Columbia Climate School
Lamont-Doherty Earth Observatory

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UNCOVERING PLANETARY MYSTERIES ON EVERY CONTINENT AND ON THE HIGH SEAS

ANNUAL REPORT 2022

Annual Report 2022

BACK TO THE FIELD

Uncovering planetary mysteries on every continent and on the high seas

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MESSAGE FROM DIRECTOR

Maureen E. Raymo

Dear Friends,

As the world slowly emerges from the pandemic and countries begin lifting their travel restrictions, Lamont-Doherty Earth Observatory researchers have reignited their fieldwork, taking their instruments and inquiries to every continent and to the high seas. They helped us make this a year of important scientific discoveries, including shedding light on the current and foreseeable impacts of climate change, and expanding our knowledge about the inner workings of our planet. Our scientists revealed secrets hidden in major faults like the San Andreas, unlocked centuries of historical climate data in old timbers taken from buildings in New York City, and closed a chapter on Viking history. They also helped get us one step closer to predicting volcanic eruptions. These are just a few examples of the amazing research we highlight in this report.

Our basic research is also leading to the solutions the world needs to cope with the escalating climate crisis. Perhaps the most visible evidence of this real-world impact is the fact that three recent winners of Elon Musk's X Prize were startups that focused on removing carbon dioxide from the atmosphere and that were underpinned by earlier research advances on the Lamont Campus.

I am also delighted to share that the National Science Foundation funded six new national Science and Technology Centers in 2021, two of which will be led or co-led by Lamont researchers. The goal of the Center for Learning the Earth with Artificial Intelligence and Physics, led by Pierre Gentine, Galen McKinley and Ryan Abernathey, is to improve our ability to predict future climate change by combining Earth observations with new computational methods that use machine learning and artificial intelligence. The approach will lead to better and more sophisticated climate models. In addition, Sonya Dyhrman, a marine microbiologist at Lamont, is co-leading NSF's Center for Chemical Currencies of a Microbial Planet which will study the chemicals and chemical processes that underpin the carbon cycle in ocean ecosystems.

I am proud to lead the world's premier climate and geoscience research institution at this critical moment, and believe that Lamont's standing and reputation comes with a responsibility to be an inclusive institution, as well as one that leads efforts to diversify the geosciences. To that end, I established two new positions within Lamont's leadership—the first is held by Dr. Vicki Ferrini, a Lamont Senior Research Scientist who is our new Associate Director for Diversity, Equity, Inclusion, and Anti-Bias (DEIA). Not only did Vicki accept this important role, she also brought in a $7 million dollar NSF grant called INSPIRE to advance the success of historically underrepresented communities in the geosciences. The second new position is the Assistant Director of DEIA and in April 2022 we welcomed Mackenzie Carr to that role. Previously, Mr. Carr worked at Hannam University in South Korea, where he was the Diversity, Equity, and Inclusion Campus Coordinator and Cultural Awareness Assistant Professor. He brings years of experience in advancing DEIA efforts with clients from diverse and multicultural settings in the workplace as well as within the community.

All this leaves me hopeful, yet there is much more to be done. Our planet is in crisis, and in order to make the best policies, the most equitable policies, the world's leaders need to be informed by science of the highest caliber. Lamont's mission has never been more essential. I hope you find the stories in this report as inspiring as I do, knowing that our scientists continue to innovate and push the boundaries of what we know about the past, present, and future of our planet Earth.

Sincerely,

Maureen E. Raymo
Director, Lamont-Doherty Earth Observatory
Co-Founding Dean, Columbia Climate School
G. Unger Vetlesen Professor of Earth and Climate Science

SCIENTIFIC EXPLORATION

Lamont-Doherty scientists travel to every corner of the world for their research. Here are a few examples.

ANTARCTICA

Giant Groundwater System Discovered in Antarctica

Former Lamont PhD student Chloe Gustafson, Lamont geophysicist Kerry Key and collaborators from six other research institutions used measurements from geophysical instruments to help create the first-ever map of a massive groundwater system circulating in the deep sediments of West Antarctica. Such systems, probably common in Antarctica, may have as-yet unknown implications for how the frozen continent reacts to, or possibly even contributes to, climate change.

NORTH AMERICA EAST COAST

New York City's Hidden Old-Growth Forests

Dendrochronologists from Lamont's Tree-Ring Laboratory took their tree corers and chain saws to Manhattan's Chelsea neighborhood, where they salvaged joists from New York City's gigantic 1891 Terminal Warehouse, an iconic structure that still occupies an entire city block between 27th and 28th Streets. The wood they brought back to Lamont for analysis revealed centuries of climate data and other historical information about the region no longer available from living trees.

THE ARTIC

Arctic Sea Ice's Last Stand?

Lamont oceanographer Robert Newton led work to calculate how long we can expect to see summer ice in the remote Arctic. The results aren't hopeful. Under both optimistic and pessimistic scenarios, by 2050 summer ice in this region will dramatically thin. Under the optimistic scenario, if carbon emissions can be brought to heel by then, some summer ice could persist indefinitely. If emissions continue on their current path, year-round ice would disappear by 2100, along with animals such as seals and polar bears that depend on it to survive.

BANGLADESH

Land Subsidence and Earthquake Risk in Bangladesh

Across much of low-lying Bangladesh, sea levels have risen and the land is sinking, due to natural compaction of sediments. This can increase flood risk and pollution of fresh water aquifers. The region also faces the risk of an earthquake so catastrophic, it could change the course of rivers. Geophysicist Michael Steckler and colleagues are studying the forces at work here with very precise measurements of the underlying geology and changing land levels. Their findings will help in the design and maintenance of the many embankments keeping the sea at bay, and will improve mapping of seismic hazards.

