CIRES

COOPERATIVE INSTITUTE FOR RESEARCH IN ENVIRONMENTAL SCIENCES

SPHERES

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Industries are meeting renewable energy goals

New CIRES center empowers educators, students

Attitudes toward climate change can influence election outcomes

Fire researchers gather new data to strengthen hazard response

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SPHERES
A publication of the Cooperative Institute for Research in Environmental Sciences

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.

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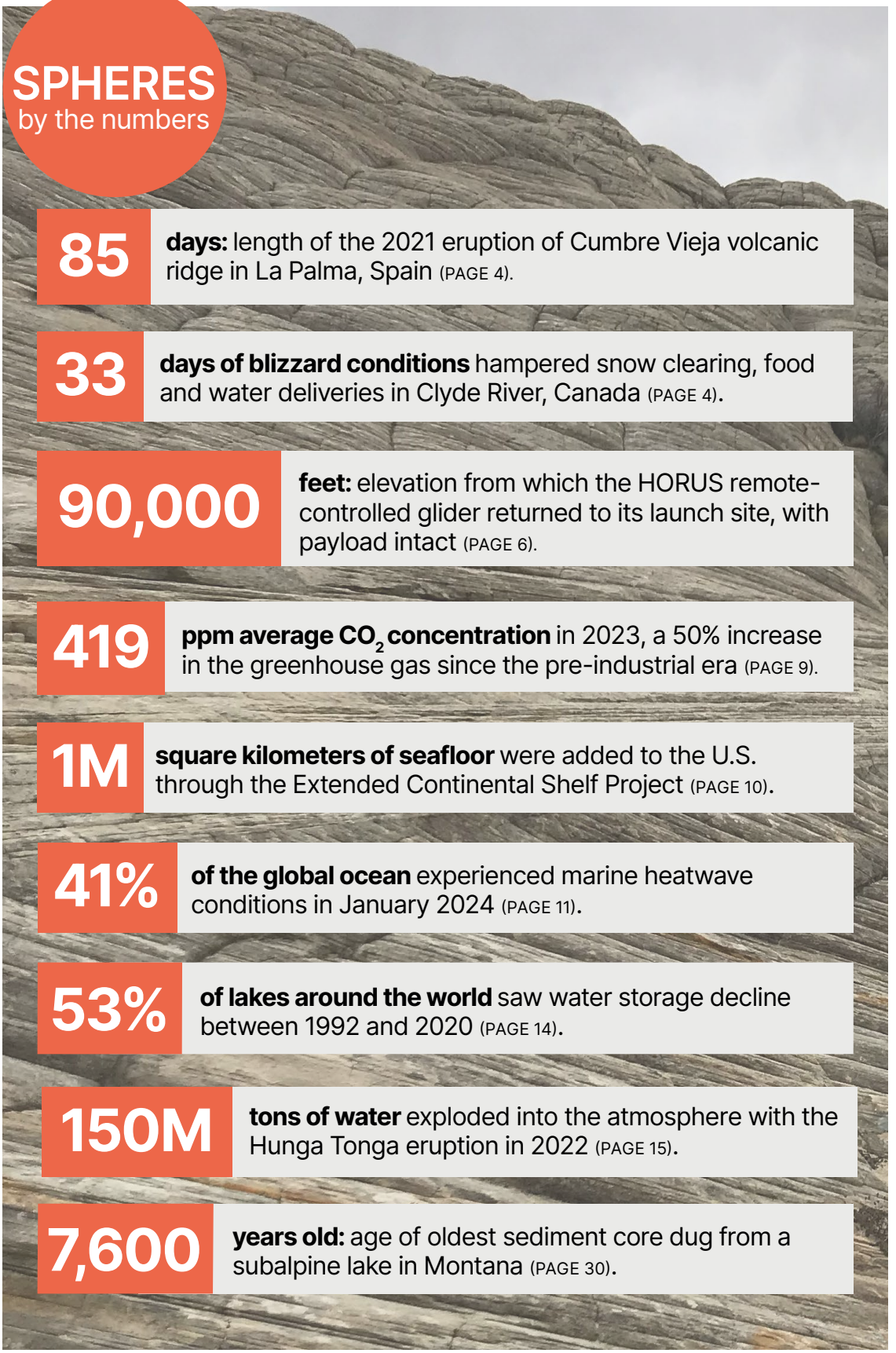
ACRONYMS

CEEE: CIRES Center for Education, Engagement, and Evaluation
CSL: NOAA Chemical Sciences Laboratory
GML: NOAA Global Monitoring Laboratory
GSL: NOAA Global Systems Laboratory
NCEI: NOAA National Centers for Environmental Information
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

On the cover: Salomé Carrasco collected grasshoppers during her summer project with RECCS, a program within CEEE that exposes community college students to hands-on scientific research. Story, page 17. Photo: Stephanie Maltarich/ CIRES



SPHERES
by the numbers

85 **days:** length of the 2021 eruption of Cumbre Vieja volcanic ridge in La Palma, Spain (PAGE 4).

33 **days of blizzard conditions** hampered snow clearing, food and water deliveries in Clyde River, Canada (PAGE 4).

90,000 **feet:** elevation from which the HORUS remote-controlled glider returned to its launch site, with payload intact (PAGE 6).

419 **ppm average CO_2 concentration** in 2023, a 50% increase in the greenhouse gas since the pre-industrial era (PAGE 9).

1M **square kilometers of seafloor** were added to the U.S. through the Extended Continental Shelf Project (PAGE 10).

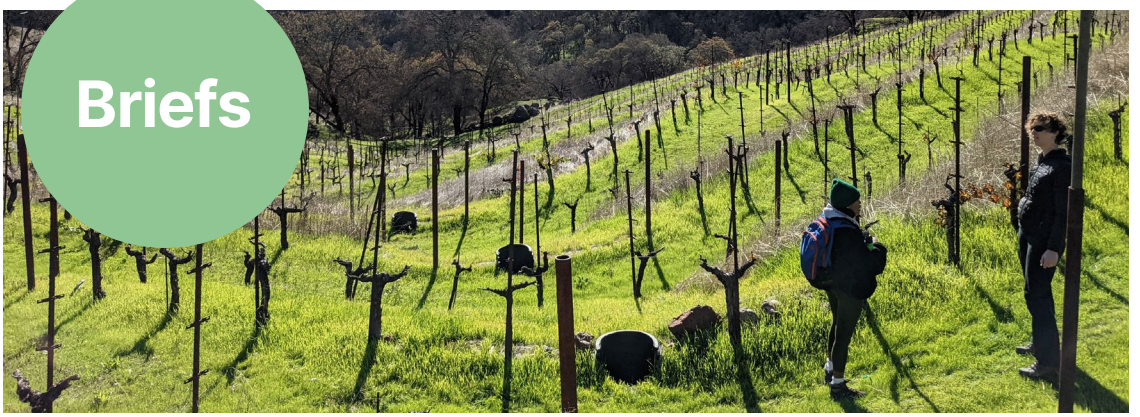
41% **of the global ocean** experienced marine heatwave conditions in January 2024 (PAGE 11).

53% **of lakes around the world** saw water storage decline between 1992 and 2020 (PAGE 14).

150M **tons of water** exploded into the atmosphere with the Hunga Tonga eruption in 2022 (PAGE 15).

7,600 **years old:** age of oldest sediment core dug from a subalpine lake in Montana (PAGE 30).

Briefs



CIRES researchers working in California's Napa Valley developed a way to measure sulfate reduction rates in agricultural soils. "We know excess sulfur is linked to mobilization of toxic metals in ecosystems," said Laura Rea, a CIRES/CU Boulder PhD student. Photo: Laura Rea

BIOGEOCHEMISTRY

Vineyard soils can support toxin-producing reactions

Sulfur, which is used as a fungicide on wine grapes, can stimulate chemical reactions in agricultural soils, possibly resulting in production of the dangerous toxin methylmercury. Recent research led by CIRES/CU Boulder PhD student **Laura Rea**, alongside others in CIRES Fellow **Eve-Lyn Hinckley**'s Environmental Biogeochemistry Group, finds evidence of sulfur reduction reactions in Napa Valley, California, vineyards, which may mean that heavy metals are mobilized into biota as well. Previous studies have found evidence of this process happening in downstream wetlands, but Rea's research shows sulfate reduction happening directly in vineyard soils. The research could help scientists and winegrowers understand the fates of sulfur in vineyards, the need to optimize fungicide applications, and the potential for the accumulation of toxic mercury in soils.

bit.ly/vineyard-sulfur

HAZARDS

Tides may influence quake activity

In 2021, the Cumbre Vieja volcanic ridge in La Palma, Spain, erupted, leading to the evacuation of thousands of people and the destruction of over 3,000 buildings. A team of scientists, including ESOC Director and CIRES Fellow **Kristy Tiampo**, used earthquake data and a tidal stress model to investigate the link between seismic activity and tides during the 85-day eruption. Their results suggest that ocean tides influenced seismic activity during those weeks. The team's findings may help scientists better understand hazards associated with eruptions on other volcanic islands.

bit.ly/tides-influence-seismic

SUSTAINABILITY

Better food access offsets environmental gains from reducing food waste

Decreasing food loss and food waste may not have the environmental benefits researchers, advocates, and policymakers expect, but it could increase access to more affordable food for people worldwide, according to a 2023 study led by CIRES/CU Boulder PhD candidate **Margaret Hegwood**. The authors explained that to understand the environmental benefits of reducing food waste and food loss, one must also consider the full picture of reducing waste: More food available would lead to lower prices, and that would create predictable changes in people's behavior.

bit.ly/food-waste-win

33 blizzard days expose challenges for Arctic community

From November 2021 to April 2022, the community of Kangiqtugaapik (Clyde River) in Nunavut, Canada, was slammed with 33 days of blizzard conditions. Recently, a team of scien-

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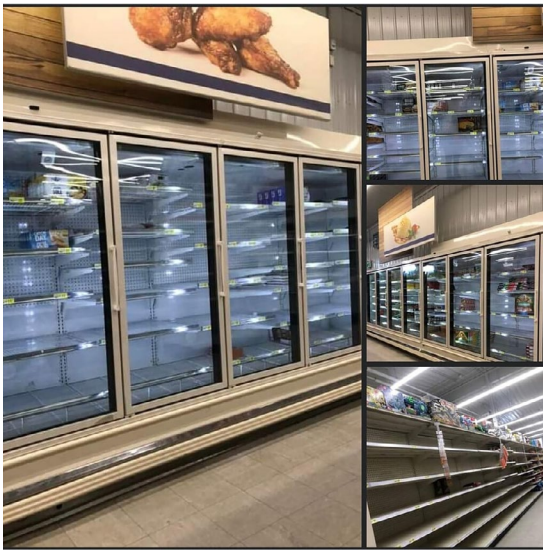

Shelves in Clyde River's only store were empty by the first week of March 2022, as the region experienced more than a month's worth of blizzards. Photo: V. Enuaraq

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tists and local partners from NSIDC's Arctic Rain on Snow Study came together to learn more about the storms and their impacts on the people who live there, most of whom are Inuit. Using meteorological data and community knowledge, the team found high winds were likely the culprit behind many of the extreme events. Local observations indicated that broken equipment hampered snow-clearing efforts, delaying vital deliveries of water and food. The findings helped the authors outline recommendations to better support Arctic communities in the face of a warming climate.

bit.ly/extreme-arctic

bit.ly/49w3Nf5

ECOLOGY

Marine predators face as much as 70% habitat loss by 2099

Twelve species of migratory fish predators, including sharks, tuna, and marlin, face widespread habitat loss due to climate change, according to work co-authored by **Jamie Scott**, a CIRES scientist in PSL. Using data from satellites, on-the-ground measurements, and an oceanographic model, an interdisciplinary team found that some species could lose upwards of 70 percent of suitable habitat by the end of the century. The study identified the Northwest Atlantic Ocean and the Gulf of Mexico as hotspots for multi-species habitat loss. The authors hope their work will help coastal communities and the fishing industry better plan and adapt to climate change.

bit.ly/fish-predators-habitat

bit.ly/Scott-predators-paper

CIRES/CU Boulder graduate students Sean Leister and Megan Thompson-Munson get a feel for field research near Gothic Mountain in rural Colorado. Photo: Stephanie Maltarich/CIRES

EDUCATION

Hands-on field work helps grad students link observations, data

For many graduate students who began their journey in academia at the onset of the COVID-19 pandemic, opportunities to get into the field were limited. In May 2023, **Jennifer Kay**, an associate professor in the Department of Atmospheric and Oceanic Sciences and CIRES fellow, decided it was time to get her students some hands-on experience by taking them on a four-day field trip to a remote research station high in Colorado's mountains. Most of Kay's students work with physics-based climate models, and the trip was an opportunity for them to learn more about how environmental data that feeds models is collected in the field. CIRES' **Gijs de Boer** and **Joe Sedlar** led the students through the snow to show them some of

AUDIO STORY

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CIRES scientist Ali Banwell and Laura Stevens, University of Oxford, install a time-lapse camera on the George VI Ice Shelf in Antarctica. Photo: Ian Willis/University of Cambridge

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the instruments supporting the NOAA SPLASH campaign, a project that collected wind, snow, and air temperature data to advance weather and water availability prediction.

bit.ly/grads-in-the-field

CRYOSPHERE

Declining sea ice, waves speed Antarctic ice flow

The Larsen B Ice Shelf in Antarctica broke up dramatically in 2002, after decades of climate warming and increased ice melt in the region, causing a Rhode Island-sized chunk of ice to shatter in just a few weeks. A cooler period began in 2011, and a thin plate of frozen seawater formed where Larsen B once lay. After warmer conditions returned in 2021-22, this "fast ice" broke up as well, just like Larsen B did 20 years before.

