USGS Contributions to the Climate Change Science Program

science for a changing world

More information at: http://geochange.er.usgs.gov

CARBON CYCLE

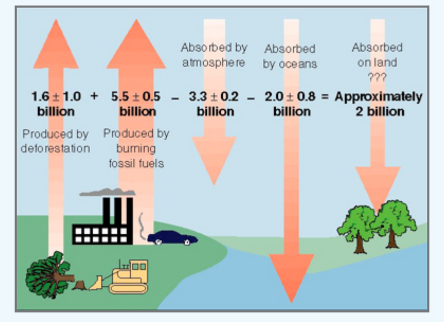
From studies of the geologic record, it is known that the distribution of carbon among major carbon sinks and reservoirs has changed with past changes in climate. Links between the global carbon cycle and the global climate system are complicated, involving atmospheric carbon dioxide (CO_2) and the "greenhouse effect". Atmospheric CO_2 concentrations are presently increasing as a result of human activities. This increase may affect the global climate. Therefore, it is important to understand the global budget of atmospheric CO_2. USGS research is conducted in cooperation and partnership with other agencies and academic collaborators in direct support of the Carbon Cycle Science Program. These USGS activities include the following:

Carbon sequestration in sediments - Redeposition of eroded soils and sediments and their associated organic carbon is sequestering large quantities of carbon, buried at the base of slopes and in wetlands, riparian areas, reservoirs, etc.

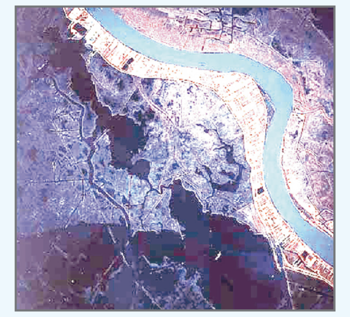
Landscape dynamics and vegetation change - Research examines the long-term dynamics of vegetation change and the impact of climate. A detailed history of vegetation change in the Western U.S. is being constructed based on the paleobotanical record of pollen and plant tissues preserved in packrat middens and buried in sediments.

Fate of Carbon in Alaskan Landscapes - Cold region forests (boreal ecosystems) contain large carbon reserves that are highly susceptible to changes in climate. Changes in fire and seasonal temperatures may cause changes in ecosystem structure, permafrost recovery, nutrient cycling, and carbon exchange. Central to the fate of these C reserves is the interaction between fire occurrence and permafrost changes in the surface layers. Process studies and modeling are being expanded to better understand the historic and modern interactions among climate, surface temperature and moisture, fire, and terrestrial carbon sequestration.

Exchanges of Greenhouse Gases, Water Vapor, and Heat at the Earth's Surface - Atmospheric turbulence transports greenhouse gases (notably: CO_2, methane, and nitrous oxide), water vapor, and heat between Earth's land and water surfaces and the overlying atmosphere. These exchanges influence climate, viability of ecosystems, distribution of biomes, and the quantity of both surface- and ground-water.

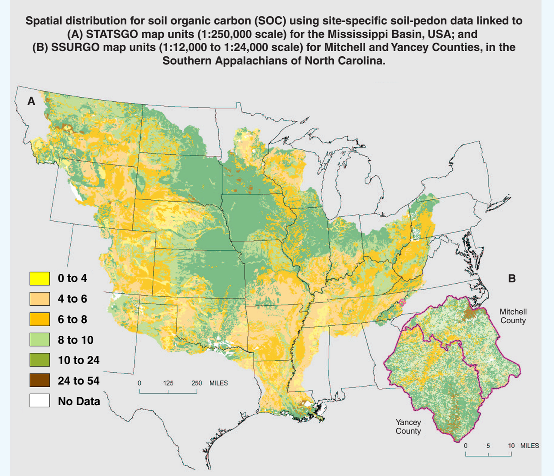


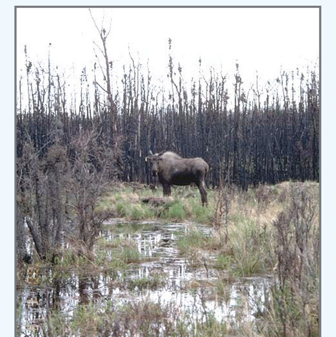
The global CO_2 budget can be defined as the balance of CO_2 transfers to and from the atmosphere. The transfers shown here represent the CO_2 budget after removing the large natural transfers which are thought to have been nearly in balance before human influence. Units are in metric tonnes of carbon per year. Budget figures shown here are for the 1980's.



Aerial photo of the Mississippi Delta near Port Sulphur, Louisiana. Land-use and industrial activity may be influencing the carbon budget of the Earth and leading to large-scale climate change. The USGS is conducting a detailed study of the Mississippi River drainage in an attempt to understand and model the contributions of this region to the world's carbon budget.

