CIRES COOPERATIVE INSTITUTE FOR RESEARCH IN ENVIRONMENTAL SCIENCES

SPHERES

Edition 11 • 2019

Taking the Arctic's temp

2016's record warmth // Pollution and clouds //
Shrinking ice cap // Data by drone

On fire

Ingredients for wildfire // What's in smoke? //
Better risk management

INSIDE:

**Sea level rise // Hey, LA: that smog ain't all from cars //
Showering with 'friends' // Pump up your spatial skills //
Widening Tropics // Unexpected superconductor**

ISSN 2380-2855

Contents

SPHERES

A publication of the Cooperative Institute for Research in Environmental Sciences

CIRES, a partnership of the University of Colorado Boulder and NOAA, is dedicated to fundamental and interdisciplinary research targeted at all aspects of Earth system science and to communicating these findings to the global scientific community, to decision makers, and to the public. Our environmental scientists explore many aspects of Earth system sciences: the atmosphere, cryosphere, hydrosphere, geosphere, and biosphere. These spheres of expertise give our magazine its name.

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ON THE COVER:
A meander in the main trunk of a meltwater river on the McCall Glacier in the Arctic National Wildlife Refuge during field work in 2013. Photo: Michael Stone/CIRES

BELOW:
Gijs de Boer, Jonathan Hamilton, and Dale Lawrence test-flew drones in Svalbard, Norway, this April, in preparation for the MOSAiC expedition. Find out more on pages 26-27. Photo: Gijs de Boer/CIRES

SPHERES by the numbers

Foliage in Monte Verde, Costa Rica. Photo: Matthew Price/CIRES

-448ºF **The relatively balmy temperature** at which rhenium and gold layers superconduct (PAGE 8)

70% **Proportion of students** showing improved spatial skills after practice (PAGE 6)

Millions **Microorganisms** living in your showerhead (PAGE 8)

4,800 **Sites around the world** where ozone pollution observations feed into a massive database (PAGE 9)

24 **Inches of sea level rise** possible by 2100 (PAGE 13)

4.5 km^3 **Ice lost** by an ice cap in the Arctic in one year—enough to cover Manhattan with 250 feet of water. (PAGE 20)

> $18 billion **Cost of wildfire damage** in the United States in 2017 (PAGE 22)

Briefs

Research by CIRES and NOAA scientists is helping improve the models NOAA relies on for wind forecasts. Photo: Andy Dingley/Wikimedia Commons

WIND ENERGY

Climate drives north-south shift of global winds

By 2100, wind resources may decrease in the Northern Hemisphere and could sharply increase in some hotspot regions down south, according to a *Nature Geoscience* study led by CIRES Fellow **Kris Karnauskas.**

The study was the first of its kind to model how climate change will shift renewable wind power over time. The team anticipates northeast Australia may experience heightened wind power, whereas the American Midwest—already heavily dotted with wind farms—may fall short.

This information could help decision makers determine where to deploy more wind power technology in coming decades to meet emission reduction standards.

bit.ly/northsouthshift

High-res forecasts hold good news for offshore wind producers

It's expensive and difficult to measure wind over the ocean, but better data could help the energy industry pick the best spots for offshore wind power. So CIRES and NOAA scientists wondered if they could get trustworthy estimates from computer weather models. They turned to HRRR, NOAA's High-Resolution Rapid Refresh weather model (see p. 8), comparing HRRR-modeled wind against observations of surface winds measured at offshore buoys. The model agreed well with the real-world data.

"We can get turbine hub-height wind speeds in coastal areas where measurements are sparse or nonexistent," concluded **Eric James,** a CIRES scientist working at NOAA. The work, published in *Wind Energy*, could help bring down the cost of offshore wind power.

bit.ly/hireswind

CLIMATE

Warmer winters boost violent crime rates in U.S.

There's a surprisingly strong link between climate and U.S. crime rates. As global temperatures climb, warmer winters in parts of the country may set the scene for higher rates of violent crimes such as assault and robbery.

"During mild winters, more people are out and about, creating the key ingredient for interpersonal crimes: opportunity," said **Ryan Harp**, a CIRES PhD student and lead author of the *GeoHealth* study.

The team used powerful climate analysis techniques to investigate the relationship between year-to-year fluctuations in climate and violent crime rates in U.S. cities since 1979. And they found it was comparatively warmer winters—not aggression-inducing summer heat—that boost crime rates.

bit.ly/crimeclimate

Researchers, volunteers to mine data from ships' logs

Researchers have added a new fleet to the scientific quest to learn more about past and

CONTINUED ON PAGE 5

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future climate from long-gone mariners. CIRES scientist Gil Compo is part of a team awarded a Digitizing Hidden Collections grant.

The funds allow researchers to digitize logbooks from U.S. naval vessels active during the Civil War-era—a time period with few marine weather observations available for modern climate and weather research. The team has already imaged more than 54,000 pages of ship documents from 1861-1879 and will publish those records in the National Archives Catalog.

Once the logbooks are digitized, researchers will enlist the help of citizen scientists through the Old Weather project. Volunteers will transcribe logbooks' handwritten entries to recover the ships' positions, weather records, oceanographic data and other historical information. So far, Old Weather volunteers have transcribed more than one million weather records.

bit.ly/miningshipdata

A dome of light and dark

CU Boulder graduate students **Amy Richman** and **Lianna Nixon** are the anchors of a CIRES-led team that will produce a planetarium show during the next year, transporting viewers to the Arctic ice where scientists from around the world will study the changing Arctic Climate.

The expedition—MOSAiC, the Multidisciplinary Drifting Observatory for the Study of Arctic Climate —is a year-long undertaking by scientists from 17 nations, freezing a German ship into the Arctic Ocean in autumn 2019, and collecting data as the vessel drifts across the top of the globe.

The dome show, supported by the National Science Foundation, will capture the Sun as it gradually drops below the horizon and ice covers the ocean. Richman, Nixon, and their colleagues will be filming as the Sun reappears in spring 2020, as scientists cheer successes and deal with storms and other challenges.

Their work is in collaboration with Fiske Planetarium, CIRES's Education and Outreach program and the broader university.

Stay tuned for a trailer in fall 2019, and a 2020 show.

https://www.mosaic-expedition.org/

ATMOSPHERIC CHEMISTRY

How much methane? Timing matters

Want an accurate estimate of methane emissions from natural gas operations? Then you may want to be mindful about when you measure, new research suggests.

Several key questions have long puzzled policymakers, researchers and regulatory agencies: How much total methane, a greenhouse gas, do U.S. natural gas operations emit? And why have different estimates disagreed?

In short, timing can be everything, according to a CSU-led study, with CIRES co-authors. Say you happen to grab air samples downwind of a natural gas facility when someone is doing maintenance activities that release short, large bursts of gas. Your data may show higher emissions than if you measured when a site was quiet, with no workers around.

These "routine," mostly short-term venting operations at natural gas production sites often occur during work hours. And this study, in the Fayetteville shale gas play, showed that aircraft measurements captured peak daytime emissions. "The key to our efforts was having everyone on the ground and in the air out in the same field, at the same time," said **Gabrielle Petron**, CIRES and NOAA lead scientist for the study.

bit.ly/emissionsgap

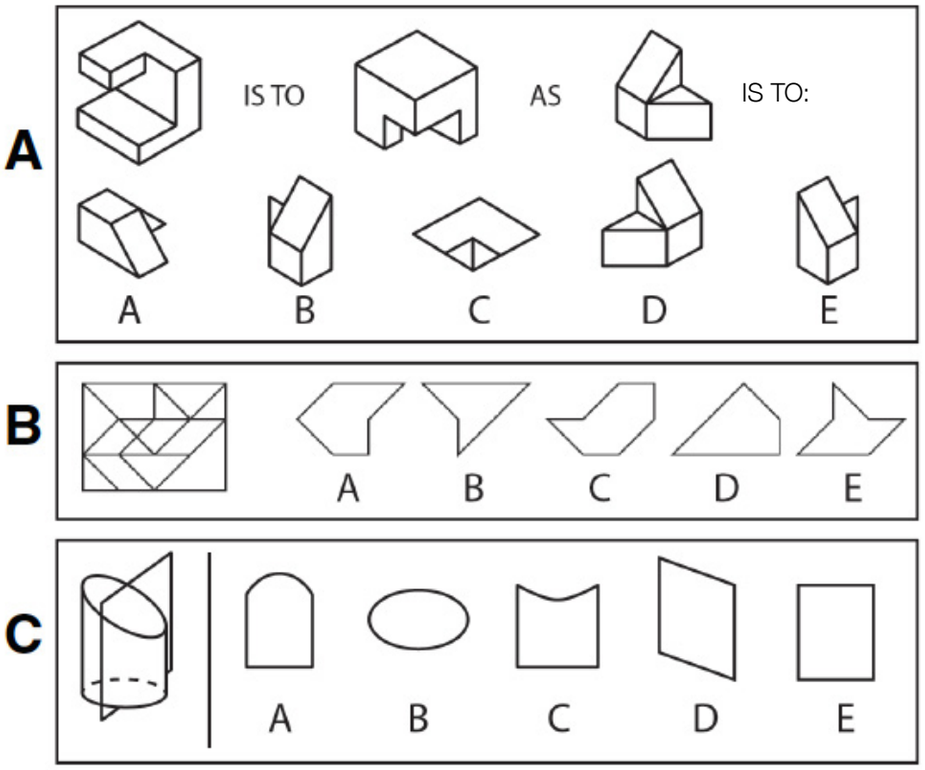
IN MEMORIUM

CIRES founding director John Christopher Harrison, 1929-2018

CIRES mourned the passing of our founding director, John Christopher Harrison, last fall; he died following a four-month battle with pancreatic cancer.

