



COOPERATIVE INSTITUTE FOR RESEARCH IN ENVIRONMENTAL SCIENCES

SPHERES

Edition 14 • 2022

Hazards surge; research does too

Scientists scrutinize wildfire's impact on flooding, air pollution—and how to build resilience

Devastating Colorado fires become living lab

Tracking ozone in the sky, on the ground

Researchers assess possibilities, concerns around climate intervention

STEM superheroes collect watershed data

Contents



SPHERES

A publication of the Cooperative Institute
for Research in Environmental Sciences

CIRES, a partnership of the University of Colorado Boulder and NOAA, conducts 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.

Briefs	4
Annual updates	8
Toolkit targets causes of extremes	10
Middle corona comes into view	11
Space weather forecasts improve	11
Film program shifts students' focus	12
CIRES scientists in The Conversation	13
Iceberg masses unjam before calving	14
Greenland rain threatens reindeer, tundra	15
Ocean, not ice sheet, shifted storms south	16
Film on Arctic expedition earns kudos	16
Milestones	17
The threat from Thwaites	18
HAZARDS: CIRES research tackles risks	20
ATMOSPHERIC CHEMISTRY: On ozone's trail	24
CLIMATE INTERVENTION: Possibilities, concerns	29
my SPHERE	33

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Above at left: "Superhero" images on trailside signs tell hikers what scientific instruments measure, by explaining each device's "superpower." Read more about this way of engaging the public with science on page 33. Illustration: Ben Weeman

On the cover: Onlookers watch smoke from the Calwood Fire in October 2020 in Boulder County, Colorado. The fire burned 10,113 acres, and destroyed or damaged 26 structures. Photo: Christina Kumler/CIRES

SPHERES

by the numbers

9

weeks of training taught undergraduates to hone in on critical parts of graphs and analyze papers more like experts (PAGE 6).

2

high, dry mountain study sites in Antarctica yielded soils with no sign of life whatsoever—a global first (PAGE 7).

#5

ranking for 2020's rate of increase in global CO₂ levels, in NOAA's 63-year record (PAGE 8).

>340K

deaths occur annually worldwide from exposure to airborne pollutants from everyday products (PAGE 9).

>200

students made short climate films with CIRES mentors, motivating change in their everyday lives (PAGE 12).

>1.75M

people read Jiménez & Peng's "Where and How to Catch COVID" in **The Conversation** (PAGE 13).

11

more hot, dry nights now than 40 years ago, so firefighters get less overnight relief (PAGE 20).

57%

of structures in the contiguous United States stand in natural hazard hotspots (PAGE 23).

CLIMATE AND THE ATMOSPHERE

Warmer clouds, cooler planet

Today's climate models are showing more warmth than their predecessors, forecasting an even hotter future. But work co-authored by CIRES Fellow **Jennifer Kay** highlights how models may err on the side of too much warming. Kay and her colleagues modified a model used in international climate assessments like the Intergovernmental Panel on Climate Change (IPCC) to better understand how warmer clouds affect climate. They found that Earth's warming clouds cool the surface more than anticipated.

Warmer clouds are more reflective than cold clouds, sending more heat back into space, and they don't precipitate as easily, remaining in the atmosphere longer. Climate models used in the IPCC don't yet account for differences between warm and cold clouds, introducing model biases that could impact future climate projections.

bit.ly/warm-clouds-cool-planet

Clouds cancel clouds

Marine plankton release chemicals that get into the air and can seed clouds; scientists have long known that this cloud-formation process can affect global climate. But new research suggests it's more complicated than previously thought—marine cloud formation depends on

whether the chemicals are emitted into clear or cloudy skies. To better understand how marine plankton influence clouds, **Gordon Novak**, now a CIRES scientist in NOAA's Chemical Sciences Laboratory, dug into data collected during a research aircraft campaign off the coast of Southern California.

The team found that one cloud-forming molecule, dimethyl sulfide, can undergo transformations that lead to another molecule (hydroperoxymethyl thioformate) that readily dissolves in water. That means cloud droplets themselves can destroy some seeds of future clouds. The findings will help scientists better understand how changes in the ocean influence clouds and global climate.

bit.ly/clouds-cancel

Microbes behind methane rise

For the last decade, climate scientists have been trying to figure out what caused a sudden and sustained rise of the potent greenhouse gas methane since 2007. A CIRES-led team in NOAA's Global Monitoring Laboratory worked with CU Boulder's Institute of Arctic and Alpine Research to determine if one of the major methane sources—fossil fuels, microbes, or biomass/biofuel burning—was responsible for the surging levels. The researchers analyzed carbon isotopes from methane captured in global air samples, and the data pointed to microbial

CONTINUED ON NEXT PAGE



Morning light on clouds near Bangor, Maine, during the 2017 Atmospheric Tomography mission.
Photo: Samuel R. Hall/National Center for Atmospheric Research

sources, including natural wetlands, shallow lakes and rivers, and human-managed sources like livestock, landfills, rice paddies, and wastewater treatment. If climate change increases microbial methane emissions from wetlands, the researchers concluded, extra methane emissions could feed back into more warming, amplifying the warming cycle.

bit.ly/wetlands-methane

Planes pollute northern stratosphere

Air pollution in the troposphere, or lower atmosphere, is generally worse in the Northern than in the Southern Hemisphere, which has fewer people and less pollution. Now, scientists from CIRES and NOAA's Chemical Sciences Laboratory report that the northern stratosphere—just above the troposphere and home to Earth's protective ozone layer—is also more polluted. They analyzed measurements of tiny particles and trace gases gathered during a NOAA-NASA airborne study, finding a more pristine upper atmosphere in the Southern Hemisphere and a Northern Hemisphere impacted by human-made pollutants. The scientists suspect emissions from aviation exhaust is a main culprit. Commercial aircraft typically cruise within the lower stratosphere, emitting

small particles and sulfur dioxide gas in their exhaust, and air traffic is largely concentrated in the Northern Hemisphere.

bit.ly/planes_pollute

Iodine-rich dust destroys ozone

A set of unexpected connections between desert dust, iodine, and ozone may help scientists understand why dusty air often has very little ozone pollution and what that means for Earth's ozone layer and even climate change. CIRES Fellow **Rainer Volkamer** and former CU Boulder graduate student **Theodore Koenig** identified iodine in dust as one of the likely reasons that dusty air is often low in ozone, which acts as an air pollutant near the surface. That iodine, once it's lifted into the air by wind, transforms into a molecule that can deplete ozone levels by about 75 percent compared to background air. But while ozone destruction may be good news at the surface, where the chemical acts as a pollutant, it's bad news high up in the stratosphere, where the ozone layer helps block harmful ultraviolet radiation from the sun. These findings have implications for geoengineering concepts that rely on dust to cool the planet; iodine in the dust would be a serious concern.

bit.ly/dust-destroys-ozone

MORE BRIEFS ON PAGE 6



Michael Gooseff, professor of Civil, Environmental and Architectural Engineering at CU Boulder, discusses fieldwork with the 2015 RECCS cohort. Photo: Amanda Morton/CIRES

EDUCATION

Seeing like a scientist

After nine weeks immersed in a research experience at CU Boulder, undergraduate students could analyze scientific papers and graphs more like experts. Researchers tracked the students' eye movements while reading complex graphs and academic papers before and after the program.

The students didn't just become book-smart—they fundamentally shifted their reading patterns when tackling scientific material, the researchers said.

The Research Experiences for Community College Students (RECCS) program, led by CIRES Education & Outreach (E&O), pairs Colorado community college students with CIRES scientists at CU Boulder and NOAA to conduct field- or lab-based independent research. "After RECCS, the students honed in on the critical parts of graphs and analyzed papers more like experts," said **Anne Gold**, director of E&O and lead author of the eye-tracking study. "They didn't just learn what scientists do—they became scientists."

bit.ly/see-like-scientist

ECONOMICS

It can't be just about growth

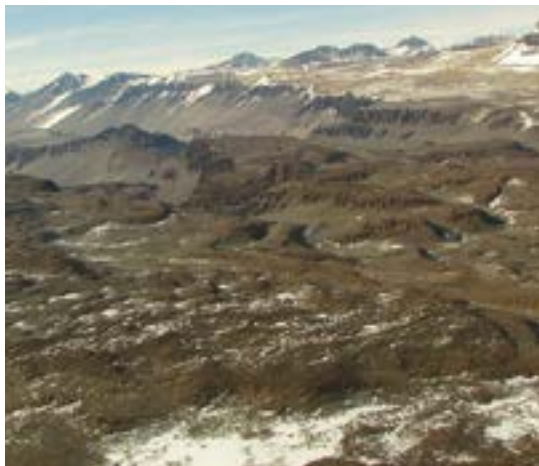
It may be time to stop being hyper-focused on economic growth as a leading indicator of a society's success, according to CIRES and CU Boulder researchers. We may be headed for a long-run decline in growth this century, whether we like it or not. And that brings challenges, particularly in countries with multicultural democracies like the United States, according to a 2021 *Nature Human Behaviour* study. CIRES Fellow **Matt Burgess** and his co-authors argue that slowing growth gives rise to inopportunities and inequality, and it also dings personal finance, mental health, and trust in the government.

To address these challenges, we might need to move away from the notion of a growing economy as central to our national identity, said Burgess, an assistant professor of environmental studies. The nation could instead focus on lessening financial inequality, increasing the public's return on investment by closing tax loopholes, or improving non-economic aspects of well-being.

bit.ly/not-just-growth

MORE BRIEFS ON PAGE 7

ECOLOGY



Nobody's home in some dry valleys

“Microbes are tough; they can live anywhere,” says CIRES Fellow and microbiologist **Noah Fierer**.

Except, maybe, not on certain rocky ridges in the interior of Antarctica. Fierer and his team, including Ph.D. student **Nicholas Dragone**, found that soils from there contained no life at all. The discovery is a first on this planet.

