EAPS Scope

NEWSLETTER OF THE DEPARTMENT OF EARTH, ATMOSPHERIC AND PLANETARY SCIENCES | 2019-2020

FEATURED THIS ISSUE

Climate
From studying tiny Antarctic microbes to designing tiny weather satellites; from mining massive datasets collected from the ocean and atmosphere to building massive global models, this issue is packed with stories of novel research and collaborations from the EAPS scientists and students working hard to hack the climate conundrum.

News
Emanuel elected to the American Philosophical Society • Royden awarded Bucher Medal • Zuber receives Kuiper Prize • Introducing two new faculty for 2020 • Ferrari named an Ally of Nature by the School of Science • Fournier, O’Gorman, Perron, Cahoy, and McGee earn promotions • Remembering Sam Bowring

Friends
Montrym Fund offers students climate research mini-grants • Introducing Artemis: MIT’s newest exoplanet hunting telescope is inaugurated in Tenerife • A milestone celebration for Nafi Toksöz • Charney Library holds its grand reopening • Student research highlights and 2019 degrees awarded • Travel the world with EAPS faculty
Dear Alumni and Friends,

Welcome to your 2019-20 EAPS Scope! This climate-themed edition is timely, coming at the end of a year with headlines crowded with climate news ranging from record heat in the Arctic Circle, to raging wildfires across Australia, California, and the Amazon, to deadly hurricanes in the Caribbean, Texas, and Japan.

At a recent MIT climate science symposium (the first in a series of six events), Susan Solomon’s keynote speech included sober forecasts for rising temperatures and sea levels even if global carbon emissions were to cease abruptly. So, there is a growing imperative for MIT to bring its scientific and technical resources to bear to better understand our climate system and help communities around the world face the climate crisis head-on.

Our work to understand Earth’s complex and intertwined processes makes EAPS uniquely qualified to help fill that pressing need, whether by sharing scientific data with leaders in government and industry, or by collaborating with peers to explore policy and technical solutions. I am greatly buoyed by the latest climate science emerging from EAPS, and by the rising generation of young EAPS scientists who are driven to not only study the intricacies of the global system, but to also use their knowledge for societal benefit—and, for many, to take a stand in calling for urgent action before it is too late to make a difference. (Indeed, I was glad to see so many faces from EAPS on the plaza at Boston’s Government Center participating in the September global climate strike.)

Here, I am proud to share some of the department’s latest climate research, and to report that our faculty and students are thriving thanks in part to the support of alumni and friends like you.

Given the urgency to seek solutions to climate and other environmental challenges, our emerging partnership with the MIT Environmental Solutions Initiative (ESI) could not be more timely. I am delighted to report that we have passed the halfway mark in our $30M fundraising campaign to create a stunning new portal to the Green Building, thanks to the generous support of members of the EAPS Visiting Committee and other donors. The Earth and Environment Pavilion will provide a shared home for EAPS, ESI, and the MIT-WHOI Joint Program in Oceanography, as well as create a place to share our research and inspire collaboration among students and faculty from across the entire MIT community.

With gratitude and best wishes for the coming year.

Rob van der Hilst

LETTER FROM THE HEAD OF THE DEPARTMENT
The pace of geoscience investigations today can hardly keep up with the urgency presented by societal needs to manage natural resources, respond to geohazards, and understand the long-term effects of human activities on the planet...recent unprecedented increases in data availability together with a stronger emphasis on societal drivers emphasize the need for research that crosses over traditional knowledge boundaries.
The Department of Earth, Atmospheric, and Planetary Sciences (EAPS) at MIT has expanded its academic program to include a new doctoral field: Computational Earth, Atmospheric, and Planetary Sciences (CEAPS). EAPS is the latest department to participate in the Computational Science and Engineering (CSE) PhD program, which has been offering PhD degrees in computation since 2013. This move resonates with the Institute’s Engineering (CSE) PhD program, which has been offering PhD degrees at the doctoral level in a computation-related field of their choice since 2013. 

Adding the PhD track will ensure that the department remains an active place that proved moonshots are worth taking. "The Gerard P. Kuiper Prize honors scientists whose lifetime achievements have most advanced society’s understanding of the planetary system. Zubér’s numerous accomplishments include her seminal 2000 paper in the journal Science combining Mars Global Surveyor laser altimetry data and gravity data to determine the crustal and upper mantle structure of Mars. Zubér became the first woman to lead a NASA spacecraft mission as principal investigator of the Gravity Recovery and Interior Laboratory (GRAIL) mission. GRAIL constructed a model of the moon’s gravitational field to spherical harmonic degree 180, which exceeded the baseline requirement of the mission by an order of magnitude. Zuber has turned her attention to many different solid bodies in the solar system, focusing on structure and tectonics, including Mercury, Venus, Mars, and Ceres. Since 1990, she has held leadership roles associated with scientific experiments or instrumentation on nine NASA missions.

The department will offer a new degree in Computational Earth, Atmospheric, and Planetary Sciences (CEAPS), which recently culminated with the creation of the MIT Department of Computational Science and Engineering (CSE) PhD program. The new program will be housed within the Earth, Atmospheric, and Planetary Sciences (EAPS) department, which has been offering PhD degrees in computation since 2013.

Computational advancements have catalyzed these efforts, and MIT’s latest investment in the new Schwarman College of Computing will help to further expand data science and machine learning techniques in the geosciences. Investments in research and collaborations like these are closing the knowledge gap on how the Earth system functions and refining what are already good projections of future climate variations—leaving no doubt of the credibility of the science and the risks posed by climate change. And as we look forward, climate findings will be a key factor to help society develop policies and use capital wisely—investing in infrastructure changes and better urban planning, as well as developing mitigation strategies and even reversal technologies. "All of you are part of an amazing institution that has proven human knowledge and achievement are limitless," Bloomberg said. "In fact, this is the place that proved moonshots are worth taking."
**AWARDS AND HONORS**

Department of Earth, Atmospheric and Planetary Sciences faculty continue to earn numerous awards and invited honors in recognition of their innovation and leadership in their respective fields.

EAPS scientists and MIT alumni contributed to the American Meteorological Society’s monograph “A Century of Progress in Atmospheric and Related Sciences: Celebrating the American Meteorological Society Centennial.” Professor Emeritus of Physical Oceanography Carl Wunsch and Cecil and Ida Green Professor of Oceanography Rappaport Family Professor Ulrike Guymer wrote the chapter “100 Years of Ocean General Circulation” and Cecil and Ida Green Professor of Atmospheric Science Kerry Emanuel authored “100 Years of Progress in Tropical Cyclone Research.”

Assistant Professor Julienne St. John joined a delegation from Belgium on a recent State Visit to Luxembourg. de Wit was invited to give an address on the future of space exploration to the King and Queen of Belgium, the Grand-Duc and Grande-Duchesse of Luxembourg, and their respective political and industrial entourage.

At TEDx Boca Raton, Associate Professor Kirill Ganyo spoke about her work with CubeSats, “How Tiny Satellites Can Help Us Weather Through Hurricanes.” The event’s theme, “Rethinking Relationships,” was selected to examine how paradigm shifts in behavior, technology and global influences impact our significance as individuals and as connected beings.

The American Meteorological Society, which is celebrating its centennial conference in Boston, is holding the inaugural Solomon Symposium in January 2020. Solomon, the Lee and Geraldine Martin Professor of Environmental Studies, has been a leader on the scientific frontiers of the world’s most important environmental challenges and instrumental in the advancement of atmospheric chemistry, climate, and environmental policy. The symposium will honor Solomon’s past achievements and ongoing contributions to atmospheric science. Sessions will highlight the history and future of environmental policy and assessments, breakthroughs in middle atmospheric and ozone science, and provide perspectives on our changing climate—one of the greatest challenges of our time. Each of these three topics will be communicated through invited talks and solicited posters.

The School of Science recently announced that 14 faculty members have been appointed to named professorships—including three from EAPS. The faculty selected for these positions receive additional support to pursue their research and develop their careers.

**MEET OUR NEWEST FACULTY**

EAPS is pleased to announce Camilla Cattania and William Frank will join the department as Assistant Professors in July 2020.