Harrison received his Ph.D. in geophysics from the University of Cambridge in 1953 and became a professor of Geological Sciences at CU Boulder in 1965. He helped establish CIRES just a few years later, serving as our first director from 1967-1972.

In 1982, Harrison left Boulder for Santa Barbara, California, and a research position at Geodynamics Corporation.



Gold's team presented this spatial exercise to their student groups during training. Answers below. Figure: Anne Gold/CIRES

A) Mental rotation: Which object is rotated in the same way as the example?
B) Seeing patterns in noise: Which shape(s) can you find in the jumble?
C) Slicing objects: Which resulting shape comes from slicing the object on a vertical plane?

Yes, you can improve your spatial skills

EDUCATION

Do you marvel at your friend's ability to assemble complex IKEA furniture and navigate a new city, or do you all-around groan at your own lack of spatial skills? Don't fret! A 2018 CIRES-led study found that you, too, can improve your spatial reasoning with practice.

And including spatial training in schools could increase the pool of students who go on to succeed in science, said **Anne Gold**, lead author of the *International Journal of Science Education* study and director of the CIRES Education & Outreach program.

"Spatial skills are crucial in geoscience careers," said Gold. "Reading a topographic map, deciphering how erosion sculpts landscapes, or recognizing how elements are arranged within a mineral all demand spatial visualization and reasoning."

The team provided training exercises to 326 undergraduate students. The students completed weekly practice exercises like mentally rotating geometric figures or cutting through geometric shapes built from modelling clay.

After one semester, 70 percent of the trained students scored higher on spatial skills tests.

The study builds upon the team's earlier work showing young adults who played with construction-based toys such as Legos as children outperformed peers in tests of spatial reasoning.

"At any age, from childhood to college-age, and even well past that—it's possible to sculpt your spatial skills," Gold said. "It's never too late."

bit.ly/spatialtrain

Answers: A) C. B) E. C) E.

Detecting methane from miles away

ECOLOGY

A field instrument developed by a collaborative team of researchers can quantify methane leaks as tiny as 1/4 of a human exhalation from nearly a mile away. CU Boulder, CIRES, NIST, and NOAAscientists "ruggedized" JILA's Nobel Prize laser technology—turning a complex, room-sized collection of instruments into a sleek, 19-inch portable unit to tote into the field near oil and gas operations. The spectroscopy instrument collects precise, nonstop data, providing game-changing information critical for safe industry operations and controlling harmful greenhouse gas emissions.

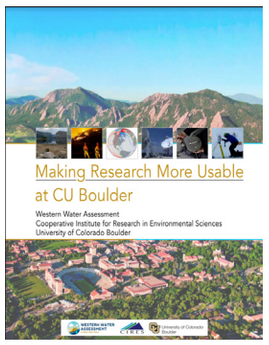
"This instrument is particularly special because it's precise, autonomous, and continuous," said **Caroline Alden**, CIRES researcher and a co-lead author of studies published in *Optica* and *Environmental Science & Technology*. "Other technologies like aircraft flybys or physically traveling to sampling sites pose a problem—if a leak occurs between sampling events, you missed it."

The instrument sits on a mobile platform that can be placed out in field sites surrounded by oil and gas operations. It swivels 360 degrees, sending out carefully tuned, invisible beams of light that intersect gas plumes—allowing researchers to identify unique absorption "fingerprints" of gases like methane and carbon dioxide. And with atmospheric models, researchers can track back to a precise leak location.

"It was a great collaborative effort," said principal investigator Greg Rieker of CU. "We ended up creating an instrument that was mobile, portable, and robust—it works better than the original, at a 10th of the cost."

bit.ly/detectmethane

Dual frequency comb spectrometer observing system set up in the field. Photo: Caroline Alden/ CIRES



For your bookshelf: *Making Research More Usable at CU Boulder*

Experts at Western Water Assessment compiled an easy-to follow checklist for making your science more usable.

The handbook provides tested, tangible methods for researchers to produce useful science for those who write legislation, implement policy, manage natural resources or public resources, or manage their own business—bridging the gap between critical scientific research and constructive societal impact.

wwa.colorado.edu/publications/reports/

You never shower alone

ECOLOGY

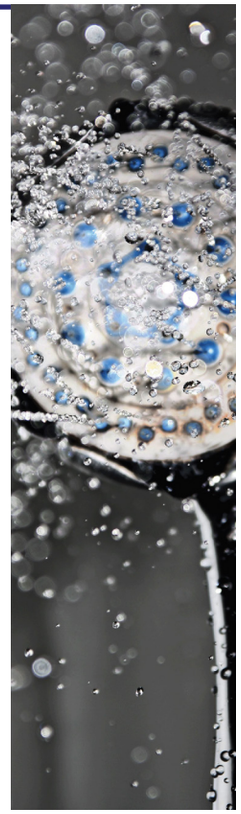
Every time you hop into the shower, you are in the company of millions of microorganisms, most of which probably won't hurt you. However, CIRES researchers have identified *Mycobacterium* as the most abundant genus of bacteria growing in the slimy "biofilm" that lines the inside of showerheads. Some of those bacteria can cause lung disease in the immunocompromised.

Matt Gebert, a CIRES researcher and lead author of the 2018 *mBio* study, and his colleagues analyzed DNA extracted from slime samples collected from hundreds of citizen scientists' showerheads across the United States and Europe. They found mycobacteria:

- are more prevalent in the United States than in Europe,
- thrive more in municipal tap water than in well water,
- are more abundant in metal showerheads than in plastic ones,
- are more common in "hot spots" where certain types of lung disease caused by mycobacteria are also common—namely parts of Southern California, Florida, and New York.

"There is a fascinating microbial world thriving in your showerhead and you can be exposed every time you shower," said **Noah Fierer,** CIRES fellow and coauthor on the study. "The kinds of water treatment systems we use, or the materials in our plumbing, can change the make-up of those microbial communities."

bit.ly/showermicrobes



Rhenium-gold sandwich superconducts

TECHNOLOGY

A CIRES chemist was part of a team that discovered a powerful new plated metal combo (image at right) that superconducts at easily attained temperatures—helping pave the road for the next critical steps in the development of cutting-edge supercomputers.

Donald David and his colleagues **Dave Pappas** and **Xian Wu** at the National Institute of Standards and Technology published the method in a 2018 *Applied Physics Letters* paper: an ultrathin layer of rhenium sandwiched between layers of gold, each measuring 1/1000th the diameter of a human hair. The finished product can superconduct at a temperature of 6 Kelvin. A superconductor is a material that has zero electrical resistance, which can result in exceedingly fast and powerful computer systems. But superconductivity requires cooling to a critical temperature, which is usually strikingly low and expensive to obtain—some superconducting circuit boards must be kept extremely cold (sometimes -455 degrees Fahrenheit or lower), using huge amounts of effort and energy.

David's team achieved this superconducting quality at a surprising critical temperature of 6 Kelvin (-448 degrees Fahrenheit), a more easily achievable temperature than most other superconductors out there. "The magnitude of this critical temperature was unexpected," said David, director of the CIRES Integrated Instrument Development Facility.

The team's electroplated rhenium meets ideal characteristics desired for use in circuit boards for ultrafast, next-generation computing applications: superconducting at higher, easier-to-achieve critical temperatures, easy to work with mechanically, non-toxic, and melts at high temperatures.

The new finding continues to draw attention from international computing giants.

bit.ly/goldrhenium

New ozone data clarify the pollutant's global impact

BY KARIN VERGOTH // CIRES Science Writer

AIR QUALITY

A powerful new dataset of ozone pollution—the Tropospheric Ozone Assessment Report (TOAR)—is helping scientists understand how, when, and why the air pollutant sometimes soars to unhealthy levels in cities and towns around the world.

The international collaboration, led by CIRES and NOAA scientist **Owen Cooper,** promises to also help scientists and decision makers understand ozone pollution's impact on crops, other plants, and even climate. "We created the largest database of surface ozone from hourly observations at more than 4,800 monitoring sites worldwide, and we're making these data freely available to anyone who wants to investigate the impact of ozone," Cooper said.

