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Earth & Space Science News

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Art's Window to the Anthropocene

China's R&D Funding Growing

INNOVATIVE WAYS TO USE

DRONES

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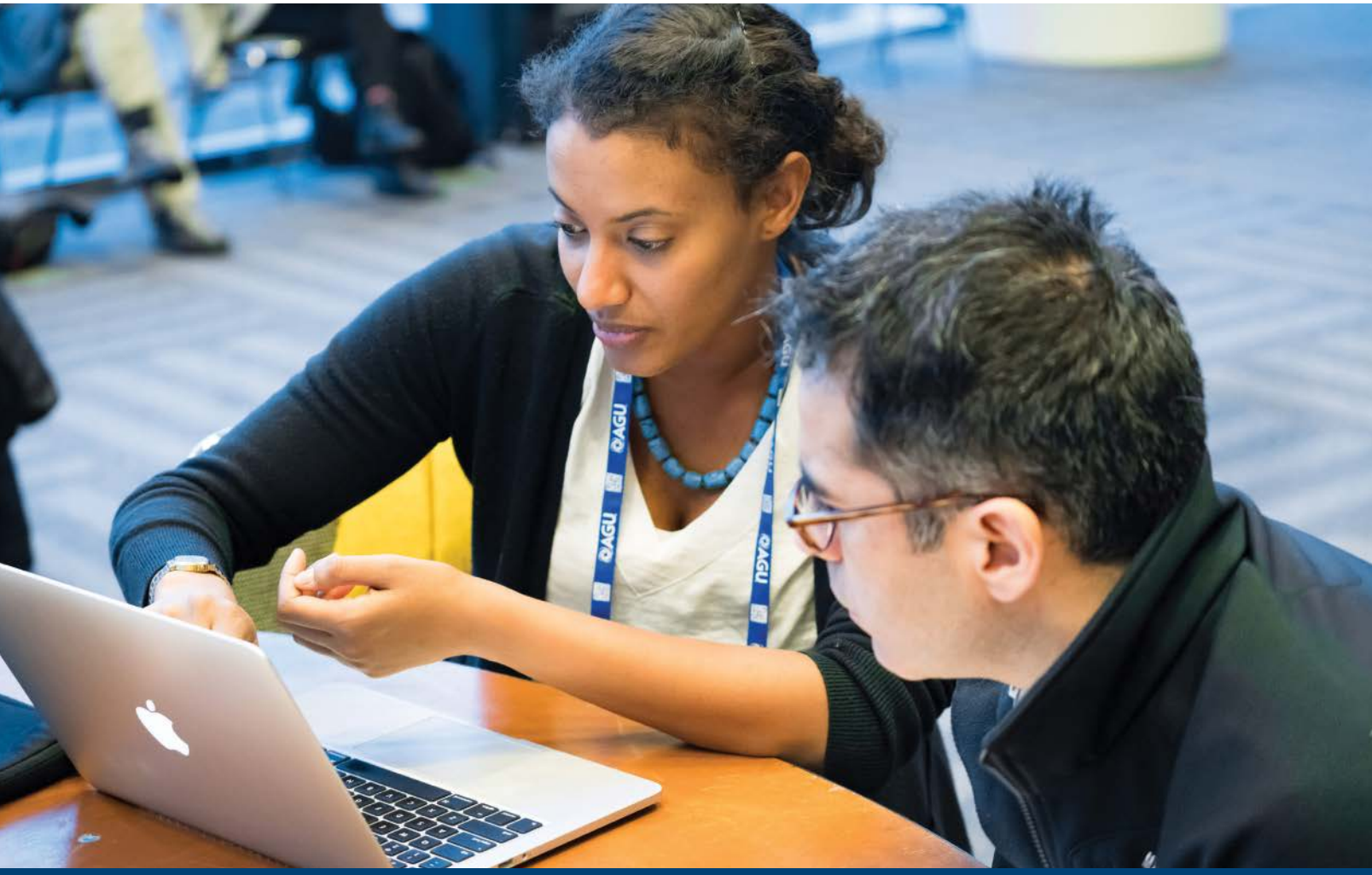
MENTORING365



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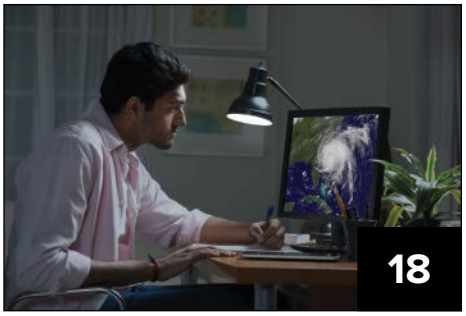

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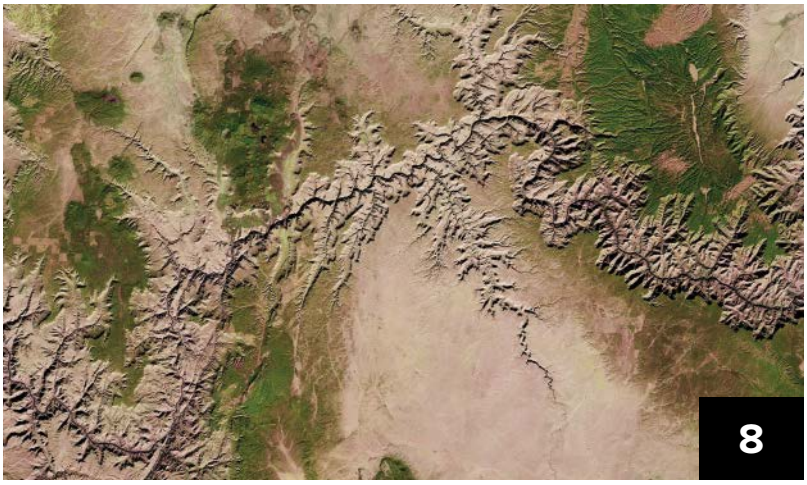

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Christine W. McEntee, Executive Director/CEO

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ADVANCING EARTH AND SPACE SCIENCE

China May Soon Surpass the United States in R&D Funding

Scientists at a satellite launch center in China's Gansu province monitor the docking of the Tiangong-1 space lab module and the Shenzhou VIII spacecraft in late 2011. If current trends continue, experts note that China will soon overtake the United States in funding levels allocated to research and development. Credit: STR/AFP/Getty Images

The U.S. National Science Board (NSB), which in January stated that China was catching up to the United States in research and development (R&D) expenditures, said in a 7 February statement that if current trends continue, it "expects China to pass the United States in R&D investments by the end of this year."

The 18 January report, *Science and Engineering Indicators 2018*, had been presented earlier to Congress by NSB, which develops the indicators, advises the president and Congress, and governs the U.S. National Science Foundation (http://bit.ly/2018-NSB). An NSB spokesperson told *Eos* that in the 6 years that the board has been conducting briefings of the biennial *Indicators* reports on Capitol Hill, "a key theme has been that China is catching up."

She continued, "Now we're at the point where next time NSB does the briefing, in 2 years, the board will be saying that China caught us. The board felt this is a significant development that is worthy of pointing out to Congress."

China's Reaction to the Report

China's rapid advance in R&D, as highlighted in the *Indicators* report, is only natural given the country's economic growth and the size of its population, according to Futao Chen, a senior science and technology official with the Chinese Embassy in Washington, D. C. However, although he welcomed China's growth, he said that its R&D expenditures are far less than the report states, and he downplayed China's leadership in R&D.

Chen, who is minister counselor for science and technology at the embassy, also said that China welcomes more scientific cooperation with the United States. He added that the United States has nothing to worry about with regard to his country's growth if China is viewed as a partner rather than as a rival.

"I don't know how soon that will be, but it seems likely in the future we will be able to [overtake] the United States in terms of the overall input in research and development. But, for me, that's absolutely normal, nothing surprising," Chen told *Eos*. He said that it would be beneficial overall if the United States increased its own research budget and added that China's research expenditures likely will slow down as economic growth slows.

Differences in Measuring Growth

The congressionally mandated *Indicators* report shows that the United States still leads the world in gross domestic expenditures on R&D, spending $496.6 billion—2.7% of its gross domestic product (GDP)—in 2015, the most recent year available for many indicators. However, the same report shows that China's $408.8 billion (2.1% of its GDP) had then surpassed the European Union's $386 billion and that Chinese R&D soared by about 18% annually between 2000 and 2015, whereas U.S. expenditures rose about 4% annually.

Chen, who previously served as inspector in the Department of Basic Research with the Ministry of Science and Technology of the People's Republic of China, said that he agrees with the overall conclusions of the report. However, he said that China's growth in R&D expenditures is much smaller than stated in the report, which converted foreign currencies into U.S. dollars via purchasing power parity (PPP) exchange rates.

The NSB report outlines pros and cons of using PPP, noting that PPPs are the preferred international standard for calculating R&D comparisons between countries. However, "PPPs for large developing countries such as China and India are often rough approximations and have shortcomings," the NSB report states.

> Chen said that China's growth in research and development expenditures is much smaller than stated in the report.

Chen agreed, saying that PPPs are not the optimal way to compare expenditures of different countries that have, for example, different cultures and consuming habits. "If you use PPP, China's capability for research and development is overexaggerated," he said.

For example, when it comes to actual money spent, Chen noted that in 2017, China's R&D expenditure was 1.76 trillion yuan, or $278 billion. In 2015, its R&D spending was 1.42 trillion yuan, or $206.05 billion, according to data from China reported by Reuters. NSB's estimates of China's R&D spending, based on PPP, are nearly double what Reuters reports for the same year.

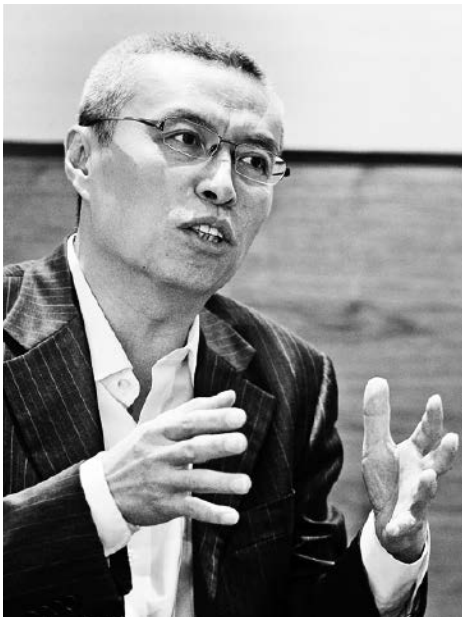
"Still Far from Becoming a Superpower"

The report shows that in education, China awarded 22% of the world's science and engineering (S&E) bachelor's degrees in 2014 compared with 10% in the United States. China awarded about 34,000 S&E doctoral degrees compared with about 40,000 in the United States.

In 2000, however, China awarded fewer than 10,000 of the world's S&E doctorates, whereas the United States awarded about 25,000. *Indicators* also shows that in 2016, China overtook the United States in the number of S&E articles published, with China publishing 18.6% of the world's total compared with 17.8% for the United States.

Chen downplayed China's number one spot in articles published, saying that the volume is there but that the quality of papers, judged by the number of citations, is still below the world average. Referring to China as a leader because of the number of publications is not accurate, he said.

"If there are tens of leaders, yes, we are one of them. But if there is only one leader, the United States is absolutely still the leader" in research output, Chen said. "I don't think it's fair to call China a superpower. We're growing fast, which is not bad, I think, but we are still far from becoming a superpower."

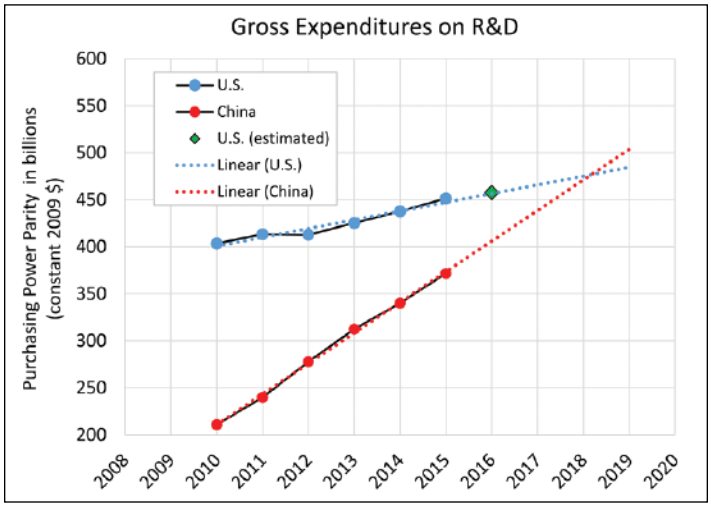


Futao Chen, minister counselor for science and technology at the Chinese Embassy in Washington, D. C. Credit: Futao Chen

Dealing with Climate Change

Chen also demurred about China stepping up to be a leader in climate change efforts, following the Trump administration's planned withdrawal from the Paris climate agreement.

"I don't think China has the intention to step in as a leader in that area, but we think that it is a major concern for the world," he told *Eos*. "China, as one of the major production countries in the world, we have our responsibility, and we have the willingness to devote more of our resources to solve the problem," he said.



In 2018, China will surpass the United States in research and development expenditures if current trends continue, according to the U.S. National Science Board (NSB). This graph, released on 7 February, is drawn from data in NSB's Science and Engineering Indicators 2018 *report and from the* National Patterns of R&D Resources, 2017 *report of the National Science Foundation's National Center for Science and Engineering Statistics. The graph was not included in the 18 January release of the 2018* Indicators *report. Credit:* Science and Engineering Indicators 2018

No Cause for Concern

Chen said that he doesn't understand why China's growth should be viewed as a concern by other countries. He mentioned, for instance, that a *Washington Post* article about the *Indicators* report cited the congressionally established U.S.-China Economic and Security Review Commission and its concerns about threats to the United States from China's growth. The commission's 2017 report to Congress, for example, noted the Chinese government's comprehensive approach to developing key dual-use technologies "to build national champions and advance its military capabilities."

However, Chen dismissed that concern as "the simple judgment that China's growth in research and development will definitely [translate] into military power growth and things like that."

He said that China's growth in R&D provides many reasons for China and the United States to cooperate scientifically, do more research together, and have more scientific and personal exchanges. Chen noted that the United States is currently China's largest partner in terms of scientific research and that the two countries are currently actively negotiating an extension for the China–U.S. Science and Technology Cooperation Agreement.

He also bristled at limitations imposed by Congress that prohibit the White House Office of Science and Technology Policy and NASA from coordinating joint scientific activities with China, saying that "scientists from different corners of the world should keep in close contact. That's the basis for scientific advancement."

> "If there are tens of leaders, yes, we are one of them. But if there is only one leader, the United States is absolutely still the leader."

"If you deem China as a partner who will be able to cooperate with you, there's nothing wrong, nothing to worry about," Chen said regarding China's growth in science and technology. "But certainly, if you make the prejudgment that China is a rival, then you may feel surprise or you may feel some unease."

By **Randy Showstack** (@RandyShowstack), Staff Writer

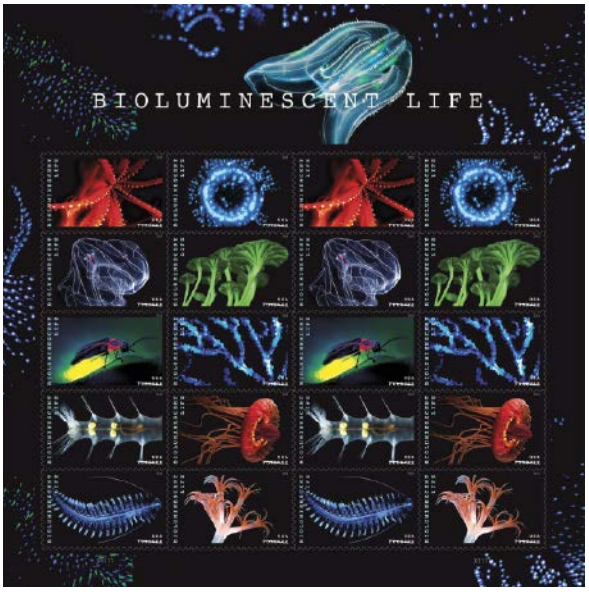
New Postage Stamps Focus on Bioluminescent Marine Life

The U.S. Postal Service has rolled out a glimmering collection of stamps showcasing bioluminescent life at a first-day-of-issue dedication ceremony in Fort Pierce, Fla. The pane of 20 stamps, released on 22 February, features 10 photographs of bioluminescent life, eight of which are marine creatures that can generate their own light.

The Forever stamps provide "a picture of our oceans that few people ever see," U.S. Postal Service spokesperson Mark Saunders told *Eos.* "We are hoping that by issuing these stamps it will open up a conversation for people to learn more" about bioluminescence and the oceans.

The collection includes photos of such marine creatures as a deep-ocean octopus, midwater jellyfish, bamboo coral, and marine worms, along with two examples of nonmarine bioluminescence: a mushroom and a firefly. The colorful images on the shimmering and highly reflective sheet of stamps "really pop out" when they are held to the light, Saunders said.

The postal service's Citizen's Stamp Advisory Committee, which annually receives about 40,000 suggestions for stamps, recommended the topic to the postmaster general as something that would resonate with the American public from a national perspective, according to Saunders. Other recent stamps have focused on U.S. national parks, the solar system, and the 2017 solar eclipse.



This full panel of bioluminescent stamps includes two full sets of eight marine and two terrestrial creatures that have the ability to light themselves up. Credit: 2018 USPS

A "Magical Phenomenon"

Deep-sea explorer Edith Widder, who took seven of the 10 photos featured in the collection, told *Eos* that she hopes the stamps can show people one of the natural wonders of the world.

"The thing most thrilling to me is the opportunity to make people aware of what I think is just absolutely the most spectacular, magical phenomenon on the planet that most people are completely unaware of. Stamps are such a great way to reach the public in ways that science so rarely gets the opportunity," said Widder, founder, CEO, and senior scientist of the Ocean Research and Conservation Association, a group based in Fort Pierce that works to protect and restore marine ecosystems.

The stamps also can provide a conservation message to people who see and use them, Widder said. "I want them to know how much extraordinary life there is in the ocean that we haven't even studied yet," she said. "The fact is, we are destroying a lot of the ocean before we even know what's in it."

The vast abundance of self-illuminating marine creatures at or below twilight depth indicates that bioluminescence "has got to be one of the most important processes in the ocean," Widder said. "If you drag a net through many regions of the world's oceans, 80%–90% of the animals in that net make light."

Widder said that organisms use a great amount of energy to create bioluminescence and that they appear to use it for multiple critical survival purposes, including attracting mates, finding food, and defending against predators.

She and another photographer featured in the stamp collection, Steven Haddock, also noted the potential that bioluminescent substances have for bioscience applications. For instance, the 2008 Nobel Prize in Chemistry went to researchers who used a green fluorescent protein first observed in the *Aequorea victoria* jellyfish as a tool for studying the spread of cancer cells and other biological processes.

