VOL. 96 • NO. 16 • 1 SEPT 2015

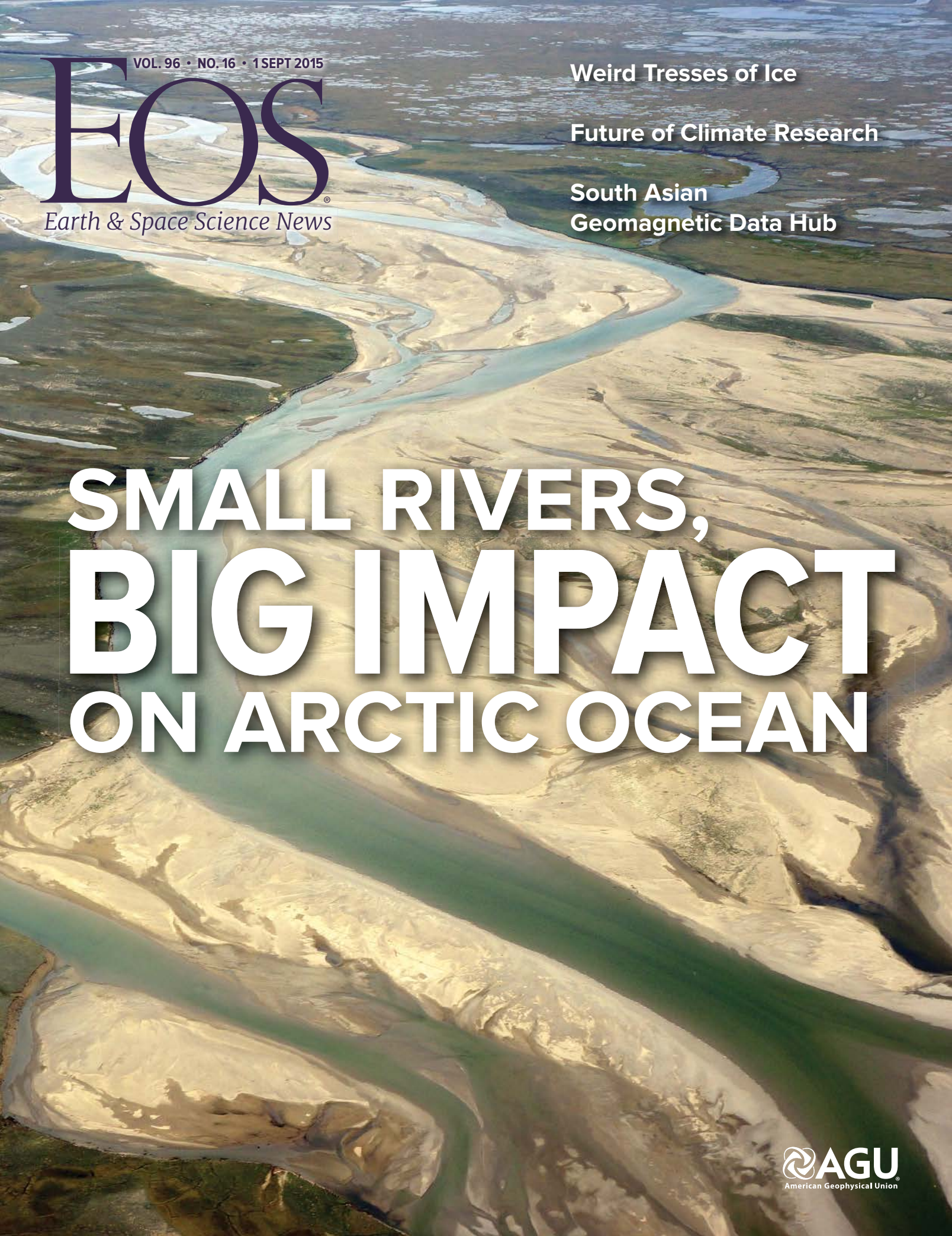
EOS

Earth & Space Science News

Weird Tresses of Ice

Future of Climate Research

South Asian Geomagnetic Data Hub



SMALL RIVERS, BIG IMPACT ON ARCTIC OCEAN

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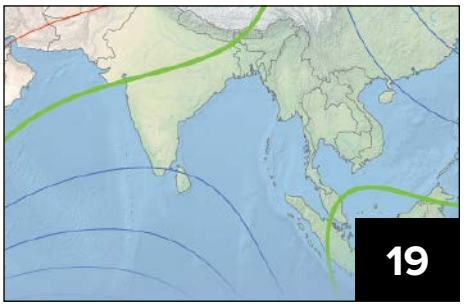
COVER

Small Rivers Could Have Big Impact on Arctic Ocean

The Mackenzie River carries the bulk of freshwater flow from North America's tundra to the North Atlantic. But what about the effects of smaller rivers from Canada's Arctic islands?

PROJECT UPDATE



Making the Northern Indian Ocean a Hub of Geomagnetic Data

A new initiative seeks to unite and network the magnetic research community in the northern Indian Ocean region.

MEETING REPORT

RESEARCH SPOTLIGHT

Past Phosphorus Runoff Causes Present Oxygen Depletion in Lakes

Sediment cores show how phosphorus pollution in the 1950s led to current, inherited hypoxia in lakes in the Alps.

DEPARTMENTS

EOS.

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Eos (ISSN 0096-3941) is published semi-monthly, on the 1st and 15th of the month except the 1st of January 2015 by the American Geophysical Union, 2000 Florida Ave., NW, Washington, DC 20009, USA. Periodical Class postage paid at Washington, D. C., and at additional mailing offices. POSTMASTER: Send address changes to Member Service Center, 2000 Florida Ave., NW, Washington, DC 20009, USA.

Member Service Center: 8:00 a.m.–6:00 p.m. Eastern time; Tel: +1-202-462-6900; Fax: +1-202-328-0566; Tel. orders in U.S.: 1-800-966-2481; Email: service@agu.org.

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Christine W. McEntee, Executive Director/CEO

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Fungus, Physics Explain Weird Tresses of Ice

Six years after Alfred Wegener published his theory on continental drift, the geophysicist scrutinized another curious relationship, one so obscure, however, that it would take almost a century to confirm his hypothesis.

During the winter of 1916–1917 in the Vosges Mountains near the French-German border, he noticed tufts of ultrafine, 4-centimeter-long strands of ice sprouting from dead branches. The first scientist to investigate the hair ice phenomenon, Wegener reported the next year a likely relationship between the projecting ice strands and fungus filaments that also caught his eye, clinging to the surface of the hair ice–bearing wood. Yet how the two were connected remained a mystery—until now.

This summer, a team of German and Swiss scientists not only identified the fungus behind these exotic ice structures but also have explained how an interplay among biological factors, atmospheric conditions, and basic properties of liquid and frozen water may lead to the delicate tresses of hair ice. The researchers published their findings on 22 July in *Biogeosciences* (http://bit.ly/EGUBiogeo), a journal of the European Geosciences Union.

Fungus Found

Hair ice grows under conditions of freezing temperature and high humidity. From 2012 until last year, the researchers created these conditions from time to time in a garden shed to conduct hair ice–growing experiments.

The researchers credit the elaborate ice coiffures subsequently created to *Exidiopsis effusa*, from the phylum Basidiomycota. It is among 11 different species of fungi that biologist Gisela Preuß, a secondary school teacher in Neustadt, Germany, and coauthor on the report, found from microscopic examination of hair ice–growing wood.

"*Exidiopsis effusa* colonized all of our hair ice–producing wood, and in more than half of the samples, it was the only species present," she said.

In the tests, killing *Exidiopsis effusa* with hot water prevented new hair ice from developing when favorable hair ice conditions were restored. Also, in the absence of the fungus, ice formed only a simple crust on the wood.

Ice Hairs Sprout Out

The new tests also tracked temperature variations and chemical composition of water and ice during hair ice growth. They confirmed hypotheses about how hair ice forms posed by other scientists who, since Wegener, also investigated the curious filaments. The growth of hair ice filaments can be seen in a time-lapse video (http://bit.ly/IceGrowVideo) taken at the Gletschergarten (Glacier Garden) in Lucerne, Switzerland.

Unlike the spiky ice crystal crusts called rime ice and hoarfrost, which grow under conditions similar to those of hair ice but with new crystals added at their tips, hair ice grows as its name implies: with the newest crystals forming at its roots, near the wood.

It's there that a film of water gets trapped between wood and ice in such a way that ice hairs sprout radially from the wood surface, like spokes of a wheel, the researchers report. Suction forces within the film draw water from within the pores of the wood toward the freezing front, maintaining the sandwiched water film while adding new crystals to the hairs.

Most known observations of hair ice have come from broadleaf forests, largely located between 45°N and 55°N latitude, in regions including Scotland, Ireland, Wales, the Netherlands, Sweden, Slovenia, Russia, the U.S. Pacific Northwest, and Canada's west coast.

Fungal Freeze Control

With or without fungal activity, "the same amount of ice is produced on wood," said study coauthor Christian Mätzler, an emeritus professor of physics at the University of Bern in Switzerland, in a press release. Although the fungus is a key player in sculpting hair ice, the resulting fibers do not encapsulate any fungus filaments. Rather, the fungus remains on the wood as white webby films.

Instead of acting as a scaffolding for ice fibers, the fungus appears to foster hair ice growth by secreting a chemical that prevents small ice crystals from reconfiguring into larger ones—a process known as recrystallization.

"The action of the fungus is to enable the ice to form thin hairs—with a diameter of about 0.01 millimeter—and to keep this shape over many hours at temperatures close to 0°C," explained Mätzler. "Our hypothesis includes that the hairs are stabilized by a recrystallization inhibitor that is provided by the fungus." This inhibitor, likely a protein, prevents damage that recrystallization would wreak on structures that are fine grained, such as hair ice filaments.

Janine Fröhlich of the Max Planck Institute for Chemistry in Mainz, Germany, who was not involved in the study, commented that *Exidiopsis effusa*'s effect on ice formation might serve as a mechanism for water collection to aid growth of the fungus. A similar process has been suggested for ice-forming lichen, she told *Eos*.

Hair ice found on the forest floor near Brachbach, Germany.

Close-up photo of melting hair ice, showing tiny water droplets on the ice filaments.

Chemical analyses of hair ice meltwater have provided clues to how the fungus may have inhibited recrystallization. Using mass spectrometry, chemist and study coauthor Diana Hofmann of Forschungszentrum Jülich in Germany, found organic compounds in the water, primarily fragments of lignin, which is the main component of wood and a substance that some fungi and bacteria can break down but animals can't. The study authors say more research is needed to determine what role the decomposed lignin may play in hair ice growth and to pin down if the lignin breakdown products are serving as the recrystallization inhibitor.

Rare Ability

Fungi capable of triggering ice crystal formation from liquid water—that is, "ice-nucleating" fungi—can also preserve small crystal ice structures by stopping recrystallization.

Fungi apparently evolved ways to trigger ice nucleation to protect themselves from damage when temperatures drop below freezing, said atmospheric chemist Thomas Hill of Colorado State University in Fort Collins, who did not participate in the study. "The main point is to protect the fungus by initiating freezing at relatively high temperatures," he said.

Among particles and organisms that are ice nucleators, anything that triggers water to crystallize at -5°C or warmer exhibits a rare ability in nature, Hill explained. He called *Exidiopsis effusa*'s apparent ability to trigger ice nucleation just below 0°C "really exceptional."

"It's satisfying to know the organism responsible for such a beautiful thing," Hill continued. He added that this and other recent discoveries show that ice nucleation seems to be much more common than previously thought. However, we still know almost nothing "about what ecological advantages it provides," he explained.

By **Christina Reed,** Freelance Writer

Leading Companies Take White House Climate Pledge

Thirteen of the biggest companies in the United States have signed on to a new initiative by President Obama to reduce greenhouse gas emissions, the White House announced in late July.

The companies—which reported more than $1.3 trillion in revenue in 2014—committed to a total of at least $140 billion in new low-carbon investments, more than 1600 megawatts of new renewable energy, and other measures at the launch of the American Business Act on Climate Pledge (see http://bit.ly/PledgeAct).

The companies also voiced support for a strong outcome at the international climate conference (see http://bit.ly/CoP21) in Paris later this year. The aim of that meeting, which will take place from 30 November to 11 December, is for thousands of delegates from nations and organizations worldwide to reach a legally binding agreement on climate change to prevent global warming of more than 2°C.

Alcoa

Alcoa officials say the company's climate pledge includes reducing carbon dioxide (CO_2) emissions through improved processes, technology, and energy efficiency at aluminum smelters, such as the Wenatchee, Wash., facility, pictured here. Worldwide, Alcoa smelters cut their CO_2 emissions by 6.8% last year, compared with levels from 2013, the company said.

More Businesses Expected to Sign On

Brian Deese, senior advisor to the president, praised the companies for "setting an example" for their industries. The White House hopes that the company pledges unveiled on 27 July are "the beginning of a substantial mobilization effort," he added.

> The White House hopes that the company pledges are the beginning of a substantial mobilization effort.

The administration intends to announce a second round of pledges "from a far broader spectrum of American companies" later this year, prior to the Paris conference, Deese said.

Pledges to Cut Greenhouse Gas Emissions

Among the companies' commitments, Alcoa pledged to reduce its greenhouse gas emissions by 50% in the United States by 2025, compared with a 2005 baseline. Kevin McKnight, the company's chief sustainability officer, said that manufacturing lighter and stronger components for products such as pickup trucks also would help to save energy.

"We think Paris is a big deal. We think that it's critical that the business community get behind government," McKnight said. He called for using the Paris meeting "to really move the world in a different direction."

Microsoft's commitment includes purchasing 100% renewable energy to operate its data and manufacturing centers and other facilities, according to Rob Bernard, Microsoft's chief environmental strategist. "We are committed to carbon neutrality," he said.

Other companies that signed on to the climate pledge are Apple, Bank of America, Berkshire Hathaway Energy, Cargill, Coca-Cola, General Motors, Goldman Sachs, Google, PepsiCo, UPS, and Walmart.

By **Randy Showstack,** Staff Writer

Comet Lander Makes a Hard Discovery

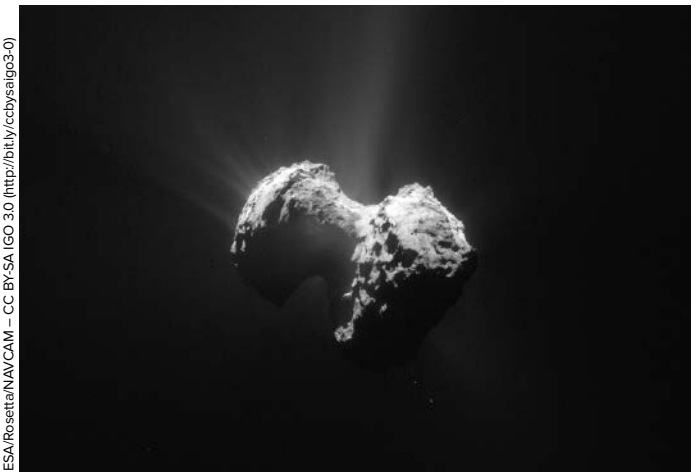
Philae's failed harpoons may have been a blessing in disguise.

Last November, the harpoons' failure to anchor the lander where it initially touched down on comet 67P/Churyumov-Gerasimenko caused the probe to bounce across the comet's landscape. Recently, mission scientists reported that Philae has found a scientific surprise at its final resting place: The ground there harbors a much harder surface than scientists thought could exist on a comet.

