# LAND

Earth's landmasses support critical ecosystems, host Earth's freshwater environments, and sustain almost all human agricultural activities. Land separates freshwater from the sea, stores nutrients essential for terrestrial and aquatic life, and holds a fossil record of Earth's climatic past. As the planet warms, the conditions favorable to many plant and animal species are expected to shift toward the poles. Individual species will differ in their ability to make the same shifts. The resulting altered species distributions will likely cause significant disruptions to established ecosystems, as habitats adjust to new species populations.[1]

Land use is inextricably linked to the carbon cycle. Changing land-use patterns, such as clearing forest to create agricultural plots, change the dynamics of the carbon cycle. Livestock such as cattle contribute a net surplus of carbon to the atmosphere in the form of methane, a powerful greenhouse gas.

NSF-supported researchers study all aspects of the land-climate connection. Through observational networks, researchers gather vital data about critical ecosystems, the hydrological cycle, the timing of seasonal events (such as wildflower blooms), and other critical indicators of land-based ecosystem health. NSF also supports geologists in the field who uncover records of past conditions, such as flood histories of river valleys and coastal plains or the fossils of ancient plant and animal species. Through such records, geologists open a window into Earth's history and learn how the land responded to past climate change events.

Mount St. Helens, May 18, 1980. Volcanic eruptions can have a significant impact on Earth's climate, releasing tons of aerosol particles into the upper atmosphere, where they may reside for several years. In addition, volcanoes can contribute greenhouse gases to the lower atmosphere. Climate modelers look at proxy data such as ice cores dating from past eruptions to learn more about the role volcanoes play in determining Earth's climate. *Credit: Austin Post, courtesy of USGS*

1 ACIA, *Impacts of a Warming Arctic: Arctic Climate Impact Assessment*, Cambridge University Press, 2004, p. 14.



Top image credit: Lynn Betts, USDA Natural Resources Conservation Service

## Sea Level

The volume of the ocean depends on its temperature (an increase in temperature causes water to expand) and the amount of liquid water on Earth. Warming resulting from the greenhouse effect causes sea-level rise because of thermal expansion and melting of land-based ice pack. Melting sea ice does not change sea level, because floating ice displaces the same volume of water that it contains.

Sea level is particularly relevant to land-based life and the people living near land's end. From 1961 to 2003, the average rate of global mean sea-level rise is estimated to be about 1.8 millimeters per year.[2] By looking at the geological record of past sea level and comparing that record to tree ring data and ice and sediment cores, researchers are learning what events trigger changes in global sea level. In one NSF-funded study, geologists found that in the last 100 million years, sea-level changes have been dominated by growth and melting of continental ice (glaciers).[3]

## Climate Change in the Geological Record

The fossil record contains evidence of how Earth responded to past climate changes. The locations of fossils show where particular species were found during what era, giving scientists an idea of how modern species might adapt to present-day global warming. NSF-funded researchers have uncovered evidence of rapid changes in the geographic distribution of plant species in response to past periods of rapid global warming. Fossil evidence reveals patterns of intra- and intercontinental migration of both plants and animals during the Palocene-Eocene Thermal Maximum, one of Earth's most significant periods of climate change, which occurred 55 million years ago.[4]

The fossilized leaves of plants from previous periods of global warming discovered in Wyoming suggest that insect damage to plants increases with rising temperature, which researchers attribute to the northward migration of voracious tropical insect species. This past migratory pattern provides important evidence about the behavior of insects during climate warming, which could have important implications for modern-day agricultural crops and ecosystems.[5]

## Center for Sustainability of Semi-Arid Hydrology and Riparian Areas

The Center for Sustainability of Semi-Arid Hydrology and Riparian Areas (SAHRA), an NSF Science and Technology Center (STC), furnishes new knowledge to elected officials, water managers, and policy experts to augment their ability to improve the sustainability of water resources in the United States and around the world. Two river basins—the Rio Grande/Rio Bravo river basin and Arizona's Upper San Pedro river basin—are the primary geographic focus of center researchers. Center scientists are working to understand the impacts of human population centers and agricultural activities, as well as emerging issues such as water markets and water banking.[6] The team has developed a model for a water-trading market by coupling a hydrological model that forecasts total water availability in a given year with an economic model that forecasts water demand by the various users. The model supports an open-market trading system, in which buyers and sellers declare bids and offers and make trades.[7]

Students participating in the NSF-sponsored Science and Technology Center for Sustainability of Semi-Arid Hydrology and Riparian Areas (SAHRA) measure evaporation rates in Patagonia, Arizona. SAHRA was established to develop an integrated, multidisciplinary understanding of the hydrology of semi-arid regions and to build partnerships with a broad spectrum of stakeholders, both public agencies and private organizations. *Credit: Jonathan Petti, SAHRA, University of Arizona, Tucson*

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2 Solomon, S., et al., Technical Summary, in *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge University Press, 2007, p. 48.

