



COOPERATIVE INSTITUTE FOR RESEARCH IN ENVIRONMENTAL SCIENCES

SPHERES

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Changes in the air

CIRES researchers probe
wildfire smoke, at-risk
infrastructure, dwindling
water resources, more
extreme weather

Building bridges

Indigenous knowledge,
Western science weave together

Students launch into STEM
through RECCS

Center advances dialogue on
environmental futures



Contents

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ACRONYMS

NOAA groups at the David Skaggs Research Center in Boulder, Colorado, include:

GML: Global Monitoring Laboratory

GSL: Global Systems Laboratory

NCEI: National Centers for Environmental Information

PSL: Physical Sciences Laboratory

SWPC: Space Weather Prediction Center

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.

Briefs	4
Annual Updates	6
Satellite loss spurs collaboration	7
COVID research draws attention	8
Sea-level rise depends where you live	8
'The dream of Indigenous scientists'	9
Polar bears get by with less sea ice	9
Drying times ahead	10
Lesson targets megafires	11
Community college to STEM career	13
Fires intensify; so does research	14
C-SEF's goal: Building bridges	16
Humans of C-SEF	17
CIRES expert calls for 'third, ethical space'	18
CIRES People	19
my SPHERE: Ozone	22
In Memoriam	24

At left: A large airtanker drops retardant on the 2022 Eagle Creek Fire near the Bear Paw Mountains in Montana. Photo: Ryan McPherson/BLM

On the cover: A sandstone wall rises into clear blue skies in Canyonlands National Park, Utah. Photo: G. Garrett Campbell/CIRES

SPHERES

by the numbers

21,600

Altmetric score of a *Lancet* paper co-authored by José-Luis Jiménez—highest ever for a CU Boulder paper (PAGE 8).

3,275

properties in Galveston, Texas, could be inundated by sea-level rise by 2100 (PAGE 8).

99

community college students have completed the RECCS program since 2014 (PAGE 13).

50%

more CO₂ was in the atmosphere in 2022-23 than in pre-industrial measurements (PAGE 6).

38

satellites were destroyed by a 'minor' space-weather event in February 2022 (PAGE 7).

20

physicians ran a climate model to learn how changes in climate can have major impacts on human health (PAGE 4).

2

NOAA/CIRES teams won 2022 Colorado Governor's Awards for High-Impact Science (PAGE 20).

1

previously unknown population of polar bears in southeast Greenland can get by with less sea ice (PAGE 9).

CLIMATE

A cardiologist and a climate scientist walk into a lab...

In September 2022, 20 medical doctors from across the United States met with world-class climate scientists from CIRES and NCAR to run a real-world climate model. While carefully punching in high-level programming codes representing specific climate and weather conditions, the physicians learned how minor changes in those variables can have major impacts on long-term climate projections—and human health.

The workshop, intended to expand doctors' understanding of the climate health crisis, was part of the Diploma in Climate Medicine run by the CU Anschutz Climate & Health Program. "Arming medical doctors with authentic knowledge of climate science is crucial for both research and medicine, and for the next generation of health practitioners to recognize the emerging face of climate change in medicine and public health," said **Kris Karnauskas**, CIRES fellow, associate professor of Atmospheric and Oceanic Sciences at CU Boulder, and a faculty instructor in the diploma program.

bit.ly/doctors-model-climate

CIRES scientists go to extremes

With support from NOAA, the American Meteorological Society (AMS) has been releasing annual reports explaining global extreme weather and climate events. CIRES scientists **Xiao-Wei Quan**, **Joel Lisonbee**, and **Amanda Sheffield** contributed a chapter in the BAMS special report, *Explaining Extreme Events from a Climate Perspective*, on precipitation and temperature ex-

Briefs

tremes in California and Nevada. At the AMS annual meeting in January 2023, NOAA Administrator **Rick Spinrad**'s comments on the impacts of billion-dollar disasters were widely quoted in news media.

bit.ly/BAMS-contribution

Potent greenhouse gas declines, confirming success of controls

A 2023 NOAA analysis shows U.S. emissions of the super-potent greenhouse gas sulfur hexafluoride (SF₆) declined between 2007-2018, likely due to mitigation efforts by the Environmental Protection Agency (EPA) and the electric power industry. The work, published in the journal *Atmospheric Chemistry and Physics*, also showed that significant disparities between NOAA's estimates for the gas, based on atmospheric measurements, and EPA's estimates, based on a combination of reported emissions and industrial activity, have narrowed, following the establishment of the EPA's Greenhouse Gas Reporting Program.

"By closely collaborating with the EPA, we were able to identify processes potentially responsible for a significant portion of this difference, highlighting ways to improve emission inventories and suggesting additional emission mitigation opportunities in the future," said lead author **Lei Hu**, a federal re-

searcher in GML who was a CIRES scientist at the time of the study.

The findings also suggest pathways to additional SF₆ emissions reductions.

bit.ly/SF6-decline

AGRICULTURE AND AIR QUALITY

As air pollution drops, fertilizer use rises, sending metals downstream

Regulations to cut air pollution in the 1970s and 1990s reduced the amount of fertilizing sulfur raining down onto crops in the Midwest. To compensate for the loss on farms, manual sulfur application boomed, far outpacing growth in nitrogen and phosphorus fertilizer use, according to **Eve-Lyn Hinckley**, a CIRES fellow, associate professor of Ecology and Evolutionary

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Biology, and lead author of a first-time sulfur fertilizer assessment, included in the December 2022 issue of *Communications Earth & Environment*. Her findings are significant because unfortunately, sulfur can make mercury more likely to make its way into the tissues of downstream fish. “We want to help people use [sulfur fertilizer] smartly and understand what it does in the environment,” said Hinckley.

bit.ly/sulfur-fertilizer

BIOLOGY AND ECOSYSTEMS

When Earth creates a volcanic island, study its microbes quickly

In 2015, a submarine volcano in the South Pacific erupted, forming the Hunga Tonga-Hunga Ha’apai island. A CU Boulder and CIRES-led research team jumped on the rare opportunity to study the early microbial colonizers of the newly formed landmass. “No one had ever comprehensively studied the microorganisms on this type of island system at such an early stage before,” said **Nick Dragone**, lead author of the study published in *mBio* in January 2023 and a Ph.D. student working with CIRES fellow **Noah Fierer**. To their surprise, the researchers discovered a unique microbial community that metabolizes sulfur and atmospheric gases, similar to organisms found in deep sea vents or hot springs. Then in 2022, the volcano erupted again, obliterating the island. “We are of course disappointed that the island is gone, but now we have a lot of predictions about what happens when islands form,” said Dragone.

bit.ly/new-microbes

MACHINE LEARNING

Scientists aim machines on cyclone detection

Too much data can make weather prediction tricky. Satellite observations that provide a high-resolution snapshot of the current atmosphere might improve forecasts, but it’s too expensive, computationally, to bring *all* regional satellite data into forecast models. What if we could use artificial intelligence to help scan those big satellite images for areas where severe weather is spinning up, and give the models more data just from those places? That question motivated CIRES scientists **Kirana Bergstrom**, **Christina Kumler**, and their colleagues in GSL to begin experimenting with machine-learning (ML) techniques and cyclones. They used ML to identify areas with rapidly evolving weather, then asked models to pull in more satellite data from those regions, to see how changes in data density affect forecasts. Eventually, the idea is to improve cyclone forecasts, of course, but the first step was just to make the technique work, Kumler said. Initial results indicate global forecast models are sensitive to these ML-driven changes in forecasting. “We showed [this union of methods] can be done, not that it’s worse or better than before,” she said. The team’s work builds on previous GSL work finding that machine-learning models can identify pre-cyclonic regions missed by other methods.