*Newly issued U.S. postage stamps of 10 bioluminescent organisms include a stamp celebrating the crown jellyfish (*Atolla wyvillei*). Credit: 2018 USPS; Photo by Edith Widder*

Encouraging a Deeper Dive into the Topic

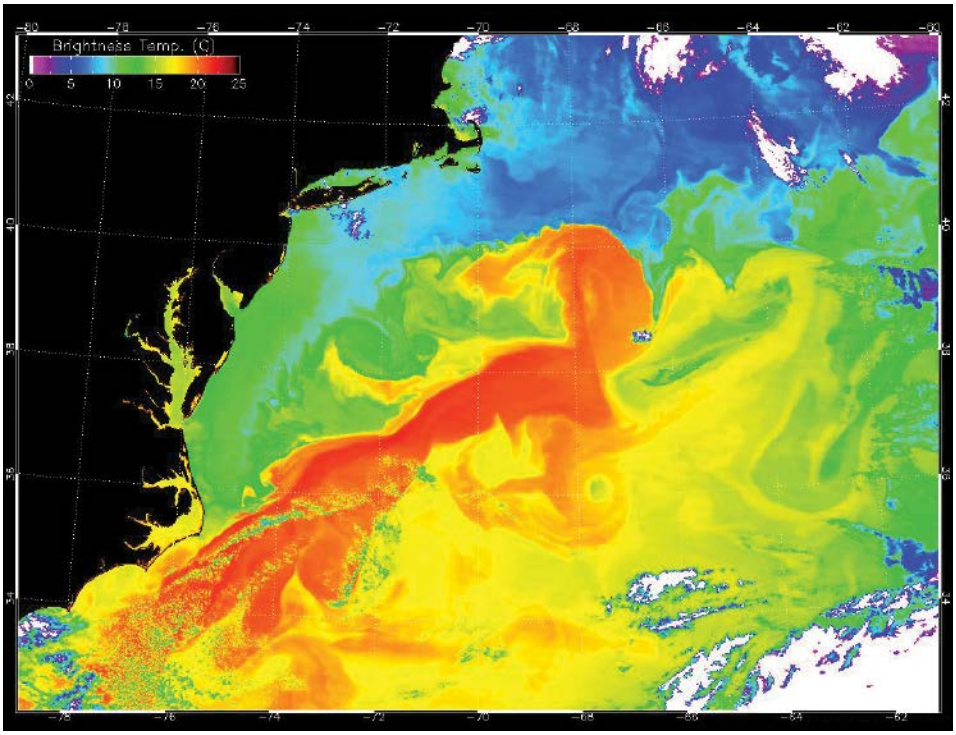
Haddock, senior scientist and marine biologist with the Monterey Bay Aquarium Research Institute in Moss Landing, Calif., took the photograph of the marine worm *Tomopteris* included on the stamp sheet. Haddock told *Eos* that the stamps could encourage people to "do a little bit deeper dive, so to speak, into the subject" of bioluminescence "and appreciate some of the unknown diversity that's out there in the ocean."

Although the beauty of bioluminescent creatures is initially what drew Haddock to study them, he said that what has maintained his interest is "the sheer number of unanswered questions," such as what chemical reactions many creatures use to produce bioluminescence.

Haddock planned to carry on with his normal work as the stamps were issued today, including sequencing genes from bioluminescent organisms. However, he confided that he and his wife might take their son on a field trip to the post office.

By **Randy Showstack** (@RandyShowstack), Staff Writer

Gulf Stream Slowed as Hurricanes Struck



The Gulf Stream is shown in this false-color image assembled from NASA satellite data. Warmer colors indicate higher "brightness temperature," a measure of heat radiation from the sea surface and the moist atmosphere above it. Credit: Liam Gumley, MODIS Atmosphere Team, University of Wisconsin–Madison Cooperative Institute for Meteorological Satellite Studies

Just days before Hurricane Irma made landfall in Florida in September 2017, a team of marine scientists were in Miami on a project unrelated to the looming storm. They were deploying an ocean glider to monitor the strong offshore current known as the Gulf Stream. Later, however, they learned from data collected by the robotic vehicle that two other Atlantic hurricanes around the same time—Jose and Maria—acted as surprisingly powerful brakes on that major current.

Winds blowing against the Gulf Stream tend to slow it down, said Robert Todd, an oceanographer at Woods Hole Oceanographic Institution in Massachusetts who is leading this glider research, but "seeing the Gulf Stream temporarily slow down by 25%–40% was not expected."

The glider's measurements also revealed that the Gulf Stream carried an unusually large volume of fresh water after Hurricane Irma pummeled Florida.

These new observations show that short-lived events like hurricanes can have a measurable impact on the flow of the Gulf Stream, said Christopher Meinen, an oceanographer at the National Oceanic and Atmospheric Administration in Miami who was not involved in the research. What's more, he continued, they "illustrate how innovative new technologies can be used to help scientists observe the ocean safely at times when the weather would make sending a research ship full of scientists out unsafe."

A Current That Drives Climate

The Gulf Stream, which originates off the Florida coast and winds up the East Coast of the United States before veering into the mid-Atlantic, ranks among the world's largest ocean currents. It transports warm water thousands of kilometers, bringing heat from the tropics to the northern Atlantic. "The Gulf Steam is an important part of the climate system," Todd said. However, its subsurface flow is monitored on a regular basis only in selected places, like the strait between Florida and the Bahamas. Along the Gulf Stream, 1,500 kilometers have not been measured in any routine, sustained way, Todd said. Now "gliders are filling in that gap."

An Unexpected Slowdown

Todd and his team launched a 2-meter-long glider from Miami on 7 September 2017. Propelled by the Gulf Stream, the vessel traveled at a speed of about half a knot—about 1 kilometer per hour—during its roughly 3-month-long journey north toward Martha's Vineyard, Mass. Along the way, the glider dove as deep as 1,000 meters and measured water temperature, salinity, the current's speed, sediments, and microorganisms like phytoplankton and zooplankton in the water column.

The researchers found that the Gulf Stream slowed down significantly for a few weeks as Hurricanes Jose and Maria passed over in middle to late September when the glider was off the coast of South Carolina. They attribute this trend to the hurricanes' winds blowing opposite to the direction of the current.

This slowdown didn't occur just at the ocean surface, the data showed. From the glider's repeated measurements at different depths, the team found that the slowdown persisted throughout the water column. "The velocity was all reduced," said Todd, who reported on his group's results on 15 February at the 2018 Ocean Sciences Meeting in Portland, Ore. (http://bit.ly/Todd-2018).

Less Salty, Too

Unlike Hurricanes Maria and Jose, Hurricane Irma traveled up Florida's west coast and therefore did not significantly contribute to the slowing of the Gulf Stream. Nonetheless, it caused a different, measurable effect. The storm's rainfall, paired with runoff from the land, added a lot of fresh water to the ocean, which the glider picked up as a signal of unusually fresh water in the Gulf Stream. "Irma was the source of that fresh water," Todd said.

Todd and his collaborators continue to monitor the Gulf Stream by deploying a glider roughly every 2 months from Miami. These hurricane-related results are just part of the team's findings based on its ongoing work. "We just happened to have one deployment that was timed well," Todd said.

By **Katherine Kornei** (email: hobbies4kk@gmail.com; @katherinekornei), Freelance Science Journalist

Assessing Damage by Laser Could Focus Postearthquake Response

Houses in Kumamoto, Japan, on 16 April 2016, after two earthquakes struck within 28 hours of one another. Credit: Taro Karibe/Stringer/Getty Images News/Getty Images

Recognizing damaged buildings soon after an earthquake can save lives. Researchers in Japan recently took advantage of the unusual occurrence of two strong earthquakes that jolted the city of Kumamoto about a day apart to investigate the prospects for using airborne lidar surveys to hasten rescues from compromised buildings.

Lidar data can feed the construction of high-resolution, three-dimensional digital maps. These maps include accurate renderings of the elevations of structures and topographic features within the scanned area.

The study indicates that if there are prequake and postquake lidar surveys of a stricken city, lidar may outperform aerial photography in providing accurate detection of damaged buildings, and the comparison could be automated. Lidar also works over a wider range of visibility and weather conditions than aerial photography or satellite imaging does.

The new results suggest that earthquake-prone cities may benefit from regular lidar surveys that would enable them to have an up-to-date basis for comparison when the next temblor strikes. If lidar methods can automatically detect collapsed buildings after an extreme event, they can better inform responders where people might be trapped under rubble or where supplies are needed, said Luis Moya, an engineer at Tohoku University in Japan. He is the lead author of a *Natural Hazards and Earth System Sciences* paper on the research that published in January (http://bit.ly/Moya-2018). "The faster we [pinpoint] the collapsed buildings, the faster we can send for help," Moya said.

> "The faster we [pinpoint] the collapsed buildings, the faster we can send for help."

One–Two Punch

On 14 April 2016, a magnitude 6.2 earthquake struck Kumamoto Prefecture on the island of Kyushu in Japan. A second quake of magnitude 7 struck 28 hours later. Given the magnitude of the first quake—now considered the foreshock—the stronger main shock took seismologists and emergency planners by surprise. The two events directly caused 50 fatalities.

Most remote sensing data are collected only after an event, and because the foreshock was initially assumed to be the main event, an airplane surveyed the area on 15 April using lidar. In this unusual case, however, the airborne survey was repeated 8 days later, after the main shock had occurred, ultimately providing Moya and his colleagues an unexpected chance to test lidar's usefulness for earthquake damage assessment.

Assessing the Potential

In most cases, postevent remote sensing information takes the form of aerial photographs. Although the resolution of those images has been improving, using the photos to identify individual compromised buildings remains difficult, Moya explained. In addition, cloud cover and darkness limit collection of optical imagery, whereas lidar works day or night, with or without clouds.

The Kumamoto main shock permanently shifted the ground in some areas. To make certain that they could still compare identical points on each building despite the shifting of entire structures, the researchers corrected the postquake data set using a method that they describe in a 2017 paper (http://bit.ly/Moya-2017).

Now that the researchers have figured out how to make the adjustments, remapping the postquake survey to its prequake cousin could go much more quickly, Moya said, by using speedier software or other modifications that so far remain to be tested. In cases in which the target area is distant from the earthquake source or the magnitude of the quake isn't too large, the permanent deformation may be small enough to neglect, he noted.

Follow the Footprints

With the surveys realigned and using building footprint data from the Geospatial Information Authority of Japan, Moya and his coauthors examined horizontal and vertical changes in buildings with a variety of damage patterns from survey to survey. After analyzing simple parameters that could be used for automatic detection, the research team found that one parameter—the average height difference between the two surveys within the building footprint—had detection accuracy similar to that of all the parameters combined.

Not all other detection methods consider the vertical displacements of structures, according to Chris Renschler, a geographer and investigator with the Multidisciplinary Center for Earthquake Engineering Research at the University at Buffalo in New York who was not involved with the study. But he thinks

the study is important. When comparing before and after optical imagery, even with high resolution, it's difficult to detect a damaged building that dropped down the height of a story with only minimal horizontal change.

When Moya's team evaluated aerial lidar's success at collapsed building detection, it determined that the technique achieved its greatest accuracy (93%) for structures that had lost 0.5 meter or more in height. To come up with that accuracy, the researchers compared their lidar results with the findings from a field assessment of damage conducted by another research group (that included one of Moya's coauthors) in Japan that was studying the impacts of the same pair of quakes, Moya said.

Moya's team determined that aerial lidar achieved its greatest accuracy (93%) for detecting collapsed structures that had lost 0.5 meter or more in height.

The Future of Damage Assessment

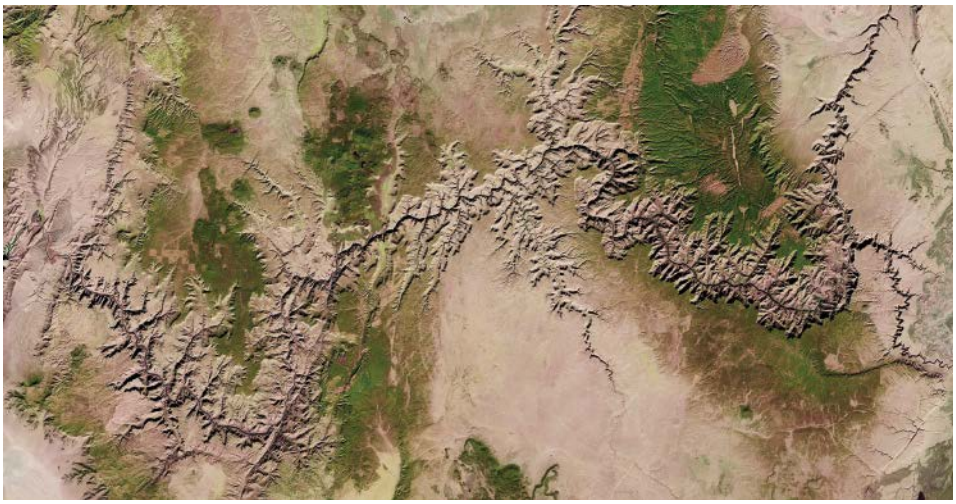
Rapid response to an extreme event is possible if accurate information is continuously gathered before the event occurs and can be followed by collecting the same kind of data after the event for quick comparisons, according to Renschler. "What is often forgotten is that emergency managers may not have the opportunity of gathering such data, but once something happens, they are really in need of that information," he said.

Decision makers in earthquake-prone communities should take note of the potential of the lidar methods demonstrated in this study, he added. "With the technology getting cheaper, communities may want to do this assessment on a continuous basis so that they are updated," he said.

In the meantime, Moya isn't waiting for decision makers. His next step is to try to combine lidar data with data from other sources to explore the possibility of identifying damaged structures with only postevent information.

By **Laura G. Shields** (email: lgshields@gmail.com; @LauraGShields), Science Communication Program Graduate Student, University of California, Santa Cruz

Report Recommends Priorities for Earth Observations from Space



A mosaic of two Landsat 8 satellite images taken in 2009 shows the Grand Canyon in the southwestern United States. A new report by the National Academies of Sciences, Engineering, and Medicine offers a 10-year plan for making the most-needed observations of our planet by U.S. spacecraft. The Landsat program has carried out space-based imaging of Earth for decades. Credit: Smith Collection/Gado/Archive Photos/Getty Images (image courtesy USGS 2009)

Nearly 60 years after the launch of Explorer 1, the United States' first satellite, a new decadal strategy for Earth observations from space calls for U.S. federal civilian agencies to coordinate and advance a U.S. program of Earth observations from space "that is robust, resilient, and appropriately balanced."

"Earth science and applications are a key part of the nation's information infrastructure," according to the National Academies of Sciences, Engineering, and Medicine (NASEM) report *Thriving on Our Changing Planet: A Decadal Strategy for Earth Observation from Space* (http://bit.ly/NASEM-Decadal). It calls for the primary U.S. civilian agencies involved with Earth observations from space—NASA; the National Oceanic and Atmospheric Administration (NOAA); and the U.S. Geological Survey (USGS), with its long-standing Landsat program—to work toward this goal in collaboration with other interested U.S. agencies.

The report, issued on 5 January and sponsored by NASA, NOAA, and USGS, identifies top science priorities for the next decade, along with observational needs and programmatic support. Together, those make up a strategy for initiating observations to study aspects of Earth that the committee believes require far more scrutiny and to achieve breakthroughs on major scientific questions, all while increasing program cost-effectiveness.

"The science alone is inspiring and compelling, but understanding and reliably predicting the Earth system is a vital economic, societal, and national security need as well," the report notes.

"We focused on the value of Earth information from space-based observations. That value is not limited to the scientific domain or potentially controversial topics," Waleed Abdalati, cochair of the NASEM committee that issued the report, told *Eos*. Abdalati is director of the Cooperative Institute for Research in Environmental Sciences at the University of Colorado Boulder and was NASA chief scientist from 2011 to 2012.

Science Priorities

To address key Earth science and applications questions, the priorities outlined in the report include five targets designated by the committee for observation: aerosols; clouds, convection, and precipitation; mass change; surface biology and geology; and surface deformation and change. The report also specifies competitive selection of three additional targets (a group dubbed "Earth System Explorer") in seven possible areas: greenhouse gases, ice elevation, ocean surface winds and currents,

ozone and trace gases, snow depth and snow water equivalent, terrestrial ecosystem structure, and atmospheric winds. The report calls for development of instruments, instrument suites, or missions to implement observational needs for the five designated targets and three Earth System Explorer targets.

The report also calls for greater attention to potential benefits from domestic and international partnerships and "the growing capability of commercial sources" and for keeping costs within anticipated budget constraints to avoid draining funds from other programs and throwing off "desired programmatic balance." If budgets prove more or less generous than expected, the report includes "rules for altering plans in a manner that seeks to ensure the overall program integrity," the document states.

Building on Earlier Reports

The report builds on earlier strategic overviews put forward by NASEM or federal government entities, including a 2007 NASEM decadal report (http://bit.ly/NAS-2007) and two prior White House studies: the 2013 National Strategy for Civil Earth Observations and the 2014 National Plan for Civil Earth Observations. Although the national strategy and the plan "represent progress toward a strategy for achieving and sustaining Earth observations," the new report states, "the U.S. has not committed the resources to collect the broad range of sustained observations needed to monitor and understand the Earth as a system." Hence, the nation has left "critical gaps in the implementation of this National Plan and a dependency on non-U.S. sources."

Earth Science Community Consensus

The plan for Earth observations provided by the decadal strategy "should keep NASA Earth Science on the right path for the coming decade if funded adequately," Steven Running, retired regents professor of ecology at the University of Montana in Missoula, told *Eos*.

The agency's Earth Science program "is of unparalleled significance to humanity in this age of rapid change," added Running, an expert in global ecosystem monitoring who served on a panel for the 2007 decadal report and is a past chair of the NASA Advisory Council's Earth Science Subcommittee. This new decadal strategy "well documents this urgency and uniqueness of mission, and identified the most critical science questions society needs to answer," and it represents an Earth science community–wide consensus on mission priorities for the coming decade, he said. However, he noted that he was disappointed that the strategy doesn't include more of a full Earth systems science plan. Studying Earth is a "systems problem," he said. So long-term storage, reprocessing, and distribution to the science community of climate data records and integration with Earth systems modeling are needed strategic planning components. "Yet this [strategy], as with the 2007 report, sticks almost entirely to planning and prioritizing flight missions," Running said.

The report builds on earlier strategic overviews put forward by NASEM or federal government entities, including a 2007 NASEM decadal report and two prior White House studies.

Who Is Paying Attention?

"The report affirmed the importance of NASA and the other satellite-enabled agencies to keep an eye on planet Earth," Ann Bartuska, vice president for land, water, and nature with Resources for the Future (RFF), an independent nonprofit research institution based in Washington, D. C., told *Eos*. However, she wondered "who is paying attention to these recommendations," because the administration still doesn't have a robust White House science structure in place.

Although Bartuska praised the report overall, she said that it would benefit from a "translation" for policy makers that provides them with a "short list" of its most important points and recommendations. The document's summary and tables, she noted, only partially meet that need. She also said she would have liked to have seen the report focus more on the value of in situ measurements that complement satellite-based systems and on agricultural uses of satellite information to forewarn of crop losses that could destabilize societies.

Bartuska served as deputy undersecretary for research, education, and economics with the U.S. Department of Agriculture from 2010 to 2017. From 2016 to 2017, she chaired the Subcommittee on Global Change Research, which steers the activities of the U.S. Global Change Research Program.

