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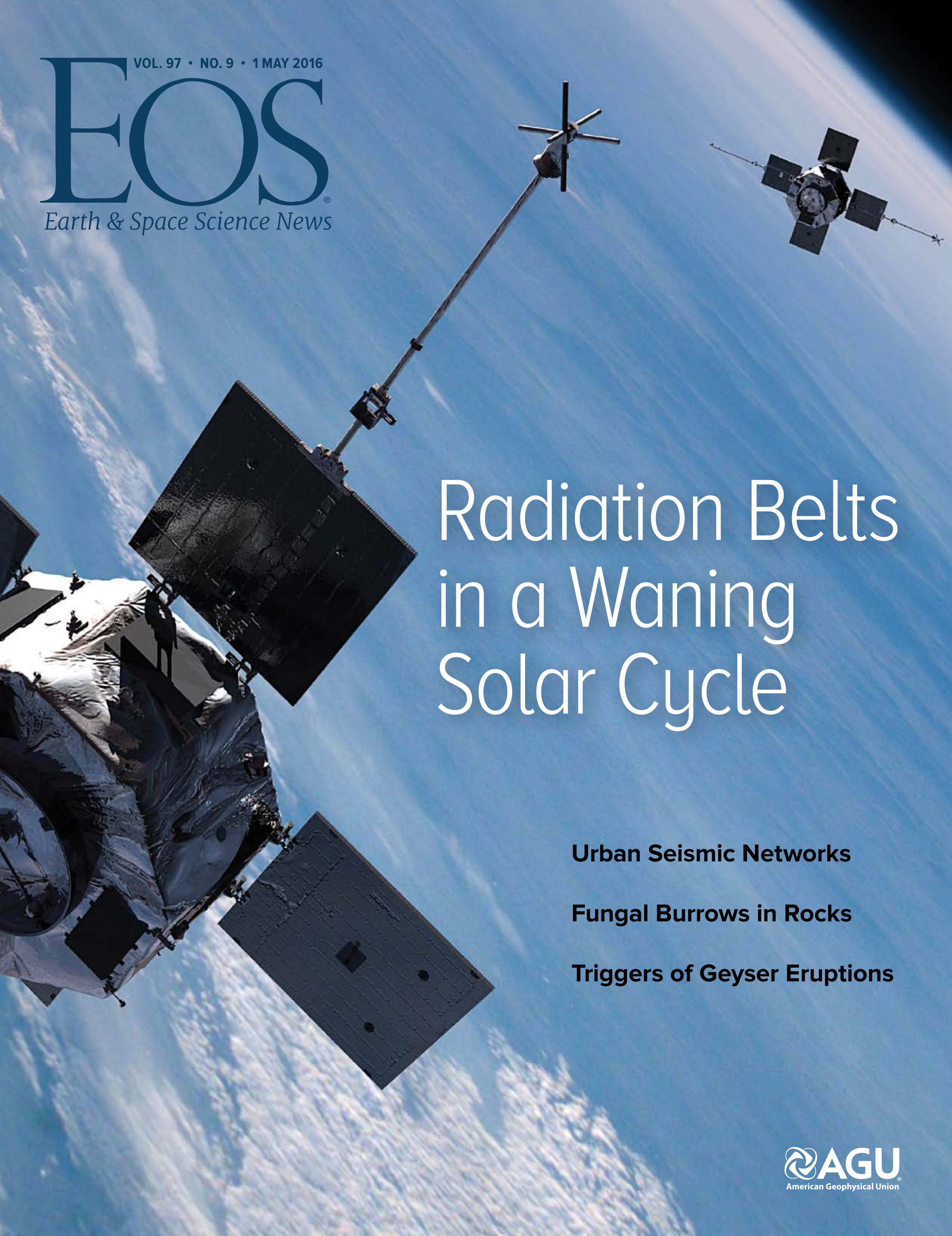

Radiation Belts in a Waning Solar Cycle

Urban Seismic Networks

Fungal Burrows in Rocks

Triggers of Geyser Eruptions

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Artist's rendition of the twin Van Allen Probes, which survey Earth's radiation belts. Credit: NASA/JHU/APL.

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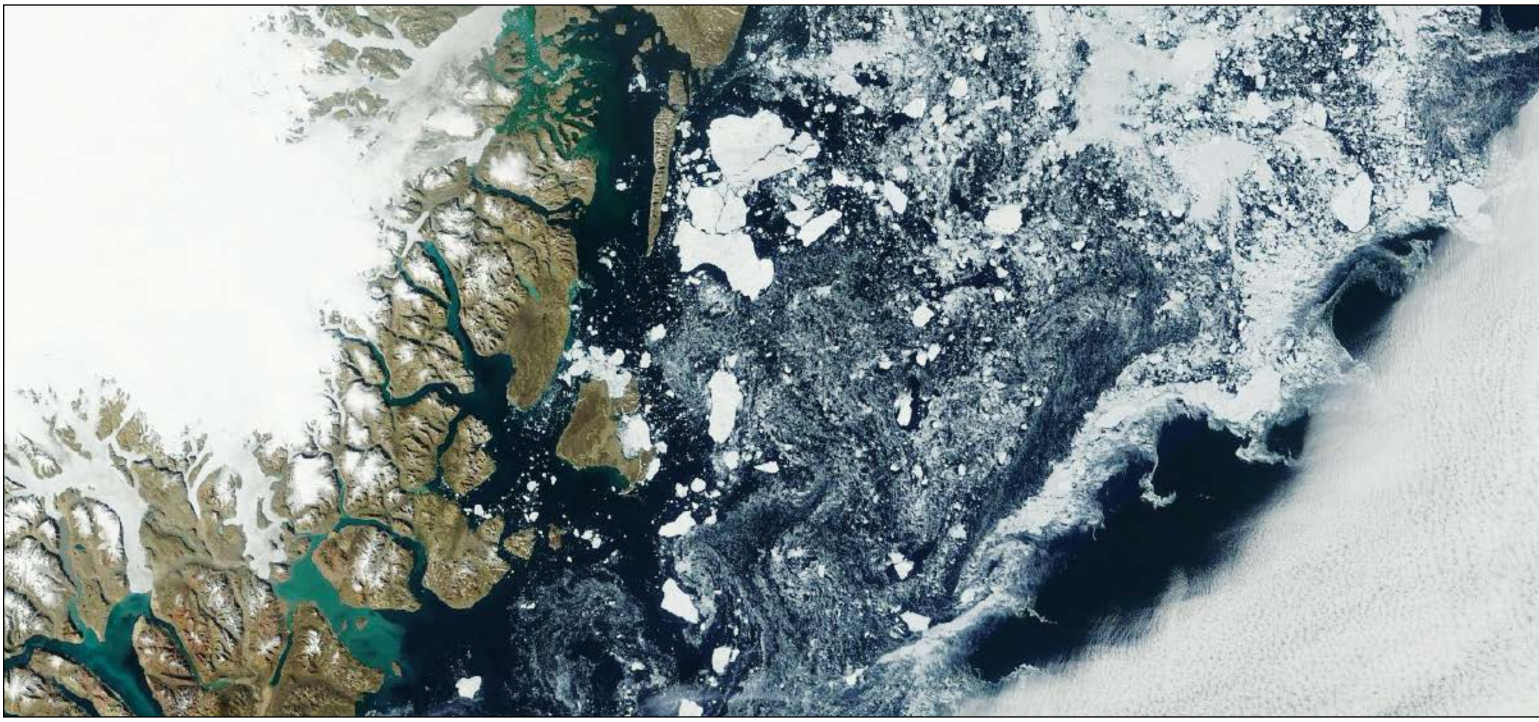
Current Carbon Emissions Unprecedented in 66 Million Years



NASA/GSFC/MODIS/Terra, CC Y 2.0 (http://bit.ly/ccby2-0)

Blocks of ice floating off the east coast of Greenland. The more sea ice melts, the more dark colors are exposed, causing the Earth to absorb more of the Sun's radiation, which speeds up anthropogenic heating.

As scientists attempt to understand how anthropogenic climate change will affect the Earth's future, they often study a period in the Earth's deep past, called the Paleocene-Eocene Thermal Maximum, when a period of natural climate change significantly heated the Earth. In a recently published *Nature Geoscience* paper, scientists established that this warming, which began 56 million years ago, was the result of a 4000-year period in which carbon was released into the atmosphere at a rate of 1.1 petagrams (or 1.1 trillion kilograms) per year (see http://bit.ly/Zeebe-et-al).

The Paleocene-Eocene Thermal Maximum (PETM) "is the biggest, most massive carbon release event since dinosaurs disappeared," said Richard Zeebe, a biogeochemist and paleoceanographer at the University of Hawai'i at Mānoa in Honolulu and lead author on the 21 March paper. Previous research had determined that this initial onset period stretched as long as 20,000 years (see http://bit.ly/slow-release), but Zeebe's team used more highly resolved data to shrink this onset time by a factor of 5.

Because the rate of carbon dioxide release is 10 times faster today, the severity of climate change's physical effects on the Earth, such as ocean acidification, could become much worse than we thought, Zeebe said.

A Different Earth

During the PETM, which lasted 100,000 years, Earth was a much different place than it is today. First and foremost, it was hotter, and the air contained much more carbon dioxide—700 parts per million, as opposed to today's 400 parts per million. During the onset of the PETM, Earth's temperature jumped because of a massive release of carbon dioxide (CO_2). The leading hypothesis for this geologically sudden event is that extensive volcanism warmed the ocean during that time, melting deep ocean hydrates that released methane, a potent greenhouse gas. Most of this methane was rapidly oxidized and became carbon dioxide, Zeebe said.

"The interesting thing is that it is [possible] that nature, over the long geological history, has also run this experiment, i.e., the rapid emission of CO_2 into the ocean [and] atmosphere, similar to what we humans are doing now," said Ellen Thomas, a paleoceanographer at Yale University in New Haven, Conn., who was not involved in the research. Having a better idea of the rate of carbon emissions "will also help in figuring out exactly where the carbon came from and why it was released."

Researchers see evidence of marine life extinction during this time due to ocean acidification, Zeebe said, especially in the deep-sea communities of tiny, shelled organisms.

Peeking into the PETM

To investigate how fast carbon was released, the researchers turned to an existing data set from a sediment core from Millville, N.J. This particular core offered the researchers much more highly resolved data than other cores used to investigate the ancient release. The layers of sediment laid down during the PETM at the New Jersey site are much thicker—tens of centimeters—than the thinner layers that other sediment cores offer to scientists, Zeebe said.

Different isotopes of carbon and oxygen locked within the sediment tell scientists a lot about past environments: A lower ratio of the heavier carbon isotope to the lighter isotope represents the time period in which carbon was emitted, and a lower abundance of the heavy oxygen isotope corresponds to the warming temperatures.

When carbon rises in the atmosphere, the ocean absorbs much of the resulting heat, so the climate can take decades to centuries to fully respond to an influx of carbon, Zeebe said. If carbon were released rapidly, researchers would find in the sediment core a lag between the carbon influx and warming temperatures. On the other hand, if carbon were released slowly, the climate's response would have kept pace with the carbon increase because of the ocean's slow adjustment, resulting in no lag.

Within the sediment core, the researchers found no lag between the massive carbon emission and the climate response, meaning that carbon was released relatively slowly compared to today.

> The researchers found no lag between the massive carbon emission and the climate response, meaning that carbon was released relatively slowly compared to today.

Using climate and carbon cycle computer models, the researchers tweaked the amount of carbon and the rate of carbon emission to match the physical data they found in the sediment core. What they found was that the PETM onset lasted, at minimum, 4000 years.

Future Climate Change

"This study provides another indication… that the rate of fossil fuel emissions significantly exceeds rates of carbon emissions during the PETM," said Lee Kump, a biogeochemist at Pennsylvania State University in University Park in an email. Kump wasn't involved in the new research but coauthored the previously mentioned paper that reported the 20,000-year PETM onset. In that study, he and his colleagues also found today's rates of carbon dioxide emissions to be 10 times higher than those during the onset of the PETM. Because the ocean absorbs much of the carbon dioxide, the consequences for marine life now, especially shelled creatures, could prove worse than during the PETM, Zeebe said.

Further, if carbon emissions are not reined in, natural feedbacks, such as the Earth's decreasing albedo due to melting ice and releases of methane from thawing permafrost, could spiral out of control with unknown consequences.