<https://journals.ametsoc.org/view/journals/apme/59/12/jamc-d-20-0117.1.xml>



The newly erupted cone of Hunga Tonga–Hunga Ha’apai (right) gave researchers an unusual opportunity to study pioneering microbes, before the landmass was destroyed by another eruption. Photo: Dan Slayback/NASA


Paramaterizing pollen for health, weather forecasts

Many of us are all-too-familiar with pollen’s sneeze-inducing power. But plumes of those particles from grasses, flowers, and trees can actually change the weather, too, scattering or absorbing incoming solar radiation and serving as ice nuclei, which can affect cloud formation and the likelihood of rain or snow.

So **Jordan Schnell**, a CIRES Earth system scientist in GSL, and colleagues, including **Allison Steiner** at the University of Michigan, are getting pollen into experimental forecast systems like the RAP-CHEM model, to better forecast the allergen’s movements as well as its influence on weather. Eventually, they hope their

pollen modules will make it into a forecast model like the next-generation Rapid Refresh Forecast System, finely enough resolved to distinguish pine pollen’s impact on Genesee, Colorado, from grass pollen’s movements in Golden, 10 miles away.

Pollen’s impact on weather patterns may be smaller than, say, the impact of a massive smoke plume from a wildfire, Schnell admitted. But averaged over long times and broad areas, it’s possibly a much more significant impact on the Earth System than we currently understand. “Right now, we’re not taking it into account at all,” Schnell said, “So we have no idea what we’re missing.”

 <p>Annual Updates</p> <p>2022 ARCTIC REPORT CARD</p>	<p>CIRES RESEARCHERS CONTRIBUTE TO THESE ASSESSMENTS EVERY YEAR.</p> <p>NOAA’s 2022 Arctic Report Card confirmed that the region continues to warm at an alarming rate, roughly twice the speed of the rest of the globe, with widespread effects including: rising ocean temperatures (at surface and at depth), early snow melt, more frequent extreme weather events and wildfires, seabird die-offs, and open water at the North Pole (with an increase in maritime ship traffic). CIRES’ Matt Druckenmiller and Twila Moon, both scientists with NSIDC, were editors. bit.ly/Arctic_rpt_card_2022</p>
<p>GML’S GLOBAL GREENHOUSE GAS REFERENCE NETWORK</p>	<p>Atmospheric levels of three key greenhouse gases — carbon dioxide, methane, and nitrous oxide — all continued to increase rapidly in 2022, to “uncharted” levels, according to NOAA’s annual assessment, released in April. CIRES scientists working in GML are critical to the tracking effort, which reported global CO₂ levels last year were more than 417 ppm (they were ~280 ppm before the Industrial Revolution). Atmospheric methane levels are now more than 2.6 times pre-industrial levels, and nitrous oxide is up 24 percent. bit.ly/greenhouse-gas-2022</p>
<p>ANTARCTIC SEA ICE EXTENT, FALL MINIMUM</p>	<p>Antarctic sea ice reached its minimum extent for 2023 at 1.79 million square kilometers (691,000 million square miles) on February 21, reaching a new record low in the 45-year satellite record. The downward trend may be a signal that global warming is finally affecting the floating ice around Antarctica, but it will take several more years to be confident of it, according to CIRES’ National Snow and Ice Data Center (NSIDC). bit.ly/antarctic_sea_ice_min_2023</p>
<p>ARCTIC SEA ICE EXTENT, FALL MINIMUM</p>	<p>Arctic sea ice reached its minimum extent for 2022 at 4.67 million square kilometers (1.80 million square miles) on September 18, tying for 10th lowest in the 44-year satellite. bit.ly/sea_ice_min_2023</p>



Starlink satellites fly overhead in Nevada, 2020. A February 2022 Starlink launch saw the loss of 38 satellites; space weather was to blame. Photo: Jeff Sullivan, CC BY-NC-ND 2.0/Flickr

Geomagnetic storm and satellite loss spur collaboration to improve forecasts, services

SPACE WEATHER Small-scale eruptions from the sun’s surface are not generally expected to endanger lives and infrastructure on Earth. But, when a ‘minor’ space-weather event in February 2022 resulted in the loss of 38 SpaceX satellites upon launch, scientists from industry, academia, and government came together to find out why, and to try to prevent expensive damage in the future.

They completed the work in record time: After publishing their findings last fall, the team is already rolling out a forecast tool in NOAA’s Space Weather Prediction Center (SWPC) to help prevent the kind of drag-related losses SpaceX suffered.

To understand what caused the satellites to burn up in Earth’s atmosphere, scientists from SWPC, CIRES/CU Boulder, and SpaceX examined space weather conditions on the day of the launch, using observations, forecasts, and numerical simulations.

What they found, published in AGU’s journal *Space Weather*, was that the geomagnetic storm had created a disturbance in the upper atmosphere that enhanced satellite drag conditions, ultimately pulling the satellites back into Earth’s

Solar Cycle 25: More flares likely

As the Sun approaches solar maximum in 2025 – the peak of its 11-year-solar cycle – the number of solar events will continue to increase, with more solar flares and eruptions, impacting lives and technology on Earth as well as astronauts and satellites in space. bit.ly/41BZagi

atmosphere, preventing them from reaching orbit. “This study demonstrates the benefits that can come from collaborative work between government and industry,” said **Tzu-Wei Fang**, lead author of the study and space scientist at SWPC.

She and her colleagues have adjusted a model called WAM-IPE, and are preparing to release a new neutral density product that can be utilized to better characterize low- and very-low Earth orbit environments. During this year’s Space Weather Workshop, SWPC ran an information-sharing “customer engagement” on the new operational product with a release targeted for the summer of 2023.

bit.ly/neutral-density-product

COVID research defies convention, draws attention

HEALTH

In 2020, a tiny speck of a virus changed the world.

As of March 2023, nearly 7 million people had died from infection by SARS-CoV-2. Without the work of a CIRES aerosol expert and his colleagues, it might have been more. And had health agencies responded more quickly to the scientists' evidence, fewer might have died. In the three years since CIRES Fellow and chemistry professor **José-Luis Jiménez** jumped into researching coronavirus, he and his colleagues have learned:

- ◆ Coronavirus particles flow in the air like smoke.
- ◆ The carbon dioxide level in a room is a good proxy for infection risk; exhaling and speaking release respiratory viruses as well as the gas.

- ◆ Disinfection of surfaces makes little difference for this virus; masking, testing, and ventilation are far more effective at preventing transmission.
- ◆ History matters. Skepticism about “miasmas” or “bad air” may have made global health leaders more reluctant to recognize airborne transmission.

