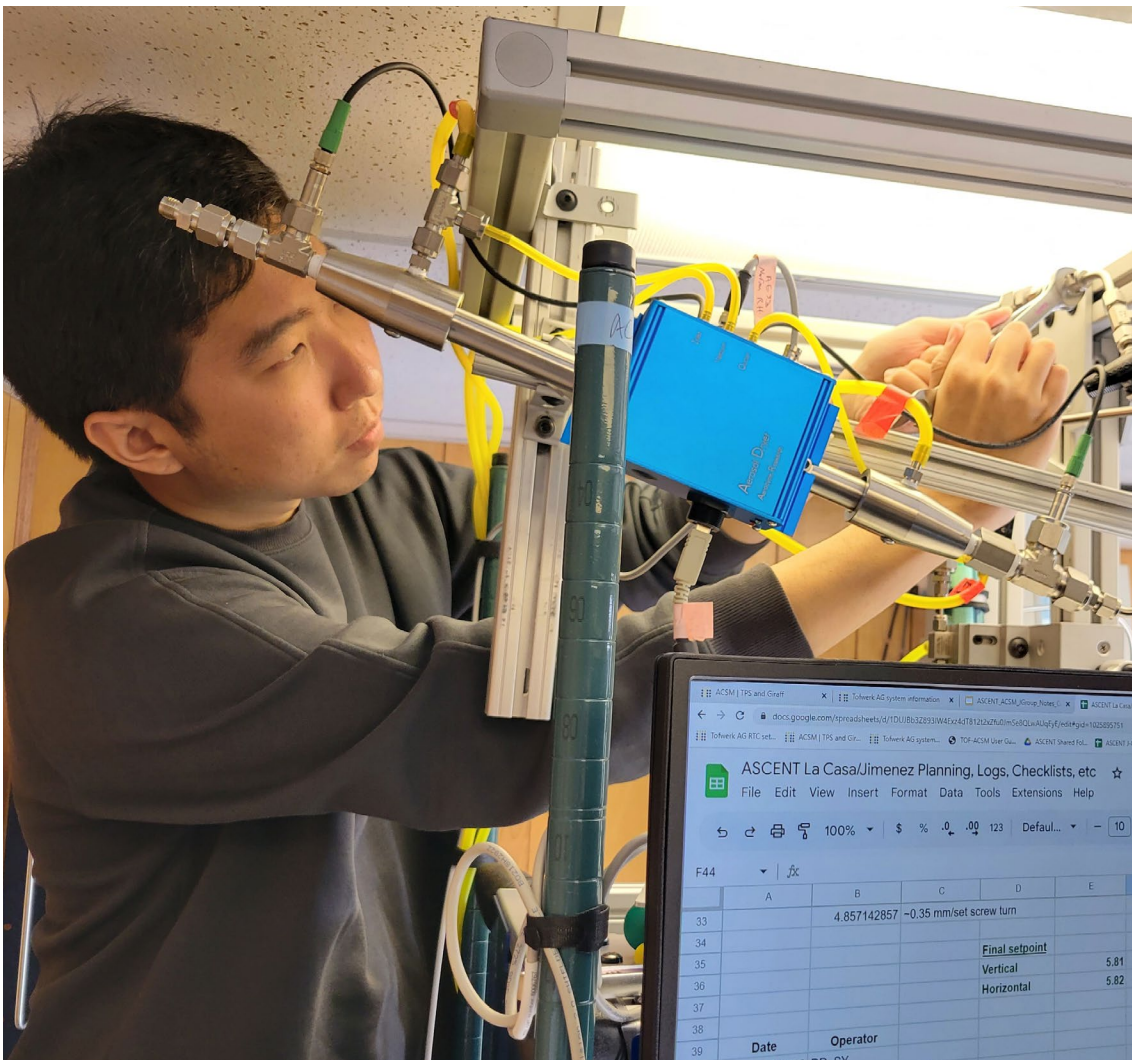
EDITION 17 • 2025

CIRES
COOPERATIVE INSTITUTE FOR RESEARCH IN ENVIRONMENTAL SCIENCES

SPHERES



HYDROSPHERE
Warmer but wetter weather could control Colorado River flow

CLIMATE SPHERE
Greenhouse gases, temps surge worldwide

FIRE SPHERE
Western US fires grow faster, destroy more buildings

BIOSPHERE
Social media posts reveal patterns in seasonal allergies

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Students research their Tribes' climate challenges

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Arctic sea ice 'fundamentally changed'

ISSN 2380-2855

SPHERES

A publication of the Cooperative Institute for Research in Environmental Sciences

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ACRONYMS

ATOC: CU Boulder Department of Atmospheric and Oceanic Sciences

CEEE: CIRES Center for Education, Engagement, and Evaluation

CSL: NOAA Chemical Sciences Laboratory

ESIIL: Environmental Data Science Innovation & Inclusion Lab

GML: NOAA Global Monitoring Laboratory

GSL: NOAA Global Systems Laboratory

NC CASC: North Central Climate Adaptation Science Center

NCEI: NOAA National Centers for Environmental Information

NIDIS: National Intergrated Drought Information System

NSIDC: National Snow and Ice Data Center

PSL: NOAA Physical Sciences Laboratory

RECCS: Research Experience for Community College Students

SWPC: NOAA Space Weather Prediction Center

CIRES at the University of Colorado Boulder has partnered with NOAA since 1967. We conduct innovative research that advances our understanding of the global, regional, and local environments and the human relationship with those environments, for the benefit of society. Our environmental scientists explore many aspects of Earth system science: the atmosphere, cryosphere, hydrosphere, geosphere, and biosphere. These spheres of expertise give our magazine its name.

Cover photo: PhD student Seonsik Yun sets up equipment inside a monitoring station in north Denver. Story, page 24. Photo: Doug Day/CIRES

SPHERES **BY THE NUMBERS**

57% **Antarctic meltwater** that is held as slush (PAGE 5).

1,850 **tree ring records** analyzed by CIRES researchers to learn more about wildfire frequency (PAGE 12).

426.90 **ppm:** average carbon dioxide concentration in the atmosphere in 2023-2024 (PAGE 15).

40% **rise** in nitrous oxide in the atmosphere between 1980 and 2020 (PAGE 15).

25 **years:** time span that precipitation, not temperature, could continue to dictate the flow of the Colorado River (PAGE 18).

30% **likelihood of flooding** following dry spell of 10-20 days without precipitation (PAGE 19).

30 **years of data** used to understand the impact of sea otters on kelp ecosystems along the coastlines of islands in Southern California and British Columbia (PAGE 21).

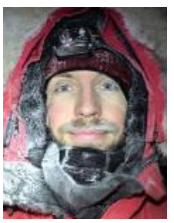
4.5 **meters:** displacement in what should have been a straight-line mile of track after 1886 earthquake in SC (PAGE 33).

5 **new fellows** recognized by CIRES (PAGE 37).

The ICECAPS-MELT field team installs and stabilizes a 14-foot wind turbine. Photo: Michael Gallagher/CIRES

Melting, north and south

Shupe



Gallagher

Researchers in Greenland hone in on ice-atmosphere interactions

Last May on the Greenland ice sheet, CIRES Fellow **Matthew Shupe**, Research Scientist **Michael Gallagher**, and three colleagues braved cold, blustery conditions to install scientific instruments that observe changes in the ice sheet-atmosphere system during the summer melt season. Over almost a month, the team installed 25 instruments that run autonomously to monitor heat, moisture, and ice structure. Over the summer, the group observed from afar the Greenland percolation zone, where conditions on the ice sheet transition from dry snow to summer melt.

"The MELT [MEasurements along Lagrangian Transects] project was the first to observe the coupled climate system in such detail autonomously in the region," Gallagher said. "Our observations provided important insight into the changes happening as anthropogenic climate change continues to impact Greenland."

The team installed radiometers, ground-penetrating radar, GPS equipment, temperature probes, and radar systems that range from ground level to many kilometers in

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the air. This suite of instrumentation used a novel, custom-engineered, renewable energy power system of both wind turbines and solar panels.

From the end of May to August 2024, the instruments collected data about energy moving in and out of the ice, firn structure, temperature variability, precipitation, cloud cover, and more. The team accessed and started analyzing the observations in real time, from labs and offices around the world.

More slush, more melt

Banwell

Willis

Slush, or water-soaked snow, makes up more than half of all meltwater on Antarctica's ice shelves during the height of summer, yet current climate models don't account for it well. Research led by the University of Cambridge, in collaboration with CIRES Research Scientist **Alison Banwell** and 2019 Visiting Fellow **Ian Willis**, used artificial intelligence techniques to find that 57 percent of all meltwater on ice shelves is held in the form of slush, the rest in surface ponds.

The researchers also found slush and ponded meltwater lead to 2.8 times more meltwater formation than predicted by current climate models since they absorb more heat from the sun than ice or snow. The results could have profound implications for ice shelf stability and sea level rise, especially because previous mapping studies have neglected slush and only mapped ponds.

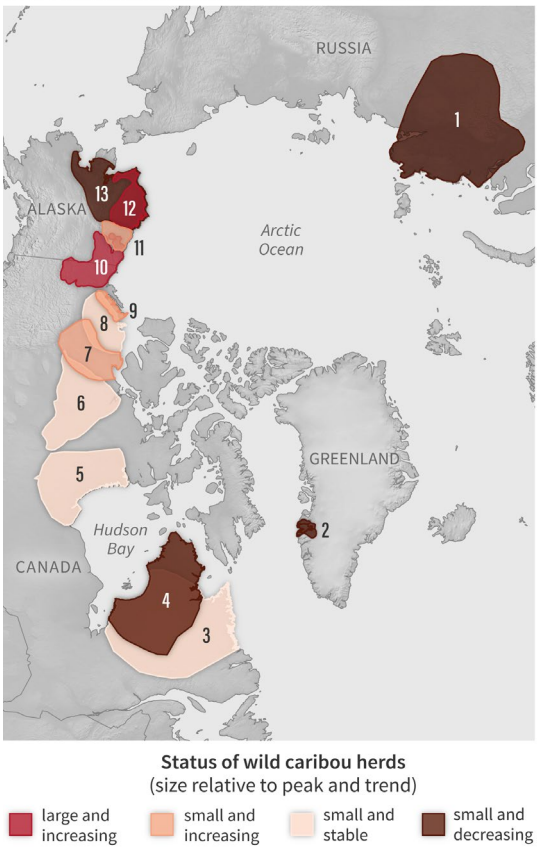
"Like meltwater, slush has a lower albedo than snow or ice, so it absorbs more heat from the sun, leading to even more melting through a positive feedback cycle," Banwell said. "So the results of our study have worrying implications for the future stability of Antarctica's ice shelves."

https://bit.ly/percolation-zone

https://icecapsmelt.org/

www.nature.com/articles/s41561-024-01466-6

CRYO SHORTS



Map shows the location and status of 13 Arctic caribou herds relative to their peak. Image: NOAA Climate.gov

2024 Arctic Report Card: Fewer caribou, higher temps, more precip

Research presented in the 2024 Arctic Report Card, written by 97 scientists from 11 countries, reveals record-setting observations that underlie ongoing changes emerging in the Arctic, including:

- Continuing high air temperatures and wildfires
- Declines of large inland caribou herds
- Increasing precipitation,

VIDEO: NOAA ARCTIC REPORT CARD

CONTINUED ON PAGE 8

Warming melts ice sheets faster than cooling refreezes

Thompson-Munson

'It's important because this porous firn can buffer the ice sheet's sea level rise contribution.'

Ice core research has helped scientists understand that it's easier to melt an ice sheet than to freeze it up again. Now, they know at least part of the reason why, and it has to do with ice's "sponginess," according to CIRES research.

A recent study used a physics-based numerical model to assess the impacts of warming and cooling on firn, the porous layer between snow and glacial ice, over the entire Greenland ice sheet. **Megan Thompson-Munson**, a former ATOC PhD student, led the study alongside her advisors: CIRES Fellow **Jen Kay** and INSTAAR Fellow **Brad Markle.**

"The amount of change that occurs within the firn layer due to warming and cooling is not equal in magnitude," Thompson-Munson said. "If we look at thousands or millions of years, we see asymmetric ice sheet behavior overall: Ice sheets can melt away quickly, but take a long time to grow. This firn asymmetry we identify is a small piece of that puzzle."

Firn covers about 90 percent of the Greenland ice sheet. It is mostly located at higher elevations where, along with snow, it acts as a buffer against sea level rise. Firn is porous and spongy, which allows meltwater to pass through on its way to the solid ice layer below, where it can refreeze, adding mass to the existing ice sheet instead of flowing to the ocean where it could raise sea levels.