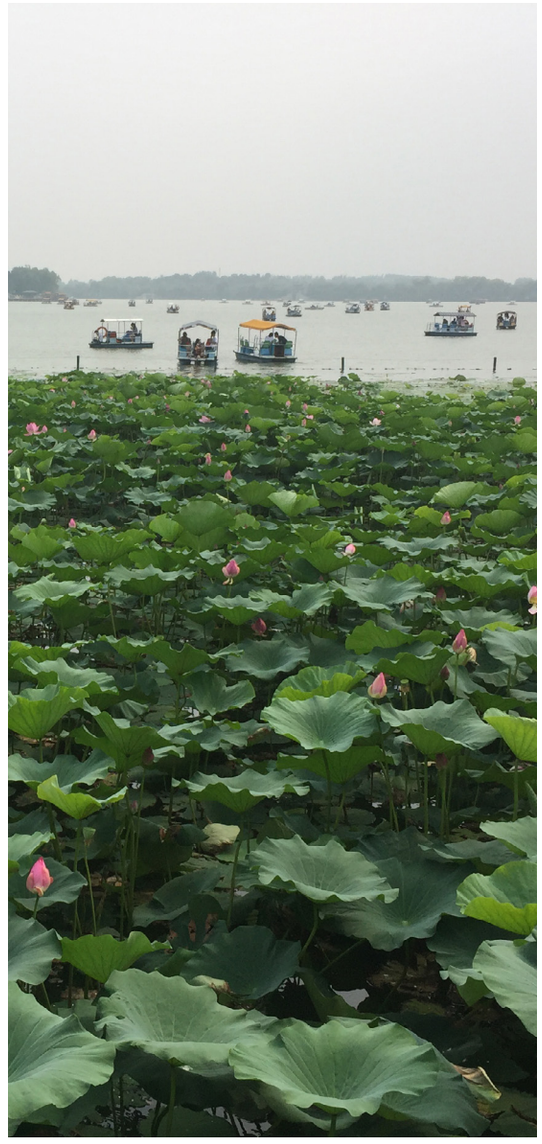
He and other CIRES scientists contributed to several new studies that use TOAR data. Among their findings:

Global Health: Although ozone pollution is dropping across many parts of the United States, western Europe and Japan, many people living in those countries still experience more than a dozen days every year in which levels of the lung irritant exceed health-based standards.

Global Vegetation: Ozone can damage crops and trees, and worldwide, the highest exposure is in areas where high emissions and climate conditions combine to promote ozone formation: parts of the southern United States, southern Europe, northern India, China, Korea, and Japan. Ozone levels in many wheat-growing parts of the world are higher than United Nations target levels set to minimize the risk of crop loss.

Pollution in China: In China, people breathe air thick with ozone two to six times more often than people in the United States, Europe, Japan, or South Korea. "China has become a hot spot of present-day surface ozone pollution," said Cooper.

bit.ly/ozoneimpact

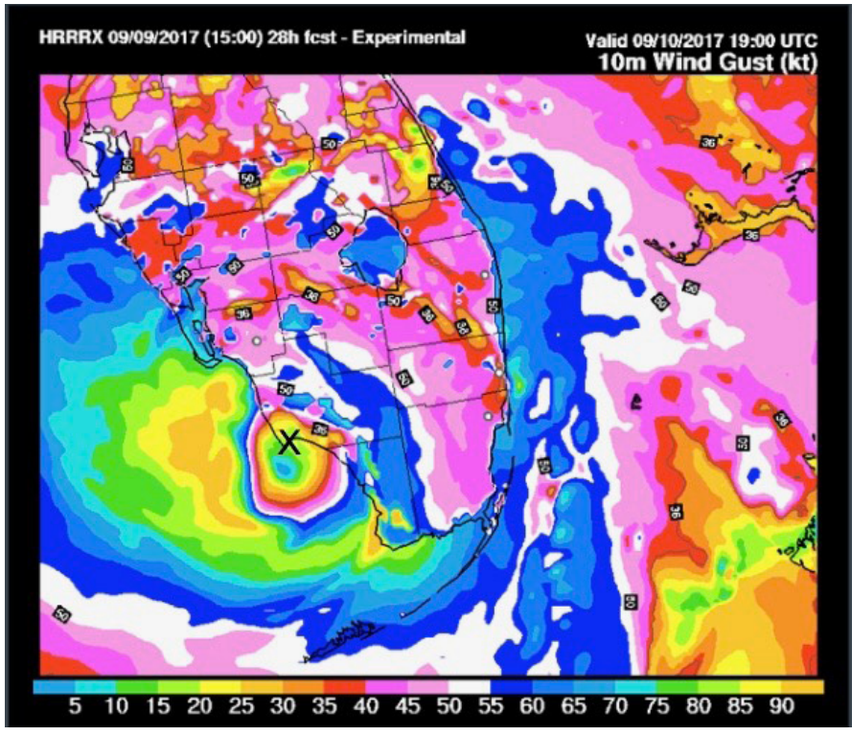


A typical hot summer day on Kunming Lake in northwest Beijing, where regional air pollution turned the sky gray. Photo: Owen Cooper/CIRES

The annual Global Burden of Disease (GBD) study is a critical resource for informed policymaking, helping users understand harm caused by hundreds of diseases, injuries, and risk factors. CIRES scientists are collaborating with GBD researchers with the goal of using TOAR data to improve global estimates of premature deaths due to long-term ozone exposure.

Better model, better predictions: Forecasters hone wind, weather, smoke projections

WEATHER



HRRRX forecasts accurately predicted the time and location of Hurricane Irma's landfall (X marks the spot) within a half county over Marco Island, Florida at 2 pm on September 10, 2017, more than one day in advance. Image: NOAA

Researchers recently upgraded two NOAA weather models that provide the foundation for many forecasts the National Weather Service issues every day and also supply important data to energy companies, emergency managers, and the aviation industry.

NOAA, CIRES, and CIRA scientists continue to improve the High-Resolution Rapid Refresh (HRRR) and its parent model, the Rapid Refresh, for the next set of upgrades expected to move into operations in another year or so.

"The HRRR is so useful in a myriad of forecast applications because it does such a good job representing all aspects of the weather—wind, precipitation, clouds, thunderstorms, even smoke, and how they evolve together in the atmosphere," said **Stan Benjamin**, NOAA Senior Scientist and CIRES Fellow.

Some key advances:

Severe Weather: The upgraded HRRR doubles the forecast period from 18 to 36 hours, providing earlier and more accurate predictions of thunderstorms, damaging winds, flooding, hail, and blizzards.

Renewable Energy: With 18 months of data from the complicated terrain of the Columbia River Basin, researchers have improved the model's wind forecasts for all users, including wind energy companies.

Wildfire Smoke Transport: The HRRR-Smoke model add-on simulates the emissions and transport of smoke from wildfires. NOAA weather forecast offices already use HRRR-Smoke in air quality and visibility forecasts, and the upgrade is scheduled to move into operations in 2020.

bit.ly/bettermodel

An experimental version of the HRRR, dubbed HRRRx, runs continuously at NOAA's Global Systems Division to demonstrate, in real time, scientific advances before they are implemented into the NOAA operational model. The next set of HRRR upgrades will include improved forecasts of low clouds, fog, and aircraft icing conditions to increase aircraft safety and airport efficiency.

Time-lapse photo from September 2018 shows the flight path of an ozonesonde as it rises over the South Pole. Scientists use balloon-borne sensors to measure the thickness of the ozone layer high up in the atmosphere. Photo: Robert Schwarz/University of Minnesota

Team seeks mysterious new source of ozone-destroying gas

OZONE HOLE

Emissions of one of the chemicals most responsible for the Antarctic ozone hole are on the rise, despite an international treaty that required an end to its production in 2010.

Trichlorofluoromethane, also known as CFC-11, is the second-most abundant ozone-depleting gas in the atmosphere and a major contributor to the giant hole in the ozone layer that forms over Antarctica each September. Ozone in the stratosphere acts like sunscreen, shielding the planet from ultraviolet radiation that can cause skin cancer and damage plants, so ozone depletion is bad news.

An international agreement called the Montreal Protocol phased out global production of CFC-11—once widely used as a foaming agent—by 2010. A 2018 *Nature* study, led by NOAA scientist **Stephen Montzka,** documented an unexpected global increase in emissions of this gas after 2012, with contributions from eastern Asia. The results imply new production of the chemical after the 2010 phase-out, which would be a

CONTINUED ON PAGE 12

A slowdown declines around 2012

Atmospheric levels of most ozone-depleting chemicals have been dropping steadily because of the Montreal Protocol—and the recovery of the ozone layer relies on that continuing decline. CFC-11 itself is still less abundant in the global atmosphere than it was in 1990, and its concentration continues to decrease even today; but something changed about 2012, perhaps some kind of industrial activity re-started. The dropoff in CFC-11's concentration slowed down then, suggesting something new was sending more of the chemical into the atmosphere.

