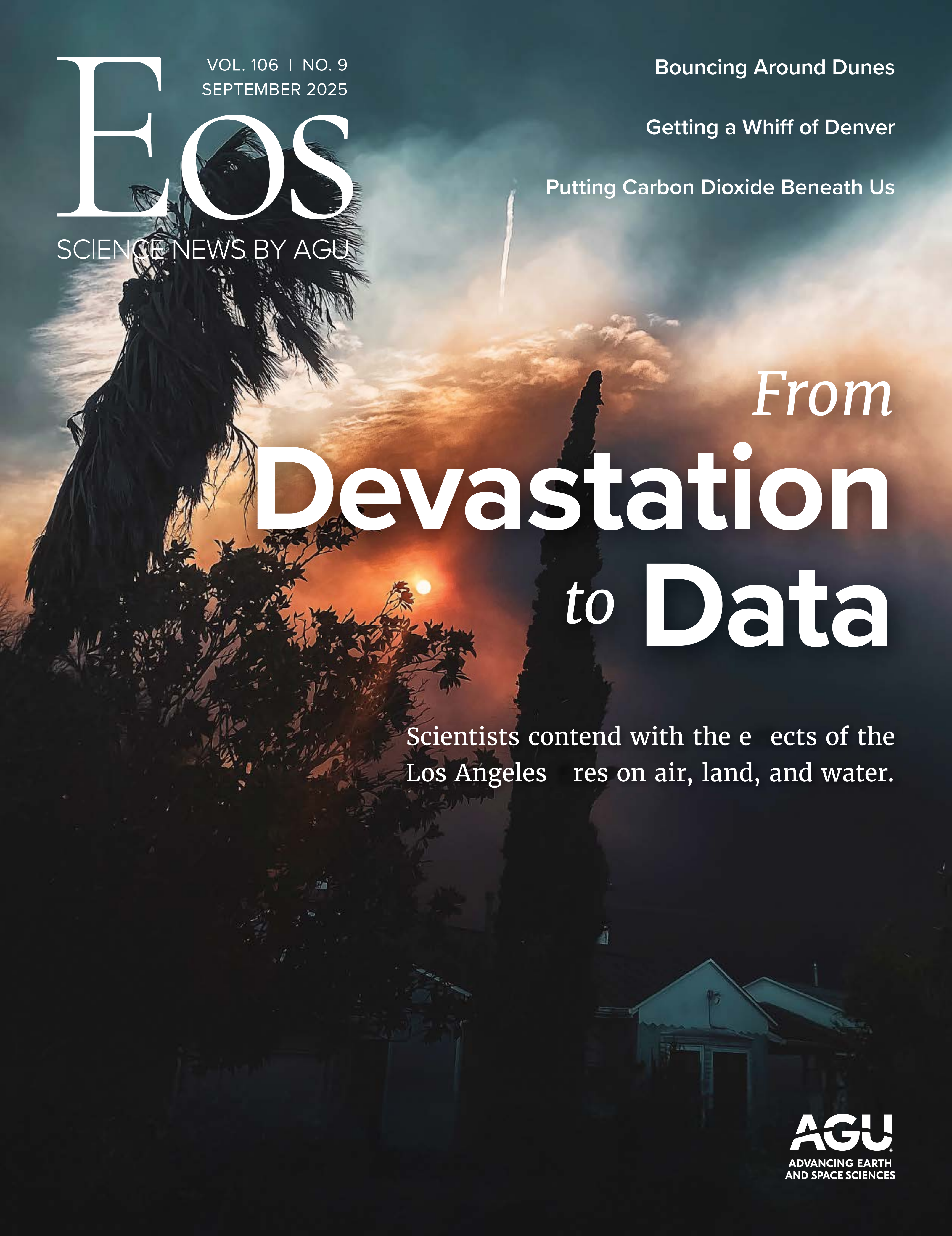

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Eos

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Getting a Whiff of Denver

Putting Carbon Dioxide Beneath Us

From Devastation *to* Data

Scientists contend with the e ects of the Los Angeles res on air, land, and water.

ADVANCING EARTH AND SPACE SCIENCES

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From the Editor

Some effects of wildfire are immediately apparent: burned vegetation, smoldering ruins, dissipating smoke. As such, the charred wakes cut through western Los Angeles County by the massive Palisades and Eaton Fires remain long after the fires were contained. This month, we shadow geoscientists investigating the less tangible, if no less serious, consequences of the fires for regional air, soil, and water quality.

• "Where There's Fire, There's Smoke," writes Emily Dieckman in her profile of air quality following the fires (p. 18)—and where there's smoke, there are unknown particulates.

• The Earth scientists consulted by Kimberly Cartier (p. 22) consider the LA fires to be a case study of "how this urban-rural interface is changing and what…recovery looks like."

• Finally, scientists are scrambling to study the effects of ash-laden water on the area's freshwater and marine ecosystems—and its water supply, writes Grace van Deelen (p. 26).

The LA fires are yet another test case for extreme events augmented by a warming climate. Thoughtful, science-based policy has never been more important, nor more relevant for the health of both our planet and ourselves.

On the Cover

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Eos

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Access to Air-Conditioning May Affect Wildfire-Related Health Outcomes

In January, wildfir s in Southern California burned tens of thousands of hectares and displaced even greater numbers of people. Still more were a ected by the resulting poor air quality: Particles in wildfir smoke that are smaller than 2.5 micrometers across, known as $PM_{2.5}$, can lead to cardiovascular and pulmonary diseases when inhaled.

The EPA website suggests that to mitigate potential health effects, people facing poor air quality who are not under evacuation orders stay indoors when possible.

"Depending on the type of building you live in, how old it is, the windows, all those kinds of things, there's always going to be transfer from outdoor pollution to indoor," explained Jennifer Stowell, a geohealth scientist at Boston University.

Because of this, the EPA also suggests using air cleaners or high-effic ncy heating, ventilation, and air-conditioning (HVAC) filters with a Minimum Efficien Reporting Value (MERV) of 13 or higher. However, little research has been done on the e ectiveness of running air conditioning (AC) to mitigate the health effect of wildfire smok .

"Since wildfire season is usually during the hottest time of the year, people without AC can be forced to choose between cooling down their homes by leaving their windows open or closing their windows to keep out smoke."

In a new study published in *Environmental Research: Health*, scientists sifted through data on more than 50 million emergency department visits during California wildfi e seasons from 2012 to 2019 (bit.ly/wildfir -AC).

Overlaying residential data on maps of wildfire related $PM_{2.5}$, they found that people living in areas with low availability of residential air-conditioning had a 22% greater risk of visiting an emergency department for a respiratory problem caused by wildfir smoke-related $PM_{2.5}$ exposure.

Access to AC Is a Factor, Regardless of Socioeconomics

The researchers used data from a national demographic survey and a predictive model that calculated the probability of residential AC ownership on the basis of demographic, socioeconomic, housing, and climate characteristics.

"It's not a perfect proxy, but it's the best that we have right now," said Stowell, who is the first author of the new study

She noted that one important limitation of the study is that it did not include data on what kinds of AC units people were most likely to have. This information would be helpful in future research because recommendations for AC usage during wildfire vary on the basis of system type. Many portable AC units bring outside air into a home, so they should be used sparingly, whereas a central HVAC system that can be set to recirculate air within a house can both filter air and help residents stay cool

Smoke from the Palisades Fire in Southern California dims the skies. Credit: greg lilly/Flickr, CC BY-NC 2.0 (bit.ly/ccbync2-0)

The team examined emergency department visits associated with wildfire smoke within subgroups classified by race, age, and social vulnerability and found that the people most likely to face health effects lived in zip codes with lower access to AC, regardless of socioeconomic status.

Stowell noted that the correlation between socioeconomic status and access to AC was weaker than the researchers initially expected. The reason for this could be that some areas of California have high socioeconomic status but a moderate climate that doesn't require AC, she said.

A Choice Between Heat and Smoke

Keith Bein, an atmospheric scientist at the University of California, Davis who was not involved in the research, said he thought the study did a good job of validating something that many researchers already assumed to be true.

When used in a well-sealed home, a high-powered HVAC system equipped with high-efficiency filters "would have a significant impact on the intrusion of outdoor air to the inside of your home," he said.

In addition to acting as a filter, an AC unit can allow people to stay cool without opening windows and letting in smoky air.

"Since wildfire season is usually during the hottest time of the year, people without AC can be forced to choose between cooling down their homes by leaving their windows open or closing their windows to keep out smoke," wrote Claire Schollaert, an environmental health scientist at the University of California, Los Angeles, in an email to *Eos*. Schollaert, who was not involved in the study, is based in Seattle, where air-conditioning is relatively uncommon. "We've experienced simultaneous smoke and heat wave events in recent years, when I've had to make this choice in my own household," she said.

Stowell said she hopes that the work will help people living in fire-prone areas better understand what steps they can take to protect their respiratory health during a fire, such as by using HVAC filters with high MERV ratings. She also hopes it will make policymakers more aware of the importance of AC access and perhaps prompt them to consider initiatives like reimbursing residents for high-quality HVAC filters

By **Emily Dieckman** (@emfurd.bsky.social), Associate Editor

Nonproducing Oil Wells May Emit More Methane Than We Thought

A new study tracked methane leaks from abandoned oil wells throughout Canada, like this one in Pioneer, Alta. Credit: Jason Woodhead/Flickr, CC BY 2.0 (bit.ly/ccby2-0)

Canada is home to more than 400,000 nonproducing oil and gas wells. These abandoned facilities still emit methane, which can contaminate water supplies and, as a greenhouse gas more potent than carbon dioxide, pollute the atmosphere. The scope of these emissions may be greater than previously understood, according to a new study (bit.ly/oil-wells-methane).

In 2023, nonproducing wells may have leaked 230 kilotons of methane, about 7 times more than the official estimates published in the government's annual National Inventory Report (NIR). The NIR, compiled by Environment and Climate Change Canada (ECCC), informs the country's greenhouse gas mitigation efforts and is submitted as part of Canada's reporting obligations to the United Nations Framework Convention on Climate Change.

Methane estimates are calculated by multiplying the total number of nonproducing wells by emissions factors determined by well characteristics such as the type of well (oil, gas, or unknown), its depth, and whether it is plugged with concrete. These emissions factors offer only a rough idea of methane leakage, however.

"It's really hard to predict emissions," said Mary Kang, a study coauthor and an associate professor of civil engineering at McGill University in Montreal. "There's a range of engineering, geological, and policy-related factors that are all playing a role in what emissions rates are observed."

Surprising Discoveries

To address this ambiguity, Kang and her colleagues measured methane flow rates at 494 nonproducing wells throughout Canada between 2018 and 2023 to define new emissions factors. Although these sites account for only a fraction of the country's abandoned wells, making uncertainty inevitable, the authors described their data as the largest set of direct methane emissions figures collected through consistent methods.

They reported that the amount of methane leaking from nonproducing wells was 1.5–16 times greater than NIR estimates.

Most of the departure from the NIR figures was driven by leaks from surface casing vents. Kang explained that emissions from these narrow slits that ring the outermost steel layer surrounding the wellbore itself indicate issues with a well's structural integrity and are trickier to manage than wellhead leaks, which may require only minor adjustments at the surface.

The researchers analyzed their measurements to gauge how different well attributes contribute to methane flow rates. Whether a well is more prone to leakage than others, they found, isn't determined by a single emissions factor such as its age or operating company.

Still, Kang was surprised to discover how much flow rates varied by province, even between wells operated by the same company in similar locations. The highest rates were observed in Alberta, where 74% of Canada's known nonproducing wells are located.

"The geology doesn't care if you're in one province or another," she said. "It's the same formation. So what's going on?"

Kang noted that each province and territory has its own emissions regulations, and policy factors might explain the difference in methane flow rates, though other geological differences such as seismic activity could also be at play.

Continuous Improvement

Complicating any study of methane emissions from nonproducing wells is the large number of sites abandoned before contemporary recordkeeping practices were established, said Maurice Dusseault, a professor emeritus of engineering geology at the University of Waterloo in Ontario, who was not involved in the research.

