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EOS

Earth & Space Science News

NEW PLANS FOR OCEAN DRILLING

A Human-Created Barrier to "Killer Electrons"

Investments in Scientific Research Drive Innovation

New Madrid Seismic Zone

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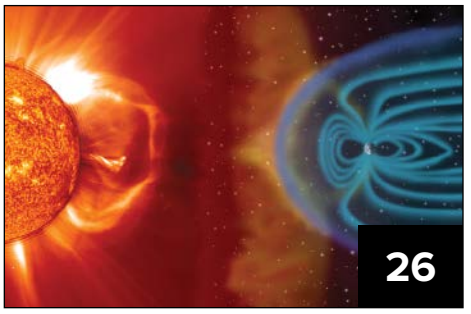

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Christine W. McEntee, Executive Director/CEO

AGU American Geophysical Union

Human Radio Transmissions Create Barrier to "Killer Electrons"

Scientists have discovered that radio transmissions from Earth have helped to build a shield-like "impenetrable barrier" in space that scatters high-energy electrons and prevents them from coming closer to our planet.

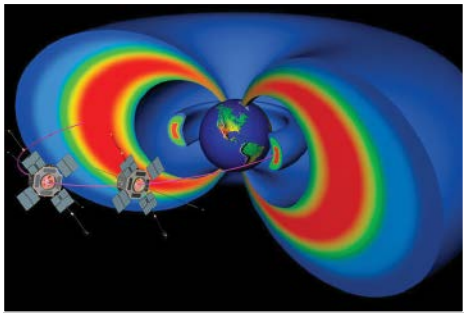
Since the 1950s, humans have communicated—particularly with submarines deep in the ocean—using very low frequency (VLF) radio transmissions at lower frequencies than your favorite sports cast or talk show. After a fortuitous solar storm on 17 March 2015, scientists discovered that it may be these very transmissions that create a protective "VLF bubble" (http://bit.ly/Space-Barrier) that blocks high-energy "killer electrons." These electrons, which can damage satellites, as well as future travelers to the Moon or Mars, zip around the Earth within doughnut-shaped regions of space called the Van Allen radiation belts.

"To us it was an amazing insight" that came from NASA's Van Allen probes. These probes continuously take measurements of the two "doughnuts" of high-energy particles that encircle the Earth, said Daniel Baker, director of the University of Colorado Boulder's Laboratory for Atmospheric and Space Physics on 14 December at the 2015 AGU Fall Meeting in San Francisco, Calif. (see http://bit.ly/barrier-talk).

"Because powerful VLF transmitters have been operating since before the dawn of the space era, it is possible that we have never observed the radiation belts in their pristine, unperturbed state," said John Foster, a scientist at the Massachusetts Institute of Technology's Haystack Observatory and lead author on the new research.

A Cosmic Electric Fence

Baker and his colleagues discovered the impenetrable barrier—which lies at the inner edge of the outer Van Allen radiation belt—in 2014 but only closely investigated natural causes. The impenetrable barrier is set up when high-energy particles from the Sun hurtle toward Earth during a solar storm. When such a storm occurs, the edge of Earth's plasmasphere—an amorphous cloud of plasma surrounding the Earth—erodes closer to the planet. When the researchers first discovered the barrier, they suspected that the plasmasphere had something to do with its development—but they weren't sure of the underlying mechanism.



NASA

Two doughnut-shaped regions of high-energy particles make up the Van Allen radiation belts. Scientists discovered that very low frequency radio transmissions from Earth may help to create an "impenetrable barrier" at the inner edge of the outer belt that keeps the belt's "killer electrons" away from Earth.

Last year, with VLF transmissions in mind, the scientists analyzed data from the Van Allen probes after the March 2015 solar storm and found that when the outer Van Allen radiation belt was recovering from the solar onslaught, the edge of the VLF bubble matched up exactly at the same distance as the impenetrable barrier, about 12,000 kilometers from Earth.

"We've got a satellite that measures all the things at the same time," Foster said. "It sees the outer edge of the VLF transmitter bubble."

The researchers found that the solar storm actually pushed the edge of the plasmasphere inside the VLF bubble, allowing the VLF waves to interact with high-energy electrons within the Van Allen belt, kicking them out of the belt. These electrons are then lost within the Earth's atmosphere, where they lose their highly energetic "killer" characteristic by spreading their energy among a vast number of other particles at lower altitudes, Foster said.

This impenetrable barrier limits "the earthward, inward extent of these high-energy killer electrons during the very time period when their acceleration, when their energization—which is part of a geomagnetic storm—is taking place," Foster said.

But this mechanism is observed only during a solar storm, when the plasmasphere is eroded, he noted.

Think of the impenetrable barrier as an electric fence around Earth. Any intruder who tries to climb the fence gets an electric shock—but the rest of the time, the fence sits idle. Our cosmic electric fence repels highly energetic electrons when they get pushed in by an outburst from the Sun. In this way, scientists don't "see" the effects of the impenetrable barrier until something "provokes" it.

"During the time period when it can be helpful"—such as during a solar storm, which has the potential to knock out communications on Earth—"it's actually there," Foster said.

Future Warfare Defense?

The U.S. Air Force has been studying the Van Allen radiation belts since they were discovered in the 1950s and once conducted experiments by detonating nuclear bombs in this region to create artificial radiation belts for potential wartime purposes. Now that scientists have discovered the protective bubble of VLF transmissions, Foster said, they can perhaps start investigating how this mechanism could be harnessed deliberately, for defense purposes.

"In any kind of a war, one tactic could be to launch a nuclear weapon into space over your enemy's territory and explode it," Foster said, which would render the enemy essentially blind, as the electromagnetic radiation would knock out all their communication satellites. But if there was a way to get rid of an artificial radiation belt quickly—by using VLF transmissions—the military would want to know about it.

> This impenetrable barrier "[limits] the Earthward, inward extent of these high-energy 'killer' electrons."

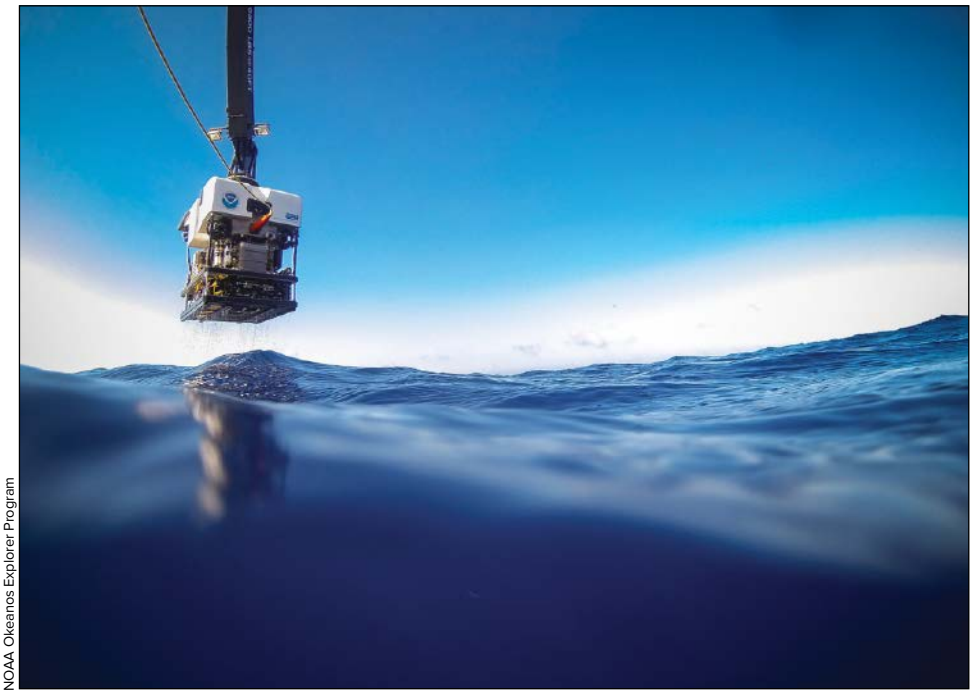
This research shows that "you can really use ground-based systems to get rid of these electrons pretty quickly," instead of trying to go into space with powerful wave emitters to defend from a potential attack, Baker said.

But that's all for a day when scientists better understand the interactions between VLF transmissions and the radiation belts—for now, Foster says that understanding this impenetrable barrier is important for protecting our satellites from the naturally occurring, high-energy particles in space.

In fact, Baker dreams that one day during a solar storm, the VLF transmitters could be turned off—just to see what would happen.

By **JoAnna Wendel,** Staff Writer

Autonomous Undersea Technologies to Vie for New XPRIZE



NOAA Okeanos Explorer Program

A mechanical arm plucks a remotely operated underwater research vehicle from the Gulf of Mexico after a deep dive in 2014. Teams competing for the newest Shell Ocean Discovery XPRIZE will strive to develop innovative technologies that advance deep ocean exploration and imaging. The National Oceanic and Atmospheric Administration owns and operates the vehicle shown here, known as Deep Discoverer.

Citing threats of overfishing and pollution to our oceans, as well as ocean ignorance so deep that our seafloor maps are worse than our maps of the surface of the Moon, the XPRIZE organization and cosponsors from industry and government launched a new contest in XPRIZE's Ocean Initiative series in mid-December. The new competition challenges tech- and science-savvy teams to rapidly develop autonomous exploration technologies to create bathymetric maps, produce high-resolution images of a specific object, and identify archaeological, biological, or geological features.

During this 3-year Shell Ocean Discovery XPRIZE competition, teams will have 12 months to design and build their initial instruments and 18 months to complete two rounds of testing. Teams must show that they can control their autonomous technologies to a depth of 4000 meters. An expert panel will judge the performance of the teams' entries.

The winnings? Royal Dutch Shell is providing $6 million in prizes, plus the National Oceanic and Atmospheric Administration (NOAA) is putting up another $1 million as a bonus award to the team that finds a specific underwater object using biological or chemical signals.

XPRIZE chairman and CEO Peter H. Diamandis and representatives of Shell Oil and NOAA announced the new competition on 14 December 2015 at the annual AGU Fall Meeting in San Francisco, Calif. (see http://bit.ly/Ocean-XPrize).

Instinct to Explore

Oceans cover two thirds of Earth and provide food for about a billion people. The seas have always been a boon to discovery as well, Jyotika Virmani, XPRIZE's senior director of energy and environment and prize operations, told *Eos*. Underwater explorers have discovered raw materials for medicines, and oceanographic research has uncovered vital knowledge about how Earth changes and evolves.

"Inherently, as a species, we're explorers," she said. "Until we do this discovery and exploration of the sea, we [won't] know what's down there." Technologies developed in the competition might aid search and rescue operations, she added.

XPRIZE encourages all types of innovators to enter the competition, Virmani said. In all XPRIZE contests so far, established experts in a field are not the only competitors. "We have new players come forward," she said.

Although the rules don't require expertise in ocean science or cartography, competitors will need to master not just mapping but also robotics, computer science, photography, digital imaging, data manipulation, and more, she noted.

Third Stage of 10-Year Initiative

With this announcement, XPRIZE launched the third in a series of five high-dollar competitions scheduled to occur by 2020, aimed at improving ocean health and promoting appreciation and understanding of oceans, said Virmani. XPRIZE held the first of those competitions in 2010 in response to the Deepwater Horizon oil spill and awarded $1.4 million to a group of scientists who demonstrated a technology that removed oil from water nearly 4 times faster than ever before. The next competition, launched in 2013 to improve the accurate measurement and understanding of ocean acidification, awarded $1.5 million to the company Sunburst Sensors for its accurate and affordable ocean pH sensor.

Michael DeGrandpre, a professor at the University of Montana in Missoula and cofounder of Sunburst Sensors, told *Eos* that the prize really pushed the team to work more quickly and efficiently. What might have been a 2- or 3-year project developing the pH sensor became a 1-year project, DeGrandpre said.

"In a lot of ways, the urgency wasn't there until the XPRIZE came along," he continued.

Since the Sunburst Sensors team won the XPRIZE in July 2015, a variety of businesses and other ventures have sought out the group for collaborations. This year, athlete Ben Lecomte will use one of their portable pH sensors as he attempts an unprecedented swim across the Pacific Ocean to raise awareness about sustainability.

For this ocean-mapping XPRIZE, teams have until June 2016 to register.

To find out more, visit http://oceandiscovery.xprize.org/ or watch the announcement on the AGU On-Demand webstream. Look for U13B Special General Session: XPRIZE Announcement 12:30–1:30 p.m., Monday, 14 December 2015 in the channel listings.

By **JoAnna Wendel,** Staff Writer

Assessing U.S. Fire Risks Using Soil Moisture Satellite Data

Mike McMillan, USFS, CC BY-NC 2.0 (http://bit.ly/ccbync2-0)

Burning trees and brush in the 2013 Rim Fire, which burned more than 1000 square kilometers in California's Stanislaus National Forest. The Rim Fire was the largest ever recorded for the Sierra Nevada mountain range.

Soaring hundreds of kilometers above the Earth, a NASA satellite monitors soil moisture in the ground far below, probing drought conditions. Scientists at NASA Jet Propulsion Laboratory (JPL) analyzed these data and combined them with wildfire information from the U.S. Forest Service and land cover data from the U.S. Geological Survey. They used the results to assess fire risks, taking the first important step toward developing predictive maps for fires throughout the continental United States.

The JPL scientists, a team led by Nick Rousseau in NASA's DEVELOP Applied Sciences Program, find that soil moisture data alone can approximately explain the distribution and extent of fires, from the Sierra Nevada to the western plains to the Florida wetlands. Their results determine how much the dryness of regions indicates fuel available for fires. They reported their findings on 16 December 2015 at the AGU Fall Meeting in San Francisco, Calif. (see http://bit.ly/SoilFire).

The Fire Next Time

Every year, wildfire outbreaks cause economic loss, property damage, and environmental degradation. Local, state, and federal agencies want to prepare for fire activity, and knowledge about particularly high risk areas would help them do so. If these new maps could be used to predict wildfire potential, then they would be an invaluable resource.