"There is no other cure than reducing emissions," Zeebe said.

By **JoAnna Wendel,** Staff Writer

Using Acid and Physical Force, Fungi Burrow Through Rock

All over the world, microbes destroy rocks to access precious nutrients such as iron locked inside. In a lab in Washington, D. C., researchers zoomed in on one particular microbe, the fungus *Talaromyces flavus*, to see just how this is done.

In a paper published recently in *Geology* (see http://bit.ly/fungus-paper), the researchers document their observations of the fungus as it obliterates its rocky environment using a mix of acid and mechanical force. Although it's known that microbes such as bacteria and fungi can wear away rocks, previous researchers estimated that fungi only contribute 1% to total bioweathering, said Henry Teng, a geochemist at George Washington University and coauthor of the paper. After watching *T. flavus* burrow into the mineral to extract essential nutrients, Teng and his team suggest that fungal weathering could actually be 40%–50% of all bioweathering.

Meal of Stone

The researchers collected the fungus from a serpentine mine in Donghai, China, where they were specifically looking for microbes that efficiently extract nutrients. Back in the lab, Teng's team looked closely at the fungal activity at the fungus-rock interface. This interface has generally been overlooked, Teng said; other scientists have focused on microbes mixed in a solution with crushed minerals. In this study, which was published 7 March, Teng and his colleagues allowed the fungus to actually colonize a sample of a mineral.

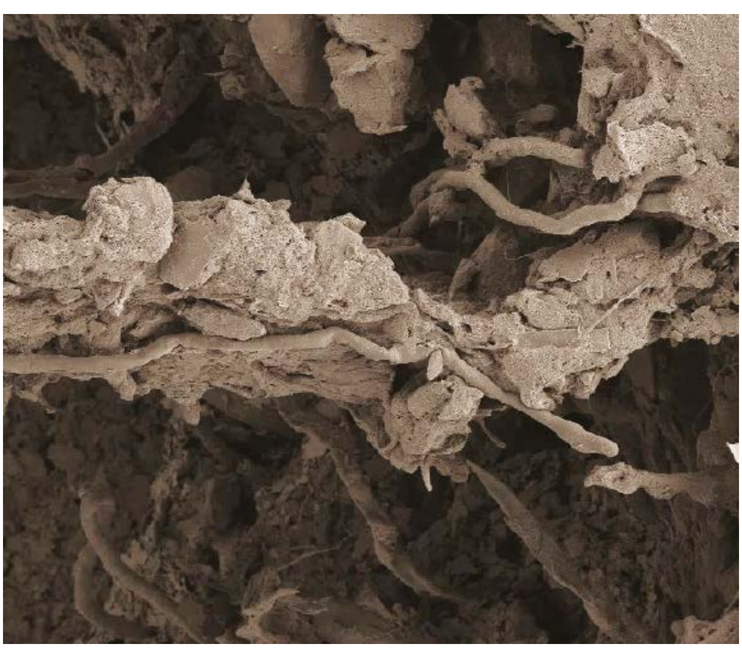
In real-world soil and rock conditions, after all, "microbes are crawling on the surface of the rock," Teng continued. "They don't stay in a suspended state."

To study the fungus's culinary routine, the researchers placed cells on tiny samples of the mineral lizardite, which usually is made up of magnesium, silicon, oxygen, and hydrogen but often contains traces of iron. After 4 days, the fungus's life ended in a cascade of chemicals as the researchers washed the mineral samples to inspect them more closely. Under a powerful microscope, the researchers could see nanometer-scale markings left over from the microbes' feast—long, thin channels and small, round pits.

The researchers then pinned down the fungus's methods of attack.

Fungal Attack

When the microbe first encounters the mineral's surface, its spores secrete acid that drops the pH by a factor of 10, creating a highly acidic environment in which to dissolve the rock and extract precious life-sustaining iron. An extra step requires the microbe to also secrete a type of chemical called a siderophore that allows it to ingest the iron. Once the fungus extracts all the iron—and lizardite doesn't contain much—it extends tiny filaments called hyphae to burrow through the remaining layer of silica to get to more nutrients, leaving behind channels stretching 200–2000 nanometers (to compare, a strand of human hair is about 80,000 nanometers thick).


Henry Teng

The researchers found the fungus Talaromyces flavus *in a Chinese mine, eating up minerals and extracting iron and magnesium.*

Further, Teng noticed places attacked by the fungus on the rock surface where the usual orderly crystalline structure of the mineral had become amorphous, "meaning there are mechanical forces involved in destroying this [mineral]," rather than just chemical forces, Teng said. He suspects that this kind of pummeling may be unique to the fungus.

Over the course of the experiment, the fungus placed on the lizardite destroyed more rock than fungus in a solution with crushed lizardite. In the solution with the fungus, the researchers didn't see the physical leftovers of the hyphae's attack, nor did they find high levels of siderophore, leading them to suggest that the fungus-mineral interface is more important than once thought.

Root Symbiosis

"Compared to bacteria, fungi are overlooked, understudied, and very few studies [looked] at these interfaces between fungi and mineral," said Steeve Bonneville, a biogeochemist at the Free University of Brussels in Belgium who was not involved in the paper, which he called "a very solid study." The new research provides evidence that "fungi can be a major player in mineral alteration and more generally in biogeochemical cycles," Bonneville said.

The *Geology* study could give scientists a better understanding of how plants absorb nutrients, said Teng. In most cases, plants don't extract nutrients from the soil themselves but rely heavily on soil microbes to break down rocks and release nutrients such as iron, nitrogen, and phosphorous, he noted.

"Most of the nutrients in rock and soil are in geological form," Teng said. "Roots cannot directly use that. Plants depend on the fungi to colonize their roots."

However, Bonneville said that the laboratory experiments used in the recent study were rather simplistic and that "there [were] no bacteria, plant roots, and no other fungi to interact with or prey on the fungal strain." In a similar study conducted by Bonneville in 2011, he and his team observed fungal colonies growing on the mineral biotite in a controlled environment that also hosted plant roots and other bacteria (see http://bit.ly/hypha-mineral). In that study, Bonneville found similar results—that fungal hyphae alter the underlying rock.

By **JoAnna Wendel,** Staff Writer

White House Summit Seeks Solutions to Water Challenges

With drought, flooding, and lead contamination of water in U.S. headlines, the White House recently held a water summit in Washington, D. C. Officials announced more than 150 government and private sector initiatives at the event to confront water-related challenges and "build a sustainable water future."

Among highlights of the summit were a commitment of more than $1 billion from the private sector to conduct research and development into advanced technologies for managing water, wastewater, and water reuse; about $4 billion in private capital for water infrastructure projects; and nearly $35 million in federal grants to support cutting-edge water research projects (see http://bit.ly/Water-Sustain). Other highlights included the release of a presidential memo and action plan on drought resilience and the National Oceanic and Atmospheric Administration's new National Water Model to increase water forecasting capabilities from 4000 to 2.7 million sites.

Technology Initiatives

Digital technology and data systems figured prominently among the initiatives announced at the summit. For example, David Henderson, managing director of XPV Water Partners, an equity and venture capital firm in Toronto, Ontario, Canada, said at the summit that the way that people manage and use water "is about to change" in large part because of digital technology including cell phones. "There is an incredible opportunity to take the productivity that we have seen from digital technologies in other sectors and apply it to the water sector. In simple terms, that means track it, measure it, change it," Henderson told *Eos*. XPV announced a commitment of $250 million, in addition to $100 million to date, to help water companies bring technology solutions to the market.

Project Water Data, another technology-focused initiative, aims to modernize data systems to support communities, agriculture, and clean waterways for wildlife, according to Joya Banerjee, senior program officer with the S.D. Bechtel, Jr., Foundation in San Francisco, Calif. The project also would highlight the value of open, integrated water data to support better decision making.

Other Water Experts Weigh In

For Peter Gleick, president of the Pacific Institute in Oakland, Calif., federal authorities and other decision makers have neglected water issues for far too long. "It was a relief to finally see the highest levels of the federal government begin to tackle our national water challenges" at the event, Gleick told *Eos*. The most important part of the summit, he said, "was the clear acknowledgment that the growing risks of human-caused climate change for water resources must now be factored into any long-term policies we choose to pursue."

The crisis in Flint, Mich., brought about by high lead levels in the drinking water supply, shook people up about the need to maintain water infrastructure, according to former U.S. Environmental Protection Agency administrator William Reilly. "Water is a basic necessity, and because it has been ubiquitous in most of our lives and we have had the benefit of having clean water come out of a tap when we turn it on, we have taken it for granted," he told *Eos* at the summit. Reilly, currently a senior adviser to the global investment firm TPG Capital in San Francisco, Calif., said that in many parts of the country water "is a resource that is under threat."

Drought Plan

The summit occurred on 22 March, 1 day after the White House issued a presidential memorandum on building national capabilities for long-term drought resilience (see http://bit.ly/drought-resilience). That document institutionalizes the National Drought Resilience Partnership (NDRP), an interagency program to coordinate federal support for drought-related efforts. The memo calls for NDRP to maintain the newly released Long-Term Drought Resilience Federal Action Plan (see http://bit.ly/drought-res-plan). The plan outlines measures to integrate data from environmental monitoring platforms to assess groundwater, soil moisture, and other indicators; study drought effects on ecosystems; and conduct research on improving agricultural water use.

By **Randy Showstack,** Staff Writer

Can Carbon Dioxide Trigger Geyser Eruptions?

The current perception of geysers—that their explosions are driven by hot water and steam—may not be exactly right. In a recent paper in *Geology,* researchers found that higher carbon dioxide (CO_2) concentrations in geyser water preceded eruptions—leading them to suggest that CO_2 is an important ingredient in triggering eruptions (see http://bit.ly/CO2-trigger).

"The common perception about geysers is that it's just water and steam—and that it's just a process of boiling," said Bethany Ladd, a research assistant at the University of Calgary in Alberta, Canada, and lead author on the paper. But "there are other things in the water, and they may have huge implications for the geyser."

Blowing Off More Than Steam

It's rare to find a geyser on Earth—about 1000 of them exist, and most of those are in Yellowstone National Park in the western United States. Geysers erupt when the hot water deep below rises toward the Earth's surface and suddenly chaotically boils.

Deep underground, the high pressures keep the water locked into a calmer state, but as the water rises, pressure is relieved, and water vapor forms in a burst of activity called ebullition, sending jets of water shooting into the air to the enjoyment of spectators. Many geysers, like Old Faithful, are so predictable that they can be scheduled into a tourist's day.

Past researchers have suggested that CO_2 might be involved in these eruptions (see http://bit.ly/Old-Faithful), but until now, no one has proven this empirically. To investigate this, Ladd and her team studied Spouter Geyser, located in the southwestern portion of the park.

Over 3 days, the researchers took 120 samples of discharge water from the geyser at different times of the day, then analyzed the samples in the lab. The discharge water can't tell the researchers everything about CO_2 concentrations in the geyser's subsurface, which is difficult to observe directly. They had to extrapolate these data by figuring out the water's temperature when it was deep below.

That extrapolation involved looking at other clues in the water, such as its ion concentrations. Dissolved minerals raise the water's boiling point, so knowing what's in the water can help researchers estimate the temperature of the source water feeding the geyser. From there, the researchers used a complicated set of calculations to figure out how much CO_2 was in the water prior to the eruption.

The researchers found that "CO_2 concentrations increased and are highest immediately prior to eruption, and then they decrease quite drastically during the eruption," Ladd said. This means that the CO_2 degassed from the water as the geyser erupted.

Visitors in Yellowstone National Park are treated to a show as the geyser known as Beehive erupts.

Bubbling Pressure

The researchers suggest that dissolved CO_2 gives the water a pressure boost that triggers the eruption. Below the geyser lies extremely hot water, but pressure from above—from any overlying water trapped in the enclosed space and from the atmosphere itself—prevents bubbles of water vapor from forming in the water and escaping. When CO_2 from the massive magma pool below Yellowstone dissolves into this water, the combined pressure from the added CO_2 gas and water molecules reaches a "bubbling pressure," as Ladd calls it.

"Water vapor pressure does not reach bubbling pressure alone," Ladd continued. "You need the contribution of CO_2 dissolved gas pressure" to reach or exceed the bubbling pressure.

When bubbles form in the water, they "induce more bubbles, and then those bubbles induce more bubbles, and then you get this big event"—an eruption—Ladd said.

