



Enter the breach

What do openings in the ice mean for the Greenland Ice Sheet?

Permafrost
carbon bomb

Arctic science and
Inuit knowledge

Safe from melting,
for now

Dust-covered snow
taxes water



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On the cover: Graduate student Daniel McGrath enters a moulin in Greenland to measure waterflow. Konrad Steffen/CIRES

\$75,000

Cost of each of the unmanned planes used by CIRES researchers to observe polynyas in Antarctica in 2009. The researchers began with four planes and lost only one during the missions. Read more about the research results on [Page 10](#).



“When the snow melts, you’ll see these big black holes. It’s kind of mysterious what’s down there. Where does this water go? What’s the impact?”

Daniel McGrath, talking about his fascination with moulins. Read more about CIRES work with moulins on [Page 8](#).

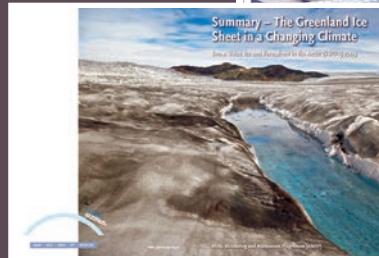


1.89 million square miles

Arctic sea ice extent in September 2010. The long-term average is 2.70 million. The difference in extent is nearly as big as the area occupied by Alaska and Texas, combined.

Author, author

CIRES Director Konrad Steffen was lead author of *The Greenland Ice Sheet in a Changing Climate*. CIRES scientist Walt Meier co-authored that report, and was also an author of *Arctic Report Card 2010*.



Relative mountain range heights

Read more about Himalayan glacier melt on [Page 20](#).

Andes
~22,000 ft.

Himalayas
~29,000 ft.

Colorado Rockies
~14,000 ft.

Alps
~15,000 ft.

Indigenous knowledge and science

Inuit forecasters with generations
of environmental knowledge help
scientists understand Arctic weather



Learn more

Listen to a podcast interview with the paper authors at
<http://cires.colorado.edu/news/press/2010/gearheardinuit.html>.

An Inuk living in the Canadian Arctic looks to the sky and can tell by the way the wind scatters a cloud whether a storm is coming. Thousands of miles away in a Boulder laboratory, scientists collect data and use computer models to make similar weather predictions. These distinct practices serve the same purpose.

But in the past 20 years, something's run amok with Inuit forecasting. Old weather signals don't mean what they used to. The cloud that scatters could signal a storm that comes in an hour instead of a day. Elsewhere, researchers had heard the reports from Arctic communities of unpredictable weather. But the stories didn't seem to match up with the researchers' models. By scientific measurement, weather around the world appeared to be growing more persistent with less variation. The disparity left scientists — including CIRES scientist Betsy Weatherhead, who has long been interested in the issue — scratching their heads.

Weatherhead contacted Shari Gearheard, a scientist with CIRES' National Snow and Ice Data Center, who lives in Clyde River, Nunavut, Canada, an Inuit community on eastern Baffin Island. For the past 10 years, Gearheard has been working with Inuit hunters and elders — in their own language, which Gearheard speaks—to document their knowledge of the environment and environmental change. Gearheard meticulously collects the stories told to her by the Inuit and makes systematic records of indigenous environmental knowledge. Through this, patterns begin to emerge, leading Weatherhead and colleague Distinguished Professor Roger Barry, a CIRES Fellow, to focus their analysis on patterns of weather “persistence” in the springtime.

Statistical analyses of day-to-day temperatures at Baker Lake, Nunavut, showed that during May to June, the persistence of temperature has recently declined, matching Inuit reports of greater unpredictability for that season.

The scientific analyses matched what the Inuits were witnessing on the ground. Weather along the Arctic



©Shari Gearheard

Photos courtesy of Shari Gearheard, CIRES NSIDC,

Lasalie Joanase, a hunter from Clyde River, Nunavut, checks weather and ice conditions while scanning for seals during spring hunting.

latitudes was behaving more unpredictably than in other parts of the world. “That’s an incredibly important parameter to care about, incredibly important,” said Weatherhead. “One way I describe it is if an inch of rain falls at my house in the month of July, I don’t need to turn on the sprinklers. But if there is one inch of rain on July 1 and no rain after that, my lawn is dead.”

“Ecosystems have evolved under a certain type of pattern. So if the pattern is changing, that could be just as important as a small increase in temperature or some of the other changes we’re talking about,” Weatherhead continued.

The study helps refine and test climate models, while also providing these models with a new category of information to consider. And Gearheard’s work with the Inuit is demonstrating the value of indigenous environmental knowledge to modern climate science.

“Indigenous knowledge didn’t always have the place it does now in research,” Gearheard added. “It’s growing. People are becoming more familiar with it, more respectful of it.”



Director of the World Data Center for Glaciology

Distinguished Professor

CIRES Fellow

Former Director of the National Snow and Ice Data Center

Hats off to Roger G. Barry

In December 2010, we wished a fond retirement to Distinguished Professor and long-time CIRES Fellow Roger G. Barry. He has directed the World Data Center for Glaciology (WDC) since 1976. Under Barry’s leadership the WDC/National Snow and Ice Data Center (NSIDC) grew from a staff of two in 1977 to about 90 in 2008, when he stepped down as Director. A leader in the cryospheric science community, Barry shares a legacy of discovery about Arctic and mountain climates and cryospheric processes, climate change, and collaborations incorporating indigenous environmental knowledge into scientific weather analysis. He published *Atmosphere, Weather and Climate* in 1968 (now in its ninth edition), *Mountain Weather and Climate* (three editions, two translations),

and three other textbooks, as well as over 200 scientific papers and chapters. Barry’s fifth and most recent book, *The Global Cryosphere — Past, Present and Future*, will be published in June 2011. His outstanding scholarly work led him to be a John Simon Guggenheim Memorial Foundation fellow in 1982, a 2001 Fulbright teaching fellow for Geography in Moscow, and a reviewer of the Intergovernmental Panel on Climate Change (IPCC) report that received the Nobel Peace Prize in 2007. He was awarded the Founder’s Medal of the Royal Geographical Society in 2008 and currently holds a Humboldt Prize Fellowship. Barry served seven years as the associate director for the Cryospheric and Polar Processes Division, and inspired nearly 60 climate and cryospheric graduate students.

Robbing the West

Dust on snow reduces Colorado River runoff by 5 percent

The cinnamon toast-like coating on snow in the Upper Colorado River Basin doesn't just ruin a scenic vista, it makes the snow melt faster and skims valuable water from the West's most important river: the Colorado.

But the news is good, in part. "By cutting down on dust we could restore some of the lost flow, which is critical as the Southwestern climate warms," said Brad Udall, director of the Western Water Assessment (WWA) — a joint program of CIRES and NOAA.

Udall is one of a team of scientists including Jeffrey Deems from CIRES WWA and the National Snow

TheScience

Water loss in the Colorado River from fast-melting, dust-covered snow may equal twice the amount Las Vegas uses in a year.

and Ice Data Center (NSIDC), who have been investigating the eyesore's impact on snowmelt and river runoff. Snow dusted with dark particles absorbs a greater fraction of the Sun's rays and melts faster than white snow, said study leader Thomas Painter of NASA's Jet Propulsion Laboratory and an affiliate of CIRES NSIDC. "It is really like taking a relatively clean snowpack and almost doubling the sunlight hitting it." Earlier snowmelt then lets the growing season of snow-covered vegetation start earlier and more water is lost through evaporation and transpiration, he said. That leaves less water for the Colorado River.

Heavy dust coatings on the snowpack are a relatively recent phenomenon: Since the mid-1800s onwards, activities such as livestock grazing and road building have disturbed the desert soil and broken up the soil crust that curbs wind erosion. Winds then whip up the desert dust — from northwest New Mexico, northeast Arizona, and southern Utah — and drop it on mountains downwind that form the river's headwaters, said Deems.

