VOL. 99 • NO. 5 • MAY 2018

EOS

Earth & Space Science News

Wicked Problems of Living in a Seismic Zone

Sampling the World's Stratosphere

Soft-Tissue Fossils

EXPLORING A RESTLESS LAKEBED

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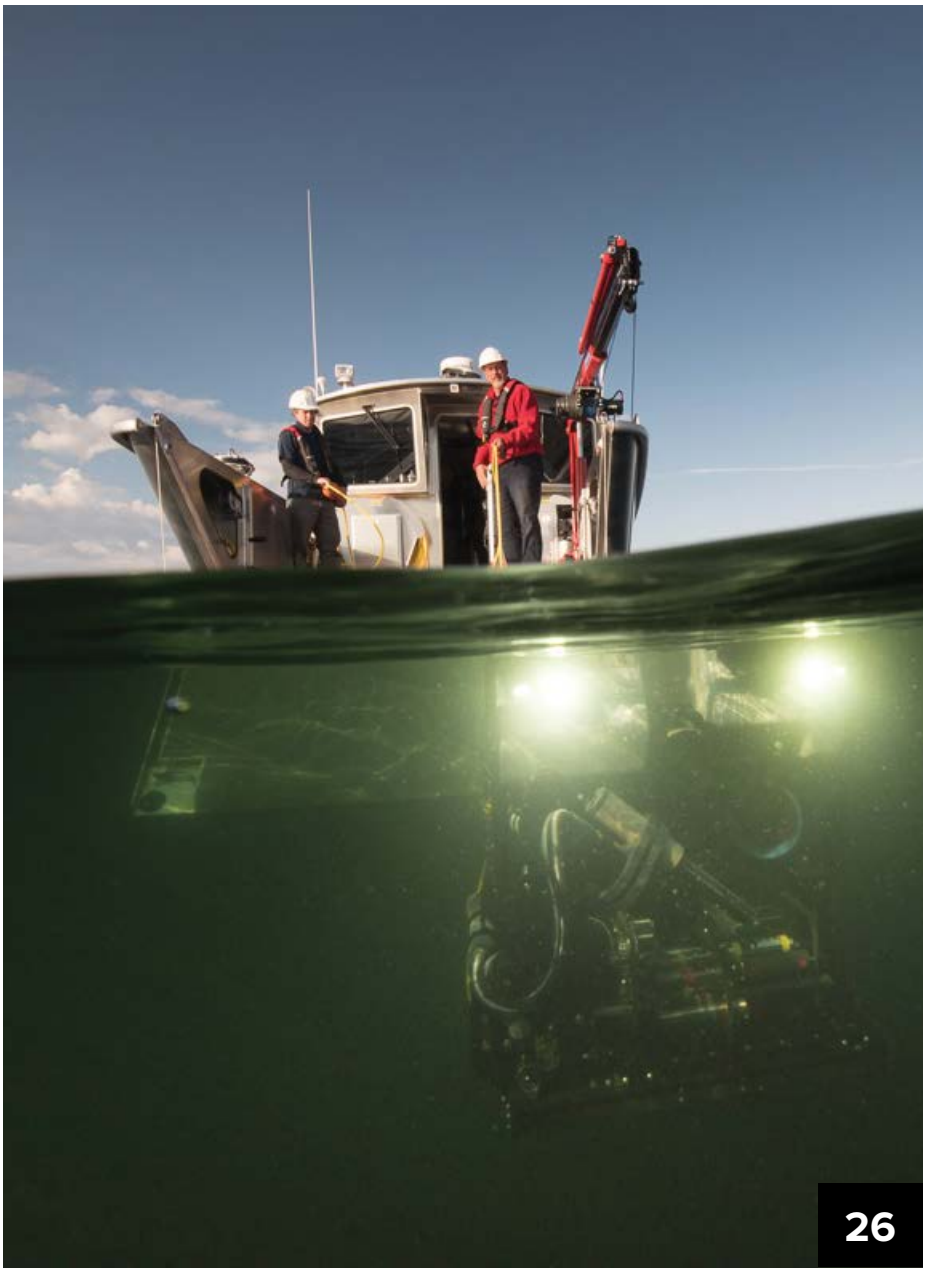

COVER

Exploring the Restless Floor of Yellowstone Lake

Yellowstone Lake, far from any ocean, hosts underwater hot springs similar to those on mid-ocean ridges. A research team is investigating the processes that drive the lake's hydrothermal systems.

PROJECT UPDATE

The Wicked Problem of Earthquake Hazard in Developing Countries

Earthquake preparation in Bangladesh is a conundrum, where crucial information is missing and investments often involve painful trade-offs.

PROJECT UPDATE

Around the World in 84 Days

In the Stratéole 2 program, set to launch in November 2018, instruments will ride balloons into the stratosphere and circle the world, observing properties of the air and winds in fine detail.

OPINION

15 Climate Models Are Uncertain, but We Can Do Something About It

Model simulations of many climate phenomena remain highly uncertain despite scientific advances and huge amounts of data. Scientists must do more to tackle model uncertainty head-on.

DEPARTMENTS

Eos

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Christine W. McEntee, Executive Director/CEO

AGU 100
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Pacific's Garbage Hot Spot Holds More Plastic Debris Than Was Thought

Crew on the R/V Ocean Starr *pulling a discarded net from the Pacific Ocean during the 2015 Mega Expedition to the Great Pacific Garbage Patch. This was one of 30 ships on that expedition. Credit: Ocean Cleanup Foundation*

The sprawling Great Pacific Garbage Patch (GPGP) is not only the largest plastic accumulation zone on Earth. It also contains 4–16 times more floating plastic by mass than previously estimated, according to a paper published 22 March in *Nature Scientific Reports* (see http://bit.ly/PlasticPatch). The 1.6-million-square-kilometer garbage patch, located in the eastern part of the North Pacific Subtropical Gyre between Hawaii and California, contains at least 79,000 metric tons and an estimated 1.8 trillion pieces of floating ocean plastic, the paper reports.

The garbage patch covers about 3 times the area of continental France and encloses buoyant plastic tonnage equivalent to 500 jumbo jets, according to the Ocean Cleanup Foundation. This nonprofit organization, headquartered in Delft, Netherlands, supported the study by providing data from two major expeditions: a 2015 "Mega Expedition" during which 30 vessels crossed the garbage patch to map it and a 2016 aerial expedition. The study was authored by scientists affiliated with the foundation, six universities, and an aerial sensor company.

The 3-year research project, which investigated the area from ships and aircraft, found that debris larger than 5 centimeters makes up more than 75% of the GPGP plastic mass, with much of that being fishing nets. Measurable pieces of microplastic less than 4 millimeters in size account for 8% of the mass.

Many Factors Behind Debris Increase

Prior estimates by other researchers put the plastic tonnage adrift in the patch at about 4,800–21,000 metric tons. The new paper suggests that the increased estimate of floating plastic mass is due mainly to more robust methods for quantifying ocean debris. However, increased levels of plastic pollution in the area—including plastic from the 2011 Tohoku tsunami—could also account for some of the difference, the authors note.

> The study results underline "the urgency of dealing with the plastic pollution problem."

Despite the enormous amount of floating plastic, the study found that it's far less than global models had predicted based on plastic inputs from land- and marine-based sources. The researchers conclude that other dispersals—including through beaching and fragmentation into ever smaller and unmeasured pieces—account for some of the shortfall compared to model predictions. Moreover, "levels of plastic pollution in deep water layers and [on the] seafloor below the GPGP remain unknown and could not be quantified through sampling," the paper states.

The Ocean Cleanup Foundation, which has an ambitious goal of cleaning up 90% of all ocean gyres by 2040, plans to take cues from the study's results as it develops a fleet of passive floating collection devices. The group plans to deploy its first cleanup system in mid-2018. Foundation founder and CEO Boyan Slat said that the study results "provide us with key data to develop and test our cleanup technology, but [they also underline] the urgency of dealing with the plastic pollution problem."

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

Rocks with Soft-Tissue Fossils Share a Mineral Fingerprint

Ultrarare soft-tissue fossils are more likely to survive in rocks containing bacteria-inhibiting minerals, according to new research that identified common mineralogical signatures for fossil-bearing rocks. Scientists hope to use these results to dig into the complexity of life surrounding the Cambrian explosion, an intense period of evolution and diversification that occurred approximately 540 million years ago, and to increase their efficiency at finding soft-tissue fossils.

"It's really important for interpreting the [fossilized] organisms that we have a good understanding of the types of preservations and how those preservations happen," said Ross Anderson, a postdoctoral research fellow at All Souls College at the University of Oxford in the United Kingdom and lead scientist on the project. With a better understanding of when, where, and why soft-tissue fossilization happens, "we might be able to more easily find fossils," he added.

The team compared the mineralogies of hundreds of rocks that hosted soft-tissue fossils with those of rocks that supported mineralized skeletons. They discovered that soft-tissue, or Burgess Shale–type (BST), fossils were more likely to exist in materials that slow down the rate of tissue decay and also promote the fossilization of organic matter. These results offer the first statistical evidence of a connection between fossil occurrence and clay mineralogy, according to the researchers.

A 508-million-year-old Marrella *fossil, approximately 2 centimeters long, from the Cambrian Burgess Shale in British Columbia in Canada. This arthropod-like organism, the most common animal fossil in the Burgess Shale, was mostly soft bodied. The mineralogy of the surrounding rock likely helped to preserve the organic soft tissues. Credit: Susan Butts*

Seeing the Guts

Much of the life that walks, swims, crawls, or slithers has a hard skeleton, and most fossils from the past 400 million years trace those skeletons. But when alive, those creatures are made primarily of soft tissues—brains, muscles, organs, etc.—that often do not get preserved because they decay too quickly. Before the Cambrian explosion, most life-forms did not have a skeleton at all—they were all soft tissue.

Fossils of soft tissues are incredibly rare but can provide a wealth of information about the ecology and biology of a creature when it was alive, Anderson explained. When a bone fossilizes, its rigid organic molecular structure gets slowly replaced by more time-resistant minerals, a process called mineralization. The type of fossilization seen in the Burgess Shale, however, preserves those delicate soft tissues without chemical alteration by compressing and sealing them within sediments, keeping them carbon-rich and nonmineralized.

"The Burgess Shale and other similar deposits…preserve some of the original organic matter in shales," Anderson said. "You do get the soft parts preserved. You see the guts. You see wholly organic organisms like worms."

Until now, though, it has been difficult to understand why soft tissues fossilized in some locations but not others. Lab experiments that Anderson's colleagues conducted in the mid-1990s suggested that the mineralogy of the surrounding material might play a key role in the preservation of soft tissues, and he sought to test that with actual fossils.

Finding the Right Minerals

To do this, the researchers examined the mineralogy of more than 200 Cambrian fossils, some newly collected and some from museums and archives. The fossils originated from 19 sedimentary layers spanning four different continents. Using X-ray diffraction, the scientists measured the chemical compositions of the sediments surrounding soft-tissue fossils and mineralized skeletons.

The team found that if a rock's mineralogy was more than 40% illite, BST fossilization was nearly impossible. Conversely, samples made of more than 20% berthierine had a greater than 90% chance of supporting a soft-tissue fossil. Berthierine, a mineral with antibacterial properties that forms in tropical, iron-rich sediments, likely inhibits enzymes that break down soft tissues and promotes fossilization, Anderson explained. These results agree with past lab experiments that explored possible fossilization pathways.

"You need to slow that process of decay down such that [the fossils] can become stable on geological timescales," he said. "And that, as it turns out, is quite rare and quite difficult to do. You need to have some unique environmental conditions."

With the two mineralogical signatures, Anderson's team could predict which clays contained BST fossils with approximately 80% accuracy. They noted, however, that the presence of berthierine does not guarantee that soft-tissue fossils will exist at a site. Climate, water chemistry, runoff, and, of course, available fauna also are important factors. High berthierine concentrations likely help tissue preservation along, Anderson said. The team published these results in *Geology* on 15 February (http://bit.ly/BurgShale).

The analysis is "fascinating," said Emma Hammarlund, a geobiology researcher at Lund University in Sweden, because it describes a "symptom of Burgess Shale–type preservation rather than the mechanism that led to the preservation of nonmineralized tissue." Hammarlund, who was not involved with the research, called the study "the first 'mineralogical guide' of its kind, predicting a mineralogy of where else to dig deeper for nonmineralized tissue in the Cambrian and earlier."

Expanding the Search

These Cambrian fossils have been found mainly in the Burgess Shale in British Columbia in Canada. Finding new sites that have similar soft-tissue fossils has been a hit-or-miss process, according to Anderson.

The researchers plan to use the results of this study to more efficiently identify locations for additional deposits of Burgess Shale–type fossils around the world and to discover fossil deposits from before the Cambrian explosion, when most life-forms did not have hard skeletons.

More BST fossils could "greatly deepen our understanding of the diversification of animal life on Earth in the Cambrian," said Hammarlund, "and, possibly, even of the preceding dawn of animal life."

By **Kimberly M. S. Cartier** (@AstroKimCartier), News Writing and Production Intern

Alaska Spotlights Its Health Risks from Climate Change

No state in the United States has experienced the domino effects of climate change quite as rapidly as Alaska has. Temperatures there have risen twice as fast as elsewhere in the country and, in turn, have altered the very fabric of Alaskan life, including how people navigate their landscape, access and store food, and maintain their health as ground thaws and frozen coastlines melt and morph.

The magnitude of this uniquely Arctic predicament motivated the Alaska Department of Health and Social Services (DHSS) to publish a report documenting the current and anticipated health impacts of climate change in Alaska specifically (see http://bit.ly/AlaskaHealth).

"We are the only Arctic state in the nation, so, by that nature, things will look different here," said Sarah Yoder, a public health specialist with Alaska DHSS and lead author of the new report that she said she hopes will be of practical value. "We'd like for communities to be able to use this tool and make adaptation strategies that are relevant to them."

Political Dogma Takes a Back Seat

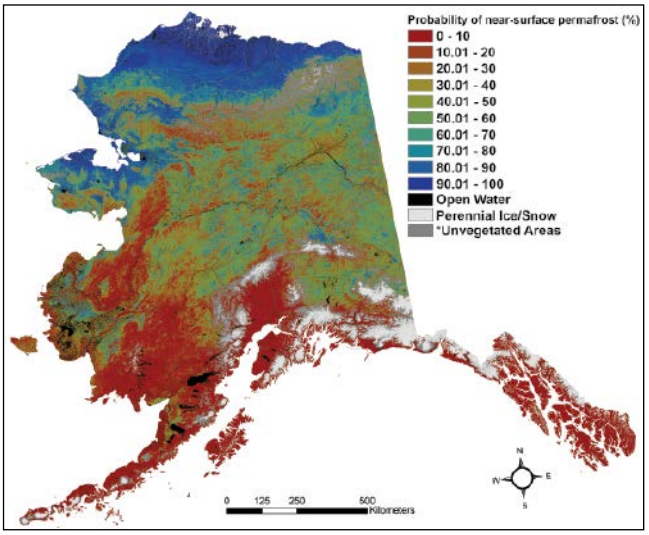
Governor Bill Walker, a registered Independent, signed an administrative order last fall to launch the Alaska Climate Change Strategy and the Climate Action for Alaska Leadership Team and hired Native Alaskan Nikoosh Carlo to fill the new position of senior climate adviser. Walker has stated that he is striving for a more sustainable future and aims to adhere to the goals proposed by the Paris climate agreement despite President Donald Trump's decision to withdraw the United States from the agreement.

With regard to health specifically, the state's leaders publicly acknowledge the threats from climate change and have committed themselves to taking action against them, even in a conservative state that helped elect a federal administration that sees little, if any, danger from human-caused climate change. "We hear people talking often about change that is already occurring, so that's hard to ignore," Yoder said, adding that she and her colleagues were well supported in producing the report.

Threats to Physical and Mental Health

Through an extensive literature review and in consultation with state epidemiologists and other health workers, Yoder and her colleagues outlined emerging health threats linked to changes in glaciers, sea ice, permafrost, and other environmental features that define the state. It's the most extensive report of its kind in Alaska; only a handful of other states, including Oregon, have produced similar reports.

The health conditions detailed within the Alaska report cover a broad scope, but many circle back to two central themes: the ability of Alaskans to safely access and store food and their vulnerability to mental illness in response to rapid change.



Alaska is the only state in the United States underlain by permafrost. As a result, it faces unique challenges as the ground destabilizes and thaws with climate change. Thawing permafrost poses numerous health risks, including increased risk of waterborne disease and changes to consumption of local food, according to an Alaska DHSS report. Colors indicate the probabilities of permafrost existing within 1 meter below the ground surface. Credit: USGS

From Wild Caught to Store Bought

Many Alaskans, particularly those within Native communities, still hunt and forage wild foods. Risks of botulism and other food-borne illnesses may increase as food storage and preservation become more challenging in a warmer climate, according to Yoder's report.

Charles Sollie Hugo, a Native elder and oral historian with the North Slope Borough in Barrow, grew up hunting with his family. However, as the times when rivers freeze have shifted to later in the fall and their thawing has begun earlier in the spring, the window of time when it's safe to traverse the land has narrowed, making caribou hunting less a part of his life, he said.

The traditional permafrost cellars that Hugo once used to preserve meat have thawed, flooded, and become inaccessible. "They are full of water," he said. "They are no longer usable. They are contaminated because the permafrost is thawing out."

Native communities now largely rely on electric freezers, but these can be expensive to run year-round, he added.

As wild foods become harder to access, Alaskans who rely on them will increasingly turn to store-bought foods that may lack the nutritional value of wild-caught foods and burden those turning to them with comparatively larger costs, said Jim Fall, a program manager in the Alaska Department of Fish and Game's Division of Subsistence who reviewed the DHSS report prior to publication.

In many cases, the cultural comparability of substitutions for traditional foods will be impossible to meet, particularly in the case of marine mammals like harbor seals and walrus, Fall said. "Where do you go to buy [those]? You can't," he said. "So there is a whole set of problems and complications that arise."

The magnitude of the change itself will make the dietary shift challenging, according to Fall. Rural Alaskans produce roughly 34 million pounds of wild foods annually, which amounts to roughly $300 million worth of food, according to a 2014 report to which he contributed (see http://bit.ly/subsist2014). "And that's probably too low," he added. "Even assuming a straightforward substitution, we're talking a lot of food and a lot of money."

Adding another layer of complication, getting to stores or transporting food to Alaskans in both rural and urban locations will become more challenging and costly as tarmacs and roads become less reliable because of permafrost thawing, noted Fall.

Fall said that he hopes Yoder's report will bring attention to such problems specific to Alaska and its unique location in the Arctic,

ultimately helping sway policy around climate change and fossil fuel emissions. "The state is a minority," he noted, referring to the rapid and dramatic environmental change facing Alaska compared with the lower 48 states. "The extent [to which it] can be communicated to the entire country is a benefit to us."

Mental and Emotional Stress

Among medical conditions cited by the report, one known as solastalgia will likely trouble many Alaskans as climate change advances, Yoder said. It's the distress one experiences because of environmental change around one's home. Australian philosopher Glenn Albrecht coined the term in the early 2000s in reference to the emotional impacts of severe drought and opencut coal mining in Australian communities, and the concept has since gained traction as a helpful way to address the mental health impacts specific to climate change.

"As people's way of life changes and as anxiety about how things around the community might change—how their ability to access traditional food sources might change, or wildfires around their homes—[these] can all impact their general feelings of well-being," said Yoder.

Solastalgia relates specifically to changes that people experience in their social roles as a result of environmental change and are especially pertinent to communities that live close to the land, as is the case across much of Alaska, said David Eisenman, a medical doctor and public health researcher at the University of California, Los Angeles. Solastalgia is its own distinct condition, but it can lead to other mental health complications, including anxiety and depression.

"There is very little good, hard research on the mental health effects of climate change, and if you ask me, solastalgia is one of the first places to look for those effects," said Eisenman, who produced a groundbreaking empirical study of solastalgia in 2015. The research looked at communities affected by wildfires in Arizona.

"We kept hearing people say the same thing," said Eisenman. "'I am grieving for the loss of the forest; I am mourning the loss of the outdoors.'"

Hugo described his own angst as caribou hunting wanes. "The lack of caribou is a big emotional letdown; it just tears your heart right from your soul," he said.

"It seems like a lot of the potential health impacts that aren't really mental health can be tied back to mental health," noted Yoder.

By **Laura Poppick** (email: laura.poppick@gmail.com), Freelance Science Journalist

Environmental Ratings Lowest Ever for Congressional Republicans

The League of Conservation Voters released its most recent environmental scorecard, which rates members of Congress on how they voted on legislation related to the environment. In 2017, several of those votes pertained to the Arctic National Wildlife Refuge in northeastern Alaska. In this undated photo, an aircraft flies over caribou on the coastal plain of the refuge. Credit: U.S. Fish and Wildlife Service via AP

A new scorecard that rates members of Congress on how they voted on environmental issues found that 46 Republican senators scored a 0% in 2017. The average score for all Republican senators was 1%, according to the League of Conservation Voters (LCV), a nonprofit environmental group based in Washington, D. C., that released the scorecard on 27 February. This is the lowest average score for Republican senators since LCV began tracking this issue in 1970, according to the group. In contrast, 27 Democratic senators earned a 100% on the scorecard, with Democrats averaging 93%.

The low Republican average score means that those senators "voted against the environment and public health at every opportunity," the LCV report states.

On the House side, 124 Republicans received a zero, with House GOP members overall receiving an average score of 5%. Among House Democrats, 84 earned a 100% score, and House Democrats overall earned a 94% average score.