3 NSF Highlight 11873: Global Sea Level Changes in the Last 500 Million Years.

4 NSF Highlight 11451: Mississippi to Montana: Plants Danced to Climate's Quick Tune.

5 NSF Highlight 16576: Fossil Record Suggests Insect Assaults on Foliage May Increase with Warming Globe.

6 NSF-Supported Research Infrastructure: Enabling Discovery, Innovation, and Learning, 2008.

7 NSF Highlight 13962: Water Trading.

Caves hold some of the highest-resolution climate records available. Cave formations called speleothems are formed from minerals dissolved in water that seeps into caves from the surrounding bedrock. Often, speleothems grow continuously over time, with annual layers of mineral deposits similar to tree rings. Recently, NSF-supported research uncovered a pristine 130,000-year-old record from cave formations in Crevice Cave, Missouri. The cave recorded changes in mid-continent climate, global climate variability, and vegetation changes during interglacial-glacial cycles. The researchers are presently analyzing samples from the cave to produce a climate record that will improve our knowledge of climate variability in North America. This climate record will be a valuable companion to other paleoclimate records.[8]

## Freshwater

Earth's landmasses host the vast majority of the world's freshwater, most of which is locked away in the vast ice sheets of Antarctica and Greenland. The remaining freshwater—in lakes, ponds, streams, rivers, groundwater, and glaciers—is the primary source of human drinking water.

Warming temperatures cause glacial water reserves to melt, precipitation patterns to change, and water in lakes and reservoirs to evaporate at a higher rate. Hence, climate change has the potential to cause serious disruptions to the drinking water supply. The ecosystems that rely on these water sources will also be affected. NSF-funded researchers study the effects a changing hydrological cycle will have on the human and natural systems that rely on freshwater systems.

## Arctic Tundra

Arctic tundra accounts for approximately 5 million square kilometers of Earth's surface. Because its frozen temperatures largely prevent the decomposition process of organic matter, the Arctic tundra is a major storage sink of carbon. NSF-funded researchers are working to understand how tundra will respond to warming temperatures, including how much methane and carbon dioxide ($CO_2$) a thawing tundra will release.

Melting of the Arctic permafrost appears to threaten Siberian lakes. *Credit: Karen Frey, University of California, Los Angeles*

## Forests

Roughly 42 million square kilometers of forest cover Earth, encompassing nearly a third of the planet's total land area. The expansion of forests removes $CO_2$ from the atmosphere, lowering greenhouse gas concentrations. Forests also absorb solar energy, which can increase local temperatures, particularly in boreal (northern) forests, where warming may have a greater effect on climate than the removal of $CO_2$.[9] All vegetation pumps moisture into the atmosphere, cooling the local land but at the same time contributing to complex atmospheric processes. The teeming life of forests and the physical structures containing it are in continuous flux with incoming solar energy, the atmosphere, the water cycle, and the carbon cycle in addition to the influences of human activities. These complex relationships both add to and subtract from the equations that dictate the warming of the planet.[10]

Forests play an integral role in Earth's climate. Tropical, temperate, and boreal forests contribute both cooling and warming effects to the local climate in varying degrees that depend on the forest's characteristics. Forests absorb carbon dioxide through photosynthesis and cool the atmosphere through evaporation and transpiration. Some forests, such as boreal forests found at northern latitudes, are darker than the surrounding terrain and absorb more of the Sun's energy, which can lead to increased warming. *Credit: Nicolle Rager Fuller, National Science Foundation*

Boreal forests are expected to advance northward, and more productive vegetation will add to carbon uptake, although it is still unclear how much carbon could be released through the thawing of tundra and subsequent decay of previously frozen organic material. Where suitable soils are present, agriculture is expected to expand northward in response to a longer, warmer growing season.[11]

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8 NSF Highlight 12612: Cave Deposits As Archives of Earth's Past Climate.