"This [technique] shows how much overall area is likely to burn, which could be a useful tool when Congress allocates resources for fire management," said Sparkle Malone, a research ecologist at Rocky Mountain Research Station in Fort Collins, Colo., who was not involved in the study.

Rousseau and his colleagues take advantage of NASA's Gravity Recovery and Climate Experiment (GRACE), which uses a pair of identical spacecraft flying in tandem 220 kilometers apart to precisely scan and measure tiny variations in the Earth's gravitational field. These variations can be used to infer the regional movement of water over time, including evolving soil moisture as well as surface water and groundwater, explained Rousseau's science adviser at JPL, John T. Reager.

Measuring Fire Risk

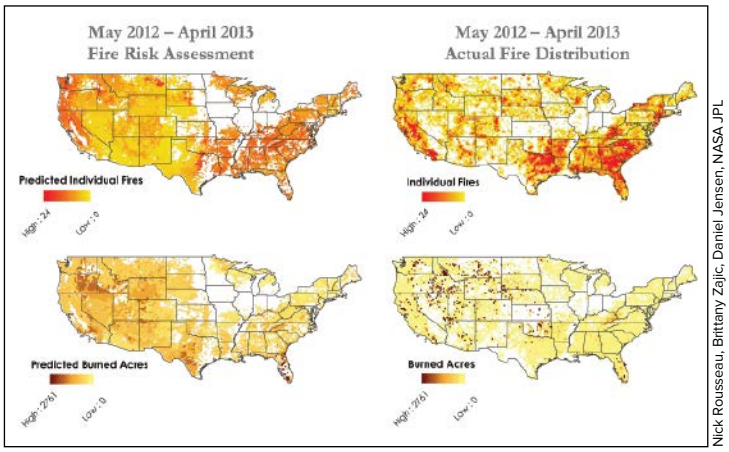
Partnering with the U.S. Forest Service, they used land cover data and fires observed over a 12-year period to train their model. In particular, they analyzed different types of land, including shrublands and deciduous and evergreen forests, which have different types of trees and vegetation that could fuel fires.

The scientists then modeled the relationship between soil moisture and fire risk and compared their predictions to satellite data from 2012 to 2013, at the beginning of the historic drought in the Southwest. They calculated the fire risk for every 125-mile (201-kilometer) pixel of the map, finding that dry areas are generally at high risk and usually coincide with more and larger fires over the time period. However, they came to the opposite conclusion for grasslands, where high moisture in the spring results in more flammable grass during the summer.

"This is the first chance anyone has had to quantify that," said Reager. "And we're doing this from *space*," he added.

Other factors need to be included in the model in the future since in addition to soil moisture, winds, forest density, and lightning also contribute to wildfire outbreaks. When the GRACE 2 satellite launches in 2017, the researchers look forward to getting higher-resolution data as well. Rousseau, Reager, and their collaborators view their current work as a step toward a more complete map of fire risk in the United States, with which they could make detailed predictions for each fire season.

By **Ramin Skibba,** Science Communication Program Graduate Student, University of California, Santa Cruz; email: raminskibba@gmail.com



Nick Rousseau, Brittany Zajic, Daniel Jensen, NASA JPL

NASA scientists developed maps that assessed fire risk and potential throughout the United States. Their model approximately explains the fires observed by the U.S. Forest Service.

Experts Urge Europe and the U.S. to Boost Cooperation in Space

ESA

Sentinel-1A, one of Europe's Copernicus satellites, monitors many aspects of the environment and provides observations used to assist responses to natural disasters and humanitarian relief efforts.

With the space surrounding Earth becoming more congested, Europe and the United States should build upon their history of space cooperation with additional joint efforts to promote responsible behavior in space and ward off dangers to their spacecraft, experts on space policy and hazards urged at a recent meeting.

Enhanced cooperation would better shield satellites against natural and manmade threats, offer solutions to global concerns such as the need for improved navigation systems, and protect "our shared values across the globe and into deep space," David O'Sullivan, European Union (EU) ambassador to the United States, said at the 9 December 2015 forum at the Center for Strategic and International Studies in Washington, D. C.

Cooperation and Autonomy

One example of cooperation already under way, O'Sullivan noted, involves the EU's Earth observation program Copernicus, which currently has two Sentinel satellites in orbit. In October, the United States and EU agreed to share the Sentinel satellites' data (see http://bit.ly/US-EU-datashare).

Another involves the American GPS system and EU's flight navigation system Galileo, which has 12 satellites in orbit. The United States and EU are working closely together on interoperability and compatibility between the systems for civilian and security use, O'Sullivan said.

The United States and Europe favor establishing interoperability and compatibility among all global navigation satellite systems, and the coordination between Galileo and GPS could serve as a model for that, said Jonathan Margolis, deputy assistant secretary for science, space, and health at the U.S. Department of State. "If the EU and the United States can set that standard going forward," Margolis said, "we are hopeful that will send exactly the right signal to other countries and exactly the right signal to commercial operators as well."

Alain Ratier, director-general of the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT), pointed to another cooperative endeavor, the Initial Joint Polar System, which began in 1998. A 2 December 2015 agreement between EUMETSAT and the National Oceanic and Atmospheric Administration (see http://bit.ly/JPS-agreement) extends until 2040 this cooperation on a system of polar-orbiting satellites to provide global weather observations. The EU and United States require autonomy, but "no one can afford independence" when it comes to providing the best weather forecasts and system redundancy, Ratier said.

Randy Showstack

Jonathan Margolis, deputy assistant secretary for science, space, and health at the U.S. Department of State.

Protection from Hazards

Security for space-based assets has declined, cautioned François Rivasseau, special envoy for space and head of the security policy division of the European External Action Service. He noted that increases in space debris and microsatellites, as well as in the numbers of countries involved in space, multiply the risks of damage to spacecraft from an accident or attack. He also warned of potential cyberattacks on satellites, which he said could be globally catastrophic. He asked, "Shouldn't we try to have a priority particularly given to the protection of space services and space based assets, considering them as critical infrastructure which, if under attack, could expose vulnerabilities" that could be widely disruptive?

Mallory Stewart, deputy assistant secretary for emerging challenges and defense policy at the State Department, identified protecting the United States and its allies "by preventing conflict from extending into space" as a key diplomatic goal of her agency. She said that all countries engaged in space activity should work together to meet "the challenges of orbital congestion and collision avoidance while promoting responsible, peaceful behavior in space."

The United States and EU also cooperate by using Earth observations from space to mitigate hazards, thereby improving security, said Frank Kelly, director of the U.S. Geological Survey Earth Resources Observation and Science Center. Kelly noted that a collaboration among space agencies, called the International Charter "Space and Major Disasters" (see http://bit.ly/IntL-Charter), provides rapid access to data from 38 satellites to aid emergency responses to disasters such as floods, volcanic eruptions, and missing aircraft. "The combined assets of the EU and the U.S. are the backbone of the charter," said Kelly, who currently chairs the charter's board.

By **Randy Showstack,** Staff Writer

White House Data Chief Stresses Benefits of Better Communication

The Earth and space sciences produce some of the best data scientists, and they need to stay in these fields, according to the chief data scientist at the White House Office of Science and Technology Policy (OSTP). "We have to make sure that the efforts and energy that everyone is doing here continues to benefit what is most important of all, which is the scientific understanding of our Earth, our climate, and how we interact as a species with our environment," DJ Patil said on 14 December 2015 at the AGU Fall Meeting in San Francisco, Calif. (see http://bit.ly/White-House-DJP).

Gary Wagner

DJ Patil, chief data scientist at the White House Office of Science and Technology Policy, spoke on 14 December 2015 at the AGU Fall Meeting in San Francisco, Calif.

Patil, who formerly held positions as a data scientist in industry and academia, said that some of his favorite hires were geoscientists. A Ph.D. mathematician, he used open data sets published by the National Oceanic and Atmospheric Administration to improve numerical weather forecasting when he was a student and faculty member at the University of Maryland.

All geoscientists also are data scientists by virtue of working with data, Patil said, urging them to learn how to use data more effectively to "take back the conversation on some key scientific issues."

Patil added, "the conversation is not ours right now, whether it's on climate or anything else. We have people that are arguing against us, not on scientific merit, not on any data. It's on a thought basis that is not grounded in any form of reality."

Some measures that would help, he said, include figuring out how to create science role models and raising the profile of scientists. "We need to create the celebrities of climate and data and oceanography and all the other things that are happening here [at the meeting], because if we don't we will continue just to lose the conversation over and over again," he said.

> "The best data products in the world aren't trying to give you more information. The best data products in the world facilitate an end goal."

Data, Communication, and Ethics

Patil said scientists also need to learn how to use data to communicate better, whether to tech-savvy people or to the general population. He said that one of the best examples of data science, and a brilliant example of communication, is the icon in weather apps that might be a happy face for a sunny day or an angry face with lightning bolts when the forecast calls for rain.

"We have taken all this science and everything and distilled it to an icon. On one side, we go 'that's embarrassing, that's horrible.' On another aspect, we go 'Oh my God, that's brilliant' because that icon provides key information and suggests what action to take and how to feel about the weather."

"The best data products in the world aren't trying to give you more information," he added. "The best data products in the world facilitate an end goal."

Patil also said that data science training should include a focus on ethics. "The power which we have and what we can do with data: just because we can doesn't mean we should," he said. "We have to start taking responsibility [for] everything that happens as a result of the data, because we command that much power."

Recent White House Data Initiatives

Patil, who is also deputy chief technology officer for data policy at OSTP, highlighted some recent White House initiatives, including a 2013 memorandum on an open data policy and an executive order making the new default for government information to be open and machine readable (http://bit.ly/Data-Lib).

Patil said that a Common Framework for Earth-Observation Data (http://bit.ly/Earth-Obs-Access) that is being developed will be "the foundational pinning of how we get to make this data interoperable."

By **Randy Showstack,** Staff Writer

Editors' note: AGU has long maintained a position statement on data. "Earth and Space Science Data Should Be Widely Accessible in Multiple Formats and Long-Term Preservation of Data Is an Integral Responsibility of Scientists and Sponsoring Institutions" was last revised and reaffirmed in February 2012 (see http://bit.ly/AGU-Data-Statement).

AGU FALL MEETING
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Michael R. Raupach (1950–2015)

Australian National University

Michael R. Raupach

Michael Robin Raupach, a gifted climate scientist and micrometeorologist, passed away on 10 January 2015, in Canberra, Australia. Michael devoted his life to science. He breathed it, dreamed it, and talked about it until days before his passing. His research early in his career served as a foundation for modern micrometeorology, and he later led groundbreaking studies on human perturbations to the global carbon cycle.

Michael received many awards over his career. He was a fellow of AGU, the Australian Academy of Science, and the Australian Academy of Technological Sciences and Engineering.

Michael received his B.Sc. in mathematical physics from the University of Adelaide in 1971. At Flinders University, he earned a Ph.D. studying turbulent exchange processes between vegetation and the atmosphere. After gaining postdoctoral experience at the University of Edinburgh, he returned to Australia in 1979. He took a position with the Commonwealth Scientific and Industrial Research Organisation (CSIRO), where he remained until 2014, when he moved to the Australian National University.

Vegetation Canopies

Michael's early work focused on understanding turbulent flows in vegetation canopies and the transport of heat, water, carbon dioxide, and trace gases. This work included the development of one of the first infrared hygrometers, which he used to take pioneering eddy covariance measurements of evaporation. Among his most significant contributions, Michael identified the roughness sublayer just above the canopy.

He also formulated the mixing layer hypothesis that explained for the first time the fundamental differences between coherent structures dominating canopy and rough-wall boundary layer flows. Michael created the now commonly used "localized near-field Lagrangian" turbulence model, which explained the failure of the widely used gradient-diffusion theory and how to correct it. His continued research in this area led to the development of inverse Lagrangian methods that were routinely used for determining scalar sources and sinks in canopies. This body of research transformed modern micrometeorology. As a colleague of Michael's put it, these breakthroughs in biosphere-atmosphere interactions were as profound as the acceptance of continental drift and plate tectonics were to geologists.

As his career progressed, Michael became interested in mass and energy exchange at increasing spatial and temporal scales. Using fluid-mechanical scaling principles, he developed averaging rules that span local- (or canopy)-scale to regional-scale exchanges of energy and matter between land and atmosphere.

The Global Carbon Project

Later in his career, Michael cofounded the Global Carbon Project a research program engaging hundreds of scientists, practitioners, and policy makers. During this period, his interests grew from purely biophysical analyses of carbon cycle fluxes to studies that measured human impacts as well.

Along with project colleagues, Michael described changes in the dynamics of natural carbon sinks on land and in the oceans, which together remove about half of all anthropogenic atmospheric carbon dioxide (CO_2). He initially detected an increase in the proportion of anthropogenic CO_2 emissions that remain in the atmosphere, suggesting that carbon sinks were losing the race against the rapid increase in carbon emissions.

Michael excelled at integrative research, and he developed the "sink rate," a diagnostic that relates carbon uptake in oceans and on land with the amount of excess atmospheric CO_2, and an attribution approach to assign rate changes to underlying causes. He showed that the efficiency of sinks was declining because of the trajectories of extrinsic factors, including the CO_2 emissions growth and volcanic eruptions, and, more concerning, intrinsic feedback responses such as sink responses to climate change and nonlinear responses to increasing CO_2, mainly in the oceans. His critical contribution was to assemble these disparate factors into a single modeling framework.

Michael pioneered research showing how global carbon emissions were tracking the most carbon-intensive scenarios of the Intergovernmental Panel on Climate Change. He also identified how a century-old declining trend—an improvement—in the carbon intensity of the global economy had ceased as emerging economies took center stage in the growth of the global economy.

Societally Relevant Research

During his last decade of research, Michael was a strong advocate for the scientific community to combine first-class and societally relevant research. He examined relationships between emissions and economic development, contributions of urbanization to global carbon fluxes, drivers of greenhouse emissions, and responsibilities of nations to address mitigation and their commitments. He also led numerous groups on behalf of the Australian Academy of Science to explore implications of Australia's population trajectory for sustainability.