In addition to the remarkably hard terrain, Philae scientists described other novel features of the lander's new home, including organic chemicals never found on a comet before—all in a set of six scientific papers published in the 30 July *Science*. The suite of discoveries may provide new insights into how comets form.

Philae initially touched down on an area of the comet called Agilkia, which has a granular surface composed of silicate grains and organics covering harder bedrock, as expected by mission scientists. But when the harpoons didn't secure the lander, it bounced twice and ultimately landed in Abydos, about 1.3 kilometers away. There Philae encountered a surface with a hardness similar to pumice.

"There is very hard material, with a little dust on the surface," said Jens Biele, payload manager for Philae at the German Aerospace Center and lead author of one of the *Science* papers (http://bit.ly/hardpapr). He compared the hardness of the newly analyzed surface to the compacted snow of a glacier, called firn snow.



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An image of comet 67P/Churyumov-Gerasimenko taken by Rosetta on 20 July 2015, from a distance of 171 kilometers.

A sturdy surface could suggest "a hard crust of the same grains that we've seen before but now glued together with probably water ice or other ice," he continued.

Comets in the Laboratory

In the early 1990s, German scientists created a comet analog in the laboratory by spraying water and dust into liquid nitrogen and exposing the mixture to a vacuum while simulating the Sun's radiation. They found that some of the water would freeze, cementing the dust particles together over a few hours. This led them to surmise that comets could have hard, icy surfaces.

> Some scientists believe comets could hold the secret to life on Earth.

However, a few years later, NASA's Deep Impact mission smashed a probe into a real comet—called Tempel 1—and found it to be weak and powdery. Other space probes similarly found a lack of hard material, namely ice, on the surfaces of other comets.

Considering the recent findings from Philae, Biele believes it's time for scientists to revisit the 1990s experiments and further explore the evolution of comets.

"Large portions of the comet seem to consist of this consolidated material that forms the spectacular cliffs and rugged landscape you see in many parts of the comet," Biele said. For now, research by a handful of European scientists on how this material coalesces and becomes hardened is just getting started, he continued.

Organics

In another of the Philae-focused *Science* papers (http://bit.ly/orgnics), scientists reported on the variety of complex organic compounds measured by the spacecraft's onboard instruments, including four compounds—methyl isocyanate, acetone, propionaldehyde, and acetamide—not previously observed on a comet. A few of these compounds, including one of the previously unseen ones, are considered important to the synthesis of biologically necessary molecules such as amino acids and complex sugars.

The compounds "would come in handy for the building of more complicated molecules," said Fred Goesmann, lead author on the paper and principal investigator for Philae's Cometary Sampling and Composition experiment. "If that is a path towards life, I don't know. But it does not look like a path in the opposite direction."

"This way the early solar system provided an environment where life would feel welcome," Goesmann continued.

Relatively small and rocky, comets formed in the early days of our solar system and originated in the Oort Cloud, a vast shell of icy bodies that inhabit the solar system's outskirts. Because organic molecules are not uncommon on comets, some scientists believe that comets could hold the secret to life on Earth.

Philae's Status

The observations analyzed in the *Science* studies were made by Philae before 15 November 2014. That was when the probe's batteries ran out after the lander's bouncy debut on the comet deposited it where it couldn't initially receive enough sunlight to recharge the cells. After Philae finally received adequate Sun exposure, it radioed mission control once in late June and again on 9 July but was silent from then until this issue of *Eos* went to press.

The lander has enough power to last until October or November, Philae project manager Stephan Ulamec said, but a problem was suspected with a transmitter unit.

Although the prospects for future scientific findings from Philae remained uncertain, project scientists seemed optimistic. "As soon as we get better radio contact, we are prepared to do more science," Ulamec said.

By **JoAnna Wendel,** Staff Writer

Hearing Sparks Concerns About Planetary Science Funding

House Science Committee

John Grunsfeld, associate administrator of NASA's Science Mission Directorate (far left), testified at a 28 July Congressional hearing on NASA solar system exploration. Other witnesses who spoke were (from left to right after Grunsfeld) Alan Stern, principal investigator of the New Horizons Mission, Southwest Research Institute; Christopher Russell, Dawn mission principal investigator and professor of geophysics and planetary physics at the University of California, Los Angeles; Robert Pappalardo, Europa mission project scientist, NASA Jet Propulsion Laboratory; and Robert Braun, professor of space technology at the Georgia Institute of Technology.

A recent Congressional hearing about exploration of the solar system alternated between amazement at recent successes, such as this summer's Pluto flyby, and acrimony about projected funding levels for planetary science at NASA.

At the 28 July hearing, Rep. Lamar Smith (R-Texas), chair of the House of Representatives' Committee on Science, Space, and Technology, lambasted as inadequate the Obama administration's budget request for NASA planetary sciences for fiscal year (FY) 2016.

"Funding levels requested by the Obama administration would slow the rate at which we can develop, build, and launch new missions," Smith said. He cited the New Horizons mission, which achieved the close flyby of Pluto on 14 July, as an example of the type of mission that could be impeded. House-approved funding levels "would allow NASA to keep planetary missions like New Horizons on track," he said.

Ranking member Rep. Eddie Bernice Johnson (D-Texas) noted that Congress needs to do its part in keeping NASA's solar system exploration program robust "by making sure NASA receives adequate and timely funding to support the development and operation" of solar system missions. She also called for funding for advanced technology development to enable missions to "continue to rewrite the science textbooks."

A Key Difference

The administration requested $1.36 billion for NASA planetary sciences in FY 2016, down $77 million from the FY 2015 enacted level of $1.44 billion. The House passed an appropriations bill calling for $1.56 billion, $200 million more than President Obama had asked for.

A key difference between the administration and House proposals is how much funding each allocates to missions to study Earth versus those to explore other planets and beyond. The House targeted NASA Earth science funding for cuts. It passed increased funding for exploration directed outward into the solar system, an endeavor popular with many House members.

More Funding Could Keep Missions Moving

At the hearing, John Grunsfeld, associate administrator of NASA's Science Mission Directorate, said that if the agency is given more planetary science funding, it could speed up the pace at which high-priority "Discovery-class" and "New Frontiers-class" planetary missions reach milestones and launch. New Horizons was the first mission under the New Frontiers program, which caps missions at $1 billion; Discovery missions are capped at $450 million.

Robert Pappalardo, the project scientist for the Europa mission at NASA's Jet Propulsion Laboratory in Pasadena, Calif., testified that the pace of possible exploration of Jupiter's moon Europa depends on the pace of the funding. "We can walk or we can crawl to get there." He added that young planetary scientists "question whether they can stay in the field because of the kinds of cuts that have happened." These cuts eliminated some research programs associated with missions.

Déjà Vu

Funding included in the House bill could move up a Europa mission launch compared to how quickly it could happen under the Administration proposal, Casey Dreier of the Planetary Society told *Eos* after the hearing. Dreier is advocacy director for the nonprofit organization, which serves space exploration enthusiasts.

The House bill also includes money for two active missions—the Mars Opportunity rover and the Lunar Reconnaissance Orbiter—that are zeroed out in the administration's request, Dreier noted. The FY 2016 proposals repeat a pattern that has recurred with every budget request since FY 2013, he said: The administration request cuts planetary science funding that Congress has restored every time.

Space Showcase

Although pending budgets for planetary science emerged as a contentious issue at the hearing, the event mainly served to showcase the recent Pluto flyby and other NASA solar system exploration missions, such as a mission to Europa and the Dawn mission to the dwarf planet Ceres and asteroid Vesta.

By **Randy Showstack,** Staff Writer

The Future of Antarctic Subglacial Lake Exploration

Antarctic Subglacial Lake Exploration: First Results and Future Plans
Chicheley, U. K.; 30–31 March 2015

Twenty years ago, scientists first theorized that Lake Vostok, the gigantic subglacial lake in central East Antarctica, harbored a unique microbial community that evolved in isolation over millions of years and contained records of ancient climate change.

We now know that more than 400 subglacial lakes exist across Antarctica, that many of them regularly discharge water to and receive water from the subglacial system, and that ice flow is affected by such behavior. In just 2 decades, the notion of the Antarctic continent as a frozen, unvarying, and lifeless place has changed because of the discovery of dynamic and extensive drainage systems at its base.

The Scientific Committee on Antarctic Research (SCAR) formed a committee in 2000 to oversee the exploration of subglacial lakes. Between 2000 and 2009, the committee encouraged the development of three programs to explore Lake Vostok, Lake Ellsworth (a deepwater lake in the center of West Antarctica), and Lake Whillans (a shallow "active" lake at the edge of West Antarctica).

To discuss the results from these pioneering programs and to plan future work, 60 researchers from 12 nations gathered in the UK Royal Society's Chicheley Hall for the seventh international meeting on subglacial lake environments (see http://bit.ly/SCARLakes). The meeting coincided with SCAR's 20-year horizon-scanning exercise, in which logistics and engineering groups identified 80 questions that could drive research in the Antarctic going forward.

> Development of technology for clean, reliable deep-ice access and in situ data acquisition is essential for subglacial lake exploration.

A view of the bottom of the second ice core to reach Lake Vostok's surface. The ice-water interface was 3769.15 meters below the ice surface.

Science Updates and Research Priorities

Participants heard how, in February 2012, Russian scientists drilled into the top of Lake Vostok using the Vostok Station ice corer and that this feat was repeated in January 2015. British scientists explained why, in December 2012, an attempt to access Lake Ellsworth was halted when a specially designed clean deep-ice hot-water drill experienced technical difficulties. U.S. scientists then described the successful clean access and sampling of subglacial Lake Whillans in January 2013, revealing a thriving microbial ecosystem in the lake water and sediments.

Scientists attending the meeting identified three priority recommendations for future research. First, development of technology for clean, reliable deep-ice access and subsequent in situ data acquisition is essential for subglacial lake exploration. Second, a variety of subglacial environments must be considered for exploration before the full extent of subglacial biodiversity and cross correlation of climate records can be evaluated. Finally, international cooperation is necessary to optimize resources, allowing the sharing of logistics, equipment, and samples.

Participants debated the merits of targets for future exploration, including deepwater lakes at the ice sheet center, hydrologically active lakes closer to the margin, former subglacial lakes now covered with thin ice, and deep sedimentary basins where extensive groundwater may exist.

Discussions also revealed that scientists now have an excellent understanding of how to execute the exploration of a subglacial lake, first envisaged 20 years ago for Lake Vostok, using hot-water drilling and a variety of instrumentation packages and proven cleanliness techniques. It is entirely feasible that this and other subglacial lakes can be explored thoroughly in the coming decade, making research priorities set at the meeting pivotal to the history of Antarctic subglacial exploration.

By **Martin Siegert,** Grantham Institute, Imperial College London, London, UK; email: m.siegert@imperial.ac.uk; **John Priscu,** Montana State University, Bozeman; and **Irina Alekhina,** Arctic and Antarctic Research Institute, St. Petersburg, Russia

Modeling the Stratosphere's "Heartbeat"

Quasibiennial Oscillation Modeling and Reanalysis Workshop
Victoria, British Columbia, Canada, 16–18 March 2015

The quasibiennial oscillation (QBO) of the prevailing winds in the tropical stratosphere between strong easterlies and strong westerlies represents the most repeatable aspect of the circulation in the atmosphere, other than the astronomically forced annual and daily cycles. The QBO is believed to be internally forced in the tropics via the interaction of the prevailing flow with vertically propagating waves.

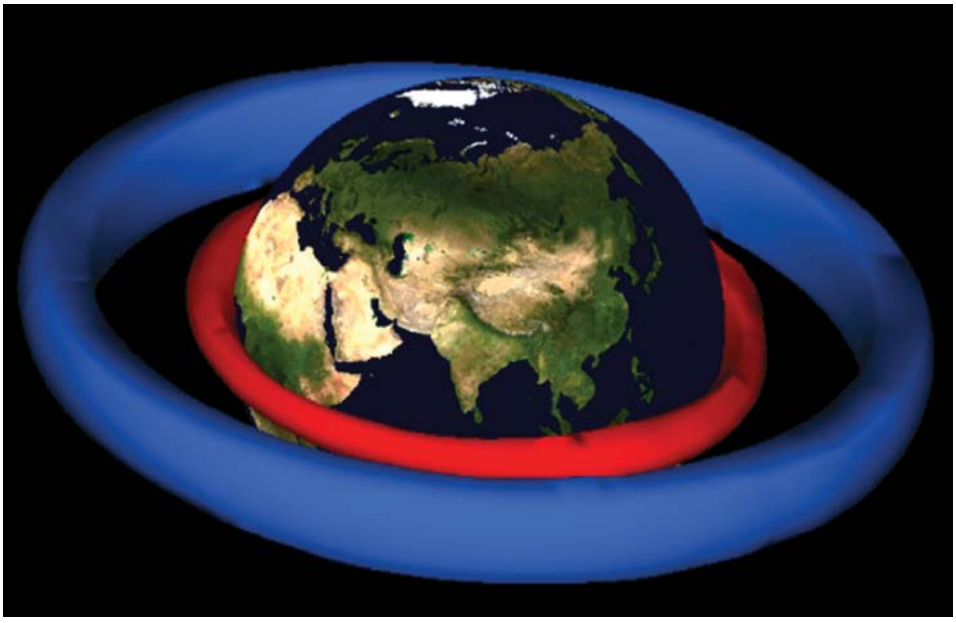
Although rooted in low latitudes, the QBO has global impacts. It is the "heartbeat" of the stratosphere, greatly influencing interannual variability in circulation and composition.

The QBO also affects the circulation at the Earth's surface and is an important consideration in extended-range weather forecasts. Unfortunately, the QBO itself is not well represented in computer models used for weather predictions. Thus, any potential that it offers for long-range weather predictions is not being well exploited by current forecasting systems.

The international QBO initiative (QBOi; see http://bit.ly/IntnlQBOi) is an effort among scientists to stimulate and coordinate computer modeling research on the QBO. The first QBOi workshop, held in mid-March, attracted 32 scientists from seven countries who reviewed achievements and remaining challenges in understanding and modeling the QBO.

What Do We Know About the QBO?

The workshop began with a review of the basic dynamical considerations underlying current theories about the QBO. Attendees agreed that the current paradigm, in which the QBO is maintained by the evolution and dissipation of vertically propagating waves, is sound but that questions remain about the dynamics behind the actual switching of the prevailing wind direction between westerly and easterly in the lowermost stratosphere. Although this switching mechanism can be clearly understood in very simplified models of the QBO that artificially constrain winds near the tropopause, meeting participants felt that in the real world this fundamental aspect of the QBO remains mysterious.



Kevin Hamilton

Visualization of the monthly mean zonal winds for August 1995 in the approximately 18–40 kilometer altitude region, with the vertical scale greatly exaggerated. The red and blue surfaces enclose regions of strong westerlies and easterlies. Plotted data are restricted to 30°S–30°N, and wind data have been time filtered to emphasize variations related to the quasibiennial oscillation.

The workshop continued with a review of results from the few global models that have produced "QBO-like" winds in the equatorial stratosphere. This review revealed common deficiencies in all current simulations, notably with QBO winds being unrealistically weak in the lowermost stratosphere and having unrealistically small cycle-to-cycle variability in the model simulations. The review of existing capabilities also highlighted rapidly growing efforts at many centers to better represent the upper atmosphere in global models used for operational weather forecasting and long-term climate projections.

Developing a Framework for Testing Models

Participants agreed on a framework for coordinated computational experimentation at the many research centers now involved in the QBOi. For the initial phase, planned for the next 12–18 months, meeting attendees identified two major paths for experimentation.