9 Bonan, G. B., Science 320 (2008): 1444.

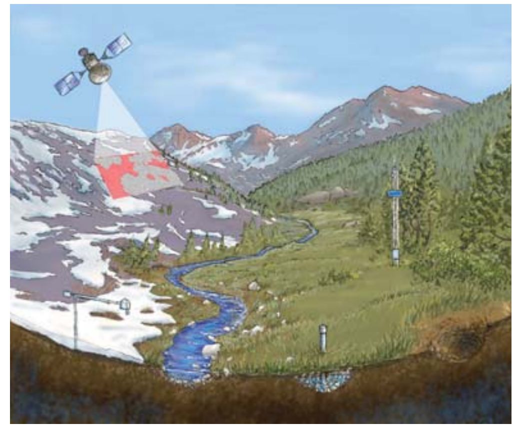
10 NSF press release 08-102: www.nsf.gov/news/news_summ.jsp?cntn_id=111694.

11 ACIA, Impacts of a Warming Arctic: Arctic Climate Impact Assessment, Cambridge University Press, 2004, p.10

## Critical Zone Observatories

To better understand land's "critical zone"—the region between the top of the forest canopy and the base of unweathered rock—and its response to climate and land-use changes, NSF created a Critical Zone Observatory (CZO) network. The CZO network represents the first set of systems-based observatories dedicated to land surface processes, which include the water cycle, the breakdown of rocks and formation of soil, the geochemical and physical erosion of that soil, the evolution of rivers and valleys, and patterns of vegetation. CZO scientists are investigating the integration and coupling of these processes and how they are affected by the presence and flux of freshwater. The CZOs will use field and analytical research methods, space-based remote sensing, and theoretical techniques.

The three CZOs are located in watersheds in the Sierra Nevada, the Front Range of the Colorado Rockies, and the Appalachian Uplands. These projects add to the environmental sensor networks in place or planned by NSF, including the National Ecological Observatory Network and the Ocean Observatories Initiative network.[12]



NSF has awarded grants to three Critical Zone Observatories to allow scientists to gain a greater understanding of environmental processes at Earth's surface. With sophisticated monitoring equipment—including satellite transceivers, stream and air chemical sensors, and weather stations—researchers are learning more about watersheds and their environments. *Credit: Roger Bales, University of California, Merced*

## Global Lake Ecological Observatory Network

The Global Lake Ecological Observatory Network (GLEON), an international ecological collaboration, is advancing our understanding of lakes' roles in the global carbon balance. Researchers from the United States are collaborating with international scientists to form a network of sensors deployed on lakes to gather data on metabolism and nutrient cycling. Using advanced cyberinfrastructure, data from this international observatory will provide information on key lake processes and functions that are affected by climate and land-use change.

The GLEON collaboration now has 22 members from nine participating countries, with plans to further extend the network. The expanded version will further test data delivery procedures that bring information from sensors to publicly accessible databases.[13]

Jim Coloso, an undergraduate researcher from the University of Wisconsin, Madison, positions a buoy in Trout Bog Lake, one of the monitoring sites of the Global Lake Ecological Observing Network (GLEON). GLEON is an international effort aimed at improving our understanding of ecological processes in the world's freshwater lakes. *Credit: Tim Kratz*

## Conclusion

Earth's landmasses host some of the planet's most important habitats, including our own. Researchers are working to understand how global climate change will affect land-based precipitation patterns and ecosystems, particularly in areas where water is already scarce and in areas of high human population density. Land-based climate records, such as those found in freshwater pond and lake sediments and in caves, give researchers information about how climate has changed at different locations over the ages. The land also contains information about sea levels during past periods of global warming; these data points can help climate modelers create more accurate projections of future sea levels. The following research highlights describe some of the many projects funded by NSF on land research. This research not only contributes to our understanding of Earth's past and present climate, it also provides the opportunity for the next generation of paleoclimatologists, ecologists, and climate modelers to gain valuable hands-on training.

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12 NSF press release 07-178: www.nsf.gov/news/news_summ.jsp?cntn_id=110586.

13 NSF Highlight 16514: Global Lake Ecological Observatory Network (GLEON) Expands Partnerships Both in the U.S. and Abroad to Advance the Scale of Lake Research.

# Land Research Highlights

## Global Sea-Level Changes in the Last 500 Million Years

Changes in global sea level can be a consequence of changes in the volume of water in the ocean or changes in the volume of the ocean basins themselves. Changes in seawater volume are primarily caused by a change in water temperature or the growth or melting of glaciers. Changes in volume of ocean basins are caused by changes in the amount of sediments carried to the oceans and underwater volcanic activity.