Beyond his scientific contributions, Michael was an example of integrity, clarity of purpose, and humility, from which we all benefited. His kindness and approachability made him a wonderful person to work and be with.

Michael's greatest joy was his family—his wife, Hilary, and their three children, Anna, Tim, and Alex. While we all miss him dearly, his personal and professional legacy will continue to influence scientists and science for decades to come.

By **Josep G. Canadell,** Global Carbon Project, Oceans and Atmosphere, Commonwealth Scientific and Industrial Research Organisation, Canberra, Australia; email: pep.canadell@csiro.au; and **Robert B. Jackson,** School of Earth, Energy, and Environmental Sciences, Woods Institute for the Environment, and Precourt Institute for Energy, Stanford University, Stanford, Calif.

Invest in Scientific Research to Drive Innovation

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Investment in basic scientific research seeds the innovation and new discoveries that transform our economy, build new industries, increase productivity, and enhance U.S. competitiveness in a global economy.

Since World War II, the United States has led the world in groundbreaking innovation that grows our economy and propels our nation forward. At the heart of this innovation is basic scientific research, which drives everything from developments that improve our daily lives, like the Internet and smartphones, to medical discoveries that save lives, like mapping the human genome.

Today, however, as our competitors in Asia and around the world are making critical investments in their own research priorities, U.S. federal science and research budgets are stagnant or even shrinking. During the space race of the 1960s, America's federal investment in research and development (R&D) reached nearly 2% of the nation's gross domestic product (GDP). Federal investment is currently at a historic low of 0.78%. (These figures are documented in recent reports from the National Science Foundation (see http://bit.ly/NSF_stats) and the American Association for the Advancement of Science (see http://bit.ly/AAAS_RD_trends) and in a recent article in *Bloomberg Business* (see http://bit.ly/bloomberg_RD).) If we want to keep the United States at the forefront of innovation, Congress must come together to strengthen our commitment to scientific research.

Basic scientific research is the seed corn of innovation and new discoveries, the kind of discoveries that transform our economy, build new industries, increase productivity, and enhance U.S. competitiveness in a global economy. In my home state of Michigan, our universities are leading exciting new research in fields ranging from biosciences to physics to aerospace engineering and advanced manufacturing. Across the country, other university labs are pursuing equally exciting research endeavors. Federal investments in this kind of research yield transformative technologies that will become the jobs and industries of the future and pay dividends for our country in the decades to come.

Certainly, the quest for greater knowledge about the dynamic planet on which we live is one such worthy investment. Geoscientists are working to analyze and predict the effects of natural disasters like earthquakes and tsunamis. Early warnings for these extreme events will save lives and reduce losses. Other Earth scientists are investigating minerals and resources needed to further economic prosperity, and climate scientists across the globe are racing to better understand the effects of human activity on our atmosphere. From weather prediction to hazard mitigation, geoscience research is essential to the well-being and prosperity of the United States and its citizens.

Over the next few months, the Senate Committee on Commerce, Science, and Transportation will be developing new legislation that will identify our federal research priorities for the coming years. In my position as ranking member of the Subcommittee on Space, Science, and Competitiveness, I have been working with my Commerce Committee colleague Senator Cory Gardner (R-Colo.) and other committee members to lead discussions and gather input from the U.S. science and research community to shape our future priorities. We have heard from experts representing industry, academia, business incubators, and government. Each expressed a common concern: Insufficient and unpredictable funding for basic research cripples U.S. research efforts and undermines our economic potential.

To ensure our nation's long-term prosperity, Congress must increase the federal government's investment in R&D to 1% of GDP. This commitment should include a focus on increased federal support for basic research because it is an essential component of any innovation economy. Together with the private sector investment in R&D, our national investment will reach almost 3% of GDP, matching China's path.

Funding for basic research is certainly not the only issue we need to address. We can enact policies to drive better buying power for each dollar invested in research. We can work to ensure that more students have access to the best science, technology, engineering, and math (STEM) education, and we can encourage entrepreneurship. But all of these fixes rest on a foundation of sustained growth of U.S. investment in basic research and technology.

Courtesy of Senator Peters's office

U.S. Senator Gary Peters (D.-Mich.).

Investments in basic research are a down payment on America's future and the key to keeping our nation on the cutting edge of an increasingly competitive global economy. As the U.S. science and research community works to discover the next major scientific advancement, we in Congress must do our part by supporting and investing in their efforts to drive economic growth, unleash increased productivity, enhance our safety and security, and make the world a better place for future generations.

By Senator **Gary Peters** (D-Mich.), Washington, D. C.; contact: www.peters.senate.gov/contact/email-gary

Editors' Note: Senator Peters is a member of the U.S. Senate Committee on Commerce, Science, and Transportation and serves as the ranking member of the Subcommittee on Space, Science, and Competitiveness. Earlier this year, Peters co-led an innovation and competitiveness working group to gather input from the U.S. science and research community and other interested parties on federal research and development policy priorities.

The Importance of Data Set Provenance for Science

Recently, an undocumented change was found in the long-term Antarctic sea ice record that seemed to reverse an established trend [*Eisenman et al.*, 2014]. It turned out that Antarctic sea ice extent was not growing nearly as fast as thought. In fact, "much of this [past] expansion may be a spurious artifact of an error in the processing of the satellite observation" (p. 1289). This misunderstanding could have been avoided if the history—the provenance—of the data had been more clearly documented. Science requires transparency and verifiability, and scientists must always ask, Are these data trustworthy? From where did they originate? How were they generated and processed? What other data were used to calibrate, validate, and process these data? In other words, what are the provenance and context of the data?

Another example where provenance and context are crucial to scientific integrity is shown in Figure 1. The recommended citation for the data set shown is a static research article [*Nerem et al.*, 2010] that does not recognize the continual updating of the data values. Although the general trend remains unaffected by revisions, the values are quite different. Sound research requires investigators to indicate exactly which version of a data set was used in a study, yet the scientific literature is rife with examples of these types of imprecise references and loose tracking of provenance.

Tackling the Provenance Problem

Data lie at the heart of these issues of transparency in published scientific research. Traditionally, it has been assumed that these issues were addressed through peer review and the self-correcting nature of science, but these methods are not proving to be fully effective in their current form. The literature is replete with cases of citing publications in lieu of data, not citing data set versions, and data set versions not being updated by data producers. Recent efforts to motivate authors to provide accurate data citations include AGU's own data policy [e.g., *Hanson and van der Hilst*, 2014; *Hanson et al.*, 2015]. Data citation alone, however, does not solve the transparency issue. Full documentation of data set provenance and context is necessary.

Governments and other funders recognize this need for data preservation, provenance, and contextual information and are increasingly provide guidelines for ensuring the credibility of information. In 1998, the U.S. Global Change Research Program (USGCRP), a confederation of 13 federal agencies active in global change research, convened a workshop to establish requirements for long-term preservation of Earth observation data.

> Data citation alone does not solve the transparency issue. Full documentation of data set provenance and context is necessary.

Participants investigated positive and negative experiences involving the reuse and reanalysis of a variety of historical data products. This workshop produced a high-level list of information needed to "ensure [a data set's] usefulness to the scientist, and subsequent generations of scientists, with no prior knowledge of the data set or product" [*USGCRP*, 1999].

Also in 1998, NASA founded the Federation of Earth Science Information Partners (ESIP) to engage a broader community of stakeholders in improving methods to make Earth science data easy to preserve, locate, access, and use. ESIP has begun to improve practices for enabling reuse of data by addressing issues of provenance and context in Earth science [e.g., *Duerr et al.*, 2011; *ESIP Stewardship Committee*, 2012; *Downs et al.*, 2015; *Mayernik et al.*, 2015] (see additional information on ESIP's role below).

Revitalizing the Effort

Despite the USGCRP workshop's early recognition that data and accompanying information merited preservation [*USGCRP*, 1999], for nearly a decade very little progress was made in implementing this understanding within relevant agencies or promoting it to the broader scientific community. ESIP now seeks to accelerate the actual implementation of the USGCRP workshop findings.

ESIP advocates new technical and normative approaches to identify, capture, and track all details necessary to demonstrate data validity and to better ensure scientific reproducibility, through the Provenance and Context Content Standard (PCCS) matrix, summarized in Table 1, developed by ESIP's Data Stewardship Committee. The PCCS matrix details the content required to describe provenance and context and identifies the major categories of data, metadata, and documentation that need to be preserved to increase trust in and understanding of research results.

ESIP's PCCS has been adopted by NASA within the Earth Science Data Preservation Content Specification (PCS) as a requirement for new Earth science missions. New missions using NASA's PCS include the Soil Moisture Active Passive (SMAP) and the Ice, Cloud, and land Elevation Satellite 2 (ICESAT2) missions. In the case of the older missions (those currently in operation or that have ended), NASA's PCS had not been included as a requirement but is used instead as a checklist for ensuring that as much of the relevant content as feasible is preserved.

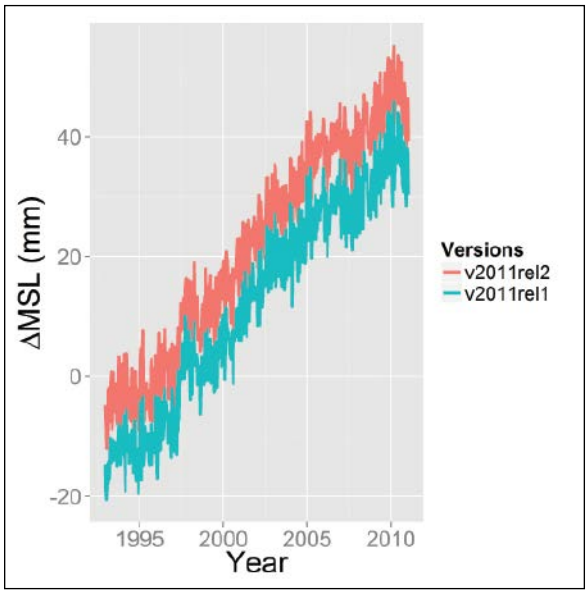

Fig. 1. This plot, constructed using data from Nerem et al. *[2010], shows two releases of "the global mean sea level time series (season signals removed)" and could raise questions about the validity of the measurements if the provenance and context of the two releases were not documented.*

Table 1. The Provenance and Context Content Standard (PCCS) Matrix[a]

CATEGORY	CONTENT
Preflight/preoperations calibration	Instrument description; calibration information
Data set products	Raw data set; level 1 data set (e.g., unprocessed sensor data); level 2 data set (e.g., derived geophysical variables); level 3 data set (e.g., variables mapped on uniform scales); level 4 data set (e.g., model outputs); discovery metadata
Data set product documentation	Team members; product requirements; product development; processing history; product algorithms; quality assessment; references; user feedback
Data set calibration	Calibration method; in situ environment; platform history; calibration data; calibration software
Data set product software	Source code; output data set description; programming considerations; exceptions; test data sets; test plans; test results
Data set product algorithm inputs	Algorithm input documentation; algorithm input data sets
Data set product validation	Software readers and display tools

[a]The PCCS matrix details the content required to describe provenance and context and identifies the major categories of data, metadata, and documentation that must be preserved to increase trust in and understanding of research results (Federation of Earth Science Information Partners, Provenance Context Content 2011-06-08 (http://bit.ly/22nzYXK)).

Although NASA is not a formally designated "preservation agency" for Earth science data, it is essential for NASA to preserve all the data and associated content beyond the lives of NASA's missions to enable continued access to data and services for active scientific research. Furthermore, NASA must ensure that the data and associated content are preserved for transition to permanent archival agencies. In fact, all agencies should do the same.

The Future of Provenance Documentation

It is becoming more common for journals to require the availability of data supporting an article (e.g., AGU publications [*Hanson et al.,* 2015] and *Nature* [*Nature Publishing Group,* 2013]). Availability of data may be broadly defined, however, and sometimes does not include the necessary documentation (provenance and context) that are necessary for reuse. This then raises the question of whether these journal policies truly ensure long-term data reuse.

Journals must require that data not only be available but also be reusable. If, for example, the provenance and context of the two releases of the data sets plotted in Figure 1 were not well documented, many would question the validity of the measurements. With information captured through the PCCS (specifically, data set calibration), the reason for the shift in values would become clearer.

The Coalition for Publishing Data in the Earth and Space Sciences (COPDESS) released a "Statement of Commitment from Earth and Space Science Publishers and Data Facilities" in early 2015 that in part states, "The major data repositories provide leading practices that should help guide the types of samples, data, metadata, and data processing descriptions that should be maintained, including information about derivations, processing, and uncertainty." This aligns with the goals of ESIP's PCCS. Signatories to COPDESS's statement of commitment (including AGU) are taking appropriate steps in this direction [e.g., *Hanson et al.,* 2015], but questions remain.

How do we truly solve the provenance problem? What needs to be documented? We'd like to do it consistently, but how do we communicate this information across disciplines? Can a single documentation standard work for all disciplines and data types, or do we need multiple domain-specific documentation standards? The community must consider the capture and preservation of provenance more seriously and begin employing appropriate practices routinely.

Journals must require that data not only be available but also be reusable.

We believe the PCCS effort initiated by ESIP is an important first step toward solving the provenance problem. Although its current emphasis is on remote sensing data, the issue goes well beyond any one discipline or method. Contributions from other disciplines and initiatives can extend and improve such practices and generally increase trust in and understanding of research results.

ESIP continues to improve the PCCS by involving other communities within Earth and space sciences and by soliciting contributions from other national and international groups and the Research Data Alliance. We welcome broader collaboration and seek to work with others documenting data provenance and context to see if this PCCS can be extended more broadly.

Returning to our example from Antarctica, *Eisenman et al.* [2014, p. 1293] conclude, "These results illustrate the need for thorough documentation and version control in observational data sets. Ideally all observational data sets, especially those used widely and included in IPCC assessment reports, would have sufficient documentation of algorithms and algorithm changes for previous and current versions of the data to be independently replicated from the raw sensor data." ESIP's PCCS defines the information necessary to do that.

