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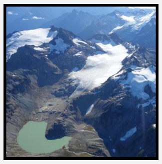
Climate Matters

News from the USGS Climate Research & Development Program

Volume 2, Winter 2014

About this issue

Science Feature



Decades of measuring glaciers: A USGS legacy

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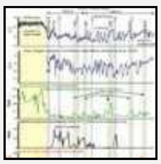

Gulf of California regional climate change during the past 55,000 years

Effects of the mountain pine beetle on forest hydrology and chemistry in the southern Rocky Mountains

Climate-Cooling Arctic Lakes Soak Up Greenhouse Gases

Land-use changes in the Prairie Pothole Region result in significant amphibian habitat losses

Tracing water supply to climate patterns

A Global Assessment of Tree Carbon Accumulation Rates

Recent Meetings

The 99th meeting of the Ecological Society of America was held in Sacramento, California from August 10-14, 2014, and its theme was "From Oceans to Mountains: It's All Ecology". USGS Climate Research & Development scientists participated in scientific sessions and workshops on these topics:

- Biodiversity: Effects Of Global Change,
- Biogeochemistry: Biogeochemical Patterns Along Environmental Gradients
- Etc.

MTNCLIM 2014, the Mountain Climate Research Conference, was held from September 15-18, in Midway, Utah. The MTNCLIM research conferences are sponsored by the Consortium for Integrated Climate Research on Western Mountains (CIRMOUNT), and are dedicated to advancing science related to climate and climate interactions with physical, ecological, and social systems of western North American mountains. Climate R&D researchers organized sessions and presented results of their research at the conference.

- The 126th Annual Meeting of the Geological Society of America was held in Vancouver, British Columbia from October 19-22, 2014. USGS Climate Research & Development scientists were among roughly 7,000 geoscientists from around the world that participated in the 2014 GSA meeting.

Upcoming Meetings

The 2014 American Geophysical Union Fall Meeting will be held from December 15-19, 2014 in San Francisco, California. Nearly 24,000 attendees are expected at this meeting, which is the largest Earth and Space science meeting in the world.

The The Pacific Climate Workshop (PACLIM) 2015 will be held at the Asilomar Conference Grounds in Pacific Grove, California from March 8-11, 2015. The theme of PACLIM 2015 is "Droughts: reconstructing the past, monitoring the present, modeling the future". This will be the 27th meeting of PACLIM, which is a biennial workshop intended to increase understanding of climate effects in the eastern Pacific Ocean and western North America by bringing together specialists from diverse fields including physical, social, and biological scientists.

The Association of American Geographers' Annual Meeting will be held in Chicago, Illinois from April 21 -25, 2015. The conference will feature more than 5,000 presentations, posters, and workshops by leading scholars, researchers, and educators.

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About this issue

Tupelo-cypress swamp, Jean Lafitte National Historical Park and Preserve.

Welcome to Climate Matters, a newsletter that highlights current activities in the USGS Climate Research & Development Program (Climate R&D). In this issue, we include a feature article about a long-term research effort that focuses on the study of several important North American glaciers. These "USGS benchmark glaciers" provide clues as to the response of glacier systems to climate change. As the authors note, "nearly all Earth's alpine glaciers are losing ice" which has significant implications for society and ecosystems. Also in this issue of the newsletter, we include summaries of six recently published papers on various aspects of climate science supported by Climate R&D, and a compilation of symposia and theme sessions from national meetings where our researchers have participated.

The Climate R&D Program continues to facilitate integration among diverse scientific disciplines and develop new research approaches to improve our understanding of how the Earth system responds to climate and land use change. In so doing, Climate R&D projects provide the unbiased, foundational research needed by the scientific community at large, natural resource managers, policy-makers and the general public so that they can make informed decisions on issues related to climate and land use change.

We have added an option to "Subscribe to Our Newsletter" on the home page to make it easy for readers to subscribe to future issues. We welcome feedback and comments to shape future issues.