Report "Hopefully" Is Important for Congress As Well

Although important for the scientific community itself, the report "hopefully" will affect members of Congress who set the budget for science agencies, Anne Nolin told *Eos*. She is a professor in the College of Earth, Ocean, and Atmospheric Sciences at Oregon State University in Corvallis and served as vice chair of the panel on water resources and the global hydrologic cycle for the previous decadal survey.

Nolin, whose specialties include mountain hydroclimatology, snow and ice in the climate system, and remote sensing, expressed concern that even members of the public with an interest in science may not immediately recognize what the report is about. "It would be great for the science-literate public to be able to get excited about it [but] I don't think people know what it is," she said.

"We say, 'decadal survey' and they say, 'What?'" she noted. "But if you say, 'road map for next-generation satellites to monitor the Earth, to look at our planet,' people go, 'Oh, that's interesting.'"

By **Randy Showstack** (@RandyShowstack), Staff Writer

Honoring Earth and Space Scientists

The Tyler Prize—known as the "Nobel Prize for the environment"—was awarded in February to **Paul Falkowski,** professor of geological and marine science at Rutgers University in New Brunswick, N.J., and **James McCarthy,** professor of biological oceanography at Harvard University in Cambridge, Mass. The prize recognizes them for pioneering research and leadership in scientific understanding of the oceans and climate change and for communicating the impacts of a warming world. Falkowski and McCarthy will receive Tyler Prize medallions and share the accompanying $200,000 monetary award.

On 22 January, the National Academy of Sciences (NAS) announced that **Paul Farmer** will receive the academy's Public Welfare Medal for his work improving the delivery of high-quality health care in resource-poor areas of the United States and abroad. Farmer is a cofounder and chief strategist of the international social justice and health organization Partners In Health; a professor at Harvard University in Cambridge, Mass.; chair of the Department of Global Health and Social Medicine at Harvard Medical School; and chief of the Division of Global Health Equity at Brigham and Women's Hospital in Boston, Mass. NAS established the Public Welfare Medal, its most prestigious award, in 1914 and awards it annually "to honor extraordinary use of science for the public good."

Four Earth and space scientists were among those recognized by the National Academy of Sciences on 17 January as recipients of medals honoring extraordinary scientific achievements. **Mark Hay,** professor and chair of environmental science and technology at Georgia Institute of Technology in Atlanta, will receive the Gilbert Morgan Smith Medal and its $50,000 prize for his research in algal ecology and work understanding how temperate coral reefs chemically interact with their environment. **Kevin McKeegan,** professor of Earth, planetary, and space sciences at the University of California, Los Angeles, will be presented the J. Lawrence Smith Medal and its $50,000 prize for his study of micrometeorites, measurements of the oxygen isotope composition of the Sun, and work improving our understanding of the formation and early evolution of the solar system. **Dean Roemmich,** professor of oceanography at the Scripps Institution of Oceanography at the University of California, San Diego, will be honored with the Alexander Agassiz Medal and its $20,000 prize for his pioneering work in studying the large-scale circulation of the ocean, his development of a vast international network of ocean sensors, and his leadership in understanding the ocean's roles in climate change. **Ewine van Dishoeck,** professor of molecular astrophysics at Leiden Observatory and Leiden University in the Netherlands and external scientific member of the Max Planck Institute for Extraterrestrial Physics in Garching, Germany, will receive the James Craig Watson Medal, a $25,000 prize, and $50,000 in research support for her leading role in molecular astronomy and astrochemistry, research investigating the chemical ingredients needed for star and planet formation and the chemical basis for life, and her outstanding mentorship of younger scientists.

Farmer and these four scientists, as well as others, will receive their medals in a ceremony on 29 April during the National Academy of Sciences' 155th annual meeting in Washington, D. C.

Syukuro Manabe and **Susan Solomon** will be honored with the 2018 Crafoord Prize in Geosciences this spring, according to an 18 January press release of the Royal Swedish Academy of Sciences. The Crafoord Prize is a geosciences complement to the Nobel prizes, which are also awarded by the academy. This year, the Crafoord Prize recognizes "fundamental contributions to understanding the role of atmospheric trace gases in Earth's climate system." Manabe, a senior meteorologist in the Atmospheric and Oceanic Sciences Program at Princeton University in Princeton, N.J., is being recognized for his pioneering work in global climate modeling and understanding the interconnectedness of Earth's atmospheric and ocean systems. Solomon, a professor of environmental studies at Massachusetts Institute of Technology in Cambridge, was chosen for her groundbreaking work solving the mystery of the Antarctic ozone hole, for integrating ozone processes into models of Earth's climate system, and for setting the groundwork for modern modeling of the stratosphere. Manabe and Solomon will receive the prize and will each give a lecture during a ceremony in Stockholm, Sweden, on 24 May. The prize includes 6 million Swedish kronor (about $750,000), to be shared equally by the laureates. The Crafoord Prize is awarded jointly by the academy and the Crafoord Foundation in Lund, Sweden.

The United Arab Emirates Research Program for Rain Enhancement Science awarded its third annual program grant to three researchers, each working on improving access to water around the world. **Ali Abshaev** of the Hail Suppression Research Center in Nalchik, Russia, received the award for a project examining the creation of updrafts for the formation of artificial clouds and rainfall. **Eric Frew,** associate professor of aerospace engineering sciences at the University of Colorado (CU) Boulder and the director of CU Boulder's Research and Engineering Center for Unmanned Vehicles, plans to use the grant for a project that will use autonomous unmanned aircraft systems for cloud seeding and observations. **Lulin Xue** of Hua Xin Chuang Zhi Science and Technology LLC in China received the grant for a project entitled "Using Advanced Experimental–Numerical Approaches to Untangle Rain Enhancement (UAE-NATURE)." Abshaev, Frew, and Xue will share the $5 million grant, which was awarded at a ceremony on 17 January during the 2018 Abu Dhabi Sustainability Week in Abu Dhabi, United Arab Emirates.

Stephen Sparks, professor of geology at the University of Bristol in the United Kingdom, was invested as a Knight Bachelor by Queen Elizabeth II for his services to volcanology and geology. During his career, Sparks has focused on volcanology and igneous petrology, mapping and monitoring volcanoes, management strategies for nuclear waste, and natural hazard risk assessment. Among his many honors, Sparks was appointed a Commander of the Order of the British Empire (CBE) in 2010; was president of the International Association of Volcanology and Chemistry of the Earth's Interior; was president of the Geological Society of London; received the 2015 Vetlesen Prize; was president of the Volcanology, Geochemistry, and Petrology (VGP) section of AGU; vice-chaired the AGU Council; and was a member of AGU's renewed Board of Directors. Sparks was awarded his knighthood as part of Her Majesty The Queen's 2018 New Year's Honours published on 29 December 2017.

Douglas D. Davis (1940–2016)

Gao Chen

Douglas D. Davis

Douglas D. Davis passed away unexpectedly on 26 December 2016, taking from us an invaluable atmospheric chemist. He was renowned for his creativity, leadership, and dogged pursuits of environmental issues.

Doug excelled in kinetics studies, pioneered a paradigm for airborne sampling, developed new measurement techniques, and enabled understanding of atmosphere-cryosphere interactions. He was one of the earliest atmospheric chemists, and he helped shepherd this field into the full-fledged discipline that it is today.

Doug was born in Madrid, Neb., on 23 February 1940. His bachelor's and Ph.D. degrees were from the University of Washington (1962) and the University of Florida (1966). Following a research fellowship at the National Bureau of Standards (NBS), Doug spent 7 years (1969–1976) on the faculty of the chemistry department at the University of Maryland in College Park. He then moved to the Georgia Institute of Technology, where he was instrumental in establishing the School of Earth and Atmospheric Sciences. He retired in 2004 but continued as an emeritus professor until his death.

Advancing Our Knowledge of the Atmosphere

Doug established the rates of stratospheric and tropospheric reactions in the 1970s. He enhanced the flash photolysis technique that he had worked on at NBS as a postdoc so that he could use it to study atmospheric kinetics.

His body of work on hydroxyl radical (OH·) and oxygen atom reaction kinetics in the 1970s was instrumental in improving our understanding of stratospheric ozone layer depletion and the formation of ozone pollution in the troposphere. His studies on the OH· reaction with hydrocarbons quantified the initial step in tropospheric ozone formation.

Doug also pioneered atmospheric chemistry measurement techniques. He founded a technique to measure OH·, a radical that plays a central role in tropospheric chemistry, using laser-induced fluorescence. His efforts to quantify OH· in the troposphere paved the way for success a decade later, but these measurements remain a challenge even today.

With colleagues, Doug developed the two-photon laser-induced fluorescence detection of nitric oxide (NO), which dramatically improved sensitivity by exciting NO molecules with two lasers of different wavelengths, effectively enhancing the signal-to-noise ratio.

Airborne Measurements of Atmospheric Composition

Doug pioneered the use of multi-instrumented aircraft to examine the atmosphere, making the first airborne sampling of a power plant plume in 1973. This work, highlighted on the cover of *Science* magazine, garnered him the honor of Maryland's Outstanding Young Scientist of 1974.

This early success led to the ambitious Global Atmospheric Measurements Experiment on Tropospheric Aerosols and Gases (GAMETAG) project in 1977–1978. Doug and his colleagues packed an aircraft with many complementary instruments provided by multiple principal investigators to characterize the composition of the atmosphere over the remote Pacific.

GAMETAG set the paradigm of using multiple instruments to sample the same air mass to decipher the chemistry of the atmosphere, and is still emulated by airborne field studies today, albeit with more advanced payloads.

Tracking the Human Influence

Over the next 2 decades, Doug led the design of airborne field studies. He examined various atmospheric phenomena, especially in the pristine atmosphere. He was a driving force behind NASA's Global Tropospheric Experiment (GTE). His collaboration with Reginald Newell of the Massachusetts Institute of Technology led to the highly successful series of Pacific Exploratory Missions in the 1990s, which documented clear signals of human activity in pristine areas.

During a campaign in 1991, Doug and Reg conspired to measure air composition near Typhoon Mireille, despite instructions from their NASA sponsors to avoid this storm. True to Doug's reputation for persistence, he, Reg, and the science team planned to sample an "organized convective event," which received no objection from sponsors and resulted in one of the most talked about flights in the history of the GTE project.

After the flight, Doug sought an effective tracer compound for convected air. Building on his seminal work on the role of iodine in the troposphere, he proposed reanalyzing air samples taken during the flight for naturally occurring methyl iodide. This was the first time that methyl iodide was used as a tracer for convection, which is now common practice.

Late in his career, Doug found that reactive nitrogen released from the Antarctic snowpack created a photochemical environment that bore no resemblance to the pristine environment that had been assumed previously, an effect that was dramatically magnified in the Antarctic. Doug devoted the rest of his life to understanding the controlling factors and effects of the chemistry in this unique environment.

A Great Teacher and Mentor

Doug's scientific curiosity, accompanied by an energy and intensity of purpose, extended to the classroom. Armed with plenty of stories from the field, he delivered lectures that brought life to the subject of atmospheric chemistry as he developed his own curriculum for this constantly evolving topic.

Doug was a consensus favorite among the graduate students, despite his reputation for being one of the hardest professors. His marathon exams were considered a rite of passage. He mentored a vast number of graduate students and postdoctoral fellows, connecting him to an astonishing number of active scientists and leaders in the field today.

Doug is survived by Christine, his wife of nearly a half century. He is also survived by his daughter, Nicole; her husband, Brett; and their two daughters, Megan and Elizabeth.

By **Jim Crawford** (email: james.h.crawford@nasa.gov) and **Gao Chen,** Science Directorate, NASA Langley Research Center, Hampton, Va.; and **A. R. Ravishankara,** Department of Chemistry, Colorado State University, Fort Collins

Computational Seismology Workshop Trains Early-Career Scientists

2017 CIG–LLNL Computational Seismology Workshop
Livermore, California, 18–22 September 2017

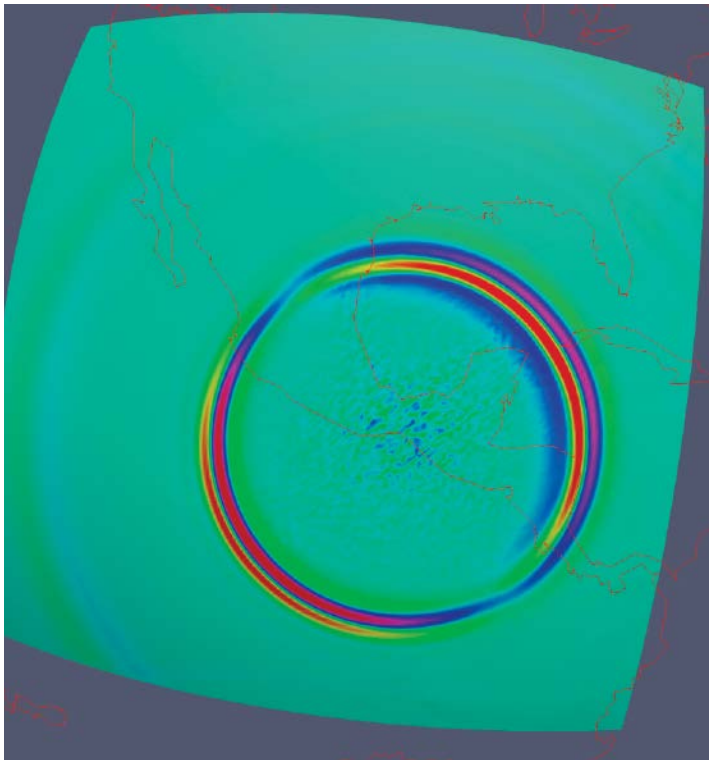


Fig. 1. The 19 September 2017 M 7.1 Mexico City earthquake, simulated by the SPECFEM3D_GLOBE program and visualized with ParaView software. Credit: Kelvin Tian, Columbia University

The Computational Infrastructure for Geodynamics (CIG), in collaboration with Lawrence Livermore National Laboratory (LLNL), held a workshop last year that focused on computational seismology. The workshop provided training in seismic waveform processing, visualization, and high-performance computing (HPC) waveform simulation. Fifty-five predominantly early-career participants—graduate students and postdocs—from the United States and 16 other countries attended. The workshop was the first of its kind to feature full access to HPC resources for research-grade example problems.

A few trends served as the backdrop for the meeting. Seismic data processing software and numerical codes for HPC simulation of the seismic wavefield have evolved substantially in recent years. The volume of seismic data has greatly increased as instrumentation and technology have advanced and barriers to deploying sensors and transmitting data have fallen. Capabilities for HPC simulation of seismic waves in realistic 3-D Earth models have also greatly increased for source and Earth structure studies, driven by advances in numerical methods and computer programs as well as the inexorable growth in computing power. These trends indicate that HPC simulations of seismic waves will become more common in research and seismic network operations.

The 5-day workshop had several elements. The main objective was practical, hands-on tutorials on the workflow involved in simulating seismic waveforms. Keynote lectures by leading researchers described how seismic simulations are advancing understanding of earthquake hazards and Earth structure. These lectures also outlined challenges that must be overcome to maximize the potential of HPC simulations and to ensure that the methods gain broader use. Participants shared their current work in poster and lightning talk sessions.

Workshop tutorials gave participants hands-on experience using four open-source codes for waveform processing and simulation. One was ObsPy, a Python-based software package for accessing, processing, and visualizing seismic waveforms, event data, and metadata. Three methods for computing synthetic seismograms were also covered, including Instaseis, which computes seismograms for radially symmetric models and can run on a laptop. Two codes compute seismograms in 3-D Earth models on parallel computers: SW4, a Cartesian finite difference code developed at LLNL, and SPECFEM3D, a spectral element code developed by a large team led by Princeton University. Participants learned how to run these codes and then processed and visualized the results.

> Trends indicate that high-performance computing simulations of seismic waves will become more common in research and seismic network operations.

LLNL provided access to 7,200 cores of its Quartz HPC cluster for 3 days during the workshop, enabling participants to run simulations on hundreds of processors simultaneously. During the workshop, the 19 September 2017 *M* 7.1 Mexico City earthquake occurred. Participants ran a simulation of this (see Figure 1) and other earthquakes with SPECFEM3D and visualized the results to exercise their newly acquired skills.

The workshop was sponsored by CIG, a National Science Foundation–funded geoinformatics project to develop, disseminate, and maintain numerical codes for geodynamics. The Seismological Society of America also provided support. LLNL provided the venue, local organization, and HPC cycles.

Details, including links to presentations and tutorials, can be found on the workshop website (http://bit.ly/CompuSeisWkshp).

By **Arthur J. Rodgers** (email: rodgers7@llnl.gov), Geophysical Monitoring Program, Lawrence Livermore National Laboratory, Livermore, Calif.; **Lorraine J. Hwang,** Computational Infrastructure for Geodynamics, University of California, Davis; and **Louise H. Kellogg,** Earth and Planetary Sciences, University of California, Davis

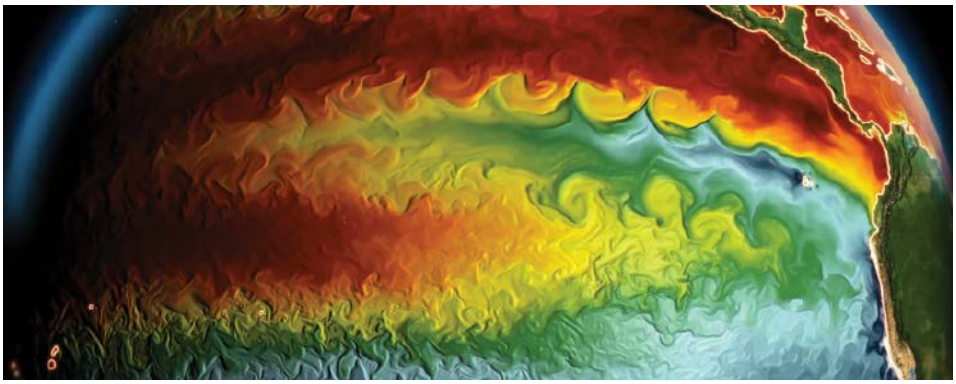
Maintaining Momentum in Climate Model Development

Climate models have gotten steadily more sophisticated over the past 5 decades, representing a wider range of timescales and spatial scales and capturing increasing degrees of complexity and interconnections among different components of the climate system. Climate models use mathematical tools to represent physical processes like evaporation of water from the ocean's surface, moisture transport in the atmosphere, or mixing of heat in the ocean; the better the math is at mimicking the processes, the more accurately the models can explain past variations and predict future conditions.

Toward this end, in 2003 the U.S. Climate Variability and Predictability (U.S. CLIVAR; https://usclivar.org) national research program, with funding from the National Oceanic and Atmospheric Administration (NOAA) and the National Science Foundation (NSF), assembled a group of climate process teams (CPTs) to focus on improving global climate models. Each team comprised 7–12 principal investigators from academia, partners from modeling centers, and several postdoctoral researchers (some of whom were embedded at modeling centers).