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Richard J. Arculus

SCIENTIFIC **OCEAN DRILLING** CHARTS A NEW COURSE

By Susan E. Humphris and Anthony A. P. Koppers

The International Ocean Discovery Program (IODP) continues the 45-year history of accomplishments set by its predecessor programs: the Integrated Ocean Drilling Program (2003–2013), the Ocean Drilling Program (1983–2003), and the Deep Sea Drilling Project (1968–1983). Guided by a new science plan, IODP provides opportunities for international interdisciplinary research teams to conduct transformative and societally relevant research through scientific ocean drilling. The United States has participated in scientific ocean drilling since the program's inception and continues to do so today through operation of the drilling vessel *JOIDES Resolution*. Highlights from recent *JOIDES Resolution* expeditions include investigating subduction and the formation of continental crust, the Asian monsoon systems, and the initiation of rifting and ocean basin formation.

A New IODP Funding Model

At the start of IODP in October 2013, the program implemented a new funding model that continues operations of three drilling platforms. The U.S. National Science Foundation (NSF), the European Consortium for Ocean Research Drilling (ECORD), and Japan's Ministry of Education, Cul-

Drill pipes, stacked and ready for use on the JOIDES Resolution. *The photograph was taken on International Ocean Discovery Expedition 351, which cored the seafloor of the northern Philippine Sea to study the formation of intraocean arcs.*

International Ocean Discovery Program JOIDES Resolution Science Operator.

The drilling vessel JOIDES Resolution *during Expedition 352 drilling a section through the volcanic stratigraphy of the outer fore arc of the Izu-Bonin-Mariana system to trace the processes of magmatism, tectonics, and crustal accretion associated with subduction initiation.*

ture, Sports, Science and Technology (MEXT) now fund and manage their own drilling platform(s) while working together to fulfill the overarching IODP science goals. Each platform provider may then develop international partners who contribute to operating costs of the drilling platform in exchange for berths during expeditions and advisory panel participation.

The *JOIDES Resolution* is operated by Texas A&M University on behalf of the NSF. In fiscal year (FY) 2015, international partners Brazil, China, Australia/New Zealand, India, South Korea, and ECORD contributed $16.5 million to the operating costs of this vessel. In addition, over the past 2 years, China and India have provided another $12 million to this platform through partial funding of expeditions.

IODP Responds to a Sea Change

In 2013, the NSF asked the National Research Council of the National Academies to undertake a study of ocean sciences to provide guidance on research and facilities priorities for the coming decade. Their report, titled *Sea Change: 2015–2025 Decadal Survey of Ocean Sciences* [*National Research Council,* 2015], recognized U.S. participation in IODP as highly relevant in addressing several of the most important issues in ocean science, including ocean and climate variability, sea level change, subseafloor exploration, geohazards, and the formation and evolution of ocean basins. The report also noted the success of the drilling program in building and sustaining long-term international partnerships.

However, *Sea Change* pointed to the high financial contribution of the United States relative to those of its international partners and urged NSF to pursue more cost-effective partnerships. In addition, *Sea Change* recommended an immediate 10% reduction in NSF's contribution to the annual budget for operation of the *JOIDES Resolution,* followed by further reductions over the next 5 years.

Three actions have been implemented to achieve the recommended 10% cut while continuing the current pace of four expeditions per year on the *JOIDES Resolution*. The successful reduction of NSF's contribution in operating the *JOIDES Resolution* primarily resulted from cost reductions and revenue enhancement since the start of the new program:

- *JOIDES Resolution* science operations are now conducted by a single entity rather than a consortium of three organizations as in the previous program, thereby reducing costs.
- The *JOIDES Resolution* Facility Board (JRFB) now organizes ship tracks that minimize transits between drill sites and the nearest port at the beginning and end of an expedition, resulting in significant savings in fuel costs.
- An IODP partner country or consortium can now provide additional funding for specific projects beyond its annual contribution, thereby increasing contributions to *JOIDES Resolution* operations.

The latter action is achieved via submission of complementary project proposals (CPPs) that are rigorously reviewed by the JRFB advisory panels. This mechanism has proven attractive, given that the *JOIDES Resolution* has already drilled two such projects, two more with Chinese support are scheduled for 2017, and two CPPs (one led by Australian scientists and one by U.S. scientists) are under review. Thanks to the funding from the two CPPs in 2017, the JRFB expects that the *JOIDES Resolution* will be able to increase operations in FY 2018 and FY 2019 to five expeditions each year.

The JRFB will be working closely with NSF to examine ways to achieve more reductions in NSF's contributions to operations of the *JOIDES Resolution*. Potential options include raising more revenue from international partners, increasing external funding through CPPs, and continuing to find efficiencies in science operations.

Planning for 2016–2017 IODP Expeditions

The JRFB is responsible for annual scheduling and long-term planning of IODP expeditions that will be conducted on the *JOIDES Resolution.* Locations of completed and upcoming drilling expeditions of the *JOIDES Resolution* since the start of the new IODP are shown in Figure 1. Expeditions are selected after a rigorous peer-review process of proposals addressing one of the four research themes in the IODP science plan (see http://bit.ly/IODP_science_plan).

For example, several upcoming *JOIDES Resolution* expeditions will focus on how Earth's climate responds to elevated levels of atmospheric carbon dioxide. Other expeditions will focus on interactions between the Earth's crust and mantle, seawater, deep fluids, and the microbial communities that may live deep beneath the seafloor. Still other expeditions will examine tectonic effects, including continental breakup and the formation of oceanic crust. These expeditions are discussed in further detail below.

Climate and Ocean Change

Three upcoming *JOIDES Resolution* expeditions will focus on how Earth's climate responds to elevated levels of atmospheric carbon dioxide and how it affects regional patterns of precipitation. IODP Expedition 361 in early 2016 will investigate the interaction between climate and the Agulhas Current off the coast of South Africa, examining how circulation between the Atlantic and Indian Oceans via this current varied during major ocean and climate reorganizations that have occurred over the past 5 million years.

Expedition 363 in late 2016 targets the Indo-Pacific Warm Pool—the largest reservoir of warm surface water on Earth—spanning the western equatorial Pacific to the eastern Indian Ocean. It will investigate the controls on sea surface temperatures and how changes in this region are linked to dynamic events like El Niño and even to the climate variability of the northern Atlantic.

In 2017, Expedition 369 off the southwest corner of Australia will recover cores to chronicle the rise and collapse of the Cretaceous hothouse, a past period of extreme warmth. This will allow scientists to seek out potential links between climate change and the tectonic history of the region.

In 2016, ECORD will sponsor IODP Expedition 364, which will drill 1.5 kilometers into the Chicxulub impact crater off the Yucatan Peninsula in Mexico in collaboration with the

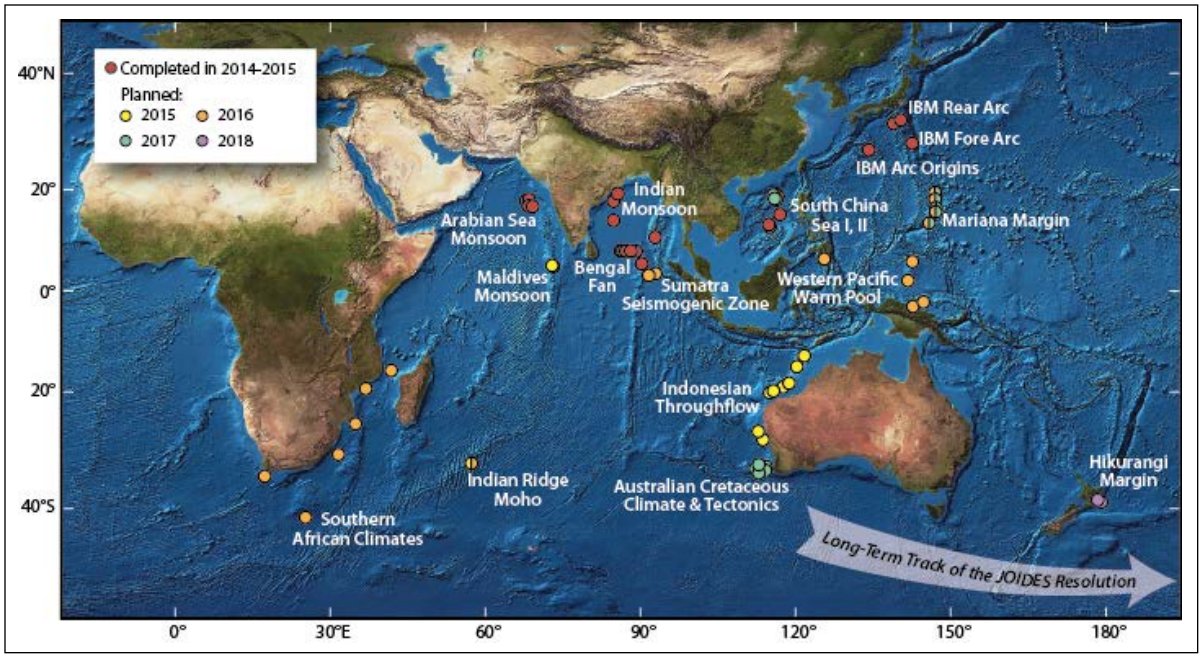

Fig. 1. Completed and planned JOIDES Resolution *expeditions in the International Ocean Discovery Program, an international scientific drilling program that explores Earth's history and dynamics.*

International Continental Scientific Drilling Program. Chicxulub, created 65 million years ago by the meteoric impact that is thought to have wiped out the dinosaurs, is the only known impact structure that has been directly linked to a mass extinction event. Studying it will provide insight into the geological structure of the impact crater, the environmental changes leading up to a mass extinction, the subsequent biologic recovery, and the effects of a large impact on the deep subsurface biosphere.

Three upcoming expeditions will focus on how Earth's climate responds to elevated levels of atmospheric carbon dioxide.

Earth Connections

Expedition 360 returns the *JOIDES Resolution* to the underwater flat-topped peak known as Atlantis Bank, in the Indian Ocean south of Mauritius, in a bid to settle a decades-long debate about the nature of the boundary between the crust and the mantle, known as the Mohorovičić discontinuity, or Moho. This is the first of two expeditions that will drill into the upper mantle at Atlantis Bank. Sampling rock across the boundary will test whether the Moho is a serpentinization front, where mantle rock (peridotite) has been chemically altered, and will further understanding of how mid-ocean ridge basalt is created.

Expedition 366 will take the *JOIDES Resolution* to the Mariana Convergent Margin, where the Pacific Plate dives underneath the Mariana Plate, creating a subduction zone. The expedition will focus on the exchange of chemicals between the crust and seawater in a subduction zone environment; the role of deep fluids in linking tectonic, thermal, and biogeochemical processes; and the composition of the microbial communities that may live deep beneath the seafloor. The expedition will drill and core at several serpentinite mud volcanoes and install instruments in the boreholes for long-term investigations of these subduction-related subseafloor processes.

China's Ministry of Science and Technology is partially funding Expeditions 367 and 368 to continue investigating continental breakup and the crustal architecture of the South China Sea. They will test two models for how plates rupture that predict different crustal structures across the transition between oceanic and continental crust. They will also examine the time lag between continental breakup and the formation of oceanic crust and the rates of extension, cooling, and subsidence.

Earth in Motion

The Nankai Trough Seismogenic Zone Experiment (NanTroSEIZE), an important project that uses the Japanese platform *Chikyu,* continues into the new IODP. Underway since 2007, the goal of this project is to drill and place monitoring instruments into the Nankai plate boundary fault system south of Japan's largest island, Honshu, which has produced massive earthquakes in the past. Planning continues in Japan for Expedition 365 to install a downhole observatory and for a later expedition to drill a 5-kilometer-deep hole through the plate boundary fault system.

The *JOIDES Resolution* will complement NanTroSEIZE with two expeditions that also focus on subduction zone processes. Expedition 362 is focused on the 2004 Sumatra seismogenic zone, where one of the largest earthquakes ever recorded generated a tsunami that killed roughly 300,000 people in coastal communities around the Indian Ocean. The earthquake occurred where the Indian Plate is being subducted under the Burma Plate, with slip occurring at unexpectedly shallow depths beneath the accretionary prism off the shore of North Sumatra. This is seismic behavior that existing models fail to explain. Expedition 362 will investigate how materials making up the subducting plate drive shallow slip and influence the region's morphology in order to understand its hazard potential and that of similar seismogenic zones around the world.

In contrast, the northern Hikurangi subduction margin off New Zealand is characterized by slow slip events that recur every 1–2 years. In 2018, the *JOIDES Resolution* will conduct riserless drilling for a multiphase drilling project that aims to discern the mechanisms behind slow slip events by sampling and monitoring the upper plate and subduction zone.

Long-Term Cruise Track of the *JOIDES Resolution*

A priority of the JRFB is to use the *JOIDES Resolution* more efficiently by developing ship tracks that minimize transit times and maximize scientific output relative to time and cost. The JRFB therefore projects the ship's track 3 to 5 years in advance on the basis of current and anticipated proposals, as well as progress in achieving the goals set forth in the IODP science plan.

At its May 2015 meeting, the JRFB projected that the *JOIDES Resolution* will follow a path from the southwestern Pacific Ocean, through the Southern Ocean, and into the Atlantic Ocean for opportunities for drilling there starting in FY 2019. It then expects that the drilling vessel will operate in the Atlantic, Mediterranean, Caribbean, and Gulf of Mexico over the next few years. The next IODP proposal submission deadline is 1 April 2016; guidelines can be found at http://www.iodp.org/submitting-proposals.