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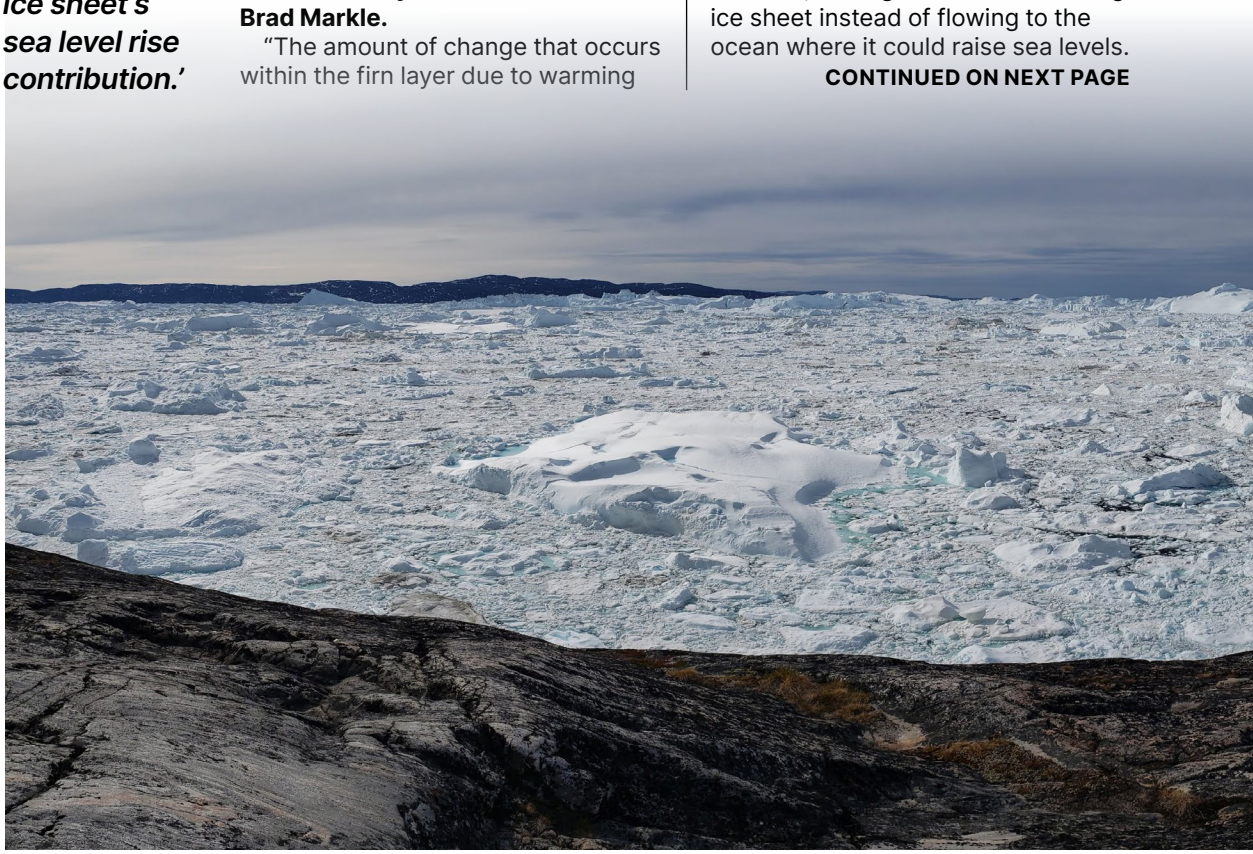

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In this study, researchers found warming temperatures are rapidly changing how efficiently firn can store meltwater, and cooling temperatures may not help the firn fully recover as much as scientists might have hoped.

"The warming depletes what we call the 'firn air content' or the 'sponginess,'" Thompson-Munson said. "So you lose more of the sponginess due to warming than can be regained due to cooling. And it's important because this porous firn can buffer the ice sheet's sea level rise contribution."

The study is the first of its kind in two ways. First, researchers looked at the impacts of both warming and cooling temperatures on Greenland firn. Second, the scope of the research covered the entire ice sheet, while previous studies focused on smaller geographical areas.

"The Greenland ice sheet loses mass faster under warming than it gains mass under cooling," Kay said. "The key advance of this study is that Greenland's firn contributes to this greater warming-than-cooling asymmetric response."

Thompson-Munson said the study highlights an important question regarding climate intervention and humans' ability to reverse Earth's warming. Any climate intervention tecniques designed to decrease temperatures in the Arctic might not preserve ice and snow as efficiently as imagined; the degree of cooling will have to exceed the degree of warming to help firn and glaciers return to normal.

"To get back to initial conditions, we'd have to cool a lot more or start changing other variables as well," Thompson-Munson said. "It's hard to reverse what we've already done."

bit.ly/warming-cooling-firn

bit.ly/firn-responds-to-warming

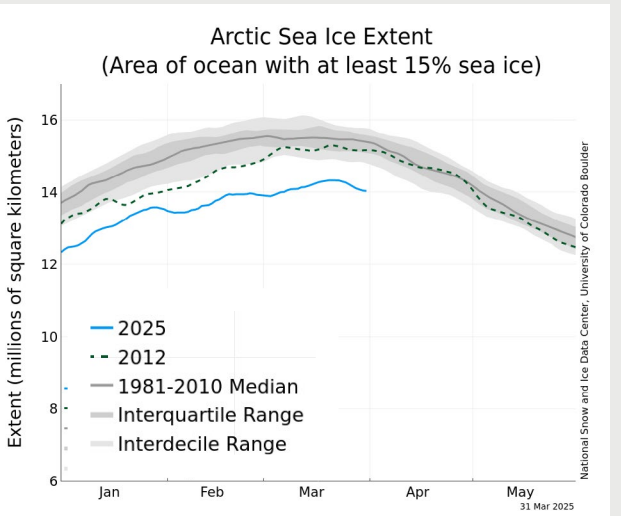
Kay

Markle

Icebergs in the Ilulissat Icefjord, Greenland. The ice sheet served as the subject for Thompson-Munson's work studying firn.
Photo: Megan Thompson-Munson/CIRES

ARCTIC SEA ICE, 2024-2025

"Fundamentally changed from earlier decades"



The last 18 years are the lowest 18 Arctic sea ice extents in the satellite record.

"Every year brings something new for the Arctic Ocean," said NSIDC Senior Research Scientist **Walt Meier**. "This summer we saw very early ice loss in Hudson Bay, open water near the North Pole, and a stubborn ice floe near the Bering Strait that persisted through the summer melt season. While it wasn't a new record low, this year's sea ice minimum is yet another example of a changed Arctic environment."

bit.ly/arctic-min-2024

Arctic sea ice reached a record-low maximum extent of 14.33 million square kilometers on March 22, 2025, according to the 47-year satellite record.

The former low was in 2017 measuring 14.41 million square kilometers.

"This new record low is yet another indicator of how Arctic sea ice has fundamentally changed from earlier decades," said Meier. "But even more importantly than the record low is that this year adds yet another data point to the continuing long-term loss of Arctic sea ice in all seasons."

bit.ly/arctic-max-record-low-2025

CRYO SHORTS

CONTINUED FROM PAGE 5

including rain-on-snow events that coat the landscape in an icy shell, making travel difficult for people and foraging challenging for wildlife

"This year's report demonstrates the urgent need for adaptation as climate conditions quickly change," said **Twila Moon**, lead editor of the 2024 Report Card and deputy lead scientist at NSIDC. "Indigenous Knowledge and community-led research programs can inform successful responses to rapid Arctic changes."

bit.ly/tundra-emits-CO2

NASA award: Tracking ice sheet melting via satellite

CIRES Fellow **Khosro Ghobadi-Far** is advancing the science of climate change with orbiting satellites. In 2024, NASA awarded him an $800,000 grant to analyze data from GRACE-FO satellites, which measure variations in Earth's gravitational field. Although gravity may appear constant to humans, it fluctuates across Earth's surface in ways that can be valuable to climate science.


Ghobadi-Far

"The variations are due to mass movement," Ghobadi-Far said. "Because of climate change and global warming, the Greenland Ice Sheet and Antarctic ice sheet are losing huge amounts of mass, and when that mass changes, it changes the gravity field of Earth."

The high-resolution data will help identify the exact locations of the largest loss on ice sheets. Understanding the differences across the

CONTINUED ON PAGE 9

CRYO SHORTS

CONTINUED FROM PAGE 8

ice sheets will help advance our understanding of how climate change impacts ice sheets across the globe.

https://bit.ly/satellite-tracking-ice

Arctic to be 'beyond recognition' by 2100

"The Arctic is warming at four times the rate of the rest of the planet," said **Julienne Stroeve**, senior scientist at NSIDC and lead author of a review paper that summarizes what the Arctic may look like in 2100. "At 2.7 degrees Celsius of global warming, we will see more extreme and cascading impacts in this region than elsewhere, including sea ice-free Arctic summers, accelerated melting of the Greenland ice sheet, widespread permafrost loss, and more extreme air temperatures. These changes will devastate infrastructure, ecosystems, vulnerable communities, and wildlife."

bit.ly/4bCxNJ7

Documenting climate change through the Extreme Ice Survey

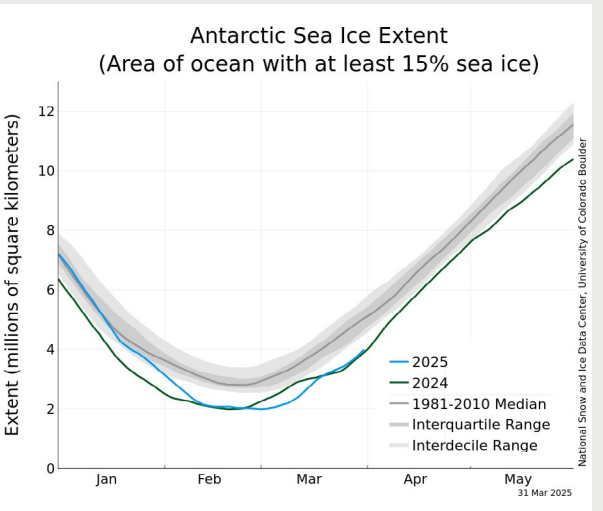
James Balog is an environmental photographer and mountaineer with a deep background in Earth science who founded the Earth Vision Institute. For fifteen years, he traveled the world, taking 1.5 million photos to document the impact of climate change on glaciers in real time. The photos are now housed at NSIDC in the Extreme Ice Survey Glacier Image Archive.

VIDEO: EXTREME ICE SURVEY

bit.ly/4c4Dyzu

ANTARCTIC SEA ICE, 2024-2025

"Finally feeling the heat"



Antarctic sea ice reached its maximum extent at 17.16 million square kilometers on September 19, 2024, second lowest in the 46-year satellite record. The record-low maximum occurred in 2023.

"The dramatic downward step in southern winter sea ice spanning the past two years points more than ever to effects from a record-warm ocean on Antarctic climate," said Senior Research Scientist **Ted Scambos**, contributor to NSIDC's Sea Ice Today and Ice Sheets Today projects.

bit.ly/antarctic-max-2024

Antarctic sea ice reached its minimum extent and tied for 2nd-lowest in 47-year satellite record in 2025.

"Antarctica seems to finally be feeling the heat," said Scambos. "Sea ice loss slowed in the Southern Ocean in November and December, climbing from record-low daily levels to near average by the end of the year. Then in January and February, sea ice loss picked up pace. Warm conditions and thinner ice cover led to the summer decline and to near-record-low sea ice levels."

bit.ly/antarctic-minimum-2025

More dangerous, more destructive

A combination of climate change and forest management practices is making wildfires more severe and destructive, according to the latest CIRES wildfire research. The total number of acres burned, the number of large fires, and the length of fire weather season have all increased in recent decades. This translates to more human impacts, especially as wildfires break out close to densely populated areas, as happened in the January 2025 Southern California wildfires.

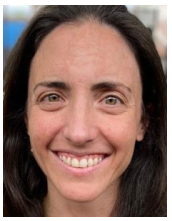
Four recent CIRES studies described on the pages that follow show how much more dangerous and damaging wildfires are becoming in the United States and offer solutions for mitigating fire impacts.

Drone's eye view: Workers from the California Department of Water Resources and the Civilian Conservation Corps install materials to protect the watershed in the Palisades burn scar area in Los Angeles County, California in January, 2025. Photo: Ken James/California Department of Water Resources

Fire risk, damage in US West intensifies

Research led by CIRES Fellow **Jennifer Balch** finds U.S. wildfires in the western states are growing more quickly than ever before. Balch and her team used satellite data to analyze the growth rates of 60,000 U.S. fires from 2001 to 2020. Their results show a staggering 250 percent increase in the average maximum growth rate of the fastest fires over the last two decades.

Balch



Iglesias

'We need to focus on what we can do to prepare communities: hardening homes and making robust evacuation plans.'

The fastest-growing fires also cause the most destruction, according to the study. Fires that grew by more than 4,000 acres a day accounted for nearly 90 percent of damages but represented less than 3 percent of total fires in the study. Fires that damaged or destroyed more than 100 structures grew by more than 21,000 acres per day at their fastest - about half the size of Washington, D.C.

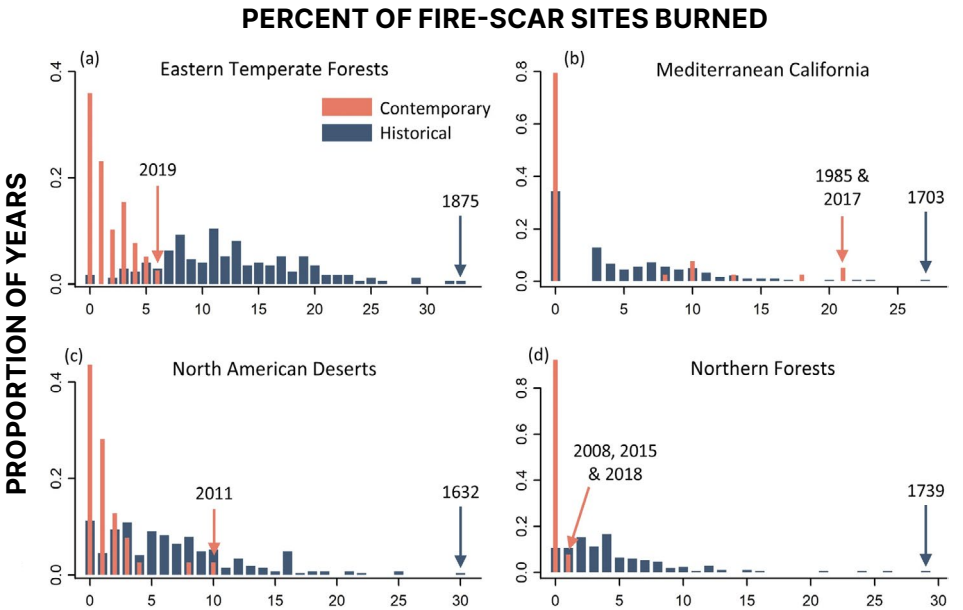
"When it comes to safeguarding infrastructure and orchestrating efficient evacuations, the speed of a fire's growth is arguably more critical than its sheer size," said **Virginia Iglesias**, a co-author of the study and a CIRES research scientist in Earth Lab.

The research highlights a critical gap in hazard preparedness across the U.S., according to the study authors. National-level fire risk assessments do not account for fire speed or provide insight into how people and communities can better prepare for rapid fire growth events.