To evaluate how the dust impacts snowmelt, the team used a hydrology model that has been shown to simulate



Center for Snow and Avalanche Studies (CSAS)

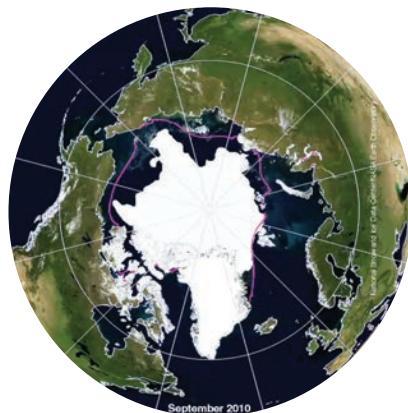
Above: Dust on snow covers a mountain range in the Rocky Mountains. **Right:** CSAS Director Chris Landry and graduate students Annie Bryant and McKenzie Skiles take samples to measure impurities in the snowpack.

snowmelt and river flows in the Colorado Basin. The researchers modeled the rate of mountain snowmelt and volume of runoff at Lees Ferry in Arizona, the point at which the water flow is gauged and subsequently allocated.

They looked at two scenarios in their models: the "lower dust" conditions prior to the disturbance of desert soils in the 20th century and the levels of dust observed between 2003 and 2008.

Snowmelt in the current dusty conditions occurred nearly three weeks earlier than in pre-settlement conditions, the results showed, and an average of 5 percent less water flowed into the river above Lees Ferry.

"That quantity of water lost is twice Las Vegas' current water right. It's about half of what the state of Arizona takes down through its Central Arizona Project and twice what the city of Denver uses in a year," said Udall. "It is a large chunk of water."



Sea ice extent in September 2010; the pink line shows long-term average for the month. NSIDC

Disappearing acts

Tracking Arctic sea ice loss

The sea ice blanketing much of the Arctic Ocean grows in the winter and shrinks in the summer, hitting a minimum every year around September. In 2010, that minimum was the third lowest since 1979, when the satellite record began, CIRES scientists calculated.

CIRES' National Snow and Ice Data Center (NSIDC) tracks Arctic sea ice extent every year. Although winds and other weather patterns leave more ice some years, less others, the sea ice has declined precipitously overall. The summertime minimum extent has plummeted at a rate of more than 11 percent per decade since 1979, according to NSIDC.

"All indications are that sea ice will continue to decline over the next several decades," said CIRES Fellow Mark Serreze, NSIDC director. "We are looking at a seasonally ice-free Arctic in twenty to thirty years."

In September 2010, Arctic sea ice stretched for only about 1.89 million square miles, less than any other year except 2008 (1.8 million square miles) and 2007 (1.65 million). The long-term average for the month of September (1979-2000) is 2.70 million square miles.

Greenland Ice Sheet losing ice mass from northwest coast

Ice loss from the Greenland Ice Sheet, which has been increasing during the past decade over its southern region, is now moving up its northwest coast, according to an international study published in 2010.

CIRES Fellow John Wahr was among international scientists who studied data from NASA's Gravity and Recovery Climate Experiment satellite system, or GRACE. The team compared GRACE measurements with others made by global positioning systems affixed to bedrock on the edges of the ice sheet.

On Greenland's northwest coast, the Earth surface rose by 1.5 inches from October 2005 to August 2009, because less ice was pressing down upon it. Although GRACE's resolution is not precise enough to pinpoint the source of the ice loss, the fact that the ice sheet is losing mass nearer to the ice sheet margins suggests the flows of Greenland outlet glaciers there are sliding downhill fast, dumping more ice in the ocean.





Ted Scambos (front) and Martin Truffer stand on the Scar Inlet Ice Shelf, a remnant piece of the Larsen B Ice Shelf. Scambos and Truffer (and Erin Pettit, not shown) are conducting a radar survey of the shelf to determine its thickness, and using GPS to measure flow speed.

After the breakup

Ground-based instruments in the Antarctic Peninsula shed light on ice sheet collapse

When a chunk of ice larger than Rhode Island broke off the Antarctic Larsen Ice Shelf and crumbled into the ocean below, in 2002, even experienced glaciologists were surprised.

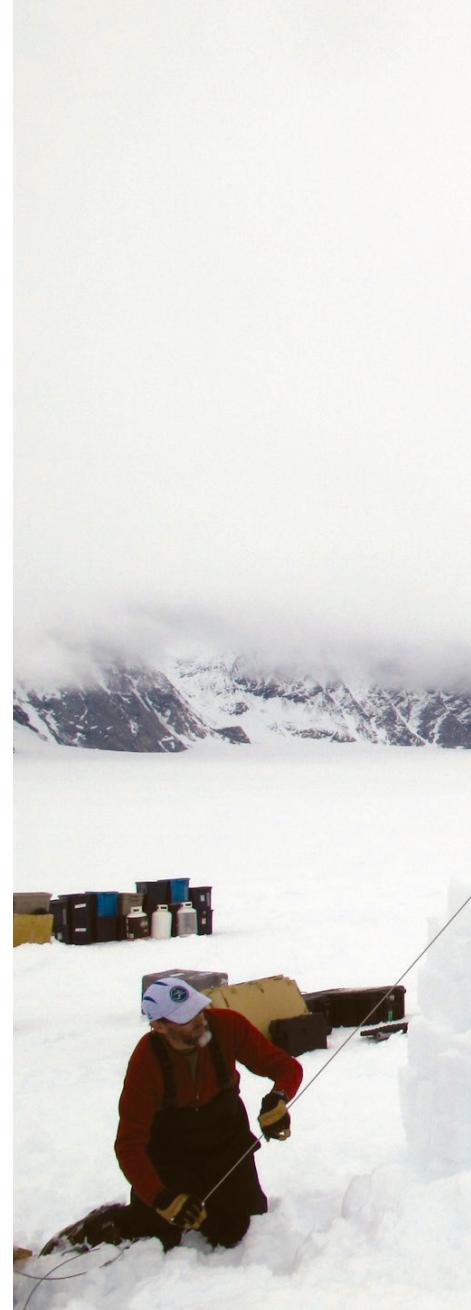
“We simply didn’t know an ice sheet could do that,” said glaciologist Ted Scambos of CIRES’ National Snow and Ice Data Center (NSIDC). “Not just break up, but collapse into a pile of rubble — that was a stunner.”

Scambos and other scientists immediately began to monitor the impacts of the ice sheet collapse on the surrounding Larson B breakup region by satellite, as part of the National Science Foundation-funded Larsen Ice Shelf System, Antarctica (LAR-ISSA) Project. They found neighboring glaciers began to accelerate at once, and within a year were moving six to ten times faster than they had been

prior to the breakup. The glaciers also began to thin rapidly and the remnant Larsen ice shelf, called the ‘Scar Inlet Shelf’, showed the same surface melting and cracking that preceded the main Larsen B breakup.

“This promises to be a great natural experiment,” Scambos said. “If we can get more data on the remnant shelf and its feeder glaciers, then we’ll really get some insight into the causes and effects of ice shelf disintegration.”

Monitoring the region by satellite alone, however, doesn’t give the whole story, Scambos said. To get a closer view, Scambos and NSIDC researchers Rob Bauer and Terry Haran travelled to the Antarctic Peninsula in December 2009 and in three months set up field-based monitoring systems. The systems, called automated meteorology-ice-geophysics systems (AMIGOS), were equipped



with weather instruments, GPS units, and cameras and were stationed on the remaining ice sheet and a nearby glacier. Since their installation, they have transmitted data and photographs back to the scientists through satellite telephone uplinks.