Spatial distribution for soil organic carbon (SOC) using site-specific soil-pedon data linked to (A) STATSGO map units (1:250,000 scale) for the Mississippi Basin, USA; and (B) SSURGO map units (1:12,000 to 1:24,000 scale) for Mitchell and Yancey Counties, in the Southern Appalachians of North Carolina.





Cold region (boreal) forests contain large carbon reserves that are today highly susceptible to changes in climate. Soils and wetlands comprise over 2/3 of the boreal carbon reserves and have sequestered large amounts of carbon since retreat of large glacial ice masses. Changes in fire and seasonal temperatures have been shown to cause changes in shallow permafrost, nutrient cycling, ecosystem structure, and ultimately carbon exchange. Large fires in the boreal forest are a basic element to forest regrowth, species diversity, carbon storage, and carbon exchange. Although fire is a primary mechanism for direct carbon loss from the ecosystem, forest regrowth and peat accumulation are mechanisms for carbon uptake. Fire disturbance drastically changes the active layer and its biogeochemistry for several decades, and this change in turn impacts the water table and bordering wetlands. In some areas, perhaps where fires are most severe or perhaps where fires recur more quickly, permafrost degrades irreversibly.

Nelson Farm near Senatobia, Mississippi

USGS carbon cycle researchers are working with USDA scientists to measure carbon exported from eroding agricultural fields in Mississippi (National Sedimentation Laboratory), Iowa (National Soil Tilth Laboratory), and Ohio (North Appalachian Experimental Watersheds). These measurements are part of a larger study evaluating the redistribution of soil organic carbon from eroding uplands to alluvial and reservoir sediments. The deposition and burial of organic-rich sediments constitutes one important mechanism for carbon sequestration.

IMPACTS ON TERRESTRIAL AND COASTAL ECOSYSTEMS, WETLANDS, FISH, AND WILDLIFE

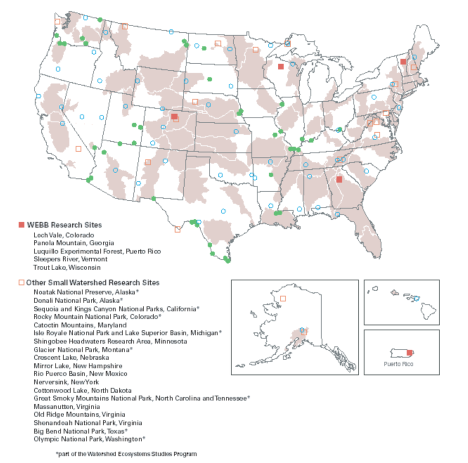
Biology and ecosystem-focused global-change related research in the USGS encompasses the themes of: (1) bird and habitat interactions; (2) potential changes in arid and semiarid ecosystems with changes in climate, management of resources, and uses; (3) coastal and interior wetland ecosystems; (4) sensitive species and island ecosystems; (5) watershed biogeochemistry; and (6) regional ecosystem responses to climatic change in and among mountain systems.

The National Parks provide the U.S. Global Change Research Program with an important outdoor laboratory and an index of change in our most treasured ecosystems. USGS research focuses on multiple stresses to U.S. Department of Interior (USDOI) lands including climate change, human population growth, land use change, air and water pollution, habitat fragmentation, and invasive species.

Wildland fire is a serious and growing hazard over much of the United States, posing a great threat to life and property. The USGS conducts fire related research to meet the varied needs of the fire management community and to understand the role of fire in the landscape; this research includes fire management support, studies of post-fire effects, and a wide range of studies on fire history and ecology.

Coastal wetlands are among the most productive ecosystems in the world and are vulnerable to the effects of sea level rise associated with global warming. Determining the potential for wetland submergence is a critical first step for managing these valuable coastal habitats into the next century. Research conducted by USGS has improved our understanding of the natural processes controlling wetland elevation and the potential for submergence of our coastal wetland habitats.

HYDROCLIMATOLOGY



The Global Change Hydrology Program was begun in 1990 to develop data, understanding, and predictive capabilities related to water and associated aspects of carbon and greenhouse gases as they interact with global systems. Global Change Hydrology has two broad components: 1) investigations of hydroclimatic variability, and 2) studies of the biogeochemistry of greenhouse gases. This includes identification of seasonal variations in regional streamflow in relation to atmospheric circulation (for regional streamflow prediction and flood/drought hazard assessment); the linkage between atmospheric circulation and snowpack accumulation (for forecasting spring and summer water supply in the western United States and for flood forecasting) as well as glacier mass balance; and the physical and chemical variability in riverine and estuarine environments in relation to large-scale atmospheric and oceanic conditions (to discriminate natural from human-induced effects on such systems). It also includes documenting the long-term behavior of hydrologic systems in response to past climatic variations and changes (from decades to hundreds of thousands of years) as well as more recent (decadal) hydrologic trends.

