Lamont-Doherty Earth Observatory
Columbia University | Earth Institute

ANNUAL REPORT | 2018

SCIENCE ON THE FRONT LINES OF OUR CHANGING PLANET

Cover:** fire fountains, Kilauea eruption, 2018. Photo by Brett Carr.* ***This page: *Lamont Associate Research Professor William D'Andrea and Lamont graduate student Lorelei Curtin prepare to acquire a lakebed core, Easter Island, March 2018. Photo by Andrea Seelenfreund.*

CONTENTS

STRATEGIC INITIATIVES

ANTICIPATING EARTHQUAKES

CHANGING ICE, CHANGING COASTLINES

CLIMATE AND LIFE

EXTREME WEATHER AND CLIMATE

REAL-TIME EARTH

Science on the Front Lines of Our Changing Planet

Above: *aboard the R/V Araon, the Korean icebreaker, on Terra Nova Bay, Ross Sea, Antarctica, February 2018. In the foreground are (left to right) field engineer Carson Witte, now a graduate student at Lamont, and Lauren Roche, a NOAA technician. Photo by Fiona Elliott.*

Lamont-Doherty Earth Observatory has been on the vanguard of understanding Earth and its changes since our inception in 1949, when Maurice “Doc” Ewing launched this extraordinary research center. Here, Marie Tharp created the first global maps of the seafloor, stunning her contemporaries with the discovery of the mid-ocean ridges and their crestal rift zones, evidence for sea-floor spreading and continental drift . Her finding was but one in a long, celebrated list of discoveries by Observatory scientists.

Lamont scientists were the first to show the role of the global ocean in climate, first to predict El Niño climate events, first to develop the seismological tools that enabled nuclear test bans, and first to design multiple generations of seismometers for deployment in global networks on Earth and on the Moon by Apollo astronauts. The Observatory serves as scientific home to the largest concentration of Earth and climate scientists in the academic U.S. Our researchers study the planet from its deepest interior to the outer reaches of its atmosphere, on every continent and in every ocean, providing a rational basis for addressing many of the difficult challenges facing humanity. Three foundational strengths drive our interdisciplinary approach: climate science, geodynamics of the solid Earth, and the study of life on our evolving planet.

This year, Lamont continued to add to its distinguished legacy with discoveries that challenge complacency and alter perceptions of the world as it was, is, and will be. We titled this report “Science on the Front Lines of Our Changing Planet” because many of our scientists answered the call to join the front lines of extreme events and environmental shifts, enabling investigative opportunities that offered particular promise for advances in understanding.

Across the Observatory, Lamont’s women and men of science strive daily to sharpen our knowledge of the interlinked processes that govern the myriad changes to our world and our environment. It is within this context of exploration, discovery, and scientific leadership that we present our annual report for 2018.

“knowledge can aid world leaders to recognize similar warning signs in the future”

Dear Friends,

The year 2018 at Lamont brought a characteristically rich mix of fieldwork, new laboratory findings, and novel numerical modeling work. Each year our scientists and students strive to increase our understanding of our planet, its governing processes, and the factors that influence both natural variability and global change. This mission took Lamont researchers this year to field areas across the continents and oceans where key phenomena could best be studied in detail, and their efforts produced discoveries that continued to expand the scientific understanding of our changing Earth.

In our report “Science on the Front Lines of Our Changing Planet,” you will journey with volcanologist Einat Lev to Kilauea, on the island of Hawaii. She and her team traveled to the front lines of this year’s highly publicized eruption, where they offered aid and relief to the emergency responders and field scientists and gathered data on the evolution of the lava flows, information that, once analyzed, holds promise for more accurate predictive models in the future.

Paleoclimatologist William D’Andrea visited Easter Island this year, to uncover clues in ancient lake sediments to the ecocide postulated to have decimated the Rapa Nui culture and to improve our understanding of the modern hydroclimate to inform efforts by the island’s current residents to sustain water security. Richard Seager’s research traced the influence of atmospheric warming on the evolution of the long-recognized line that divides the arid western United States from the humid eastern U.S. Park Williams illuminated how heat and drought contributed to this year’s unprecedented spate of deadly wildfires and likely will fuel similar destructive forces into the future. Radley Horton showed how the combination of heat and humidity will pose an existential threat to human health in an increasing number of vulnerable areas. Maureen Raymo reflected on a career sparked (in part) by the explorer Jacques Cousteau, which led her to contribute broadly to science and made her one of her field’s most celebrated researchers. Natalie Boelman and graduate student Ruth Oliver exploited machine-learning-powered “ears” to listen for changes in migratory patterns of birds in the warming Arctic. Xiaomeng Jin and Arlene Fiore devised a method to study from space the formation of ground-level ozone. Christopher Zappa journeyed to Alaska’s Kotzebue to work closely with indigenous villagers to initiate a new kind of study of evolving sea ice. Sonya Dyhrman, Matthew Harke, and Kyle Frischkorn traveled to the middle of the Pacific to gather water samples that yielded evidence of a symbiotic relationship among the diatoms and phytoplankton that help generate the air we breathe.

Highlights of the year’s research at the Observatory described in this report and the many additional examples of new scientific findings by Lamont scientists this past year are enabled, in large part, by the many friends, alumni, and staff who support our research and educational programs. Your contributions lead directly to improved understanding of Earth’s past and present, and enhance our ability to address the most urgent environmental challenges ahead for all of us. We deeply appreciate the generosity of our donors and the scientific progress made possible by their gifts.

For another year, thank you for your support.

Sean C. Solomon
Director

On the Front Lines at Kilauea

Above: *lava flow, Kilauea eruption, 2018. Drone image from Einat Lev.*

In the early spring, volcanologists monitoring the ground around Kilauea, the most active volcano on the island of Hawai'i, noticed a significant increase in seismicity, a sign of an impending eruption. Meanwhile, in Palisades, New York, Lamont volcanologist Einat Lev was also watching developments at Kilauea closely, scanning United States Geological Survey (USGS) reports and keeping in regular touch with friends and colleagues directly tasked with monitoring volcanic activity.

Lev had a particular interest because of her prior experience at Kilauea, having studied the lava lake that has occupied the summit crater since 2008. Her fascination with this volcano came to a crescendo on May 3, 2018, when the anticipated eruption began. Lev started searching for a way to help response efforts and to place her team sufficiently close to the newly opened fissures to observe the developing phenomenon. It took her several days to lock down a plan, obtain a permit, and book plane tickets for herself and her two postdoctoral researchers. All of this she carefully orchestrated so as to serve as well the response team on the ground.

"I didn't want to go there without coordination", Lev said. "Obviously, they closed the region. I tried to work directly with the USGS, but they're not allowed to work with anyone external, so I had to find other ways. I contacted colleagues at the University of Hawai'i-Hilo and learned they had a permit to go in. They are people I've worked with before, and since we all had the proper certifications and drone operational and field experience, they invited us to join them. When we heard that, we bought our tickets. I felt I really needed to be there."

This expedition would lead Lev and her team to the front lines of an active, dangerous volcanic eruption, thrusting her into the center of the action and the news media spotlight. Lev's first-person accounts and analysis made for lead stories across major outlets, including CNN, BBC, and NPR. Her descriptions brought home the immediacy of the situation.

Above: *lava from the Kilauea eruption entering the ocean, 2018.* ***Opposite page:*** *(left) fire fountains, Kilauea eruption, 2018; (right) Lamont Associate Research Professor Einat Lev in profile in this night image taken in Leilani. Photos by Julie Oppenheimer.*

"Our volcanology team at Lamont-Doherty Earth Observatory is on-site to witness this historic natural event, and to be of service to the local authorities in their constant, exhausting chase to monitor the eruption and protect the public," Lev wrote, while chronicling her activities on the scene.

Lev's team was prepared to support the effort and offered both sophisticated drones and reinforcements to relieve the already exhausted UH-Hilo team, the USGS scientists, and emergency-response workers.

"We had brand new equipment. It was an opportunity for us to try it within the context of a dynamic event for the first time. Our drone has both a standard video camera and an infrared video camera. It was very helpful because the team in Hilo had similar equipment but not a single drone that could conduct both video and the thermal imaging at the same time. To get that coverage they needed two flights. Using our equipment was faster and more efficient," added Lev.

The three-person Lamont team also joined shifts as the necessary 24/7 monitoring continued.

"While we were not allowed to fly our drones ourselves, we could serve as the required flight observers, help with the setup and provide equipment, so the official responders could have a break. Our team helped reduce the load on them," said Lev.

Ultimately, the eruption forced the evacuation of thousands of people. The lava flow consumed 700 homes. A series of as many as 18,000 earthquakes forced the closure of Hawai'i Volcanoes National Park, and lava haze ("laze"), spatter, and lava bombs became serious health threats. For volcanologists, however, the Kilauea eruption – more than 100 days long – was also an opportunity to study an enigmatic planetary process as it unfolded.

"For those of us grounded in the academic theory of what lava does and the physics behind lava flows, it was fascinating to see the response on the ground. We were part of it all, what the road crews have to deal with, what the fire crews have to deal with, how the community responds, and how people evacuate or don't evacuate. Seeing all of this unfold and not just reading about it was really fascinating. People think lava moves slowly, that it's not a rapid-response emergency. But actually, at Kilauea, things kept changing. Overall, 22 fissures erupted, and the active sites kept jumping around. The response had to be very dynamic. Many times I thought a fissure was done, but then it would start again. It was really about responding to what was happening," Lev said.

Lev has been studying the science of volcanoes since her arrival at Lamont in 2009, but her work at Kilauea was revelatory for her.

"It's different experiencing something with your body and your eardrum from thinking about it mathematically", noted Lev. "It was definitely the most emotional connection to my subject that I've had…ever. For us that was the greatest benefit from going there, a chance to develop an intuitive connection to a subject we've long been studying from afar."

Lev believes these observations and the ongoing sampling led by the USGS will inform volcanology, advancing science's understanding, improving predictive modeling, and strengthening the case for a uniform methodology for responses to eruptions elsewhere. In the spring, during the weeks prior to the Kilauea eruption, she had been part of a cadre of volcanologists working on a proposal to the National Science Foundation to fund a data sharing and response coordination system. After her work on the front lines at Kilauea, she believes even more strongly that such a system is essential.

"The response was so complex at Kilauea, in the United States, a modern country with modern systems, and still there was room for improvement. This eruption and the response to it should serve as the model and a lesson for the future."

A Body of Work on Fire

Above: *wildfire in Stanislaus National Forest, California, 2013. U.S. Forest Service photo by Mike McMillan.*

California's wildfire season this year made headlines throughout late summer, with front-line firefighters reporting that local agencies were overwhelmed by the pace and severity of the blazes. Said one deputy chief, "Normally during the fire season, Cal Fire will respond to about 300 individual fires per week. This year, in just one week, the agency responded to 1,000 fires." By mid-September, a total of 6,324 fires had burned a cumulative area of 1,493,506 acres, according to the California Department of Forestry and Fire Protection and the National Interagency Fire Center. Fifteen people were killed, including eight civilians and six firefighters.

Lamont bioclimatologist Park Williams was saddened but not surprised. His research has focused on the correlation between intensifying hot and dry spells and the rapidly rising increase in forest fire risk.

"It makes sense that this year was a really big fire year, because it was a record-breaking hot summer. And what we see with fire statistics is that heat is really the single most important climate variable to fire."

Above: *this 2016 Montana fire devoured more than 8,000 acres of forest, along with more than 60 homes and outbuildings. Photo by Mike Daniels.*

"It makes sense that this year was a really big fire year, because it was a record-breaking hot summer. And what we see with fire statistics is that heat is really the single most important climate variable to fire," said Williams. A 2016 study that he and a colleague published in the Proceedings of the National Academy of Sciences showed that human-induced climate change has doubled the area affected by forest fires in the U.S. west over the last 40 years. According to the study, between 1984 and 2015 heightened temperatures and resulting aridity caused fires to spread across an additional 16,000 square miles than would otherwise have been consumed – an area larger than the states of Massachusetts and Connecticut combined. The authors warned that further warming will increase substantially the frequency and severity of wildfires in coming decades.

"If it weren't for the warming trend, we would've had about half as much forest fire over the last 40 years," said Williams. He cautioned against reading this as a simple equation. The growing fires in the western U.S. are also a product of a century of forest management. Fire, as dangerous and chaotic as it can be, has traditionally been a natural ecological process, typically started by lightning. Historical fires tended to be low burning and mild by comparison to the rapidly spreading crown fires common today.

"There are many natural ecological processes that depend on fire, and over the last century, as we've removed fire from the western U.S., forests have been out of whack. So not only are our ecosystems forced to function in an unnatural way because of the exclusion of fire, now when fires occur there is that much more fuel to intensify and spread the flames," explained Williams.

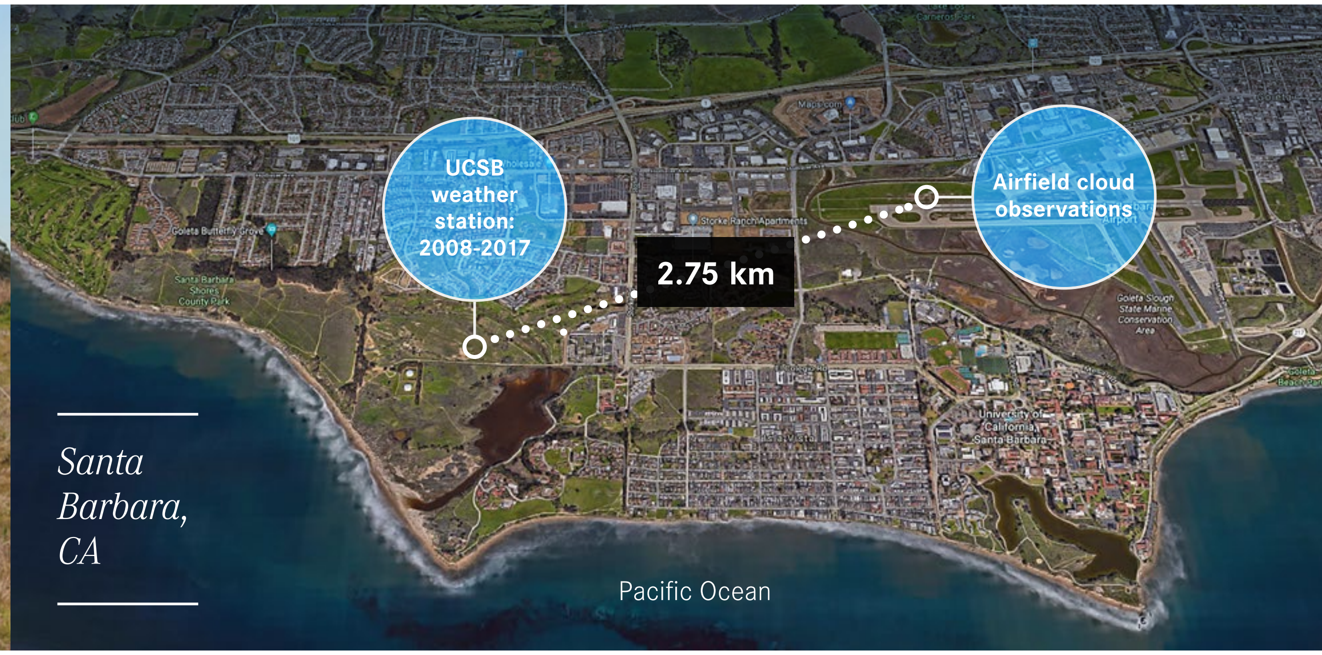
1910 was a turning point in American forest management history. It was a very dry year, and the usual number of forest fires had multiplied. Forest management officials saw this as a reason to change their approach and to dedicate their resources to putting out forest fires. Throughout the decades since then, firefighting improved, in effect short-circuiting the natural fire process.

"We kept getting better and better at fighting fire right through the 1980s. Back then the experts didn't anticipate this huge blow-up of fires. Firefighters thought that fires would stay small because they were really good at fighting them. They used to think fires that burned more than 100 acres were really big fires. And now such small fires are minor. Now we have fires that consume 100 acres per second."

According to Williams' research, the trajectory promises to worsen as the Earth continues to warm, drying the overabundance of vegetation and priming western North America for massive fires.