**Camilla Cattania** is a seismologist with experience in numerical modeling, earthquake physics, and statistical seismology. She has developed new models of aftershock triggering based on static stress changes and studied swarms driven by magmatic intrusions and dynamic triggering. A separate but complementary aspect of her research consists of analytical and numerical modeling of slip on a single fault. Cattania has applied ideas from fracture mechanics to investigate the interaction between seismic and aseismic slip on isolated asperities, a topic she is now exploring in a wider range of tectonic settings and including additional physical processes. Her research concerns tectonic earthquakes but is also pertinent to so-called micro-seismicity induced by human action, such as hydrocarbon extraction, waste water injection, subsurface geothermal carbon sequestration, and geothermal energy production.

Cattania’s theoretical and computational studies of tectonostrophies, tectonostrophics and earthquakes complement current research in seismology, geomechanics, and rock physics at EAPS and MIT’s Civil and Environmental Engineering, via the Earth Resources Laboratory.

Cattania received her bachelor’s and master’s degrees in experimental and theoretical physics from the University of Cambridge. She earned a PhD in geophysics from the GFZ German Research Center for Geosciences/University of Potsdam, where she was a guest scientist. She later joined the Woods Hole Oceanographic Institution as a guest investigator, before becoming a postdoctoral fellow at Stanford University and GFZ German Research Center for Geosciences/University of Potsdam. Cattania is now a postdoctoral scholar at Stanford University.

**William Frank** specializes in geophysics. His research examines physical mechanisms that control deformation within the Earth’s crust. Understanding the continuum of rupture modes and fault instability within the Earth—from shallow stick-slip earthquakes to deep slow transients, to still deeper steady creep—is key to improving estimates of earthquake hazard and our comprehension of the destructive earthquake cycle. His multidisciplinary approach combines seismological techniques with geodetic observations to yield knowledge about the evolution of faulting processes in time and space and how the solid Earth responds to tectonic, volcanic, and anthropogenic forcings. Frank’s observational work on earthquakes and crustal deformation complements current research within the department on seismology, geodesy, geomechanics, and rock physics, and will pair with the more theoretical and numerical approach of incoming Assistant Professor Camilla Cattania.

Frank received his bachelor’s degree in Earth Systems Science from the University of Michigan. He earned his master’s and doctoral degrees in Geophysics from the Institut de Physique du Globe de Paris, and stayed on as a postdoc after obtaining his PhD. After this, Frank joined MIT as an NSF postdoctoral fellow in the research group of German Prieto, followed by his current position as an assistant professor of Earth sciences at the University of Southern California.
A STEWARD FOR OCEAN AND CLIMATE HEALTH

Ferrari receives Ally of Nature Fund Award from the School of Science.

The world is continuously changing and evolving—but amid the richness and complexity, there is a need to understand the processes that drive climate change and the impacts of human activities on the environment. Kerri Cahoy joined the faculty at MIT in 2014 and is an expert in understanding the physical processes that govern the Earth's climate and the response of the atmosphere, the hydrological cycle, and climate extremes to climate change. Her research focuses on the role of tropical oceans and land areas in shaping climate patterns and the importance of understanding the interactions between the ocean and atmosphere.

PAUL O'GORMAN joined the MIT faculty in 2008. He leads the Ferrari Group, which is contributing to the creation of a better-informed understanding of the Earth's climate system. The group's research is focused on the role of the ocean in the Earth's carbon and heat budgets, demonstrating through theory and observation that small-scale turbulent motions play a crucial part in shaping the climate system.

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RECENT FACULTY PROMOTIONS

The Executive Committee of the Corporation has approved the promotion of five EAPS faculty: Gregory Guevara to associate professor; Paul O'Gorman and Taylor Perron to full professor; and tenure for Kerry Cahay and David McGee.

Gregory Guevara joined the faculty at MIT in 2014 and is an expert in molecular phylogenetics, inferring the evolutionary histories of genes and genomes with molecular lineages across geological timescales—specifically, by examining the complexities of the horizontal gene transfer mechanism.

Taylor Perron, faculty member since 2009 and current EAPS associate department head, studies how landscapes form and evolve, both on Earth and on other planets. His approach combines theory and numerical modeling, field and remote sensing observations, analysis of data from planetary missions, and laboratory experiments.

Erik Volckaert joined the faculty at MIT in 2014 and is an expert in molecular phylogenetics, inferring the evolutionary histories of genes and genomes with molecular lineages across geological timescales—specifically, by examining the complexities of the horizontal gene transfer mechanism.

Kirkle Chapman, holding a joint appointment in MIT's Aeronautics since 2011, leads the development of transport, Advanced, and Telecommunications, Spacecraft (TARA) Lab. She develops nanosatellite laser communication systems and weather sensors, such as the Microsized Microwave Atmospheric Satellite (MikMAS) and the Microwave Radiometer Acceleration Technology (MiRAT) mission.

David McGee joined EAPS faculty in 2012 and investigates the atmosphere’s response to past climate changes, documenting historical precipitation and winds using geochemical measurements of stalagmites, lake deposits, and marine sediments to understand the patterns, pace, and magnitude of past hydroclimate changes.

IN MEMORIAM

SAMUEL BOWRING | 1953-2019

Robert R. Schrock Emeritus Professor of Geology Samuel A. Bowring died on July 17 at age 65. Known for his exceptional skill as a field geologist and innovator in uranium-lead isotopic geochronology, Bowring worked to achieve unprecedented analytical precision and accuracy in calibrating the geologic record and reconstructing the co-evolution of life and the solid Earth.

Bowring received an A.B. and M.A. in geology from Dartmouth College in 1977 and a Ph.D. in geology from Brown University in 1981. He joined the faculty of EAPS at MIT in 1991, where, in addition to fostering the careers of over two dozen graduate students and postdoctoral associates, he demonstrated a career-long commitment to advancing undergraduate education. For more than twenty years, Bowring served as a first-year and undergraduate advisor, eventually being named a Margaret MacVicar Faculty Fellow in 2006 by the Institute program which recognizes faculty for “exemplary and sustained contributions to the teaching and education of undergraduates at MIT” and later earning the MIT Everett Moore Baker Memorial Award for Excellence in Undergraduate Teaching in 2007.

Bowring was also instrumental in guiding Terascope, a first-year learning community created jointly by EAPS and the Department of Civil and Environmental Engineering. Bowring became associate director of the program in 2006, going on to serve as director from 2008 to 2015.

In addition to being named a member of the National Academy of Sciences and the American Academy for the Advancement of Science, Bowring was a fellow of the AGU and was recognized by the organization with both the Norman L. Bowen Award and Walter H. Bucher Medal. He was also a fellow of both the Geological Society of America and the Geological Society of America.

One of Bowring's earliest contributions which transformed what we thought we knew about the early evolution of the Earth was his work on the Acasta gneiss complex, pushing back the date of the oldest-known rocks to 4.03 billion years.

Bowring is known for his exceptional skill as a field geologist and innovator in uranium-lead isotopic geochronology. His lab has developed methods for not only tracing naturally-occurring sources and establishing natural regional baselines, but also for documenting variations which correlate with anthropogenic inputs associated with urbanization and industrialization.

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VITAMINS, TOO

ANTARCTIC MARINE MICROBES NEED THEIR VITAMINS, TOO

AFTER WEEKS OF BREAKING THROUGH thick sea ice to arrive at our sample station, all of us exhaled a sigh of relief, only to inhale the pungent smell of dimethyl sulphide, a climate-active gas produced by microscopic marine plants. Were we in the midst of a flourishing phytoplankton bloom so large it could be seen from space and smelled from miles away? I was in awe because until that moment, I had only studied and grown the phytoplankton responsible for this bloom, *Phaeocystis antarctica*, under controlled lab conditions in a small flask. Thanks to the efforts of 50 crew members and scientists aboard the NSF icebreaker the *R/V Nathaniel B. Palmer*, I was able to deployed aboard the *R/V Palmer* to study how microbes and their interactions—both invisible to the naked eye—collectively impact an entire ecosystem.