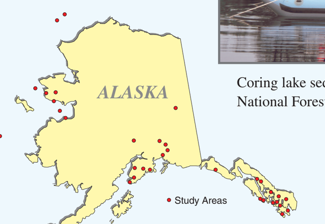
The U.S. Geological Survey initiated the Water, Energy, and Biogeochemical Budgets (WEBB) program in 1991 to understand the processes controlling water, energy, and biogeochemical fluxes over a range of temporal and spatial scales and to understand the interactions of these processes, including the effects of atmospheric and climatic variables. WEBB research watersheds form a geographically and ecologically diverse set of environments for investigating the interactive effects of changes in CO_2, climate, and biogeochemistry on the terrestrial carbon cycle; how global change will affect biogeochemical interactions with the hydrologic cycle and surface energy balance; and how global change will affect biogeochemical controls over the transport of water, nutrients, and materials from land to freshwater ecosystems.

Late winter snow and ice on the Sheepscot River in coastal Maine. USGS scientists are studying 20th century trends in river flows, river ice, and lake ice in New England to analyze hydrologic effects of observed climate variability. Significantly earlier spring snowmelt runoff, river-ice breakups, and lake-ice breakups have occurred in the last 30 years.

CLIMATE HISTORY IN ALASKA

Sampling of deposits (bogs, lakes, and natural exposures) that contain fossil pollen, plant macrofossils, and sometimes ostracodes and diatoms allows reconstruction of the late Pleistocene and Holocene history of environmental change in southern Alaska, focusing upon the past 50,000 years. High-latitude ecosystems are highly sensitive to climatic change, and therefore understanding their history of environmental responses to past climate changes provides not only information about those past responses but also provides a basis for predicting future responses to a variety of possible climatic scenarios. So far the project has focused upon the late Quaternary history of Tongass National Forest in southeastern Alaska, Chugach National Forest, and adjacent areas of south-central Alaska, and Western Alaska.

USGS climate researchers core lake sediments at Zagoskin Lake, Saint Michael Island, in western Alaska. The fossil pollen and spores in the sediment are studied to reconstruct the history of climate changes and ecosystem responses at high latitudes.

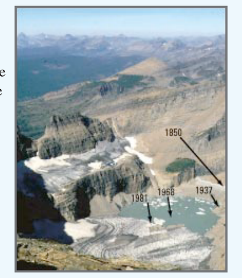


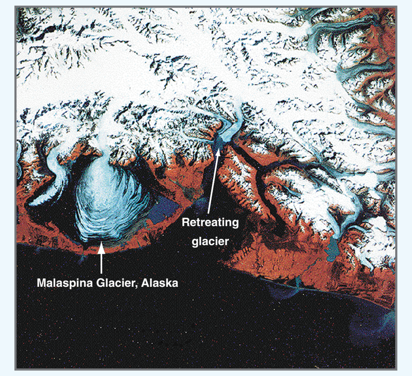
Coring lake sediments in Cavern Lake, Tongass National Forest, southeastern Alaska.

GLACIER STUDIES

Glaciers are particularly sensitive to changes in regional and global climate. Seasonal changes in sea ice and snow cover and decadal changes in glacier area can be monitored regionally and globally with image data from Earth-orbiting satellites. The U.S. Geological Survey has played a leading national and international role in using satellite image data to provide baseline data and other information about glaciers from a global perspective. NASA and USGS scientists are also carrying out experimental geodetic airborne, satellite laser altimetry, radar interferometric, and other remote-sensing surveys of glaciers. The 11-volume Satellite Image Atlas of the World (USGS Professional Paper 1386 A-K) is being compiled by more than 80 scientists representing 45 institutions and 25 nations, and includes a compilation of accurate maps (in both printed and digital formats) which show coastal changes in floating (ice fronts) and grounded (ice walls) glacier ice during the past 30 years. Seven volumes have been published to date: B, Antarctica; C, Greenland; E, Glaciers of Europe; G, Glaciers of the Middle East and Africa; H, Glaciers of Iran Jaya, Indonesia, and New Zealand; I, Glaciers of South America; and J, Glaciers of North America.

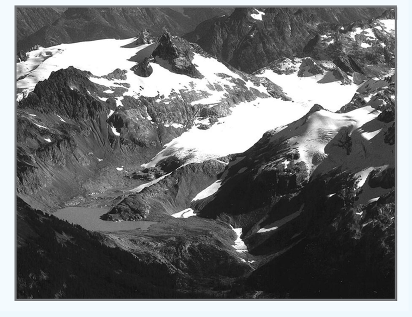
Grinnell Glacier in Glacier National Park, Montana; photograph by Carl H. Key, USGS, in 1981. The glacier has been retreating rapidly since the early 1900's. The arrows point to the former extent of the glacier in 1850, 1937, and 1968. Mountain glaciers are excellent monitors of climate change; the worldwide shrinkage of mountain glaciers is thought to be caused by a combination of a temperature increase from the Little Ice Age, which ended in the latter half of the 19th century, and increased greenhouse-gas emissions.