She and M. Cathryn Ryan, also of the University of Calgary, published their findings online on 7 March.

In a complementary paper published in *Geology* in February, Shaul Hurwitz, a research hydrologist at the U.S. Geological Survey in Menlo Park, Calif., looked at several Yellowstone geysers and found similar results (see http://bit.ly/dissolved-gas).

Hot Water Explosions

These findings might help scientists better understand hydrothermal explosions, Ladd said. Such eruptions occur when a shallow reservoir of hot water suddenly flashes to steam and explodes, sending rocks and debris flying.

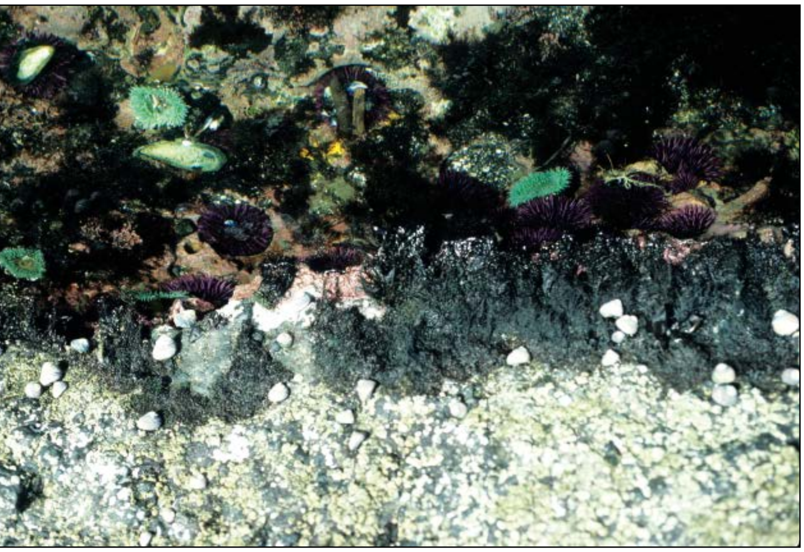
In September 2014, Japan's Mount Ontake volcano erupted in a hydrothermal explosion, expelling a massive flow of ash and heat and killing 57 people. Earlier this year, a different team of researchers found that volcanic gases, including CO_2, had been flowing into the mountain's underground system for the last 10 years (see http://bit.ly/He-Ontake).

In Hurwitz's study, the researchers suggest that this gas buildup could have triggered the eruption by ramping up pressure in subterranean water. They also suggest that seismic activity could help bring this gas into the subsurface plumbing—in Japan, the Ontake eruption occurred 2.5 weeks after seismicity in the area increased, Hurwitz and his colleagues reported.

In Yellowstone, the researchers also note, swarms of small tremors are common and can bring fluids—including gases like CO_2—into the subsurface cracks. By monitoring changes in thermal waters, especially after earthquake swarms, scientists could possibly anticipate hydrothermal hazards.

By **JoAnna Wendel,** Staff Writer

Tide Pools Mimic Climate Change in Everyday Cycle



Dr. Dwayne Meadows, NOAA/NMFS/OPR

Tide pool in the University of California Bodega Marine Reserve.

Simply by breathing, tide pool critters acidify their environment, affecting their ability to build their shells and skeletons. A team of researchers noticed this intriguing effect while testing equipment along the rocky California coast.

In tide pools at the Bodega Marine Reserve, research scientist Lester Kwiatkowski of the Carnegie Institution for Science in Stanford, Calif., and colleagues observed a dramatic change in tide pool pH between day and night while they were evaluating some lab instruments. The researchers looked closer, sampling the water during low tide at periodic times during the day and night to study its chemistry, and they discovered a seesaw pattern in which the pools' pH dropped each night and then reverted to more alkaline conditions during the day.

In a paper published recently in *Scientific Reports*, the researchers describe the pattern as an influence of two different types of "breathing" that alternately dominate tide pool chemistry: When the Sun shines during the day, photosynthesizing organisms such as algae take up carbon dioxide (CO_2) and release oxygen, which raises the pH of the tide pool. After sunset, that process stops, and other organisms continue to respire by taking up oxygen and releasing CO_2—similar to the way humans breathe—dropping the pH and acidifying the water, Kwiatkowski said.

The kinds of "breathing" taking place and their effects on water chemistry weren't entirely new information. But the researchers realized that this microcosm of life offered a highly accelerated analogue of the global phenomenon of ocean acidification.

"As the communities respire, they produce CO_2, which lowers the pH in a very similar way to what we would expect to happen on decadal and centennial time scales due to climate change," said Kwiatkowski, the lead author on the 18 March paper (see http://bit.ly/Tide-Pools).

Hard Day's Night

The oceans are acidifying worldwide from people pumping vast quantities of CO_2 into the air. When the ocean absorbs CO_2, the molecule reacts with water to form carbonic acid, which builds up and threatens marine organisms that have shells or skeletons made from the compound calcium carbonate.

To create calcium carbonate, many sea creatures collect calcium ions and carbonate ions from seawater. Corals, for instance, use calcium carbonate to make skeletons, whereas other creatures, including snails, clams, and mussels, create shells. A more acidic ocean can interfere with this process of building skeletons and shells.

The tide pools studied by Kwiatkowski and his colleagues host skeleton builders such as coralline algae and shell builders such as mussels and limpets as well as noncalicifying organisms such as sea grass and red, brown, and green algae.

From the chemistry of the water, the researchers gleaned information about the growth and dissolution of the calcium-rich frameworks of the inhabitants. The team specifically looked at how the aragonite saturation state—a number that tells scientists how much aragonite (a form of calcium carbonate) is available for creatures to use—affected tide pool creatures at different times of the day. A high saturation state value means there is enough aragonite available for the organisms to use. When this number is low, calcium carbonate already incorporated into sea creatures' bodies dissolves back into the water.

The researchers found that during the day when water pH was less acidic, the calcifying organisms grew more, even when the availability of aragonite was relatively low. On the flip side, at night, when acidity rose again, these organisms were much more sensitive to the availability of aragonite, and their shells and skeletons began to dissolve.

Many of the photosynthesizing organisms also calcify, Kwiatkowski noted, so he speculates that perhaps the extra energy provided by photosynthesis makes them less sensitive to the availability of aragonite and therefore more resilient against any daytime dissolution.

Real Effects of Ocean Acidification

Beyond identifying a handy natural laboratory for studying ocean acidification and its effects, the new findings also forebode worsening nighttime stress to come for tide pool inhabitants. In the past century, greenhouse gas emissions have already dropped the pH of the ocean by 30%. And as humans pump more and more CO_2 and other greenhouse gases into the atmosphere, the ocean's pH is expected to drop even more. As a result, tide pools will start each night more acidic than they already are, leading to deeper dissolution of shells and skeletons in the nocturnal hours. "You're going to have an ocean acidification effect on top of the respiration effect and that is likely to increase the rates of nighttime dissolution," Kwiatkowski said.

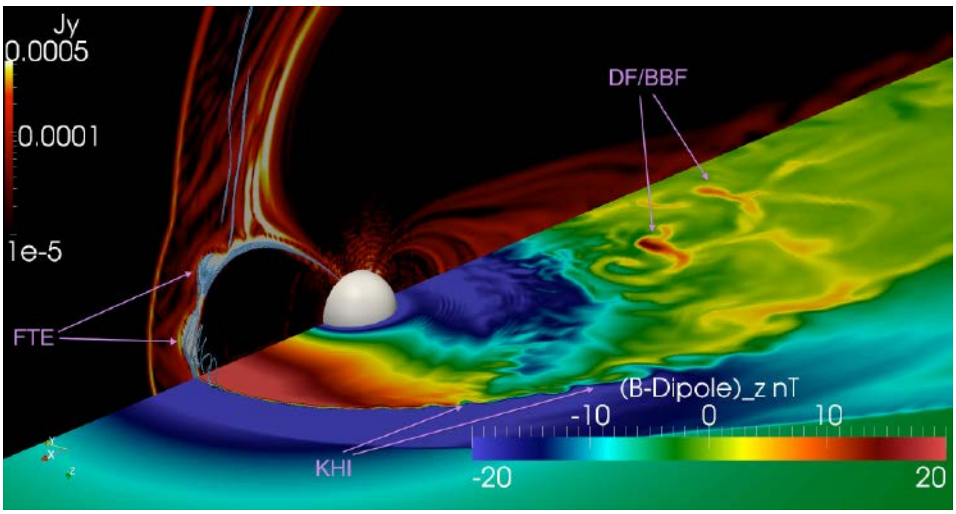
"Tide pool communities are considered more resilient to change because they are adapted to large swings in carbonate chemistry on a daily basis," said Joanie Kleypas, a marine ecologist and biologist at the National Center for Atmospheric Research in Boulder, Colo., who was not involved in the research. "The paper emphasizes the need to take into account both the biological and geochemical aspects of calcification."

Because this research covered only four specific tide pools, it remains to be seen how widely the researchers' findings apply, Kwiatkowski said. Given that creatures living in the studied tide pools—mussels, crabs, algae, sea grass, and more—are ubiquitous in coastal temperate zones, he suspects that his team's observations have broad significance.

By **JoAnna Wendel,** Staff Writer

Great Mysteries of the Earth's Magnetotail

Workshop on Magnetotail Reconnection Onset and Dipolarization Fronts
Laurel, Maryland, 16–18 September 2015



Viacheslav G. Merkin

Dipolarization fronts (DFs), bursty bulk flows (BBFs), flux transfer events (FTEs), and Kelvin-Helmholtz instability (KHI) in a high-resolution simulation of an idealized substorm. The simulation was performed using the Lyon-Fedder-Mobarry global magnetosphere model.

Charged particles trapped by Earth's magnetic field form its plasma environment, the magnetosphere. The solar wind, the flow of plasma emanating from our star, stretches the magnetosphere on the nightside—the magnetotail—away from the Sun. Other planets also form magnetotails, and in the course of their interaction with the solar wind they accumulate energy and then release it explosively. Substorms are the most violent examples of such explosive processes, with their impressive manifestation in auroral brightening, and they have long been associated with the onset of magnetic reconnection.

Magnetic reconnection—ubiquitous throughout the universe—is the poorly understood process that breaks and reconnects oppositely directed magnetic field lines and converts magnetic field energy to plasma kinetic and thermal energy. The mechanisms and driving forces behind magnetic reconnection, particularly in the magnetotail, have remained controversial for several decades because of the fundamental physical complexity and limitations of observations.

Through various observations NASA established a close relationship between magnetic reconnection and other key signatures of the magnetotail activity, such as dipolarization fronts (DFs; thin sheets of electrical current associated with coherently structured disturbances) and bursty bulk flows (BBFs; brief high-speed flows in the plasma sheet). These observations were conducted by the Time History of Events and Macroscale Interactions during Substorms (THEMIS) and Geotail missions, as well as the European Space Agency's Cluster and other missions.

> Even with more data, a complete understanding will also require major improvements in the physical realism of current global and regional models.

However, major fundamental questions remain, including the pre-onset configuration and the stability of the magnetotail, the role of DFs in driven versus spontaneous reconnection onset scenarios, the role of ideal magnetohydrodynamic instabilities resulting in buoyancy and flapping plasma motions, and the general properties of DFs and BBFs throughout the tail.

These observational and theoretical challenges, together with the launch of NASA's dedicated reconnection Magnetospheric Multiscale (MMS) mission, motivated us to convene a workshop on magnetotail reconnection onset and dipolarization fronts (see http://bit.ly/MRODF-home). The goal was to gather scientists with diverse views and approaches to these topics and to have an open forum with ample opportunity for discussions.

To provide a broader context for the primary topics of the workshop, we also invited presentations discussing similar processes at the magnetopause, in the solar corona, and in laboratory experiments, leading to a balanced mix of theoretical, simulation, and observational presentations. Summaries of the presentations are available in the online supplement (see http://bit.ly/MRODF-supplement).

The lack of sufficient observations was a permeating theme throughout the workshop. Even with the five THEMIS spacecraft distributed throughout the magnetotail, we can barely capture the spatial and temporal complexity of these processes.

Thus, existing data are mostly insufficient to provide stringent constraints on models, which would require multiscale spatially distributed measurements. These could be provided, for example, by a constellation-class mission combining observations on different scales and involving more satellites than the present missions. However, even with more data, a complete understanding will also require major improvements in the physical realism and resolution of current global and regional models.