"Fires have gotten faster in the western U.S. in just a couple of decades," Balch said. "We need to focus on what we can do to prepare communities: hardening homes and making robust evacuation plans."

bit.ly/fire-speed-not-size
bit.ly/speed-not-size-paper

Eaton suffered extensive damage to homes and vehicles during the 2025 urban wildfires in southern California. Photo: Ken James/California Department of Water Resources



Percent of selected sites burned in the historical (pre-1880) and contemporary (1984–2022) time periods for four eco-regions. Image: bit.ly/4j7rz6E

Guiterman

'It's a harbinger for far more bad fires to come unless we can get more beneficial management fires on the landscape.'

Fewer forest fires burn today — and that's a bad thing

Two studies show recent U.S. fires are burning only a fraction as often as they did historically, and as a result, today's fires are larger and more severe than those in the past.

The studies, led by CIRES, the USDA Forest Service, and others, compared tree-ring data from historically burned areas with maps of modern fire perimeters across the U.S. and Canada.

The results show that before European colonization of the Americas, Western U.S. forests burned on average every 11 years. But since 1985, those same forests have burned five times less frequently: every 59 years on average, making them much more severe, when they do occur.

In fact, much of North America is in a "fire deficit," according to the studies. Contemporary fire frequency is about 20 percent of what it was historically, even including recent record-breaking fire years like 2020.

The findings suggest that expanded use of low-severity prescribed and managed fire would help restore forest resilience. Traditional burning practices used by Indigenous peoples often had a stabilizing effect on forests by clearing out brush and debris—lowering the amount of flammable forest fuels available.

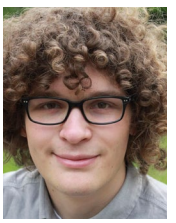
Modern fires, by contrast, are more severe because of rising temperatures, drier conditions, and the amount of available fuel. The new studies show contemporary fires are burning hot enough to kill trees in places where they had historically survived during a fire.

"It's a harbinger for far more bad fires to come unless we can get more beneficial management fires on the landscape," said CIRES Research Scientist **Chris Guiterman**, co-author of both studies.

Study 1: bit.ly/fires-less-often-more-severe

Study 2: bit.ly/4j7rz6E

Researchers install air quality monitoring equipment in a home affected by the Marshall Fire. Photo: Will Dresser/ CIRES



Dresser

de Gouw

Post-fire pollutants linger indoors

Wildfires are not just destroying homes and buildings: they're also affecting indoor air quality, even months after a fire.

Research led by **Will Dresser**, a graduate student in Chemistry working with CIRES Fellows **Joost de Gouw** and **Christine Wiedinmyer**, found compromised indoor air quality following 2021's Marshall Fire — the most destructive wildfire in Colorado history.

In the weeks following the fire, which burned nearly 1,000 homes in Louisville and Superior, residents reported unpleasant odors and layers of ash covering many surfaces in their homes.

Ten days after the fire, CIRES researchers set up field instruments in a home bordering a block in Superior where houses burned to the ground.

The instruments found gases harmful to human health were trapped indoors and lingered for weeks. Concentrations of certain volatile organic compounds (VOCs) were similar to those recorded in urban Los Angeles in the 1990s immediately after the fire but decreased slowly over the five-week study.

The results suggest the home acted like a sponge for harmful gases during the fire and slowly returned these pollutants to indoor air afterward.

"Based on prior research, we had expected these VOCs to disappear from the home within hours, but it took weeks," de Gouw said. "This means we don't understand how and where these chemicals get trapped inside a home."

bit.ly/compromised-indoor-air

'We had expected these VOCs to disappear from the home within hours, but it took weeks.'

Days-old smoke disturbs clean air far downwind

The summer of 2023 was Canada's most intense wildfire season on record. Smoke from these fires poured into the upper U.S. Midwest, where it generated record-breaking ozone pollution, according to research conducted by CIRES and NOAA scientists in CSL. A study detailing the findings found ozone pollution caused by these massive fires was the worst in decades.

"On June 3, 2023, every ozone monitor in Iowa, about a dozen of them, exceeded the ozone standard of 70 parts-per-billion," said **Owen Cooper,** a NOAA researcher in CSL who led the study.

One of the startling findings was that even when the smoke was days old and more than 1,000 miles downwind from the fires, it still contained the ingredients necessary for continued ozone production.

"Looking at the ozone and PM2.5 [particulate matter with a diameter of 2.5 micrometers or less, representing fine inhalable particles] exceedances in the decades prior to 2023, we can see that the 2023 wildfires were truly extraordinary," said CIRES' **Kai-Lan Chang**, a co-author of the study.

bit.ly/record-breaking-Midwest-ozone

Residents leave only after most destructive fires

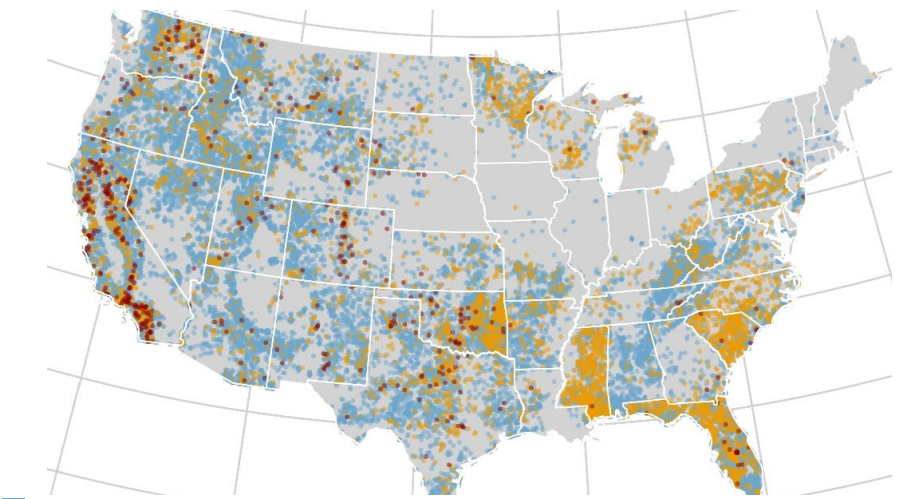
It's common for residents to leave an area after a major natural disaster. But when it comes to wildfires, new research shows only the most extreme fires influence migration out of an affected area.

CIRES Fellow **Jennifer Balch** and Research Scientist **Lise St. Denis** were part of a team that analyzed human migrations after more than 500 U.S. wildfires between 1999 and 2020. They found only the most destructive wildfires — those that destroyed more than 250 structures — were severe enough to cause significant migration away from a burned area.

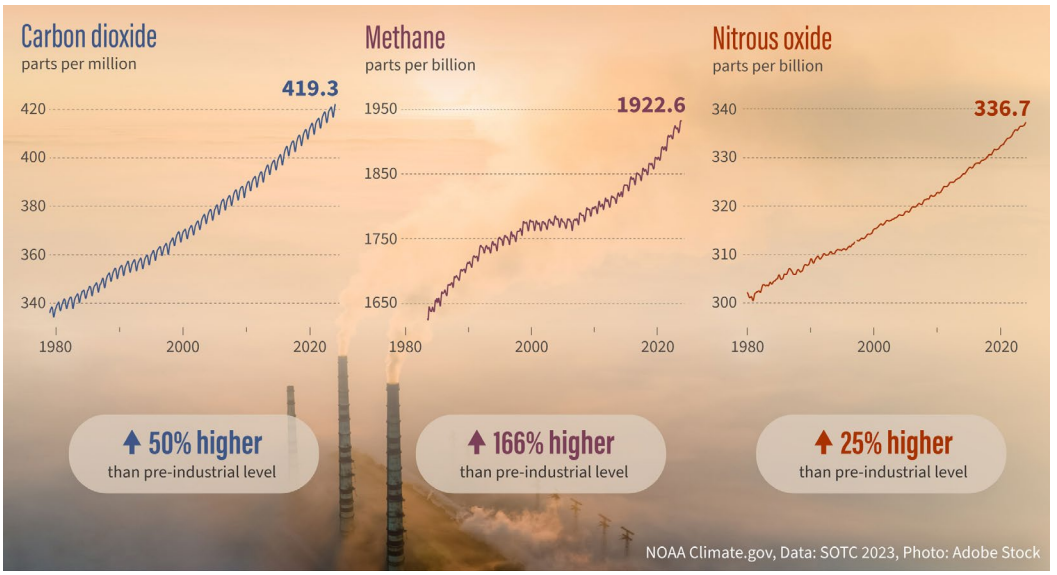
The findings suggest that, for the past two decades, people rarely left areas after a fire and did so only when a majority of structures were damaged or destroyed.

The authors suspect housing costs are one reason why people rarely move after a fire. Recent research has linked rising housing costs in California cities to the expansion of cheaper housing in suburban and rural wildfire-prone places. Therefore, some residents may have limited ability to move due to housing affordability constraints.

bit.ly/3FIp5wX

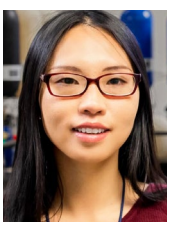


Map shows the geographic distribution of wildfires with destruction levels and points of origin reported in the Incident Command System33 dataset from 1999 to 2020 in the contiguous U.S. Sources: Wildfire data are from the U.S. National Incident Management System/Incident Command System33.
Image: bit.ly/3FIp5wX



The three dominant greenhouse gases in Earth's atmosphere — carbon dioxide (left), methane (center), and nitrous oxide (right) — all reached new highs in 2023. Image: NOAA

Greenhouse gases, temps surge worldwide



Lan

'We're definitely not on the right path to limit global warming.'

Research from CIRES, NOAA, and partners found global temperatures and the three major greenhouse gases continued to climb in 2023 and 2024. NOAA and Scripps Institution of Oceanography reported that carbon dioxide levels surged to a seasonal peak of just under 427 parts per million in May 2024. When combined with 2023's increase of 3.0 ppm, 2022 to 2024 saw the largest two-year jump in the annual peak in NOAA's record.

In addition, scientists from NOAA, CIRES, and other institutions reported that greenhouse gases, global temperatures, sea levels, and ocean heat content all reached record highs in 2023. Their findings were published in the *Bulletin of the American Meteorological Society*'s annual State of the Climate report last August.

"It's a critical time for us to reduce greenhouse gas levels in the atmosphere," said **Xin (Lindsay) Lan**, a CIRES scientist in GML who leads the lab's annual reporting of greenhouse gas trends. "Instead, we're still seeing a rapid increase of those key greenhouse gases, and we're definitely not on the right path to limit global warming."

The report also showed the previous nine years (2015 to 2023) were the nine warmest on record and the Arctic had its fourth-warmest year in the 124-year record.

A study released by the Global Carbon Project showed emissions of nitrous oxide, the third most important human-made greenhouse gas, rose 40 percent from 1980 to 2020. Nitrous oxide is accumulating in Earth's atmosphere faster than at any other time in human history and its current growth rate is likely unprecedented in the last 800,000 years, according to the study.

"Fundamentally, society needs to take drastic measures to reduce global warming by reducing the greenhouse gas emissions that are within our control," Lan said.

bit.ly/surging-CO2
bit.ly/record-highs
bit.ly/nitrous-oxide-grows

CLIMATE SHORTS

Heat, not lack of precip, drives western US droughts

Higher temperatures triggered record drought in the American West from 2020 to 2022, according to work by UCLA, NOAA, and CIRES scientists. The work found that evaporative demand, or the atmosphere's thirst, has played a larger role than reduced precipitation in droughts since 2000. During the 2020 to 2022 drought, evaporation accounted for 61 percent of the drought's severity.

"This study further confirms we've entered a new paradigm where rising temperatures are leading to intense droughts with precipitation as a secondary factor," said **Veva Deheza**, director of NOAA's NIDIS.

bit.ly/heat-not-lack-of-precip

Injecting light-reflecting particles could brighten marine clouds

A method of intentionally cooling Earth's surface to combat climate change could be more effective than scientists previously thought, according to CIRES-led research. Stratospheric aerosol injection (SAI) involves using aircraft to disperse microscopic particles throughout Earth's stratosphere, where they would reflect a small portion of sunlight back into space and cool Earth's surface. The study, led by CIRES scientist **Jake Gristey** (CSL), with CIRES Fellow **Graham Feingold**, finds the cooling effect of SAI would be enhanced if it were conducted over a region with cloud cover.

The work suggests SAI would brighten marine clouds and make them about 10 percent more reflective.

bit.ly/technique-might-cool-more

A USGS team member install instruments on a pier in Clearwater Beach, Florida before Hurricane Ian made landfall.
Photo: NHCI

Scientists create blueprint for hurricane risk by monitoring waves, storm surge

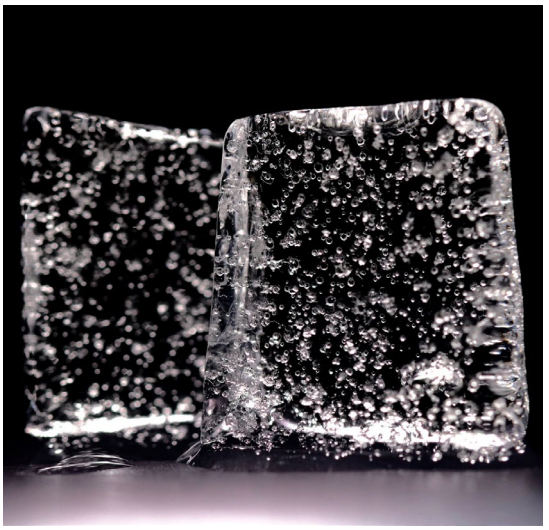
As powerful hurricanes approach the coast, they generate storm surge and dangerous wave conditions that can cause extensive flooding, significant landscape changes, and destruction of property. The National Oceanographic Partnership Program (NOPP) Hurricane Coastal Impacts (NHCI) project, supported by CIRES scientists, including **Gijs de Boer**, who is now working at Brookhaven National Laboratory, uses observations and models to understand how waves and storm surge evolve in the nearshore environment and impact natural and man-made landscapes during hurricanes. The work, which began in 2022, is critical for improving hurricane coastal impact modeling and will help communities better assess the risks associated with hurricanes.