A history of well abandonment practices in Ontario illustrates how hard it is to identify older wells throughout Canada (bit.ly/orphan-wells). The first oil well in Ontario was drilled in 1858, but records were not mandatory in the province until 60 years later. And surface casings were often removed when a well closed so that the steel could be reused. This means that some legacy wells cannot be detected with conventional magnetic techniques.

Still, Dusseault praised the researchers for their rigorous pursuit of better emissions estimates.

Kang and her colleagues returned to the fi ld this year and last year, measuring methane fl w at additional known well sites and revisiting previous sites to observe how leakage changes over time.

Meanwhile, their work is already affec ing how the country approaches methane emissions. "Continuous improvement is a key principle of Canada's NIR," wrote ECCC spokesperson Cecelia Parsons in an email, noting that the improvement plan in the 2025 NIR draws from the new research.

By **Lauren Schneider** (@laur_insider), Science Writer

Fallowed Fields Are Fueling California's Dust Problem

Researchers found that most anthropogenic dust in California comes from unplanted fields. Credit: Mark Stebnicki/Pexels

California is responsible for more than a third of the vegetables and three quarters of the fruits and nuts grown in the United States. But water constraints are leaving more and more fi lds unplanted, or "fallowed," particularly in the state's famed farming hub, the Central Valley.

In a study published in *Communications Earth and Environment*, researchers showed that these fallowed agricultural lands are producing a differe t problem: dust storms, which can cause road accidents and health problems and can have far-reaching environmental impacts (bit.ly/fallow-fi ld-dust). Using remote sensing methods, the team found that 88% of anthropogenic dust events in the state come from fallowed farmland.

California's frequent droughts could mean a rise in fallowed farmland. In 2014, the state passed the Sustainable Groundwater Management Act (SGMA), a policy aimed at ensuring the sustainability of groundwater resources. A report by the Public Policy Institute of California suggested that to meet the SGMA's demands, farmers may need to fallow hundreds of thousands of additional hectares, potentially worsening dust events (bit.ly/PPIC-report).

Tracking Down Agricultural Dust

Dust can come from both natural sources, such as when wind blows across a desert, and anthropogenic sources, such as when transportation, construction, or agricultural activities kick up particles.

Previous studies identified agriculture as a significant source of human-generated dust, but study author Adeyemi Adebiyi and his colleagues wanted to narrow down which agricultural practices produced the most (bit.ly/agricultural-dust).

"If you stop irrigating the land, it becomes dry, and we're already in a dry climate. It's easy for it to become a new dust source."

Fallowed land was a logical culprit. "If you stop irrigating the land, it becomes dry, and we're already in a dry climate," said Adebiyi, an atmospheric scientist at the University of California, Merced. "It's easy for it to become a new dust source."

The researchers started by pinpointing fallowed land across California between 2008 and 2022 using U.S. Department of Agriculture datasets. The data showed that 77% of the state's fallowed land was in the Central Valley.

The team then examined NASA satellite images of atmospheric aerosols, identifying which aerosols were dust particles on the basis of the way they scatter light. When they overlaid the regions that regularly experienced dust events with the agricultural data, they saw that dust events were tightly associated with fallowed fields.

The problem appears to be getting worse. Between 2008 and 2022, both the area of fallowed land and corresponding dust levels have increased: In this period, the amount of dust in the atmosphere over the Central Valley grew by about 36% per decade.

Having grown up in California and spent the first decade of his career studying dust in the Central Valley, Thomas Gill, an Earth scientist at the University of Texas at El Paso who wasn't involved in the study, has long worried that land use changes could lead to dust issues. "This study by Adebiyi et al., unfortunately, shows that my worries have been coming true," he said.

Daniel Tong, an atmospheric scientist at George Mason University in Virginia who also wasn't involved in the study, agreed that the work provides some much-needed conclusive data on the connection between land use and dust levels. "This is a very useful study," he said.

Adebiyi's team used additional remote sensing data to determine that compared with nearby nonfallowed land, fallowed fields have lower soil moisture and are about 4.2°C hotter. Combined with a lack of vegetation, these factors work together to make such areas more prone to wind erosion. "These fallowed land locations are emblematic of the properties you would normally see in a typical desert-type location," Adebiyi said.

Far-Reaching Effects

Dust from fallowed fields has wide-reaching consequences. "California is already the state with the largest number of fatalities caused by dust storms," said Tong, who authored a 2023 study about windblown dust fatalities in the United States (bit.ly/dust-deaths). One concern, he said, is that more dust storms could increase road accidents. Dust also contributes to respiratory problems and cardiovascular disease and can carry the *Coccidioides* fungus, which causes the dangerous infection valley fever. Cases of valley fever increased by 800% in California between 2000 and 2018.

"There's also been a great population increase in the Central Valley," Gill said. "So not only do you have more particulate matter, but you have more people living there who are vulnerable to its effects."

Fallowed fields and the dust they produce may also work counter to the groundwater management goals of the SGMA. The Central Valley dust blows east into the Sierra Nevada Mountains, where it speeds snowmelt, a significant reservoir of water for the state. The researchers also found that the heat concentrated in fallowed fields can spread out to nearby fields, causing surrounding crops to need more water.

"It's a double whammy," Adebiyi said.

He noted the importance of preventing fields from becoming completely bare while still conserving water. One strategy is to plant native, drought-resistant plants that protect the soil from wind erosion without needing much irrigation.

One strategy is to plant native, drought-resistant plants that protect the soil from wind erosion without needing much irrigation.

The researchers are now conducting similar studies on the connection between fallowed lands and dust in other agricultural states, such as Kansas, Montana, and Washington. Their findings suggest that addressing dust problems will become increasingly important nationwide.

"The implications are beyond California," Adebiyi said. "They're across the United States."

By **Andrew Chapman** (@andrewchapman.bsky.social), Science Writer

Mini Dunes Form When Sand Stops Bouncing

Next time you explore a beach or a desert, look down at the sand. You might spot patches of small ripples just a few centimeters tall. Wind can shape these miniature dunes in less than half an hour and blow them away just as quickly. Unlike the processes that form larger dunes that define desert landscapes and shorelines, those that shape mini dunes have eluded researchers.

"There have been some observations of such small, meter-scale bedforms but not many quantitative studies," said Camille Rambert, a doctoral student at École Supérieure de Physique et de Chimie Industrielles de la Ville de Paris and the first author of the new research. "And there have not been any models to explain their formation."

Recently, a group of researchers used high-resolution laser scanning in the Namib Desert in Namibia to watch how tiny dunes form. Those scans informed dune formation models, which found that the key factor is how sand grains bounce on smooth versus grainy surfaces.

Blowing in the Wind

Although small sand bedforms are a common phenomenon in most sandy places, their ephemeral nature has made it challenging for geomorphologists to decode what makes a small dune form where only flat featureless sand had existed.

A team of researchers, including Rambert, set out to the Namib Desert in coastal southern Africa seeking to understand how these bedforms take shape. The team used a laser scanner sitting on the surface to collect repeated high-resolution topographic maps of nearby flat areas, roughly 5 meters wide × 5 meters long, nestled between larger dunes. The scanner measured the distance from the laser emitter to the ground, as well as near-surface wind speed and direction.

The team could detect vertical changes to the surface of about half a millimeter and horizontal changes of about a centimeter.

"More sand can be transported on a consolidated surface than on the erodible surface."

Geomorphologist Jo Nield uses a high-resolution laser scanner to study small dunes in Namibia's Namib Desert. Credit: Matthew Baddock

"From those measurements, we can deduce how bedforms evolve," Rambert said. "Do they grow and migrate, or do they shrink?"

The group developed a mini dune formation model on the basis of well-established physics governing large dune formation, but with a key twist: The small dunes started on consolidated surfaces like gravel or hard-packed sand rather than on an erodible foundation such as loose sand. That di erence altered how far wind could transport a sand grain and whether the grain bounced or stuck when it landed.

"This difference in surface materials affects the sand transport," Rambert said. "More sand can be transported on a consolidated surface than on the erodible surface."

If a grain wasn't swept away by the next gust of wind, its presence made the surface a little rougher and more likely to trap the next grain of sand—and the next. The gradual buildup of grains into tiny bumps altered near-surface wind patterns, which helped trap even more sand and created distinctive dune patterns in the bedform.

These patches of mini dunes disappeared when a strong enough wind blew the sand grains o the consolidated surface. If the wind had been gentler, those patches might have continued growing.

The researchers found that their model observations accurately portrayed what they saw in the laser scans from the Namib. They published these results in *Proceedings of the National Academy of Sciences of the United States of America* (bit.ly/mini-dunes).

"This study highlights the importance of bed heterogeneities, such as whether a surface is sand covered or not, in how meter-scale bedforms evolve," Joel Davis, a planetary geologist at Imperial College London in the United Kingdom, wrote in an email. "It's intriguing [that] those small-scale variations in dynamics...could influence whether these small bedforms become a larger dune eld, or simply disappear." Davis was not involved with the research.

Dunes Beyond Earth

Scientists have discovered dunes on both Mars and Saturn's moon Titan, but the instruments that have explored those distant worlds are far less advanced than the laser scanners on Earth.

"Studies like these, on the dynamics of Earth dunes, are particularly useful for investigating dunes in a planetary setting, such as on Mars or Titan," wrote Davis, who studies Martian dunes.

Some of Mars's dunes form inside craters, which presumably trap a lot of loose sand, but they are also found outside the craters in less sandy areas. "We don't really know why they have formed in these locations, but perhaps bed heterogeneities are a control on this," Davis wrote. "It would be interesting to see if we could identify any metre-scale bedforms in these expansive interdune areas of Mars...similar to the Namibia examples."

What's more, Earth's dunes tend to be either very short (centimeters) or very long (tens to hundreds of meters). Though hundreds of dunes near Mars's north pole are the same shape as Earth dunes, most of them are 1–2 meters long. Planetary geologists are still puzzling over why.

"This is a hotly debated topic that is rapidly evolving," wrote Lior Rubanenko in an email. Rubanenko, a planetary surfaces researcher at the Planetary Science Institute in Tucson, Ariz., was not involved with the new research.

"Mars, and also other planetary bodies such as Titan, are, in a way, laboratories where the physical conditions are di erent than on Earth—di erent atmospheric density, di erent grain size and material type," Rubanenko wrote. "This allows us to conduct and observe 'planet-size' experiments which challenge our current paradigms."

"Mars, and also other planetary bodies such as Titan, are, in a way, laboratories where the physical conditions are different than on Earth"

"Comparing observations of dunes between these planets can help us better understand the mechanisms that govern sand transport and dune formation," he added.

By **Kimberly M. S. Cartier** (@astrokimcartier.bsky.social), Staff Writer

Some Tropical Trees Benefit from Lightning Strikes

Every now and then, some trees apparently just need a jolt.

When struck by lightning, the large-crowned *Dipteryx oleifera* sustains minimal damage, whereas the trees and parasitic vines in its immediate vicinity often wither away.

That clearing out of competing vegetation results in a nearly fifteenfold boost in lifetime seed production for *D. oleifera*, researchers estimated.

An Instrumented Forest

Barro Colorado Island, in central Panama, is home to what researchers who work in the area call "one of the best-studied patches of tropical forest on earth." That's because cameras and devices to measure electric fie ds are constantly surveying the forest from atop a series of towers, each about 40 meters high. Those instruments can reveal, among other information, the precise locations of lightning strikes.

"This is the only place on Earth where we have consistent lightning tracking data with the precision needed to know [whether a strike] hit a patch of forest," said Evan Gora, an ecologist at the Cary Institute of Ecosystem Studies and the Smithsonian Tropical Research Institute.

Such infrastructure is key to locating trees that have been struck by lightning, said Gabriel Arellano, a forest ecologist at the University of Michigan in Ann Arbor who was not involved in the research.

"It's very difficul to monitor lightning strikes and find the specific trees that were affected," he explained, because a strike to a tropical tree rarely leads to a fir . More commonly, tropical trees hit by lightning look largely undamaged but die off slowly over a period of months.

Follow the Flashes

To better understand how large tropical trees are affected by lightning strikes, Gora and his colleagues examined 94 lightning strikes to 93 unique trees on Barro Colorado Island between 2014 and 2019. In 2021, the researchers traveled to the island to collect both ground- and drone-based imagery of each directly struck tree and its environs.