Forty-eight scientists attended the workshop (seven remotely), and international participants came from Sweden, Austria, Russia, the United Kingdom, Belgium, and China. We received an overwhelmingly positive response, and we plan to repeat the workshop in the fall of 2016. In the interim, we will be engaged in discussions with the workshop participants to refine the topics, scope, and science questions, as well as logistical items such as the workshop location and time.

By **Mikhail I. Sitnov** and **Viacheslav G. Merkin,** Johns Hopkins University Applied Physics Laboratory, Laurel, Md.; email: mikhail.sitnov@jhuapl.edu; and **Joachim Raeder,** Space Science Center, University of New Hampshire, Durham

How Will Sea Ice Loss Affect the Greenland Ice Sheet?

On the Puzzling Features of Greenland Ice-Core Isotopic Composition
Copenhagen, Denmark, 26–28 October 2015

Sea ice near western Greenland in summer 2014.

The modern cryosphere, Earth's frozen water regime, is in fast transition. Greenland ice cores show how fast these changes can be, presenting evidence of up to 15°C warming events over timescales of less than a decade. These events, called Dansgaard/Oeschger (D/O) events, are believed to be associated with rapid changes in Arctic sea ice, although the underlying mechanisms are still unclear.

The modern demise of Arctic sea ice may, in turn, instigate abrupt changes on the Greenland Ice Sheet. The Arctic Sea Ice and Greenland Ice Sheet Sensitivity (Ice2Ice) initiative, sponsored by the European Research Council, seeks to quantify these past rapid changes to improve our understanding of what the future may hold for the Arctic.

Twenty scientists gathered in Copenhagen as part of this initiative to discuss the most recent observational, technological, and model developments toward quantifying the mechanisms behind past climate changes in Greenland. Much of the discussion focused on the causes behind the changes in stable water isotopes recorded in ice cores. The participants discussed sources of variability for stable water isotopes and framed ways that new studies could improve understanding of modern climate.

Recent fieldwork campaigns illustrate an important role of stable isotopes in atmospheric vapor.

The participants also discussed how climate models could provide insights into the relative roles of local and nonlocal processes in affecting stable water isotopes within the Greenland Ice Sheet. Presentations of modeling results showed how a change in the source or seasonality of precipitation could occur not only between glacial and modern climates but also between abrupt events.

Further, indications from recent fieldwork campaigns illustrate an important role of stable isotopes in atmospheric vapor and diffusion in the final stable isotope signal in ice. This feature complicates the quantitative interpretation of ice core signals but also makes the stable ice isotope signal a more robust regional indicator of climate, speakers noted. Meeting participants agreed that to further our understanding of these relationships, we need more process-focused field and laboratory campaigns.

In addition, the participants reviewed the biggest uncertainties and challenges that arise when comparing observed and simulated isotope variations and discussed whether any additional information would be available in water with heavier isotopes of oxygen or hydrogen (e.g., deuterium excess and ^{17}O excess).

At the end of the workshop, the participants agreed on a suite of idealized modeling experiments to simulate the isotopic signature of D/O events. Several modeling groups, using various models (the Community Earth System Model, the European Centre Hamburg Model, etc.), will run these simulations. Using a set of common boundary conditions, the different mechanisms that might give the observed stable isotope signal on Greenland can be tested and their importance formally quantified.

With this understanding of isotope signaling, we can present additional constraints on the nature of the climate changes during rapid events. The results will also shed light on what causes D/O cycles, a question that remains unanswered 30 years after their discovery in the ice record.

Acknowledgments
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Predicting the Risks and Occurrence of Extratropical Cyclones

5th Workshop on European Storms: Impacts and Predictability
Bern, Switzerland, 31 August to 2 September 2015

NASA

Two extratropical cyclones formed south of Iceland on 20 November 2006, illustrating serial clustering, in which successive cyclones depend on previous ones.

Extratropical cyclones can have devastating effects on society. A cluster of more than 10 extreme European storms in the winter of 2013–2014, for example, claimed several lives, destroyed property, disrupted transportation and business, and caused total insured losses of more than $3.3 billion. Climate change–driven weather extremes and increasing population are expected to produce dramatic increases in losses from such events.

Several interdisciplinary storm workshops have been organized since 2011 to address scientists' and stakeholders' need for better understanding of the risk and predictability of such extreme events (see http://www.stormworkshops.org). The 5th Workshop on European Storms, held in Bern, Switzerland, brought together 80 dynamical meteorologists, climatologists, statisticians, stakeholders, and risk model developers from insurance, model vendor, and engineering consultant companies.

One focus of the discussion was serial clustering of storms—the dependency between successive cyclones. Serial clustering occurs around the edges of the Atlantic storm track and over Europe. New results confirm that serial clustering is mainly due to modulation of storms by the North Atlantic Oscillation, and it is projected to decrease slightly under future climate change. However, the large natural variability of storm counts makes it unlikely that such changes will be detectable.

Workshop participants also discussed mesoscale processes leading to high-impact wind and/or precipitation situations during the life cycle of extratropical cyclones. Extratropical cyclones have complex mesoscale structures, including fronts and conveyor belts that are affected by diabatic processes, in which heat is gained or lost. Recent results show that precipitation and wind extremes often occur simultaneously and that such compound extremes occur in as many as 35% of extreme weather events along the west coast of Europe.

Nevertheless, the resolution of global climate models and reanalysis products is not yet sufficient to accurately characterize mesoscale structures such as sting jets. Hence there is a need for dynamical downscaling to complement current efforts that analyze the large-scale patterns that potentially lead to such events.

Workshop presentations showed that downscaling can help in defining event sets appropriate for risk modeling. Because of the large uncertainties in the parameterization of wind gusts, there is still a need to carefully recalibrate the vulnerability curves in the loss models.

Another industry-relevant topic is how "extreme" a storm can become. Discussions on this topic centered around maximum precipitation and minimum central pressure of

Compound extremes occur in as many as 35% of extreme weather events along the west coast of Europe.

cyclones. A spatiotemporal statistical model suggests that at present, there is a high probability of experiencing substantially deeper central pressures than has been observed in the past 50 years.

Finally, workshop participants examined the predictability of storms over seasonal and longer time scales. New results suggest a small, yet noticeable increase in the ability to forecast cyclone-related losses for the North Atlantic European region. Other results discussed showed that the serial clustering of storms within a season is due to the memory generated by the climate system, possibly related to phenomena including ocean circulation and sea ice, although the physical processes have not been firmly established. This serial clustering suggests an unexplored source of predictability.

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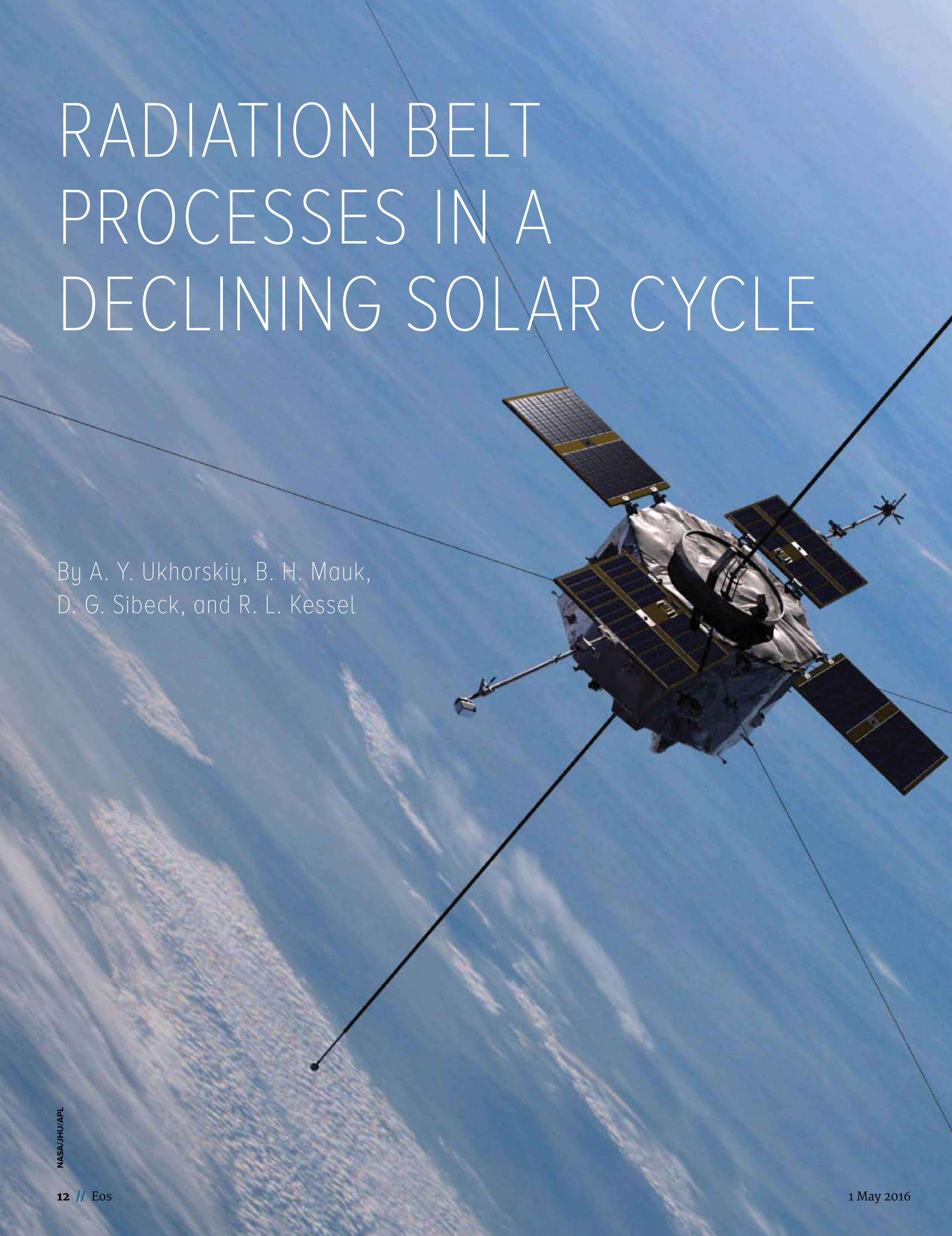
RADIATION BELT PROCESSES IN A DECLINING SOLAR CYCLE

By A. Y. Ukhorskiy, B. H. Mauk, D. G. Sibeck, and R. L. Kessel



NASA/JHU/APL

NASA's Van Allen Probes began an extended mission last year to advance understanding of Earth's radiation belts.

The morning of 30 August 2012 saw an Atlas 5 rocket launch of the twin Radiation Belt Storm Probes, the second spacecraft mission in NASA's Living With a Star program. The probes settled into an elliptic orbit that cut through Earth's radiation belts, home to highly variable populations of energetic particles dangerous to astronauts' health and spacecraft operation. Renamed the Van Allen Probes soon after launch, the spacecraft are equipped with instruments designed to determine how these high-energy particles form, respond to solar variations, and evolve in space environments.

During their prime mission, the Van Allen Probes verified and quantified previously suggested energization processes, discovered new energization mechanisms, revealed the critical importance of dynamic plasma injections into the innermost magnetosphere, and used uniquely capable instruments to unveil inner radiation belt features that were all but invisible to previous sensors.

Now, through an extended mission that began 1 November 2015, the Van Allen Probes will advance understanding of the dynamics of near-Earth particle radiation. The overarching objective of this extended mission is to quantify the mechanisms governing Earth's radiation belt and ring current environment as the solar cycle transitions from solar maximum through the declining phase.

The Van Allen Probes mission extends beyond the practical considerations of the hazards of Earth's space environment. Twentieth-century observations of space and astrophysical systems throughout the solar system and out into the observable universe show the universality of processes that generate intense particle radiation within magnetized environments such as Earth's. Earth's radiation belts are a unique natural laboratory for developing our understanding of the particle energization processes that operate across the universe.