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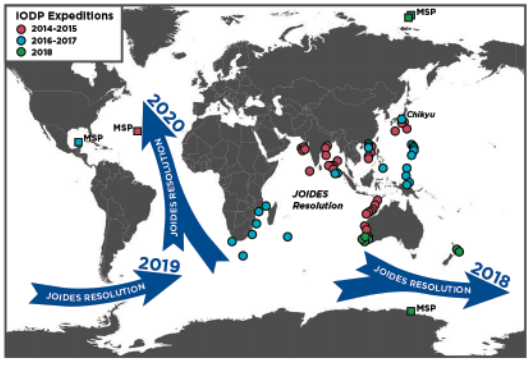
Editors' Note: Susan Humphris is the past chair and Anthony Koppers is the current chair of the JOIDES Resolution Facility Board.

CALL FOR PROPOSALS
Scientific Ocean Drilling

IODP
INTERNATIONAL OCEAN DISCOVERY PROGRAM

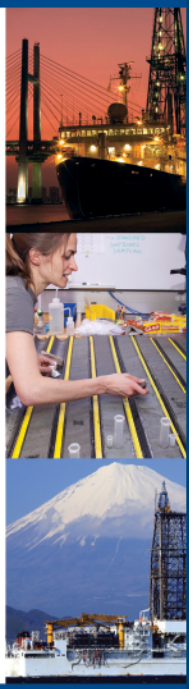
The International Ocean Discovery Program (IODP) explores Earth's climate history, structure, dynamics, and deep biosphere as described at **www.iodp.org/Science-Plan-for-2013-2023**. IODP provides opportunities for international and interdisciplinary research on transformative and societally relevant topics using the ocean drilling, coring, and downhole measurement facilities D/V *JOIDES Resolution* (JR), D/V *Chikyu* and *Mission-Specific Platforms* (MSP).

The JR is planned to operate 10 months per year in 2018 and 2019 under a long-term, global circumnavigation track based on proposal pressure. Future JR expeditions are projected to follow a path from the southwestern Pacific Ocean, through the Southern Ocean, and into the Atlantic Ocean for opportunities starting there in 2019. The JR is then expected to operate in the Atlantic, Mediterranean, Caribbean, and Gulf of Mexico starting in 2020. Although JR proposals for any region are welcomed, pre- and full proposals for these future operational areas are strongly encouraged.



MSP expeditions are planned to operate once per year on average, and proposals for any ocean are welcomed. *Chikyu* operations will be project-based, and new proposals to use *Chikyu* in riser mode must be Complementary Project Proposals (with cost-sharing).

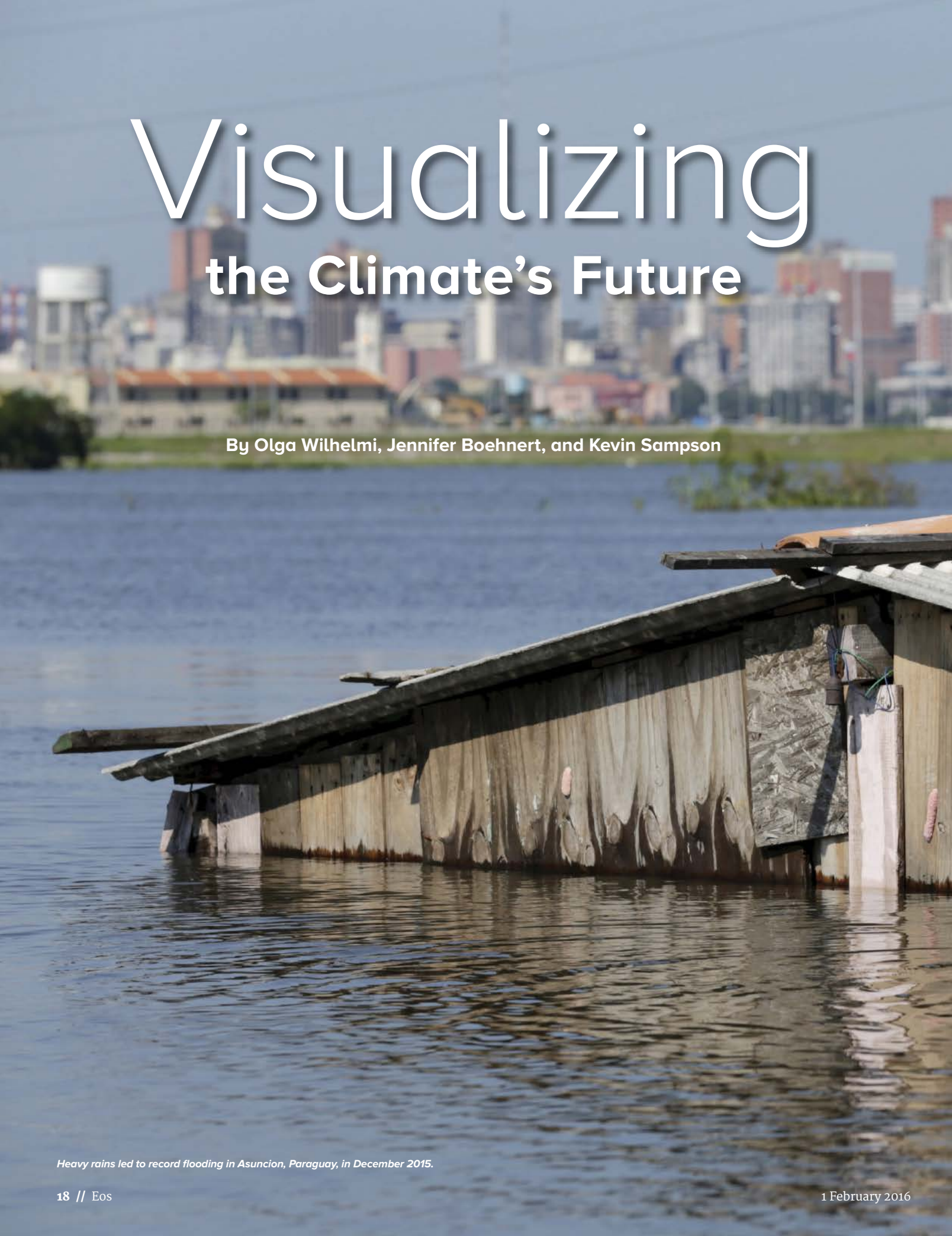
IODP aims to foster joint projects with the International Continental Drilling Program (ICDP). We therefore also invite proposals that coordinate drilling on land and at sea.



Submission Deadline: April 1, 2016 • More information: www.iodp.org • Contact: science@iodp.org

Visualizing the Climate's Future

By Olga Wilhelmi, Jennifer Boehnert, and Kevin Sampson



Heavy rains led to record flooding in Asuncion, Paraguay, in December 2015.

As communities plan for and adapt to climate change, demand for usable climate information is growing. To do their jobs and protect their communities and themselves, policy makers, planners, businesses, and citizens need to know how factors like temperature and precipitation will change in the decades ahead.

Climate models are designed to provide such information. However, for nonscientists to be able to use model results, the raw data that such models produce must be translated into visually and conceptually comprehensible formats.

A New Opportunity

In the past 2 decades, the increased accessibility of the Internet and advances in geospatial data portals have led to new, innovative ways to display, communicate, and distribute scientific information. With respect to climate model simulations in particular, geographic information systems (GIS) and advanced Web application technologies such as advanced browser-based user interfaces and data processing capabilities have proven essential for helping scientists and nonscientists examine changes in the climate and devise strategies for adaptation (e.g., planning for extreme heat events

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A new interactive website makes climate model results accessible to a wide range of users, such as urban and regional planners seeking to prepare for future heat events.

and droughts) and mitigation (e.g., reducing greenhouse gas emissions) [*Sundaresan et al.*, 2014].

Although research and computational challenges still exist at the nexus of geographic information and climate sciences, a growing number of computer-based applications use spatially explicit information to help people working in climate change decision making and adaptation planning [*Wilhelmi et al.*, 2015]. Examples of such applications can be found in the U.S. Climate Resilience Toolkit (see https://toolkit.climate.gov/), a set of resources designed to help citizens, communities, businesses, resource managers, planners, and policy leaders manage their climate-related risks and opportunities and improve their resilience to extreme events.

One of the tools in the toolkit is the Climate Inspector (see http://bit.ly/climate_inspector), which provides a simple yet effective visualization of future climate simulations from the Community Climate System Model (CCSM), one of the leading global climate models.

Here we describe the application's capabilities, available data, and underlying technology. We also discuss current and future work that the Geographic Information Systems Program at the National Center for Atmospheric Research (NCAR) is doing to expand the Climate Inspector approach to providing usable climate information to researchers, educators, and the general public.

An Interactive View

The Climate Inspector is an interactive Web application that builds on GIS mapping and graphing capabilities to visualize projected temperature and precipitation changes throughout the 21st century (Figure 1). The application is a product of a nearly 10-year relationship between the NCAR GIS Program and the users of the NCAR GIS Climate Change Scenarios portal [*Wilhelmi et al.*, 2015] (the Community Climate System Model [*Gent et al.*, 2011] was used to derive data products).

Climate Inspector represents a new approach to exploring climate model outputs on the Web. This approach integrates spatial and temporal dimensions of climate modeling as well as the range of modeling experiments for multiple variables.

Our experiences distributing climate data to the GIS community, addressing frequently asked questions about climate model simulations, and responding to users' requests for maps and graphs that convey complex scientific concepts in a usable way motivated us to develop the Climate Inspector. Since its release in 2014, the Climate Inspector has received more than 14,000 page visits, evidence of its popularity as a tool for communicating climate change information in a visually appealing and understandable way to the public.

Harnessing a Powerful Model

We generate the Climate Inspector's maps and graphs from a large data set of climate simulations by the NCAR Community Climate System Model Version 4 (CCSM4) [*Gent et al.*, 2011]. These simulations were prepared for the Coupled Model Intercomparison Project phase 5 [*Taylor et al.*, 2012] and used in the Fifth Assessment Report of the *Intergovernmental Panel on Climate Change* [2014].

Data distributed through the Climate Inspector include simulations of 20th century climate and 21st century climate with four different representative concentration pathway scenarios, which represent possible future greenhouse gas concentration projections. With the Climate Inspector, users can explore how temperature and precipitation may change according to different representative concentration pathways (RPCs); investigate climate changes around the globe and through time; inspect climate trends, variability, and uncertainty; and download maps and data at approximately 1° spatial resolution. A place-name search allows users to select locations from a database of inhabited places across Earth.

Harnessing Technology

We used a number of technologies to build the Climate Inspector. All the CCSM4 climate simulations are stored as Network Common Data Form (NetCDF) data files. NetCDF is a platform-independent data format that supports the creation, access, and sharing of scientific data.

Data files are served by a Thematic Real-time Environmental Distributed Data Services (THREDDS) Data Server—a Web server that provides metadata and data access for scientific data sets, using a variety of remote data access pro-

tocols. The map in the Climate Inspector is generated through a Web Map Service request, and the data used in the creation of the interactive graphs are retrieved by an Open-source Project for a Network Data Access Protocol (OpeNDAP) request.

The Climate Inspector also uses Environmental Systems Research Institute (Esri) ArcGIS for Server technology for generating a base map showing state and country boundaries. The base map layer offers a number of scales, which are turned on and off depending on the zoom level. We used the OpenLayers 2 JavaScript library to build the map and the Data-Driven Documents library to generate the graphs.

The Climate Inspector is licensed under the Berkeley Software Distribution BSD 3-clause open-source license. The source code is available upon request from a private repository on GitHub.

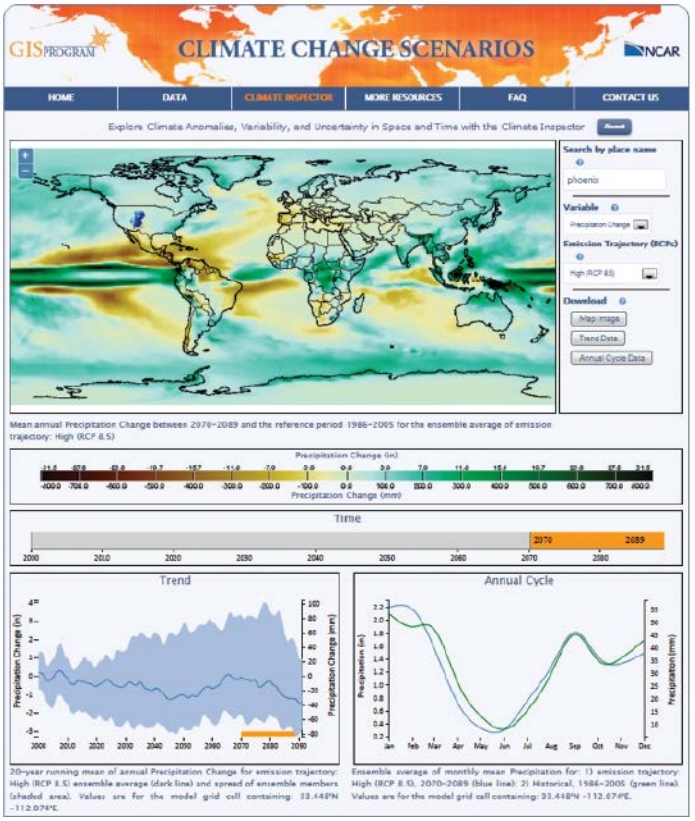

Fig. 1. Screenshot of the Climate Inspector: an interactive Web-based application for global climate change data visualization and exploration.

Expanding Uses

Flexibility and extensibility are Climate Inspector's key advantages as a platform for distributing and visualizing complex climate modeling data in a usable way. We have shown how the concept and the application of Climate Inspector can be expanded for sector-specific climate services.

An example of such extension is the Extreme Heat Climate Inspector (see http://bit.ly/heat_inspector). Extreme heat and climate change are growing public health concerns, and this application uses the mapping and graphing Web-based technology of Climate Inspector to provide data that officials will need in order to prepare for public health emergencies and mitigate urban heat. These data come from research on how occurrences of extreme heat events may vary as a result of climate change [*Oleson et al.*, 2013]

For simulating future climate and extreme heat, *Oleson et al.* [2013] used NCAR's Community Land Model coupled to an urban canopy model to quantify rural and urban summer heat stress over the United States and southern Canada at fine spatial resolution (0.125° in latitude and longitude) for the present day and for the middle of the 21st century, using one possible climate change scenario (i.e., RPC 8.5).