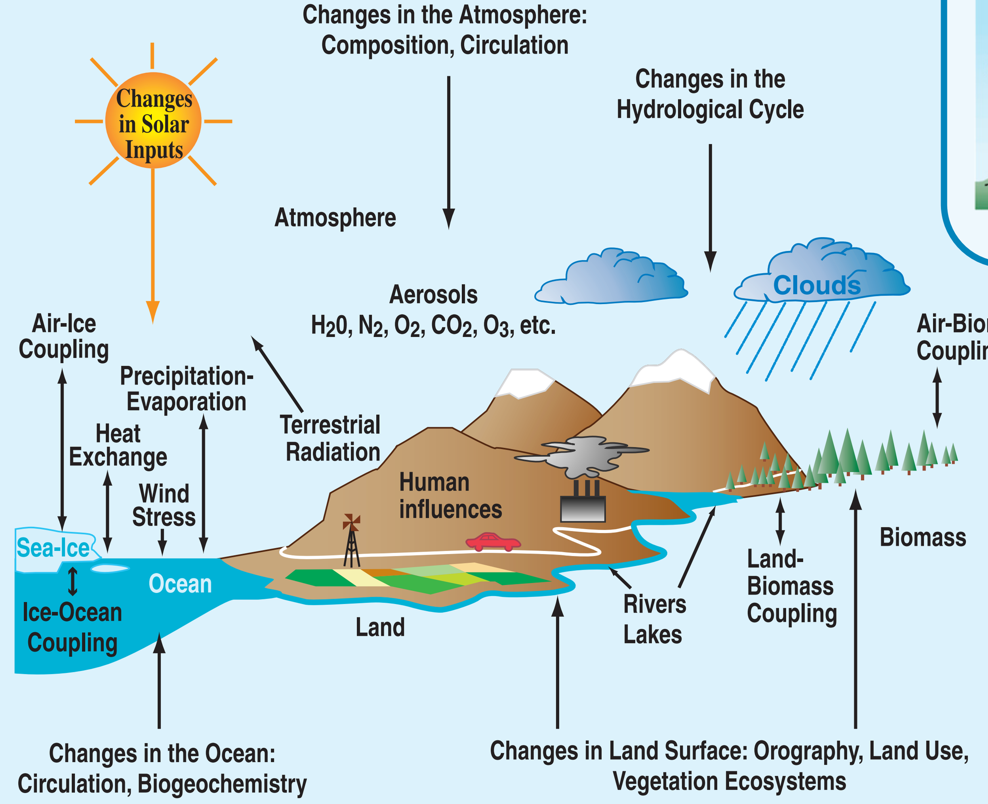




The world's glaciers react to and interact with changes in global and regional climates. Most mountain glaciers have been retreating since the latter part of the 19^{th} century.

USGS scientists are closely monitoring glaciers in Alaska to document if climate change is impacting Alaska's temperate glaciers. The USGS assessment shows that throughout the state, more than 98% of valley glaciers that terminate at an elevation below 1,000 m are retreating, thinning, or stagnating. Since 1986, Hubbard Glacier, one of the few advancing glaciers, has twice temporarily blocked the entrance to Russell Fiord. Glaciers and ice sheets are sensitive indicators of changing climate. On a global basis, the USGS is combining field observations with satellite- and aerial-remote-sensing to compile a baseline inventory of the health of Earth's glaciers during the first decade of Landsat, 1972-1981. This compilation serves as a benchmark for documenting cryosphere change on a global scale. Additionally, the USGS has produced the longest glacier mass balance record in North America. This forty-year-long record has provided a unique record of glacier response to climate variations in the latter half of the 20^{th} century. The South Cascade Glacier in Washington, one of the USGS monitoring sites, has dramatically retreated, losing 20 m of water equivalent averaged over the entire surface of the glacier since the mid 1970's.