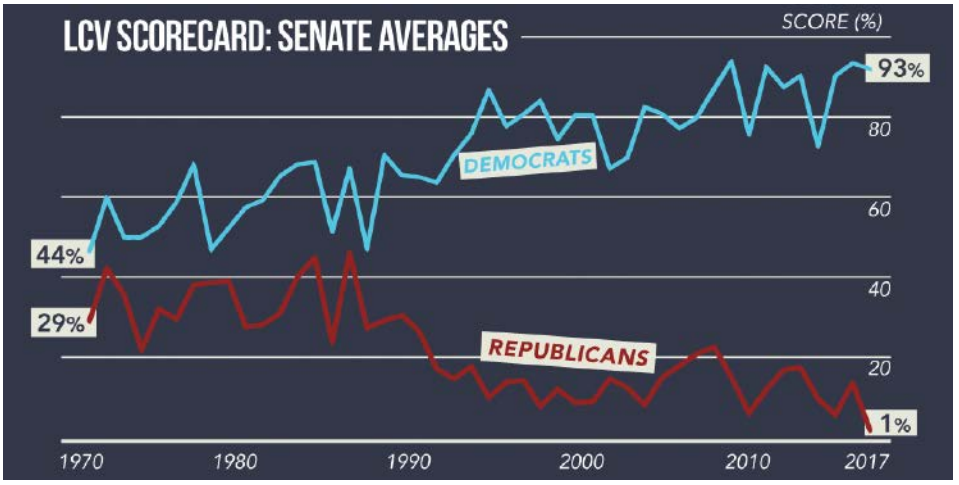
"At the federal level, 2017 was an unmitigated disaster for the environment and public health, with President Trump and his cabinet quickly becoming the most anti-environmental administration in our nation's history," Tiernan Sittenfeld, LCV's senior vice president for government affairs, said at a briefing to release the report (see http://bit.ly/LCV-score-crd). "The Republican-led Congress repeatedly refused to stand up to President Trump's extreme antienvironmental agenda and his attacks on our air, water, land, wildlife. This is particularly shameful in a year when climate change–fueled hurricanes and wildfires caused so much devastation. Fortunately, Senate Democrats, led by Sen. [Chuck] Schumer"—the minority leader from New York—"maintained a green firewall of defense to block any egregious events throughout 2017."

Votes That Were Counted

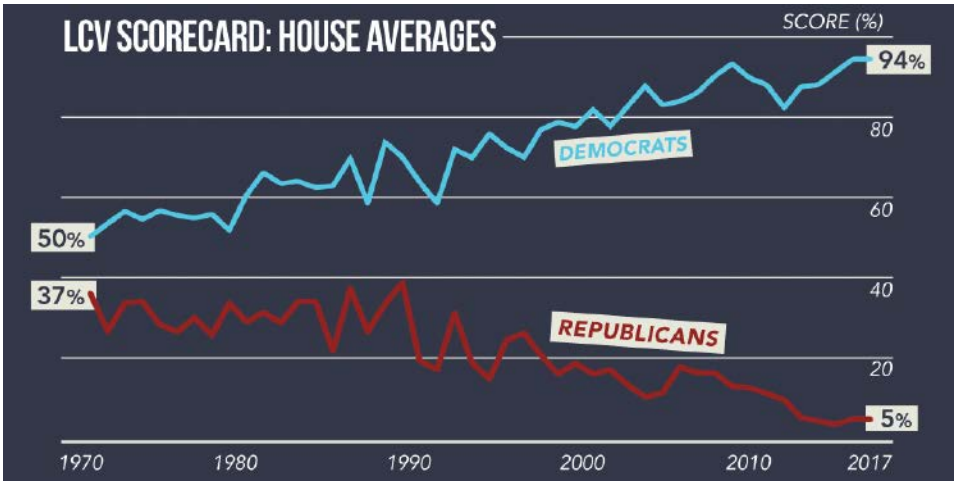
The report graded members of Congress on the basis of specific votes that LCV and other environmental and conservation organizations determined were key indicators. On the Senate side, members were scored on how they voted in 19 instances. These included eight votes to confirm the administration's cabinet or subcabinet nominees, whom the report labeled as "historically anti-environmental." Among them was Environmental Protection Agency administrator Scott Pruitt. The report said that Pruitt "has aggressively gutted the agency from the inside." Other votes counted in the scorecard were the recent tax bill that opens the Arctic National Wildlife Refuge to fossil fuel development and legislation that would threaten drinking water and public lands.

In the Senate, "what this year's results show is a dramatic crash on the Republican side of the aisle, which is in many respects a very sad testament to what has become of the GOP," Sen. Sheldon Whitehouse (D-R.I.) said at the briefing. Only 14 Senate Republicans scored zero in 2016 compared with the 46 who did in 2017. House numbers were fairly stable, with 122 House members receiving a zero in 2016 compared with 124 with that score in 2017. Whitehouse said that the low scores for Republicans in both houses "very clearly show a party that has been completely captured by the polluting industries."

At least one Republican senator, Thad Cochran of Mississippi, paid little regard to his LCV grade of zero. "As a lifelong Republican, Sen. Cochran tends not to score highly with liberal activist groups," a spokesperson for the senator told *Eos*. "Senator Cochran's career reflects a careful understanding of the importance of protecting and preserving our nation's natural resources. He has a strong record of making decisions on environmental issues that are in the best interests of Mississippi and our nation, and supporting legislation and policies that promote cooperative conservation programs."



An environmental voting scorecard issued by the League of Conservation Voters shows a sharp drop in Senate Republican scores between 2016 and 2017. Credit: League of Conservation Voters



The average environmental voting record for House Republicans falls far below that for Democrats, according to the League of Conservation Voters. Credit: League of Conservation Voters

Looking at Votes by Climate Caucus Members

For House members, LCV graded 35 votes on issues related to public lands, climate change, water resources, clean air, deregulation of environmental rules, and other environment-relevant topics.

Republican House members who belong to the bipartisan Climate Solutions Caucus averaged a 16% score, which is more than 3 times higher than the overall Republican average, according to the report. However, the report concluded that members of the caucus, which was founded in 2016 to explore policy options on climate change, need to do more. "Joining the caucus can be an important step, but it's simply not enough," the report states. "We need these Republican members to vote for climate action, to lead on real solutions, and to push their colleagues and party leadership to do better."

The head of a group that has worked closely with the caucus said that the scorecard is valuable but does not provide the whole picture about the importance of the caucus.

In a statement provided to *Eos*, Mark Reynolds, executive director of the Citizens' Climate Lobby (CCL), said, "We think the scorecard plays the essential role of providing pressure on members of Congress to do better on environmental issues, especially climate change. However, we don't think the scorecard accurately captures the emerging work being done by the caucus to develop bipartisan solutions to climate change." The lobby is a grassroots advocacy organization based in Coronado, Calif., that focuses on national policies to address climate change. A CCL analysis published on 28 February found that 15 of the 34 caucus members who are Republicans improved their environmental voting scores since joining the caucus, despite the fact that only five of the 35 tracked votes are "climate-relevant" (see http://bit.ly/CCLobanalysis).

"Much is happening behind the scenes, thanks to the caucus, and we think patience will eventually be rewarded with major legislation to address climate change," Reynolds added.

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

House Science Subcommittee Hearing Targets Sexual Harassment

A congressional panel in late February heard testimony about the impact of and fight against sexual harassment in the sciences. Four women prominent and successful in their fields spoke about the need to reform not just the laws but also a harmful culture that considers such behaviors permissible and fosters systemic inequity.

"We talk a lot about getting more women in the sciences," said Rep. Suzanne Bonamici (D-Ore.), but "we need to be able to keep them there when they get there." Bonamici sits on the Subcommittee on Research and Technology of the House Committee on Science, Space, and Technology, which held the 27 February hearing (see http://bit.ly/SH_hearing).

According to the witnesses, antiharassment policies must grow more comprehensive and include more input from experts; findings and procedures require greater transparency, and violations must provoke tangible consequences. Overall, the entire scientific community, especially those in leadership positions, must strive to change a culture that treats harassment as commonplace, they said.

"We cannot afford to lose another brilliant scientist because she did not feel safe in her lab," said Rep. Daniel Lipinski (D-Ill.), ranking member of the subcommittee.

Clarity, Transparency, and Informed Policy Making

No standard harassment policy prevails at American universities and research institutions, nor is there a consistent definition of what actions constitute harassment, some witnesses noted.

Kathryn Clancy, an associate professor of anthropology at the University of Illinois at Urbana-Champaign, explained that antiharassment policies need to be explicit about acceptable and unacceptable behaviors, easily accessible to all, and taught as part of standard workplace training. They also need to address the problems actually occurring in that workplace, said Clancy, who conducts research on workplace climate in the sciences.

"We need to do a lot more of the hard work, not just slapping on a policy and saying 'OK, sexual harassment is fixed,'" Clancy said. Scientific institutions should ask themselves, "What is the culture at our organization, and is this the culture that we want?" she added.

Attorney Kristina Larsen told the subcommittee that many antiharassment policies focus mainly on legality and the potential for litigation, instead of addressing more prevalent, but technically legal, smaller harassments. Larsen represents women and underrepresented minorities in science, technology, engineering, and mathematics (STEM) fields who are facing discrimination, harassment, and retaliation.

"Don't write a zero-tolerance policy until you're really clear on what you're not tolerating," she advised in her testimony. We need to base policies on "the conduct that is actually damaging" to victims and not worry "about whether it is legal or illegal under the law," she said.

Fieldwork Amplifies Problems

Field research conducted far from a formal academic environment increases the need to have clear and explicit ethical policies and codes of conduct, said Chris McEntee, executive director and CEO of AGU, publisher of *Eos*.

"The Earth and space sciences typically involve remote field settings," she noted in her testimony. "When coupled with a male-dominated environment and power structure, these situations can amplify the problem."

Clancy highlighted that field research brings added uncertainty about antiharass-

RapidEye/E+/Getty Images

ment policies. "In field sciences, we found that the majority of our respondents were not aware of a code of conduct or sexual harassment policy for their field site. And [only] a very small number of people, who were actually harassed, even knew what the reporting mechanism was," she said.

Principal investigators, supervisors, and field site directors should develop and enforce implicit and explicit codes of conduct and bear responsibility for them, she added.

Making Consequences for Harassers Real

Witnesses and members of Congress at the hearing lauded the National Science Foundation (NSF) for its 8 February decision requiring grant-seeking universities to maintain clear antiharassment policies and to report policy violations to NSF (see http://bit.ly/NSF8Feb).

"No taxpayer dollars should be awarded to a university researcher who engages in harassment and inappropriate behavior toward a colleague or student under their charge," Rep. Lamar Smith (R-Texas), who chairs the House Committee on Science, Space, and Technology, said during the hearing.

Rhonda Davis, head of NSF's Office of Diversity and Inclusion, who also testified at the hearing, noted that NSF's new guidelines were prompted by the fact that American universities do not have a universal ethics policy regarding sexual or other types of harassment or any requirement for universities to develop such policies beyond the scope of federal protections, like Title IX.

Consistent and visible enforcement of antiharassment policy will help mitigate the harassment "epidemic," said Clancy, citing her research. "Across workplaces, it's consistent that if you have consequences… you do see less harassment in those workplaces," she explained.

The four witnesses who testified before the House Subcommittee on Research and Technology on 27 February. From left to right are Rhonda Davis, Kathryn Clancy, Kristina Larsen, and Chris McEntee. Credit: House Committee on Science, Space, and Technology

The fear of backlash for reporting harassment falls on the targets of harassment, not the harassers, said McEntee, who encouraged sanctions against harassers for violating ethics policies.

"People don't change because they feel the light; people change because they feel the heat," said Larsen. "And there is no heat in academics…. We have a problem with enforcement."

Davis said that NSF's new policy includes independent and anonymous avenues for anyone, including students, to report harassment directly to NSF, which may reduce the fear of backlash.

Culture Change Needed

All of the witnesses called for culture change in the scientific community, where, they said, harassment is allowed to persist and is deemed tolerable.

"Let's move away from a culture of compliance and towards a culture of change," Clancy said, by "focusing on the behaviors we want to see."

Clancy and McEntee called for better informed training in how to recognize harassing and harmful behavior and how to safely diffuse a situation from the outside. This type of bystander intervention, especially from those in leadership positions, they explained, would have a twofold effect: first, showing the harasser that such behavior is not acceptable or tolerated in the workplace and, second, demonstrating that vulnerable persons are visible, heard, and supported by those with the power to effect change.

Speaking directly to victims of sexual harassment, Clancy added, "I see you, and I think of you, and I thank you for getting up every day, and I derive strength from you. I hope you know how much you mean to those of us who do this work."

Subcommittee chairwoman Barbara Comstock (R-Va.) (left) speaks with witness Rhonda Davis of NSF after the hearing. Credit: Kimberly M. S. Cartier

By **Kimberly M. S. Cartier** (@AstroKimCartier), News Writing and Production Intern

Stanley "Stan" Ruttenberg (1926–2017)

Rebecca Ruttenberg

Stanley Ruttenberg

Stanley Ruttenberg, a scientist of truly remarkable breadth and accomplishment, died in Louisville, Colo., on 12 February 2017 at the age of 90. His career of more than 50 years stands as a testament to how much can be achieved for the geosciences by a dedicated, committed scientist who had no Ph.D. and occupied few positions of real administrative authority.

Stan's career began conventionally enough with his attending Johns Hopkins University and then transferring to the Massachusetts Institute of Technology, where he earned a B.S. in physics in 1946. He followed that with an M.A. in physics at the University of California, Los Angeles. There he started to pursue a Ph.D., working initially in atmospheric electricity under Robert E. Holzer. Ultimately, Stan's irrepressible and wide-ranging interests diverted him from that endeavor but led to a different set of accomplishments that were surpassing in many ways.

Stan's love of the outdoors led to more than just camping trips. With his talent for building things, he joined forces with his friend Dick Kelty to design a backpack carrying the Kelty name. His love of classical music, combined with his love of electronics, led to his tinkering with reel-to-reel tape decks. He used these to record the signal from an artificial aurora experiment in White Sands, N.M., for a fellow student's Ph.D. project. He was invited into the home of Arnold Schoenberg because he had the equipment to play the composer's studio recordings.

At the National Academy

Stan served at the National Academy of Sciences (NAS) in Washington, D. C., from 1955 to 1964, where one of his early landmark achievements was to influence how scientists dealt with the research data gathered during the International Geophysical Year (IGY; 1957–1958). One lasting legacy of the IGY has been the World Data Center (WDC) system.

Stan at the time headed the program office of the IGY. Making use of that position, he worked with many others who recognized the consummate importance of preserving data for succeeding generations to establish the WDC-A and WDC-B (United States and Russia, respectively). Recalling the prescience of those early planners, Stan and Henry Rishbeth in a 1994 paper noted the expectation even in the 1950s that data centers "should be prepared to handle data in machine-readable format, which at that time meant punched card and punched tape" (see http://bit.ly/worlddatacenters).Throughout his long career, Stan was a frequent adviser and overseer of the expanding and ever more comprehensive network of World Data Centers.

During his tenure at NAS, he served on the Committee for Polar Research, the Space Science Board, and the Geophysics Research Board. He served as executive secretary of the U.S. Committee for the International Years of the Quiet Sun and as secretary of the Panel on the World Magnetic Survey. While at NAS, Stan was also technical adviser for the award-winning film series *Planet Earth* and was so again when the series was updated in 1980–1985.

Invited to UCAR

Through the IGY, Stan met Walter Orr Roberts, solar physicist and president of the University Corporation for Atmospheric Research (UCAR) in Boulder, Colo., who invited Stan to become assistant to the president. Stan accepted in 1964 and stayed at UCAR in many capacities for the next 30 years, until his retirement.

Stan was the consummate facilitator, enabling scientists everywhere to meet, plan, and act. Among his many positions was secretary of Working Group 6 of the International Committee on Space Research, which held numerous meetings advocating advances in space science and instrumentation, leaving Stan to write and disseminate its reports, many of which were very influential. Ever the Renaissance man, Stan added an erudite preface, structured around the inspiring poetry of Lord Byron, to a lengthy report (http://bit.ly/oceansats) advocating oceanographic satellites.

One of the hallmarks of Stan Ruttenberg's career was his willingness to let others take credit for the many achievements in which he had a significant role. By the early 1970s, leading atmospheric scientists had for years been advocating a major field campaign to understand and parameterize tropical convection within the Global Atmospheric Research Program (GARP). The resulting program in 1974, GARP Atlantic Tropical Experiment, or GATE (http://bit.ly/sloangate), was staggering in its scope (39 ships and 13 aircraft). Stan's behind-the-scenes, "leave few fingerprints" role in the success of this program was characteristic of the way he worked.

Advocating for Gender Equality

It is not unusual today to bring graduate students into the field to help with research, but mainly as a learning experience. In 1974, the UCAR GATE student program was a true pioneering effort.

Stan coordinated with the National Science Foundation (NSF) to oversee and fund the program. One of his decisions, perhaps obvious today but not in 1974, was to make this program open to qualified women and men equally. This met resistance, but according to Eugene Bierly (personal communication, 2017), the responsible NSF program manager at the time, Stan was "foot-stompingly insistent" that women were to have an equal chance of being selected, and that is what happened. The precedents set by the UCAR program are among the reasons that it is now second nature for faculty and agency program managers to leave a small place in their budgets for student participation.

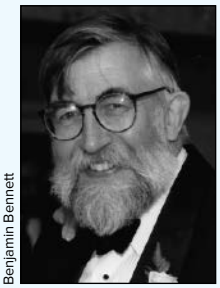
Legacy of a Renaissance Man

Outside of the sciences, Stan left a legacy as a Renaissance man as well, not least for his seminal role in bringing the music of Gustav Mahler to thousands through his leadership of the Colorado MahlerFest. He considered his being chosen for the International Gustav Mahler Society Gold Medal his greatest honor, yet with characteristic modesty asked for the medal, which was awarded in 2005, to go to the Colorado MahlerFest itself.

Stan is survived by his two daughters, Alison and Rebecca, and will be missed by many.

By **Edward Zipser** (email: ed.zipser@utah.edu), University of Utah, Salt Lake City

Joseph B. Walsh (1930–2017)



Benjamin Bennett

Joseph B. Walsh

Joseph B. "Joe" Walsh died on 30 August 2017 at the age of 86 in Adamsville, R.I., where he had lived for many years. Joe was well known in the rock mechanics community, although perhaps underappreciated outside it. The influence of his work is broad and profound nonetheless.

Seismologists who interpret the high velocities of compressional waves compared with those of shear waves (high V_p/V_s ratios) as indicators of high pore pressures, oil explorers who recognize oil and gas zones in tomographic images, and geophysicists identifying high permeability and water content from electrical conductivity measurements all rely on Joe's foundational work. The reason is that these scientists are not so much measuring the properties of the rock as measuring the influence of its cracks. Joe, in a series of classic papers in the 1960s and 1970s, did the fundamental work establishing the profound effects of cracks on the elastic and transport properties of rock.

By recognizing this influence, Joe was able to provide, for example, rational explanations for relationships between the constitutive relations for permeability and electrical resistivity, to predict how increasing effective pressure changes permeability, and to understand the influence of surface roughness on joint transmissivity, or the coefficient of friction. Whole fields of study are based on those beginnings.

Early Career

Joseph B. Walsh was born in Utica, N.Y., the son of Joseph B. and Ann (née Bowman) Walsh. He grew up in upstate New York before moving to Massachusetts to attend the Massachusetts Institute of Technology (MIT), from which between 1952 and 1958 he received bachelor's, master's, and doctor of science degrees in mechanical engineering.

His D.Sc. work yielded a paper with Frank McClintock in which they developed what became known as the modified Griffith theory for brittle fracture in compression. After graduating from MIT, Joe spent 2 years in industry, including a stint with a consulting company in Stockholm. This job morphed into a globe-circling trip in a VW Bug, ending with Joe in California, substantially poorer financially but much richer in experience.

Returning to Massachusetts, he applied his skills in solid mechanics as an engineer at the Woods Hole Oceanographic Institution, where he was responsible for the design of the pressure hull for the pioneering submersible *Alvin*.

Joe joined the geology and geophysics (later Earth, atmospheric and planetary sciences) department at MIT in 1963, beginning a 25-year collaboration with W. F. Brace. It was a very fruitful combination: Joe did the theory, and Bill did the experiments. The Walsh-Brace period was one of rapid development in rock mechanics on many fronts. A host of graduate students and postdocs (including most of us) were trained under their guidance, many of whom went on to productive research careers in academia and industry.

Theory Grounded in Reality

Joe's papers are both succinct and eloquent. He identified the most pertinent elements of each problem and focused his analysis exclusively on those aspects. His chosen tools were pencil, paper, and the fundamental principles of mechanics.

Joe arrived at work each day impeccably attired in coat, tie, and slacks. Sitting at his desk, he would dive into his cool mathematical treatments, seemingly abstract but always securely attached to reality. As a result of his training with McClintock, Ali Argon, and others in MIT's mechanical engineering department, Joe always tested his work with experimental or observational data, thus providing a perfect interface with Brace's group.

A Taste for Conversation and Rugby

Despite his analytical proclivity, Joe was not detached socially. To all who knew him, he was a quiet, unassuming man with a wry sense of humor. He liked people and had catholic tastes in his choice of company. At lunchtime, he could be found at a local diner, talking to machinists, custodians, or academics. In the evening, he might dine at one of several classic private social clubs in the Back Bay.

His gentle demeanor gave no clue that in his younger years he was an avid rugby player and the founding director of the U.S. Rugby Foundation. Joe was equally at ease bantering with a surly waitress or securing a large donation for the rugby foundation from an influential industrial magnate.

A Very Active Retirement

Joe retired from MIT in 1986 and settled in Rhode Island. In "retirement," Joe continued to conduct theoretical studies of fluid flow in fractured rocks and of rock friction. He was appointed visiting scholar in the Department of Earth, Environmental and Planetary Sciences at Brown University in 1999, and he continued in that capacity until his passing, having been reappointed only a few months before.

Joe eagerly mined experimental rock friction data at Brown, which he used as a starting point for his analyses. Armed with his famous and formidable yellow legal pad and No. 2 pencil, Joe worked closely with experimentalists at Brown and elsewhere to establish a physical basis for rate and state friction laws.