NHCI project website: bit.ly/3RIKYEK

STORY MAP: HURRICANE COASTAL IMPACTS

de Boer

CLIMATE SHORTS



Air bubbles in an Antarctic ice core. Scientists can analyze the chemistry of air bubbles to learn about Earth's atmosphere and climate in the past. Photo: Thomas Bauska/British Antarctic Survey

Wildfires, methane spiked with past climate swings

The last glacial period saw rapid shifts in temperature and tropical rainfall around the world. A study led by **Ben Riddell-Young**, a CIRES postdoctoral researcher in GML, provides the first evidence that wildfires were also a feature of these periods of abrupt change.

Previous research has shown atmospheric methane, a greenhouse gas, spiked during periods of abrupt climate change in the last Ice Age. Riddell-Young and his colleagues analyzed carbon and hydrogen isotopes from methane gas trapped inside air bubbles in an Antarctic ice core. They found that the methane spikes were most likely due to increased wildfire activity. "Understanding what this burning really means for the carbon cycle is one of the places the research is headed next," said **Edward Brook**, a co-author of the study.

bit.ly/methane-spikes

'Deny, doubt, delay'

Conceptual artist **Beatie Wolfe** used methane data from GML to illustrate global smoke emissions in her award-winning art piece "Smoke and Mirrors." The visualization is accompanied by advertising slogans used by oil companies to "deny, doubt, and delay" climate change science.

MULTIMEDIA: SMOKE & MIRRORS

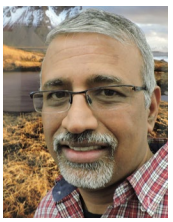
https://beatiewolfe.com/smoke-and-mirrors

A blue-footed booby (*Sula nebouxii*) contemplates visitors in the Galapagos. Photo: Kathy Bogan/CIRES

Cool, nutrient-rich water may buffer Galápagos from climate impacts

While most of the world's oceans are warming, a "cold pool" just west of the Galápagos Islands is getting colder. This cool, nutrient-rich water fuels the islands' famed biodiverse ecosystems and local economies. **Mikell Warms**, a CU Boulder PhD candidate in ATOC, and CIRES Fellow **Kris Karnauskas** used a high-resolution global climate model to investigate the impacts of atmospheric carbon dioxide on this region of the Pacific Ocean. They found the cold pool will persist thanks to vertical ocean mixing and a strong, cold undercurrent even if atmospheric carbon dioxide rises to 550 parts per million, which could happen by 2050 if current emissions do not change. The work suggests the western edge of the Galápagos Islands could become a climate refuge, shielding plants and animals from severe climate change impacts felt elsewhere in the Pacific Ocean.

bit.ly/galapagos-cold-pool



Rajagopalan

'Yes, the temperature is warming, but that's not the full story — you add precipitation and you get a fuller picture.'

Hoerling

The authors analyzed flow records at Lees Ferry (above), finding it "more likely than not that Lees Ferry flows will be greater during 2026-2050 than since 2000, as a consequence of a more favorable precipitation cycle," said Martin Hoerling, the paper's lead author. Photo: National Park Service

Warmer but wetter weather could control Colorado River flow

The Colorado River's future may be a little brighter than expected, according to CIRES-led work. Warming temperatures, which deplete water in the river, have raised doubts that the Colorado River could recover from a multi-decade drought.

A recent study accounting for both rising temperatures and precipitation in Colorado's headwaters finds that precipitation, not temperature, will likely continue to dictate the flow of the river for the next 25 years.

Precipitation falling in the river's headwaters region is likely to be more abundant than it has been during the last two decades. The work may support policymakers, water managers, states, and Tribes as they look for answers on how to govern the Colorado River's flows in the coming decades.

"It's a sort of nuanced message," said **Balaji Rajagopalan**, CIRES fellow and co-author of the study. "Yes, the temperature is warming, but that's not the full story — you add precipitation and you get a fuller picture."

CIRES Affiliate **Martin Hoerling** and Rajagopalan worked with colleagues from several institutions to

CONTINUED ON PAGE 36

Timing of rain could help predict floods

With record rainfall projected to continue in the future, many worry extreme flooding will follow suit. But CIRES-led work found an increase in precipitation alone won't necessarily increase disastrous flooding — instead, flood risk depends on how many days have passed between storms.

In the study, CIRES Fellow and Western Water Assessment Director **Ben Livneh** and Postdoctoral Researcher **Nels Bjarke** looked for a new way to understand soil moisture and how it impacts flooding.

The research team knew soil moisture is important when understanding floods, but measuring soils effectively is challenging. So they found a proxy for soil moisture: precipitation intermittency, the length of a dry spell between precipitation events.

Simply put: After a prolonged time since the last rain, it takes a larger storm to generate flooding; with fewer days between storms, a wider range of conditions can lead to flooding.

"We can actually understand changes in flood risk based on the number of days since the last rain event," Livneh said. "We wanted to make it straightforward because soil water is hard to predict."

The 2013 floods in Boulder are a real-life example of how precipitation intermittency could be applied to flood projections. Seven days of heavy rain nearly doubled the previous record for rainfall. The event displaced hundreds and caused $2 billion in property damage, according to NOAA.

Forecasters and emergency managers could use the paper's findings to anticipate very real flooding risks. Since wide-ranging observations of precipitation exist, forecasters can take the findings of this paper and use intermittency to help predict the likelihood of a flood.

'We can actually understand changes in flood risk based on the number of days since the last rain event.'

"As we enter the era of big data, we can benefit from simple proxies like the dry-spell length as a way to more intuitively understand extreme events," Livneh said.

bit.ly/rainfall-timing

bit.ly/rainfall-timing-paper

Livneh

Bjarke

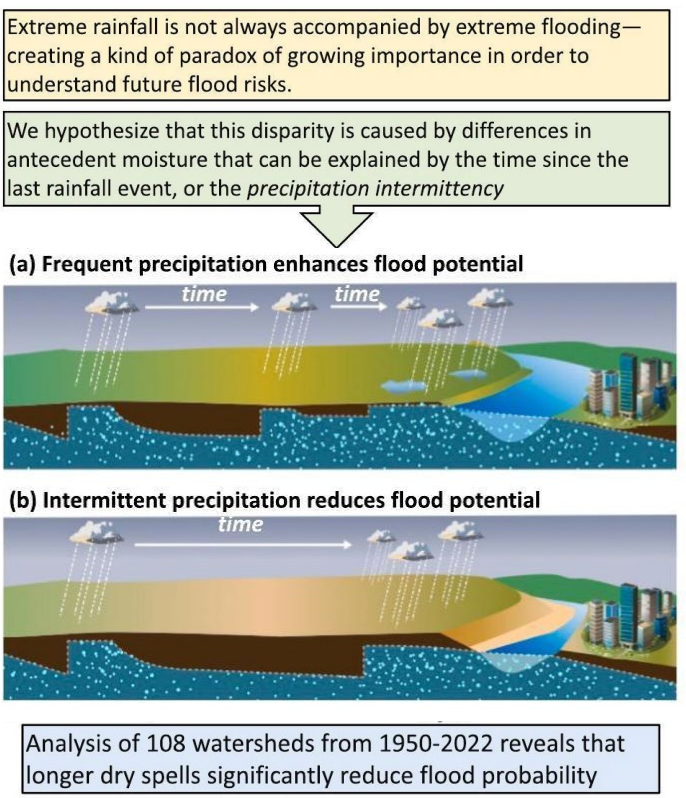


Image: bit.ly/rainfall-timing-paper

HYDRO SHORTS

Satellite observations will improve flood prediction

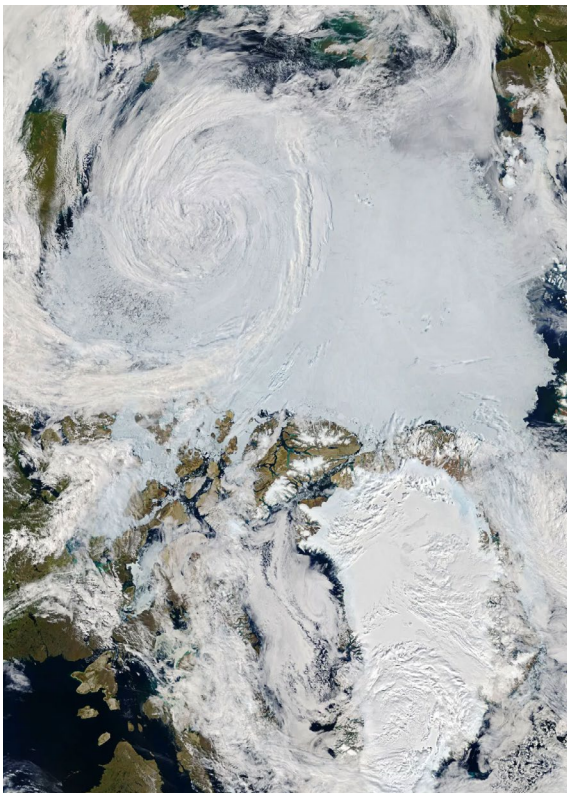
The hazard posed by floods is increasing as populations grow in flood-prone, high-density areas around the world. In 2024, NASA and the French Space Agency introduced a new tool to help predict floods on Earth's rivers, lakes, and reservoirs: The Surface Water and Ocean Topography (SWOT) satellite. The satellite is the first of its kind to measure the height of all water surfaces on Earth, and its observations will improve flood forecasts. CIRES Research Scientist **Toby Minear** is leading an effort to incorporate SWOT data into global river discharge and hydraulic models to predict the potential for flooding and the timing of floods. SWOT is a major resource for studying river flooding even in prosperous areas, like the U.S., because the U.S. has historically underestimated the amount of flood-prone areas.

www.nasa.gov/missions/swot/international-swot-mission-can-improve-flood-prediction/

'Thirstwaves' increase, intensify, and last longer since 1980

Researchers from CIRES and the University of Idaho have coined a new term — thirstwaves — to describe extended periods of atmospheric thirst. In a new paper, **Mike Hobbins**, a CIRES researcher in PSL, and **Meetpal Kukal**, a research hydrologist at the University of Idaho, define thirstwaves as periods where evaporative demand is elevated for extended periods. They analyzed thirstwaves in the contiguous United States from 1980 to 2021 and found these events have become 17 percent more intense and 23 percent more frequent over the past four decades. They also found thirstwaves are lasting longer than in the past and are now much more likely to occur during the growing season. This information can help farmers better manage their water resources and improve crop yields.

bit.ly/thirstwaves



A cyclone swirls over the Arctic Ocean on July 28, 2020. Photo: NASA Earth Observatory

Arctic cyclone disrupted sea ice, ocean currents for days

Work co-authored by CIRES researchers **Ola Persson** and **Amy Solomon** in PSL fills gaps in understanding the dynamic relationship between air, sea ice, and the ocean. During the 2019-2020 MOSAiC expedition, Persson and a large international team of scientists collected rare data from Arctic sea ice in winter. When an Arctic cyclone passed over the research vessel, the team collected observational data from surface meteorological stations, weather balloons, radars, and buoys. The unique collection of interdisciplinary observations at the same time provided an opportunity for the team to perform an in-depth analysis of how Arctic sea ice and the ocean respond to significant weather events. They found specific wind features within the cyclone produced profound changes in the sea ice and affected ocean currents for several days after the event.

bit.ly/arctic-cyclone

Giant kelp forests shelter diverse species (here, Channel Islands National Park off the coast of southern California). Photo: Christina E. Kumler/CIRES

Sea otters help kelp forests recover — but how fast depends on where they are

Kelp forests are dense groups of brown algae that provide shelter to many species in the ocean. When sea otters, an important keystone species, were reintroduced along the coastlines of Pacific Ocean islands in the 1970s and 1980s, researchers saw kelp forests return to areas that had been destroyed by sea urchins – a favorite food of sea otters. Recent CIRES research found that while the otters play a vital role in kelp forest recovery, their level of influence depends on what other species they interact with in salty ocean waters.

Langendorf

"We always thought keystone species control their ecosystems the same way, regardless of where they are or what else is in the ecosystem," said **Ryan Langendorf**, lead author of the paper and former CIRES postdoctoral researcher. "A more modern view is that they are still very important, but they can have different effects in different places."

The new study compared data from the reintroductions of sea otters in Southern California and British Columbia. Regeneration of the kelp forests had occurred much faster in B.C. than in California. To understand these differences, Langendorf developed a novel community model using information from the earlier studies, then created a movie of species interactions from both sites. The model highlighted how all living things — sea otters, urchins, and kelp — interacted over time.

In California, there was more competition among the different urchin, kelp, and other species, which slowed down the influence sea otters had on the entire system.

Meanwhile in Canada, otters had a greater impact on the urchin population, because that web of interactions among species was not as complex.

"Being able to turn common survey data into a movie of species reacting to changes in their environment and each other feels like renewed hope for a field that more than ever needs to offer useful advice about how to help the many complex living systems we live with and cherish," Langendorf said.

https://bit.ly/otters-kelp

Organic sulfur compounds "might not be a sign of life" on other planets

A recent CIRES study found that certain biosignature molecules may not indicate life is present on other planets, contrary to previous research. CIRES scientists in Chemistry created dimethyl sulfide gas in a chemistry lab with no organisms present, suggesting the molecule may not be as strong an indicator of extraterrestrial life as previously thought.

Living organisms on Earth can create organic molecules that contain sulfur, including dimethyl sulfide. In the new study, CIRES researchers created it using only light and gases found in many planets' atmospheres. They concluded that organic sulfur compounds might not be robust biomarkers but could instead serve as markers of metabolic potential.

Browne

Reed

"The sulfur molecules that we're making are thought to be indicators of life because they're produced by life on Earth," said CIRES Fellow **Ellie Browne**, who led the study with Visiting Fellow **Nathan Reed**. "But we made them in the lab without life — so it might not be a sign of life, but could be a sign of something hospitable for life."

Reed noted that the results are relevant only to one type of planetary atmosphere. "There's a wide variety of atmospheres, and we only looked at small differences in one — you can't study every atmosphere that exists in a lab," he said.

bit.ly/life-on-other-planets

A scientist measures how much dead coral skeletons protect algae from grazing herbivores. Photo: Kai Kopecky/CIRES

Coral skeletons shelter seaweed, hinder reef regrowth

Coral reefs are complex ecosystems, and new research shows that complexity can impede coral recovery after bleaching events.