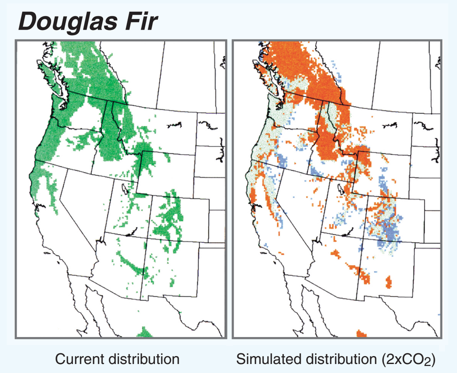


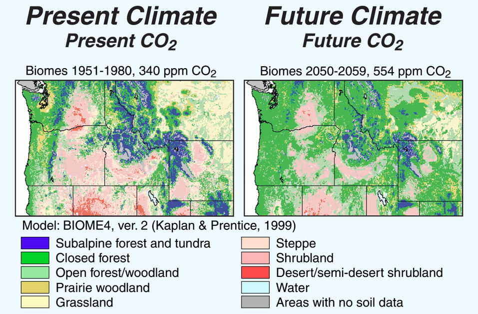
from Trenberth et al., 1996

CLIMATE-VEGETATION MODELING

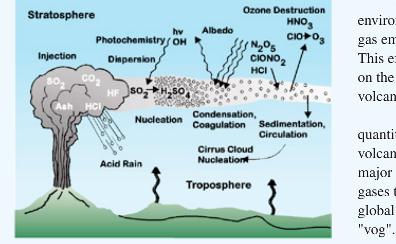
Vegetation changes caused by climatic variations and/or land use may have large impacts on forests, agriculture, rangelands, natural ecosystems, and endangered species. Climate modeling studies indicate that vegetation cover, in turn, has a strong influence on regional climates, and this must be better understood before models can estimate future environmental conditions. To address these issues, the USGS is investigating vegetational response to climatic change, and vegetation-land surface impacts on climate change. The project involves calibration of the modern relations between the range limits of plant species and climatic variables that are then used: 1) to estimate past climatic fluctuations from paleobotanical data for a number of time periods within the late Quaternary; 2) to 'validate' climate model simulations of past climates; 3) to explore the potential influences of land cover changes on climate change; and 4) to estimate the potential future ranges of plant species under a number of future climate scenarios.

Shown here is the modern distribution of Douglas fir (*Pseudotsuga menziesii*) and the potential distribution under a simulated future "greenhouse" climate with carbon dioxide levels twice those of pre-industrial times (a "$2xCO_2$" climate). Green represents sites where the species lives today (left panel) and where it could continue to live under the $2xCO_2$ simulated climate (right panel). **Red** indicates where it could not survive under the $2xCO_2$ simulated climate. **Blue** represents sites where it cannot live today but potentially could live under the simulated future conditions.





IMPACTS OF VOLCANIC EMISSIONS

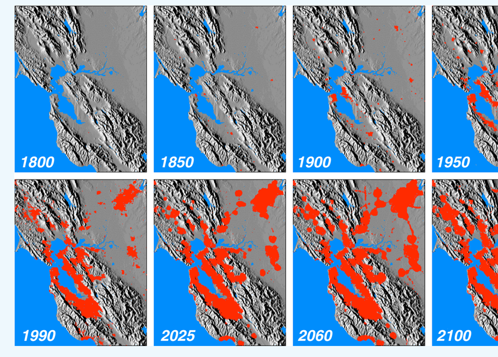


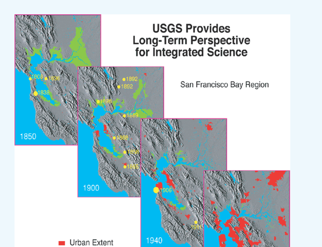
Gases from volcanoes give rise to numerous impacts on climate, the environment, and people. U.S. Geological Survey scientists are inventorying gas emissions at many of the almost 70 active volcanoes in the United States. This effort helps build a better understanding of the dynamic processes at work on the Earth's surface and is contributing important new information on how volcanic emissions affect global change.

A significant component of volcanic gas research involves measuring the quantities of gas that volcanoes release into the atmosphere. Huge amounts of volcanic gas, aerosol droplets, and ash are injected into the stratosphere during major explosive eruptions. Some gases, such as carbon dioxide, are greenhouse gases that promote global warming, while others, like sulfur dioxide, can cause global cooling, ozone destruction, and polluted air known as volcanic smog or "vog". Studies of volcanic emissions allow scientists to compare volcanic gas output to emissions from man-made sources and to assess the effects of both past and future eruptions on the Earth's climate.

USGS researchers collecting samples from the Pu'u O'o vent of the Kilauea Volcano, Hawaii, to determine the kinds and amounts of gases and particles emitted.

LAND SURFACE CHARACTERIZATION AND URBAN DYNAMICS

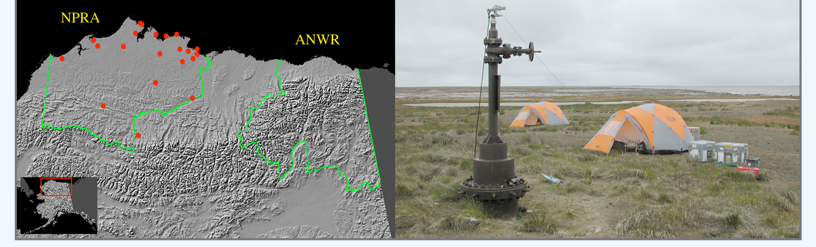




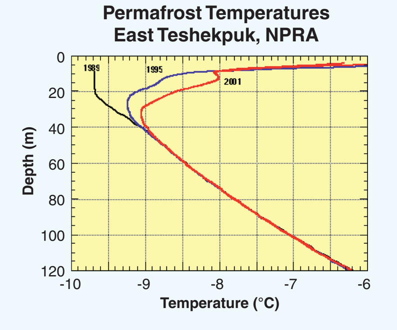
Metropolitan areas in the United States are growing at unprecedented rates, creating extensive urban landscapes. Many of the farmlands, wetlands, forests, and deserts that formed the America of 1900 have been transformed during the past 100 years into human settlements. Almost everyone has seen these changes to their local environment but without a clear understanding of their impacts. It is not until we study these landscapes from a spatial perspective and the time scale of decades that we can begin to measure the changes that have occurred and predict the impact of changes to come. The Urban Dynamics project analyzes land-use change in urban environments in order to provide a historical perspective of land-use change and an assessment of the spatial patterns, rates, correlation, trends, and impacts of that change. This project develops and refines methods for land-use reconstruction, geographic analysis, modeling, prediction, monitoring, and impacts assessment.