Of note: Many of Jiménez' co-authored papers on the coronavirus are now among the most talked-about papers in the scientific literature. For example, “Ten scientific reasons in support of airborne transmission of SARS-CoV-2” in *The Lancet* earned an Altmetric score (a measure of online attention for an individual research output) of more than 21,500, the highest ever for a CU Boulder paper.

bit.ly/10-reasons-airborne

Proportions of homes potentially inundated in 2100

Housing type, topography, and local variations in projected sea level rise all play a role



Atlantic City, NJ
(~3,146 properties
out of ~35,000)



Miami, FL
(~588 properties
out of ~330,000)



Galveston, TX
(~3,275 properties
out of ~21,000)

Total homes studied
Inundated homes



Newport-San Pedro, CA
(~2,493 properties
out of ~204,000)

Will sea-level rise get you down? It depends...

CLIMATE

Rising seas have already claimed some homes along

U.S. coasts, and given that about 40 percent of the U.S. population lives on coasts, it is important to know how coastal homes will fare in the future.

Turns out, it matters where you live.

In one recent assessment, researchers at the Federal Reserve Bank of Kansas City, CIRES, and NOAA's National Centers for Environmental Information used data on housing, topography, tides, and elevation to project how many homes might be affected by sea-level rise in four metro areas. Galveston emerges as a higher risk for inundation, due in part to expected higher

sea-level rise (1.04 m by 2100 in a mid-range scenario) and topography. Newport-San Pedro, by contrast, sees “only” 0.54 m of sea-level rise by 2100, and a steep elevation gradient moving inland from low-lying beaches to higher-elevation neighborhoods protects some homes from rising waters.

“Our risk-matching methods could be used by other researchers and practitioners to assess risk in other coastal markets (e.g., commercial real estate) or for various housing strata and populations (e.g., owner-occupied vs. renters),” the authors concluded. They published their findings in the journal *Environmental Systems and Decisions*.

bit.ly/SLRthreats

EDSC: ‘The dream of Indigenous scientists’

BIG DATA

The NSF-funded Earth Data Science Corps (EDSC) program has helped build a next-generation big-data workforce that’s more diverse than yesterday’s, by engaging Earth science data interns from Tribal colleges and schools serving historically underrepresented groups. Last year’s participants used data-science skills training and project-based learning to direct powerful Earth data analytics on questions that matter to their communities.

Celeste Terry, an enrolled member of the Oglala Sioux Tribe and a junior at Metropolitan State University of Denver, had extensive coding experience already but had never used many of the analytical techniques she learned through EDSC. “To then apply what we had learned to address varying unmapped geological challenges facing our tribal communities and actually have the tools to accomplish that...was really amazing,” she said.

“This is the dream of Indigenous scientists,” said **Elisha Yellow Thunder**, a third-year participant in EDSC and graduate student at South Dakota State University: “It’s to take this kind of result to our Elders and be able to say ‘Look what we did. Where do you want us to take this now?’”

CIRES/Earth Lab scientist **Nathan Quarder** co-led the EDSC program, including analysis of student skill sets and mindsets before and after. He cited “significant growth in participants’ Python and data science skills, as well as their science identity and sense of belonging to a larger community of scientists... It’s been really inspiring to see how far they are able to come in a short amount of time.”

In spring 2023, EDSC will continue under a new banner through the ESIIL Stars program, esiil.org/esiil-stars.

bit.ly/EDSC-2023



A newly discovered polar bear population on the southeast coast of Greenland uses glacier ice to survive despite limited access to sea ice. Photo: Thomas Johansen/NASA

Meet the polar bears getting by with less sea ice

CRYOSPHERE

Can polar bears survive with limited access to sea ice? Some can, under the right circumstances. In 2022, a team of scientists, which included NSIDC’s **Twila Moon**, described in *Science* a previously unknown subpopulation of polar bears living in southeast Greenland. While polar bears generally rely on sea ice as a platform to hunt seals, these polar bears have access to sea ice for less than four months of the year; for the other eight-plus months, they hunt from chunks of freshwater ice that break off Greenland’s glaciers into the ocean.

“The marine-terminating glaciers in Southeast Greenland are a fairly unique environment,” said Moon. “These types of glaciers do exist in other places in the Arctic, but the combination of the fjord shapes, the high production of glacier ice, and the very big reservoir of ice that is available from the Greenland Ice Sheet are what currently provides a steady supply of glacier ice.”

The fact that bears can survive here suggests that fjords with marine-terminating glaciers could be small-scale climate refugia—places where some polar bears could survive as sea ice on the ocean’s surface declines.

bit.ly/greenland-bears



Comparing 2019 to 2021: Lake Shasta

California's Lake Shasta in 2019 (left) and 2021 (right) reveals tan "bathtub rings" as its water level dropped to 49 percent of its historical average. Hot and dry summers have led to groundwater depletion, and recent rains have not been enough to reverse drying trends. Photos: NASA Earth Observatory

Drying times ahead

Fast-evolving droughts, shifting atmospheric rivers portend water challenges

HYDROLOGY

We generally think of drought as the slow-moving sloth of environmental processes, but fast-evolving drying events are becoming more common, according to recent research led by USGS' North Central Climate Adaptation Science Center, hosted at Earth Lab in CIRES.

That recent work by **Virginia Iglesias, William Travis**, and **Jennifer Balch**, published in *Weather and Climate Extremes* shows, "that fast droughts have been speeding up in the last few decades and now set in faster than the most rapidly-developing droughts of the last 70 years." Shifts in temperature and precipitation are key drivers of so-called 'flash' droughts, as are atmosphere-ocean interactions like El Niño.

Scientists with CIRES and NOAA have been

leading efforts to define flash drought, and to develop tools and strategies to monitor and mitigate it. NOAA's National Integrated Drought Information System hosted the 2nd National Flash Drought Workshop, May 2-4, 2023 in Boulder, Colorado, to discuss the state of the science, resources, and tools related to flash drought.

Intense droughts adversely affect soil erosion and soil nutrient cycling, the probability of fire, air quality, and the availability of water for agricultural and urban areas, and fast-drying events are now challenging forecasting, warning, and response capabilities like never before.

As the planet warms, more quick-onset droughts are likely, according to Travis: "Faster droughts are not necessarily more intense events, but with a warmer atmosphere drying out the soil more quickly, future droughts are likely to set in faster and become more intense."

Fast droughts aren't the only climate flip-flop being revealed by researchers. Other recent work

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Students, teachers ‘puzzle out’ the story behind megafires

‘An opportunity to connect students to the phenomena and inspire them to identify mitigation strategies’

EDUCATION & OUTREACH

Wildland fires are becoming bigger and more frequent in the United States, impacting more people and communities than ever before. After a devastating 2020 Colorado wildfire season, which included the three largest-recorded fires in state history, educators from CIRES and CU Boulder collaborated with teachers and former CIRES scientist and fire ecology expert **Natasha Stavros** to develop an innovative lesson that addresses the science behind large, destructive fires. Now, this “Data Puzzle” is helping students across the country dive deeper into the causes and patterns associated with megafires in the western United States.

“We want to bring contemporary science stories into classrooms,” said **Jon Griffith**, a CIRES Education and Outreach associate and co-creator of Data Puzzles. “Megafires have been in the news a lot, and we saw an opportunity to connect students to the phenomena and inspire them to identify mitigation strategies.”

Produced by CIRES Education & Outreach, Data Puzzles combine classroom-friendly scientific datasets and NSF’s Ambitious Science Teaching instructional frame-

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A mule deer watches educators participating in a fire ecology workshop as they set up a transect to measure the post-fire plant regeneration in the East Troublesome Fire burn area near Rocky Mountain National Park. Photo: Jon Griffith/CIRES

Data Puzzles

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work, which leverages students' existing knowledge and encourages ongoing changes in thinking.