First, groups will run long simulations with versions of their models that produce the most realistic mean flow oscillations. The groups will then repeat these runs under significantly perturbed global climate conditions. Participants decided that there should be a common set of model fields saved at frequent intervals so that assessors can diagnose the wave–mean flow interactions in these experiments.

As its second focus, the QBOi will also specify ensemble forecast experiments to be run for seasonal time scales from realistic initial states. Following the workshop, the QBOi executive committee created a blog to host ongoing discussion of QBOi issues (see http://bit.ly/QBOiBlog).

Acknowledgments

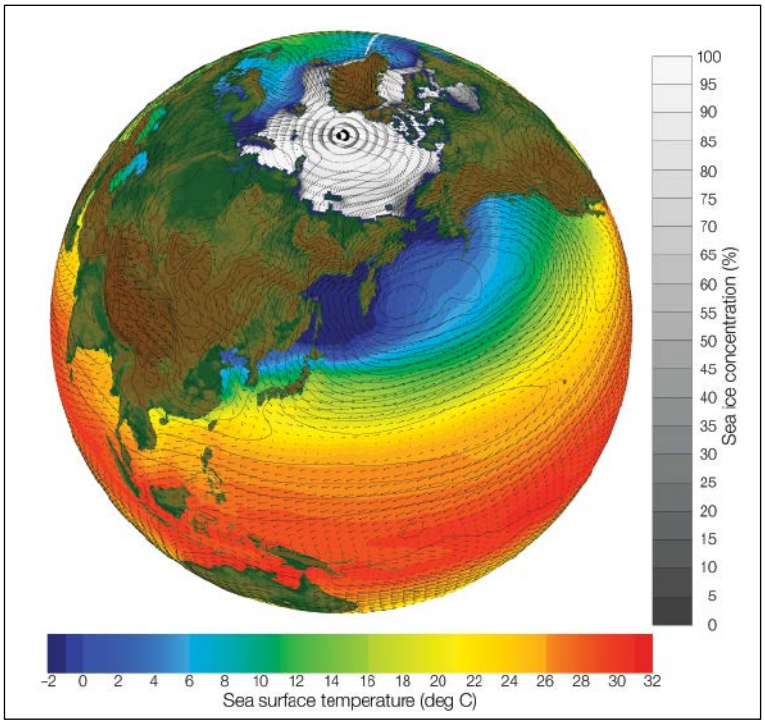
Lesley Grey and James Anstey provided help key to achieving the workshop goals. We gratefully acknowledge funding from the UK Natural Environment Research Council and the Stratosphere-Troposphere Processes and Their Role in Climate project and local support from the Canadian Centre for Climate Modelling and Analysis. Sharon deCarlo helped produce the illustration.

By **Kevin Hamilton,** International Pacific Research Center, University of Hawai`i, Honolulu; email: kph@hawaii.edu; **Scott Osprey,** Atmospheric, Oceanic and Planetary Physics, University of Oxford, Oxford, UK; and **Neal Butchart,** Met Office Hadley Centre, Exeter, UK

Future Directions for the World Climate Research Programme

As climate uncertainties increase on many fronts, the international climate research community is taking stock of its current research efforts and developing an evolving set of strategies to address these uncertainties with relevance and skill. The community displays a strong sense of urgency and commitment, even in the face of substantial social, political, and financial obstacles. However, representatives and leaders of the community must address cuts and redistribution of research funding, support the efforts of numerous volunteers, and develop and disseminate a compelling message to sustain the focus and commitment of this valuable research community.

With partners from the national and international assessments community, climate scientists urgently need to evaluate recent research as well as scientific and political outcomes from a mutual and timely vantage point of viewing assessment report products in light of ongoing research and, conversely, of scrutinizing the directions of ongoing climate research following recent national and international assessments. However, valid concerns have emerged within the research community about the present focus and impact of climate research and about the probable effort and impact of subsequent assessments. These concerns center around the quality of subsequent products: How can the research community ensure substantial rather than incremental improvements, and will the impacts justify the efforts?



This image, taken from a broader simulation of climate in the 20th century generated by the Community Climate Model (CESM), depicts environmental variables including sea surface temperatures and sea ice concentrations. Simulating past conditions and comparing them to past observations helps scientists verify a model's accuracy.

To address these concerns, science leaders from the World Climate Research Programme (WCRP) and the Intergovernmental Panel on Climate Change (IPCC) are in deep collaboration. Together, they have outlined several knowledge gaps.

Speaking for WCRP, we recognize that addressing these knowledge gaps requires continual reexamination. WCRP's evolution must ensure relevant and timely science outcomes in the context of immediate and longer-term efforts to mitigate climate change while recognizing political and funding challenges.

Research and Assessment Communities Meet

In the absence of an internationally agreed-upon and funded climate research strategy, the WCRP, on behalf of the World Meteorological Organization, the International Council for Science, and the Intergovernmental Oceanographic Commission, assumes the daunting tasks of planning and coordinating international efforts on climate research. The WCRP, a multinational consortium established in 1980, has undergone internal refreshment and refocusing since 2011.

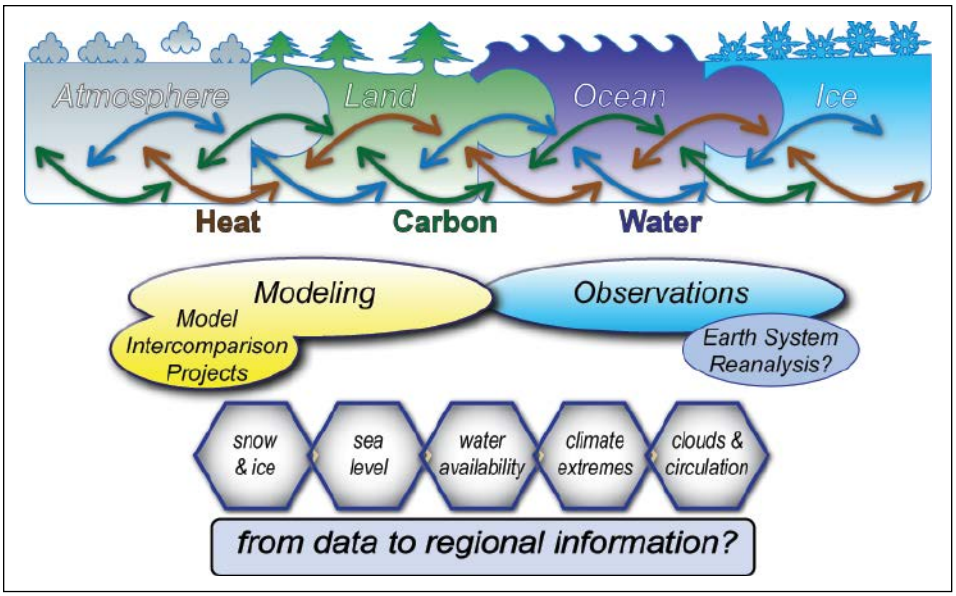
Following extensive engagement with the research community, WCRP identified five climate science "grand challenges." These call for community focus and rapid progress on the following topics:

- clouds and atmospheric circulation
- regional sea level
- climate extremes
- water availability
- rapid cryosphere changes

As the WCRP grand challenges developed, the IPCC, the United Nations organization charged with producing periodic climate assessments, was working on its Fifth Assessment Report (AR5). This report, based largely on WCRP-led or -coordinated research and modeling activities, was released in 2014. AR5 Working Group I (*Climate Change 2013: The Physical Science Basis*; see http://bit.ly/IPCCWG1) placed special emphasis on WCRP's work.

The Joint Scientific Committee of WCRP, working closely with Working Group I leaders, organized a "Lessons Learnt for Climate Change Research" meeting to discuss AR5 soon after its publication. WCRP invited more than 75 researchers to convene in Bern, Switzerland, in September 2014, where they simultaneously evaluated AR5 and revisited the WCRP grand challenges. The meeting participants, a good mixture of lead authors of IPCC AR5 and WCRP project leaders, evaluated climate science, WCRP directions and plans, and future needs for research and assessments.

The "Lessons Learnt" meeting was conducted in partnership with the Technical Support Unit of IPCC Working Group I and the International Space Science Institute at the University of Bern. It had substantial financial support from the Swiss Federal Office for the Environment. Attendees primarily discussed the Working Group I report, but they also considered the reports from Working Group II (*Climate Change 2014: Impacts, Adaptations, and Vulnerability*; see http://bit.ly/IPCCWG2) and Working Group III (*Climate Change 2014: Mitigation of Climate Change*; see http://bit.ly/IPCCWG3). A few weeks later, in November 2014, one of us (D.C.) attended the 7th Science Steering Committee meeting of the World Weather Research Programme (WWRP), where urban environments emerged as one convergent and overlapping area of mutual focus for WWRP and WCRP.



The World Climate Research Programme (WCRP) seeks to understand and predict present and future flows of heat, water, and carbon in atmospheric, land, oceanic, and ice systems through skillful use, intercomparison, and sharing of models and observations. WCRP presently focuses its efforts through grand challenges (hexagons). We recognize the need to increasingly ensure continuity and fidelity from global climate data to socially useful regionally focused information.

No Research Gaps, but Knowledge Gaps Remain

The "Lessons Learnt" group in Bern was asked to identify research gaps in AR5, particularly in the Working Group I report. Their response was emphatic: almost none. Nearly every researcher could identify areas of scientific progress since the 2012 and 2013 cutoff dates for the AR5 materials.

It was no surprise that systematic scrutiny, including a premeeting survey, turned up no serious omissions or weaknesses based on the research available at the time of the report. The conduct of AR5 and Working Group I processes were thorough, inclusive, and highly professional. Anticipating this result, the meeting's Steering Committee structured meeting topics and sessions much more around the issue of knowledge gaps—challenges ahead rather than omissions behind.

The overall approach of AR5 was to assign calibrated uncertainty language to key findings, either through specifying a qualitative level of confidence (e.g., medium or low confidence) or, where the science permitted, a quantified certainty of assessment conclusions. This allowed the Steering Committee to extract and expose a series of key uncertainties in observations, forcing factors, fundamental understanding, and global and regional projections.

The committee then challenged meeting participants to assess WCRP activities, particularly the previously identified WCRP grand challenges, in light of these uncertainties. Perhaps not surprising (but certainly not inevitable), the group found a good match between goals of the WCRP grand challenges and knowledge gaps identified in the AR5 Working Group I report.

Matching Research Activities to Knowledge Gaps

Despite an overall coherence between AR5 Working Group I knowledge gaps and WCRP plans, a meeting-wide cross analysis of uncertainties versus ongoing activities exposed four areas for which the WCRP's grand challenges seemed either deficient or in need of broadened or expanded research.

> Valid concerns have emerged within the research community about the present focus and impact of climate research.

Ocean Heating and Circulation. Ocean heating, particularly in the deep ocean, was identified within the WCRP sea level grand challenge and was prominent within the premeeting survey. However, ocean heating and circulation, linked to decadal prediction challenges, seemed too weakly represented in the meeting agenda and hidden or at least subdued in the WCRP grand challenges.

Annual to Decadal Time Scales. The need for greater emphasis on understanding natural variability and forced change on annual to decadal time scales is relevant, and indeed urgent, for predictions of climate extremes (particularly those related to water availability) and other climate impacts on regional spatial scales.

Short-Lived Climate Forcers. There is a need for better descriptions and incorporation of aerosols and other so-called short-lived climate forcers into understanding and prediction on annual to decadal time scales and on local to regional spatial scales.

Biogeochemical Cycles. The need is growing to incorporate interactive components of the carbon and other biogeochemical cycles, including terrestrial and oceanic geochemical and ecological sources and sinks, into analyses and models.

Thinking Decadally

Despite great progress in modeling potential future conditions, the goal of increased predictive skill on decadal time scales emerges as a clarion theme. This theme, although hardly new, suggests an encompassing challenge and direction for WCRP. As weather forecasting extends from daily to weekly out to seasonal scales, climate predictions must move from centennial scales through decadal toward seasonal.

Weather and climate communities recognize this need despite enormous scientific and technical challenges. We suspect that fragmented organizational structures, with various seasonal and decadal initiatives and projects scattered within WCRP and between WCRP and its weather research counterpart, WWRP, reflect a very real scientific complexity. Unfortunately, this fragmentation may portend a hesitant approach to integrating these efforts.

At the same time, we recognize a need for WCRP and WWRP to work together to address urban populations and environments where hourly to decadal time scales, regional geographic scales, and integrated coupled weather-climate modeling capabilities become more urgent and more challenging. In particular, we understand that local decisions about investments in, for example, coastal infrastructure require mutually consistent predictions of extreme storm events and climate trends.

Gathering Data

Virtually every speaker and every report given at the "Lessons Learnt" discussions in Bern

emphasized a need for better and more systematic sources of and access to data. Recognizing the extremely positive impact of meteorological reanalyses across and beyond atmospheric research and modeling, we anticipate movement by the major modeling centers toward broader Earth system reanalyses.

It seems timely to initiate a broad effort to gather existing but so far narrowly used climate data products from across the physical, chemical, biological, and ecological communities into a more uniform and assimilation-friendly format. We recognize substantial technical challenges arising from variable spatial resolutions and temporal extents, but we contend that such a planetary diagnosis effort represents a long-avoided task whose implementation would reverberate strongly through science and data communities.

Challenges Ahead

As WCRP pursues new directions, we confront four interlinked obstacles:

- Funding is decreasing generally, and it is increasingly earmarked and allocated for purposes other than fundamental climate research.
- Despite confirmation of the validity, indeed urgency, of the WCRP grand challenges, we have only a mixed record of implementation and a weak record of public engagement.
- Our tendency across WCRP is to overload and overwork a few key individuals, especially female individuals.
- Our most careful and creative products continually and increasingly clash with social or political comfort and convenience.

WCRP has developed through the accretion of good ideas and worthy plans, reflecting the emerging complexity and expanding facets inherent in analysis and prediction of a rapidly evolving climate system. Although we describe here the recent and necessary reassessment of the WCRP activities, we see a need for additional and continual refinement in light of priorities and resources.

With a small number of staff serving management and coordination roles at the center and across the projects, WCRP always and increasingly relies on enthusiastic volunteers who build and sustain the international science community. We observe an optimistic sense of urgency and possibility within that community—the collective overt determination to not simply repeat past steps or continue past processes emerging from the "Lesson Learnt" meeting confirms their motivation.

If we as representatives and leaders fail to confront funding, implementation, capacity, and messaging issues, we risk a serious and disabling loss of confidence and commitment within and across this most valuable climate resource.

Acknowledgments

We thank Thomas Stocker, cochair of IPCC AR5 Working Group I, and our colleagues within WCRP and from the Working Group I Technical Support Unit for extraordinary cooperation and support.

By **Guy Brasseur,** Chair, WCRP Joint Scientific Committee; also at Max Planck Institute for Meteorology, Hamburg, Germany; and **David Carlson,** Director, WCRP, Geneva, Switzerland; email: dcarlson@wmo.int

A view of the Kellett River, which drains to the west coast of Canada's Banks Island into the Arctic Ocean.

Robie W. Macdonald

SMALL RIVERS COULD HAVE BIG IMPACT ON ARCTIC OCEAN

By Matthew B. Alkire, Andrew D. Jacobson, Gregory O. Lehn, and Robie W. Macdonald

On the north coast of North America, the biggest river is the Mackenzie, carrying some 300 cubic kilometers of freshwater from Canada's Northwest Territories to the Arctic Ocean every year. Ocean currents eventually bring a fraction of this freshwater between Canada and Greenland through Davis Strait and into the North Atlantic.