They recorded six metrics about the condition of each directly struck tree and its cadre of parasitic woody vines, known as lianas—including crown loss, trunk damage, and percent of the crown infested with lianas. Lianas colonize the crowns of many tropical trees, using them for structure and competing with them for light. Think of someone sitting next to you and snatching half of every bite of food you take, Gora said. "That's effe tively what these lianas are doing."

The team also surveyed the trees surrounding each directly struck tree. The electrical current of a lightning strike can travel through the air and pass through nearby trees as well, explained Gora. Where a struck tree's branches are closest to its neighbors, "the ends of its branches and its neighbors' will die," Gora said. "You'll see dozens of those locations."

Thriving After Lightning

On average, the researchers found that about a quarter of trees directly struck by lightning died.

But when they divided up their sample by tree species, *D. oleifera* (more commonly known as the almendro or tonka bean tree) stood out for its uncanny ability to survive lightning strikes.

The nine *D. oleifera* trees in the team's sample consistently survived lightning strikes, whereas their lianas and immediate

A D. oleifera *tree in Panama is shown just after being struck by lightning in 2019 (left) and 2 years later (right). The tree survived the strike, but its parasitic vines and some of its neighbors did not. Credit: Evan Gora* neighbors did not fare so well. “There was a pretty substantial amount of damage in the area, but not to the directly struck tree,” said Gora of the species. “This one never died.”

Ten other species in the researchers’ cohort of trees also exhibited no mortality after being struck by lightning, but those samples were all too small—one or two individuals—to draw any robust conclusions from.

Gora and his collaborators estimated that large *D. oleifera* trees are struck by lightning an average of 5 times during their roughly 300-year lifespan. This species’ ability to survive those events while lianas and neighboring trees often died back should result in overall reduced competition for nutrients and sunlight, the team reasoned.

Using models of tree growth and reproductive capacity, the researchers estimated that *D. oleifera* reaped substantial benefit from being struck by lightning—particularly in regard to fecundity, or the number of seeds produced over a tree’s lifetime.

“The ability to survive lightning increases their fecundity fourteenfold,” Gora said.

The researchers furthermore showed that *D. oleifera* tended to be both taller and wider at its crown than many other tropical tree species on Barro Colorado Island. Previous work by Gora and his colleagues has shown that taller trees are particularly at risk of getting struck by lightning.

It’s therefore conceivable that *D. oleifera* are essentially evolving to be better lightning rods, said Gora. “Maybe lightning is shaping not just the dynamics of our forests but also their evolution.”

These results were published in *New Phytologist* (bit.ly/lightning-trees).

Gora and his collaborators hypothesized that the physiology of *D. oleifera* must confer some protection against the massive amount of current imparted by a lightning strike. Previous work by Gora and other researchers has suggested that *D. oleifera* is more conductive than average; higher levels of conductivity mean less resistance and therefore less internal heating (bit.ly/tree-conductivity). “We think that how conductive a tree is, is really important to whether it dies,” said Gora.

Continuing to ferret out other lightning-hardy tree species will be important for understanding how forests evolve over time. And that’s where more data will be useful, said Arellano. “I wouldn’t be surprised if we find many other species.

By **Katherine Kornei** (@KatherineKornei), Science Writer

Denver’s Stinkiest Air Is Concentrated in Less Privileged Neighborhoods

Denver’s smells are not equally distributed. Credit: Nils Huenerfuerst, Unsplash

The skunky smell of pot smoke. Burning stenches from a pet food factory. Smoke from construction sites. These are the smells to which communities of color and lower income people in Denver are disproportionately exposed at home and at work, according to a new study.

The study, published in the *Journal of Exposure Science and Environmental Epidemiology*, is one of the first to examine the environmental justice dimensions of bad odors in an urban setting (bit.ly/smelly-Denver).

In recent years, a wealth of research has shown that people of color and those with lower incomes are exposed to more air pollution, including nitrogen oxides and particulate matter. Air pollution causes or exacerbates cardiovascular and respiratory illnesses, among other health problems, and increases the overall risk of death.

Odors pose real health risks.

Odors are more challenging to measure than other kinds of air pollution because they are chemically complex mixtures that dissipate quickly. “Odors are often ignored because they’re difficult to study and regulate,” said Arbor Quist, an environmental epidemiologist at the Ohio State University who was not involved with the research.

Whereas other kinds of air pollution in the United States are limited by federal laws and regulated at the state level, smells are typically regulated under local nuisance laws.

Though somewhat subjective—some folks don’t mind a neighbor toking up—odors can have a big impact on how people experience their environment and whether they feel safe. Bad smells can limit people’s enjoyment of their homes and yards and reduce property values.

Odors are more than a nuisance: they pose real health risks. Exposure to foul smells is associated with headache, elevated blood pressure, irritated eyes and throat, nausea, and stress, among other ills.

University of Colorado Denver urban planning researcher Priyanka deSouza said that local regulation of odors gives municipalities an opportunity to intervene in environmental health. “Odor is one of the ways municipalities can take action on air pollution,” she said.

Previous research on ambient odor air pollution has focused on point sources, including chemical spills and concentrated animal-feeding operations such as industrial hog farms. DeSouza said that Denver's unusually robust odor enforcement system made it possible to study the environmental justice dimensions of smelly air over a large geographical area.

Making a Stink

The city maintains a database of odor complaints that includes a description of the smell and the address of the complaint.

DeSouza's team used machine learning to identify themes in complaints made from 2014 to 2023. They found four major clusters: smells related to a Purina pet food factory, smells from a neighbor's property, reports of smoke from construction and other work, and complaints about marijuana dispensaries or various retail or industrial sources.

They used the text of the odor complaints and the locations of the complaints to deduce the likely source of the odor. For instance, complaints about the pet food factory often included the words "night," "dog," "bad," and "burn." Marijuana-related complaints frequently used the words "strong" and "fume."

They also matched complaint locations against the addresses of 265 facilities that have been required by the city to come up with odor control plans for reasons including the nature of their business or because five or more complaints have been filed about them within 30 days. (Growing, processing, or manufacturing marijuana occurs in 257 of these facilities.)

Less privileged census blocks—those with lower property values, higher percentages of non-white workers and residents, as well as residents with less formal education and lower median incomes—were more likely to contain a potentially smelly facility, according to the analysis. DeSouza said this is likely due to structural racism and historical redlining in Denver.

The facilities are concentrated in a part of the city that is isolated by two major freeways. Previous research has shown that people in these neighborhoods are exposed to more traffic-related air pollution, and that people of color, particularly Hispanic and Latino populations, are more likely to live there (bit.ly/Denver-pollution).

Yet people living and working in those areas weren't more likely to register a complaint about bad smells than people in other parts of the city.

In fact, most of the complaints came from parts of the city that are gentrifying. DeSouza said it's not clear why people who live or work near a stinky facility aren't more likely to complain than people who live farther away from one.

It may be that wind is carrying smells to more affluent neighborhoods, where more privileged people are more aware of Denver's laws and feel empowered to complain.

The study team, which includes researchers from the city's public health department, is continuing to analyze odors in the city. The next step is to integrate information about wind speed and direction with the odor complaints.

Quist said that the study is unique in that it factors in potential exposures in the workplace, where people spend a large part of their day. Workplace exposures can also have health effects that aren't captured in research that looks only at where people live. "A lot of research has focused on residential disparities," she said, adding that the inclusion in the analysis of facilities that have had to submit odor-monitoring plans is also significant. "This is an important paper," she said.

"Odors are often ignored because they're difficult to study and regulate."

DeSouza said she suspects that people who live and work near smelly facilities may not be complaining because they feel disenfranchised. "People are resigned to odors; they have been living there a long time, and they don't feel they have a voice." If residents in less privileged neighborhoods were to successfully lodge an odor complaint and get results, it may make them feel more connected in general to the city government, she added.

"I'm really interested in supporting policy action," she said. "We're trying to get residents to be aware that they can complain."

By **Katherine Bourzac,** Science Writer

Climate Change Made Extreme Heat Days More Likely

Sixty-seven extreme heat events occurred between May 2024 and May 2025. All of these events—including a deadly Mediterranean heat wave in July 2024, extreme heat in South Sudan in February 2025, and an unprecedented March 2025 heat wave in central Asia—broke temperature records, caused major harm to people or property, or did both.

According to an analysis published in May, each of these extreme events was made more likely by climate change (bit.ly/extreme-heat-events). The number of days with extreme heat is now at least double what it would have been without climate change in 195 countries and territories. Climate change added at least an extra month of extreme heat in the past year for 4 billion people—half the world's population.

"There's really no corner of the globe that has been untouched by climate-driven extreme heat," said Kristina Dahl, a researcher at the climate change research and communication nonprofit Climate Central who was part of the report team. "Half the world's population is experiencing an extra month of extreme heat. The numbers are staggering."

"Sixty-seven extreme heat events occurred between May 2024 and May 2025."

The authors of the report say that it serves as a stark reminder of the dangers of climate change and the urgent need for better early-warning systems, heat action plans, and long-term planning for heat events around the globe.

The report was created by scientists at Climate Central; World Weather Attribution, a climate research group; and the Red Cross Red Crescent Climate Centre.

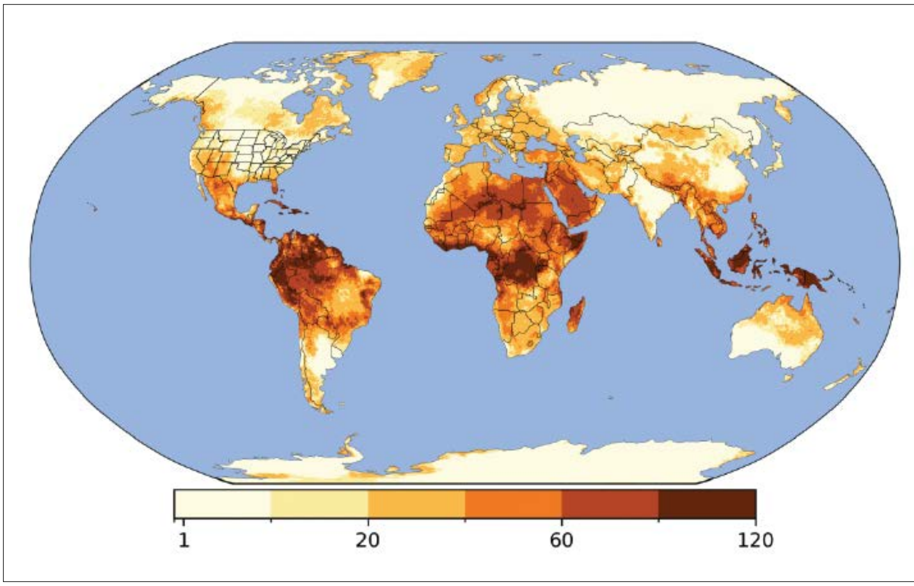
More Frequent Heat

In the new report, scientists calculated the number of days between 1 May 2024 and 1 May 2025 in which temperatures in a country or territory were above 90% of the historical temperatures from 1991 to 2020. Then they analyzed how many of these extreme heat days were made more likely by climate

Between May 2024 and May 2025, climate change added an extra month of extreme heat for half the world's population. Credit: James Day/Unsplash change using the climate shift index, a methodology developed by Climate Central that compares actual temperatures to a simulated world without human-caused climate change.

The team found that climate change made extreme heat events more likely in every country.

Of all the countries and territories, the Federated States of Micronesia added the greatest number of extreme heat days (157) due to climate change, and Aruba had the most extreme heat days in total (187) over the study period. The report's authors estimate that in a world without climate change, Aruba would have experienced just 45 days of extreme heat.



The authors of the report calculated the number of extreme heat days (denoted by the colors in the scale bar) added by climate change in the past year. Credit: World Weather Attribution, Climate Central, and Red Cross Red Crescent Climate Centre

"There's really no corner of the globe that has been untouched by climate-driven extreme heat."

Other Caribbean and Oceanian islands were among the countries and territories most strongly affected by climate change

The United States experienced 46 days of extreme heat, 24 of which were added by climate change.