Debra Willard
Program Coordinator
Climate Research & Development Program

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Decades of measuring glaciers: A USGS legacy

Overview

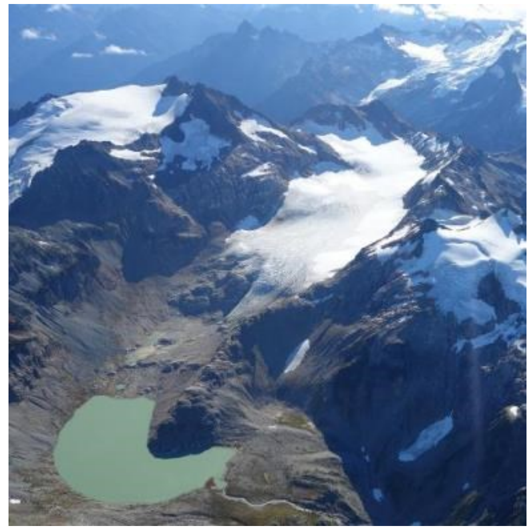

Figure 1: Alpine glaciers, such as the South Cascade glacier in Washington State, contain much less ice than the planet's polar ice sheets but are responding rapidly to climate change.

Glaciers are large, persistent masses of ice that move slowly across the land surface under their own weight and are influenced by changes in temperature and precipitation. Their response to those changes have impacts on physical, biological, and social systems, because glacier changes affect water availability and quality, sea level, and ocean circulation systems.

Large polar ice sheets (i.e. Antarctica and Greenland) contain most of the planet's land ice. However, it is the smaller alpine glaciers found in mountains (Figure 1) that have shown the most rapid response to recent climate change, have the most immediate impact on human water supplies, and have, thus far, contributed the most to sea level rise (Meier et al., 2007; Gardner et al., 2013). Documenting how these alpine glaciers are affected by climate change is helping us to better understand how glacier change affects ecosystems and resources. Additionally, this research will improve the accuracy of estimates of future glacier change that can guide decision-makers and stakeholders.

Today, nearly all Earth's alpine glaciers are losing ice (Gardner et al., 2013). Shrinking glaciers are often the most visible indicators of mountain ecosystems responding to climate change. Notably, rates of mass loss for North American glaciers are among the highest on Earth. North American glacier shrinkage impacts downstream hydrological networks by changing the total discharge, flow regime, and chemistry of rivers and oceans. The USGS is actively involved in measuring these glacier changes. Its research efforts in this regard are critical to understanding and adapting to the ecosystem shifts driven by climate change.

Measuring glacier change

Resolving the relationship between climate change and glacier length and thickness is accomplished through mass balance investigations – the snow and ice accounting system for glaciers. Traditionally, determining whether a glacier is gaining or losing mass involves measuring the change in mass at specific sites with snow stakes and snow pits (Figure 2), and then extrapolating these point values over the entire glacier surface. Measurements are generally made twice annually to determine seasonal mass gains and losses as well as the net change over the entire year.

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Figure 2: USGS scientists dig a spring snow pit on a glacier. Snow pits allow measurement of winter snow accumulation by excavating through the entire year's thickness and simultaneously measuring a snow density profile through this thickness.

Recent technological advances in remote sensing provide new opportunities to quantify how glaciers are changing. Image- and radar-based Digital Elevation Models (DEMs) provide 3D representation of a glacier's surface (Figure 3), with meter-scale precision. DEMs allow field measurements to be extrapolated over the entire glacier. Moreover, repeat acquisitions over several years can be compared to determine total volume change of the glacier, which can be used to improve traditional stake and pit estimates of long-term mass balance trends.

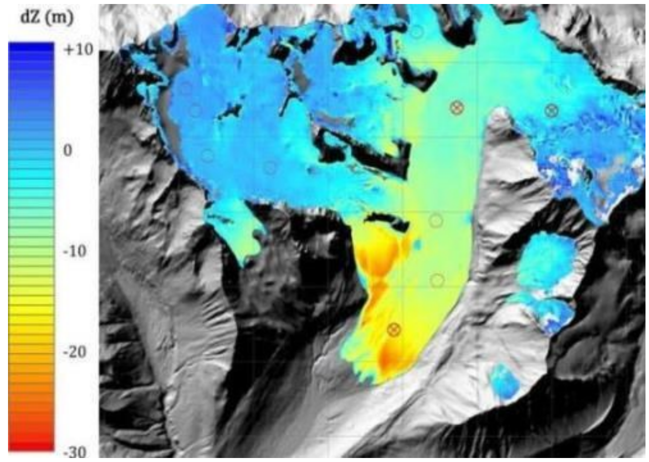

Figure 3: Digital Elevation Models (DEMs) quantify the size and shape of a glacier at a specific time. Two DEMs can be compared to estimate glacier volume change over the interval between DEM acquisitions. This image shows elevation differences (meters) across Gulkana Glacier, Alaska, over a 5 year interval (2010-2014). The difference documents rapid thinning near the glacier terminus and thinning over most of the glacier, with thickening only in the uppermost reaches.