Freshwater entering the North Atlantic through the Davis Strait has the potential to disrupt deep convection and thereby inhibit global thermohaline circulation, an important process by which ocean currents redistribute heat and help moderate the climate. Furthermore, the collection of this river runoff into coastal currents will also lower the saturation state of calcium carbonate and exacerbate ocean acidification in this already vulnerable area of the world.

The Mackenzie isn't the only river draining into the Arctic and delivering nutrients to the North Atlantic, however. Numerous smaller rivers flow across the North American mainland and the Canadian Arctic Archipelago (CAA), the islands north of Canada and west of Greenland.

To assess the importance of these small rivers to freshwater export from the Arctic region, we've started a project called Assessing the Impact of Small, Canadian Arctic River Flows (SCARFs) to the Freshwater Budget of the Canadian Archipelago. This new research project compares the chemical signatures of small rivers spread across the CAA with those of larger North American rivers such as the Mackenzie and Yukon. It also seeks to ascertain whether CAA rivers significantly contribute to the total volume of freshwater draining through Davis Strait.

What Volumes Do Small CAA Rivers Hold?

Only a few CAA rivers are currently gauged, but data available from the Water Survey of Canada suggest that the mean annual discharge ranges between roughly 3 cubic kilometers per year (Ellice River) and 16 cubic kilometers per year (Back River). Compared to the annual discharge of the Mackenzie River (~300 cubic kilometers per year), these individual contributions are quite small.

However, *Lammers et al.* [2001] estimated that the total runoff from CAA rivers could be as high as about 200 cubic kilometers per year. Therefore, when taken together, CAA rivers may substantially contribute to the amount of Arctic freshwater draining through Davis Strait.

Sampling the Rivers

To determine whether CAA rivers have unique geochemical signatures, we collected samples from eight CAA rivers during June and July 2014. Working out of small hamlets, we sampled two easily accessible rivers (the Coppermine and Kangiqtugaapik rivers) and flew to more remote locations to sample the rest (the Ellice, Back, Hayes, Kujjuua, Cunningham, and Thomsen rivers). To minimize our environmental impact, we consulted with local community leaders about site selection and hired wildlife monitors to accompany the team into the field.

The sites were chosen far enough upstream to ensure that saltwater was not intruding from the ocean and con-

The estuary of the Hayes (top) and Back (bottom) rivers in the central Canadian Arctic Archipelago, two of the eight rivers sampled during June–July 2014 as part of a project that aims to assess the impact of small Canadian rivers on the freshwater budget of the Arctic Ocean. The rivers exhibit very different turbidities, marked by a sharp boundary between the turbid Hayes and the transparent Back. Sampling occurred within days of breakup in which small bits of ice continued to drift downstream from the Back River.

taminating them. At each site, researchers waded into the river and used an extendable pole to obtain bulk water samples from the central channel. The bulk samples were then filtered and subsampled on shore to determine their chemical makeup, including major anions (chloride, sulfate, and bicarbonate), major cations (calcium, magnesium, sodium, potassium, and strontium), barium, strontium isotope fractions ($^{87}Sr/^{86}Sr$), dissolved organic carbon (DOC), stable oxygen isotopes ($\delta^{18}O$), total alkalinity, and nutrients (nitrate, nitrite, ammonium, phosphate, and silicic acid). The team also measured water temperature, pH, and conductivity with portable meters and collected bed load sediments.

Although each site was sampled just prior to or immediately after the river flows peaked from spring meltwater, the geochemistry is expected to vary slightly as discharge decreases over the summer. To assess seasonal variations, we trained local workers from the communities of Kugluktuk and Clyde River to collect water samples on a weekly basis between June and October in 2014–2016.

The Mackenzie Versus the Rest of the CAA

Preliminary results (Figure 1) indicate substantial variability among the CAA rivers as well as significant differences from larger North American rivers such as the Mackenzie. Overall, CAA rivers have lower alkalinities, as well as lower concentrations of barium and DOC, compared to the Mackenzie River.

However, total alkalinities measured in rivers draining the western CAA (Coppermine, Cunningham, Kujjuua, and Thomsen Rivers) approach that of the Mackenzie River. Six of the eight rivers have similar DOC concentrations that are only slightly lower than that of the Mackenzie River, whereas the two northernmost rivers (Cunningham and Kangiqtugaapik Rivers) have much lower concentrations.

One major factor contributing to the difference in chemical composition between the rivers is the variation in geology and vegetation within the various drainage basins. For example, the Mackenzie drainage basin extends primarily through subarctic forests that cover a highly erodible mountainous terrain, which fills the river with runoff material derived from the diverse rocks that get dissolved and suspended in the water [*Guay and Falkner,* 1997].

In contrast, the drainage basins of the smaller CAA rivers are much less geologically and biologically diverse. The area between the Mackenzie River and Hudson Bay, for example, is composed mostly of Precambrian shield crystalline rocks and tundra [*Yunker et al.,* 2002]. However, dissolved and suspended materials are not necessarily

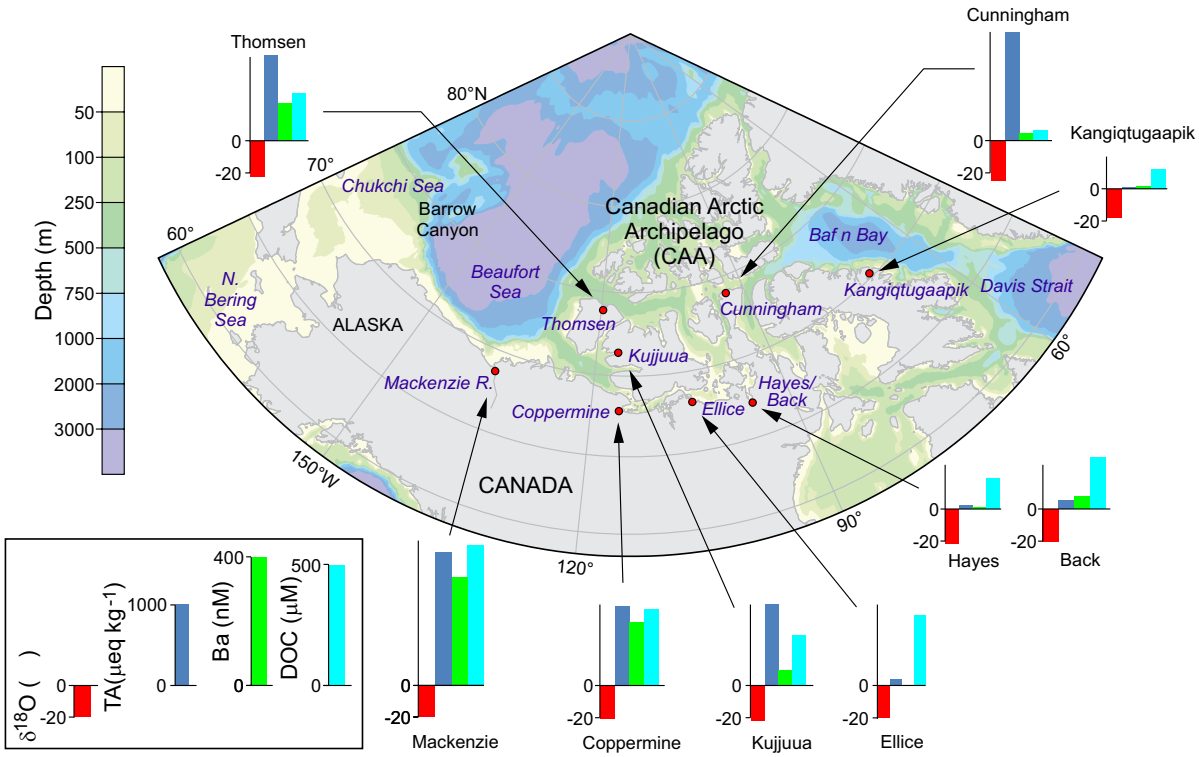


Fig. 1. Map of river sampling locations. Bar graphs show the measured values of stable oxygen isotopes ($\delta^{18}O$, red), total alkalinity (TA, dark blue), barium (Ba, green), and dissolved organic carbon (DOC, light blue). Mackenzie River values shown are flow-weighted averages from Cooper et al. *[2008].*

very similar from location to location; we see some regional differences across the CAA that we hope to understand further as studies continue.

Another factor is that different basins have different types of water sources for their runoff. Whereas the Mackenzie River receives waters from lakes and numerous tributaries extending far southward, the CAA rivers have much smaller drainage basins contained entirely within the Arctic Circle. As a result, seasonal accumulations of snowmelt and glacial discharge contribute a comparatively larger fraction of the annual runoff.

These combined effects create distinct chemical weathering regimes that produce geochemical signatures starkly different from those of the Mackenzie River. We intend to continue our chemical analysis to find out more about these rivers and their drainage basins.

Identifying the Origin of North Atlantic Freshwater

The freshwater that flows through the CAA peaks during summer months and tends to be concentrated in currents that swiftly flow along the southern coasts of various channels toward Baffin Bay [e.g., *Melling et al.*, 2008]. These currents then move through Davis Strait and into the North Atlantic. Thus, the incorporation of discharge from numerous CAA rivers into these boundary currents may significantly impact the chemical signature of freshwater getting into the North Atlantic.

If these rivers indeed influence freshwater export through Davis Strait, their comparatively dilute chemical signatures likely serve to lessen chemical concentrations observed from North America's runoff as a whole. Given that Siberian rivers also have comparatively lower chemical concentrations (e.g., barium and total alkalinity), mixing the Mackenzie and Yukon waters with freshwater from smaller rivers yields a geochemical signature that may look like Siberian runoff.

This similarity may make it hard to distinguish between freshwater from the major North American rivers, from the CAA rivers, and from the Siberian rivers exiting the Arctic Ocean via Nares Strait. Studies focused on the geochemical composition of the freshwater exiting the Arctic via Nares and Davis straits are critical for better understanding freshwater export to the North Atlantic.

Current River Sampling

Currently, we are in the middle of our 2015 field season. We have revisited three of our sites—the Coppermine, Back and Hayes, and Ellice rivers—and have successfully collected samples from each. We have also collected samples from the estuaries adjoining these rivers using small inflatable boats equipped with outboard motors and a pumping system to collect water from eight depths that extend from the surface down to 15 meters.

The samples should allow us to capture important geochemical modifications to river water as it enters more saline waters of higher ionic strength. We also get an idea of the size of the river plume and how it spreads into each estuary.

Using a CastAway® conductivity-temperature-depth profiler, we can gauge the total volume of freshwater within the estuaries. Estimating volumes is important, especially for rivers that are not gauged.

Robie W. Macdonald

The team collects water from the Kangiqtugaapik River (near Clyde River) while explaining the process to Esa Qillaq and Noire Iqaluqjuak, residents of Clyde River hired to collect samples on a weekly basis between June and October 2014–2016. In the image, Matt Alkire wades into the river and collects water from the central channel using an extendable pole, Greg Lehn rinses the bottle three times before a final sample is kept, and John Kelly (far right) explains the sampling process to Qillaq and Iqaluqjuak.

In conjunction with salinity, oxygen and strontium isotopic compositions will be used to quantify contributions from river runoff, sea ice melt, and submarine groundwater discharge (the outflow of fresh groundwater from the offshore seabed). Finally, we will determine the likelihood that river runoff will get caught up in the eastward flowing boundary currents moving toward Baffin Bay and eventually to Davis Strait and the North Atlantic.

Similar data collection campaigns are planned for the 2016 field season.

Data, associated reports, and tutorials summarizing project goals, sampling strategies, and analytical techniques are available on the project website (http://www.canadianriversproject.org/). Data are also copied to the Cooperative Arctic Data and Information Service of the Arctic Observing Network.

Acknowledgments

This project was funded by the National Science Foundation under grant OPP-1303766. We thank John Kelly; Kenn Borek Air, Ltd.; Polar Field Services; Parks Canada; the Ilisaqsivik Society; and the Hunters & Trappers Organizations of Kugluktuk, Cambridge Bay, Gjoa Haven, Ulukhaktok, Sachs Harbour, and Clyde River for their help and support of this work.

References

Cooper, L. W., J. W. McClelland, R. M. Holmes, P. A. Raymond, J. J. Gibson, C. K. Guay, and B. J. Peterson (2008), Flow-weighted values of runoff tracers ($\delta^{18}O$, DOC, Ba, alkalinity) from the six largest Arctic rivers, *Geophys. Res. Lett., 35,* L18606, doi:10.1029/2008GL035007.

Guay, C. K., and K. K. Falkner (1997), Barium as a tracer of Arctic halocline and river waters, *Deep Sea Res., Part II, 44,* 1543–1569.

Lammers, R. B., A. I. Shiklomanov, C. J. Vörösmarty, B. M. Fekete, and B. J. Peterson (2001), Assessment of contemporary Arctic river runoff based on observational discharge records, *J. Geophys. Res., 106*(D4), 3321–3334.

Melling, H., T. A. Agnew, K. K. Falkner, D. A. Greenberg, C. M. Lee, A. Münchow, B. Petrie, S. J. Prinsenberg, R. M. Samelson, and R. A. Woodgate (2008), Fresh-water fluxes via Pacific and Arctic outflows across the Canadian polar shelf, in *Arctic-Subarctic Ocean Fluxes: Defining the Role of the Northern Seas in Climate,* edited by R. R. Dickson, J. Meincke, and P. Rhines, pp. 193–247, Springer, New York.

Yunker, M. B., S. M. Backus, E. G. Pannatier, D. S. Jeffries, and R. W. Macdonald (2002), Sources and significance of alkane and PAH hydrocarbons in Canadian Arctic rivers, *Estuarine Coastal Shelf Sci., 55,* 1–31.