Recently, researchers from Rutgers University reviewed global sea-level changes from the past 543 million years using oxygen isotopes, a sensitive indicator of temperature, and ice volume changes. They found that the highest sea level (about 100 ± 50 meters above present sea level) was during the Late Cretaceous, between 80 and 65 million years ago. The scientists also concluded that in the past 100 million years, sea-level changes were dominated by growth and melting of continental ice (glaciers). **Highlight ID: 11873 GEO/EAR**

## Mississippi to Montana: Plants Danced to Climate's Quick Tune

Fossil leaf from the Bighorn Basin, Wyoming.
*Credit: Scott Wing, Smithsonian Institution*

Scientists have found that a period of rapid global warming 55 million years ago, called the Paleocene-Eocene Thermal Maximum (PETM), caused major changes in where plants grew. The PETM was caused by a massive release of carbon into the atmosphere and ocean, making it an analog for the global warming that is expected as humans continue to add carbon dioxide ($CO_2$) to the atmosphere, primarily by burning fossil fuels. The PETM raised global temperatures by as much as 10 degrees Celsius (18 degrees Fahrenheit). Plant fossils dating to the PETM in Wyoming are the same as plant fossils that have long been known from rocks of similar age in Mississippi, Louisiana, and Texas. These southern plants spread from the Gulf Coast to Wyoming, a distance of some 1,000 miles, within 10,000 years or less.

The southern plants grew throughout the PETM in Wyoming, then disappeared, presumably unable to survive there as the global climate cooled at the end of the event. The return to a cooler climate brought a different set of plant invaders to Wyoming. Relatives of linden and wingnut emigrated from Europe to North America across Arctic land bridges during periods of peak warmth, then established themselves in Wyoming forests after the global heat wave had passed. A similar pattern of intra- and intercontinental migration can be found in animals that lived during the PETM, suggesting that they, too, moved in concert with rapid climate change.

Scott Wing, of the Department of Paleobiology at the Smithsonian Institution, led an international team of researchers in a study of fossilized leaves and pollen found in the Bighorn Basin of northwestern Wyoming. The Bighorn Basin is a well-known treasure trove for fossils because enormous amounts of sediment were deposited there as the Rocky Mountains rose. These sediments and the fossils they contain are now exposed in spectacularly eroded badlands. Fossilized mammals and chemical analysis of rocks were key in determining the age of the leaf fossils, which are the first discovered from the PETM period. **Highlight ID: 11451 GEO/EAR**

## Fossil Record Suggests Insect Assaults on Foliage May Increase with Warming Globe

Ellen Currano collecting fossil leaves from a site that is 57 million years old in the Bighorn Basin, Wyoming. Credit: Ellen Currano

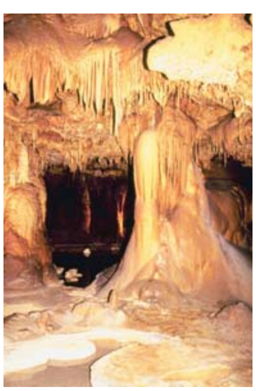
A sudden global warming 55 million years ago, called the Paleocene-Eocene Thermal Maximum (PETM), was caused by a massive release of carbon into the atmosphere and oceans, making it an analog for the global warming that is expected as humans add carbon dioxide ($CO_2$) to the atmosphere. The PETM event raised global temperatures as much as 10 degrees Celsius (18 degrees Fahrenheit). Previous research linked the PETM with mass extinctions of bottom-dwelling marine organisms and the migration of mammals across Arctic land bridges. The plants alive during that time have also indicated a fast-changing climate, allowing southern-dwelling trees and shrubs to move north in a hurry.

New results of a study by a team of researchers from Pennsylvania State University, the Smithsonian Institution, the University of Maryland, the University of California-Santa Barbara, and Wesleyan University indicate a link between temperature and insect feeding on leaves. Study researcher Ellen Currano of Penn State and the Smithsonian Institution, says, "When temperature increases, the diversity of insect feeding damage on plant species also increases."

Currano collected the study fossils from the badlands of Wyoming, gathering leaves from five sites representing time zones before, during, and after the roughly 100,000-year temperature spike called the PETM. Researchers found that the PETM plants were noticeably more damaged than fossil plants before and after that period. The PETM plants, many of which are legumes (the family that now includes beans and peas), show damage with greater frequency, greater variety, and a more destructive character than plants from the surrounding geologic time periods.