In addition to scientific interactions, Joe also educated younger scientists at Brown by his example of the importance of a proper lunch, the joys of poetry (Joe could, and did, recite many poems from memory), and the meaning of savoir faire. Joe continued his scientific work up to the time of his death.

Joe's work often took him overseas. He served as a visiting scientist at the University of Cambridge in England; the University of Edinburgh, Scotland; and the South African Chamber of Mines in Johannesburg.

Although his name is not a household word outside the rock mechanics community, Joe has been well recognized for his accomplishments. In 2007, he received the Rock Mechanics Research Award, in 2000 he was honored as a Life Fellow at the University of Cambridge, and in 1993 he was elected a Fellow by AGU.

By **Christopher H. Scholz** (email: scholz@ldeo.columbia.edu), Lamont-Doherty Earth Observatory, Columbia University, Palisades, N.Y.; **David L. Goldsby,** Department of Earth and Environmental Science, University of Pennsylvania, Philadelphia; and **Yves Bernabé** and **Brian Evans,** Department of Earth, Atmospheric and Planetary Sciences, Massachusetts Institute of Technology, Cambridge

Toward a Satellite-Based Monitoring System for Water Quality

Water Quality Workshop for End Users
Greenbelt, Maryland, 27 September 2017

Declining water quality in inland and coastal systems has become, and will continue to be, a major environmental, social, and economic problem as human populations increase, agricultural activities expand, and climate change effects on hydrological cycles and extreme events become more pronounced. Providing governments and nongovernmental groups with timely observations on the time and location of anomalous water quality conditions can lead to more informed decisions about the use, management, and protection of water resources.

By observing the color of the water, satellite sensors provide information on the concentrations of the constituents that give rise to these colors. These constituents include chlorophyll *a* (the primary photosynthetic pigment in phytoplankton), total suspended solids (an indicator of sediments and other insoluble material), and dissolved organic matter. Other environmentally relevant optical characteristics include turbidity and water clarity.

A 1-day workshop at NASA's Goddard Space Flight Center introduced the concept and potential capabilities of a satellite-based, near-real-time water quality monitoring tool. This tool will complement existing field monitoring programs by automatically alerting water resource and ecosystem managers to potentially hazardous water quality conditions, resulting in more timely and informed decision-making.

The workshop brought together more than 340 environmental specialists, economists, scientists, industry representatives, and legal advisors from state and federal agencies and the private sector. The primary requirements that workshop attendees identified for developing this warning system include automated, near-real-time processing of Landsat-Sentinel imagery, the development of robust anomaly detection algorithms, and support for ongoing implementation and calibration and validation efforts. The workshop further aimed to identify the next steps toward making such a near-real-time system a reality with input and guidance from end users.

The workshop featured a series of short presentations on the perspectives of end users on the potential value of satellite data for water quality monitoring. These presentations covered a broad range of topics, including monitoring harmful algal blooms in California, Utah, Oklahoma, Oregon, and Florida; identifying sites for aquacultures in New England; and concerns about pipeline leaks contaminating waterways. Other talks highlighted the need for improved satellite technology (e.g., hyperspectral missions) with sunglint mitigation strategies in the future to enable more precise and accurate estimations of water quality conditions from space.

The NASA Goddard team is currently developing a prototype system for select regions (e.g., Florida's Indian River Lagoon, Lake Mead, and Oregon reservoirs) to evaluate the performance of such an expedited service. The team, in collaboration with water authorities, will initiate algorithm development, prototyping, testing, and implementation of the system.

All presentations are available on the meeting's website (https://go.nasa.gov/2FYBcW6).

The Water Quality Workshop was sponsored by the NASA Goddard Applied Sciences office. We thank Steve R. Greb, Richard Stumpf, Maria Tzortziou, and Jeremy P. Werdell for serving on the organizing committee.

A workshop last September introduced the concept and possible capabilities of using satellite imagery to monitor water quality in near-real time. This natural-color image from NASA's Landsat 8 satellite shows the Caspian Sea around the Tyuleniy Archipelago on 16 April 2016. Sea grasses or benthic algae cause the dark green colors, and most of the fine lines are caused by winter ice gouging the seafloor. Credit: Norman Kuring, NASA

By **Nima Pahlevan** (email: nima.pahlevan@nasa.gov; @nima_pahlevan), NASA Goddard Space Flight Center, Greenbelt, Md.; also at Science Systems and Applications, Inc., Greenbelt, Md.; **Steve G. Ackleson,** Naval Research Laboratory, Washington, D. C.; and **Blake A. Shaeffer,** U.S. Environmental Protection Agency, Research Triangle Park, N.C.

U.S. and China Assess Ecosystem Effects of a Fading Cryosphere

Impacts of a Changing Cryosphere on Lakes and Streams in Mountain Regions: A China–United States Cooperation Workshop
Qinghai, China, 21–27 August 2017

Participants in the China–U.S. cryosphere workshop transit the shores of Qinghai Lake, 3,260 meters above sea level, near China's Bird Island preserve. The lake's shoreline habitats serve as a key breeding ground for many species, including the famous bar-headed goose that migrates over the Himalayas each year. Credit: Jim Elser

Global climate change produces cascading effects on ecosystems. The cryosphere—the frozen-water domain—of high mountain regions is especially vulnerable to these changes, and the effects extend to downstream aquatic ecosystems. Glaciers and snowpack, the key cryospheric components of high mountain systems, are sensitive to increases in temperature, shifting atmospheric circulation patterns, and varying amounts and forms of precipitation.

Losses of glacial ice and permanent snowpack as well as thawing permafrost are widespread and have complex causes; they affect key aspects of alpine lakes and streams that include temperature, water discharge, and nutrient supply. Documenting, understanding, and forecasting these effects are challenging and require broad interdisciplinary collaboration.

To address these global challenges, the U.S. National Science Foundation (NSF) and the National Natural Science Foundation of China (NSFC) jointly funded a workshop that brought together experts in limnology, aquatic biogeochemistry, atmospheric science, glaciology, and hydrology from the United States and China (see http://bit.ly/US-China-cryosphere). The workshop focused on linking these fields to better understand how changes observed in the cryosphere affect lakes and streams in mountain regions.

Upon arriving at Qinghai Lake, participants attended a welcome event that included remarks from the co-organizers and NSF and NSFC dignitaries. The second day of the workshop featured talks from U.S. and Chinese participants that addressed cutting-edge issues of ecology in the cryosphere. These included such topics as the formation of "new" proglacial lakes, the effect of glacier runoff on downstream aquatic ecosystems, and emerging techniques to detect microbial life in the cryosphere. Later that evening, the group hiked around a local Tibetan monastery while discussing such scientific topics as the processing and degradation of organic carbon in the cryosphere.

On the third day, U.S. and Chinese team members traveled to Chaka Lake, a large salt lake in Qinghai Province. Participants continued their scientific discussions surrounding the downstream aquatic biological effects of a changing cryosphere as they walked on the salt beds of the shallow lake. One topic of discussion was the algal blooms in Qinghai Lake, which are comparatively rare for this region.

The fourth day was spent mostly in three breakout groups: climate, cryosphere, and ecology. Each group summarized major patterns, themes, and contrasts of the changing cryosphere across Asia and North America.

> The consensus-driven view that emerged from sharing data related to cryosphere dynamics was needed to enhance U.S.-China collaborations.

Participants debated existing open research questions in the field of ecology in high mountain systems to generate iterations of a conceptual diagram.

The last day was spent linking the respective breakout groups through discussions and the finalization of a conceptual diagram that depicts the group's key conclusions. The diagram relates the effects of a changing cryosphere on the ecology of lakes and streams in high mountain regions. It shows global drivers that affect climate at high elevations, followed by the consequences for snow cover and glacier mass balance (which then affect more specific physical characteristics in the cryosphere, such as albedo and the production of aeolian dust). It also includes the ecological responses to these drivers, such as changes to algal and microbial communities.

This consensus-driven view, which emerged from sharing data related to cryosphere dynamics, was needed to enhance U.S.–China collaborations. A farewell banquet solidified newfound collaborations and friendships across the U.S. and Chinese teams.

By **Alia L. Khan** (email: alia.khan@colorado.edu; @AliaLaurenKhan), National Snow and Ice Data Center, Cooperative Institute for Research in Environmental Sciences, University of Colorado Boulder

Vetting New Models of Climate Responses to Geoengineering

Seventh Meeting of the Geoengineering Model Intercomparison Project
Newry, Maine, 26 July 2017

One proposed method of temporarily slowing global climate change is to thin high-altitude clouds, such as these cirrus clouds, to allow more heat to escape Earth's atmosphere. Credit: Ron Clausen, CC0 1.0 (http://bit.ly/ccby1-0)

Approaches to slowing the rate of global climate change take many forms. One potential way to buy a bit of time while nations work on the more permanent solution of reducing greenhouse gas emissions is to use various geoengineering methods. Such methods include recapturing carbon compounds already in the air, shading Earth's surface from the Sun's rays, and making Earth's surface more reflective to reduce surface warming. Because any such efforts could have wide-ranging effects, mathematical models and simulations are necessary to evaluate the possible outcomes of proposed geoengineering efforts before they can even be considered for deployment.

Approximately 30 scientists met last summer to discuss the latest science and future directions in the Geoengineering Model Intercomparison Project (GeoMIP). This international effort, an official part of the Coupled Model Intercomparison Project Phase 6 (CMIP6), is the largest source of information about the robust climate model response to solar geoengineering: a collection of proposed technologies designed to quickly, temporarily offset the effects of global warming.

A major focus of the meeting was GeoMIP's contribution to CMIP6. Attendees raised questions about the ability of the participating Earth system models to simulate cirrus clouds and potential aerosol–cloud interactions associated with cirrus thinning. The meeting produced a recommendation to demote the currently proposed cirrus thinning experiment to a tier 2 experiment, effectively making it an optional simulation. In its place, the attendees decided to substitute an overshoot simulation, which models geoengineering deployment as a temporary means of reducing temperatures quickly while mitigation and negative emissions (also known as carbon dioxide removal) efforts ramp up.

Attendees raised questions about the ability of the participating Earth system models to simulate cirrus clouds and potential aerosol–cloud interactions associated with cirrus thinning.

There was also discussion of papers to be submitted to the GeoMIP special issue of *Atmospheric Chemistry and Physics*. As of early April, 24 papers had been published and 7 more were under review for this special issue, which prepublishes papers as soon as they become available. Among those submitted are two GeoMIP papers on sea spray geoengineering containing analyses of the most recently available GeoMIP simulations.

The GeoMIP Testbed continues to provide a platform on which new ideas can be vetted before being adopted by a large number of models. Attendees discussed a recent proposal to the GeoMIP Testbed that involves simulations of direct injection into the stratosphere of sulfuric acid droplets all of similar size, as opposed to the customary simulation of injecting gaseous sulfur dioxide into the stratosphere. This proposal, which meeting participants agreed needs to be vetted in climate model simulations, is designed to determine whether modifying the stratospheric injection strategy can overcome the problem of sulfate aerosol particle growth, which makes the sulfate species less reflective and more prone to falling out of the atmosphere.

Existing proposals to the GeoMIP Testbed, such as G4Foam (brightening the marine surface in select locations) and G4SSA (stratospheric sulfate aerosol geoengineering simulations with specified, internally consistent aerosol surface area density and stratospheric chemical constituents), have been vetted with single models. Meeting participants agreed that they are ready to be considered by the broader GeoMIP community.

Attendees identified a continuing need to involve new communities, focusing particularly on interactions with researchers planning small-scale field tests. There are ongoing efforts to integrate the impact assessment and social science communities into GeoMIP. This project continues to pursue geographic diversity, partnering with many of the major worldwide geoengineering research projects, for example, those in Europe and China.

By **Ben Kravitz** (email: ben.kravitz@pnnl.gov), Atmospheric Sciences and Global Change Division, Pacific Northwest National Laboratory, Richland, Wash.; and **Alan Robock,** Department of Environmental Sciences, Rutgers University, New Brunswick, N.J.

Climate Models Are Uncertain, but We Can Do Something About It

As climate models become increasingly complex, how do we ensure that their predictions remain robust? The answer involves shifting our focus. Credit: photocanal25/DigitalVision Vectors/Getty Images

Model uncertainty is one of the biggest challenges we face in Earth system science, yet comparatively little effort is devoted to fixing it.

A well-known example of persistent model uncertainty is aerosol radiative forcing of climate, for which the uncertainty range has remained essentially unchanged through all Intergovernmental Panel on Climate Change assessment reports since 1995. From the carbon cycle to ice sheets, each community will no doubt have its own examples.

We argue that the huge and successful effort to develop physical understanding of the Earth system needs to be complemented by greater effort to understand and reduce model uncertainty. Without such reductions in uncertainty, the science we do will not, by itself, be sufficient to provide robust information for governments, policy makers, and the public at large.

Model Wiggle Room

As British statistician George Box famously said, "all models are wrong, but some are useful." Less known is what Box said next: "The scientist cannot obtain a 'correct' [model] by excessive elaboration" [*Box,* 1976].

Most modelers would probably disagree that current model developments are excessive. But the point that Box was making is that models are only representations of reality and are therefore full of uncertain numbers, many of which cannot be defined experimentally. Even elaborate representations based on good process-based understanding are uncertain. In other words, our model simulations have an enormous number of degrees of freedom. We can think of this as wiggle room.

So how much wiggle room do we have in our models, assuming we have decided what the key processes are? In a model with, conservatively, 20 important and uncertain processes, each associated with a single uncertain parameter, the model outputs can be sampled from 20-dimensional space. This is a hypercube with around a million corners.

This complex space remains almost entirely unexplored because limited computational resources usually force research teams to settle on one "variant" of the model arrived at through tuning.

What We Lose When Settling on One Model Variant

Selecting one model variant means that we never get to see many other perfectly plausible variants of the model, which may exhibit quite different behaviors when used to make predictions.

What is the problem with selecting one "best" model variant from the enormous set of potential variants? After all, we have drawn on years of experience and substantial resources at a model development center to select it.

The problem is that useful or not, one variant of a model tells us nothing about the uncertainty of the model predictions. To determine the uncertainty in the model predictions, we would need to identify all the plausible model variants, that is, those that can be judged as consistent with observations. But with so many degrees of freedom, there are, of course, a huge number of plausible model variants.

Every model developer recognizes the problem of trying to find a plausible model as the "balloon-squeezing problem." Yes, we've squeezed the balloon at one point to generate a plausible model when judged against particular observations, but this creates a bulge of less plausible solutions somewhere else.

Model Intercomparison Projects

Model intercomparison projects are the main way that the community explores some of the uncertainties. The idea is simple: Each model is like a differently shaped balloon, so comparing these models may reveal models' strengths and weaknesses.

How useful is diversity across multiple models? Model diversity can tell us a lot about model realism when we discover unique or common model deficiencies. But when it comes to understanding and reducing uncertainty, we need to bear in mind that a typical set of, say, 15 tuned models is essentially like selecting 15 points from our million-cornered space, except now we have 15 hopefully overlapping, million-cornered spaces to select from.

Although these models are individually well chosen and form a "collection of carefully configured best estimates" [*Knutti et al.,* 2010], they clearly aren't a representative sample of all possible models. Your statistics instructor would tell you to go and collect more data before drawing any inferences.

The Dangers of Using a Small Set of Models

We need to be very wary of using a small set of models to observationally constrain model predictions.

An example of observational constraint (or model screening) is the multimodel Atmospheric Chemistry and Climate Model Intercomparison Project study [*Shindell et al.,* 2013], in which five models were selected from nine on the basis of their skill in simulating aerosol optical depth. The five models had a smaller range of simulated aerosol radiative forcing than the nine. The authors were open about the procedure, noting that the set of screened models would probably be different if uncertainties in aerosol emissions had been accounted for.

But the emissions in this case were just one of many important uncertainties in the million-cornered hypercube. Without any estimate of uncertainty in the model predictions, such screening cannot provide a statistically robust estimate.

Many studies use emergent constraints to attempt to narrow the multimodel range. In this approach, a linear relationship between an unobservable variable of interest (like aerosol forcing or future temperature) and an observable variable (like aerosol optical depth or sea ice cover) simulated by multiple models is used to read off the "observationally constrained" value of the variable of interest. But

with only a small set of models drawn from a potentially much larger set, there is a risk that such correlations may be artificially inflated, regardless of whether the relationship can be interpreted physically.

As an example, Figure 1a shows how aerosol forcing correlates with optical depth in a set of 200 model simulations in which 27 model parameters were perturbed. The correlation coefficient is 0.55. Figure 1b shows the correlation coefficient for many samples of 15 models drawn randomly from the 200.

The example shows that there is quite a high chance of finding sets of 15 models with a linear correlation that is much higher than that of the entire population of models. If each model in a multimodel ensemble sampled the wider uncertainty space, our belief in the effectiveness of strong multimodel emergent relationships might be reduced.

A Way Forward

Scientists appear to have no option but to carry on this way, despite evidence that our progress toward reducing climate model uncertainty is very slow and knowing that we are overlooking many uncertainties. Models with higher complexity will undoubtedly have greater fidelity for some problems, but it is doubtful whether such model "elaboration" will get us any closer to reducing the overall uncertainty. In fact, it may have the opposite effect [*Knutti and Sedláček,* 2012].

We suggest a different framework. If the scientific community wants to reduce uncertainty, then it needs to treat uncertainty as one of the primary scientific challenges and tackle it directly.

Alongside current approaches of model development and refinement (which we certainly don't reject), we advocate that more needs to be done from a system uncertainty point of view. Many funding proposals and publications often have the stated aim of "reducing uncertainty," usually by process elaboration, but the climate modeling community tends to treat model uncertainty as a secondary challenge and rarely plans strategically for its reduction.

However, there are some very useful statistical techniques that can generate model outputs across the million-cornered space based on a manageable number of training simulations. These and other statistical techniques are being applied successfully across a range of complex science problems as diverse as hydrology [*Beven and Binley,* 2013], disease transmission [*Andrianakis et al.,* 2015], galaxy formation [*Rodrigues et al.,* 2017], aerosol modeling [*Lee et al.,* 2013], and, increasingly widely, climate science [*Qian et al.,* 2016].

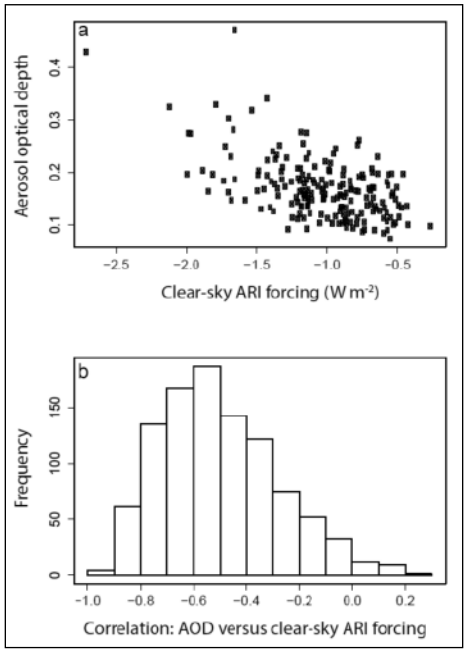


Fig. 1. Correlation between modeled aerosol optical depth (AOD) and clear-sky aerosol–radiation interaction (ARI) forcing over Europe in a climate model perturbed-parameter ensemble of 200 members. Each point in Figure 1a is a model simulation with a different setting of 27 model input parameters that affect aerosol emissions and processes. Figure 1b shows the range of correlation coefficients that can be generated by randomly selecting many sets of 15 members of the ensemble from the set of 200.

Once the model uncertainty has been comprehensively sampled using an arbitrarily large sample of model variants, some of the important sources of uncertainty can be made clear. It is then possible to screen models in a statistically robust procedure, such as through "history matching" [*Craig et al.,* 1996]: seeing whether past real-world behavior matches model output. Structural deficiencies can even be detected by comparing with observations using a statistical framework [*McNeall et al.,* 2016].

We feel that faster progress is much more likely if scientists integrate such uncertainty quantification approaches into wider model development and the intercomparison activities that underpin much of climate model assessment.

The Weight of Neglected Uncertainty

More robust statistical procedures are not straightforward or undemanding in terms of computing resources, nor are they the whole solution to the problem of developing robust climate models [*Knutti et al.,* 2010]. Hundreds of simulations are required to build the statistical picture, and ever larger volumes of data need to be handled. It is unlikely that any more than a few modeling centers could commit to this approach.

But we need to weigh up how much effort should go into model "elaboration" versus efforts to tackle uncertainty. They are not the same problem.

It would be a shame if the endeavors of 10,000 geoscientists led us to a point of exquisite model beauty, only to discover that these exquisite models were burdened by an accumulation of decades' worth of neglected uncertainty. At the very least, we won't understand the uncertainty in a collection of elaborate models unless we make more effort to calculate it.

Acknowledgments

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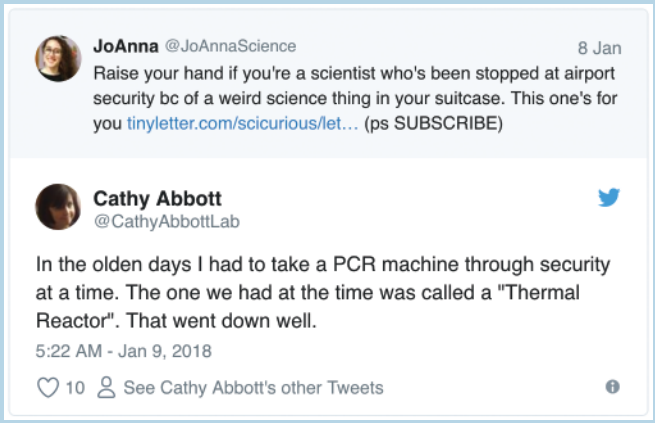
By **Kenneth S. Carslaw** (email: k.s.carslaw@leeds.ac.uk), **Lindsay A. Lee, Leighton A. Regayre,** and **Jill S. Johnson,** School of Earth and Environment, University of Leeds, Leeds, U.K.