Glaciers are made of several materials with different densities (given in units of kg m-2): snow that fell in the most recent winter (200-500 kg m-2), firn (snow from previous winters, 500-900 kg m-2) and ice (900 kg m-2). Because of these highly variable densities, average mass balance estimates for a glacier are presented in water-equivalent (w.e.) units. In this system, the densities and thicknesses of snow, firn and ice layers are first converted to water equivalent units. Then changes in mass balance are represented as a uniform water equivalent thickness over the entire glacier area.

Unified USGS Glaciology

Since the late 1950s, USGS has maintained a glacier mass-balance program at three North American glaciers. These 'Benchmark Glaciers' include Washington's South Cascade Glacier, and Alaska's Gulkana and Wolverine glaciers (Fig. 4). Results from this program form the longest continuous record of North American glacier mass balance. Similar measurements began at Sperry Glacier, Montana in 2005.

Figure 4: Locations of four monitored glaciers in the Unified USGS Benchmark Glacier program.

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In 2013, research at these independent sites was unified into a single project, with an ultimate goal of measuring changes in glacier mass across the principal North American climate zones that support them. Common field and analysis methodologies will enable comparison among the glaciers, and provide an improved understanding of both the causes and magnitudes of glacier change over long time periods at a continental scale.

Each benchmark glacier is influenced by a unique climatology. In Alaska, the measurements capture changes in both continental and maritime climate zones. Alaska's maritime climate zone is characterized by relatively warm and wet weather while the continental climate zone is characterized by extreme winter cold, warm or even hot summers, and substantially less precipitation than along the coast. Washington's maritime climate zone includes some the highest precipitation recorded for the lower 48 states of the United States. Montana's Intermountain climate zone reflects a blend of maritime influences from the west and continental influence from the Arctic and Great Plains, which meet along the continental divide.

Currently, historic data from the benchmark glaciers is being reanalyzed with consistent analysis techniques across the four glaciers. An emphasis on generalized algorithm development will allow other mass balance programs to be analyzed using the same algorithms (e.g., Taku Glacier in Alaska).

The fully unified USGS Benchmark Glacier project will allow mass balance records from different parts of North America to be directly compared to better understand the response of glaciers to climate changes. The two Alaskan benchmark glaciers have already undergone this comparative reanalysis, which revealed differences in variability and trends between the coastal and continental glaciers (O'Neel et al., 2014). For example, Figure 5 shows short-lived mass gains (positive slopes) at Wolverine Glacier; in the 1980's the cumulative mass balance indicates gains since the 60s (positive values). These episodes of growth result from the abundant snow accumulation and cool summers that characterize Alaska's coastal climate zones. In contrast, the persistent mass loss at Gulkana glacier exemplifies the stronger dependence of continental glacier mass balance on summer temperature.