Of the 67 extreme heat events that occurred in the past year, the one most influenced by climate change was a heat wave that struck Pacific islands in May 2024. Researchers estimated that the event was made at least 69 times more likely by climate change.

The findings are not a surprise to Nick Leach, a climate scientist at the University of Oxford who was not involved in the report. "We've understood the impact of climate change on temperature and extreme heat for quite some time...[including] how it's increasing the frequency and intensity of extreme heat," he said. Research has consistently shown that heat events on Earth are made more likely, more intense, and longer lasting as a result of climate change (bit.ly/extreme-weather-attribution).

Leach said that the new report gives a good overview of how climate change is influencing heat waves worldwide. However, defining extreme heat as temperatures above the 1991–2020 90th percentile creates a relatively broad analysis, he said. Studies using a stricter definition of extreme heat may be more relevant to the impacts of extreme heat, and studies estimating those impacts are typically more policy relevant, he said.

"Only comprehensive mitigation, through phasing out fossil fuels, will limit the severity of future heat-related harms."

The report's authors chose the 90% threshold because heat-related illness and mortality begin to increase at those temperatures, Dahl said.

Taking Action on Heat Waves

For rising global temperatures, "the causes are well known," the report's authors wrote. Burning of fossil fuels such as coal, oil, and gas has released enough greenhouse gases to warm the planet by 1.3°C (2.34°F; calculated as a 5-year average); 2024 marked the first year with average global temperatures exceeding 1.5°C (2.7°F) above preindustrial temperatures.

"Only comprehensive mitigation, through phasing out fossil fuels, will limit the severity of future heat-related harms," the authors wrote.

Extreme heat puts strain on the human body as it tries to cool itself. This strain can worsen chronic conditions such as cardiovascular problems, mental health problems, and diabetes and can cause heat exhaustion and heat stroke, which can be deadly.

Extreme heat is particularly dangerous for already-vulnerable populations, including those with preexisting health conditions, low-income populations lacking access to cool shelter, and outdoor workers.

By **Grace van Deelen** (@gvd.bsky.social), Staff Writer

Real Climate Solutions Are Beneath Us

As the world blows past 1.5°C of anthropogenic warming and looks increasingly likely to hit 2.6°C–3.1°C by the end of the century, plenty of controversy still exists, even among geoscientists, about how to slow, stop, or reverse the rapid climate change we are causing. As so many studies have documented, such warming will cause inundation of many coastal cities, trillions of dollars in damage from extreme weather, widespread species extinctions, and unrelenting heat waves. It will also fundamentally threaten financia sectors and economies at all scales.

The scale of mitigation needed to keep warming to below 2°C–3°C goes beyond reducing annual emissions.

To mitigate these outcomes, humanity's first priority should be to drastically reduce its annual emissions of roughly 40 gigatons (40 billion metric tons) of carbon dioxide (CO_2), the greenhouse gas most responsible for driving warming. Without this reduction, other measures will be only modestly effective at best

But unfortunately, at this point, the scale of mitigation needed to keep warming to below 2°C–3°C goes beyond reducing annual emissions. We must also remove and store carbon that has accumulated in the atmosphere.

Reducing Annual Emissions Isn't Enough

The need for emissions reductions has been articulated accurately, passionately, and compellingly for decades. Yet global emissions continue to set new records, increasing 1% in each of the past 3 years.

Meanwhile, even as clean and renewable energy (CRE) growth has set its own records, global fossil fuel energy consumption has continued to rise, with oil, gas, and coal still accounting for more than 81% of total energy consumption (only 4% less than 20 years ago).

Even under favorable political conditions, CRE consumption, which as a share of global primary energy consumption is growing at roughly 1% per year, has a long way to go to catch up to the roughly 2% annual growth in global energy consumption. Once CRE growth catches up, it could still take decades to reach something like global energy decarbonization, during which we would emit several times more CO_2 than we already have.

Not only has focusing on annual emissions failed to reduce them, but it's also not our annual emissions that are causing the 1.5°C of warming we're witnessing. It's how much CO_2 we have already emitted.

The cumulative emissions of 1.8 trillion tons (1,800 gigatons) of CO_2 from energy and industry taken from geologic reservoirs and dumped into the atmosphere will stay there (and in the ocean) for thousands of years.

Even on that happy day when we finally start reducing emissions, we will be the farthest we have ever been from solving the problem, and in fact, we will still be adding to it.

A Big Opportunity

Scientists and practitioners across many disciplines and sectors can play roles in climate change mitigation. Research in the geosciences is fundamental to understanding carbon reservoirs and fl xes between them, as well as past, present, and possible future e ects on climate. But it seems clear by now that more climate science, and even better communication of it, is unlikely to inspire the collective or political action needed to activate significant mitigation. So what else can geoscientists offer

Some see a role in helping to extract natural resources to fi l the staggering projected demand for metals such as copper and rare earth elements and to promote the kind of technology-driven sustainability invoked by the mining industry.

Geoscientists also contribute to informing approaches to adaptation and resilience, though neither of those constitute mitigation and, in the long run, they are much more expensive than mitigation. The economic impacts of warming have been estimated to be about 12% of global GDP (gross domestic product) per 1°C of warming, and our current trajectory is projected to reduce global GDP by as much as 40% by 2100, with much greater losses in some regions.

The biggest opportunity—and perhaps the biggest responsibility—for geoscientists to contribute to mitigation is through facilitating durable carbon dioxide removal (CDR). Concerns are sometimes raised about CDR as a form of climate intervention, or geoengineering, yet it is far less risky than the

Calcite precipitated in basaltic bedrock, as seen here in Fort George Canyon, located in British Columbia, stores carbon durably. Credit: Peter Reiners centuries-long geoengineering experiment of using the atmosphere as a sewer. Indeed, removing gigatons of CO_2 per year is essential to net zero strategies and avoiding disastrous amounts of warming, as unequivocally stated by the Intergovernmental Panel on Climate Change, the Energy Transitions Commission, and the American Physical Society.

Keys to Carbon Removal

Three principles are generally considered fundamental to CDR. First, CO_2 already in the atmosphere must be taken out. This principle distinguishes it from point source carbon capture and storage (CCS), which simply reduces new CO_2 emissions from fossil fuel energy and industry sources while competing with clean energy.

Many approaches to CDR exist. Direct air capture (DAC), for example, is a rapidly developing method in which CO_2 is pulled straight from the atmosphere. Biomass carbon removal and storage (BiCRS) methods capture a fraction of the 480 gigatons of CO_2 that plants naturally absorb each year and prevent it from cycling back to the atmosphere by converting biomass to forms that can be isolated and stored.

Other approaches focus on managing ecosystems to stimulate more removal of CO_2 than would occur naturally, the second principle of CDR. Examples include various strategies for enhanced rock weathering in croplands or forests and for marine CDR, such as using nutrients to promote biomass growth and raising the alkalinity of seawater so it pulls more CO_2 from the air.

Third, and most important, is the fact that however CO_2 is removed, it must be stored durably, with minimal likelihood of returning to the atmosphere for a long time. Using captured carbon to create marketable stu like fertilizers and chemicals may seem economically savvy, but it's not a durable approach. The entire global industrial demand for CO_2 is less than 1% of our annual emissions, and much of this carbon goes right back to the atmosphere or is used for enhanced oil recovery (EOR) to extract more petroleum.

So-called nature- or land-based CDR approaches like aff restation, agricultural practices, and soil management are intuitively appealing alternatives that can remove and store CO_2 and, if done right, improve ecosystem health. But these methods are also not very durable. Land plants hold a mass of carbon (~1,650 gigatons in all terrestrial vegetation) almost equivalent to our cumulative emissions, and soils hold 4 times more. However, most of the carbon in plants and soil cycles back to the atmosphere through natural decomposition and disturbances on timescales of years to decades.

Furthermore, anthropogenic warming-driven disturbances to forests and soils, which are becoming bigger and more frequent, may further weaken the durability of nature- and land-based CDR. The 2023 Canadian wildfires alone released almost 3 gigatons of CO_2, almost 4 times the annual emissions of global aviation. (These disturbances also threaten to destabilize ancient peat and permafrost, which globally hold a carbon stock equivalent to 5 times our cumulative emissions—yet another reason to pursue CDR.) So although nature- and land-based CDR provides collateral benefits and is inexpensive and ready to deploy, in the context of net zero emissions accounting, it makes sense only as an o set for analogous biogenic (e.g., land use and forestry) emissions, not for the 82% coming mostly from fossil fuel burning.

Apart from the three fundamental principles of CDR, the potential to apply approaches at a scale large enough to make a significant di erence is a key consideration. The scalability of DAC, for example, faces energy and expense concerns. And making a dent in the cumulative emissions load with nature- and land-based approaches like afforestation would require unreasonably huge amounts of land that already has many other competing uses.

Meanwhile, the ocean, which already holds about 140,000 gigatons of CO_2, o ers potential because of its vast size as well as its longer residence times compared with other near-surface reservoirs, notwithstanding questions about its future warming-induced durability.

The Substantial Subsurface

CDR approaches are diverse and evolving, but it is becoming increasingly clear that for both capacity and durability, it's hard to beat subsurface geologic reservoirs. The amount of carbon in Earth's crust is millions of times larger than in all near-surface reservoirs

The Mammoth direct air capture facility in Iceland, operated by Climeworks, began pulling carbon dioxide from the air in 2024. Credit: ©Climeworks

Carbon dioxide removal is far less risky than the centuries-long geoengineering experiment of using the atmosphere as a sewer.

combined, and it stays down there orders of magnitude longer.

Estimates suggest that enough subsurface storage capacity exists for at least tens of thousands of gigatons of recaptured CO_2, and recent feasibility analyses showed that achieving storage rates of at least 5–6 gigatons of CO_2 per year by 2050 is realistic and consistent with current technological trajectories.

Realizing gigaton-scale CDR will be a major challenge—one that requires building support and further developing the needed methods. A few approaches show the most potential.

Captured CO_2 can be compressed and injected as a supercritical fluid (sCO_2) into saline aquifers or depleted oil and gas fields deep below fresh groundwater and overlain by impermeable rocks. This approach will likely be the main storage route for CO_2 captured by DAC, as well as by emissions-sourced CCS, and it is something we already know how to do from decades of practice (albeit mostly for EOR). Under the right conditions, several trapping mechanisms minimize the chances of escape for CO_2 stored this way.

Another promising approach is direct mineralization, which involves injecting CO_2, either as a supercritical fluid or dissolved in water, into reactive mafic and ultramafic rocks to form carbonate minerals. Use of this method is ramping up to scales of millions of tons per year in some places.

Other, relatively new but promising BiCRS methods that leverage the carbon-capturing power of plants involve subsurface injection (often into depleted oil and gas reservoirs) of biomass-derived carbon in the form of bio-oil, pyrolyzed agricultural or forest waste, or other organic (e.g., municipal or livestock) waste.

Challenges for Geoscientists

Given our still-increasing emissions trajectory and our need for scalable carbon storage solutions, it's hard to imagine that CDR through durable subsurface storage won't grow in the next few decades, especially if carbon policies and incentives shift from favoring emissions reductions and avoidance to removals. With the fossil fuel industry's interest in propping up its energy production assets, CDR's cousin CCS may also proliferate. Either way, it is likely that the subsurface will increasingly be the focus of attention and action.

It is time for geoscientists to step up and take on a central role in advancing mitigation solutions.

As this focus grows, we must recognize that the subsurface is an increasingly busy place, where water, energy, and mineral resources—not to mention as much as 90% of all microbial life and 10%–20% of all biomass on the planet—interact. This is where the geosciences come in.

At sites like this one, the Icelandic company Carbfix injects carbon dioxide dissolved in water into underground geologic reservoirs, where it reacts with rock to form carbonate minerals. Credit: Siljaye/Wikimedia Commons, CC BY-SA 4.0 (bit.ly/ccbysa4-0)

After a century of the fossil fuel industry directly and indirectly defining much of the discipline's research and educational emphases, it is time for geoscientists to step up and take on a central role in advancing mitigation solutions, specifically durable carbon storage and responsible subsurface management.