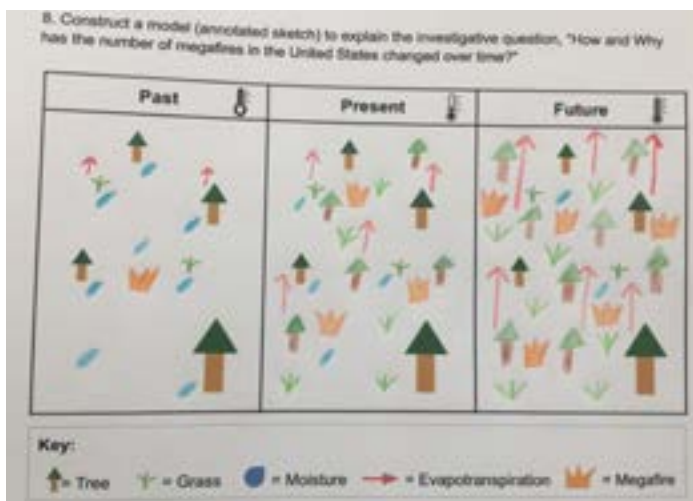
"[Ambitious Science Teaching] is a framework for organizing the complex work that science teachers do daily, weekly, monthly, and annually to support science learning experiences that are deeply connected to young people's questions, ideas, and interests," said **Melissa Braaten**, assistant professor of Education at CU Boulder and Ambitious Science Teaching coauthor.

Each Data Puzzle peels back the layers of a different environmental concept—from warming in the Arctic to drought in the Colorado River Basin. In communities that have experienced or are at risk for wildfires, the megafire lesson provides an opportunity for teachers and students to engage with data relevant to their daily lives.

"I was very excited to be able to work with authentic data around the topic of wildfires, as they have had a profound impact in my region and my community, including students," said Sandy Smith, a science teacher at Falcon Home-school Academic Program in Colorado Springs. Smith was one of the three teachers who helped develop and test the megafires lesson in their classrooms.

To develop the megafires Data Puzzle, the CIRES and CU Boulder education team and the three teachers joined forces with Stavros, who guided the team as they explored potential options for a wildfire-focused lesson plan and provided the data for the team's final selection—megafire frequency over time.

"I really liked knowing that my science could help shape how the next generation thinks about climate and wildfire," Stavros said. "It was fun to think about how to boil down the complexity of the topic into something that students... could understand."



Data Puzzle participants used a worksheet to illustrate the way rising temperatures affect moisture, vegetation, and megafires.

The megafires Data Puzzle asks, "How and why has the number of megafires changed over time?" and challenges students to organize new information and evidence into an explanatory model addressing the question. To create their model, students read background information, participate in discussions, and complete activities using the megafire dataset.

"My middle school Earth science students were fascinated by the topic," Smith said. "They had to come up with a model and revise that model. It was challenging, but ultimately very satisfying when they found that they could do it."

Materials for the megafires Data Puzzle, including a teacher guide, slide deck, and student worksheet, are free and available online. In summer 2023, Griffith will lead a free teacher workshop about the megafires lesson. And soon, a new virtual reality tour of burn areas in Rocky Mountain National Park will take students "into the field" and help guide them through the lesson exploring impacts of wildfire on the environment.

"My hope is that Data Puzzle resources inspire curiosity and hope in students and that the framework acts as a road map for teachers and scientists to help students make sense of exciting science phenomena," said Griffith.

bit.ly/data-puzzle-megafire



Community college alums forge careers in STEM after RECCS

EDUCATION & OUTREACH

Nearly every summer since 2014, community college students have plunged into research in offices, labs, and field sites in and around Boulder, Colorado, through the Research Experience for Community College Students (RECCS) program. Now, former RECCS students are using the skills they gained during the nine-week program to forge their own paths in STEM (Science, Technology, Engineering, and Math).

“RECCS was essential to my current career,” said **Marianne Davenport**, a 2015 RECCS student from the Community College of Denver who now works for the Forest Health Protection program at the U.S. Forest Service (USFS). “It showed me that research was something that I could do and opened my mind to exploring graduate school.”

Led by the CIRES Education & Outreach program and funded by CIRES and the National Science Foundation, RECCS pairs community college students from Colorado and neighboring states with scientists from CIRES, CU Boulder, and NOAA for an authentic research experience in environmental or Earth science. During the program, students learn research, writing, and communication skills, enabling them to build the confidence to transition to a four-year program in the STEM disciplines. For some students, RECCS is the spark that launches their professions.

“The networking during RECCS played a great role in my career,” said Davenport. “My RECCS mentor was at USGS at the time and introduced me to the group I currently work with.”

Davenport returned to school after 15 years working in banking, finance, and healthcare, with plans to go into physical therapy. After RECCS, she changed paths and transferred to the University

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2015 RECCS intern Marianne Davenport conducts field work at Golden Gate Canyon State Park, Colorado. Photo: Marianne Davenport

W I L D F I R E



The 2022 Hog Butte Fire in southwest Alaska burned 40,000 acres. Photo: Ryan McPherson/BLM

Fires intensify; so does research

Where it happens, how it behaves, how to mitigate its effects

Fires spread less in areas where Indigenous practices were in play

On the Navajo Nation in northern Arizona, CIRES researcher **Chris Guiterman** fired up a chainsaw to cut a cross-section from a fire-scarred ponderosa pine stump. He was looking for tree rings offering clues to past moisture, drought, and fire. By studying a network of nearly 5,000 trees in the Southwest, Guiterman and

his colleagues discovered a typical climate-fire pattern from 1500 to 1900 when rainfall and drought took turns fueling growth and fire. But where the Apache, Navajo, and Jemez did traditional burning to clear the underbrush of grasses, small trees, and shrubs, their actions limited fire spread. The findings suggest that emulating that frequent burning on a larger scale could blunt the role of climate in triggering wildfires today,

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which are damaging homes, infrastructure, water sources, and air quality—and risking lives.

Over the past year, wildfire research by Guiterman and CIRES scientists has deepened understanding of how humans and climate change impact wildfires, and how destructive those impacts are becoming—and what we need to do about it.

bit.ly/wildfire-buffer

What wildfire does to the air

CIRES scientists working in NOAA laboratories **Owen Cooper** and **Elisabeth Andrews** led and contributed to the World Meteorological Organization's *Air Quality and Climate Bulletin No. 2*, an annual report focused on the global distribution of particulate matter, highlighting the health impacts of smoke from extreme wildfires globally. They found that hot, dry conditions fed particularly intense wildfires across western North America in 2021, causing widespread increases in particulate pollution that exceeded World Health Organization air quality guidelines; 2021 ranked among the top five years in total annual emissions since 2003.

To better protect community health and safety from the impacts of wildfire and prescribed burns, a module within NOAA's High-Resolution Rapid Refresh (HRRR) short-term weather model has successfully predicted the transport of wildfire smoke and the smoke's impact on visibility and weather over the United States.

Ravan Ahmadov, a CIRES scientist in NOAA's GSL who helped lead the development of HRRR-Smoke, said that future validation and model improvements should boost accuracy of smoke movement and concentration.