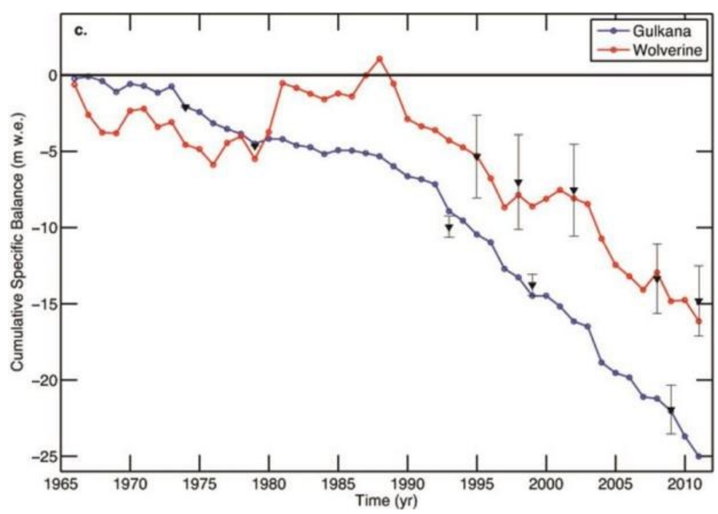

Figure 5: Cumulative annual mass balance for the two Alaska USGS benchmark glaciers, showing the traditional field data (red and blue lines) as adjusted by geodetic mass balance estimates (points with error bars). The bold horizontal line at zero demarks positive versus negative mass changes, with glacier growth and advance indicated when curves pass above this line.

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Additionally, as traditional field measurements are combined with remote sensing data, the short-lived remote sensing records can be linked to the longer field records. Just as geodesists have linked the tide gauge and satellite records to better understand sea level rise, glaciologists aim to link field and satellite records to gain regional insight into changing glaciers.

Implications of glacier change

Although the total volume of mountain glacier ice is small compared to the polar ice sheets, the aggregate mass loss is contributing to sea level rise at rates similar to those of the ice sheets. Much of the melt water is delivered into rivers and has direct impacts on surrounding populations through changes in water quality and availability.

Glacier runoff also links the physical and biological components of ice-covered ecosystems. Meltwater has a pronounced impact on the physical properties of rivers and streams, affecting temperature, nutrients, and turbidity, which in turn control the structure and biodiversity of downstream ecosystems.

As we work toward understanding the complex relationship between glaciers and the climate system, the degree to which biophysical linkages permeate glacier-covered ecosystems is increasingly evident. The broad scientific approach being undertaken by the USGS is beginning to resolve these uncertainties, in ways that identify regional trends in mountain glaciers and their environments, including changes to streamflow, ecosystem function, oceanic circulation patterns, and contributions to global sea level.

Further Reading:

Arendt, A., S. Luthcke, A. Gardner, S. O'neel, D. Hill, G. Moholdt, and W. Abdalati, 2013, Analysis of a GRACE global mascon solution for Gulf of Alaska glaciers, Journal of Glaciology, Vol.59, no. 217, p. 913 –924, doi: 10.3189/2013JoG12J197.

Gardner, Alex S., et al., 2013, A Reconciled Estimate of Glacier Contributions to Sea Level Rise: 2003 to 2009, Science, Vol. 340, p. 852-7.

Meier, Mark. F., et al., 2007, Glaciers Dominate Eustatic Sea-Level Rise in the 21st Century, Science, Vol.317, no.5841, p.1064-7.

O'Neel, S., E. Hood, A. Arendt, and L. Sass, 2014, Assessing streamflow sensitivity to variations in glacier mass balance, Climatic Change, Vol.123, no. 2, p.329-341. doi: 10.1007/s10584-013-1042-7.

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Gulf of California regional climate change during the past 55,000 years

Separated from the cool waters of the mid-latitude North Pacific by the Baja California Peninsula and extending for over 1000 km, the Gulf of California (GoC) provides a critical pathway for monsoon moisture to enter the southwest US from the tropical eastern Pacific. A high-resolution study of a sediment core collected in the central GoC spans the past 55,000 years and reveals that Holocene (past 11,500 years) surface water conditions are unique. This implies that, before the Holocene, summer monsoonal moisture likely did not penetrate into the southwest US along the modern pathway through the GoC. Prior to the Holocene, tropical monsoon moisture appears to have taken a more direct pathway into the southwest US over Pacific waters off Baja California that were likely warmer than those of the GoC.

The study used fossilized remains of diatoms and silicoflagellates, two groups of marine microorganisms that are reliable indicators of past climate conditions. The results of this investigation indicate that temperatures and biologic productivity in central GoC waters varied greatly from about 55,000 years ago until the beginning of the Holocene interglacial and are related to global climate conditions.

For example, between about 55,000 and 27,000 years ago, numerous periods of massive iceberg creation (Heinrich events) were associated with rapid collapse of the northern hemisphere ice shelves. These events resulted in the release of large volumes of freshwater that in turn led to the temporary disruption of global ocean circulation patterns. Immediately following each Heinrich event were periods of rapid warming known as Dansgaard-Oeschger (D-O) events. These D-O events have been particularly well documented in the north Atlantic Ocean.