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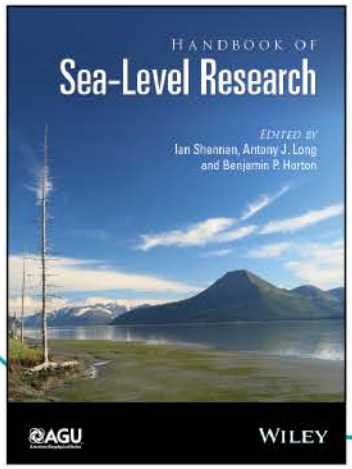

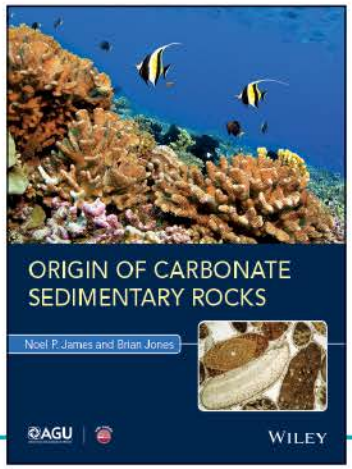

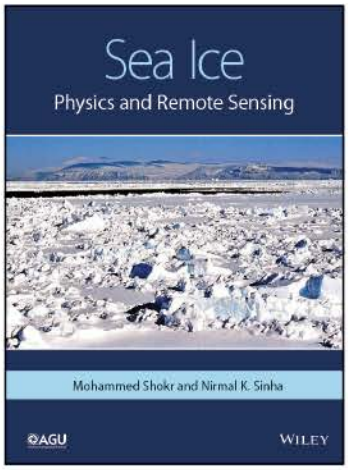

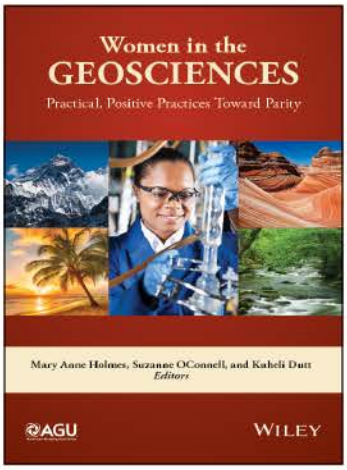

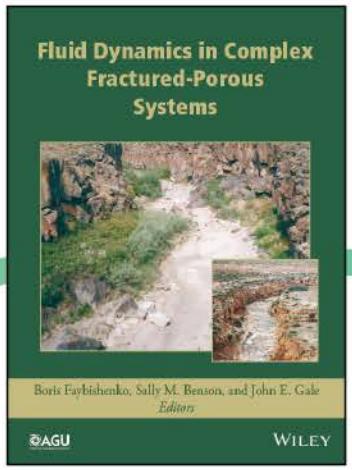

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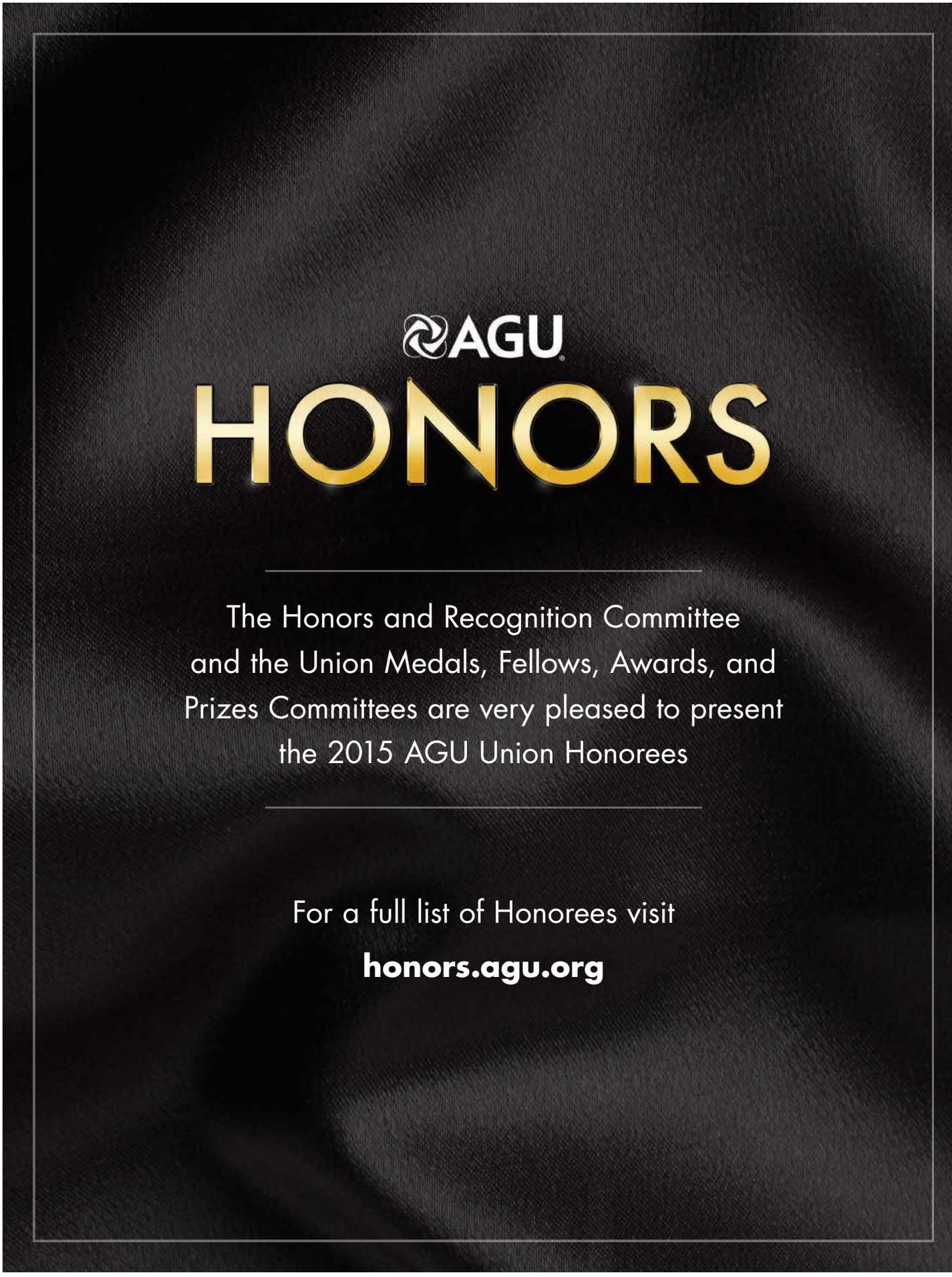
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Making the Northern Indian Ocean a Hub of Geomagnetic Data

By Kusumita Arora, Nandini Nagarajan, Alan Thomson, and Alik Ismail-Zadeh

A new initiative seeks to unite and network the magnetic research community in the northern Indian Ocean region.

Earth's magnetism is a complex, dynamic phenomenon, resulting from the motions of charged particles in the core, mantle, and ocean, as well as from static magnetic materials in the crust.

Although geoscientists have known for nearly two centuries that the Earth behaves like a magnet, they are still unraveling many mysteries. For instance, how is the magnetic field generated and sustained by the Earth's outer core, and how much do the planet's mantle and crust contribute to the overall magnetic field? And what can variations in the geomagnetic field tell us about its interactions with solar and interplanetary magnetic fields as well as what's under the surface?

Answers to these questions are of interest not just to academics. They can also help prospectors looking for minerals or oil, and they are critical to protecting assets such as satellites from solar storms. But getting a precise map of the

NOAA/NGDC & CIRES

Magnetic declination in and around South Asia. Contour interval is 2°; red contours are positive (east); blue contours are negative (west); green is the zero line. The Uniting and Networking the Magnetic Community in the Northern Indian Ocean Region (MAGNIO) initiative aims to provide higher contour density than what can be found in this snippet of the World Magnetic Field Model.

Earth's magnetism requires robust sources of data spanning the planet.

Such data are lacking over many areas of the world. A new initiative, Uniting and Networking the Magnetic Community in the Northern Indian Ocean Region (MAGNIO), is now trying to fill a geomagnetic data gap in one of the world's least surveyed areas: the northern Indian Ocean.

A Magnetic World

Researchers monitor variations in the geomagnetic field from the ground or from space. The gathered data, along with improved modeling techniques, enable scientists to produce precise estimates of contributions to the overall geomagnetic field from the ocean, crust, mantle, and core. Input data from locations evenly distributed over the globe are critical for a well-defined and realistic model of geomagnetism [*Christensen and Olsen*, 2003; *Sabaka et al.*, 2004].

Scientists use magnetic field anomalies to explore for minerals in the crust, delineate ocean currents, monitor field variations in real time for drilling applications, and prospect for oil and gas in off-shore areas. Scientists also try to model the variations of the geomagnetic field to assess how baseline readings skew navigation and to protect satellite- and ground-based technology from the effects of magnetic disturbances in the Earth's magnetosphere and ionosphere resulting from solar storms.

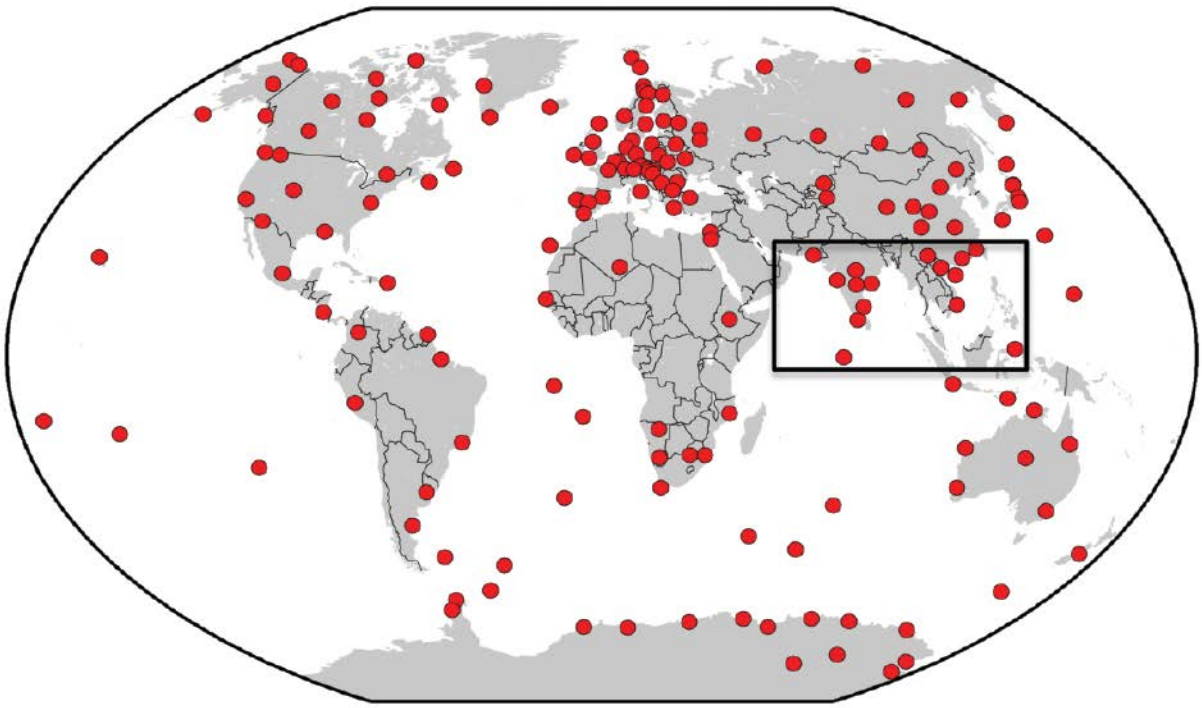
Sparse Data

Some parts of the globe, especially Europe, have dense networks of geomagnetic monitors. But other regions produce little geomagnetic data. One of these is the northern Indian Ocean (NIO), a region encompassing 18 million square kilometers that although prone to significant magnetic field variations, hosts relatively few (around 20) observatories with stable data series. Compounding the shortage of facilities, technical and other problems have caused breaks in data records at many of the region's existing magnetic observatories.

This sparse data coverage is especially unfortunate because the NIO is a prime location to estimate and model the effects of several important geomagnetic phenomena, such as the equatorial electrojet—a daytime ribbon of east-west current within the ionosphere that flows roughly along the magnetic equator (where magnetic inclination is zero). The region is also a good place to study solar quiet currents, which are generated by worldwide solar-driven winds in the ionosphere and result in a daily enhancement of magnetic fields [*Pedatella et al.*, 2011; *Onwumechili*, 1997].

Magnetic variation in the NIO also contains the signals of electromagnetic induction caused by the ocean waters as well as subsurface conductive bodies, which most commonly are associated with the presence of fluids or thermal anomalies in the crust and mantle. Thus, study of the magnetic field could also help geologists decipher the crust-mantle configuration associated with the Indian Ocean geoid low (where the Earth's surface deviates from the ellipsoidal shape by more than 100 meters) and the Andaman-Sumatra subduction zones, which produce megaearthquakes and tsunamis [*Kuvshinov*, 2008].

When combined with data from the European Space Agency's satellite-based Swarm Mission, a constellation of three satellites carrying highly accurate magnetometers, concurrent ground measurements could be espe-



Geomagnetic observatories of the world. The black rectangle indicates the northern Indian Ocean region. Credit: INTERMAGNET.

The Northern Indian Ocean is a prime location to estimate and model the effects of several important geomagnetic phenomena.

cially valuable in helping scientists resolve structures of the shallow subsurface and fine details of the ionosphere.

Existing Regional Initiatives in the NIO

Several countries in this region, including India, Pakistan, Myanmar, Indonesia, Sri Lanka, and Vietnam (Figure 1), have long made magnetic measurements for different applications. These countries' geological and meteorological agencies produce maps of magnetic field anomalies for exploration, identify short-time scale variations in the local magnetic field, and build continuous observatories and arrays for studying source fields and electromagnetic induction occurring in the Earth's crust.

In 2010 the National Geophysical Research Institute of the Council of Scientific and Industrial Research (CSIR-NGRI) in India along with other partners initiated a project for continuous measurement of magnetic variations at islands in the northern Indian Ocean. At present five island observatories are operating, three in the Andaman-Nicobar region and two in the Lakshadweep-Maldives area.

The new data have produced encouraging preliminary results, highlighting links between variability of magnetic variations and ionosphere-atmosphere interactions [*Hamid et al.,* 2014; *Chandrasekhar et al.,* 2014], as well as correlations between subsurface geometry and models of induced response of ocean-continent boundaries [*Samrock and Kuvshinov,* 2013].

MAGNIO: A Regional Network

In recognition of efforts to expand the geographical range of magnetic observations, the International Council of Science (ICSU) awarded funding to the International Union of Geodesy and Geophysics (IUGG), with the goal of uniting and networking the magnetic community in the northern Indian Ocean region. The IUGG project team includes researchers from CSIR-NGRI in India, the Indian National Science Academy, the Regional Office for Asia and Pacific in Malaysia, and the World Data Center (WDC) for Geomagnetism at the British Geological Survey in Edinburgh. This core group created the MAGNIO project.

The MAGNIO project aims to establish links between interested agencies—those who use magnetic data for regional interests and global modeling—and those generating data, including nations and institutions that would like to begin or revive magnetic data acquisition procedures. Therefore, both the producers and users of magnetic data need to be identified and linked in this initiative.

Pooling existing data into an integrated database could provide a valuable knowledge base in the region. Such an effort would require the close involvement of agencies that acquire the data.

For example, new ground-based measurements of magnetic variations with a time resolution of 1 minute or better in the NIO region would provide an ideal window of opportunity to augment satellite measurements, which at best record highly accurate but temporally sparse data at a particular position only once in several days.

Strengthened with the addition of continuous time series from ground stations, the satellite data will contribute to models of equatorial magnetic variations.

Such models could be used for diverse scientific and technocommercial activities, including exploration, navigation, satellite communication, and deep drilling. Thus, establishing links between scientists and stakeholders could be mutually beneficial for all.

MAGNIO Objectives

The ICSU Grants Programme supports collaborative scientific initiatives of relevance to science and society through seed funds for the duration of only 1 year. The grant was awarded for 2014–2015, and we plan on using it to leverage funds from other sources.

In addition, we plan to pursue the MAGNIO project goals through a variety of programs and activities:

- running MAGNIO-focused sessions during various international workshops and seminars to bring togetther data producers and users to discuss issues pertaining to data requirements and the current constraints on acquisition
- documenting and implementing common practices of data acquisition and analysis and consolidating results and findings over the NIO region
- enhancing participation of data acquisition agencies from India, Maldives, Sri Lanka, Indonesia, Thailand, Vietnam, and Myanmar by pooling their data, thereby providing coherent data coverage
- benchmarking magnetic measurements in the region against international standards of observatory practice (as stipulated by the International Real-Time Magnetic Observatory Network (INTERMAGNET))
- seeding a forum or platform that will continue to grow and develop the activities of the current project, so that existing and new observation groups as well as user groups are linked to a coherent regional database

Recent Efforts

Now that MAGNIO has been operating for about a year, several initiatives are well under way. During the XVI International Association of Geomagnetism and Aeronomy (IAGA) Workshop last year, we organized training classes, lectures, and hands-on activities for the benefit of observers from NIO countries and others attending the workshop. Participants from Maldives, Sri Lanka, and India were present. During this workshop several agencies in Europe expressed interest in collaborating with stakeholders in the NIO.