When CIRES/CU Boulder graduate student **Naomi Ochwat** analyzed satellite data of the region, she found the 2022 breakup was due to a combination of two things: low sea ice concentrations around the Antarctic Peninsula and large ocean waves that were able to reach the coastline in part due to that lack of sea ice. She found the glaciers behind this plate of ice responded to the breakup by thinning, moving more quickly downstream, and retreating, creating lots of icebergs at remarkable rates.

Ochwat suspects that what happened to Larsen B and the ice that replaced it could signal what's to come for Antarctica's larger ice sheets: declining sea ice, more fast ice breakup, and an increase in ice sheet retreat.

Weight of pooling water can fracture, collapse ice shelves

Heavy meltwater lakes can bend and break ice shelves, potentially leading to their collapse, according to recent work led by **Alison Banwell**, a CIRES scientist in the Earth Science and Observation Center. The study, which focused on a meltwater lake basin on the surface of the George VI Ice Shelf in Antarctica, provides the first field-based evidence of an ice shelf fracturing from the weight of pooling meltwater. "We believe these types of circular fractures were key in the chain reaction-style lake drainage process that helped to break up the Larsen B Ice Shelf," Banwell said. As the climate warms and melt rates in Antarctica increase, fracturing could cause other vulnerable ice shelves to collapse, allowing inland glacier ice to spill into the ocean and contribute to sea level rise. The work will help scientists better predict which ice shelves might be most susceptible to future breakup.

bit.ly/meltwater-lakes

INSTRUMENTATION

Revolutionary glider system passes key milestone

GML scientists have made a significant step forward in their quest to develop a reliable,

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cost-effective way to study Earth's stratosphere. In May 2023, the High-altitude Operational Return Uncrewed System (HORUS) remotely controlled glider, carried to an altitude of 90,000 feet by a weather balloon, returned to its launch location on Colorado's Pawnee National Grasslands with its scientific payload intact.

The successful mission marked the next step in a four-year effort to deploy and recover an atmospheric sampling and measurement system from that altitude in controlled airspace. The glider, developed by scientists at CIRES, NOAA, and other institutions, provides a predictable and trackable trajectory back to its launch location, making it easy for FAA air traffic control to ensure the safety of other aircraft.

bit.ly/3Ude77A

SEA LEVEL RISE

Sinking land elevates flooding risk for Lagos, Nigeria

Scientists in the CIRES Earth Science and Observation Center recently took a detailed look at how sea level rise is likely to impact the coastal city of Lagos, Nigeria. They predict Lagos will experience significant increases in flooding by the end of the century when accounting for land subsidence along the coastline. The findings will likely be meaningful to Nigerian city planners and emergency managers in the face of a rapidly changing climate.

The new work combined sea level rise projections with the impact of subsidence, or downward land motion (for example, when groundwater depletion lowers the elevation of a city). The team used data and models to project coastal flooding in Lagos, down to the millimeter in some places, and made predictions with and without subsidence included. Their findings show that accounting for land subsidence results in few changes in predicted vulnerable areas by 2030, but after that, the differences become more significant. Future efforts will focus on identifying areas that will flood in places with higher population densities.

"A lot of global sea level rise projections for flooding don't always include the vertical land motion component," said CIRES/CU Boulder geophysics PhD student **Joel Johnson**, who works with CIRES Fellow **Kristy Tiampo**. "As more time goes on, decades into the future, we can see how much more area is at risk of flooding with the vertical land motion as opposed to without it."

bit.ly/subsidence-and-flooding

SPACE WEATHER

Solar Cycle 25 heats up with record-setting flares

Recent X-class solar flares and radio blackouts are just a few of the signs that the peak of Solar Cycle 25 is fast approaching, and heliophysicists expect to see more intense solar activity in the coming months.

Solar Cycle 25 began in December 2019 and was originally expected to peak around July 2025. But SWPC announced in January the current cycle will likely hit its peak sooner—sometime in 2024—and with more activity than was predicted when the cycle began. More than 30 CIRES researchers work in SWPC, including **Mark Miesch**, who serves as the center's solar cycle lead.

As the Sun moves closer to its maximum activity, forecasters expect to see more sunspots, solar flares, and coronal mass ejections. SPWC forecasters expect the maximum number of sunspots for the cycle to reach between 137 and 173. Forecasters have already seen elevated activity from the Sun starting at the end of 2023 and going into 2024. An X-class solar flare erupted on December 31, 2023, and was the strongest solar flare of the current solar cycle at the time. However, three X-class solar flares erupted within 24 hours on February 22, 2024, one of which was stronger than the December 31 flare. As of early April, it was the strongest solar flare of this solar cycle. In addition, a radio blackout and CME occurred on March 28, but luckily, the CME was not directed toward Earth.

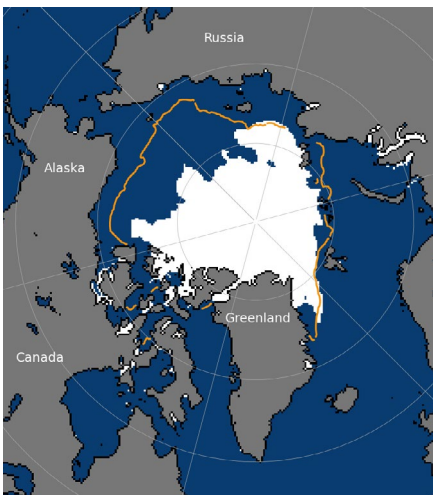
bit.ly/solar-25

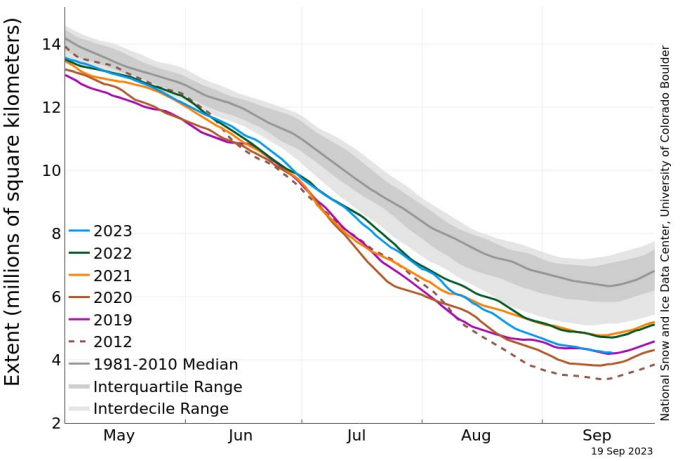
Annual Updates

ARCTIC and ANTARCTIC SEA ICE

- On September 19, 2023, Arctic sea ice likely reached its annual minimum extent of 4.23 million square kilometers (1.63 million square miles). This is the sixth-lowest in the nearly 45-year satellite record. The last 17 years, from 2007 to 2023, are the lowest 17 sea ice extents in the record.
- On February 20, 2024, Antarctic sea ice likely reached its minimum extent of 1.99 million square kilometers (768,000 square miles). This amount tied for the second-lowest extent in the 1979 to 2024 satellite record. This is the third consecutive year that Antarctic sea ice has reached a minimum below 2.0 million square kilometers (772,000 square miles).

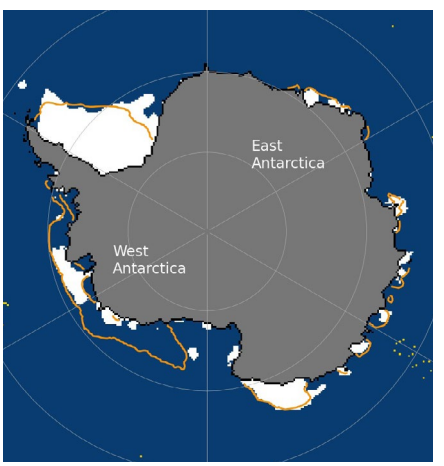
ARCTIC SEA ICE EXENT / September 19, 2023 (Area of ocean with at least 15% sea ice)

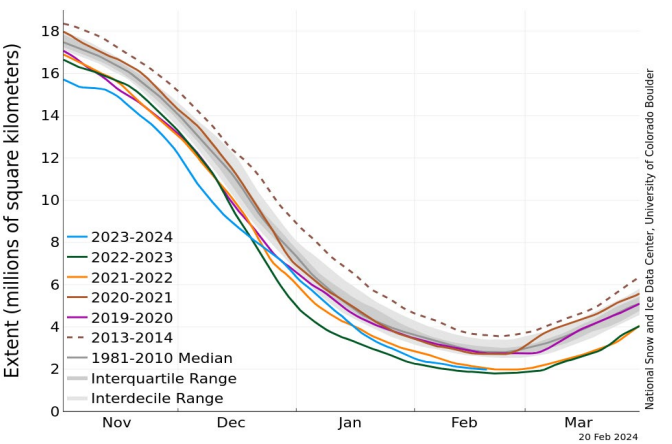




bit.ly/Arctic-ice-6th

ANTARCTIC SEA ICE EXENT / February 20, 2024 (Area of ocean with at least 15% sea ice)





bit.ly/Antarctic-ice-third

GREENHOUSE GAS LEVELS

The global average surface concentration of **carbon dioxide**, averaged over the year, was 419.3 parts per million (ppm). In 2023, the annual increase in carbon dioxide was 2.8 ppm. This was the 12th consecutive year carbon dioxide increased by more than 2 ppm, extending the highest sustained rate of carbon dioxide increases during the 65-year monitoring record. Atmospheric carbon dioxide is now 50 percent higher than pre-industrial levels.

Atmospheric methane rose to an average of 1922.6 parts per billion (ppb). The 2023 methane increase was 11.1 ppb, lower than the record growth rates in 2020, 2021, and 2022, but still the 5th highest since renewed methane growth started in 2007. Atmospheric methane levels are now more than 150 percent higher than pre-industrial levels.

In 2023, levels of **nitrous oxide** climbed by 1 ppb to 336.7 ppb. Increases in atmospheric nitrous oxide during recent decades are mainly from the use of nitrogen fertilizer and manure from the expansion and intensification of agriculture. Nitrous oxide concentrations are now 25 percent higher than pre-industrial levels of 270 ppb.

bit.ly/gases-update

VIDEO STORY

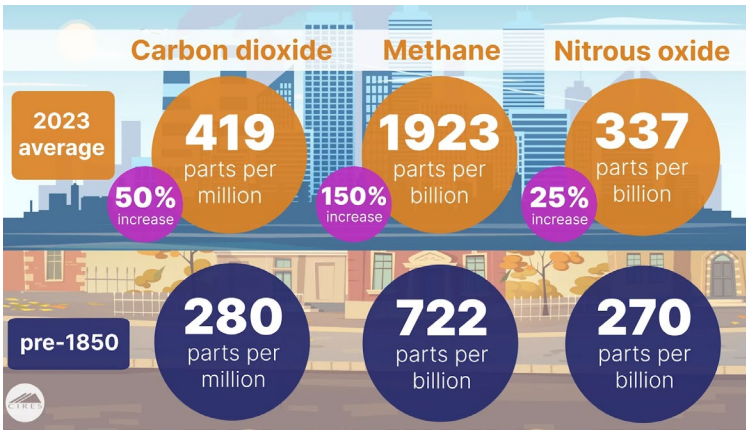


Image: Lauren Lipuma/CIRES

OZONE HOLE SIZE

The 2023 Antarctic ozone hole reached its maximum size at 26 million square kilometers (10 million square miles) on September 21, which ranks as the 12th largest since 1979, according to annual satellite and balloon-based measurements made by NOAA (including CIRES) and NASA.

During the peak of the ozone depletion season from September 7 to October 13, the hole this year averaged 23.1 million square kilometers (8.9 million square miles) in area, approximately the size of North America.