In the central GoC, D-O events are associated with abrupt increases in biologic productivity (Figure 1), attesting to a strong link with surface waters conditions in the North Atlantic. Diatom and silicoflagellate assemblages suggest that sea surface temperatures (SSTs) rose in the GoC during the warm D-O events. This implies that transport of monsoonal moisture to the southwest US likely increased during warm D-O events. Cave speleothem isotope records from Arizona and New Mexico have been interpreted to reflect decreased winter precipitation during warm D-O events. Limited precipitation proxy evidence from packrat middens, however, is supportive of increased summer precipitation in the southwest US during some of the warm D-O events.

These results support the sensitivity of the GoC and hence monsoonal rainfall in the southwest US to Pacific SST variations. Future scenarios from climate models call for warmer Pacific SSTs, which may result in conditions similar to the pre-Holocene situation, with different sources and seasonality of precipitation than the modern southwest US.

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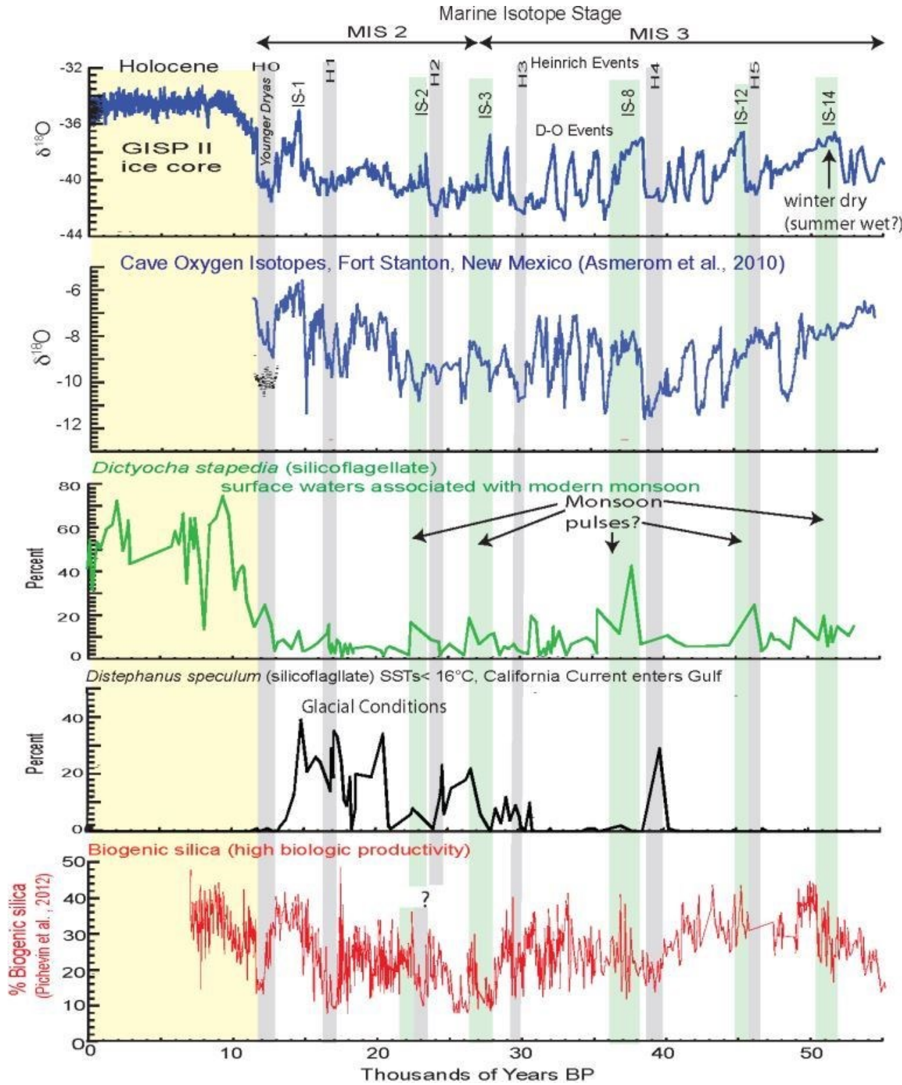