In other air news, a team of atmospheric scientists, including researchers from CIRES and NOAA, demonstrated that big, vertical plumes of smoke generated by large wildfires contribute as much as a quarter of the black carbon and organic aerosol in the lower stratosphere and have a major long-term impact on climate.

That air pollution may be intensifying because wildfires have gotten larger, more frequent, and more widespread across the U.S. since

2000, according to another CIRES-led paper.

Virginia Iglesias, an Earth Lab scientist, and colleagues analyzed data from over 28,000 fires that burned between 1984 and 2018. The results, which confirmed a suspected and worrisome shift in fire dynamics, show a trend that is challenging fire-suppression efforts and threatening lives, health, and homes in their path.

bit.ly/wildfire-risingheat

bit.ly/wildfire-forecast-win

bit.ly/persistent-plume

bit.ly/wildfire-frequency

Infrastructure in harm's way

The scope of that destruction is becoming evident, in part, through the work of several Earth Lab scientists in research led by **Philip Higuera**, a fire ecologist and professor at the University of Montana, during a sabbatical at CIRES. Their analysis also showed that, across the West, fire destruction per acre has nearly tripled—from 1.3 structures destroyed per 1,000 hectares burned between 1999 and 2009 to 3.4 from 2010 to 2020. They found people were mainly to blame for wildland fires that destroyed structures, igniting 76 percent. Along with reducing those accidental ignitions, rethinking how we build in fire-prone areas is key to preventing future disasters.

That pattern of destruction, and cost to humans, builds upon the past work of CIRES fellows **Jennifer Balch** and **Ben Livneh**. Balch's 2022 paper with colleagues showed that nighttime fires have become more intense in recent decades as hot, dry nights are becoming more commonplace, a trend they expect will continue to increase the intensity, speed and duration of fires. Livneh, director of the Western Water Assessment, recently co-authored a paper that examined streamflow and climate data for 179 river basins and found that large fires tended to be followed by larger increases in streamflow which may increase flood risk, while his ongoing work shows that post-fire runoff pollutes rivers and streams with debris and contaminants.

bit.ly/wildfire-burns-more-homes

bit.ly/hotter-nights-more-fires



C-SEF Director Matt Burgess looks on as former U.S. Rep. Claudine Schneider converses with participants at a C-SEF “Get Serious” seminar. In Congress, Schneider sponsored the Global Warming Prevention Act of 1989, and earned a reputation as one of the House’s strongest environmental advocates. The seminar focused on her insights into how to bring people together over climate issues. Photo: CIRES

C-SEF’s goal: Building bridges

Center aims to catalyze clear thinking on environmental futures

In a rapidly changing world, humans are facing a growing number of environmental challenges, including rising temperatures, dwindling water resources, and more extreme weather events. CIRES’ new Center for Social and Environmental Futures (C-SEF) is bringing social and environmental sciences together to better understand how these challenges will impact people and communities, and to help inform solutions.

“One of our goals is to connect researchers studying the human dimensions of environmental problems to each other and to natural scientists,” said **Matthew Burgess**, CIRES fellow, assistant professor of Environmental Studies, and director of C-SEF.

Research at C-SEF focuses on the intersection of humans and the environment, in the near future on a local scale (the ‘here and now’) and in the long-term on a more global scale (the ‘big picture’). The work will help scientists

examine how development trends—such as economic growth, geopolitics, and migration patterns—will be impacted by climate change, and how communities, businesses, governments, and stakeholders can work together to build resilience and solve problems related to today’s environmental challenges.

“People are at the center of developing effective solutions to climate change and other environmental issues,” said **Lisa Dilling**, a CIRES fellow, professor of Environmental Studies, and core faculty member of C-SEF. “One of our goals is to ensure that social science helps inform solutions to solve the critical and urgent environmental issues of our time.”

C-SEF is led by Burgess and supported by Dilling and three other core faculty: **Max Boykoff**, a CIRES fellow and professor and chair of Environmental Studies; **Kris Karnauskas**, a CIRES

CONTINUED ON PAGE 21

Humans of C-SEF

Kath Landgren, Postdoctoral Visiting Fellow



At C-SEF, Landgren is using mathematical models to study public support for climate policy. She is passionate about multidisciplinary research that brings together mathematicians and scientists to solve problems. When she

needs a break from work, you can find her in the gym, weightlifting. And one day, she hopes to travel across Eurasia by train.



Flores (left) and family in Glacier National Park

Alexandra Flores, 2022 C-SEF Summer Fellow

During her time with C-SEF, Flores studied barriers to bipartisan cooperation on climate change, focusing on the role of political polarization. She will complete her Ph.D. in psychology and neuroscience at CU Boulder this summer. In her free time, Flores likes to hike and camp with her husband, and they added recently another adventurer to their family—a baby girl born in March 2023. In fall 2023, Flores will start as an assistant professor of Psychology at Williams College in Massachusetts.



Dancer (right) and friends at a 'murder mystery' event

Ashley Dancer, PhD Student in Environmental Studies

Ashley Dancer currently studies trends in environmental impacts and economic growth. This summer, she will dig into research on political polarization and climate change. Dancer has a varied background—from real estate and land-use policy to meteorology—and was a U.S. Air Force weather officer for five years. When she was a kid, she wanted to be a Siberian tiger, and when she realized she couldn't, she decided to pursue a career that nurtured her love of nature and the natural world.

Audrey Gaudel, Research Scientist II



Audrey Gaudel's C-SEF work focuses on environmental justice. Gaudel, a C-SEF fellow who has been with CIRES for eight years, is analyzing PM_{2.5} (particulate matter) and carbon monoxide data collected by migrant

firefighters battling wildfires in the western U.S. Her other work with NOAA CSL focuses on tropospheric ozone. Gaudel grew up in Paris, France. When she's not doing science, she is passionate about the performing arts.

CIRES expert calls for ‘third, ethical space’ to weave Indigenous knowledge, Western science

There is opportunity and urgency in bringing together Indigenous knowledge and Western science, where different perspectives can be shared



Rattling Leaf

and climate challenges can be addressed more effectively, says **James Rattling Leaf**, CIRES research associate, and tribal engagement specialist at the North Central Climate Adaptation Center.

A citizen of the Rosebud Sioux Tribe, Rattling Leaf has long worked to create a “third, ethical space” where, he says,

“Western science and traditional people can come together to share knowledge and understanding, and work together on things that are important to our society.”

Rattling Leaf, who is also the tribal liaison for the CIRES Environmental Data Science Innovation & Inclusion Lab (ESIIL), co-authored an article in *Nature Climate Change* this spring, calling for the co-production of knowledge for climate science. The piece emphasized that the two different understandings of the world can complement one another and, together, can help humanity respond to the ongoing climate crisis. But for that third space to thrive, we must have “structured and unbiased funding mechanisms that value knowledge co-production,” say the authors.

Rattling Leaf, who describes himself as a “bridge builder” was also a delegate at the UN 2023 Water Conference in New York, and a participant in two recent White House events focused on climate action. The White House events came on the heels of a historic release, by the Biden-Harris Administration, of government-wide guidance on recognizing and including Indigenous knowledge in federal research, policy, and decision-making.

“We need these robust processes of recognizing and respecting both ways of knowing,” says Rattling Leaf. “We have to understand that traditional knowledge is not Western science, it’s different, yet they can still work together to solve problems.”