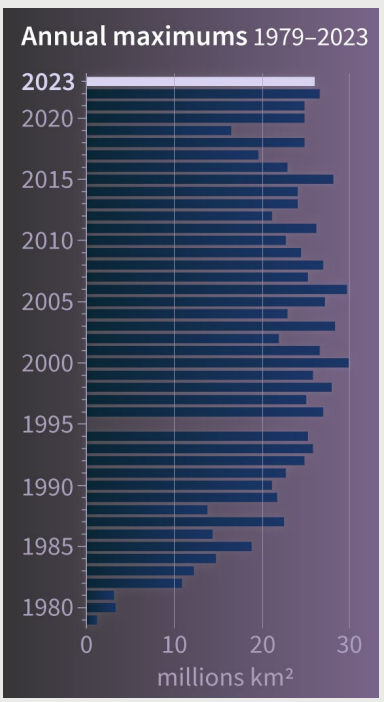


Image: NOAA/NASA

"It's a very modest ozone hole," said NASA's **Paul Newman**. "Declining levels of human-produced chlorine compounds, along with help from active Antarctic stratospheric weather, slightly improved ozone levels this year."

bit.ly/ozone-12th

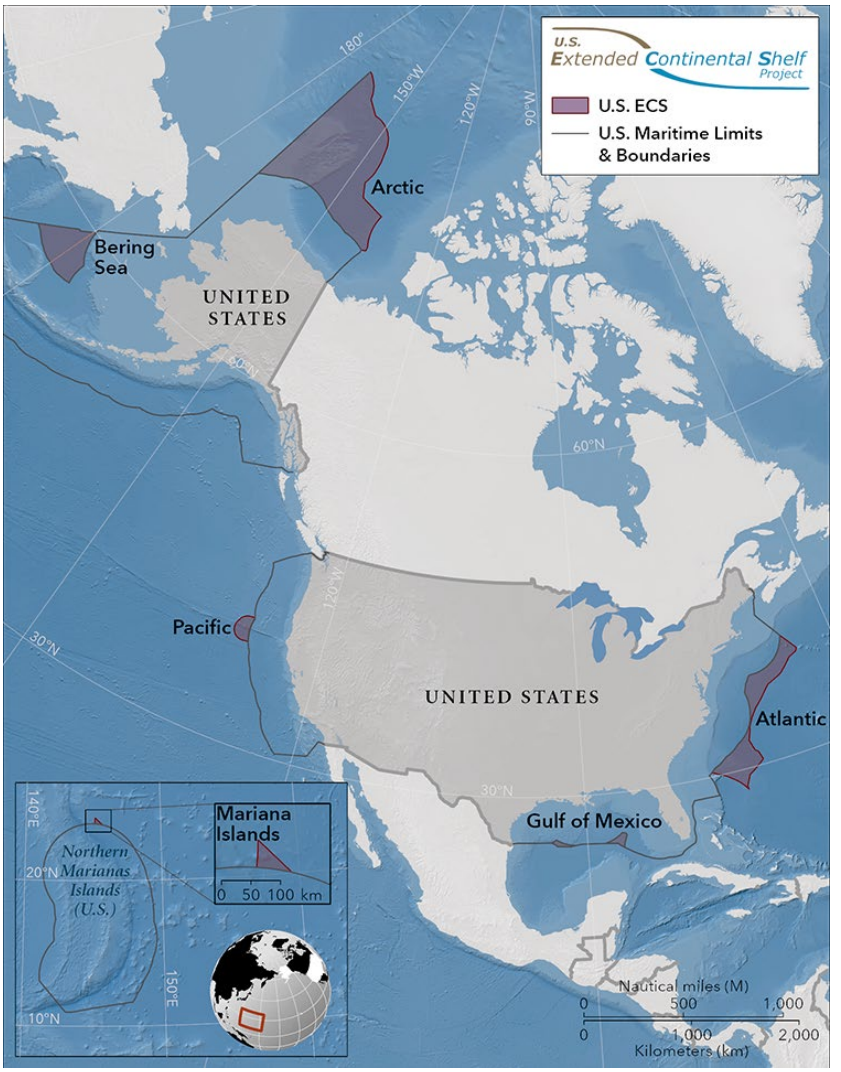
US gains over 1 million square km additional seafloor

MAPPING

The United States now has sovereign rights over an additional one million square kilometers of seafloor—twice the size of California—thanks to a government-led project to define the limits of the U.S. extended continental shelf that culminated in December 2023.

Extended continental shelf (ECS) areas are parts of the seafloor a country has sovereign rights over that extend more than 200 nautical miles from its coastline. Defining an ECS region requires precise mapping of seafloor topography to define where the physical continental shelf ends and the deep ocean begins.

More than 300 people across 14 federal agencies have worked on the project since 2003. CIRES scientists in NOAA's NCEI analyzed the geophysical data collected by NOAA and partners. The ECS Project Office used those analyses to determine the U.S. ECS outer limits.



Red-toned areas shows the newly defined boundaries of the seven areas where the United States has extended continental shelf.
Image: U.S. State Department

VIDEO

Determining the ECS limits helps scientists understand the geologic history of remote areas of the seafloor and contributes much-needed data to the ongoing international effort to map the entirety of Earth's seafloor by 2030.

The mapping efforts also revealed some interesting features of the seafloor. Researchers determined the precise depth of the Challenger Deep in the Pacific Ocean—the deepest spot in the world's oceans—at 10,994 meters. In the Arctic Ocean, researchers mapped scrapes on the seafloor made by glaciers and pockmarks made by exploding gases.

"We've grown the United States and it's now up to us to explore, learn new science, and then steward, manage, and help preserve these areas for future generations," said **Barry Eakins**, a marine geophysicist who led the CIRES ECS team.

Temperatures rise on oceans' surface, in the depths

CLIMATE CHANGE

Marine heatwaves—periods of persistent uncharacteristically warm ocean temperatures—can have significant impacts on marine life, coastal communities, and economies. Recent observations by researchers in PSL show marine heatwaves occurring across vast regions of the planet's oceans. From early 2023 through August, the percentage of global oceans considered to be in a heatwave skyrocketed from less than 20 to nearly 40, before leveling off in the fall. Many areas of global oceans will likely drop out of heatwave conditions as El Niño conditions wane and La Niña conditions begin. You can follow the PSL marine heatwave forecast here: https://psl.noaa.gov/marine-heatwaves/#report.

Meanwhile, recent NOAA research shows marine heatwaves also happen deep underwater. In a paper in *Nature Communications*, a team of researchers at NOAA, CIRES, and NCAR used a combination of observations and computer models to generate the first broad assessment of marine heatwaves in deep water along the continental shelves of North America.

The scientists found deep-water marine heatwaves persisting longer than their surface counterparts, with larger warming signals.

Furthermore, deep-water marine heatwaves can occur with little or no evidence of warming at the surface. "This… can be happening without managers realizing it until the impacts start to show," said PSL scientist **Dillon Amaya**. That's important information for managers of commercially important fisheries.

bit.ly/ocean-bottom-heat

bit.ly/global-ocean-heat

Researchers head for a day of sampling in Wrangell St. Elias National Park, Alaska. Photo: Ethan Welty/INSTAAR

New online course trains scientists on field risks

FIELD RESEARCH

Alice Hill has spent many hours of her adult life in remote locations around the world: she's traversed technical peaks in Alaska and Patagonia, rowed boats down rapids in Peru, and collected water samples in high alpine Kyrgyzstan. As a mountain hydrologist and field instructor for the National Outdoor Leadership School, Hill understands the complexities of working in remote locations with groups of people. But over the years, Hill realized the goals of scientific fieldwork and outdoor education didn't always align.

"I think an inherent goal in outdoor education is to create a group environment supportive of learning and that requires leadership development and group awareness," Hill said. "Whereas with science, it always comes with this overarching goal of collecting the data."

So Hill started talking with colleagues about how to do both: build safe and supportive teams collecting data in the field. In 2019, Hill, CEEE Director **Anne Gold**, and ESOC Director **Kristy Tiampo** launched FieldSafe, a workshop for building safe and inclusive teams. And in 2023, the program stepped into its next phase

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GOES-18 satellite set for space weather forecasting

INSTRUMENTATION

Instruments monitoring the Sun and space weather aboard the GOES-18 satellite reached full operational maturity in December 2023, thanks to a coordinated effort by CIRES and NOAA scientists. Their work brought the instruments to full maturity just 21 months after launch, less than half the time it took to validate similar instruments on the GOES-16 and GOES-17 satellites. Together, observations from GOES-18 instruments allow forecasters to provide warnings of space weather hazards responsible for communications disruptions and power blackouts. They also monitor energetic particles from the Sun that can cause radiation hazards to satellites and astronauts aboard the International Space Station.

bit.ly/mature-GOES-18

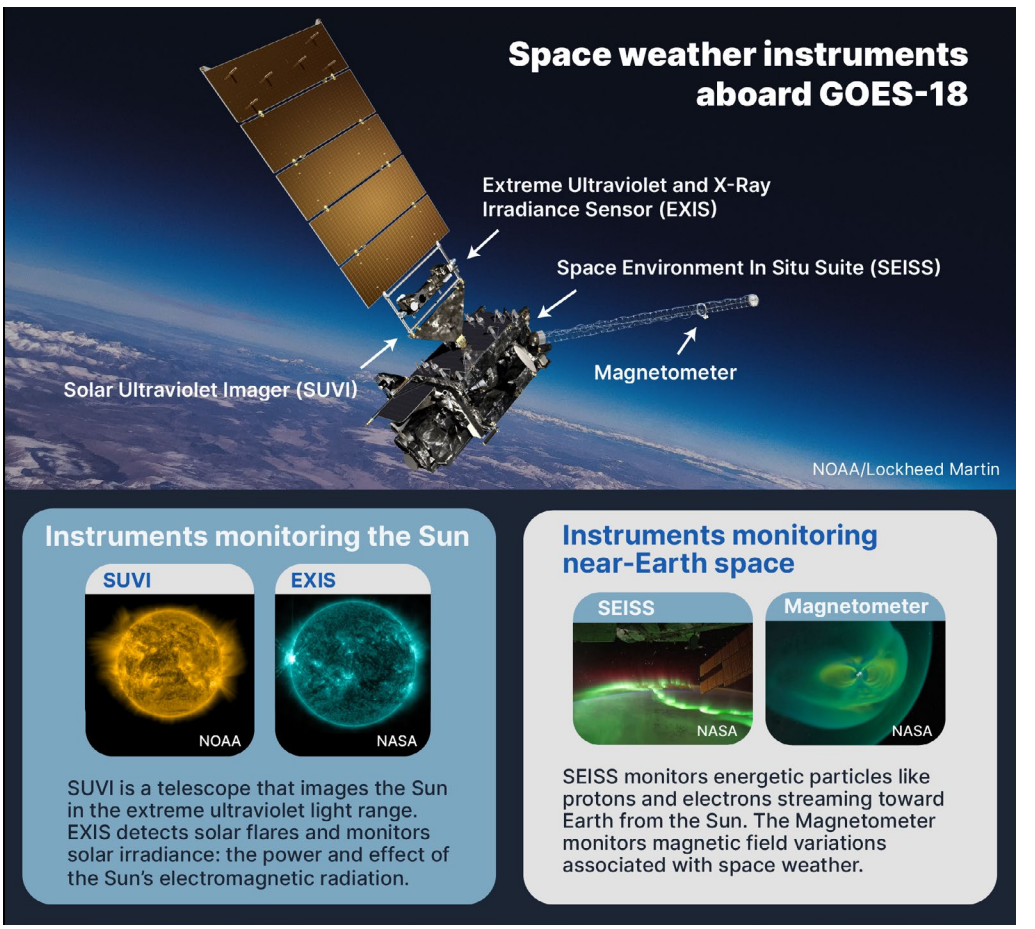

Image: Lauren Lipuma/CIRES

FieldSafe

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with three more years of support from NSF. The next steps include the move of the workshop to a Massive Online Open Course format, which will launch as the "ADVANCing FieldSafety" course in May 2024. The course will reach a wider audience with new content topics and an evaluation element. "We need to understand and study how effective the trainings are: do they actually help?" Anne Gold said. "Or what *does* make field environments more inclusive and safe?"

bit.ly/FieldSafe

Voters' take on climate change can swing US elections

POLITICS AND POLICY

When voters cast their ballots in the 2016 and 2020 presidential elections, many were driven by their concern for climate change, according to research out of CU Boulder's Center for Environmental Futures (C-SEF). The report determined that views on climate change played a significant role in whom people voted for, concluding that the climate issue very likely cost Republicans the 2020 election, all else equal.

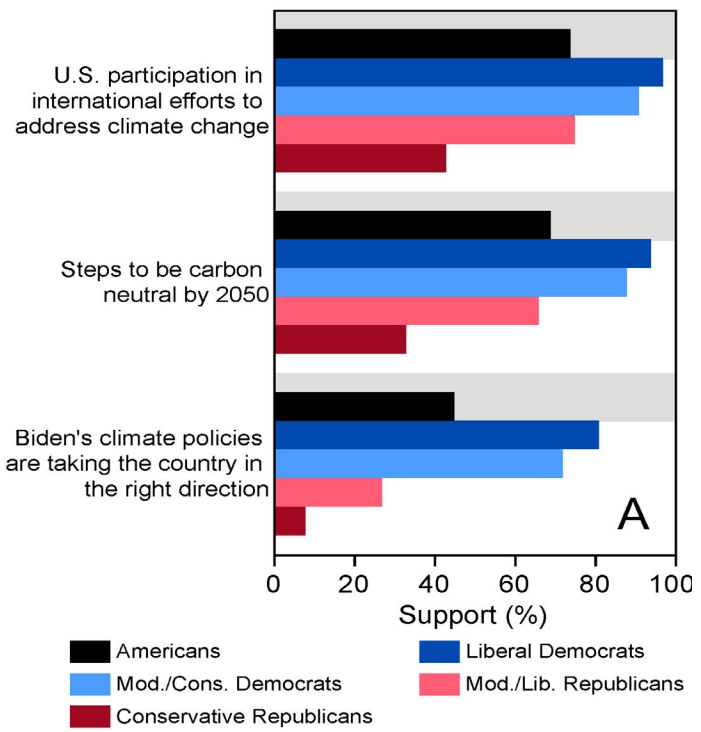
"This is obviously information that politicians and advocates across the political spectrum will want to know, heading into the 2024 election cycle," said **Matthew Burgess**, CIRES fellow and C-SEF director. "How to reduce political polarization of climate change is one of the questions our research group is most interested in currently, and this provides some insight."