Scambos hopes the field-based studies will give insight not only into the causes of ice sheet breakups, but into threshold conditions for breakups. With this greater understanding, scientists could forecast what areas of the Antarctic might be close to a big change in terms of ice stability and what the regional environmental implications of the disintegration might be, he said.

The ground-based instrumentation has already added to scientists’ un-



Above: Terry Haran (left) and Martin Truffer steady the tower during the installation of the AMIGOS-3 station on Flask Glacier. The station (from the top) has a GPS antenna, an Iridium uplink antenna for data transmission, solar panels, a weather instrument boom arm, and an electronics enclosure (white box) for gathering, processing, and transmitting the data.

derstanding of the system, Scambos said. The temperature sensors have shown that there is no specific melt season and frozen season. “A melt can happen at any time of the year,” he said. Also, the observations show that the temperature of the remaining ice sheet is now within the range at which most ice sheets break up. “Sometime in the next decade, it will disintegrate.”



Martin Truffer checks radar profile data of the ice sheet on Leppard Glacier, Antarctica. Radar profiles of the ice thickness will be repeated to look for changes in the ice.

Crevasses

A moving ice sheet forms crevasses as it fights the forces of friction. Meltwater flows into the crevasses, warming the ice's interior and causing new fractures to form as the water freezes and expands.

Supraglacial Rivers

Meltwater travels an icy river system en route to a moulin. During peak discharge, this process takes about 2.5 to 3 hours.

Interior Meltwater

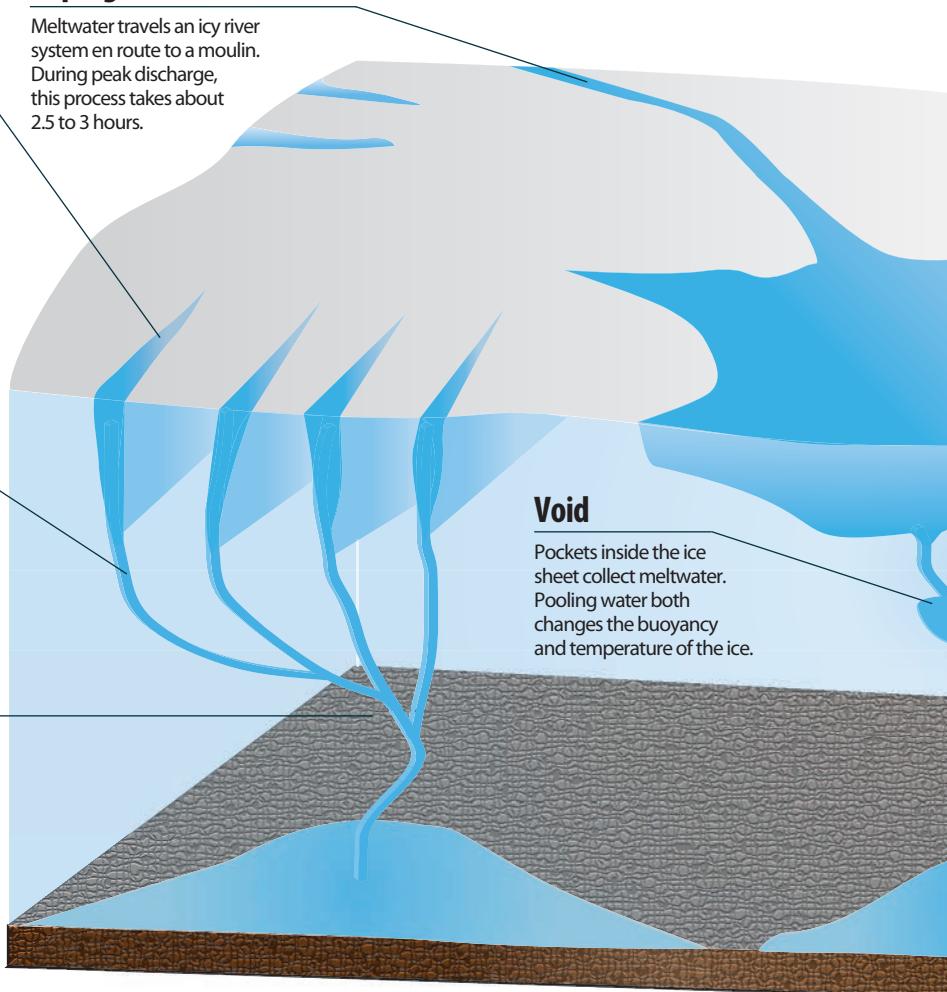
Myriad internal fractures allow meltwater to drain through the ice.

Warm Ice

Warmer water seeks a temperature equilibrium, so it transfers heat to nearby ice. The subsequently warmer ice moves much faster than cooler ice.

Void

Pockets inside the ice sheet collect meltwater. Pooling water both changes the buoyancy and temperature of the ice.



CIRES' sense of ice

Scientists have a pretty good idea that melt is responsible for about half the current loss of the Greenland Ice Sheet. Less well-understood are the mechanisms for the other 50 percent – the breaking apart of the ice itself and its loss into the sea. Now, several closely-related studies about water's effects inside glaciers and the Greenland Ice Sheet are revealing a clearer picture of the forces that influence the behavior and loss of ice.

Matter of momentum

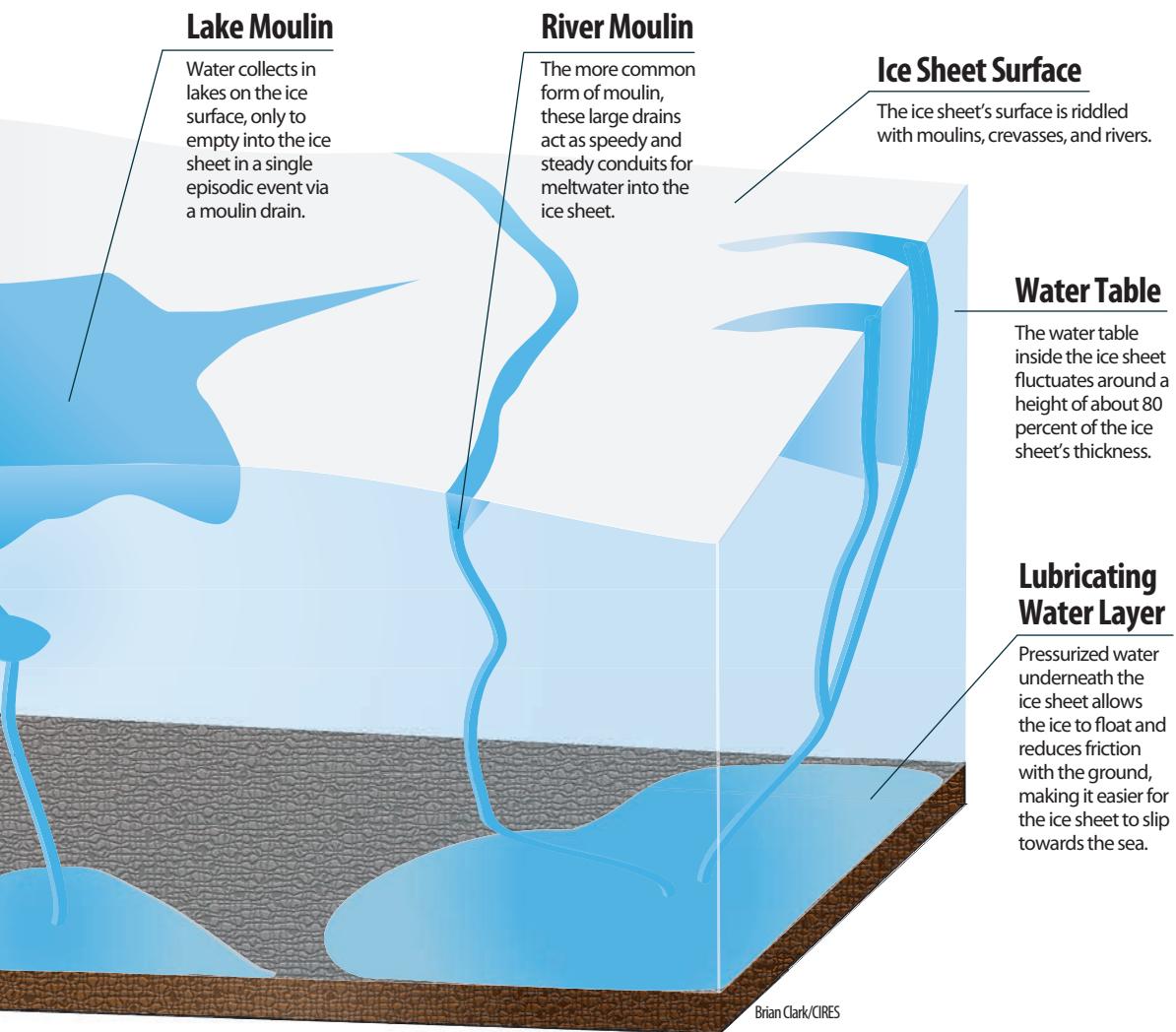
Fly over the Greenland Ice Sheet during the melt season, and there's a good chance you'll see turquoise rivers snaking their way across the ice surface. Often, mysterious drains, called moulins, swallow these rivers, taking water on a journey through the ice. While moulins have fascinated mountaineers and glaciologists for decades, little is known about where this water goes or its impact on the movement of the ice sheet.