The team studied soils from 11 different mountains. Those from lower, less frigid areas contained some bacteria and fungi; but in some of the soils from the two highest, driest, coldest

mountains 300 miles from the South Pole—nobody was home. “We can’t say they’re sterile,” says Fierer. “Microbiologists are used to finding millions of cells in a teaspoon of soil; so a minuscule number—say, 100 living cells—could potentially escape detection. But as far as we can tell, they don’t harbor any microbial life.”

bit.ly/dry-valleys

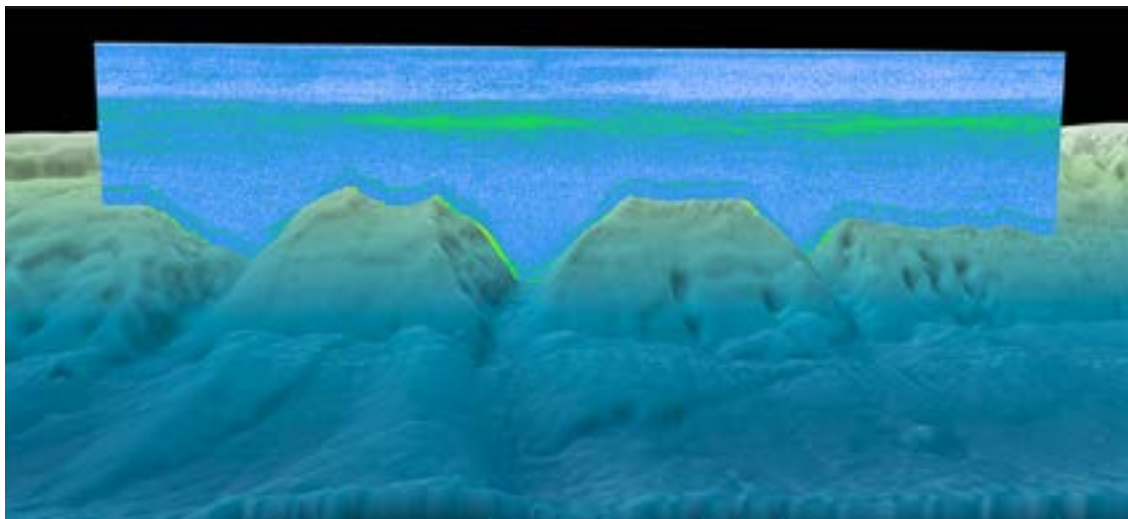
BIG DATA

New center taps AI to advance NOAA goals

The new NOAA Center for Artificial Intelligence (NCAI) aims to apply AI and machine learning techniques to better understand and predict changes in climate, weather, oceans, and coasts, supporting NOAA’s mission. CIRES scientists in NOAA’s National Centers for Environmental Information are contributing to this effort through two pilot projects:

- ◆ **Magnetic navigation:** The team spearheaded a competition challenging the data science community to help build machine learning models that use satellite data to forecast changes in Earth’s magnetic field.
- ◆ **Water column sonar data:** They developed an AI and cloud-ready “data lake”—a storage repository for vast amounts of raw

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CIRES scientists in NCEI are creating an AI and cloud-ready storage repository for water column sonar data like these, collected by NOAA’s Okeanos Explorer in the North Atlantic Ocean. In this image, a layer of marine organisms (in bright green) floats in the water column above the rolling seafloor topography. Image: NOAA NCEI

data—to help researchers detect and speculate fish and zooplankton. In the future, NOAA’s National Marine Fisheries Service could use this tool to quickly analyze large volumes of data that inform fish stock assessments.

bit.ly/new-NCAI



MODELING

Grant expands sharing, access to Earth surface models

The National Science Foundation awarded a CU Boulder team a highly competitive grant to build OpenEarthScape, a set of models and

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CIRES RESEARCHERS CONTRIBUTE EVERY YEAR TO THESE ASSESSMENTS.

AMS' STATE OF THE CLIMATE IN 2020	<ul style="list-style-type: none"> • 2020 was among the three warmest years in records dating to the mid-1800s. • New high temperature records were set across the globe. • Sea level, ocean heat content, and permafrost broke records set in 2019. • CO₂ levels in the atmosphere hit record highs in 2020. <p>bit.ly/2020_top3_warmest</p>
GML'S GLOBAL GREENHOUSE GAS REFERENCE NETWORK	<ul style="list-style-type: none"> • CO₂ and methane levels rose in 2020, despite the economic slowdown caused by the coronavirus pandemic response. • The global CO₂ average in 2020 rose 2.6 ppm to 412.5 ppm, the fifth-highest rate of increase in the 63-year record. <p>bit.ly/CO2_Methane_2020</p>
NOAA'S ANNUAL GREENHOUSE GAS INDEX (AGGI)	<ul style="list-style-type: none"> • The AGGI reached a value of 1.47 in 2020, similar to previous years. • That means 47 percent more heat—attributable primarily to human activity—was captured by Earth’s climate system in 2020 than in 1990. <p>bit.ly/AGGI_2020</p>
CO₂ PEAK AT MAUNA LOA 2021	<ul style="list-style-type: none"> • Atmospheric CO₂ in 2021 peaked in May at a monthly average of 419 ppm, the highest level in the 63-year measurement record. <p>bit.ly/CO2_at_MaunaLoa_2021</p>
ARCTIC SEA ICE EXTENT, FALL MINIMUM	<ul style="list-style-type: none"> • Arctic sea ice in September 2021 was at its highest minimum since 2014, with an average of 4.92 million km² (1.90 million square miles). • Despite that good news, however, the last 15 years (2007-2021) have had the 15 lowest September extents on record. <p>bit.ly/sea_ice_min_2021</p>
2021 ANTARCTIC OZONE HOLE	<ul style="list-style-type: none"> • The 2021 Antarctic ozone hole reached its maximum area on October 7. At 9.6 million square miles, or roughly the size of North America, the ozone hole was the 13th largest since 1979; measurements made at the South Pole showed the hole was also the 8th “deepest” since 1986. <p>bit.ly/Antarctic_ozone_2021</p>

simulations to help anticipate changes in river flow, beach erosion, landslides, and more. The \$2.56-million grant will support five years of work by Earth scientists and modelers in developing a suite of open community cyber resources. The project, headed by CIRES Fellow and Professor of Geology **Gregory Tucker**, is a collaboration with researchers from Tulane University, INSTAAR, the University of Washington, Western Washington University, and the National Center for Atmospheric Research. OpenEarthScape is intended to be open source and shareable with the entire scientific community.

bit.ly/surface-science-grant

COMMUNICATIONS

Print media hitting mark on climate

Good news: Major print media around the world have been representing human contributions to climate change more accurately over the last 15 years, hitting a 90 percent scientific accuracy rate on average. According to the 2021 study with CU Boulder and CIRES authors, media's coverage of climate change is becoming less biased—headlining the idea that high-circulation print media no longer present climate change as a controversy.

“Two decades ago, print media frequently gave equal credence to both legitimate climate experts and outlier climate deniers. Now, it's not portrayed as a two-sided debate,” said **Lucy McAllister**, a former CIRES Ph.D. student and lead on the *Environmental Research Letters* study.

The paper updates previous findings by CIRES Fellow **Max Boykoff** that showed significant bias in climate coverage pre-2002. Bias remains, however, in current climate coverage by more conservative media outlets.

bit.ly/climate-news-accuracy

AIR QUALITY

Particles from paints, pesticides can kill

Scientists have long understood that atmospheric particles small enough to be inhaled can damage people's lungs. Studies have estimated that fine particle pollution, often called PM_{2.5}, leads to 3-4 million premature deaths globally per year, possibly more. More recently, CU Boulder, NOAA, NASA, and others have shown that emissions from everyday products are increasingly important in forming pollutants in urban air. A CIRES-led study built on those findings, showing anthropogenic secondary organic aerosol—tiny particles that form from chemicals emitted by paints, pesticides, fuels, etc.—is a significant indirect source of deadly fine particles. The researchers calculated that as many as 340,000-900,000 people worldwide die each year from exposure to air pollution caused by particles formed from everyday product emissions. That's more than 10 times as many deaths as previously estimated.

bit.ly/deadly-particles



A cropduster sprays pesticide in California. Photo: USDA via Wikimedia Commons



Texas Army National Guardsmen assist a motorist stuck on snow and ice during extreme winter weather conditions in February 2021. Photo: U.S. National Guard via Wikimedia Commons

New toolkit helps researchers diagnose causes of extreme heat, drought

CLIMATE Scientists studying heatwaves, cold spells, and droughts have gotten better at attributing these extreme events to underlying causes, including human-influenced climate change and climate phenomena such as El Niño. Now, CIRES and NOAA researchers are developing a new tool to help scientists quickly evaluate the causes of extreme events.

“Understanding the causes of extreme climate and weather events will help communities and emergency and resource planners better anticipate and plan for future events,” said **Joe Barsugli**, a CIRES scientist in NOAA’s Physical Sciences Laboratory working on the new tool.

The tool builds on what Barsugli and other scientists have learned about explaining temperature and drought extremes within a chang-

ing climate. Users will first assess the likelihood of extreme events by examining them within a historical context and then explore the influence of multiple causes using climate models.

For example, to determine the cause of heat and drought extremes in the United States, scientists must consider how historical temperature trends vary by region. They need to know the reasons for the difference between the “warming hole” in the eastern United States—where daily maximum temperatures have not appreciably increased—and the strong warming seen in western states.

This will allow them to answer questions including if these temperature patterns will persist, or if changes are likely.

bit.ly/new-tool-extremes

The Sun's middle corona finally comes into view

SOLAR PHYSICS

By using a NOAA telescope in a novel way, CIRES researchers working in NOAA's National Centers for Environmental Information (NCEI) captured the first-ever images of dynamics in the Sun's elusive middle corona. Those observations reveal how the middle corona influences the solar wind and eruptions from the Sun, a finding that could improve space weather forecasting.

NOAA's GOES-17 satellite (now GOES-West) doesn't orbit high enough for its Solar Ultraviolet Imager (SUVI) to capture those solar events. So the researchers directed SUVI to take pictures from different angles (to the left, right, and pointing straight at the Sun), and then created mosaic images from the pictures.

This technique allowed them to see the middle corona—the place on the Sun that drives the

solar wind and big eruptions that travel to Earth and can affect various technologies here, including blocking radio communications, damaging power grids, and diminishing navigation system accuracy.

“The middle corona connects to the stuff that connects to us, and we haven't observed it before,” said **Dan Seaton**, who was a CIRES scientist in NCEI when he led the study. His team's observations revealed surprising connections between the inner corona, with its complex magnetic structure, and the outer corona, where solar wind starts that can impact Earth.