In their assessment, published in January 2024, Burgess and his co-authors, two C-SEF graduate students, and researchers from Vanderbilt University and the University of California Santa Barbara, sought to understand the importance of climate change as a voter issue in the two most recent presidential elections. The team used data from the nonpartisan Voter Study Group to analyze how issue opinions and demographics affected the 2016 and 2020 elections.

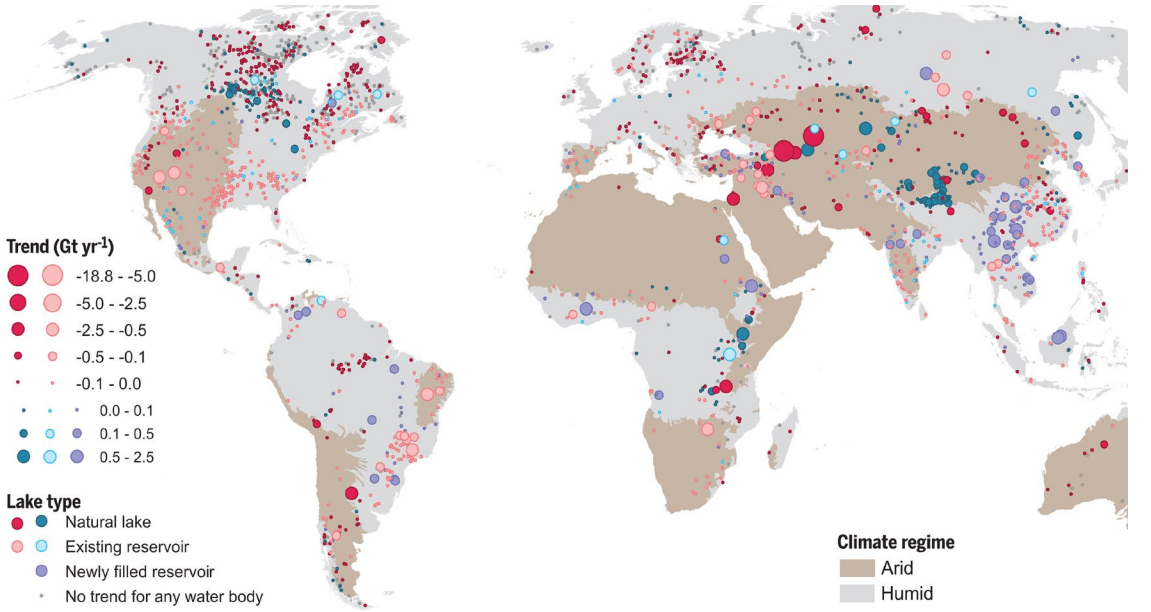
The researchers used several techniques to assess how climate change opinion shaped voters' choices: logistic regression, a machine learning model, and a simulation of the Electoral College in which they could turn the role of climate change on or off. Their conclusion: Republicans could have gained at least a 3-percent swing in the popular vote, which almost certainly would have been enough to have taken the White House in 2020.

The team found personal views on climate change were one of the strongest predictors of voting behavior in 2020, especially among independents. Not surprisingly, they found the majority of Democrats and independents are worried about climate change. And, many younger and moderate Republicans also see climate change as an important issue—one-quarter of Republicans who think climate change is "very important" voted for President Biden in 2020.

bit.ly/voting-through-climate-change



Public and partisan support for general positions about climate policy, from Pew Research, 2022-2023. The gray-shaded regions visually separate national opinion from party-level opinion. Image: Burgess et al.



A research team used recent and long-term satellite data to determine how water storage levels in lakes have changed over decades. Image: Fangfang Yao et al., *Science* 2023

Satellites reveal widespread decline in global lake water

HYDROLOGY

More than 50 percent of the largest lakes in the world are losing water, according to a groundbreaking assessment published on the cover of *Science* in May 2023. The key culprits are not surprising: a warming climate and unsustainable human consumption.

INTERACTIVE GRAPHIC

Since then, the paper has been downloaded over 65,000 times, nearly 400 news outlets covered the story, and the work continues to be relevant as news surrounding climate change focuses on water sources worldwide.

Lead author **Fangfang Yao**, a 2020 CIRES visiting fellow, now a climate fellow at the University of Virginia, said the news is not entirely bleak. With this new method of tracking lakewater storage trends and the reasons behind them, scientists can give water managers and communities insight into how to better protect critical sources of water and important regional ecosystems.

"This is the first comprehensive assessment of trends and drivers of global lakewater storage variability based on an array of satellites and models," Yao said.

Yao and colleagues from CU Boulder, including CIRES Fellows **Ben Livneh** and **Balaji Rajagopalan**, and others from Kansas State University, France, and Saudi Arabia, created a technique to measure changes in water levels in nearly 2,000 of the world's biggest lakes and reservoirs, which represent 95 percent of the total lakewater storage on Earth.

For the paper, the team used 250,000 lake-area snapshots captured by satellites between 1992-2020 to survey the area of 1,972 of Earth's biggest lakes. They collected water levels from nine satellite altimeters and used long-term water levels to reduce any uncertainty. For lakes without a long-term level record, they used recent water measurements made by newer instruments on satellites. Combining recent level measurements with longer-term area measurements allowed

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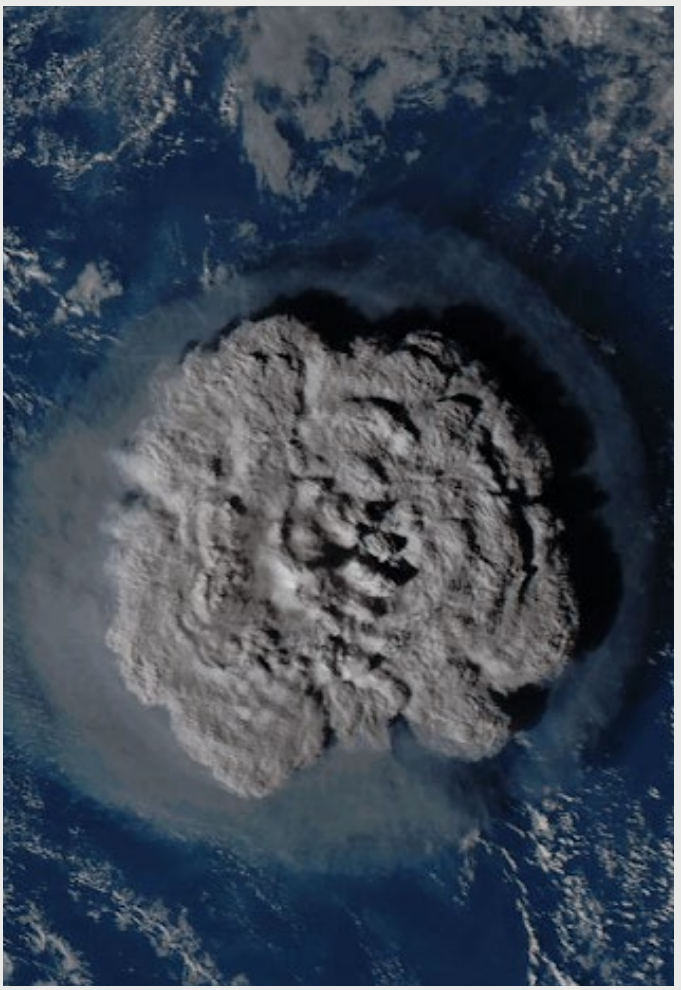
Underwater eruption changed stratospheric chemistry

ATMOSPHERE The eruption of the Hunga Tonga-Hunga Ha'apai volcano in January 2022 produced the largest underwater explosion ever recorded by modern scientific instruments. The blast spewed water and gas higher into Earth's atmosphere than any other eruption in the satellite era.

Two 2023 research papers show how that water vapor depleted ozone in the stratosphere and caused an unexpectedly rapid formation of aerosols. Observations by CIRES and NOAA scientists taken in the immediate wake of the eruption found stratospheric ozone concentrations decreased by as much as 30 percent in some areas.

"Until now, sulfur has been the primary focus of research on eruptions," said CIRES' **Elizabeth Asher**, who led one of the studies. "Hunga Tonga showed that other gases, like water vapor, can have a profound impact on these outcomes."

bit.ly/Hunga-Tonga-explosion



Himawari-8 satellite image of the Hunga Tonga-Hunga Ha'apai volcanic eruption on January 15, 2022. The eruption sent roughly 150 million tons of water up into the stratosphere, according to a new study. Photo: Japan Meteorological Agency/NASA SPoRT

Lake decline

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scientists to reconstruct the volume of lakes dating back decades.

The results were staggering: 53 percent of lakes globally experienced a decline in water storage. The authors compare this loss with the magnitude of 17 Lake Meads, the largest reservoir in the United States.

While the majority of global lakes are shrinking, 24 percent saw significant increases in water storage. Growing lakes tend to be in underpopulated areas in the inner Tibetan Plateau and northern Great Plains of North America and in areas with new reservoirs such as the Yangtze, Mekong, and Nile river basins.

The authors estimated roughly one-quarter of the world's population, two billion people, resides in the basin of a drying lake, indicating an urgent need to incorporate human consumption, climate change, and sedimentation impacts into sustainable water resources management.

bit.ly/global-water-storage

Front row (left to right): Ami Nacu-Schmidt, Alicia Christensen, Mariama Dryák-Vallies
Second row: Katie Boyd, Katya Schloesser, Alexandra Padilla, Hilary Peddicord, Alyse Thurber, Christine Okochi
Third row: Chelsea Zaniboni, Anne Gold, Jon Griffith, Meg Littrell, Emily Ward, Beth Russell
Back row: Daniela Pennycook, Gina Fiorile-Desranleau, Patrick Chandler, Alex Kirst, Shilpi Gupta

‘We want to empower people’

CEEE inspires scientific curiosity, community, action

Increasingly, people are searching for ways to build community and make sense of and respond to today’s environmental challenges. To meet that need, a team of educational researchers, evaluators, curriculum developers, and outreach and engagement experts at CU Boulder launched a new center: the CIRES Center for Education, Engagement, and Evaluation (CEEE). Formerly known as the CIRES Education & Outreach program, the new center is dedicated to three broad goals: excellence and inclusion in environmental science education, career development and training for scientists, and engaging with diverse audiences.

“Our goal is to bridge the gap between scientific research and societal impact,” said **Anne Gold**, director of CEEE. “We want to empower people to become informed agents of change in environmental challenges.”

CEEE (pronounced “C-triple-E”) currently runs over 30 projects that connect environmental science and people to inspire curiosity, community, and action. The center’s education work is innovative, culturally responsive, and evidence-based. For example, the HEART Force

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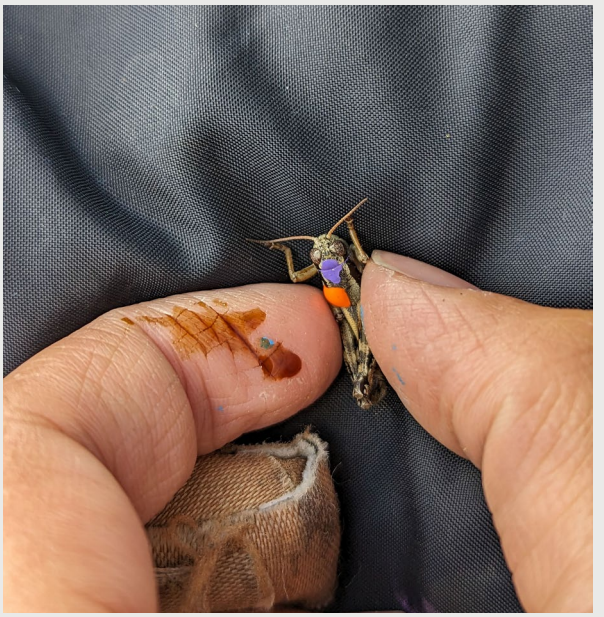
curriculum uses small-group activities and scenario-based games to empower students, teachers, and communities to build resilience to environmental hazards. CEEE engages with diverse audiences, including through We are Water, which brings a traveling exhibition that weaves together community knowledge and locally relevant science topics about water to rural, Indigenous, and Latino communities in the desert Southwest.