Last year we also made a presentation on the goals and intentions of MAGNIO at the International Conference on

Data Sharing and Integration for Global Sustainability (SCIDATACON) Workshop. Participants discussed several issues relevant to geomagnetic data, including how to bring the same standards of visibility, funding, and utility to data archiving and preservation that the research community has achieved with data acquisition.

Future meetings and discussions with stakeholders and collaborators are planned for early next year.

CSIR-NGRI has initiated dialogue with the University of Peradeniya in Sri Lanka to set up a new observatory in that country. Observatories in the Philippines and Indonesia have also expressed interest in being part of the MAGNIO project and subsequent follow-up programs.

Future Steps

In the first phase of MAGNIO operations, we are pursuing the following activities:

- establishing contacts among targeted observatories in the northern Indian Ocean region
- evaluating the observatories in terms of instrumentation, data acquisition, and processing
- defining a scheme and creating documents for upgrading, standardizing, networking, and archiving data from geomagnetic observatories
- planning for a future meeting of representatives from participating observatories

Progress on the above activities is well under way.

We envision that the culmination of the MAGNIO project will be the formation of a forum or consortium that will develop further action plans, depending on priority areas of interest of the participants and availability of funds. We anticipate that this group will do the following:

- make a decision on the recording and delivery of 1-second or 1-minute data
- prepare a website to facilitate compilation of information and easy exchange between participants and to handle technical and scientific queries
- implement the actual processes of upgrading, standardizing, networking, and archiving data
- encourage all participant observatories to upload data to the WDC (Geomagnetism) in Edinburgh
- include the user community in the forum/consortium for appropriate usage of improved products

We recognize that the concept of real-time data sharing is novel to many agencies in the region. However, as we progress with our objectives, the mutual benefits of access should smooth the way to greater collaboration.

We hope to build on this progress so that MAGNIO and the longer-term organization that emerges from it can integrate researchers and users in NIO more fully into the global scientific community, with benefits for all.

References

Chandrasekhar, N. P., et al. (2014), Evidence of short spatial variability of the equatorial electrojet at close longitudinal separation, *Earth Planets Space, 66,* 110–125.

Christensen, U. R., and P. Olson (2003), Secular variation in numerical geodynamo models with lateral variations of boundary heat flow, *Phys. Earth Planet Inter., 138,* 39–54.

Hamid, N. S. A., et al. (2014), Relationship between the equatorial electrojet and global Sq currents at the dip equator region, *Earth Planets Space, 66,* 146–157.

Kuvshinov, A. V. (2008), 3-D global induction in the oceans and solid Earth: Recent progress in modeling magnetic and electric fields from sources of magnetospheric, ionospheric and oceanic origin, *Surv. Geophys., 29,* 139–186, doi:10.1007/s10712-008-9045-z.

Onwumechili, C. A. (1997), *The Equatorial Electrojet,* Gordon and Breach, Amsterdam.

Pedatella, N. M., J. M. Forbes, and A. D. Richmond (2011), Seasonal and longitudinal variations of the solar quiet (Sq) current system during solar minimum determined by CHAMP satellite magnetic field observations, *J. Geophys. Res., 116,* A04317, doi:10.1029/2010JA016289.

Sabaka, T. J., et al. (2004), Extending comprehensive models of the Earth's magnetic field with Oersted and CHAMP data, *Geophys. J. Int., 159,* 521–547.

Samrock, F., and A. Kuvshinov (2013), Tippers at island observatories: Can we use them to probe electrical conductivity of the Earth's crust and upper mantle?, *Geophys. Res. Lett., 40,* 824–828, doi:10.1002/grl.50218.

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Past Phosphorus Runoff Causes Present Oxygen Depletion in Lakes

A view of Lake Geneva. New research shows that phosphorus-containing fertilizers may have permanently shifted the oxygen balance in Alpine lakes.

Under normal conditions, plenty of oxygen can be found below the surface of lakes, rivers, and oceans. However, human activity since the 1950s appears to be wreaking havoc on underwater oxygen supply.

Jenny et al. examined the oxygen levels in three lakes in the French Alps over the course of the past 11,500 years. Using sediment cores, which preserve a layer-by-layer history of the lakes' environments, the team observed a sharp drop off in oxygen levels during the early 1950s. They attribute the decline to the phosphorus-containing compounds that gained popularity in agriculture around the same time. As rainwater washed phosphorus fertilizers and urban wastewaters into tributaries, the overall nutrient level in the lakes rose to unnaturally high levels, allowing bacteria and algae to flourish. As these creatures grew in number, they consumed the lake's oxygen, depleting its supply.

The authors also observed something curious: The lakes remained hypoxic even after phosphorus usage was curtailed later in the 1960s and 1970s, suggesting that the balance had been permanently shifted, likely because of the change in the internal loads of organic matter and phosphorus. Temperature was not shown to have caused the regime shift to hypoxia in the lake but did change how much of the lake was affected by hypoxia: Increased temperatures increased the affected volume, whereas decreased temperatures and increased river flow into the lake shrank it.

Accordingly, the authors suggest that restoring the natural winter river flood regime now limited by dams could help correct the oxygen depletion and counteract the effects of global warming and phosphorus pollution. (*Global Biogeochemical Cycles,* doi:10.1002/2014GB004932, 2014) **—David Shultz, Freelance Writer**

Rethinking How Tropical Convection Works

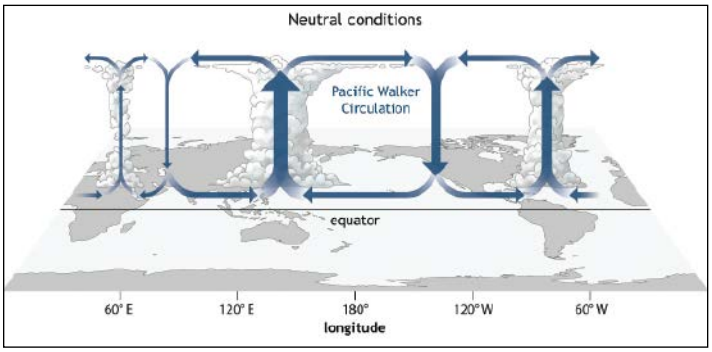
The Walker circulation is an east–west or west–east trending air circulation pattern located over the tropics and forms one of two major convective patterns in Earth's tropical atmosphere. Specifically over the tropical Pacific, air just above the surface flows from east to west; as warm air rises over the western Pacific, it produces rain clouds, which wring the air of moisture. This lofted cool air travels east across the Pacific until it sinks, pushing air on the surface back to the west and completing the cycle, forming a convection cell.

This air circulation drives global weather patterns and is tied to monsoons—as well as to the El Niño effect, in which this circulation grinds to a halt and then reverses. This disrupts weather patterns around the world, causing tens of billions of dollars in economic damage.

Scientists typically model the Walker circulation in the atmosphere including the effect of damping—in which the winds lose energy due to friction and radiative cooling. This is a standard feature throughout climate models of the tropics.

Now *Stechmann and Ogrosky* have overturned this conventional wisdom, discovering that damping does not play a major part in the Walker circulation and does not need to be included in simulations. Instead, they revamped the model for the Walker circulation: The currents of air simply depend on the natural response to the atmosphere being heated by clouds.

The authors analyzed data collected by the National Oceanic and Atmospheric Administration and National Centers for Environmental Prediction/National Center for Atmospheric Research to reconstruct the large-scale atmospheric wave patterns that accompany Walker circulation and reflect its strength. They then used a simple model to simulate the atmospheric wave patterns that account for heat and momentum losses, including any damping. They found that damping wasn't necessary to model the Walker circulation and that variations in the amount of cloud heating in the atmosphere are responsible for its behavior.



NOAA

A schematic of Walker circulation cells during neutral conditions.

The team also discovered that these variations in cloud heating are proportional to the amount of energy that radiates from Earth into space, called the outgoing longwave radiation (OLR). This allowed the team to use satellite observations of OLR to estimate atmospheric heating. This means that future studies could use such satellite data—including archived data—to easily estimate the strength of the Walker circulation over time. (*Geophysical Research Letters*, doi:10.1002/2014GL062257, 2014) **—Catherine Minnehan, Freelance Writer**

What Climate Information Is Most Useful for Predicting Floods?

Natural climatic cycles such as the El Niño–Southern Oscillation and the North Atlantic Oscillation (NAO) can have a strong influence on floods and other weather events across the globe. As a result, measures of these climatic cycles' strength could help predict how hydrological phenomena could unfold.

However, standard indices that quantify the cycles' intensities often reduce these large-scale, three-dimensional phenomena to a single number. As a result, these indices may vary strongly in their predictive ability from place to place. As *Renard and Lall* found, basing predictions on a model that uses raw climatic data yielded more reliable predictions in a case study involving floods.

Guillaume Dramais, Irstea

A typical flood in southern France.

Climate fields are defined as observations of a climatic variable that spans a large spatial domain. Because a climate field does not reduce data to a single number, the authors suggest it could produce more accurate predictions than a numerical climate index might, at least in those regions where standard climate indices have little predictive ability.

The authors built a two-step probabilistic model that relies on a climatic field to predict the occurrence of floods in an area. The approach uses a probabilistic model to extract from the climate field the most relevant information for the target area. From there, the authors do another set of calculations that provide the probabilities of occurrence of these extreme events.

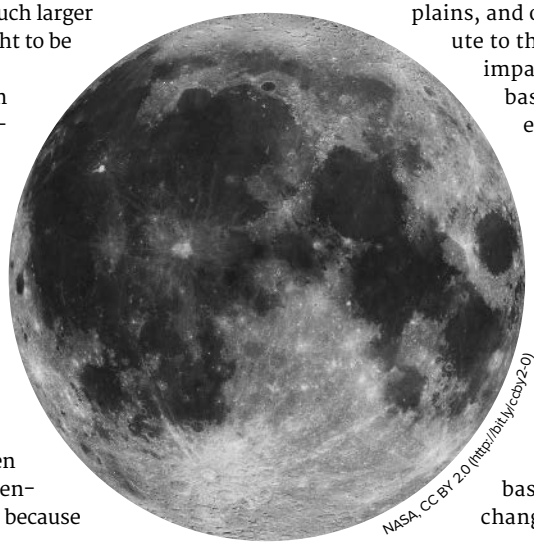
To test their framework, the authors pitted it against three climate indices: the NAO index, the Scandinavian pattern, and the east Atlantic–western Russia oscillation. In their case study, the authors compared their predictions for the number of autumn floods in 16 catchments in southern France against predictions informed by the three climate indices.

The authors found that their model made much more reliable predictions than the indices did. In particular, under specific climate conditions, their model was able to predict the occurrence of extreme events with high probability, whereas predictions based on climate indices did not have the capacity to make such predictions. The authors say that although their method holds promise, future work should scrutinize the assumptions that the model makes about the relationships between climate and hydrology. (*Water Resources Research*, doi:10.1002/2014WR016277, 2014) **—Puneet Kollipara, Freelance Writer**

How Did the Moon Get Its Shape?

Scientists have known for hundreds of years that the Moon's rotational and tidal bulges are much larger than expected. The deformation is thought to be a remnant from when the Moon orbited much closer to Earth than it does today. The problem is, the bulges we see require an unusual eccentric orbit—one that scientists do not think the Moon ever had. *Keane and Matsuyama* solved this problem by discovering a new component to the Moon's global figure.

The Moon is not perfectly spherical because strong forces pull it in different directions. There are two main forces: bulging at the equator due to lunar rotation and bulging on the nearside and farside due to tidal forces between the Earth and the Moon. The observed lunar deformation is much larger than scientists would expect, given the Moon's current orbit and rotation rate. Scientists believe that this extra deformation arises because the Moon "froze" its shape billions of years ago when it orbited closer to Earth and thus had much larger forces pulling on it.



The Moon's impact basins can help scientists investigate its mysterious deformation.

The authors investigated whether impact basins, volcanic plains, and other lunar gravity anomalies could contribute to the lunar figure. They found that one single impact basin—the giant South Pole–Aitken basin on the far side of the Moon (and the largest impact basin in the inner solar system)—could explain most of the Moon's anomalous figure.

Accounting for the South Pole–Aitken basin (and 30 other large gravity anomalies), they found that the Moon's figure actually formed on a low-eccentricity, synchronous orbit, consistent with what scientists believe for the early orbit of the Moon. Furthermore, the formation of the basin reoriented the entire Moon approximately 20°.

Thus, not only did the South Pole–Aitken basin reshape the Moon, but it even slightly changed which side of the Moon we see from Earth. (*Geophysical Research Letters*, doi:10.1002/2014GL061195, 2014) **—Catherine Minnehan, Freelance Writer**

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Atmospheric Sciences

Associate Professional Specialist/ Professional Specialist Position in Intraseasonal-to-Decadal Real-time Predictions and Predictability Research

In collaboration with NOAA's Geophysical Fluid Dynamics Laboratory (GFDL), the Atmospheric and Oceanic Sciences Program at Princeton University is seeking candidates with a strong computational and technical background to fill an associate professional specialist/professional specialist position.

Candidates will join a vibrant research team and play a leading role in supporting real-time seasonal forecasting of climate using complex models simulating the Earth system. The position will require performing predictions every month, as well as research into predictability. This will involve configuration, running and analysis of state-of-the-art coupled climate models running on supercomputers.

Initial appointment is for one year with the possibility of renewal subject to satisfactory performance and available funding. Some amount of travel (to conferences or workshops) may be required. Salary commensurate with experience.

Complete applications, including a CV, copies of recent publications, names and contact information for at least 3 references are required in order to solicit letters of recommendation; applications should be submitted by October 15, 2015 for full consideration. Applicants should apply online to http://jobs.princeton.edu, Requisition #1500566. For additional information, contact Gabriel Vecchi (gabriel.a.vecchi@noaa.gov).

This position is subject to the University's background check policy. Princeton University is an equal opportunity employer and all qualified applicants will receive consideration for employment without regard to race, color, religion, sex, sexual orientation, gender identity, national origin, disability status, protected veteran status, or any other characteristic protected by law.

FACULTY POSITIONS IN ATMOSPHERIC CHEMISTRY at the University of California, Irvine

The Department of Chemistry at the University of California, Irvine (Irvine, California), has two openings for outstanding scientists in atmospheric chemistry. It is anticipated that one will be at the Assistant Professor and one at Full Professor level, although applicants at all levels will be considered. These positions are part of an integrated, across-campus initiative in air quality and climate. We seek to build this initiative through cross-cutting and transformative research programs that complement existing activities at UCI, with an emphasis on interdisciplinary activities involving particles and their roles in air quality and climate. Studies linking fundamental chemistry to biological effects of air pollutants are of particular interest. Candidates must have a PhD in Chemistry or a related field. Preference will be given to applicants who have a demonstrated record in applying fundamental chemistry to problems of atmospheric significance. The position requires both the establishment of a vigorous research program and a strong commitment to excellence in teaching at both the undergraduate and graduate levels. Applications must be submitted electronically via the Internet at: https://recruit.ap.uci.edu/apply/JPF02997. Applicants should upload a cover letter, a curriculum vita (including a publication list), and a concise statement of proposed research. A separate statement that addresses past and/or potential contributions to diversity, equity and inclusion should also be included in the application materials. Names and contact information for three references must be provided; letters should not be requested at this time. Applications and supporting materials should be received by October 1, 2015 for full consideration. The University of California is an Equal Opportunity/Affirmative Action Employer advancing inclusive excellence. All qualified applicants will receive consideration for employment without regard to race, color, religion, sex, national origin, disability, age, protected veteran status, or other protected categories covered by the UC nondiscrimination policy.