Hunting down CFC-11

The 2018 *Nature* paper reporting an unexpected rise CFC-11 emissions sparked an international search to find the new source of this potent ozone-depleting chemical. Reporters from *The New York Times* and investigators from the Environmental Investigation Agency spoke with people at polyurethane foam production sites in China; several of them said they'd used CFC-11 until recently. However, Chinese authorities have not found evidence for widespread use or production of CFC-11 in China since the paper was published.

Now, Montzka and several colleagues from around the world have new results from a closer look at eastern Asian emissions, based on recent measurements in the region. The international team reported that eastern mainland China accounts for about half or more of the global CFC-11 emission increase that has occurred since 2012.

Spotting the signal of climate change in tropical widening

CLIMATE

Earth's tropical belt—that broad swath of land and sea north and south of the equator—is expanding, spreading slowly both north and south. The changes, which are happening for a mixture of reasons involving climate change and natural variability, can shift climate zones poleward, drying out areas accustomed to more rain or pushing storm tracks into new patterns.

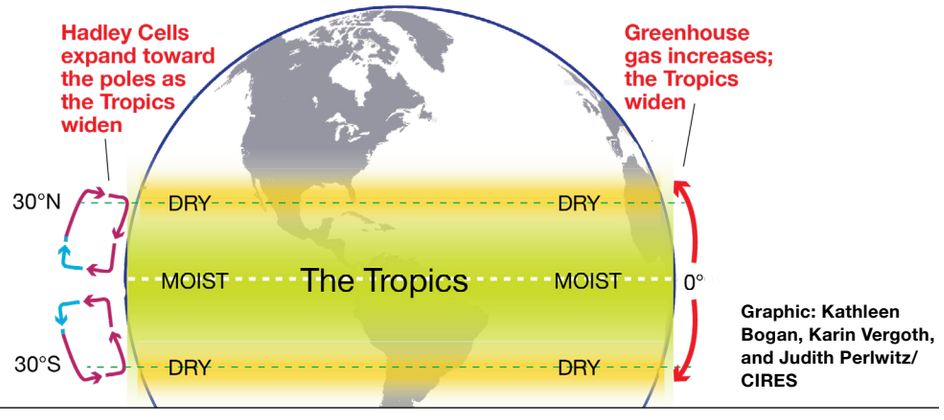
To better understand the future of tropical widening and its consequences, a team of CIRES and NOAA researchers determined to figure out whether they could spot the climate change signal within those natural swings up and down. Specifically, they wanted to know when they might be able to pick the signal out of the noise.

Tropical width is the distance between the latitudes where air from tropical rainfall systems descends in the Northern and Southern subtropics (called the Hadley Circulation). When the Hadley cell (and therefore, the Tropics) expands, that means subtropical dry zones, mid-latitude jet streams, and storm tracks all shift towards the poles.

The researchers used large sets of climate models to simulate tropical expansion due to both human activity and natural variability. When they factored in projections of rising temperatures, they found that by around 2058, tropical expansion caused by global warming will likely be larger than the natural year-to-year variability—and a big enough signal to spot.

These results, published in 2018 in the *Journal of Climate*, could help those in highly populated subtropical regions that are at increasing risk of drought from widening tropics. In those regions, such a drying trend can play out in larger, more intense, and more frequent forest fires, and also severe water shortages that could lead to food insecurity.

bit.ly/tropicswiden



Graphic: Kathleen Bogan, Karin Vergoth, and Judith Perlwitz/ CIRES

Team seeks mysterious new source of ozone-destroying gas

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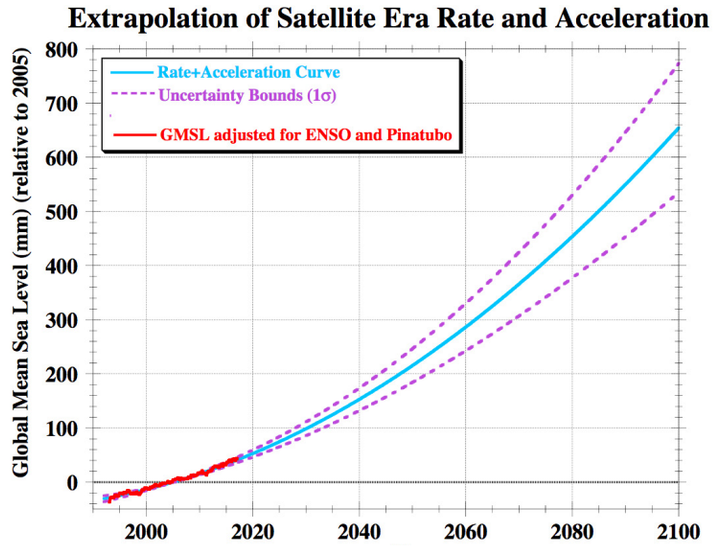
violation of the Montreal Protocol.

"This is taking us away from timely recovery of the ozone layer," said Montzka, who is also a CIRES Fellow. "Further work is needed to figure out exactly why emissions of CFC-11 are increasing and if something can be done about it soon."

Nine CIRES co-authors provided measurements, modeling, and data analysis for the 2018 study. And several of the authors, including Montzka, are now working to track down the precise location of those CFC-11 emissions. They're relying on data from NOAA's global network of atmospheric sampling stations and drawing insight from several short-term global atmospheric campaigns that they participated in, such as the Atmospheric Tomography Mission (ATom) and HIPPO (HIAPER Pole-to-Pole Observations).

bit.ly/risingcfc11



How does climate change-related warming of air and water contribute to sea level rise?

1) Warm water expands, known as "thermal expansion."

2) Melting land ice flows into the ocean.

Scientists project sea level rise on an upward curve (blue) to the end of the century. The dotted purple line shows the range of uncertainty, and red shows adjusted GMSL (global mean sea level) to date. Figure: Nerem et al. 2018

Faster and faster

25 years of satellite records show sea level could rise twice as quickly as other projections indicate

BY KATIE WEEMAN // CIRES Science Writer

CLIMATE CHANGE

Global sea level rise is not cruising along at a steady 3 mm per year, it's accelerating a little every year, like a driver merging onto a highway, according to a powerful assessment by CIRES Fellow **Steve Nerem** and colleagues. The scientists harnessed 25 years of satellite data and calculated that the rate is increasing by about 0.08 mm/year every year—which could mean an annual rate of sea level rise of 10 mm/year, or even more, by 2100.

"This acceleration has the potential to double the total sea level rise by 2100 as compared to projections that assume a constant rate—to about two feet instead of one," said Nerem, a professor of Aerospace Engineering Sciences at the University of Colorado Boulder and lead author of a *Proceedings of the National Academy of Sciences* study published in 2018.

If the oceans continue to change at this pace, sea level will rise 26 inches by 2100—enough to cause significant problems for coastal cities, according to the new assessment by Nerem and colleagues from across the country.

Scientists have used satellite altimeters to measure increases in sea level since 1992. But detecting acceleration is challenging. Episodes like volcanic eruptions can create variability: the eruption of Mount Pinatubo in 1991 decreased global mean sea level, for example. Global sea level can also fluctuate due to climate patterns such as El Niños and La Niñas which influence ocean temperature and global precipitation.

So Nerem and his team used climate models to account for the volcanic effects and they used other datasets to pull out the El Niño Southern Oscillation effects, ultimately uncovering the underlying sea-level rate and acceleration over the last quarter century. They also used satellite data to determine that the acceleration is largely driven by melting ice in Greenland and Antarctica.

The team used tide gauge data to assess potential errors in the altimeter estimate—tide gauges provide the only assessments of the satellite instruments from the ground, said co-author **Gary Mitchum**, from the USF College of Marine Science.

Others have used tide gauge data to measure global mean sea level acceleration, but scientists have struggled to

CONTINUED ON PAGE 17

Perfect timing: How to capture the Milky Way

PHOTO AND TEXT BY
PATRICK CULLIS // CIRES

As a specialist in astrophotography, I'm constantly watching the weather and phase of the moon to balance the brightness between sky and land. A full moon lights the land but washes out stars and turns the sky blue. During a new moon, the stars are glorious but the landscape is pitch black.

My favorite time to photograph is during a crescent moon that is about 25 percent illuminated. In that phase, the moon provides a soft light without harsh shadows on the landscape, while not washing out the stars.

After some initial attempts in 2016, I knew I could capture something special about the Maroon Bells, and set a goal for myself to capture the Bells via a year-long project throughout 2017. I had the camera gear and car packed and ready to go at a moment's notice when conditions aligned.

I went there five times that year. September 25 was the final opportunity during the fall aspen season to photograph with the Milky Way. There were still a handful of days before the leaves would fall, but the next night the moon was going to move in front of the center core of our galaxy, effectively ending photographic opportunities for the year.