That information could improve how forecasters detect and track solar eruptions, including coronal mass ejections that can wreak havoc with Earth's technology.

bit.ly/sun-in-new-light



This illustration depicts space weather impacts to satellites, aviation, and the power grid. Image: NOAA

Model takes us 'from the Sun to mud,' improving space-weather forecasts, warnings for Earth

SPACE WEATHER

In 2021, NOAA's National Weather Service began using a CIRES-developed model to better forecast how events 93 million miles away, on the surface of the Sun, can affect those of us on Earth. Incoming space weather can briefly blot out radio communications here, distort GPS signals, nudge satellite trajectories, and force astronauts to seek weather-worthy shelter.

“The new model will help our forecasters deliver better and more timely space weather forecasts and warnings,” said Michael R. Farrar, director of NOAA's National Centers for Environmental Prediction.

The Whole Atmosphere Model and Iono-

CONTINUED ON PAGE 13

Network keeps Sun in sight 24/7

In 2021, NOAA's Space Weather Prediction Center began processing and disseminating a dizzying array of data that describe current conditions on the Sun, collected by six identical telescopes around the world trained on the star. The Global Oscillation Network Group (or GONG) data, once processed, help space weather forecasters anticipate if potentially disruptive space weather is heading our way. CIRES research scientist **Andy Marble** is helping NOAA manage the transition and processing of these important solar data.

Lights, climate, action: Film program shifts focus of middle, high school students, mentors

EDUCATION & OUTREACH

The Lens on Climate Change (LOCC) program transformed the students and mentors who participated, empowering them to engage with climate science and solutions, even outside of school, and inspiring career changes. Two recent studies on LOCC's impacts showed that participants didn't just gain skills and knowledge—they felt motivated to take action toward sustainable futures.

In LOCC, led by CIRES Education & Outreach (E&O), middle and high school students produced films documenting the effects of climate and environmental changes on their lives and in their communities. The program, which ended in 2019 after five years, involved over 200 students and 59 science and film mentors.

The process of creating a short film about the place-based impacts of climate change was a transformative experience for students who participated in LOCC, according to research led by CIRES E&O's **Megan Littrell**. Youth partici-

pants reported that this more personal connection with climate change shifted their perspectives and inspired them to continue learning and communicating about climate change with others in their communities. "It was inspiring to see how the program really changed the way they thought and empowered them to make changes in their everyday lives," Littrell said.

Mentors gained skills in teaching and communication and built relationships and networking connections through training and program activities, according to a second paper led by CIRES E&O's **Katie Boyd**. Several mentors expressed that their experiences with LOCC inspired them to change their career path toward STEM education.

The two studies confirm that STEM learning and mentorship training can lead to transformative shifts in participant's skill sets, educational interests, and career development.

bit.ly/LOCC-transformed

bit.ly/LOCC-mentors



Nederland, Colorado middle and high school students interviewed Tad Pfeffer (INSTAAR) about the Arapahoe Glacier during the LOCC project. Photo: David Oonk/CIRES

THE CONVERSATION



Jimenez



Peng



Balch



Moon



Druckenmiller



Karnauskas

CIRES scientists spark dialog on issues of the day

COMMUNICATIONS

Scientists across CIRES published short, timely articles on their research via The Conversation—an independent publisher of commentary and analysis, authored by academics and edited by journalists. CIRES researchers reached more than a million readers through The Conversation during the last year, and the platform served as a launching point for media outlets around the world to pick up on critical research findings.

- ◆ By far the most widely read piece by a CU Boulder expert was an essay by CIRES Fellow **José-Luis Jiménez**, research scientist **Zhe Peng**, and others: “Where and how you’re most likely to catch COVID.” The English and Spanish versions of the story earned a combined 1.75 million reads. Doz-

ens of outlets picked up the piece including *The Denver Post*, the World Economic Forum, and others. On Twitter, thousands shared Jimenez’s tweet featuring the team’s compelling and easy-to-follow table of risk, which highlighted different locations and masking scenarios.

bit.ly/conversation-catch-COVID

- ◆ **Jennifer Balch**, CIRES Fellow and director of CIRES/CU Boulder’s Earth Lab, joined forces with colleagues from the University of Montana to urge the U.S. public to skip wildfire-sparking fireworks last July. Over 35,000 readers viewed Balch’s story, and 46 publishers shared the news including *The Sun*, *Popular Science*, and many others.

bit.ly/conversation-skip-fireworks

CONTINUED ON PAGE 14

Space weather forecasts

CONTINUED FROM PAGE 11

sphere Plasmasphere Electrodynamics Model, or WAM-IPE, has been taking shape at CU Boulder, NOAA’s Space Weather Prediction Center, and the agency’s Environmental Modeling Center for more than 15 years.

The team’s work—first led by CIRES’ **Timothy Fuller-Rowell** and then by **Tzu-Wei Fang** (now a NOAA employee)—has resulted in a first-of-a-kind model that brings space weather forecasts down to Earth.

Other forecast systems consider how events on the the Sun send material streaming toward

Earth, and how that perturbs our magnetosphere, creating spectacular aurora and risks to satellites, aircraft communication, and even astronauts.

“WAM-IPE closes the final link, taking us from the Sun to mud, considering everything that comes up from the troposphere and down,” Fuller-Rowell said. It’s in the troposphere that terrestrial weather takes shape, convective storms form, and winds flow. Such weather can change how space weather affects human technologies.

NOAA called the WAM-IPE Model “a research-to-operations success story.”

bit.ly/space-weather-model



Scientists use time-lapse cameras at the edge of a proglacial fjord in Greenland. At the right is one of ground-based radar interferometers used to record the movement of icebergs. Photo: Ryan Cassotto/CIRES

Slushy iceberg masses unjam just before calving

CRYOSPHERE

Shortly before Jakobshavn Isbræ, a tidewater glacier in Greenland, calves massive chunks of ice into the ocean, there's a sudden relaxation in the slushy collection of icebergs floating along the glacier's terminus, according to recent CIRES-led research. Scientists refer to this collection as "ice mélange."

"It only takes a small bit of strain for the mélange to stretch or relax a little bit, and so it's no longer an ice jam," said **Ryan Cassotto**, a researcher in CIRES' Earth Science and Observation Center and lead author of the study published in *Nature Geoscience*.

To understand what was happening to the ice mélange during calving events, Cassotto and his colleagues set up ground-based radar interferometers on Jakobshavn Isbræ's proglacial fjord. They found that between calving events,

icebergs within the mélange moved together as a cohesive unit.

But just before a calving event, the ice mélange relaxed and icebergs began to move independently of each other. "When the ice mélange loses its structure, it loses its ability to impede calving," Cassotto explained.

The research team used a particle dynamics model to simulate the movement of individual icebergs and found that only a small downfjord expansion of the ice mélange is needed to trigger a change in its structure.

This study is the first to show that an ice mélange largely free of sea ice can control the timing of calving. The work may help scientists predict when major episodes of calving are about to occur and better understand future sea-level rise scenarios.

bit.ly/icebergs-push-back

The Conversation

CONTINUED FROM PAGE 13

- ◆ **Twila Moon** and **Matt Druckenmiller**, CIRES researchers with the National Snow and Ice Data Center, wrote about how human-caused warming is paving the way for disruptions that affect ecosystems and communities far and wide—findings from the 2021 NOAA Arctic Report Card. Nearly 50 news outlets from around the globe ran the essay. bit.ly/conversation-Arctic-report
- ◆ Over 80K people read an essay by CIRES Fellow **Kris Karnauskas**: He provided insight on what forecasters and climate scientists looked for during last summer's Atlantic hurricane season. bit.ly/conversation-hurricanes
- ◆ And more! bit.ly/CU-on-the-conversation



Threats to communities from warming temperatures in Greenland were apparent in 2012, when summer melt from the Russell Glacier, shown here, and others in southwest Greenland caused record flooding, badly damaging a steel bridge in the downstream village of Kangerlussuaq. Photo: Mike MacFerrin/CIRES

More Greenland rain threatens reindeer, tundra

CRYOSPHERE

When rain fell at the highest point on the Greenland Ice Sheet in August 2021, it was the first time since records began in 1950, and made headlines around the world. Now, research co-authored by National Snow and Ice Data Center (NSIDC) scientists suggests that these kinds of events will become more common across the Arctic, with more and more rain falling as the climate warms.

A rainier Arctic has huge implications for communities and ecosystems in the region, explained **Mark Serreze**, director of NSIDC and co-author of the paper. “Tundra vegetation, permafrost conditions, and wildlife will all be affected, as well as human activities, such as reindeer herding, that have been practiced for centuries. Icy layers left by rain-on-snow events that interfere with foraging have led to massive die offs of reindeer.”

To evaluate the impact of climate change on Arctic precipitation, the team analyzed data

from the sixth phase of the Coupled Model Inter-comparison Project, which points to more rapid warming and sea-ice loss in the Arctic than in previous projections.

The updated models produced a larger and faster increase in precipitation as well. Their predictions indicate increased rainfall year-round, and decreased snowfall in summer and autumn due to a combination of global warming, Arctic amplification of warming, and sensitivity of precipitation to warming. In the models, the changes in precipitation cause the transition from snow- to rain-dominated summer and autumn to occur decades sooner than predicted in previous work.

These results suggest that precipitation changes that were once expected with 2°C (3.6 °F) of global warming are now possible under 1.5°C (2.7°F) of global warming, meaning that stricter mitigation strategies will be needed to deal with the impacts of more rain falling in the Arctic.

bit.ly/rainy-Greenland
go.nature.com/3D0KHzn

Ocean, not ice sheet, shifted storms south

CLIMATE

Twenty thousand years ago, large ice sheets loomed over North America, and researchers thought the ice, itself, pushed storms south, drenching the Southwest and leaving the Pacific Northwest dry. But a CIRES-led study suggests that ocean temperatures are the real culprit behind the dramatic shift in circulation.

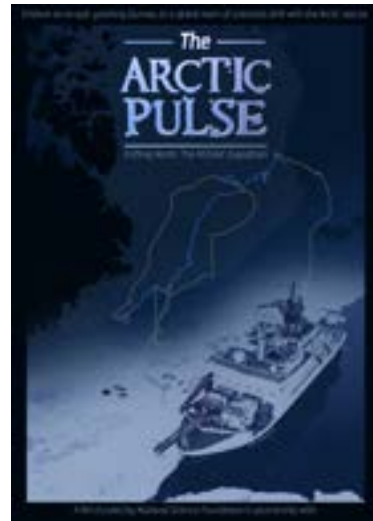
“Although there is no chance that a 3-km-tall ice sheet will suddenly appear over North America, modern climate can produce similar changes in North Pacific ocean temperatures that could temporarily swap the climates of the Southwest and the Pacific Northwest,” said **Dillon Amaya**, a former CIRES Visiting Fellow turned NOAA researcher and lead author of the 2021 paper published in *Earth and Planetary Science Letters*.