His most recently published research – which identified a clear relationship between fire occurrence and the reduction of cloud cover over coastal California – is the result of more than a decade of investigations of wildfires and fieldwork that dates back to Williams' years as a graduate student in California.

"It is really tough to imagine how things will look after another couple of decades of warming. We are seeing a reemergence of fire after a century of exclusion. That is not all bad. It's a different type of fire from the naturally occurring ecological process, however. Now we have people living in these areas, and fire is dangerous. Towns built into forests are increasingly at risk. And we're going to see some towns unavoidably burning down. Those towns should be prepared,"



“areas where clouds have decreased, the fires should become more intense and more difficult to contain”

Left: *low-level clouds over Los Angeles (seen in early afternoon) and other urban areas of coastal southern California are becoming rarer, leading to increased fire risk. Photo by Park Williams.*

Above: *weather station operated by the University of California, Santa Barbara. Photo by Park Williams. Aerial view of Santa Barbara, from Google Maps.*

Then, while at the University of California, Santa Barbara, he and his colleagues studied the importance of clouds for forests. The main tool for his fieldwork was a single weather station that Williams helped build in 2007. This weather station has since been collecting very accurate measurements of radiation.

“It’s been recording the amount of sunlight and also the amount of radiation that the ground reflects back upwards. And it’s been logging the amount of longwave thermal heat that comes down from clouds and up through the ground. This type of very careful sets of radiation measurements is actually very rare, and we now have a 10-year record of these measurements made every 10 or 15 minutes.”

That weather station is adjacent to Santa Barbara Municipal Airport. Williams was able to use those radiation measurements along with the tens of thousands of coincident cloud measurements made routinely from the airport. From this analysis, he and his colleagues quantified the relationship between clouds and the radiation or energy balance near Earth’s surface.

“That’s how we were able to determine that if you lose, say, 30 % of clouds at 10 am there is a specific amount of watts per square meter of extra sunlight.”

This 2018 study linked increasing summer temperatures brought on by a combination of intensifying urbanization and warming climate to the dissipation of once common low-lying morning clouds in many southern coastal areas of the state, and in turn to the increased risk of wildfires. As clouds decrease, the rate of larger, more intense fires escalates.

Urban pavement and infrastructure do not cool off as quickly as the surrounding countryside, resulting in warmer nights and mornings, and reduced evaporation from wet soils and vegetation often results in warmer days. This so-called heat-island effect makes cities generally hotter than rural areas. At the same time, overall temperatures have been rising in California because of global warming, and this warming has boosted the effect. In the 2018 study, Williams and his colleagues found a 25 to 50 percent decrease in low-lying summer clouds since the 1970s in the greater Los Angeles area.

Williams’ team also discovered that periods of less cloud cover during the summer are correlated with lower vegetation moisture, and thus a greater danger of fire.

However, the study did not find that the total area burned each summer has increased as a result of decreases in cloud shading. There are too many other factors at play, said Williams. These include yearly variations in rainfall, winds, locations where fires start, and, most importantly, decreases in burnable area as urban areas have expanded and steady increases in the effectiveness of firefighting.

“But the dice are now loaded, and in areas where clouds have decreased, the fires should become more intense and more difficult to contain. At some point, we’ll see if people can continue to keep up.”

Williams says this year’s record-breaking wildfires in inland California are not a consequence of the dissipation of clouds over the coastal area of the state. Instead, they are the result of a combination of factors, including global warming and its drying impact; multiple decades of decreasing precipitation due to natural variability in the atmospheric circulation pattern over the Pacific Ocean region; the increasing number of people, the sources of most fires in California; and dense vegetation that has been aided by a century of firefighting.

Williams is now in the process of researching the history of drought in North America. Specifically, he is examining thousands of tree-ring records to study the infamous megadroughts that occurred in the western United States and Mexico during the Medieval period approximately 800–1200 years ago. Relating those tree-ring records to more recent climate records, Williams finds that after a relatively wet 400 years, the western United States is currently 19 years into a drought that so far is on pace to rival the worst megadroughts of the past 1200 years.

Above: *Lamont Associate Research Professor Park Williams. Lamont photo.*

Easter Island's Climate Past

Easter Island, also known by its Polynesian name Rapa Nui, is a tiny island in the middle of the vast Pacific Ocean and is widely known for its great coastal beauty and for the moai, a collection of nearly 1,000 ancient carved sculptures of people, many of which once rested atop stone platforms called ahu. These statues, which face inland, away from the sea, are considered to be products of extraordinary ingenuity and craftwork, and they are also signposts of a once well-established island civilization.

"The moai represented important ancestors in every lineage, incarnating the spirits and the power of the founding ancestors," observed archeologist Andrea Seelenfreund in her 2015 book entitled "Rapa Nui."

"The moai represented important ancestors in every lineage, incarnating the spirits and the power of the founding ancestors"

***Opposite page:** moai on Easter Island, March 2018. Photo by William D'Andrea.*

Above: *Lamont Associate Research Professor William D'Andrea. Photo by Raymond Bradley.* ***Bottom right:*** *(left to right) James Van Hook, William D'Andrea, Nicholas Balascio, and Lorelei Curtin with coring equipment on Easter Island, March 2018. Photo by Andrea Seelenfreund.* ***Opposite page:*** *moai on Easter Island, March 2018. Photo by William D'Andrea.*

The statues are illustrative of the island's mysterious past. Around 1400 A.D. as many as 10,000 people lived on the island, but by the early 1800s there were just 100 people surviving. The virtual disappearance of a population and the remarkable artifacts the Polynesian Rapanui people left behind, intrigue and attract thousands to the ecologically fragile place, feeding an industry which, while economically essential to the island's 6,000 residents, is exacerbating a growing crisis: a water shortage. From a look at Easter Island on a map or satellite image it might seem unlikely that this tiny volcanic island in the middle of the eastern Pacific Ocean would struggle for fresh water.

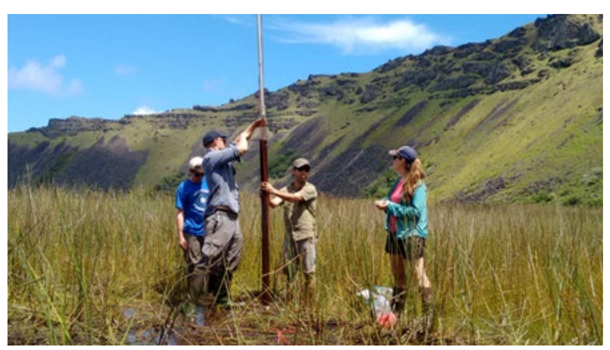
"You would think it's just wet and raining there all the time, but that's not the case," said Lamont Associate Research Professor William D'Andrea. "There is a dry zone in the southeastern Pacific because of the Andes, and it influences the amount of rain that falls. There is evidence that Easter Island has gone through extreme wet and dry periods in the past."

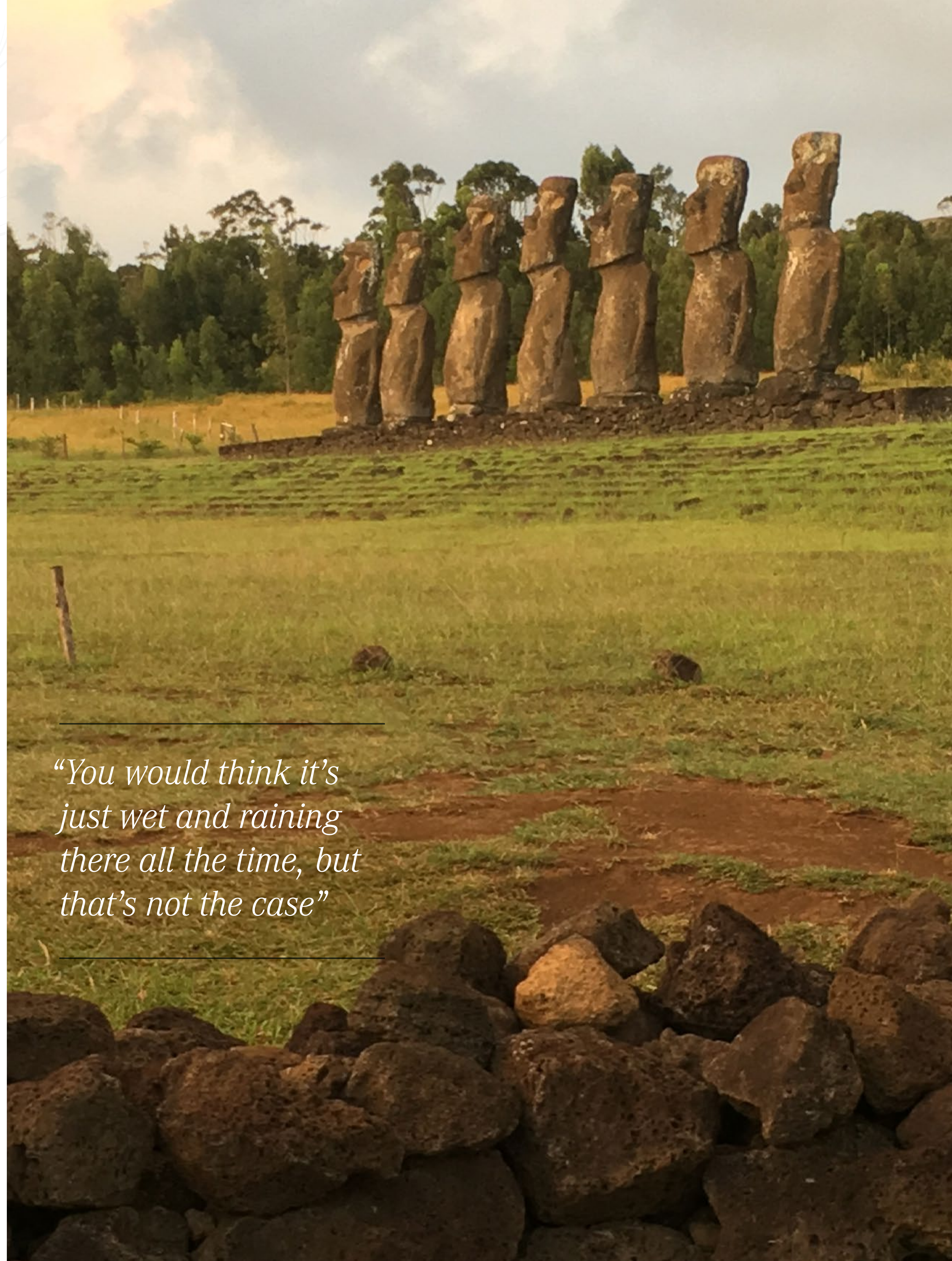
An opportunity to investigate this drought pattern for a major research project – funded by the Center for Climate and Life at Lamont, the Vetlesen Foundation, the Explorers Club of New York, and the College of William and Mary Reves Center for International Studies – and the mystery surrounding the enigmatic people of Rapa Nui, drew D'Andrea and a team to the island in March 2018. The collaborative field team, which also included Lamont's Lorelei Curtin; archaeologist Andrea Seelenfreund from Chile's Universidad Academia de Humanismo Cristiano; Nicholas Balascio and James Van Hook from the College of William and Mary in Virginia; and Raymond Bradley from University of Massachusetts, Amherst, successfully collected sediment cores from the wetlands of Rano Kau, Rano Raraku, and Rano Aroi, recovering geologic records that likely span the past 30,000 years on Rapa Nui and which they are now using to examine many aspects of climatic, environmental, and human land-use history.

During the expedition, the team observed that the lake at Rano Raraku, the famous quarry from which the ancient Rapanui people carved the moai, is completely dried up and the lakebed is exposed. This marked change occurred only in the past year or two – previously the lake was a site of an annual local competition that involved swimming and boating. This competition had to be relocated to the ocean this year because of the desiccation of the lake.

"No one we met remembered a year when they couldn't do the competition in this lake," said D'Andrea. "The most relevant and interesting question is, are we seeing something to indicate this is where water resources are headed into the future? Is this island facing a future with less freshwater, or is this just an aberration?"

To answer these questions, the researchers use the sediments gathered, which accumulate year after year like pages of a book, to see if there is a common thread, tracing both the population changes through time and the impact of natural and anthropogenic climate change. D'Andrea, a paleoclimatologist, studies how environments have evolved by reconstructing climate history from the molecules preserved in lake sediment cores. Lipid molecules from plants and algae are preserved in the sediments that accumulate each year on the bottom of lakes and the ocean. D'Andrea analyzes these compounds to learn how temperature, precipitation, and evaporation have changed throughout the island's history.





"You would think it's just wet and raining there all the time, but that's not the case"

Above: *Orongo, a stone village and ceremonial center, is the site of important cultural activities for the Rapanui people, March 2018.* **Right:** *Easter Island research team members (left to right) Arone Rapu, Andrea Seelenfreund, James Van Hook, Lorelei Curtin, Dionisio (Peter) Teao, Nicholas Balascio, William D'Andrea, and Nico Teao. Photos provided by William D'Andrea.*

This is the first time that scientists are analyzing Easter Island lakebed cores with this method. "I became interested in the research after talking to colleagues who had been working there before and had been wrestling with a couple of different problems. They were trying to understand the climate history, but the tools they were using were limited. They hadn't tried to use the type of measurements that we make in our lab," said D'Andrea. Colleagues wanted D'Andrea's help to ascertain when people first arrived on Rapa Nui and what the climate was like then.

"We know that it must have been drier in the past, because this lake had dried out for thousands of years. During that time, it wasn't accumulating any new sediment. Polynesians settled Rapa Nui sometime between 600 and 1200 A.D., which is late compared with other Pacific islands. Was the timing of their arrival somehow related to water availability? And did they have to deal with extended periods of drought during their 1,000 years on the island?"

The long-held prevailing theory about the demise of the Rapanui culture is that they mismanaged the resources of the island. As the story goes, they destroyed the island's ecology and therefore it could no longer support them, and because of that their entire culture collapsed; this concept has been termed "ecocide."

But, there's controversy about whether the Easter Islanders really represent an example of people whose resource use and potential resource mismanagement led to the downfall of their culture.

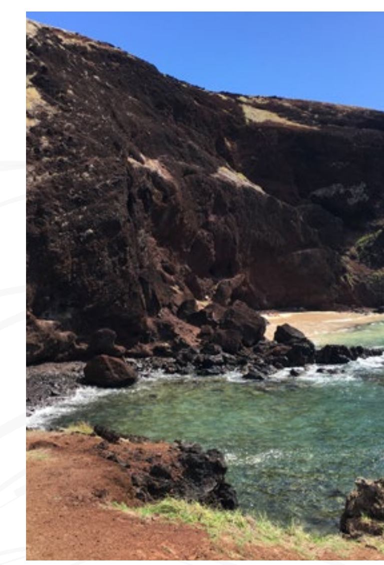
The ecocide theory is often used to suggest an allegorical comparison between the demise of the Rapanui society and what could happen to all of humanity as the impact of global warming and exploitation of resources continue to cause environmental degradation.

Above: *(front to back, at right) Andrea Seelenfreund, Nicholas Balascio, James Van Hook, and Lorelei Curtin hike out of the Rano Kau caldera.* ***Opposite page:*** *(left) Rano Kau caldera; (right) Easter Island coastline. Photos by William D'Andrea.*

"But the evidence for that narrative on Rapa Nui is weak and incomplete," said D'Andrea. "The idea has been challenged. So we would like to weigh in and help understand what kinds of natural climate changes the Rapanui people had to deal with, and also help provide new evidence about when they first arrived. We seek to uncover new objective, observational evidence to address some of these questions."

By evaluating the molecular remains in the sediment cores, D'Andrea and team hope to illuminate Easter Island's mysterious past and at the same time inform a deeper understanding of human resilience and vulnerability to climate change.

"The idea has been challenged. So we would like to weigh in and help understand what kinds of natural climate changes the Rapanui people had to deal with, and also help provide new evidence about when they first arrived. We seek to uncover new objective, observational evidence to address some of these questions."