CHINA

Dinosaurs Took Over Amid Ice, Not Warmth

Two hundred million years ago, the Triassic-Jurassic Extinction killed off the big reptiles who ruled the planet, and apparently cleared the way for dinosaurs to take over. Why did dinosaurs thrive when other creatures died? Research led by Lamont's Paul Olsen presents the first physical evidence that Triassic dinosaurs regularly endured freezing conditions. Excavations in China's Junggar Basin revealed dinosaur footprints along with odd rock fragments that only could have been deposited by ice. During the extinction, cold snaps happening at the poles spread to lower latitudes, killing off the coldblooded reptiles. Dinosaurs, already adapted, survived and spread out. The rest is ancient history.

ALASKA

Community Collaboration Tracks the Impact of Climate Change in Alaska

Oceanographer Christopher Zappa has been leading a collaborative research project with residents of the Iñupiaq city of Kotzebue, on Alaska's northwest coast. They're investigating how climate change has impacted the region's seal hunting season. By combining hunters' knowledge of ice conditions needed for seal hunting with data from satellite images, their work has shown that since 2003, declining sea ice has reduced the hunting season by one day or more per year, dramatically shrinking the seal habitat in the process. The Iñupiaq people have depended on seals for food and clothing for generations. Ice Edge, a feature length film, chronicles the years-long study and the relationships it forged.

BRAZIL

The Amazon River's Outflow

After a COVID hiatus, Lamont marine biologist Ajit Subramaniam resumed his research on the Amazon River's outflow into the Atlantic Ocean, exploring how Brazil's deforestation and other changes in the Amazon Basin are affecting the ocean microbiome. This is a critical scientific question to answer. The ocean's billions of tiny organisms form a major sink for atmospheric carbon dioxide, the most pervasive greenhouse gas causing Earth's current global warming.

SUB-SAHARAN AFRICA

Air Pollution Is Harming People in the Global South at an Alarming Rate

Lamont's Daniel Westervelt, Steven Chillrud, Róisín Commane, Beizhan Yan, and other Columbia researchers are working to improve air quality in cities in the Global South. Their project, the Clean Air Toolbox for Cities (CAToolbox) aims to close data-collection gaps in several African countries, as well as in India and Indonesia. They're deploying state-of-the-art air-quality monitoring networks and supporting local community efforts to mitigate the health effects from pollution through legal and policy means. The project has already produced important results, revealing frequent periods of unsafe levels of air pollution in cities in Togo, Ghana and the Congo, among others.

CHANGING ICE, CHANGING COASTLINES

Unabated climate change will lead to profound changes on our planet, perhaps none more so than the swelling of our seas and alteration of our coasts. About one out of three people in the world–and more than half of all Americans–live within 60 miles (ca. 100 km) of the ocean. Of these, some 600 million live in coastal areas less than 30 feet (ca. 9 m) above sea level.

The extent to which our planet's massive polar ice sheets will respond to warming air and ocean temperatures remains one of the largest uncertainties in climate-model predictions of future sea-level rise.

Our scientists are determined to reduce this uncertainty, and have taken their instruments to some of the world's most remote and extreme environments. One such place is the massive West Antarctic Ice Sheet (WAIS), which holds enough ice to raise global sea level by about 12 feet (ca. 3.7 m) if it were to melt completely. WAIS is considered to be highly vulnerable to climate change because so much of it rests on bedrock thousands of meters below sea level, in contact with the warming waters of the Southern Ocean. Just how vulnerable? That's what Jonathan Kingslake, Jacqueline Austermann, and Benjamin Keisling have set out to answer. They're part of an international team of researchers drilling more than a kilometer through WAIS and into ancient sediments deposited during times in Earth's history when temperatures were as warm as those we expect to see in the coming decades. The sediment cores will shed light on how much of WAIS actually melted during these warmer periods. The new data will help reduce uncertainty in climate models and could reveal if there is a tipping point in our climate system that could cause large amounts of land-based ice to melt and oceans to rise swiftly.

Working in a different section of WAIS known as Whillans Ice Stream, Chloe Gustafson, Kerry Key and others used surface-based imaging instruments to create the first-ever map of a massive groundwater system circulating far under the Antarctic ice. The confirmation of the existence of deep groundwater dynamics has transformed our understanding about the behavior of ice streams, which are regions of fast flow within an ice sheet. These systems, probably common in Antarctica, could cause some ice sheets to hasten their march toward the sea, depending on how the groundwater reservoir reacts to warming ocean water and thinning ice.

The reasons for the transition from 41,000-year glacial cycles to 100,000-year glacial cycles and the intensification of ice ages that occurred about a million years ago has long puzzled climate scientists. Maayan Yehudai, Steven Goldstein, Joohee Kim, Karla Knudson, Louise Bolge, and Alberto Malinverno may have found the answer. Their analysis of deep-sea sediment cores taken in the north Atlantic, where ancient waters passed by and left chemical clues, provide evidence that each new ice age removed layers of ‘slippery’ continental soils. This exposed the 'stickier' crystalline bedrock underneath, causing ice sheets to cling more tightly to their beds, grow thicker and become more stable, thus triggering cycles of significantly longer and colder ice ages.

As sea levels rise, so does the risk of flooding and storm surges to coastline communities. Polar scientist Marco Tedesco and colleagues at Columbia’s Center for International Earth Science Information Network have created a new dataset that combines information about social vulnerability with data on mortgages, evictions, and threats from climate change for the entire US. Their work could help identify communities where vulnerable groups are at risk of being pushed out by rising flood-insurance rates and real estate values. The group has made the new dataset freely available to other researchers interested in exploring issues at the crossroads of racial, social, and climate justice.