There will be no shortage of challenges. Mining, geothermal, and oil and gas production and disposal activities have already increased subsurface fluid fluxes well beyond pre-Anthropocene rates, and projections of these fluxes in 2050 are many times higher. In the United States alone, in addition to the more than 4 million oil and gas production wells, almost a million underground injection wells dispose of a huge variety of both hazardous and nonhazardous materials and waste.

Scaling subsurface carbon storage to gigatons per year will mean injecting massive quantities of a variety of CO_2 and carbon-bearing solutions into a wide range of geologic reservoirs and associated waters, creating not only engineering challenges but also challenges of illuminating the efficacy and hazards of injections under many different conditions. Although we understand relatively well how sCO_2 and dissolved CO_2 behave in some types of subsurface environments, we know almost nothing about the behaviors of novel carbon storage fluids like bio-oil and slurried or torrefied biowaste.

Geoscience's role in responsible subsurface management will also involve providing new perspectives on basins and igneous provinces to address questions of rock permeability and composition that are important for durable storage, as well as for assessing critical risk factors. Risk factors include how fluids migrate and interact with faults and other permeability barriers, the potential for mineral dissolution to mobilize metals and change fluid fluxes, fresh groundwater contamination, and induced seismicity.

Much of this work will necessarily be transdisciplinary, challenging scientists accustomed to traditional and disciplinary emphases to develop shared language and approaches. For example, understanding how carbon storage affects microbial communities (e.g., through species diversity and methanogenesis) and human communities and translating this understanding through public engagement and policies will require geoscientists to collaborate and communicate with biologists, engineers, planners,

Hydrogeochemists Ji-Hyun Kim and Rebecca Tyne sample groundwater in the Paradox Basin in Utah to understand connections among subsurface rocks, fluids, and microbial communities and how they may be affected by anthropogenic activities, including carbon storage. Credit: Jennifer McIntosh

industry, governments, Indigenous communities, and others.

Rising to the Occasion

Durable carbon storage for CDR may be beneath us literally, but we must not let it be beneath us figuratively.

Public sentiment toward CDR is improving, although many geoscientists still consider it a distraction from cutting emissions or, worse, a deterrent that will disincentivize emissions reductions. But this largely theoretical risk—which, it's worth pointing out, is also posed by pursuing adaptation and resilience—can be addressed by creating separate targets for CDR and emissions reductions and by other means of deploying CDR strategically.

Others may see durable CDR as being complicit with the fossil fuel industry and its tragic delay and distraction tactics or as antithetical to intuitively appealing nature-based approaches. But we need to be clear-eyed about the fact that humanity's cumulative emissions, both to date and in the future (even under optimistic projections), put us on a path that requires gigatons per year of durable CDR to have any hope of avoiding 2°C–3°C of warming. And however it is done, most of that captured carbon needs to be stored in geologic reservoirs.

Developing and responsibly managing subsurface carbon storage pose historic challenges for the geosciences. Rising to meet these challenges will serve society and the planet by helping mitigate disastrous outcomes of climate change. It may also shift long-standing public perceptions of the field as anachronistic and out of touch and create an inspiring mission for new generations of geoscientists.

By **Peter Reiners** (reiners@arizona.edu), University of Arizona, Tucson

Read the article at Eos.org

The Palisades Fire approaches the Pacific Ocean along the Pacific Coast Highway in Malibu on 7 January. Credit: Wally Skalij/Los Angeles Times via Getty Images

FALLOUT FROM THE FIRES

In January 2025, the Palisades and Eaton fires ravaged more than 150 square kilometers across cities and wildlands in Los Angeles County. Even as they were personally affected, LA-area scientists worked diligently to understand how fires at the urban-wildland interface create unique hazards via air, land, and water.

In the future, hot and dry conditions enhanced by climate change will continue to raise the risks of fires like these. The work of these scientists can provide a blueprint for rapid hazard assessment, health risk mitigation, and urban planning in other fire-prone communities.

WHERE THERE'S FIRE, THERE'S SMOKE

Using both existing and newly launched monitoring instruments, researchers work to better understand air quality during and after the Los Angeles wildfires.

By Emily Dieckman

Gale Sinatra and her husband fled their Altadena, Calif., home on 7 January with little more than overnight bags.

"We thought they'd get the fire under control and we'd get back in," Sinatra said.

When the couple did return, weeks later, it was to dig through the rubble of their former home, burned to the ground by the Eaton Fire.

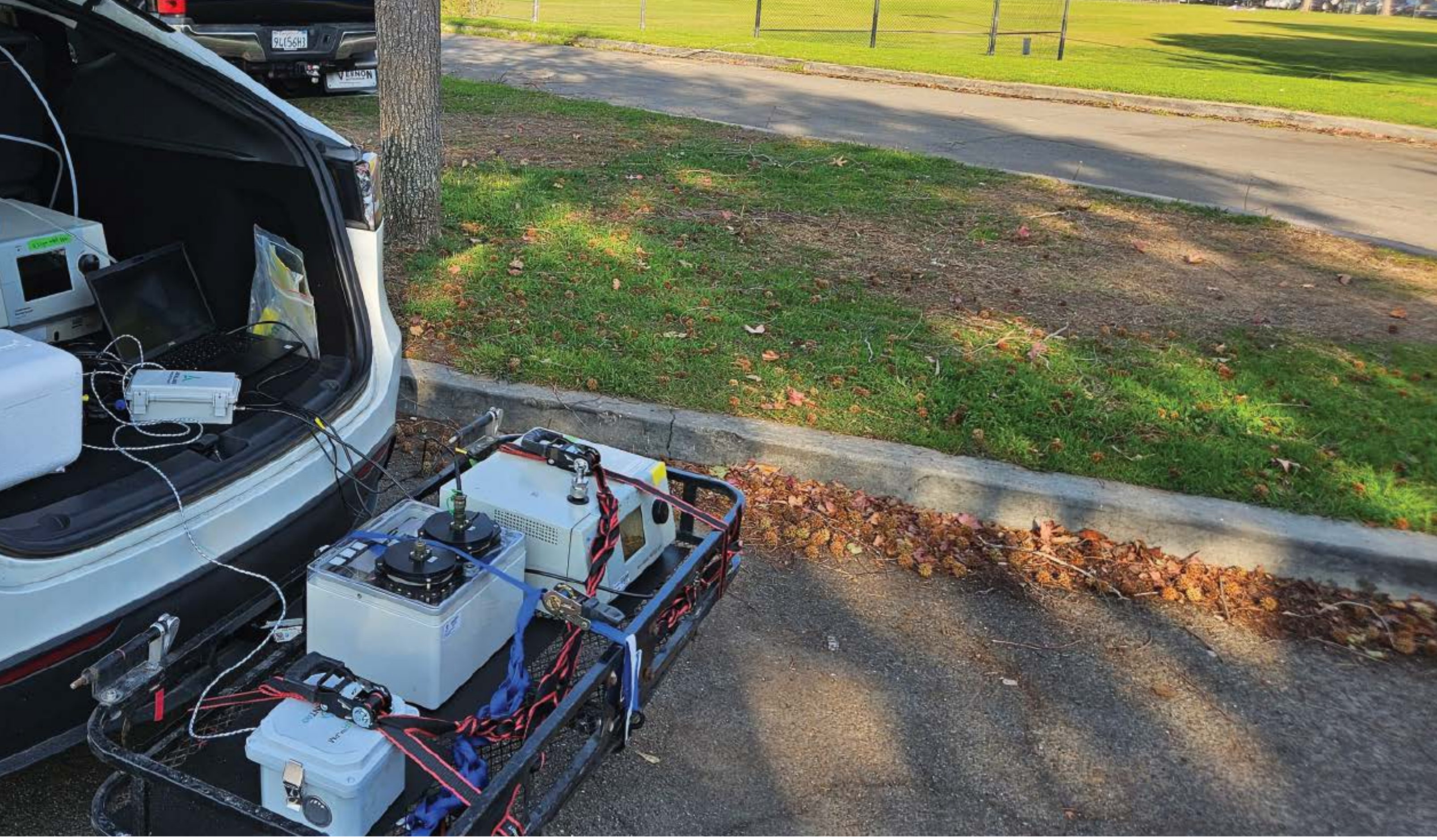
Though they escaped with their lives, health hazards were not behind Sinatra, her husband (who chose not to be named for this story), and others from their neighborhood. The Eaton and nearby Palisades fires filled the Los Angeles Basin with a toxic haze for days, and cleanup efforts threatened to loft charred particles long after the fires were out.

In the weeks following the fires, teams of scientists from around the country joined community members to learn more about respiratory health risks and how to protect against them.

Urban Fires Versus Wildfires

Inhaling smoke from any fire can be harmful. Smoke contains hazardous components, including volatile organic compounds (VOCs) and particulate matter, such as dust and soot.

About 90% of the particulate matter (PM) in wildfire smoke is $PM_{2.5}$, or particles smaller than 2.5 micrometers in diameter—



These instruments are used by Michael Kleeman to monitor air quality from the back of a car in Victory Park in Altadena, as far north as he can go in the area without entering the evacuation zone. Credit: Michael Kleeman

small enough to enter the bloodstream and deep areas of the lungs.

Urban wildfir s present their own dangers, because they burn not just through trees and other vegetation but through homes and infrastructure as well.

"How do you melt an entire refrigerator?"

When Sinatra returned to her former home, she was struck by everything the fir had burned. "I just found it very eerie standing in my kitchen, going, 'Where's my refrigerator?'" she said. "How do you melt an entire refrigerator?"

The January fir s in Los Angeles tore through not only Altadena, an unincorporated inland community, but also neighborhoods along the coast.

Three air quality monitoring stations in Southern California run by the Atmospheric Science and Chemistry Measurement Network (ASCENT), detected levels of lead, chlorine, and bromine at orders of magnitude higher than usual.

Older houses sometimes have lead paint, asbestos ceilings, or wooden decks and fences treated with preservatives containing arsenic. PVC piping contains chlorine. And ame retardant often contains brominated organic compounds. When these materials are burned and released to the air, they can be dangerous.

Michael Kleeman, a civil and environmental engineer at UC Davis, explained that inhaling urban wildfir smoke or the particles kicked up from dust and ash during remediation e orts can present risks that aren't immediately apparent. "It's not a heart attack a day or three after the exposure. It's, like, a cancer risk way down [the road]," Kleeman said. "The long-term exposure [risk] can be insidious."

Mobilizing Quickly

Southern California is no stranger to wildfir s.

Existing air quality monitoring e orts in the area, such as those by the South Coast Air Quality Management District (AQMD), the U.S. EPA, and ASCENT, have their own

Cleanup efforts, such as those for the Eaton Fire by the California Army National Guard, seen here, can kick up hazardous dust and ash particles. Credit: Spc. William Franco Espinosa, U.S. Army National Guard/Flickr, CC BY 2.0 (bit.ly/ccby2-0)

Smoke plumes from the Palisades Fire (left) and the Eaton Fire are seen from space on 9 January. Credit: ESA, contains modified Copernicus Sentinel data, CC BY-SA 3.0 IGO (bit.ly/ccbysa3-0igo)

sophisticated instruments. Less detailed but more widespread data on particulate matter come from networks of off-the-shelf air quality measuring tools—such as PurpleAir monitors and Clarity Sensors—that are set up by residents or community organizations.

Permanent air quality measuring efforts offer one source of public information that residents like Sinatra can consult to make decisions about when to stay indoors or return to a burned area. But when the Palisades and Eaton fires broke out, researchers set out to supplement these efforts with more granular monitoring.

In January, researchers from Harvard University; the University of California, Los Angeles (UCLA); the University of Texas at Austin; the University of Southern California (USC); and UC Davis launched the Los Angeles Fire Human Exposure and Long-Term Health Study, or LA Fire HEALTH.

While many Los Angeles residents, including Sinatra, were still under evacuation orders, LA Fire HEALTH researchers were traveling into evacuation zones.