For nearly 80 days at sea, we transited along Antarctic continental shelves from the Amundsen Sea to Terra Nova Bay in the Ross Sea. These marginal seas are the most productive areas of the Southern Ocean, where phytoplankton are fueled by continuous sunlight during the summer in the Antarctic circle and essential metals from glacial and sea ice melt. These blooms ultimately sequester significant amounts of atmospheric carbon dioxide through photosynthesis, biosynthesis, and export of particulate carbon (in cells) to ocean depths. In Antarctic seas, phytoplankton communities are typically dominated by one of two microbial groups: diatoms or the colonial *P. antarctica*. Recent observations in Terra Nova Bay show a shift in the phytoplankton community from diatoms to *P. antarctica*. However, what combination of environmental factors determine community composition is not fully understood.

The mission of our scientific research cruise called CICLOPS (Cobalt and iron Co-limitation Of Phytoplankton Species) was to examine how cobalamin (vitamin B12) and iron co-limit phytoplankton species and to investigate if these micronutrients control phytoplankton community composition in Antarctic seas. I was there to examine the curious case of vitamin B12 cycling, an example of a non-conservative interaction between phytoplankton and bacteria that has ecosystem-scale impacts.

Nearly a decade ago, scientists discovered that both iron and vitamin B12 could limit the highly productive phytoplankton communities of the Ross Sea. This was the first oceanic region shown to be limited by a vitamin—indeed by any organic resource. It is expected that B12 can not only limit overall productivity here, but that vitamin availability can modulate the community composition. Like us, most eukaryotic phytoplankton require vitamin B12 for protein and DNA synthesis. Vitamin B12 contains the trace metal cobalt, which is found in vanishingly low concentrations (picomolar), and can only be synthesized by certain bacteria and archaea. Ultimately, phytoplankton depend on these microbes for their vitamin supply. It is likely that in exchange for B12, bacteria benefit from an increased supply of their food source: organic carbon produced by the growing phytoplankton.

The ocean microbiome has many such beneficial interactions that are complex and important but challenging to study, and thus have not been integrated into most global marine ecosystem models. As a microbial oceanographer, I focus on these relationships—such as the exchange and cycling of organic resources like B12—that are the ‘invisible threads’ binding microbial communities together.

During our two-month cruise, we transited nearly a third of the way around Antarctica, hugging the continental shelves and chasing blooms in the polynyas (seasonal seas that form due to melting sea ice), from a *P. antarctica* bloom in the Amundsen Sea to a diatom-dominated community in the Ross Sea. The science team used trace metal clean techniques to collect seawater and filter large volumes, which we studied looking for information on phytoplankton community DNA, RNA, and proteins, as well as nutrient concentrations. We also incubated some samples onboard, in which we tested whether the local community was limited by iron, B12, or a set of other potentially limiting nutrients.

Onboard, for my own incubation experiments, I used radio-labeled cobalt chloride (*CoCl2*) and vitamin B12 to track the cycling of these micronutrients within the natural seawater microbial community. While cobalt is part of vitamin B12, it has other biological functions and thus the two cycles are related but distinct. To date, we collected the largest set of concurrent cobalt and B12 uptake rates, with hundreds of samples that allow us to distinguish how fractions within the natural seawater microbial community (e.g., larger phytoplankton versus bacteria) drive the ecological cycling of these essential micronutrients.

My research has me traveling between the field, lab, and office from Woods Hole to Cambridge, MA. While at Woods Hole Oceanographic Institution (WHOI), I work with the Saito lab to study the response of *P. antarctica* single cells and colonies to B12 and iron limitation by analyzing their growth and metabolic response through measuring their cellular metals and proteins under different conditions. While at MIT, I work with the Follows lab and MIT Darwin Project to develop models of *P. antarctica* life cycle stages to improve their representation in global marine ecosystem models. Between both locations, I analyze the field data to understand how the physical environment and local marine microbial community drive the patterns of cobalt and B12 uptake we observed while at sea. In my research, I strive to have a multi-scale approach to study how microbial processes and interactions can impact ecosystem structure and dynamics, with feedbacks on the environment and ultimately climate. Oceanography is an inherently interdisciplinary science, a necessary approach to study complex ecosystems from multiple spatial, temporal, and biological scales.

My experience researching polar microbial oceanography in the field, lab, and models has further motivated my interest in understanding Antarctica’s role in a changing global climate. Increased glacial melt and decreased sea ice is altering the supply and availability of trace metals like iron and cobalt to Antarctic marine microbial communities. I believe that by shining a spotlight on the climate change impacts to Antarctica’s sensitive microbial ecology, we can highlight the immediate consequences of climate change on the base of polar ecosystems. Such a fundamental change to the base of Antarctic food web has ramifications for ocean life from krill to whales, global fisheries, ecosystem stability and Earth’s climate. The changes occurring in the Antarctic region affect us all, despite how remote the frozen continent and ocean may seem.

Read more about the research: [www.bit.ly/Antarctic-microbes-Vitamins](http://www.bit.ly/Antarctic-microbes-Vitamins)

**Phaeocystis antarctica**

**Diatoms**

**Kril**

*Vessel transect plot (left) depicting the 60-day research area of the codetaker R/V Nathaniel B. Palmer as it transited almost a third of the waters along the Antarctic continental shelf for the NSF-funded CICLOPS cruise.*
Within the Earth’s atmosphere, the question of how biology changes the geologic record is critical. This is because the Earth’s atmosphere is a dynamic system that is constantly changing, and these changes can leave a record in the form of fossils or other geological features. Understanding how these changes occurred can provide valuable insights into the history of life on Earth, including the evolution of complex life and the development of the modern atmosphere.

The history of the Earth’s atmosphere is closely tied to the evolution of life. For example, the Great Oxidation Event (GOE) around 2.7 billion years ago marks a significant shift in the Earth’s atmosphere, with the oxygen levels rising from near-zero to around 20% of today’s levels. This event was driven by the rise of photosynthetic bacteria, which began to produce oxygen as a byproduct of photosynthesis.

The GOE had a profound impact on the Earth’s environment, and it is thought to have affected everything from the chemistry of the oceans to the behavior of ancient organisms. However, the exact timing and nature of the GOE are still subjects of ongoing research, with different studies suggesting that the event occurred over millions of years.

To better understand the GOE, researchers are using a range of tools, including isotopic analysis and the study of ancient rocks. These tools allow scientists to track the changes in the Earth’s atmosphere and to infer the presence of early forms of life.

In addition to the GOE, other major events in Earth’s history have also had a significant impact on the atmosphere. For example, the rise of the greenhouse effect around 550 million years ago helped to warm the Earth and create the conditions necessary for the evolution of complex life.

Today, scientists are continuing to study the Earth’s atmosphere, using a range of tools and techniques to understand how it has changed over time and what factors have driven these changes. By studying the Earth’s atmosphere, we can gain a better understanding of how life has evolved and how it continues to shape the planet today.
The Advanced Global Atmospheric Gases Experiment celebrates a milestone anniversary, solves a chlorofluorocarbon mystery, and fills an atmospheric data gap in equatorial Africa.

"You have literally changed the world," said Susan Solomon, Lee and Geraldine Martin Pro- fessor of Environmental Studies in MIT’s EAPS, addressing attendees of the Advanced Global Atmospheric Gases Experiment (AGAGE) 40th anniversary conference held at MIT in 2018.

AGAGE, an international network of scientists, research institutions, and advanced instrumen- tation has been providing continuous global greenhouse and ozone-depleting gas detection via an expanding infrastructure of state-of-the-art monitoring stations since 1978.

As the conference’s keynote speaker, Solomon recounted how AGAGE data on the long atmo- spheric lifetimes of chlorofluorocarbons (CFCs) informed her research—most notably, her discovery identifying the chemical mechanism behind the formation of the Antarctic ozone hole. This research led to the global ban of CFCs through the Montreal Protocol and subsequent healing of the ozone hole—a posterchild of climate success.