How high did sea levels rise during the most recent warm period in Earth's history? Using sophisticated measurements made across the Bahamas, a Lamont team concluded that seas peaked at least 4 feet (ca. 1.2 m) higher than today. While still daunting, these levels are much lower than previous estimates, and are roughly in line with what most current models project for the next 100 years. Continue reading for a more detailed look at this research.

Some Past Sea Levels May Not Have Been as High as Thought, Says Study of Rising and Sinking Landmasses

By Kevin Krajick

One big mystery of climate science surrounds widely accepted evidence that during the planet's most recent warm interglacial period, ending about 117,000 years ago, global sea levels peaked as high as 9 meters (ca. 30 ft) higher than today. Back then, temperatures were about 2 degrees C warmer than those of preindustrial times, a mark we may surpass by century's end, if not sooner. Yet, models of future sea level rise hover around a meter or so within the next 100 years. What are we missing, and how much should it scare us?

A study by Lamont scientists offers an answer. It says that previous research into past sea levels may have failed to accurately correct for long-term ups and downs of the land itself. Based on new measurements made across the Bahamas, the researchers produced lower—though still daunting—estimates for the last interglacial. They say seas peaked at least 1.2 meters (ca. 4 ft) higher than today, with an unlikely upper limit of 5.3 meters (ca. 17 ft).

"To get to 9 meters of sea level rise, you'd have to melt large parts of Greenland and Antarctica," said lead author and former Lamont postdoctoral research scientist Blake Dyer. "This suggests that didn't happen. So maybe we should feel not as bad about the future. On the other hand, our lower estimate is bad, and our upper one is really bad."

Key to the study: as ice sheets build, they depress the land beneath them. But the Earth is elastic. What goes down in one place goes up someplace else, as when you squeeze a rubber ball. Corollary deformations outside the icy regions may creep for hundreds or thousands of miles over hundreds or thousands of years, moving mainly through the planet's pliable mantle. When ice melts, the process goes in reverse, as previously ice-covered regions rebound, while those on the fringes sink, in seesaw fashion.

Such movements, known as glacial isostatic rebound, can skew estimates of past water levels, and scientists have struggled to adjust for them. Previous studies have suggested that topographic ripples from North America's glaciations have traveled down all the way to the Bahamas, but exactly on what scale is uncertain.

To find out more, the researchers trekked along the coasts of seven islands, measuring the elevations of fossil coral reefs; fossilized edges of ancient beaches, nearshore sand deposits, and fossil dunes. They found similar sequences of similar ages on each island—but the elevations varied according to latitude. This meant the variations could not have been produced by water levels alone; movements of the land had to be considered. Putting all the measurements together, they concluded that islands to the north probably sank as much as 10 meters (ca. 33 ft) during the interglacial, while those to the south sank only about 6 meters (ca. 20 ft). They combined these findings with hundreds of different models of glacial isostatic rebound, and this produced the new, lower sea-level estimates.

One catch: evidence for the much higher estimates comes from the Mediterranean, the Indian Ocean and Australia. This hints that, among other things, we may be missing information about the size and distribution of ice sheets preceding the last interglacial. "Models of ice sheets are still in their toddlerhood," said Lamont director and study coauthor Maureen Raymo. "The easy thing to say would be, 'Oh we showed that sea levels were not so bad, and that's terrific.' The harder answer, the more honest answer, is that maybe things were different then, and we're not in the clear."

To improve their answers, the researchers plan to re-examine past sea-level markers along the coasts of Denmark, France, England, and South Africa.

PLANETARY RUMBLINGS

In an extraordinary year of field research, our scientists pushed the frontier of knowledge about the geophysical mechanisms and mysteries hiding deep below the Earth's surface in order to better understand, and ultimately help mitigate, the risks of our ever-rumbling planet.

Terry Plank, Einat Lev and Nick Frearson are leading the world's first open-data, real-time, multi-sensor community experiment on active volcanoes. The AVERT project (Anticipating Volcanic Eruptions in Realtime) provides scientists with the infrastructure needed to predict a volcanic eruption hours to months before one occurs. This would be welcome news to the 800 million people around the world who live within 60 miles (ca. 100 kilometers) of an active volcano.

Frearson and his engineering group at Lamont hand-built low-power sensor systems with satellite uplinks and on-board computers that could remotely measure, analyze and transmit data on gas emissions, tiny earthquakes, and ground inflation. This information helps scientists pinpoint rising lava—all in real time. This summer, the team made the long journey to the eastern Aleutian Island of Umnak, Alaska, home to the Okmok caldera, one of the most explosively active volcanoes in the region. Working out of a ranch that was once a former WWII-era military base, the team shared a helicopter with scientists and engineers from the Alaska Volcano Observatory to set up their new instruments on the flanks of Okmok.

Reliable eruption forecasts have long eluded us, largely because scientists do not fully understand why magma starts or stops moving below the surface in the weeks, months, or years ahead of eruptions. Work by Dan Rasmussen and Plank shows that it is the magma's water content that controls the depth at which the magma is stored under volcanoes like Okmok. The more water, the greater the depth. These findings are important because they connect magma depth to water content, and it is this water that fuels explosive eruptions. Their work also challenges the prevailing theory that magma stops rising when its density equals that of surrounding rock.

In their quest to unlock the planet's geologic secrets, Lamonters also took to the open seas. Cecilia McHugh, Leonardo Seeber, Michael Steckler and colleagues from other universities spent three weeks on the R/V Pelican coring and mapping the seafloor and sub-seafloor between Haiti and Jamaica. Their goal was to evaluate earthquake potential along the Enriquillo-Plantain Garden fault zone, which forms part of the northern boundary of the Caribbean and North American plates. Their expedition discovered stresses along the underwater plate boundary, as well as a rich record of past earthquakes, including the disastrous 1692 Port Royal and 1907 Kingston earthquakes. This new data will help scientists better understand the geohazard risks faced by the 15 million people who live in these two countries.