On the Greenland Ice Sheet, CIRES' graduate student Daniel McGrath and colleagues installed a gauging station to measure meltwater drainage into a moulin, during a 15-day period at the peak of the melt season. Their plan was

to study the timing of water traveling across the surface of the ice and the impacts of it falling into moulins.

McGrath and his colleagues found that although it takes about three hours for meltwater to travel through the ice surface stream system, once it enters the moulin, it is transferred to the water table below in less than 30 minutes, almost instantaneous by glaciological standards. Rapid pulses of meltwater can set off chain reactions that temporarily boost ice sheet velocity. These moulin surges differ from meltwater drainage via crevasses, which is often slow and steady, and thus less likely to influence the speed of the ice sheet.

Next up, McGrath says, is to watch the system evolve over an entire melt season. "This was just a snapshot in time."



Feeling the pressure

Porous ice sheets hold a lot of water, the effects of which are still relatively unknown. CIRES' graduate student William Colgan took a look inside moulins to see how the Greenland Ice Sheet handles the added pressure from meltwater. All signs point toward a temporary boost to the ice sheet's speed.

Colgan developed a model to study how meltwater moves from the surface of the ice sheet through its interior, and compared this model with ice velocity data collected from the field.

He found that the water table inside the ice rises and falls each year in response to summer melt. Furthermore, the ice sheet's velocity appears to be tied to how the water table rises each day. In high melt years, the water table rises quicker, creating a short-lived surge in movement. That's likely because the ice is buoyant, Colgan said. "We found that the ice isn't really bearing any weight. It's floating."

Also of note was that water drains slowly in the months after the melt season, keeping the base water table high, around 80 percent of the ice sheet's total thickness, where it will be built upon the next year.

There's little concern, however, that the ice sheet could suddenly skate to the sea during peak melt season, due to the added water pressure below. "The

calving of the ice as a result of this additional movement is not that significant in the grand scheme of things," said Colgan.

Warming the ice

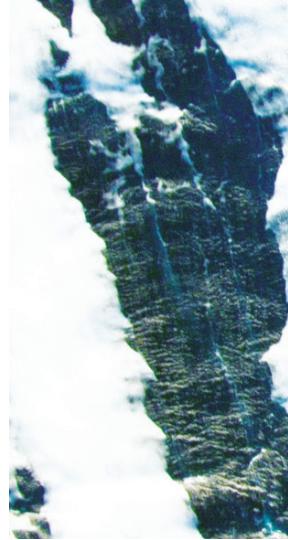
Ice sheets are feeling the heat from within as meltwater flowing through them carries warmth to the interior via crevasses, fractures, and moulins. A new modeling study shows that such warming can greatly accelerate the thermal response of an ice sheet to climate change.

CIRES' postdoctoral researcher Thomas Phillips, Harihar Rajaram of CU-Boulder, and CIRES Director Konrad Steffen worked with models supported by physical data and found that an ice sheet can respond by warming on the order of decades, rather than the centuries projected by conventional thermal models.

"We are finding that once such water flow is initiated through a new section of ice sheet, it can warm rather significantly and quickly, sometimes in just 10 years," said lead author Phillips. "We've termed this process cryo-hydrologic warming."

Ice flows more readily as it warms, the newly named mechanism means that a warming climate can increase ice flows much faster than previously thought. It will still take thousands of years for the ice sheet to disappear, said Steffen.

Unmanned aircraft take hardiness to Antarctic extremes



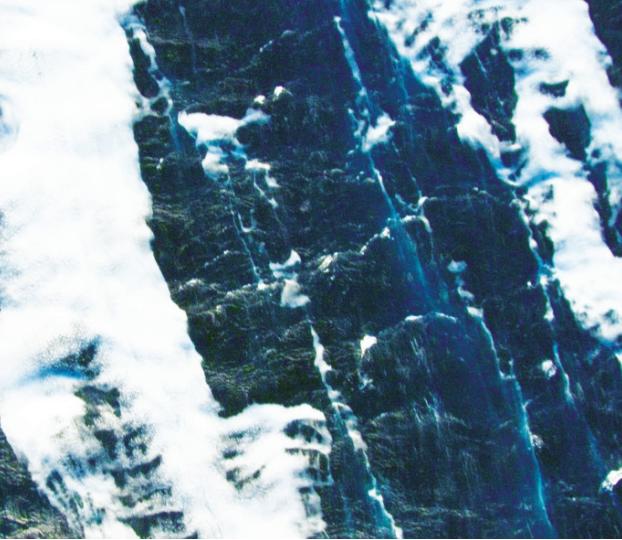
With a click and release, a small white and orange-tipped plane lifted off from the roof of a truck racing down an icy runway. With barely a wobble, the unmanned aircraft swooped into the white sky above the Antarctic, launched by researchers on the ground. For the duration of its flight, the robotic plane would be largely on its own as it collected data from such hard-to-reach and extreme environments as Antarctica.

This unmanned aircraft logged a series of record-setting research flights in its tenure in Antarctica in 2009, providing CIRES researchers and colleagues with some of the first three-dimensional observations of gaping holes in the Antarctic sea ice, known as polynyas, and the blasting winds that help form them.

“These were some of the longest flights on record for scientific applications, and certainly the longest in Antarctica,” said CU-Boulder Research Professor James Maslanik.

Using unmanned planes roughly 9 feet across, Maslanik and CIRES Fellow and Associate Professor John Cassano gained a unique glimpse into the Terra Nova Bay polynya, a stretch of open water that at times yawns 2,000 square miles in area, nearly twice the size of Rhode Island.





The goal of the Antarctic mission was to measure moisture and heat exchanges between the ocean and atmosphere and to eventually unravel the effect of polynyas on global climate, Cassano said.

“In polar regions, sea ice often reduces interactions between the ocean and atmosphere, but in polynyas, open water persists even in the heart of winter,” he said. “It’s in these areas that large amounts of heat and moisture are lost from the ocean to the atmosphere. Instruments aboard the unmanned planes have provided some of the first direct measurements of this heat loss in winter.”

Polynyas can affect global currents, Cassano said, as the cold and salty waters left exposed sink and interact with the oceanic conveyor belt — a phenomenon known as the thermohaline circulation, which moves seawater around the globe through changes in salinity and water temperature. In places where the thermohaline circulation emerges at the ocean surface, it substantially influences weather and climate.