When Your Weird Science Gets Stopped at Airport Security

We all know airport security is difficult—you've got to take off your shoes, empty your pockets, and, if you're a scientist, try to explain to the scary-looking security officer that the bag of suspicious white powder in your carry-on is, in fact, powdered limestone, not an illegal substance.

Scientists taking home rock samples or field gadgets have it tougher at airports these days. Here are 14 examples of scientists getting stopped at airport security because of a strange science-related item in their luggage.

1. Because She's Holding a Thermal ~~Detonator~~ Reactor!



2. Gneiss Chert

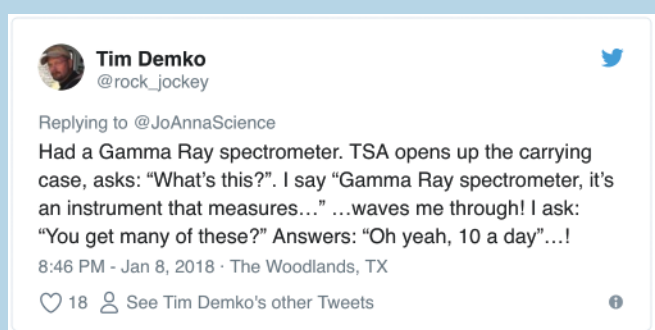
3. Seriously, Officer, It's Oregano

4. What's in the Bag?

5. But at Least You Packed Your Own Bag, Right?

6. Yeah, Yeah, Science Equipment. But What's with the Yam?

7. Ten Every Day? This Deserves More Explanation...



8. What, Don't You Mail Rocks?

Kirsten Dutton
@KirstenDutton

Replying to @JoAnnaScience
Surprisingly hasn't happened to me yet but have shocked my fair share of post office employees by being asked about the contents of the parcel I'm sending and replying 'rocks' with total seriousness! ⛏️
8:42 PM - Jan 8, 2018
♡ 10 See Kirsten Dutton's other Tweets

9. Is There a Geologist in the House?

Leslie Almberg
@VOLCANOTEACHER

Replying to @JoAnnaScience
I was with a friend who had a 1L bottle of magnetite sand and a rock hammer in her carry-on trying to go through security in the Manila airport. I've never seen security officers jump away from the X-ray machine!! I instantly called out, "we're geologists!" #crazygeologists
7:56 PM - Jan 8, 2018
♡ 26 See Leslie Almberg's other Tweets

10. It's Not What You Think, I Swear

Jen O'Keefe
@PalyJen

Replying to @PalynoAngie and 2 others
😂 Oh yes. My favorite flash drive has caused my pack to be completely emptied at security twice now.
7:25 PM - Jan 8, 2018
♡ 23 See Jen O'Keefe's other Tweets

11. To Paraphrase Monty Python, Every Rock Is Sacred

Nuzhat Tabassum
@ThenSheAppears

Leh Airport in Ladakh, India
Security: Ma'am, are there... rocks in your suitcase?
Me: ... Yes
Security: Are they sacred rocks?
Me: *in my head* They're sacred to me...
twitter.com/joannascience/…
7:25 PM - Jan 8, 2018
♡ 17 See Nuzhat Tabassum's other Tweets

12. When I Said, "See for Yourself," I Didn't Mean Actual C4

Mathias Köster
@thelostgeo

That time TSA thought the white and mushy #clay is plastic explosives, and the quick swipe test returned a "positive" for explosives, too = instant attention! 😬😅
twitter.com/JoAnnaScience/…
5:41 PM - Jan 8, 2018
♡ 5 See Mathias Köster's other Tweets

13. Oh, Sure, It's Powdered "Limestone" from Afghanistan

Richard Shaw
@Rashaw_Rocks

Replying to @JoAnnaScience
A squeaky bum moment taking home samples of high-purity limestone from Afghanistan. Small bags of white powder! There were a few questions!
6:19 PM - Jan 8, 2018
♡ 9 See Richard Shaw's other Tweets

14. That's Not a Knife...

Robyn Inglis
@rhinglis

Replying to @JoAnnaScience
Maseru airport, sitting in cafe after check in "excuse me ma'am, do you have knives in your checked bag?". TBF, the putty knife that slices neatly through sediments may have looked a little off, but it was my *checked* bag!
5:11 PM - Jan 8, 2018
♡ 8 See Robyn Inglis's other Tweets

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

The WICKED PROBLEM of EARTHQUAKE HAZARD in DEVELOPING COUNTRIES

By Michael S. Steckler, Seth Stein, S. Humayun Akhter, and Leonardo Seeber

Mitigating earthquake hazards in the urban regions of Bangladesh is a "wicked" problem, requiring difficult trade-offs among competing priorities and risk assessments that are hampered by a lack of information. Dhaka, the capital of Bangladesh, shown here, has a mixture of dense residences and skyscrapers. Credit: S. H. Akhter

Earthquake preparation in Bangladesh is a conundrum, where crucial information is missing and investments often involve painful trade-offs.

Many developing nations in earthquake-prone areas confront a tough problem: How much of their limited resources should they use to mitigate earthquake hazards? This decision is difficult because major earthquakes are infrequent, and it is unclear when one may happen, how big it could be, and how much harm it may cause. Moreover, these nations have profound immediate needs, including such ongoing rapid transformations as urbanization.

Tough societal challenges for which crucial information is missing and proposed solutions involve complex interactions with other issues are called "wicked" problems [*Rittel and Webber,* 1973]. These contrast with "tame" problems in which necessary information is available and solutions, even if difficult and expensive, are straightforward to identify and execute.

A close look at issues involved with mitigating earthquake risk in Bangladesh illustrates what researchers and disaster managers can do to address wicked problems in

disaster management. The examination shows that wicked problems, despite their complexity, can be approached with strategies that should reduce vulnerabilities and potentially save lives.

Wicked or Tame?

Updating the United States' aging infrastructure is a tame problem because what is wrong and how it can be fixed are clear. In contrast, addressing climate change is a wicked problem because its effects are uncertain and the best strategies to address them are unclear [*Stang and Ujvari,* 2015].

Natural hazard problems can be tame or wicked. Earthquake hazard mitigation for San Francisco is a relatively tame problem. Studies of regional geology and past earthquakes have been used to infer shaking in future earthquakes and develop mitigation approaches, including codes for earthquake-resistant construction. The population is affluent and aware enough to accept these measures, although financing and carrying out these measures is still challenging.

In contrast, earthquake hazard mitigation in Bangladesh and its surroundings is a wicked problem (Figure 1). Bangladesh is the world's most densely populated nation, with 160 million people, approximately half the U.S. population, crowded into an area the size of Iowa. The region lies on the boundary between plates whose collision uplifts the Himalayas, but complex geology and sparse data make it difficult to assess earthquake hazard. Thus, it is difficult to decide how much of the limited resources available should be used for earthquake hazard mitigation, given other more immediate needs.

For example, 31% of Bangladeshis live below the national poverty line, according to data from 2010 (see http://bit.ly/Bangladesh-poverty). Per capita gross domestic product is only about $1,200, so Bangladesh needs to devote resources to economic growth. Bangladesh also needs resources to address challenges resulting from the nation's low elevation. Almost half the population lives within 10 meters of sea level, so the country is very vulnerable to tropical cyclones, riverine flooding, and rising sea level.

Hazards, Risks, and Vulnerability

"Hazards" are the natural occurrences of earthquakes or other phenomena over which we have no control, whereas "risks" are the dangers they pose to lives and property. In this formulation, risk is the product of hazard and vulnerability. We want to assess hazards—to estimate their significance—and develop methods to reduce vulnerabilities and mitigate the resulting losses.

We can assess hazards only as best we can, but risks are affected by human actions that increase or decrease vulnerability, such as where people live and how they build. A disaster occurs when, because of high vulnerability, a natural event has major negative consequences for society.

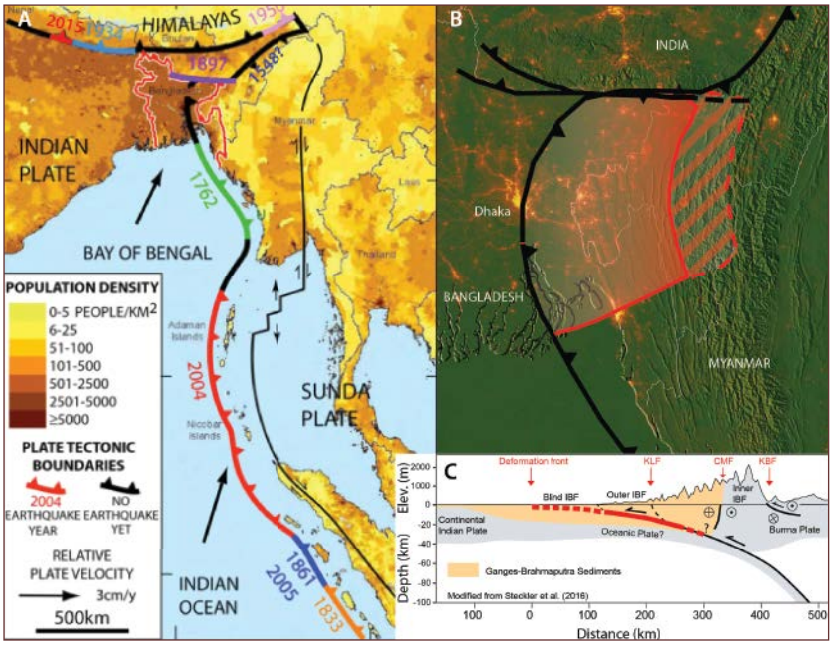


Fig. 1. (a) Major tectonic boundaries of the northeastern Indian plate. Numbers represent the years for major historic earthquakes. The base map shows population density. Bangladesh, at the northern end of the Bay of Bengal, has more than 1,000 people per square kilometer and is situated on a seismic gap. (b) Topographical image from NASA's Shuttle Radar Topography Mission (green) of the area around the seismic gap in Bangladesh, with an overlay of nighttime lighting as a proxy for population density (from C. Small). The black lines show the major thrust systems with ticks on the upper plate. The red overlay shows the locked megathrust [from Steckler et al., *2016]. The striped area shows the uncertain downdip limit of the locked zone based on two models for the structure. The lighter coloring for the updip (western) portion of the megathrust is due to the uncertainty regarding whether the frontal part will rupture in the next megathrust earthquake. (c) Cross section showing the locked megathrust in red, with dashed portions indicating the uncertain updip and downdip limits. Credit: Figure 1a modified from* Steckler et al. *[2008]; Figure 1c modified from* Steckler et al. *[2016]*

Vulnerable Urban Areas

Assessments of hazards, vulnerabilities, and risks illustrate another factor that makes the earthquake problem particularly wicked for developing countries: Many are rapidly urbanizing and thus increasing their vulnerability such that earthquake hazards will have amplified effects. For example, in their humid subtropical environment, rural Bangladeshis traditionally have relied on modest homes with walls of mud or bamboo, which are less dangerous and more easily rebuilt than large concrete structures.

Along the Himalayan plate boundary, more than 50 million people now live in cities of at least a million inhabitants, including the capitals of Bangladesh, Bhutan, India, Nepal, and Pakistan. These rapidly growing, crowded megacities are filled with multistory concrete buildings that are likely vulnerable to earthquakes. Dhaka, Bangladesh's capital, is one of the world's fastest growing megacities (see http://bit.ly/Dhaka-growth). Some 16 million people currently live in Dhaka, and the potential collapse of services and accessibility after an earthquake compounds their risks.

Small Shifts, Big Effects

Urban vulnerabilities are expressed only when hazards trigger them. And in Bangladesh, hazards have the potential to be great.

This view of Dhaka, Bangladesh, shows the contrast between a waterfront neighborhood with densely packed small houses and the skyscrapers in the more affluent Gulshan neighborhood. Credit: Michael Steckler

The Indian tectonic plate moves northward toward Eurasia at a pace of about 50 millimeters per year (Figure 1). This continuing collision has raised the great Himalayas and caused large destructive earthquakes along the plate boundary. Bangladesh is at the boundary's northeastern end, the structure of which is complicated and poorly understood.

The plate boundary forms a roughly east–west arc along the Himalayas, bends 180° around the eastern Himalayan syntaxis, and then transitions into a broad zone of roughly north–south trending folds and thrusts, the Indo-Burma Ranges [*Steckler et al.,* 2008]. The boundary continues southward to the Andaman-Sumatra subduction zone. Although the deformation zone that accommodates the motion between India and Southeast Asia is often called the Burma platelet, multiple active structures indicate that this "platelet" is not rigid.

Until recently, it was unclear whether the India–Indo-Burma motion included convergence [*Gahalaut et al.,* 2013] and caused megathrust earthquakes. However, GPS data show that although the motion is highly oblique, it has a significant convergence component [*Steckler et al.,* 2016]. This deformation, at 13–17 millimeters per year, appears to be loading the locked shallow megathrust, along which India subducts beneath Burma (Figures 1b and 1c). The strain from this deformation will likely be released in future large earthquakes, like those at other subduction zones [*Steckler et al.,* 2016].

What We Know and What We Don't

These new data provide only some of the information needed to estimate the danger of future earthquakes. Scientists also need better estimates of how often large earthquakes may happen on sufficiently close active faults, how big they may be, and how much shaking they may cause. Results are compiled in earthquake hazard maps predicting how much shaking is expected to occur with a certain probability within a certain period of time. These maps are used to prepare for earthquakes, notably via building codes that prescribe earthquake-resistant construction.

Although we have no way of knowing the future, we can make estimates with information about past earthquakes. For example, the Juan de Fuca plate subducts beneath northern California, Oregon, Washington, and British Columbia much as India subducts beneath the Indo-Burma Ranges. This area, known as the Cascadia subduction zone, was widely considered to be mostly aseismic until geological records became available. These records showed that large earthquakes happened some 530 years apart over the past 10,000 years, although the intervals are irregular [*Goldfinger et al.,* 2012]. The most recent, in 1700 CE, is thought to have had a moment magnitude (M_w) of about 9.

We can gain insight into what to expect if we assume that the future will resemble the past when we derive earthquake hazard maps, but Earth does not always cooperate, and surprises are inevitable [*Stein et al.,* 2012]. Add to this a lack of information, and Bangladesh's situation becomes much more challenging.

Hazard assessment for the Indo-Burma boundary is like the assessments for Cascadia before evidence of past megathrust earthquakes became available. Dhaka has been shaken by both teleseismic (distant) and local earthquakes during recent times [*Akhter,* 2010], but there is little documentation of past megathrust earthquakes. As a result, there is no good way to estimate how often such earthquakes may occur, how big they may be, or how much shaking they may cause.

The limited historical records we do have indicate that no megathrust earthquake has ruptured beneath Dhaka since 1610. If this is true, then the strain from more than 5 meters of motion has been stored on the megathrust. If this strain were released in one earthquake, it would have M_w ~8.2. If it has been longer since the last earthquake, the next temblor may be even bigger. Such a large earthquake seems possible: The plate boundary segment to the

south ruptured in 1762 in an earthquake estimated as M_w 8.5–8.8 [*Cummins,* 2007; *Wang et al.,* 2013].

Furthermore, the subduction zone here is extremely large and complex. Field geology and seismic data [*Sikder and Alam,* 2003; *Betka et al.,* 2016] indicate that the megathrust is unusually broad and shallow, but it is uncertain whether and how often it ruptures seismically. It's also unclear whether slip in an earthquake would taper to the west or whether the frontal zone would rupture in separate, less frequent earthquakes [*Wang et al.,* 2014]. Might only some of the megathrust earthquakes propagate to the thrust tip near Dhaka? Splay faults rooting the folds and other faults within the plate boundary zone are also possible sources of damaging earthquakes [e.g., *Debbarma et al.,* 2017]. The multiple scenarios increase the uncertainty in seismic hazard assessment.

Tackling the Problem

Although protecting millions of urban dwellers in Bangladesh might seem daunting, it is not hopeless; Bangladesh has tackled this kind of problem before. Over a span of decades, Bangladesh has successfully reduced the risk from tropical cyclones. Shelters have been built along the coast, and a network of volunteers warns people when to evacuate. A cyclone in 1970, before the program began, killed 300,000–500,000 people. By 2007, 1.5 million people took refuge in shelters ahead of Cyclone Sidr, reducing the death toll to about 4,300. Efforts continue to increase the stock of cyclone shelters and promote recovery after storms.

Similar efforts are beginning for earthquakes. The Ministry of Disaster Management and Relief has adopted 12 July as Earthquake Day, to be observed with earthquake drills and seminars to increase awareness. Scientists are preparing hazard maps for the country, although the maps are preliminary and are bound to have large uncertainties.

Initial studies and planning efforts are devoted to exploring the consequences of large earthquakes [*World Bank and Earthquakes and Megacities Initiative,* 2014]. Assessment of the building stock typical in developing nations shows its vulnerability to earthquakes. In Dhaka, ~21% of the buildings are easily damaged, unreinforced masonry (brick) construction. About 77% are reinforced concrete but have not been designed to resist earthquake shaking. Moreover, in many cases the site preparation and construction are thought to be poor. Although a building code was enacted in 2006, enforcement is limited, and newer buildings may be as vulnerable as older ones. For example, Dhaka's Rana Plaza opened in 2009 when the code was in place. In 2013, it collapsed, killing more than 1,100 people.

A further problem is that Dhaka and most of Bangladesh are located on the sediments of the Ganges-Brahmaputra Delta. Earthquake shaking in thick sediments is generally enhanced relative to hard rock, but the amount depends on the size and shape of the basin and the sediment properties. Surface sediment is prone to liquefaction and sand boils, in which strong shaking causes saturated soil to lose strength or develop high pore pressure and sand eruptions. For example, the 2017 M_w 5.7 earthquake in Tripura, India [*Debbarma et al.,* 2017], caused sand boils and damaged buildings in northeastern Bangladesh about 40 kilometers away.

Reasonable Risk Reduction Steps

The case study of Bangladesh illustrates the challenge of how to address an uncertain hazard, given limited resources [*Stein and Stein,* 2014]. How much mitigation is enough? Mitigation is like buying insurance; we spend money today to reduce consequences of events possible tomorrow. More mitigation reduces future losses but costs more now; resources used for mitigation are not available for other purposes. Money spent making existing schools earthquake resistant cannot be used to build schools or hire teachers for communities that have none [*Kenny,* 2009].

Ideally, if the hazard were well understood, economic models could be used to develop mitigation strategies. The total cost of natural disasters to society is the sum of the expected loss in future disasters and the cost of mitigation. This total depends on the amount of mitigation, shown schematically by the U-shaped curve in Figure 2.

If we undertake no mitigation, we have no mitigation costs (left side of the curve) but expect high losses, so it makes sense to invest more in mitigation. Increased mitigation should decrease losses, so the curve goes down. Eventually, however, the cost of more mitigation exceeds the reduced losses, and the curve rises again. These additional resources would be better invested otherwise. The optimum mitigation is the sweet spot at the bottom of the curve.

Uncertainties in our ability to assess hazards and resulting losses limit our ability to determine an optimal strategy. Moreover, given limited resources, a community is likely to spend less than the optimum anyway. Fortunately, spending less is better than doing nothing (Figure 2), and we can still suggest strategies that make sense given the high uncertainty and limited resources. This approach follows the idea that "the best is the enemy of the good": Requiring too much safety would cost so much that nothing is likely to be done.

Public education and understanding are needed to raise support for any level of investment. Recent nearby earthquakes, like the 2004 Sumatra, 2015 Gorkha, and 2016 Manipur earthquakes, which caused shaking and damage in Bangladesh, have raised earthquake awareness in the country. The scientific community is providing better understanding and monitoring of tectonics and earthquake processes in and around Bangladesh. These developments offer Bangladesh the opportunity to increase earthquake preparedness and reduce earthquake risk [*Akhter,* 2010].

Building New Versus Fixing Old

As the population shifts from rural to urban, the extensive construction that follows provides an opportunity for earthquake risk reduction. This opportunity stems from one key idea: A crucial step to mitigating earthquake risk in Bangladesh is enforcing the building code.

Studies show that a moderate degree of safety is achievable with a modest, perhaps 5%–10%, increase in building costs [*Schulze et al.,* 1987]. Over time, natural turnover of buildings will make communities more resilient. Thus, an approach to reducing risk is to plan the desired fraction of safer buildings over time and to incentivize new safer construction over modifying unsafe existing buildings.

Because strengthening (retrofitting) an older building can cost between 25% and 70% of the building's value, we recommend this approach for only the most critical structures [*Arikan et al.*, 2005; *McMonies*, 2016]. For example, the Bangladeshi government has decided to retrofit some fire stations.

Outside of critical infrastructure, the ideal case is when tenants would pay more for ensuring the safety of their buildings. However, conditions are not always ideal.

Erdik and Durukal [2008] report on similar issues faced in Istanbul, a comparable setting. Assessments showed that retrofits would cost about 40% of replacement value. Their study showed that Istanbul residents viewed this "as an investment with no financial return and, as such, no conceivable reduction in insurance premium, property tax, or building permit fees would be sufficient to create an incentive for retrofitting." This response was rational, unless one postulates a high probability of major damage on a short timescale [*Kenny*, 2009]. Hence, a major retrofitting program would require large investment of public funds, which is unrealistic given other needs.

Putting It All Together

Recommendations by *World Bank and Earthquakes and Megacities Initiative* [2014] favor raising public earthquake awareness; building competency for architects, engineers, planners, and construction professionals; improving emergency response; and planning land use in a risk-sensitive manner. Ongoing programs, such as the annual U.S.–Bangladesh Pacific Resilience Disaster Response Exercise and Exchange, the Global Facility for Disaster Reduction and Recovery program, and the Comprehensive Disaster Management Programme, build toward these goals.

