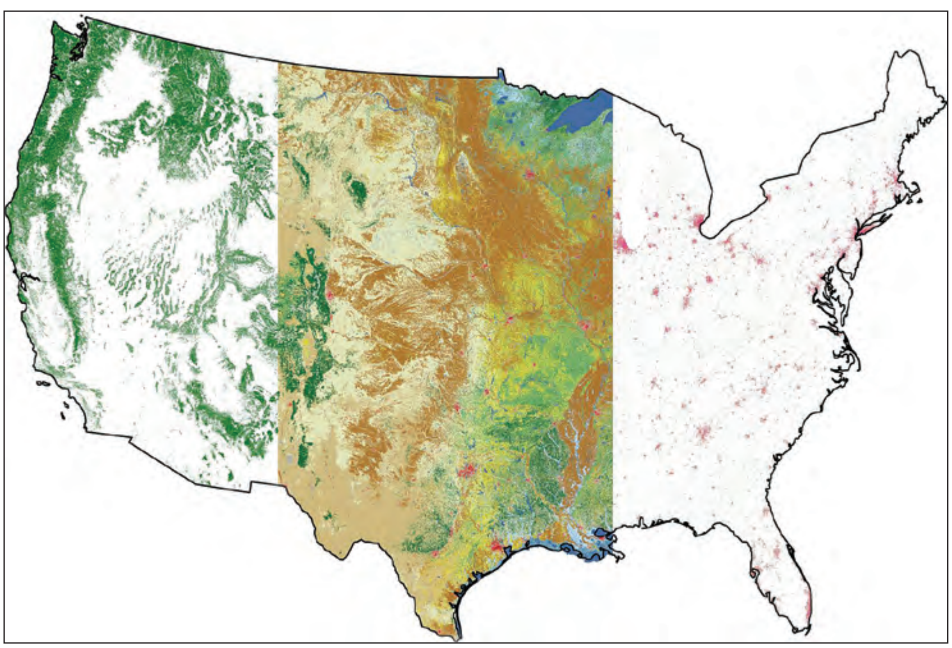

**Figure 3.** Outline of the contiguous United States with land cover data layers displayed. The NLCD contains multiple layers of precise data that can be built or deconstructed, merged with other types of data, and analyzed to answer vital questions about the Nation's land resources. Illustrating how the data can be separated or combined, the graphic depicts various degrees of tree canopy in the West and urban imperviousness in the East. In the central States, 16 distinct classes of land cover are consolidated in a colorful mosaic.

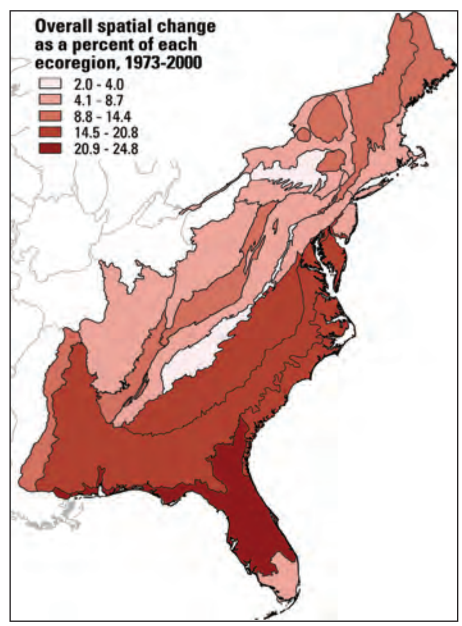


**Figure 4.** Map showing the overall spatial change between 1973 and 2000 measured in the 20 ecoregions of the eastern U.S. The amounts of change range from a low of 2.0 percent (light pink) in the Blue Ridge ecoregion to a high of 24.9 percent (dark red) in the Southern Coastal Plain. Ecoregions with larger amounts of change typically have active forest harvesting and regrowth occurring.