Ronald Prinn, director of MIT’s Center for Global Change Science and TEPCO Professor of Atmospheric Science in EAPS, co-founded AGAGE amid growing concerns about the effects of industrial chemical emissions on the atmosphere, and has led the network from its 1978 inception. The project, which began as the Atmospheric Lifetime Experiment (ALE) and Global Atmospheric Gases Experiment (GAGE), merged theory with experimental research, and now boasts 13 primary stations with sophis- ticated instruments measuring over 50 gases, 20-40 times per day, with sources and sinks inferred using high-resolution 3-D models and supercomputers. Today, AGAGE data is often combined with NOAA surface data, and NASA and NOAA aircraft and satellite data, yielding a more comprehensive picture of atmospheric gases, and has allowed for major advance- ments in atmospheric science and global emissions policy.

Acknowledging AGAGE’s international position with access to new data, conference attendees discussed the network’s evolution, impacts, and bright future. “Our network is unique in that it provides estimates of global, national, and city emissions,” said Paul Fraser, AGAGE Cape Grim station scientist and an atmospheric chemist who established the network’s first Southern Hemisphere mea- surements of CFCs in the late-1970s. “It allows us to say, yes, we have emissions problems, and this is where they’re coming from. And that en- ables us to then specifically identify industries that might be involved and to help them in their efforts to reduce these emissions.”

That capability can be critical to ensure compliance with international environmental agreements such as the Montreal Protocol, said Ray Weiss, AGAGE experimental leader and a professor at the Scripps Institution of Ocean- ography in La Jolla, CA. "The only way to make sure [environmental policies] are working is to quantify what’s actually going into the atmo- sphere, whatever it’s gases that affect climate or the ozone layer," Weiss said. “The important thing is to keep doing it. It’s not exciting, but it has to be done independently.”

His point was well-illustrated when AGAGE scientists discovered the precise source of mys- terious new emissions beginning around 2012 of CFC-11, one of the worst ozone-depleting substances banned by the Montreal Protocol. According to Prinn, two AGAGE stations in South Korea and Japan, together with high-level- el modeling, were the keys to this discovery.

To identify the exact source, AGAGE scientists, including Prinn group researchers, created computer simulations that could back-track the emissions’ trajectory based on known global atmospheric circulation patterns. They were able to pinpoint the new emissions to a handful of industrial areas in eastern China. The discovery, published in Nature earlier this year, represented “an important and particularly policy-relevant milestone in atmospheric scientists’ ability to tell which regions are emitting ozone-depleting substances, greenhouse gases, or other chemicals, and in what quantities,” commented Weiss.

While the international collaborators confirmed the source of a substantial fraction of the newly detected CFC-11 emissions, they couldn’t ac- count for all of them. This means that there are likely other industrial sites in violation of the Montreal Protocol either in other parts of east Asia or elsewhere. “The AGAGE network does not yet have the geographical distribution required to monitor emissions from all industrialized areas,” said Prinn.

The network’s latest addition came in early 2019 thanks to collaboration between EAPS scientists and the Rwandan government. Dis- cussions of the Rwanda Climate Observatory began in 2008 when Rwanda’s then-president, Paul Kagame, visited MIT. Prinn notes that Kagame hoped to create world-class scientific infrastructure in Rwanda to provide domestic opportunities for talented and accomplished young Rwandan scientists, who would otherwise often leave the country for prestigious jobs elsewhere. It seemed to Prinn like a per- fect location for a new AGAGE station, the first on the African continent.

While scouting for a location for the new station, Prinn’s then graduate student, Kath- erine Potter PhD ’11, met Jimmy Gasore from the National University of Rwanda, who soon joined Prinn’s group to build the new Rwandan observatory and obtain his PhD in 2017. For his thesis, Gasore collected data from the fledg- ing station, and through computer analysis, estimated carbon dioxide and methane sources and sinks in Africa, a part of the world severely lacking in greenhouse gas observations. This provided a novel baseline for global scientists and regional policy makers. With his MIT PhD, Gasore returned to Rwanda as Chief Scientist of the new observatory in 2018.

But AGAGE’s planned expansion will not end with Rwanda noted Prinn, as increased moni- toring of climate-changing and ozone-deplet- ing gases becomes more crucial with climate change. Additional measurements are needed to improve understanding of global and regional trends in greenhouse gas emissions, and to help verify national and regional compliance to the Montreal Protocol and climate action pledges made in the Paris Agreement. Future sites of interest include Brazil, India, and Germany.

Read more about the research: www.bit.ly/agage-cfc

Left: Derek Cunnold, Hillel Magid (local Barbados Station technician), Ronald Prinn, and Fred Alyea during a site visit to the early flagged Point, Barbados station. Right: Chief Scientist Jimmy Gasore PhD ’17 gives a tour of the Rwandan Climate Observatory to scientists from East Africa and the European Union. This new AGAGE site on Mt. Musanze is a collaboration between the government of Rwanda and MIT, staffed by Rwandan researchers.
To help communities plan for weathering storms to come in a changing climate, EAPS scientists use novel methods to examine the behavior and impacts of hurricanes — from deep time to the present.

**By Kate A. Petrich** | EAPS NEWS

VIDEOS READY TO APPEAR online, one after another. Cellphone footage shot by people inside their homes, of flood water and waves crashing against the windows, of bent trees, pelted with uprooted street signs and mailboxes. The photographers pace while their homes fill with water, narrating as all the things that seemed unyielding and permanent give way.

On September 1, Hurricane Dorian struck the Bahamas as the most powerful storm to make landfall there in recorded history; joining the ranks of three other Atlantic hurricanes to have made landfall at full, devastating Category 5 strength in just the last two years, at a combined cost of over $200 billion in damage and thousands of lives. Unfortunately for those living on coasts and islands, storms of this magnitude—once a more rare occurrence—are likely to become more frequent. As a leading authority on the physics of tropical cyclones, Cecil and Ida Green Professor of Atmospheric Science and co-director of MIT’s Lorentz Center Kenny Emanuel puts it plainly: “Climate change, if unimpeded, will greatly increase the probability of extreme events.”

And yet, in the face of this threat, coastal communities continue to grow. In talks, Emanuel points to the fact that the global population exposed to hurricanes has tripled since 1970. More information about impending storms and the damage they are likely to inflict could greatly improve outcomes for residents living in these areas, and EAPS scientists are working on novel research that will allow us in the future to more effectively predict the behavior of hurricanes and help affected communities build more resilient coastal infrastructure.

“[O]ur primary goal is to better understand the processes that dictate how the ocean and the atmosphere interact within hurricanes, and hopefully be able to use that understanding to improve hurricane intensity forecasts,” explains Casey Densmore, a master’s student in the MIT-WHOI Joint Program. According to Densmore, warm ocean waters intensify hurricanes, powered by the extra heat. However, escalating storm winds on the ocean’s surface can cause large scale water mixing, which cools the surface water and causes the storm to weaken.

If forecasters had a better understanding of this feedback loop, they could use ocean temperature data in the path of a hurricane to more effectively predict storm intensity over time, especially as it makes landfall. But to build more accurate predictive models, researchers need to first observe large scale changes in ocean temperatures in real time.

Densmore and his research team are helping to fill this data gap, having flown several missions into Hurricane Dorian aboard airplanes operated by the US Air Force 53rd Weather Reconnaissance Squadron (better known as the Hurricane Hunters) and deploying airborne expendable bathythermograph (AXBT) buoys, which sink when they hit the ocean and transmit information about the temperature profile of the entire water column.

Recent MIT-WHOI Joint Program graduate Katie Castagno, PhD ’19 is also a hurricane hunter, but the storms she pursues ended hundreds, maybe even thousands of years ago. While not apparent, evidence of these ancient storms can be found at the bottoms of coastal marshes and ponds.

Her strange vessel glides across the surface of a shallow coastal pond. Like some sort of technol-ogy from the movie Waterworld, it consists of ca-noes lashed to plywood. On top, a tripod supports a vertical, aluminum tube attached to a repur-posed cement mixer engine. After finding the right spot, Castagno initializes the engine, and the tube works its way down into the sediment.

The sediment core she extracts contains a secret history: a 2,000-year timeline of heterogeneous layers of deposition. Some represent organic detritus from the pond; others signify major storm events, times when blowing wind and water transported sand from nearby beaches.