Kopecky

While storms can kill coral and wash away their skeletons, heat waves bleach and kill corals but leave their skeletons intact. In a recent study, **Kai Kopecky**, a CIRES scientist in ESIIL, worked with colleagues to study reefs on Mo'orea, an island in French Polynesia. They found coral skeletons left in place by a 2019 bleaching event prevented fish from nibbling on seaweed growing in the reef, enabling the seaweed to quickly colonize the reef and outgrow new, young corals.

The skeletons reduced fish grazing on seaweed by about 80 percent, allowing the seaweed to cover about 45 percent of the dead reef in two years.

Kopecky now wants to know if removing dead skeletons from the reef could stimulate coral recovery or at least mitigate the impacts of bleaching.

"In coral reefs, this is a novel idea and strategy," he said. "But if you look to other ecosystems — like prescribed burns in forests to remove dead wood — people have been increasingly thinking about manipulating dead stuff in ecosystems for management purposes."

bit.ly/dead-coral

Social media posts reveal regional patterns in seasonal allergies

Many U.S. adults suffer from seasonal allergies, but scientists have struggled to track allergy trends because cases don't always require medical care. Some allergy sufferers venture online to post about their symptoms or search for remedies, and CIRES scientists in Ecology and Evolutionary Biology recently harnessed that information to track allergy intensity across the country.

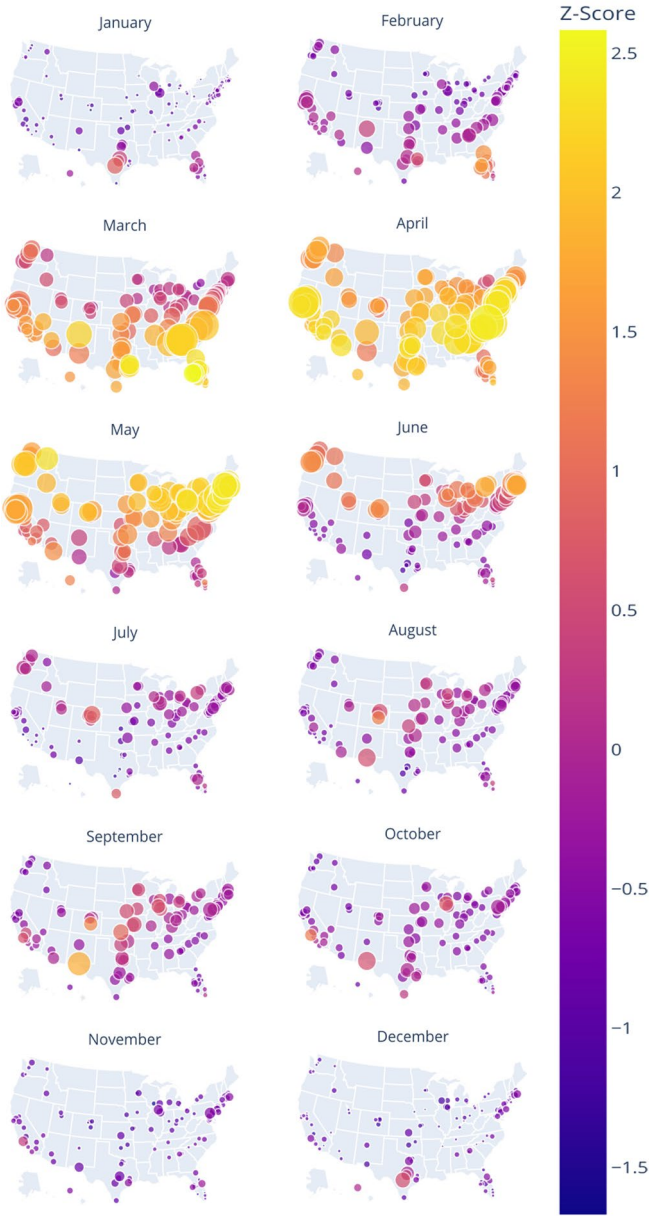
Stallard-Olivera

The work, led by Ecology and Evolutionary Biology PhD Student **Elías Stallard-Olivera**, reveals important regional patterns in allergy symptoms, including an allergy "hotspot" in the Southeast and a surprising winter allergy season in Colorado, Texas, and Florida.

When they dug into the online data, the researchers found that spring (March through May) is the dominant allergy season across the U.S., with fall (September through October) coming in second. However, peak intensity and timing varied by region. In Florida, allergy season peaks in March; In the Midwest and Northeast, the peak is in April and May.

Researchers plan to use this study's findings to investigate the link between weather and seasonal allergies and to identify specific allergens, including molds and pollens, responsible for the spikes in seasonal allergies. "Now that we know when allergies are most likely to spike, the next step is better to determine the specific triggers of allergies and why the spikes occur when they do," said CIRES Fellow **Noah Fierer,** a co-author of the study.

bit.ly/social-media-allergies



Seasonal patterns in allergy intensity across the 144 counties in the United States with a population above 500,000, based on the Z-score of Twitter post volume averaged across 2016–2022 related to seasonal allergies.

Figure: bit.ly/seasonal-allergies-study

CIRES Fellow Jose Luis Jimenez and PhD Student Seonsik Yun set up air quality monitoring instruments at *La Casa*, an National Science Foundation-funded project in Denver.
Photo: Doug Day/CIRES

Breathe easily

From Denver's rooftops to the Great Salt Lake, CIRES researchers have been monitoring air quality (AQ) to find new insights into pollution sources. Their work can give residents and decision-makers the data they need to improve the air we all breathe.

24/7 measurements set new standards for AQ data collection

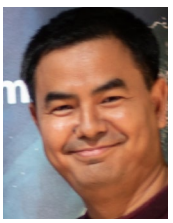
CIRES scientists in Fellow **Jose-Luis Jimenez's** research group are helping lead a program to identify sources of pollution nationwide. The National Science Foundation-funded Atmospheric Science and Chemistry mEasurement NeTwork (ASCENT) consists of 12 air quality monitoring sites scattered across the U.S., from national parks like Yellowstone and Joshua Tree to densely populated cities like Denver and Houston.

A suite of instruments at each site runs day and night, taking in new data from the air every second, minute, and hour of each day, providing quality data with a chemical specificity at a frequency rarely done on a longer-term basis.

CONTINUED ON PAGE 28

Air, ground campaigns track ozone, pollutants in urban West

CIRES researchers and federal colleagues in CSL embarked on two field campaigns last summer to study pollutants around Denver and Salt Lake City, the two largest metro regions in the Mountain West.



Baidar

In July, researchers fanned out across Colorado's Denver-Julesburg basin, one of the most densely drilled oil and gas regions in the country. They used specialized instruments mounted on airplanes, ground vehicles, and stationary sites to measure greenhouse gases and air pollutants that contribute to the high summer ozone pollution that has long plagued the Denver metropolitan area.

It had been ten years since the last major air quality study took place in the area, according to **Sunil Baidar**, a CSL scientist who led the twin studies.

"We need to understand the changing landscape of emission sources to help the state develop strategies to meet air quality standards across the Denver metro area and northern Colorado Front Range," Baidar said.

In July and August, CSL researchers used many of the same mobile platforms to study sources of ozone pollution in Salt Lake City, which has has a history of poor air quality. The project measured the type and distribution of pollutants that cause ozone development, as well as characterisitics of the atmospheric boundary layer that keeps pollutants trapped near the Earth's surface.

bit.ly/rocky-mountain-ozone

By deploying measuring instruments on commercial flights, researchers will be able to collect "data over multiple cities multiple times a day, in different seasons, and under varying weather conditions," said GML scientist Colm Sweeney. Photo: MaxPixel

NOAA partners with United to collect data from commercial flights

CIRES scientists are contributing to a NOAA and United Airlines partnership to use commercial flights to measure air pollutants, a first step toward continual monitoring of pollutants and greenhouse gases above U.S. cities.

NOAA and United announced in July 2024 that they plan to equip a Boeing 737 with sophisticated instruments that will measure greenhouse gases and other pollutants during domestic flights. The multi-year agreement is designed as a test for a potentially larger network of instrumented commercial aircraft.

NOAA and other agencies already use aircraft to measure pollutants, but these campaigns are costly and limited in range. Installing instruments on commercial airliners would vastly increase the number of samples researchers could analyze.

"We'll be collecting data over multiple cities multiple times a day, in different seasons, and under varying weather conditions," said **Colm Sweeney**, who leads the GML commercial aircraft program. "This will allow scientists to more accurately measure U.S. emissions… at just 1 percent of the cost of deploying research aircraft," Sweeney said.

CIRES scientists in GML are modifying instruments to operate untouched for months at a time while installed in a commercial aircraft; adding to the suite of instruments a computer that can record parameters like latitude, longitude, and altitude; and designing a system to retrieve the data remotely. They will also help analyze the data once the measurements have been quality controlled.

bit.ly/noaa-united-partnership

Mmmmm! Wait: What's that aroma, really?

Coggon

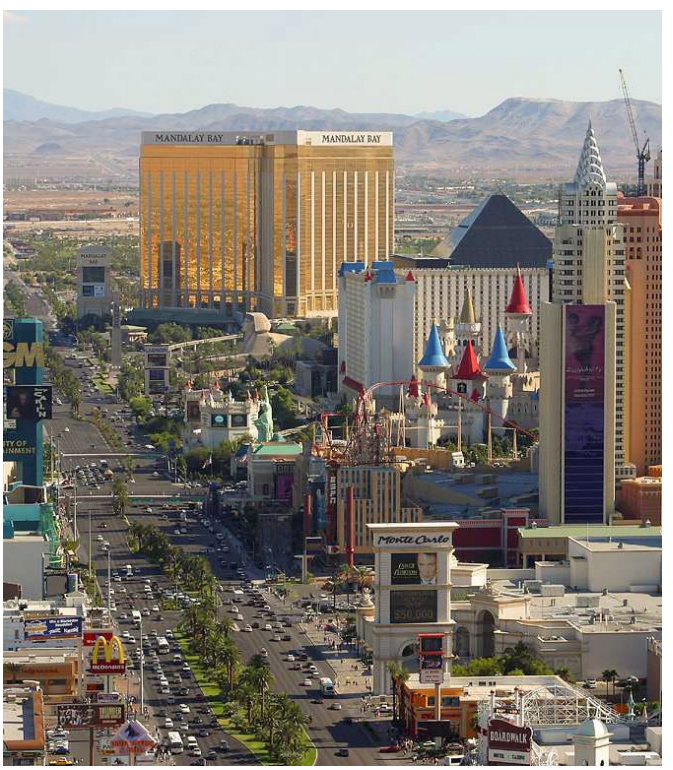
Researchers drove a mobile laboratory around Las Vegas Strip in 2021 and found that, at times, VOCs from cooking activities were on par with vehicle emissions. Current air quality models don't account for those impacts. Image: Wikimedia Commons

If there's one thing CSL scientists have learned in their years investigating urban air pollution, it's this: if you can smell it, there's a good chance it can impact air quality.

And when it comes to delicious food smells, the impact could be significant, according to a CSL study quantifying cooking emissions in downtown Las Vegas.

Las Vegas is home to one of the highest restaurant densities in the United States — a whopping 666 restaurants per 100,000 people. It also has persistent air quality concerns, with significant impacts from the Las Vegas Strip — a high-traffic entertainment district with a concentration of casinos, hotels, bars, and restaurants.

In the summer of 2021, CSL's **Matt Coggon** and colleagues from CIRES and NOAA outfitted a mobile laboratory with specialized instruments capable of identifying and measuring hundreds of different airborne volatile organic compounds (VOCs). In June and July, the researchers drove their mobile laboratory around Las Vegas to map air quality differences across residential, commercial, and entertainment districts. They focused particularly on the Las Vegas Strip, cruising up and down the busy avenue at different times of the day and night.



Coggon and his team found that, on average, 21 percent of human-made VOCs in Las Vegas's outdoor air were from cooking activities. Depending on the time of day, cooking VOCs ranged from 10 to 30 percent of the total.

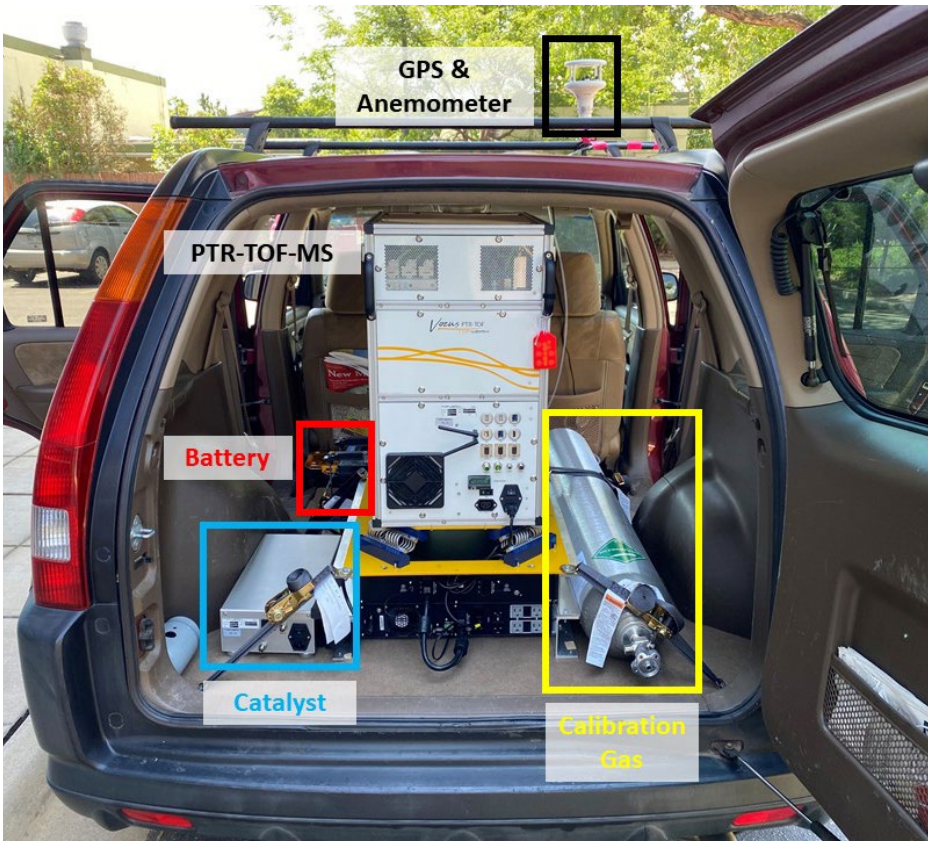
In Coggon's estimation, this makes cooking emissions the single largest source of urban VOCs missing from current air quality models, which could have important ramifications for regulatory policy.