Amaya and his colleagues used a climate model to evaluate the impact of Northern Hemisphere ice sheets on West Coast ocean-atmosphere dynamics during the Last Glacial Maximum. But when they allowed their model to account for air-sea interactions more realistically, the ice sheet’s brightness, or albedo, caused North Pacific Ocean temperatures to cool. These ocean temperature changes altered the atmosphere’s circulation, shifting west coast precipitation south.

The work shows that ocean temperatures, not ice sheets themselves, are directly responsible for reorganizing North Pacific atmospheric circulation and West Coast precipitation patterns during the Last Glacial Maximum.

“This study highlights the need for a holistic view of the climate system,” said coauthor and CIRES Fellow **Kris Karnauskas**. “Without accounting for the interaction between the atmosphere and ocean, you can end up with the right answer for the wrong reason.”

bit.ly/ocean-not-ice-sheet



Kudos for planetarium film on Arctic expedition

COMMUNICATIONS

Drifting North: The Arctic Pulse, an award-winning

360-degree film by CIRES videographer **Lianna Nixon**, has made a worldwide splash—shown in planetariums around the globe and accepted into multiple international film festivals, including the Jena Fulldome Festival 2021, Berlin Lift-Off Film Festival 2022, Festival of International Virtual and Augmented Reality Stories 2022, and the Blue Water Film Festival.

The film follows an international team from 20 countries—including CIRES’ and PSL’s **Matthew Shupe**, MOSAIC co-lead, and many other CIRES scientists—over the course of an epic year-long expedition to the Central Arctic. The Multidisciplinary Drifting Observatory for the Arctic Climate (MOSAIC) team froze the German icebreaker *R/V Polarstern* into the sea ice, then drifted with the floe from September 2019 to October 2020 to take an unprecedented look into the Arctic climate system.

bit.ly/MOSAIC-film

RESEARCH UPDATES: In February 2022, MOSAIC researchers published in the journal *Elementa* three overview articles on Arctic atmosphere, snow and sea ice, and ocean—presenting the most complete picture to date of the climate processes in the Central Arctic.

bit.ly/MOSAIC-atmosphere

bit.ly/MOSAIC-seaice

bit.ly/MOSAIC-ocean

M I L E S T O N E S

IN MEMORY

With sadness, we report the deaths of three longtime members of the CIRES family in early 2022: **Vijay Gupta, Jon Rush** and **Tingjun Zhang**. Vijay was a CIRES Fellow and a professor of Civil, Environmental, and Architectural Engineering who retired in 2012; he passed away peacefully, his family said. Jon, a longtime CIRES Administrator, died after a long battle with lung disease and esophageal cancer. Tingjun, a former CIRES Fellow and longtime NSIDC scientist, had fought cancer and lung disease for years. We miss them all.

HONORS

The University of Colorado Board of Regents named CIRES Fellow and chemistry professor **José-Luis Jiménez** a “Distinguished Professor,” the highest honor the CU system bestows on a faculty member.

CIRES scientists were involved in several projects that earned 2021 NOAA Bronze Medals (the agency’s highest honor):

- ◆ NCEP’s **Ed Gille** helped implement a repeatable process to certify scientific data services as trusted sources of information.
- ◆ **Antonietta Capotondi, Gijs de Boer, Ola Persson, Matthew Shupe, and Amy Solomon** (PSL) were critical to the development of a fully coupled, ocean-ice-atmosphere model that delivers sea-ice forecast guidance to the NWS Alaska Region.
- ◆ GSL’s **Eric James** and **Tanya Smirnova** were part of a team lauded for improving lake-effect snow and ice forecasts through an innovative coupling of weather and coastal hydrodynamic models.
- ◆ GSL researchers **Raffaele Montuoro, Kate Zhang, Haiqin Li**, and CSL’s **Stuart McKeen** helped develop the Global Ensemble Forecast System-Aerosols (GEFS-Aerosols) model to support air quality alerts and visibility forecasts.

Clarivate recognized **Noah Fierer, José-Luis Jiménez, Jonathan Leff (formerly CIRES), Jennifer Kay**, and **Julienne Stroeve** as 2021 “Highly Cited Researchers.”

The 2021 U.N. Climate Change Conference in Glasgow (COP26) included three presenters from

the National Snow and Ice Data Center: NSIDC Director **Mark Serreze** on “Greenland’s Future,” **Twila Moon** on “Greenland’s Tipping Point,” and **Walt Meier** on “Impact of Lost Sea Ice/ Ecosystem Collapse.” **Gina Fiorile** from CIRES Educations & Outreach discussed “U.S. Climate Action Center at COP26.”

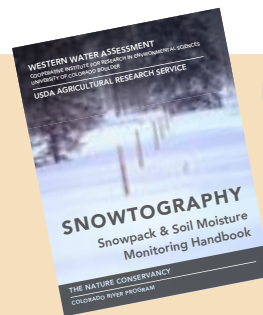
bit.ly/Greenlands-future
bit.ly/Greenlands-tipping-point
bit.ly/lost-sea-ice
bit.ly/climate-empowerment

CIRES 2022 Graduate Student Research Awards recognized seven outstanding individuals: **Sarah Becker, Corinne Walsh, Sarah M. Jaffe, Zachary Schiffman, Shane Zhang, Karl Alexander Widney**, and **Ian Geraghty**.

FUNDING

NOAA renewed its support of the CIRES-based Western Water Assessment (WWA) with a grant of more than \$5 million for five more years.

CONTINUED ON PAGE 28



BOOKS

Western Water Assessment’s **Liz Payton** collaborated with other scientists in The Nature Conservancy and the USDA

Agricultural Research Service to produce *Snowtopography*, a best-practices handbook for establishing snow and soil moisture monitoring stations.

<https://www.colorado.edu/resources/colorado-river-resources/snowtopography-handbook>



Research vessel *Nathaniel B. Palmer* negotiates ice along the Thwaites Glacier in 2019. Aleks Mazur/ITGC

The threat from Thwaites

Vulnerable glacier losing its grip on Antarctic coast

CRYOSPHERE

Critical changes are happening to Antarctica's Thwaites Glacier this decade, setting the scene for a chain reaction that poses a major threat for higher sea-level rise this century. The Florida-sized glacier is retreating rapidly as warm ocean water slowly erases its ice from below, leading to faster flow, more fracturing, and the eventual threat of collapse, according to an international team of scientists. If it does collapse, ensuing sea level rise could put millions of people living in coastal cities in danger zones for extreme flooding in the coming decades to centuries.

"Thwaites is the widest glacier in the world," said **Ted Scambos**, CIRES senior research scientist. "It's doubled its outflow within the last 30 years, and the glacier in its entirety holds enough water to raise sea level by over two feet. And it could lead to even more sea-level rise in coming centuries, up to 10 feet, if it draws the surrounding glaciers with it."

Scambos is the U.S. lead coordinator for the International Thwaites Glacier Collaboration (ITGC), a team of nearly 100 scientists dedicated to studying the vulnerable glacier, funded by the U.S. National Science Foundation and U.K. Natural Environmental Research Council. The five-year collaboration is aimed at collecting instrument data throughout the glacier and the adjacent ocean, and modeling ice flow and the future of the ice sheet. Their

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Thwaites findings grab international headlines

Scambos and a panel of ITGC experts presented their findings in a press conference at the 2021 American Geophysical Union Fall Meeting, making an international splash. More than 40 news outlets around the globe covered the results including CNN, *The New York Times*, PBS, *The Washington Post*, BBC, *Science*, *Nature*, *The Guardian*, and many more.

"If Thwaites were to collapse, it would drag most of West Antarctica's ice with it," said Scambos. "So it's critical to get a clearer picture of how the glacier will behave over the next 100 years." ITGC research, including future sea-level projections, will be vital for policymakers in efforts to mitigate and adapt to the impacts of global sea level rise, the team said.

work has revealed major changes in the ice, the surrounding water, and the area where it floats off the bedrock below.

Thwaites sits in West Antarctica, flowing across a 120-km stretch of frozen coastline. One third of the glacier, along its eastern side, flows more slowly than the rest. It's braced by a floating ice shelf, an extension of the glacier held in place by an underwater mountain ridge. The ice shelf inhibits faster flow of the upstream ice. But the brace of ice slowing Thwaites won't last for long, said **Erin Pettitt**, an associate professor at Oregon State University.

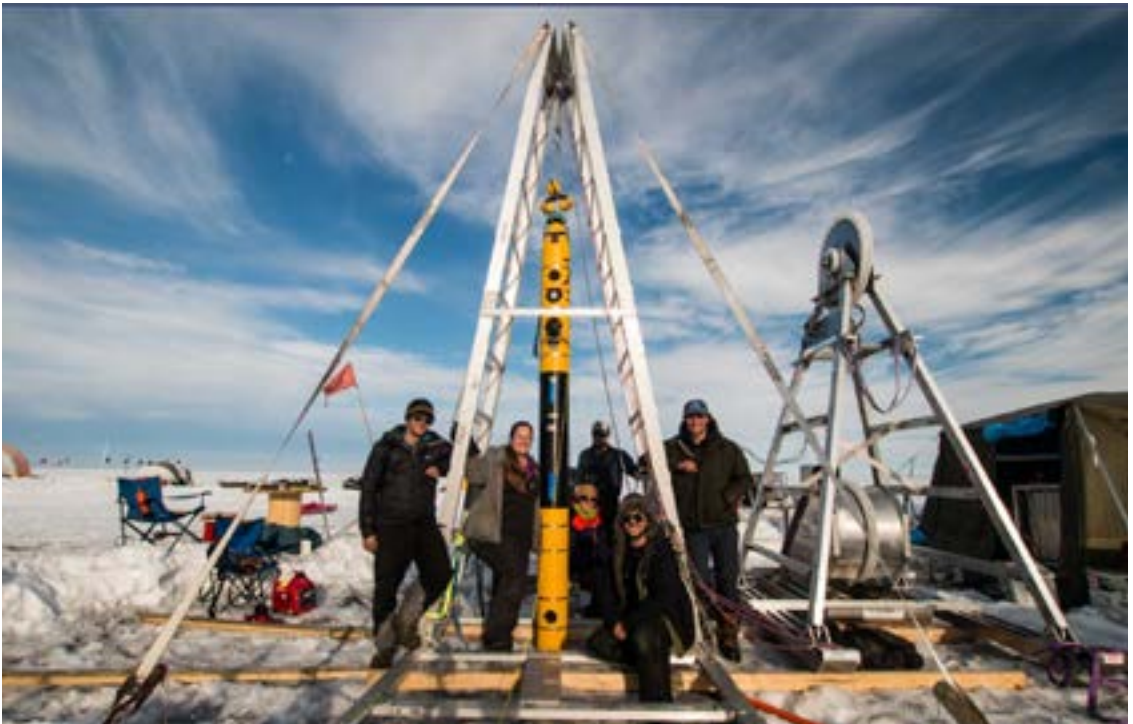
Warmer ocean water circulating beneath the floating eastern side is attacking this glacier from all angles, her team has found. This water is melting the ice directly from beneath, and as it does, the glacier loses its grip on the mountain ridge and is pushed to the breaking point by the giant glacier behind it. Massive fractures have formed and are growing, accelerating the glacier's demise, said Pettitt. This floating extension of the Thwaites Glacier will likely survive only a few more years.