A New Research Paradigm:

Where Data Science Meets Community Life

***Above:** scientists and residents of Kotzebue, Alaska, pose with the unmanned aerial system used in a cooperative program by both groups to study changes in Arctic sea ice. Photo by Sarah Betcher/ Farthest North Films.*

Physical oceanographer Christopher Zappa grew up on the coast north of Boston, where he developed a deep appreciation and intellectual curiosity about the sea. It follows that his work at Lamont is rooted in the oceans. Zappa studies climate physics, and more specifically how ocean waves impact the transfer of heat and mass between the ocean and the atmosphere. His work has recently taken him on an unusual journey of investigation and friendship. This past spring, Zappa and his colleagues completed the second year of a four-year project to study the seasonal variation in sea ice in the Chukchi Sea off northwestern Alaska, both with highly sophisticated technology and through the traditional knowledge of villagers in the local village of Kotzebue.

"I love the way they say good morning there," says Zappa. "Uuvlaaluataq (pronounced oov-la-lua-tuck). It means great day, good morning. Everyone greets each other with this." Zappa and his colleagues spent a few weeks in the village last year, but this spring they spent five weeks in Kotzebue during April and May.

"The more time we spend in the community, the more we become part of the community. Being invited into their homes is a big honor," said Zappa.

"The more time we spend in the community, the more we become part of the community. Being invited into their homes is a big honor"

Above: *Lamont engineers (left to right) Scott Brown and Tej Dhakal prepare the unmanned aerial system (UAS) for flight.* ***Opposite page:*** *(upper left) Kotzebue, Alaska, advisory council member, John Goodwin, cuts into a sea-ice core; (upper right) members of the flight team discuss UAS operations at an open house with the local community; (lower right, left to right) University of Washington graduate student Jessica Lindsay and NOAA scientist Peter Boveng survey the sea ice with LIDAR (light detection and ranging); (lower middle, left to right) University of Alaska, Fairbanks, graduate student Kate Turner and advisory council member Cyrus Harris read data after a CTD (conductivity, temperature, depth) cast; (lower left, left to right) Christopher Zappa, Alex Whiting, Cyrus Harris, Kate Turner, Jessica Lindsay, and Sarah Betcher during interviews by the local radio station in Kotzebue (photo courtesy KOTZ Radio). All photos by Sarah Betcher/Farthest North Films except as indicated.*

Kotzebue, a tiny town with a population of about 3,000, drew national focus in late 2015, when President Barack Obama came to announce federal grant programs to help residents cope with coastal erosion and high energy costs, and in some extreme cases relocate altogether. Tribal leaders told reporters that the visit was an important gesture for those who have long sought federal support to deal with such challenges.

"Alaska native traditions that have set the rhythm of life in Alaska for thousands of years are being upended by decreasing sea-ice cover and changing seasonal patterns," read a White House statement. Sea ice has been receding up and down the coast of Alaska, impacting the many local communities. The importance of village traditions and their close ties to the "rhythm of life" in their environment has inspired this first-of-its-kind study funded by the Gordon and Betty More Foundation. It has taken Zappa and his colleagues into a deep study of the melting sea ice, which involved deploying redesigned remote-sensing instruments, and has also required in-depth conversations with Kotzebue elders to enlist the wisdom and insights of the indigenous community. By integrating the native coastal community's

> *"Alaska native traditions that have set the rhythm of life in Alaska for thousands of years are being upended by decreasing sea-ice cover and changing seasonal patterns"*

observations with a powerful unmanned aerial system (UAS), Zappa anticipates developing a uniquely nuanced study of the dynamics of sea ice melting. Such an understanding will help inform and prepare Alaska's coastal communities and will ultimately gauge the role of climate change on this pattern.

"The whole project is about bridging science and traditional knowledge to understand how sea ice is changing in Kotzebue Sound and how it impacts their traditions. A lot of the traditional life of the village is spent on the ice, so the changing ice impacts what they are able to do and when," explained Zappa.

Zappa, who runs a UAS lab at Lamont, has redesigned remote-sensing instruments typically found aboard research ships or aircraft to conduct research in environments such as Kotzebue's. The drones' range and maneuverability allow his teams to fly their instruments low over sea ice across a wide area that ships can't always reach while also avoiding interference from a ship's heat and movement and significantly cutting costs. The result is unmatched data on sea ice movement and new insights into changes in the environment.

"When we fly our unmanned aerial vehicles (UAVs) we don't know what to anticipate. With this technology, we are able to send back data to our ground station. Once we see an area with interesting features we want to study, we can alter the UAV flight path and conduct high-density sampling in that specific region," said Zappa.

The overarching approach to this research project is guided in a unique way. Typically, research fieldwork begins with clearly defined objectives, specific questions to be addressed and, ideally, answered. However, the Kotzebue research began with a series of meetings with local elders of the village. From the very beginning, the local advisory council was to have a voice in setting the agenda.

> *"The whole project is about bridging science and indigenous knowledge to understand how sea ice is changing in Kotzebue Sound and how it impacts their traditions"*

Above: Lamont Research Professor Christopher Zappa. Photo by Sarah Betcher/ Farthest North Films.

"We came up with topics based on the interests of the indigenous community. We went in with a clean slate. We formed an advisory board of elders from the community that we worked with to develop the scientific questions," said Zappa.

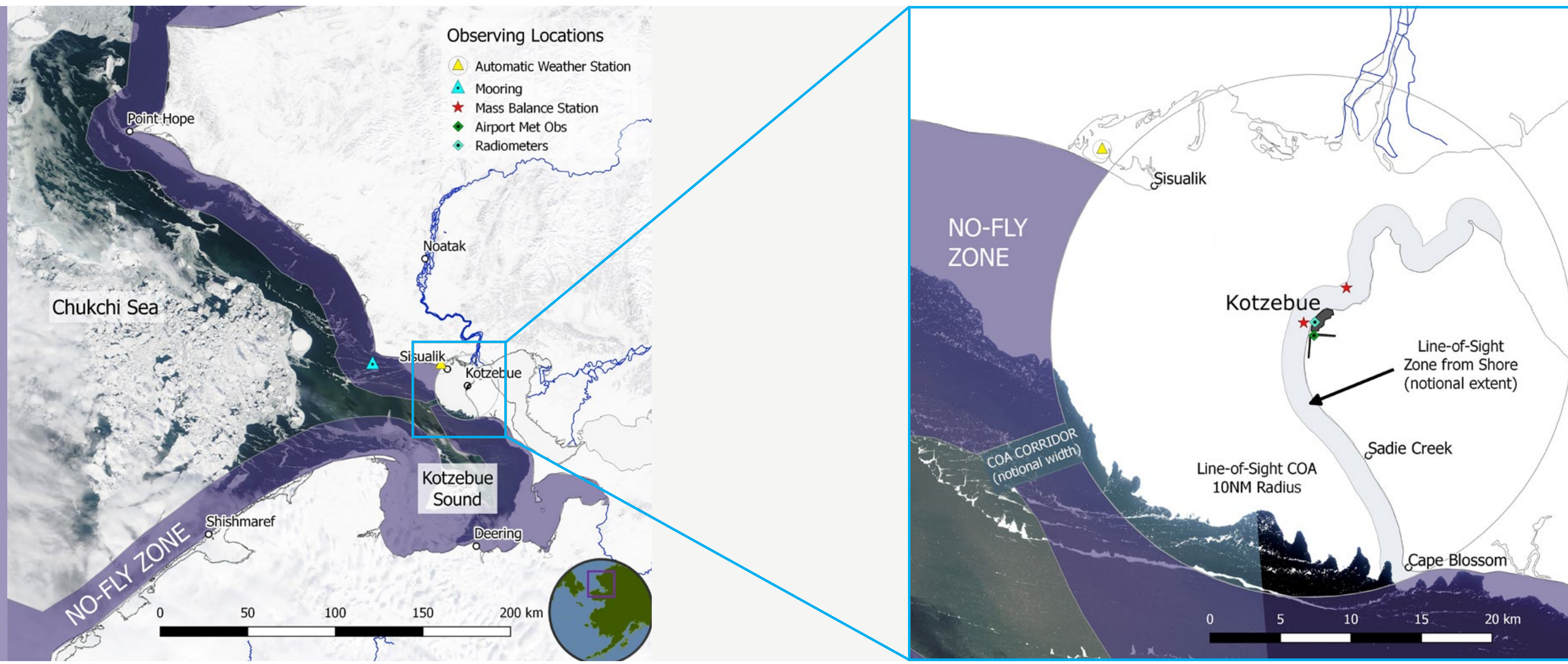
For the first year of the project, Zappa and his colleagues worked with Kotzebue elders to define the questions most vital to the community. Among them: which species of marine mammals and birds occupy the system west of Kotzebue prior to the ice break up within the sound, what environmental factors control marine mammal use of Kotzebue Sound, what environmental factors control the length of the bearded seal (Ugruk) hunting season in the sound, what determines the ice transport processes in the sound, what snow and ice surface properties promote ringed seal (Nutchuk) den integrity and pupping success, and what role does the sea ice play in sediment transport in the sound.

The environmental controls on the ice breakup are especially important to the community, as hunters count on stable landfast ice to enable them to travel from the beach to ice farther offshore, where they conduct their time-honored traditional hunt of ringed seals. Furthermore, the ice breakup defines the beginning of the bearded seal hunt. The bearded seal hunting season is determined both by the availability of suitable sea-ice habitat and the accessibility of this habitat from Kotzebue, which is determined in part by the development of a channel through the landfast ice created by outflow from the Noatak River. Early disintegration of the pack in the sound and delayed breakup of the shorefast ice has led to a severely shortened season in recent years. The hunting of the seals is part of the Kotzebue tradition and was once critical to the villagers' survival.

"The ice is still critical for subsistence; traditional hunts are central to the fabric of the community and something the community wants to keep going," said Zappa. Preliminary findings flesh out a pattern of melt seasons that has varied significantly. This year, Zappa observed a major anomaly in that the melt period was much earlier than usual.

"It's my first time working with an indigenous community. It's both challenging and rewarding. Challenges include incorporating a new perspective on how to do science. It's rewarding as we are accessing different perspectives. Having access to the villagers' documented history is and will be very helpful," said Zappa. "The indigenous community has a wealth of knowledge because for many generations they have always been there in Kotzebue to observe the coastal Arctic ice system. It's part of their tradition."

Below: (left) annotated satellite image mosaic of Kotzebue Sound and the Chukchi Sea showing the no-fly zone (shaded purple) and the 10-mile radius approved for unmanned aerial system flight under a certificate of authorization (COA) from the Federal Aviation Administration; (inset) map of Alaska showing the borders of the left panel; (right) expanded view of the work area around Kotzebue; selected geographic names and multi-year observing locations are marked and labeled. Figure by Carson Witte.



In the Oceans, Survival Is Symbiotic

New Research Illuminates a Microscopic Mystery

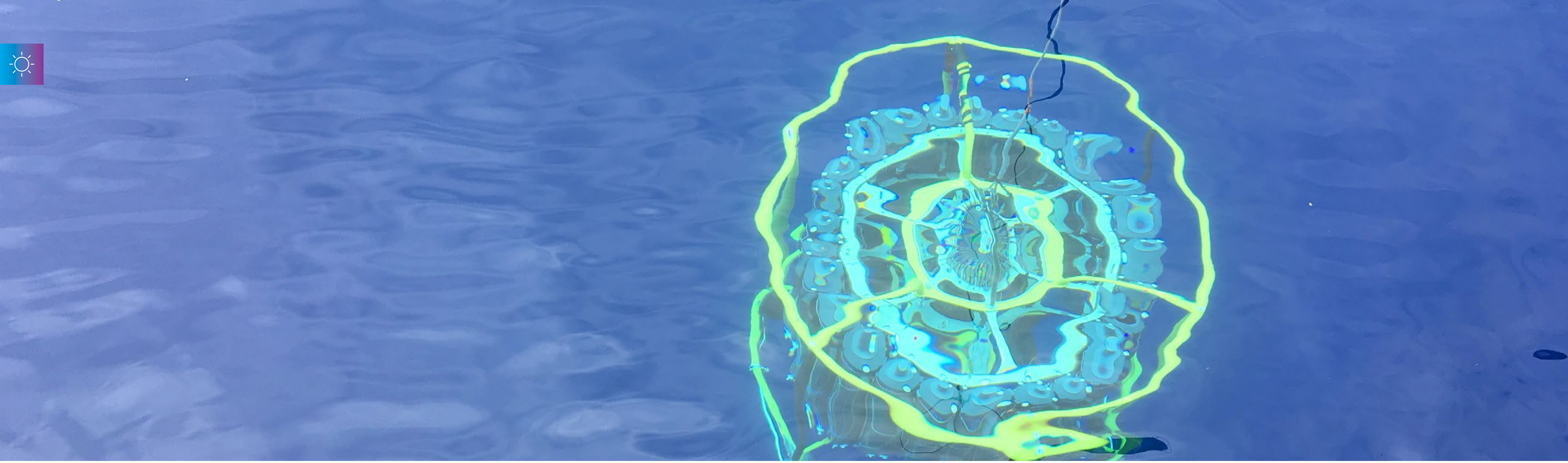
Above: *Matthew Harke (at right in red jacket) braces for a soaking by a wave crashing over the R/V Kilo Moana's fantail in May 2018. Image from a video by Ian Bishop of the University of Rhode Island.*

In the world's oceans, microbes capture solar energy, catalyze key biogeochemical transformations of important elements, produce and consume greenhouse gases, and comprise the base of the marine food web. Microbial ecologists working in Sonya Dyhrman's laboratory at the Lamont-Doherty Earth Observatory strive to understand the oceans' ecosystem processes by studying a multitude of creatures, most too small for the human eye to see. These are the tiny microbes called phytoplankton that live beneath the ocean's surface, taking in carbon dioxide, sunlight, and nutrients to produce oxygen. That oxygen is essential to human survival.

"One of our lab's mottos is 'take a breath, thank a phytoplankton,'" said researcher Matthew Harke. Diatoms, a type of microscopic phytoplankton, are estimated to produce one-fifth of the oxygen we breathe.

"The unseen microbial world underpins fisheries, climate, and the very function of ocean ecosystems, and we want to know how those ecosystems are going to shift in the future," explains Dyhrman.

"The unseen microbial world underpins fisheries, climate, and the very function of ocean ecosystems, and we want to know how those ecosystems are going to shift in the future"



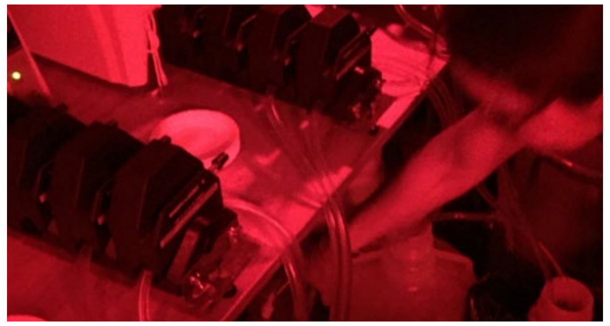
Above: *CTD (conductivity, temperature, depth) monitor after being lowered beneath the ocean surface. Photo by Matthew Harke.* ***Bottom:*** *(left) water sampling at night, under red light so as not to alter the photochemistry of the phytoplankton; (right) water sampling rosette lowered off the R/V Atlantic Explorer in the North Pacific; (far right) shipboard filtering station. Photos by Kyle Frischkorn.*

Among the questions driving Dyhrman's team is how these all-important diatoms survive and thrive under difficult conditions. A study authored by Harke and members of the Dyhrman team published in August in The ISME Journal sheds new light.

The discovery characterizes a symbiotic relationship between diatoms and bacteria.

"We had a feeling this friendly relationship was critical to the diatom's success, but their relationship was largely uncharacterized," said Harke.

He and his team describe a function similar to that of human digestion. As the human microbiome is critically important to our health, this research demonstrates that these bacterial partnerships are equally important to phytoplankton survival. The microscopic organisms the team chose to study were a diatom and its symbiotic nitrogen-fixing cyanobacteria partner. Because these organisms are very difficult to culture in the lab, the Dyhrman team had to sail to the middle of the Pacific Ocean, hundreds of miles off the coast of Hawaii, to find them. There, a large region of ocean trapped by currents is known as the North Pacific Subtropical Gyre (NPSG).