"It was surprising even to us that emissions from food cooking can be on par with vehicle traffic when it comes to VOCs," Coggon said.

Spatial mapping revealed that cooking emissions were mostly concentrated along the Strip, roughly correlated with the density of nearby restaurants, and at highest levels during the evening hours when dining and other entertainment activities peaked.

The team cautions that the particularly high density of restaurants in Las Vegas may mean that these measurements represent an upper limit on how much cooking matters for air quality in the U.S. Even so, research in other cities provides early indications that cooking emissions may be a significant, unsolved piece of the air quality puzzle in major cities worldwide.

bit.ly/delicious-smells



Rutherford

Researchers loaded devices onto a passenger vehicle and drove around to assess pollutant sources. Photo: Madison Rutherford/CIRES

Mobile lab pinpoints hyperlocal emissions sources in north Denver

In the summer of 2022, CIRES researchers in Chemistry used a mobile laboratory to study the air in the Elyria-Swansea neighborhood of Commerce City, a heavily polluted urban area north of Denver. The neighborhood is near a Suncor Energy oil refinery, the Robert W. Hite wastewater treatment plant, local industrial shops, and several major highways.

Chemistry Phd Student **Madison Rutherford**, Applications Scientist **Abigail Koss**, and CIRES Fellow **Joost de Gouw** drove instruments around Commerce City on six different days to identify the sources of volatile organic compounds (VOCs) in the area.

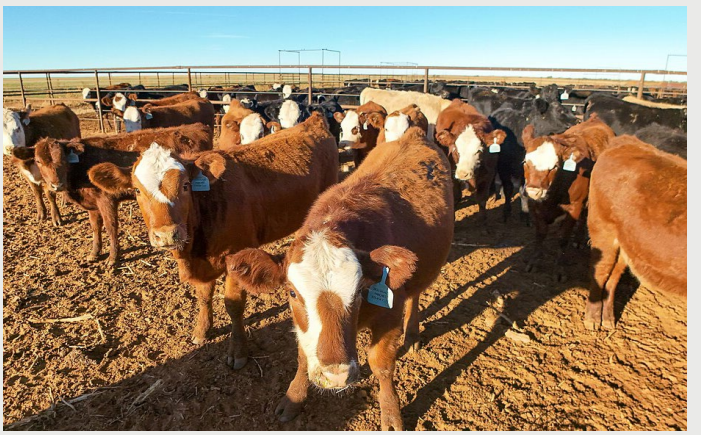
Their results, published last year, show the highway north of the neighborhood is not a major VOC contributor, nor is the wastewater treatment plant. However, the wastewater treatment plant did emit some sulfur-containing and aromatic compounds, which could contribute to odor some days.

The Suncor oil refinery and a small woodshop were both major contributors to VOCs in the neighborhood. The oil refinery consistently had high concentrations of many aromatics and heavier compounds, including air toxics such as benzene.

The woodshop contributed large amounts of solvents such as toluene and acetone to the air around it. This shows that small industries with unreported emissions can strongly affect VOC levels nearby.

The findings can help residents of Denver and regulatory bodies better understand local air pollution and its sources.

bit.ly/mobile-lab-in-north-Denver



Feedlot in northern New Mexico

Can changing cow chow cut down on methane?

On feedlots across the U.S., cows produce methane, a greenhouse gas 28 times more potent than carbon dioxide. Cows also produce ammonia, which reacts with acids in the atmosphere to create aerosols that can be dangerous to human health.

To test the potential impact of cows' diet on their methane and ammonia production, a team of CIRES researchers in Chemistry and colleagues, led by Chemistry PhD Student **Nathan Sweet**, set up an experiment on a Kansas feedlot. The team separated the cows into two groups — one that ate corn and another that ate sorghum — and used lasers to measure the gases they produced. Preliminary findings reveal small differences in ammonia emissions between the corn and sorghum lots.

bit.ly/cow-chow

Day

24/7 measurements

CONTINUED FROM PAGE 24

"This network may help push forward the next generation of air quality measuring," said CIRES Research Scientist **Doug Day**. "Governments may adopt these instruments in the future if these efforts show the value of measurements."

Day estimates about 80 percent of the data will contribute to research related to health, specifically air quality impacts. The other 20 percent will further scientific understanding of particles' effects on clouds, climate, and visibility.

bit.ly/rooftop-science

Good news for ozone layer

The hole that opens annually in the ozone layer over Antarctica was relatively small in 2024 compared to other years, and scientists project the ozone layer could fully recover by 2066.

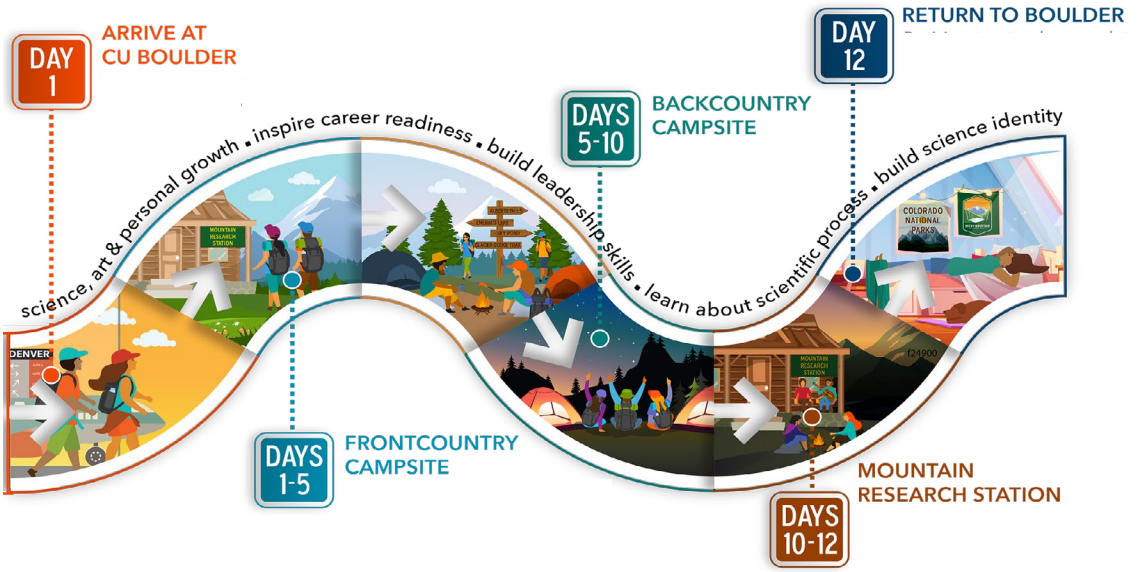
During the peak of ozone depletion season from September 7 through October 13, the 2024 ozone hole ranked the seventh-smallest since recovery began in 1992. That's when the Montreal Protocol, an international agreement to phase out ozone-depleting chemicals, started to take effect.

The improvement last year was likely due to a combination of declines in chlorofluorocarbons (CFCs), ozone-depleting chemicals phased out by the Montreal Protocol, along with an unexpected infusion of ozone carried by air currents from north of the Antarctic, according to NOAA scientists.

And there's more good news: NOAA and CIRES scientists found last year that levels of a related class of ozone-depleting chemicals, hydrochlorofluorocarbons (HCFCs), peaked in 2021 and are now declining as nations comply with restrictions called for by the Montreal Protocol.

"Without the Montreal Protocol, this success would not have been possible, so it's a resounding endorsement of multilateral commitments to combat the impacts of human-induced climate change," said **Luke Western**, a former research fellow with GML.

bit.ly/2024-ozone-hole



Field opportunities – and more – knock through Girls On Rock

With her team, **Melisa Diaz**, former CIRES PhD student and now assistant professor at The Ohio State University, used the strata of Rocky Mountain foothills to build the curriculum for the field expedition program Girls on Rock. This tuition-free expedition for high school youth, ages 16 to 17, interweaves field science, art, and backcountry travel.

Through experiences in an outdoor environment, participants learn:

- Team building skills
- Skills in communication, leadership, and mentoring
- The geology of the Rockies and the Traditional Ecological Knowledge about the geology of the Rockies
- Principles of scientific research and what it takes to pursue a career in science

When Girls on Rock started in 2018, the program was mostly volunteer-run and lacked a consistent curriculum. Now, with three years of funding from NSF, Diaz and her team have designed a new base-level model they plan to tweak over the next few years after acquiring feedback from past participants. When the program ends each summer, CEEE evaluators run focus groups to determine how well it met learning objectives, understand its impact on participants, and provide new insights for the upcoming program.

bit.ly/girls-on-rock

Online course enhances field experience for all

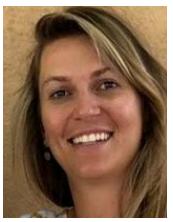
ADVANCEing FieldSafety is a new, free, online CU Boulder course offering tools to promote safe and welcoming field environments. Harassment and misconduct have been a consistent issue in geoscience fieldwork for decades, and individuals who have experienced these issues often step back from fieldwork or leave the geosciences entirely.

Topics covered in the course include improving team culture and interpersonal communication, establishing mutually acceptable norms

CONTINUED ON PAGE 36

Middle-schoolers plan for resilient future

Educational resources developed by CEEE help local students lead and engage in community discussions on resilience, according to CIRES research. CEEE Curriculum Developer **Katya Schloesser** led a case study to examine how educational tools have helped students develop a sense of agency and grow in their understanding of community resilience while confronting climate change.



Schloesser

The researchers looked at the effectiveness of HEART Force and Earth Force RISE Challenge, which provide place-based curricula, scenario-based role-play games, and support for connecting with community leaders.

The study took a deep look into the actions of students in Estes Park, Colorado who have experienced major climate-fueled hazards like the 2013 floods and the 2020 East Troublesome and Cameron Peak wildfires. Specifically, the research focused on students participating in a middle school Environmental Resilience Team, an after-school group that encourages students to promote public awareness, mitigation, and policymaking to increase resilience to natural hazards.

The group visited the state Capitol to lobby for statewide legislation to establish a Wildland-Urban Interface (WUI) building code board to mitigate wildfire risk in high-risk areas. Results from the study found students and educators gained actionable tools from CEEE's education models, helping them to lead and engage in community discussions on resilience.

bit.ly/students-resilience

Workshop participants play HEARTForce wildfire resilience simulation game. Photo: Kathy Bogan/CIRES

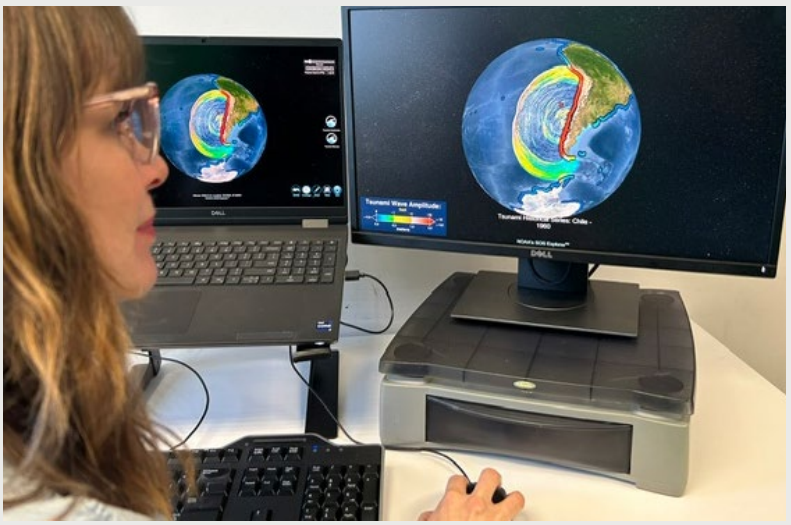
CLEAN supports networks that generate climate action

Researchers from CEEE led a first-of-its-kind study analyzing social networks of organizations involved in climate change education in the U.S. The study found climate change education plays a critical role in helping people connect to climate action by engaging in their communities. Results also showed the Climate Literacy and Energy Awareness Network (CLEAN) helps connect individuals and organizations involved in climate change education. The findings of the study will help expand the network using targeted strategies to generate collaborative climate action.

bit.ly/CLEAN-pause

bit.ly/CLEAN-social-networks

Immerse yourself in Earth and space: Free download of SOS Explorer®



SOS Explorer® in use on a desktop computer. Photo: Hilary Peddicord/CIRES

NOAA's Science on a Sphere® (SOS) released a free software version that allows you to explore Earth and space data on a virtual globe at home or in your hand. The software takes SOS® datasets, originally designed to be seen on a six-foot sphere in large museum spaces, and makes them accessible for educators, students, and curious people everywhere.

bit.ly/SOS-explorer

Students, researchers co-create ice sheet exhibit

Twenty-thousand years ago, ice sheets nearly as tall as North American's highest mountains covered huge swaths of the continent. Today that pattern is reversed, and CIRES scientists went beyond the research to create an interactive, engaging museum exhibit on the subject for general audiences.

Dillon Amaya, a researcher at NOAA PSL, and his colleagues, including **Kris Karnauskas**, CIRES fellow and associate professor in ATOC, used a climate model to study the different patterns of ice sheets across North America. They partnered with NSF NCAR and CU Boulder's ATALS institute to create an exhibit based on the research.