One such researcher was Nicholas Spada, an aerosol scientist who headed down to Los Angeles from UC Davis on 14 January to set up four cascading impactors in Santa Monica (near the Palisades Fire), Pasadena (near the Eaton Fire), Hollywood, and West Hills. These briefcase-sized instruments act like coin-sorting machines, Spada said: They take an air sample, then sort particles into eight different size categories.

The cascading impactors collected eight samples every 2 hours until 10 February. Their measurements showed that not only were toxic elements such as lead and arsenic present in the air throughout the sampling period but also a high proportion of their mass—about 25%—was in the form of ultrafine particles (on the order of nanometers). Such particles aren't filtered by N95 masks and can penetrate deep into the body when inhaled, Spada explained.

Southern California community members got in on the efforts to monitor air quality, too. In the weeks following the fires, Melissa Bumstead and Jeni Knack, codirectors of Parents Against Santa Susana Field Laboratory, gathered air and ash samples in Pasadena, Altadena, Santa Monica,

Topanga, and Pacific Palisades, then sent them to laboratories, including Spada's, for testing.

Arsenic in all of the ash samples and lead in about a third of them exceeded EPA regional screening levels (which, Spada noted in communications to residents, are based on what's safe for ingestion by a child and are relatively conservative).

"This is going to help people in the next iteration of fir s to know what to do," Bumstead recalled telling residents in sampling areas.

After the Ashes

The next fir , Sinatra said, is something that weighs on her as she and her neighbors consider the prospect of rebuilding.

When rain fin lly arrived in Southern California on 26 January, it helped extinguish the fir s and tame the dust disturbed by remediation e orts, reducing the risk that people would inhale toxins.

Community members got in on the efforts to monitor air quality.

Still, those toxins were also present in the soil and water. When Sinatra and her husband returned to the charred site of their home, they took every precaution they'd heard about from the news, the EPA, community leaders, and neighbors: They wore respirators, hazmat suits, goggles, and two pairs of gloves each to protect themselves.

Concerns about potential long-term consequences of the air they had already breathed, as well as the soil beneath them, linger as they wait for more data.

"Everyone feels there's a signific nt chance of a future fir ," Sinatra said. We're "wondering about whether it would be safe to live up there, [in] regards to the soil quality and the air quality, and whether it's going to happen again."

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Read the article at Eos.org

BURNING URBAN AND WILD LAND ALIKE

When more densely populated Altadena and Pacific Palisades burned along with surrounding wildlands, hazards didn't stop when the fires were contained.

By Kimberly M. S. Cartier

The 2025 Palisades and Eaton Fires torched scrub-lined slopes of the San Gabriel and Santa Monica Mountains, as well as buildings, streets, cars, and infrastructure.

Before the flames were even contained, scientists from throughout the Los Angeles (LA) metro area turned to the skies, their labs, and their communities to study the extent of the damage. Their work is informing residents and other researchers about how hazards have shifted in the weeks and months after containment, and how they could change in the years to come.

Scientists are learning how the fires, which burned along the urban-wildland interface, were distinct from strictly urban or rural fires in terms of chemistry, topographic changes, and follow-on hazards.

During Containment

While firefighters were still battling flames on the ground, an airborne surveyor team took stock of the damage, mapping the scope and extent of the fires and assessing which areas needed immediate remediation.

A researcher from the University of Southern California (USC) collects a sample of dust in early February near a structure burned in the Eaton Fire. Credit: Cecilia John

On 11 January 2025, NASA’s Airborne Visible/Infrared Imaging Spectrometer 3 (AVIRIS-3) flew over Los Angeles County mounted on a B200 research plane. The instrument provided some of the first aerial data assessing the scope of the Palisades Fire while it was still smoldering. It flew over the Eaton Fire soon thereafter.

“We immediately looked for methane or natural gas,” said Robert Green, principal investigator for AVIRIS-3 at NASA’s Jet Propulsion Laboratory in Pasadena. Natural gas leaks can pose health and safety risks to first responders. The instrument did not detect any abnormalities.

“But then we realized we had this dataset and could do advanced spectroscopic mapping of the burn severity and the burn products—the char and the ash,” Green said.

AVIRIS-3 data showed that the Eaton Fire burned more wildland area than urban area, largely because fire managers focused prevention efforts on areas in which people were endangered, Green explained. Initial maps of burn severity, which were provided to first responders, showed that within the burn area, nearly all structures suffered moderate to severe surface-level burns. Very few patches of urban vegetation survived.

“We’ve never had an urban fire like this to collect datasets.”

The instrument completed subsequent surveys of the Eaton and Palisades burn scars in late May.

“We’ve never had an urban fire like this to collect datasets,” Green said. “There’s a whole bunch of new spectroscopic compounds established by burning these [urban] materials, which are different than those you would find in a natural environment.” These surveys will help scientists track combustion products and how long they persist in the soil.

Lead Laden

After the fires were contained, many local scientists mobilized with the tools and people they had at hand—themselves, their students, and even their children—to collect ash, dust, and soil samples. They and fellow residents wanted to know what chemicals enter the environment when wildland-urban fires burn, how bioavailable they are, and how long they present a danger.

Many scientists homed in on lead contamination. Of the more than 7,000 homes and structures that burned, most were built before 1975, when lead-based paint was commonly used. Lead that enters the body is easily absorbed into blood and can cause significant neurological harm, especially in children. It is particularly dangerous when inhaled or ingested as fine dust, and fire ash and dust are key exposure routes. Resi-

On 19 February, a debris flow in Topanga Canyon blocks roads west of the Palisades burn area. Credit: Seulgi Moon

dents wondered when it would be safe for children and pets to play outside and whether it was safe to eat vegetables from their gardens.

Time was of the essence to collect samples, explained Joshua West of the University of Southern California (USC) in LA, not only because of the potential health impact but also because imminent wind and rain threatened to redistribute or wash away the fir s' by-products.

"We were scrambling to get ready for the rain," West said. "A lot of these data, from a scientific point of view, are perishable."

A team of USC scientists, including West and Earth scientist Seth John, tested dust and ash along the edges of the Altadena burn scar in late January. Over several weekends, the scientists used handheld instruments to measure the lead concentrations in dust that had accumulated on streets and playgrounds. They also collected samples for further analysis in the lab.

EPA's thresholds for levels of lead in residential soil and playgrounds are 200 parts per million generally and 100 parts per million for sites with multiple sources of exposure. The researchers found that a few roadside spots exceeded those thresholds but no playground samples did.

The team also found a strong correlation between lead levels and proximity to burned structures but not to wildland.

"It seems very clear that there is higher lead in the areas with destroyed structures," John said.

Wildland ash had low concentrations of lead.

"No amount of lead is safe," John cautioned. "That said, these levels are elevated, but I wouldn't say they're elevated to extremely toxic levels." The researchers found similar trends in dust near the Palisades burn scar.

The USC team returned to the same locations every few weeks to collect more roadside dust samples. As of June, lead concentrations were slowly going down but were still elevated in most of the sample locations in Altadena, John said.

> **"We were scrambling to get ready for the rain. A lot of these data, from a scientific point of view, are perishable."**

The Risks of Rain

As cleanup e orts began in earnest and residents started returning, they were aware of the lingering hazard of debris ows and landslides from the charred slopes of the San Gabriel and Santa Monica Mountains.

The mountains are steep, and gravity slowly moves soil, rocks, and sand downhill, explained Emily Geyman, a graduate student researching climate and surface processes at the California Institute of Technology (Caltech) in Pasadena. Low brush and scrappy mountainside shrubs typically interrupt that ow and accumulate that debris before it reaches foothill neighborhoods.

"Once you incinerate that [vegetation], those sand grains that are perched at this angle that should be unstable come cascading down," Geyman said.

What's more, fir s can mobilize contaminants and change soil chemistry so that it repels, rather than absorbs, water and loosens soil so it's more likely to fall downslope, explained West, who also studied the potential for debris ows in the San Gabriels. Gravity funnels sand and debris into natural channels where it builds up, compounding runo and erosion risks.

Studies of past wildfir s in the San Gabriels have shown that between 20 and 50 years' worth of soil erosion happens during the first 2 years following a wildfir .
Sudden erosion can damage infrastructure, fill debris basins, and strip ecosystems of critical soil nutrients and structure.

Between 25 January and 24 March, Geyman and other Caltech researchers conducted 10 uncrewed aerial vehicle (UAV) lidar surveys above the Eaton Fire burn scar. They surveyed mountain catchments and debris basins—artifici lly dug repositories to contain ows—before and after every major rain since the fir s.

"These are probably some of the firs fir s in which we have the post-fir , pre-rain topography at really high resolution," West said. "Being able to capture that time sequence going forward is one of our big goals."

A signific nt rainfall on 13 February triggered debris ows in almost every mountain catchment in the Eaton Fire burn area, Geyman said. Using pre-rain and post-rain lidar scans, the researchers estimated that 680,000 cubic meters of material cascaded downhill, "equivalent in volume to about 270 Olympic-sized swimming pools," Geyman added.

Debris basins captured most of the ow before it a ected residential neighborhoods. "The debris basin infrastructure largely did its job," Geyman said. Debris flows have not caused any additional loss of life.

The Paths Ahead

UAV surveys continue, and scientists are monitoring debris channels to assess the ongoing risk of landslides and debris ows.

"We plan to continue the surveys before and after each major rain event [through] winter 2026 or until…the loose sediment released from the hillslopes during the fir is cleared out," Geyman said.

Lidar data will help scientists understand which debris flow mechanisms are most

One of AVIRIS-3's quick-turnaround data products is this aerial map of the fraction of burn material, char, and ash within the spectrum of each pixel. Values from 0 (no burn, dark) to 1 (entirely burned, red) describe the burn fraction of the exposed surfaces. Nearly all structures have moderate to severe surface burning (yellow), and few pockets of vegetation (green) survive. Credit: AVIRIS-3/NASA/JPL, via Rob Green

likely, track the volume of material at which flows become imminent, and help inform hazard maps to aid emergency response.

After the initial rush of dust, ash, and soil collection, many research groups shifted to community-led sampling efforts. John and West, for example, set up a free community sampling program for lead in soils and received more than 1,000 samples by mid-May. Some groups are reaching out to residents who want their soil tested or who want to contribute to scientific efforts. Other teams at UCLA and Loyola Marymount University created similar lead soil testing programs for communities.

The AVIRIS-3 team is working with laboratory scientists to match the aerial spectral signatures to those of burn products in ash samples. Green said that every burn compound the team catalogs will help efforts to protect first responders during future urban fires and inform future instruments that could identify when burnable material builds up in fire-prone areas.

Additional flyovers may happen when AVIRIS-3 flies to or from its home base in LA, Green said. Those data could be used to track how environmental damage such as toxic ash contamination and soil erosion change over time.

"That might inform our understanding [of] how this urban-rural interface is changing and what the recovery looks like," Green said.

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Read the article at Eos.org

SCRAMBLING TO STUDY SMOKE ON THE WATER

Timely action shows the impact of urban fires on freshwater and marine ecosystems.