Relatedly, Anne Bécel, Tanner Acquisto, Brian Boston, and Brandon Shuck spent more than a month on the R/V Marcus G. Langseth off the west coast of Mexico, above where the young Cocos oceanic plate dives beneath the North American plate. They conducted the first-ever seismic imaging study of a portion of the subduction zone called the Guerrero seismic gap, which produces 'slow earthquakes' that release energy over many days or months. In contrast, most of the subduction zone has produced large earthquakes over the past 100 years, including the dramatic 8.0-magnitude Michoacán earthquake of 1985 that killed more than 10,000 people in Mexico City. The team's discoveries could unlock the secrets of slow earthquakes and the long-term hazards they pose to the people living nearby.

Continue reading to learn about the scientific discoveries we made at another dangerous fault...

A Slow-Motion Section of the San Andreas Fault May Not Be So Harmless After All

By Kevin Krajick

Most people know about the San Andreas Fault, the 800-mile-long seismic monster that cleaves California from south to north. Lesser known: the San Andreas is actually made up of three major sections that appear to move independently. The north segment was the source of the 1906 earthquake that leveled San Francisco; the southern one, the 1994 quake that hit near Los Angeles, collapsing a freeway and killing scores. The central segment, lying between the other two, is relatively harmless, with opposing tectonic plates slipping by each other at a steady, gentle pace without ever sticking together and building up stresses that can cause devastating jolts.

At least that is the story most scientists have been telling so far. But a study led by former Lamont graduate student Genevieve Coffey suggests that the central section, too, has hosted many major earthquakes that have gone unnoticed only because they occurred before written records.

The research team analyzed rocks from near the bottom of a 3.2-kilometer-deep borehole near the city of Parkfield, using a new method developed largely at Lamont. When earthquake faults slip, friction along the moving parts can cause temperatures to spike. This cooks the rocks, altering the makeup of organic compounds in sedimentary formations along the fault path. By calculating the degree of heating in these so-called biomarkers, geochemists can spot past events and roughly extrapolate the sizes of resulting earthquakes.

The researchers found many such altered compositions in a band of highly disturbed sedimentary rock lying between 3,192 and 3,196 meters (ca. 2 mi) below the surface. In all, they say the blackish, crumbly stuff showed signs of more than 100 quakes. In most, the fault appears to have jumped more than 1.5 meters (ca. 5 ft). This would translate to at least a magnitude 6.9 quake, the size of the deadly Northridge event. But many could well have been larger, as the method for estimating earthquake size is still evolving. Some could have been as big as the 1906 San Francisco disaster.

When did these quakes happen? Trenches dug across the central section have revealed no disturbed soil layers that would indicate quakes rupturing the surface in the last 2,000 years. But 2,000 years is an eye blink in geologic terms, and excavations could be missing any number of more recent quakes that did not rupture the surface.

To get at the timing, the researchers used a second new technique. Heated biomarkers run along narrow bands, from microscopic to just an inch or so wide. Other scientists have long used the ratio of radioactive potassium to argon to measure the ages of rocks; more argon means older rock. Conveniently for the authors, heating along faults drives out argon, resetting the radioactive "clock," so that the heated rock appears younger than identical, unheated material nearby.

The rocks in question formed tens of millions of years ago in an ancient Pacific basin, but the rocks in the thin slip zones came out looking as young as 3.2 million years. This sets out only an upper limit, as the scientists still do not know how thoroughly the clock may have been reset; some quakes could have taken place just a few hundred or a few thousand years ago. The group is now working to refine the age interpretations.

"People should not be alarmed," said Lamont geologist and study coauthor Stephen Cox. "Building codes in California are now quite good. Seismic events are inevitable. Work like this helps us figure out what is the biggest possible event, and helps everyone prepare."

PEOPLE OF THE PAST

Cores of ice, sea-floor sediments and rocks pulled from deep below the surface help Lamont researchers reconstruct our planet as it was millions, sometimes billions, of years ago–a time long before humans walked and settled the land. These records have been critical to our understanding of macro processes such as plate tectonics, sea-level changes and changes in atmospheric composition. However, to better understand the relationship humans have had with their natural environments, and the conditions that were dominant when past societies rose and fell, our researchers look for clues in shorter-lived, organic materials. They may have to travel halfway around the world hunting for these clues, but sometimes all it takes is a subway ride.

Edward Cook, Caroline Leland, and other scientists of Lamont's Tree-Ring Laboratory are used to trekking into some pretty remote places in search of ancient trees: the Peruvian Andes, the rainforests of Myanmar, the Himalayas of Nepal and Bhutan, and the steppes of central Mongolia.

But in 2019, they took their tree corers and chain saws to Manhattan's Chelsea neighborhood to salvage joists removed from New York City's gigantic 1891 Terminal Warehouse, an iconic structure that still occupies an entire city block between 27th and 28th Streets. The joists they brought back to Lamont for analysis revealed centuries of climate data and other historical information about the region no longer available from living trees. The wood came from longleaf pines–some of which were mere saplings in the 1500s–that grew in ancient, long-gone forests of the northeastern United States. Studying these timber species, their ages, and provenances, unlocks information about the history of U.S. logging, commerce and transport. Tree-ring scientist Mukund Palat Rao considers the old wood a wonderful resource for science. "They're inside old buildings, which are being demolished at a rapid pace. We're trying to collect whatever we can."