While dating each layer of sediment, Castagno’s research team discovered something odd: layers, representing hundreds of years, were missing from some of the cores. She suspects that these missing layers represent times that the marsh or pond was damaged by erosion, which is problematic. Coastal ponds and marshes protect inland areas from hurricane damage, and modern storms can deposit additional sediment, making them even more resilient. However, as Castagno explains, “there may be a suite of conditions such as: one huge storm [or] several storms ... that could cause this destruction, particularly as today’s marshes are often increasingly degraded.”

Evaluating and mitigating this type of erosion lies at the heart of Rose Palermo’s research. Clicking through a few decades’ worth of satellite images reveals that Barnegat Bay Peninsula, Long Beach Island, and Siltuate, barrier islands located along the northeastern coast of the United States, are slowly washing away. “Barrier island erosion is a problem because there are communities that depend on them for their housing and livelihood … They also protect the mainland coast from waves and storms, and losing that barrier would put the mainland at higher risk of erosion and flooding,” explains Palermo. Sea level rise driven by global climate change accelerates erosion, as do certain coastline development practices—something local residents can more easily control.

Palermo, who is also a graduate student in the MIT-WHOI Joint Program, works with a multidisci-plinary team of economists, statisticians, oceanogra-phers, and sediment transport experts to model outcomes of different shoreline interventions. Their model balances intervention costs against the benefits, and forecasts changes in the stability of barrier islands. They also protect the mainland coast from waves and storms, and losing that barrier would put the mainland at higher risk of erosion and flooding.”

Eyes on the Storm

To mitigate the hazards these storms present, the scientists’ work to understand the processes that drive hurricane behavior is vital to informed deci-sionmaking for communities and policymakers—on everything from emergency preparedness and evacuation plans to sustainable engineering and urban development—pursuing the ultimate goal to protect economies, ecosystems, and human life.

Read more about the research: www.bit.ly/eyes-storm

One option she has evaluated, called “nourishing,” adds sand at intervals meant to keep pace with shoreline erosion. While this is a money- and resource-intensive strategy, Palermo’s model shows that certain beach nourishment regimes pay for themselves over time. “Our influence on the stability of barrier islands is dramatic, both through development on the coast and the modifications we make through beach manage-ment projects,” comments Palermo.

In records tracked since 1971, each year on average tropical cyclones wreak $700 billion in damage worldwide, and have overall claimed almost half a million lives. And while these storms have all passed, researchers like Emanuel, Castagno, Densmore, and Palermo know another deadly storm is not far off. With rising atmospheric and ocean temperatures predicted to make future tem-pons more frequent and intense, rising sea levels will only compound the danger with potential for unprecedented storm surge and coastal flooding. To mitigate the hazards these storms present, the scientists’ work to understand the processes that drive hurricane behavior is vital to informed decision-making for communities and policymakers—on everything from emergency preparedness and evacuation plans to sustainable engineering and urban development—pursuing the ultimate goal to protect economies, ecosystems, and human life.

Read more about the research: www.bit.ly/eyes-storm

By Kate A. Petrich | EAPS NEWS
A tropical trigger for ice?

Over the last 540 million years, the Earth has witnessed three major ice ages—periods during which global temperatures plummeted, producing extensive ice sheets and glaciers that have stretched beyond the polar caps.

Now scientists at MIT, the University of California at Santa Barbara, and the University of California at Berkeley have identified the likely trigger for these ice ages. In a study published in Science, the team reports that each of the last three major ice ages were preceded by tropical “arc-continent collisions”–tectonic pileups that occurred near the equator, in which oceanic plates rode up over continental plates, exposing tens of thousands of kilometers of oceanic rock to a tropical environment.

The scientists say that the heat and humidity of the tropics likely triggered a chemical reaction between the rocks and the atmosphere. Specifically, the rock’s calcium and magnesium reacted with atmospheric carbon dioxide, pulling the gas out of the atmosphere and permanently sequestering it in the form of carbonates such as limestone. Over time, the researchers say, this weathering process, occurring over millions of square kilometers, could pull enough carbon dioxide out of the atmosphere to cool temperatures globally and ultimately set off an ice age.

“We think that arc-continent collisions at low latitudes are the trigger for global cooling,” says Oliver Jagoutz, an associate professor in MIT’s Department of Earth, Atmospheric, and Planetary Sciences. “This could occur over 1-5 million square kilometers, which sounds like a lot. But in reality, it’s a very thin strip of Earth, sitting in the right location, that can change the global climate.”

A trigge in the tropics

When an oceanic plate pushes up against a continental plate, the collision typically creates a mountain range of newly exposed rock. The fault zone along which the oceanic and continental plates collide is called a “suture.” Today, certain mountain ranges such as the Himalayas contain sutures that have migrated from their original collision points, as continents have shifted over millennia.

In 2016, Jagoutz and his colleagues retraced the movements of two sutures that today make up the Himalayas. They found that both sutures stemmed from the same tectonic migration. Eighty million years ago, as the supercontinent known as Gondwana moved north, part of the landmass was crushed against Eurasia, exposing a long line of oceanic rock and creating the first suture; 50 million years ago, another collision between the supercontinents created a second suture.

The researchers looked to see whether ice ages even further back in Earth’s history were associated with similar arc-continent collisions in the tropics. They performed an extensive literature search to compile the locations of all the major suture zones on Earth today, and then used a computer simulation of plate tectonics to reconstruct the movement of these suture zones, back through time. In this way, they were able to pinpoint approximately where and when each suture originally formed, and how long each suture stretched.

“We showed that this process can start and end glaciation,” Jagoutz says. “Then we wondered, how often does that work? If our hypothesis is correct, we should find that for every time there’s a cooling event, there are a lot of sutures in the tropics.”

Exposing Earth’s sutures

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They identified three periods over the last 540 million years in which major sutures, of about 10,000 kilometers in length, were formed in the tropics. Each of these periods coincided with each of three major, well-known ice ages, in the Late Ordovician (455 to 440 million years ago), the Perm-Carboniferous (353 to 280 million years ago), and the Cenozoic (35 million years ago to present day). Importantly, they found there were no ice ages or glaciation events during periods when major suture zones formed outside of the tropics.

“We found that every time there was a peak in the suture zone in the tropics, there was a glaciation event,” Jagoutz says. “So every time you get, say, 10,000 kilometers of sutures in the tropics, you get an ice age.”

He notes that a major suture zone, spanning about 10,000 kilometers, is still active today in Indonesia, and is possibly responsible for the Earth’s current glacial period and the appearance of extensive ice sheets at the poles.

This tropical zone includes some of the largest ophiolite bodies in the world and is currently one of the most efficient regions on Earth for absorbing and sequestering carbon dioxide. As global temperatures are climbing as a result of human-derived carbon dioxide, some scientists have proposed grinding up vast quantities of ophiolites and spreading the minerals throughout the equatorial belt, in an effort to speed up this natural cooling process.

But Jagoutz says the act of grinding up and transporting these materials could produce additional, unintended carbon emissions. And it’s unclear whether such measures could make any significant impact within our lifetimes.

“It’s a challenge to make this process work on human timescales,” Jagoutz says. “The Earth does this in a slow, geological process that has nothing to do with what we do to the Earth today. And it will neither harm us, nor save us.”

However, Lee Kump, dean of the College of Earth and Mineral Sciences at Penn State University, sees at least one silver lining for this slow, natural sequestration process in the Earth’s future: “Emissions of carbon dioxide from human activity today rival the most massive volcanic episodes in Earth history, far exceeding the capacity of rock weathering feedbacks to counter the buildup,” says Kump, who was not involved in the research. “However, as anthropogenic carbon emissions wane, natural restoration processes like these will begin the multimillennial repair job of restoring atmospheric carbon dioxide to pre-Anthropocene levels.”

Read more about the research: www.brit.tsu.tropical-trigger

Over the last 540 million years, as the Earth’s tectonic plates have shifted, MIT researchers have found that periods of major tectonic activity (orange lines) in the tropics (green belt) were likely triggers for the ice ages coinciding with those same periods.

Figures courtesy the researchers.
For collecting weather data, these tiny satellites measure up to their billion-dollar cousins.  