The Extreme Heat Climate Inspector allows users to explore projected changes in temperature as well as the five commonly used heat stress indices: the National Weather Service heat index, apparent temperature, simplified wet bulb globe temperature, humidex, and discomfort index. Through this interactive application, users can see the variations in high heat stress days and nights in cities and rural areas across the United States and can explore spatial patterns and seasonality of extreme heat across the United States, southern Canada, and northern Mexico.

Growing Urgency

As climate science and modeling evolve and the need for usable climate information becomes more urgent, the role of geospatial technologies, driven by the needs of users across research, education, government, and the private sector, will become more prominent. The new approach to exploring global climate change across space and time, as well as the two applications described here (Climate Inspector and Extreme Heat Climate Inspector), illustrates how we can integrate disciplinary knowledge from climate sciences, Web-based technologies, and GIS.

The concept of interactive data exploration, visualization, and distribution, developed through Climate Inspector applications, has great potential for delivering usable climate information to a broad range of users.

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Cooling Galápagos Sea Surface Temperatures Affect Local Penguins

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Galápagos penguins, the only penguins found in the Northern Hemisphere.

Famous for their tortoises and important role in the fiction of Kurt Vonnegut, the Galápagos Islands are often lauded as a home for a variety of species that exist nowhere else and thus contribute to the overall biodiversity on Earth. Among the list of animals endemic to the archipelago are the Galápagos penguins, which are typically around 49 centimeters in length and the only penguins found in the Northern Hemisphere.

The bird's ability to thrive at this tropical latitude is a result of ocean upwelling, the confluence of processes that cause cold water from the depths to be pushed closer to the surface. Most upwelling—like the kind that takes place along continental coastlines like California—is wind driven (also known as Ekman upwelling). In contrast, upwelling in the Galápagos is driven by topography. The Equatorial Undercurrent flows eastward at anywhere between 50 and 300 meters beneath the surface, hugging the equator all the way from Papua New Guinea to the Galápagos. When it reaches the islands, the waters are pushed around to the north or south—but also upward, piling up like water behind a dam. This forces colder, nutrient-rich waters up from the depths toward the islands, resulting in cooler surface temperatures and an ideal habitat for the penguins.

Here *Karnauskas et al.* investigate the impact of multidecadal climate variability on this upwelling and its implications for the penguin population. Using relatively high resolution satellite observations, the scientists analyzed sea surface temperatures in the region adjacent to the Galápagos between 1982 and 2014. Although it seems counterintuitive, the warming of Earth's climate actually coincides with a decrease in average sea surface temperature along the west coast of the Galápagos Islands. The team attributes the finding to a strengthening of the Equatorial Undercurrent.

Trends in the tropical trade winds, according to the scientists, have gradually nudged the Equatorial Undercurrent farther to the north—aligning it more squarely with the Galápagos Islands and thus causing sea surface temperatures to drop by as much as 0.8°C over the study period. The penguin habitats appear to have shifted accordingly, and the populations have thrived most where the waters are coldest. The authors suggest that their study represents an example of how global climate change can have important and variable effects at local scales, especially where the viability of ecosystems is concerned. (*Geophysical Research Letters,* doi:10.1002/2015GL064456, 2015) **—David Shultz, Freelance Writer**

Correction

The article "Holly Gilbert Receives 2015 Athelstan Spilhaus Award" in the 15 January 2016 issue of *Eos* magazine included the wrong version of Holly Gilbert's response. For the correct version, please visit http://bit.ly/Eos_Gilbert.

New Insights into the Complicated World of Tropical Convection

Dramatic tropical storms owe their powerful impact to complex processes taking place in the Earth's atmosphere. Differences in density drive the movement of air in the atmosphere as warm, moist air rises from the surface of the Earth and meets the colder, denser air of the upper atmosphere. This imbalance is the basis for the winds and weather conditions that define Earth's climate zones; thus, examining the turbulent behavior of the atmosphere is key to understanding weather patterns and climate conditions.

The tropics are unique because heat transfer here is driven primarily by convection—the tendency of hot air to rise and displace cooler, denser air. The physics of convection is chaotic and complex, however, so scientists are forced to look at its large-scale average behaviors. In a new study, *Raymond et al.* focused on the troposphere, the lowest layer of the atmosphere, to pinpoint broad variables that influence this average convection behavior.

Using results from studies of tropospheric convection during the formation of tropical cyclones, the researchers showed how rotation of the atmosphere in these incipient tropical storms controlled the average properties of convection, including the rainfall it produces, and the effects of convection on the subsequent intensification or dissipation of the storms themselves. The researchers recognized that rotation is a ubiquitous feature of the atmosphere, even in the tropics, and they went on to hypothesize that the complex web of interactions between convection and rotation that is evident in tropical cyclones is central to the dynamics of virtually all important weather features in the tropics.

Additional observations and modeling will help to test these hypotheses and further improve our understanding of the Earth's atmosphere. (*Journal of Advances in Modeling Earth Systems* (*JAMES*), doi:10.1002/2015MS000467, 2015) **—Lily Strelich, Freelance Writer**

Dave Raymond

The chaotic complexity of convection, seen in this picture taken during field observations in the western tropical Pacific.

Alaskan Wildfires Influence Permafrost Recovery

M. Torre Jorgenson

Aerial view after a recent wildfire in the Tanana Flats, interior Alaska, showing the collapse of the ground surface after permafrost thawing and subsequent water impoundment.

At high latitudes, permafrost—ground that remains frozen year round—sequesters massive amounts of carbon, making it an important variable in global climate dynamics. As Earth continues to warm, permafrost extent is decreasing, and the thaw is changing the associated surface ecosystems. Here *Brown et al.* examine the impact of wildfires on permafrost in the Tanana Flats region of Alaska.

Using a suite of field experiments, such as core sampling, in combination with computer modeling, the authors examine wildfires in the region from 1930 to 2010 and analyze their impact on permafrost and the surrounding ecosystem. According to the team, fires played a significant role in the degradation of permafrost in the area, and in some instances, the resulting thaw was enough to permanently alter the composition of the affected landscape.

Because ice occupies a larger volume than liquid water and has far greater mechanical strength, when it melts, the soil tends to settle and collapse. In areas like the Tanana Flats, this collapse can cause the ground level to recede below the local water level, thereby transforming a forested terrestrial area into a boggy wetland. Once this transition occurs, the liquid water aggregates in pools and can promote even more thawing.

Fires can rapidly accelerate the thawing of permafrost, but the team concludes that whether or not an ecosystem recovers (refreezes) following the disturbance is subject to several variables. Fire severity is a major driver: The extent of permafrost degradation is dependent on the depth of burning into the insulating organic surface layers. The team's analysis also shows that vulnerability of permafrost after a wildfire increased during the 1970s—concurrent with an overall increase in air temperatures. Because thawing begets more thawing in these ecosystems, the team suggests that a climatic tipping point may be on the horizon for the Alaskan interior, especially if global temperatures continue to rise and wildfires become more abundant. (*Journal of Geophysical Research: Biogeosciences*, doi:10.1002/2015JG003033, 2015) **—David Shultz, Freelance Writer**

Aftershocks of Old Quakes Still Shake New Madrid Seismic Zone

The New Madrid Seismic Zone (NMSZ) is a fault system spanning approximately 240 kilometers across Illinois, Arkansas, Tennessee, Kentucky, and Missouri. The paleoseismic history, ongoing seismic activity, and high population density make the NMSZ a key region for seismic research focusing on fault activity and, ultimately, improving community preparedness.

Large earthquakes may be few and far between, but the zone is constantly active and undergoes diverse forms of movement, including "creep"—the ongoing fault displacements that are too subtle to constitute an earthquake. Specifically, afterslip describes creep that occurs along a fault after it has ruptured in a large seismic event. Identifying the source of present-day crustal strain that will lead to future earthquakes is a vital step for improving awareness of seismic hazards and how they evolve.

Here *Boyd et al.* investigate such activity by analyzing GPS data from monitors across the NMSZ collected between 2000 and 2014. The team modeled the data for a range of deformation mechanisms—processes by which strain accumulates in materials at the grain scale—including steady subsurface creep and regional strain, or prolonged rock deformation, and time-dependent afterslip and viscoelastic relaxation resulting from previous earthquakes.

The region has been the source of several major earthquakes over the past thousand years, including three events in the winter of 1811–1812 that topped magnitude 7. Previous studies have suggested that the Reelfoot fault was responsible for a large quake in 1450 and one of the 1812 events, but other large events are attributed to the Cottonwood Grove fault and other nearby faults.

Although debate has been ongoing for more than a decade about whether there is significant strain in the NMSZ, whether present-day activity represents a long-lived aftershock sequence, and whether the NMSZ will continue to produce damaging earthquakes in the near future, the authors argue that current surface deformation can be partly explained by afterslip from the 1450 and 1812 Reelfoot events and suggest that much of the recent activity in the NMSZ may be the result of a long-lived aftershock sequence from previous large earthquakes.

The authors stress that this conclusion does not erase the possibility that the NMSZ is still in an active phase and will continue to produce new, powerful earthquakes over relatively short recurrence intervals. This study is an argument for the continuing threat of high seismic hazard due to the New Madrid Seismic Zone and for the critical importance of resilient infrastructure and adequate preparation. (*Journal of Geophysical Research: Solid Earth,* doi:10.1002/2015JB012049, 2015) **—Lily Strelich, Freelance Writer**

Cloud Overlap Observations Put Simulations to the Test

Clouds at different heights sometimes overlap, stacking one above the other. This overlap strongly affects how much heat enters or escapes the atmosphere, impacting Earth's climate. However, the fine-scale resolution needed to study cloud layers hinders detailed models of the overlap.

Most cloud overlap studies have adopted a wide-angle approach, focusing on either the whole troposphere or on tall cumulonimbus clouds, which are responsible for thunderstorms. Now *Corbetta et al.* have validated a 2011 fine-scale simulation of overlap among low-lying, cotton ball–like cumulus clouds.

For different times of day between April and August 2013, the authors collected cumulus cloud composition and position data at the Jülich Observatory for Cloud Evolution in western Germany. They calculated the ratio between per pixel cloud volume and per pixel cloud area at different altitudes. A higher ratio indicates more overlap between clouds at different heights.

The daily volume-to-area ratios observed for the cumulus clouds matched nicely with simulated ratios, and the scientists also found that both observed and simulated cloud overlap behaviors fit the same type of mathematical function.

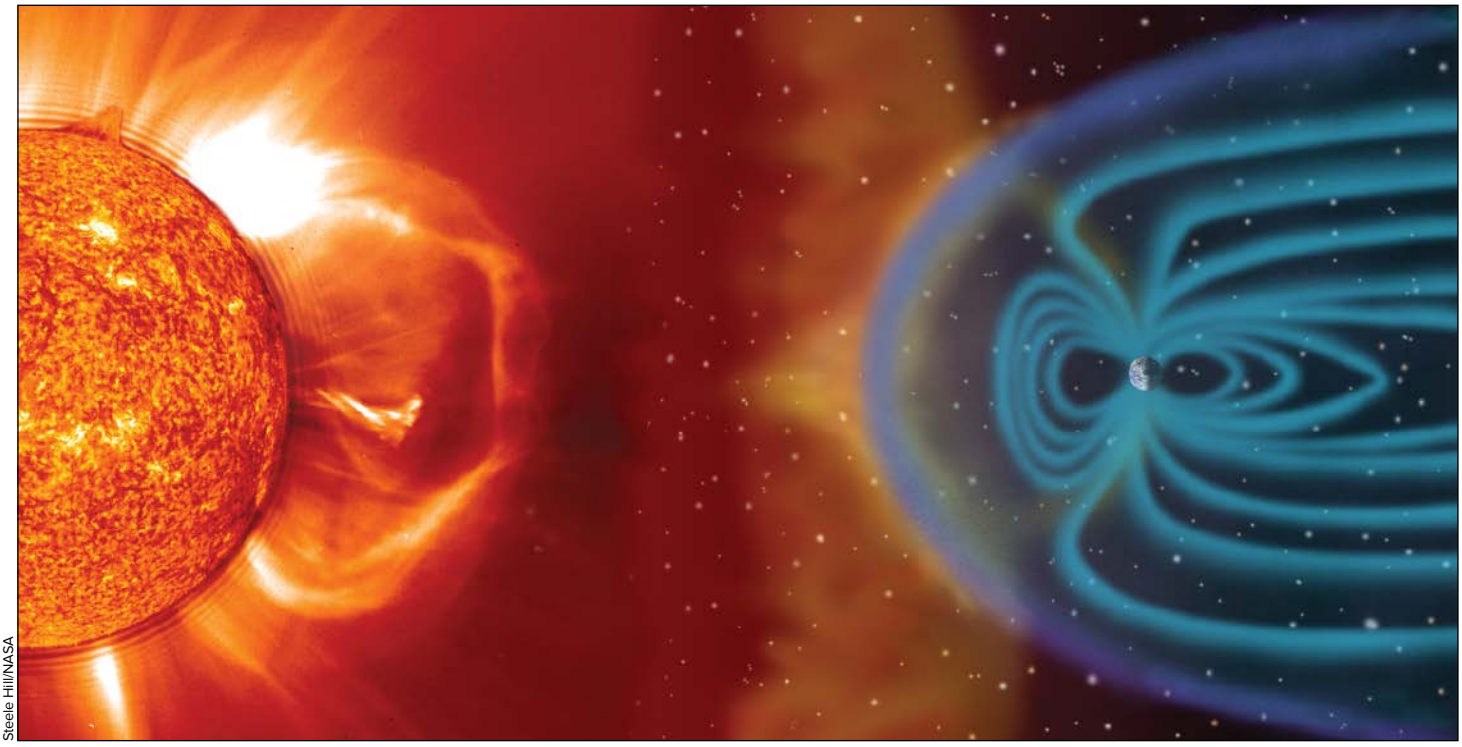
The close match between the observations and simulated data suggests that computer models could be used to reliably predict cumulus overlap behavior and that incorporating them into global climate models could improve forecasts of weather and climate.