The unmanned aircraft also measured airflow, to help researchers understand the interaction between the polynya and the severe winds that whip over the Antarctic continent. The constant blasting of these winds, called katabatic winds, helps keep the Terra Nova Bay polynya free of new sea ice and open throughout the winter, said Cassano. He said he suspects the polynya influences local wind patterns by creating a low pressure area that can spin off small but intense cyclones.

Cassano and his colleagues are currently analyzing data collected during the Antarctic mission.

“There have been a lot of models and theory-based studies describing polynyas and their climate feedbacks,” Cassano said, “but we can’t fully understand them until we measure them.”

An unmanned plane takes off from the top of a truck during a research trip in Antarctica in 2009. The small unmanned aircraft helped CIRES researchers and colleagues observe the global climate effect of polynyas (above), gaping holes in Antarctic sea ice.

The coolest member of the data family

NASA’s Distributed Active Archive Center (DAAC) collects, archives, and shares data on the cryosphere

Akin to an army of diligent scribes, the data centers of NASA’s Earth Observing System Data and Information System (EOSDIS) record and order information about the planet, 24-7.

This family of information gatherers collect and collate information from the polar-orbiting satellites about the Earth’s land surface, the biosphere, the atmosphere and the oceans, creating a foundation scientists around the world can use to improve their knowledge of the planet. One member of that family, the Distributed Active Archive Center (DAAC) based at CIRES National Snow and Ice Data Center (NSIDC), chronicles the story of the cryosphere.

DAAC keeps tabs on changes in glacier velocity in Alaska, ice-sheet elevation in Antarctica, and the extent and mass of Arctic sea ice, among other things. Operation IceBridge, for example, collects airborne remote-sensing measurements and combines them with ground-based observations to depict rapidly changing portions of land and sea ice in polar regions.

“The ice sheets aren’t standing still, they are changing,” said DAAC manager Ron Weaver of NSIDC. “They are changing much faster than what the common opinion was in the ‘90s, before we had the first IceSAT satellite.”

“One of the things that the data center does is reveal how scientists do their work,” said Weaver. At DAAC, researchers not only provide data, they detail the algorithms used in processing scientific information. These are then archived and made available to other scientists.



“The ice sheets aren’t standing still, they are changing . . . much faster than what the common opinion was in the ‘90s.”

**Ron Weaver, NSIDC,
DAAC manager**



A bird's-eye perspective

When it comes to looking at changes in glaciers and sea ice, Waleed Abdalati, Director of the CIRES Earth Science and Observation Center (ESOC) doesn't just visit the Earth's chillier regions, he uses satellites to inform his research.

Abdalati believes these satellite and airborne remote-sensing technologies are essential to understanding and anticipating how the Earth, and its climate, are changing. In particular, he has used satellite data in his research on understanding glaciers and ice sheets. The process of looking at Earth using satellite and aerial data is termed remote sensing.





NASA appointment

NASA Administrator Charles F. Bolden selected CIRES Fellow Waleed Abdalati to serve as NASA's "Chief Scientist" starting in January 2011. During his two-year appointment with NASA, Abdalati will advocate for the agency's science while retaining his faculty appointment at CU-Boulder.

sensing has revealed is that there are also changes on the scales of hours and days. These big ice beasts are not sluggish at all; they are very dynamic, very active.

Is the same true in other research disciplines?

Remote-sensing observations from space also tell us how healthy forests are and what kinds of vegetation or land cover types exist. We can track urban sprawl, the movement of population types from one place to the other, and the genesis and decay and the intervening trajectory of hurricanes, for example. All these observations have very real world applications to weather, to longer-term climate, and to the distribution and behavior of life on Earth.

What other challenges face the remote-sensing community right now?

The challenge facing the scientific community right now is really the loss or reduction of our assets in space. Of the 14 NASA Earth-observing system satellites launched over the last decade that are still operating, 13 are past their expected design lives.

The Earth is changing in remarkable and dramatic ways that will affect our lives. Just as we are realizing how and why these changes are occurring, our technical ability to observe and understand them is diminishing. Frankly our success, in the future, as a society is intimately linked to our ability to anticipate what is coming. That ability is becoming compromised at a time when we need it most.

on the planet

Can you explain why it is so important to use remote sensing for looking at the Earth's environment?

Remote sensing is observing a medium or a process without ever coming in direct contact with that phenomenon. When you are looking from space, when you are looking from 400-500 miles away, or in some cases thousands or twenty thousand miles away, you get a really different perspective.

We can use remote sensing to better understand our planet as a system, which without the context, perspective, and the scale of observations that remote sensing provides, is really very difficult, if not impossible.

How has remote sensing informed your research?

In my own discipline of understanding ice cover, I think remote sensing has literally rewritten the textbooks of how ice behaves and how it changes. For example, just by watching, taking pictures from space, we have been able to observe very, very rapid changes in Greenland and Antarctic ice cover. We used to think the enormous ice sheets responded slowly to climate, and that is only partially true. We are still seeing the effects of climate change thousands and thousands of years ago being expressed in today's ice cover, but what remote

Ice core isotopes may reveal more than temperature

Since the 1960s, scientists have used natural isotopes — versions of the same atom that vary slightly in weight — as scientific fingerprints. Carbon isotopes help archeologists date ancient human remains, for example. And in ice cores extracted from layers of compacted snow, oxygen and hydrogen isotopes have long been understood to speak to the temperature at the time.

“We know that’s *kind of* right, in a *general* sense,” says CIRES Fellow and Associate

TheScience

Climate clues locked in icy isotopes could give researchers a high-definition view of Arctic climate.

Professor David Noone, emphasizing the adjectives. But it could be that isotopes say as much about patterns of sea ice or clouds as temperature, Noone said. “Nobody has checked this with modern techniques.”

So he’s about to. With a four-year, \$2-million grant from the National Science Foundation, Noone

and his colleagues will set up a unique combination of advanced, laser-based instruments in Summit, Greenland; Reykjavik, Iceland; and Eureka, Canada. They plan to track how various factors — evaporation from oceans, creation of clouds, patterns of moist air movements, the settling of snow into compacted layers, and temperature — affect isotopes in the snow layers.

If Noone’s team can unravel those factors and how they create isotopic signatures in Greenland snow, then other scientists will be able to use the results to extract more information about past climates. Perhaps ice core data — which Noone calls “underutilized” — will help climate researchers better understand changing patterns of cloudiness and sea-ice cover in the Arctic, as well as temperature.

The project could fill in the picture much as corrective lenses can help a near-sighted person see more than just the broad outline of a distant tree, Noone said. With glasses, branches and leaves suddenly appear. “And there’s a chance,” he said, “that when we hold up our lens we’ll discover ‘Oh, it’s a shrub!’ or ‘That’s two trees.’”



Tracking Europe’s “weather machine”

Greenland Climate Network (GC-Net) will leap into public service in 2011, providing up-to-the-hour weather and ice-sheet information to the Danish office of the World Meteorological Organization. The data provided by the weather stations deployed on the Greenland’s Ice Sheet should boost Europe’s weather prediction capabilities.

“The Greenland Ice Sheet is the weather machine for Europe,” said CIRES Director Konrad Steffen. “Any changes of circulation in Greenland, such as cyclone frequency, have a large effect on weather in Central and Northern Europe.”

To improve predictions, weather forecasters need more accurate pressure readings, temperature, and wind velocity information. “The GC-Net provides this basic information on time to be part of an hourly worldwide distribution of standard meteorology data,” said Steffen.

These forecasts will also be helpful closer to home, he said. “GC-Net will improve local forecasts for Greenland, which are essential for transport and the fishing industry.”