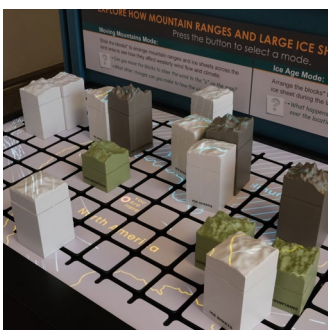
As part of an ATLAS class, CU Boulder computer science students created exhibit prototypes based on the CIRES-led research. One team's project, which used augmented reality to demonstrate how winds change in response to different elevations, evolved beyond the classroom, eventually becoming a permanent display at NSF NCAR.

ATLAS offered a class to CU Boulder computer science students who in turn translated the CIRES-led research into an exhibit prototype."It's often hard for the average person to comprehend how drastically different the climate was in the past," said Amaya, lead on the exhibit collaboration. "It's my hope that this exhibit can help illustrate some of these exotic climate interactions so that visitors can leave with a better physical intuition for how and why things were so wildly different."

Installed in 2024, the exhibit will run at NSF NCAR indefinitely.

bit.ly/Winds-Thru-Time

bit.ly/NCAR-exhibit



In this hands-on simulation, visitors can arrange tall and short colored blocks to recreate North American ice sheets and mountains, and see how they affect wind and climate. Photo: Ashley Safford/ATLAS

VIDEO: WINDS THROUGH TIME

Tribal students focus research on their communities' climate challenges

'As far as I know, I am the first, or one of the first, Oglala Sioux Tribal members to conduct climate change research on the Pine Ridge Indian Reservation that involves the feedback of the tribal members.'

In 2020, NC CASC created a pilot Tribal Climate Leaders Program (TCLP). TCLP provides Indigenous students with science education and research opportunities while supporting the integration of their new knowledge and experience with their tribes.

One Tribal climate leader is **Shelby Ross**, a member of the Oglala Sioux Tribe. After completing a master's degree in environmental science and engineering, Ross worked for the Tribe's natural resources department, where she learned about its first-ever climate adaptation plan. She quickly found areas for improvement: The report lacked sections on the way climate impacts the health of the Tribe's members.

Ross is now pursuing a PhD in geography and environmental health at CU Boulder, and she credits the TCLP for turning her research idea into practical information her tribe can use.

Ross's research focuses on type 2 diabetes and how extreme weather events induced by climate change are making the disease worse. Native American and Alaska Native adults are three times more likely to be diagnosed than non-Hispanic white adults.

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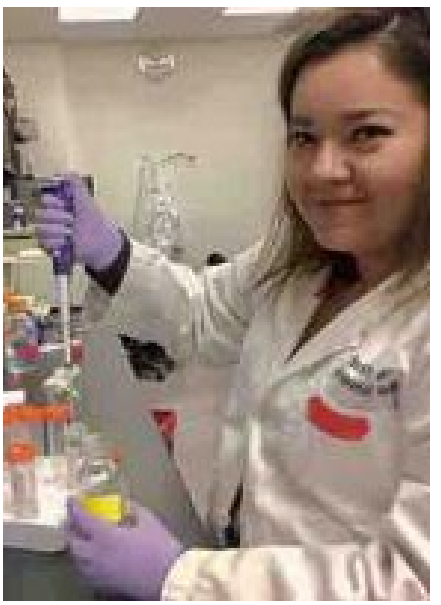


Shelby Ross, an enrolled member of the Oglala Sioux Tribe, is researching the impact of extreme weather on type 2 diabetes as part of her PhD. Photo: TCLP/NC CASC

How to partner with Indigenous communities through TEK

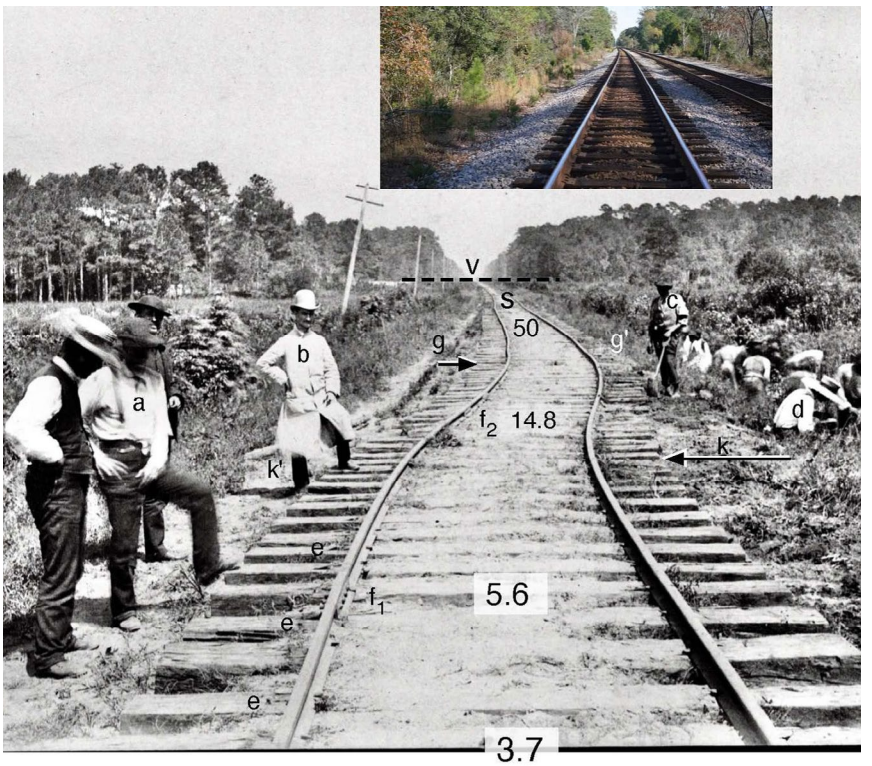
NC CASC created a story map for scientists and managers interested in partnering with Tribes and communities, available online or downloadable as a pdf or plain text.

The story map defines Traditional Ecological Knowledge (TEK) and provides guidance on best practices for braiding Western science and TEK to more fully understand the ecological and societal impacts of climate change. The map addresses data sovereignty and collaboration and how to promote partnerships based on equity, respect, and mutual understanding.

TEK STORY MAP

According to the story map, TEK consists of dynamic systems of knowledge that include "embodied, place-based, and process-oriented ways of life which have a special value to Indigenous planning efforts, their collective flourishing, and the pursuit of self-determination."

TEK is an ongoing relationship with the environment, not something of the past. Efforts to integrate TEK into Western scientific systems must understand this fundamental concept to respectfully relate to Tribal partners or Indigenous communities.



Bilham

'Converting the numbers into a convincing story turned out to be a nightmare.'

Computer analysis of this photo reveals distances (in meters) and offsets after the 1886 quake. Photo: From Blilham and Hough, 2024

Dusty archives inspire new story about 1886 Charleston earthquake

Late on August 31, 1886, while many people were asleep, a large quake rocked Charleston, South Carolina and the surrounding region, toppling buildings, buckling railroad tracks, and causing sand to bubble from liquefaction. The shaking left approximately 2,000 structures damaged and at least 60 people dead.

The 1886 Charleston earthquake was one of the most powerful earthquakes to strike the eastern United States, but mystery shrouded its cause.

Over a century after the quake, CIRES Fellow **Roger Bilham**, a research scientist at CU Boulder, and **Susan Hough**, a seismologist at the United States Geological Survey (USGS), picked up the trail. The scientists dug deep into old field notes, prompting surprising discoveries about the event — from the fault that caused the shaking to the earthquake's magnitude.

To start, Hough and Bilham dissected the written accounts of the event, including those by Earle Sloan, a mining engineer who took meticulous notes and measurements of the damage to three railroads radiating from Charleston.

"Converting the numbers into a convincing story turned out to be a nightmare," Bilham said. "The 1886 notes inadvertently included entry errors and typos that shifted the positions of buckles indiscriminately hither and thither."

In hopes of unscrambling the muddle, the team traveled to Charleston in 2022. They quickly zeroed in on a section of the railroad track in Summerville, northwest of Charleston, where Sloan had recorded severe track disturbances.

Using GPS, the scientists identified a 4.5-meter (14.8-foot) displacement in what should have been a straight-line mile of track. They

CONTINUED ON PAGE 34

GEO SHORTS

Schulte-Pelkum

How to build a continent

Scientists have long wondered how lower-density continental crust forms from its higher-density source magma. One proposed process — lithospheric foundering — involves the physical separation and loss of dense material from the lithosphere, which comprises the crust and upper mantle. **Vera Schulte-Pelkum**, a CIRES research scientist in Geological Sciences, and a colleague from Scripps Institution of Oceanography imaged the crust-mantle boundary deep beneath the Sierra Nevada in California using seismic waves. They found evidence that dense portions of the lithosphere are peeling away and sinking into deeper parts of the mantle. Their work suggests that removal happened several million years ago in the southern part of the mountains and is still ongoing in the central part, creating deep, small earthquakes. The study provides important evidence of a fundamental continent-building process.

bit.ly/lithosphere-peeling

Materna

Two California faults creep at snail's pace

"Creep" is a geologic process that occurs when faults slip or move slowly without earthquake activity. In 2023, two fault systems in California experienced large, shallow slip events, and a team led by CIRES Fellow **Kathryn Materna** captured the movement using high-resolution ground- and space-based measurements from GPS and radar. They found that the slip on each fault began spontaneously and then moved to other locations along

CONTINUED ON PAGE 35

Dusty archives

CONTINUED FROM PAGE 33

discovered that Sloan had described an offset at the same location.

The offset likely meant a fault beneath the tracks had moved. Modern geologists had identified the Summerville fault in that location, but nobody had linked it to the 1886 earthquake.

"It was a moment of serendipity that opened up a whole new dimension to the project," Hough said.

Bilham and Hough built several mathematical rupture models for movement on the Summerville fault that could explain both the archaeological and geological evidence. Their model pointed to a 7.2 magnitude earthquake, which was consistent with the large "felt" area of the earthquake and previous estimates.

Bilham continued to sift through historical documents to sort out why railroad tracks 20 miles from Summerville had buckled and been torn apart. A photograph taken the day after the Charleston earthquake showed what appeared to be a displacement of a railroad track where it crossed a swamp. Previous studies used the photo to infer faulting in the area, but those findings were inconsistent with what Bilham and Hough had discovered in Summerville.

The scientists constructed a virtual 3D view of the deformed railroad tracking using the original photo, which led to another stunning realization: most of the buckled tracks around Charleston hadn't recorded faulting, they had recorded the contraction and compression of seismic waves racing from the epicenter of the earthquake.

Bilham and Hough's research shows that even after 137 years, scientists can still learn new things about old earthquakes. Their research, published from 2023 to 2025, may help communities far from plate boundaries, where seismic activity is less frequent, better assess their risk for future earthquakes.

"There is a tendency to assume all knowledge is on the internet and readily available," Hough said. "Our efforts confirm how much value there can be in considering the dusty original sources of data."

bit.ly/dusty-archives

Associated papers:

bit.ly/relic-railroad-reveals

bit.ly/SC-quake-intensities

bit.ly/SC-quake-strain

Cumbre Vieja erupts, October 2021. Photo: Benjamín Núñez González via Wikimedia Commons

Current seismic activity mirrors data from before 2021 Cumbre Vieja eruption

In 2021, the Cumbre Vieja volcanic ridge in La Palma, in Spain's Canary Islands erupted, destroying over 3,000 buildings. Since then, seismic activity has continued, raising fears that another eruption might be possible. A team of scientists including ESOC Director and CIRES Fellow **Kristy Tiampo** used deformation measurements and a model to investigate ongoing changes. They found a fresh injection of magma in the southwest part of the island and a pressurized region in the central-eastern part of the island where the crust is weak due to recent volcanic activity. These changes are similar to the early stages of the 2021 eruption, warranting attention from hazard response teams and decision-makers.

Tiampo

bit.ly/after-LaPalma-quake

GEO Shorts

CONTINUED FROM PAGE 34

the fault. Their work showed that the speed of slip propagation ranged from 0.4 to 9 km per day, which is about how fast a snail or sloth moves.

bit.ly/snails-pace-creep

New model provides insight into river shifts

Gravel-bed rivers that cut into bedrock are common in mountainous regions. The speed at which these rivers cut into or incise bedrock is controlled by how easily rock can be eroded and the river's ability to transport rock pieces and sediment downstream.

Research led by **Vanessa Gabel,** a PhD candidate in Geological Sciences at CU Boulder and CIRES, presented a new mathematical model of a river profile evolution that captures bedrock erosion, sediment transport, and channel formation. The model will make it easier for scientists to predict how rivers change due to a changing landscape and environmental conditions.

bit.ly/gravel-bed-rivers

Colorado River

CONTINUED FROM PAGE 18

analyze data from a suite of models, including climate projections from the Intergovernmental Panel on Climate Change (IPCC). They determined that while warming temperatures have depleted Colorado River flows in recent decades, precipitation variations have mostly explained the swings between wet and dry periods since 1895.

Because of this, climate models forecasting a 70 percent chance of increased precipitation offer hope that the river's near-term future is not necessarily drier than the last two decades.

"This will compensate for the negative effects of more warming in the near term," said Hoerling, the paper's lead author.

The authors analyzed flow records at Lees Ferry, the dividing point of the river's upper and lower basins, since 1895. They confirmed natural changes in precipitation have ebbed and flowed over the past century, dictating extreme wet and dry periods for the river. For example, the current megadrought that began in 2000 has resulted mostly from low precipitation that reduced the river it to dry sandy river beds in Mexico.

Looking ahead, the team used climate models, including the latest climate projections from the IPCC, to predict the river's flow 25 years into the future. Most of the water that feeds the Colorado River begins as snow in the region's headwaters — mountains above 10,000 feet in Colorado and Wyoming. The area represents a small slice of the basin's geography, about 15 percent, but generates 85 percent of the water that flows through seven states. So precipitation in this "upper basin" is integral to flows in the entire river system. And the team found it is likely to increase, partially offsetting further declines linked to rising temperatures.

While an increase in precipitation is likely, the study finds a low probability that precipitation might not recover and could decline even further. Ongoing warming would further reduce water resources, resulting in even lower flows at Lee's Ferry than those that have led to today's crisis.