Each CPT tackled a particular physical process (e.g., mixing by internal waves in the ocean or formation of clouds in the atmosphere) and how it is represented in one or more global climate models. The CPTs have a universal mission: to help make better predictions of the Earth system by improving the representation of physical processes in climate and weather models. Over the years, CPTs have made significant advances in model performance, allowing us to better represent, understand, and predict climate change.

Funding for these teams was renewed in 2010, but this funding has now come to an end. Yet we still require improvements to climate models to more accurately predict how environmental conditions will vary in coming years and decades. Thus, the CPTs' vital work is not finished, and this effort must continue to receive support.



By focusing in-depth on a single climate modeling problem for a finite time, climate process teams have accelerated scientific understanding of particular processes, such as the distribution of internal wave energy in the world's oceans. Shown here is a map of sea surface temperatures generated by NOAA Geophysical Fluid Dynamics Laboratory's CM2.6 ocean simulation. Credit: NOAA GFDL

CPT Successes

Past CPTs have produced important improvements in global climate models. New convective parameterizations [*Bretherton and Park,* 2009], improved ocean model representations of shear-driven mixing [*Jackson et al.,* 2008], bottom boundary mixing [*Legg et al.,* 2006], and mixed-layer submesoscale restratification [*Fox-Kemper et al.,* 2008] are all now included in one or more state-of-the-art global climate models.

By focusing in-depth on a single problem for a finite time, CPTs have accelerated scientific understanding of particular processes. Successful examples of this in the oceanographic community include a more complete picture of the ocean internal wave energy distribution [*MacKinnon et al.,* 2017] and new research into ocean submesoscale processes that are not typically resolved by global climate models [*Boccaletti et al.,* 2007].

> By focusing in-depth on a single problem, CPTs have accelerated scientific understanding of particular processes.

Boundary layer cloud processes have proven to be very difficult to parameterize in global climate models, yet they play a critical role in modulating Earth's climate, making their accurate representation in climate models necessary to understanding Earth's climate and its response to forcing [*Bretherton and Park,* 2009; *Guo et al.,* 2015]. But thanks to CPTs, targeted studies have now led to a firmer grasp of the role of clouds in Earth's energy balance.

CPTs also led focused research efforts to improve representation of sea ice and iceberg processes in climate models that have led to better climate predictions of iceberg calving size distribution over the Antarctic Peninsula [*Stern et al.,* 2016].

The CPTs were instrumental in helping the involved scientific communities to develop strong and enduring links between academia and modeling centers, allowing better use of resources and expertise. *Waterhouse et al.* [2014], for example, synthesized ocean mixing data from a variety of observing platforms over a long period to provide an observational benchmark for improved mixing parameterizations in global ocean models. This synthesis product has the potential to increase our understanding of global ocean processes, such as the meridional overturning circulation, along with the heat and energy balance of the global climate.

Taking Stock

The second round of CPTs has come to an end, and members of the U.S. CLIVAR Process Study and Model Improvement Panel perceived a need to review the benefits the teams provide and to devise a plan for future efforts. The panel decided to seek input from the observational, modeling, and theoretical communities on how best to achieve a translation of process understanding into climate model improvements.

Researchers now have a better understanding of the role of clouds in Earth's energy balance, thanks to the work done by CPTs on improved convection schemes in climate models. For example, water condensation in rising air masses forms the characteristic "tower" structure of cumulonimbus clouds, like this cloud formation over Africa. Credit: NASA

To collect feedback on the utility of CPTs, the panel sent surveys to representatives of U.S. modeling centers, process studies, recent satellite missions, recent CPTs, and U.S. CLIVAR working groups. The results of these surveys confirmed broad community interest for a scoping workshop to identify processes for which newly available observational data and understanding could inform future model improvements. Subsequently, a workshop was held at Princeton University in October 2015 that brought together 90 leaders from the community to discuss a path forward (see http://bit.ly/CLIVAR-2015).

CPT activities have advanced climate models further than would have been possible with traditional funding mechanisms and smaller groups of principal investigators.

All of the outreach and information gathered from the community emphasized that CPT activities have advanced climate models further than would have been possible with traditional funding mechanisms and smaller groups of principal investigators working on such projects. This is evident in a comprehensive U.S. CLIVAR white paper [*Subramanian et al.,* 2016] that shows the need for launching a new CPT-like effort and addresses the questions of what form such an effort ought to take, which areas need to be tackled, and how such an effort might be implemented.

Moving Ahead

The white paper recommends that CPT activities continue, drawing on feedback from the surveys and the workshop. The community's consensus is that new activities should retain many successful aspects of the past CPTs. These include the formation of teams involving modelers, observationalists, and theoreticians. Team members should be drawn from modeling centers as well as from academia, and funds should support postdocs dedicated to the task.

The white paper also lends strong support to approaches involving multiple modeling centers and multiple agencies that are well suited to delivering sustainable and comprehensive improvements to climate models. New developments should enlarge the scope of such activities to consider not only teams built around the theme of improving the representation of a specific process but also new teams focused on coupled processes and model component interactions to address specific biases or climate phenomena. New activities should also consider the emerging computational and expanded observational capabilities.

The U.S. CLIVAR survey demonstrates that the climate science community broadly supports future mechanisms to facilitate the translation of process understanding into improvements in climate models over the coming decade.

We encourage our colleagues to form the cross-institutional collaborations among modelers, theoreticians, and observationalists that will enable these model improvements, and we hope that funding agencies will continue to welcome these team efforts. For further information on CPTs and future agency funding opportunities, please see http://bit.ly/CLIVAR-CPT.

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A Window into the Emerging Anthropocene...Through Art

Wheat Fields After the Rain (The Plain of Auvers), *1890, Vincent van Gogh. Oil on canvas. With a scientist's eye, a painting enthusiast can marvel not only at van Gogh's brushwork but also at the shifting landscapes. Although the painting has nothing from the built environment, the scene nonetheless shows the stamp of human influence: farmland.*
Credit: Carnegie Museum of Art; acquired through the generosity of the Sarah Mellon Scaife family

Anyone can wax poetic about a museum painting: Look at those brushstrokes! That composition! The artist's use of light and shadows! The feelings evoked by the color! But how many people can look at a painting and extract information about a landscape's geology or see an Earth that humans have begun to change, for better or worse?

Enter Albert Kollar, a geologist and collection manager at the Carnegie Museum of Natural History in Pittsburgh, Pa.

Scientists love to insert themselves into artistic conversations. For example, did volcanic ash or mother-of-pearl clouds give rise to the sky's vivid colors in Edvard Munch's *The Scream?* What can Frederic Edwin Church's *Aurora Borealis* tell us about the role science played in inspiring art? Kollar is no different. A geologist by training, Kollar recently became interested in what 19th-century landscape paintings—specifically, the landscapes hanging in the nearby Carnegie Museum of Art—can tell us about how the Anthropocene has evolved.

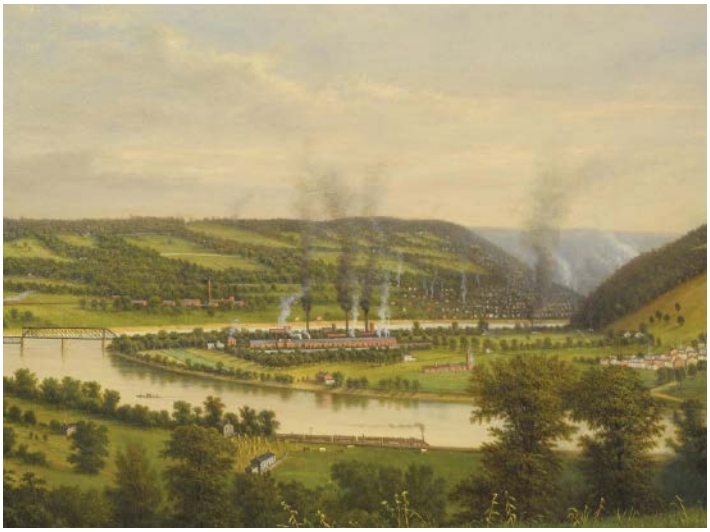
"Landscape paintings that were done in the 19th and early 20th centuries are recording information that modern scientists can extract out," Kollar said. "We can look back 150 years and see that what started out as just a landscape that an individual saw was also the beginning of the Industrial Revolution."

Many scientists note that atmospheric concentrations of greenhouse gases began to rise significantly during the Industrial Revolution, which spanned the mid-18th century to the mid-19th century. This was a time when major economies shifted from agrarian to machine manufacturing.

But what can art show about these transitions? *Eos* caught up with Kollar after his talk on the subject (see http://bit.ly/GSAKollar) at the Geological Society of America's annual meeting held last October in Seattle, Wash.

Here are five works from the Carnegie Museum of Art's collection that were painted during the Industrial Revolution, paired with Kollar's discussion of the geological features and Anthropocene effects captured by the artist. Tour with us, as we delve into some art appreciation with a geoscience lens.

The Pittsburgh Bessemer Steel Company



The Pittsburgh Bessemer Steel Company, *circa 1884, William Coventry Wall. Oil on canvas. Credit: Carnegie Museum of Art; bequest of Charles J. Rosenbloom*

This painting shows sedimentary rocks eroded by a "river during the Pleistocene," Kollar said, which formed a cutbank, sandbar, and floodplain of deposits from the Holocene age. Carbon dioxide and nitrogen dioxide pour from the riverboats' exhaust stacks.

Steamboat on the Ohio

Steamboat on the Ohio, *circa 1896, Thomas Pollock Anshutz. Oil on canvas. Credit: Carnegie Museum of Art, Patrons Art Fund; gift of the A. W. Mellon Educational and Charitable Trust*

Anshutz, perhaps without even knowing it, painted modern-day sedimentary rocks and river rocks around 10,000 years old, Kollar said. But the real focus here is all the emissions sources. The black smoke rising from the steel mill contains "emissions from combustion," which include carbon dioxide, he explained. Once again, Kollar noted that the river seen here is a source of methane. A steamboat in the foreground also burns coal, releasing carbon dioxide.

Pittsburgh Fifty Years Ago from the Salt Works on Saw Mill Run

Pittsburgh Fifty Years Ago from the Salt Works on Saw Mill Run, *circa 1884, Russell Smith. Oil on canvas. Credit: Carnegie Museum of Art; gift of the Howard Heinz Endowment*

Here Kollar sees a floodplain born of Holocene deposits less than 10,000 years old. He highlighted the salt factory, "where salt or brine water was extracted from subsurface Pennsylvanian-age sandstone." Brine was then boiled using heat from burning coal, which released carbon dioxide. You can also spot a tugboat burning coal and more coal burning in the background—all sources of carbon dioxide. He also pointed out that the river is a natural source of methane "when vegetation from land enters the water and decomposes."

Le Grand Pont, Rouen

Le Grand Pont, Rouen, *circa 1896, Camille Pissarro. Oil on canvas. Credit: Carnegie Museum of Art*

Pissarro also painted emissions, Kollar noted. Black, carbon dioxide–filled smoke rises in the background. White smoke from wood-burn riverboats also contains carbon dioxide and nitrogen dioxide. But the story here is that of humans harnessing a river. You have "floodplain deposits and river channeled to control flooding and raise [the] river level for river commerce," Kollar said.

The Lucy Plant, Carnegie Steel, Pittsburgh, *circa 1935–1936, Ernest Fiene. Oil on canvas. Credit: Carnegie Museum of Art*

The Lucy Plant, Carnegie Steel, Pittsburgh

This painting shows Andrew Carnegie's first steel mill. Kollar sees how the mill was built on the floodplain of the Allegheny River. The furnace releases carbon dioxide from its billowing black smoke, as does the tugboat. Coal mining also releases methane, and power generation for electricity and heating releases carbon dioxide.

The colors here are stark: black, white, and brown; the industrial building dominates what would otherwise be a quaint landscape of a town. There's a contradiction here, Kollar noted. All the while the greenhouse gases loft high into the sky, the "winter landscape [reflects] sunlight, thereby keeping temperatures cooler," Kollar said.

By **JoAnna Wendel** (@JoAnnaScience), Staff Writer

A NEW MASSIVE OPEN ONLINE COURSE ON NATURAL DISASTERS

By John Stix, John Gyakum, Karolane Caissy, Angela Guadagno, Alexander Steeves-Fuentes, Wei Wei Yan, Frank Roop, Pierre-André Vungoc, Claire Walker, Adam Finkelstein, and Laura Winer

Since 2000, McGill University in Montreal, Que., has offered a course with the simple title of Natural Disasters. The course, which teaches students the scientific principles underpinning hurricanes, tornadoes, avalanches, and more, has proven quite popular among the students; attendance has grown from about 50 to more than 600.

But that number pales in comparison with the 12,345 students who enrolled in this course after McGill University selected Natural Disasters as one of a small number of courses to develop into a high-quality massive open online course (MOOC) in 2013.

MOOCs have gained popularity since 2012. These courses allow anybody anywhere access to learning opportunities that were formerly restricted to small numbers. MOOCs typically attract thousands of students, at little or no cost to the students.

We planned and designed the original course as well as the MOOC. For the MOOC,

Jose Luis Pelaez Inc./Blend Images/Getty Images

we kept a set of objectives in mind. First and foremost, we wanted to reach out to the largest number of people possible, from all regions of the world, who were interested or involved in some aspect of natural hazards and natural disasters. In particular, we wanted to reach people in remote regions and developing countries who would not otherwise have been able to participate in such a course.

We believe that when these participants are provided with information and educational tools, at no cost to them, they can better understand how, where, and why natural disasters occur. Because better understanding can lead to empowerment and change, the MOOC participants could use this knowledge to help reduce and mitigate the effects and consequences of natural disasters in their own communities.

Assembling the MOOC

Our vision was of a MOOC that would be highly dynamic for the students. That is, we wanted to make sure that the professors' lectures would be only one of several elements in the course. The diverse range of activities included student polls, discussions, and short assessments that tested the students' comprehension. The assessments included multiple-choice questions, calculations, and geographic system pattern recognition, elements that actively engaged students in their learning.

This approach required a team of instructors and support staff with different and complementary skills. The two professors were the visual interface for the students; in essence, they were the "front end" of the course. The design team comprised a coordinator, an active learning specialist, a videographer, a programmer, and a group of student assistants who had taken the McGill course and were familiar with its content.

The course components included lectures, student activities (including three hands-on lab experiments), demonstrations by the professors, assignments, case studies by the students, and two multiple-choice exams.

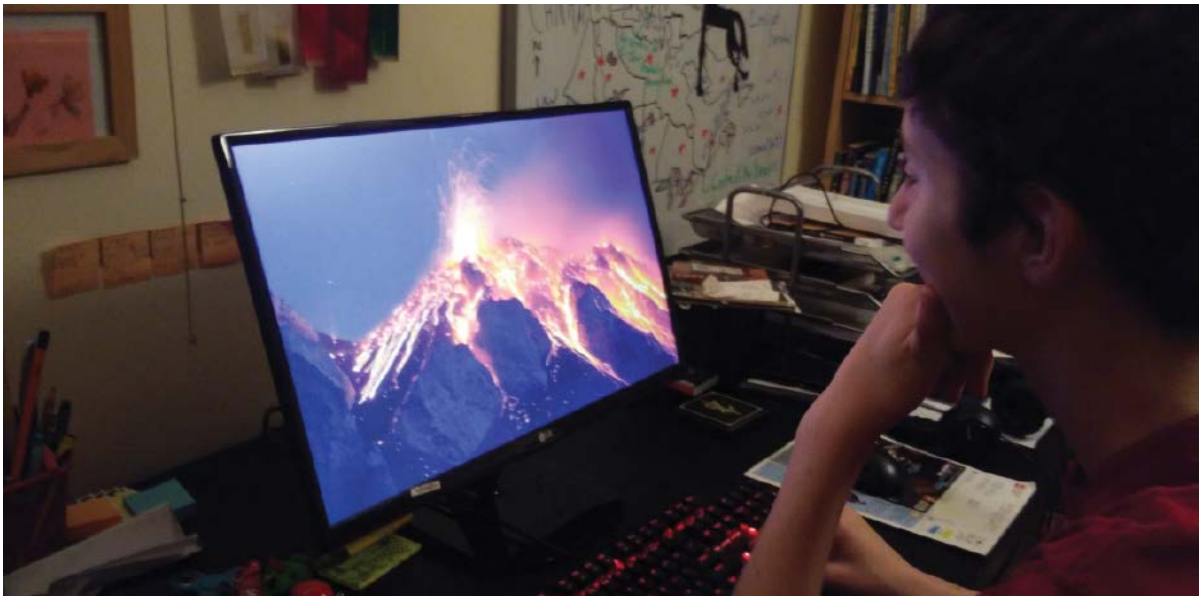
MOOC Content

The course covered a range of topics, including hurricanes, tornadoes, El Niño, ice storms, avalanches, landslides, earthquakes, and volcanoes. We synthesized many course topics with a series of lectures on climate change, or global warming, and its consequences. Practical demonstrations embedded within the lectures illustrated the principles behind each particular phenomenon. Here we drew on our experience doing live demonstrations for the on-site students in the McGill course. For example, we simulated a volcanic "eruption" using diet cola and Mentos candy.

We built social science into each topic. For volcanoes, we showed the importance of hazard maps and the need for people to communicate and take action when necessary to stay out of harm's way. As an illustration, we discussed the disastrous 1985 eruption of Colombia's Nevado del Ruiz volcano. Because of poor communication, people failed to flee from a volcanic mudslide, even though hazard maps were available showing safe and unsafe areas. For earthquakes, we examined the role that efficient communications, such as rapid text messaging, could play in public safety efforts.

We also examined climate change as a moral issue, comparing and contrasting greenhouse gas contributions and impacts between developed and developing countries. Finally, we discussed urban growth and human activities, looking at intelligent and not so intelligent choices people make in terms of where they live and how they build.

For each topic, students were required to complete an assignment that tested their knowledge and allowed them to apply the principles they'd just learned. They also completed two multiple-choice exams during the course,



One massive open online course (MOOC) enables participants all over the world to better understand how, where, and why natural disasters occur by providing them with information and educational tools, at no cost to them. Credit: John Stix

one halfway through and another at the end. We designed a "mini case study" in which students chose a topic or event that interested them, researched the topic, wrote up the essentials in roughly a page, and then submitted their written product to the scrutiny of three of their peers.

Students also collaborated to create interactive global hazard maps using a third-party tool called ZeeMaps (Figure 1).

Students competed in *Stop Disasters!* (http://bit.ly/Stop-Disasters), an online disaster simulation game from the International Strategy for Disaster Reduction, an effort organized by the United Nations Office for Disaster Risk Reduction (Figure 2). A display on the MOOC interface gave high scores and invited students to challenge and beat their student assistants.