The simulations were made using the large eddy simulation (LES) technique, which models turbulence in the atmosphere. Following their success here, the researchers call for further verification of the usefulness of the LES method for virtually exploring cloud overlap. (*Geophysical Research Letters*, doi:10.1002/2015GL065140, 2015) **—Sarah Stanley, Freelance Writer**

NOAA/AOML/Hurricane Research Division, Photographer: C. True

Real and modeled cumulus clouds using the large eddy simulation (LES) technique. Fine-scale simulations of overlap between cumulus clouds like these could improve weather and climate forecasts. Inset generated by Roel Neggers using the LES simulation ParaView at the Jülich Observatory for Cloud Evolution.

Model of Solar Cycle's Impact on Climate Gets Upgrade



Steele Hill/NASA

The solar cycle can affect the Earth's climate through solar radiation and energetic particles. Energetic particles emitted by the Sun interact with the Earth's magnetic field (depicted above, not to scale) and can precipitate into the Earth's atmosphere. Scientists can study the effects of the solar cycle on climate using models such as the Whole Atmosphere Community Climate Model.

The Sun's impact on the climate is a hot and tangled topic. Mounting evidence suggests that the 11-year solar cycle can affect climate and temperatures—the most famous example being Europe's Little Ice Age, when the Sun went through several nearly sunspotless cycles from 1645 to 1715. Of course, there is a much larger factor acting on Earth's climate: the warming trend from the turn of the 20th century, mostly due to human carbon emissions. On shorter timescales, however, the Sun's solar cycle can have a significant impact on the physics and chemistry of Earth's atmosphere.

Now scientists have an upgraded model to help them figure out exactly how these processes work.

Over the course of the 11-year cycle, the rotation of the Sun slowly twists its magnetic field into knots, creating dark sunspots. Although the overall brightness of the Sun varies by only 0.1%, the twisted bundles of magnetic energy can boost its ultraviolet (UV) radiation by 4%–8% at the solar cycle's peak. These powerful UV rays trigger chemical reactions in the stratosphere that bind oxygen atoms and molecules to form ozone. Since ozone itself is a good absorber of UV radiation, it can heat the stratosphere near the equator, which affects the winds that circle the globe.

Increased solar activity also excites Earth's magnetic field, sending high-energy particles hurtling into the upper atmosphere. During the long polar night, this can generate large amounts of the nitrogen compounds nitric oxide (NO) and nitrogen dioxide (NO_2), which eventually descend into the stratosphere and destroy ozone.

To study the effects of these often-competing processes, scientists construct simulations using models such as the Whole Atmosphere Community Climate Model (WACCM) produced by the National Center for Atmospheric Research. *Peck et al.*, at the University of Colorado Boulder, use the latest version, WACCM4, and benchmark its treatment of the solar cycle against its predecessor, WACCM3.

They find that the results are largely similar to the previous model, with a few new twists. As before, when solar activity peaks, the increased UV light boosts ozone levels in the stratosphere over the equator and midlatitudes by 2%–3%. However, the atmosphere's vertical circulation is stronger in WACCM4, which brings twice as much NO and NO_2 down into the stratosphere over Antarctica, more than doubling the destruction of ozone there.

One complication is a long-standing bias in the model, called the cold pole problem, which seems to be exacerbated in WACCM4. This results in stratospheric winter temperatures over the South Pole that are too low and an Antarctic polar vortex that is too strong. However, the Arctic polar vortex is significantly more accurate in WACCM4 than in the previous version.

Overall, the wind and temperature results from the model are mostly consistent with the previous version. The authors say that the results validate WACCM4 and lay the groundwork for a new round of studies that may refine our understanding of the solar cycle's impact on climate. (*Journal of Advances in Modeling Earth Systems* (*JAMES*), doi:10.1002/2014MS000387, 2015) **—Mark Zastrow, Freelance Writer**

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Atmospheric Sciences

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Hydrology

Tenure-Track Assistant Professor Position GROUNDWATER HYDROLOGIST University of Wyoming

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This position will become part of a major research thrust in water resources at the University of Wyoming. Groundwater resources are of immense impo11ance to societal and

ecological needs. Approximately half of Wyoming water resources are from groundwater, and subsurface resources provide critical water to agriculture, oil and gas development, and municipalities. There are tremendous research challenges in groundwater resulting from changing climate signals and human population patterns, and emerging techniques provide outstanding opportunities for groundwater hydrologists to better quantify the fate and transport of water in a changing west. We seek a groundwater hydrologist with experience in laboratory and field approaches for describing complex subsurface processes. Areas of specific interest include, but are not limited to, surface-groundwater interaction, unsaturated flow and contaminant transport.

As a member of the faculty of the Department of Civil and Architectural Engineering, the successful candidate will integrate his or her research with the goals of the new Wyoming Center for Environmental Hydrology and Geophysics (http://www.uwyo.edu/epscor/wycehg/) and provide academic support to the PhD program in Water Resources, Environmental Science and Engineering (http://www.uwyo.edu/wrese/).

UW faculty have access to world-class computational resources as described at: https://arcc.uwyo.edu/. The depat1ment is supported by 22 tenured or tenure-track faculty and offers ABET-accredited baccalaureate programs in both civil engineering and architectural engineering to approximately 300 undergraduate students. The department also offers graduate programs at the Masters and PhD levels to roughly 60 graduate students.

Laramie is a picturesque and friendly town offering a reasonable cost ofliving, good K-12 public schools and easy access to outdoor activities in the Rocky Mountain region. Additional information on the Department, College, and Laramie is available at: http://www.uwyo.edu/civil , http://ceas.uwyo.edu and http://www.laramie.org.

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Ocean Sciences

Assistant Professor, Tenure Track. The University of Washington School of Oceanography invites applications for a full-time (100% FTE), 9-month, multi-year tenure-track Assistant Professor (0116) position. A Ph.D. or foreign equivalent is required on the date of appointment. We seek to hire a physical oceanographer with strong dynamical and/or observational interests. The applicant's research focus may be at any scale, from coastal to global, from mixing to climate. Applicants should demonstrate interest in interdisciplinary collaboration, and complement the research of our current faculty. University of Washington faculty engage in teaching, research and service. The successful applicant will be expected to contribute to the teaching mission of the department at the graduate and undergraduate levels. The University of Washington and the School of Oceanography promote diversity and inclusivity among our students, faculty, staff, and public. Thus, we seek candidates whose research, teaching, and/or service have prepared them to fulfill our commitment to inclusion, and have given them the confidence to fully engage audiences in higher education from a wide spectrum of backgrounds.

The University of Washington (UW) is located in the greater Seattle metropolitan area, with a dynamic, multicultural community of 3.7 million people and a range of ecosystems from mountains to ocean. The UW serves a diverse population of 80,000 students, faculty and staff, including 25% first-generation college students, over 25% Pell Grant students, and faculty from over 70 countries. A recipient of the 2006 Alfred P. Sloan Award for Faculty Career Flexibility and a National Science Foundation ADVANCE Institutional Transformation Award to increase the advancement of women faculty in science, engineering, and math (see www.engr.washington.edu/advance), the UW provides a wide range of networking, mentoring and development opportunities for junior faculty.

Questions pertaining to this search can be addressed to Dr. Parker MacCready, Search Committee Chair (pmacc@uw.edu). More information on the School of Oceanography can be found at http://ocean.washington.edu.

Applicants should submit a cover letter, curriculum vitae with publication list, statements of research and teaching interests with reference to how their teaching and/or research demonstrate a commitment to diversity and inclusion through scholarship or by improving access to higher education for underrepresented individuals or groups, and the names and contact information of four references. We request letters of recommendation from these references to be sent separately. Electronic materials are preferred; send to oceanjob@uw.edu with Assistant Professor PO Position in the subject line. If you are only able to send a hard copy, please address it to Ms. Su Tipple, School of Oceanography, University of Washington, Box 357940, Seattle, WA, 98195, USA. Individuals with disabilities desiring accommodations in the application process should notify Su Tipple at 206-543-5060. Applications, including letters of recommendation, should be received prior to February 1, 2016, to ensure full consideration.

University of Washington is an affirmative action and equal opportunity employer. All qualified applicants will receive consideration for employment without regard to race, color, religion, sex, sexual orientation, gender identity, national origin, age, protected veteran or disabled status, or genetic information. The University of Washington is recognized for supporting the work-life balance of its faculty and offers a wide range of professional development and networking opportunities for junior faculty and a comprehensive benefits package, including access to campus child-care and health/vision/dental plans for spouse, domestic partner, and/or dependents. Details can be found at http://www.washington.edu/admin/hr/benefits/forms/ben-summaries/faculty.pdf

The Department of Ocean and Resources Engineering of the School of Ocean and Earth Science and Technology (SOEST) at the University of Hawaii at Manoa

Invites applications for a full-time tenure-track position, at the rank of assistant or associate professor. Ocean and Resources Engineering is an ABET accredited graduate program offering MS and PhD degrees. Applicants must have a PhD degree in Ocean Engineering or a closely related discipline received no later than June 31, 2016. Other requirements include demonstrated ability as a teacher and student mentor, demonstrated capacity for high-quality research, and excellent communication skills. Established extramurally funded projects and practical and/or professional experience with ocean structures, marine systems, or related topics is highly desirable. Interested applicants should submit a detailed resume, external citation report (preferably via Web of Science), teaching and research plans, copies of three relevant publications, tran-

scripts (copies acceptable with application, official document upon hire), and names and address of three references to orejob@hawaii.edu. Position #: 0084447 is available to fill on August 1, 2016, subject to position clearance and availability of funding. Application review will begin January 15, 2016, and will remain open until filled. For complete job announcement go to webpage: http://www.ore.hawaii.edu/OE/ore_jobs.htm Questions: call 808-956-7572. The University of Hawaii is an Equal Opportunity/Affirmative Action Institution.

Solid Earth Geophysics

Tenure-Track Faculty Position in Geophysics (position number 198994, requisition number 1500158F)

The Department of Physics at New Mexico State University invites applications for a tenure-track faculty appointment in Computational Geophysics. Candidates with computational skills in seismology, crustal and mantle dynamics, and thermo-mechanical properties of rock systems are invited. A strong computational and physics background is required. The NMSU Physics Dept. offers Bachelor's degrees in Physics and Engineering Physics and Master's and Doctoral degrees in Physics and Geophysics. Current research areas in the department include high-energy nuclear and particle physics, solid-state/condensed-matter physics and materials science, optics, and geophysics. There are additional university strengths in Astronomy (helioseismology and planetary physics), Electrical and Computer Engineering, and Mechanical Engineering. The successful candidate is expected to initiate and maintain an active, externally funded research program, supervise graduate students, and to teach at both undergraduate and graduate levels. Appointment will be at the Assistant Professor level. A Ph.D. degree in Physics, Geophysics, or related field is required, and postdoctoral experience is highly desired.

Applications must be filed electronically at (http://jobs.nmsu.edu) and the deadline for applications is February 15, 2016. Applicants should attach a resume, a statement of research interests, a short description of the candidate's teaching philosophy and the names and addresses of at least three persons familiar with the candidate who are willing to provide letters of reference. The position is anticipated to start in Fall, 2016.

For further information or questions please contact the Head of the Search Committee, Prof. Tom Hearn, at thearn@physics.nmsu.edu . NMSU is an Equal-Opportunity/Affirmative-Action employer; Minorities, Females, Veterans, and those with a Disability are particularly encouraged to apply.

Interdisciplinary/Other

Assistant Professor in Tectonics/Structural Geology, Department of Geology, University of Maryland, College Park.

The Department of Geology at the University of Maryland invites applications for a tenure-track assistant professor in Tectonics/Structural Geology, broadly defined. Possible research areas of interest include, but are not limited to: active tectonics and natural hazards, basin analysis, climate-tectonics interactions, crustal evolution, geodesy, microtectonics, orogenesis, planetary geology, and tectonophysics. The appointee will be expected to develop and maintain an active, externally funded research program that will involve both graduate and undergraduate students, and to participate fully in teaching at all levels, including structural geology. We particularly encourage applications from those who integrate across traditional disciplinary boundaries both within the Department of Geology (http://www.geology.umd.edu) and throughout the College of Computer, Mathematics, and Natural Sciences (http://www.cmns.umd.edu). Candidates from underrepresented groups are encouraged to apply.

A Ph.D. in Geology or a related discipline is required at the time of appointment. The appointment may begin as early as August 1, 2016. Applications should be submitted online at http://ejobs.umd.edu/postings/38311 and should include the following: a letter of application stating research and teaching goals; a complete CV; and contact information for three (3) professional references. Review of applications will begin in January 2016, and will be ongoing until the position is filled.

The University of Maryland, College Park, an equal opportunity/affirmative action employer, complies with all applicable federal and state laws and regulations regarding nondiscrimination and affirmative action; all qualified applicants will receive consideration for employment. The University is committed to a policy of equal opportunity for all persons and does not discriminate on the basis of race, color, religion, sex, national origin, physical or mental disability, protected veteran status, age, gender identity or expression, sexual orientation, creed, marital status, political affiliation, personal appearance, or on the basis of rights secured by the First Amendment, in all aspects of employment, educational programs and activities, and admissions.