Robust risk management is practical, even for developing nations. It involves recognizing uncertainties and developing policies that should give a reasonable outcome for a range of the possible hazard and loss scenarios. It requires accepting the need for humility in the face of the complexities and capriciousness of nature while making realistic policies that the public accepts. Although long-term investments in risk reduction compete with immediate needs, they will pay back handsomely should a major earthquake strike.

Acknowledgments

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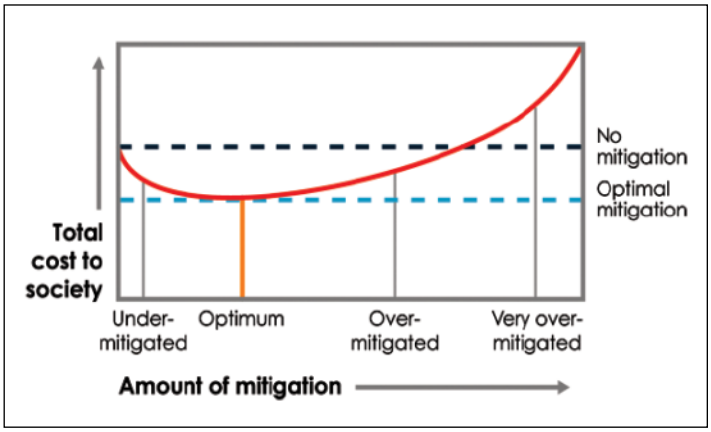

Fig. 2. The total cost to society of natural disasters depends on the amount invested in mitigation. The optimal mitigation level minimizes the total cost, the sum of the expected loss and the mitigation cost. In reality, a community is likely to spend less than the optimum, but spending less than the optimum is better than spending nothing. Credit: Stein and Stein *[2014]*

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Dave Lovalvo and Todd Gregory deploy ROV Yogi *from R/V* Annie II *in Yellowstone Lake.*
Credit: Chris Linder, Woods Hole Oceanographic Institution

EXPLORING THE RESTLESS FLOOR OF YELLOWSTONE LAKE

By Robert Sohn, Robert Harris, Chris Linder, Karen Luttrell, David Lovalvo, Lisa Morgan, William Seyfried, and Pat Shanks

Yellowstone Lake, far from any ocean, hosts underwater hot springs similar to those on mid-ocean ridges. A research team is investigating the processes that drive the lake's hydrothermal systems.

Yellowstone Lake, the largest high-altitude freshwater lake in North America, covers some 341 square kilometerwws of Yellowstone National Park in northwestern Wyoming. Hot springs, geysers, and fumaroles in and around the lake serve as constant reminders of the volcanically and seismically active Yellowstone caldera below.

The vent fields on the floor of Yellowstone Lake are a significant part of the world's largest continental hydrothermal system and thus form an important part of the Earth's thermal budget and geochemical cycles. Continental hydrothermal systems are a primary source of economically important metal deposits, provide geothermal energy resources, support exotic ecosystems that are just beginning to be explored, and, in some set-

tings such as Yellowstone, pose significant geological hazards.

Continental hydrothermal systems are typically located in dynamic geological environments where the rocks through which fluids flow are perturbed frequently. Understanding the cause-and-effect relationships between these perturbations and hydrothermal flow can yield valuable insights into subsurface processes that are otherwise difficult to observe [e.g., *Manga et al.,* 2012; *Wilcock,* 2004].

Our team of researchers has embarked on a multiyear project to understand how the Yellowstone Lake hydrothermal system responds to geological and environmental forcing (Figure 1) [*Morgan et al.,* 2003; *Farrell et al.,* 2010]. Fieldwork for the Hydrothermal Dynamics of Yellowstone Lake (HD-YLAKE) project began in the summer of 2016 and continues through 2018. The project has major funding and logistical support from the National Science Foundation, the Yellowstone Volcano Observatory, the U.S. Geological Survey, and the National Park Service.

A Not-So-Peaceful Alpine Lake

Yellowstone Lake is a large freshwater alpine lake that sits atop a vigorous hydrothermal system [*Morgan et al.,* 1977]. This hydrothermal system is sensitive to such geological and environmental processes as lake-level fluctuations, wind-driven waves, earthquakes, solid Earth tides, and caldera deformation cycles. These processes affect the pressure that confines the lake floor vent fields and the temperatures and stresses acting on the subsurface materials through which fluids flow.

The northeastern part of the lake hosts large hydrothermal explosion craters, including the Mary Bay explosion crater, which, with a diameter of about 2.6 kilometers, is the largest documented such feature in the world [*Morgan et al.,* 2009]. The number of large (>100-meter-diameter) hydrothermal features in and around the northern part of the lake dramatically illustrates the area's sensitivity to perturbations. Hydrothermal explosion craters form when subsurface liquids flash to steam in response to a rapid pressure drop (which could occur in response to a sudden change in lake level caused by an earthquake inside the caldera, for example) and represent an extreme example of a cause-and-effect relationship between geological processes and the thermodynamic state of the hydrothermal fluids.

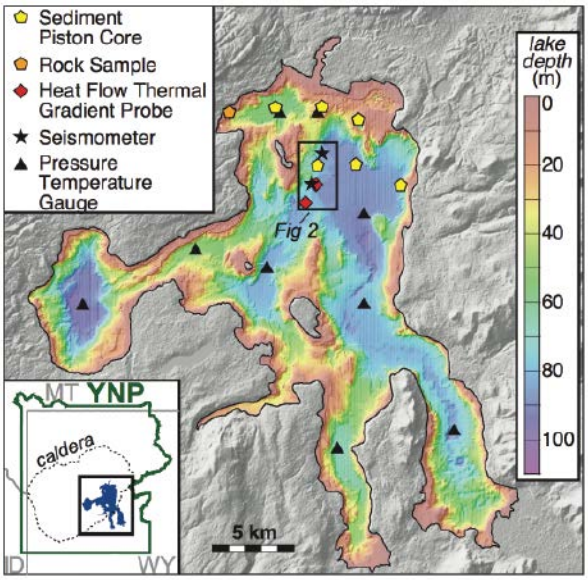

Fig. 1. Yellowstone Lake bathymetry, including piston core and pressure–temperature gauge locations from the 2016 campaign. The black box shows the location of the map in Figure 2. Stevenson Island is the small elongated feature west of the focus area. The inset map shows the location of Yellowstone National Park, the 630,000-year-old Yellowstone caldera, and Yellowstone Lake.

> Perhaps we will learn just why this peaceful and beautiful alpine lake is prone to fits of explosive violence.

Our project seeks to understand these relationships by observing how the temperature and composition of the hydrothermal fluids, the heat flow of the system, and the microbial communities inhabiting the vent fields respond to forcing. Our field strategy uses a two-pronged approach: geophysical and geochemical monitoring of the active system and analyses of sediment cores to study the postglacial (~15,000-year) history of hydrothermal activity beneath the lake.

In 2016, we deployed a network of pressure-temperature gauges, heat flow equipment, and seismometers on the lake floor (Figures 1, 2, and 3). We collected sediment gravity cores from the top meter of the lake bed, sediment piston cores as long as 12.1 meters, gastight hydrothermal fluid samples, and samples of filamentous microbial material. In 2017, we began analyzing these data and samples; collected another set of samples and heat flow measurements; and deployed a full-scale network of monitoring instrumentation, including 10 lake bottom seismometers and two in situ chemical sensors, at the focus site (Figures 2 and 4). Monitoring equipment on the lake floor will be recovered in August 2018.

Sampling the Sediment Record

The HD-YLAKE project seeks to reconstruct the relationship between the long-term history of hydrothermal activity in Yellowstone Lake and its influence on limnological and climate-driven processes in the lake and its watershed. In 2016, using the National Lacustrine Core Facility's (LacCore) Kullenberg corer, we collected eight

sediment piston cores from six different geologic environments in the lake's northern basin (Figure 1):

- an inactive hydrothermal dome
- an active graben
- a hydrothermal explosion crater with active vents
- an area with multiple hydrothermal explosion deposits
- an area with landslide deposits
- the study focus site in the deepest part of the lake

At the site in the deepest part of the lake, hydrothermal fluids discharge at temperatures as high as 170°C, the hottest hydrothermal vent fluid temperatures yet measured in the park.

Preliminary examination of the split piston and gravity cores reveals that many contain multiple hydrothermal explosion deposits. The cores have been scanned for geophysical and geochemical parameters, and analyses are under way to determine their mineralogy and major-element, minor-element, and stable isotope composition. Geochemical analyses of pore fluid samples from the cores will provide insight into the fluid chemistry below the lake floor and constrain the nature and lateral extent of hydrothermal fluids in sediments surrounding the vent fields. Analyses of diatom populations, pollen, and charcoal preserved in the cores will link the limnological and watershed response of the lake to past climate, hydrothermal, and geologic activity.

New Technologies from Many Sources

An exciting aspect of this project concerns the technologies being developed to study the lake floor vent fields. For example, the Global Foundation for Ocean Exploration engineered a new research vessel (R/V *Annie II*) and a remotely operated vehicle (ROV *Yogi*) that together provide an unprecedented lake science platform.

R/V *Annie II,* a 40-foot-long (~12-meter-long) vessel powered by jet drives, can support ROV dives without having to anchor. The interior cabin is a fully climate controlled ROV operations center, with banks of high-definition video monitors and rack-mounted electronics. ROV *Yogi* is a sleek (500-kilogram) platform that carries a five-function robotic manipulator, along with several high-definition cameras and light-emitting diode (LED) lighting.

In 2016 and 2017, we used ROV *Yogi* to locate lake floor vents, deploy temperature probes, acquire vent fluid and rock samples, and sample filamentous microbial "streamer" communities. In 2016, R/V *Annie II* also supported the bathymetric and side-scan sonar mapping missions conducted by a type of autonomous underwater vehicle called Remote Environmental Monitoring Units (REMUS) that generated maps of the vent fields southeast of Stevenson Island with a horizontal resolution of about 10 centimeters.

University of Minnesota researchers developed a gastight hydrothermal fluid multisampler that can acquire fluid samples at ambient pressure from lake floor vents. The sampler includes a manifold inlet system with 12 gastight chambers for vent fluid sampling. In addition to collecting vent fluid samples, we also deployed in situ chemical sensors that monitor pH and oxidation-reduction (redox) conditions at a number of vent sites.

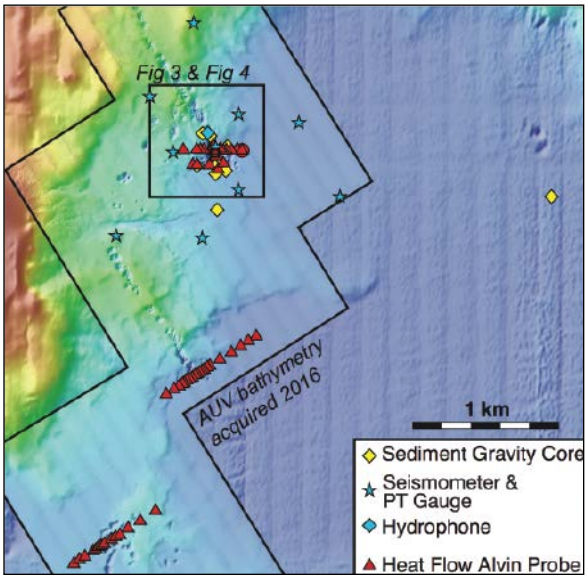

Fig. 2. Instrument deployments at the hydrothermally active focus site. High-resolution (10-centimeter pixel size) bathymetric data were acquired with the autonomous underwater vehicle REMUS 600 within the outlined region.

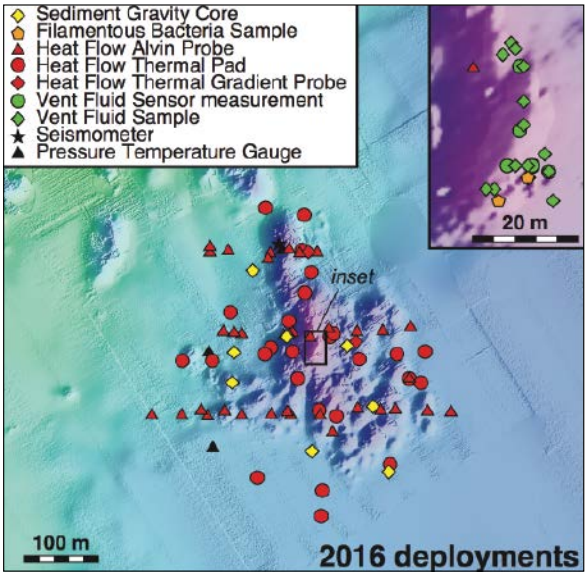

Fig. 3. Instrument deployment and sampling sites from 2016 fieldwork. The ubiquitous pockmarks shown in this map are generated when hydrothermal fluids dissolve silica as they flow through the sediments, and the most vigorous hydrothermal discharge in the lake occurs within the dense set of pockmarks shown here. The inset map shows detail of vent fluid and microbial sample sites in an especially active part of the system, on the wall of a large pockmark.

The combination of in situ sensor data with coregistered vent fluid samples is providing new insight into geochemical controls on lake floor hydrothermal processes. Metagenomic analysis of microbial communities associated with the fluid samples will reveal links

HD-YLAKE scientists aboard the Kullenberg corer, operated by the National Lacustrine Core Facility, on their way to a coring site. The Absaroka Range mountains are in the background. Credit: C. Linder, Woods Hole Oceanographic Institution

between geothermally established redox interfaces and microbiological colonization.

Oregon State University researchers are using a new thermal gradient probe that provides heat flow data over 1-year deployment intervals. This, along with a heat flow probe designed by the Deep Submergence Laboratory at Woods Hole Oceanographic Institution, has been adapted for use with ROV *Yogi* to carefully measure heat flow adjacent to hot springs and other lake floor features.

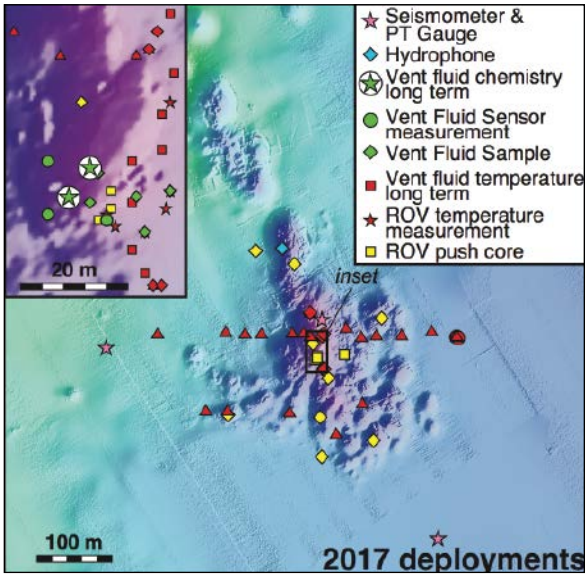

Fig. 4. Instrument deployment and sampling sites from 2017 fieldwork. The hydrophone marked here recorded audio-quality data at 44 kilohertz for 24 hours to characterize acoustic signals generated by bubble discharge. The inset map shows detail of sampling and monitoring instruments deployed in a highly active part of the system.

The Ocean Bottom Seismograph Lab at Woods Hole Oceanographic Institution modified its seismometer's instrument design to allow for the first seismic measurements on the floor of Yellowstone Lake. In 2017, we deployed 10 of these seismometers in a network centered around the focus site hydrothermal area, and one of the seismometers was equipped with a signal processing card designed by scientists at Institut des Sciences de la Terre in France that allows the hydrophone (called the Bubblephone) to monitor high-frequency acoustic signals generated by the discharge of gas bubbles (e.g., steam, carbon dioxide, hydrogen sulfide) on the lake floor.

Louisiana State University researchers deployed a network of pressure-temperature gauges that can detect water level changes of about 1 centimeter. The lake-wide network deployed in 2016 provides a synoptic view of seasonal lake-level and water temperature changes, as well as the enigmatic seiche waves [*Luttrell et al.*, 2013] that occur in the lake throughout the year. The focus site network deployed in 2017 (Figure 3) allows us to characterize how such environmental processes as wind-driven waves, ice cover, and seasonal lake-level changes affect hydrothermal activity.

Reaching Out and Moving Ahead

Yellowstone National Park draws more than 4 million visitors annually. The HD-YLAKE project is taking advantage of the excellent opportunities provided by this high level of visibility to educate the public about the geological and

biological processes associated with the lake floor vents in a variety of ways.

In 2016, photographer Chris Linder joined the research team to document the fieldwork, publishing photo essays on the project website (https://hdylake.org) and collecting multimedia material for video "chapters" focusing on different aspects of the project science. The team also began a new collaboration with educators at the Buffalo Bill Center of the West in Cody, Wyo., to produce educational materials for school groups and virtual visitors to the museum.

Fieldwork in 2018 will focus on recovering the monitoring network from the lake floor, including seismometers, temperature and heat flow probes, and fluid chemistry probes. We will also be collecting a new suite of heat flow measurements, sediment gravity cores, hydrothermal fluid samples, and microbial samples. This will mark the end of our fieldwork and a shift in emphasis to data analysis and modeling.

We will integrate monitoring data from the present-day system with historical data from the coring program to develop system-scale models of the hydrothermal system, including its response to forcing mechanisms. The models will provide insight into the subsurface dynamics and the spatial and temporal evolution of the system, including triggering mechanisms for catastrophic hydrothermal explosions.

Our field studies and analysis thus far have already started to change our understanding of the complex interacting systems at work beneath and within Yellowstone Lake. We are eager to recover our lake floor monitoring instruments this coming summer and begin the discovery process in earnest. Perhaps we will learn just why this peaceful and beautiful alpine lake is prone to fits of explosive violence.

Acknowledgments

The HD-YLAKE project is funded by the National Science Foundation's Integrated Earth Systems program (EAR-1516361), with major in-kind support from the U.S. Geological Survey's Yellowstone Volcano Observatory. Fieldwork is made possible by the Yellowstone Center for Resources, the Fisheries and Aquatic Sciences Program, and the Xanterra Parks & Resorts Company. The HD-YLAKE team also thanks the National Park Service rangers and staff for support of our field activities. All work in Yellowstone National Park was completed under an authorized Yellowstone research permit (YELL-2017-SCI-7018).

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In preparation for the Stratéole 2 project, scientists launch a helium balloon near Mahé in the Seychelles islands. Stratéole 2 balloons will circle Earth, drifting with the wind as their instruments collect atmospheric measurements. Credit: Philippe Cocquerez, CNES

Around the World in 84 Days

In the Stratéole 2 program, set to launch in November 2018, instruments will ride balloons into the stratosphere and circle the world, observing properties of the air and winds in fine detail.

By Jennifer S. Haase, M. Joan Alexander, Albert Hertzog, Lars Kalnajs, Terry Deshler, Sean M. Davis, Riwal Plougonven, Philippe Cocquerez, and Stephanie Venel

Jules Verne's adventure novels *Five Weeks in a Balloon* and *Around the World in 80 Days* highlighted some of the great technological advances of the late 19th century that revolutionized travel and captured the imagination of the public [*Verne*, 1863, 1873]. Among those inspired by the novels was Nellie Bly, an American journalist for the *New York World* who set off in November 1889 to complete a journey by rail and steamship, following Verne's imagined path around the world in a record 72 days [*Bly*, 1890] (Figure 1).

Bly's accounts demonstrated how new technology, such as the transcountry railroads in the United States and India and the Suez Canal, brought exotic destinations within reach. The revolutionary development of submarine cables and the electric telegraph allowed Bly to keep her editors, and the larger connected world, aware of her progress in near-real time.

The France-U.S. collaborative Stratéole 2 project is planning its own series of balloon trips, which will circle the world near the equator for 80 days (more or less), as did these fictional and factual 19th-century

adventurers, demonstrating new technology and sending back new observations from the voyage via satellite.

Drifting with the Winds

Scientists with the Stratéole 2 project will release superpressure balloons, designed to drift in the lower stratosphere, from the Seychelles islands in the Indian Ocean (Figure 2). Superpressure balloons contain a fixed amount of helium sealed inside an envelope that does not stretch. This type of balloon is not fully inflated when it is launched, but it expands to its full volume as it rises to an altitude where the gas density inside the balloon matches the density of the surrounding air and where it drifts with the wind.

Each balloon will carry as many as four instruments. As each collects high-accuracy measurements of meteorological variables, chemical tracers, clouds, and aerosols, the horizontal motions are nearly identical to those of the surrounding air mass. These measurements will advance our knowledge and understanding of cirrus clouds, aerosols, and equatorial waves in the tropical tropopause layer (TTL; the transition region between the troposphere and the stratosphere) and in the lower stratosphere.

The Stratéole 2 research program will begin with a five-balloon technology validation campaign in Northern Hemisphere (boreal) fall–winter 2018–2019, followed by 20 balloon flights in boreal fall–winter 2020–2021. In the second campaign, 10 balloons will fly at an altitude near 20 kilometers, just above the TTL, and another 10 will fly near 18 kilometers, within the TTL.

From past experience, we expect each balloon to fly for more than 2 months. Typically, a balloon will fly for about 84 days before chaotic atmospheric motions or interactions with Rossby waves push it outside of the deep tropics. A final 20-balloon campaign in 2023–2024 will drift in the opposite direction because of the shifting phase of the quasi-biennial oscillation (QBO), a dominant, periodic east–west oscillating feature in tropical lower stratospheric winds.

Challenges Aloft

The Stratéole 2 campaign targets the TTL, the primary entry point for tropospheric air into the stratosphere. As air slowly ascends across the TTL, the coldest temperatures encountered at the cold point tropopause (CPT) freeze water vapor into ice crystals. The formation of ice crystals dehydrates the air and regulates the amount of humidity reaching the global stratosphere, giving the TTL an outsized importance considering its geographic extent.