By Grace van Deelen

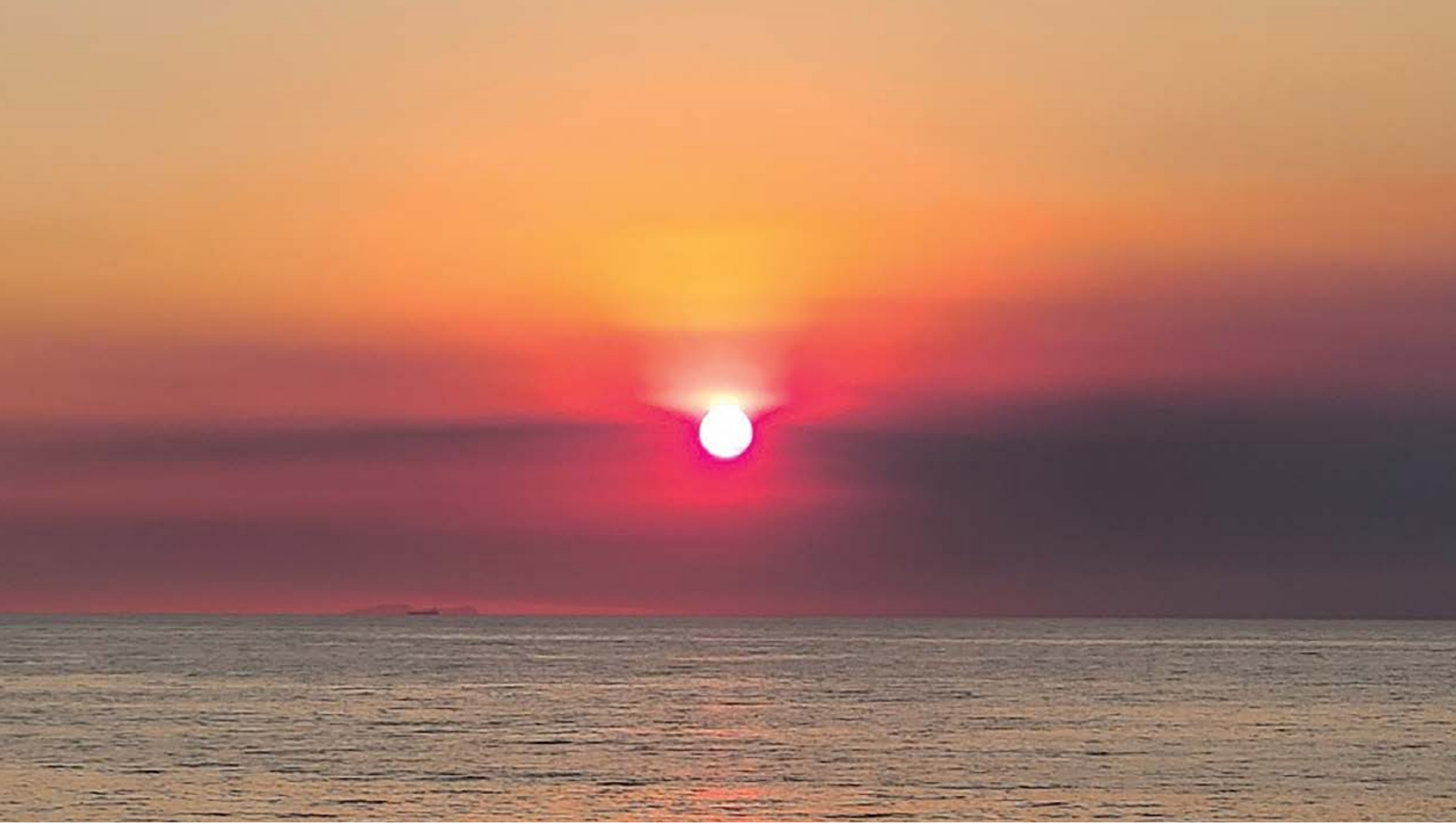
As multiple fires raged through Los Angeles in January 2025, Bernadeth Tolentino had one more thing to worry about: kelp.

Tolentino, a marine biologist and graduate student at the University of Southern California, is part of a lab that runs a gene bank of kelp spores. The repository preserves genetic diversity and allows scientists to bolster struggling populations.

As the roaring res turned homes, cars, and businesses into chemical-laden ash, Tolentino realized that runo from post- re rains would eventually carry that ash to the sea.

> **"It felt great to be able to apply what I know to jump on this really urgent matter."**

The ash threatened to block sunlight and pollute the water surrounding one particular kelp population in Santa Monica Bay—a population not represented in the gene bank. She needed to reach the kelp before runo damaged viable spores.



Even kilometers off the Pacific coast, those on board a CalCOFI (California Cooperative Oceanic Fisheries Investigations) monitoring cruise observed ash in the air on 9 January. Credit: Rasmus Swalethorp/Scripps Institution of Oceanography, University of California, San Diego

The dive team, including Tolentino, scrambled to apply for permits, gather their equipment, and coordinate dives before rainstorms carried too much toxic runo   to the site. “It was a little bit of a rush job,” she said.

They dove four times, collecting spores from southern sea palm, feather boa, and golden kombu kelp, which may be used to restore regional ecosystems in the future.

Tolentino was one of many water quality and marine scientists who collected valuable, time-sensitive information after the LA fir s. “It felt great to be able to apply what I know to jump on this really urgent matter,” she said.

Ash in the Water

On 8 January, a day after the Eaton Fire began, scientists from the California Cooperative Oceanic Fisheries Investigations (CalCOFI) were about 80 kilometers away on a routine monitoring cruise. CalCOFI has been monitoring the state’s coastal waters for more than 75 years, collecting oceanographic and ecological data.

As the fir s raged, scientists on the deck of the CalCOFI vessel recognized that they had a “perfect opportunity to study the ocean impact of this very devastating urban fir ,” said Julie Dinasquet, a marine microbiologist at the Scripps Institution of Oceanography, University of California, San Diego, who works closely with the CalCOFI team. Here was a chance to collect real-time data on the environmental impacts of an urban fir without needing to plan and launch a separate expedition.

Those on board were shocked at the effect the fires were having on the ocean.

Those on board were shocked at the e ect the fir s were having on the ocean, Dinasquet said. They had to wear masks and goggles when the smoke became too potent.

Some particles that landed on the water were big enough to see with the naked eye. The largest chunks the group measured were 5 centimeters wide—quite unusual given how far from the fir s the samples were taken, said Douglas Hamilton, an Earth systems scientist at North Carolina

On board the CalCOFI cruise on 9 January, researchers from NOAA Fisheries’ Southwest Fisheries Science Center hold up a plankton net full of ash and debris collected from the ocean surface. Credit: Rasmus Swalethorp/Scripps Institution of Oceanography, University of California, San Diego

State University who collaborates with the CalCOFI team.

Closer to shore, the onboard team pulled up a plankton net that was full of black ash. And water samples, typically fill d with plankton, were fill d instead with soot and debris.

Hamilton thinks that particles traveling from the primarily urban fir s to the ocean contained more toxic material than that from blazes burning primarily biological fuels (such as brush) would have been.

Scientists know that falling ash and runo from wildfir s that burn mostly vegetation add nutrients to the ocean, sometimes spurring primary production and altering ocean biogeochemistry. The samples from the CalCOFI cruise will shed light on how urban fir s can also a ect ocean biogeochemistry—a rather new fi ld, Hamilton said.

Ash from urban fir s contains very different chemicals than ash from burned areas of less developed land, and therefore might have very di erent e ects on the ocean. “We’re adding this extra layer of complexity,” Hamilton said. “How does this urban wildfir change the narrative of the way that we’ve been thinking about how wildfir s might be impacting ocean ecosystems? This is really the first time this has been able to be observed.”

“It’s important that we do this work, that we try to find these things out quickly and let the public know what we found.”

Dinasquet plans to analyze the composition of the ash and water samples collected on board the CalCOFI cruise and compare them with ash transported from fir s in less developed areas. Hamilton will create models that could be used to project how future urban fir s may a ect the ocean.

The January fir s were the first large coastal urban fir s to have a ected the ocean at such a scale. “This is an absolutely tragic event, but it’s the first of its kind,” Hamilton said. “So we need to learn from that.”

Rushing for Runo

Fires’ e ects on marine ecosystems don’t come from just the air: As rainwater percolates through burned neighborhoods, runo carries pollutants through the watershed and into the ocean, too.

When rainstorms hit after the fir s, Adit Ghosh was ready. More rainfall meant more runo and a chance to collect samples that might shed light on how toxic metals such as lead, arsenic, iron, and vanadium, as well as organic pollutants, move through the watershed.

Ghosh, a geobiologist at the University of Southern California, and his colleagues monitored the forecast in the weeks after the fir s. No matter the hour, when they

AltaSeads Conservancy curator Michael Marty-Rivera places kelp spores in biobank storage. Credit: Taylor Griffith

expected rain, they headed out to four field sites to collect runoff.

The team especially wanted to sample runoff from the first storms to hit the area after the fires, as that water, they hypothesized, would contain the highest amounts of pollutants. During the first storm, which occurred in late January, the team stayed out until nearly midnight, filling bottles and vials with runoff.

At one point during the sampling, a University of California, Los Angeles professor led the research team around a burned neighborhood in Mandeville Canyon. Ghosh did a double take at the remains of one of the houses—he'd seen it burn down, live, on television.

"You see it on TV, but when you walk up to it, you see the devastation," he said. "It really hit home. It was really sad."

As this magazine went to press, the team had not finished analyzing all of the samples, but preliminary results had shown that lead and arsenic are elevated in runoff from burned urban areas, though not above EPA limits. Lead and arsenic may have been elevated in the area already, as they are regularly derived from several natural and urban sources.

Ghosh and his team want to collect streamflow samples from the unburned watersheds during next year's winter storms to see how the contamination they've found compares with background levels.

Ghosh hopes that a full analysis of the data will help scientists and the public understand how chemicals in runoff differ between burned and unburned, and urban and less developed, areas. Ghosh and his collaborators also plan to create time series analyses for each of the pollutants they sampled to show how concentrations of pollutants in runoff change over time after a fire and over the course of multiple rainstorms.

"If there's another fire somewhere, we can have a better understanding of how those [water quality] risks are going to linger after the event," he said.

Ghosh said he feels that as a member of the Los Angeles community, he has a responsibility to use his skill set to help area residents understand how the fires may be affecting their water.

"It's important that we do this work, that we try to find these things out quickly and let the public know what we found."

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Read the article at Eos.org

Former U.S. Department of Energy Leader Reflects on a Changing Landscape

Asmeret Asefaw Berhe is sworn in virtually as the director of the Office of Science at the U.S. Department of Energy in 2021. Credit: Teamrat A. Ghezzehei

Shortly after President Joe Biden took office in 2021, he nominated Asmeret Asefaw Berhe, then a biogeochemist at the University of California, Merced, to oversee the Department of Energy's (DOE) Office of Science. After a 15-month vetting process involving interviews, a mountain of paperwork, and, ultimately, Senate confirmation, Berhe, an AGU medalist, became the first person of color and the first Earth scientist to hold the position. She served in the position for just under 2 years.

Now, with science and diversity programs under attack, she reflects on her path to leadership in a new commentary in *AGU Advances.*

Berhe became familiar with DOE's science program as a graduate student at the University of California, Berkeley. She later received DOE funding, collaborated with researchers from various national laboratories, and mentored scientists who went on to secure DOE positions. She says that, combined with guidance from her mentors, these experiences helped her develop the skills she needed for her DOE appointment, not only in science but also in managing, accounting, mediation, and ethical guidance.

Berhe, who was born in Eritrea and was one of only a few undergraduate women at Asmara University studying soil science, prioritized basic research, robust science communication, and promoting diversity in STEM (science, technology, engineering, and mathematics) in her DOE role.

Providing opportunities in STEM for people from all walks of life starts with equalizing the distribution of funding, she writes. She cited an American Physical Society report that found that 90% of federal research funding in 2018 went to the top 22% of institutions, even though the vast majority of students—especially those from low-income backgrounds—attend other schools. Under Berhe's tenure, DOE began asking grant applicants to demonstrate plans for collaborating with schools less likely to receive funding, enabling scholars from diverse backgrounds to access DOE resources.

Berhe thinks recent efforts to end diversity, equity, and inclusion (DEI) programs arise at least in part because of a misconception around what DEI means. These programs are often misconstrued as serving only gender or racial minorities from urban environments, when, in fact, many are intended to serve a much wider range of Americans, she writes.

Today's political climate sometimes leaves Berhe with feelings of despair. But she remains hopeful that with time, the next generation of scientists will benefit from opportunities like those she's had.

"Together, we will weather this storm," she writes. (*AGU Advances*, https://doi.org/10.1029/2025AV001757, 2025) **—Saima May Sidik**, *Science Writer*

Mapping the Ocean Floor with Ancient Tides

In shallow coastal waters around the world, mud and other fine-grained sediments such as clay and silt form critical blue carbon sinks. Offshore infrastructure such as wind turbines and oil platforms, as well as fishing practices such as bottom trawling, can have major effects on the seafloor. So knowing the locations of these mud-rich sedimentary deposits is key to making coastal management decisions.

Ward et al. set out to map three mud depocenters—large offshore muddy deposits—in the coastal waters around Great Britain and Ireland. The mud-rich areas they selected were Fladen Ground, northeast of Scotland in the North Sea; the Celtic Deep, southeast of Ireland; and the Western Irish Sea Mud Belt, in the Irish Sea.