More than 3,000 miles (ca. 4,800 km) to the east, in the remote Faroe Islands, Lorelei Curtin and William D'Andrea were also after secrets left by past societies. The data they sought was not trapped in old timbers, but in the remnants of sheep poop buried in lake-bottom sediments. Archeologists have long believed the Vikings were the first people to reach the archipelago, but the Lamont team's analysis confirmed the presence of a previously unknown population that settled the area around 500 AD—some 350 years before the Vikings. A deeper dive into this extraordinary finding is on the next page.

Humans Reached Remote North Atlantic Islands Centuries Earlier Than Thought

By Kevin Krajick

The Faroe Islands, a small, rugged archipelago midway between Norway and Iceland, is one of the few places on Earth that remained unsettled by humans until historical times. Towering cliffs dominate the coasts, and strong winds rake the tundra interior. Archaeological excavations have suggested that the first people to find them and stay were Viking seafarers, who arrived around 850 AD.

Evidence recovered from the bottom of a lake by Lamont scientists shows that an unknown band of humans settled there some 350 years before the Vikings. They found sediments containing signs that domestic sheep suddenly appeared on the previously mammal-free islands around the year 500.

The researchers sailed in a small inflatable vessel onto a lake near the site of an ancient Viking locale on the island of Eysturoy. Here, they dropped weighted open-ended tubes to the bottom to collect sediments dropped year-by-year and built up over millennia, forming a long-term environmental record. The cores penetrated about nine feet of muck, recording some 10,000 years of environmental history. The scientists were looking to investigate the long-term climate of the islands, not the history of their inhabitants, but came up with a surprise.

Starting at 51 centimeters (ca. 20 inches) down in the sediments, they found signs that large numbers of sheep had suddenly arrived, most likely between 492 and 512, but possibly as early as 370. The giveaways: fragments of sheep DNA, and two distinctive types of lipids produced in sheep digestive systems—so-called fecal biomarkers. An overlying layer of ash deposited from a known Icelandic volcano eruption in 877 helped them reliably date the sediment sequences.

“You see the sheep DNA and the biomarkers start all at once. It’s like an off-on switch,” said Lamont paleoclimatologist William D’Andrea, who co-led the study.

The study is not the first to suggest that someone was there before the Vikings. The first physical evidence came with a 2013 study by other researchers of charred barley grains found underneath the floor of a Viking longhouse. The researchers dated the grains to between 300 and 500 years before the Norse; barley was not native to the island, so someone must have brought it. However, archaeologists wanted to see corroboration before declaring the case closed.

Some Medieval texts are suggestive. St. Brendan, an early Irish navigator, was said to have set out across the Atlantic with comrades from 512 to 530, and supposedly found a land dubbed the Isle of the Blessed. Later speculations and maps say this was the Faroes—or the far southerly Azores, or the Canary Islands—or that Brendan actually reached North America. In 825, the Irish monk and geographer Dicuil wrote that hermits had been living in some unidentified northern islands for at least 100 years. There was no proof for any of this.

The Lamont scientists speculate that the early settlers could have been Celts, though not necessarily monks. Many Faroese place names derive from Celtic words, and ancient Celtic grave markings dot the islands. DNA studies of the modern Faroese show that their paternal lineages are mainly Scandinavian, but their maternal lineages are mainly Celtic.

“We see this as putting the nail in the coffin that people were there before the Vikings,” said lead author Lorelei Curtin, who did the research as a Lamont graduate student. She noted that while the Faroes look rugged and wild today, practically all the vegetation feeds Faroese sheep, who in turn provide food and wool for the human population.

A HOTTER, DRIER WORLD

Our planet is in crisis. Since the beginning of the Industrial Revolution, we have added more than two trillion tons of carbon dioxide into the atmosphere, threatening to forever alter the relatively stable climate system in which humanity has grown and flourished for the last ten thousand years.

The disappearance of land and ocean species is progressing at rates unseen since the time of the dinosaurs. Each year, tens of thousands of people flee their homes because of extreme weather, extended droughts, wildfires, and other climate-related stressors searching for stable access to food, water, and safety. Societies will face these challenges for decades to come. By studying the past and by modeling the future, Lamont researchers are helping put the present into context, and working to ensure we develop smart adaptation policies and management practices to meet these challenges.

Using data from tree rings, satellites, and observational stations, Park Williams, Benjamin Cook, and Jason Smerdon confirmed that the 23-year-long megadrought currently parching southwestern North America is the worst the region has seen in at least 1,200 years.

Life-supporting reservoirs such as Lake Mead and Lake Powell are shriveling, while prolonged, triple-digit heatwaves are making cities like Phoenix and Las Vegas more dangerous during summers. While this region started experiencing cycles of megadroughts well before humans started pumping greenhouse gases into the atmosphere, climate change is increasing their severity and duration: warmer temperatures increase evaporation, which dries out soil and vegetation. These human-driven influences have made the current megadrought in the American Southwest more than 40% more severe than it would have been in a world absent the human influence.

Droughts and heat waves are also driving increased fire incidence in the American West, with complicated impacts on water resources. Williams, Smerdon, and Cook–along with Arianna Varuolo-Clarke, Justin Mankin, and Caroline Juang–analyzed stream flow and climate data from 179 river basins to show that wildfires in the western U.S. are increasingly impacting the region's rivers and streams. Fires actually elevate stream flow for years after they have burned away vegetation that would otherwise draw water out of the soil. But they could also increase the risks of catastrophic landslides and floods in the affected areas, in addition to impacting water quality. Understanding the role of wildfires will become increasingly important to the region's water-supply managers in their calculations of water availability and allocation for western communities.

Work by Corey Lesk and Radley Horton showed that climate change may cause heat and drought events to coincide more often, which could deliver a one-two punch to maize and soy farmers. They found that, when compared to previous projections of future climate risk to crops, these stronger relationships between high temperatures and low moisture could cause yields to drop an additional 20% in parts of the eastern U.S., and by up to 40% in parts of eastern Europe and southeastern Africa. Without strong and rapid cuts in greenhouse gases, overall supplies of staple foods could be increasingly damaged by compound climate extremes. This raises the risks of higher food prices and reduced food security, even in developed countries.