Diversity, equity, inclusion, accessibility, and justice are core values of the center. CEEE is dedicated to broadening participation in environmental science through research opportunities and education experiences for learners and communities that have been historically underserved by science education. The new center strives to make environmental science more welcoming and inclusive, for example, through the Polar Science Early Career Community Office, which provides career development and training opportunities to early career researchers in the polar sciences.

Evaluation and educational research are central to all aspects of CEEE's work. A recent publication led by the center showed that immersive research experiences inspire students to explore their science identity and build a sense of belonging in the science community. Efforts like these lay the foundations for the team and others in the science education field to design impactful and inclusive learning experiences.

"We hope our work inspires a new generation of learners to come together to address environmental challenges with confidence and understanding and contribute to making environmental and geosciences welcoming and inclusive," Gold said.

bit.ly/new-CIRES-center



For her RECCS research, Salomé Carrasco counted grasshoppers at three different elevations, part of a project to track how different species of insects are adapting to climate change. She used non-toxic paint to mark each insect.
Photo: Stephanie Maltarich/CIRES

AUDIO STORY

Students build science chops through immersive research experience

EVALUATION

Each summer, community college students from Colorado and surrounding states converge on the CU Boulder campus to participate in the immersive Research Experience for Community College Students program. A recent CEEE-led study revealed that when RECCS alumni head home, they leave with more than scientific and professional skills—they also gain more confidence in their ability to do science and a greater sense of belonging in the science community. Eighty-four RECCS alumni are currently enrolled in or have completed undergraduate or graduate degrees in STEM.

bit.ly/ceee-immersive

bit.ly/ceee-immersive-paper

MORE CEEE PROJECTS ON NEXT PAGE

A boy plays life-size Connect 4 during the We are Water exhibit's opening day celebration at Aztec Public Library in New Mexico. The display encouraged visitors to line up plant, animal, landscape, and weather tokens to learn about the ecology of the Four Corners Region. Photo: Daniela Pennycook/ CEEE/CIRES

Impact award honors We are Water

ENGAGEMENT

In 2023, CO-LABS recognized the CIRES We are Water team with a Governor's Award for High-Impact Research. The Pathfinding Partnerships Award honored the ongoing program and the partnerships that were integral to the program's success.

We are Water is a collaboration among CIRES CEEE, Western Water Assessment, Indigenous education organizations, local libraries, and climate scientists. The NSF-funded program is hosted in public libraries in Colorado, Utah, New Mexico, and Arizona. The primary goal is to engage people in important conversations about the desert Southwest's most critical topic: water.

bit.ly/we-are-water-awarded

Middle-schoolers walk through burn area, witness fire's impact

EDUCATION

In September 2023, 75 eighth graders from STEM Launch Middle School in Thornton dug into CEEE's Future of Forests curriculum in the classroom to learn how forests recover after wildfires. A month later, the students loaded into charter buses and drove to Rocky Mountain National Park where they spent the day observing forests impacted by wildfires. The field trip was made possible by funding from CU Boulder's Office for Public and Community-Engaged Scholarship. "I think a lot of times students think of science as a set of established facts that can be disconnected from their daily lives," said CEEE's **Jon Griffith**, who developed the Future of Forests curriculum. "In this project, I was excited to support students in developing and applying new understandings of the dynamic nature of post-fire landscape recovery."

bit.ly/eighth-graders-in-RMNP

Educators offer mental health strategies for climate anxiety

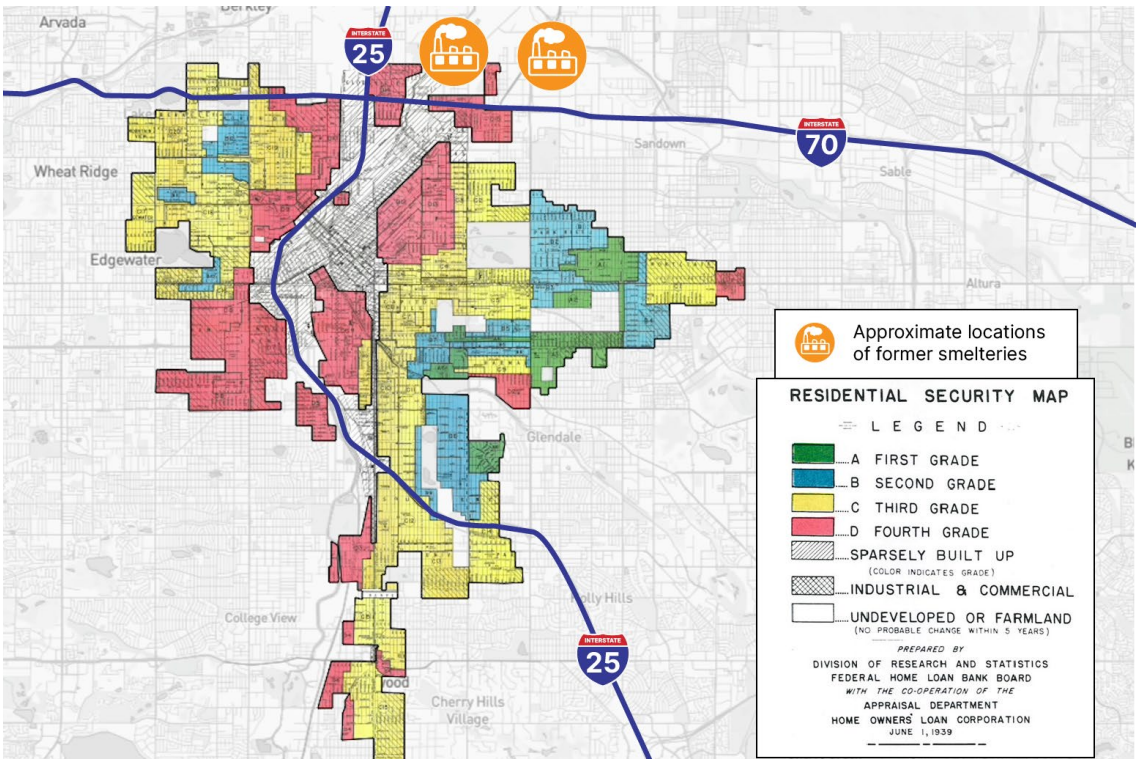
EDUCATION

Headlines about climate change often focus on devastating impacts, including extreme events and hazards. As a result, many young people experience feelings of hopelessness and anxiety. A CEEE-led paper shares key strategies for educators to support students' mental health when teaching about climate change, including using a trauma-informed approach, encouraging action, and cultivating hope and resilience.

bit.ly/climate-mental-health-in-education

Air, water inequalities

CIRES conducts research addressing environmental issues that disproportionately affect some communities



Historically redlined districts of Denver graded "D" were originally populated by smeltery and railroad workers, who were typically immigrants and people of color. Today, those neighborhoods are still predominantly populated by people of color and experience the worst air pollution in Denver. The city's two major interstates, I-25 and I-70, pass through those neighborhoods. Image: Federal Home Loan Bank Board with additions by Lauren Lipuma/CIRES

History lesson: Communities of color still breathe Denver's worst air

History determines who gets to breathe fresh air, according to a recent study looking at how pollution impacts communities of color in Denver.

CIRES graduate student **Alex Bradley**, who led the work, found people of color, specifically those of Hispanic/Latino and American Indian/Alaska Native heritage, are exposed to higher levels of air pollution than non-Hispanic whites in Denver. The difference is due to where the groups tend to live, with people of color typically residing in historically redlined neighborhoods many decades after the practice ended. They also tend to live nearer to highways.

The practice of redlining is only one facet of discrimination the authors focused on that has resulted in unequal pollution distribution. The results align with a growing body of work showing communities of color experience worse air quality around the country.

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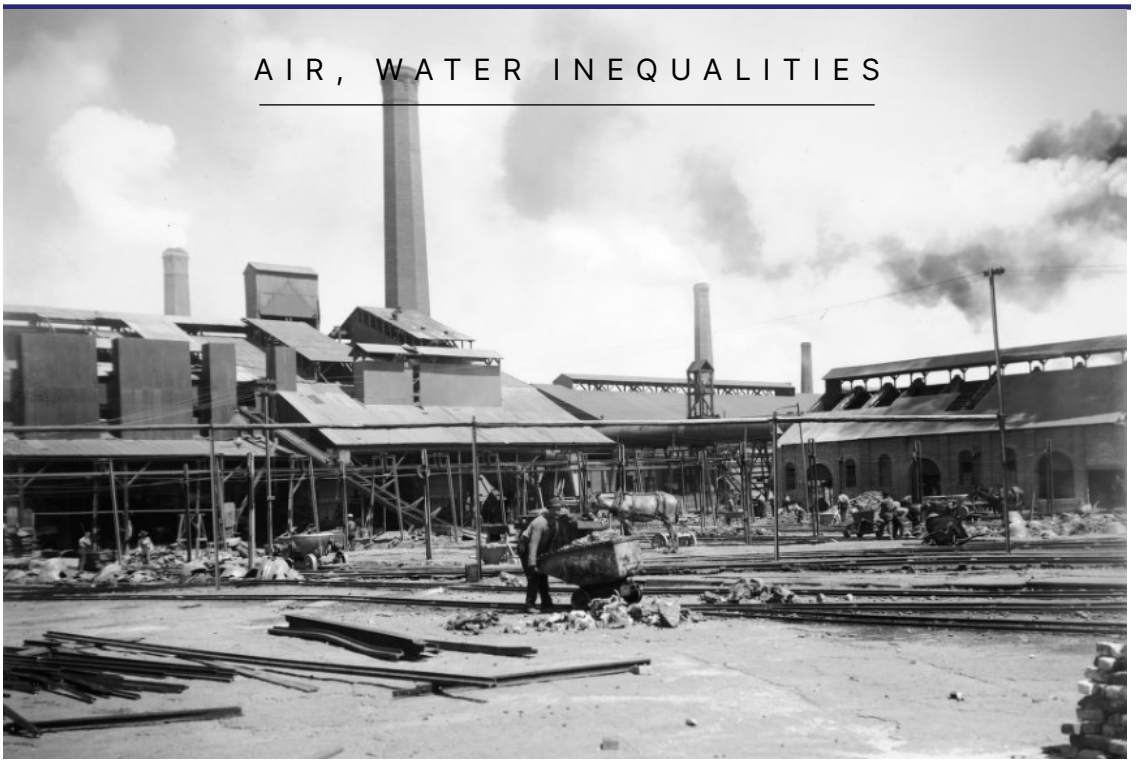

A man works at the Denver Globe Smelter, year unknown. Photo: Denver Public Library and History Colorado.

Denver's worst air

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"Every city has a story of why people live where they do, and that affects who is impacted most by pollution," Bradley said.

Bradley and his colleagues, including CIRES Fellow **Joost de Gouw**, focused on two pollutants in the study: nitrogen dioxide and fine particulate matter. The team used satellite images and satellite-based models to measure and estimate pollution levels in Denver's neighborhoods.

They combined the satellite data with historical redlining maps created in the 1930s by the Homeowners' and Loan Corporation (HOLC), which graded neighborhoods A-D. The lower the grade a neighborhood received, the less likely its residents were to get their mortgage insured. This practice, known as redlining, made it difficult or impossible for residents of certain neighborhoods to access mortgage financing.

"We find districts that were graded A in 1939 have lower air pollution than the districts that were graded D," said Bradley.

The authors then used 2020 census tracks to find a correlation between pollution and race to quantify their results further. They discovered that non-Hispanic white and Asian/Asian American populations experience far less air pollution than Hispanic/Latino, and American Indian and Alaska Native communities.

VIDEO STORY

The group applied the same process to 200 other cities in the U.S. that also practiced redlining. The results were similar across the board: People of color fare worse today, while non-Hispanic whites fare better.

Finally, the authors looked at transportation, with its known impact on air quality. Emissions from traffic, both gas and diesel emissions, are higher in census tracks predominantly of people of color, who are more likely to live closer to major highways.

Bradley hopes providing the first in-depth study of Denver's air quality impacts on communities of color will provide a tool for change.

"People living in these communities will not be surprised by our data," Bradley said. "I hope this work helps others recognize these issues are real and quantifiable."

bit.ly/worst-air-in-denver

Isabella Vicenza, student at Barnard College, (left), Yoshira Ornelas Van Horne (center), an environmental health scientist at Columbia University who wears monitoring equipment, and CIRES/NOAA scientist Audrey Gaudel measure air pollutants in the South Bronx on a rainy day in August 2023. Photo: Lauren Lipuma/CIRES

Scientists walk NYC neighborhoods to map air quality differences

VIDEO STORY

In August 2023, CIRES scientist **Audrey Gaudel** strode through New York City to take detailed readings of air pollutants at street level, an effort she hopes will provide residents of New York with the tools they need to fight for better air.