Greenland's ice sheet real-time, real fast

The intimidating vastness of the Greenland Ice Sheet is a familiar backyard to CIRES Director Konrad Steffen. He has amassed more than 20 years of meteorological and glaciological data as part of the Greenland Climate Network, or GC-Net, a series of automated weather stations tracking changes in Arctic conditions.

The project stands poised to enter a new phase of research, providing more complete weather information to the World Meteorological Organization (WMO) in Geneva, and the Danish Meteorological Institute (see sidebar on p. 14). Already, the long-running and extensive datasets are revealing some surprising trends about the polar climate: Steffen and his colleagues have shown that polar regions are responding much faster to climate change than expected.

"Since 2000, Greenland's ice sheet has gone from losing 50 gigatons of ice per year to 250 a year," says Steffen. "That's two times all the ice in the European Alps."

This rapid response to warming is largely due to the ice sheet's albedo — the surface's ability to reflect light — says Steffen. Melting snow is not as bright as fresh snow, so it absorbs more energy and becomes warmer. The resulting darker meltwater also absorbs more light, so overall, more ice melts into water and runs into the ocean. By scientist's calculations, Greenland's ice loss (about half from melt, half from iceberg calving) accounts for about 30 percent of the global sea-level rise originating from ice.

Steffen expects the meltwater trend to continue in the coming years. "We were able to detect a two-degree-Celsius (almost four-degree-Fahrenheit) increase in mean temperature per decade at Swiss Camp, which is huge," says Steffen.

Current weather and climate models are not very good at picking up the increase in ice loss from melting and iceberg calving, but data collected by GC-Net are likely to help. Each of 18 stations currently active around the ice sheet collects a host of information, including temperature, humidity, wind velocity, solar and Earth radiation, and ice-sheet elevation, beamed back hourly via satellite to Steffen's office in Boulder,



Photos/Konrad Steffen

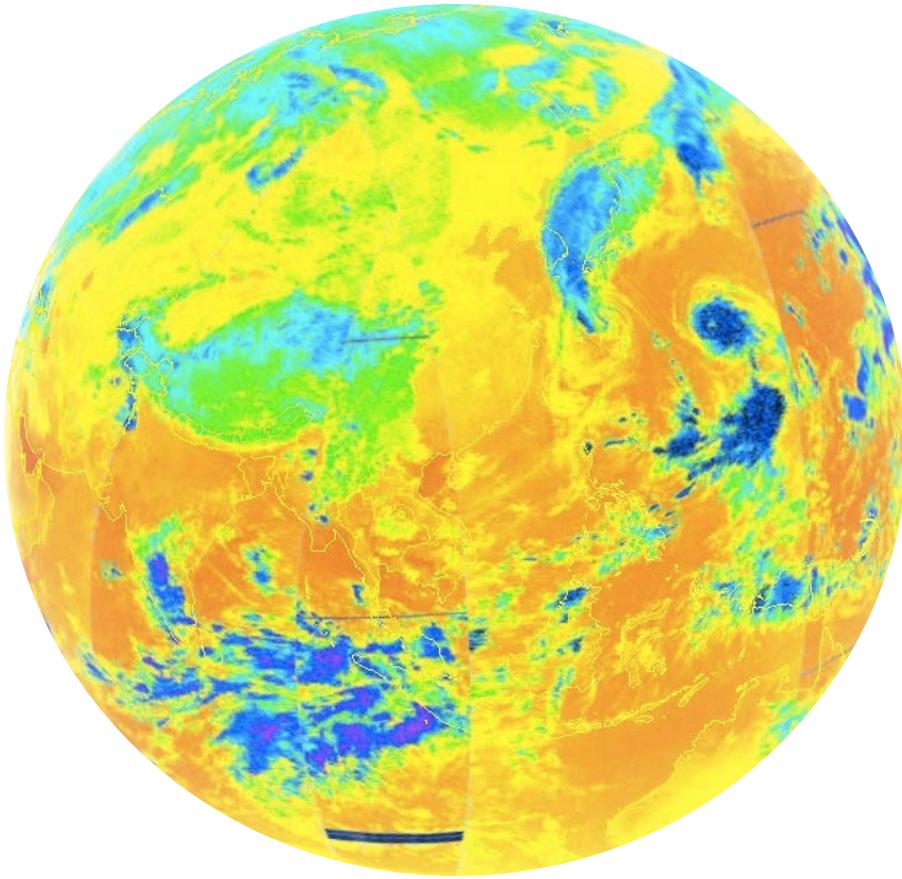
Swiss Camp on the Greenland Ice Sheet in 1990, and then during the snowy year of 1995. Natural variability imposes ups and downs in snow levels and temperatures, but overall, it's getting warmer.

Colorado. The data ultimately become available to other researchers, and provide a high-resolution dataset to compare against regional models used to project future changes. "To understand changing seasons and forcing, we need higher-resolution data, which is provided by GC-Net."

Beaming data back by satellites requires a substantial effort: Steffen and his team travel once a year to Greenland to check on some of the stations personally. The researchers have endured white-out blizzards, rebuilt collapsed camps, and perfected their extreme environment electronic skills — all to bring back the data that's providing the most intimate view yet of Greenland's changing climate.

"It's worth it," says Steffen. "This kind of long-term monitoring in polar regions is crucial to understanding how the ice sheet is responding to rising temperatures and changes in precipitation."

This project is sponsored by NASA and the National Science Foundation.



Nimbus II HRIR
Google Earth image,
September 23, 1966.
Note the cooler
temperatures of the
Himalayan Plateau,
the warm waters of
the Gulf of Tonkin
and typhoons Ida and
Helen.



Not forgotten

CIRES scientists extract sea-ice data from aging records

Scientists today who study polar sea ice conditions rely on satellite records reaching back to 1979. But CIRES researchers in the National Snow and Ice Data Center (NSIDC) are learning to extend their understanding of Earth's poles by sifting through some of the oldest Earth-observing satellite data for new information.

"This irreplaceable data has relevance to climate change and should be saved as a part of the climate data record," the NSIDC-led team concluded during an Innovative Research Program (IRP) poster presentation at CIRES in November 2010 (the original research was funded by CIRES' IRP).

When NASA launched the Nimbus satellites in the 1960s, primarily to make twice daily, global, meteorological observations, no methods existed

to detect features such as the margins of the sea ice cover in the Arctic and Antarctic. Computer processing power was too weak to support much experimentation.

TheScience

Decades-old satellite images can be "reprocessed" to extend the scientific record of Arctic sea ice extent and understanding of climate changes in the region.

But in 2007, John Moses at the NASA Goddard Earth Science Data and Information Service began recovery of 45-year-old digital satellite data from the Nimbus Polar orbiter. NSIDC scientist Walt Meier and project manager David Gallaher heard about the work, and they wondered if this early NASA satellite data might also yield information about sea ice conditions before 1979.

The window of opportunity for recovering the old data was closing rapidly. Only the third-generation copy of the digital infrared data still existed along with a single copy of the Nimbus visible light films. In addition,



Original (top) and reprocessed (bottom) images of Earth. NASA

the original Nimbus researchers were now in their late '70s and '80s, and contact with them would be critical to answering some instrumentation questions. These recovered data could be valuable to other Earth science researchers as well.

Meier and Gallaher worked with Dennis Wingo at NASA's Lunar Orbiter Image Recovery Project to read and reprocess old Nimbus satellite images, removing errors resulting from the limits of the original processing. Wingo and his staff are experienced in reprocessing old digital data, having recently recovered stunning lunar images from the 1960s. The team finally managed to extract a global infrared image, captured in late September of 1966, at higher resolution than seen before. That's the time of year when Arctic sea ice would normally have been reaching its end-of-season minimum extent.

Much work remains: the researchers seek to reprocess 5000+ Nimbus I, II, and III half-orbit records, develop post-processing algorithms to improve quality, and will then need to painstakingly compare images to separate clouds from ice.