Postdoctoral Scientist in "Multi-Decadal Internal Climate Variability and Its Role in Climate Change"

The Atmospheric and Oceanic Sciences Program at Princeton University, in cooperation with NOAA's Geophysical Fluid Dynamics Laboratory (GFDL), seeks a postdoctoral scientist for research related to multi-decadal internal (natural) climate variability and its potential role in explaining observed climate changes. A key focus is to improve understanding of the role of low frequency internal climate variability in the current "hiatus" in global warming, as well as previous hiatus and accelerated-warming periods during the 20th century. Such understanding plays an important role in the detection and attribution of observed climate changes. The research will use various approaches to understand the physical mechanisms causing the observed decadal changes including quantification of contributions from both internal climate variability and responses of the climate system to various natural and anthropogenic forcing agents (e.g., greenhouse gases, aerosols, and volcanic eruptions). The research will make extensive use of both observations and a variety of

modeling tools. The selected candidate will have a Ph.D. and one or more of the following attributes: (a) a strong background in climate/ocean dynamics or coupled air-sea interactions, (b) experience conducting and analyzing coupled climate model experiments, and (c) strong diagnostic skills in analyzing simulated and observed data sets.

This is a two-year position (subject to renewal after the first year contingent upon satisfactory performance and funding availability) based at GFDL/NOAA in Princeton, New Jersey. Complete applications, including a CV, publication list, names of 3 references for letters of recommendation, and a one-to-two page statement of research interests should be submitted. Review of applications will begin as soon as they are received and continue until the position is filled. Applicants should apply online to http://jobs.princeton.edu, Requisition #1500509. For additional information on the position, please contact Rong Zhang (Rong.Zhang@noaa.gov) or Tom Knutson (Tom.Knutson@noaa.gov). This position is subject to the University's background check policy.

Princeton University is an equal opportunity employer and all qualified applicants will receive consideration for employment without regard to race, color, religion, sex, sexual orientation, gender identity, disability status, protected veteran status, or any other characteristic protected by law.

Hydrology

ASSISTANT PROFESSOR, HYDROLOGIST

The Department of Ecosystem Science and Management and the Penn State Institutes for Energy and the Environment (PSIEE) at The Pennsylvania State University invite applications for a faculty position in hydrological sciences. The position will be filled at the Assistant Professor level, commensurate with experience, on a 36-week academic year appointment, with 75% research and 25% teaching responsibilities. The position will be co-funded by the College of Agricultural Sciences and PSIEE, with the tenure home residing in the Department of Ecosystem Science and Management.

We are seeking an outstanding candidate with a demonstrated interest in forested ecosystems, and having a background in hydrology and ecosystem sciences. Research expertise is desired in areas such as ecohydrology, forest hydrology, integrated water resources management, isotope hydrology, limnology, watershed modeling, or watershed processes. The successful candidate will be expected to develop strong, interdisciplinary research collaborations on campus, and to develop a nationally recognized, externally funded, interdisciplinary research program engaging graduate students.

Candidates will be expected to engage in instruction at both the undergraduate and graduate levels and enhance the Department's existing curriculum, and to maintain high pedagogical standards in the courses being taught. The position will include other faculty-related activities, including advising undergraduate students and service on departmental committees. The successful candidate will complement and advance existing water- and energy-related research and education activities within the Penn State Institutes of Energy and the Environment (PSIEE; http://www.psiee.psu.edu). This position is one of four new faculty positions in water science, engineering, and policy that will be filled over the next three years in conjunction with the creation of a new interdisciplinary PSIEE Water Institute. This water initiative serves to expand the already strong and diverse interdisciplinary program of water and energy research and education at Penn State.

A Ph.D. is required at time of appointment. Post-doctoral or academic experience and extramural grant writing experience are desired. The ability to communicate effectively, to provide leadership, and to contribute to the land-grant mission of the University is important. An ability to relate to a diverse population of faculty, staff, and students is required.

Visit http://apptrkr.com/635469 to apply. Applications received by September 30, 2015 will receive full consideration, though review will continue until the position is filled. Candidates will need to upload a curriculum vitae, copies of transcripts, statements of teaching and research experiences and interests, up to three relevant publications, and a list of references.

CAMPUS SECURITY CRIME STATISTICS: For more about safety at Penn State, and to review the Annual Security Report which contains information about crime statistics and other safety and security matters, please go to http://www.police.psu.edu/clery/ , which will also provide you with detail on how to request a hard copy of the Annual Security Report.

Penn State is an equal opportunity, affirmative action employer, and is committed to providing employment opportunities to all qualified applicants without regard to race, color, religion, age, sex, sexual orientation, gender identity, national origin, disability or protected veteran status.

Geoscience and Water Sustainability - Tenure-track Position

The Department of Geology and Environmental Science at the University of Pittsburgh (http://www.geology.pitt.edu) invites applications for a tenure-track assistant professor position in geoscience and water sustainability, pending budgetary approval. We seek applicants to expand our current research in sustainability and who link field-based geoscience research to quantitative sustainability themes. Areas of expertise may include, but are not limited to: catchment hydrology in urban, managed, and natural systems; land-atmosphere interactions; soil moisture analysis; the interacting roles of climate variability and land use change on hydrologic processes; or physical models of ecohydrologic and hydropedologic processes from the plot to the global scale. The successful candidate will complement existing research clusters and establish an externally- funded, internationally recognized research program.

Review of applicants will begin on October 15, 2015 and continue until the position is filled. A PhD is required at the time of appointment, with an anticipated start date in Fall 2016. Please apply online to: https://facultysearch.as.pitt.edu/apply/index/OTY=. Applications should include: 1) a cover letter; 2) a CV; 3) statements of research and teaching interests; 4) names and contact information of four references; and 5) copies of three relevant publications. Direct questions to the Search Committee Chair, Dr. Daniel Bain, dbain@pitt.edu, 412-624-8766. The University of Pittsburgh is an Affirmative Action/Equal Opportunity Employer and values equality of opportunity, human dignity and diversity.

Ocean Sciences

Oceanography - Coastal Systems and Processes - Assistant/Associate Professor

The Department of Ocean, Earth and Atmospheric Sciences at Old Dominion University invites applications for a tenure-track faculty position to begin by fall 2016 in the area of coastal systems and processes. Specific areas of research we are most interested include:

- Processes and histories of sedimentary systems in the coastal zone, including the effects of sea level rise on estuaries, lagoons, marshes, tidal wetlands or barrier islands;
- The impacts of climate (past and future) on hydrologic processes in coastal environments;
- Coastal zone hydrogeology, including the effects of sea level rise on coastal aquifers, and the interactions of groundwater discharge with coastal aquatic systems.

The successful candidate will have expertise in quantitative investigations of coastal dynamics and those with field oriented interests are particularly encouraged to apply. We also welcome applications from candidates employing modeling, remote sensing and/or laboratory approaches.

It is anticipated that this position will be filled at the Assistant Professor level, but exceptional candidates at the Associate level will be considered. Candidates at the Associate Professor level must demonstrate substantial research accomplishments of peer-reviewed publications, a consistent record of peer-reviewed funding as a PI, current active competitive grants, and a strong and successful graduate and undergraduate teaching and mentoring record. Applicants must hold a Ph.D. degree in ocean or earth sciences or a related science discipline and postdoctoral experience is preferred. The successful candidate will demonstrate strong potential for outstanding accomplishments in research and teaching as an individual and as a member of collaborative teams.

The department has a robust undergraduate and graduate program with students pursuing BS, MS and PhD degrees and the successful applicant will be expected to teach undergraduate and graduate courses that support our existing curricula in ocean and earth sciences as well as graduate courses in his/her area of specialty. Many opportunities exist for disciplinary and interdisciplinary interactions with more than 25 other faculty in OEAS, its Centers for Coastal Physical Oceanography and Quantitative Fisheries Ecology and other centers and departments within the university. Information about the Department and its facilities can be found at: http://www.odu.edu/oeas.

Applications should contain a cover letter, CV, succinct teaching and research statements, copies of three relevant publications published in the last five years and contact information for three professional references. Complete applications must be submitted electronically as a single PDF file at https://jobs.odu.edu/. Please submit this PDF file under the category "Media Portfolio".

Applications received by September 1, 2015 will be given preference in review with the position open until filled. Old Dominion University welcomes the opportunity to work with candidates to identify suitable employment opportunities for spouses.

Old Dominion University is an equal opportunity, affirmative action institution. Minorities, women, veterans, and individuals with disabilities are encouraged to apply.

Postdoctoral Research Associate in Oceanic Variability, Predictability and Change

The Atmospheric and Oceanic Sciences Program at Princeton University, in association with NOAA's Geophysical Fluid Dynamics Laboratory (GFDL), seeks a postdoctoral research associate or a more senior for research related to intraseasonal-to-decadal oceanic variability, predictability and change. A key focus will be systematic comparison of observations and dynamical models to understand the character of and causes behind past changes to the ocean, with focus on the impact of the ocean on intraseasonal-to-decadal predictability. This would likely include assess-

ment of and modifications to coupled and ocean data-assimilation systems. This will include assessments of predictability arising both from natural variability and radiative forcing changes. The research will also examine interactions between natural decadal variability and the climate system response to radiative forcing changes, including attribution of observed ocean changes. The research will make extensive use of both observations and a variety of modeling tools, including newly developed high-resolution global climate models. The selected candidate will have one or more of the following attributes: (a) a strong background in physical oceanography, climate dynamics, or a closely related field; (b) experience using and analyzing advanced climate models and ocean observational datasets, and (c) strong diagnostic skills in analyzing large data sets.

Candidate must have a PhD. Initial appointment is for one year with the possibility of renewal subject to satisfactory performance and available funding.

Complete applications, including a CV, publication list, at least 3 letters of recommendation, and a statement of research interests should be submitted by October 15, 2015 for full consideration. Applicants should apply online to http://jobs.princeton.edu, Requisition #1500567. For additional information, contact Gabriel Vecchi (gabriel.a.vecchi@noaa.gov).

This position is subject to the University's background check policy. Princeton University is an equal opportunity employer and all qualified applicants will receive consideration for employment without regard to race, color, religion, sex, sexual orientation, gender identity, national origin, disability status, protected veteran status, or any other characteristic protected by law.

Solid Earth Geophysics

Faculty Position in Geophysics at the University of Arizona

The Department of Geosciences at the University of Arizona seeks applications for a tenure track faculty position in geophysics in the broad areas of geodynamics, seismology and/or geodesy. Candidates must hold a PhD degree by the time of appointment. Postdoctoral or other postgraduate research experience is desirable. We anticipate hiring at the tenure-track assistant professor level. The appointee is expected to develop and maintain a vigorous, collaborative, externally funded research program and to teach at the undergraduate and graduate level. Screening of applications will begin Sept. 10, 2015 and the search will continue until the position is filled. To apply, please submit: a cover letter, including references, curriculum vita, and statements of research and teaching experience and interests at this website: https://uacareers.com/postings/3687

EMPLOYMENT ANNOUNCEMENT

Researcher Position in Climate and Atmospheric Chemistry

Research Center for Environmental Changes
Academia Sinica
TAIPEI, TAIWAN

The Research Center for Environmental Changes invites applications at the Assistant, Associate and Full Research Fellow levels in the following fields:

1) Diagnostics and modeling of climate variability and change, and climate model development;
2) Atmospheric chemistry, particularly relevant to the changes in regional atmospheric composition and air quality.

One position for each field beginning in 2016 is available. Applicants are expected to have a doctoral degree in related fields by start of the appointment. Further information about the Research Center for Environmental Changes and related research can be found at http://www.rcec.sinica.edu.tw/.

Applicants should send their curriculum vitae, research plan and the names of three referees, before October 15, 2015, to:

Dr. Huang-Hsiung Hsu, Chair
Researcher Search Committee
Research Center for Environmental Changes,
Academia Sinica,
128, Academia Road, Section 2
Taipei 115, Taiwan
Tel: +886-2-2652-5173
Fax: +886-2-2783-3584
E-mail: hhhsu@gate.sinica.edu.tw

, and also a copy to Dr. Charles C.-K. Chou (ckchou@gate.sinica.edu.tw).

Both regular and electronic mails are acceptable. Upon receipt of the application, an acknowledgement email will be sent to the applicant within a week. Applicants who do not receive the acknowledgement email please contact the Chair of the Researcher Search Committee via email or telephone for confirmation.

Interdisciplinary/Other

ASSISTANT PROFESSOR OF EARTH AND ATMOSPHERIC SCIENCES (Exploration Geophysics)

Applications are invited for a tenure track position as Assistant Professor in the Department of Earth and Atmospheric Sciences at the University of Nebraska-Lincoln. The successful candidate will be expected to participate in teaching and curricular development of undergraduate and graduate courses, to advise and direct graduate students, and to develop a rigorous research program that is supported by external funding. It is expected that the research program will include field and subsurface-based studies of exploration geophysics. Ability to contribute to growing petroleum geoscience-related teaching and research activities within the Department of Earth & Atmospheric Sciences will be considered as an advantage. The candidate should demonstrate strong potential for research and teaching and must hold a Ph.D. in Geology, Geophysics, or a related field at the time of appointment.

The Department of Earth and Atmospheric Sciences offers B.S. degrees in Geology and Meteorology-Climatology, as well as M.S. and Ph.D. degrees in Earth and Atmospheric Sciences. Primary research areas within the geological sciences include sedimentary geology, paleontology and paleobiology, petroleum geosciences and geobiology. Research in atmospheric sciences is focused on meterological hazards, climate change, and remote sensing. Additional active research areas include Climate System Science, Geoscience Education and Hydrological sciences. Additional information about our department can be found on our web site: http://eas.unl.edu.

To apply, go to http://employment.unl.edu, search for requisition #F_150159 and complete the "faculty/administrative form". Applicants must attach a cover letter, curriculum vitae, statements of research and teaching interests, and names of at least three references via the above website. We will begin to review applications on October 12, but the position will remain open until it is filled.

The University of Nebraska is committed to a pluralistic campus community through affirmative action, equal opportunity, work-life balance, and dual careers.

For further information, contact Dr. Chris Fielding, Search Committee Chair by email, phone, or mail at: cfielding2@unl.edu, 1-402-472-9801; Department of Earth & Atmospheric Sciences, University of Nebraska-Lincoln, 214 Bessey Hall, Lincoln NE 68588-0340.

Assistant Professor Mineralogy/Petrology/Earth Materials West Virginia University

The Department of Geology and Geography at West Virginia University seeks to hire a tenure track Assistant Professor specializing in Earth Materials. This could include expertise in Igneous, Metamorphic, Sedimentary or Organic Petrology, Mineralogy, Geomicrobiology or related fields. The successful candidate will have the opportunity to develop a vigorous externally-funded research program. The new hire will also teach core undergraduate classes covering the origins of rocks and minerals, as well as graduate courses in the area of his/her expertise.

Requirements include: a Ph.D. in Earth Science by the start date, evidence of potential to establish a strong externally-funded research program, ability to publish in peer-review journals, and a commitment to teaching excellence at the undergraduate and graduate levels.

Qualified applicants should: (1) submit a single PDF file including a statement of research interests, a statement of teaching philosophy, and a curriculum vitae; (2) submit PDF files of up to 3 publications; and (3) arrange for three letters of reference to be sent. All documents should go to earthmaterials@mail.wvu.edu.