A hotter, drier world threatens the population and health of livestock, as well as the traditional pastoralist societies that depend on them. On the next page, read about the novel methods we're using to better understand the past climate of Mongolia, which happens to be located in one of the fastest-warming regions on the planet.

New Way of Analyzing Tree Rings Confirms Unprecedented Central Asia Warming

By Sarah Fecht

A relatively new way of analyzing tree rings have allowed Lamont researchers and international colleagues to reconstruct historical temperatures in Mongolia back to 1269 CE. The new reconstruction confirms that summer temperatures since the 1990s are the warmest the region has seen in the past eight centuries.

Lamont Adjunct Research Scientist Nicole Davi led the project team, which included Mukund Rao, Robert Wilson, Laia Andreu-Hayles, Rose Oelkers, Rosanne D'Arrigo, Brendan Buckley and Caroline Leland of the Lamont-Doherty Tree Ring Lab.

Central Asia is one of the fastest-warming places on the planet. In just the past 15 years, summer temperatures have warmed nearly 3 degrees F, or almost three times the global average rate. Rapid warming is already causing extreme droughts, harming fragile ecosystems and causing devastating livestock losses for pastoralists, who have traditionally formed the backbone of the Mongolian economy.

To date, there are only a handful of long-term climate records in Central Asia that can help to put these trends into context. Analyzing the rings from trees can tell scientists about temperature and precipitation patterns hundreds or thousands of years in the past. However, suitably old trees and logs in this region can be difficult to sample, in part due to their remoteness.

The scarcity of tree-ring data in the region makes the new reconstruction all the more important. To create it, Davi and her colleagues analyzed tree-ring cores that were originally collected in 1998 and 2005 for a project led by her mentor, Gordon Jacoby, co-founder of the Tree Ring Lab at Lamont. Jacoby had been trying to reconstruct the region's temperature history using ring widths, but the data wasn't strong enough, so he set it aside. Before Jacoby died in 2014, Davi asked permission to take over the project.

The cores come from a combination of living Siberian larch trees dating back 400 to 500 years, and relict wood—ancient trees that had fallen over but hadn't decayed, thanks to the cold and dry conditions. "When we find relict wood it's super exciting because we know we can go back further in time," said Davi.

To get new information out of Jacoby's samples, the team turned to a promising method that came into use a few years ago. Called delta blue intensity, the method looks at how well each ring reflects blue light in its latewood (the darker band that forms later in the growing season) compared to in the lighter early wood. Less dense wood, which results from cooler conditions, absorbs less blue light.

The stronger results from the delta blue light technique allowed the team to build a model of summer temperatures in the region from 1269 to 2004 CE. The reconstruction matches up well with data from regional weather stations dating back to the 1950s, as well as cooling events associated with several large-scale volcanic eruptions.

For Davi, publishing these findings feels personally meaningful. "Gordon Jacoby was my Ph.D. advisor, mentor, and friend," she said. "We had countless adventures doing fieldwork together. Bringing closure to some of the research that he started definitely feels good."

The reconstruction also adds context to the warming of the past several decades, and to global climate models showing what it could look like in the future.

THE AIR WE BREATHE

The World Health Organization estimates that 6-7 million people die prematurely every year from strokes, heart disease, lung cancer, and respiratory illnesses caused by the air they breathe. Air pollution is a major killer of children—those in the Global South, as well as those who live in poverty in the U.S. and other high-income countries. Developing effective policies and responses to this threat depends on the availability of consistent and reliable air-quality data, something that's hard to come by in places where the most vulnerable live, work and play. In Africa alone, nearly half a billion children live in areas with no reliable air-quality monitoring.

A large, interdisciplinary group of Columbia researchers co-led by Lamont's Daniel Westervelt have been working to change this reality. Their project, the Clean Air Toolbox for Cities (CAToolbox) is closing data-collection gaps in several African countries, as well as in India and Indonesia, by deploying state-of-the-art air-quality monitoring networks. The team is also supporting local community efforts to mitigate the health effects from pollution through legal and policy means. Lamont's Steven Chillrud, Róisín Commane, and Beizhan Yan are also part of CAToolbox. The project has already produced important results. Air monitoring in Togo's capital, Lomé, for example, revealed that the city frequently experiences unsafe levels of air pollution. The team has published similar studies for Ghana and the Congo.

Closer to home, Lamont atmospheric geochemist Róisín Commane and colleagues from the University of Albany embarked on a mission to locate New York state's largest sources of methane emissions, using a mobile laboratory housed in a cargo van. Their goal is to measure, and hopefully help reduce, emissions from landfills, cities, farms, waste treatment plants, and other sources where mitigation measures could be put in place. "There is a really large methane signal from New York City that is a mixture of many different sources," said Commane. "Our work is focused on identifying and quantifying the contributions of these different sources to overall methane concentrations so we can help state regulators and policymakers." Methane is the second-largest contributor to climate change behind carbon dioxide, and it accounts for 35% of New York's greenhouse-gas emissions.

And in Ohio's Belmont County, Westervelt and Lamont PhD student Garima Raheja gave their time and technical expertise to help communities and advocacy organizations set up air sensors to monitor emissions from nearby fracking facilities. What they found was both empowering... and concerning. Read about it on the next page.

Community-Led Science Uncovered High Air Pollution From Fracking in Ohio County

By Sarah Fecht

Residents of Belmont County in eastern Ohio have long suffered from headaches, fatigue, nausea and burning sensations in their throats and noses. They suspected these symptoms were the result of air pollution from fracking facilities that dominate the area, but regulators dismissed and downplayed their concerns.