**BIG STORMS ARE GETTING BIGGER.** But now, some researchers from MIT are saying that the best way to study and understand these monster storms may just be to make the satellites that track them... smaller.

Kent Cahoy, associate professor in MIT’s departments of Aeronautics and Astronautics (AeroAstro) and Earth, Atmospheric and Planetary Sciences (EAPS), recently worked on a study with AeroAstro PhD candidate Angela Crews and researchers from MIT Lincoln Laboratory comparing weather data collected by a low-cost satellite about the size of a shoebox with data from a traditional weather satellite.

“The bottom line is that this tiny satellite collected data that is as good as the data from a billion-dollar government satellite,” says Crews, the study’s lead author.

The diminutive CubeSats, as they are known, have a number of advantages over larger cousins like the NOAA-20 satellite, starting with weight: MicroMAS-2A weighs in at less than 4 kilograms vs. the NOAA-20’s much beefier 2,300 kg. Big satellites also need their own dedicated launch vehicle, while CubeSats can swoop away as secondary payloads. They have a speed advantage, too. NOAA-20 experiences perhaps 44 intrusions over the course of a year, MicroMAS-2A experiences ~5,700. Instead of discarding the data or correcting for it, they plan to use the intrusions as a calibration source due to their frequency.

The researchers say they are just scratching the surface of the what CubeSats can do, and that in the coming years they could have groundbreaking advancements in commerce, shipping, and military applications.

“CubeSats will continue to let us test new and better technologies—new chips, new electronics, new sensors—faster because we can get on orbit more quickly to see how they work, and do a better job of designing these instruments, cost everyone less money and get us more data,” says Cahoy.

Abridged and adapted from the original: www.bit.ly/weather-view

**DEPLOYED AIR QUALITY** can be a major bonus of climate mitigation policies aimed at reducing greenhouse gas emissions. By cutting air pollution levels in the country where emissions are produced, such policies can avoid significant numbers of premature deaths. But other nations downwind from the host country may also benefit.

A new study co-led by Noelie Eckley Selin, associate professor in MIT’s Institute for Data, Systems, and Society and the Department of Earth, Atmospheric and Planetary Sciences (EAPS), shows that if the world’s top emitter of greenhouse gas emissions, China, fulfills its climate pledge to peak carbon dioxide emissions in 2030, the positive effects would extend all the way to the United States, where improved air quality would result in nearly 2,000 fewer premature deaths.

The study estimates China’s climate policy, air quality, and health co-benefits resulting from reduced atmospheric concentrations of ozone, as well as co-benefits from reduced ozone and particulate air pollution (PM2.5) in three downwind and populous countries: South Korea, Japan and the U.S. as ozone and PM2.5 give a well-rounded picture of air quality and can be transported over long distances, accounting for both pollutants enables a more accurate projection of associated health co-benefits in the country of origin and those downwind.

Using a modeling framework that couples an energy-economic model with an atmospher- ic chemistry model, and assuming a climate policy consistent with China’s pledge to peak CO2 emissions in 2030, the researchers found that atmospheric ozone concentrations in China would fall by 1.6 parts per billion in 2030 compared to a no-policy scenario, and thus avoid 5,100 premature deaths—nearly 60% of those resulting from PM2.5. Total avoided premature deaths in South Korea and Japan are 1,200 and 3,500, respectively, primarily due to PM2.5; for the U.S. total, 1,900, ozone is the main contributor due to its longer lifetime in the atmosphere.

Total avoided deaths in these countries amount to about four percent of those in China. The researchers also found that a more stringent climate policy would lead to even more avoid- ed premature deaths in the three downwind countries as well as in China.

The study breaks new ground in showing that co-benefits of climate policy from reducing ozone-related premature deaths in China are comparable to those from PM2.5, and that co-benefits from reduced ozone and PM2.5 lev- els are not insignificant beyond China’s borders.

“The results show that climate policy in China can influence air quality even as far away as the U.S.,” says Selin. “This shows that policy ac- tion on climate is indeed in everyone’s interest, in the near term as well as in the longer term.”

The other co-leader of the study is Valerie Karplus, the Assistant Professor of Global Econ- omics and Management in MIT’s Sloan School of Management. Both co-leaders are faculty af- filiates of the MIT Joint Program on the Science and Policy of Global Change. Their co-authors include former EAPS graduate student and lead author Mingwei Li PhD ’19, former Joint Pro- gram research scientist Da Zhang and former MIT postdoc Chiao-Ting Li.

Read more about the research: www.bit.ly/policy-across-pacific

**A NEW VIEW ON WEATHER**

It was operational in space, whereas CubeSats can be built and deployed in just a year or two.

“You can build them faster, which means you can put new technology on quicker instead of waiting 10 years for new technology infusion on a government program,” Cahoy says.

Yet the most important thing isn’t necessarily what CubeSats can do alone; it’s what multiple CubeSats can accomplish in concert. Oxygen and water vapor naturally emit signals in the microwave portion of the electromagnetic spectrum; when those sig- nals are measured at different heights by multiple satellites in a low-earth orbit constellation, they have the combined power of the instruments on a larger satellite, and can be fed into weather models for enhanced modeling and forecasting of hurricanes, tropical storms, and thunderstorms, including 3-D reconstruction.

“A constellation of CubeSats lets you get data over the same spot multiple times on the same day, which is not possible with the standard government weather satellites right now, which maybe give you data over the same spot once a week,” Cahoy says. “If you’re tracking a tropical storm or a hurricane and you want to use data to update your forecasting models, that’s not as good as you would like it.”

**IMPROVED WEATHER DATA** can be a major climate-related benefit of the CubeSats project, according to Kerri Cahoy, associate professor in the Departments of Earth, Atmospheric and Planetary Sciences (EAPS) and Aeronautics and Astronautics (AeroAstro). Cahoy and her research team recently won a NASA grant to conduct another year of CubeSat measurements, which are expected to increase the number of CubeSat measurements by 50 percent in 2018.

The researchers are also working on a project to deploy CubeSats in space to collect data on the Earth’s climate, with the goal of improving weather forecasting models. The CubeSats will use a new technology called the TROPICS instrument, which can provide real-time data on cloud patterns and precipitation.

The CubeSats will continue to use test new and better technologies—new chips, new electronics, new sensors—faster because they can get on orbit more quickly to see how they work, and do a better job of designing these instruments, cost everyone less money and get us more data,” says Cahoy.

Abridged and adapted from the original: www.bit.ly/weather-view

The researchers are also saying that the best way to study and understand these monster storms may just be to make the satellites that track them... smaller.
Hacking The Climate Conundrum

EAPS scientists engage in out-of-the-box thinking to tackle some of the most pressing questions surrounding global change and long-term sustainability.

From the same hackathon, the proposal “One Small Step” by EAPS students Deepa Rao and Craig McLean with others, took bronze. They developed a survey to help make individuals aware of their carbon footprint, contextualize their lifestyle choices to available options, and provide actionable information to encourage more sustainable living. By synthesizing available data on state-level economic sectors with the corresponding carbon footprint, people could calculate their footprint and see other locally available, lower carbon options. The goal was to make data more personally meaningful and bring awareness of state and national policies impacting choices.

Last year, MIT also hosted Climate Changed, an event co-sponsored by the MIT Environmental Solutions Initiative (ESI) and the MIT School of Architecture and Planning—with award funding from the Leonardo DiCaprio Foundation—which explored the agency of models in the future for the built environment. The symposium and exhibition included the Climate Modeling Alliance (CliMA), a partnership between EAPS and other MIT students taking top places. The idea that snatched gold, which came from EAPS’ Joleen Heiderich, Jakub Jakobski, Sam Levang, Sebastian Essink, and others, was an app that would use machine learning to generate climate-change-related mortality risk-assessments for different areas of the world and at different times, based on available climate data.

Climate change represents a global problem, and the only way that we can really address it is to partner with as many organizations and people as we can,” said Zuber at MIT’s inaugural Climate Night event in April.