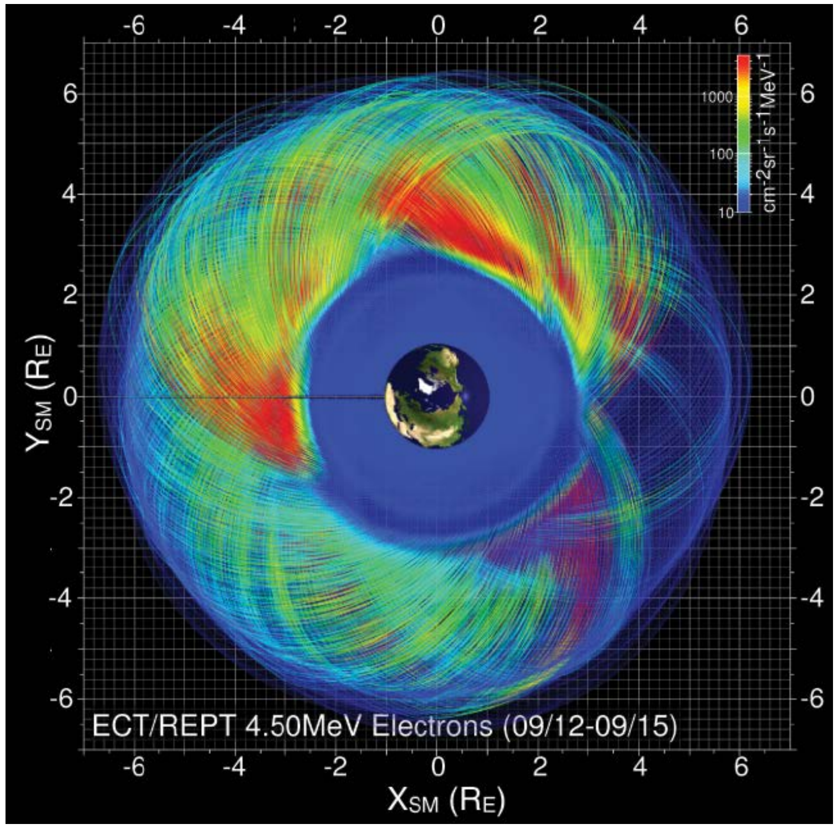


Fig. 1. As their orbits precess around Earth, the probes sample various acceleration and loss mechanisms that sculpt global distributions of radiation belts and ring current populations. The figure shows the intensity (marked with color) of electrons accelerated to 4.5 megaelectron volts along the spacecraft orbit projected onto the equatorial plane (in the solar magnetic coordinate system).

Effects of the Solar Cycle Decline

The sunspot number reached a peak in April 2014. From historical measurements, we can expect that radiation belt activity will keep intensifying with the decline of the solar cycle: The biggest radiation belt enhancements during geomagnetic storms of two previous solar cycles occurred in their declining phase. As the solar cycle wanes, high-speed solar wind streams become more prominent compared to the solar coronal mass ejections that tend to prevail during solar maximum. Not surprisingly, the two biggest geomagnetic storms of this decade occurred on 17 March and 21 June 2015.

The local time positions of the apogees of the Van Allen Probes' orbits drift westward and complete a full circle around Earth over a period of about 2 years (Figure 1). By the end of the extended mission (roughly June 2019), the Van Allen Probes will be the first inner magnetospheric mission to circle Earth four times, enabling us to quantify how the relative roles of various acceleration and loss mechanisms change with the decline of the solar cycle.

Understanding Local Particle Energization

Particle acceleration mechanisms have been a key focus of the Van Allen Probes mission. The probes have provided the first definitive evidence that at times, local particle acceleration within the heart of the radiation belts dominates over other processes that invoke transport and adiabatic compression of particle population from distant regions. The local acceleration is attributed to quasilinear particle interactions with electromagnetic waves called whistler waves. Whistler waves transfer energy from copious low-energy particles to sparse high-energy particles. (Listen to audio clips from the Electric and Magnetic Field Instrument Suite and Integrated Science instruments aboard the Van Allen Probes at http://bit.ly/Whistler-showcase.)

At the same time, the probes have also discovered highly unexpected nonlinear wave structures in the heart of the radiation belt. Such structures can rapidly energize very low energy (~10 electron volts) electrons up to intermediate energies (~100 kiloelectron volts (keV)), thereby providing a seed population for subsequent acceleration to radiation belt megaelectron volt (MeV) energies by the whistler waves. The probes have also observed whistler waves with unusually large amplitudes that are likely to more rapidly accelerate keV particles to MeV energies with nonlinear processes. A key aim of the probes' extended mission is to sort out the relative importance of quasilinear and nonlinear interactions for the buildup of radiation belt intensities.

To determine the relative importance of nonlinear interactions, we need to measure the evolution of the wave fields and particle distributions along field lines. In the extended mission, Van Allen Probes will provide two unique opportunities for such measurements. First, by adjusting slightly the orbital phase of one spacecraft with respect to the other, we can roughly align them along the same magnetic field line and thus sample field-aligned evolution of particles and wave fields.

Coordinating with Japan's Exploration of Energization and Radiation in Geospace (ERG) spacecraft, planned for launch in summer 2016, will afford us the second opportunity to sample wave interactions simultaneously at different magnetic latitudes. ERG, by design, will sample at higher magnetic latitudes than the probes. Using three-point measurements from ERG and the probes will provide a more global view of wave-particle interactions at different magnetic latitudes, important for quantifying nonlinear effects.

Investigating Particle Loss

Defining particle loss mechanisms is critical to understanding dynamic variability of the radiation belt intensities. The Van Allen Probes and the associated Balloon Array for Radiation-Belt Relativistic Electron Losses (BARREL) have conducted joint experiments for quantifying particle precipitation, which is the scattering of particles from radiation belts into the atmosphere. The BARREL mission launched multiple high-altitude balloons to measure precipitation of relativistic electrons into the atmosphere along field lines that map to the radiation belts. Within the belts, the Van Allen Probes measure the plasma waves that drive these losses.

Exceedingly close correlations have been observed between the so-called whistler-mode "hiss" waves and electron precipitation modulations, suggesting that losses capable of depleting radiation belt intensities can happen globally on time scales as short as 1 to 20 minutes.

Another process that can rapidly deplete radiation belt intensities during geomagnetic storms is the occurrence of magnetosphere distortions that can cause the particles to stream out of the magnetosphere into the interplanetary environment.

It is a goal of the Van Allen Probes extended mission to understand the relative importance of precipitation and interplanetary particle losses. NASA's Magnetospheric Multiscale (MMS) mission, launched in March 2015, provides an ideal opportunity to observe directly these escaping electrons at the magnetosphere boundary (the magnetopause) while the Van Allen Probes measure inner magnetospheric losses and the processes that drive these losses. During major loss events, the MMS spacecraft will skim the dayside magnetopause region for extended intervals. With its unusually sensitive energetic electron sensors, MMS will directly measure escaping radiation belt electrons.

Ring Current Generation

The buildup of the intermediate energetic ion population (reaching keV levels) during geomagnetic storms creates a source of hot plasma pressure in the inner magnetosphere that drives the so-called global "ring current" system that encircles Earth. This ring current controls the magnetic field configuration, which in turn governs the motion of radiation belt particles. Energetic ions also provide the energy source for an array of different wave modes that play a significant role in radiation belt particle acceleration and loss.

A surprising discovery of the Van Allen Probes prime mission was that a substantial fraction of hot plasma pressure is produced by dynamic small-scale injections that rapidly (in a matter of minutes) transport hot particles radially into the inner magnetosphere. Such injections were known to be common within the magnetotail but were previously thought to be infrequent in the inner magnetosphere.

The structure and occurrence rate of the injections remain unknown, and the amount of hot plasma transported remains poorly quantified. The extended mission will quantify the properties of small-scale injections in the inner magnetosphere and explore their role in the buildup of hot plasma pressure during storms. This investigation will be greatly facilitated by the recent adjustment of the spacecraft's orbits, which doubled the cadence of simultaneous two-point, radial-aligned measurements, necessary to quantify the properties of dynamic injections.

The Mission Continues

Over the past 3 years, the Van Allen Probes mission has radically changed our understanding of Earth's inner magnetosphere and radiation belts. As of October 2015, the Van Allen Probes' bibliography (http://rbspgway.jhuapl.edu) contains more than 210 publications, including a number of articles published in high-profile journals such as *Nature* and *Science*.

With all instruments returning quality data, both spacecraft healthy, and the remaining propellant sufficient to support spacecraft operations well into 2019, we expect many more quality publications and science discoveries from the extended mission. Stay tuned!

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Tiny Accelerometers Create Europe's First Urban Seismic Network

By Antonino D'Alessandro

When a strong earthquake hits an urban area, prompt rescue operations can minimize the number of victims. Logically, the probability of saving a human trapped under debris or injured during the course of a disaster decreases exponentially as a function of time, vanishing almost completely after about a few hours. *Tokyo Fire Fighting Department Planning Section* [2002] has quantified this further, stating that rescue within 3 hours is desirable and survival rate is drastically lower after 72 hours.

Past disasters—like the magnitude 6.6 quake that struck Iran on 26 December 2003—support this assessment. As a result of that earthquake, more than 43,000 people died, and only 30 were saved, despite the intervention of 1600 rescuers from 43 nations. This tragic outcome is likely related to the fact that many rescuers didn't arrive until after 3 days.

The impact of a strong earthquake on an urban center can be considerably reduced by an efficient emergency management center, through timely and targeted actions immediately following the quake. A real-time urban seismic network—sensors laid out in a grid through a city—could help emergency management centers by providing immediate alert and postearthquake information summarized in maps of ground motion.

Researchers are using new technological advances to develop one such urban seismic network in Acireale, Italy.

If an earthquake were to shake Acireale, Italy, iconic structures such as the Cathedral of Acireale, shown above (effect added), could be vulnerable to collapse.

© AGF Srl / Alamy Stock Photo

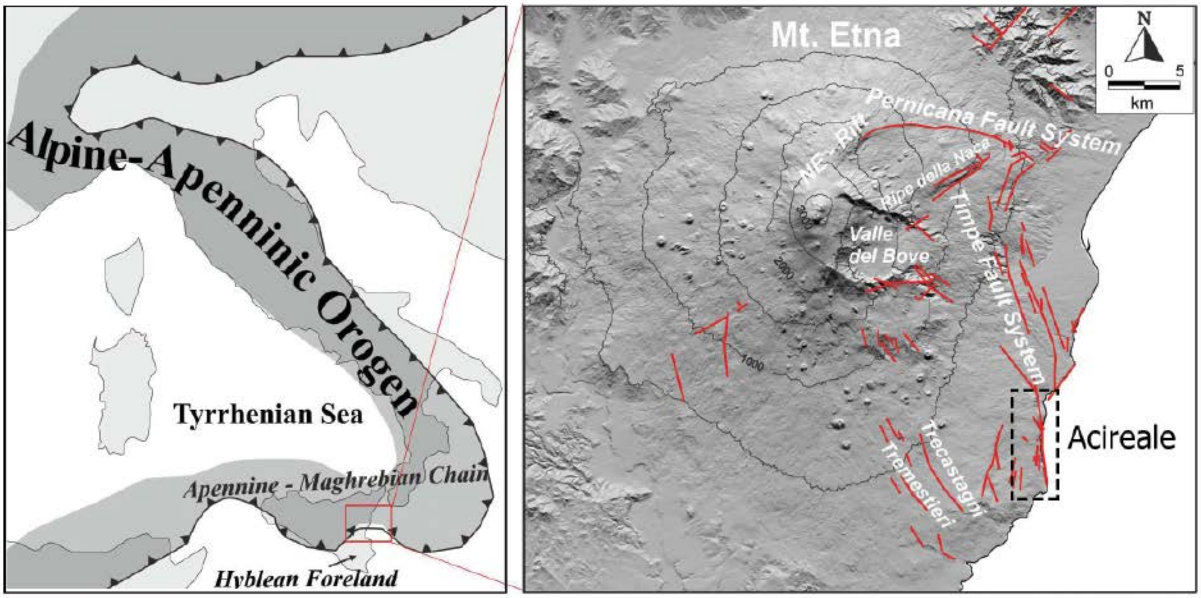

Fig. 1. Map showing the (left) location and (right) main tectonic and structural features of Sicily's Etna volcano; the dashed rectangle encloses the area where scientists will deploy the first European Urban Seismic Network based on microelectromechanical systems (MEMS) technologies.

The network will not use traditional seismometers; rather, it will harness the less expensive technology of accelerometers. Once operational, it will be the first urban seismic network in Europe.