<https://www.nature.com/articles/s41558-023-01633-4>

CIRES scientists speak up at Utah legislature, U.S. Senate, in White House report



Womack

After CIRES’

Carrie Womack et al. (CSL) linked halogen emissions from a magnesium refinery to Salt Lake City’s wintertime air pollution, Utah’s legislature took up the issue. Womack and others testified

about the research in early 2023 and, in March, lawmakers passed a bill requiring the Division of Air Quality to track regional halogen emissions and report back to the legislature by the end of 2024.

CIRES Director **Waleed Abdalati** testified before the U.S. Senate Subcommittee on Space and Science in December 2022, about Landsat and the future of U.S. satellite-based Earth observations. “The view from space ... provides a context, scale, and perspective of change critical to predicting weather, managing hazards, meeting the challenges of climate change, and so much more,” Abdalati said during the subcommittee hearing, convened by Sen. John Hickenlooper (D-CO).

President Biden’s 2023 *Economic Report of the President* cited 2021 work by **Virginia Iglesias** and her Earth Lab colleagues. The report noted that rising costs from extreme weather (such as wildfire) are driven by both changing climate and development in risky areas.

New Fellow Hinckley connects ecosystem, agricultural science to real-world solutions



Hinckley

In 2022, CIRES welcomed a new member to the Council of Fellows—ecosystem biogeochemist **Eve-Lyn Hinckley**, associate professor of Ecology and Evolutionary Biology at CU Boulder. Hinckley’s research explores how humans fundamentally change biogeochemical and water cycles, with an emphasis on pesticide and fertilizer use in agriculture.

Her work spans multiple sectors—from taking detailed measurements in the field and lab to collaborating with farmers and policymakers to inspire meaningful regulatory change. “Throughout my career, I’ve been motivated to work directly with decision-makers, from local to state level and beyond—taking my science out of the lab to speak with land managers, farmers, state regulators, and policymakers,” Hinckley said. When she’s not doing research or teaching, you’ll find Hinckley spending time with her family or hiking along Colorado’s Front Range.

bit.ly/hinckley-CIRES
bit.ly/hinckley-CUBoulder

WWA’s Liz Payton is water chapter lead for Fifth National Climate Assessment



Payton

Across the nation, floods, droughts, heatwaves, wildfires, sea level rise, and other hazards are being amplified by climate change. To understand these changes, Congress mandates that the U.S. Global Change Research Program prepare and submit a *National Climate Assessment* (NCA) every four years. The Fifth NCA (NCA5) is currently in development. Its 32 chapters will cover climate

trends and projections for the coming decades and their implications for the nation, with topics ranging from energy to ecosystems. In 2021, Western Water Assessment’s **Liz Payton** was appointed to lead the water chapter. In this role, she has been responsible for selecting and managing an author team, chapter development and writing, and ensuring that the narrative is clear, accurate, and accessible to a broad audience. The NCA5 will be released in late 2023.

CONTINUED ON PAGE 20



Dryak

Mariama Dryak: Dynamo behind center for early career polar scientists

As Earth’s poles are transforming, amid Arctic warming, sea ice melting, and glaciers rapidly retreating, the Polar Science Early Career Community Office (PSECCO) is building a community of U.S.-based early-career polar scientists. NSF-funded PSECCO is housed in the CIRES Education & Outreach program and INSTAAR, another institute at CU Boulder.

“We want PSECCO to be a hub for resources, opportunities, and funding for early career researchers to support their work in making the polar sciences a more accessible, safe, and inclusive space,” said PSECCO Director **Mariama Dryak**. Since February 2022, Dryak has been putting those goals to work—she’s grown PSECCO’s online community, amassing nearly 1,000 followers on Twitter and 255 on Slack; she’s organized 24 community-building, learning, and professional development events; and she’s helped distribute \$17,670 in funding to early career polar researchers for conference travel and for belonging, accessibility, justice, equity, diversity, and inclusion work.

bit.ly/Dryak-leadership
<https://psecco.org/>

CIRES People

CONTINUED FROM PAGE 19

CIRES, partners win statewide awards for high-impact research

CIRES, CU Boulder, and NOAA researchers contributed to two projects which earned 2022 Governor’s Awards for High-Impact Research by CO-LABS, a Colorado organization supporting federal research. One award was in the “Path-finding Partnership” category for rapid-response science in service to communities after the Marshall Fire; and another in the “Technology Transfer” category for a breakthrough space weather model that serves several economic sectors with better impact forecasts.

“These two award-winning teams exemplify the best of the CU Boulder and NOAA collaboration,” said Vice Chancellor for Research and Innovation and Dean of the Institutes **Massimo Ruzzene**. “This high-impact work could not have happened without all contributors: federal, university, and other key experts.”

CO-LABS is a non-profit organization that supports the state’s federally funded research centers and runs an annual competition to highlight some of Colorado’s most high-impact science. The organization hosted the award ceremony on December 14, 2022 at the Denver Museum of Nature & Science.

Abdalati serves NASA, CIRES

In February 2022, NASA appointed CIRES Director **Waleed Abdalati** to the NASA Advisory Council (NAC). NAC members advise and make recommendations about important agency programs and topics to the NASA Administrator. And in June 2022, CU Boulder appointed Abdalati to a third, four-year term as CIRES director, following a vote by the CIRES Council of Fellows recommending that action. “Waleed has guided CIRES to achieve an outstanding national and international reputation through a rare combination of vision, leadership, and an acute sensitivity to community and societal needs,” said Ruzzene.

Community college students forge careers in science after RECCS

CONTINUED FROM PAGE 13

of Colorado Denver (UCD), where she earned a bachelor’s degree in biology. She also continued her RECCS research as an intern with the USGS, studying the mountain pine beetle epidemic in ponderosa pine forests along Colorado’s Front Range. And Davenport didn’t stop there—she completed a master’s degree at UCD, studying bark beetles while doing seasonal work for the U.S. Forest Service. Then in 2021, she moved into a full-time position with the USFS.

While Davenport was in the field during the 2015 RECCS program, another community college student was in a lab nearby, planting the seeds that would sprout into her career in STEM.

“Honestly, I was very nervous when I applied for [the RECCS] internship... [I went] back to school for a better degree in America when I was 28 years old, so I never thought I would do anything related to science,” said



Vanderburgh

Caihong Vanderburgh, whose RECCS project dug into soil microbes. “The RECCS program gave me a lot more confidence in myself.”

Vanderburgh went on to graduate *summa cum laude* from Metropolitan State University with a bachelor’s in biology. Now, she’s a research associate in the Fierer Lab at CIRES—the very same place that helped ignite her own science journey nearly eight years ago.

“The students who participate in the RECCS program have different backgrounds and experiences, but they are united in their excitement about research and their eagerness to learn,” said **Alicia Christensen**, the RECCS program manager at CIRES Education and Outreach.

Since its inception, RECCS has served 99 students. In May 2023, another 15 community college students will embark upon STEM journeys at CIRES, CU Boulder, and NOAA—studying the oceans, the atmosphere, and beyond.

bit.ly/RECCS-alums

Building bridges

CONTINUED FROM PAGE 16

fellow and associate professor of Atmospheric and Oceanic Sciences; and **Kathryn Wendell**, executive director of the Center for Ethics and Social Responsibility in the Leeds School of Business. The central team, whose members also guided the development of the center, serve as the center’s primary governing body, overseeing its research, education, and outreach activities.