Hackathons in Curators of Ideas

One way to help break researchers out of silos and provide novel solutions to problems is through ad hoc interdisciplinary collaborations and competitions. MIT’s EarthHack 2019 is just one example, where roughly 30 innovators from multiple academic institutions grouped into impromptu teams and spent a 12-hour period through ad hoc interdisciplinary collaborations and competitions. MIT’s EarthHack 2019 is just one example, where roughly 30 innovators from multiple academic institutions grouped into impromptu teams and spent a 12-hour period brainstorming global climate change solutions—with EAPS and other MIT students taking top places. The idea that snatched gold, which came from EAPS’ Joleen Heiderich, Jakub Jakobski, Sam Levang, Sebastian Essink, and others, was an app that would use machine learning to generate climate-change-related mortality risk-assessments for different areas of the world and at different times, based on available climate data.

CLIMATE CHANGE IS NO ORDINARY PROBLEM

As global temperatures soar, harm to societies and natural systems increases with the potential for irreversible damage, so addressing it will require multi-pronged approaches, anchored by the work of climate and geoscience experts. MIT Vice President for Research and E.A. Griswold Professor of Geophysics Maria Zuber, who helped to launch MIT’s Climate Action Plan, realizes the need for more aggressive but pragmatic transition to a zero-carbon society with input from an engaged cohort of industry, government, academic foundations, philanthropists, and the public.

"Climate change represents a global problem, and the only way that we can really address it is to partner with as many organizations and people as we can," said Zuber at MIT’s inaugural Climate Night event in April.

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CAUE BORLINA

During my PhD research in the Weiss Paleomagnetism Lab, I have been working to understand what magnetism can tell us about the evolution of stars, formation and evolution of planets, and conditions for the emergence of life. I focus on the magnetism recorded in micrometer-sized rock inclusions.

Magnets are everywhere. Our very own Earth is a massive one that produces a large-scale magnetic field detectable at the surface of our planet; its time origin, however, is unknown. Magnetic fields produced by planets can help shield their atmosphere from solar winds and radiation. This has immediate consequences for habitability conditions relevant, for example, for the early Earth. Understanding the timing of Earth's magnetic field can help constrain the conditions during which life emerged. Because very little of the rock record from the first billion years of the Earth is available, we have to use what we can—in this case, micrometer-sized minerals four billion years old—known to be the only survivors of these early years. The magnetic fields from these minerals can only be measured with a few magnetometers, like the one in our lab.

Another of my projects examines how our solar system formed through the lens of magnetic fields; magnetic fields are thought to be the key for the formation of planetary systems. Measuring ancient magnetic fields that were recorded in very small inclusions located in some meteorites is helping us to understand this relationship.

I plan on pursuing this line of research further as a career, studying the connection between planetary formation, habitability, and magnetism.

MARJORIE CANTINE

What was the Earth like during the evolution of the first animals? My research in the Bergmann Lab to answer this question helps us understand how and why animals evolved on Earth. It may also help elucidate what conditions could lead to the emergence of complex life elsewhere in the universe.

I focus on Earth’s surface environments about 550 million years ago. At this time, early animals lived in the oceans. The sedimentary rocks deposited in these ancient seas—like limestone, sandstones, and shales—record both physical and chemical information about the environments in which they formed. The global carbon cycle, erosion and weathering, and climate all had a role to play in shaping early animal habitats—and the rocks I study record evidence of these forces. I use field and laboratory techniques to test hypotheses about their role in shaping animal habitats. I also use radioactive isotopes within my samples to date events in the rock record. These dates are useful for understanding the relationship between animal evolution and other key changes in erosion and perturbations in the carbon cycle.

My efforts to understand the world of early animals has taken me to five continents, eight countries, the Arctic Circle, and many collaborators’ labs. Unraveling this exciting story has required aerial drones and state-of-the-art mass spectrometers, as well as hiking boots and battered field notebooks, and I’m looking forward to where the adventure takes me next.

JAMES HALL

When most people think of fossils, they imagine the lithified bones of an ancient organism in a museum display. However, the fossils that I study from around Death Valley are drastically different; they are casts and molds of soft-bodied organisms, with no modern analog, which existed near the end of the Precambrian Era, about 542 million years ago. Soft-bodied preservation is rare within the fossil record, but is prevalent in this time period globally.

My work in taphonomy, the study of fossilization, is centered around understanding the biogeochemical processes controlling the preservation of these soft-bodied organisms. Specifically, I am interested in the interactions between microbes—which can act to both decay the organism and produce minerals which help preserve it—and clay minerals, which can shield soft tissue from microbial decay. What makes these fossils especially interesting is how well the structure of the organism is retained, even with a low abundance of replaceable minerals produced by microbial processes. Scientists have proposed many hypotheses, such as the presence of microbial mats, to explain how this fossilization process occurs; however, experiments using soft-bodied marine organisms to elucidate the processes are lacking.

State-of-the-art global climate models (GCMs) disagree on how tropical rainfall will change with climate change, especially the pattern of changes. Consequently, we look to simpler models as tools for understanding the underlying mechanisms.

Studying with Paul O’Gorman, my dissertation is focused on the dynamics of precipitation in the tropics. As the addition of greenhouse gases warms the atmosphere, the amount of water vapor (specific humidity) in the air increases. What effect does this additional water vapor have on rainfall over tropical oceans? Does rainfall over tropical oceans go up at the same rate as water vapor? Previous authors used simple models to learn that, on average, tropical rainfall does not increase as much as water vapor because the large-scale circulation of the atmosphere changes, too. The combined effects of changes in water vapor and the changes in the circulation contribute to complicated changes in rainfall which are very hard for state-of-the-art climate models (GCMs) to simulate.

Through the use of simple models, we are learning that the circulation changes are important for the pattern of rainfall changes over tropical oceans, but a source of disagreement in GCMs. Further, we are learning that these circulation changes are largely tied to horizontal gradients in temperature at lower levels of the tropical atmosphere. This work is very exciting because it contributes to understanding the complicated and nuanced ways that the climate responds to greenhouse gases, and why climate models sometimes disagree on aspects of these responses.
Today, ECCO stands as the foundational framework says. “That’s what ECCO has been. From all corners of the globe, researchers and governmental bodies to exchange taking, including an international network of re-

in 2009. It was a massive under-

and thus its role in climate, Wunsch wrote for

Department of Earth, Atmospheric and Planetary

emeritus of physical oceanography in MIT’s

Nearly 20 years ago, Carl Wunsch, professor

bigger picture.

Still, the resulting new datasets often existed

made continuous, mass measurements possible.

understanding how the ocean behaved required

of an error estimate on all scales, is “an unglam-

odology, including at least some approximation

ing of the accuracies and precisions of this meth-

hemispheric survey on schedule to take advantage of

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more detailed reviews of the planetary targets
discovered by the project.

“We are delighted to have supported the new Artemis telescope. It was very exciting to see it in action in Tenerife and to meet the international SPECULOOS team,” said Colin Masson after the inauguration, “We are looking forward to hearing about their future discoveries!”

The researchers hope to continue to build out the SPECULOOS Northern Observatory. Currently, there is an additional platform ready to host a twin telescope to Artemis, and the project has reserved space to accommodate a total of four telescopes at Teide. A fully-operational SNO will allow them to complete the Northern Hemis-

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“We with SPECULOOS’ de Wit says, “we are giving

it our best shot at enabling the identification of

habitats beyond Earth within the next decade.”

Read more about the research: www.bit.ly/artemis-inauguration

HUNTING RED WORLDS IN NORTHERN SKIES

Introducing Artemis, MIT’s newest exoplanet-hunting telescope in the SPECULOOS network at Mount Teide in the Canary Islands.

WITH A NEW TELESCOPE situated high on a plateau in Tenerife, Spain, MIT planetary scientists now have an additional way to search for Earth-sized exoplanets. Artemis, the first telescope of the SPECULOOS Northern Observatory (SNO) was completed at the Mount Teide Observatory, operated by the Instituto de Astrofísica de Canarias (IAC) in June 2019. It joins a network of one meter robotic telescopes as part of the SPECULOOS project (Search for habitable Planets Eclipsing Ultra-Cool Stars), which looks for terrestrial planets orbiting very faint, ultra-cool dwarf stars. The other four network telescopes that make up the SPECULOOS Southern Observatory (SOS) are already scanning the Southern Hemisphere skies at the Paranal Observatory in Chile.