This sequestered water forms an ecosystem that tends to be low in resources, such as nitrogen and phosphorous. It is an ocean desert compared with coastal ecosystems that are nutrient rich. The Dyhrman lab has been taking part in an ongoing, collaborative investigation of the NPSG known as the Simons Collaboration on Ocean Processes and Ecology, or SCOPE. The study, funded by a multi-million-dollar grant from the Simons Foundation, engages scientific partners around the world. The team sifted through thousands of liters of seawater, which they collected over four days in July 2015.

"Because the organisms are microscopic, we used molecular tools to explore their interactions. From the filtered water, we sequenced all of the genes that were turned on and off by this partnership and used a supercomputer to reconstruct how their metabolisms were intertwined over day-night cycles," explained Harke.

Importantly, the research suggests that these bacterial "friends" can help diatoms survive the harsh conditions of the open oceans where plant nutrients are scarce. For instance, the research witnessed shared gene expression patterns indicative of sharing of resources needed for growth. The bacterium in this partnership is able to capture nitrogen gas and convert it into a useable form, feeding the diatom much-needed nitrogen in exchange for protection (diatoms have a glass-like shell) and carbon. The research also found genetic evidence for how the two organisms stay together and reproduce.

"With this study, we have provided a new view of how this partnership works, providing insight into a baseline that we'll need to study to predict what to expect in a future ocean," said Harke. The NPSG contains one of the largest biomes on Earth. "As climate continues to change, these oligotrophic (nutrient starved) oceans are predicted to expand, likely making these partnerships more important."

Eavesdropping on the Arctic:

What Migratory Birds Have to Say about Climate Change

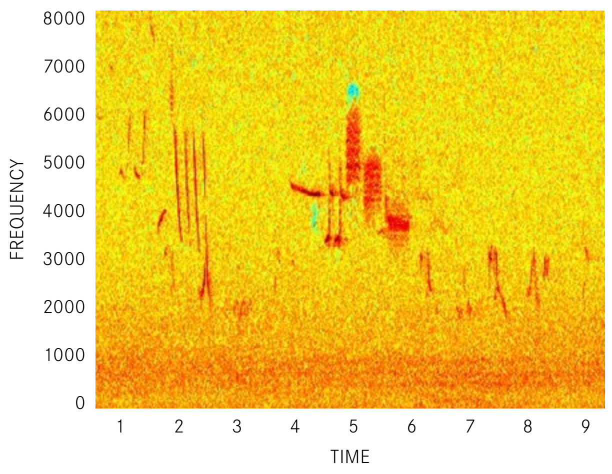
Above: *a Gambel's White-crowned Sparrow in snow near Toolik Field Station on the North Slope of Alaska in May 2018. Photo by John Wingfield.*

Millions of songbirds flock to the far north each spring, lured by an abundance of food and a relative lack of predators. But spring has been coming earlier to the Arctic and so have some migratory birds, raising new questions about how these species are responding to changing climate. To develop a clearer picture of how climate change is transforming tundra life, Lamont researchers have implemented automated tools for tracking birds and other animals in remote places, giving them an earful of clues about how wildlife is adapting to generally warmer temperatures and more variable weather.

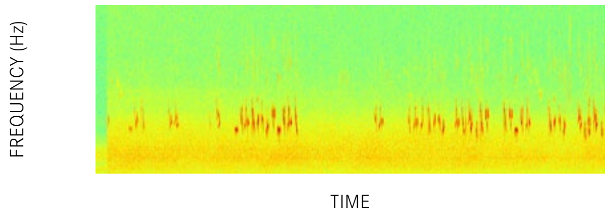
Over five breeding seasons, Lamont ecologist Natalie Boelman and her colleagues recorded birdsong from several remote outposts on Alaska's North Slope. Her goal: to understand how songbird breeding habits are changing as the Arctic warms two to three times faster than the rest of the planet. Boelman initiated the study by developing a machine-learning-informed algorithm designed to sift out extraneous ambient noise. Later she and Columbia Engineering researcher Dan Ellis teamed up to garner a two-year $200,000 grant from the university's Data Science Institute, intended to foster collaboration in the natural and computational sciences.

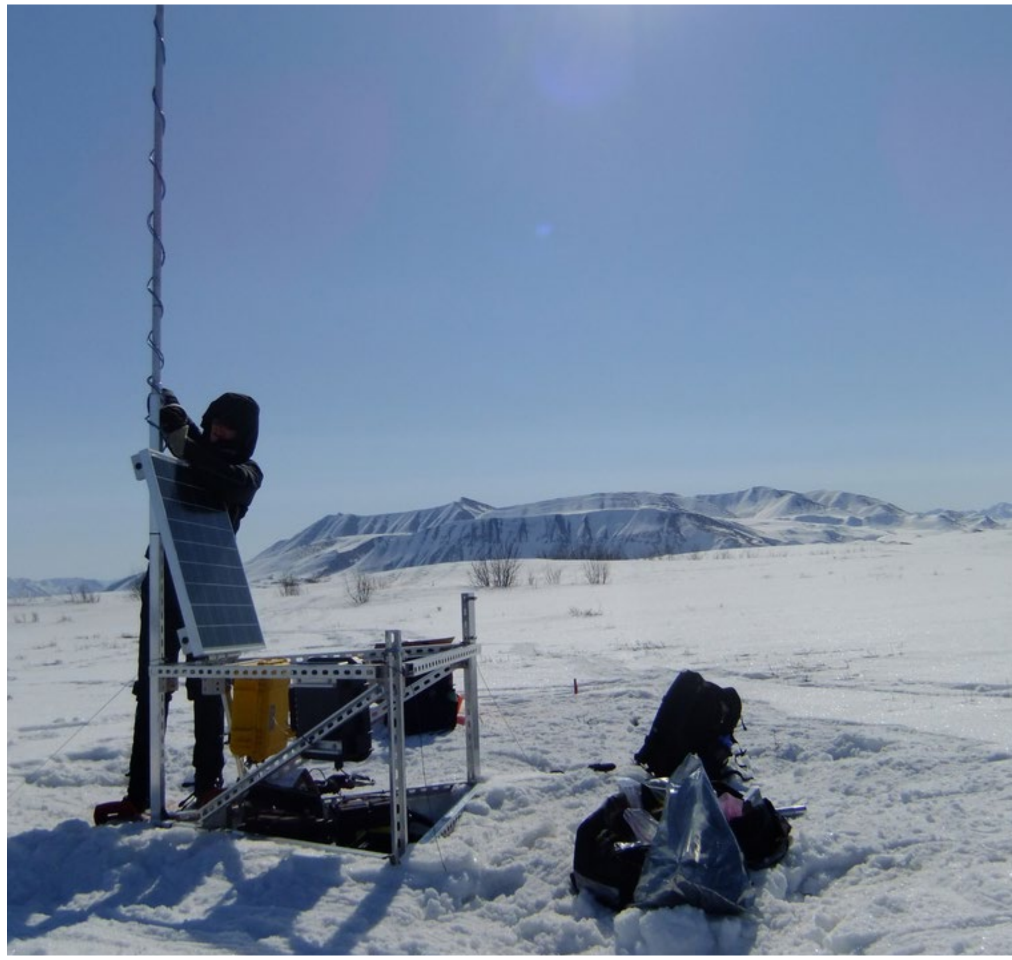
Far-flying and too small to tag with GPS receivers, songbirds are a challenge to study in the wild. With this novel approach, Boelman and her colleagues set out microphones to let the birds come to them. From the foothills of Alaska's Brooks Range, four microphones recorded at regular intervals from early May through July, over five years, starting in 2010. From the 1.7 terabytes of data captured, the researchers sought to discern when the birds are arriving.

GWCS Spectrogram



Spectrogram





Above: *a Lapland Longspur singing near Toolik Field Station in arctic Alaska. Photo by John Wingfield.* ***Opposite page:*** *(left) visual representation of the sound spectrum through time of songbirds singing near Toolik Field Station in arctic Alaska, from a paper by Ruth Oliver and others; (right) Shannan Sweet sets up a microphone near Toolik Field Station in arctic Alaska. Photo by Heather Greaves.*

This year the team published a study with their findings, describing how, by applying the algorithm to the thousands of hours of recordings at the breeding grounds on Alaska's North Slope, they were able to pick out birdsong from wind, trucks, and other noise, and estimate the amount of time the birds spent singing and calling each day, and when they arrived en masse.

The researchers also turned the algorithm loose on their data with no specific training to see if it could pick out birdsong on its own and approximate an arrival date. In both cases, the computer's estimates closely matched what human observers had noted in the field. Their unsupervised machine learning method could potentially be extended to any dataset of animal vocalizations.

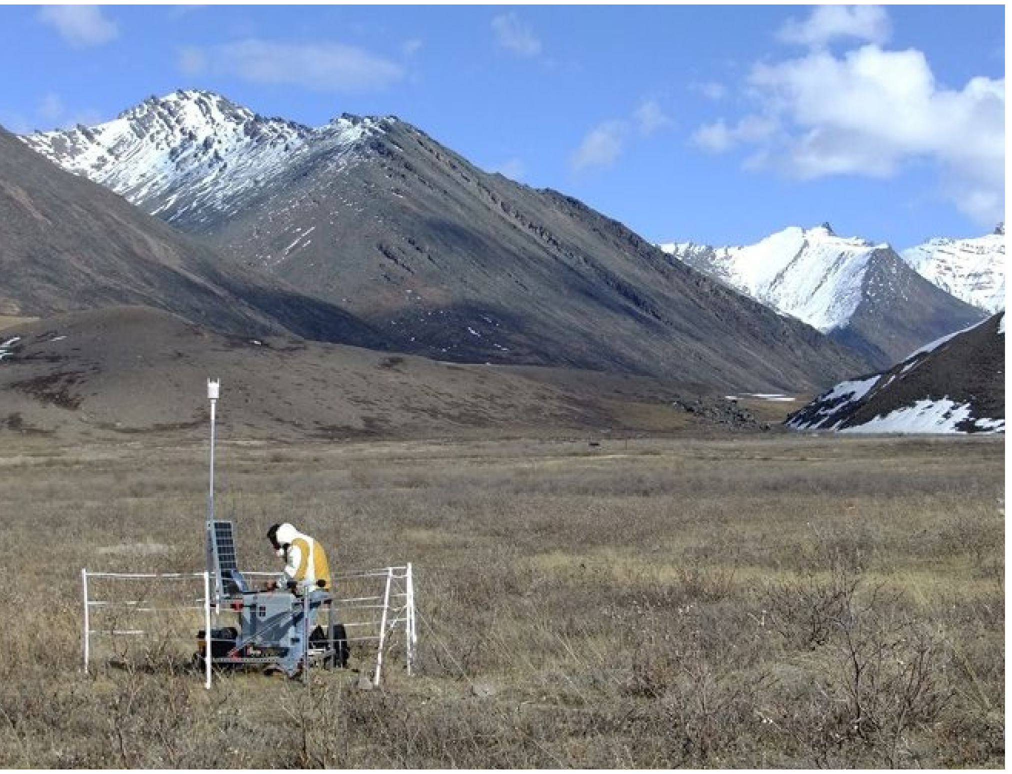
"Our methods could be retooled to detect the arrival of birds and other vocal animals in highly seasonal habitats," said the study's lead author, Lamont graduate student Ruth Oliver.

The team wanted to pin down when the birds were arriving and if the species mix would shift as plants favoring warmer temperatures expand their range. White-crowned sparrows prefer woody shrubs, but Lapland longspurs prefer open grasslands. With shrubs expected to dominate the area by 2050, sparrows could end up pushing out longspurs and other tundra-adapted birds.

The published work was a first step. In the next phase of their research, the team hopes to develop the tool further to distinguish between sparrows and longspurs, among other species, to spot population-level trends.

Species-specific identification from sound recordings is a complex problem that other researchers are also trying to crack. At Cornell University, Andrew Farnsworth and his colleagues are using deep learning tools in a project called BirdVox to classify recordings of migratory bird calls at night, when there's less competing noise to filter out. Wildlife Acoustics, a company near Boston, is building low-cost field recorders and developing software to track the comings and goings of birds, as well as frogs, bats, and whales, by the sounds they make. "We want to know what species are present when humans are not," says Farnsworth. "We're trying to teach the machine to classify sound the way the human brain does."

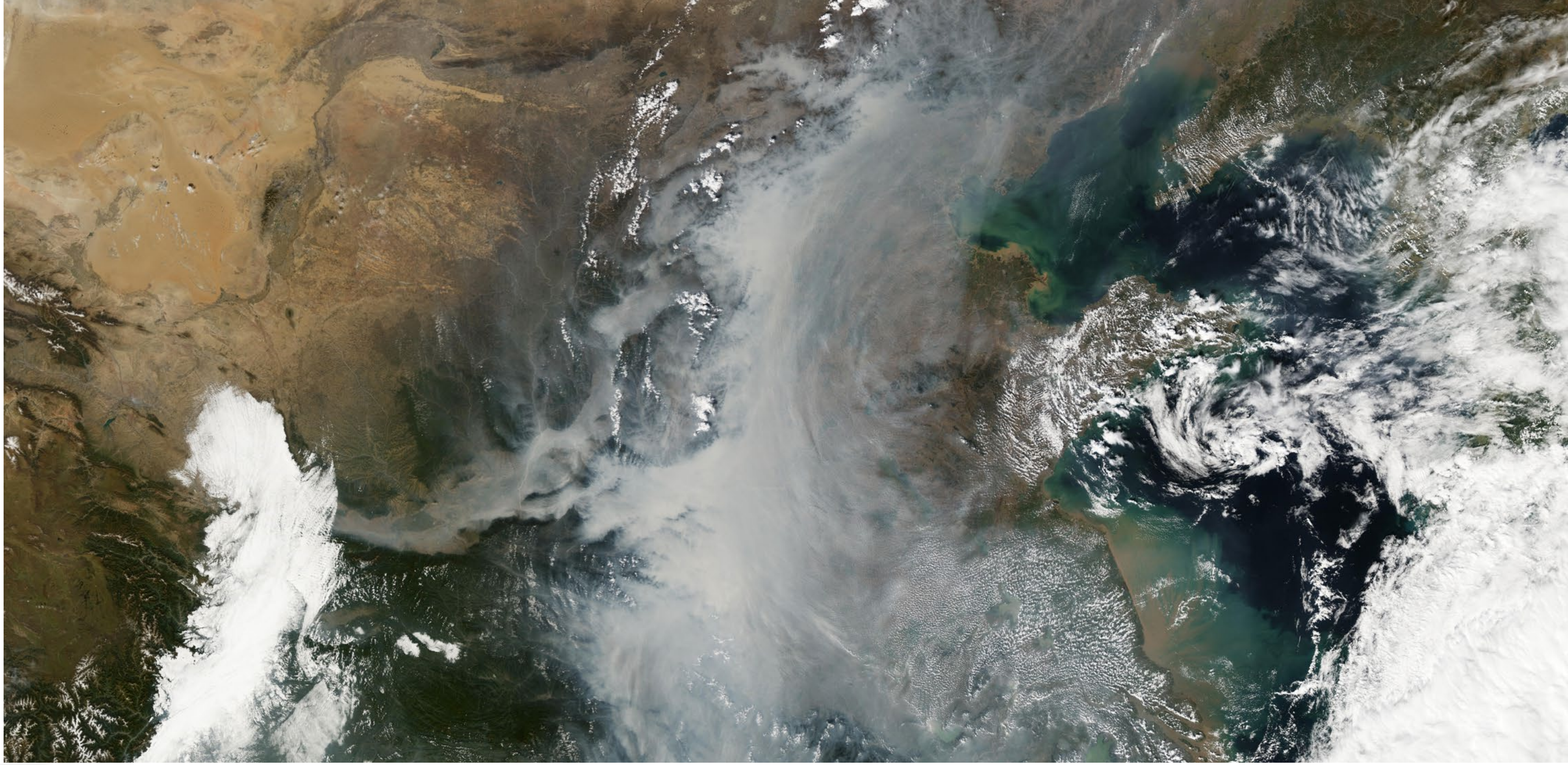
"Ice is dynamic and complex, and we don't have the data yet."