I was extremely lucky that the thin wisp of cloud appeared on the horizon and drifted upward above the peaks. When it first appeared, I was disappointed that it was going to mar the shot, but I soon realized what a blessing it was. Similar to an assistant holding a reflector during a portrait session, it provided just enough indirect light to the landscape while letting the Milky Way dominate the sky. Finally, a brief reprieve from the wind happened at the perfect time.

I took more than 150 photos that night and this is the only shot where the water was calm enough to show a clear reflection.

Paints, pesticides, perfumes play a big role in air pollution

BY KATY HUMAN // CIRES
Communications Director

AIR QUALITY

It happens to most of us on occasion: You walk into an elevator or a break room and a colleague's cologne is suddenly overwhelming.

What if that product does more than trigger a coughing or sneezing fit? What if it also contributes to air pollution outdoors—the kind that keeps runners indoors and sends heart patients into distress?

Turns out it does.

CIRES scientists and NOAA colleagues published several foundational papers in 2018, showing just how much of urban air pollution comes from non-traditional sources: household cleaners, pesticides, paints, perfumes and other products containing chemicals refined from petroleum.

These chemicals belong to a class of chemicals called volatile organic compounds (VOCs); once applied, they evaporate quickly.

In the air, sunlight can trigger those VOCs to react with nitrogen oxides and other compounds to form ozone and particulate matter—two types of pollution that are regulated because of their effects on air quality and human health.

In one study, based in Los Angeles, a team led by CIRES' and NOAA's

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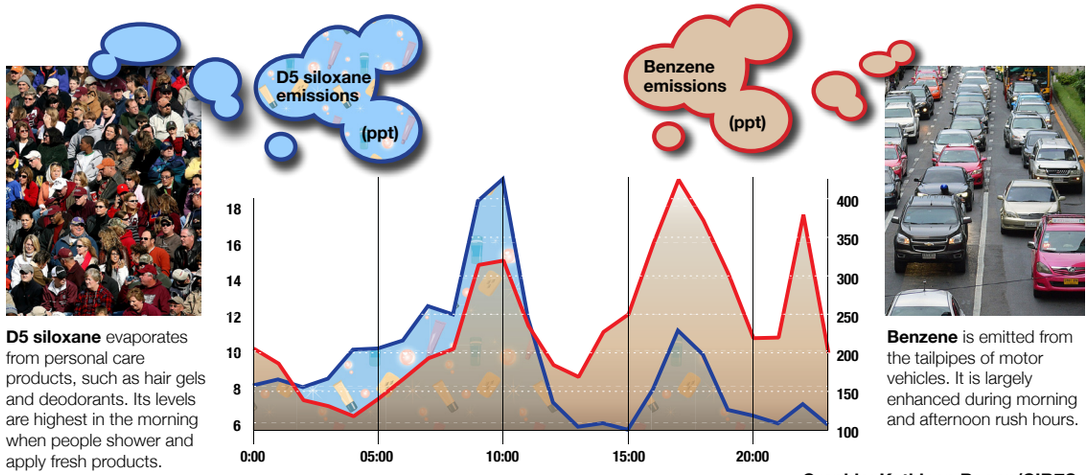
In LA Basin, personal and cleaning product emissions rival vehicles'

In the *Science* paper, McDonald and his colleagues pointed out that modern cars and trucks are getting cleaner, emitting fewer pollution-forming compounds than older vehicle models. That's in large part why the importance of chemical product emissions became more obvious.

People use far fewer petroleum-based chemicals in products than they do in fuels, of course—15 times less, according to the assessment. But while we close gas tanks after filling them and use emissions control devices at the pump, our paints, perfumes and household products often evaporate directly into the atmosphere. McDonald's team found that these non-traditional sources contribute roughly as much to the VOC pollution problem in LA as the transportation sector does.



D5 siloxane evaporates from personal care products, such as hair gels and deodorants. Its levels are highest in the morning when people shower and apply fresh products.

Benzene is emitted from the tailpipes of motor vehicles. It is largely enhanced during morning and afternoon rush hours.

Graphic: Kathleen Bogan/CIRES

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Brian McDonald found that chemical products now rival motor vehicle-related emissions as the top source of urban air pollution.

"As transportation gets cleaner, those other sources become more and more important," McDonald said. "The stuff we use in our everyday lives can impact air pollution." Their work appeared in *Science* in February 2018.

And then McDonald's colleague, CIRES' and NOAA's **Matthew Coggon**, turned his instruments on Boulder, Colorado. Coggon and his team found that emissions of siloxane, a common ingredient in shampoos, lotions, and deodorants, are comparable in magnitude to the emissions of major components of vehicle exhaust, such as benzene, from rush-hour traffic. Their work appeared in *Environmental Science & Technology*.

Such results have important implications for regulations, **Brent Stephens** of the Illinois Institute of Technology told *The Washington Post* soon after McDonald's study published. "We have traditionally focused on transportation and industrial emissions to the outdoor environment," Stephens said. "Volatile chemical products are now relatively more important emissions sources, and they come from both indoor and outdoor sources… and we don't regulate the vast majority of indoor environments."

bit.ly/personalplumes

Personal plumes

By happenstance, Coggon and his colleagues detected daily peaks in emissions of a chemical called D5 siloxane, short for decamethylcyclopentasiloxane. D5 siloxane is added to personal care products like shampoos and lotions to give them a smooth, silky feeling. "We detected a pattern of emissions that coincides with human activity: people apply these products in the morning, leave their homes, and drive to work or school. So emissions spike in the morning during commuting hours, and decay throughout the day as these chemicals wear off from our skin," Coggon said.

Faster and faster: Sea level rise

CONTINUED FROM PAGE 13

pull out other important details from tide-gauge data, such as changes from more active ice sheet melt.

"Satellite records play an important role in validating climate model projections," said John Fasullo, a climate scientist at the National Center for Atmospheric Research and co-author of the 2018 *PNAS* paper. "And climate models are critical for interpreting satellite records, such as in our work where they allow us to estimate the background effects of volcanic eruption on global sea level."

bit.ly/sealevelaccel

In 2016's record warmth, a glimpse of the Arctic's future

BY KARIN VERGOTH // CIRES Science Writer

The extraordinary Arctic heat of 2016 could not have happened without the steep increases in greenhouse gas concentrations caused by human activity and the resulting loss of sea ice during the past 150 years.

Record-low sea ice in 2016 was responsible for about 60 percent of that year's record warmth, CIRES and NOAA scientists found after evaluating ocean and atmospheric observations with advanced modeling tools. Sea ice loss meant the ocean's heat could warm the atmosphere across wide expanses of ice-free or barely frozen Arctic Ocean.

But Arctic sea ice loss alone couldn't explain the totality of 2016's record warmth. Other factors from far outside the Arctic also played a role, including the 2015-16 El Niño and intrusions of warm air from lower latitudes.

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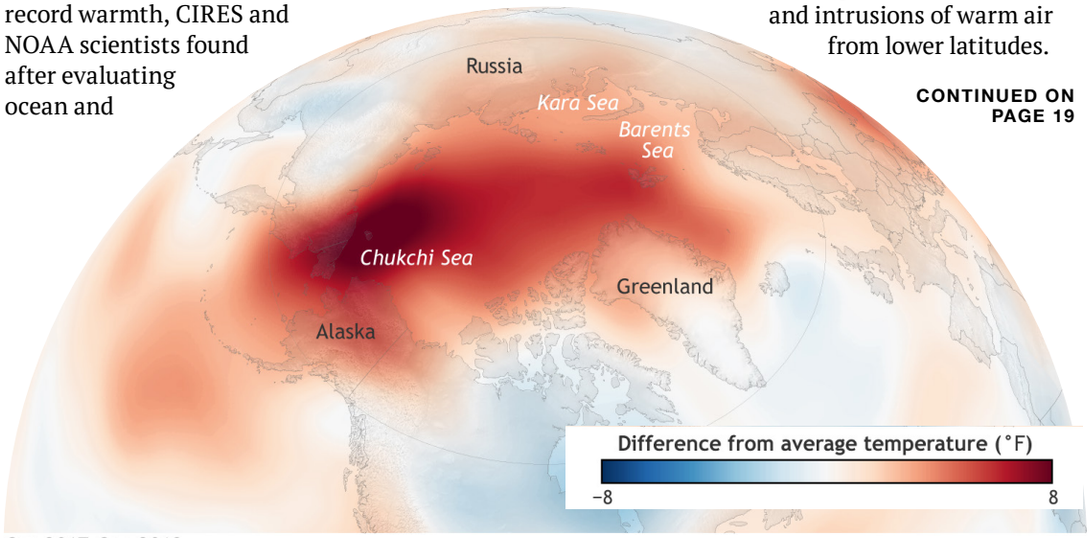