Goals of an Urban Seismic Network

Urban seismic networks allow the disaster's first responders to manage available resources, such as personnel and equipment needed to rescue people. Rescue operations and verification of damage to buildings could then be carried out based on a logical priority according to where the highest shaking was measured by the seismic network. Such an approach would minimize secondary effects induced by an earthquake and allow officials to protect critical infrastructure, thereby mitigating the economic and social costs of the earthquake.

> **The sensitivity and the dynamic range of sensors are high enough to allow the researchers to record earthquakes of moderate magnitude even at a distance of several tens of kilometers.**

Accelerometers to the Rescue

The high costs associated with the construction and installation of traditional seismic stations has made it nearly impossible to realize a true seismic network on an urban scale. However, recent technological developments in the field of microelectromechanical systems (MEMS) sensors, which can be configured to detect minute accelerations, may allow scientists to create an urban seismic network at low cost.

MEMS sensors are a set of highly miniaturized devices that receive information from the environment and translate physical quantities they sense into electrical impulses. Depending on how the sensors are configured, they can measure phenomena of various kinds: mechanical (sound, acceleration, and pressure), thermal (temperature and heat flux), biological (cell potential), chemical (pH), optical (intensity of light radiation and spectroscopy), and magnetic (intensity of flow). The MEMS devices that will be used in the project integrate a three-axis accelerometer, which can measure both constant accelerations (usable as a tilt sensor) and those that vary in time (used to measure the oscillation induced by an earthquake).

In the 1990s, MEMS sensors revolutionized the automotive airbag system and are today widely used in laptops, games controllers, drones, and mobile phones. When configured to measure ground shaking, the sensitivity and the dynamic range of these sensors are high enough to allow the researchers to record earthquakes of moderate magnitude even at a distance of several tens of kilometers [*D'Alessandro and D'Anna,* 2003; *Evans et al.,* 2014]. Because of their low cost and their small size, MEMS accelerometers could be easily installed in urban areas to achieve a seismic network with a high density of measuring points.

In the past decade, a number of research institutes that focus on geophysics and seismology have shown interest in this promising technology. In California and Japan, scientists are developing networks consisting entirely of MEMS sensors. These include the Quake-Catcher Network, managed by Stanford University [*Cochran et al.,* 2009; *Chung et al.*, 2011; *Kohler et al.,* 2013]; the Community Seismic Network, managed by the California Institute of Technology

[*Clayton et al.*, 2011; *Kohler et al.*, 2013]; and the Home Seismometer Network, managed by the Japan Meteorological Agency [*Horiuchi et al.*, 2009].

First European Urban Seismic Network

In September 2015, the Italian Ministry of Education, University and Research funded a 3-year project to create the first European urban seismic network using MEMS technology. The project is called Monitoring of Earthquakes through MEMS Sensors (MEMS project).

We chose the municipality of Acireale, Italy, an urban area particularly vulnerable to earthquake hazards [*Azzaro et al.*, 2010, 2013], as a pilot site for the MEMS project (Sicily, Italy; Figure 1). Acireale is located on the southeastern slopes of Sicily's Etna volcano and is vulnerable to damage from tectonic and volcanic earthquakes.

Founded in the 14th century, Acireale contains many seismically vulnerable buildings of historical and cultural value. In the past 2 centuries, more than 190 damaging earthquakes have occurred in the Etna region, almost one per year. This includes an earthquake sequence that began with a main shock on 29 October 2002—following this magnitude 4.4 event, more than 400 buildings in Acireale were declared uninhabitable [*Azzaro et al.*, 2010].

We aim to develop an urban seismic network comprising about 200 MEMS stations (Figure 2). Each station will consist of a three-axis digital MEMS accelerometer connected to a computer for on-site signals preprocessing. Each station will be supplied with a GPS for time synchronization and an Internet connection for data trans-

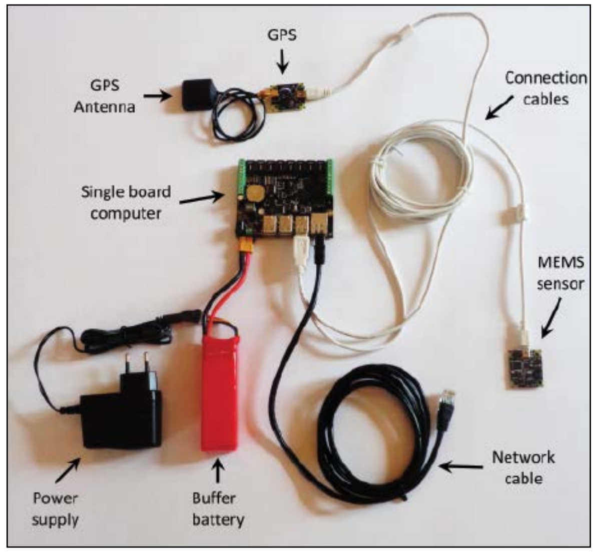

Fig. 2. The internal devices that will constitute the MEMS accelerometric stations. The sensor, single-board computer, and GPS are manufactured by Phidgets, Inc.

mission to a processing center. Should an earthquake cause a power outage, the station can function autonomously for about 2 hours, thanks to the buffer battery shown in Figure 2.

The MEMS stations will be located mainly inside buildings characterized by high vulnerability (old buildings that weren't built to withstand high shaking) and high flux of people moving in and out, such as schools, hospitals, public buildings, and places of worship. The geometry of the network will be designed to create homogeneous coverage of the urban center, with a high enough density of stations in the vicinity of the well-known faults.

The network's success will depend on our ability to implement algorithms able to prevent false alarms. Such algorithms will allow the creation of a shaking map only if a significant percentage of the MEMS stations have simultaneously detected a shaking event—if shaking is human made (e.g., an explosion), only the nearest stations would detect it, but an earthquake would be recorded by many stations. Automatic detection of patterns in waveforms that signal a specific seismic source will also be helpful.

What Can We Learn?

If all goes well, the network will be operational by the end of 2017. The seismic waveforms captured by the sensors will be processed in real time to identify several shaking parameters that will be used to create shake maps at the urban scale. The earthquake waveforms collected by the network will also be used to reconstruct the movement along the faults that caused the earthquakes so as to map seismic hazards and risks on a fine scale for the area covered.

The system could be used to implement a site-specific earthquake early warning system [*Horiuchi et al.*, 2009]. Such a system could enhance the safety margin of specific critical engineered systems—such as energy plants or high-speed railway networks—in real time, mitigating the seismic risk by triggering automatic actions that aim to shelter people from exposure to shaking.

If successful, the MEMS project could provide a useful tool to reduce the seismic risk by increasing the safety of the population of the urban area covered by the network. Such a system could be quickly extended to other areas of high seismic risk, revolutionizing how communities monitor earthquakes. Communities would no longer need to focus on the characterization of earthquakes in terms of focus parameters (e.g., hypocenter and magnitude). Instead, networks like the MEMS project would characterize shaking by direct measurements of how shaking affects a city, neighborhood by neighborhood.

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Eos Wins Gold Medal for Most Improved Publication

(background) © Pakhnyushchyy – stock.adobe.com

Some of the Eos *magazine covers from 2015, its initial year.*

Eos magazine received a gold medal for most improved magazine or journal in the Association TRENDS 2015 All Media Contest. The magazine was one of nearly 400 entries in the contest's 22 categories.

Eos was a weekly print tabloid newspaper from 1979 to 2014. Eos.org, the daily Earth and space science news website, was launched 9 December 2014. At the end of that month, the tabloid was phased out, and in mid-January 2015 the newly launched companion semimonthly magazine was sent to members of AGU.

This is the third award garnered by the website and magazine in a little more than a year. Several months after launch, Eos.org received a best in class award for science/technology websites from the Interactive Media Council, Inc. In June 2015, Eos.org won a silver EXCEL Award from Association Media & Publishing for Web publishing design excellence.

The Association TRENDS All Media Contest is an annual competition that recognizes creative and effective communication vehicles developed by associations over the prior year.

AGU members may receive the magazine upon request to service@agu.org. Others can read an online PDF of each issue (see https://eos.org/current-issues).

By **Barbara T. Richman,** Editor in Chief, Eos.org; email: brichman@agu.org

AGU FALL MEETING

Fall Meeting Chair Candidate Search

Submission Deadline 13 May

The AGU Meetings Committee seeks an individual to fill the position of chair of the Fall Meeting Program Committee. The Fall Meeting is the premier meeting of the Earth and space sciences community. Candidates must be highly organized and dynamic and have strong leadership abilities.

The Fall Meeting chair also serves as an ex officio member of the AGU Meetings Committee. The time commitment is approximately 10–15% of one's time, depending on management style. The chair receives an annual honorarium of $2,500 USD, and expenses are paid to attend relevant meetings.

This position is responsible for the 2017, 2018, and 2019 AGU Fall Meetings. The chair will

- Preside over the Union-appointed Program Committee
- Ensure that excellent scientific sessions are produced for Union program
- Work with section and focus group committee members to ensure the development of both disciplinary and interdisciplinary sessions
- Implement existing and new scientific program initiatives and have complete authority for the arrangement of the scientific program
- Serve as a member of the Meetings Strategy Taskforce
- Attend two face-to-face committee meetings

For additional information or to be considered for this position, please send a curriculum vitae with a letter of interest to Lauren Parr, Director of Meetings at meetingsdirector@agu.org.

The AGU Meetings Committee will review applications and select candidates to interview for the position. Telephone interviews will be conducted in June 2016.

fallmeeting.agu.org/2016/chair-selection/

Record-Breaking Sulfur Dioxide Release From Icelandic Eruption

Lava erupts from a fissure in Iceland's Holuhraun lava field on 4 September 2014. New research shows that the eruption released about 1130 kilograms of sulfur dioxide per second—the highest rate ever recorded for a basaltic fissure eruption.

In late August 2014, lava began to erupt from a fissure in the Holuhraun lava field, part of Iceland's Bárðarbunga volcanic system. For the next 6 months, the eruption released sulfur dioxide gas into the atmosphere nearby, surpassing health limits and causing acid rain that rusted farm equipment. It released 1.6 cubic kilometers of lava—the largest eruption Iceland had seen in over 2 centuries.

The Holuhraun lava field lies above the mantle plume that drives Iceland's volcanic activity. Few studies have measured sulfur dioxide gas flux from eruptions above mantle plumes. Now *Gauthier et al.* have found that during its first 3 months, the 2014–2015 eruption released an average of about 1130 kilograms of sulfur dioxide per second—the highest rate ever seen for a basaltic fissure eruption.

The team used thermal infrared data from the Spinning Enhanced Visible and Infrared Imager (SEVIRI) on board the geostationary Meteosat satellite to measure sulfur dioxide in the gas plume and calculate a release rate. They also used lava samples to compare magma sulfur levels before and after degassing and to infer how much sulfur dioxide must have been released.

Both of these methods are known to pose challenges; weather conditions and ash in the gas plume can complicate satellite measurements, whereas the lava sample method relies on an accurate estimate of the total amount of magma erupted. Often the satellite method gives a much higher gas release rate than the lava sample method.

In this case, both techniques gave similar rates. Meteosat data showed a rate of 1200 kilograms of sulfur dioxide released per second, whereas the lava sample method gave a rate of 1050 kilograms per second. The few other mantle plume eruptions that have been studied in this way have also shown similar results for both techniques.

The scientists also directly sampled the gas plume to examine trace elements, which can pollute or fertilize nearby ecosystems when released by a volcano. It was the first time trace elements had been analyzed during an Icelandic eruption, and they found that tremendous amounts of toxic metals, including 6 tons of highly poisonous cadmium, had been degassed during the eruption in 2014. They also found that trace metals released at Holuhraun showed volatility similar to that of those released by eruptions of similar volcanic systems in Hawaii and Ethiopia.

The team also used the gas samples to measure proportions of radioactive isotopes. They found that a polonium isotope likely escaped during degassing of carbon dioxide from the magma beneath the central Bárðarbunga volcano, followed by shallow sulfur dioxide and hydrogen chloride degassing at Holuhraun. The data indicate that magma traveled at a speed of about 0.75 meter per second to the eruption site.

Besides causing health problems and acid rain, sulfur dioxide released by volcanoes can affect Earth's climate. Studies like this one could lead to improved sulfur dioxide measurements and strengthen understanding of volcanoes' impact on their surroundings. (*Journal of Geophysical Research: Solid Earth,* doi:10.1002/2015JB012111, 2016) **—Sarah Stanley, Freelance Writer**

The North Atlantic Ocean's Missing Heat Is Found in Its Depths

Earth's oceans quietly and effectively moderate the globe's temperature. As greenhouse gases blanket Earth in an insulating haze, the oceans sequester much of the atmosphere's heat in their depths. Ocean temperatures rise as warm air is sucked out of the atmosphere, but some oceanic regions absorb more heat than others, and these thermodynamics are in constant flux.