Above: *Gonzalo Sanchez, of Sanchez Industrial Designs, sets up a microphone near Toolik Field Station in arctic Alaska. Photo by Heather Greaves.*
Right and opposite page: *a Gambel's White-crowned Sparrow singing near Toolik Field Station in arctic Alaska. Photo by John Wingfield.*

The longer the data set, the greater chance that a climate change signal will become evident. For Boelman, five years proved too short in a region known for big year-to-year swings in weather and temperature, which appear to be growing more extreme with climate change. In a prior study based on eyewitness observations, the team reported that both sparrows and longspurs appeared to time their arrival and breeding to local conditions. When a late spring delayed snowmelt by 10 days in 2013, the birds arrived 3 to 6 days later than usual and hatched their young 4 to 10 days later. These findings suggest that Arctic-breeding birds may have the flexibility needed to adjust to the increasingly extreme and unpredictable environmental conditions. However, future generations may encounter conditions that exceed their current range of flexibility.

"It is still unclear how songbirds will cope if spring comes even earlier or later than it did during our study period," said Boelman. "Species also time their migration and breeding with day length, which isn't shifting with climate change. Species with a migratory response hard-wired to day length alone may not adapt as well to a changing environment." Boelman recently received support from the National Science Foundation to continue and expand the work both in geographic and analytical scope. She will be deploying ~100 microphones in Canada and Alaska with the goal of understanding how environmental dynamics influence migration timing of waterfowl and songbirds.



Clearing the Air: Strategy from Space

Above: smog over China. Image from the Moderate Resolution Imaging Spectroradiometer (MODIS) on NASA's Terra satellite.

The Environmental Protection Agency has a saying about ozone: "good up high, bad nearby." Ozone pollution near Earth's surface is one of the main ingredients of summertime smog. But it is not directly measurable from space, because the abundance of ozone higher in the atmosphere masks the surface. Researchers in Arlene Fiore's Atmospheric Chemistry Group at Lamont have used satellite measurements of two different precursor gases that contribute to ozone formation to track changes in this chemistry over the past decade, during which emission controls were put in place to lower surface ozone. The group's observational analysis may help air-quality managers assess the past success of their programs and identify the most effective approaches to reduce emissions and improve air quality in the future.

Unlike at high altitude, where ozone acts as Earth's sunscreen to harmful ultraviolet radiation, ozone at low altitudes is a health hazard contributing to respiratory problems such as asthma and bronchitis. It is formed through complex chemical reactions initiated by sunlight and involving two types of gases: volatile organic compounds (VOCs) and nitrogen oxides (NOx). The group's study included a major gas of each type, the VOC formaldehyde and nitrogen dioxide (NO2), which are both measurable from space.

Opposite page: *(left) smog shrouds eastern China; when the MODIS instrument on NASA's Terra satellite acquired this image on December 7, 2013, thick haze stretched from Beijing to Shanghai, a distance of about 1,200 kilometers (750 miles); (right) air pollution over the Pearl River delta; in January 2018, stagnant winds caused pollution to accumulate in the region, leading local authorities to encourage residents to stay indoors to avoid serious health effects; this MODIS image captured clouds (white) and haze (gray) blanketing the delta. Both images are from Jeff Schmaltz, LANCE MODIS Rapid Response.*

"We are using satellite data to analyze the chemistry of ozone from space," said group member and study lead author Xiaomeng Jin. Through a combination of computer models and space-based observations, Jin and colleagues used the concentrations of the precursor molecules to infer whether ozone production at a given location increased more in the presence of NOx, VOCs, or a mix of the two. Their study regions focused on North America, Europe, and East Asia during the northern summer, when abundant sunlight triggers the highest rates of ozone formation. To understand their impact on ozone formation, the team investigated whether VOC or NOx was the ingredient that most limited ozone formation. If emissions of that molecule can be reduced, then ozone formation will be reduced – critical information for air-quality managers.

"We are asking: 'If I could reduce either VOCs or NOx, which one is going to get me the biggest bang for my buck in terms of the amount of ozone that we can prevent from being formed in the lower atmosphere?,'" said Fiore, who is also a member of NASA's Health and Air Quality Applied Sciences Team.

"We are asking: 'If I could reduce either VOCs or NOx, which one is going to get me the biggest bang for my buck..."

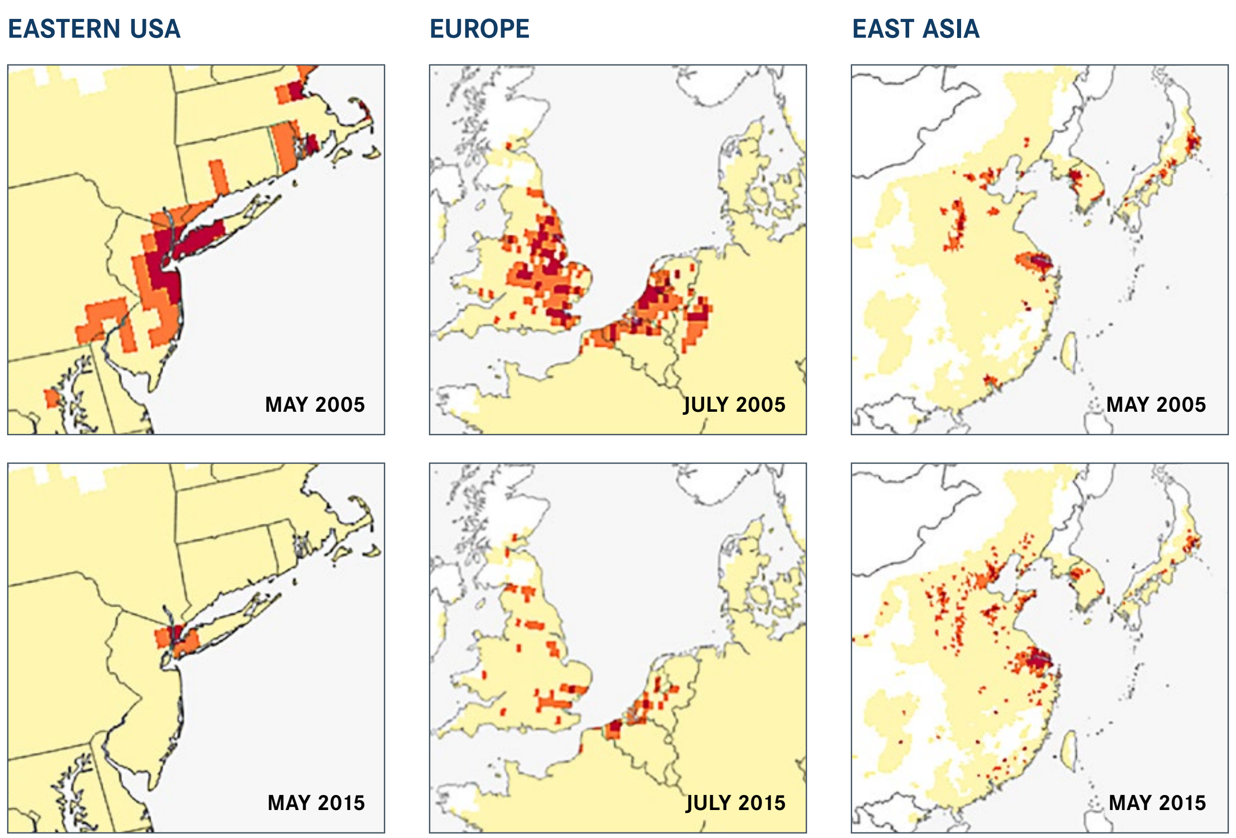
Fiore says the approach described in their study has important implications for ongoing work. Understanding trends and variability in atmospheric composition of chemical species such as ozone (both a greenhouse gas and an air pollutant) is a major driver of her group's research. Many processes cause atmospheric ozone to vary, including climate and meteorology, natural and anthropogenic sources, as well as sinks through chemical reactions or uptake by the terrestrial biosphere and other surface processes. This application is an example of how researchers can use ever-growing satellite records to learn about one piece of this puzzle, in this case the changing emissions of ozone precursors.

As the major components of air pollution (ozone and particulate matter) also affect the climate system (through their interactions with the planet's radiation budget), understanding changes in ozone formation chemistry connects to broader interests in the interactions between climate and air quality. "In our group, we're keenly interested in understanding the impacts of changes in these air pollutants on the climate system," said Fiore.

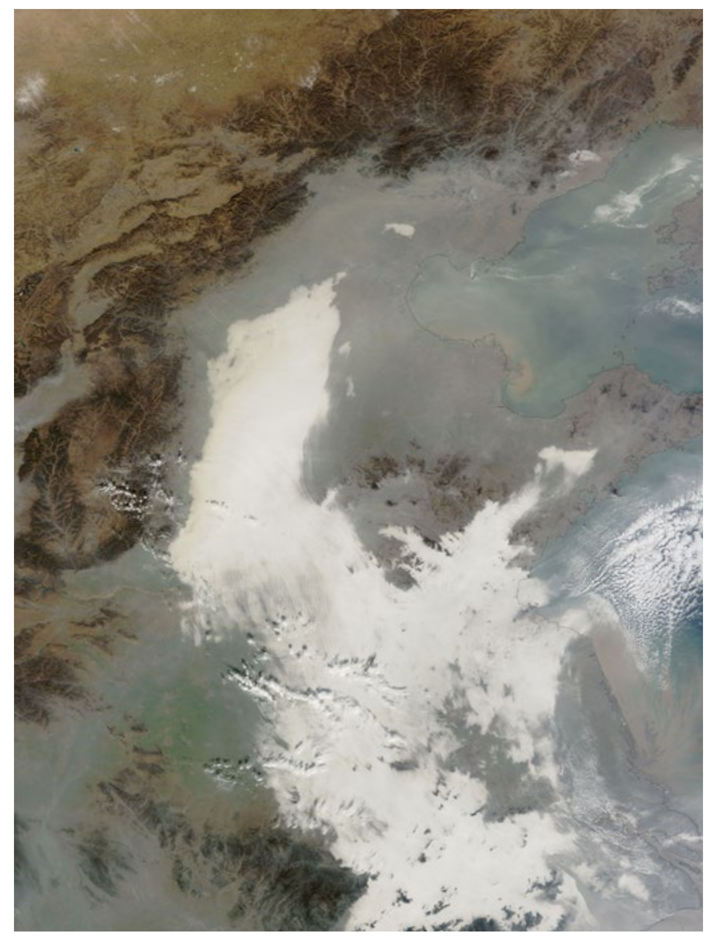
"This research has not fundamentally changed our understanding of ozone formation chemistry," said Fiore.

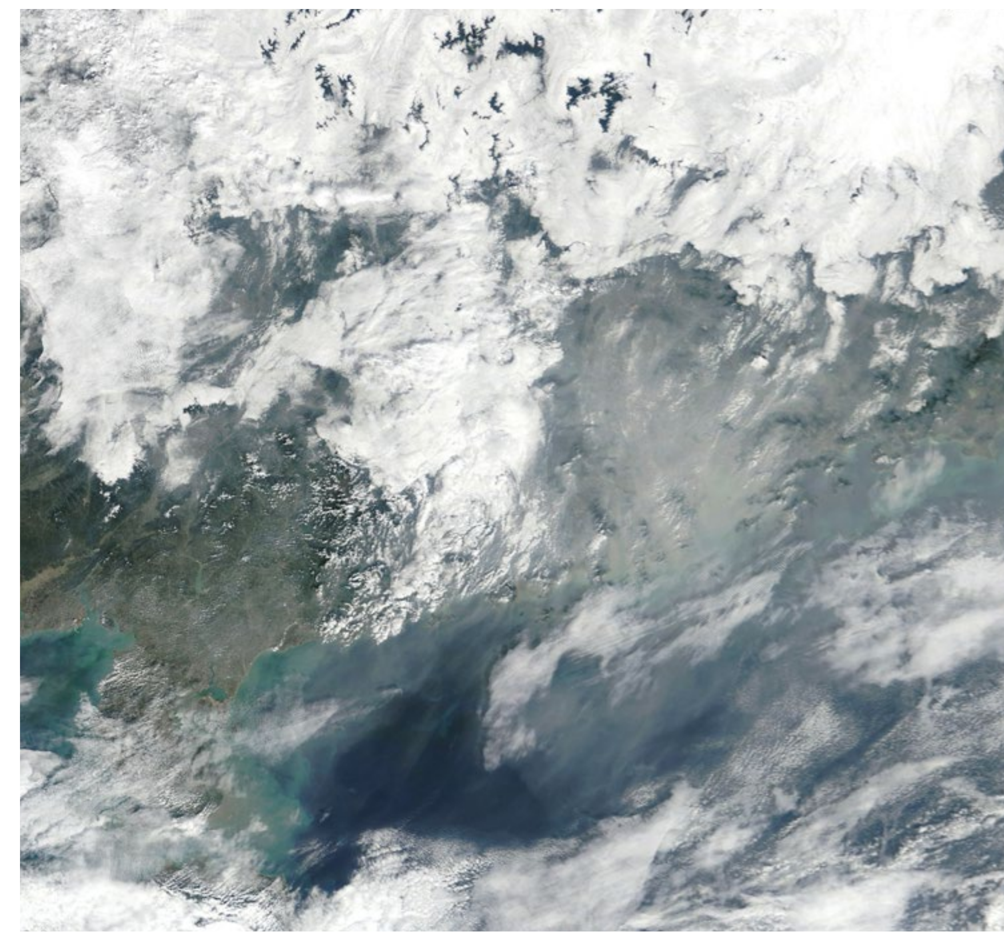
What is new is that, for the first time, researchers are able to observe how this chemistry varies in space and time. Newer work by Jin looks at even finer temporal and spatial scales, with the aim of understanding how ozone formation chemistry changes on the most polluted days compared with average conditions.

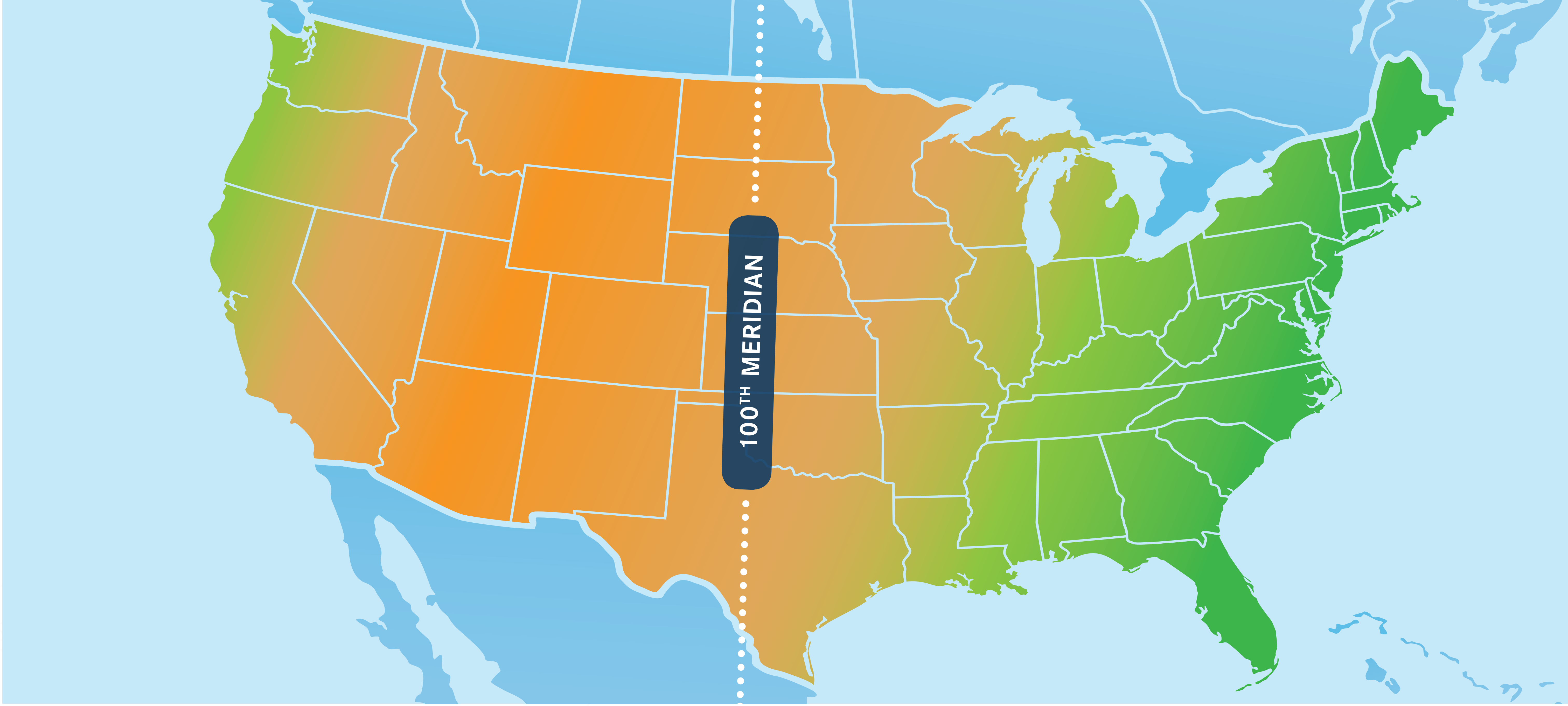
Among the most pressing questions for Fiore and air-quality research is how to clear the most unhealthy conditions as quickly as possible. "Billions of people on the Asian continent are breathing very unhealthy air most days of the year," noted Fiore. "Which lessons learned and success stories from other regions are best suited to rapidly clearing the air and lowering the associated health burden in these areas?"