Biologists are already aware that insects in the tropics consume more plants and that warming temperatures are causing organisms to widen their ranges. In addition, research has shown that plants grown under higher concentrations of $CO_2$ are less nutritious, so insects must eat more plant tissue to get the same sustenance. These earlier studies support the recent findings about the PETM. Because food webs that involve plant-eating insects affect as much as three-quarters of organisms on Earth, the researchers believe that the current increase in temperature could have a profound impact on present ecosystems, and potentially on crops, if the pattern holds true in modern times. **Highlight ID: 16576 GEO/EAR**

## Cave Deposits as Archives of Earth's Past Climate



Speleothems (cave formations) can provide valuable information to researchers seeking clues about Earth's climate past. Speleothems are slow-growing deposits of minerals dissolved in groundwater. Paleoclimatologists can obtain climate proxy information from the thickness of the deposited layers and the presence of isotopes of certain elements within the layers. Credit: © 2009 JupiterImages Corporation

Researchers have obtained a 130,000-year high-resolution record of climate from speleothems (cave formations) in the mid-continent of North America. The primary field site—Crevice Cave, Missouri—was located south of the former Laurentide Ice Sheet during the past interglacial-glacial cycle. The researchers hypothesize that the site is well situated to record changes in mid-continent climate, global climate variability, and vegetation changes during interglacial-glacial cycles. Previous studies by the researchers indicate that speleothems from Crevice Cave have grown continuously over tens of thousands of years. The researchers expect to produce a high-resolution stable isotope record, dated by the thorium-230 technique, from the North American mid-continent covering most of the last interglacial-glacial cycle. This research will improve our knowledge of Holocene climate variability of North America from a new paleoclimate data archive. **Highlight ID: 12612 GEO/ATM**

## Water Trading

Economists and hydrologists are working together at the Sustainability of Semi-Arid Hydrology and Riparian Areas (SAHRA) Center, an NSF Science and Technology Center, for and with water managers to explore lease/market-based water allocation in New Mexico. They have coupled a hydrological model that forecasts total water availability in a given year with an economic model that forecasts water demand by the various users to support a market for water trading among the users. The model supports an open market trading system in which buyers and sellers declare bids and offers and make trades.

The model is updated as new information becomes available on water availability, and it tracks impacts on river flows downstream. The current evaluation is that the model supports a robust market with the potential to save significant amounts of water through more effective management. Based on successes with a prototype model for the Middle Rio Grande in guiding farmers' choices on crops and the amount of land to irrigate, the SAHRA researchers were asked by the New Mexico state engineer to develop a pilot water-leasing project for the Mimbres Basin, an agricultural area that presents many challenges in microcosm. There, the project is successfully providing real-time tools for choosing crops, setting flow rates, and allocating water as flows recede in dry periods. **Highlight ID: 13962 GEO/EAR**

## Global Lake Ecological Observatory Network Expands Partnerships in the United States and Abroad to Advance the Scale of Lake Research

An international collaboration called GLEON (Global Lake Ecological Observatory Network) is advancing ecological understanding of the role of lakes in the global carbon balance and helping researchers understand lake metabolism and lake response to dramatic weather events, such as hurricanes. With funding from the National Ecological Observatory Network (NEON), a group of researchers from the United States is collaborating with international scientists to form a network of sensors deployed on lakes to gather data on lake metabolism and nutrient cycling. Data from this international observatory will provide information on key lake processes and functions that are affected by climate and land-use changes, and will develop processes that will be useful in developing NEON.

A recent supplemental grant to GLEON has allowed for the expansion of this network in the United States and internationally. The GLEON collaboration now has 22 members from nine countries participating, with more in the planning stages. Several sites in northern Europe were added; students and researchers from Sweden and Finland joined the project; and lakes in northern Scandinavia were instrumented with sensors and linked to the network. Argentina and Chile are expected to participate in the future. In addition, Lake Sunapee in New Hampshire has been set up to automatically download, archive, and publish sensor network data using technologies that conform to emerging GLEON standards. The expanded network will test the dataflow procedures developed to bring information from sensors to publicly accessible databases, as well as the event detection schema developed to help electronically distinguish between biological and physical events such as lake inversion after a storm and sensor failure. As more sensors come online and are linked to the network, it will become necessary to automate processes as data from thousands of sensors stream into the database.