NOAA's Climate Data Modernization Program may get involved in scanning the 200,000+ visible light images acquired by the early Nimbus missions, which are vital, along with the infrared data, in determining sea ice extent.

It could be well worth it: Success extracting the polar monthly sea ice extents for the years 1962-1978 (from Nimbus and other satellite data) would mean adding 16 years of data to a critical climate dataset of 32 years, today — an extension of 50 percent.

Story courtesy of NSIDC.

Goodbye, ice — hello, snow and rain

Model predicts increasing autumn precipitation for Arctic Ocean

The Arctic Ocean is losing its sea-ice blanket, but not its rain or snow. In fact, autumn precipitation is on the rise, says Julienne Stroeve of CIRES' National Snow and Ice Data Center.

Stroeve is trying to understand how thawing Arctic sea ice impacts the Northern Hemisphere climate. As the air becomes warmer and moister from that thawing, cyclones might become more frequent and intense, she says, which could make for more rain or, in the colder months, snow.

To test both theories, Stroeve used a sophisticated computer program created by NSIDC Director and CIRES Fellow Mark Serreze to track down cyclones. Into this program, she fed reanalysis data values (see sidebar at right) for sea-level pressure. The program used the data to identify when and where cyclones had occurred in the region from 1979 to 2008. Then, Stroeve then looked again at the reanalysis data to see the levels of rain and snow that accompanied the cyclones.

Applied over the Arctic Ocean, the program predicts that cyclones will become both more intense and frequent, leading to autumn downpours or snowy showers. An increase in cyclone intensity would be no surprise, Stroeve said, as the water-heavy atmosphere is ripe for the cyclones. "You just have more energy for storms," she said.

The program, however, output something unexpected: While there was a total precipitation increase for the entire region, a large proportion of this precipitation came from the North Atlantic region — a region that is always ice-free. "When you look at the spatial patterns of where the increased precipitation is happening, it is not exactly where you would expect it to be," Stroeve said. "So that leaves you unable to conclusively attribute it to reduced sea-ice extent."

Reanalysis

In reanalysis, weather and climate researchers reconstruct past weather conditions on Earth, starting with incomplete observations. Reanalysis datasets combine real, historic observations with modern numerical weather forecast models that incorporate understanding of how the atmosphere works. The technique allows researchers to "hindcast" historical conditions for locations where no observations were taken.

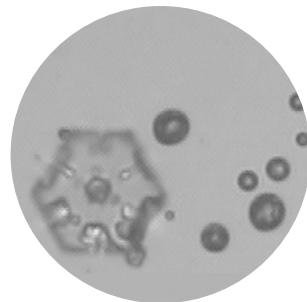
Two factors could be playing a part in this unexpected result, Stroeve said. Potentially, the loss of sea ice could be driving circulation changes, making for stronger North Atlantic storm tracks that are dumping more precipitation in the region, she said. Or it simply could be too early to detect an emerging pattern between sea ice loss and more precipitation. "These really large open water areas have only just recently happened," she said. "So the time period for a robust signal is relatively short."

Stroeve plans to continue investigating the relationship between sea ice and regional precipitation with climate models. "We hope to get at causation by using models," Stroeve said. "With models we can isolate the atmospheric and terrestrial response to depleted Arctic sea ice."



"These really large open water areas have only just recently happened. So the time period for a robust signal is relatively short." Julienne Stroeve

An ice crystal is born



A new ice crystal

Huddled around a monitor in her laboratory, Margaret Tolbert and two of her graduate students stare intently at a white screen filled with a bunch of black specks, waiting.

A machine pumps water vapor into the sample. Then, as if by magic, little spears of translucent material sprout from a particularly large speck in the lower right-hand corner of the screen. “Look, there one goes!” says Tolbert, Distinguished Professor and CIRES Fellow.

And just like that, an ice crystal is born.

By studying ice formation at this tiniest of scales, Tolbert seeks to understand a much bigger phenomenon: cirrus clouds, which affect climate. “Clouds are one of the largest uncertainties for climate predictions,” said Tolbert.

Airplane contrails, fossil fuel emissions, and biomass burning all create particles that can seed the formation of these wispy, ice-laden heat-trapping clouds. Those human activities are changing — while cirrus clouds only occupy 3 percent of busy flyways now, by 2050, scientists expect that number to be closer to 20 percent. So Tolbert and her colleagues are scrutinizing the basic processes that form the clouds, to better understand the influence of human activities.

Clouds are made up of thousands and thousands of ice crystals. Yet, in a batch of particles, ice will only form on

one out of every 10,000.

Tolbert and her team want to find out what makes the one particle in a batch so ice-worthy.

To do that, Tolbert and her graduate students coat tiny discs with lab-grown versions of air particles found in the tropical tropopause — a cirrus cloud-laden stretch of atmosphere about 12 miles above the tropics. The team then creates pockets of tropical tropopause-like atmosphere in the lab, so they can subject the particles to conditions of temperature, pressure, and water vapor that lead to ice formation.

Then, they wait to see which one will be the most attractive for ice formation.

Size, chemical content, and physique influence why one particle gets the ice crystal and others don’t. Larger inorganic particles, for example a speck of soil dust with lots of rough edges, seem to make primo ice surfaces, Tolbert found.

Not only that, but once one particle grows ice, the rest are out of luck. Chances are, all the ingredients have been used up, says Tolbert. “It’s like first come, only served.”

Student Focus: Kelly Baustian

After investigating what makes a lab-generated particle conducive to ice formation, scientists are turning their attention to particles collected directly from the environment.

Kelly Baustian, a graduate student with Distinguished Professor and CIRES Fellow Margaret Tolbert’s group, collected particle samples at the Desert Research Institute’s Storm Peak Laboratory in Steamboat Springs, Colorado, in January 2010, to find out which particles lend themselves to ice cloud formation in nature.

Samples of particles collected from the great outdoors were brought back to the lab and put through paces similar to their laboratory-generated counterparts.

During preliminary work, Baustian observed that, just as with lab-generated particles, ice will only form on certain ones. Analysis of chemical and physical composition will help suss out what makes one particle so ice-friendly and others not, the researchers expect, and results can be compared with those from laboratory-generated samples.

These results could help researchers better understand how airborne particles, such as those emitted from factories or airplanes, can lead to the formation of ice crystals that make up climate-warming cirrus clouds.

“Working with these samples has given me a new appreciation for the complexity of our atmosphere,” said Baustian, “and how susceptible it is to human alteration.”



Kelly Baustian earned a Graduate Student Research Fellowship to support her work.

CIRES offers graduate student fellowships.

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Highest-elevation glaciers

A case study from the Nepal Himalaya shows no melt over large areas, and relatively small contribution to streamflow

The most striking feature of Asia's Himalaya Mountains — their breathtaking height — makes Himalayan glaciers far less vulnerable to melting than their lower-elevation counterparts.

It's cold at 18,000 feet and above. Really cold. All the time.

That may seem perfectly obvious, said CIRES Fellow Richard Armstrong, but the basic facts appear to have eluded many people.

"We have all heard these stories about how Himalayan glaciers are melting faster than anywhere else, drinking water is disappearing, there will be widespread catastrophic floods, etc. . . ." said Armstrong, a glaciologist at CIRES National Snow and Ice Data Center. "Well, when you start looking, there's really no data to support those statements."

A couple of years ago, when a colleague of his was approached by the World Bank, Armstrong agreed to help search for data from Himalayan glaciers, to assess

the veracity of water resource fears.

"The World Bank is approached by people wanting to borrow money to build dams, and they wanted to know if there's going to be any water left to fill them," Armstrong said.

So Armstrong and his colleagues set about trying to estimate, for a remote and difficult-to-access region, how much streamflow came from glacial melt as opposed to monsoon rains and the melt of the seasonal snow cover.