PERMAFROST MONITORING

The Department of Interior's (DOI) permafrost network in Alaska is part of a global network of permafrost monitoring stations (GTN-P) designed to monitor for changes in the solid-earth component of the earth's cryosphere. Changes in permafrost temperature and active-layer thickness reflect changes in surface climate over time, and therefore serve as useful indicators of climate change. GTN-P is one of several global networks designed to monitor for changes in the terrestrial component of the earth's climate system. The GTN-P network is able to monitor the active layer (the surface layer that freezes and thaws annually) and the thermal state of the underlying permafrost. Active layer measurements are made using automated semi-permanent surface instrument stations, whereas the deeper permafrost is monitored through periodic downhole temperature measurements in boreholes. DOI's contribution to GTN-P results from collaboration among USGS, U.S. Bureau of Land Management, and U.S. Fish and Wildlife Service.

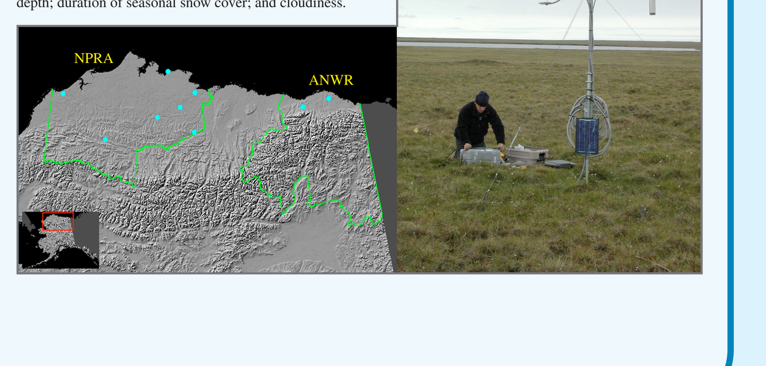


The subsurface permafrost monitoring network currently covers federal lands in and near the National Petroleum Reserve Alaska (NPRA). Subsurface temperatures are measured periodically with downhole sensors that indicate the depth and thickness of the active layer and permafrost, and yield subsurface temperature profiles. These measurements are important for determining the long-term terrestrial response to climate change.

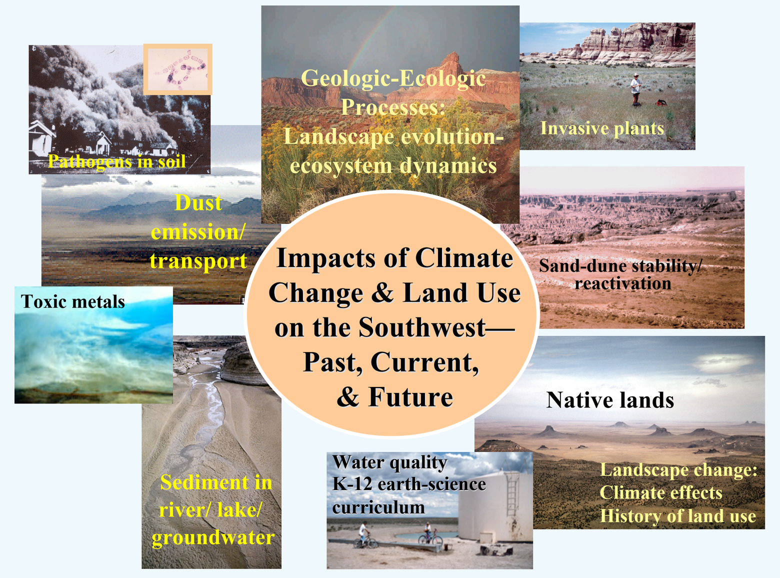


Temperature profile from one of 21 deep boreholes in the NPRA array showing the response of permafrost to the significant warming of the 1990's.

DOI's active-layer monitoring network spans federal lands in the National Petroleum Reserve Alaska (NPRA) and the Arctic National Wildlife Refuge (ANWR). Most of the stations depicted here were installed in 1998. Current plans call for an expansion of the network to improve spatial coverage on federal lands. In its current configuration, stations in the network monitor continuously for: changes in active-layer and shallow permafrost temperatures (5-120 cm depths); active-layer thaw depth; air temperature; snow depth; duration of seasonal snow cover; and cloudiness.



INTERACTIONS OF CLIMATE WITH PHYSICAL, BIOGEOCHEMICAL, HYDROLOGIC, AND HUMAN SYSTEMS, SOUTHWESTERN U.S.