Jennifer Katzung, C-SEF’s office manager, keeps the team organized and helps plan and promote events.

Research fellows and graduate research assistants also play a pivotal role in advancing C-SEF’s goals. In 2022, six fellows— **Ashley Dancer, Alex Flores, Audrey Gaudel, Sara**

Hoose, Ekaterina Landgren, and Heather Yocum—worked on projects related to climate policy, economic growth, bipartisan cooperation, and more.

“My hope for C-SEF is that we will be a catalyst for creativity, collaboration, clear thinking, and pragmatism in addressing environmental problems, and that we will build bridges across academic disciplines and sectors of society,” said Burgess.

Since opening its doors in 2022, C-SEF has hosted 10 events, including the Social Science and Sustainability Technology workshop in October 2022 and the Bipartisan Youth Climate Advocacy Panel at the UN Right Here, Right Now Conference in December 2022.

cires.colorado.edu/content/center-social-and-environmental-futures-c-sef

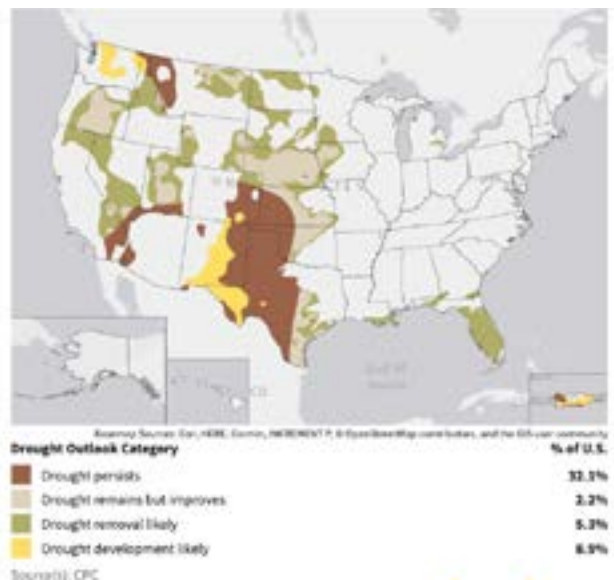
Drying times ahead

CONTINUED FROM PAGE 10

examined how rainmaking ‘atmospheric rivers’ may also shift in the future. Atmospheric rivers are named for their long, sinuous flows of air that carry huge amounts of water vapor. As a key feature of the global water cycle, they can be a blessing or curse, boosting snowpack in mountain areas, which feeds rivers and reservoirs, or dumping too much rain at once, causing dangerous flooding.

A NOAA-led study, with input from CIRES researchers, used regional climate model data to show how climate change will likely shift the frequency and intensity of atmospheric rivers in the western United States. “What this study found is that the extreme events are getting more extreme and potentially happening more often, and the moderate ones are happening less frequently,” said **Mimi Hughes**, a federal research scientist in NOAA’s Physical Sciences Laboratory and lead author of the paper in *Climate Dynamics* (co-authored by CIRES scientists **Dustin Swales** and **James Scott**).

Precipitation from atmospheric rivers is critical to residents, ecosystems, and economies in California, Washington, and Oregon, and the researchers’ investigation shows it shifting in ways



NOAA's three-month drought outlook from March 2023

that will make managing that resource more difficult in the future. For example, wet seasons in California, which account for more than 50 percent of the state’s annual precipitation, will likely be shorter, more variable, and more volatile. Meanwhile, many mountainous regions of the western United States could experience decreased cool season total precipitation.

bit.ly/faster-droughts
bit.ly/atmo-rivers-drying



OZONE

For better and for worse

EARTH'S PROTECTIVE LAYER

With support from CIRES experts, NOAA tracks and studies the health of Earth's protective ozone layer—ozone molecules which, high in the stratosphere, absorb the Sun's ultraviolet rays and shield biological systems on Earth from harmful radiation. In 1989, the nations of the world agreed to protect Earth's ozone layer, which had been degraded by ozone-depleting chemicals. With declining emissions of those chemicals, overall, there's tantalizing evidence that the ozone layer is recovering—a rare, **good-news environmental trend**. There are more reasons to get to know this part of the atmosphere better; scientists are still discovering how human activities can impact it.

GENEVA, SWITZERLAND

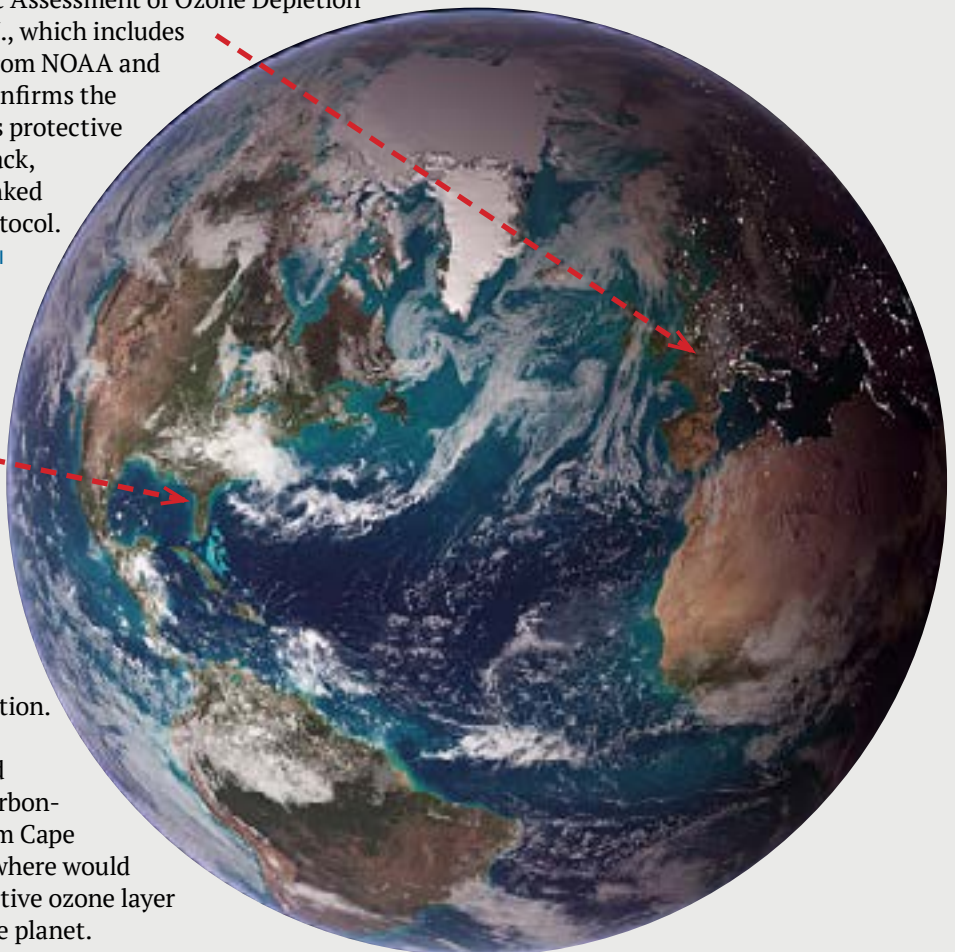
The "2022 Scientific Assessment of Ozone Depletion" report from the U.N., which includes key contributions from NOAA and CIRES scientists, confirms the **recovery** of Earth's protective ozone layer is on track, thanks to efforts linked to the Montreal Protocol.