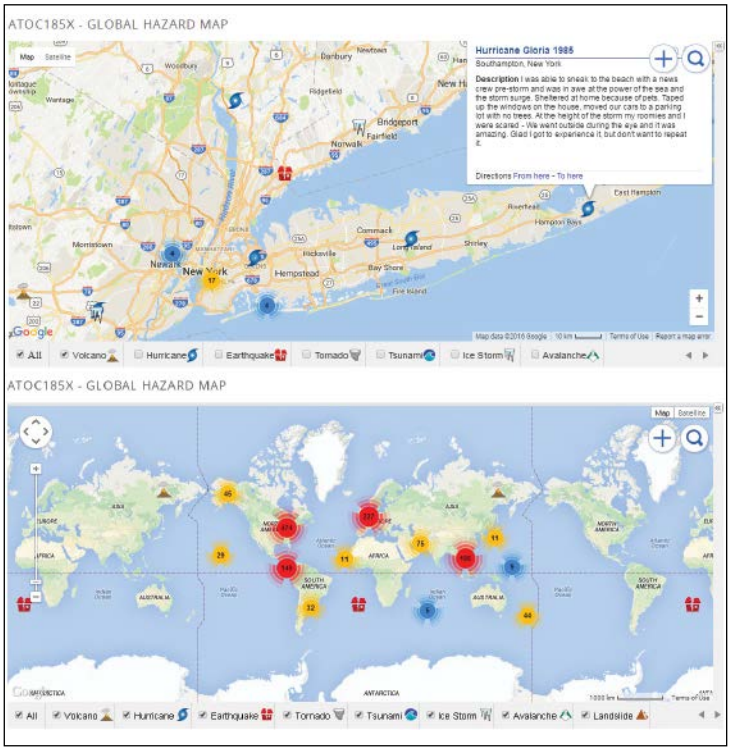


Fig. 1. Students in the MOOC were asked whether they had ever had a personal experience with any of several types of natural events or disasters. If yes, they could mark the geographic location, write a brief description, and post a photo of the event or disaster. In this way, the course compiled a remarkably diverse range of experiences that could be viewed by everybody using the maps.

Launching the MOOC

The initial offering of the MOOC ran from late May to late August 2014, with 12,345 students from 178 countries enrolled. We located these online students using their IP addresses (Figure 3) and found that at registration, the four countries with the most students were the United States (24%), India (11%), Canada (5%), and the United Kingdom (4%). The median age of participants was 29, with 34% aged 25 years or younger, 37% aged 26–40, and 20% aged 41 years or older (10% of participants did not indicate their age).

We offered our course through edX, a nonprofit entity that offers MOOCs from a large number of universities and other organizations (see https://www.edx.org). The course layout included a detailed syllabus, the courseware containing the material for the different topics, a page where students could view their results and progress, and a help section including frequently asked questions.

Fostering Discussion

In addition to instructional content, the course layout contained a discussion board for students and student assistants and "screenside chats," during which the professors could answer students' questions and address any events or topical points of interest, including natural hazards or natural disasters currently in progress.

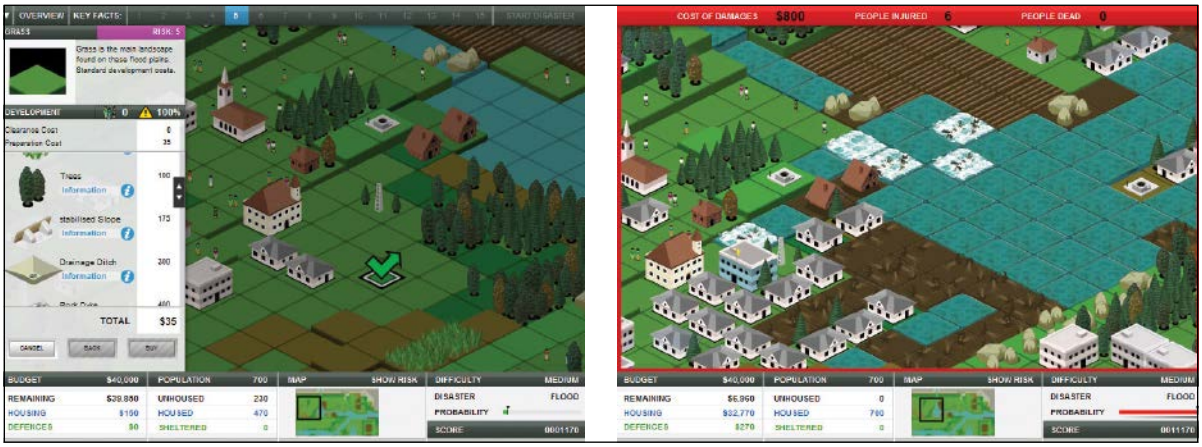


Fig. 2. Students could run a number of disaster scenarios using the computer simulation game Stop Disasters! *(left) In this example, a player is given a fixed budget to develop land and install protective measures for a flood scenario. (right) The flood is in progress, inundating trees and land that had been developed for housing. Credit: UNISDR*

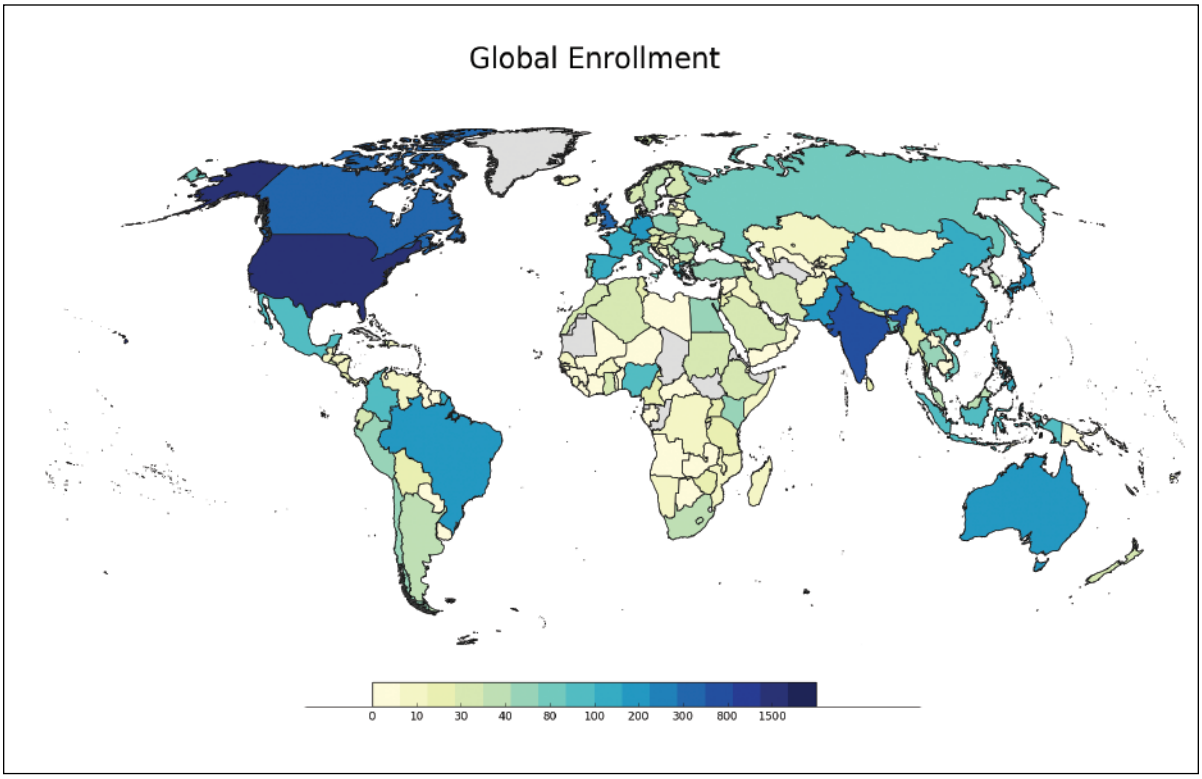


Fig. 3. Global distribution of 2014 course participants. Credit: McGillX

Two student assistants were tasked with addressing the many questions and concerns raised by the students as quickly and efficiently as possible. Over the span of the course, each student assistant contributed some 500 comments on the discussion forum. We received overwhelmingly positive feedback from students regarding this thorough and reliable discussion monitoring system.

Many students had an exceptional understanding of the course material, enabling them to respond to questions as well. When a student correctly responded to a question, staff endorsed the post and added any relevant additional information, thus indicating to all students that the response was correct.

Student participation in the *Stop Disasters!* game was especially impressive: Several students managed to surpass the high scores of the assistants, and they gave one another tips and tricks on how to improve their game scores. Online gaming appears to be an increasingly valuable learning resource in today's connected society [see, e.g., *Mani et al.*, 2016].

As part of their final project in the course, students shared their mini case studies, on a topic of their choice, with their peers on the discussion forum. The assistants read most of these case studies and found that generally, the quality of the research performed far exceeded expectations.

A New Way to Learn

We offered the MOOC again in 2015 and 2016. There are plans to license the course in China, and we are also thinking about developing specialized natural disaster MOOCs that would address, for example, the polar regions or the tropics.

No one on Earth is immune from the risk of natural disasters. Our course can make an important contribution to understanding and mitigating this risk. The course is accessible to a broad range of learners, from high school students to adults and seniors, and it can be used in developed and developing countries alike. The only requirements are Internet access and a passion for learning. We are excited about future developments in this field.

Acknowledgments

We are most grateful to Anthony Masi, former provost at McGill and leader of the McGillX initiative, who provided financial support and much encouragement for this project.

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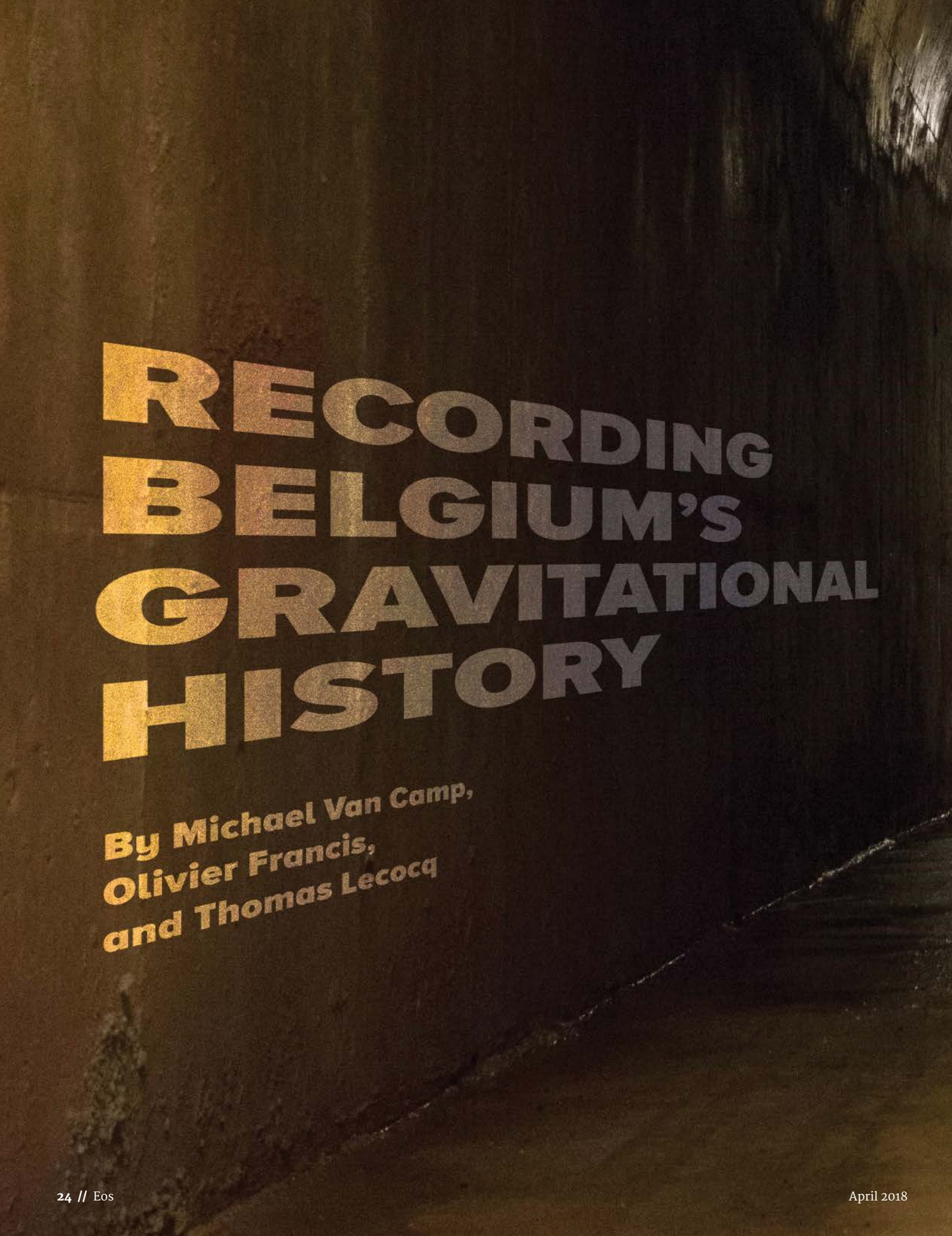
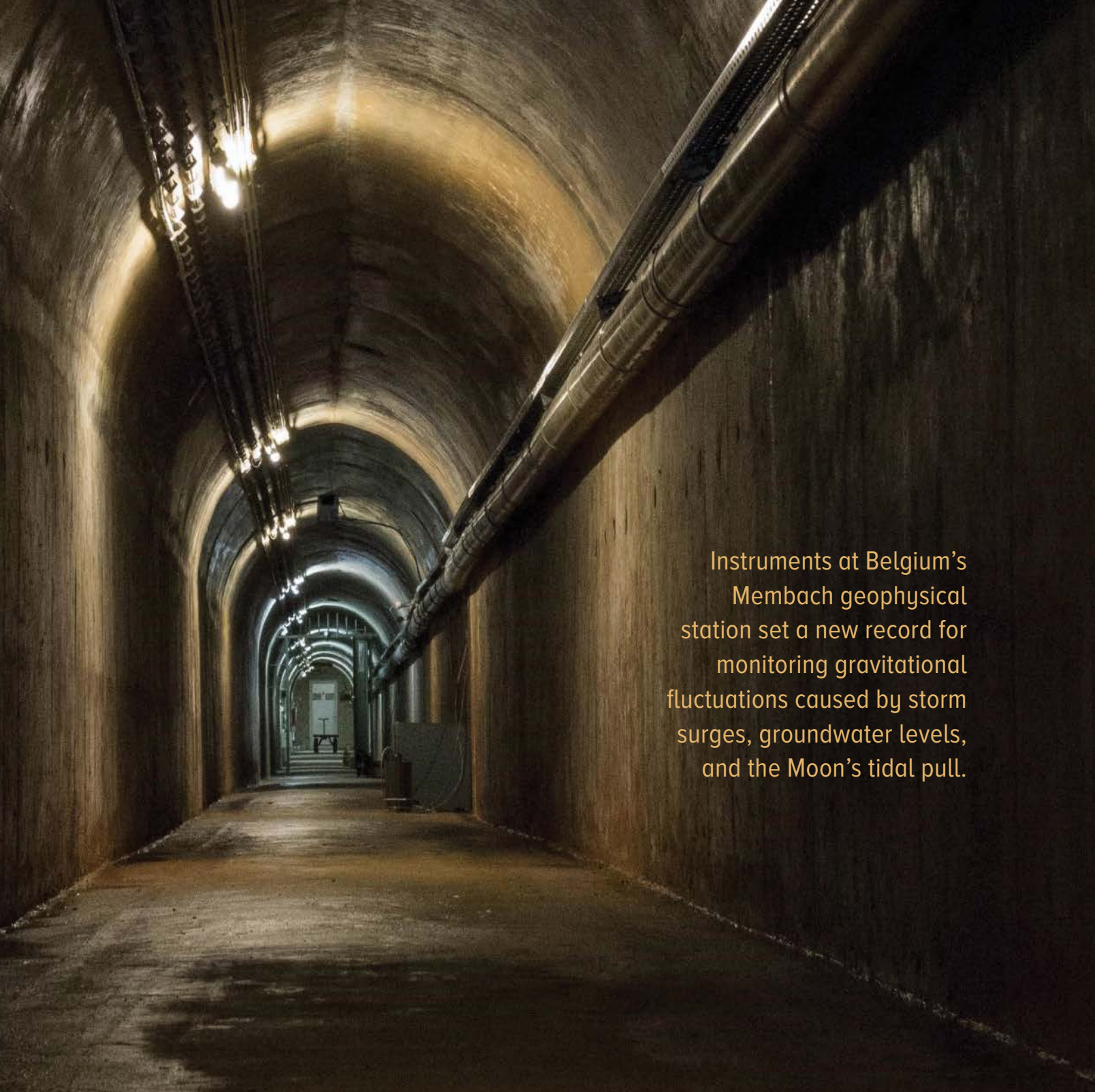


Recording Belgium's Gravitational History

By Michael Van Camp, Olivier Francis, and Thomas Lecocq



Instruments at Belgium's Membach geophysical station set a new record for monitoring gravitational fluctuations caused by storm surges, groundwater levels, and the Moon's tidal pull.

Deep beneath the surface of a Belgian forest, a silver-colored sphere of niobium metal floats in a vacuum that is only slightly warmer than the temperature in outer space, suspended by a magnetic field that exactly balances the force of Earth's gravity. Small fluctuations in the gravitational field pull and tug on the sphere, shifting its position ever so slightly, perturbing the magnetic field and sending electrical signals to nearby sensors.

This has been going on for the past 22 years, setting a new world record for the longest continuous gravitational measurement in the same location using this type of instrument. What's more, it is also the longest levitation of a superconducting mass.

The niobium sphere, about the size of a ping-pong ball, is encased in a metal cylinder, which is attached to vacuum lines and a tank of liquid helium that serves as a refrigerant. As long as the temperature inside the con-

At the end of this 130-meter-long gallery 48 meters beneath the surface of eastern Belgium (50.6085°N, 6.0095°E) sits an instrument that has recorded minuscule changes in Earth's gravitational field for more than 22 years. Credit: E. Coveliers, ROB

tainer is kept below 9.2 K, niobium's superconducting transition temperature, magnetic field lines flow around rather than through the sphere, keeping it suspended in the center of its little chamber. Niobium wire coils, also kept at this low temperature, offer no resistance to the electrical current that flows through them, producing the perfectly stable magnetic field that levitates the niobium sphere.

This otherworldly setup is the basis of an instrument called a superconducting gravimeter (SG). The SG measures fluctuations in Earth's gravitational field with a sensitivity far greater than previously possible using older instruments, which used reference weights attached to mechanical springs. For more than 2 decades, the SG C021 instrument in Belgium has faithfully recorded mass shifts caused by groundwater movements, the weight of storm surge water on the surface, and other phenomena that affect the nearby gravitational field [*Van Camp et al.,* 2017].

A Record for Longevity

Last September, the instrument, located at the Membach seismological station in eastern Belgium (see http://bit.ly/ROB-Membach), set records for the longest continuous time spent measuring gravity variations using a single SG in the same place, as well as the longest superconducting levitation of an artifact. On 18 September 2017, this instrument, which began operation 4 August 1995, had monitored gravity changes continuously for 8,081 days, or 22 years and 45 days. The previous record (8,080 days) was held by the SG T020, which measured at the Metsähovi research station in Finland from 10 August 1994 to 23 September 2016.

The superconducting gravimeter C021 (made by GWR Instruments, Inc.) resides inside a blue dewar of liquid helium in the Membach underground station. Credit: E. Coveliers, ROB.