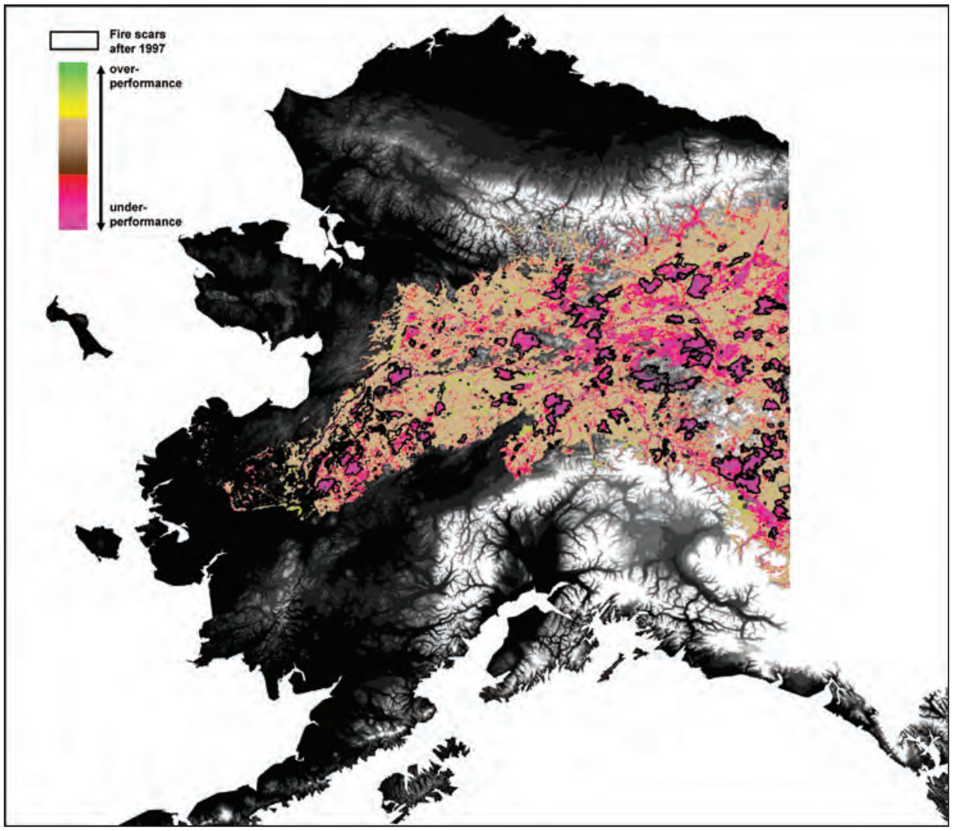


**Figure 5.** Ecosystem productivity of coniferous boreal forests in the Yukon River Basin, Alaska, in 2004. Elevation is shown (black = low, white = high) in nonconiferous areas and outside the Yukon Basin. Black lines outline where fires occurred after 1997, revealing underperformance.

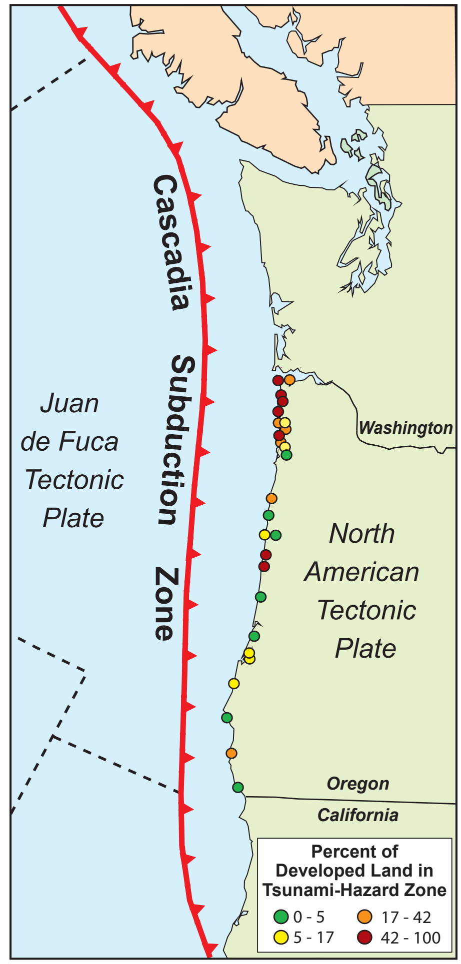


**Figure 6.** Graphic image showing the regional extent of the Cascadia subduction zone and the coast that is vulnerable to tsunamis created by earthquakes in this zone. Based on NLCD 2001 and tsunami-hazard data, the amount of developed land in hazard-prone areas varies considerably among Oregon coastal communities. GAM research successes in conveying the concept of societal vulnerability to the leaders of coastal communities in Oregon have led to formal interagency agreements with State agencies in Washington and Hawaii for similar research there.

observations indicate that in 20 of the eastern ecoregions, there has been steady deforestation over the past 30 years. This finding is important because of its relationship to water quality, species biodiversity, and climate.