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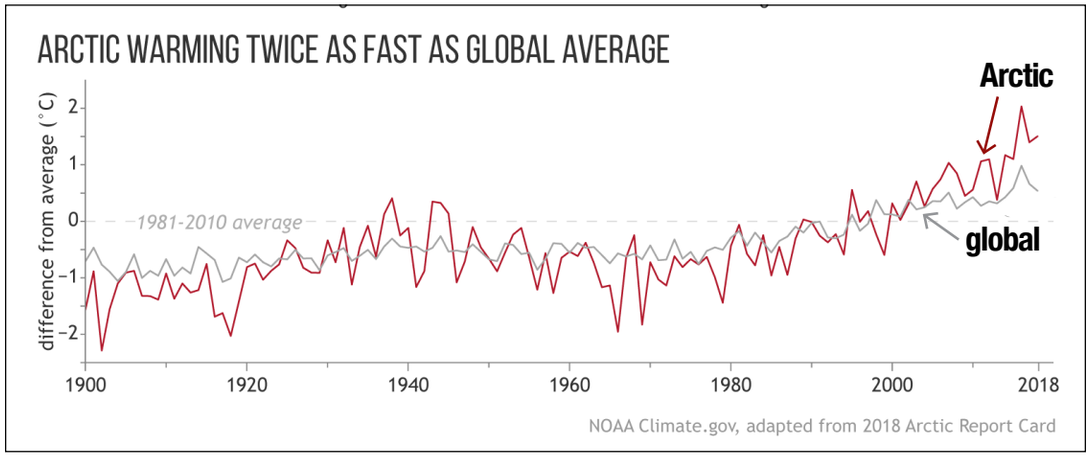

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The scientists concluded that there was near-zero probability that the Arctic could have been as warm as it was in 2016 if greenhouse gas concentrations, ocean temperatures, and sea ice were at late 19th Century levels.

"It's been said the Arctic is the canary in the coal mine," said paper co-author **Martin Hoerling,** a NOAA meteorologist. "The canary really chirped loudly in 2016. This is where the signal is clearly emerging beyond the noise, and it affirms predictions of how climate change will unfold on Earth."

The research appeared in the journal *Weather and Climate Extremes*.

Long-term measurements have shown for many years that the Arctic is warming twice as fast as the rest of planet. One key reason is sea ice loss. Ice and snow cover reflect sunlight, while dark ocean water absorbs heat. Thick ice prevents ocean water from transferring heat to the atmosphere, but open water and thin ice allow massive transfers of heat to the air, which then slows the re-formation of autumn ice in a self-reinforcing cycle. Today, much of the Arctic sea ice pack is thin and only one year old, with few areas of multi-year thick ice.

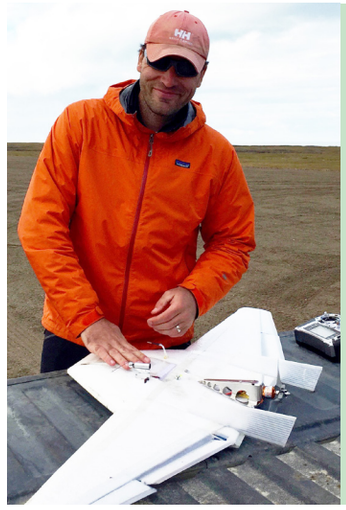
To evaluate the role of global warming in this heat event, lead author **Lantao Sun**, then a CIRES scientist working at NOAA, employed a widely used weather forecast model to investigate how sensitive the Arctic climate is to various factors, such as greenhouse gas levels, sea surface temperatures, sea ice extent, and others. Sun found the model could replicate 40 years of actual Arctic temperature observations with a high degree of skill, including the striking upward trend since 1980.

To further explore which factors contributed to the record temperatures, Sun and his colleagues ran the same model, but set greenhouse gas levels, sea surface temperatures, and sea ice extent to levels that typified the late 1800s. This so-called "counterfactual" set of model runs helped test whether the record temperatures of 2016 could possibly be within the range of natural variability.

The result? "This kind of extreme heat did not happen in the simulations of late 19th Century climate," Hoerling said. "The region could not experience these temperatures without increased greenhouse gas loading and the loss in sea ice cover."

As a glimpse to the future, the study also projected that the extraordinary temperature anomalies of 2016 will likely become the typical annual surface temperature within a mere decade. By the middle of the 21st century, the difference between temperatures of the "old Arctic" and 2016 is expected to double again as more and more sea ice is lost, Sun said.

bit.ly/2016arcticwarm



Bird's-eye view of the Arctic

It's expensive and sometimes dangerous to collect data in the remote Arctic environment. Drones, tethered balloon systems, and other unmanned technologies can help fill those data gaps—collecting weather data over difficult-to-sample surfaces and contributing to better weather and climate models, according to a recent CIRES study. Recently the Department of Energy has boosted use of unmanned aerial vehicles and tethered balloons to collect critical data, thanks in part to work by CIRES scientists who will conduct similar operations under National Science Foundation funding during the MOSAiC expedition (see MOSAiC story on page 5, and mySpheres on pages 26-27).

bit.ly/birdeyearctic

CIRES and NOAA scientist Gijs de Boer preparing a DataHawk 2 for launch in 2015. Photo: Gijs de Boer/CIRES

Pollution changes Arctic clouds, influencing climate

Air pollution on Alaska's North Slope can affect the types of clouds that form downwind, according to a CIRES-led study. Using aircraft observations, CIRES researchers and partners compared clouds in two coastal regions: Oliktok Point, close to the Prudhoe Bay oilfield, and the more pristine Utqiaġvik (formerly Barrow). Pollution from oil and gas activities led to clouds with smaller droplets producing less drizzle or rain, which can in turn influence local climate.

Arctic clouds can either cool or warm the surface, depending on their specific properties and the season. In summertime, clouds generally cool the surface by reflecting sunlight, but changes in droplet size may alter the degree of that cooling. And because the Arctic is warming more rapidly than the rest of the planet, better understanding those clouds—and the pollution that affects them—is crucial to understanding future global climate change.

Russian ice cap recedes at unprecedented rate

BY KATIE WEEMAN // CIRES Science Writer

CIRES fellow **Mike Willis** harnessed satellite images to capture the dramatic speedup of the Vavilov Ice Cap in 2015, when the Russian glacier accelerated from about two inches per day to a whopping 82. His team's findings have challenged scientists' assumptions about the stability of the cold ice caps dotting Earth's high latitudes.

"In a warming climate, glacier acceleration is becoming more and more common, but the rate of ice loss at Vavilov is extreme and unexpected," said Willis.

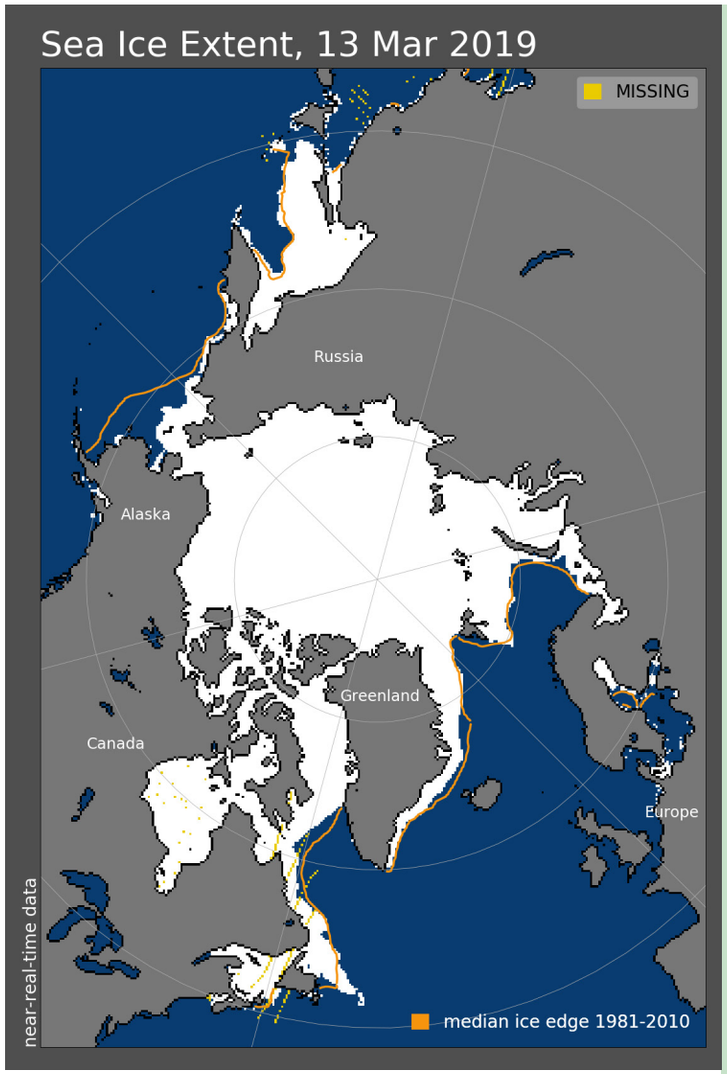
Glaciers and ice caps like Vavilov cover nearly 300,000 square miles of Earth's surface and hold about a foot of potential sea-level rise. Scientists have never before seen such acceleration in this kind of ice cap, and the authors of the *Earth & Planetary Science Letters* paper say it's possible that other, currently stable ice caps may be more vulnerable than expected.