Since the mid-2000s, the North Atlantic Basin's upper layers have stopped storing as much atmospheric-derived warmth—to the point where it lost its crown as the greatest-warming basin, in the mid-2000s, to the tropical waters of the Indian and Pacific Oceans. In the Atlantic, heat moved down from the upper layers of the ocean into the deeper sea, hiding much of the water's warming.

The first part of the North Atlantic's transformation occurred when the waters of the eastern North Atlantic mixed in the winter of 2005, *Somavilla et al.* explain in a new paper: Swirling ocean waters changed the overall characteristics toward a saltier, warmer, and denser environment. This newly dense water sinks down from the surface, carrying along the warmth it absorbed during its stint at the top. This transfer of heat down to the depths wasn't a one-time occurrence during the winter of 2005 either; it continued on by altering the flow of the ocean itself.

Mixing the waters and increasing densities have altered the ocean circulation patterns, the authors suggest. The local currents actually flipped around from a southward flow to a northward flow in the eastern North Atlantic. This reversal in direction brings warmer salty water up from the tropics only to sink down to the North Atlantic's deeper waters because of the salt's higher density. The North Atlantic Subpolar Gyre also contracted, which allows even more warm and salty water from the tropics to make its way north.

magann/Adobe Stock

The Atlantic Ocean once absorbed the most atmospheric heat of any ocean as greenhouse gases continued to trap the Sun's warmth, but a shift in oceanic patterns hid most of that heat deep below the surface.

This continuous supply of salty southern waters continues the process of oceanic convection in which the warmer water on the surface cycles down to deeper layers of the ocean. However, the oceans can't store or hide away the heat forever; eventually, they will reach capacity and be unable to buffer the globe's warming as effectively. (*Geophysical Research Letters,* doi:10.1002/2015GL067254, 2016) **—Cody Sullivan, Writer Intern**

Are Earthquakes Predictable?

On 27 March 1964, a monster earthquake struck beneath Alaska's Prince William Sound. A 9.2 on the Richter scale, the tremor was the most powerful recorded earthquake in U.S. history. Five months later, a letter published in *Nature* reported that a magnetometer in the city of Kodiak had recorded disturbances in the Earth's magnetic field just before the quake struck. In the 50-plus years since, several more studies have shown magnetic changes—that they labeled anomalous—preceding quakes.

Such anomalies have provided scientists and the lay public with the tantalizing notion that earthquakes might come with warnings and might even be predictable. Unfortunately, strong evidence that these anomalies are directly related to impending quakes has never been found. Conversely, recent research has shown that the majority of magnetic changes recorded before earthquakes to date were related to malfunctioning equipment, problems with analyses, or normal magnetic fluctuations that arise as the Earth's magnetic field clashes with solar wind. Still, the search for earthquake precursors persists.

Here *Masci and Thomas* look at two of the most recent reports suggesting that precursory signals may lie in ultralow-frequency (ULF) magnetic data—electromagnetic waves with frequencies between 0.001 and 10 hertz. ULF signals are generated by interactions between the Sun and the Earth's magnetic field at the magnetosphere, some artificial noises, and processes beneath the Earth's surface. However, any changes in ULF signals attributed to earthquakes thus far are suspect, according to the authors, as they may be explained by disturbances in the geomagnetic field in response to Sun-Earth interactions. Further, any valid mechanism by which fault zones would generate precursory electromagnetic perturbations remains to be seen.

First, the authors refute the claim made by J. L. Currie and C. L. Waters (*J. Geophys. Res. Space Physics,* 2014, doi:10.1002/2013JA019530) that the magnetic polarization ratio—a relationship between components of the geomagnetic field—is a valid measure in the search for precursor signals. According to the authors, the polarization ratio cannot be considered as a promising parameter to identify possible earthquake precursors in ULF magnetic field data. They also contend that the superposed epoch analysis—a statistical analysis that spotlights weak signals—fails to show preseismic and coseismic ULF magnetic signals before the Japanese earthquakes studied by P. Han et al. (*J. Geophys. Res. Space Physics,* 2014, doi:10.1002/2014JA019789) and, as such, cannot be used to predict future quakes.

The search for precursory signals in ULF magnetic data has been thoroughly pursued for decades with little progress toward practical results, the authors conclude. (*Journal of Geophysical Research: Space Physics,* doi:10.1002/2015JA021336, 2015) **—Kate Wheeling, Freelance Writer**

Gamma Ray Bursts Leave Their Mark in the Low Ionosphere

Gamma ray bursts are the most energetic phenomena in the universe, the product of explosions in far-away galaxies that release vast amounts of energy as gamma rays that race through our solar system. The potential harm of gamma ray bursts drives an important question for scientists: How do rays interact with Earth's atmosphere?


NASA/Swift/Aurore

An artist's rendering of a dark gamma ray burst, where dust absorbs the visible light but high-energy X-rays and gamma rays escape into space.

Here *Nina et al.* use statistical analyses to look at the behavior of the ionosphere during gamma ray burst events. When gamma rays hit the atmosphere, they ionize the air, which increases the electron density and the ion density. This density increase affects the structure of the ionosphere and how radio waves travel through it, so ionospheric perturbations can be detected by measuring the strength of radio signals bounced into the atmosphere and back. The researchers looked at a sample of 54 gamma ray burst events detected by the telescopes aboard NASA's Swift satellite to distinguish the relationship between these events and the low perturbations they identified as periods of radio wave strength.

Scientists measured perturbation time and location with very low frequency/low-frequency (VLF/LF) radio signals emitted from Germany, the United Kingdom, Italy, Iceland, Australia, and the United States and picked up by a receiver in Serbia. The researchers found that VLF/LF radio signals were a reliable method of gamma ray burst detection. They were able to detect ionospheric reactions immediately after the start of a gamma ray burst or with a time delay—as much as 60–90 seconds.

The team detected short-term reactions in the low ionosphere that did not lead to intense long-term reactions. The brief perturbations occurred at different times related to the bursts, indicating that there might be some secondary processes that influence ionization in the low ionosphere. In the future, gamma ray bursts could be detected by some of these secondary processes.

Further studies will help to shape these conclusions and improve gamma ray burst detection—fundamental to expanding scientific knowledge of our solar system. (*Geophysical Research Letters,* doi:10.1002/2015GL065726, 2015) **—Lily Strelich, Freelance Writer**

Satellite Shows Earth's Magnetic Field Bent During a Solar Storm

The solar system is awash in potentially harmful radiation from the Sun and cosmic sources, but the Earth faces it with a shield—its magnetic field, which traps and repels most particles, preventing them from piercing through to the ground.

However, when the Sun unleashes solar storms that slam into Earth, our planet's magnetic field buckles and lets in more radiation. These particles can penetrate to lower latitudes during these storms, which can be hazardous to satellites, astronauts, and even airline flight crews that spend a long time on great circle routes near the poles. How far toward the equator these particles can go—what scientists call the geomagnetic cutoff—is an important indicator of how the magnetic field behaves during these storms.

Here *Adriani et al.* report observations during a geomagnetic storm on 14 December 2006. The measurements were taken by the Payload for Antimatter Matter Exploration and Light-Nuclei Astrophysics (PAMELA) instrument, built by an Italian-led European and Russian consortia and launched on a Russian Earth observation satellite. They represent the first time that scientists have been able to directly measure the cutoffs for protons with such high kinetic energies—from 80 megaelectron volts to several gigaelectron volts, or tens to thousands of times more energy than typical solar wind particles.

From its pole-to-pole orbit, PAMELA was able to take detailed, repeated measurements, returning to the same region every 94 minutes to track the evolution of the storm. The researchers found that the changes in the geomagnetic cutoff are related to a complex stew of variables related to the configuration of the magnetic field. The best metrics included the total strength of the Sun's magnetic field, the strength of the Sun's magnetic field in the north–south direction, and the *Kp* index, which measures the strength of a geomagnetic storm.

The team also found that the magnetic cutoff latitudes changed by different amounts depending on the particles' rigidity (the ratio of momentum to electric charge). At the peak of the storm's fury, particles that would normally be confined close to Earth's polar circles could swoop as much as 7° lower. For particles with higher rigidity, the cutoff changed less, as they were already capable of encroaching much lower—deep into the subtropics. (*Space Weather,* doi:10.1002/2016SW001364, 2016) **—Mark Zastrow, Freelance Writer**

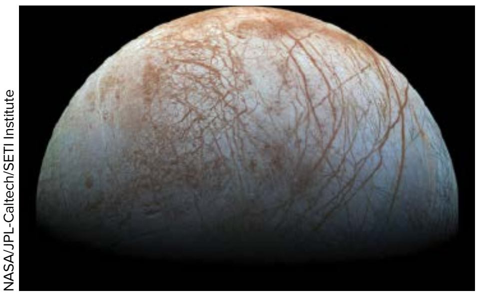
Hubble Gazes at Europa's Aurora

The thin oxygen atmosphere of Jupiter's icy moon Europa has been the subject of speculation for more than 2 decades, ever since scientists deduced its existence after spotting the telltale glow of ultraviolet auroras.

Now *Roth et al.* report the results of a 5-month observation campaign by NASA's Hubble Space Telescope, from late 2014 through spring 2015. By combining that data set with previous Hubble observations as far back as 1999, the authors have created the most detailed yet of Europa's auroras.

On Earth, auroras are mostly driven by the Sun, as plasma particles from solar wind stream toward the poles and collide with the atmosphere. But Jupiter has its very own sources: the volcanoes of its moon Io and the fast rotating magnetic field. The plasma that the volcanoes spew gets trapped by Jupiter's magnetic field, forming a disk of plasma. Because Jupiter's magnetic field—like Earth's—is tilted, this plasma disk is also tilted. This tilt creates a choppy environment for the moons of Jupiter like Europa, whose orbital path weaves in and out of the disk.

The team found that this weaving has a big influence on the strength of the auroras. When Europa is deep inside the disk, plowing through the plasma, the auroras light up the strongest. The brightest spots of the aurora were at the poles, and they tend to be stronger at the pole that is facing the densest layer of the disk.



NASA/JPL-Caltech/SETI Institute

The scarred icescape of Europa's surface conceals more water than all of Earth's oceans—but its thin oxygen atmosphere has also captivated scientists with its ultra-violet auroras.

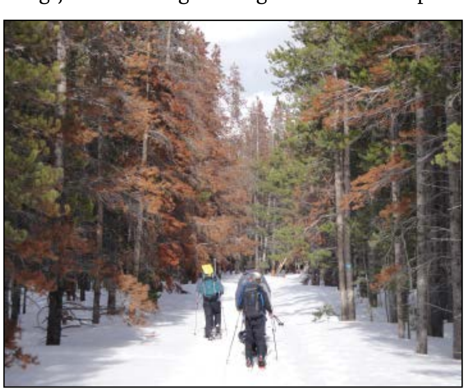
Other information the team gleaned from the data includes determining how much oxygen is in Europa's atmosphere to better precision than ever before by measuring the relative strengths of different emission lines. Also, on several occasions, Hubble had a view of Europa while it was in Jupiter's shadow—but nothing much changed, which suggests that the Sun doesn't play much of a role in the auroras.

Many mysteries remain. One is that unlike on Io, Hubble didn't see strong auroras near the equator of Europa. Another is that the aurora on the right half of Europa, as seen from Earth, is consistently brighter than that on the left. One explanation for the difference could be that the local time on Europa affects the aurora. From Earth's vantage point, the right-hand side of Europa corresponds to late afternoon and dusk, whereas the fainter left-hand side coincides with dawn. (*Journal of Geophysical Research: Space Physics,* doi:10.1002/2015JA022073, 2016)

—Mark Zastrow, Freelance Writer

Bark Beetles Cause Big Tree Die-Offs, but Streams Flow Steadily

The native bark beetle is an important player in healthy forest ecosystems across western North America, cycling nutrients, shaping habitats for insects and fungi, and altering the vegetative landscape.



Juan Fernandez, NCALM

An aerial view of a forest north of Laramie, Wyo., showing trees affected by a decades-long bark beetle epidemic. The blight has killed billions of trees across western North America, but this die-off does not seem to be changing annual streamflow.