Other members of the ITGC found threats to Thwaites' stability in all parts of the glacier,

drilling access holes to study conditions below the ice. Results show water in the "grounding zone," the area where the glacier lifts off the seabed, is warm and salty—prime conditions for melting. The team also collected data with a remote-controlled underwater robot lowered through a borehole, revealing a "chaotic" grounding zone: warm water, rugged ice, and a steep, sloping bottom that allows the water to quickly melt the ice sheet from below. Tidal movement physically forces warm water between the ice and bedrock, accelerating melting as the ice approaches the floatation point.

And looking ahead, there's another serious problem with the Thwaites Glacier system: the bedrock shape of West Antarctica makes the region vulnerable to runaway ice-cliff failure, because increasingly tall, unstable cliffs could be exposed as the ice retreats, the team said. While new modeling shows that the process has its own braking as large icebergs and frozen ocean ice build up at the cliff face, the process appears to allow for periods of very rapid retreat as Thwaites continues to pull back from the ocean front.

bit.ly/threat-from-Thwaites



Part of the ITGC team poses with the underwater remote-controlled robot used to collect data below the ice. Photo: Britney Schmidt and Daniel Dichek/ITGC

CIRES researchers intensify focus on wildfire, other risks

Wildfire's night brakes are failing

Cool, moist nights have historically helped firefighters slow a speeding fire. But due to a changing climate, nighttime fires have become more intense in recent decades, as hot, dry nights are more common, according to a 2022 *Nature* study led by CIRES Fellow and Earth Lab Director **Jennifer Balch**. There are now 11 more flammable nights every year in the U.S. West than there were 40 years ago—a 45 percent spike, the team found. “Firefighters don’t get the breaks at night they used to get,” said Balch. “They have to battle flames 24/7.”

bit.ly/hotter-nights-more-fires

Flooding, landslides up post-fire

Forest fires have increased the amount of water flowing in nearby rivers and streams—and the impact can continue for years after the smoke clears. So, as the number of forest fires rises in the western United States, the region is at increased risk for flooding and landslides, according to a 2022 *Proceedings of the National Academy of Sciences* study coauthored by **Ben Livneh**, CIRES Fellow and director of the Western Water Assessment. Lead author **Park Williams** of UCLA and team reported that the heavy flows and debris-contaminated

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Burnout operations roll into the night during the 2016 Hunter Creek Fire west of Cody, Wyoming. Since the 1980s there has been a 45 percent increase in “flammable” nights. Photo: Rob Gonzalez-Pita/CIRES



High school student Raney Moore talks with community members at the Hotchkiss Wildfire expo in May 2022. Photo: Katya Schloesser/CIRES

Resilience game gets all too real

Students use firsthand experience to level-up fire preparedness

EDUCATION & OUTREACH

When Rebecca Chernin, a science teacher at East Grand Middle School in Grand County, Colorado, began engaging students in wildfire role-playing games, she didn't expect that her community would be engulfed by fire a few short weeks later. The games were part of the Hazard Education, Awareness, and Resilience Task Force (HEART Force) curriculum, a project run out of CIRES Education & Outreach.

On October 14, 2020, it was no longer an educational game: The East Troublesome Fire broke out, forcing Chernin and many of her students to evacuate.

The return to school after the fire was difficult for many. "It was a little too close to home, and I quickly transitioned to another unit because it was hard for me as the leader of the classroom to still be up there," Chernin explained. But by January 2021, both she and her students were ready to revisit the hazard resilience curriculum.

As part of a semester-long class project, one team of students led a wildfire awareness campaign to increase knowledge about and preparedness for wildfire in their community. The students researched wildfire information and interviewed the fire chief and impacted community members. They then created short public service announcement videos about how to properly extinguish a campfire, how to properly store firewood, and what to pack in case of evacuation.

"I have been teaching for eight years and I've never seen a student group so engaged and wanting to come to class and wanting to give up their lunch periods," Chernin said. "It was wonderful to see the students get so passionate about something."

Chernin used to have nightmares about the fire, but after taking action with her students, the dreams went away. She found a way to heal through her experience with HEART Force and she believes that her students and the community members they interviewed did too.



Flooding destroyed homes and businesses near Longmont, Colorado in 2013. Photo: U.S. National Guard

When it rains it pours: floods, underinsurance dog some mobile home communities



PHD STUDENT HIGHLIGHT

When coronavirus canceled **Aislyn Keyes'** Fulbright Fellowship last summer, she found the next best thing: a summer research opportunity with the CIRES-based Western Water

Assessment (WWA). A CU Boulder ecology Ph.D. student who applies network analysis to food webs and ecosystem services, Keyes was intrigued with the idea of doing something “completely different.” So she spent the summer digging for data that would help the WWA team better understand the vulnerability of mobile home parks to one specific natural hazard: flooding.

Keyes focused on Colorado, Wyoming, and Utah, and she gathered flood vulnerability scores (Flood Factor) for mobile home parks across all three states, as well as average scores for every county. “Most of the mobile home parks have lower flood risk than average for the zip code,” she found. “But for those who have higher risk, that risk is much, much higher.”

This was especially true in Colorado, where floods in 1997 (Loveland-Fort Collins) and 2013 (the Front Range) severely impacted mobile home residents, damaging or destroying 120 and 1,300 mobile homes, respectively.

Keyes also found some evidence of disproportionate uninsured or underinsured mobile homes relative to other homes in the same zip codes—likely due to the lack of available, affordable flood insurance for mobile home residents.

“I hope someone takes a deeper look at that,” said Keyes, who returned to her Ph.D. work at the end of the summer. “It’s a pretty big social justice issue, especially again here in Colorado, where a lot of the affordable housing takes the form of manufactured homes.”

Her summer investigating flood vulnerability was a good lesson in unintended consequences, which indirectly parallels her own work, Keyes said. “Everything is interconnected, and any type of decision needs to consider the perspectives and wellbeing of everyone, not just those of one group—or one species.

bit.ly/floods_underinsurance

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water following a fire can create challenges for infrastructure and communities.

bit.ly/fires-increase-flood

Large wildfires + rising heat = more air pollution in the U.S. West

Large wildfires and severe heatwaves are happening more often at the same time, worsening air pollution across the U.S. West, according to a 2022 *Science Advances* paper. On one day in 2020, harmful levels of air pollution blanketed more than two-thirds of the region, home to about 43 million people. The study, co-authored by **Jordan Schnell**, a CIRES scientist in NOAA's Global Systems Laboratory, presented evidence that air pollution is magnified when wildfires and extreme heat occur simultaneously: Smoke sends fine particulate matter into the air and the heat triggers ground-level ozone that's harmful to human health.

bit.ly/fires_pollution

Develop with caution: Majority of structures are in risky locations

More than half of the structures in the contiguous United States are exposed to potentially devastating natural hazards, according to a CIRES-led paper in *Earth's Future*. And where we develop open land, cities, and towns is contributing to this trend. To evaluate the impact of development on natural hazard risk, **Virginia Iglesias**, a research scientist with CIRES/CU Boulder's Earth Lab, and her colleagues built maps of natural hazards and com-

Teach tsunamis in the classroom

Lindsey Wright, a CIRES researcher in NCEI recently developed a guide for educators on how to use the Tsunami Events (1850 to Present) Time-Lapse Animation tool, which shows how tsunami events evolve over time. The free tool and corresponding "Tsunami Time" worksheet can help teachers facilitate engaging, hands-on Earth science learning for middle and high school students.

bit.ly/tsunami_classroom

pared them to a dataset of historical land-use. They found that 57 percent of structures in the contiguous United States are located in natural hazard hotspots, despite these hotspots making up only about a third of the land.

bit.ly/risky-development

Researchers hustle to study fire's effects right next door

The smell of smoke still lingers in parts of Superior and Louisville, Colorado, where the Marshall Fire tore through December 30, 2021. CIRES and NOAA scientists rapidly deployed in the area to understand the indoor and outdoor air-quality consequences of the suburban firestorm. Among the initial results of the work: Opening windows and using air filters with activated carbon improved indoor air significantly.

bit.ly/research_hustle



CIRES scientist **Christine Wiedinmyer** checks instrumentation set up in a home to assess indoor air quality impacts of the Marshall Fire. Photo: Kelsey Simpkins/CU Boulder



Haze cloaks mountains beyond downtown Las Vegas. Researchers found a large proportion of the city's spring and summer ozone pollution may come from sources far afield. Story, page 27. Photo: Pixabay

On ozone's trail

CIRES scientists track pollutant on city streets, high in the air

Many of us are familiar with the air pollutant ozone, which often plagues cities on hot summer days and can trigger a variety of health problems in children, the elderly, and people of all ages who have lung diseases such as asthma. Ground-level ozone forms in the air when sunlight sparks a reaction between volatile organic compounds and nitrogen oxides, which are emitted from consumer products, industry, and vehicle tailpipes.

Fires can also eject massive quantities of gases into the atmosphere, and these cocktails of chemical emissions can produce ozone pollution, which can then be transported up to thousands of miles.

In several recent studies, CIRES scientists have illuminated, in detail, various ways ozone pollution can form and evolve.