## Ecosystem Performance and Climate Change

Land management is an important tool for controlling the levels of greenhouse gases in the atmosphere, a contributing factor to climate change. Whether land-based ecosystems remove carbon dioxide ($CO_2$) from the atmosphere (a sink) or contribute $CO_2$ to the atmosphere (a source) is influenced by the productivity of the land. GAM scientists use spatial data from remote sensing and other sources, coupled with integrating models, to quantify the carbon cycle performance of ecosystems (fig. 5).

## Societal Vulnerability

Societal vulnerability to natural hazards is a function of how communities occupy and use hazard-prone land. To better understand community vulnerability, GAM researchers and their partners use spatial data from the National Land Cover Database (NLCD 2001) and socioeconomic sources to quantify variations in land cover, human populations, and economies in relation to predicted hazard-prone land (fig. 6). This geographic information helps local, State, and Federal officials make informed and realistic decisions that strengthen community preparedness for, response to, and recovery from disasters. Developing and applying new approaches for understanding and communicating community vulnerability to natural hazards, including climate change, helps the Nation improve its ability to reduce risk and increase resilience.

## Ecosystem Geography

Ecosystem management is a strategy for the integrated management of land, water, and living resources that promotes conservation and sustainable use in an equitable way. Ecosystems are widely recognized as fundamental components of biodiversity that need to be conserved and, in some cases, restored. GAM researchers have undertaken the classification and delineation of ecosystems for the conterminous United States at a scale that is appropriate for ecosystem management. GAM researchers use the biophysical characteristics of landform, surficial geology, bioclimate, and land cover to define and map ecosystems after determining sound methodologies for generating these core components (fig. 7). They also compile each biophysical component as a national data layer. The resulting geographic information database for ecosystems is available—as integrated composite ecological footprints or as separate core component data layers—to researchers and to land managers responsible for making science-based decisions.

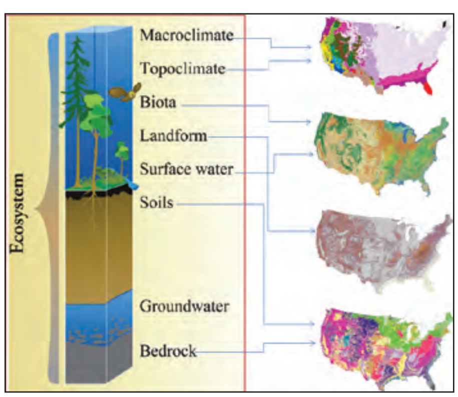


**Figure 7.** Illustration of the data layers of biophysical components that can be combined in ecosystem databases.

USGS scientists have also developed a Global Data Toolset (GDT) that integrates Web-accessible analytical tools and data to analyze and display ecosystem information. The GDT supports landscape analyses at scales ranging from site-based projects, to regional studies, to global applications. The GDT provides new data and tools for monitoring key land variables at a global scale.

### Ecosystem Restoration—Chesapeake Bay

Excessive nutrients and sediments are the leading causes of impairment to the health of the Chesapeake Bay. Land uses and land-management practices throughout the 64,000-square-mile Chesapeake Bay watershed contribute the majority of nutrients (nitrogen and phosphorus) to the estuary and are a major source of sediments in the upper Bay; therefore, managing land uses and changes to the land are the main activities needed to restore water quality in the Chesapeake.

In order to identify future environmental consequences of land change, eight- to ten-year forecasts of land change have been produced to establish nutrient and sediment reduction goals in the Chesapeake Bay watershed (fig. 8). Longer term forecasts of land change are needed given the rapid rate of urbanization and land change and evidence that increased nutrient loads from urban development may be impeding progress in reducing nutrients. USGS and its partners—Woods Hole Research Center, Shippensburg University, and the Maryland Department of Planning—are developing a model to forecast land changes in the bay watershed through the year 2030. USGS expertise in land change and water-quality modeling are key components of this effort. The land-change forecasts will be coupled with a watershed model to simulate future nutrient and sediment loads to the bay. This information will be used by State agencies and local governments to help make informed decisions concerning environmentally sound land use policies as a means of maintaining nutrient and sediment reductions.