"We thought this work would be a literature search," Armstrong said. "But we couldn't find any real research in this area."

What his team did find in the literature were plenty of big numbers. Glacier termini were retreating 10 to 60 m a year. There were estimates that glacial melt provides 50, 60, 70 percent of the flow of the Ganges.

It sounded quite dire, but the researchers knew first that termini measurements are not the last word



iStockphoto

keep their cool

on glacial melt, especially at the higher elevations. Termini can retreat even when glaciers are gaining mass overall, through snowfall at higher elevations. Moreover, the streamflow estimates had no robust calculations to support them.

So the team began looking for raw data. Little or no data were available across much of the Himalaya, but the team identified nine basins in Nepal that contained digital glacier maps, stream gauge data, and the availability of NASA's Shuttle Radar Topography Mission — so high-quality digital elevation data were available.

"We got everything we needed, thanks to the collaboration and co-operation of various institutions in Nepal," Armstrong said.

After developing a method to estimate the current mass balance on the Nepalese glaciers, one that took into consideration their high elevations, the team

reached two key conclusions: 1) Glacial melt contributes from 2 to 20 percent of the streamflow in the basins studied, much lower than anecdotally estimated, and 2) More than 50 percent of the surface area of the

Nepalese glaciers never melts at all, during any time of year.

Globally, the prognosis for glaciers is dismal, said Armstrong. He spent years studying glaciers in the mountains of Washington State, where many glaciers are currently retreating and melting rapidly. There's little doubt that glaciers in many locations across North America and the European Alps are melting, and that the same is true throughout the world at elevations below 14,000 feet.

But the glaciers of the Himalaya at elevations of 18,000 feet and above are holding their own quite well, Armstrong said. "It's a bit simple, but the situation changes when you go up, when you're at elevations that the rest of the world doesn't see."

TheScience

Himalayan glaciers resist melt across 50 percent of their surface, and contribute much less to streamflow than assumed.

Frozen carbon bomb

Thawing frozen ground will unleash yet more carbon into atmosphere

As ground, previously frozen for millennia, begins to thaw out in warmer temperatures, it will unleash vast quantities of carbon into the atmosphere, further confounding attempts to slow down global warming.

“The amount of carbon we are talking about is equivalent to half the amount of carbon released into the atmosphere since the dawn of the Industrial Age,” said CIRES scientist Kevin Schaefer, with the National Snow and Ice Data Center (NSIDC) who is looking at the effect of a thawing Arctic on climate. “That is a lot of carbon.”

The carbon from the frozen ground — known as permafrost — will make its impact not only on the climate, but also on international strategies to reduce global warming, Schaefer said. “If we want to hit a target carbon concentration, then we have to reduce fossil fuel emissions even lower than previously calculated to account for the additional carbon from permafrost,” Schaefer said.

“Otherwise we will end up with a warmer Earth than we want.”

The carbon comes from decaying plant and animal material entombed in soil thousands of years ago. Once the ground froze, in the Ice Age of the Pleistocene, it trapped and preserved the decaying biomass. Schaefer equates the mechanism to the freezing of broccoli in a home freezer: “As long as it stays frozen, it stays stable,” he said. “But you take it out of the freezer and you put it in the refrigerator, and it will thaw out and decay.”

Now, a warming climate is thawing out the frozen ground and the biomass will start to decay, releasing carbon into the atmosphere like any other decomposing plant material, Schaefer said.

To predict just how much carbon will enter the atmosphere and when, Schaefer and CIRES Fellow Tingjun Zhang (also part of the NSIDC) modeled the thaw and decay of organic matter currently frozen in permafrost under potential future warming conditions as predicted by the Intergovernmental Panel on Climate Change.

They found that between one-third and two-thirds of permafrost will disappear by 2200. “The reason it takes

Tim Schaefer, Lin Liu, and Tingjun Zhang drilling a permafrost core sample near Deadhorse, Alaska.



is ticking

TheScience

One-third to two-thirds of permafrost will disappear by 2200, according to a new estimate. That thaw could thwart people's efforts to limit greenhouse gas concentrations in the atmosphere.

so long is because basically you are talking about melting a huge block of ice," Schaefer said.

The scientists used the model to predict how much carbon the thawing will release. They estimate an extra 190 ± 64 gigatons of carbon will enter the atmosphere by 2200 — about one-fifth the total amount of carbon currently in the atmosphere today. Carbon emissions from thawing permafrost will require greater reductions in fossil fuel emissions to limit the atmospheric carbon dioxide. "It means the problem is getting more and more difficult all the time," said Schaefer. "It is hard enough to reduce fossil fuel emissions in any case, but now we saying that we have to reduce it even more."



Scientists to author 5th Assessment Report

The Intergovernmental Panel on Climate Change selected several CIRES researchers to serve as lead authors for the 5th Assessment Report, due in 2013-2014.



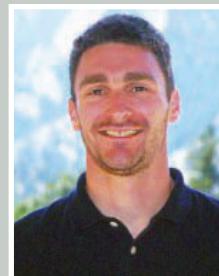
CIRES Director Konrad Steffen and Fellow Tingjun Zhang will be lead authors on the cryosphere chapter.



CIRES senior scientist Judith Perlwitz will be a lead author of a chapter on detecting and attributing climate change.



CIRES Fellow Steve Nerem will be lead author of a new chapter on sea-level change.



Affiliated with CIRES, NCAR researcher Jean-Francois Lamarque will be lead author on a chapter on anthropogenic and natural radiative forcing.



MySphere

How people work,
research, and relax at CIRES

- 1 In 2009, the steel posts that had supported a platform with three insulated tents, six skidoos, and other equipment for over 20 years collapsed.
- 2 A major loss was the six-person sauna, for bathing and warming up. Steffen said he hopes to rebuild in 2011 — there wasn't time in 2010. "The science came first," he said, "and we had so many things to do."
- 3 When snow blocked the sauna's more accessible entrance, researchers and visitors climbed through the roof hatch.



Swiss Camp

CIRES Director Konrad Steffen has conducted research and maintained a station on the Greenland Ice Sheet since 1990. He and his colleagues lived and worked in roughly the same setup — three insulated tents and a plywood sauna — for more than two decades.

In 2009, much of the station collapsed when thick steel supports finally buckled. In the summer of 2009, Steffen and his colleagues spent two extra weeks in Greenland, rebuilding.

Two new insulated tents (11) now support science work and a kitchen, and the bunk tent has been replaced with old-school but reliable “Scott Tents” from England (12). One or two people can sleep in each canvas tent, where the temperature typically hovers about minus 20 degrees Celsius.

“That’s a good temperature for sleeping,” Steffen said. “If you want to, you bring in a bottle with hot water from the kitchen to warm up.”

Electricity from solar panels and a wind turbine (13) power all electrical equipment at Swiss Camp.



Photos/Konrad Steffen

4 Swiss Camp supported three “tents,” with 8-inch-thick walls made from layers of insulation and fabric. One served as bunkhouse, another as a “work tent” with computers and other equipment, and a third as kitchen. In the kitchen tent, Steffen dished up dinner for the then-Speaker of the House during a visit in 2007.

5 Wind shredded several layers of the kitchen tent sometime between late 2007 and early 2008. A *Rolling Stone* reporter on his way to Swiss Camp brought in the blue tarp as a temporary fix.

6 Instrument tower for climate measurements.

7 Skidoo fuel.

8 Melting ice left a pool of water under the Swiss Camp in 2009. Snow levels at Swiss Camp are dropping, through some years, it still snows enough to block doors.

9 Propane for cooking and heating.

10 Spare generator fuel.



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CIRES is a cooperative institute of the University of Colorado at Boulder and the National Oceanic and Atmospheric Administration.

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