SPECULOOS is led by Michael Gillon at the University of Liège in Belgium with partnership with MIT and several other institutions and financial supporters. Julien de Wit, assistant professor in MIT’s Department of Earth, Atmospheric and Planetary Sciences (EAPS) and a SPECULOOS collaborator, spearheaded the project’s expansion with Artemis. He assumes the role of Artemis principal investigator and SNO co-principal investigator with Gillon. Picking up near-infrared wavelengths, Artemis will gather pictures of a section of the sky each night, focused on target stars in order to catch the drop in brightness characteristic of a planetary transit. The researchers will examine the roughly 800 nearest ultra-cool dwarf stars visible in the Northern Hemisphere to find more planets that may have a temperate climate and be suitable for in-depth characterization of their atmospheres and molecular composition with the next generation of observatories, like NASA’s James Webb Space Telescope (JWST) and the European Space Agency’s Extremely Large Telescope (ELT).

The researchers hope to identify about 15 temperate planets with the SPECULOOS network in time for their atmospheres to be studied with the JWST, which is expected to launch in 2021.

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discovered by the project.
EAPS and MIT celebrate the birthday of M. Nafi Toksöz, whose work in seismology and imaging launched the influential Earth Resources Laboratory and inspired a new generation of scientists.

“This Part May” geophysics alumni Dan Burns PhD ’87, Chuck Peng PhD ’94, Ken Tubman PhD ’84, Mary Willis PhD ’83, and Jie Zhang PhD ’97 joined forces to help reunite over 60 alumni, current and emeritus faculty, and friends to celebrate the 85th birthday of beloved Emeritus Professor Nafi Toksöz. In their former college town, guests reconnected, sharing heartfelt and funny stories about their advisor and his unfailing support and generosity. Many alumni credited their career successes to their years in MIT’s Earth Resources Laboratory (ERL), which Toksöz founded in 1982 and led until 1998. Toksöz’s achievements in ERL include seismic exploration for hydrocarbons, full-sonic logging, rock physics, vertical seismic profiles, seismo-electric, and seismological applications for the Apollo program.

“ERL was like a big family with Nafi at the head”, said Burns who acted as MC, inviting attendees to recount their favorite memories of their advisor. “ERL was a place where you can say anything and everybody would listen,” said Burns. 

“As the evening concluded, Tubman thanked all for coming and encouraged his peers to show their appreciation for Toksöz by making a gift to the M. Nafi Toksöz Fellowship Fund. ‘Let’s double the Toksöz Fund so that it will support a graduate student for a full academic year!’” If you’d like to help, please consider making a gift by visiting www.bit.ly/erl-giving—or contact Angela Ellis at aelisi@mit.edu. There is also a new Nafi and Helena Toksöz Fund for Baker House.

The Space was originally dedicated as a departmental gathering space. The student-initiated project, made possible by generous alumni donations, transformed the space into a bright, cramped space into a bright, multi-purpose common space where members of ERL can interact socially and academically.

“When this project was first proposed. It aligned beautifully with some of the things that I personally really want for the department, which is to create more space—higher quality space—for students,” said Robert van der Hilst, EAPS Department Head and Schlumberger Professor of Earth and Planetary Sciences. From securing funding to completion of construction, the renovation was nearly a year in the making. A wall was knocked down to increase square footage and add much-needed light. Flexible furniture configurations were also added to help foster community interactions.

“The purpose of this place is for everyone to feel like they have a place to interact with colleagues, meet with speakers, host community events, or have small group meetings,” said EAPS Associate Professor Paul O’Gorman, who led the library project committee. “The door is always open.”

About Jule Charney

Late MIT Professor Jule Charney is remembered as a man who brought people together through a combination of wisdom, optimism, and charm. Now, the building where his groundbreaking work on modern dynamical meteorology took place has a dedicated space worthy of such a reputation.

Recently MIT Department of Earth, Atmospheric and Planetary Sciences (EAPS) faculty and students unveiled a renovated Charney Library on the 14th floor of the Green Building, right across the hall from the famed professor’s former office.

The student-initiated project, made possible by generous alumni donations, transformed the space into a bright, cramped space into a bright, multi-purpose common space where members of ERL can interact socially and academically.

“When this project was first proposed. It aligned beautifully with some of the things that I personally really want for the department, which is to create more space—higher quality space—for students,” said Robert van der Hilst, EAPS Department Head and Schlumberger Professor of Earth and Planetary Sciences. From securing funding to completion of construction, the renovation was nearly a year in the making. A wall was knocked down to increase square footage and add much-needed light. Flexible furniture configurations were also added to help foster community interactions.

“The purpose of this place is for everyone to feel like they have a place to interact with colleagues, meet with speakers, host community events, or have small group meetings,” said EAPS Associate Professor Paul O’Gorman, who led the library project committee. “The door is always open.”

At the event, O’Gorman thanked members of the Charney Library Project committee who contributed to the efforts, including Assistant Professor Andrew Babbin, Darius Collozo, Angela Ellis, Michael Richard, Scott Wade, and graduate students Ruhini Shivamoggi and Rose Palermo. Shivamoggi spearheaded the renovation project after hearing feedback about the lack of meeting spaces for students at the 2017 EAPS Program in Atmospheres, Oceans and Climate (POAC) retreat. Shortly after, she wrote a proposal for funding and recruited Palermo to help design a space best suited to the community’s needs.

The renovations went beyond cosmetic upgrades to include a new selection of contemporary textbooks—particularly important for MIT-WHOI Joint Program students who commute between Woods Hole and Cambridge. This effort took the expertise of MIT librarian Christine Sherratt, who also helped sort old books—many of which belonged to Charney himself.

The space was originally dedicated as a departmental library in 1983 in honor of Charney. During the rededication, Carl Wunsch, EAPS professor emeritus of physical oceanography, described how previously Charney had used the area as his personal library during his tenure from 1956 until his death in 1981, pointing out, “It’s very useful for people to know that this really was the scientific home for the Atmospheric and Ocean Dynamics Project.”

Read more about the legacy of Jule Charney’s contributions to science and MIT: www.bit.ly/charney-library-renewal

Special thanks to the following alumni for their kind support, with special gratitude to Dr. J. Shukla and Dr. Rich Bolduc for their matching donations:

Richard R. Babcock, Jr. PhD ’78 (XIX), John R. Bates PhD ’10 (XIX), Mark A. Case PhD ’78 (XIX), Richard C. DeWeaver 103 (XIX), Michael R. Had 123, Gerald Herman SCD ’79 (XIX), L. Scott Allenbach 89 (XVII), SM ’92 (XVII), Richard D. Rosen ’69 (XVIII) PhD ’74 (XIX), Jagadeesh Shukla 76 (XIX)
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* Jointly awarded through the MIT-WHOI joint Program
SUPPORT THE DEPARTMENT


The Department of Earth, Atmospheric, and Planetary Sciences (EAPS) is MIT’s hub for interdisciplinary research into the inaccessible depths of Earth, distant planets, and asteroids, turbulent oceans and atmospheres, and the origins of life.

We are training tomorrow’s scientific leaders. Our fundamental research seeks to understand all aspects of the natural world, leading us to a better understanding of today’s unprecedented global challenges—like climate change, pollution of our air and waters, escalating risks from hurricanes, earthquakes, landslides, rising seas, and threatened natural resources.

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Thank you for your continuing support for EAPS and MIT.
Looking south from Langjökull Ice Cap, Central Iceland. This image was captured by Cecil and Ida Green Career Development Professor Brent Minchew during fieldwork deploying GPS stations to record fluctuations in ice flow velocity caused by seasonal melt of the glacier’s surface. Minchew and his current group of geophysicists, glaciologists, mechanicians, and geodesists seek to understand how glaciers evolve in response to climatic changes and how they, in turn, impact landform evolution and the global carbon cycle. Using interferometric synthetic aperture radar data and optical imagery, Minchew and his team innovate techniques and software to measure and create detailed maps of ice flow and mechanics, and develop dynamical models.

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