The SG measurement principle is based on monitoring the levitation of a 4-gram superconducting niobium sphere. As far as we know, no object has ever been levitated for such a long time. In 1995, currents were injected into the superconducting coils, causing the sphere to levitate. More than 22 years later, the currents persist. This isn't new physics—in theory, a superconducting current can flow forever—but it is at least worthy of a place in the "cabinet of curiosities" of solid-state physics.

Relative and Absolute Measurements

Best practices in the science of gravity measurement require maintaining reference stations where gravity is monitored continuously for the long term. Operating high-quality observatory stations such as Membach at the state of the art has given scientists a thorough knowledge of the instrument. The resulting excellent measurements have proven useful in retrieving elusive geophysical and geodetic signals.

On average, one absolute gravity measurement is performed every month at the Membach station to complement the SG data, which measure changes in gravity. Absolute gravity is measured by repeatedly dropping a test mass inside a vacuum chamber and tracking its free fall using a laser interferometer.

These numerous absolute data points, combined with data from the SG, enabled the study of the uncertainties associated with the setup of an absolute gravimeter (AG) [*Van Camp et al.,* 2005].

The SG provides voltage variations (caused by the movement of the sphere), which are then calibrated into an acceleration expressed in nanometers per square second or microgals (1 microgal = 10 nanometers per square second, or one billionth of the standard gravitational acceleration g). In 1996, Membach scientists compared data from the SG C021 with an FG5 ballistic AG, determining the calibration factor at the parts per thousand level [*Francis,* 1997]. This precision is required to assess solid Earth tidal models, which simulate the Moon's and Sun's gravitational effects on the solid parts of Earth.

Signal Drift or Geophysical Trend?

The gravimeter's sensitivity to signals is defined using a mathematical transfer function, which can be experimentally determined from the size of the sensor's response to specific signals of known strength. The first determination of an SG transfer function was performed in Membach [*Van Camp et al.,* 2000]. SGs drift by a few billionths of g per year. We determined this tiny drift by comparing the SG C021 to the frequent AG measurements [*Francis,* 1997].

We had originally assumed that the SG instrumental drift was linear; even then, we could separate the instrumental drift from actual geophysical trends. Later, when more AG and SG data became available, *Van Camp and Francis* [2007] found a nonlinear, exponentially decreasing drift of the SG, most likely caused by the aging capacitance bridge, magnetic variations, gas adsorption onto the sur-

face of the levitating sphere (which floats in a small amount of residual helium), and/or helium gas pressure variations within the sensing unit, which is kept immersed in liquid helium.

From Evaporating Dew to Earthquakes and Storm Surges

Long-term fluctuations in gravity records remain poorly understood (Figure 1) despite their importance for geodesists. Long-period gravity changes are most likely induced by climatic or hydrogeological variations. Membach was one of the first SG sites where a comprehensive hydrogeological investigation could clearly show and quantify the influence of changes in groundwater within the unsaturated zone [*Van Camp et al.*, 2006]. The effect is about 50 nanometers per square second (5×10^{-9} *g*) over the course of a year.

Using rainfall modeling at the Membach station and another in Vienna, Austria, *Meurers et al.* [2007] improved solid Earth tidal analysis by 10%. The Membach SG is also able to measure the diurnal evapotranspiration from the deciduous forest

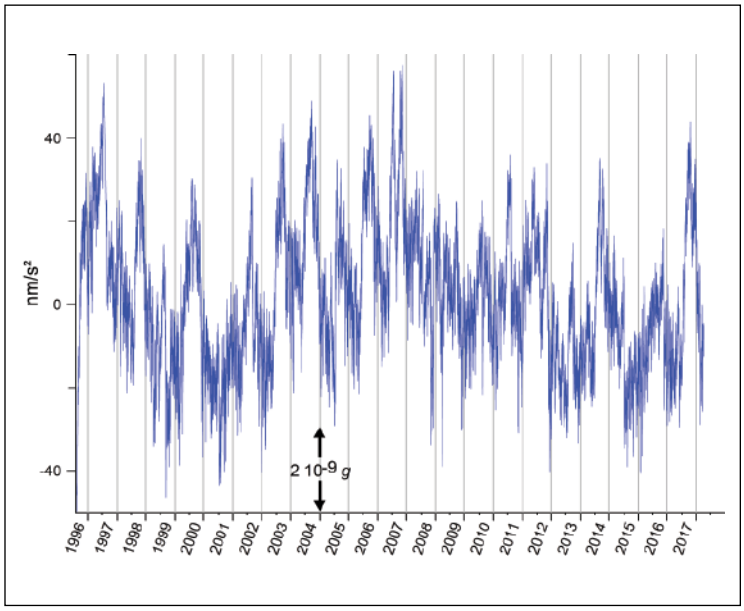


Fig. 1. This 22-year time series shows gravity changes in nanometers per square second monitored by SG C021, after correcting for instrumental drift and tidal, polar, and atmospheric effects. What remains is essentially due to hydrogeological effects. For example, during the summer, gravity increases because there is less groundwater above the instrument. The long-term variations remain poorly understood.

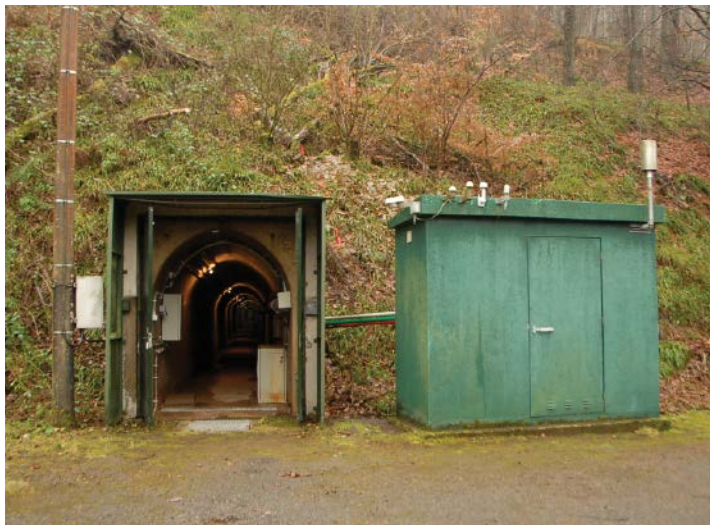
above the station: *Van Camp et al.* [2016] identified average daily changes in gravity smaller than 1 nanometer per square second (10^{-10} *g*), equivalent to a depletion of 1.7 millimeters of water per sunny summer day, which is at the limit of the resolution of terrestrial gravity measurements in the time domain.

On the large end of the scale, after a large earthquake, seismic waves interfere and cause Earth to ring like a bell at frequencies between 0.3 and 20 millihertz. The spectra of Earth's bell-like normal vibrational modes provide valuable information on the structure of the planet. SGs outperform the outstanding long-period STS-1 model seismometers at vibrational frequencies below 10 millihertz. For the lowest-frequency modes (below 1.5 millihertz), correcting for atmospheric pressure effects can improve resolution still further. The Membach instrument could demonstrate that SGs could outperform the STS-1 seismometers [*Van Camp,* 1999]. In the same spirit of innovation, the SG C021 was the first to stream real-time data to the Incorporated Research Institutions for Seismology (IRIS; https://www.iris.edu) seismic data center [*Van Camp et al.,* 2008].

Storm surges in the North Sea also affect local gravity by loading Earth's crust, depressing it as much as a few centimeters along the coastlines. Instruments at the Membach station, 200 kilometers from the coast, successfully measured an increase in gravity of about 20 nanometers per square second associated with one such storm [*Fratepietro et al.,* 2006]. Such a wind-stressed effect was first observed along the Baltic Sea by an SG in Finland [*Virtanen and Mäkinen*, 2003]. In both cases, the phenomena were later confirmed using geodetic measurements from GPS.

Twenty-Two Years and Counting

Despite providing numerous results of time-varying gravity, the ever young SG C021 is not willing to retire. Many scientific laboratories maintain an interest in the long-term monitoring of gravity. The staunch SG C021 is still contributing to numerous projects, including understanding long-period gravity variations (see http://bit.ly/long-period-gravity) and relative seismic velocity deviations (see http://bit.ly/LARGE-MEM) caused by groundwater changes [see also *Lecocq et al.,* 2017].



This doorway leads to the underground seismic monitoring station near Membach, Belgium. A superconducting gravimeter at this station has measured tiny fluctuations in Earth's gravitational field continuously for more than 22 years, setting a world record. Credit: Michel Van Camp

Acknowledgments

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From the bottom of acid lakes to high up in the sky, autonomous vehicles are changing the way scientists view and study Earth.

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13 Innovative Ways Earth Scientists Use Drones

By JoAnna Wendel

Humans are limited. We can't fly, breathe underwater, or survive in high temperatures. So we've left much of our scientific endeavors to instruments that extend and collect information beyond our senses, like seismometers that detect waves moving through Earth, lidar instruments that can measure elevation, and sensors that can determine the salinity of the oceans.

A new technology is increasingly furthering scientists' ability to capture Earth's vast, unreachable spaces: drones. These remote-controlled vehicles—sometimes called unmanned aerial vehicles (UAV) or autonomous underwater vehicles (AUV)—can travel to hazardous places humans try to avoid, like up close to a volcanic eruption or underneath meters of sea ice.

Drones are scattered across the planet, engaged in some heavy science. Below are some of the many ways

these robots help us to understand our world and the changes we make to it.

1 To Find Sources of Pollution

Scientists have invented an instrument that when affixed to a drone can help them detect and find the source of air pollution at ultrafine scales. The instrument uses spectroscopy to pinpoint the composition of a gas in a given area and precisely measure its concentration. Applications range from understanding dynamics at the boundaries of atmospheric layers to detecting chemical weapons. For more, see http://bit.ly/Eos-AirDrone.

2 To Study Why Climate Change Affects the Arctic So Severely

Scientists working on Alaska's North Slope are using drones to monitor gas concentrations in three dimensions over the Arctic. Some drones have even dropped buoys into the surface ocean. Combined, these instruments help researchers study the physics of the transition region between frozen sea and open water. This transition is a crucial element of climate models in the Arctic. For more, see http://bit.ly/Eos-ArticDrone.

3 To Peer into Volcanoes

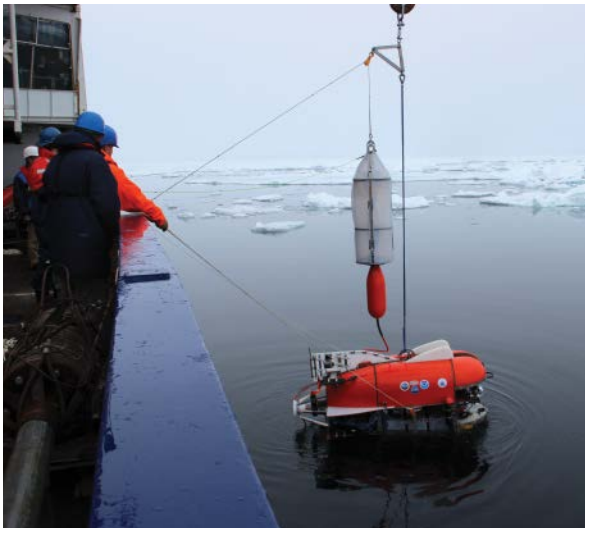
Researchers used drones to peer down the throat of one of the world's most active volcanoes: Stromboli, in Italy. The drone flew through clouds of ash plumes above the erupting volcano and snapped high-resolution pictures and videos of Stromboli's active and nonactive vents. For more, see http://bit.ly/Eos-VolcanoDrone.

An airborne spectroscopy system mounted on a remote-controlled multicopter. Credit: Jennifer Lauren Lee/NIST

4 To Show That Typical Ground Truths Overestimate Earth's Albedo

Researchers use satellites to study how Earth reflects and absorbs light. They rely on on-the-ground weather stations to calibrate their measurements. However, some drone-operating scientists recently found that these weather stations may be overestimating how much light gets reflected because they don't take into account certain surrounding topography. The drones helped to show that in some cases, albedo in certain places can be overestimated by up to 10%. For more, see http://bit.ly/Eos-AlbedoDrone.

A sonar-equipped drone surveys Costa Rica's Laguna Caliente in the Poás volcano. The lake is 3 times more acidic than battery acid. Credit: David McFarlane



An Arctic drone, the Nereid Under Ice, launches from the R/V Polarstern *in 2014. Credit: Chris German, WHOI*

5 To Explore the Expanse of Sea Ice Beyond the Decks of Icebreaker Ships

Researchers working in the Arctic and Antarctic have piloted drones to altitudes of 500 meters above the ice. Images collected helped scientists study the distribution of ice floes, mechanisms of pancake ice formation, and ocean wave–sea ice interactions. Drones in these environments can provide crucial information on how sea ice recovers in autumn, a time when harsh conditions hinder many research expeditions. For more, see http://bit.ly/Eos-SeaIceDrone.

6 To Study Propagating Cracks in Glaciers

In 2015, researchers used a drone to monitor a crack that had sprouted in Greenland's Bowdoin Glacier. Over several days, the drone captured thousands of images, allowing researchers to model the crack's propagation. Someday, these kinds of data may allow scientists to predict when an iceberg might calve from a glacier. For more, see http://bit.ly/Eos-IcebergDrone.

7 To See an Entire Floodplain from the Sky

Scientists are using drones to help them study the geologic remnants of the Lake Missoula floods, in which more than 2,000 cubic kilometers of water burst from a glacial dam and flowed across the Pacific Northwest as many as 100 times between 18,000 and 13,000 years ago. The drones survey wide swaths of land, searching for large-scale ripple marks and flow scars—features too vast to see from the ground. For more, see http://bit.ly/MissoulaDrone.

A view of the port bow of the USS Conestoga *covered with marine organisms, including a giant Pacific octopus. In 2014, NOAA scientists used an AUV to identify the shipwrecked Conestoga. Credit: NOAA ONMS*

8 To Help Detect Gas Leaks Underwater

Researchers have tested a method that can help AUVs pinpoint dangerous gas emissions from underwater sources, such as oil wells or stored natural gas. The idea goes like this: When broad surveys detect some form of underwater leak, researchers deploy a drone to find it. Then each location where the drone fails to detect the origin of the leak will be used to update a map so that it shows regions where the drone has the next-highest probability of finding the leak. For more, see http://bit.ly/Eos-GasDrone.

9 To Map the Bottom of Highly Acidic Lakes

Across Earth are 35 volcanic lakes that can build up gas to the point where the waters sometimes explode. In 2016, scientists traveled to Laguna Caliente in Costa Rica to test out an autonomous underwater vehicle—basically, a drone that can swim. For more, see http://bit.ly/Eos-AcidDrone.

10 To Visit Under-Ice Ecosystems

In 2014, some scientists tested an AUV in the ocean near Greenland, sending it to examine the under-ice ecosystem. The drone revealed a world that surprised the researchers: one in which high amounts of algae and other biology likely support a diverse food web under the ice. Researchers hope that a better understanding of the existing ecosystems will help them see how climate change may alter those ecosystems. For more, see http://bit.ly/Eos-IceDrone.

11 To Help Track Underwater Avalanches

In 2015, researchers deployed AUVs to help them place beach ball–shaped benthic event detectors on the seafloor in Monterey, Calif. The balls are engineered to roll with material that slides down continental slopes. Through these sensors, scientists hope to understand how quickly and how far sediment flows during underwater avalanches. For more, see http://bit.ly/Eos-AvalancheDrone.

12 To Find Shipwrecks

In 2014, National Oceanic and Atmospheric Administration (NOAA) scientists sent an AUV equipped with sonar capabilities to investigate an ancient shipwreck about 5 kilometers off the coast of Southeast Farallon Island. Five years prior, a routine sonar survey of that patch of ocean floor had revealed a previously overlooked shipwreck. The drone, along with another remotely operated vehicle that took pictures and videos, discovered that the shipwreck was the long-missing USS *Conestoga,* which researchers had been searching for since it vanished 95 years ago. For more, see http://bit.ly/Eos-ShipwreckDrone.

13 To Detect Ever-So-Slight Changes in Earth's Elevation

Drones in the Jet Propulsion Laboratory's Uninhabited Aerial Vehicle Synthetic Aperture Radar program help researchers study Earth's surface. The autopiloted crafts are programmed to fly the same path again and again, using radar signals to gather information about the surface. When these signals are compared with one other, scientists can see how the land has changed between flights. These craft can detect land subsidence and the tiny changes in elevation after an earthquake. For more, see http://bit.ly/SAR-Drone.

Author Information

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Revised AGU Position Statement Addresses Climate Intervention

AGU has adopted a revised position statement on climate intervention, defined as purposeful intervention by humans to alter Earth's climate. The updated position statement, approved 12 January 2018 by AGU's Board of Directors, replaces a prior AGU statement in which such interventions were referred to as "geoengineering solutions."

The statement, titled "Climate Intervention Requires Enhanced Research, Consideration of Societal and Environmental Impacts, and Policy Development," also discusses two distinct categories of intervention that are most prevalent in current research: carbon dioxide removal and albedo modification (see http://bit.ly/intervention-statement). In addition, the statement includes updated references, such as two 2015 reports by the National Academies.

A panel of subject matter experts who are also AGU members crafted the newly adopted position statement in 2017. The group worked to ensure that the statement was updated to reflect current scientific understanding in the field.

Panelists

David Victor (Chair)
University of California, San Diego, and Brookings Institution

Ken Caldeira
Carnegie Institution for Science

Piers Forster
University of Leeds

Ben Kravitz
Pacific Northwest National Laboratory

Marcia McNutt
National Academy of Sciences

Joyce Penner
University of Michigan

Alan Robock
Rutgers University

Naomi Vaughan
University of East Anglia

Jennifer Wilcox
Colorado School of Mines

"Climate intervention could play a key role in managing the effects of climate change, but our scientific understanding of its impacts remains poor," said David Victor of the University of California, San Diego, and the Brookings Institution, who chaired the panel. He stressed that more research is needed to better understand the potential risks and opportunities of climate intervention.

Under Current Discussion by Policy Makers

This update to AGU's position on this topic is timely, given that the U.S. House of Representatives Committee on Science, Space, and Technology recently held a hearing on climate intervention. The hearing, on 8 November 2017, titled "Geoengineering: Innovation, Research, and Technology," addressed current scientific understanding of geoengineering, the need for research, and the need for caution in implementation.

AGU has taken a public position on climate intervention (then called geoengineering) since 2009 by adopting a statement on 13 December of that year in collaboration with the American Meteorological Society (AMS). AMS had adopted the statement during the preceding summer. AGU independently revised and reaffirmed its initial statement in February 2012.

Resources for Policy Makers and AGU Members

Position statements by scientific societies can serve as resources for policy makers as they seek to understand science issues and craft legislation. AGU develops and maintains position statements to provide scientific expertise on significant policy issues related to the understanding and application of the Earth and space sciences.

AGU encourages its members to use the organization's position statements to guide conversations with students, local communities, policy makers, and other members of the public. AGU makes available its position statements in the AGU Resource Center (see http://bit.ly/AGU-policy-resources). They, along with AGU's Advocacy Policy, are valuable resources for those looking to connect with the public on issues related to Earth and space sciences.