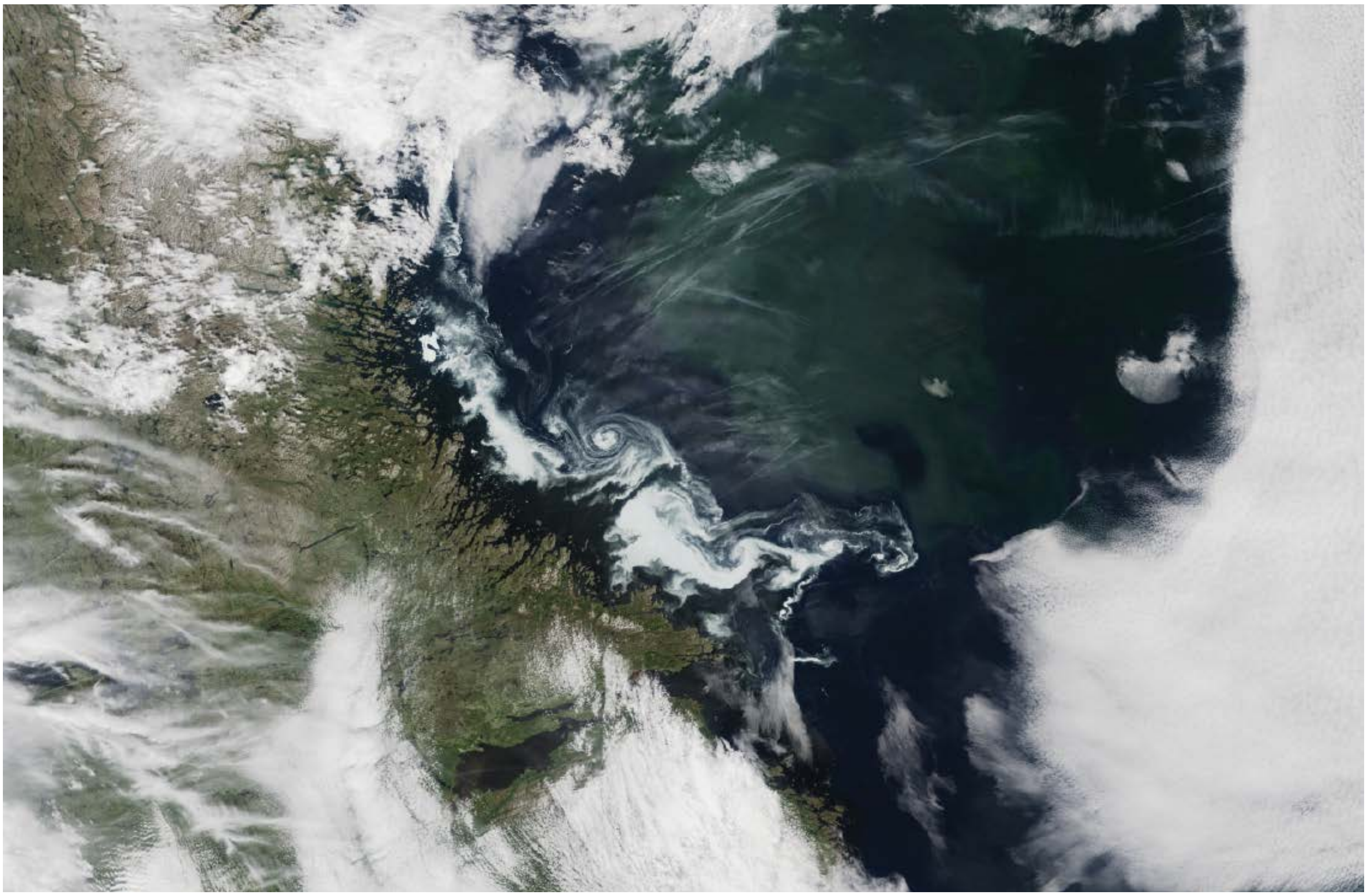
Their location on the seafloor makes these muddy deposits notoriously difficult to map. Furthermore, contemporary sedimentary deposits do not necessarily stem from modern conditions—some deposits are relicts from past ocean behavior.

To address these challenges, the authors built a paleotidal model that can re-create factors dictating the behavior and movement of ocean water, such as water depth and the speed and path of tidal currents. They reconstructed ancient seafloor topography using past sea level changes interpreted via glacial isostatic adjustment models. Using this reconstruction, they simulated the tidal conditions driving the formation of the mud deposits as far back as 17,000 years ago.

The model revealed that mud settled differently across the three focal areas. In the Celtic Deep and the Western Irish Sea Mud Belt, mud appears to have accumulated over the past 10,000 years and continues to accrue today. Conversely, in Fladen Ground, the mud deposits are the result of past sea conditions and are preserved by today's calmer tidal conditions.

The results demonstrate how modeling past conditions can help map today's carbon stores, especially in data-limited areas. (*Journal of Geophysical Research: Oceans*, https://doi.org/10.1029/2024JC022092, 2025) **—Aaron Sidder**, *Science Writer*

Water Density Shifts Can Drive Rapid Changes in AMOC Strength



A new study examines how variations in Atlantic Ocean circulation at high latitudes—such as in the Labrador Sea, pictured here—are related to variations farther south. Credit: NASA Earth Observatory image by Jesse Allen, using data from the Land Atmosphere Near real-time Capability for EOS (LANCE)

In the Atlantic Ocean, a system of currents carries vast amounts of warm, salty surface water northward. As this water reaches higher latitudes and becomes colder, it sinks and joins a deep, southward return flow. This cycle, known as the Atlantic Meridional Overturning Circulation (AMOC), plays an important role in Earth's climate as it redistributes heat, nutrients, and carbon throughout the ocean.

Although scientists know that the strength of the AMOC—meaning how much water it transports—can vary over time and across regions, it has been unclear how changes in strength at high northern latitudes may or may not be linked to changes farther south.

Petit et al. applied high-resolution climate modeling to uncover connections between AMOC variability at the midlatitude of 45°N and the current's behavior at higher subpolar latitudes. High-latitude AMOC observations used in the modeling were captured by the Overturning in the Subpolar North Atlantic Program (OSNAP) instrument array, a network of moorings and submersibles deployed across the Labrador Sea between Greenland and Scotland.

The researchers discovered that subpolar AMOC strength, as captured by OSNAP data, does not affect midlatitude AMOC strength. However, they did find that the density of the subpolar AMOC water beginning its journey south affects subsequent midlatitude AMOC strength.

Changes in the water's density at high latitudes appear to be driven by changes in atmospheric pressure that affect wind stress and buoyancy at the sea surface. The team's analysis indicates that within a time span of 1 year, these subpolar density changes propagate southward along the far western side of the North Atlantic, creating a steeper density gradient at midlatitudes and, ultimately, affecting AMOC strength there.

The findings suggest that OSNAP density measurements could be used to monitor midlatitude AMOC strength. The study's results could also help inform the design of future ocean-observing systems to deepen understanding of the ocean's role in Earth's climate, according to the researchers. (*Geophysical Research Letters*, https://doi.org/10.1029/2025GL115171, 2025) **—Sarah Stanley,** *Science Writer*

Charting a Path from Fire Features to Health Outcomes

Wildfires are increasingly encroaching on urban areas, leading to a wide range of health problems. This photo shows a structure lost in the January 2025 Palisades Fire in California. Credit: CAL FIRE/Flickr, CC BY-NC 2.0 (bit.ly/ccbync2-0)

Wildfir s are creeping into urban environments with alarming frequency, and they are connected to health problems ranging from respiratory illnesses to hypertension to anxiety. Studying the links between wildfir s in these areas and health is challenging because wild re smoke and ash contain a mix of chemicals from burned buildings, cars, and electronics, leaving researchers and communities with many unanswered questions.

Barkoski et al. published the GeoHealth Framework for Wildland Urban Interface Fires to help researchers quickly visualize the relationships between urban wildfires and health outcomes, as well as identify data gaps and future research priorities. The framework is also intended to improve the coordination among di erent groups working to support wildfire preparedness, response, and recovery. The researchers built the framework using the example of the 2020 Walbridge Fire, which burned more than 22,250 hectares in Sonoma County in California. This example helped them understand the types of geoscience and health data that are available and that are needed after a wildland-urban interface fir .

To apply the framework, users defin a question and then map various wildfir and health factors and the ways they are connected. For example, they may select environmental factors preceding a specifi fire, such as land use and recent weather patterns; characteristics of the fire, including its size and the kinds of materials it burned; and factors that in uenced its spread, such as fir fight r response, wind, and topography.

The team suggests pulling data from sources such as the U.S. Geological Survey, NASA, NOAA, EPA, electronic health records, and public surveys.

These inputs and the known and hypothesized connections among them help users to identify which pollutants a fir may generate, how humans may encounter these pollutants (such as through the air or drinking water), and how these encounters may a ect the likelihood of physical or mental health consequences.

The scientists also note that the framework can be expanded and adapted to apply to new research questions. For instance, if researchers want to better understand how wildfir exposure a ects the biological mechanisms of disease, they could incorporate epidemiological, toxicological, and clinical research studies into the framework. These studies might include more detailed information about how wildfir smoke harms health, such as gene variants that predispose people to asthma. (*GeoHealth*, https://doi.org/10.1029/2025GH001380, 2025) **—Saima May Sidik,** *Science Writer*

The Goldilocks Conditions for Wildfires

As the global climate continues to warm, fire seasons have intensi fi d, and large-scale wildfi es have become more frequent. Factors such as vegetation type, land use patterns, and human activity all a ect the likelihood of ignition, but wildfir proliferation ultimately depends on two factors: climate and fuel availability.

Kampf et al. studied relationships between re, fuel, and climate in western North America, western and central Europe, and southwestern South America. Each of the three temperate regions includes desert, shrub, and forest areas, as well as local climates ranging from arid to humid.

The researchers pulled information on total burned area and wildfire frequency in these regions between 2002 and 2021 from the GlobFire database, and they sourced data on land cover and biomass during the same period from NASA's Global Land Cover Mapping and Estimation (GLanCE). They also used precipitation and evapotranspiration data from TerraClimate to calculate the mean annual aridity index (mean annual precipitation divided by mean annual evapotranspiration) for each region.

The researchers found that over the 20-year study period and across all three regions, fir s burned smaller areas of land in zones with either very dry climates or very wet climates as opposed to zones of intermediate aridity. They suggest that this trend is explained by the lack of vegetation su ient to fuel widespread fires in dry zones and, in wet zones, by weather conditions that dampen the likelihood of fir s. In contrast, burned areas were larger in the intermediate zones where biomass abundance and weather conditions are more conducive to fueling fir s.

Of the three regions studied, North America had the largest total burned area, fraction of area burned, and fir sizes. The researchers note that the fragmentation of vegetated areas in South America and Europe (largely caused by the Andes Mountains and extensive agricultural use, respectively) has likely limited the sizes of fir s and burned areas in those regions. They also point out that rising temperatures and aridity are increasing the risk of large wildfir s in all three regions, suggesting that fir managers need to be fle ible and responsive to local changes. (*AGU Advances*, https://doi.org/10.1029/2024AV001628, 2025) **—Sarah Derouin,** *Science Writer*

Dear *Eos:*

As the annual monsoonal flood pulse started to rise on the Mekong River in June 2025, our team from the University of Southampton (Julian Leyland, Steve Darby, Gustavo Nagel, and Chris Tomsett), working with Cambodian colleagues including Vutha Srey, undertook multibeam sonar surveys of a reach of the river near Roka Koang, Cambodia.

As part of the HIDDEN SAND (Holistic Investigation of the Distribution, Extraction, and Networks associated with SAND) project, we're quantifying how sand mining is reshaping the riverbed and how it affects the local community. In this photo by Andy Ball, also of the University of Southampton, our survey vessel (right) passes close to sand barges traveling downstream to local and global markets in Phnom Penh.

—**Steve Darby**, University of Southampton, Southampton, U.K.

Send us your Postcards from the Field