"Policymakers who must especially take into account risks of extended dry times, might consider this non-zero threat that the river could yield only 10 million acre-feet of water a year during 2025-2050," Hoerling said.

bit.ly/brighter-COriver-future

Tribal students

CONTINUED FROM PAGE 32

Her initial questions focused on whether events like hail storms, extreme winds, and blizzards create barriers to healthcare and food access.

"There is limited Native American-led climate change research that focuses on Native American communities in general, and of those studies, there is even less that focus on the potential of climate impacts to Native American health," Ross said. "As far as I know, I am the first, or one of the first, Oglala Sioux Tribal members to conduct climate change research on the Pine Ridge Indian Reservation that involves the feedback of the tribal members."

"Ross's research addresses critical questions and needs within her community in ways that honor tribal sovereignty and center Indigenous knowledge," said **Clint Carroll**, associate professor of Ethnic Studies at CU Boulder. "This is the value and promise of the TCLP now and into the future, as we seek support to continue this important program: To provide insight on pressing issues that Indigenous nations confront by merging CU Boulder's climate science programs and resources with the lived experiences, knowledge, and relationships that Indigenous students bring to the research process."

https://bit.ly/TCLP-Ross

Online course

CONTINUED FROM PAGE 29

and standards for fieldwork (including codes of conduct), and implementing field safety protocols and emergency response planning in field campaigns. The goals of the course include training field scientists to identify unsafe and harmful behaviors, respond appropriately to mitigate these behaviors, support those impacted by the behaviors, and proactively plan to reduce the likelihood and impact of these behaviors in the future.

The course includes a toolkit research teams can tailor to their own expeditions. CIRES Fellow **Anne Gold**, the program's principal investigator and CEEE director, said she's received positive feedback from field researchers who have implemented some of the strategies laid out in the course. One researcher told her the strategies helped normalize some of the difficult conversations teams need to have in the field and changed the experience for the better.

bit.ly/fieldsafe

MILESTONES

CO Governor's Award for High-Impact Research

Mendoza

VIDEO

Manuel M. Mendoza, a former CIRES Visiting Fellow in Geological Sciences , won an Outstanding Early Career Scientist Award, one of the Governor's Awards for High Impact Research from CO-LABS. His work used Distributed Acoustic Sensing (DAS) to research earthquakes in Utah and the Pacific Northwest. DAS fires lasers into fiber optic cables to document ground motions and earthquakes with high resolution. The cutting-edge technique can identify weak tremors from tectonic plate movements, thus advancing geoenergy-related earthquake detection. By tapping into existing infrastructure, DAS can expand opportunities to collect seismic data relatively cheaply. Mendoza now works at the U.S. Bureau of Reclamation in Denver.

bit.ly/Mendoza-CGA

2024 Highly Cited Researchers

Fierer

Jimenez

CIRES Fellows **Noah Fierer** and **Jose Luis Jimenez** were recognized as 2024 Highly Cited Researchers by Clarivate for Academia and Government. Citations of their papers ranked in the top one percent for their fields and publication year in the Web of Science™ over the past decade.

bit.ly/Fierer-Jimenez-highly-cited

AMS Editor's Award

Duda

Research Meteorologist and Atmospheric Scientist **Jeff Duda** won the 2024 American Meteorological Society Editor's Award for providing extremely thorough, constructive, and timely reviews of numerous manuscripts.

Karnauskas

AGU 2024 Lectures

CIRES Fellow and Associate Professor of ATOC **Kris Karnauskas** earned this award recognizing "significant contributions to and promise in the ocean sciences."

bit.ly/Karnauskas-Turco

Capotondi

AGU recognized CIRES Fellow and NOAA PSL Senior Research Scientist for Dynamics and Multiscale Interactions **Antonietta Capotondi** for "outstanding contributions to, as well as unselfish promotion of cooperation in, atmospheric and oceanographic research."

bit.ly/Capotondi-Sverdrup

New CIRES Fellows

The CIRES Council of Fellows welcomed five new members in 2024. The fellows are CU faculty, researchers, and NOAA scientists who are experts in Earth sciences. The new fellows include:

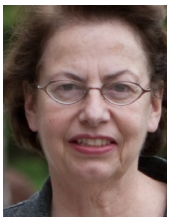
- **Antonietta Capotondi**, senior research scientist in PSL who studies ocean circulation and its impact on climate change.
- **Anne Gold**, Director of CEEE and a national leader in geoscience and climate education.
- **Matthew Shupe**, senior research scientist in PSL and NSIDC who studies Arctic cloud and atmospheric processes.
- **Katherine Siegel**, an interdisciplinary environmental scientist and assistant professor in the CU Boulder Department of Geography, who teaches in the Earth Data Analytics certificate program.
- **Christine Wiedinmyer**, CIRES and CIESRDS Associate Director for Science, whose research focuses on the emissions, transport, and fate of pollutants in the atmosphere and how they impact air quality, climate, and health.

https://bit.ly/new-CIRES-fellows-2024

https://bit.ly/siegel-CIRES

MILESTONES

Veronica Vaida retires



Vaida

Professor of Chemistry and CIRES Fellow **Veronica Vaida** retired in 2024 after a 40-year career. Her teaching and research have followed an interdisciplinary path at the interface of physical chemistry and environmental science, focusing on planetary atmospheres such as those of contemporary and ancient Earth. She earned countless awards and honors and was elected to the American Academy of Arts and Sciences and the National Academy of Sciences for her contributions to science.

https://bit.ly/vaida-retires

NIDIS awards $4.9M to advance drought monitoring, prediction

NOAA's NIDIS announced $4.9 million in funding for NOAA labs and research partners to improve drought monitoring and prediction in the American West. This research combines $3.1 million in funding from NIDIS and $1.8 million from the Inflation Reduction Act to improve decision-makers' capacity to protect life, property, and ecosystems in the region from drought.

Water Fellows Kiara Bonilla and Ethan Durham listen to sessions during the Water Fellows Convening in Denver in February 2025. Photo: The Colorado Water Center

Water Fellows Program trains future water professionals

Four undergraduate students studying environmental engineering, sociology and environmental studies, atmospheric sciences, and geology participated in the inaugural CU Boulder Water Fellows program, hosted this year by Western Water Assessment. The program prepares the next generation of water leaders through training, networking, and mentorship from professionals across Colorado. The CU Boulder Fellows attended monthly meetings with guest speakers and traveled to water-focused conferences like the Colorado Water Congress, Colorado 9 Basin (C9 Summit), and the Colorado Water Fellows Convening meeting — a gathering of all 45 fellows in Denver.

bit.ly/WWA-Water-Fellows

USGS awards CU Boulder five years' funding to host NC CASC

NC CASC has been advancing the development of actionable science to help people and wildlife adapt to a changing environment since 2018. NC CASC works in the North Central region of the U.S., encompassing the states of Colorado, Wyoming, Montana, North Dakota, South Dakota, Kansas, and Nebraska.

NC CASC fosters innovative and applied research in support of Tribal, federal, state, and local natural resource management and decision-making. The center recognizes the importance and value of Traditional Ecological Knowledge (TEK) in addressing the impacts of climate change.

In 2024, the United States Geological Survey awarded CU Boulder an additional five-year cooperative agreement to continue hosting the center. NC CASC's work includes projects focused on sustaining bison grazing on Badlands and Wind Cave National Parks and adjacent Tribal lands; modeling future snowpack that supports species like wolverines; and providing climate science and data for the Sicangu Lakota (Rosebud Sioux) Climate Adaptation Plan.

bit.ly/NCCASC-funding

TOP O' SPHERES

CIRES' most-read, most-liked news and social media posts since May 2024

TOP NEWS STORIES

(May 2024 - April 2025)

1 CIRES researchers find compromised indoor air in homes following Marshall Fire

December 2024

Read it on page 13

bit.ly/compromised-indoor-air

2 Fire speed, not size, drives threat to people, infrastructure

October 2024

Read it on page 11

bit.ly/fire-speed-not-size

3 Precipitation may brighten Colorado River's future

May 2024

Read it on page 18

bit.ly/brighter-COriver-future

4 Sea otters help kelp forests recover — but how fast depends on where they are

March 2025

Read it on page 21

bit.ly/otters-kelp

5 CIRES researcher Manuel M. Mendoza receives Colorado Governor's Award

November 2024

Read it on page 37

bit.ly/Mendoza-CGA

6 Ice shelves fracture under weight of meltwater lakes

May 2024

Read it in Spheres 2024

bit.ly/ice-shelves-fracture

TOP SOCIAL MEDIA POSTS

(May 2024 - April 2025)

CIRES stands with federal colleagues and collaborators

52 likes, 17 shares
https://bsky.app/profile/cires.colorado.edu/post/3ljbgyhymak2c

27 likes, 21 shares
https://www.instagram.com/p/DGogeD6zpvT/

390 likes, 51 shares
https://www.linkedin.com/feed/update/urn:li:share:7301364105783758849/

51 likes, 18 shares
https://www.facebook.com/CIRESnews/

The role of NOAA in US weather forecasting

(The Conversation piece by Christine Wiedinmyer and Kari Bowen)

80 likes, 47 shares:
https://bsky.app/profile/cires.colorado.edu/post/3lhw2kehpfx2x

96 likes, 13 shares
https://www.instagram.com/p/DF8FokrzX3W/

146 likes, 28 shares
https://www.linkedin.com/feed/update/urn:li:share:7295113215724642304/

46 likes, 25 shares
https://x.com/CIRESnews/status/1889347419290169427

Twila Moon in climate stripes poncho at AGU24

309 likes, 43 shares
https://bsky.app/profile/cires.colorado.edu/post/3lcxvoky37s2f

52 likes, 2 shares
https://www.instagram.com/insights/media/3520163039918134596/

Xinzhao Chu and team in Antarctica

49 likes, 2 shares
https://www.instagram.com/insights/media/3557801198420353279/

Four CIRES researchers join Council of Fellows

69 likes
https://www.linkedin.com/feed/update/urn:li:share:7241460938669752322/

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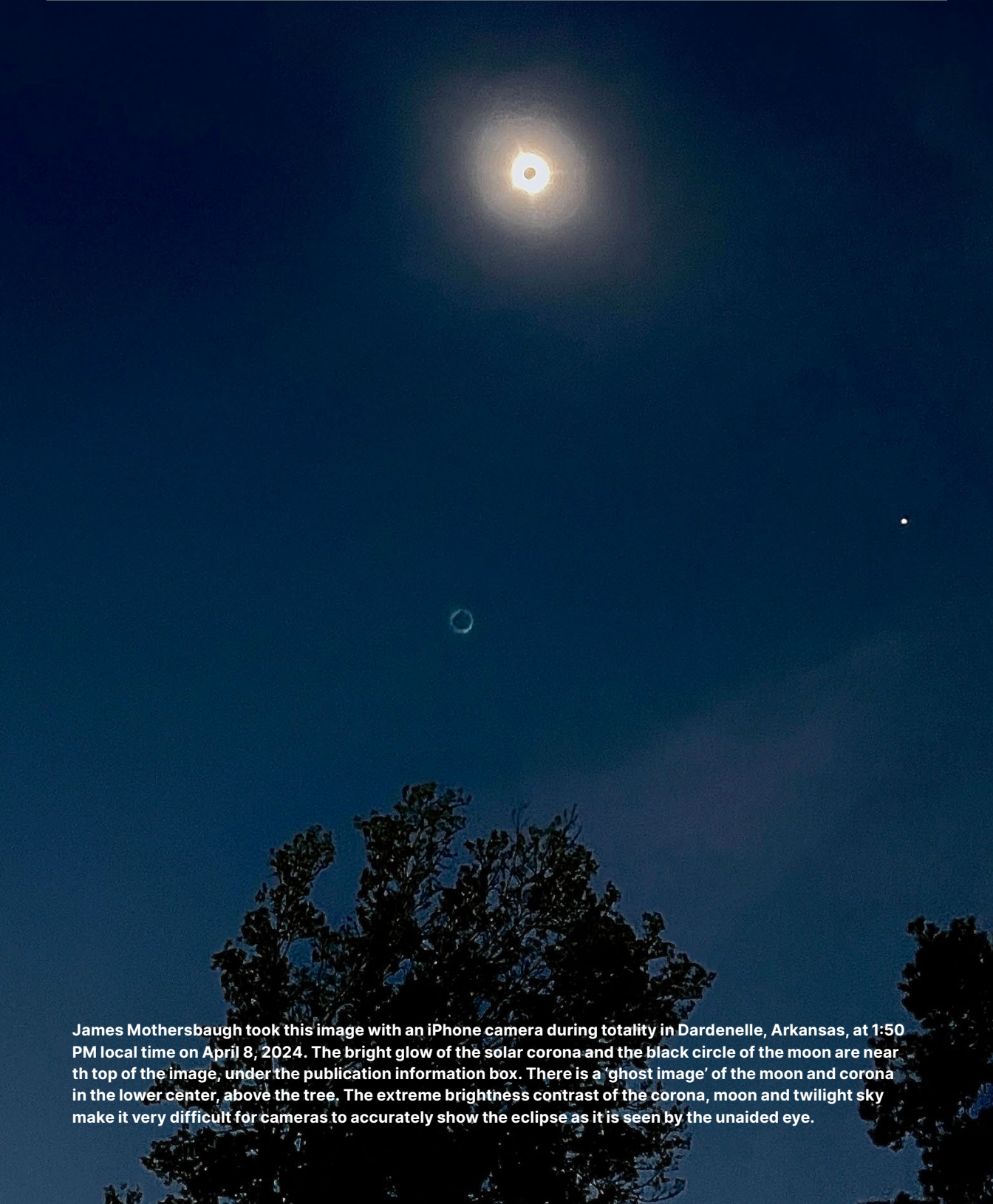

James Mothersbaugh took this image with an iPhone camera during totality in Dardenelle, Arkansas, at 1:50 PM local time on April 8, 2024. The bright glow of the solar corona and the black circle of the moon are near th top of the image, under the publication information box. There is a 'ghost image' of the moon and corona in the lower center, above the tree. The extreme brightness contrast of the corona, moon and twilight sky make it very difficult for cameras to accurately show the eclipse as it is seen by the unaided eye.