Central Gulf of California records for the past 55,000 years of biogenic silica and environmentally-sensitive silicoflagellates compared with the GISP II (Greenland) ice core oxygen isotope record and the speleothem cave oxygen isotope record from Fort Stanton, New Mexico. Color shading: Holocene = yellow; Heinrich events = gray; periods of possible enhanced monsoon pulses during warm interstadial = light green. The figure demonstrates the sensitivity of both Gulf of California surface water conditions and southwestern US cave isotopes (precipitation) to Heinrich events and warm interstadial events. Modified from Barron et al. (2012): doi:10.1029/2011PA002235

The paper, published in Marine Micropaleontology in 2014, can be found at http://dx.doi.org/10.1016/j.marmicro.2014.02.004

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Effects of the mountain pine beetle on forest hydrology and chemistry in the southern Rocky Mountains

View of pine forest affected by mountain pine beetle epidemic in Rocky Mountain National Park

The mountain pine beetle is the main cause of insect-induced tree mortality in western North America. Over the past fifteen years, pine forests in the southern Rockies experienced the most severe mountain pine beetle epidemic in recorded history, with up to 50% mortality of mature pine trees. Contributing factors include an abundance of mature trees in dense lodgepole forests, drought stress, and warming temperatures. These factors have allowed the mountain pine beetle to expand its elevation and latitudinal ranges into areas formerly too cold for its survival.

The death of large numbers of pine trees represents a profound change in the pine forest landscape of the western U.S., which covers millions of acres. USGS and university scientists are working together to assess possible effects of the mountain pine beetle epidemic on the hydrologic cycle, nutrient and carbon cycles, and water quality. The results of three recent studies are presented here.

In a study in Rocky Mountain National Park, scientists used chemical and isotopic tracers of water to determine whether beetle-induced tree mortality influences the hydrologic cycle. Results indicate that forest transpiration, which can be thought of as evaporation from plant leaves, decreased after trees infested by the mountain pine beetle died. Soil moisture and ground evaporation increased below dead trees, and the net effect was increased groundwater recharge and groundwater contributions to stream flow.

In two related studies, scientists looked at changes in the characteristics of nutrients, water, and carbon associated with soil and streams within pine-beetle affected forests to determine how the epidemic affected forest and aquatic ecosystems. Soil nutrients and soil moisture increased in affected areas as uptake by dying trees declined. Despite these changes in soil fertility, little change has been seen in nutrient or carbon concentrations in streams, leaving aquatic ecosystems mostly unaffected. It appears that small, young trees, which formerly were shadowed by the large, mature trees that were killed by the pine beetles, have been able to take advantage of the increase in soil moisture, nutrients, and light. The young trees are now growing rapidly, rebuilding the forest in a natural succession process.

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Results from these studies indicate that pine forests can be surprisingly resilient, even in the face of large-scale insect outbreaks. Hydrologic effects in insect-infested forests were modest, and changes in water quality were minimal. Selective clearing of dead trees may help reduce visual impacts and fire hazard; however, more aggressive forest management techniques, such as clear cutting, can cause ground disturbance that might be detrimental to ecosystem health.

The papers, published in Nature Climate Change, Applied Geochemistry, and Proceedings of the National Academy of Sciences, are available at: http://www.nature.com/nclimate/journal/v4/n6/full/nclimate2198.html, http://www.sciencedirect.com/science/article/pii/S0883292711001752, and http://www.pnas.org/content/110/5/1756

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Climate-Cooling Arctic Lakes Soak Up Greenhouse Gases


Thermokarst lakes, formed when permafrost thaws and creates surface depressions that fill with melted water, are a prominent feature of Arctic landscapes.

Thermokarst lakes, which form when ice-rich permafrost thaws, have long been considered major sources of carbon dioxide and methane to the atmosphere. However, new research led by University of Alaska Fairbanks (UAF) and USGS scientists indicates that arctic thermokarst lakes stabilize climate change by storing more greenhouse gases than they emit into the atmosphere. Countering a widely-held view that thawing permafrost accelerates atmospheric warming, new research published in Nature suggests arctic thermokarst lakes are 'net climate coolers' when observed over longer, millennial, time scales.