Gaudel, who works in CSL, led the pilot project to map two air pollutants in the city: ozone and fine particulate matter. Gaudel and her colleagues took to the hot summer streets to map differences in levels of these pollutants among New York's neighborhoods, paying particular attention to areas known to have poor air quality. They carried a backpack outfitted with several instruments to measure air quality as they walked. The project will give New Yorkers more detailed information about the air they breathe. Air quality varies greatly between different New York City neighborhoods, and poor air quality is often seen in lower-income neighborhoods. Residents of the South Bronx, for example, experience far worse air quality than residents of wealthy Manhattan neighborhoods only a bus or subway ride away.

Gaudel's preliminary results show that along the Hudson River and in Central Park, the largest green space in Manhattan, the air is less polluted with fine particulate matter than in places without trees or grass. But along the Hudson, the air is more polluted with ozone.

"We hope our project will provide residents of New York City with the resources they need to advocate for better air quality," Gaudel said.

bit.ly/NYC-street-monitoring

National assessment: Climate change impacts on water are profound, unequal

Climate change is intensifying rainfall and floods, deepening droughts, and shifting weather patterns across the globe, according to the Fifth National Climate Assessment (NCA5), released at the end of 2023. These impacts are disproportionately affecting the most frontline populations in the U.S., according to the report.

"Climate change will manifest through profound changes to the movement, amounts, and timing of water," said **Liz Payton**, a CIRES water resources specialist and lead author of the NCA5's water chapter.

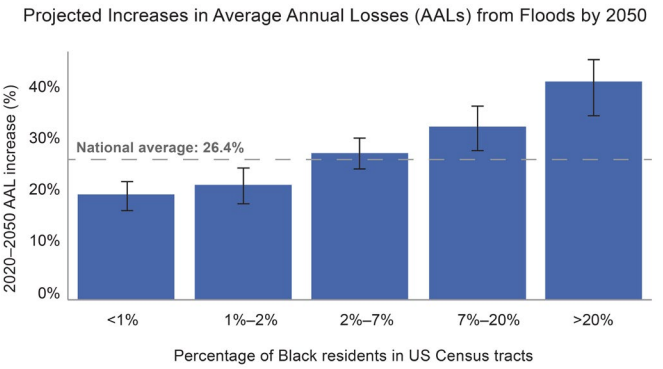
The NCA is a congressionally-mandated report released every four years by the U.S. Global Change Research Program. It synthesizes scientific knowledge about current and projected trends in global climate change for the recent past and the next 25 to 100 years.

Overall, the report found climate change impacts on water are dire, but that science advances are increasingly helping to shape decisions. For example, the report cites international collaboration among two provinces, eight states, and several sovereign Tribes and First Nations to manage the water in the Great Lakes, addressing both flooding and coastal wetland health.

By contrast, there has been little to no progress in other areas, such as managing the country's aging water infrastructure. The NCA5 is now in the hands of Congress and decision-makers so they can understand the current implications of climate change, including impacts on water, and what the country can expect in the future.

bit.ly/nca-water

nca2023.globalchange.gov/



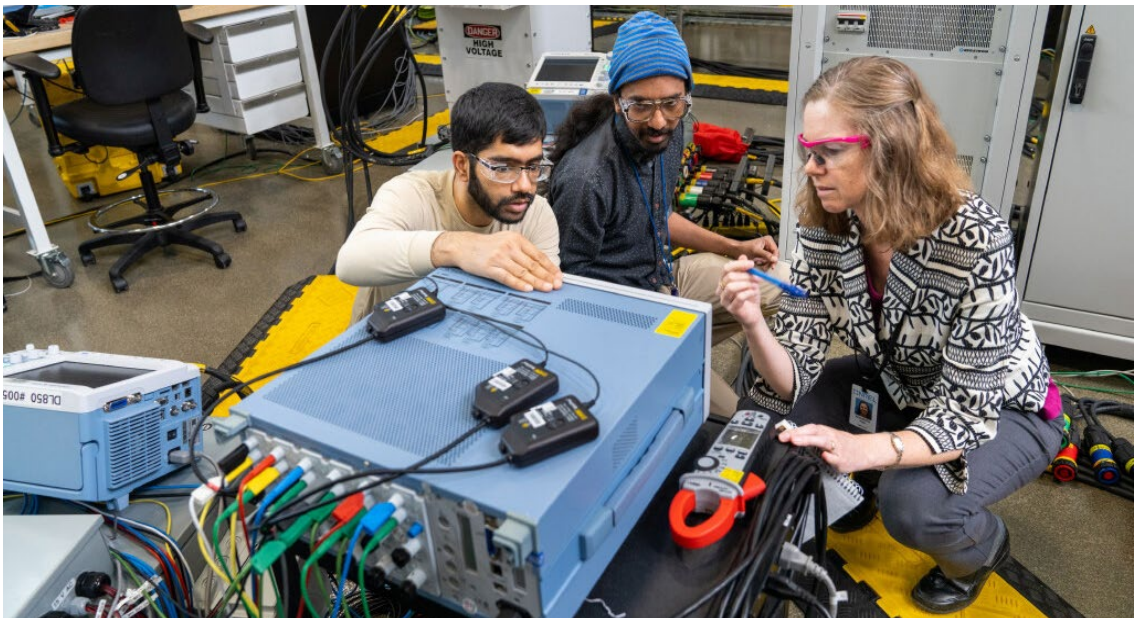
Average annual losses—economic damages in a typical year—due to floods in census tracts with a Black population of at least 20 percent are projected to increase at roughly twice the rate of that in tracts where Black residents make up less than 1 percent of the population. Brackets at the tops of the blue bars represent 95 percent confidence intervals. Image: Adapted from Wing et al. 2022130

NEW AT CIRES

Becca Edwards joined CIRES as the new CIRES diversity, equity, and inclusion (DEI) director in August 2023, bringing decades of experience in science and inclusive teaching. She has grown the CIRES DEI program, launching a bi-monthly newsletter, running workshops and speaker events, and facilitating group learning.

James Rattling Leaf, Sr. joined CIRES in September 2023 as the institute's first-ever Tribal advisor. He is helping CIRES researchers build relationships with Tribes, by working to understand their current ways of engaging with Indigenous people and helping to educate researchers on how to build strong relationships. Rattling Leaf is based in Rapid City, South Dakota, and visits Boulder regularly.

The energy transition is underway. CIRES scientists are exploring how policy and industry intersect, installing new offshore wind instruments, and implementing net-zero energy use at a prominent NOAA observatory.



National Renewable Energy Laboratory electrical engineering researchers (left to right) Subhankar Ganguly, Kumaraguru Prabakar, and Annabelle Pratt worked with the San Diego Gas & Electric Company to support a transition to a full renewable energy microgrid for Borrego Springs, California, in 2023. Photo: Werner Slocum / NREL

Study: Industry outpacing policy in renewables transition

Utilities in the United States have made pledges that put them on pace to transition to 100 percent renewable electricity by 2060, and although state mandates have played a role, it's the utilities themselves that are leading the transition, according to a CU Boulder-led analysis.

"Many people feel the transition on the policy side isn't going fast enough," said **Matthew Burgess**, a CIRES fellow, CU Boulder assistant professor, and co-author of the recent paper in *Climatic Change* analyzing the energy transition. "But the private sector is moving faster than we thought. A lot has to do with technology, costs going down, natural gas replacing coal, and renewables replacing fossil fuels—policy is not the only lever."

In the study, Burgess and **Grace Kroeger**, an Environmental Studies undergraduate student at CU Boulder, compared state renewable energy targets with utilities' own goals. They looked at 30 years of data to assess what shifts utilities have made so far to achieve renewable energy standards, as well as what state-level regulations may have pushed utilities to make changes.

The authors combined the data into projections of when utilities are likely to fully decarbonize. What they found may be surprising to

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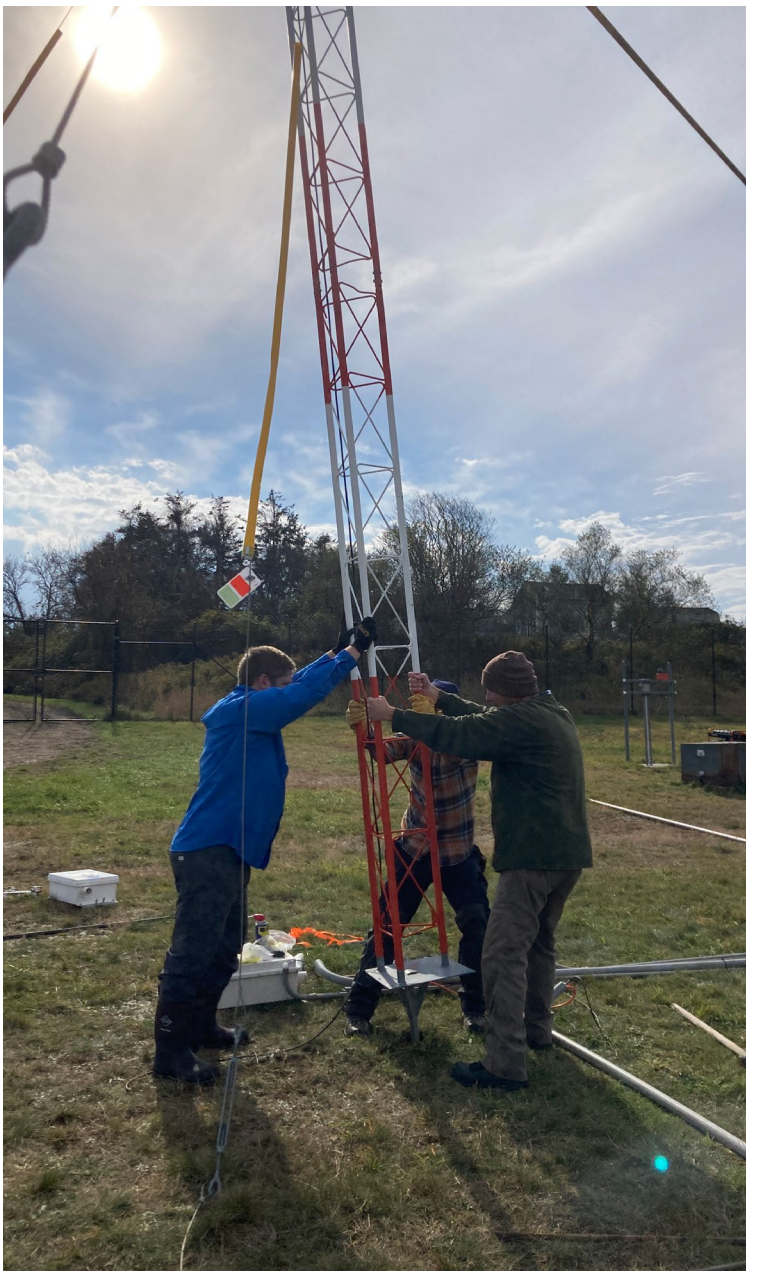
New NOAA instruments to capture wind data offshore from New England



Wind power is an essential source of renewable energy, but it's dependent on weather conditions. Electric grid operators keep the grid stable by increasing or decreasing power from fossil fuel generation stations as the wind increases and subsides. An economic study found that improvements to NOAA's operational weather prediction models, which are used to make decisions on the different sources of energy generation, can save electrical utilities—and their customers—hundreds of millions of dollars per year.

That's why NOAA and the Department of Energy, together with CIRES and other academic and industry partners, launched the third Wind Forecast Improvement Project (WFIP-3) at the end of 2023, a two-year investigation of wind and weather conditions off the coast of New England.

The researchers installed 20 meteorological nstruments on Martha's Vineyard and Nantucket Island, Massachusetts, and Narragansett and Block Island, Rhode Island. In 2024, team will install instruments on buoys and a barge to capture wind data from the water's surface closer to the installed offshore wind turbines.

bit.ly/new-england-wind-offshore

bit.ly/about-WFIP-3

Emiel Hall (GML), Joseph Sedlar, and Gary Hodges (CIRES and GML) raise a tower on Block Island as part of NOAA's third Wind Forecast Improvement Project. The collaborative project aims to improve weather forecasting in the area, especially for offshore wind farms in construction or planned for the area. Photo: Laura Bianco/NOAA and CIRES

Renewables transition

CONTINUED FROM PAGE 23

some: Industry, overall, is outpacing policy. Utility companies are on track to meet or exceed the goals of states with stated policies and mandates. The authors project the electric grid will decarbonize 100 percent by 2060 if utilities continue to be true to their word. When nuclear power is included in renewable energy portfolios, the decarbonization may come as early as 2050.

The study revealed another surprise: Utility companies plan to decarbonize across the board, even in states without renewable energy policies or goals.

The authors noted that the findings were based on what utilities have stated they plan to do in the future, which is not guaranteed. However, when looking at historical data, they found utilities have already transitioned to renewables and away from fossil fuels faster than planned.

Despite the good news, neither states nor utilities are on track to decarbonize as fast as the Biden Administration's goal, announced in April 2023: to eliminate fossil fuels from the U.S. energy sector by 2035. This announcement didn't come with policy or mandates to aid a transition.