Right: *ozone production over the Eastern United States, Europe, and East Asia in 2005 and 2015, derived from satellite observations. Yellow, orange, and red colors indicate different situations for ozoneformation chemistry. NASA Earth Observatory image by Joshua Stevens.*







The Line in America's Psychogeography Shifts East

The 100th meridian, which divides the arid western United States from the humid eastern U.S., is a well-ingrained element of American lore. American geologist and explorer John Wesley Powell first recognized this north–south dividing line in 1878 and argued that in areas west of the meridian development had to take account of environmental limits. A couple of years ago, Lamont-Doherty Earth Observatory climate scientist (a newly elected AGU Fellow; see page: 56) Richard Seager was handed a small cleaning cloth printed with a population map and saw compelling evidence for Powell's imaginary line.

"I immediately noticed there were two straight lines, one in the Sahel at the southern edge of the Sahara and also a straight north–south line at the hundredth meridian. This means that once you get to the 100th meridian there is a tremendous drop off in the population density to the west." said Seager. While Congress ignored Powell's advice, it was clear to Seager that the environment had in fact greatly influenced how the West was developed.

"once you get to the 100th meridian there is a tremendous drop off in the population density to the west"

Right: *wheat field and brewing storm, Kansas. Photo by commons.wikimedia.org.* ***Opposite page:*** *horses graze about 300 miles east of the 100th meridian, eastern Oklahoma. Photo by Kevin Krajick.*

Bottom: *Palisades Geophysical Institute Lamont Research Professor Richard Seager. Lamont photo.*

Seager and his team were already working on a large NSF-funded research project on climate variability and change across the North American west and its implications for land, water, and ecosystems. Exploring the dividing line and its storied history and social ramifications was an enticing direction to push that work.

Two summer interns and two research papers later, Seager's inquiry has yielded measurable proof that Powell's line – the longitudinal boundary cutting northward through the eastern states of Mexico and on to Texas, Oklahoma, Kansas, Nebraska, the Dakotas, and the Canadian province of Manitoba and beyond – not only is a real climate divide but is also reflected in population and agriculture differences on opposite sides, and, as a result of climate change, has shifted and will continue to shift eastward. Since 1979, the year when accurate satellite imagery began to be acquired on a routine basis, that line has migrated about 140 miles east, expanding the arid climate of the western plains to the east.

Seager believes that the implications are large. These changes in humidity, rainfall, and aridity are bound to influence agricultural decisions on how the land is used and what crops are grown, which in turn will create new and different domestic and international crop markets. This shifting line is likely to impact as well the wallets and the dinner plates of families throughout America.

"changes in humidity, rainfall, and aridity are bound to influence agricultural decisions"

"As the line moves eastward as aridity increases, you would expect the corn area to become increasingly restricted into the Midwest, where it's humid enough for the crop. You would also expect wheat to move eastward, and you would also expect range land to move eastward. But there's a problem there, because as you move eastward you go to lower altitudes and higher temperatures, which will push beef productivity down. It's too hot for the animals. So, there will be agricultural consequences of these increases in aridity," said Seager.

He predicts that as drying progresses, just as farms west of the 100th meridian are typically larger than those to the east, farms to the east of the current divide will have to become larger in order to remain viable. Farmers may need to turn from corn to wheat or some other more suitable crop. Corn is a very high-demand crop in the U.S. for use as animal feed and as a ubiquitous sweetener in American processed foods. Farmers might turn to irrigation of corn, but that process is expensive, and whether they irrigate will depend on groundwater availability and how markets respond.

"Corn is a high-value product. It's going into processed food because people love sweet things, and it's going into animal feed because people love their meat. You might see production more restricted and higher prices for corn-based products, which could lead to a change in U.S. food production that would be beneficial to health. More wheat and less corn and meat mean a better diet," Seager added.

For now, Seager's papers on the 100th meridian continue to draw the media spotlight. Dozens of publications covered the findings, and even now, months after the studies were released, Seager is receiving invitations to deliver talks outlining his work defining and tracking the aridity divide.

"What's unique about this story is the way it combines historical perspectives on the development of the West with future projections about climate and impacts to our economy and food," noted Seager.

"More wheat and less corn and meat mean a better diet"

A CONVERSATION WITH MAUREEN RAYMO

Lamont's Core Repository– A Living Library of Earth History

__Above:__ (clockwise from left) Bruce C. Heezen Lamont Research Professor Maureen Raymo; photo by Garry Tutte, SOI Foundation; Lamont Core Repository, 2018; photo by Steve Aaron, KRB; Maureen Raymo with ocean core; Lamont photo.

Lamont's Maureen Raymo is one of the most influential figures in her fields of paleoclimate and marine geology. Now, at mid-career, she has not only shaped our understanding of the how ice ages fluctuate and how sea levels change, but she is also among the world's most honored researchers. Raymo was elected to the National Academy of Sciences in 2016. In 2014, she was awarded the Wollaston Medal of the Geological Society of London, becoming the first woman to win the award in the medal's 183-year history. She joined the company of Victorian giants Charles Darwin and Louis Agassiz and such major 20th-century figures as climatologist Sir Nicholas Shackleton and James Lovelock, originator of the Gaia hypothesis.

Today Raymo is the Bruce C. Heezen Lamont Research Professor and the Director of the Core Repository at the Lamont-Doherty Earth Observatory of Columbia University.

Q: When did you know you wanted to study the oceans?

I wanted to be an oceanographer by the time I was eight-years-old. My dad was making little cartoon books for me and my siblings. He asked each of us what we wanted our books to be about. Mine was my imaginary adventures with Jacques Cousteau. By that time, I had seen The Undersea World of Jacques Cousteau. The program had a powerful impact on me. I have always felt this connection to the ocean.

Q: How did you come to pursue your specific research?

I began my career in marine geology here at Lamont as a graduate student in the 80s, and I spent a lot of time as a student sampling cores in the repository. My particular interest was studying the history of the ice ages, the glacial/interglacial cycles that have characterized the last few million years. In particular, I looked at cores in the North Atlantic where I would examine ice-rafted detritus material that was brought in by icebergs and try to figure out what it could tell us about how cold the Atlantic was through time.

Q: How would you describe Lamont's Core Repository, its history, and its importance to climate science?

The Core Repository has been at Lamont for decades. We are a facility funded by the National Science Foundation, and we operate as a working museum. We have over 40 miles of core drawn from almost 20,000 locations around the world's oceans. We archive, curate and preserve them for posterity. We make samples available to scientists to study.

Q: What exactly are cores and why are they so important?

Cores are the tubes of sand and sediment pulled from the ocean's floor. They include everything that goes into the ocean, everything that washes in from land, is blown in by wind, or falls out of sky (in the case of volcanic ash) as well as all the fossil remains of microorganisms that live and die in the ocean. All of that material falls to the bottom of the ocean and accumulates layer by layer, stratigraphically–with the deepest sediments being the oldest and the sediment at the seafloor being the youngest. So, cores are like a tape recorder of what went on over the Earth through time.

Q: When did Lamont begin gathering cores?

One of the original undertakings of Lamont, which was established 70 years ago, was to study the world oceans in the aftermath of World War II and during the Cold War era of submarine warfare. Lamont had two research vessels. They were nearly always at sea and rarely came into the port, and among their activities was coring the bottom of the ocean to see what was down there. Because of this practice, tens of thousands of cores came back to Lamont where we now archive and study them.

Q: What discoveries were made possible by studying cores?

Probably the most exciting information that scientists were able to extract from cores has to do with the climate history of the Earth. Almost everything we know about how the planet's climate changes naturally through time we have learned through the study of deep-sea cores over the past few decades.

Q: How do researchers extract information from cores?

The material that is in these cores is very fine, ranging in size from fine clay to the size of a grain of sand. Analyzing cores involves a tremendous amount of time at a microscope. I love sitting at a microscope for hours, looking at the fossils in the cores, organizing them by species, and picking out certain ones for geochemical analysis.

Q: Are the cores in the Core Repository relevant to ongoing research?

Yes. Our collection has been amassed from all over the world, and the cores are a valuable resource. It has become much more difficult to secure financial support to go out to sea. The heyday of vast ocean exploration seems to have passed. So, when researchers want to study a region they can come here and often find existing material rather than going through a long multi-year process of trying to get out there on a ship. Many of our cores have never been examined beyond the initial description when they were collected. Only about half have been studied in depth. Every now and then people strike gold in here, finding overlooked cores and generating new data that lead to important scientific papers.

Q. So there are still secrets here at the repository?

Yes, there are still secrets to discover.

__Above:__ Bruce Heezen with graduate student in the Lamont core lab in the 1950s, and two photos of ocean cores from the repository.

PROFILE: RADLEY HORTON

Lamont Associate Professor Radley Horton. Lamont photo.

Radley Horton:

Finding Answers, Spreading the Message of Caution and Hope

Lamont Associate Research Professor and climatologist Radley Horton is determined. His work, investigating extreme weather events, discerning the limitations of climate models, predicting the current and future ramifications of climate change, and generating adaptation strategies, is matched by his commitment to communicating his findings and the underappreciated threats associated with global warming.

"It's real. It's us. It's serious. The window of time to prevent widespread, dangerous impacts is closing fast," Horton recently told a group of business leaders. He believes that to confront climate change effectively, scientists must translate their work clearly and regularly to stakeholders and society's power brokers.

"We have to meet them in their decision-making context," he explains.

In the past year, research from Horton's group has underscored the impacts of extreme heat on commercial aviation, illuminated how the tree-killing southern pine beetle will expand its range of devastation should minimum temperatures continue to increase (as predicted), and how the combination of hot and humid weather will endanger the health and livelihoods of many global populations. A research paper on this last topic this year captured widespread public attention, especially given the recent trend of record-breaking summer temperatures from one year to the next.

"Within the next two generations, heat and humidity could create an existential threat to some coastal populations who lack access to air conditioning."

Most projections about future intensifying heat waves leave out humidity, which can greatly magnify the effects of heat alone. Horton and his colleagues produced forecasts that the combined impact of heat and humidity will markedly increase in many areas. At times, such conditions may surpass the ability of humans to work outdoors or, in extreme cases, even survive. Health and economies would suffer, especially in regions where people work outside and have little access to air conditioning. Potentially affected regions include large swaths of the already muggy southeastern United States, the Amazon, western and central Africa, southern areas of the Middle East and Arabian Peninsula, northern India, and eastern China.

The research made use of global climate models to map current and future "wet bulb" temperatures, which reflect the combined effects of heat and humidity. (The measurement is made, in principle, by draping a water-saturated cloth over the bulb of a conventional thermometer; it does not correspond directly to air temperature alone.) The study found that by the 2070s, high wet-bulb readings that now occur only once a year could prevail 100 to 250 days of the year in some parts of the tropics. In the southeastern United States, wet-bulb temperatures now sometimes reach an already oppressive 29 or 30 degrees Celsius; by the 2070s or 2080s, such weather could occur 25 to 40 days each year, say the researchers.

Lab experiments have shown wet-bulb readings of 32 degrees Celsius are the threshold above which many people would have trouble carrying out normal activities outside. This level is rarely reached anywhere today. But the study projects that by the 2070s or 2080s the mark could be reached one or two days a year in the U.S. southeast and three to five days per year in parts of South America, Africa, India, and China. Worldwide, hundreds of millions of people would suffer. The hardest-hit area in terms of human impact, the researchers say, will probably be densely populated northeastern India.

Horton's work is global in scope. His ability to convey the concepts of climate change and its potential impact continue to elevate both his profile and that of his profoundly important science.

Radley Horton: In His Own Words

Q: What are some of your earliest memories, and do you think your childhood influenced your decision to become a climatologist?

Some of my earliest memories include going up to the top floor of our Brooklyn home to listen to the wind and thunder and watch the lightning with my mom. There was a back window where we could watch that metallic glow the city would get during evening thunderstorms. And I remember falling asleep to the sound of breaking ocean waves during summers on Fire Island. I also used to find comfort in numbers and Atlases, memorizing arcane facts like the most extreme minimum temperatures experienced around the world.

Q: How did you come to choose climate research for your life's work?

It was not a linear path. While extreme weather was always a fascination growing up, I actually studied liberal arts as an undergraduate, and it was not until a post-undergraduate internship project that involved climate and ecosystems that I realized, in order to make a certain kind of impact, I would need an advanced degree.

Q: You describe your approach to climate research as having a "big picture" perspective. How does this perspective guide the research you pursue?

I think my liberal arts background has helped me to (1) steer towards societally impactful climate research questions, (2) sense how assumptions embedded in detailed quantitative approaches to projections can paradoxically lead to underestimates of the range of possible outcomes, and (3) understand that for many societal decisions, a general picture of how climate may change, rather than precise information, is all that is needed, since climate is one of many factors driving a decision.

Q: You say the window for mitigating the devastating effects of climate change is closing. What would you most want people to understand right now?

I want people to understand these small changes we talk about – the one degree of global warming to date, the less than one foot of sea level rise over the last century – tend to sound like nothing. Actually, these changes have already profoundly modified the frequency with which we experience coastal flooding and already lead to much more dangerous heat extremes than we've seen in the past. I want people to understand that the frequency and intensity of extreme events have already changed dramatically due to human activities like fossil fuel combustion and land use change. The change in extreme event statistics to date suggests the urgent need to reduce greenhouse gas emissions and to adapt.

Q: What worries you most about the future of Earth?

I'm worried that we have underestimated how sensitive the climate is to greenhouse gases. I'm worried that we are going to see climate changes occur faster than climate models suggest. If we look, for example, at Arctic sea ice, the late summer ice volume has decreased much faster than any climate models have suggested. That finding opens the door to the possibility that, even if we somehow stabilize greenhouse gas concentrations, we may already be locked into a total loss of late summer Arctic sea ice. That ice loss in turn could have unforeseen consequences on things we take for granted, like the ebb and flow of mid-latitude weather systems, their impact on heat waves, and heavy rain events. I'm concerned about what other monsters lurk in the climate system.

Q: What gives you hope for the future?

I get to instruct undergraduate students every semester as part of Columbia's undergraduate program in Sustainable Development. And every semester I'm struck by how, in the face of all this daunting data, the majority of students remain optimistic, have a "can do" attitude, and are committed to making the world a better place. They have come to terms with existential questions, but in general they don't get hung up on those questions. They usually say, "let's get to work and do our part," even though, quite frankly, we in the prior generations have unfairly dealt them a poor climate hand. Their work ethic and their technical abilities are so far beyond where I was in college. They are a source of optimism for me because we are going to need a tipping point to break in our favor in the climate solutions space. Their generation can be that transformation, whether through scientific discovery, interdisciplinary solutions, or simply refusing to work for, purchase from, or invest in either fossil fuel majors or those that fail to consider how their assets and mission will be impacted by our changing climate.