By **Elizabeth Landau** (email: elandau@agu.org), Assistant Director, Public Affairs, AGU

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Scientists Create Catalog of Alto Tiberina Fault in Italy

A colocated seismic and GPS station belonging to the Alto Tiberina Near Fault Observatory multidisciplinary network. The station is situated on the western flank of the Upper Tiber Valley in the northern Apennines of Italy. Credit: Lauro Chiaraluce

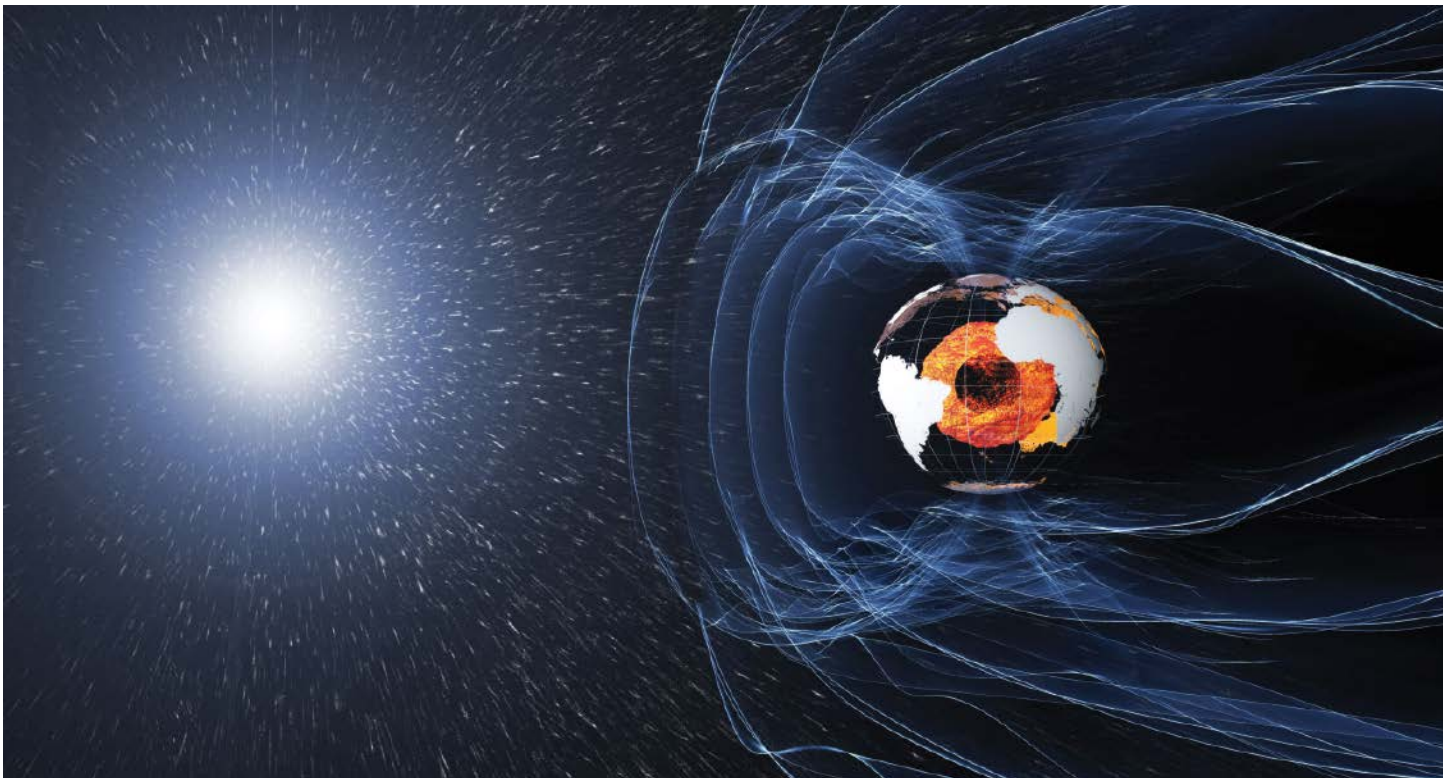
The Apennine Mountains dominate the Italian peninsula, spanning 1,200 kilometers and reaching peaks as high as 2,912 meters. In the northern part of the range lies the Alto Tiberina fault. In a recent study spanning 4.5 years, scientists from Italy's Istituto Nazionale di Geofisica e Vulcanologia (INGV) created a detailed catalog of the seismic activity in the region that is giving them the best look yet at the fault's behavior and seismic potential.

The Alto Tiberina fault is a normal fault, meaning that the two overlapping slabs of Earth's crust are being pulled apart, with the hanging wall sliding down the face of the footwall. This movement can occur in either abrupt slips or gradual "creeping." The Alto Tiberina fault is also categorized as low angle, meaning that the angle formed by the fault line with the horizontal plane is small, about 15°–20° in this case. The anatomy of faults like Alto Tiberina is often dominated not by large occasional earthquakes but by consistent clusters of tiny ones, a concept known as microseismicity.

To get a more complete picture of what was going on at the fault, *Valoroso et al.* used a dense network of seismic and geodetic sensors to record data on the crust's movement in the region from 2010 to 2014 at depths between 4 and 16 kilometers. The networks belong to the Alto Tiberina Near Fault Observatory, a modern multidisciplinary research and monitoring infrastructure managed by INGV. They detected more than 37,000 quakes with a magnitude of less than 3.9, occurring at a very consistent rate of approximately 2.2 events per day. The enormous trove of data provided the most detailed record to date of how the fault is evolving over time and in space.

In particular, the authors found 97 clusters of small repeating earthquakes. These miniquakes tended to occur in pairs, and the time interval between them seems to predict the rate at which the hanging wall slides down the footwall. Using these results, the authors suggest that this consistent creeping may drive the behavior of the fault at large, which previously has been calculated to be slipping at a rate of 1.7 millimeters per year. (*Journal of Geophysical Research: Solid Earth*, https://doi.org/10.1002/2017JB014607, 2017) **—David Shultz, Freelance Writer**

Tracing Electric Currents That Flow Along Earth's Magnetic Field



An illustration of Earth's magnetic field lines, which are generated by the planet's swirling liquid outer core and curve as they get buffeted by the solar wind. Credit: ESA/ATG Medialab

That planet Earth is essentially a giant magnet is not a great secret: A compass works because one end of its magnetized needle is constantly drawn toward the North Pole. Scientists believe that Earth's magnetization is caused by a sea of liquid metal flowing past its solid iron core, creating electric currents and, in turn, magnetic fields.

Earth's magnetic fields extend to the ionosphere—a layer of plasma and neutral gases about 50–500 kilometers above Earth's surface—and the magnetosphere, which starts at the outer edges of the ionosphere and stretches many thousands of miles into space. Magnetic fields from Earth and the Sun affect the behavior of charged particles in the magnetosphere.

Earth's magnetic field is highly conductive and carries charged particles in a predictable fashion along field lines (giving rise to aptly titled field-aligned currents). Starting in the early 1900s, scientists conceptualized an exchange of energy and momentum between the solar wind (a stream of charged particles emitted by the Sun that flows throughout the solar system) and our planet's own magnetic field.

Since then, we have learned more about the distribution of field-aligned currents throughout the ionosphere. In addition, the Active Magnetosphere and Planetary Electrodynamics Response Experiment (AMPERE) satellite network more recently has allowed scientists to study large-scale field-aligned currents in great detail, collecting data as often as every 10 minutes.

In a new paper, *McGranaghan et al.* combine data from AMPERE and a constellation of three European satellites known as Swarm to compile a data set of small-scale (up to about 150 kilometers wide), medium-scale (about 150–250 kilometers wide), and large-scale (wider than 250 kilometers) field-aligned currents.

The researchers found that many differences between small-scale and large-scale currents—such as their behavior, the dependence of their behavior on local time and solar wind conditions, and how closely their orientation aligns with that of the planet's magnetic field—are not straightforward. For example, they found that small-scale field-aligned currents potentially contribute a disproportionate amount of heat to regions of the ionosphere and the thermosphere (an upper layer of Earth's atmosphere).

If future studies of field-aligned currents incorporate data from a variety of scales, scientists will be able to understand better the complexities of the space environment and the resolution needed to capture them. The researchers note that this better understanding, in combination with new and improved physics, has the potential to critically affect our understanding of the system at large. (*Journal of Geophysical Research: Space Physics*, https://doi.org/10.1002/2017JA024742, 2017) **—Sarah Witman, Freelance Writer**

Reckoning with Climate's Most Challenging Questions

From heat waves, drought, and wildfires to record-low Arctic sea ice levels to flooding and heavy rainfall, scientists worldwide have struggled to understand the most critical aspects of climate. In the coming decades, as these symptoms persist, humans must—in the interest of environmental health and to prevent trillions of dollars in economic losses—be prepared to deal with the impacts these changes will have on roads and buildings, agriculture, water availability, and other critical infrastructure.

Following years of discussion among climate scientists, natural resource managers, and policy makers, the World Climate Research Programme has identified seven Grand Challenges for the climate community. Now *Weatherhead et al.* have outlined an overarching plan for addressing these challenges with observations that will help resolve previously unanswered questions regarding climate change, variations, and extremes.

The team of researchers agreed that existing Earth observation systems are limited, leading to large unacceptable uncertainties regarding future climate and the risks associated with extreme events. These limitations are partly technological, but more problematic is a lack of coordination and planning. Scientists, environmental managers, and other officials tend to focus on specific, individual problems related to weather prediction, land resource management, agriculture, or air pollution, rather than examining the big picture, the Earth system as a whole. Plus, the national and international agencies that oversee environmental issues have wildly different budgeting and decision-making structures. The team suggests that there ought to be a comprehensive Earth-observing system that could allow scientists to test hypotheses that consider the entire environmental system.

The researchers also emphasize that rather than letting the available technology determine what scientific studies can be done, we should aim to let science questions drive the technology we choose to invest in. They compare the situation to the search for the Higgs boson, in which the standard model of particle physics served as a scientific blueprint for experimentation and numerous countries invested in funding and staffing the Large Hadron Collider (the facility at which the elusive particle was eventually detected). In terms of Earth's environment, climate models and data—which shed light on clouds and air circulation, melting ice, extreme weather, sea level and coastal changes, water for the world's food-producing regions, the carbon cycle, near-term climate, and more—can be effectively coordinated to provide a similar scientific blueprint in the future. The economic value of being able to provide input to these challenging societal needs far outstrips the current investment in Earth observations.

By collaboratively investing in the collection of climate data—via satellite, piloted aircraft, drones, ground-based sensors, and contributions from citizen scientists—the researchers say, countries can continue to develop continuous, long-term (multidecadal) data records spanning all seasons and regions of the globe. With these records, scientists can better understand environmental processes, answer key questions about climate, and improve weather and climate predictions years (even decades) in advance. In turn, with more accurate forecasts, policy makers and other officials could more effectively work to mitigate and adapt to changes and potentially develop responses such as geoengineering: engineering Earth itself to adapt to the changing climate.

In addition, the researchers say, there would need to be a system in place to ensure that all observations are efficient and are effective at addressing proposed science questions. They recommend setting quantifiable performance goals to best serve science and society, again, treating these observations as an investment for society rather than an indulgence to satisfy curiosity.

This study outlines a different vision for climate observations of the future, where observations are viewed as a necessary part of infrastructure to serve society and allow for cost-effective planning of infrastructure and human activity. This alternative perspective allows an assessment of the value of these observations and ensures that nations, companies, and individuals have the information they require to make critical decisions. By developing a cohesive Earth-observing system, scientists and policy makers alike can be singularly empowered to better understand and respond to our world's changing climate. (*Earth's Future,* https://doi.org/10.1002/2017EF000627, 2018) **—Sarah Witman, Freelance Writer**

Correction to "Postcards from the Field" from March 2018: The coordinates of La Romaine 3 reservoir are 51.12°N, 63.42°W.

The Curious Case of the Ultradeep 2015 Ogasawara Earthquake

On 30 May 2015, a powerful earthquake struck west of Japan's remote Ogasawara (Bonin) island chain, which lies more than 800 kilometers south of Tokyo. Although it caused little damage, the magnitude 7.9 quake was noteworthy for being the deepest major earthquake ever recorded—it occurred more than 100 kilometers below any previously observed seismicity along the subducting Pacific plate—and the first earthquake felt in every Japanese prefecture since observations began in 1884.

The 680-kilometer-deep earthquake was also notable for its unusual ground motion. Instead of producing a band of high-frequency (>1 hertz) seismic waves concentrated along northern Japan's east coast, as is typical for deep subduction-related earthquakes in this region, this event generated strong, low-frequency waves that jolted a broad area up to 2,000 kilometers from the epicenter. To explain this uncharacteristic wavefield, *Furumura and Kennett* analyzed ground motion records from across the country and compared the results with observations from a much shallower, magnitude 6.8 earthquake that occurred within the Pacific slab in the same area in 2010.

The results indicated that the peculiar ground motion associated with the 2015 earthquake was due to its great source depth and to its location outside of the subducting slab. The team found that the ultradeep event was missing high-frequency components and generated milder ground motions at regional distances, whereas the 2010 earthquake included the high-frequency components but was narrowly focused.

After contrasting three-dimensional numerical simulations of seismic wave propagation from both events, the researchers concluded that waves originating from a deep source outside of the slab can develop a distinctive, low-frequency wavefield as they interact with continental crust and the region's subducting slabs. Because this wavefield is usually concealed by higher-frequency, slab-guided waves, the few existing examples of this phenomenon will likely provide valuable information on local crustal structure and, in the case of the 2015 Ogasawara event, the morphology of the Pacific plate. (*Journal of Geophysical Research: Solid Earth*, https://doi.org/10.1002/2017JB014519, 2017) **—Terri Cook, Freelance Writer**

Fracking May Cause More Earthquakes Than We Thought

Human activities that change stresses in Earth's surface—like hydraulic fracturing (or fracking) and wastewater disposal—are known to cause earthquakes, even in areas where earthquakes are not historically common. In hydraulic fracturing, a slurry of water, sand, and chemicals is pumped through the ground at high pressures, cracking open rocks to release oil and natural gas. This produces tiny earthquakes that usually can't be detected without sensitive instrumentation.

Disposing of wastewater by injecting it into the crust can also trigger quakes: As the increased fluid pressure migrates away from the well, it can reach a well-oriented fault that is close to breaking and cause it to slip. Because these deeper faults are often larger, they can produce larger earthquakes. Understanding the relationship between these processes and earthquakes is crucial to mitigating seismic hazards.

Gas drilling and flaring in North Dakota, visible from the Suomi National Polar-orbiting Partnership satellite, in 2012. This type of activity can cause earthquakes. Credit: NASA

To assess this connection, *Yoon et al.* zeroed in on a sequence of earthquakes that occurred in central Arkansas in 2010 and 2011. At that time, several companies were extracting natural gas from the Fayetteville Shale, one of the largest gas fields in the country.

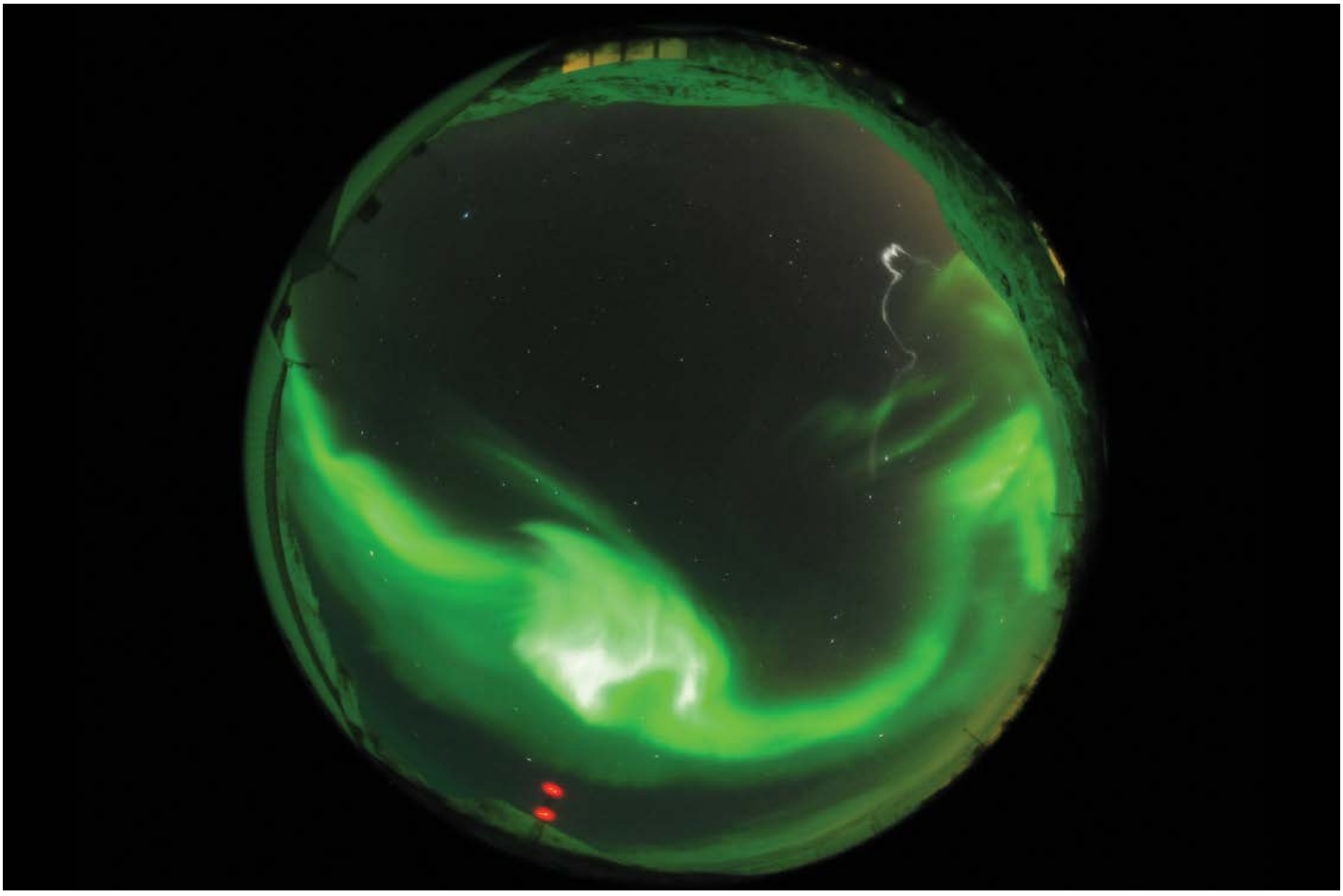
Soon after wastewater injection began in July 2010, scientists started to detect seismic activity in the surrounding region, which led to a series of felt earthquakes. When a magnitude 4.7 earthquake struck on 27 February 2011, the Arkansas Oil and Gas Commission issued an emergency order to stop all wastewater injection. After that, seismicity decreased but for months afterward remained higher than the historical rates.

To understand how this earthquake sequence got started, the researchers analyzed seismic activity in the area before the quake, between June and September 2010. Because Arkansas has only a few instruments to record ground shaking, they used an advanced data mining algorithm inspired by the Shazam music recognition app to detect the 1,740 largest quakes, which formed 16 tight clusters. They compared these data to public records on wastewater injection and fracking activity in the area.