The addition of European lakes will provide a new set of environments to understand lake metabolism and the local and regional phenomena that drive changes in metabolism. In addition, it will provide the opportunity to explore adding existing sensor systems to the current cyberinfrastructure framework. This addition will permit testing of the robustness of the cyberinfrastructure design and the development of plug-and-play technology, and exploration of the challenges that arise from integrating different sensors and protocols. **Highlight ID: 16514 BIO/DBI**

## Arctic River Transport

The Lena River, some 2,800 miles (4,400 kilometers) long, is one of the largest rivers in the world. The Lena Delta Reserve is the most extensive protected wilderness area in Russia. *Credit: USGS EROS Data Center Satellite Systems Branch*

The Pan-Arctic River Transport of Nutrients, Organic Matter, and Suspended Sediments (PARTNERS) project is a 5-year project funded by NSF. The overall objective of the project is to use river water chemistry as a means to study the origins and fates of continental runoff. Understanding sources and fates of river discharge is important because rivers make an enormous contribution to the freshwater budget of the Arctic Ocean. Selected parameters focusing on tracers of river water are being measured in the six largest rivers that drain the watershed of the Arctic Ocean: the Yenisey, Lena, Ob', Mackenzie, Yukon, and Kolyma Rivers.

Analyses of long-term data on river discharge into the Arctic Ocean show an increase over recent decades. If the change in river discharge is linked to global warming, future discharge increases could be large enough to significantly affect the Atlantic thermohaline circulation. In this project, scientists are finding that dams on large Siberian rivers greatly affect the seasonality of discharge; however, on an annual basis, neither dams nor forest fires are making significant contributions to the observed increases in Eurasian river discharge. The project includes representatives of government agencies responsible for discharge and water quality monitoring in Canada, Alaska, and Russia. This will lead to greater comparability of river hydrochemical data in the Arctic Ocean. The group has found, through preliminary analyses of new river water samples, that the Arctic rivers are rather distinct chemically, suggesting that tracing the river water in the Arctic Ocean may be feasible. **Highlight ID: 11160 OPP/ARC**

## Fossil Fuel Burning Interrupts Natural Carbon Cycle

See *Atmosphere* section.

**Highlight ID: 12620 GEO/ATM**

## Closing in on the Missing Carbon Dioxide Sink

Led by National Center for Atmospheric Research scientist Britton Stephens, a team of researchers have found an explanation that puts a new perspective on the "missing" carbon sink. Their findings greatly diminish the apparent discrepancy between overall carbon emissions and the rate of increase of atmospheric carbon dioxide ($CO_2$). Additionally, the team's research indicates that $CO_2$ uptake in tropical forests is actually much larger than previously thought, but in northern latitudes it is much lower.

This family is clearing the rain forest to plant coffee in the Mato Grosso region in western Brazil, near the Bolivian border. Clearing land by the slash-and-burn technique, which is common in the tropics, releases carbon dioxide, methane, and other gases in amounts sufficient to affect the atmosphere around the globe. *Credit: Patrick Zimmerman, © University Corporation for Atmospheric Research*

The scientists analyzed records of atmospheric $CO_2$ concentrations collected by aircraft, several of which extend over more than 20 years. Until recently, however, the data were not synthesized to provide a clear picture of carbon fluxes on global scales. In comparing annual mean airborne $CO_2$ observations to a variety of atmospheric models, the team found that the models most closely corresponding to observed $CO_2$ levels also predicted less $CO_2$ per year going into northern forests (up to 3 billion tons less). In the tropics, these models show intact forests emitting almost 6 billion tons less $CO_2$ per year than previously thought.

These results suggest that northern countries cannot rely on their forests to help offset their $CO_2$ emissions as much as they might have hoped and that the tropical countries can help slow down global warming by preserving their forests.

Tropical deforestation is still considered a significant source of atmospheric $CO_2$, so these results imply strong uptake in intact tropical forests. While previous local-scale studies suggested strong uptake in intact tropical forests, such results disagreed with the atmospheric model predictions. Uptake of human-generated $CO_2$ by forests over the next few decades can slow warming and possibly give us more time to find solutions. **Highlight ID: 15904 GEO/ATM**

## Climate-Induced Floods in the Upper Mississippi River

Researchers hypothesize that climate warming favors more frequent flooding events in areas such as the Upper Mississippi River valley. *Credit: Susie Shapira, Federal Emergency Management Agency*

In the past, warm climate episodes favored an increased likelihood of widespread early spring rainfall on melting snow, leading to more frequent large floods on the Upper Mississippi River (UMR). James Knox at the University of Wisconsin-Madison examined layered deposits of sediments along the Mississippi River and correlated flood deposits with average annual temperatures. An unusually high frequency of large overbank floods took place in the UMR valley during the relatively warm Medieval Period, between about A.D. 1000 and A.D. 1400. The UMR floods were highly sensitive to an atmospheric circulation that favors an inflow of warm, moist air masses to the UMR valley. When these moist air masses collide along frontal boundaries with cooler air masses from high latitudes, widespread heavy rains fall in the upper Midwest, followed by UMR flooding.