USGS and collaborating scientists are seeking to understand how climate and land use have influenced surficial geologic processes that modify landscapes and ecosystems. Combined with monitoring of current conditions, such understanding is then used to model the landscape's response to future changes in climate and land use over time-scales of seasons, years, and decades. The information and interpretations can be used by federal, state, and local agencies, as well as by Native American governments, for land-use planning, management of resources, and remediation of human-health hazards. Project scientists work with other geologists, biologists, hydrologists, geographers, cartographers, educators, and archeologists to address questions about:

(1) The interaction of physical and biologic processes critical for ecosystem functions.
(2) The role of eolian dust for soil fertility, invasion of exotic species, hydrology, and surface stability in deserts.
(3) The causes and timing of changes in alluvial environments (rivers, streams, hillslopes), such as flooding, the cutting and filling of arroyos, and sediment discharge.
(4) The interrelations among climate, vegetation, and eolian (wind-related) processes.
(5) Landscape stability of the Navajo and Hopi Nations in relation to climatic variability as well as historic and pre-historic land use; here, we also assess causes of high levels of arsenic and uranium in groundwater and springs, and we help develop a culturally-based K-12 earth-science curriculum.
(6) The soil-ecologic habitats of the fungal spore pathogen that causes Valley Fever through airborne transmission; potential hazards to human health related to land use, climate, and dust generation.
(7) How future climatic variations will affect the Southwestern land surface (in terms of flooding, landslides, erosion, sand-dune activity, dust-storm frequency).
(8) How prehistoric cultures adjusted to past climatic changes and environments.

Automated Remote Digital Imaging System (ARDIS) is a means of automatically acquiring color digital images of dust storms. The images are used to determine the directions from which dust particles become airborne, the intensity and duration of the dust event, and the meterological conditions at the time, in conjunction with nearby CLIM-MET stations. The system is placed on top of a mountain to provide views of dust events from 9-20 km away.

CLIM-MET stations are meterological/geological stations that are designed to function in remote areas for long periods of time without human intervention. These stations monitor weather variables including temperature, wind, and precipitation; site variables including soil moisture and temperature, and eolian particle movement; and collect samples of dust for mineralogical and geochemical analyses. Data are automatically recorded at regular intervals.

EOLIAN HISTORY OF NORTH AMERICA

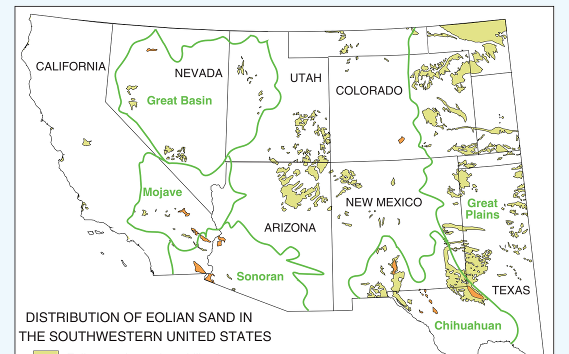
Eolian (wind-blown) deposits are both a blessing and a curse: they contain a valuable record of past climate changes but are deposits that could be reactivated in the future, with serious consequences for the natural resources, food supply, infrastructure, and wildlife of the country. This project researches the records of climate change in eolian deposits of the U.S. and assesses the potential for renewed activity of wind-blown sediments.

The objectives of this study are: (1) to test hypotheses about the role of dust in climate change; (2) to investigate records of natural climate variability in loess (dust) deposits; (3) to understand the processes responsible for sand dune activity in the U.S.; and (4) to assess the potential for reactivation of stabilized sand dunes in the U.S. under changing conditions of climate and land use.

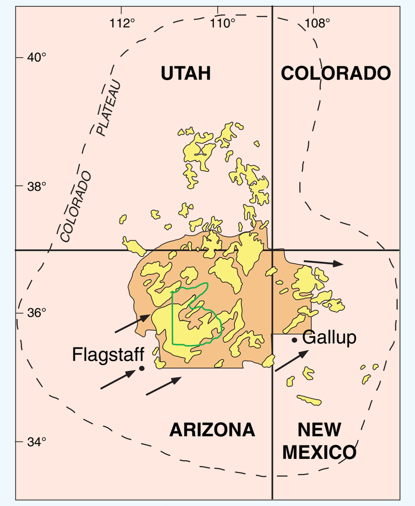
The approach used in this study of windblown sediments is to examine stratigraphic sections where detailed records of past climate change can be found. Sediments are analyzed for their age, composition and source materials. In assessing the potential for future reactivation of eolian sediments, study is made of (1) modern eolian sands that are active now and the environmental factors that favor such activation, and (2) study of past geologic periods when eolian sands were active.

The areas of study for the project include the Central Lowlands (Midwest), the Great Plains, the western United States, and Alaska. Some cooperative work has also been done with the Geological Survey of Canada in the Prairie Provinces of Canada.