AWARDS AND HONORS

Above: (left to right) Palisades Geophysical Institute Lamont Research Professor Richard Seager, Associate Professor Bärbel Hönisch, Professor Sidney Hemming, and Eugene Higgins Professor Steven Goldstein. Photo by Miriam Cinquegrana.

America Geophysical Union Honors Five Lamont Researchers in 2018

The Lamont-Doherty Earth Observatory is scientific home to more than 200 researchers. Their collective body of work includes profound discoveries that span many decades and have strongly shaped our understanding of the planet. This year, five of Lamont's outstanding scientists who study a range of planetary processes – from continental growth, magma formation, deglaciation, and ocean circulation to droughts and ocean acidification – received important honors from the American Geophysical Union (AGU).

The AGU is the world's largest Earth and space science society, with more than 60,000 members. Thus, recognition from this organization constitutes a substantial honor. This year the AGU named geochemist Sidney Hemming, Professor and Chair of the Department of Earth and Environmental Sciences and Deputy Director for Education at Lamont, and climate scientist Richard Seager, Palisades Geophysical Institute Lamont Research Professor, to its prestigious roster of 2018 Fellows. No more than 0.1% of AGU members are elected Fellows in a given year.

Hemming is an isotope geochemist highly regarded for her studies of the history of deglaciation and ocean circulation from ice-rafted debris. Her research on understanding past environmental and climate changes has led her to take part in many oceanographic expeditions. Two years ago, Hemming served as co-chief scientist on an International Ocean Discovery Program expedition to obtain marine sediment cores from the seafloor around southern Africa. The goal of that expedition was to understand the history of the greater Agulhas Current during the past five million years and how it has been connected to southern African climate variations. Hemming received news of her fellowship this summer during a geological field trip to Botswana, Mozambique, and South Africa to sample sediments from the Zambezi and Limpopo Rivers.

Seager is well known for his work on climate change and its impacts. Seager studies climate variability and change on time scales from seasons to millennia, with a particular focus on the causes of droughts and how climate change will impact global hydroclimate. One of his recent research findings has been the documentation an eastward shift of the boundary, approximately at the 100th meridian, between the humid eastern United States and the arid western plains, work that has brought attention and new understanding to an important aspect of climate change and its impacts on agriculture.

"Election to fellowship in AGU is highly competitive. This recognition of Sid and Richard indicates that a broad committee of their peers across all disciplines in Earth and space science has affirmed that their research contributions have been important advances of high scientific impact," said Sean Solomon, Director of Lamont.

Above: former Lamont graduate student Kassandra Costa. Lamont photo.

In addition, the AGU is awarding three Lamont scientists with section awards. Lamont Associate Director of Geochemistry and Higgins Professor of Earth and Environmental Sciences Steven Goldstein is to receive the Norman L. Bowen Award from the Volcanology, Geochemistry and Petrology Section. The Paleoceanography and Paleoclimatology Section is giving its Willi Dansgaard Award to Associate Professor Bärbel Hönisch and their Harry Elderfield Outstanding Paper Award to graduate student Kassandra Costa.

The Norman L. Bowen Award is given annually for outstanding contributions to volcanology, geochemistry or petrology. Goldstein's research involves using chemical and isotopic tracers to investigate deep Earth processes and climate change. His studies include the history of continental growth as well as magma formation processes at mid-ocean ridges, ocean islands, and island arcs. Previous recipients of this award have included Earth Institute Director and Lamont geochemist Alex Halliday and Arthur D. Storke Memorial Professor Peter Kelemen.

The Dansgaard Award is given in recognition of innovative interdisciplinary work, mentoring, and societal impact, and specifically recognizes significant contributions in the Paleoceanography and Paleoclimatology section within 8-20 years post-degree. Dansgaard honorees show exceptional promise of continued leadership in paleoceanography or paleoclimatology. Hönisch studies ocean acidification and particularly how marine ecosystems, productivity, and genetic diversity will respond to climate change.

"It is such a great honor to know my colleagues are thinking highly of my work, and I am humbled to follow the fantastic scientists that received the Dansgaard Award before me, including our own Jerry McManus," said Hönisch. "Colleagues have often acknowledged the professional services I do, and it is such a joy to receive recognition for my scientific contributions as well. This is a first one for me."

The AGU is presenting the Elderfield Award for the first time this year. Organization leaders say the honor is intended to promote excellence in the next generation of paleoceanographers and paleoclimatologists. Costa investigates the interface between climate, biogeochemistry, and the environment.

"The selection of our colleagues for these prestigious awards and honors recognizes their sustained and unique contributions to enlightening our understanding of the Earth and its atmosphere and oceans," said AGU president-elect Robin Bell. Bell serves as Palisades Geophysical Institute Lamont Research Professor.

The awards are presented at the AGU Annual Fall meeting, which will be held December 10-14, 2018, in Washington, D.C.

OUR DONORS

Our Donors

We are grateful to the many friends and alumni 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.

The following gifts were made to Lamont between July 1, 2017 and June 30, 2018. With appreciation, we acknowledge the generosity of the following.

$2,000,000 +

CGG

$1,000,000 +

George and Wendy David
Daniel Morton Ziff
Dirk Ziff

$500,000 to $999,999

The G. Unger Vetlesen Foundation

$100,000 to $499,999

Paul M. Angell Family Foundation
Anonymous (2)
Walter R. Brown
The Henry L. & Grace Doherty Charitable Fdn.
Charles Hayden Foundation
Sarah E. Johnson
Gordon and Betty Moore Foundation
The Pinkerton Foundation
William and Judith Ryan
Todd C. Sandoz
The Simons Foundation
Richard M. Smith
University of Hawaii Foundation
World Surf League Pure Foundation

$50,000 to $99,999

Anonymous (2)
Botwinick-Wolfensohn Foundation, Inc.
The Brinson Foundation
Mark and Barbara Cane*
Comer Science and Education Foundation
Riverkeeper, Inc.

$10,000 to $49,999

Anonymous (4)
Daniel Bennett
Chevron
Jeffrey Stuart Gould
Frank and Joanne Gumper*
Hudson River Fdn for Science & Environmental Research
Linden Trust for Conservation
Florentin J-M. R. Maurrasse
Robert and Catherine Murray Charitable Trust
National Geographic Society
Orange and Rockland Utilities, Inc.
Terry A. Plank
Seismological Society of America

$5,000 to $9,999

Dennis M. Adler and Robin Aronow
Anonymous
Paul B. Barton
Donald D. Beane
Lawrence L. Hope
Robert W. Kay
The Merck Company Foundation
Amelia Estelle Prounis-Raftopoulos and Haralambos Raftopoulos
Verizon Foundation

$1,000 to $4,999

AllianceBernstein
Anonymous (3)
O. Roger Anderson*
The Atkinson Family Foundation
Joseph F. Azrack
Robert Buchanan
John V. Byrne
Kathleen Callahan
Millard F. Coffin
John Peter de Neufville
Jishu Deng and Yuan Yuan
H. James Dorman
Double H, LLC
David Eckert
ExxonMobil Foundation
Andre Henrique Moscal Fiorotto, Esq.
Andrew Forman and Ana Reyes
Rosalie Frost
Bill Glass
John Kendrick Hall*
Ellen M. Herron
Holly Hodder*
Baerbel Hoenisch
Jean Owen Izard
Stanley Jacobs
Kevin Jones and Mohi Kumar
William and Patricia Larrabee
Kenneth and Jeanne Levy-Church
Farhana Mather
Gregory and Carol Mountain
Cary L. Mrozowski
Stephen A. Myers
Thomas O'Brien
Virginia McConn Oversby and Lars Werme*
Robert and Martha Page
Jenik R. Radon, Esq.
Kaara Radon
Maureen E. Raymo
James H. Robertson
Roxiticus Fund
Peter and Meredith Rugg
Paul Settelmeyer
Siemens Emergency System
Sean and Pamela Solomon
Kenneth Sommers
Stanley W. Stillman
Yongjun Su and Xiong Wen
Andrew Taylor
Taylor Rental
John Toggweiler
Bruce and Sara Tucker

$500 to $999

Steven Beasley
Robert C. Berenbroick, Esq.
Marc Carrasco
Kenneth W. Ciriacks
Bruce L. Deck
Diane C. Falconer
Stephen Farinelli
Paul Jeffrey Fox
James and Nancy Hays
Helmholtz Centre Potsdam
Susan Holgate and Robert Barron
Joseph P. D. Hull, Jr.
Richard Kuczkowski and Jean Mia Leo
Anyi Li
Kimberly Martineau
Richard and Denise Quittmeyer
Michael and Martine Rawson
Ethan Casey Rouen
Qian Song
Superior Audio Visual
Pamela Van Hoven Clark
Howard Worzel

Up to $499

Mark and Polina Adelson
Warren and Mary Adis
Yash Pal Aggarwal
James J. Alberino and Tuula Pasola-Alberino
Robert J. and Paula M. Alexander
Peter F. Almasi
Mashael AlShalan
Walter and Mildred Alvarez
Eric A. Anderson
Rockne and Eva Anderson
Thomas and Nancy Anderson
Alexander and Andrea Anesko
Anonymous (7)
Jayne Y. Averitt
Emil S. Bahary
Muawia and Nimat Barazangi
Anna Barranca-Burke
Olivia Barry
Anne Barschall
Ronne Bassman-Agins
Marilyn Barton
Matthew C. Baum
Sherry E. Beckman
Richard L. Berger
Ellen Berman
Margo A. Bettencourt
Birdz Trust
Werner Bischoff
Ingi T. Bjarnason
Sean A. Blanton
The Braewold Fund
Kirsten Brashares
J. Ernest and Rebecca Breeding
Deborah E. Brown
Hannes and Mary Ann Brueckner
Douglas Brusa
Donna Buono
James Butler
Francesco de Lujn Campora
Steven C. Cande
Ross S. Cann
Danielle Flug Capalino
Howard S. Caplen
Philip and Brigitte Carmichael
Ryan Carmichael
Damon A. Chaky
Jennifer Chang and Mathew Pordes
Richard L. Chiaramonte
George L. Choy
Thomas A. Christopher and Suzanne B. O'Connell
Louis Cizek
David A. Clifton
Climate Central Inc.
Kim Cobb
John and Sigrid Colgan
Thomas Conlon
Robert B. Cook
David W. Cooke
Vernon F. Cormier
Paul A. Creeger
Marliese R. Daglian
Patricia A. Daly, OP
Irene C. Davis
Yvette De Felice
The Delta Air Lines Foundation
Vivian DelValle
Ryan and CloEve Demmer
Fred Devan
Alexandra Dimant

Our Donors (cont.)

Dominican Convent of Our Lady of the Rosary
James Donohue
Frank Eckelmann
Robert Eisenstadt
Brenda Ekwurzel
Randall W. Erickson
Peter and Pauline Eschweiler
Michael N. Evans
Carol E. Faill
Emily Fano
John A. Farre
Meghan Fay
Betsy F. Feeney
Ian and Esperanza Felstead
Jim and Jenelle Fishbein
Myron H. Fliegel
Susan Flood
Laura G. Flug
Michael F. Forlenza
Eugene A. Friedberg
Mary Carol M. Frier
Judith Kohlbach Fulton
Maria L. Gagos
Naira Gagoulachvili
James B. Gaherty
Herman Galberd
Judith Gallant
Fei Gao and Juan Li
Pablo O. Garcia
Edward A. Garvey
John Geddie
Daniel T. Georgi
Alice H. Gerard
Marshall Gilbert
Carolyn G. Stern
Susan B. Glantz
Glenn and Elizabeth Goldman
Dorota Gonera
Elizabeth Goodman
Avantika Goswami
Thomas A. Graves
Paul J. and Muriel S. Grim
Thomas P. Guilderson
Renee Haas
Douglas E. Hammond
Timothy B. Harwood
Carol Hasto
David and Ellan Heit
Sean M. Higgins
Jeremy Hise
Lofton and Ruby Holder
Ann E. Holmes
Kay F. Huey
Julia Hunkins
Mei Hunkins
Robert D. Jacobi
Lynn J. Jehle
Ge Jin
IBM International Foundation
INTURN
Jefferies & Company, Inc.
Florence Katzenstein
Fred J. and M. Whitney Keen
Paul Keenan
William Kelemen and Karen Wachsman
Lydia V. Kesler
Jennifer Kingslake
George W. Kipphut
Dalia Kirschbaum
Daniel and Lois Kobal
Peter Kocubinski
Kurt Krueger
John T. and Marilyn D. Kuo
Stephen and Audrey Kurtz
Carla LaGrassa
Alexander E. Lancaster
Chris Langdon
Leo F. Laporte
Aaron J. Lebovitz and Donna T. Myers
Jack C. Lee
Roy S. Levine
Robert and Barbara Liebermann
Tzen-Ying Jenny Ling
Thornton C. Lockwood
James D. Lowell
Robert and Marcia Lupton
Swadesh Mahajan and Kalpana R. Sutaria
Susanna E. Maiztegui
Marvin H. Malater
Maurice Malin
Camille I. Mancuso
Charles and Janet Mangano
Carrie Marlin
Glenna Marra
Stephen Marshak
Joshua Martiesian
George Martin
Douglas and Rhonda Martinson
Robert and Michelle Maryott
Rachel Marzen
Audrey A. Massa
Maria Matasar-Padilla
Arthur and Annette McGarr
Cecilia McHugh
Terrence R. McInnis
Nicholas Mehmel
James and Dorothy Mellett
Marian V. Mellin
Pablo G. Mendez
Alyssa N. Meyers
Peter J. Michael and Rebecca P. Roe
John J. Michels
Donald S. Miller
George and Sylvia Miller
Nancy R. Mintz
Linda L. Moeller
Susan L. Moeller
Martin W. Molloy
Emily B. Morris
Joseph B. Morris
Lawrence and Ursula Neuman
Leslie Nina
Mame Noonan
Becky Nordensten
Karen Northrop
Frank E. Nothaft
Sally Fricke Oesterling
Alice Olick
Curtis R. Olsen
Peter and Susi Orbanowski
Michael and Nancy Passow
Michael and Renee Perfit
David and Agnes Peterson
Lisa Phillips
Kah and Chooi Phon
The PIMCO Foundation
Lucille Posner
Emma Clare Rainforth
Robert and Beatrice Rasmussen
William S. Reeburgh
Priscilla Rich
Michael Rodman and Lorraine Banyra
William D. Romaine
Louise Rosen
Jay B. Rosenstein
Allen Rosso
Casey Roth
Celine S. Ruben-Salama
William F. and Virginia C. Ruddiman
Gray Russell
Richard A. and Kay H. Ryder*
Christine I. Sacks
Andres Estrada
Rita T. Salemo
Robert Samuels
Constance A. Sancetta*
Christopher Sanders
Nicholas Santella
Marc L. Sbar
Stephen Schlussel
Robert C. Schneider and Regina M. Mullahy
Shonda Schultz
Christina Sebastian
B. Alan and Lynne Seidler
Kathleen and Christopher Semergieff
Amar Sen and Erhmei Yuan
John H. Sindt
Jason E. Smerdon
Michael and Diane Smerdon
Xiaodong Song
Charlotte K. Sorger
Stamford Mineralogical Society, Inc.
Donald and Karen Steinmetz
David Joseph Stevens
Diliana Stoyanova
Oscar and Amy Strongin
Charles N. Tacke
Ingrid Tamm
The Graves Family Trust
Paul M. Thompson
Don and Mary Tobin
Raleigh and Catherine Tozer
Mariana S. Tupper
Mykola Turchak
UBS
Marcie Van Auken
Edward E. Vassallo
Stacey L. Vassallo
Christina Vellios
Jill Viola
Valerie Vivian
Thomas V. Wagner
Dongyi Wang
Hongyan Wang and Shuyu Liu
Xuejin Wang and Lingqiao Ma
Robert and Gloria Weber
Ellen Weeks
Carl Weiss
John F. Wehmiller and Paula Lawrence-Wehmiller
Shr-Jin Wei
Stephen H. Weinstein
Robert Went
Gisela M. White
William and Shirley Wilcox
Stephen and Debbie Wilkowski
Arthur Winoker
Joshua Wolfe
Daniel Wolff
James Wood
Bill Worzel
Liqing Xu
Gary Yacopino
Wenchang Yang
Jianqiong Zhan
Gary W. Zielinski
Seymour and Audrey Zubkoff

**Torrey Cliff Society Members are supporters who have included the Observatory in their estate plans. If you have made provisions for the Observatory, or would like to learn more about planned giving opportunities, please contact Stacey Vassallo at staceyv@LDEO.columbia.edu.*

We have made every effort to ensure this listing of gift contributors is complete, and we apologize for any errors or omissions. To report corrections, please email staceyv@LDEO.columbia.edu.