This research led to the hypothesis that climate warming favors increased variance in flood magnitudes, including an increased incidence of relatively large, extreme floods. Although this hypothesis may seem at odds with the common idea that warming favors droughts and reduced runoff, the hypothesis recognizes that most large floods on the UMR involve snowmelt, especially when coupled with widespread rainfall. Warm winters and early springs favor the occurrence of rain on melting snow in the UMR watershed. Since about 1950, there have been nearly twice as many large floods as would be expected as a result of statistical chance. Most of these post-1950 large floods involved snowmelt, but they also increased the potential for occasional heavy summer rains, because warm air masses typically contain larger quantities of precipitable water vapor than cool air masses. **Highlight ID: 16447 GEO/ATM**

## Social Scientist Tackles Deforestation in Maine

Deforestation is a widespread problem, with implications for forest products, erosion, water quality, biodiversity, tourism, recreation, and climate change. To understand the processes at work and what might stem the tide, James Acheson, professor of anthropology and marine sciences at the University of Maine, used NSF funding to investigate the forest harvesting and conservation decisions of small forestland owners (less than 5,000 acres) in Maine, the most heavily forested state. The research bears directly on the effects of human behavior on the future of forested land in the United States.

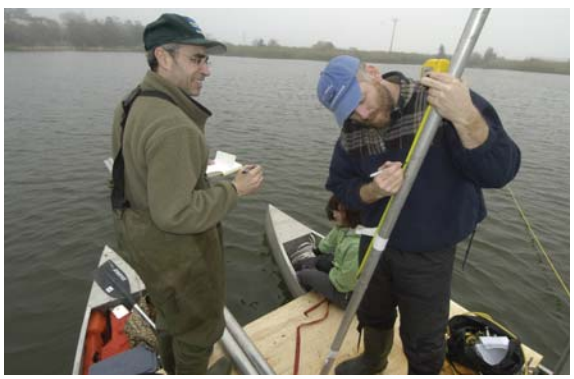
Acheson's research revealed four different types of forestland owners: (1) contractors, who buy land, harvest the wood, and resell the land; (2) local business owners, who develop land for houses; (3) large forest products firms; and (4) small landowners, many of whom live or vacation on their forest parcels. Satellite photos revealed that 40 percent of the parcels harvested between 2000 and 2005 were converted to housing. Large-scale clear-cutting has ceased, but heavy harvesting persists as contractors, corporations, and other private owners respond to market opportunities. Only a small subset of small landowners—those who are better off, are more educated, and do not expect to receive an income from their land—are doing a good job of forest conservation.

If Maine and the United States are going to keep their forests and all the benefits that come with them, action will be needed, and soon. Otherwise, forest acreage and quality will diminish rapidly as a result of a tidal wave of development sprawl. Private ownership is not necessarily detrimental to forest conservation, but forest landowners need incentives to save their trees. **Highlight ID: 15772 SBE/BCS**

## Climate Change Effects on Water Supply

To answer the question "How is global climate change affecting water supply in the western United States?" climate scientists from the Scripps Institution of Oceanography and the Lawrence Livermore National Laboratory are collaborating with researchers from the San Diego Supercomputer Center (SDSC). The scientists first run a model of the global climate on supercomputers, then zoom in to see the impact on the western U.S. region, then analyze the results and verify the model's accuracy by comparing the results with real-world observations. An important challenge facing the scientists is how to handle the large amounts of data generated, which can reach many terabytes (a terabyte is 1,000 gigabytes). To manage the data, move it between institutions, and share it, they are using a special tool called the Storage Resource Broker, developed by data experts at SDSC. **Highlight ID: 14379 OD/OCI**

## A Stormy Past



Jeffrey Donnelly (right) of the Woods Hole Oceanographic Institution (WHOI), and his colleague, prepare to extract a sediment core from Oyster Pond, Massachusetts. Donnelly is studying climate change by looking for evidence of major hurricanes over centuries recorded in the sediments of coastal areas. *Credit: Tom Kleindinst, Woods Hole Oceanographic Institution*