The ice crystals form thin cirrus clouds, which have a global impact on the balance between incoming solar radiation and radiation reflected back into space at tropical latitudes. Water vapor and cirrus feedbacks are extremely important in climate system models.

The underlying processes that control the formation and sublimation (direct conversion of ice crystals to water vapor) of these clouds remain strongly debated. These processes involve the interplay of deep convection, microphysics, aerosols, wave-induced temperature variations with timescales ranging from minutes to weeks, and the balance of forces driving large-scale slow ascent of air in the tropics.

The superposition of wave-induced fluctuations on the average upwelling motion forces the temperatures in the TTL to extreme values at the CPT—less than −94°C at times and well below those expected from radiative equilibrium. These same waves also drive the QBO, which has an important long-range indirect influence on high-latitude seasonal forecasts. The waves, generated by convection below, transport momentum vertically across the TTL and drive QBO wind variations as the momentum dissipates in the stratosphere.

Satellite and in situ observations can track the wind reversals of the QBO, but most general circulation models cannot replicate the QBO using current methods. This shortcoming is due to a combination of inadequate spatial resolution and a lack of small-scale wave drag applied at the subgrid scale.

Even when models do simulate the QBO, doubts remain on the contribution from various families of waves with

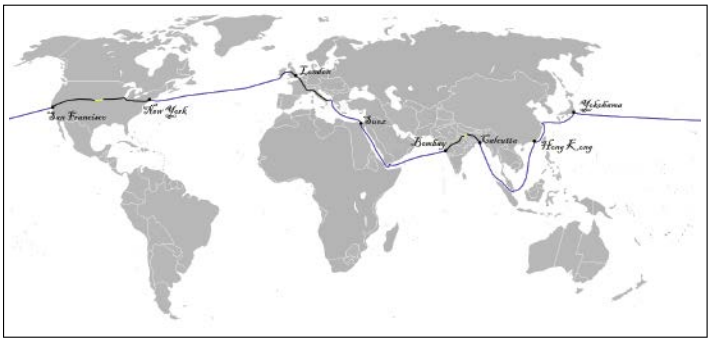

Fig. 1. In 1889–1890, real-life New York World *reporter Nellie Bly completed Jules Verne's imagined path around the world (shown here) in slightly less than Verne's "80 days." Neither Bly's journey nor Verne's* Around the World in 80 Days *actually involved balloon travel, but Verne's book drew on his previous novel,* Five Weeks in a Balloon. *The earlier novel inspired the idea of incorporating balloon travel for one leg of the trip in the 1956 movie* Around the World in 80 Days *that has become a beloved misconception about Verne's later book. Credit: Roke/Wikimedia Commons, CC BY-SA 3.0 (http://bit.ly/ccbysa3-0)*

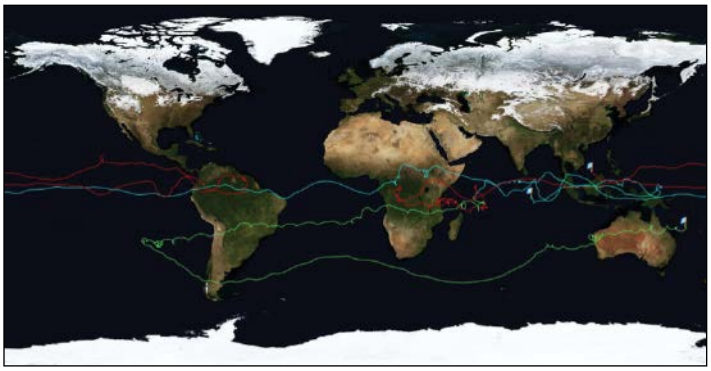

Fig. 2. Early test flights of the French National Center for Space Studies (CNES) superpressure balloon system during February–May 2010 followed a tropical route. The flight durations of the three balloons were 92, 78, and (yes!) 80 days, respectively. The traces of the balloon paths show some wave structure, and the balloon paths reversed direction when the quasi-biennial oscillation, a periodic east–west oscillating feature in tropical lower stratospheric winds, changed phase. Credit: A. Hertzog

different scales and frequencies. As a result, even models that internally generate a QBO were unable to forecast the anomalous disruption of the oscillation that occurred in February 2016 [*Osprey et al.,* 2016].

Science Objectives

The overarching objectives of Stratéole 2 are to explore processes that control the transfer of trace gases and momentum between the equatorial upper troposphere and the lower stratosphere. The instruments will provide fine-scale measurements of water vapor, temperature, and aerosol/ice at the balloon gondola and also within several kilometers below flight level, documenting air composition and investigating the formation of cirrus in the upper TTL.

The balloons also provide unique measurements of equatorial waves over the full spectrum from high-frequency buoyancy waves to planetary-scale equatorial waves, providing information needed to improve representation of these waves in climate models. Stratéole 2 balloons will sample the whole equatorial band from 20°S to 15°N, thus complementing the widespread (but limited-resolution) spaceborne observations and the high-resolution (but geographically restricted) airborne and ground-based measurements from previous field missions.

Past balloon campaign measurements sampling the Antarctic stratospheric vortex [see *Podglajen et al.,* 2016] have been used to make accurate estimates of wave momentum fluxes as well as to explain springtime stratospheric ozone loss rates; we expect similar successes with our current campaigns.

Other Stratéole 2 science objectives include contributions to operational meteorology and satellite validation. Wind analyses and forecasts have notably large errors in the tropics because sparse tropical wind measurements cannot be modeled in a straightforward way through their dynamical relation to temperature, as they are at higher latitudes. Thus, reducing these errors requires a higher density of measurements. Stratéole 2 balloon flights will address this data shortage by providing unprecedented, accurate wind observations in the equatorial regions of the upper troposphere and lower stratosphere. In particular, the project will collect measurements over oceanic areas that are otherwise devoid of any stratospheric wind measurements.

The data will also contribute to the validation of Atmospheric Dynamics Mission Aeolus (ADM-Aeolus) wind products. An innovative European Space Agency mission, ADM-Aeolus, due to be launched in September 2018, is designed to perform the first spaceborne wind lidar measurements, providing unprecedented global coverage.

The ensemble of Stratéole 2 instrumentation (see http://bit.ly/Strateole2-instruments) includes in situ measurements of pressure, temperature, and winds every 30 seconds and less frequently sampled observations of ozone, aerosols, water vapor, and carbon dioxide, plus remotely sensed cloud structure from microlidar and directional radiative fluxes. Instruments providing profiles will include GPS radio occultation receivers that measure temperature profiles to the side of the balloons. Novel reel-down devices suspended as far as 2 kilometers directly below the balloons will also provide profiles to explore the fine-scale distribution of temperature, aerosol/ice, and humidity.

A fully inflated superpressure balloon in the lab at the French National Center for Space Studies. Credit: Philippe Cocquerez, CNES

Capturing temperature variations in high-resolution profiles, in particular, from the unique balloon platform, is an approach that will provide new insights into equatorial wave processes. Measuring ozone in combination with water vapor and carbon dioxide enables us to discover correlations among these tracers that describe transport processes at the top of the TTL, including convective overshoots that rapidly transport air from the surface into the TTL.

Data Dissemination

The Stratéole 2 data policy is in compliance with World Meteorological Organization (WMO) Resolution 40 (WMO Cg-XII; see http://bit.ly/WMO-data) on the policy and practice for the exchange of meteorological and related data and products. Within 12 months of the end of each balloon campaign, the Stratéole 2 data set will be freely available to the scientific community through the Stratéole 2 Data Archive Center (S2DAC), which is scheduled to launch its website in July 2018. S2DAC will collect and make available the balloon observations and associated ground-based and satellite data, reanalyses, and model outputs. S2DAC includes a primary, full repository at the Dynamic Meteorology Laboratory (LMD) in France and a secondary mirror site at the Laboratory for Atmospheric and Space Physics (LASP) in Boulder, Colo., in the United States.

In addition, during the balloon campaigns, a subset of the Stratéole 2 data set, specifically flight-level winds, will be disseminated on the Global Telecommunication System (see http://bit.ly/WMO-GTS) for their assimilation into numerical weather prediction systems. We invite and encourage the use of Stratéole 2 data by the broader scientific community, and potential users can watch for future campaign updates on the project website (http://bit.ly/Strateole2).

Up, Up, and Away

In the spirit of Verne's imagined use of new technologies and Bly's real-world application of those technologies to explore the world, the Stratéole 2 campaign will scientifically explore the tropical tropopause and lower stratosphere from a long-duration superpressure balloon platform. The use of multiple balloons will permit extensive

Stratéole 2 balloon flights will collect measurements over oceanic areas that are otherwise devoid of any stratospheric wind measurements.

exploration of the finely layered features and unique processes occurring in this remote part of the atmosphere. With the involvement of the broader scientific community, analyses of the Stratéole 2 measurements hold promise to provide a new and deeper understanding of these processes and the connections of this region to global chemistry, dynamics, and climate variability.

Acknowledgments

Major funding for the Stratéole 2 campaign is provided by France's National Center for Space Studies (CNES) and National Center for Scientific Research (CNRS), as well as by the U.S. National Science Foundation (NSF).

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This superpressure balloon, shown here at launch, is not fully inflated. As it rises, the volume of helium sealed inside increases until the spherical balloon is fully inflated, giving it a fixed density. Once the balloon has reached the atmospheric level where the air has the same density, it drifts with the wind, providing accurate wind measurements. Credit: Philippe Cocquerez, CNES

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AGU100 ADVANCING EARTH AND SPACE SCIENCE

Virtual Poster Showcase Experienced Steady Growth in 2017

In 2017, more than 200 students participated in the Virtual Poster Showcase (VPS), an AGU program designed to help students share research without traveling to an in-person conference. This program has been continually advancing in size and scope since it was created in 2013.

Diana Orlandi of the University of Pisa in Italy presents her poster by video as part of the fall 2017 Virtual Poster Showcase. Diana's submission to the graduate showcase's Planetary and Space Division was titled "Magmatic processes and formation of Pavonis Mons (Tharsis, Mars)." Credit: Diana Orlandi

Four embellishments added to VPS in 2017 helped to scale up the program as well as to add value for the student participants and their faculty and research advisers.

1. A year ago, two high school instructors helped pilot the participation in VPS of 21 groups of high school juniors and seniors. Some of these students stated that they expected the experience to strengthen their college applications.

2. A university instructor incorporated VPS into the curriculum of her spring graduate course in science communication. This meant that all aspects of the VPS process (abstract submission, poster creation, video presentation of the student's project, participation in a peer evaluation component, and responses to feedback from professionals serving as judges) were considered for the students' final grades in the course.

3. As part of a partnership between AGU and the American Geosciences Institute, all 447 VPS abstracts from 2015 onward are now available and searchable within GeoRef, the world's largest database of geoscience abstracts.

4. A geographic information system (GIS) map of all VPS participants and their abstracts, and the location of each lead author's institution, has been created to share the abstracts with the entire Earth and space science community (see http://bit.ly/vps-GIS). This GIS visualization is a project between University of Texas at El Paso professor Raed Aldouri and his GIS class.

Global Participation

In 2017, VPS offered spring and fall showcases that continued to draw students from around the globe. For the third consecutive year, the fall showcase attracted U.S. undergraduate students who had completed summer research programs known as Research Experiences for Undergraduates (REUs). The National Science Foundation funds those programs nationwide.

VPS is not just for those in the United States nor just for undergraduate students. Nearly half of the participants in VPS's 2017 events were graduate students from around the world. Overall, VPS's non-U.S. participants in 2017 came from 15 countries and five continents.

Building Student Confidence

Taking part in the Virtual Poster Showcase continues to increase students' experience

preparing and presenting research. Nearly four out of five students in the 2017 showcases reported a boost in confidence in their poster preparation and presentation skills. Survey respondents also said that having a VPS abstract will ultimately help them in the next steps of their careers.

During the two VPS events in 2017, presentations featured a wide array of research that spanned many subdisciplines within the Earth and space sciences, from environmental degradation caused by zinc smelting to modeling solar wind parameters in the Martian atmosphere. The first-place winners of the spring and fall showcases are listed below. Information about other winners can be found on the Virtual Poster Showcase recognition page (http://bit.ly/VPS-recognition).

Spring 2017 winners:

- Graduate showcase: Babak Jalalzadeh Fard, Northeastern University, "Effective mitigation and adaptation strategies for public health impacts of heatwaves for Brookline, MA"
- Undergraduate showcase: Jacob Smith, Clemson University, "The effect of atmospheric CO_2 on the chemical weathering of silicate minerals as measured by cation flux in the vadose zone"
- High school showcase: Hannah Kim, Thomas Jefferson High School for Science and Technology, "The effect of disease resistance on the bacterial community of the fecal microbiome of *Crassostrea virginica*"

Fall 2017 winners:

- Graduate showcase: Ruadhan Magee, University of Queensland, Australia, "Magma dynamics recorded in clinopyroxene megacrysts: Investigating the destructive 1669 eruption of Mount Etna"
- Undergraduate showcase: Caitlin Hoeber, San Jose State University, "Spatial and temporal effects on diversity of Monterey Bay's microbiome"

Each first-place winner of the 2018 graduate and undergraduate showcases will receive a travel grant to attend the 2018 AGU Fall Meeting in Washington, D. C., along with complimentary meeting registration.

Getting Ready for the Next Showcase

The fall 2018 showcase will accept abstracts from 3 July through 2 October. VPS offers an excellent means for students to share their research and get valuable feedback from their peers and professionals in the Earth and space sciences. Visit http://virtualposter.agu.org or email vps@agu.org to learn more about how you can participate in this year's fall showcase and future showcases.

To everyone who helped make VPS a continued success this past year, AGU's Virtual Poster Showcase staff offers its heartfelt thanks. It is only through the generous volunteerism of professionals who sign up as VPS judges and through the VPS program's collaborations with other professional societies and individuals within the scientific community that the VPS program can continue to strive toward AGU's mission of advancing Earth and space science.

Register and submit your abstracts today.

By **Pranoti M. Asher** (email: pasher@agu.org), Manager, Higher Education, AGU; and **Nathaniel Janick,** Career Services Coordinator, AGU

A Novel Way To Track Magma Flow

Researchers test a new way to track magma flow following a 2014 eruption at Iceland's Holuhraun lava field, pictured here. Credit: Robert S. White

In August 2014, after traveling for weeks through subterranean channels, molten rock surged through cracks in the 84-square-kilometer Holuhraun lava field north of Iceland's most voluminous glacier. It was the largest volcanic eruption in Europe in 230 years and was recorded in detail by a dense network of seismic sensors deployed by the University of Cambridge to monitor volcanic activity in the area. A new study now shows that scientists can accurately track underground lava flow with far fewer sensors, a boon in regions with scarce seismic data.

In the 2-week period leading up to the eruption, magma snaked its way through fissures in the rock, forming a moving structure called a dike. From the tip of one dike rippled migrating swarms of more than 30,000 earthquakes. The dense network of more than 70 traditional seismic monitoring stations recorded the earthquakes, providing a convenient baseline for testing alternative measurement systems.

Traditional earthquake sensors rely on two types of seismic waves, called *P* waves and *S* waves, to determine where an earthquake has occurred. The farther away the earthquake is, the greater the distance is between the arrivals of these two wave types, which travel at different speeds. Here *Caudron et al.* used a novel method called seismic amplitude ratio analysis (SARA) to track the melting rock's underground path.

In contrast to traditional methods, SARA requires only the background amplitude of seismic waves to locate where an earthquake originates. Although previous studies have shown that the method can complement the traditional approach and reveal the path of traveling magma, it has never been directly compared with such a high-resolution set of traditional sensors. Using just 15 stations, the team was able to track the magma's trajectory with remarkable accuracy. The SARA technique also revealed new dynamics in the magma's flow. The technique could help scientists track volcanic activity in settings where there aren't many monitoring stations, the team says. (*Journal of Geophysical Research: Solid Earth*, https://doi.org/10.1002/2017JB014660, 2018) **—Emily Underwood, Freelance Writer**

Solid-Fuel Use Puts Human Health at Risk

Humans have been harnessing fire for millions of years, and today nearly 40% of Earth's population uses solid fuel like wood, hay, dung, charcoal, and coal to heat their homes and cook their meals. However, breathing in the soot and ash particles that these fuels emit when burned can be harmful. Fine particles—known as $PM_{2.5}$ because they are, at most, 2.5 micrometers in diameter—are able to travel deep into the lungs. With long-term exposure, they can lead to pneumonia, pulmonary disease, and lung cancer.

Here *Kodros et al.* study the impact of solid-fuel use on premature death. This topic has been examined extensively, but past studies have looked primarily at $PM_{2.5}$ exposure within households and in the open air as separate entities, whereas this study considers $PM_{2.5}$ exposure as a whole. The researchers also tested highly sensitive parameters to show the uncertainty with which premature deaths can be attributed to the use of solid fuels.

The researchers examined data on all deaths across the globe caused by exposure to $PM_{2.5}$, both in the home and outdoors, during 2015. They used a mathematical model to estimate that $PM_{2.5}$ exposure from solid-fuel use was responsible for around 2.8 million premature deaths that year. They also found that if they had calculated household and open-air exposure deaths separately, their total estimate would have been about 18% higher—a major difference.

Although combining the two sets of data is an improvement over past studies, the team's calculations show that the method still has large uncertainties in the relationship between $PM_{2.5}$ exposure and premature death. The factors that introduced the most uncertainty in their estimates varied by country. For example, in India, China, and Latin America, it is unclear exactly what percentage of the population uses solid fuels for heating and cooking, which leads directly to uncertainties in estimates of deaths attributed to solid-fuel smoke. Conversely, in sub-Saharan Africa, where a known, large percentage of the population uses solid fuels, the uncertainty in the underlying health data (i.e., records of what diseases people died from) is the leading contributor to the uncertainty in the researchers' estimates.

Nearly 40% of Earth's population uses solid fuels for heating and cooking indoors, which can cause health problems. Credit: Karan Singh Rathore, CC BY 2.0 (https://bit.ly/ccby2-0)

This study provides a solid reference point for future research looking to improve estimates of deaths attributed to solid-fuel use. In the event that better data become available from these regions, scientists will be better equipped to make more accurate estimates—and help people around the world reduce their exposure to harmful pollutants. (*GeoHealth*, https://doi.org/10.1002/2017GH000115, 2018) **—Sarah Witman, Freelance Writer**

Space Weathering Asymmetrically Alters Lunar Crater Walls

The lack of an atmosphere exposes the Moon and other airless bodies, like asteroids, to space weathering. In this process, some combination of micrometeoroids and a stream of charged particles known as the solar wind alters celestial surfaces, making them darker and redder through the production of nanometer-scale iron particles.

The relative contribution of micrometeoroids and the solar wind to space weathering on the Moon has been unclear, with lunar soil samples providing scant insight. In a new study, *Sim et al.* took a different approach, using the optical properties of craters to show that the solar wind likely plays a dominant role in lunar space weathering.

The research team used data from a Japanese lunar orbiter known as Kaguya (or SELENE) to investigate light reflected off the walls of 1,872 lunar craters with diameters ranging between 5 and 120 kilometers. It divided each crater wall into four parts: equator facing, pole facing, east, and west. The team then analyzed differences in optical properties between the walls of craters at different latitudes and longitudes.

Astronauts aboard the Apollo 11 spacecraft snapped this photo of the 80-kilometer-wide crater Daedalus on the far side of the Moon in 1969. Credit: NASA

The researchers found that at higher latitudes, pole-facing walls were less weathered—in other words, brighter and less red—than equator-facing walls. This finding is consistent with the geometry of the solar wind, which strikes the Moon mostly in a direction parallel to the equator. Pole-facing walls of craters located closer to the Moon's poles angle more steeply away from the solar wind and are therefore more protected from it.

Meanwhile, differences between east and west facing walls varied with longitude in a way that suggests they are shielded from the solar wind whenever the Moon passes through the elongated tail of Earth's magnetic field.

Together, these directional differences suggest a dominant role for the solar wind in lunar space weathering. Micrometeoroids are unaffected by Earth's magnetic field, so if they played a bigger role, one would expect more uniform weathering of lunar craters.

The mathematical relationships between crater wall reflectance and solar wind exposure seen in this study should hold true for other airless bodies and for other topographical features, such as hills, valleys, and volcanoes. Accounting for these effects could improve the accuracy of other measurements making use of optical data from airless bodies, such as surface age, mineralogy, and water abundance. (*Geophysical Research Letters*, https://doi.org/10.1002/2017GL075338, 2017) **—Sarah Stanley, Freelance Writer**

What Causes Flash Floods in the Middle East?

Across the vast expanse of the Middle East, the climate varies with the terrain, but it is typically hot and dry throughout most of the region. Extreme precipitation events, although rare, are a crucial part of the region's climate. These sporadic storms recharge the area's freshwater stocks, supporting agriculture in the otherwise dry environment. But they can also cause deadly and economically devastating floods. Researchers have long sought a better understanding of the factors driving extreme precipitation events in the Middle East to improve our ability to predict major storms. This endeavor has been made more complicated and more urgent by climate change.

Previous studies have linked heavy-rainfall events to two atmospheric features. Stratospheric potential vorticity (PV) intrusions, which occur when air from the stratosphere invades the upper troposphere, have been shown to precede extreme precipitation events in, for example, the Alps, southern Africa, and northwestern Africa. Atmospheric rivers, in which moisture travels along plumelike tracks, have been linked to rain and flooding in North America and Europe. Atmospheric rivers are often detected using vertically integrated water vapor fluxes (IVT), but few studies have looked at data on both IVT and PV intrusions.

Here *de Vries et al.* combined both into a single algorithm to detect extreme precipitation in an area covering eastern Egypt, southern Israel, Jordan, and parts of Saudi Arabia—all regions with low annual rainfall that nonetheless have been hit repeatedly with devastating rainfall events. The authors used data from a global reanalysis project, Interim-ERA, to identify stratospheric PV intrusions and IVT structures from 1979 to 2015 as well as extreme precipitation events, defined as days with rainfall that exceeds the 97.5th percentile.