With the technical assistance of volunteer scientists from Lamont, MIT and the American Geophysical Union's Thriving Earth Exchange, local advocacy groups set up their own network of low-cost sensors. They found that the region's three EPA sensors were not providing an accurate picture: The low-cost sensors revealed concerning levels of air pollution, and correlations between local spikes and health impacts. The researchers and community organizations published their findings in the journal *Environmental Research Letters*.

Belmont County is booming with new infrastructure to extract and process natural gas. Fracking is known to emit pollutants including particulate matter and volatile organic compounds such as benzene, toluene and ethylbenzene, which have been linked to respiratory and cardiovascular health problems.

Concerned about the fumes and the lack of information and transparency, two activist groups, Concerned Ohio River Residents and the Freshwater Accountability Project, wanted to set up a high-density monitoring network. After submitting their proposal to the Thriving Earth Exchange—a program that enables collaborations between community groups and volunteer scientists—they were paired with Garima Raheja, a PhD candidate who studies air pollution at Lamont.

With advice from Raheja and other scientists, the community members bought 60 low-cost sensors to monitor particulate matter and volatile organic compounds in the air. Then they identified areas of highest concern, and recruited residents to install and maintain the sensors in backyards, churches, and schools in those areas.

Based on two years of data from their sensor network, the team found that many sites frequently experienced days when air pollution exceeded levels recommended by the World Health Organization. For example, in the city of Martins Ferry, where a sensor took measurements for 336 days, it measured unsafe levels of air pollution on 50 of those days.

"It is kind of wild," said Raheja, "considering that it's generally a clean area. I think any number of days above WHO guidelines is really concerning for an area like this."

EPA sensors likely missed these details because the agency relies on high-grade monitors that cost hundreds of thousands of dollars apiece, so the network is sparse. In contrast, the citizen scientists' sensors cost only a few hundred dollars each, so they were able to set up a denser network.

Information from the air quality sensors has helped residents know when to close their windows, wear masks or update indoor air purification systems.

The data also offered a shared language that community members could use to articulate their complaints to the EPA, Ohio Department of Natural Resources, and the Ohio Department of Health.

"None of the Ohio regulators would come to witness the extreme air pollution events that made my wife and me very sick," said community member Kevin Young. "Now that we have data to substantiate the harmful amounts of the air pollutants, it seems the regulators are taking us more seriously."

The scientists and community groups hope to continue working together. They're applying for grants to scale up their sensor network, and networking with other concerned community groups who want to get started on similar programs.

EDUCATION AND OUTREACH

During the pandemic, our staff and partners built an impressive library of online curricula, resources and other materials that helped us reach thousands of students in the New York region and beyond. While we will continue to make use of these resources in our programming for years to come, we were very excited to restart our outdoor and in-person educational experiences for science learners of all ages.

SUMMER INTERN PROGRAM

The Lamont Summer Intern Program accepted 33 undergraduate interns from more than twenty U.S. colleges and universities in 2022. The ten-week program is run by Lamont scientists Dallas Abbott and Mike Kaplan, with help from Clara Chang and Bennett Slibeck. Fifty Columbia-affiliated scientists and graduate students also served as mentors in the program, helping students explore research careers and develop self-confidence in their independent research. Students also work on their communication abilities, their scientific identities, and form lasting professional relationships with scientists.

SECONDARY SCHOOL FIELD RESEARCH PROGRAM (SSFRP)

Lamont's Secondary School Field Research Program (SSFRP) brings high school students, undergraduates, and science teachers to the campus each summer for six weeks of field and laboratory research. This year, we hosted 72 students, who collaborated with Lamont scientists on various research projects in a tiered mentoring system. Research teams are composed of high school students, one or two undergraduate mentors with a teacher contact, and a Lamont researcher as science support. Ben Bostick, Bob Newton, Margie Turrin, Susan Vincent, Magdaly Sevilla, and a number of other Lamonters served as mentors for this group of aspiring future Earth scientists.

HUDSON RIVER FIELD STATION

SCIENCE SATURDAYS

Over the summer, we hosted hundreds of community members and families at the Field Station, building a strong following. Many families returned week after week, reinforcing their connection to the Hudson River and their commitment to environmental stewardship. Our community events focused around Science Saturdays: free, family-friendly programs that involve the community in field sampling and exploration of the Hudson River. Participants enjoyed our hands-on and experiential activities, such as seining and fish identification, water chemistry sampling, community science opportunities, and the development and use of different science games.

SCHOOL AND AFTER-SCHOOL FIELD STATION VISITS

With Covid-19 restrictions lifting in schools, teachers were ecstatic to get their students out of the classroom and into the field to learn from the natural world. We have had considerable interest from K-12 and undergraduate school groups and after-school programs to visit the Field Station to enhance their curriculum with place-based learning opportunities and field sampling. Each visit is specifically catered to the grade and current curriculum; our program offerings cover topics such as biology, chemistry, geology, physics, and microbiology.

TEACHER AND EDUCATOR WORKSHOPS

We know that many teachers are uncomfortable bringing their students out into the field without some training. To address this, we collaborated with the New York State DEC in several summer workshops that helped prepare teachers to take their students out into the Hudson River for science education experiences.

YOUTH TRAINING

This year, we hosted the Cornell Cooperative Youth for Climate Action Group at the Field Station to explore the resources we have at hand and to discuss how climate may affect our community going forward. After the program, a small team of the participants worked with us after to host their final projects at the Field Station, where they introduced our resources to their peers. This is an excellent example of how our work can empower young people to carry forward the knowledge they've learned as well as their sense of stewardship.