Assistant Professor Strategic Natural Mineral Resources – Economic Geology – Missouri University of Science and Technology

The Department of Geosciences and Geological and Petroleum Engineering invites applications for a full-time tenure-track faculty position in economic geology – strategic natural mineral resources, at the Assistant Professor level, to begin August, 2016. The successful candidate will be expected to develop an active externally-funded research program that investigates processes related to ore genesis, mineral resources, ore deposit exploration, and demonstrate a commitment to interdisciplinary research. We seek individuals who will integrate their research with excellence in teaching at both the graduate and undergraduate levels. Teaching responsibilities will include service courses as well as courses in the individual's area of expertise. The Department currently has 20 full-time faculty, and 318 undergraduate and 241 graduate degree-seeking students with established B.S., M.S., and Ph.D. programs in Geology & Geophysics, Petroleum Engineering, and Geological Engineering. Closely associated departments include Mining Engineering and Environmental Engineering. Local area establishments with potential collaborative research opportunities include the U.S. Geological Survey (Mid-continent Geospatial Mapping Center), Missouri Department of Natural Resources, Fort Leonard Wood (U.S. Army), the Missouri S&T Rock Mechanics and Explosives Research Center (RMERC), Materials Research Center (MRC), and Energy Research and Development Center (ERDC). Visit our department web pages for more information on faculty and research (http://gse.mst.edu/). Questions regarding this position should be directed to the chair of the search committee, Dr. David Wronkiewicz (wronk@mst.edu).

A Ph.D. in Geology and/or Geophysics is required. The final candidate is required to provide an official transcript showing completion of the terminal degree listed in the application materials submitted. A copy of transcripts must be provided prior to the start of employment. In addition, the final candidate may be required to verify other credentials listed in application materials. Failure to provide the official transcript or other required verification may result in the withdrawal of the job offer.

Applications must include a letter describing interests and possible contributions to our programs, curriculum vita, statements of teaching interests and research goals, up to five reprints of published work, and the names and contact information of three referees. Review of applications will begin on February 15, 2016 and continue until the search is completed.

All application materials including resume/vita, cover letter, reference letters, portfolio, etc., must include the position reference number in order to be processed and must be submitted electronically to: http://hraadi.mst.

Lamont-Doherty Earth Observatory
COLUMBIA UNIVERSITY | EARTH INSTITUTE

Two Faculty Positions in Solid Earth Dynamics, Structure, and Evolution and/or Ocean, Atmosphere and/or Climate

The Department of Earth and Environmental Sciences (DEES) is seeking outstanding scientists to fill two open-rank faculty positions, in the areas of solid earth dynamics, structure and evolution and/or ocean, atmosphere and/or climate. Appointment can be at any rank from tenure-track assistant professor to tenured full professor.

Columbia University's vibrant program in these fields is one of the most highly rated in the United States and includes a world-class research and graduate training program, mostly based at Lamont-Doherty Earth Observatory (LDEO) in Palisades NY, and involving 100+ scientists and 90+ graduate students, as well as an undergraduate program on the Manhattan campus. Primary appointments are within DEES with 9 months of institutional salary support. The positions are based at, and will include affiliation with, LDEO. Secondary affiliation with Columbia's International Research Institute for Climate and Society (IRI) and Department of Applied Physics and Applied Mathematics are possible, as is close collaboration with the American Museum of Natural History and NASA's Goddard Institute for Space Studies.

The successful candidates will develop high-impact research programs focused on problems of global significance and have demonstrated excellence in teaching or potential for such in the case of entry level appointments. Applicants should address the specific ways they would contribute to the research and teaching mission of DEES/LDEO. Minimum requirements for the position are demonstrated scientific creativity and a Ph.D. in a related field. Early-career scientists are especially invited to apply. Application review will commence on January 20, 2016 and continue until the positions are filled. For more information and to apply for either position please visit our online site at:

https://academicjobs.columbia.edu/applicants/Central?quickFind=61767

Columbia University is an Equal Opportunity/Affirmative Action employer -- Race/Gender/Disability/Veteran.

edu/hr/employment . Acceptable electronic formats are PDF and Word.

Missouri University of Science and Technology Human Resource Office Position Reference Number #00065394(Geoscientist).

Missouri University of Science and Technology is an affirmative action/equal opportunity employer.

GDL Foundation Fellowships in Structure and Diagenesis

The GDL Foundation supports study and research of chemical and mechanical interactions, structural diagenesis, in sedimentary basins. Practical applications are of particular interest.

We are currently seeking applications from M.S. and Ph.D. candidates, post-doctoral researchers, and scientists for fellowships, up to $10,000, based on specific proposals for research and participation in meetings and conferences to share results.

Submit applications (available at: www.gdlfoundation.org) by April 1, 2016.

Student Opportunities

The Joint Global Change Research Institute in College Park, MD, seeks multiple Post Doctoral Associates (Job# 305007/ 305008)

To conduct research on hydrologic and water demand modeling at both regional and global scales and integrated analysis of energy-water-land-climate linkages in Latin America using GCAM. The successful candidate must have a Ph.D. in hydrology, engineering, or related field. For more details and to apply, please visit www.globalchange.umd.edu/employment/

PhD Fellowships in Remote Sensing are available immediately in Virginia Tech's Interdisciplinary Graduate Program.

Remote Sensing is an interdisciplinary field which is evolving rapidly to address a wide range of scientific and societal problems. Virginia Tech's Remote Sensing graduate program spans nine departments in five separate colleges and covers all aspects of Remote Sensing, including engineering, theory, data analysis, applications, and policy. Students in the program pursue a Ph.D. in a core discipline in their home department while taking additional interdisciplinary courses which count toward a Remote Sensing Certificate. Interested applicants are encouraged to visit our website (http://rsigep.frec.vt.edu/) to learn more about the curriculum, specific research themes, the application process, and how to communicate with prospective advisors. General questions can be directed to rs_igep@vt.edu.

PhD in Climate Decision Making through EPP at Carnegie Mellon.

We seek PhD students with technical backgrounds to address 1) public understand and perceptions of GHGs, climate and low emission energy portfolios; 2) decarbonizing the energy system; 3) future of nuclear; and 4) risks of dead ends in scaling up climate policies. See: www.epp.cmu.edu and http://CEDMcenter.org. Contact: ebass@cmu.edu.

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UNIVERSITY of VIRGINIA

Associate or Full Professor, Civil and Environmental Engineering

The School of Engineering and Applied Science (SEAS) and College of Arts and Sciences at the University of Virginia seeks candidates for a tenure-eligible or tenured Associate or Full Professor with joint appointments in the Department of Civil and Environmental Engineering (CEE) and the Department of Environmental Sciences (EVSC). This position will lead a cluster of seven new faculty working in the area of Resilience in the Face of Environmental Change and provide academic leadership in the area of Global Water Resilience. The selected candidate will be expected to teach courses at the intersection of environmental engineering and science disciplines, mentor graduate students and participate in the research mission of the University. The candidate's research area should complement current University focus areas with a particular emphasis in changing regional and global water resources and water quality in relation to human welfare. Salary, rank and tenure status are dependent upon qualifications and experience. The primary appointment will be determined based upon specialty of the incumbent.

Candidates must have a PhD in Civil Engineering, Environmental Engineering, Earth and Environmental Sciences, or a closely related discipline as well as demonstrate a strong history of service to the profession. A record of excellence in teaching, research, service, outreach, and leadership in Environmental Engineering and/or Environmental Science; a vision and a long-term commitment to help bring these departments to new heights of international excellence; extensive experience in teamwork and effectively leading interdisciplinary groups; excellent communication (oral and written), interpersonal, and team building skills; skills in institutional advancement and a track record of securing funding, especially from external agencies; commitment to diversity and respect for others are required. Preference will be given to candidates who are internationally recognized for research under the broad umbrella of resiliency in the face of environmental change and to those who are effective mentors to students and an effective classroom instructor.

The award of tenure-eligible requires documentation of excellence in one area (research or teaching), scholarship and regional reputation. The award of tenure requires documented excellence in two areas (research or teaching), scholarship and emerging national reputation.

The University of Virginia is annually ranked as one of the premier public institutions in the United States and is located in Charlottesville, a picturesque small but cosmopolitan city perennially ranked as one of the best places to live in the U.S.

To apply, visit **https://jobs.virginia.edu** and search on **Posting Number 0617880**. Complete a Candidate Profile online, attach a cover letter stating your interest in the position along with research and teaching interests and a CV.

For nominations and additional information about the position, please contact James A. Smith, **jsmith@virginia.edu**. Please include the nominee's contact information and know the search will be carried out with full confidentiality.

For additional information about the application process, please contact **cee-evsc-search@virginia.edu**.

A more detailed position description can be found at the departments' websites at **http://www.evsc.virginia.edu** and **http://cee.virginia.edu**.

The University of Virginia is an Equal Opportunity/Affirmative Action Employer. Women, Minorities, Veterans and Persons with Disabilities are encouraged to apply.

EARTH & SPACE SCIENCE

virtual poster showcase

Abstracts Open for Virtual Poster Showcase #1 for Undergraduates in February

With the easy-to-use online interface, students need to take only these three simple steps to present their research.

1. **Submit an abstract to Virtual Poster Showcases**

2. **Prepare and upload a poster and video presentation**

3. **Judge the posters of peers online and receive comments on the submitted poster**

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AGU

Postcards from the Field

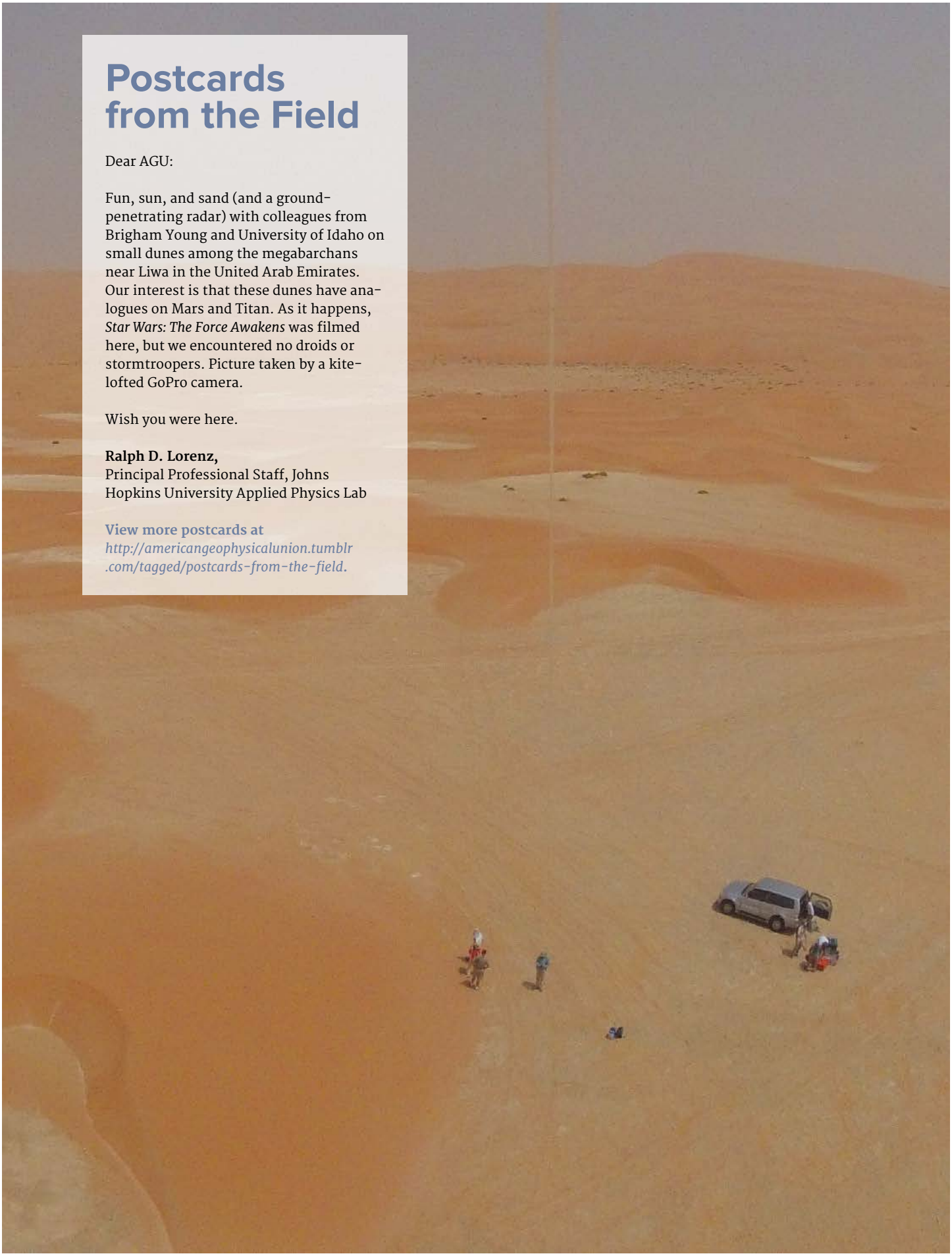
Dear AGU:

Fun, sun, and sand (and a ground-penetrating radar) with colleagues from Brigham Young and University of Idaho on small dunes among the megabarchans near Liwa in the United Arab Emirates. Our interest is that these dunes have analogues on Mars and Titan. As it happens, *Star Wars: The Force Awakens* was filmed here, but we encountered no droids or stormtroopers. Picture taken by a kite-lofted GoPro camera.

Wish you were here.

Ralph D. Lorenz,
Principal Professional Staff, Johns Hopkins University Applied Physics Lab

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



AGU CHAPMAN CONFERENCE

Plan to Attend a Chapman in 2016

Chapman Conference on the Slow Slip Phenomena

21–25 February
Ixtapa, Guerrero, Mexico

Registration Deadline: 3 February

Chapman Conference on Currents in Geospace and Beyond

22–27 May
Dubrovnik, Croatia

Housing Deadline: 15 February

Chapman Conference on Emerging Issues in Tropical Ecohydrology

5–9 June
Cuenca, Ecuador

chapman.agu.org

AGU

HONORS PROGRAM

2016 Call for Nominations

Nominate your colleagues for a prestigious AGU Union Prize, Award, Fellowship, or Medal

Nomination Deadline: 15 March

Section and Focus Group Awards and Lectures

Nomination Deadline: 15 April

New Union Awards for 2016

Africa Award for Research Excellence in Earth and Space Science

William Kaula Award

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