FINANCIALS

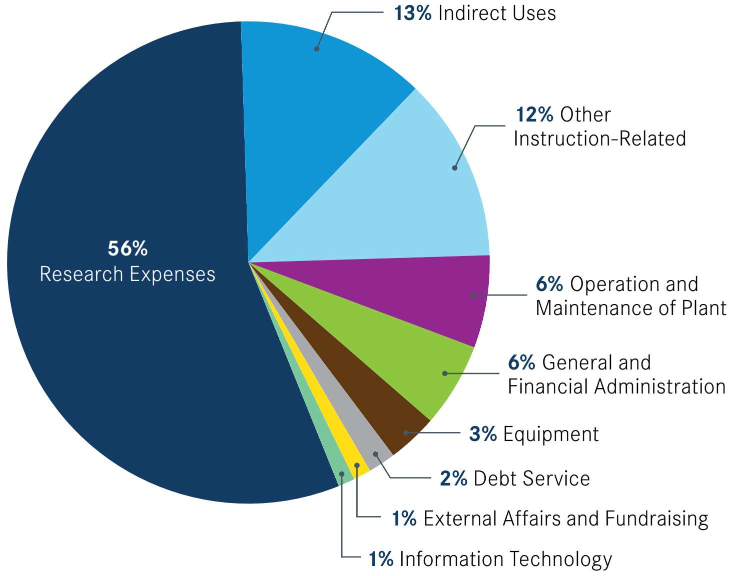
Statement of Activities

Above: *Radley Horton in Bolivia in 2017, on an expedition that was part of a World Wildlife Fund project to target developing countries most vulnerable to climate change. Photo by Manishka De Mel.*

Sources of revenue	FY'17	FY'18
National Science Foundation	42,037	39,998
National Aeronautics and Space Administration	4,824	4,561
National Oceanic and Atmospheric Administration	1,215	1,769
National Institute of Environmental Health and Safety	1,641	1,618
Department of Energy	1,273	1,618
Office of Naval Research	1,097	585
U.S. Geological Survey	741	380
Environmental Protection Agency	242	137
New York State	154	125
Miscellaneous Federal Funds	646	665
Total Government Grants - Direct & Indirect	**53,870**	**51,456**
Private Grants	4,205	6,089
Endowment Income*	7,589	7,455
Gifts	4,223	4,037
Miscellaneous	587	763
Indirect Sources	10,649	8,535
Total Non-Government Sources	**27,253**	**26,879**
Total Sources	**81,123**	**78,335**

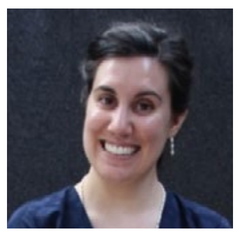
Uses of Revenue	FY'17	FY'18
Research Expenses	44,076	42,426
Operation and Maintenance of Plant	4,741	4,738
General and Financial Administration	4,106	4,318
Other Instruction-Related	9,710	9,411
Equipment	2,657	2,560
Debt Service	1,405	1,405
External Affairs and Fundraising	1,022	906
Information Technology	817	849
Indirect Transfers	9,652	9,672
Total Uses of Revenue	**78,186**	**76,285**
Net Operating Gain/(Loss)	**2,937**	**2,050**
Capital Expenses	(457)	(619)
Subtotal Non-Operating Expenses	**(457)**	**(619)**
Beginning Fund Balance	**9,444**	**11,924**
Ending Fund Balance*	**11,924**	**13,355**

Breakdown of Revenue Uses



Awards and Honors

2018 was another notable year for honors and awards to Lamont workers. Lamont hosts 12 members of the National Academy of Sciences, two National Medal of Science recipients, two MacArthur “genius grant” winners, and two of the first three female winners of the Wollaston Medal of the Geological Society of London. At the end of this year, Robin Bell, who has served as President-elect of the American Geophysical Union since early 2017, will assume the presidency of the largest Earth and space science society in the world, with more than 60,000 members in 139 countries. AGU’s Fall Meeting is the premier opportunity each year for scientists from across disciplines to share their latest research and develop new collaborations.



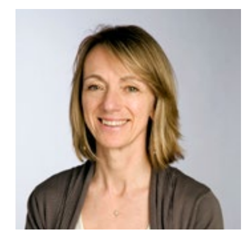
Kassandra Costa, a former graduate student in the Department of Earth and Environmental Sciences, received the 2018 Dansgaard Award from AGU’s Paleoceanography and Paleoclimatology Section. The Elderfield Award recognizes “a late stage Ph.D. graduate student in the PP Section to recognize and promote excellence in the next generation of paleoceanographers and paleoclimatologists.”

Steven Goldstein, Higgins Professor of Earth and Environmental Sciences and Associate Director of Lamont’s Geochemistry Division, received the 2018 Norman L. Bowen Award from AGU’s Volcanology, Geochemistry and Petrology Section. The Bowen Award “is given annually by the VGP Section for outstanding contributions to volcanology, geochemistry or petrology.” Goldstein’s research encompasses ocean circulation, chemical oceanography, and mantle geochemistry.

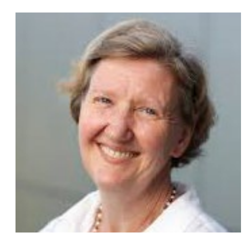
Sidney Hemming, Professor and Chair of the Department of Earth and Environmental Sciences and Deputy Director for Education at Lamont, was named a 2018 Fellow of the American Geophysical Union, a designation that “recognizes exceptional contributions to Earth and space sciences.” Hemming was selected for her major contributions applying geochemical and isotopic tracers in sediments to reveal key geological processes and events through Earth`s history.

Bärbel Hönisch, Associate Professor of Earth and Environmental Sciences, received the Willi Dansgaard Award from AGU’s Paleoceanography and Paleoclimatology Section. The Dansgaard Award is given “for significant contributions in the PP Section within 8–20 years post-degree.” Hönisch’s research focuses on understanding the role of the ocean and in particular the role of marine carbonate chemistry in global climate change.

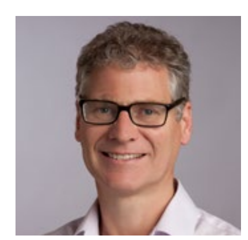
Albrecht Hofmann, visiting Senior Research Scientist at Lamont, was elected a Foreign Member of the Royal Society for his exceptional contributions to science. An Emeritus Director at the Max Planck Institute for Chemistry, Hofmann is a geochemist who has made seminal contributions to our understanding of Earth’s mantle and crust. He earlier received the Goldschmidt Medal from the Geochemical Society and the Hess Medal from the American Geophysical Union and is a Foreign Associate of the U.S. National Academy of Sciences.



Kerstin Lehnert, a geochemist and Doherty Senior Research Scientist at Lamont, received the 2018 Ian McHarg Medal at the European Geosciences Union (EGU)’s 2018 General Assembly in Vienna. The medal is awarded each year by EGU’s Division on Earth and Space Science Informatics “for distinguished research in information technology applied to Earth and space sciences.”



Terry Plank, Arthur D. Storke Memorial Professor in the Department of Earth and Environmental Sciences, received the 2018 Wollaston Medal from the Geological Society of London. A geochemist and igneous petrologist, she has made major contributions to the understanding of magma production and geochemical recycling at plate subduction zones.



Richard Seager, Palisades Geophysical Institute Lamont Research Professor, was named a 2018 Fellow of the American Geophysical Union. Seager is a climate scientist who was recognized for his pioneering contributions in tropical climate dynamics and for improving our understanding of precipitation variations and drought linked to natural and human causes.

Lynn Sykes, Higgins Professor Emeritus at Lamont, received an honorary Doctor of Science degree from Columbia University in 2018 for his contributions to the establishment of the theory of plate tectonics and to the development of seismological methods for identifying and characterizing underground nuclear explosions, a key methodology that underlies the Comprehensive Nuclear Test-Ban Treaty.

Margie Turrin, Director of Educational Field Programs in Lamont’s Office of Education and Outreach, received the 2018 Outstanding Educator Award from the Hudson River Environmental Society. The Society recognized Margie’s “development of science education projects for groups from informal community education to K12 and undergraduate students. Her projects and publications range from engaging students and the public in the polar regions, to understanding our Earth and environment, human interactions and impacts on their environment, Hudson River education, biodiversity, mapping and spatial skills assessments.”

Christopher Zappa, a physical oceanographer and Lamont Research Professor, received a 2018 teaching and research award from the Fulbright U.S. Scholar Program to Italy. The scholarship was given to support fieldwork in southern Italy, where Zappa applied multispectral imaging techniques to detect, identify, evaluate, and track toxic cyanobacteria as well as other signs of environmental contamination along the Mediterranean coastline near Naples, as part of a broader investigation of pollution pathways.

Learning the Planet

We've developed an updated strategic framework that will guide our activities and programming as we transition to a more proactive state of operations and focus our activities on long-term outcomes. It is an exciting time for LDEO and, more broadly, the field of Earth science. The principal activities and accomplishments during 2018 within our five strategic areas are outlined below:

Advancing Research and Pedagogy

In this area, we have focused on engaging in educational research that will produce evidence-based strategies and measures that inform our knowledge of the kinds of learning environments, curricula, and support networks that are needed to advance student learning in Science, Technology, Engineering, and Mathematics (STEM). From the research perspective, we have been carrying out work on three projects funded by the National Science Foundation (NSF), one under their Cultivating Cultures for Ethical STEM Initiative (CCE STEM), one under the Innovative Technology Experiences for Students and Teachers (ITEST) initiative, and the third under our ongoing Climate Change Education Program.

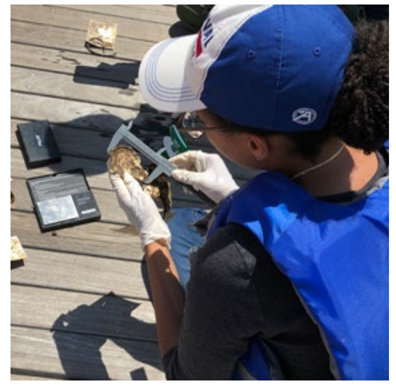
Creating research experiences for students traditionally under-represented in STEM/ Sustainability fields

Under this strategic area, we are creating and implementing authentic research experiences in which learners from all backgrounds, races, and ethnicities engage directly in doing hands-on scientific work alongside researchers to further the development of their science literacy skills.

This summer, we launched four pilot projects for high school and undergraduate students, as part of our NSF INCLUDES (Inclusion across the Nation of Communities of Learners of Underrepresented Discoverers in Engineering and Science) program. Each pilot operated at a satellite location, with sites including the Hudson River Park in New York City, Cary Institute of Ecosystem, Dominican College in, and Rutgers University. Participants worked on projects that included studying the impact of microplastics in the Raritan River in New Jersey, stream ecology studies in Dutchess County, ecology and microbiology of the Sparkill Creek in Rockland County, and the impact of the New York City waterfront pilings on the waterfront ecology.

At the undergraduate level, we were awarded a grant renewal from the NSF to continue our Research Experiences for Undergraduates (REU) program, which focused on diversifying recruitment strategies to target liberal arts colleges as well as community colleges to ensure a larger cohort of under-represented STEM groups in the program. Our recruitment efforts resulted in students coming from Dominican College, Orange County Community College, Dutchess Community College, Housatonic Community College, Queensborough Community College, Kingsborough Community College, and the Borough of Manhattan Community College.

Opposite page: *(clockwise from top) Ashawna Abbott (right) and Kait Rose (left) pull a net as part of a fish diversity activity in the Hudson River for a STEM workshop; Margie Turrin (seated, left) and Laurel Zaima (standing, far left) work with Yonkers Riverside High School to design "Scientists as Superheroes" (photo by Kelly Jakob); young attendees at the World Science Festival City of Science event learn about glacial clay; attendees at the World Science Festival City of Science event build their own "sediment cores"; teachers participate in a New York City Department of Education workshop on bringing data into the classroom. All photos by Margie Turrin except as indicated.*



__This page:__ (above) Student Conservation Association members trained during the Day in the Life of the Hudson River Program; (far bottom) high school students work with undergraduate mentors from New York City, as part of the summer INCLUDES program; (right, clockwise from upper left) high school students Chloe Rosa (left image) and Ashana Neale (right image) learn about oysters as part of the INCLUDES project; (left to right) Rutgers University postdoctoral scientist Sarah Gignoux-Wolfson, Rutgers undergraduate Deyvonn Jones, and high school students Garrett Joyce, Loriann De Sousa Rego, and Riya Goal work on microplastics in the environment and their impact on zebra fish. All photos by Margie Turrin.

Strengthening STEM instruction

This strategic area has focused on preparing educators to have sufficient content knowledge as well as pedagogical approaches in order to ensure that classroom teaching in STEM subjects at school mimics how STEM research is done in the real world.

For example, we have worked with the New York City Department of Education's STEM office over the past year to deliver tailored Professional Development workshops designed to engage teachers in current research and practice in STEM. We developed multiple workshops connected to the Hudson River, as well as a series on local climate impacts from the polar-regions.

Ensuring innovative curriculum development

Along with strengthened STEM instruction, LDEO is playing a role in the development of innovative curricula. Through our collaborative efforts, we prioritize the 21st century skills (e.g., collaborative work, problem solving through data, and critical thinking) over rote learning, and we have emphasized thinking outside of the box when it comes to curricula.

In fall 2017, we piloted a class at the Grace Church School in Manhattan where students were presented with an introduction to science communication and learned about "real-world" communication issues related to science research and policy. The course was designed by the E&O Office at Lamont and is one of many examples of how a research institution such as Lamont can partner and develop strong communities of practice with schools on STEM themes to connect students more deeply and directly to science learning.

Increasing public engagement in STEM through outreach

Our last strategic area is perhaps our broadest, with an aim to engage public audiences in the ongoing scientific work that we do so that the work of LDEO becomes more accessible to people of all ages. We're doing this through sustained participation in events such as speaker series, science fairs, and citizen science and community engagement efforts. Lamont's Hudson River Field Station is a particularly exciting aspect of our outreach in LDEO's own backyard. The station is moving quickly toward completion with funding for the exterior of the building having enabled that work to move forward.

In addition to our annual Open House, LDEO is committed to participating in the SUBMERGE Marine Science Festival at Hudson River Park, the Sun/Earth Day at the American Museum of Natural History, the Girls in Science and Engineering Fair at the Intrepid Museum, and the World Science Festival's Fish Count and City of Science Fair in Washington Square Park. These events reach more than 25,000 people per year and have served as a great way of sharing our work with the communities around us.

Department of Earth and Environmental Sciences

Much of our formal education is taught through the Department of Earth and Environmental Sciences (DEES), which was named in 2010 by the National Research Council as the best Earth science Ph.D. program in the country, a ranking that reflects Lamont's exceptional people, resources and affiliated programs. Globally, U.S. News & World Report 2017 ranked Columbia #4 for geoscience programs. The students in DEES bring enthusiasm and innovative ideas, lend fresh energy to our investigations and help inspire future research.

In the fall of 2018, DEES welcomed 19 new graduate students who hold citizenship in four different countries. Many of our new and continuing graduate students were recipients of prestigious fellowships this year.

__This page:__ (clockwise from upper left) Laurel Zaima works with attendees at the Lamont-organized World Science Festival NYC Great Fish Count at Fort Washington Park; Mercy College McNair students visit the Lamont Field Station at Piermont Pier to explore field research; undergraduates from the region participate in a student workshop on the Hudson River. All photos by Margie Turrin.

__Back cover:__ deploying a mooring in Terra Nova Bay, Antarctica, from the R/V Araon. Photo by Christopher Zappa.

Lamont-Doherty Earth Observatory
Columbia University | Earth Institute

61 Route 9W
Palisades, NY 10964

ldeo.columbia.edu