Incorporating published data from the circumpolar arctic, new field observations of Siberian permafrost and thermokarst features, radiocarbon dating, atmospheric modeling, and spatial analyses, the research shows how thawing permafrost is impacting climate change and greenhouse gas emissions.

Thermokarst lakes occur in the Arctic and cold mountain regions when ice-rich permafrost thaws and creates surface depressions that fill with melted freshwater, converting what was previously frozen land into lakes. New research indicates that these lakes initially formed in ice-rich regions of North Siberia and Alaska after the atmospheric warming associated with deglaciation (predominantly forming between approximately 15,000 and 10,000 years ago), and were large sources of methane to the atmosphere. As peat began accumulating rapidly in partially drained and fully drained lake basins, which also led to permafrost re-aggradation, the lakes started acting as carbon sinks. Roughly 5,000 years ago more carbon was being taken up by the peat in these lake basins than emitted as carbon dioxide and methane, turning these lakes into a net carbon sink on a global scale. Thus, while methane and carbon dioxide emissions following thaw led to immediate radiative warming, net carbon uptake in peat-rich sediments that occurs over millennial timescales ultimately leads these lakes to have a net cooling effect.

Because roughly 30% of global permafrost carbon is concentrated within 7% of the permafrost region in Alaska, Canada, and Siberia, this study's findings renew scientific interest in how carbon uptake by thermokarst lakes offsets greenhouse gas emissions. Through its data collection, the study expanded the circumpolar peat carbon pool estimate for permafrost regions by more than 50%.

This paper, published in Nature, is available at http://www.nature.com/nature/journal/v511/n7510/full/nature13560.html

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Land-use changes in the Prairie Pothole Region result in significant amphibian habitat losses

The northern leopard frog (*Lithobates pipiens)* is one of several amphibian species dependent on both wetland and grassland habitats of the northern Great Plains.

Amphibians are an important component of both aquatic and terrestrial ecosystems. Unfortunately, populations of amphibians have been disappearing from global ecosystems at an alarmingly high rate. Many of the declines in amphibian populations have been attributed to habitat loss due to changes in land-use practices.

In the Prairie Pothole Region, an agriculturally dominated area of approximately 820,000 km2 in the northern Great Plains of North America, land-use changes have resulted in significant habitat loss for amphibians. Here, the agricultural focus has shifted from production of small grains (e.g., wheat and barley) to row crops (e.g., corn and soybeans). Increased profitability associated with row-crop production has led to vast tracts of grasslands being removed from conservation programs (e.g., the U.S. Department of Agriculture's [USDA's] Conservation Reserve Program) and returned to crop production. Wetlands and the terrestrial grasslands surrounding wetlands are vital components of the habitat required by amphibians in the northern Great Plains.

USGS research scientists modeled the effects of land-use/land-cover change on amphibian habitats in the Prairie Pothole Region of the northern Great Plains over a six-year period (2007-2012). They also made projections of the results of continued losses of conservation grasslands on the region's amphibian habitats. Over the six years modeled, amphibian habitats declined by approximately 22%, largely resulting from the conversion of over 1.2 million ha of the region's conservation grasslands to croplands over the same period. Continued losses of conservation grasslands could result in loss of an additional 26% of currently available amphibian habitat. From a frog's perspective, this habitat loss translates into a loss of the wetland breeding sites, deep-water and terrestrial overwintering sites, and upland feeding areas needed to maintain populations.

Identifying the significant role that conservation grasslands play in providing habitat for amphibians helps meet the information needs of USDA as they assess the costs and benefits of maintaining conservation grasslands on agricultural landscapes. Information obtained under this effort also will be of use to other federal, state, and non-governmental agencies and organizations interested in sustaining landscapes and ecosystems.

The paper, published in *Biological Conservation*, is available at: http://www.sciencedirect.com/science/article/pii/S0006320714001347

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Tracing water supply to climate patterns

Forested mountain watersheds provide an important water source for humans and ecosystems, which may be vulnerable to changes in precipitation patterns related to regional or local changes in atmospheric dynamics. Although climate modeling scenarios suggest that precipitation in the Caribbean Basin is likely to decrease over the next century, we have lacked the hydrologic data needed to understand the relative importance of two major climate patterns to streamflow and groundwater: mountain-influenced (orographic) precipitation from trade winds (including rain and cloud water) and deep convective precipitation (including tropical storms and hurricanes).