A small number of these earthquakes correlated with wastewater injection. The vast majority correlated with fracking operations at 17 out of 53 nearby production wells active during this time. Compared with quakes typically caused by fracking, these events were bigger, more numerous, longer lasting, and farther from the well, all of which indicate a high level of stress in the area. Deeper, larger faults would also have been highly stressed and unstable, easily prone to slipping and generating felt earthquakes with a magnitude greater than 4.

This study bolsters the case that earthquakes are triggered not only by wastewater disposal but also by hydraulic fracturing. It also demonstrates how sensitive, efficient, cost-effective monitoring techniques—inspired by new data mining technologies—can help scientists understand the big picture of earthquake activity. Continuous monitoring before, during, and after fracking and wastewater injection could offer new information to help shape policy aimed at reducing earthquake hazards. (*Journal of Geophysical Research: Solid Earth*, https://doi.org/10.1002/2017JB014946, 2017) **—Sarah Witman, Freelance Writer**

Sounding Rockets Probe the Northern Lights Above Norway



An all-sky image with the breakup aurora (bottom) and a trail of the luminescent puff (top right). Credit: National Institute of Polar Research, Japan

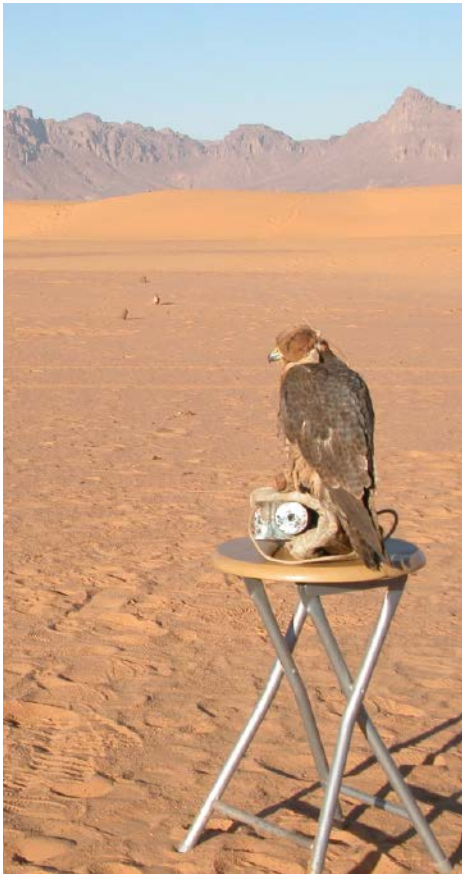
When a dazzling aurora lights up the polar skies, it's a sign of a disturbance in Earth's magnetosphere, the magnetic shield that protects our planet from solar radiation. The aurora borealis and aurora australis—also known as the northern and southern lights—occur when solar particles penetrate Earth's magnetic field and collide with oxygen and nitrogen, releasing photons that make the sky glow blue, green, red, and yellow. Now, thanks in part to the lucky timing of a sounding rocket, researchers have obtained rare measurements of wind speeds near an aurora as it began to dance.

Auroras often start with a single arc that brightens as it darts poleward and then breaks into many shimmering bands of light. Scientists aren't entirely sure of what causes this dance, called a substorm, but one hypothesis is that it occurs when a surge of solar plasmas shifts the direction of wind in the upper reaches of Earth's atmosphere, causing energy in the magnetosphere to contract and then snap back like a rubber band.

Oyama et al. set out to investigate this dynamic process near the Andøya Space Center in Norway, where scientists frequently launch sounding rockets into the thermosphere, a thick, electron-dense atmospheric layer that begins roughly 85 kilometers above Earth and absorbs much of the Sun's ultraviolet radiation. The sounding rocket released luminescent puffs of vapor into the thermosphere just as the substorm began, allowing the team to measure nearby wind speeds. The team also used a ground-based optical imaging tool called a Fabry-Pérot interferometer to measure wind speeds on the basis of shifting wavelengths of light near the auroral arc.

Taken together, the two measurements reveal that although wind speeds within about 70 kilometers of the auroral arc increased sharply as the substorm gained intensity, winds between 160 and 200 kilometers away from the arc's edge were not affected. The finding adds to scientists' understanding of how energy and mass flow throughout the dynamic layers of Earth's magnetized upper layers of atmosphere and could help scientists predict the effects of major disturbances such as solar flares. (*Journal of Geophysical Research: Space Physics*, https://doi.org/10.1002/2017JA024613, 2017) **—Emily Underwood, Freelance Writer**

Medieval Temperature Trends in Africa and Arabia



To better characterize temperature fluctuations in Africa and Arabia during medieval times, researchers synthesized paleotemperature records from across the region, including from (left) the Tanzanian portion of Lake Tanganyika and (right) the Sahara in southeastern Libya. A core from Lake Tanganyika represents one of the few medieval paleotemperature reconstructions that are available from the East Africa Rift. Credit: (left) Andreas31, CC BY-SA 3.0 (http://bit.ly/ccbysa3-0); (right) © Karsten Battermann

Reconstructions of Northern Hemisphere temperatures have repeatedly indicated that the Afro-Arabian region experienced climate perturbations, including an extended period of anomalously warm conditions, during medieval times. Because this Medieval Climate Anomaly represents the closest analogue to modern warming, it defines a crucial baseline by which modern postindustrial climate trends can be compared.

Although the Medieval Climate Anomaly has also been documented in other parts of the world, its occurrence on the Arabian Peninsula and the African continent, which together make up about one quarter of Earth's landmass, is less certain. This is due to the lack of high-quality proxy records, such as ice cores and tree rings, in the region. To help fill this gap, *Lüning et al.* correlated and synthesized the findings of 44 published paleotemperature case studies from across the region and mapped the resulting trends of the anomaly's central period, which lasted from about 1000 to 1200 CE.

The results indicate that the majority of onshore Afro-Arabian sites experienced warming during the Medieval Climate Anomaly. The one exception was the southern Levant, which endured a cold phase during the same interval. From offshore records, the team also documented cooling in locations that currently experience cold-water upwellings but generally warmer conditions away from these upwelling zones during the same period.

In some records, the researchers noted the presence of obvious cold spikes during intervals corresponding to decreased solar activity or declining ocean cycles. This, they argue, suggests that solar forcing and changing ocean circulation are the most likely causes of medieval-era climate change.

This study represents a step toward globally characterizing the Medieval Climate Anomaly, an improved understanding of which will help scientists refine global climate models and improve hindcasting. To date, however, very few paleotemperature data exist from Afro-Arabia; the authors note that all of West Africa is currently represented by a single data point. Systematic research will be necessary to adequately reconstruct medieval paleotemperature patterns and their causes across this vast region. (*Paleoceanography and Paleoclimatology*, https://doi.org/10.1002/2017PA003237, 2017) **—Terri Cook, Freelance Writer**

First Near-Global Measurements of Isotopic Nitrous Oxide

Nitrous oxide (N_2O) is a double-edged sword. Whereas the World Health Organization lists the compound as an essential medicine for its anesthetic properties, it is also a greenhouse gas nearly 300 times more potent than carbon dioxide, as well as the stratosphere's greatest ozone-depleting substance.

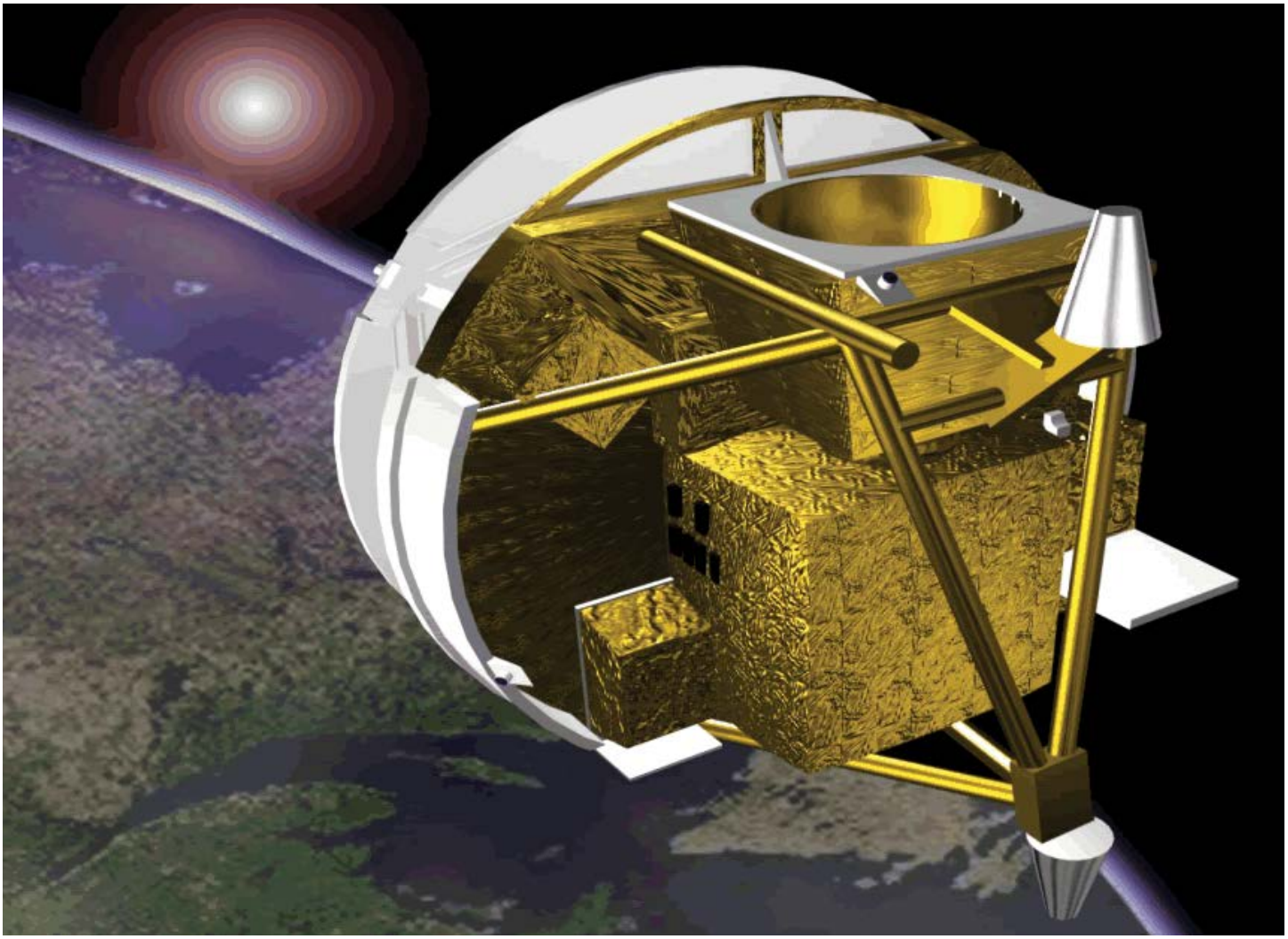
Because N_2O has both natural and anthropogenic sources, pinpointing its origin and understanding how this gas circulates through the atmosphere are crucial steps for reducing its climatic and environmental impacts. Although isotopic variants of nitrous oxide can be used to trace its flow through the atmosphere, scientists have been unable to fully harness these tools due to the severe constraints imposed by having to collect data from aircraft and high-altitude balloons.

Bernath et al. have measured, for the first time, near-global distributions of three isotopic derivatives of N_2O in the upper troposphere and the stratosphere using infrared remote sensing data collected by the Atmospheric Chemistry Experiment (ACE) aboard the Canadian SCISAT satellite. The results, which span the period 2004–2013, show that ultraviolet photolysis increases the relative abundances of the heavier N_2O molecules at higher altitudes and toward both poles.

These observations agree with the researchers' Whole Atmosphere Community Climate Model predictions, which suggest that the observed distributions of isotopic N_2O are due to seasonally increased sunlight over the poles. The extra light enriches the heaviest isotopes during each hemisphere's summer and autumn seasons.

In addition to representing a valuable technological advance, these results have important implications for improving models of atmospheric circulation, understanding seasonal oscillations in the stratosphere, and quantifying the various N_2O sources, including production by high-energy particle bombardment in the upper atmosphere. (*Geophysical Research Letters*, https://doi.org/10.1002/2017GL075122, 2017)

—Terri Cook, Freelance Writer



New research uses data from the SCISAT satellite to track atmospheric nitrous oxide. Credit: NASA

Humans to Blame for Higher Drought Risk in Some Regions

Despite doubts raised by recent studies, new research confirms that a drying trend has emerged in the midlatitudes of Earth's northern continents, that this is mainly attributable to anthropogenic climate change, and that this threat to global water and food supplies might have been underestimated by most CMIP5 models. Credit: C Watts, CC BY 2.0 (http://bit.ly/ccby2-0)

The world's population relies on the global water cycle for food security and economic prosperity. However, human activities may be jeopardizing this critical resource; new research by *Douville and Plazzotta* confirms that human emissions of greenhouse gases have already begun to alter the water cycle, resulting in a drying trend and increased risk of drought in certain parts of the world.

To many researchers, these new findings are not surprising. For more than a decade, observational and numerical modeling studies have predicted that anthropogenic emissions would cause warming that could change the water cycle and expand dry regions.

Other recent studies have cast serious doubts on these predictions. Two studies cautioned that simplified calculations used to process observational data could result in incorrect predictions of evaporation due to warming over land. Other researchers uncovered large uncertainties in climate predictions made by the fifth phase of the Coupled Model Intercomparison Project (CMIP5), a widely used multimodel tool for climate analysis.

The authors of the new study set out to address these doubts. They performed a three-pronged analysis, investigating recent observational data and long-term CMIP5 projections of drying trends over the midlatitudes of the northern continents in summertime.

In addition, the researchers applied a previously developed algorithm to distinguish between anthropogenic and natural influences on observed variations in sea surface temperatures and sea ice concentration. Then they performed multiple climate simulations to determine the causes of recent changes in soil moisture and other land-based variables.

The results of the analysis suggest that a summertime drying trend has indeed emerged over the midlatitudes of the northern continents and that anthropogenic climate change is the main cause. This drying appears to be the beginning of a long-term trend.

The findings also suggest that in the absence of direct observations, most CMIP5 models previously underestimated long-term summertime drying. However, the authors stress that further work is needed to improve strategies for attributing climate changes to specific causes, especially with the upcoming release of CMIP6, which will provide new historical climate simulations.

Meanwhile, the authors say, addressing anthropogenic global warming should remain a central strategy to maintaining water supplies and food security around the world. (*Geophysical Research Letters*, https://doi.org/10.1002/2017GL075353, 2017) **—Sarah Stanley, Freelance Writer**

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Atmospheric Sciences

Faculty Positions in Atmospheric Sciences The Department of Atmospheric Sciences, National Central University (NCU) in Taiwan invites applicants for one to two faculty positions at the assistant, associate or full professor levels that will start from 1 August 2018. Outstanding candidates with Ph.D. degree and independent research experience are encouraged to apply. We especially welcome applicants with expertise in one or more of the following research areas: (1) Large-scale dynamics, diagnostic analysis, and modeling. (2) Studying the high-impact weather using state-of-the-art observational instruments, analysis techniques or advanced models. Particular consideration will be given to candidates working in areas that complement and enhance the existing research programs in the department. The successful candidates will be expected to have a strong commitment to teaching at both the undergraduate and graduate levels in Mandarin or English, including supervising and mentoring of graduate students, maintaining strong research program, and provide effective service to the department, university and larger professional community. Applications should include a cover letter, a curriculum vitae, research and teaching statements, and three recommendation letters. For full consideration applications should be submitted through Academic Jobs Online (https://academicjobsonline.org) before March 11, 2018. Inquiries about the position should be directed to the search committee at atmsearch@atm.ncu.edu.tw.

Interdisciplinary

Graduate Student Research and Teaching Assistantships. The Department of Environmental, Earth, and Atmospheric Sciences (EEAS) at the University of Massachusetts Lowell (www.uml.edu/sciences/eeas) offers several graduate research and teaching assistantships for motivated students for the Fall 2018 semester. Several positions are currently open. Information about the positions can be found on our webpage.

The University of Massachusetts Lowell (also known as UMass Lowell) is an urban public research university in Lowell, Massachusetts, with nearly 1,150 faculty members and 18,058 students. EEAS offers unique interdisciplinary study programs encompassing Geosciences, Meteorology, Hydrology, and Environmental Chemistry. EEAS offers undergraduate and graduate degrees in Environmental Sciences, with concentrations in Environmental Studies, Geosciences, and Atmospheric Sciences. Graduate School admission policies are found under https://www.uml.edu/grad/.

THE HONG KONG UNIVERSITY OF SCIENCE AND TECHNOLOGY

Faculty Positions
Ocean Science

The University is a world-class research institution with over 600 faculty members whose research ranges from science to engineering, business and social sciences. It is ranked No. 1 in Asia by QS World University ranking in 2011-2013. Located in the Clear Water Bay area, HKUST's campus has a magnificent ocean view and is widely known as one of the most beautiful campuses in the world. The city of Hong Kong ranks among the most international and dynamic cities.

The University has set up Department of Ocean Science under the School of Science in February 2018. The new department will primarily focus on marine ecology (existing strength), oceanography, and ocean technology covering coastal region to deep-sea. The Department is seeking applications for tenure-track positions at the ranks of Assistant Professor or above in physical, chemical, biological oceanography, ocean sensor and sensing technology and ocean data science.

Applicants should have a PhD degree in any of the above fields, preferably with at least 2 years of post-doctoral experience. Successful candidates should have strong research track records. They are expected to establish an independent research program and contribute to the missions in undergraduate and postgraduate education of the newly established Department of Ocean Science. The medium of instruction is English.

HKUST offers internationally competitive salary commensurate with qualifications and experience. Fringe benefits include annual leave, medical and dental benefits. Housing benefits will also be provided where applicable. Initial appointment for Assistant Professor/Associate Professor will normally be on a three-year contract, renewable subject to mutual agreement. A gratuity will be payable upon successful completion of contract.

Application Procedure

Application materials including a cover letter, detailed curriculum vitae, research accomplishment and proposal (maximum 3 pages), three representative publications and teaching statement (maximum 1 page) should be sent to the Chair of Search and Appointments Committee (ocessearch@ust.hk). Applicants should arrange at least 3 letters from referees directly to the Chair of Search and Appointments Committee to complete their application. The recruitment process will continue until all positions are filled.

(Information provided by applicants will be used for recruitment and other employment-related purposes only.)

Postcards from the Field

Hey, AGU!

Here we are, having fun with the sediment catch of the day. We have been collecting sediment samples before and after Hurricane Harvey from a modern flood delta in San Luis Pass on the Texas coast to look at grain size changes. Fall has brought sunny but crisp weather to the coast—perfect for sailing and sampling!

Pictured are (from left to right) Rachel Clark, Delaney Robinson, Carolina Ramon, and Ben Chang.

Cheers!

—Carolina Ramon, Department of Earth and Atmospheric Sciences, University of Houston, Houston, Texas

View more postcards at *http://americangeophysicalunion.tumblr.com/tagged/postcards-from-the-field.*

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