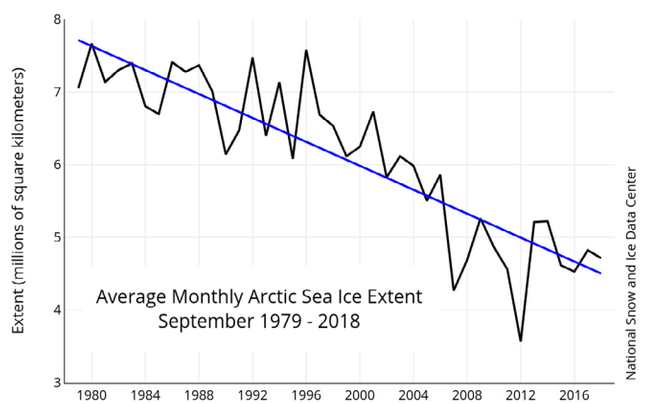
Willis and his team played the part of forensic ice detectives, piecing together the history of the ice cap's deterioration by spying on it from a constellation of satellites. They watched ice on the cap creep slowly forward for several years, accelerate slowly in 2010, then surge rapidly in 2015.

Researchers suspect the ice cap sped up dramatically when the bottom of the ice cap became wetter, as it dipped below sea level, and when the front of the glacier advanced onto slippery marine sediments. By 2015, the sediments and rock at the bed beneath the ice had become so slippery that the material couldn't stop the ice from flowing—it had become a nearly frictionless zone.

Satellite image of the ice cap. Watch the video of the collapse: bit.ly/vavilovcollapse
Photo: NASA/USGS

The Vavilov Ice Cap lost about 1.2 km^3 in total volume into the ocean in the 30 years before the speedup—but in the one year between 2015 and 2016, the ice cap lost about 4.5 km^3 of ice, enough to cover Manhattan with about 250 feet of water. And it's unlikely the ice cap will ever be able to recover ice mass in today's warming climate.





NSIDC tracks long-term decline in Arctic sea ice

Every winter, Arctic sea ice grows until it blankets several million miles of the Arctic Ocean, reaching its maximum in March. By late March, it's often melting again, hitting a minimum around late September. Researchers at the National Snow and Ice Data Center, part of CIRES at CU Boulder and funded largely by NASA and other agencies, track this waxing and waning of the ice, which depends greatly on the ups and downs of weather. But embedded in those natural variations are some troubling long-term trends. September sea ice extent, for example, has dropped on average 12.8 percent per decade.

https://nsidc.org/arcticseaicenews/

Bookshelf: *Brave New Arctic: The Untold Story of the Melting North*

In the 1990s, researchers in the Arctic noticed major environmental changes: floating summer sea ice had begun receding, ocean circulation was shifting, the Arctic's perennially frozen ground was warming, and treeless tundra was being overtaken by shrubs. *Brave New Arctic* is Arctic climate scientist **Mark Serreze's** (CIRES Fellow and NSIDC Director) first-hand, insider account of how researchers from around the globe came together to solve the mystery of these puzzling cryospheric changes.

WILDFIRE REPORT

Recipe for wildfire

Fuel + aridity + ignition = a bad season

BY KATIE WEEMAN //
CIRES Science Writer

Three key ingredients can make for an extreme wildfire year in the western United States, according to CIRES-led research: a wet winter, a dry summer and fall and a heaping spoonful of human-caused ignitions. Stir to combine and you've got a recipe that cranks up the heat from bake to broil. That's what happened in 2017, triggering one of the largest and costliest U.S. wildfire seasons in recent decades.

"In 2017, we saw a pile-on of extreme events across large portions of the western United States," said **Jennifer Balch**, director of CU Boulder's Earth Lab, which is part of CIRES. "The wettest winter, the hottest summer and the driest fall—all helping to promote wildfires."

The 2017 wildfire season cost the United States more than $18 billion in damages. That year, 71,000 wildfires scorched 10 million acres of land—destroying 12,000 homes, evacuating 200,000 people and claiming 66 lives. For comparison, 2016 saw only 5.4 million acres burned.

Climate change likely helped maximize fuels and dryness, and people's behavior contributed the sparks in 2017, noted the 2018 study published in *Fire*. And although naturally occurring climate variability influences environmental conditions that affect wildfire, that variation is superimposed on an anthropogenically warmer

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world, so climate change is magnifying the effects of heat and precipitation extremes, Balch says.

The research team sought to pinpoint the precursors that led to these fires, to support decision makers considering policies that might prevent or minimize future fire disasters. The study found it was ample amounts of three major fire-triggering ingredients—fuel, aridity and ignition—that came together in 2017 to set the West ablaze.

The recipe for western wildfire:

Step 1: Start with wet ingredients. Increased winter precipitation early in 2017 fed the growth of fine grasses across the western United States—grasses that would later serve as fuel for fire.

Step 2: Add dry ingredients. Summer and fall in 2017 then swept the West with a wave of dry, arid conditions, baking the dense fields of grasses into dehydrated kindling.

Step 3: Light the burner. With the an abundance of dry grasses acting as fuel, the scene was set for the third trigger: ignition. Nearly 90 percent of total wildfires last year were caused by people; previous work by Balch and her team has illuminated just how extensively humans exacerbate wildfire. Human activity triples the length

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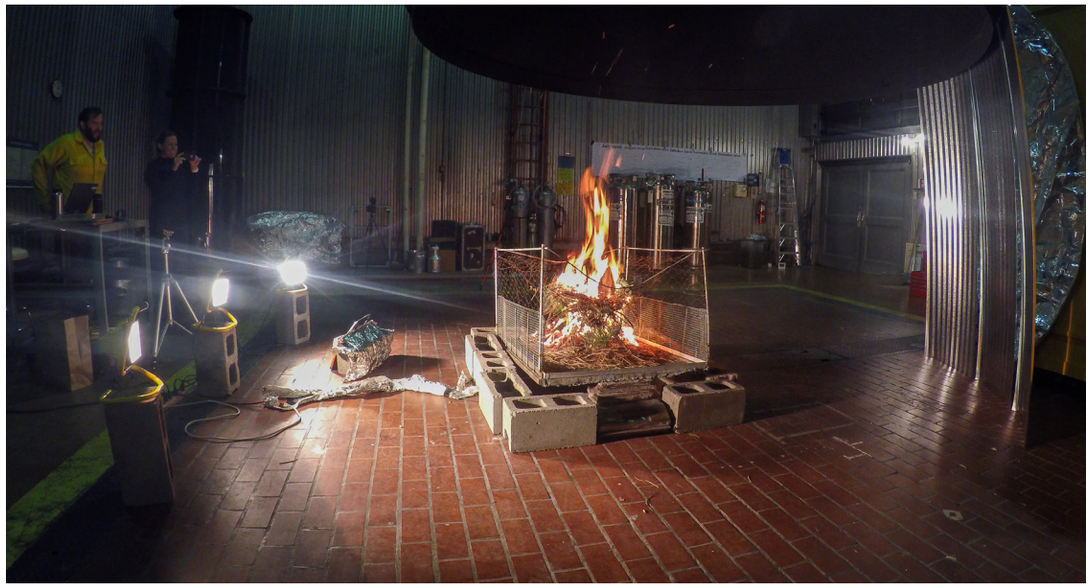
The 2017 Thomas Fire burned more than 113,000 hectares from early December 2017 to late January 2018 in Ventura and Santa Barbara counties, making it the largest fire in California's modern history. Satellite photo: NASA Earth Observatory



CIRES and NOAA scientists burned more than 100 fires made from various fuels found in the West, and sampled the emissions continuously with state-of-the art instruments. Photo: Henry Worobec/ University of Montana

Wildfire temperatures key to understanding what's in smoke

Study informs 2019 FIREX-AQ field campaign

BY KARIN VERGOTH // CIRES Science Writer

When wildfires burn, they don't only damage land, homes, and businesses. Wildfire emissions, which can be transported over long distances, can be toxic and contribute to secondary air pollutants such as ozone and fine particles. Since those pollutants affect human health and the environment, scientists want to know what's in wildfire smoke. And it turns out what matters most for the composition of smoke is not only what kind of fuel is burning, but also the temperature at which it burns.

"If we know the temperature of a fire, we can better estimate what comes out of it," said **Carsten Warneke**, a CIRES researcher at NOAA. "With that information, we might be able to simplify emissions models, better predict the downwind impacts of wildfires, and get much better forecasts for air quality."