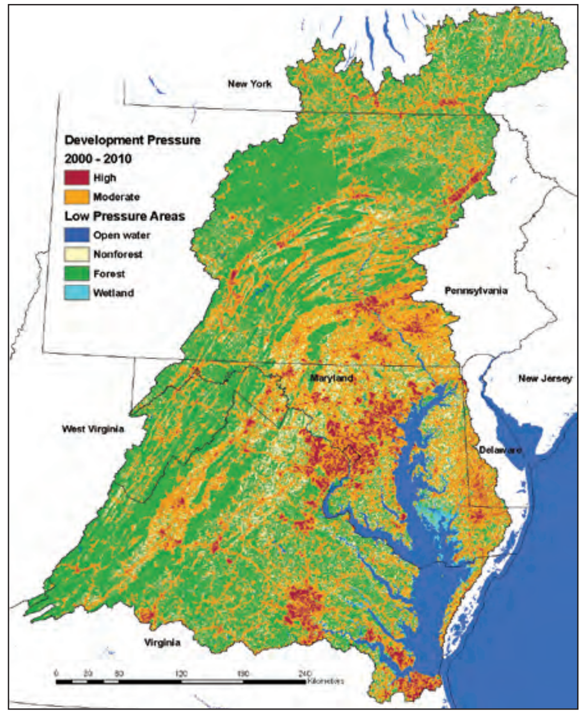


**Figure 8.** Map of Chesapeake Bay watershed showing high-urban development pressure. Red areas denote lands under high development pressure—land that has experienced a significant increase in impervious surface and (or) residential housing over the 1990s. Areas within close driving proximity to the high-pressure areas are represented in orange as moderate-development pressure. All lands under low-development pressure are represented by their dominant land cover class (e.g., open water, nonforest, forest, or wetland).

### Phenology

Phenology is the study of periodic plant and animal life-cycle events that are influenced by environmental changes, especially seasonal variations in temperature and precipitation driven by weather and climate. GAM scientists investigate the relationship of phenology to the abundance, diversity, and geographic distribution of organisms using time-series analysis of satellite imagery (fig. 9). With sufficient observations and understanding, phenology can be used as a predictor for important environmental processes and variables at local to global scales and could drive a variety of ecological forecast models.

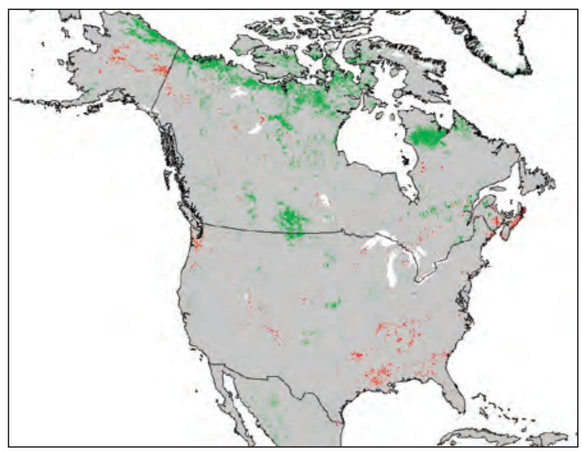

**Figure 9.** Map outline of North America showing trends in growing season greenness from 1982 to 2003, derived from satellite data. Areas in green depict regions that have increasing productivity during this period, primarily as a result of extended growing seasons, but also because of land use change. Red areas show a decline in productivity as a result of land use change, fires, and other factors. The new National Phenology Network will provide a means of connecting the satellite data to ground-based observations and will present a ready means of communicating some of the impacts of environmental change to citizens.

## Scientific Collaboration and Contributions

The GAM Program collaborates with other USGS science programs, such as Status and Trends of Biological Resources, National Water-Quality Assessment, and National Biological Information Infrastructure. It contributes to Bureau initiatives, including the Southern California Multi-Hazards Demonstration Project, as well as disaster response and assessments, such as those for Hurricane Katrina and western wildfires. The GAM Program supports the research objectives of the U.S. Climate Change Science Program and is an active participant in international global science initiatives.

Program partners and customers include the scientific community, State and Federal agencies, and public organizations that make land-management decisions or influence and shape policy. The GAM Program works closely with stakeholders within the Department of the Interior bureaus that have land-management roles, such as the Bureau of Land Management, the National Parks Service, Fish and Wildlife Service, and the Bureau of Reclamation. Partners and customers also include other national agencies with research, regulatory, or land-management roles, such as the U.S. Environmental Protection Agency, the U.S. Forest Service, the National Oceanic and Atmospheric Administration, and the National Aeronautics and Space Administration. The program supports our Nation's international efforts, working with the Department of State, the U.S. Agency for International Development, foreign governments, multinational organizations, and nongovernment organizations in analyzing land cover and conducting environmental analyses around the globe.

*By Jon C. Campbell*

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