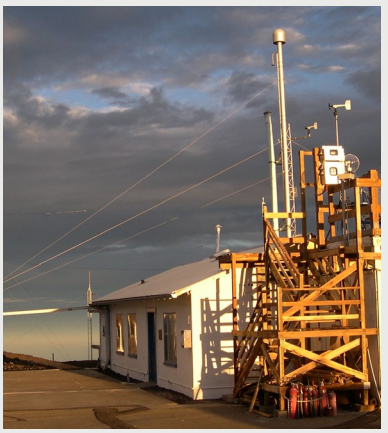
bit.ly/renewable-by-2060

Boykoff sees "end of an era of fossil fuel consumption" after COP28

In November 2023, CIRES Fellow **Max Boykoff** attended his seventh Conference of the Parties, COP28 in Dubai, as the head of a delegation from four University of Colorado campuses. The conference concluded with a monumental agreement: a transition away from burning fossil fuels like oil and coal, which are driving climate change. The agreement marks the first time in history that a U.N. climate summit mentioned reducing the use of all fossil fuels. "It is an important step forward," said Boykoff, also a professor in CU Boulder's Department of Environmental Studies. "It is a signaling of the end of an era of fossil fuel consumption."

Boykoff

bit.ly/Boykoff-COP28



Mauna Loa Observatory to go net-zero once post-eruption access is restored

The U.S. Department of Energy awarded NOAA $5 million to help convert the Mauna Loa Atmospheric Baseline Observatory in Hawaii to a net-zero carbon facility. The Mauna Loa observatory is the benchmark site for monitoring greenhouse gases that are driving climate change. The observatory has been without road access and electricity since November 2022, when lava from the erupting Mauna Loa volcano buried a little more than a mile of the access road and destroyed power poles.

Switching the site to renewable energy will help prevent future interruptions from volcanic activity. The observatory already uses roof collection systems to capture water needed to run the eight-acre campus, so it would be the first Department of Commerce facility to be net-zero for both electricity and water. Construction for the project will begin once road access is restored.

bit.ly/Mauna-Loa-net-zero

Machines, do the science!

Artificial intelligence has become an indispensable tool for environmental scientists, and across CIRES, researchers are asking machine learning systems to identify trends in wildfire data, produce visualizations, retrieve observations from international datasets, and even track down the source of a small earthquake swarm. Below are a few examples; learn more by searching "machine learning" on cires.colorado.edu/publications.

CONFERENCE HIGHLIGHT

New technique provides earlier warning of power outages

When strong space weather storms buffet Earth's magnetic field, geomagnetically induced currents can trigger power outages: In 1989, an estimated six million Canadians in Quebec lost power for nine hours following such an event. While power companies invest in mitigation strategies for those induced currents, CIRES and other scientists have looked to the Sun to see if they can provide earlier warnings of the incoming space weather at fault.

Hu

CIRES postdoctoral researcher **Andong Hu** led the development of a machine learning model that drew insight from several readily available sources of data: solar wind, the electrical conductivity of Earth's surface, and our planet's magnetic fields. The hope was to improve on the scant 10-minute warnings scientists can currently give power companies.

It worked. The researchers tested their method on the 50 largest geomagnetically induced currents to hit the U.S. power grid since 2000. The new technique outperformed the traditional one, predicting geomagnetically-induced currents up to 60 minutes in advance.

"Having a one-hour lead time can have a huge difference, especially in helping us to protect the power system and its infrastructure," said Hu, who presented the work at the American Geophysical Union 2023 Fall Meeting in San Francisco.

bit.ly/predicting-power-disruptions

MICROBIAL ECOLOGY

A.I. can predict microbe habitats

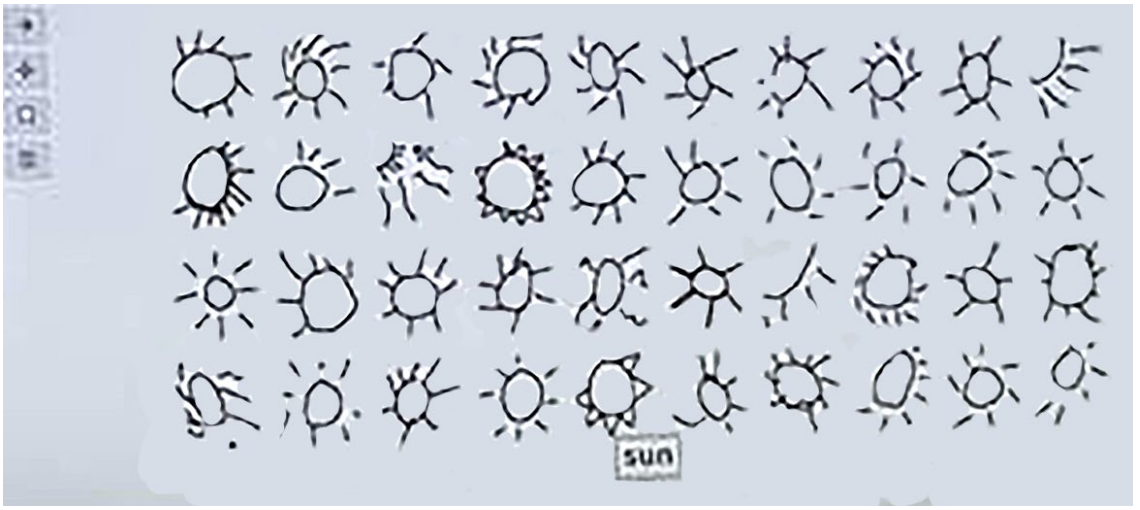
Using machine learning techniques, CIRES microbial ecologists have learned how to predict bacteria's environmental pH preferences from a quick look at their genomes. The new approach promises to help guide ecological restoration efforts, agriculture, and even the development of health-related probiotics.

"We know that in any environment, there's a ton of bacteria with important ecological functions, but their environmental preferences often remain unknown," said CIRES Fellow **Noah Fierer**, a professor of ecology and evolutionary biology at CU Boulder. "The idea is to use this technique to figure out the basics of their natural history."

Understanding whether certain bacteria thrive in acidic, neutral, or basic environments is just a first step, said lead author **Josep Ramoneda**, a CIRES visiting scholar. "You could use this approach to anticipate how microbes will adapt to almost any environmental change," including changes caused by climate warming. More than 9,500 people have downloaded the 2023 *Science Advances* paper.

bit.ly/microbe-preferences

Paper: bit.ly/AI-and-microbes



During an 8th Grade Science Days event at NOAA last year, students drew these suns to test if an A.I. image classification system could correctly identify them as suns, not rainbows or tornadoes.
Photo: Susan Cobb/GSL

EDUCATION

Middle schoolers doodle to test A.I.

Bergstrom

To help middle school students understand how A.I. is useful in weather model development, CIRES' **Kirana Bergstrom** built an image-classification A.I. program to interpret weather-related doodles. Students visiting NOAA's Boulder labs for the annual 8th Grade Science Days in 2023 put her A.I. system through the paces, feeding it hand-drawn suns, rainbows, tornadoes, and hurricanes, to see if it could classify them. Bergstrom, an A.I. researcher based in GSL, deliberately built her system to be only 80 percent effective, so she could inspire conversation about challenges that come up when training an A.I. system to recognize weather phenomena in, for example, satellite data.

Tutorial resources on GitHub:
bit.ly/bergstrom-tutorial
bit.ly/8th-graders-check-out-AI

ECOSYSTEMS

Hackathon's wildfire prediction experiments show promise

If only there were a crystal ball to tell us where the next wildfire might strike… Well, someday soon, there could be an A.I.-sort of crystal ball. In a competitive hackathon last November, a team of researchers from Nigeria, California, Florida, and Idaho experimented with predicting ecosystems' resistance to wildfire based on spectral diversity of satellite imagery. Their initial results convinced a panel of expert judges that the approach was worth pursuing. The team will visit the CIRES-based Environmental Data Science Innovation & Inclusion Lab sometime this year, so they can pursue the research with cyberinfrastructure and technical support from the NSF-funded team.

bit.ly/ESIIL-hackathon-wildfire-team

As the climate shifts and human populations expand into new places, research about fire and its behavior, past and present, is key to managing this hazard.

NOAA's Twin Otter aircraft flies over California's Mosquito Fire, the state's largest wildfire of 2022, as scientists onboard measure different aspects of the fire's behavior. Photo: Alan Brewer/CSL

Data from sky, ground illuminate fire behavior

Researchers use aircraft, pickup trucks to collect information simultaneously, lay groundwork for improved forecasting

Wildfire behavior is notoriously hard to predict. Forecasters use computer models to anticipate where a wildfire could spread and how intense it might get, but accurate forecasts need good observations. It's difficult to get close enough to track a fire's behavior.

VIDEO STORY

To meet that challenge, researchers from NOAA and CIRES designed the California Fire Dynamics Experiment (CalFiDE) to capture coordinated wildfire observations in real time. They packed instruments onto a NOAA Twin Otter aircraft to measure fire intensity and spread, wind profiles, and smoke plume chemistry. The plane flew repeated passes over five different wildfires in California and Oregon during 2022, including the Mosquito Fire, California's largest wildfire that year.

At the same time, they drove pickup trucks around each fire's perimeter, collecting data on wind speed and air temperature while the Twin Otter was flying above. It's the first time these kinds of measurements have been taken together during active wildfires.

Researchers had to coordinate closely with emergency management personnel to get close enough to take measurements while staying safe.

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Brian Carroll, a CIRES scientist working in CSL, led the study detailing CalFiDE's first results. While the findings are preliminary, many of the measurements they captured are completely new. "Hopefully someday this kind of data could be used in real time to help inform firefighting efforts," Carroll said.

The scientists are particularly interested in how ozone is produced in a wildfire plume. Carroll and his colleagues recorded high ozone concentrations in several of the fires. They are trying to understand how ozone levels could get so high in a fire where a thick smoke plume blocks out nearly all the available sunlight; the chemical reactions that produce ozone require sunlight.

CalFiDE observations are providing valuable input for forecasting models as well, helping forecasters evaluate whether their models accurately represent a fire's dynamics and how the fire interacts with the local weather.

"Is the rate of spread captured correctly? Do we compute correctly the amount of heat being produced by this fire?" said **Adam Kochanski**, a wildfire researcher at San Jose State University who was involved in the campaign. "That's why you need to have this comprehensive set of observations: if you miss even one of the components, everything breaks apart."

bit.ly/CALFIDE

While the Twin Otter flew above, researchers drove trucks around the perimeter of the Mosquito Fire to measure wind speed and air temperature. Photo: Richard Marchbanks/CIRES and CSL

'We need Smokey Bear for the suburbs'

CIRES Fellow and fire ecologist **Jennifer Balch** sat down with the CU Boulder Today campus e-newsletter last summer, to talk about how wildland fires do not only happen in remote forests and what we can do about them. Her research shows that humans are responsible for more than 97 percent of the ignitions that threaten homes, and 84 percent of all wildfires. Here are excerpts from that conversation:

CUBT: How would you characterize our relationship with fire?

Balch: Fire is an integral part of who we are and how we live. We use it in our stoves, we use combustion to fuel our economy, we use it culturally. So, it's not surprising to me that we also play a role in starting wildfires.

What role are humans playing?

I like to think about three major ingredients to fire: ignitions, fuels, and a hot, dry climate. People are changing all three. We provide the vast majority of ignitions—anything from

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If there's smoke, there's ozone

Invisible pollutant in the West threatens air quality

During the summer of 2021, smoky haze from wildfires in Arizona, California, and the Pacific Northwest shrouded Colorado's Front Range almost daily. Denver logged a record number of days when ground-level ozone pollution, which has long bedeviled the metro area, exceeded national health-based standards.

"The smoke was unpleasant, to be sure," said **Andrew Langford**, a research chemist with CSL and lead author of a paper on wildfire-related ozone published in 2023. But the particulates, visible as smoke, only exceeded air quality standards a few times that summer. Ozone, by contrast, violated limits on more than half of the days. "You can't see ozone, so this was a much more insidious problem," Langford said.

His team from CSL, GSL, and CIRES analyzed surface observations and upper air measurements taken with lidar in 2021 to detect wildfire smoke aloft and estimate how much ozone was in the smoke. They found that maximum daily 8-hour average ozone concentrations were 6 to 8 ppb higher in the smoky summer of 2021 than in 2019, 2020, or 2022. Lidar measurements showed the extra ozone imported with wildfire smoke to be as much as 12 ppb on some days.

That creates a serious challenge for the Intermountain West, where many large metro areas regularly flirt with national standards, even without wildfire smoke. Some 200 U.S. counties are in non-attainment with the Environmental Protection Agency's current ozone standard, and the agency is currently deciding whether to tighten it even further.

Langford said that the prospect of more smoke arriving on the wind should encourage air quality managers to keep the focus on cleaning up air in local areas. "It will be more and more important to reduce the sources of ozone that we have some control over," he said.

CIRES postdoc Kyra Clark-Wolf holds a lake sediment core she gathered from a raft on Silver Lake, Montana. The sediment preserves pollen, charcoal, and other indicators of past ecosystems. Photo: Phil Higuera/University of Montana

Cores show subalpine wildfire resilience

Fires have always been part of subalpine forest ecology in the Northern Rockies, but scientists haven't been able to study forest recovery from those fires in detail—until now. By analyzing lake sediment cores from a Montana subalpine lake, researchers found remarkable resilience in the forests' response to fires. Over 4,800 years, during wet periods and dry periods, these subalpine forests consistently recovered from wildfires, growing back vegetation and leaving evidence of their resilience in lake sediment cores.