These cedar-covered hills near North Platte, Nebraska are glacial-age dust deposits. They are thicker and accumulated faster here than anywhere else in the world. Project researchers have new evidence that the huge dust clouds from this period kept the climate cool after the last glacial period ended, showing the importance of dust to climate change.



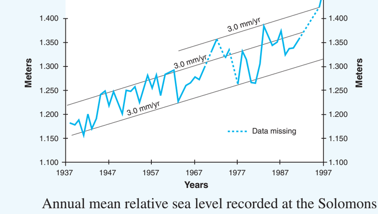
Sand dunes and eolian sheet sands are widely distributed over the southwestern United States, particularly in the southern Great Plains and the southwestern deserts and high plateaus. In the driest parts of the southwest, there are areas of active sand dunes, but most parts have dunes that are stabilized by vegetation and the sand is not moving at present.



The biggest impacts of active sand dunes in the Colorado Plateau region would be on the Navajo and Hopi people, whose reservation land is either on, or downwind of, the largest areas of sand dunes. Many Navajo and Hopi homes are on or near sand dunes; reactivation of dunes would obviously have a negative effect on living conditions. Sheep and cattle are important to the economy of the Navajo and Hopi, and much of the vegetation required for grazing is dune vegetation. In addition, dry farming is practiced in much of the area, some of it on sand dunes. Thus, reactivation of sand dunes in the area would have serious impacts on living conditions, grazing, and farming.

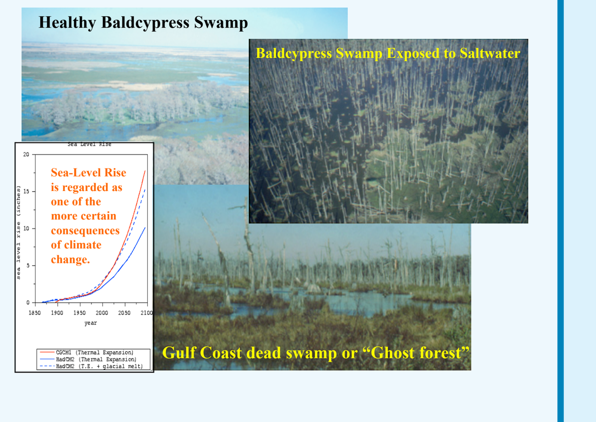
SEA-LEVEL CHANGE

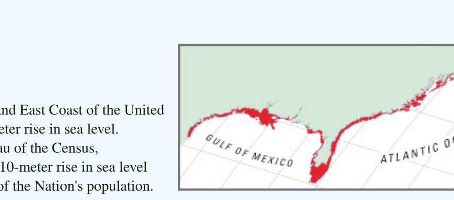
Global sea level and the Earth's climate are closely linked. As the climate has warmed following the "Little Ice Age" in the 19th century, sea level has been rising about 1 to 2 millimeters per year due to the reduction in volume of ice caps, ice fields, and mountain glaciers in addition to the thermal expansion of ocean water. If present trends continue, including an increase in global temperatures caused by increased greenhouse-gas emissions, many of the world's mountain glaciers, will disappear. For example, at the current rate of melting, all glaciers will be gone from Glacier National Park, Montana, by the middle of the 21^{st} century. During cold-climate intervals, sea level falls because of a shift in the global hydrologic cycle: water is evaporated from the oceans and stored on the continents as large ice sheets and expanded ice caps, ice fields, and mountain glaciers. Global sea level was about 125 meters below today's sea level at the last glacial maximum about 20,000 years ago. Sea levels during several previous interglacials were about 3 to as much as 20 meters higher than current sea level. The evidence comes from two different but complementary types of studies. One line of evidence is provided by old shoreline features. Wave-cut terraces and beach deposits from regions as distinct as the Caribbean and the North Slope of Alaska suggest higher sea levels during past interglacial times. A second line of evidence comes from sediments cored from below the existing Greenland and West Antarctic ice sheets. The fossils and chemical signals in the sediment cores indicate that both major ice sheets were greatly reduced from their current size or even completely melted one or more times in the recent geologic past. The USGS role in sea-level research is national in scope and ranges from remote sensing and geologic mapping of wetlands to studies of coastal erosion and evidence of older shorelines in the geologic record.



Annual mean relative sea level recorded at the Solomons Island, Maryland, tide gauge 1937-97 (from National Oceanic and Atmospheric Administration).

Extreme high tide, March 1, 1998, Hoopers Island, Eastern Shore, Chesapeake Bay, Maryland. In the Chesapeake Bay, the USGS is conducting research to reconstruct the detailed pattern of relative sea-level change during the last 6,000 to 8,000 years.





Red shows areas along the Gulf Coast and East Coast of the United States that would be flooded by a 10-meter rise in sea level. Population figures for 1996 (U.S. Bureau of the Census, unpublished data, 1998) indicate that a 10-meter rise in sea level would flood approximately 25 percent of the Nation's population.