More people, more products, more pollution

Lotions, sprays contribute bigtime to urban ozone levels

On hot summer days, you might apply deodorant, sunblock, and bug spray. You may spray an air freshener in the laundry room where a damp pile of workout clothes sits. Those personal care products you spritz and swipe are now responsible for a significant amount of the ozone pollution that plagues major urban areas, according to CIRES-led research.

In New York City, during a July 2018 heatwave, air samples collected by an instrumented NOAA

mobile laboratory helped CIRES and NOAA scientists dissect why ozone levels reached an unhealthy 115 parts-per-billion (ppb)—and those fragrant personal care products emerged as one of several culprits.

The team modeled the July 2, 2018 heatwave to understand what pushed ozone levels from 94 ppb upwind of the city (an already elevated level) to 115 ppb downwind. The models showed that volatile organic compounds (VOCs) from fossil fuels added 8 ppb, while VOCs from consumer products added 11 ppb—and about half of that was from fragrant consumer products.

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CIRES and NOAA scientists drove a mobile laboratory, filled with instruments capable of identifying and measuring hundreds of different VOCs in the air, from Boulder, Colorado, to New York City for three weeks of sampling in March and July 2018. Photo: Brian McDonald/NOAA

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“The big takeaway is how much VOC emissions from consumer products increase as urban population density increases, and how much these chemicals actually matter for producing ozone,” said **Matthew Coggon**, a CIRES researcher working in the NOAA Chemical Sciences Laboratory (CSL) and lead author of a 2021 paper in the *Proceedings of the National Academy of Sciences*.

VOCs are a class of carbon-based compounds that arise from many sources—natural ones like pine forests, and human-made ones, including fossil fuel emissions. Volatile chemical products, or VCPs, are a category of VOCs that share two

characteristics: key ingredients must evaporate for them to function, to carry scent or make them stick to a surface; and these evaporative components are typically derived from fossil fuels.

VOCs are one of two critical ingredients needed to produce ground-level ozone pollution and urban smog—nitrogen oxides are the other. Air-quality regulations typically target both to control ozone pollution.

For decades, regulators made progress in reducing urban smog by controlling VOCs generated by the transportation and electric power sectors. A groundbreaking paper published in

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Wildfire smoke lingers, produces ozone, and spreads around the world

2021's record-breaking fire season across the western United States and Canada fouled skies as far downwind as Boston and New York City with wildfire smoke, a visible reminder that fires can impact air quality thousands of miles away. Using data gathered in two recent NOAA airborne field campaigns, CIRES and NOAA researchers have learned how wildfire smoke contributes to ozone pollution, near and far.

Researchers participating in the NOAA-NASA FIREX-AQ field campaign spent a month in 2019 flying through and studying wildfire plumes. One research team, including scientists from CIRES, CU Boulder, NOAA, NASA, Caltech, and other

institutions, mined the data to better understand how wildfire smoke impacts air quality, specifically production of ground-level ozone, as the chemistry in wildfire plumes evolved. In their 2021 *Science Advances* paper, the researchers showed that wildfires increase regional ozone across the western United States. They also detailed how, when wildfire smoke mixes with urban pollution, ozone production ramps up—meaning that wildfires near cities are a recipe for air quality problems.

The changing chemistry of wildfire plumes goes something like this: Just downwind of a fire,

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Smoke streams from a wildfire during the 2019 FIREX-AQ field campaign, which collected data to better understand how wildfire smoke impacts air quality. Photo: Samuel Hall/NCAR



A NOAA monitoring station maps ozone between Las Vegas and Barstow, California. Photo: Andy Langford/NOAA

What happens in Vegas may have come from somewhere else

For years, CIRES scientists in NOAA’s Chemical Sciences Laboratory and their federal colleagues have investigated why some regions of the U.S. Southwest experience springtime episodes of high ozone pollution. In a recent study in the journal *Atmospheric Chemistry and Physics*, they reported that a large proportion of spring and summer ozone pollution in Las Vegas may be coming from sources outside the city, including pollution transported across the Pacific Ocean and from wildfires. That non-local ozone can reach the surface, contributing a striking 50-55 ppb to ozone levels in the greater Las Vegas area. This average amount represents 70-80 percent of the 70 ppb regulatory threshold in current U.S. National Ambient Air Quality Standards.

bit.ly/las-vegas-spring-air

CIRES scientists partner in new global bulletin

Human-caused emissions of air pollutants fell during the 2020 COVID-19 economic slowdowns, improving air quality in some parts of the world, while wildfires and sand and dust storms worsened air quality elsewhere, according to the World Meteorological Organization’s first *Air Quality and Climate Bulletin*. CIRES scientists working in NOAA laboratories contributed to the report, which highlights connections between air quality and climate change—including an estimated 4.5 million deaths worldwide from particulate matter and ozone pollution in 2019, the most recent year of available data.

bit.ly/WMO-bulletin

More people, more products, more pollution

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2018 by CIRES and NOAA scientists, led by then-CIRES scientist **Brian McDonald**, showed that, as a result of these tailpipe improvements, fossil fuel-based chemicals in a wide range of consumer products are now as important to air quality as the VOCs emitted from cars and trucks.

A growing body of work, much of it led by CIRES scientists, has since shown that VCPs are ubiquitous, contributing up to half or more of the total anthropogenic VOC emissions in several U.S. and European cities. A study by CIRES researchers **Georgios Gkatzelis** and **Chelsea Stockwell**, for example, has established that VCPs make up nearly half of the VOC emissions in Boulder, Colorado. Vehicle traffic

dominates the remainder.

The New York City study showed that current air-quality models don’t accurately simulate either the emissions or atmospheric chemistry of VCPs, according to Coggon. The team says the models must be updated to capture the full impact of these consumer products on urban air quality. In areas where ozone pollution is a problem, new strategies to control VOC sources may need to be devised, he said.

“We know now that these products are making ozone pollution worse,” Coggon said. “We can’t control what the trees are emitting, but what we can do is look for ways to make these common everyday products less polluting.”

bit.ly/ozone-in-NYC

Milestones

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WWA is working with the University of Wyoming, the University of Utah, water providers, rural communities, and Tribes to understand the compounding effects of rapid economic transitions and climate change, and to build community resilience. CIRES Fellow and Assistant Professor of Civil, Environmental, and Architectural Engineering **Ben Livneh** succeeded CIRES Fellow **Lisa Dilling** as WWA director.

APPOINTMENTS

NASA appointed CIRES Director **Waleed Abdalati** to the NASA Advisory Council (NAC) in February 2022. NAC members provide advice and make recommendations about important agency programs and topics to the NASA Administrator.

CU Boulder's Benson Center named **Matthew Burgess**, a CIRES Fellow and assistant professor in the Environmental Studies Program, as a Faculty Fellow for 2021-22.

Liz Payton, Water Resources Specialist at Western Water Assessment, is the Water Chapter Lead for the Fifth National Climate Assessment.

TRANSITIONS

Former CIRES Director and CIRES Fellow **Robert Sievers**, a pioneer in the fields of environmental and analytical chemistry, retired in January 2022. Among his many accomplishments, he created novel devices for processing and delivering inhalable pharmaceuticals, including a needle-free version of the measles vaccine. During his distinguished research career, Dr. Sievers also:

- ◆ advised 44 Ph.D. students,
- ◆ directed CIRES for 13 years (1980-93),
- ◆ served 12 years as CU Regent (1990-2002),
- ◆ spent two years as dean of the Graduate School,
- ◆ attracted tens of millions of dollars in sponsored research to CU,
- ◆ authored 200 publications, books, book chapters, and
- ◆ obtained more than 30 patents.

Smoke brings ozone with it

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ozone production is vigorous, but the rate of its formation slows as the plume mixes with ambient air. Then sunlight converts chemicals in the smoke into key ingredients of volatile organic compounds, necessary for ozone formation. And when fire plumes mix into urban atmospheres rich in nitrogen oxides—emitted from consumer products, industry, and vehicle tailpipes—ozone formation begins again, harming air quality.

In a related study, CIRES and NOAA researchers found wildfire smoke is much more widespread and plays a much bigger role in contributing to ozone pollution than previously thought. The 2022 *Proceedings of the National Academy of Sciences* study relied on data collected during the 2016–2018 NASA Atmospheric Tomography Mission, which used the NASA DC-8 research aircraft to sample the air in the most remote regions of the troposphere over the Pacific, Atlantic, Arctic, and Southern oceans.

Using detailed measurements of ozone and “tracer” compounds, whose chemical makeup allows scientists to identify their source, the researchers were able to classify air masses as urban, fire, or mixed origin and to estimate the quantity of ozone arising from each source. They found the signature of fire virtually everywhere, even in the most far-flung parts of the globe—something their chemical transport models had failed to predict.

Most surprising, however, was the discovery that even in the heavily populated Northern Hemisphere, ozone from fire emissions was roughly equal to that from urban ozone sources. In the less-heavily developed Southern Hemisphere and the Tropical Atlantic, ozone attributed to fires was 2 to 10 times higher than that from urban sources.

“We’ve known for many years that, starting with the Industrial Revolution, urban emissions have led to increasing global ozone levels,” said **Ilann Bourgeois**, a CIRES scientist in CSL who led the study. “What we didn’t expect to find was that fire emissions are actually contributing equal or greater amounts of ozone to the remote atmosphere than urban pollution.”

bit.ly/smoke-increases-ozone

Exploring the science behind controversial concepts

Opportunities, challenges abound as scientists strive to understand new field's mechanics, potential risks

Last summer's barrage of extreme weather around the globe—including record heat waves, wildfires, droughts, and floods—has amplified calls for urgent action to address climate change. Especially controversial are calls for climate intervention projects meant to keep the planet cooler. CIRES researchers at NOAA and at CU Boulder are working to understand how various climate intervention strategies might work and what the consequences might be—intended and unintended.

Team suggests step-by-step evaluation of research, with “exit ramps”

Aware of the potential for complications, scientists recently urged caution in the pursuit of climate intervention technologies.

In an opinion article published in the *Proceedings of the National Academy of Sciences*, a CIRES-led team proposed six ‘checkpoints’ that should be continuously assessed during climate intervention research, to be sure at each step that the research goal is technically feasible and socially acceptable. The authors used marine cloud brightening (MCB) to illustrate their proposed approach.

“MCB is now being evaluated as a potentially viable option, and therefore it is incumbent on us to create the structure for a future research program,” said NOAA scientist and CIRES Fellow **Graham Feingold**.