As sediment settles into lake bottoms, it preserves pollen, charcoal, and other indicators of past ecosystems, with the oldest layers at the bottom. To collect the sediments, re-

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Lakebed cores

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searchers hand-drilled 13 cores into the lake bottom. The oldest core measured about seven meters long, meaning it was about 7,600 years old, with ash layers indicating time stamps like the Mount St. Helens and Crater Lake eruptions.

Back in the lab, researchers sliced the mud-like samples into hundreds of half-centimeter intervals. "I thought we might see different ecosystem responses to past fires between wet and dry periods," said **Kyra Clark-Wolf**, a CIRES postdoctoral researcher with the North Central Climate Adaptation Center, who led the study. "But what we found was that there wasn't really a clear difference based on climate, but just a lot of variability within the record, which is something that hasn't been shown before."

The study concluded that a modest increase in fire activity wouldn't be uncharacteristic for the Northern Rockies subalpine ecosystems—yet. "We know that our climate conditions are increasingly getting outside of the range of variability that we've experienced in recent millennia," said **Phil Higuera**, former CIRES visiting fellow, director of the University of Montana's Paleoecology and Fire Ecology Lab, and a co-author of the study. "Global temperatures are getting warmer and conditions are getting drier."

bit.ly/resilient-subalpine-forests

Smokey Bear

CONTINUED FROM PAGE 29

debris burning, to driving a car with a hot tailpipe off the side of the road, to cigarettes, to campfires, to fireworks. We've also been changing our landscapes in different ways that change the amount of fuel that's available to burn—over 20 years we studied, there were 59 million homes that were within a kilometer of a wildfire. And then the third piece is a hot, dry climate. The science is very clear that humans, through our fossil fuel combustion, have been contributing to warming the planet.

How are fires changing?

Since 2000, wildfires in the United States have gotten four times larger and three times as frequent. We're also seeing more nighttime burning as a function of warming nights. We're seeing more extreme fire behavior. And we're seeing fires happening in the wintertime. Twenty-five percent of over a million human-started wildfires we analyzed were started by debris burning. The next biggest category is arson, then heavy equipment, campfires, children, and smokers.

What can individuals do?

We need to be thinking about how our daily activities are contributing to ignitions, particularly during high-wind conditions and very dry periods of the year.

We need to be talking about how to reduce campfires and fireworks and not use lawn equipment that sparks. And we need to be thinking about what we are building our homes with, choosing materials like roof types and fencing that are not as flammable. Wood fencing can be a conduit for fire, essentially a wick to pull fire into neighborhoods.

We can also reduce the fuel around our homes, creating fire breaks and removing flammable plants. Junipers, for example, have very high oil content, and they're extremely flammable.

What can society do?

There's a lot of undeveloped area that's going to be developed in the next 10 to 20 years. We need to consider where those homes are going and what they're going to be built out of. We have floodplain maps to help guide where we build, but we don't have the equivalent fire maps. We also need high-level constraints, either carrots or sticks, to help us change where we're putting homes and flammable landscapes, particularly in the West.

bit.ly/suburban-Smokey-Bear

CIRES and NOAA scientists collected soil and air samples to determine how safe it would be to reoccupy or rebuild homes damaged or destroyed by the Marshall Fire. This aerial view shows some of the more than 1,000 homes incinerated by the flames. Photo: Adam Schultz/The White House

Seeking answers in the aftermath

Researchers test burned homes, areas for toxins

Is it safe to move back into a smoke-damaged house?

Potentially harmful chemicals lingered in the dust left that settled indoors after the Marshall Fire, according to a first-of-its-kind study published in the summer of 2023. After the fire, a multidisciplinary team of scientists from across CU Boulder visited several homes in the burn area, picking four houses to study in depth. They scraped dust from window sills and installed monitors to track particles in the air minute-by-minute.

Their results revealed what may be the most detailed story to date of what happens to indoor air quality in homes that survive this kind of fire. Dust samples, for example, showed elevated concentrations of potentially harmful materials like polycyclic aromatic hydrocarbons (PAHs), which the Environmental Protection Agency (EPA) considers carcinogens.

The concentrations of contaminants in the collected dust, like PAHs and some heavy metals, were higher in those samples than in dust from Boulder County homes outside the burn zone. But levels weren't above the typical range for many urban areas in the U.S.

In fire-adjacent homes, airborne levels of particulates did, however, increase with human ac-

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Aftermath

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tivity, such as when a cleaning crew vacuumed and mopped: Concentrations of particles in the air nearly doubled during that time. Overnight in the same house, the team saw airborne particles spike about once every 20 minutes—likely due to the home's HVAC system switching on and off.

The team can't be sure what risk, if any, the particles posed to the health of people living in these neighborhoods. But they hope that their results could one day help the survivors of future wildfires make informed decisions about when they can move back into their homes.

bit.ly/indoor-air-after-Marshall

Are there risks to rebuilding on scorched earth?

Toxic metal levels were somewhat higher in soils on properties burned during the Marshall Fire than on unburned ones, according to a study led by CIRES/CU Boulder PhD students **Sierra Jech** and **Cliff Adamchak**. But those concentrations were still lower than levels of concern for human health, the team found.

Three months after the fire, Jeck, Adamchak, and colleagues from CU Boulder and Colorado State University had permission to sample soils from 58 properties, half burned and half outside the fire perimeter. They also collected soils from nearby grasslands (burned and unburned) to assess the impacts of fire in areas without homes or cars.

Their analysis showed:

- Soils on burned properties had measurably higher concentrations of copper, zinc, lead, and chromium than unburned properties.
- Metals were not elevated in the non-residential grasslands, underscoring the impact of burned vehicles and homes in post-fire soil contamination.
- Concentrations of potentially toxic metals were at levels well below the estimated thresholds of concern determined by the EPA.

"Studies like this one are important to share broadly, because it would be very easy for residents to be fearful or concerned about soil contamination when rebuilding on their properties, in the absence of data," said CIRES Fellow and CU Boulder biogeochemist **Eve-Lyn Hinckley**, who co-authored the work.

bit.ly/Marshall-soils

Can lessons from the fire improve future forecasts, warnings?

During the two days before the Marshall Fire, weather models began to suggest high winds for December 30, 2021, and NOAA's National Weather Service (NWS) issued a high-wind warning across the urban areas of Boulder County. The warning triggered a burning ban, but not a Red Flag Warning—which indicates hazardous fire weather conditions are imminent or occurring—because the relative humidity was higher than the NWS's 15 percent threshold.

The fire evolved in one hour from a grass fire into a suburban firestorm with sustained hurricane-force winds that blew without a break for 11 hours, becoming the most costly wildfire in Colorado history.

In an analysis, CIRES scientist **Stan Benjamin** in GSL, together with NOAA scientists and meteorologists in Boulder, examined the forecasting challenges posed by the windstorm as well as the operational challenges that followed. The authors said reexamining the conditions that led to fire has helped underscore ways to improve readiness, forecasts, and warning dissemination:

- Strict relative humidity criteria for red flag warnings could be relaxed, and additional focus devoted to the potential rate of fire spread—especially in the face of extreme winds.
- New tools such as GSL's Hourly Wildfire Potential Index can improve awareness of rapid changes in hazardous fire weather conditions for first responders.
- Fire warnings could be disseminated via the Federal Emergency Management Agency's existing Wireless Emergency Alerts, which can be broadcast from cell towers to mobile devices in a target area.

bit.ly/Marshall-forecasting-challenges

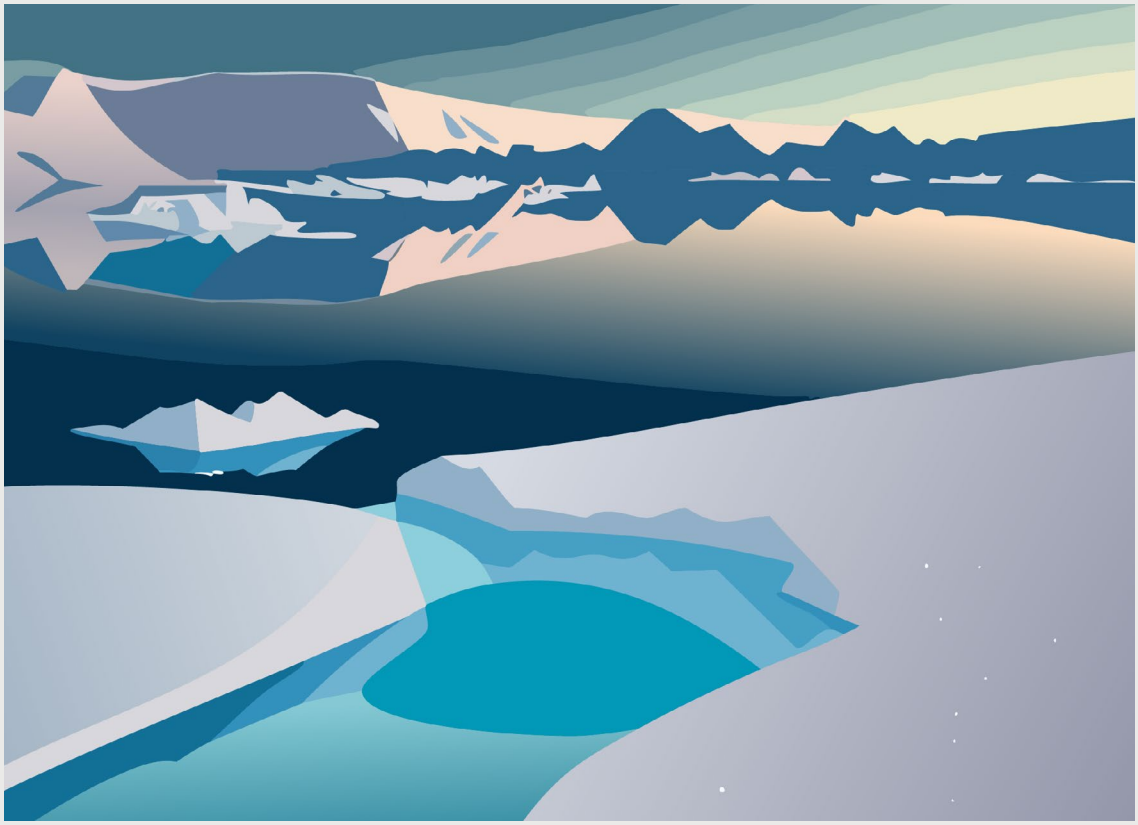
my SPHERE

Words make these pictures

Illustrations on pages 34 and 35 are from an A.I. image-generation experiment are meant to playfully reflect a linguistic one. In the real experiment, CIRES researchers found that people who have been to Greenland used more complex, nuanced, even emotional language to describe the place than people who had never been. With prompts that incorporated language from the results, Adobe Illustrator's A.I. picked up on those differences.

Images: Adobe generative A.I. and Kathy Bogan/CIRES

Above: Word cloud from responses of people who had never been to Greenland, and (below) the image from generative A.I. using prompts from dominant words in the word cloud.



Above: Image from generative A.I. using prompts from dominant words in the word cloud below, built from responses of Greenland 'experts.'

Teachers have long known this: One of the best ways to engage students in a science lesson is to get them outdoors looking at plants, sampling the local stream, or sketching in open parkland. Researchers have shown that such place-based teaching often inspires learners to take personal or even political action.

Now, CIRES education experts are working to figure out how to use this "sense of place" when the things that students need to learn about are too far away to visit: melting glaciers in the Arctic, for example, or Antarctic ecosystems.

The first step: Figure out how to measure a "sense of place." In a paper published last fall, experts from the CIRES Education, Engagement, and Evaluation team used tools from cognitive psychology and linguistics to evaluate the language people used to describe Greenland—some had been there, some had not. Their words and phrases differed remarkably. Those who had been to Greenland had a much more complex sense of place, used emotional words more often, and included natural features and cultural attributes that others often did not.

Next for the team: Design e-field trips to distance places with virtual reality or 360-degree videos. And then test if students begin using more complex, nuanced language to describe the places. If they do, that might be a good indicator that virtual field trips can inspire engagement and deeper learning.

bit.ly/greenland-sense

SWOT satellite paints portraits of water

INSTRUMENTATION

CIRES' **Toby Minear,** who is part of the CIRES Earth Science and Observations Center, worked on the calibration and validation of inland data products for NASA's Surface Water and Ocean Topography (SWOT) satellite mission, which launched in December 2022. The satellite altimeter will analyze how Earth's surface water bodies change over time and catalog the fine details of ocean surface topography.

In June 2023, SWOT captured these before and after images of the breach of Ukraine's Kakhovka Dam. These images show extensive flooding of the Dnieper River, also called the Dnipro, in the wake of the breach. https://go.nasa.gov/4daO7Bc

SPHERES

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