First, the team demonstrated the success of the algorithm for four major precipitation events that inflicted severe damage in the Middle East: a 1979 storm that killed 50 people and displaced over 66,000, a 1994 storm that killed 600 people, another in 2005 that killed 29 people, and another in 2009 that caused 161 deaths and $900 million in damages. The authors found that in all four cases, stratospheric PV intrusions and IVT structures were clearly apparent. Next, a climatological analysis showed that PV and IVT features coincided with nearly 90% of all extreme precipitation days over the 37-year study period. Both PV and IVT occurrences were highly associated with the precipitation severity and mirrored seasonal rain trends, frequently appearing in October and tapering off around May. The longer the features persisted, the farther south the PV intrusions extended; the larger the IVT values were, the more extreme the rainfall was. IVT incursions were a particularly strong predictor of extreme precipitation days.

False alarms—or days in which both IVT and PV intrusions were present but the weather was dry—were not infrequent, but the authors found that in many of those cases, a key ingredient for extreme rainfall was missing: high tropospheric moisture content.

Finally, the authors evaluated the performance of the algorithm against precipitation observations. PV and IVT features contributed to about 40%–70% of the annual rainfall amounts and 50%–90% of the extreme precipitation days. This result provides strong evidence of the importance of PV and IVT in extreme precipitation events in the region.

The algorithm ultimately allows researchers to identify local-scale extreme rainfall events on the basis of large-scale meteorological features. The tool could help to improve both weather forecasts and warning systems and could help researchers evaluate how extreme precipitation events respond to a changing global climate. (*Journal of Geophysical Research: Atmospheres*, https://doi.org/10.1002/2017JD027587, 2018) **—Kate Wheeling, Freelance Writer**

Preserving a 45-Year Record of Sunspots

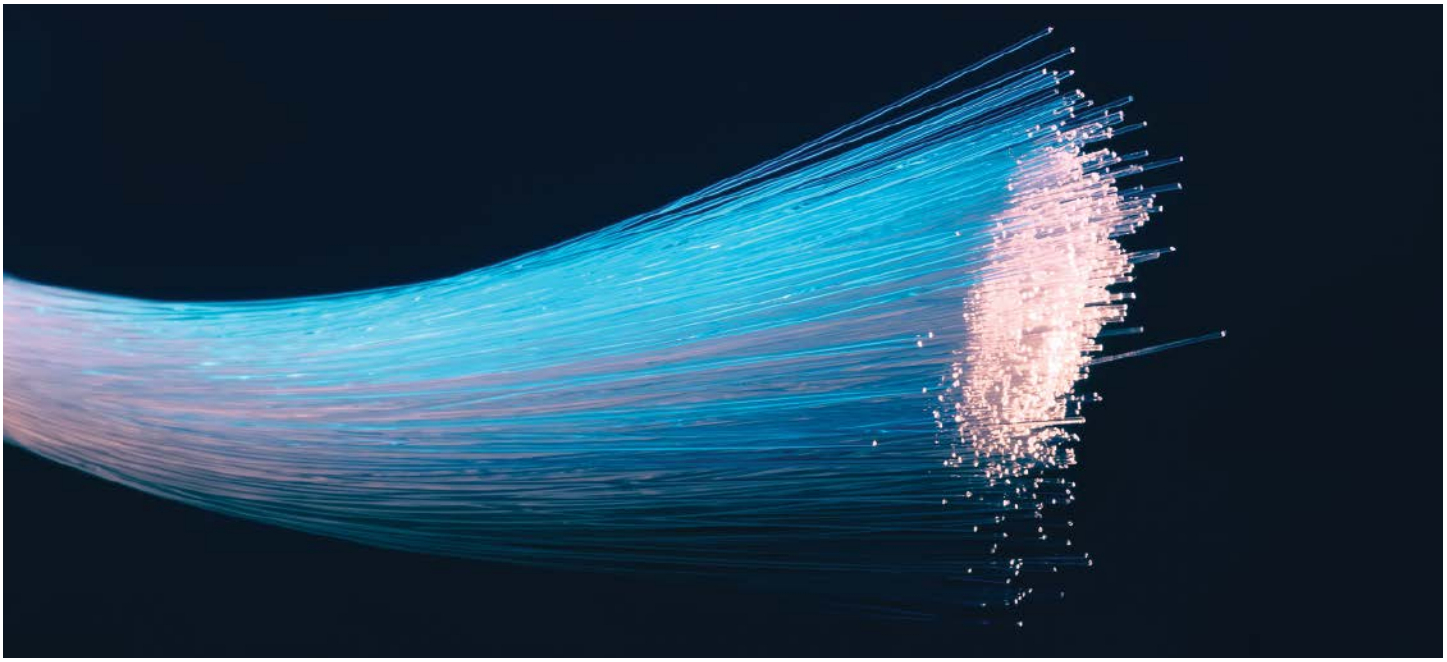
In 1964, the late solar researcher Patrick McIntosh launched an ambitious effort to track sunspots, the relatively cool, dark blotches on the Sun caused by disturbances in the star's magnetic field. He traced sunspots and other solar surface features from daily photographs, creating a map of the full Sun approximately every 27 days. This led to important advances in the prediction of solar flares and helped to reveal the large-scale organization of the Sun's magnetic field. Now scientists are working to preserve and digitize McIntosh's project, a uniquely consistent record of solar activity over 45 years.

The Sun's magnetic field is driven by the interior flow of hot plasma, or electrified gas, which creates a magnetic generator called a dynamo. McIntosh's records showed that the location and number of sunspots and filaments—huge arcs of dense plasma that appear as dark lines on the Sun's surface—are indicators of just how this dynamo works.

By carefully documenting the position and number of sunspots over time, for example, McIntosh's record illustrated how the Sun's entire magnetic field reverses polarity every 11 years. The number of visible sunspots helps researchers predict this flip: When the Sun emits more X-ray and ultraviolet radiation, during a period called the solar maximum, the number of sunspots peaks. When solar activity dwindles during the solar minimum, sunspots dwindle. McIntosh's maps were unique for also tracking the position of filaments and other features that also change as the magnetic field evolves, drifting poleward or toward the Sun's equator at different stages of the solar cycle.

Webb et al. scanned and digitally processed the hand-drawn maps that McIntosh created, known as synoptic maps, to create a free, public online archive. Ultimately, they plan to use the data to investigate long-term variations in the Sun's activity and invite other researchers to use it as well. In recent years, the maps have provided important context for coronal mass ejections, the explosive bursts of solar wind plasma from the Sun that create the northern and southern lights and can pose a threat to Earth's communication systems and power grids. (*Space Weather*, https://doi.org/10.1002/2017SW001740, 2017) **—Emily Underwood, Freelance Writer**

Fiber-Optic Networks Can Be Used as Seismic Arrays



A bundle of fiber-optic cables. Credit: kynny/Stock/Getty Images Plus/Getty Images

Over the past century or so, seismometers have helped us to detect, study, and even forecast earthquakes. The simplest seismometers are made up of a weight hanging from a spring. A pen attached to the weight records slight movements or vibrations, known as seismic waves, on a rotating spool of paper; the spool, frame, and base of the instrument move with the Earth while the suspended weight remains stationary. More modern versions use a computer to record electrical voltages generated by the instrument's movements.

Scientists' ability to study the movements of Earth has so far been limited, however, by the logical locations of seismometers. The instruments are sparsely dispersed across the globe and are clustered mainly on land.

In a new paper, *Lindsey et al.* used a novel seismic recording approach to study seismic waves from earthquakes for the first time. The technique, called distributed acoustic sensing, repurposes underground fiber-optic cables (normally used for telecommunications, such as Internet, television, and telephone service) up to tens of kilometers long.

To make the ground motion measurements, the scientists used pulses of laser light traveling inside a fiber-optic cable. The photons scatter off randomly distributed manufacturing imperfections inside the fiber and travel back to a light detector. Using a reference loop of fiber, the scientists could measure the length of the cable by producing an interference pattern whose time-varying amplitude provides a fingerprint of the individual distances to different scatterers inside the experimental fiber length. By monitoring how this fingerprint changes from one pulse to the next, researchers can measure the time rate of change of the path length in a segment of the experimental fiber and deduce how segments of the fiber undergo compression and tension as the ground moves.

Laser pulses were used to make these measurements continuously at a rate of 1,000 times per second over weeks to months. Comparing information gleaned from the pulses' interference patterns to data recorded by traditional inertial seismometers allowed the scientists to see how precisely this new distributed fiber-optic method picks up seismic signals during earthquakes.

The researchers tested this technique at three locations: Fairbanks, Alaska; a region of northern California called the Geysers, home to one of the world's largest geothermal fields; and the Stanford University campus in California.

In Fairbanks, the researchers found that the ground motion recorded with the fiber-optic cable was comparable to that recorded with a traditional seismometer. At the Geysers, they were able to use an L-shaped array of cables to track the arrival of several phases of an earthquake that occurred in 2016. Beneath Stanford University, they installed fiber-optic cables in a plastic telecommunications conduit and in the process discovered that seismic waves are still detectable when the fiber-optic cable is minimally coupled to the soil.

The spatial resolution of the data collected—one ground motion measurement every meter for kilometers—allowed the researchers to use the array nature of fiber-optic seismology to learn more about the way faults rupture and how seismic waves fan out in the solid Earth. The hope is that these findings will lead to more extensive seismic studies using fiber-optic cables for distributed acoustic sensing. By improving the way that scientists study earthquakes, this advancement could help mitigate the damaging effects that earthquakes have on lives, homes, and public infrastructure. (*Geophysical Research Letters*, https://doi.org/10.1002/2017GL075722, 2017) **—Sarah Witman, Freelance Writer**

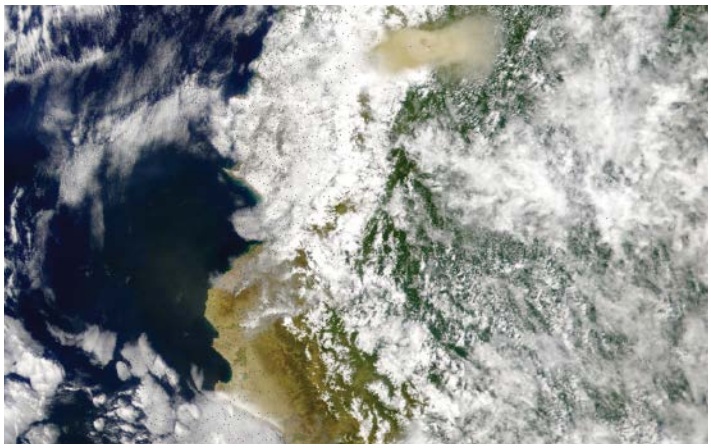
Using Radar to Understand How Volcanic Eruptions Evolve

The rate at which a volcano extrudes lava is a key variable for tracking changes in volcano behavior, magma supply, and potential hazards to people and property. Locally, lava extrusion can have variable effects, from small-scale doming to large-scale changes in a landscape due to lava flows. Accurately measuring these changes, however, is often difficult because of infrequent satellite observations and sparse ground-based measurements.

To overcome this challenge, *Arnold et al.* used high-resolution radar satellite imagery to investigate both ground deformation and constructional topographic changes at El Reventador, one of Ecuador's most active volcanoes. Using data collected from two missions, the German Aerospace Center's TerraSAR-X add-on for Digital Elevation Measurement (TanDEM-X) and the Canadian Space Agency's RADARSAT-2, the researchers analyzed differences in surface roughness during the volcano's most recent eruptive phase, which began in 2012. They then used these results to map the extent and thickness of 39 new lava flows, whose bulk volume (through 24 August 2016) they estimate to be 56 million cubic meters.

The results show that this method is sensitive enough to document differences in the rate of lava extrusion, which is slowly decreasing at El Reventador. The method was also capable of detecting low-magnitude deformation of the volcanic edifice, including the intrusion of a small vertical dike near the summit associated with the start of the eruptive phase.

The study demonstrates the tangible benefits of using radar imagery to supplement other measurements of changing topography in active volcanic settings. It also represents an important step forward in our understanding of the evolution of the ongoing El Reventador eruption and long-lived volcanic activity in general. (*Journal of Geophysical Research: Solid Earth*, https://doi.org/10.1002/2017JB014580, 2017) **—Terri Cook, Freelance Writer**



Using satellite radar, researchers have measured 39 new lava flows and the intrusion of a small dike near the summit of El Reventador, a long-lived stratovolcano in Ecuador. Credit: NASA

A New Tool That Illuminates Tiny Fractures in Coal

Tiny micrometer-scale fractures, or "cleats," permeate coal beds and create networks that often harbor a form of natural gas known as coal seam gas. Coal seam gas consists primarily of methane and is extracted for energy production in a growing number of countries, including the United States.

Coal seam gas has generated controversy in certain regions, with some raising questions about its potential environmental effects. This has created interest in applying advanced characterization methods to better understand gas production from these resources and control its environmental impacts. A new paper by *Jing et al.* validates a new strategy to advance understanding of coal cleat networks, which is key to modeling the flow of gas through the tiny cracks.

The new strategy builds on an existing method in which X-ray microcomputed tomography (micro-CT) imaging is used to analyze rock properties. A shortcoming of this method is that "noisy" micro-CT data of coal can create the appearance of extra cleats and connections between cleats where there are none.

To address this problem, the authors of the new study recently developed a new discrete fracture network (DFN) model—a computational tool for analyzing fractures in rocks. The new model, published in 2016, incorporates certain coal cleat characteristics (shape, length, and orientation) gleaned from micro-CT images, but it was unclear how well it captured connections between the tiny fractures. These connections control how gas will be produced from coal beds.

The authors have now put their new DFN model to the test. First, they used a micro-CT instrument to scan a coal sample from the Moura coal mine in Australia. Then they constructed three different representations of the sample's internal cleat network: one using the original micro-CT images, one using micro-CT images that were filtered to remove noisy data, and one using the DFN model, which incorporated some of the micro-CT data.

The researchers then developed and applied a series of mathematical tests to compare the accuracy of the three representations. They found that the unfiltered micro-CT images showed extensive connections between individual cleats, especially at smaller scales. Meanwhile, the filtered images and the DFN model showed lower levels of connectivity at both small and whole-sample scales.

The authors concluded that the developed DFN model more realistically captures cleat connections than do typical segmented micro-CT images. It also requires less computing power and avoids the trade-offs between sample size and image resolution, which often hamper the micro-CT method. Thus, the DFN model could improve simulations of gas flow through coal, with potential applications for commercial extraction. (*Journal of Geophysical Research: Solid Earth*, https://doi.org/10.1002/2017JB014667, 2017) **—Sarah Stanley, Freelance Writer**

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- *Eos* is not responsible for typographical errors.

∗ Print-only recruitment ads will only be allowed for those whose requirements include that positions must be advertised in a printed/paper medium.

Atmospheric Sciences

Division Director, Division of Atmospheric and Geospace Sciences

Serves as Division Director in the Division of Atmospheric and Geospace Sciences (AGS), Directorate for Geosciences (GEO). The mission of the Division of Atmospheric and Geospace Sciences is to enable fundamental research as well as to support relevant infrastructure and education that advances understanding of the behavior of the earth's atmosphere and its interactions with the sun. Included are studies of physics, chemistry, and dynamics of earth's upper and lower atmosphere and its space environment, research on climate processes and variations and studies to understand the natural global cycles of gases and particles in earth's atmosphere. The Division also provides support for participation by the United States scientific community in international scientific research endeavors, such as the World Climate Research Program.

The Division works with individual grants and at national research facilities, including the National Center for Atmospheric Research (NCAR), and with the U.S. atmospheric sciences academic community to direct funding towards advancing the frontiers of knowledge, developing the next generation of researchers, and enhancing the public's understanding of atmospheric sciences.

The Division Director provides leadership and management to the Division's programs, assists the Assistant Director in carrying out Directorate-wide responsibilities such as the preparation of budget submission for Congress, provides oversight and management of the Division budgets, and oversees the recruitment of scientific staff. The incumbent also supervises and provides leadership and guidance to administrative and support personnel within the Division. Externally, the Division Director represents the Division in a variety of NSF-wide and interagency activities related to research and education, and in interactions with the community.

The successful candidate will possess an established record of significant achievement in research administration as well as leadership responsibility in academia, industry, or government. In addition to having a strong record of research and education accomplishments within his or her technical communities, the Division Director must be experienced and competent in technical, financial, and administrative management. He/she must work well with people, be an effective communicator, and act as a mentor to continuously develop the diversity of talent and skills of his or her colleagues at all levels.

Email Applications to exesrch@nsf.gov

Geochemistry

Analytical Specialist, Department of Geological Sciences, Brigham Young University

The Department of Geological Sciences at Brigham Young University (BYU) invites applications for a full-time, continuing faculty status-track Professional Faculty position beginning as early as the Fall of 2018.

We are seeking an individual with interest and experience in managing analytical facilities. Experience in the operation and maintenance of at least some of the following is essential: X-ray diffraction, liquid scintillation and alpha counting, ICP and XRF spectrometry, stable isotope analyzers. Field expertise may include shallow sediment coring, geophysical surveying, and water chemistry sampling. This professional faculty position is designed to assist and collaborate with Professorial faculty, as well as mentor graduate and undergraduate students. The successful candidate will not conduct a self-guided research program. Moreover, the successful candidate will spend much of his or her time working with students one-on-one or in small groups, and may be assigned to teach an instrumental methods course. The position requires a PhD in the geological sciences or a related field.

Excellent research infrastructure exists within the Department, including laboratories and field equipment that support a wide-range of geophysical, geochemical, isotopic, and petrologic studies. Excellent computational facilities are also available within the Department and University.

The Department consists of 13 Professorial and 3 Professional faculty, and offers B.S. and M.S. degrees. Research areas include environmental geology, hydrogeology, continental magmatism, structure and tectonics, stratigraphy, paleontology, planetary geology, mineral surface chemistry, geophysics, climate studies, and petroleum geology.

Applicants should send by US mail a curriculum vitae, graduate transcripts, a statement of experience managing analytical facilities, and the names and contact information for three references to: Chair, Search Committee, Dept. of Geological Sciences, PO Box 24606, S-389 ESC, Brigham Young University, Provo, UT, 84602. Applications will be considered until May 31, 2018.

Brigham Young University is an equal opportunity employer. All faculty are required to abide by the university's Honor Code and Dress and Grooming Standards. Preference is given to qualified candidates who are members in good standing of the affiliated church, The Church of Jesus Christ of Latter-day Saints. Successful candidates are expected to support and contribute to the academic and religious missions of the university within the context of the principles and doctrine of the affiliated church.

Hydrology

Multiple Post-doctoral and Research Fellow Positions in Water Sciences

The College of Hydrology and Water Resources (CHWR) at Hohai University (HHU), China invites applications for multiple post-doctoral positions in water sciences, to start as early as March 2017. The positions are open until filled. The salaries will be internationally competitive and commensurate with candidates' experience and skills.

Established in 1915, HHU is the leader of innovation and development of higher education in hydraulic engineering and water sciences in China. HHU has played as China's key force to solve its major water security issues. HHU is located at Nanjing, Jiangsu, China. Nanjing is the internationally recognized capital of Jiangsu province, one of the largest cities in China. Situated in the heartland of the Yangtze River Delta, it has long been a major center of culture, education, research, politics, economy, transport networks and tourism.

CHWR is a key component of HHU and is the first college established nationwide devoted solely to the study of hydrology and water resources. The college has strong faculty members and research fellows with sufficient funding, and is the key contributor of a national key laboratory and a national engineering center.

CHWR seeks:

Positions:

1. 2 positions in the field of smart water management, planning, utilization and protection, water policy in the support of new generation technologies (big data, artificial intelligence, Internet of Things and new materials).

2. 1 position in the field of evolution and protection of water ecology and water environment, water eco-environmental simulation in response to global change and coupled modeling of hydrodynamics and water quality.

3. 2 positions in the field of large-scale, meso-scale, or fine-scale urban flood or water resources management model.

Primary Duties & Responsibilities

The successful candidates will conduct independent, externally funded research programs in their field of expertise. Support for developing an active research agenda is provided through departmental support. CHWR will provide strong support to help successful candidates to apply for national and provincial research grants.

Experience & Qualifications

• Candidates must hold a Ph.D. in hydrology, water resources, hydrodynamics, atmospheric sciences, environmental science, ecology, computer science, material science and other related fields, preferably from one of the international top 50 universities (as listed in the latest US News Best Global Universities Rankings).

• Candidates should demonstrate a strong potential for publishing fundamental or applied basic research (first author of at least two papers published in internationally recognized journals).

• Candidates who have not graduated from one of the international top 50 universities (as listed in the latest US News Best Global Universities Rankings) must show very strong skills in innovative research and publications.

Salary:

• Basic salary: About 320,000 RMB/year.

• Bonus: Associated with published papers and other scientific deliverables in the group.

• Funding support: Support from national and provincial research grants.

Review of applications will begin upon receipt of applications and will continue until the positions are filled. Applications should be sent to: tao.yang@hhu.edu.cn and kzhang@hhu.edu.cn.

Interdisciplinary

Assistant/Associate/Full Professors-Geophysics, Geodesy, Space Physics, Planetary Sciences

The Department of Earth and Space Sciences at the Southern University of Science and Technology of China (SUSTech) invites applications for tenure-track (or tenured) faculty positions at the ranks of Assistant, Associate, and Full Professors. Applicants must have earned doctoral degrees in Geophysics, Geodesy, Space Physics, Planetary Sciences or closely related fields. Successful applicants will be expected to establish a robust, externally funded research program and demonstrate strong commitment to undergraduate and graduate teaching, student mentoring, and professional services. These positions will remain open until filled.