MCB would seek to make low-level clouds over the ocean more reflective and longer-lived by injecting them with small particles of salt generated by spraying seawater into the air. Theoretically, water vapor would collect on the surface of the salt particles, creating additional cloud droplets to reflect more sunlight back out to space.

This may be easier said than done, according to a 2022 study published in the *Journal of the Atmospheric Sciences* by CIRES and NOAA Chemical Sciences Laboratory (CSL) researchers. Using a sophisticated computer model that accurately simulates miniscule changes in cloud droplets, the researchers found that to successfully reflect more sunlight, they had to get both the size and number of the cloud seed particles just right. To make matters even more complicated, the optimal particle size was likely case- (or cloud-) dependent.

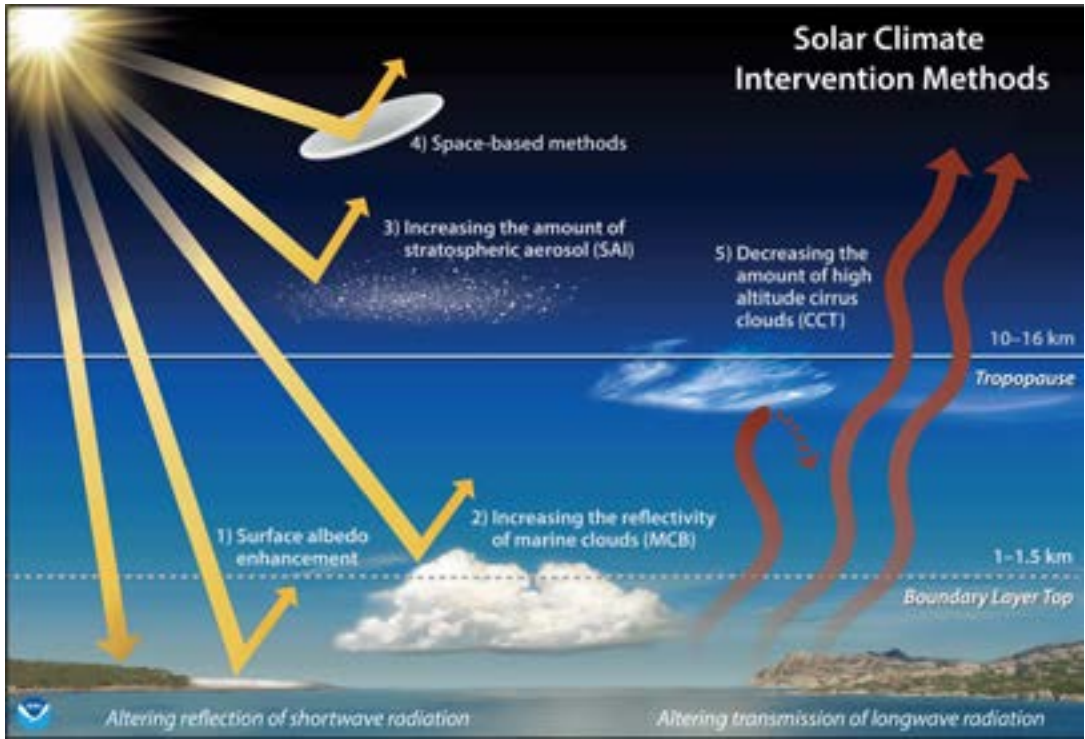
“It’s really not so easy as just spraying seawater up and hoping for the best,” said lead author **Fabian Hoffmann**, a researcher at Germany’s Ludwig-Maximilians-Universität and a CIRES Visiting Fellow at the time of this research.

“There are complex microphysics at play. If your particles are too large or too small, too many or too few, you could get little or no cloud brightening, or even less reflective clouds, as a result.”

In the opinion piece, the authors suggested scientific checkpoints for research into MCB, including the abilities to:

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CLIMATE INTERVENTION



This illustration depicts several theorized methods to cool the Earth by altering the amount of solar radiation striking the surface. Image: Chelsea Thompson/NOAA

“Exit ramps”

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- ◆ Generate and deliver appropriately sized particles to the right altitude and that once there, the particles would act to form cloud droplets that scatter sunlight efficiently;
- ◆ Show that the cooling effect of MCB would be measurable, in order to demonstrate that the method would work as intended;
- ◆ Clarify the risks of negative impacts on coastal communities and ecosystems; and
- ◆ Predict any other unintended consequences, such as MCB affecting precipitation patterns in vulnerable regions like the Amazon.

Beyond addressing science gaps, the researchers suggested an equitable governance structure to incorporate input from experts in fields outside the physical sciences—such as ethics, sociology, and ecology—in decisions about research feasibility and funding.

For example, if researchers reached a point where there was scientific confidence in the predictability of MCB-influenced precipitation changes, a decision about whether or not to continue the research would consider ecological and societal impacts on different communities or regions.

“Policymakers and potentially affected communities need a seat at the table to ensure that the information scientists generate is usable and relevant to their needs,” said **Michael Diamond**, a CIRES Visiting Fellow working in CSL and the paper’s lead author. Although they focused on MCB, the scientists advocated for a similar research framework to assess the viability of other climate intervention proposals, such as stratospheric aerosol injection, which would cool the planet by spreading millions of tons of light-reflecting particles in the stratosphere, home to Earth’s protective ozone layer.

bit.ly/exit_ramps

“We need to know how it would perform, how to do it... and what the risks and effects would be”

Solar geoengineering requires coordinated, international research that’s subject to governance, and should be complemented by a robust portfolio of climate mitigation and adaptation policies, according to a 2021 report from the National Academies of Sciences, Engineering, and Medicine.

CIRES Fellow **Lisa Dilling** served as a member of the committee that wrote the assessment of solar geoengineering—climate intervention strategies designed to cool Earth either by adding small reflective particles to the upper atmosphere, injecting salt particles into shal-

low marine clouds, or by thinning high-altitude clouds that can absorb heat.

“Research is needed since there’s just simply not enough understanding of solar geoengineering yet,” said Dilling. “We need to know how it would perform, how to do it, and what the risks and effects would be. But equally important is how the research proceeds—making sure that any research that is undertaken follows a set of principles and mechanisms to ensure that it is transparent, encourages public engagement, and is coordinated with other countries.”

bit.ly/solar_geoengineering

Reflect sunlight into space... but the Mediterranean could dry out, and Scandinavia get wetter

In one widely considered climate intervention scheme, reflective particles would be injected or transported into the stratosphere, where they would reflect sunlight and cool the planet. It works in nature: Large volcanic eruptions cool the planet.

But a 2020 modeling study led by CIRES and NOAA researchers highlights the vast challenges and potential downsides of such a method. The study in the journal *Atmospheric Chemistry and Physics* explored a group of 20 simulations to project how sulfate aerosol injections into the stratosphere could reflect enough sunlight to counter global warming.

Lead author **Antara Banerjee**, a former CIRES research scientist working in NOAA Chemical Sciences Laboratory, found that to obtain zero global-mean temperature change by the end of

the century, as much as 50 million metric tons of sulfur dioxide would need to be continuously injected into the stratosphere every year.

But her modeling simulations indicated there would be a risk of significant unintended side effects. For example, while the simulations mitigated about two-thirds of expected winter-warming trends, a robust surface warming every 30 years still occurred. The simulations also pointed to reduced winter precipitation in the Mediterranean, when the arid region normally receives most of its annual moisture, although that loss of winter precipitation would be balanced by an increase in summer moisture. The opposite would occur in Scandinavia, which would see wetter winters and drier summers.

bit.ly/particles_in_stratosphere

Use natural solar-powered lofting... but stratospheric, weather consequences could be harmful

The dynamics that lift smoke from large wildfires into the stratosphere could potentially be employed one day to help temporarily cool the planet, based on the findings of another modeling study led by NOAA, with CIRES and CU Boulder scientists.

Inspired by a giant fire cloud generated

over the Pacific Northwest in 2017, researchers investigated whether heat from the sun could loft light-reflecting material mixed with heat-absorbing particles several miles into the stratosphere from lower altitudes. Once in the stratosphere, the reflective material would dim

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Australian bushfires offer opportunity to test climate models

From late 2019 to early 2020, Australian bushfires spewed almost 1 million metric tons of smoke into the atmosphere, the largest input of wildfire smoke to the stratosphere observed in the satellite era. The smoke had measurable effects on the atmosphere of the Southern Hemisphere, providing researchers an unprecedented opportunity to study particle transport, microphysics, chemistry, and climate impacts—all key components in climate intervention modeling research.

A team led by **Pengfei Yu**, a former CIRES scientist in CSL, used a climate model to study the phenomenon, including its role in the large Antarctic ozone hole that formed in 2020. “These massive high-altitude clouds of smoke serve as excellent opportunities to constrain and test our climate models for various purposes: understanding past, present and future climate ... as well as simulating



A 2020 satellite image of eastern Australia shows bushfire smoke drifting over the Pacific Ocean. Photo: NOAA/NESDIS

the efficacy and climate implications of solar management strategies,” said Yu, now at Jinan University in Guangzhou, China.

bit.ly/giant_bushfire

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sunlight and cool the planet below. A description of the process, called solar-powered lofting, was published in the journal *Science Advances*.

The team used the NCAR Community Earth System Model to simulate solar-powered lofting and calculated the amount of light-absorbing black carbon particles required to effect substantial lofting.

The model successfully reproduced the lofting in the 2017 Pacific Northwest fire plume.

“Reflecting sunlight with stratospheric aerosols, effectively mimicking what large volcanic eruptions do, may buy some time for decarbonization efforts to ramp up. We don’t have the technology to do this today, but nature has shown us one way someone might propose to do it in the future,” said **Karen Rosenlof**, a CSL researcher and one of the paper’s lead authors.

The scientists concluded that solar-powered lofting is potentially feasible using existing aviation technology. It could also be easier, less expensive, and just as effective as introducing aerosols directly into the stratosphere, they said. Model simulations show that as little as 10

micrograms of heat-absorbing black carbon per cubic meter would be enough to loft air containing sulfur dioxide, which converts to light-reflecting particles, into the lower stratosphere in just a matter of days.

Currently, no aircraft or other platforms can directly deliver large amounts of aerosol material or aerosol precursors to high enough altitudes and disperse the material evenly. Importantly, even less effort has been invested in understanding the practical aspects of aerosol injection in the stratosphere.