Estimates of past storm strengths and frequencies are extremely valuable to researchers trying to tease out the influence of human activities on climate. Jeffrey Donnelly of the Woods Hole Oceanographic Institution (WHOI) examined the mess left by hurricane storm surges—not Katrina on the Gulf Coast, but those in the New York City area. He found at least 10 layers of sand left behind by likely hurricanes in the past 700 years. Donnelly hopes to reconstruct the history of intense storms in southern New England and Long Island by looking at the deposits left by land-falling hurricanes and storm surges in backbarrier salt marshes and kettle ponds found at different heights throughout the area. So far, his group has found sand layers that correspond to the known great storms of 1991, 1954, 1938, 1893, 1788, and 1693. Many additional layers indicate storms that date back to 1642–1477, 1434–1347, 1316–1257, and even to 1190–1034 and earlier.

While considered rare in the New York City area, land-falling hurricanes have likely occurred many times throughout the past 3,500 years. With six severe storms, likely hurricanes, in the past 700 years, the frequency of land-falling hurricanes in the New York City area is equal to that in southern Rhode Island and higher than that in southern New Jersey. Initial findings suggest that alternating periods of frequent and infrequent hurricane activity have occurred in the past, possibly tied to changes in climate. Donnelly's group identified the time periods of high hurricane activity in western Long Island to be 3500–3050 years before present (BP) and 2200–900 BP, nearly synchronous with evidence of high activity found in the Caribbean and northern Gulf Coast. **Highlight ID: 14009 GEO/EAR**

## Interdisciplinary Project Explores Interactions Between Land Use and Climate Change at Regional and Local Scales in Eastern Africa

What is the impact of human use of land on the local and regional climate? Land-use conversions like deforestation and the expansion of agriculture alter soil moisture, surface reflectance, and other land conditions, which greatly affects local and regional climates. Similarly, changes in the local climate—

such as rising temperatures and rainfall variability—can affect agriculture, forestry, and other land uses, leading to changes in land-use patterns. These processes are being addressed by the NSF-supported Climate-Land Interaction Project (CLIP), which involves researchers at Michigan State University, Purdue University, the National Oceanic and Atmospheric Administration, and other collaborating institutions, such as the University of Dar es Salaam and Makerere University in Africa, and the University of East Anglia in the United Kingdom.

The core question addressed by CLIP scientists is "What is the magnitude and nature of the interaction between land use and climate change at regional and local scales?" This question is being examined in eastern Africa, a region that is undergoing extremely rapid land-use change, including expansion of cropping into savanna lands, increasing irrigation, deforestation, and urbanization. The region straddles the equator and is characterized by a heterogeneous landscape that ranges from glaciated volcanoes and montane forests to coffee, corn, and banana farms, and wide expanses of semi-arid savanna grasslands.

CLIP links climate models, crop-climate models, meteorological and satellite image data, and models of land-use change to assess how climate changes affect land use and vice versa. The land-use change models are informed by socioeconomic and biophysical spatial data and by the results of expert systems workshops and role-playing scenarios. The expert systems provide reality-based initial model parameterization and, later, evaluation of the land-use change models. They are central to understanding the human dynamics that respond to economic and other forces, and that lead individuals, groups, and organizations to change land-use practices. The land-use changes affect surface-atmosphere fluxes and alter regional climates, and the expert systems also contribute to the understanding of how people respond to altered climatic conditions. Participants in the expert systems and the role-playing scenarios bring their personal experiences from growing up on farms and their professional insights as government officials and scientists in their fields of environment, finance, and planning. By assessing future scenarios under different resource opportunities and constraints, they provide critical information on the decisionmaking processes that different actors employ. **Highlight ID: 11085 SBE/BCS**

## Calibration of Earth History

Accurate dates are essential for understanding a vast array of geological and evolutionary processes, from the causes of mass extinctions to the rates of past climate perturbations to rates of evolution and the timing and causes of mountain building. Although long recognized by paleontologists and others, only recently have geochronologic techniques been refined to produce dates with uncertainties of much less than a million years. In the coming decade, precise geochronology will revolutionize our understanding of Earth history and the rich record of geological, biological, and climate processes. The goal of the EARTHTIME project is to foster an unprecedented national and international collaboration among geochronologists, paleontologists, evolutionary biologists, and stratigraphers, with the goal of producing a high-resolution timescale against which the record of biological evolution, climate change, and oceanic chemistry can be calibrated for at least the past 550 million years. Among other things, the project will require the development of analytical protocols and standards so that geochronologic data from different labs are comparable and can provide dates with uncertainties that approach 0.1 percent. **Highlight ID: 7844 GEO/EAR**