The U.S. West faces a future with more frequent and intense wildfires, according to climate projections and in part because of policies that have long encouraged fire suppression. Against that backdrop, CIRES and NOAA scientists are teaming up with NASA scientists to lead a multi-year field campaign—Fire Influence on Regional to Global Environments and Air Quality, or FIREX-AQ—to better understand the air quality and climate effects of wildfires.

Fires produce complex emissions, releasing thousands of different volatile organic compounds (VOCs) that are often difficult to measure. Scientists initially thought wildfire emissions were mostly dependent on the type of fuel

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What's in smoke

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burned—for example, Douglas fir, Ponderosa pine, or sagebrush. To better understand those emissions in a controlled environment, CIRES and NOAA scientists ignited over 100 fires made from various fuels found in the western United States and sampled the emissions continuously with state-of-the art instruments.

The researchers found that understanding fire emissions may be much simpler than they previously believed: it's the temperature of the burn and not what's burning that's key. They could explain around 85 percent of the variability of the VOC emissions once they knew how hot a fire was.

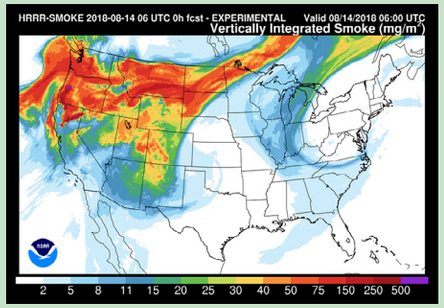
In the lab, single fires burned at both higher and lower temperatures at different stages, releasing different VOCs at different times. During lower-temperature stages, fires produced more tiny particles called aerosols, which can get into people's lungs and mix in the atmosphere to form haze and other air pollutants downstream.

Such results will help researchers this summer during the FIREX-AQ mission, which is focused on how western U.S. wildfires affect the atmosphere, including climate. But lab data won't be a perfect guide to field work, because real wildfires often combine high and low temperature processes. Ultimately, the goal of FIREX-AQ is to produce the kinds of data and understanding that will help experts manage fires and their impacts on air quality and climate.

bit.ly/wildfiretemps

Emergency managers use NOAA/CIRES smoke forecasts

Last summer, meteorologists used a new smoke module added to NOAA's High-Resolution Rapid Refresh model to brief the National Park Service on fires near Yosemite National Park. HRRR-Smoke, developed by CIRES and NOAA scientists, simulates fire emissions and movement of wildfire smoke, providing critical information to partners and the public. Based on those smoke forecasts, emergency managers near Yosemite evacuated and closed parts of the park expected to be impacted by poor air quality and visibility.



Recipe for wildfire

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of the average fire season.

And this pattern is likely to continue: Computer climate models project an increased risk of extreme wet winters in California, the paper noted, and a decrease in summer precipitation across the entire West Coast. Those models also tend to project a delay in the onset of fall rain and snow.

"We expect to see more extreme fire seasons in years to come," said **Megan Cattau**, Earth Lab researcher and a co-author of the study. "It's becoming increasing critical that we strengthen our wildfire prediction and warning systems, support suppression and recovery efforts and develop sustained policies that help us coexist with fire."

Some policies like smarter building practices and better wildfire prediction are already underway in some places, and in consideration elsewhere. Other proposed policies, including increased logging, proposed in 2019 by White House officials, are unlikely to work as thinning all forests is not possible, said Balch.

"The 2018 wildfire season followed many of the same triggers as 2017," said Balch. "Fuels in the southern Rockies were very dry and experienced many wildfires in the summer due to severe drought and low snowpack."

And the 2019 fire season will most likely follow a similar recipe, the authors say.

my Sphere

Drones at the top of the world

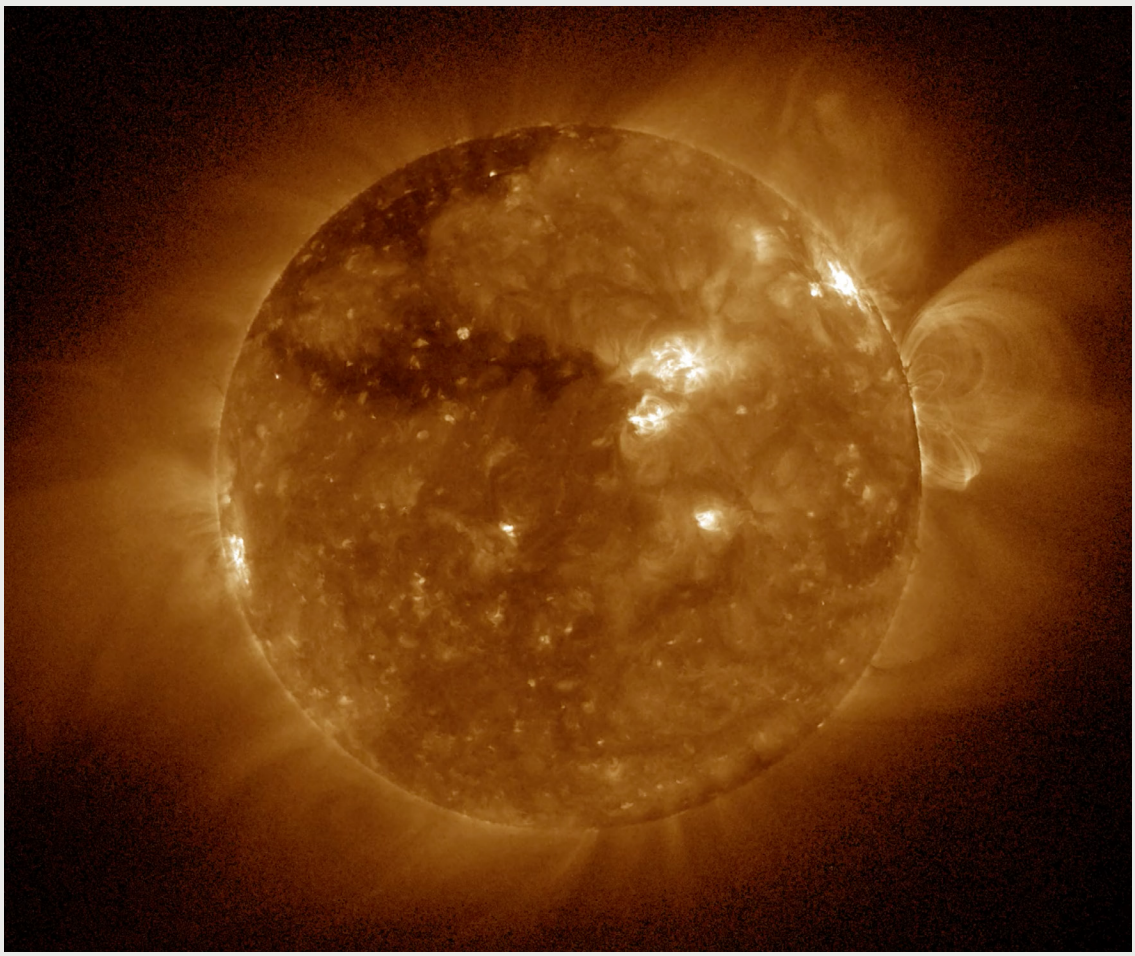
CIRES' Gijs de Boer (left) and colleagues from CU Boulder flew drones in Svalbard, Norway this April, testing several types of drones and instruments they'll use during MOSAiC, an international expedition to better understand Arctic climate. Starting in September 2019, their ship will drift with Arctic sea ice for 12 months, letting scientists gather data in every season. Learn more about MOSAiC, p. 5.

1 Dale Lawrence and 2 Jonathan Hamilton from the CU Boulder Aerospace Engineering Sciences department get ready to launch two drones (3 DataHawk 2, and 4 Tarot 680 Pro) that collect data on near-surface atmospheric conditions in the Arctic, including thermodynamics, winds, and radiation.

5 This drone, called Pilatus, has a wingspan of six feet and weighs in at about 55 pounds with instruments. Drones help researchers sample over much larger areas than ground-based instruments can cover and can be directed to specific interesting and difficult-to-reach locations, too.

6 The team chose Svalbard (78 degrees north latitude) to test the equipment in a location that mimics the MOSAiC mission environment.

7 There's a reason for that sign.



A new view of the Sun

When the Sun flared dramatically in September 2017, causing geomagnetic storms and radio blackouts on Earth, a new type of NOAA solar telescope captured the drama. The instrument—the Solar Ultraviolet Imager or SUVI—was the first of a class of four planned instruments that observe the solar corona in ultraviolet wavelengths. The first launched in 2016 on the GOES-16 satellite and went operational in December 2017 on the newly named GOES East; the second is on sister satellite GOES West, and two more are to come. The instruments have a large field of view to image phenomena at greater heights than other solar imagers. That will help scientists better understand solar eruptions and flares, improving models and forecasts. CIRES and NOAA scientists are responsible for processing and archiving SUVI data at NOAA's National Centers for Environmental Information.

bit.ly/newviewsun

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