Pico del Este and the Rio Mameyes, El Yunque National Forest, Puerto Rico. Orographic clouds (as shown) are a significant source of annual precipitation and streamflow.

In a comprehensive study at the USGS Water, Energy, and Biogeochemical Budgets (WEBB) site in the Luquillo Mountains of Puerto Rico, measurements of hydrogen and oxygen isotopes from precipitation were matched to weather type and cloud height to determine the distinctive “isotopic signature” of each climate pattern. Isotope signatures of streams and groundwater were also generated and compared to those of the weather type and cloud height in order to determine the source of these important components of regional water supply.

The result of this study was counterintuitive – despite being only 25-35% by volume, mountainous precipitation originating from trade winds comprised 59% of stream baseflow and groundwater. Explanations for this result included: 1) frequent low-intensity mountain rain events filled the available space in low-permeability tropical clay soils, so that intense rain from large convective storms flowed rapidly into streams instead of infiltrating into the soil; and 2) high contributions of cloud water deposition, which is not measured in standard rain gages and therefore is not accounted for in traditional water balance methods, may play a more significant role in the local hydrology than expected.

In another part of this study, researchers evaluated whether the precipitation patterns in the Luquillo Mountains have been influenced by regional climate changes. The scientists found that rainfall amount and intensity increased over the past 20 years, contradicting global climate model projections for drying in the Caribbean, but agreeing with projections of increased rainfall intensity. Global climate models do not simulate precipitation on relatively small mountain ranges. Given the importance of orographic

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precipitation found in this study, regional climate models may be a better approach to developing climate change projections for water management planning in mountainous watersheds.

This research also shows that measuring rainfall totals in the tropics is not enough to determine water availability; rather, it is equally important to understand the interaction between rainfall source and the permeability and storage properties of tropical soils. The methods developed here can be applied to hydrology studies elsewhere in the tropics, because atmospheric temperature gradients and climate controls on rain isotopic signatures are similar.

The paper, published in Water Resources Research in 2014, can be found at: http://onlinelibrary.wiley.com/doi/10.1002/2013WR014413/abstract

The supplemental water stable isotope data are published in: http://pubs.usgs.gov/of/2014/1101/

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Climate Matters

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A Global Assessment of Tree Carbon Accumulation Rates

The world's biggest trees — such as this large western white pine (*Pinus monticola*) in California's Sierra Nevada mountain range — are also the world's fastest-growing trees, according to an analysis of 403 tree species spanning six continents.

Forests are key components of the global carbon cycle, potentially contributing substantial feedbacks to ongoing climatic changes. It is therefore remarkable that no consensus has existed about how tree growth – and thus the rate at which individual trees accumulate carbon from the atmosphere – changes with tree size. One widely-held belief is that trees have a lifetime growth pattern similar to humans: rapid growth early in life followed by declining growth later in life. However, a small group of studies have instead found continuously increasing growth rates in trees, with the largest trees growing the fastest. So, we have been confronted with two mutually exclusive generalizations about the fundamental nature of tree growth, but have lacked a global assessment to distinguish between the two.

To address this information gap, USGS scientists assembled an international team of researchers to analyze growth measurements of 673,046 trees belonging to 403 tree species, representing tropical, subtropical, and temperate regions across six continents.

Results of the analyses were unequivocal. For the vast majority of species (97%), mass growth rates continued to increase up through the largest trees in the data set. At the extreme, a giant tree can add the mass equivalent of an entire medium-sized tree to the forest in a single year.

These results add to the growing body of evidence suggesting that although trees may age (i.e., suffer cumulative exogenous injuries through time), they do not senesce (suffer an inevitable, endogenous physiological decline). Most significantly, the results highlight the disproportionately important role of large trees in determining rates of carbon exchange between forests and the atmosphere – information that will improve our ability to forecast the role of forests in the global carbon cycle and to devise appropriate adaptation and mitigation strategies for managing forests in the face of rapid climatic changes.

The paper, published in Nature, is available at: http://www.nature.com/nature/journal/v507/n7490/abs/nature12914.html

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