bit.ly/Montreal_protocol_emerges

CAPE CANAVERAL, FLORIDA, US

Projected growth in rocket launches for space tourism, moon landings, and perhaps travel to Mars has many dreaming of a new era of space exploration. But CIRES-led work shows that a tenfold increase in hydrocarbon-fueled launches from Cape Canaveral and elsewhere would **damage** the protective ozone layer on our one habitable planet.

bit.ly/space-travel-ozone



ASIA

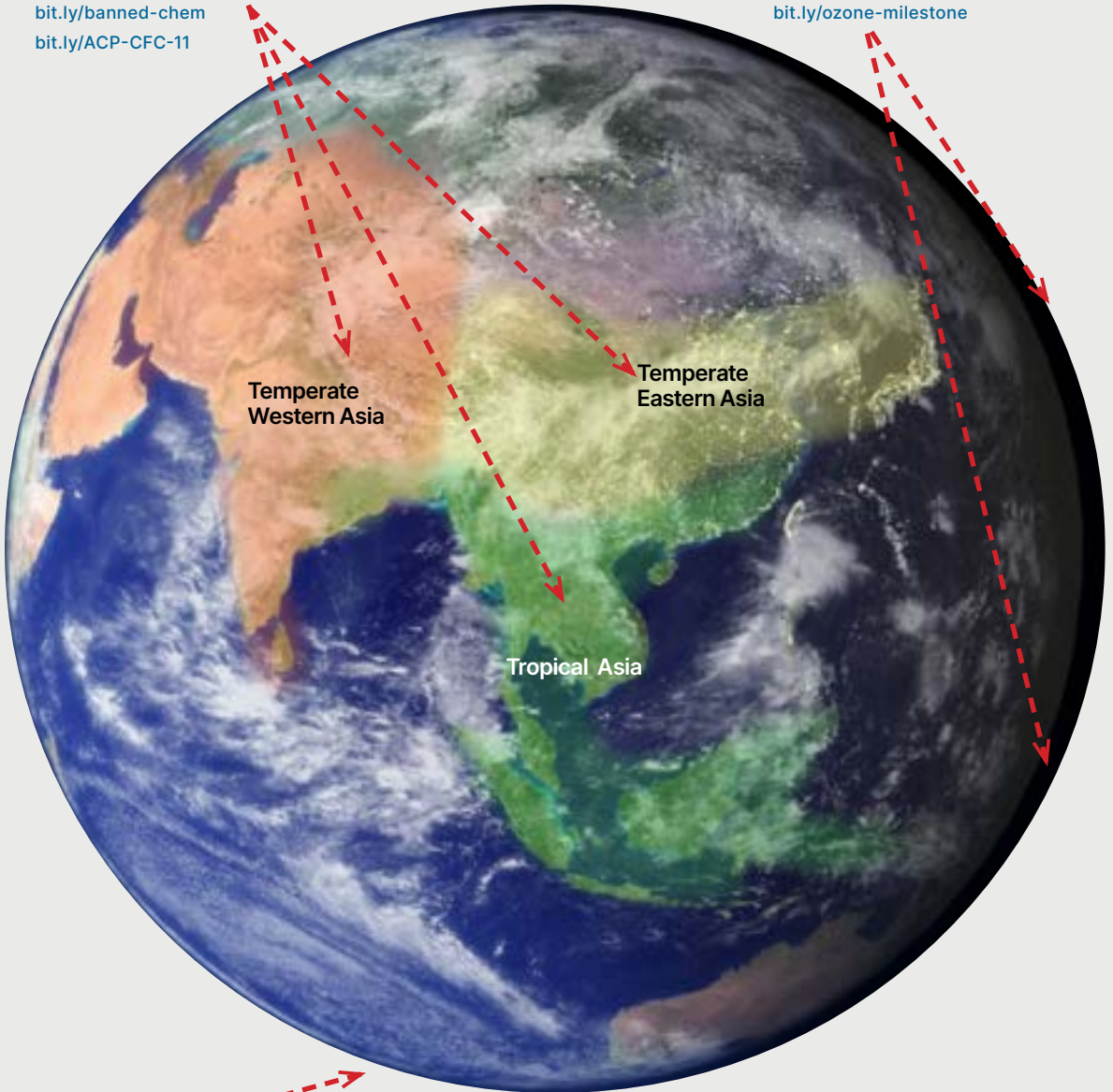
Human activities in three regions of Asia—eastern China, temperate western Asia, and tropical Asia—were responsible for a sudden increase in emissions of the ozone-destroying chemical CFC-11 between 2010 and 2018, according to CIRES and NOAA investigations. After NOAA and CIRES researchers reported the surprising increase of CFC-11 in 2018, emissions of the chemical **declined quickly**.

bit.ly/banned-chem
bit.ly/ACP-CFC-11

MID-LATITUDE STRATOSPHERE

In early 2022, the overall concentration of ozone-depleting substances in the mid-latitude stratosphere returned to levels not observed since 1980, before ozone depletion had become significant. NOAA made the announcement based on an annual assessment by federal and CIRES scientists

bit.ly/ozone-milestone



ANTARCTICA

In 2022, the ozone hole over Antarctica had an average area of 8.91 million square miles (23.2 million square kilometers), slightly smaller than in 2021 and well below the average seen in

2006 when the size of the hole peaked. CIRES researchers at NOAA are critical to the agency's efforts to understand the South Pole's seasonal ozone hole and to anticipate its future.

bit.ly/Antarctic-ozone-hole-2022



Greenland names glacier honoring former CIRES director Koni Steffen

A marine-terminating, Greenlandic glacier in the north of the island was named “Sermeq **Konrad Steffen**,” for the prominent researcher who was CIRES director from 2005-2012. The committed glaciologist—“Koni” to his friends—died in a tragic accident in 2020 while doing fieldwork in west Greenland. The naming is a significant cultural honor in recognition of his major contributions to Greenlandic science and society. It marks the first time in decades that official Greenlandic maps have named glaciers after non-native people (two other researchers were also recognized). Steffen had dedicated 40 years of his working life to research on climate change, notably in the Arctic and Antarctic, and established a series of weather stations on the Greenland Ice Sheet that continue to deliver data to this day. He also documented air temperature and melt rate increases used by research groups globally to make significant discoveries. bit.ly/Koni-glacier

Professor of Geological Sciences Peter Molnar

“What is the most important question?” is the approach renowned geophysicist, **Peter Molnar** (1943-2022), took throughout his groundbreaking career and instilled in his students and colleagues. Molnar, who was a CIRES fellow and distinguished professor of Geological Sciences, left a legacy of exceptional scholarship and character. He received some of the most prestigious awards in his field—including the Royal Swedish Academy of Sciences’ Crafoord Prize in Geosciences for his field-changing contributions to the understanding of global plate tectonics, including the deformation of continents and the structure and evolution of mountain ranges. The Geological Society of America gave Molnar the International Distinguished Career award, writing: “With stunning breadth and clarity, Peter Molnar has revolutionized our understanding of the mechanisms of and controls on Earth’s geologic evolution during the past several hundred million years.”

bit.ly/molnar-legacy



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