Additionally, we offered trainings on both the Hudson River and local Climate Change for the summer Rock¬land County Conservation and Service Corps (RCSC) members. As in the past, we brought on two Corps members to help with our summer high school student Next Gen program. Many other RCSC team members assisted with Science Saturdays, which enabled us to expand our programming.

DAY IN THE LIFE OF THE HUDSON AND HARBOR EVENT IN 2022

We hosted a successful in-person event with 4,200 students and their adult chaperones in this year's field sampling event.

NEXT GENERATION OF HUDSON RIVER EDUCATORS

Margie Turrin and Laurel Zaima helped high school students explore how to connect and share the value of the Hudson River and broader environmental resources with communities, in culturally meaningful ways. The students were part of a six-week summer program at Lamont's Hudson River Field Station called the Next Generation of Hudson River Educators. The program aims to give students from under-represented communities the opportunity to explore and gain a passion for the environmental sciences.

OUR DONORS

We are grateful to the many alumni, friends, and supporters who sustain our research and educational endeavors through their financial contributions. Annual support is critical to the advancement of our mission, the stability and ongoing operations of the Observatory, and the maintenance and stewardship of our campus.

With deep appreciation, we acknowledge the generosity of our donors for gifts made during our fiscal year between July 1, 2021 and June 30, 2022.

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We have made every effort to ensure this listing of gift contributions is complete, and we apologize for any errors or omissions. To report corrections, please contact us.

FINANCIALS

LDEO FY2022 Statement of Activities (In 1,000s)

SOURCES OF REVENUE	FY'21	FY'22
National Science Foundation	34,283	38,423
National Aeronautics and Space Administration	4,040	4,494
National Oceanic and Atmospheric Administration	1,471	1,894
National Institute of Environmental Health and Safety	891	400
Department of Energy	636	1,316
Department of State	130	211
Office of Naval Research	132	155
Woods Hole Oceanographic Institution	162	38
U.S. Geological Survey	378	153
Environmental Protection Agency	86	166
New York State	253	130
Miscellaneous Federal Funds	88	179
Total Government Grants—Direct & Indirect	**42,550**	**47,559**
Private Grants	4,343	5,103
Endowment Income	7,274	7,305
Gifts	1,946	1,701
Miscellaneous	600	439
Indirect Sources	7,201	5,531
Total Non-Government Sources	**21,364**	**20,079**
TOTAL SOURCES	**63,914**	**67,638**

USES OF REVENUE		
Research Expenses	35,474	39,729
Operation and Maintenance of Plant	5,109	5,569
General and Financial Administration	4,296	2,878
Other Instruction-Related	10,205	9,863
Equipment	1,899	1,874
Debt Service	1,434	1,420
External Affairs and Fundraising	852	872
Information Technology	874	902
Indirect Transfers	3,916	4,674
Total Uses of Revenue	**64,059**	**67,781**
NET OPERATING GAIN/(LOSS)	**(145)**	**(143)**
Capital Expenses	(340)	(285)
Endowment Corpus	0	(300)
Total Uses of Revenue	**(340)**	**(585)**

AWARDS

Lamont-Doherty Earth Observatory's outstanding scientists and researchers garnered several awards in FY2021. We are proud to share a selected list of awardees.

JACQUELINE AUSTERMANN

Jacqueline Austermann, Assistant Professor, Department of Earth and Environmental Sciences, and Seismology, Geology, and Tectonophysics Division, Lamont-Doherty Earth Observatory

Science News' 10 Scientists to Watch in 2022

ROBIN BELL

Robin Bell, Marine Geology and Geophysics Associate Director and Palisades Geophysical Institute Lamont Research Professor

Fulbright award to work in Australia in the academic year 2022-2023

NICHOLAS CHRISTIE-BLICK

Nicholas Christie-Blick, Professor, Department of Earth and Environmental Sciences, and Seismology, Geology and Tectonophysics Division, Lamont-Doherty Earth Observatory

Fellow of the American Association for the Advancement of Sciences (AAAS)

PIERRE GENTINE

Pierre Gentine, Associate Professor, Department of Earth and Environmental Engineering and Department of Earth and Environmental Sciences

James B. Macelwane Medal

DENNIS V. KENT

Dennis V. Kent, Adjunct Senior Research Scientist, Biology and Paleo Environment Division, Lamont Doherty Earth Observatory

John Adam Fleming Medal

KERSTIN LEHNERT

Kerstin Lehnert, Doherty Senior Research Scientist in the Marine Geology and Geophysics Division and Director of the Geoinformatics Research Group at Lamont

Doris-Schachner-Medal by the German Mineralogical Society (Deutsche Mineralogische Gesellschaft DMG)

MAUREEN E. RAYMO

Maureen E. Raymo, Co-Founding Dean, Columbia Climate School; Director, Lamont-Doherty Earth Observatory; G. Unger Vetlesen Professor of Earth and Climate Sciences Department of Earth and Environmental Sciences, Columbia University

Member of The Royal Swedish Academy of Sciences in the Class for Geosciences, Environmental Champion Award from New York State Senator Elijah Reichlin-Melnick

WILLIAM B.F. RYAN

William B.F. Ryan, Special Research Scientist, Marine Geology and Geophysics Division, Lamont-Doherty Earth Observatory

Lyell Medal by the Geological Society of London

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Marc W. Spiegelman, Arthur D. Storke Memorial Professor, Department of Earth and Environmental Sciences

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Mingfang Ting, Lamont Research Professor, Ocean and Climate Physics Division, Lamont-Doherty Earth Observatory; Adjunct Professor, Department of Earth and Environmental Sciences

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SPAHR C. WEBB

Jerome M. Paros/Lamont Senior Research Professor, Seismology, Geology and Tectonophysics; Adjunct Professor, Department of Earth and Environmental Sciences

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