Recently, however, booming bark beetle populations have devastated forests across the western United States and Canada.

Warmer temperatures, drought, and previous management practices have contributed to a bark beetle epidemic, which started in the mid-1990s and continues to drive extensive tree mortality. Following early studies of forest hydrology, scientists predicted an increase in streamflow due to massive declines in snow evaporation from deteriorated forest canopy and water use by trees. In a new study, however, *Biederman et al.* assess 50 years of streamflow observations before and after beetle impact in the headwaters of the Colorado River to compare these predictions with actual stream behavior.

The researchers used streamflow data from the U.S. Geological Survey National Water Information System and multiple empirical and modeling approaches to assess how streams responded during a decade following extreme tree die-off. They performed a double mass analysis comparing cumulative annual streamflow in eight beetle-infested catchments to a nearby control catchment that was not infested by bark beetles. They also compared the amount of precipitation that became runoff before and after die-off and used a climate-driven model to analyze the beetle's impact on streamflow over time.

This comprehensive analysis yielded a surprising result: Rather than the increase predicted in earlier research, the team found little significant change in annual streamflow—and in one catchment, streamflow even declined. They attribute this major deviation to increased evaporation of snowpack and soil moisture as dying forests expose the land surface to solar radiation and wind, a topic examined in *Biederman et al.* (*Water Resour. Res.,* doi:10.1002/2013WR014994, 2014). The authors use these results to highlight the challenges faced by land and water managers during a period of changing climate and widespread ecosystem disturbance. (*Water Resources Research*, doi:10.1002/2015WR017401, 2015) **—Lily Strelich, Freelance Writer**

Recent Studies Crack Open New Views of Glacial Crevasses


Horst Machguth

Deep cross-cutting crevasses near the terminus of Narsap Sermia, Greenland. Studying crevasse dynamics helps scientists to assess how glaciers respond to climate change.

Crevasses—cracks caused by stresses due to ice movement—score the surface of nearly every glacier on Earth. Although crevasses can span just a few millimeters in width and depth, some are tens of meters wide or deep and can stretch for hundreds of meters along a glacier.

Scientists routinely use crevasses to study not only the form and flow of glaciers but also how they may amplify glacier response to climate change. However, crevasses can also obscure ice core records or annual layering patterns, and they pose safety hazards to scientists and their equipment.

In a new study, *Colgan et al.* review 6 decades of glacier crevasse field research as well as satellite observations and computer modeling. Scientists have long ventured onto glaciers to study the pushing and pulling forces that produce crevasses. It is well known that after a crevasse opens, ice flow can transport it downstream, curving and rotating it on the way. Newer studies, however, now show that competing fracture processes can produce rotated and curved crevasses without downstream transport. The authors note that older studies may need to be reinterpreted in the context of such new insights.

Recent direct observations of glaciers also show mounting evidence that contrary to long-standing assumptions, crevasse formation can begin at depth within the ice and not at the surface. The authors say this could present a paradigm shift for interpreting "buried" crevasses.

High above the ice, remote observations have also shed new light on crevasses. Satellites have yielded unprecedented high-resolution images of crevasse patterns around the world. These images have shown that crevasse fields are not static, but instead change through time—ultimately in response to climate. The authors say that autonomous ground vehicles and aircraft equipped with ground-penetrating radar could further uncover previously unattainable details of a crevasse life cycle.

The team also reviewed crevasse modeling techniques. Despite recent transformative improvements in large-scale glacier flow models, the most popular small-scale models that simulate crevasse formation have remained mostly unchanged for at least 20 years. The authors propose combining recently developed ice fracture simulations with large-scale models to gain insight into the spatial distribution of crevasses over time.

Rounding out their review, the team discusses how crevasse mechanisms influence meltwater production and retention in the context of climate change. For example, crevassed glacier surfaces more readily trap solar radiation than noncrevassed surfaces, promoting melting. However, much more knowledge is needed to understand just what the climate change impacts of crevasses will be. *(Reviews of Geophysics,* doi:10.1002/2015RG000504, 2016) **—Sarah Stanley, Freelance Writer**

New GPS Satellite Technique to Monitor Ionospheric Disturbances

As modern society grows more and more dependent on technology, researchers are becoming increasingly interested in space weather phenomena that can interfere with our gadgets. Although they are still a long way from learning to predict these high-altitude disturbances, scientists are working to understand them better. The ionosphere is the strip of atmosphere 60–1000 kilometers above ground where molecules become ionized by solar radiation. When space weather events like solar or geomagnetic storms strike or when earthquakes, tsunamis, or hurricanes occur on Earth, they can trigger disturbances in the ionosphere's electron density, called traveling ionospheric disturbances (TIDs). These disturbances can travel through the atmosphere for thousands of kilometers in the form of waves, which degrade radio signals and navigation systems. Scientists often use specialized ionospheric sounders, both in space and on Earth, to collect current information about ionospheric activities. Recently, they have become interested in the thriftier possibility of using conventional GPS satellites. However, the movement of the satellites, which orbit Earth every 12 hours, can affect their ability to collect reliable information. In a recent study, *Penney and Jackson-Booth* looked into the limitations of current techniques for using GPS satellites to monitor TIDs and crafted their own strategy: Over a period of 18 months, the team used a short-baseline, three-receiver array to gather TID data from all available GPS satellites. The study showed how to measure TID velocities using receivers spaced only 3 kilometers apart, so there was a delay of only 30 seconds or less between pairs of receivers observing the TID waveform.

Overall, the researchers found that the new GPS method gave more reliable information about TIDs than existing methods. The small number of receivers meant less information, but with less to comb through the researchers were able to discern more intricate details of the TID waves. A smaller data field also made it easier to focus on specific parameters, such as the rate at which the total electron content changes as a wave travels through the ionosphere. (*Radio Science,* doi:10.1002/2015RS005767, 2015) **—Shannon Kelleher, Writer Intern**

At the Intersection of Ice and Water


Martin Truffer

LeConte Glacier, Alaska, one of the first glaciers for which it was shown that subaqueous melting is an important process.

Glaciers around the globe are shrinking, and they're disappearing fastest at glacial fronts—locations where the ice meets water. Over the past 20 years, roughly half of the ice loss from Greenland's ice sheet has occurred at glacial fronts. To predict how the world's glaciers will respond as bodies of water around the world warm and sea levels rise, scientists must first uncover the processes driving ice loss. Both melting and calving—when chunks of ice break off from glaciers—whittle away at glaciers' mass: Tidewater calving has consumed entire ice fields in Alaska, for example. But forecasting glacial behavior is complicated by the fact that similar climatological conditions can produce varying behaviors: Some glaciers are observed to advance even while their neighbors melt away.

Ice loss via calving has been well studied, but the thermodynamic processes driving melting of glaciers submerged in water are less well understood, despite the fact that much of Antarctica's ice loss has been attributed to melt beneath floating ice shelves. To fill in this gap, *Truffer and Motyka* sought to find out how subaqueous melt would affect glacial stability in varied environments around the world. The authors made use of data collected by many teams using multiple methods on subaqueous melt rates, including radar, direct measurements of melt, and measures of water temperature and salinity.

Melting rates are influenced by the temperature of the water, heat transfer across the boundary between the water and the ice, and even the shape of a fjord, which affects the flow of currents over the ice and thus the transport of heat. At the same time, the thermodynamics of the water body into which glaciers are submerged can affect their shape. According to the authors, this two-way relationship, together with variations in water temperature and salinity, can account for much of the confusingly varied behavior of glaciers that end in water.

By analyzing glacier behavior in different settings around the world, the team found that subaqueous melt has a profound influence on glacier behavior—up to a point. Melting may trigger a glacier to rapidly retreat, but once that retreat is well under way, the process of melting may take a backseat to mechanical processes such as calving as the ice becomes increasingly unstable. The study provides new insights into the feedback systems at play in rapidly changing glacial fronts. (*Reviews of Geophysics,* doi:10.1002/2015RG000494, 2016) **—Kate Wheeling, Freelance Writer**

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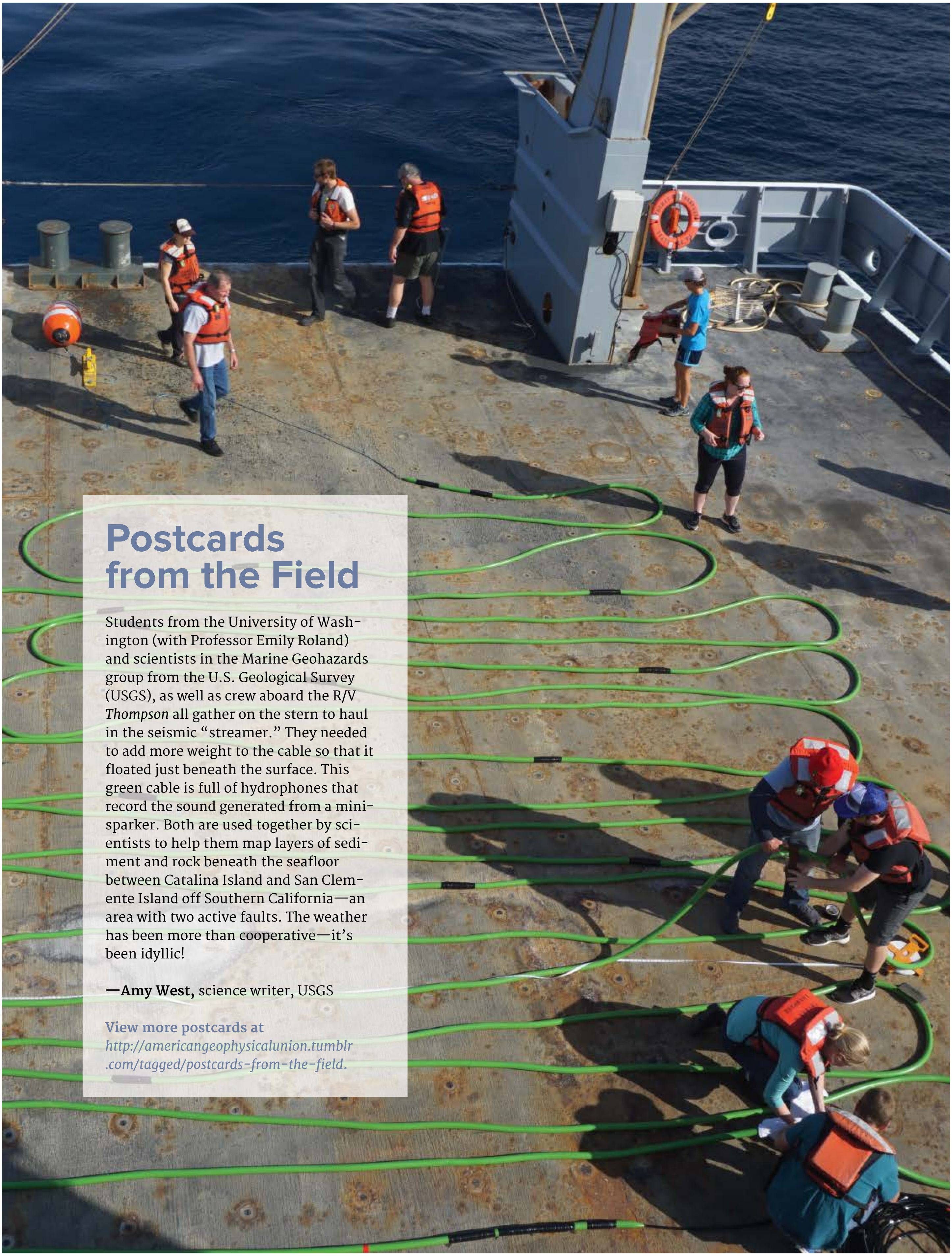

Postcards from the Field

Students from the University of Washington (with Professor Emily Roland) and scientists in the Marine Geohazards group from the U.S. Geological Survey (USGS), as well as crew aboard the R/V *Thompson* all gather on the stern to haul in the seismic "streamer." They needed to add more weight to the cable so that it floated just beneath the surface. This green cable is full of hydrophones that record the sound generated from a mini-sparker. Both are used together by scientists to help them map layers of sediment and rock beneath the seafloor between Catalina Island and San Clemente Island off Southern California—an area with two active faults. The weather has been more than cooperative—it's been idyllic!

—**Amy West,** science writer, USGS

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