Rosenlof said this study is not meant to encourage implementation of planet-cooling methods, but to provide the scientific foundation for societal decision-making. The scientists associated with this study acknowledge, as have many others, that increasing the number of aerosols in the stratosphere would likely have unintended consequences, such as increased stratospheric temperatures, changes in surface precipitation patterns, and possible depletion of the stratospheric ozone layer that absorbs harmful ultraviolet radiation.

bit.ly/solar_lofting

Meet these superheroes of science

SPLASH instruments, signage offer a bit of STEM education for watershed wanderers

ILLUSTRATIONS BY BEN WEEMAN

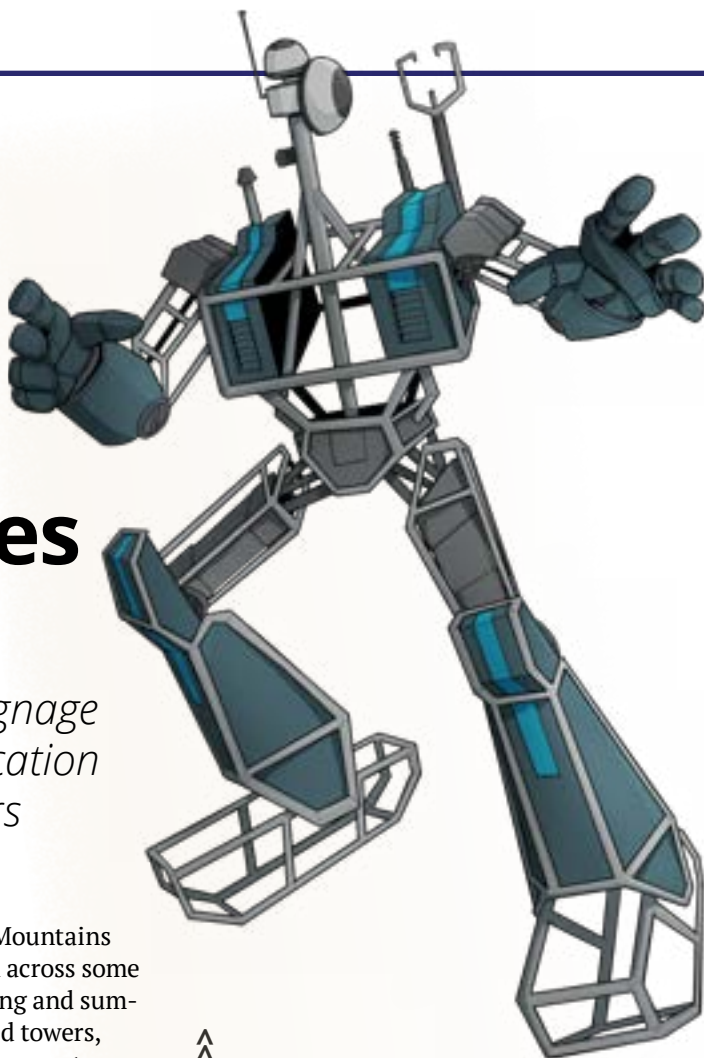
Hikers and hunters in the West Elk Mountains near Crested Butte, Colorado, may run across some curious-looking contraptions this spring and summer. A network of radars, instrumented towers, and individual sensors is measuring temperature, precipitation, soil moisture, snowpack properties, and more, to improve prediction of weather and river flow in a watershed critical to the region's water supply. Near the instruments, atmospheric scientists installed a lighthearted set of signs, giving each device a Transformer-like identity. The signs are meant not only as public information, explaining the instruments' purposes (or "Super Powers"); they also encourage visitors to leave important equipment undisturbed. These instruments form the infrastructure of SPLASH, a year-long Study of Precipitation, Lower Atmosphere and Surface for Hydrometeorology, a project of CIRES, NOAA, various universities, federal and state organizations, and industry.

More about the research:

bit.ly/more_SPLASH

Meet more SPLASH Superheros in a visual "StoryMap:"

bit.ly/superheroes_of_SPLASH



Femme de la Flux (aka ASFS)

SUPER POWER: On its own for long periods in faraway places, Femme de la Flux continually measures the energy transferred between Earth and sky.



Photo: Gijs de Boer/CIRES and NOAA

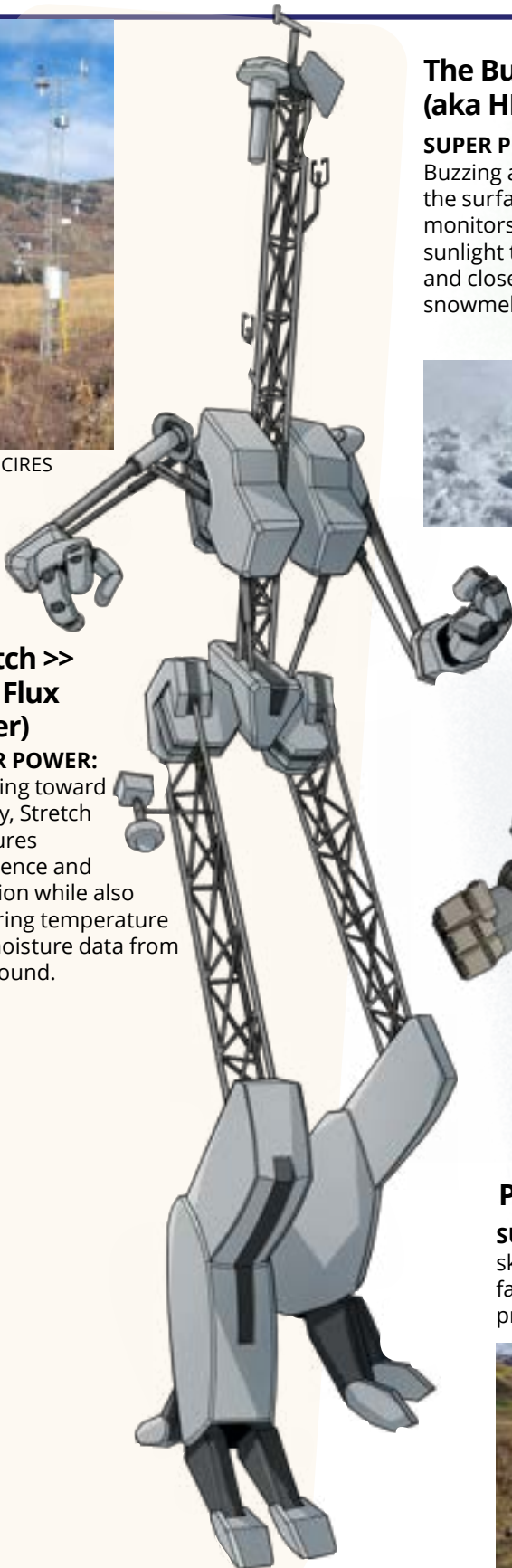
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Photo: CIRES

Stretch >> (aka Flux Tower)

SUPER POWER: Reaching toward the sky, Stretch measures turbulence and radiation while also gathering temperature and moisture data from the ground.



The Buzz >> (aka HELiX)

SUPER POWER: Buzzing along close to the surface, the Buzz monitors how much sunlight the Earth reflects and closely watches snowmelt.



Photo: Gijs de Boer/CIRES and NOAA



Phasor (aka Snow Level Radar)

SUPER POWER: Keeping a steady eye on the sky, Phasor measures where in the atmosphere falling snow turns to rain and how that precipitation contributes to river flow.



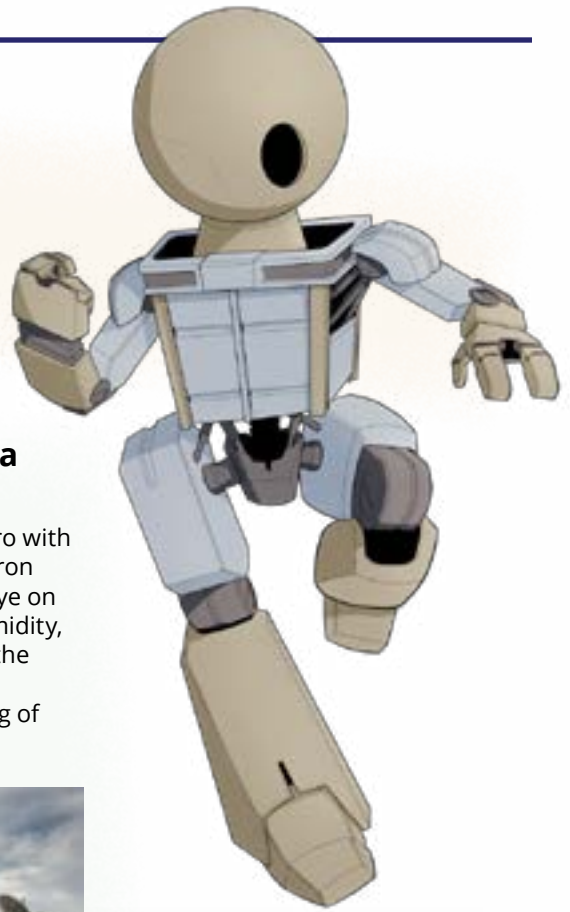
Photo: Dave Costa/CIRES and NOAA



Photo: NOAA

MegaX >> (aka X-Band Radar)

SUPER POWER: The most active member of the team, MegaX focuses its beam skyward to map out where snow and rain are falling across a large area.



<< Multitron (aka CLAMPS)

SUPER POWER: A hero with many sensors, Multitron keeps a continuous eye on the temperature, humidity, clouds, and winds in the lower atmosphere, to improve early warning of impending storms.



Photo: NOAA/NSSL

Winged Wonder >> (aka RAAVEN)

SUPER POWER: Soaring high, Winged Wonder observes the ever-changing atmosphere in any condition, battling turbulence and storms to help improve prediction tools.



Photo: CIRES





Red/blue senators float ideas about Western climate

POLICYMAKERS

CIRES Director **Waleed Abdalati** (not shown) served as the science pro on a September 2021 Colorado River raft trip with Senators Mitt Romney (R-Utah) and Michael Bennet (D-Colorado). Bennet invited Romney, along with farmers, ranchers, business people, members of local governments, and one scientist, to raft together for a day and talk about climate resilience in the two states, and how the West can lead with climate solutions. The bipartisan team floated for more than six hours along the “Moab Daily” section of the river—a slower-than-usual ride because of low water.

bit.ly/director-rafts

Photo: Paige Waltz/Sen. Mitt Romney’s office

SPHERES

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