SUSTech is a young university at Shenzhen, China (next to Hong Kong) since 2011 which is set to become a world-leading research university, to lead the higher education reform in China, to serve the needs of innovation-oriented national development and the needs of building Shenzhen into a modern, international and innovative metropolitan. These positions are created with a significant development to establish a vigorous research program in Earth and Space Sciences at SUSTech to serve the national call for China's important role in this field.

To apply send a cover letter, complete vitae with list of publications, and three names of references to hiring@sustc.edu.cn, or to Dr.Xiaofei Chen, Chair Professor at Department of Earth and Space Sciences, Southern University of Science and Technology, No 1088, Xueyuan Rd., Xili, Nanshan District, Shenzhen, Guangdong, China 518055.

Data Analyst

The Data Analyst will be responsible for focusing on flood analysis and development initially, with planned vectoring to data intelligence analysis duties, for both science and non-science applications to support property and non-property business segments.

A data analyst will need to have familiarity with scientific data analysis, data inference techniques and programming. Will have a general background in physical and mathematical sciences, applied data intelligence analysis, and statistical data mining. Preferred individual in this role would also have capabilities in GIS spatial analytics and development of disruptive data technologies. ArcGIS, R, Python application and language familiarity.

JOB ACCOUNTABILITIES

• Adapting and running geophysical models, supporting senior scientists in the diagnosis and interpretation of model-based results.

• Assisting scientists, senior scientists and management in the manipulation of data, systems analysis and database administration.

MINIMUM REQUIREMENTS

• 3 to 5 years of experience in an applied science, preferably the geophysical sciences

• A data analyst will need to have familiarity with scientific data analysis, data inference techniques and programming.

• General background in physical and mathematical sciences, applied data intelligence analysis, and statistical data mining.

• Familiarity with UNIX/Linux development environment.

• Comfortable working with large datasets to support analysis objectives.

• MatLab, Python experience. Familiarity with R or similar languages is a plus.

• Ability to understand, compile and manipulate finite difference geophysical models. Familiarity with ADCIRC storm surge model is preferred.

• Software development skills. Seasoned diagnostic skills for quality assurance.

• Preferred individual in this role would also have experience and skills in GIS supported spatial analytics and data mining techniques and data analytics technologies.

• Proven ability for collaborative work on technical project teams. Candidate must have a track record of providing valuable input under the guidance of a principal investigator.

Email Applications: CareersUSA@renre.com

Development of a New Global Atmospheric Model from 0–150 km for High-Altitude Weather Prediction

The Space Science Division of the US Naval Research Laboratory (NRL) in Washington, DC seeks a highly motivated individual to perform scientific research & development (R&D) of a state-of-the-art global numerical model of the atmosphere extending from the ground to 150 km altitude, which can provide the foundation of a future high-altitude operational numerical weather prediction (NWP) capability. The system will be based around an emerging Navy dynamical core (NEPTUNE: Navy Environmental Prediction System Utilizing the NUMA Core) solving the deep-atmosphere nonhydrostatic equations on the sphere using spectral element (SE) techniques. This work supports NRL's broadly-based long-term R&D objectives of providing focused state-of-the-art environmental situational awareness for the globally deployed Navy.

Candidates should have a masters or Ph. D. in atmospheric science, computational fluid dynamics, physics, or a related discipline that demonstrates strong theoretical grounding in the dynamics and/or physics of the atmosphere. Candidates will require strong programming skills in working with complex Fortran codes that use up to 1 million processors on massively parallel high-performance computers, and an ability and willingness to work within large team environments distributed across several geographically displaced NRL research centers (including periodic work-related travel).

Additional knowledge, experience or interests in any of the following areas are advantageous, but not formally required, for this position:

• Interests in the deep atmosphere (0–150 km altitude), with an emphasis on those dynamical and physical processes affecting evolution on time scales in the 0–5 day range.

• R&D experience with state-of-the-art atmospheric dynamical cores (e.g., SE/Galerkin methods, implicit/explicit time integrators, structured/unstructured/adaptive grids, static mesh refinement, and species transport algorithms).

• R&D experience developing fast physics parameterizations for the stratosphere, mesosphere and thermosphere. Relevant examples include (but are not restricted to): "scale-aware" "gray-zone" and stochastic parameterizations; radiative/chemical heating and cooling rates; diffusive separation of thermospheric species, and; drag effects of gravity waves, viscosity and ion-neutral coupling.

• Programming credentials in Fortran, C/C++, python, and MPI/OpenMP.

All applicants for federal positions must be US citizens. Formal applications and any questions should be emailed to Dr. Steve Eckermann (stephen.eckermann@nrl.navy.mil; Tel. 202-404-1299). Applications will be accepted until 11 May 2018 or until the position is filled. NRL is an equal opportunity employer. Further back-

ground to this research can be found at www.nrl.navy.mil/ssd/branches/7630.

Faculty Positions available in the School of Environmental Science and Engineering

The Southern University of Science and Technology (known as SUSTech or SUSTC) (http://www.sustc.edu.cn/en) was founded in 2011 with public funding from Shenzhen City. A thriving metropolis of 20 million people bordering Hong Kong, Shenzhen has often been referred to as the "Silicon Valley of China" with strong telecommunication, biotechnology and pharmaceutical sectors. Widely regarded as a pioneer of higher-education reform in China, SUSTech aims to become a top-tier international university that excels in interdisciplinary research, talent development and knowledge discovery. English is the language of instruction.

The School of Environmental Science and Engineering at SUSTech was established in 2015 to provide a new platform for performing cutting-edge research and for training the next generation of environmental scientists, engineers and managers who are interdisciplinary, innovative and global-thinking. Currently the school has 28 full-time faculty and research staff, including two academy members, eight recipients of the Thousand Talents Program, and four recipients of the young investigator awards by the National Natural Science Foundation of China (http://ese.sustc.edu.cn/en/). The school is planning to fill two dozen more tenure-track/tenured positions over the next few years. In addition to a generous startup package to each tenured or tenure track faculty position, the school was recently awarded a 3-year enhancement grant of 50 million RMB (~7 million USD) to strengthen its core areas of research. Moreover, the school is in line to receive 120 million RMB (~18 million USD) for research instrument capability development.

Applications are invited for faculty positions at all ranks. Areas of interest include, but are not limited to, water pollution and treatment, environmental (soil, groundwater, ecosystem) remediation and restoration, hydrology and water resources engineering, biogeochemistry, environmental microbiology, atmospheric chemistry, air pollution control, air quality engineering, solid waste treatment and utilization, environmental health risk assessment and interventions, remote sensing of the environment, macroecology and global change, and environmental management. Highly competitive salaries and benefit packages will be provided to tenure-track/tenured faculty. New hires may also be eligible for additional government support such as the Shenzhen City's Peacock Program and the Thousand Talents Program (http://www.sustc.edu.cn/en/faculty_en).

Applicants are required to have a Ph.D. in environmental science and engineering, earth and atmospheric sciences, or related disciplines. Postdoctoral experience is preferred but not required. Candidates must have a proven and consistent track record of high-quality scientific publications and good communication skills. To apply, submit the following materials electronically to iese@sustc.edu.cn: 1) Cover Letter; 2) Curriculum Vitae (with a complete list of publications); 3) Statement of research and teaching interest; 4) PDFs of three recent publications; and 5) Names and contact information for 3-5 references. All positions remain open until filled. For additional information, please contact Xiaoli Wang (email: wangxl@sustc.edu.cn, phone: +86-755-8801-0821).

NASA Postdoctoral Program (NPP) Application Deadline July 1, 2018

The NASA Postdoctoral Program (NPP) supports NASA's goal to expand scientific understanding of Earth and the universe in which we live.

This announcement reflects recent increases to the NPP annual base stipend and the annual travel allowance provided to fellows.

The NASA Postdoctoral Program offers US and international scientists the opportunity to advance their research while contributing to NASA's scientific goals. The NPP supports fundamental science; explores the undiscovered; promotes intellectual growth; and encourages scientific connections.

Engage in NASA research in Earth science, planetary science, heliophysics, astrophysics, aeronautics and engineering, human exploration and operations, space bioscience, and astrobiology.

Details:

UPDATED! Annual stipends start at $60,000, with supplements for high cost-of-living areas and certain degree fields

UPDATED! Annual travel budget of $10,000

Relocation allowance

Financial supplement for health insurance purchased through the program

Appointments renewable for up to three years

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Faculty Position in Extreme Environments

at the Ecole polytechnique fédérale de Lausanne (EPFL)

The EPFL School of Architecture, Civil and Environmental Engineering (ENAC) invites applications for the Ingvar Kamprad Chair, a tenured Associate or Full Professor position in its Institute of Environmental Engineering (IIE). The appointee will join the newly formed EPFL Centre for Changing Alpine and Polar Environments (CAPE), based in Sion, Switzerland, and contribute to research and teaching activities within IIE. This appointment is one of several CAPE professorships, and offers unrivalled collaboration opportunities at the local and European levels. The appointee will also participate (and represent EPFL) in the Swiss Polar Institute, which promotes collaborative research within Switzerland and internationally.

The holder of this Chair will be an internationally recognized scholar in quantifying impacts of climate change on frozen water resources at large scales in Alpine and Polar environments. This area of activity is interpreted broadly, and potentially considers ice physics and dynamics, remote sensing of polar caps/glaciers and interpretation of physical changes, physically based and data-intensive modelling of mountain/polar hydrological systems, snow physics, and implications for mountain/polar water resources.

In this context, we seek an outstanding individual who will lead an internationally recognized research program that leverages the opportunities offered by CAPE/EPFL. The professor will be committed to excellence in research and in undergraduate and graduate level teaching, and will contribute to the teaching program in Environmental Engineering at EPFL, which views basic and translational research as the foundation for environmental adaption and engineering design.

With its main campus located in Lausanne and its developing antennae in neighbouring cantons in Switzerland, EPFL is a growing and well-funded institution fostering excellence and diversity. It is well equipped with experimental and computational infrastructure, and offers a fertile environment for research collaboration between different disciplines. The EPFL environment is multilingual and multicultural, with English serving as a common interface. EPFL offers internationally competitive start-up resources, salaries, and benefits.

The following documents are requested in PDF format: cover letter including a statement of motivation, curriculum vitae, publications list, concise statements of research and teaching interests (3-5 pages) as well as the names and addresses, including emails, of at least five references (may be contacted at a later stage). Applications should be uploaded to the EPFL recruitment web site:

https://facultyrecruiting.epfl.ch/position/10977280

Formal evaluation of the applications will begin on **May 1, 2018** and the search will continue until the position is filled.

Further enquiries should be made to the Chair of the Search Committee:

Prof. D. Andrew Barry
Director of the Environmental Engineering Institute
E-mail: extreme-environments@epfl.ch

For additional information on EPFL:
http://www.epfl.ch; http://enac.epfl.ch; https://valais.epfl.ch/Home

EPFL is an equal opportunity employer and a family friendly university.

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Astrophysics
Biological Sciences
Cosmochemistry
Earth Science
Heliophysics Science
Interdisciplinary/Other
Planetary Science
Technology Development
Available NASA Centers:
Ames Research Center
Armstrong Flight Research Center
Glenn Research Center
Goddard Institute for Space Studies
Goddard Space Flight Center
Jet Propulsion Laboratory
Johnson Space Center
Kennedy Space Center
Langley Research Center
Marshall Space Flight Center
NASA Astrobiology Program
NASA HQ
Solar System Exploration Research Virtual Institute
Stennis Space Center
Wallops Flight Facility
NOTE: Not all centers participate in every application round… please refer to the website for current opportunity locations
Eligibility:
US citizens, Lawful Permanent Residents and foreign nationals eligible for a J-1 visa as a Research Scholar
Recent and Senior-Level PhD recipients
Application Deadlines
Three each year–March 1, July 1, and November 1
To learn more about specific opportunities and to apply, please visit: https://npp.usra.edu/opportunities/

Ocean Sciences

President's Professor of Fisheries and Ecosystems

Additional position details:
The College of Fisheries and Ocean Sciences invites applications for an Associate Professor/Professor of Fisheries and Ecosystems. While the position is expected to be hired at the associate or full professor rank, exceptional candidates at the assistant level will be considered. This tenure-track position is fully funded for 12 months over the first 3 years, and thereafter receives 9-months of funding with the expectation that the incumbent will secure grants for 3 months of summer support annually. The position will be based at either of our CFOS locations in Juneau or Fairbanks, Alaska. The successful applicant will help train the next generation of fisheries scientists, biologists and biometricians to meet workforce needs of state and federal fishery management agencies, nongovernmental and tribal organizations, and the fishing industry. The incumbent will be a nationally and internationally renowned leader in fisheries science and sustainable fishery management. The successful candidate will possess cutting-edge expertise in one or more of the following areas: (1) multispecies or ecosystem models, (2) fisheries assessment methods and management strategy evaluations that incorporate environmental and ecological interactions, (3) modeling of species-environment relationships, (4) ecosystem-based fisheries management, or (5) other ecosystem approaches to fisheries. The incumbent will lead a vigorous Alaska-based fishery research program that involves undergraduate and graduate students, as well as postdoctoral researchers. The President's Professor will teach graduate courses as well as upper division undergraduate courses in the new Baccalaureate Program in Fisheries and Ocean Sciences jointly offered by UAF and the University of Alaska Southeast.

This hire is a vital part of our strategy to strengthen the fisheries program in CFOS at both the graduate and undergraduate levels. The incumbent will further enhance the profile of UA through service in both state and federal fisheries management arenas, such as serving as member of organizations such as the North Pacific Fishery Management Council's (NPFMC) Scientific and Statistical Committee, a group of experts responsible for setting science-based catch limits for federally managed commercial fisheries in Alaska.

UAF is Alaska's research university and Alaska offers unparalleled opportunities for freshwater and marine fisheries research. CFOS has 52 faculty, over 100 graduate students and more than 50 undergraduate students engaged in research in Alaskan waters and throughout the world (www.cfos.uaf.edu). The College offers academic programs in Fisheries at the Bachelor's, Master's, and Doctoral levels in Fairbanks, Juneau, Kodiak, and Seward. These and other facilities throughout the state are linked by modern videoconference and distance-delivery technology. The Department of Fisheries maintains a strong program that includes 15 tenured or tenure-track faculty, two research faculty members, and four other faculty with primary appointments outside of the fisheries program.

Qualified applicants must have a Ph.D. in fisheries, ecology, or a related field from an accredited university.

Duties: Teaching, Research and Service

Applicant Instructions:
Interested applicants must apply online. If you need assistance applying to this posting, please contact the UAF Office of Human Resources at 907-474-7700. Specific questions about the position can be directed to Dr. Gordon Kruse, Search Committee Chair, at 907-796-5458 or at ghkruse@alaska.edu.

Required Applicant Documents:
Brief Cover Letter
Statement of Interest and Qualifications (including research, teaching, and outreach plans)
Curriculum Vitae (CV)
Contact information for three professional references (address, email and phone number)
Also, please note that a 10-minute overview presentation that describes the candidate's vision for a research program based in Alaska will be required of those candidates selected for a phone interview.

Review Date:
Review of applications will begin upon receipt. Early applications are welcome but must be received no later than May 6, 2018, by 11:55 PM Alaska Standard Time to ensure full consideration. Applications received after this time and date may not be considered for this position. This position will remain open until filled.

Education required for this position:
Qualified applicants must have a Ph.D. in fisheries, ecology, or a related field from an accredited university.

Type and length of experience required for this position:
Applications are encouraged from creative individuals with strong scientific and academic backgrounds who will complement the expertise of existing faculty and contribute to the conservation and sustainable use of Alaska's world renowned fishery resources.

Postdoctoral research experience (preferred)

Knowledge, skills and abilities required for this position:
Applicants must be proficient in English, have experience teaching at the university level, and have a strong research and publication record appropriate to their experience and date of degree. The successful applicant will be a leader in fisheries science and sustainable fishery management. Candidates for this position should possess cutting-edge expertise in one or more of the following areas: (1) multispecies or ecosystem models, (2) fisheries assessment methods and management strategy evaluations that incorporate environmental and ecological interactions, (3) modeling of species-environment relationships, (4) ecosystem-based fisheries management, or (5) other ecosystem approaches to fisheries.

Background Check: The successful applicant is required to complete a background check. Any offer of employment is contingent on the background check.

UNAC: This position is part of the United Academics union (UNAC) and is subject to union dues as a condition of employment in a collective bargaining unit.

Training Policy: It is the policy of the University of Alaska Fairbanks that all employees are required to attend training to meet the requirements of the positions they hold, and to complete the required training within a specified period of time to remain employed at UAF. The policy can be located at: http://www.uaf.edu/chancellor/policy/04.07.010/

Tobacco-Free Campus: UAF Campus is a tobacco free campus. For more information, please go to: http://www.uaf.edu/tobaccofreecampus/

Notice of Nondiscrimination: The University of Alaska is an affirmative action/equal opportunity employer and educational institution. The University of Alaska does not discriminate on the basis of race, religion, color, national origin, citizenship, age, sex, physical or mental disability, status as a protected veteran, marital status, changes in marital status, pregnancy, childbirth or related medical conditions, parenthood, sexual orientation, gender identity, political affiliation or belief, genetic information, or other legally protected status. The University's commitment to nondiscrimination, including against sex discrimination, applies to students, employees, and applicants for admission and employment. Contact information, applicable laws, and complaint procedures are included on UA's statement of nondiscrimination available at www.alaska.edu/nondiscrimination

Postcards from the Field

Hi, All!

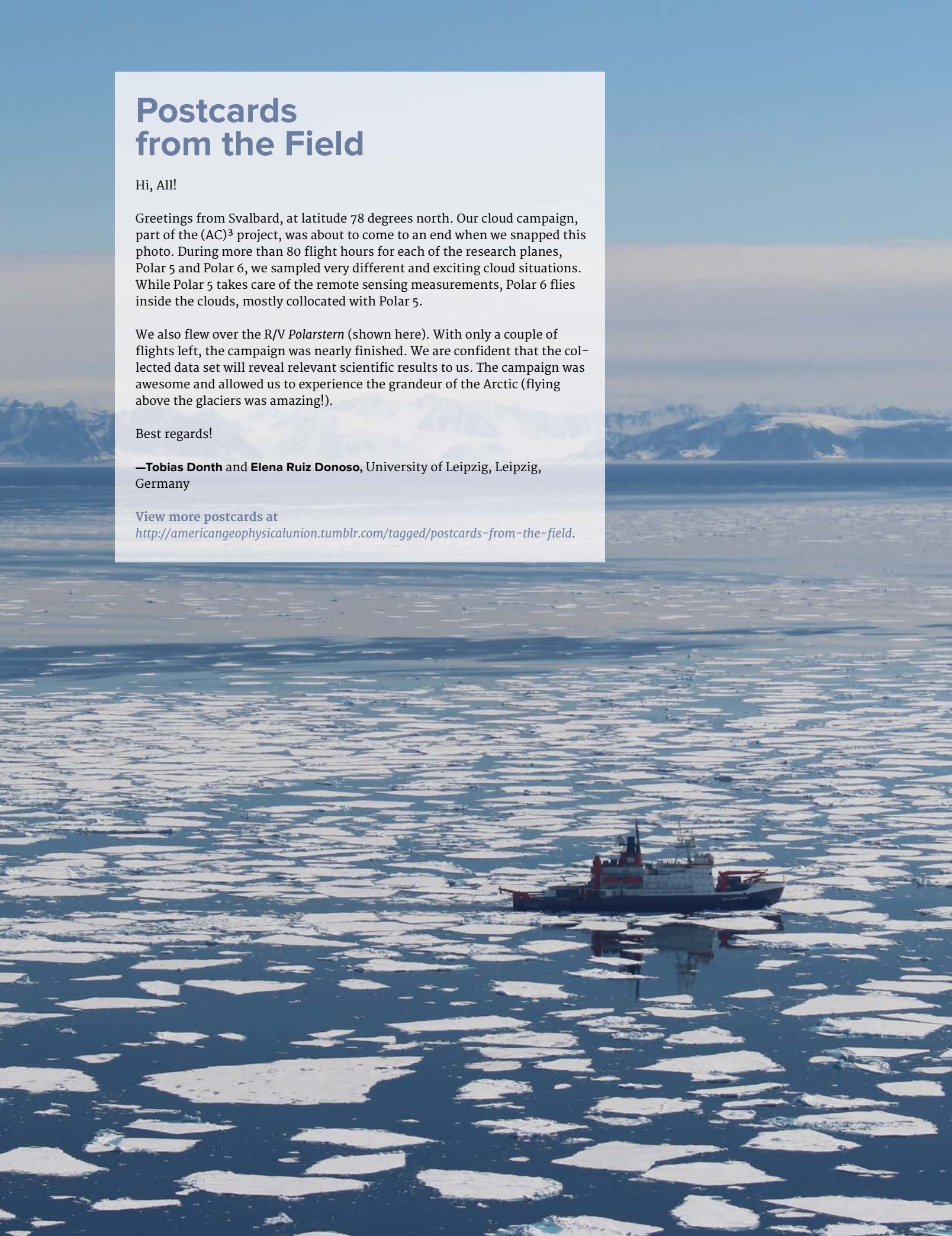
Greetings from Svalbard, at latitude 78 degrees north. Our cloud campaign, part of the (AC)³ project, was about to come to an end when we snapped this photo. During more than 80 flight hours for each of the research planes, Polar 5 and Polar 6, we sampled very different and exciting cloud situations. While Polar 5 takes care of the remote sensing measurements, Polar 6 flies inside the clouds, mostly collocated with Polar 5.

We also flew over the R/V *Polarstern* (shown here). With only a couple of flights left, the campaign was nearly finished. We are confident that the collected data set will reveal relevant scientific results to us. The campaign was awesome and allowed us to experience the grandeur of the Arctic (flying above the glaciers was amazing!).

Best regards!

—Tobias Donth and **Elena Ruiz Donoso,** University of Leipzig, Leipzig, Germany

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



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