Review of applications will begin Sept. 30, 2015 and continue until the position is filled. The anticipated start date is August of 2016.

For additional information, please see http://pages.geo.wvu.edu/earthmaterials or contact the search chair: Jaime Toro at jtoro@wvu.edu or (304) 293 9817.

West Virginia University is an EEO/Affirmative Action Employer and welcomes applications from all qualified individuals, including minorities, females, individuals with disabilities, and veterans.

Associate Director, Environmental Studies Program

Assistant Professor of the Practice, Department of Earth and Environmental Sciences

Boston College seeks a teacher, scholar, and administrator to serve as Associate Director of the Environmental Studies Program and Assistant Professor of the Practice in the Department of Earth and Environmental

Sciences and with a summer 2016 start date. The Program offers both a major and minor to undergraduate students in the Morrissey College of Arts & Sciences. The successful candidate will have demonstrated academic, leadership, and program development abilities. This position is a nine-month, full-time non-tenure track academic position with faculty rank and teaching responsibilities.

For more information and to apply visit: http://apply.interfolio.com/30751. We will begin reviewing applications on October 1, 2015 and continue until the position is filled.

Faculty Position in Earth and Planetary Science At Rice University Department of Earth Science

We seek creative and promising candidates across the broad spectrum of earth and planetary science who complement the disciplines represented in our department.

Successful candidates are expected to direct an active research program, supervise graduate research, and teach courses for undergraduate and graduate students. Details about the department and its facilities can be found at http://earthscience.rice.edu

Please send a CV, research and teaching statements, and names of four or more references to esci-search@rice.edu.

Equal Opportunity Employer -- Females/Minorities/Veterans/Disabled/Sexual Orientation/Gender Identity

Two Full-Time Permanent Research Positions in the National Research Program, U.S. Geological Survey, Reston, Virginia.

Flow and Transport in Fine-Grained Geologic Media (Position 1)

The National Research Program (NRP) (http://water.usgs.gov/nrp/) of the U.S. Geological Survey seeks candidates for a full-time permanent research position in subsurface flow and transport at the GS-11, GS-12, or GS-13 grade, in any of the following series: Research Hydrologist, Research Geologist, Research Petroleum Engineer, and/or Research Physicist. Salary Range: ($63,722 to $118,069). This is a position for an early-career scientist to conduct research on fluids in fine-grained, low-permeability formations, including shales, mudrocks and clays. USGS seeks to better understand fluid flow and transport in these environments when subjected to natural and human-induced changes on engineering to geologic time scales. An important aspect of the position will be to develop analysis capabilities in multi-phase fluid transport and / or poromechanical coupling. The successful candidate will focus on behavior at formation and larger scales, and will integrate theoretical and numerical analysis with field and laboratory data.

A completed or pending Ph.D. in a relevant subject area is desired, as is competence in numerical simulation methods. Experience with field and laboratory investigative techniques is also desirable. Good communication skills are essential.

Sediment Radionuclide Geochemistry (Position 2)

The U.S. Geological Survey seeks candidates for a full-time permanent research position in sediment radionuclide geochemistry at the GS-11, GS-12 or GS-13 grades. This early-career interdisciplinary position in the National Research Program (http://water.usgs.gov/nrp/) may be filled under these job series: Research Chemist or Research Geologist or Research Hydrologist. Grade and salary ($63,000 to approximately $100,000) will be based on education and experience. Prior to starting employment with the USGS, a successful applicant will have demonstrated educational and research accomplishments, through the obtainment of a Ph.D (or equivalent education and experience) in a field related to radionuclide geochemistry. Experience will include analyses of radioisotopes in environmental samples (naturally-occurring or nuclear fuel cycle generated radionuclides) as well as research in areas such as heavy/trace metal geochemistry, mineralogy, and soil or sediment science. The applicant will have demonstrated scientific vision, leadership, and productivity in exciting, societally-relevant, and collaborative inter-disciplinary research topics.

The successful candidate will lead development of laboratory capabilities and research applications in the area of radionuclide geochemistry. The scientist will collaborate with hydrologists, geologists, chemists, ecologists and microbiologists in the USGS and provide assistance and direction in methods development for the Center for Sediment Dynamics and Forensics (CSDF), a developing center of excellence. The CSDF is expected to apply a full range of observational and experimental techniques in both the laboratory and the field. Examples of techniques to be employed by the CSDF include: radiometric techniques (14C, 137Cs, 7Be, 210Pb, 234U/238U, and other radioisotopes), optically stimulated luminescence, electron spin resonance, X-ray diffraction mineralogy, stable isotopes of light and heavy elements, major-element analysis, geochemical phase analyses, organic molecular markers, rare earth and trace element distributions, and carbon and nutrient analyses.

To Apply:

The positions will be located in Reston, Virginia in the Eastern Branch of the National Research Program (NRP). The NRP is a program in the USGS Water Mission Area and offers a stimulating and collegial environment for research in water-related earth science to meet current and anticipated national needs. NRP researchers collaborate with scientists nationally and internationally as well as with other USGS scientists nationwide.

The on-line vacancy announcements, which will be posted at the Office of Personnel Management's USAJOBS website (www.usajobs.gov) contains additional information regarding qualification requirements. The vacancies will be open for 30 days starting on or about September 1, 2015. Applications (resumes and questionnaire responses) must be received online BEFORE midnight Eastern Time on the closing date posted in the USAJOBS Vacancy Announcement. It is important that candidates view the Vacancy Announcement in their entirety to be sure that all required documents are submitted. Incomplete application packages cannot be considered. For further information, please contact: Greg Desmond (703-648-4728, gdesmond@usgs.gov, Position 1 and 2) or Pierre Glynn (703-648-5823, pglynn@usgs.gov, Position 1 and 2), or Katherine Skalak (703-648-5435, kskalak@usgs.gov, Position 2) in the Eastern Branch of the NRP.

US Citizenship is required for this position. For any US Citizen (including current or former Federal employees), the Vacancy Announcement number for Position 1 is: ATL-2015-1005. For any US Citizen (including current or former Federal employees), the Vacancy Announcement number for Position 2 is: ATL-2015-1182. The USGS is an Equal Opportunity Employer.

Two Positions: Stratigraphy/Sedimentology and Geomorphology/Climatology Denison University

Denison University invites applications for two tenure track positions in the Department of Geosciences, to begin in August 2016. We seek broadly trained scientists engaged in the study of (1) Sedimentology and/or Stratigraphy, and (2) Geomorphology and/or Climatology. We welcome candidates that combine these specialties in innovative ways, and are willing to consider joint applications. Successful candidates should demonstrate potential to be outstanding teachers, active scholars, and contributors to the continued growth of the Department and College. Candidates must have a Ph.D. at the time of appointment.

We seek colleagues who are committed to teaching excellence in the liberal arts tradition, are field-based, have broad interests beyond their individual specialties, and will provide a balance of classroom, field, and laboratory experiences for our students. Candidates must have the desire and ability to teach courses at all levels of the curriculum. The typical teaching load is three lab courses per year. In addition, successful candidates are expected to maintain vibrant and productive research programs that actively incorporate undergraduate students.

Denison University is a highly selective, private residential liberal arts college enrolling approximately 2100 undergraduate students from

across the country and around the world. The college is located in the village of Granville, Ohio, 25 miles east of Columbus. For more information about Denison, visit our website at www.denison.edu.

All application materials will be handled electronically at https://employment.denison.edu. (Please clearly indicate the desired position.) Applications must include: 1) a letter of application addressing the position requirements listed above; 2) a current curriculum vita; 3) academic transcripts of undergraduate and graduate course work (unofficial acceptable); 4) a statement of teaching philosophy and experience; and, 5) a statement of your research program in a liberal arts context. In addition, please include the contact information for three persons who know your teaching and scholarship well, who will then be requested to upload reference letters. Completed application materials submitted by October 15, 2015 will receive full consideration, and evaluation will continue until the position is filled. For those attending, we plan to meet with selected candidates at the 2015 GSA Annual Meeting in Baltimore, MD.

To achieve our mission as a liberal arts college, we continually strive to foster a diverse campus community, which recognizes the value of all persons regardless of religion, race, ethnicity, gender, sexual orientation, disability, or socioeconomic background. For additional information and resources about diversity at Denison please see our Diversity Guide at http://denison.edu/forms/diversity-guide. Denison University is an Affirmative Action, Equal Opportunity Employer.

Visiting Assistant Professor of Geology - Energy.

The Geology Department at Allegheny College invites applicants for a four-year appointment (subject to a satisfactory performance review in the second year), with a start date of January 2016. A Ph.D. is preferred at the time of appointment but strong ABD candidates will be considered. There is the potential for conversion of the position to a tenure-track contract after the four-year appointment. We seek a geoscientist with teaching and/or research interests in an energy-related field to develop and teach a new introductory energy course and to help us shape a new interdisciplinary minor in energy and society. Our vision for the position is to have someone move beyond traditional petroleum geology and help develop a curriculum related to fossil fuels as a stepping stone to future sustainable energy. Successful candidates will have a strong commitment to liberal arts undergraduate education and will work as part of a small and active departmental team. Previous internships and/or work in the energy industry is an asset, as is prior teaching experience. The appointee will advise and work closely with undergraduate students in course work and advising, including senior research projects, and will provide evidence of excellence in teaching and ongoing scholarship. Other teaching will include introductory environmental geology, college-wide first-year/sophomore seminars, and/or other advanced geology courses based on the expertise of the candidate and needs of the department. The teaching load will typically involve two lab courses per semester.

Allegheny College is a highly selective private liberal arts college in NW Pennsylvania with a dedicated faculty of teacher-scholars. The Department of Geology has a tradition of excellent undergraduate education and active involvement in student-faculty research. Facilities include a computer lab with GIS software, a trailer mounted drill rig, x-ray diffraction, ion and gas chromatography, Flame/Furnace AAS, JEOL SEM-EDS-CL, and well-equipped instructional labs. Applicants should send a letter of application, teaching statement, research statement, cv, transcripts, and have three letters of reference sent. All documents should be addressed to Energy Search, Department of Geology at Allegheny College and sent electronically to 2015GeoEnergySearch@allegheny.edu. Review of applications will begin October 19, 2015. More information on Allegheny College and the Department of Geology may be obtained at http://sites.allegheny.edu/geo/. Applicant must be authorized to work in the United States to be considered. Allegheny College is an Equal Opportunity Employer with a strong commitment to diversity, inclusion, and equity. Women, veterans, individuals with disabilities, and members of other underrepresented groups are highly encouraged to apply. Allegheny does not discriminate on the basis of race, color, religion, gender, gender identity, gender expression, sexual orientation, age, or national origin.

Wiess Post-Doctoral Research Fellowship - Department of Earth Science, Rice University

The Department of Earth Science at Rice University is launching a Wiess Post-Doctoral Research Fellowship competition in the broad fields of Earth, atmospheric, and planetary sciences. The principal selection criteria for the fellow are scientific excellence and a clearly expressed research plan to address questions at the forefront of Earth science, broadly defined. Additional details about the fellowship and the department can be found at http://earthscience.rice.edu

Please send a cover letter, 3-pg research proposal, CV, and names of four references to esci-postdoc@rice.edu. The application deadline is November 1, 2015.

Equal Opportunity Employer--Females/Minorities/Veterans/Disabled/Sexual Orientation/Gender Identity

Student Opportunities

Two Postdoctoral Research positions are currently available in the Department of Earth and Environmental Science at the University of Pennsylvania.

We seek an individual with a strong background in mineralogical and microchemical characterization to study a variety of Earth materials, including rock fulgurites (melt, crystals, and associated deformation features caused by lightning strikes on rocks), airborne dust, and materials associated with frictional sliding of experimental and natural faults. Experience with light microscopy and various electron beam instruments, specifically SEM, ESEM and analytical TEM, is essential. Previous experience characterizing materials associated with environmental health issues (e.g., airborne particulates) is preferred but not required.

We seek another individual with experience in studying impact-induced melting and deformation in rocks to investigate rock fulgurites resulting from lightning strikes. The successful candidate will apply modeling, theoretical and/or experimental approaches to understanding the formation of fulgurites and associated shock microstructures, and will work closely with the post doc described above to inform models and theory with microstructural observations. A key goal will be to understand similarities and differences between shock-induced planar deformation features in fulgurites with similar features in rocks deformed by meteoric impacts or experimental shock loads.

Both positions are available for one year and may be renewable based on performance and the further availability of research funds.

Please send a letter of interest, CV, and the names and contact information of 3 references to Prof. Reto Gieré (giere@sas.upenn.edu). Interested candidates are encouraged to arrange for an interview at the upcoming Goldschmidt Conference. Evaluation of applications will begin immediately and continue until the position is filled. Penn is an affirmative action, equal opportunity employer.

NASA Goddard Space Flight Center

Earth Sciences Division

The Earth Sciences Division at NASA's Goddard Space Flight Center, in Greenbelt, Maryland, is soliciting statements of interest for full-time PhD level civil servant scientist positions for early career through senior levels, in the following areas:

Evapotranspiration Remote Sensing
We seek a scientist with expertise in remote sensing of evapotranspiration. Experience in thermal observation-based evapotranspiration estimation, microwave soil moisture retrieval, and vegetation stress assessment based on hyperspectral observations is highly desirable. The incumbent will be expected to apply these techniques for improving understanding of the water cycle and for direct societal benefit, and to contribute to the design and development of future Earth observing missions.

Snow Remote Sensing
We seek a scientist to develop advanced techniques for remote sensing of snow water equivalent. Experience in retrieving snow properties based on active and passive microwave, LIDAR, visible, and signal-of-opportunity (SoOp) observations is highly desirable. The incumbent will be expected to improve understanding of the global water cycle, to develop applications of direct societal benefit, and to participate in the design and development of future Earth observing missions.

Global Regional Ecosystem Modeling
We seek a scientist with expertise in ecosystem modeling to support studies of the global biosphere, biogeochemical cycling, and land-atmosphere interactions. Interested scientists should have experience developing and using diagnostic and/or prognostic ecosystem models to investigate the response of vegetation systems to climate variability, ecosystem disturbance, and human activities, and to better constrain carbon, water, and other biogeochemical fluxes. We seek an individual who will pursue hypothesis-driven research, and build next-generation capabilities by incorporating new remote sensing data sets to drive global and regional models and validate results. The position will interface with atmospheric and hydrologic modeling groups within GSFC, including the Global Modeling and Assimilation Office (GMAO).

Radiative Transfer
We seek a scientist with expertise in the design and development of line-by-line and multiple scattering radiative transfer models of solar and thermal radiation with application to terrestrial-type atmospheres at the Goddard Institute for Space Studies, New York. Specific experience in the use of numerical parameterizations (e.g., k- distributions) and analysis and interpretation of spectral and/or polarimetric measurements are highly desirable, as are interests in terrestrial climate, solar system planets, including exo-planet applications. Also highly desirable are programming skills in FORTRAN and/or similar computer languages.

Satellite Remote Sensing Scientist
We seek a senior/mid-career remote sensing scientist to provide science leadership and direction to the diverse group of civil servants and contractors in the Laboratory's atmospheric constituent remote sensing group. The incumbent will be expected to lead the ongoing retrieval of atmospheric constituents; maintenance and improvement of ongoing and development of new multi-decadal, multi-instrument data products; collaborate with ground-based observations to validate space-based observations; and collaborate with modeling groups to use the space-based observations to answer Earth System Science questions. A background in remote-sensing instruments and/or the retrieval of atmospheric constituents, trace gases and/or aerosols by satellite remote sensing is highly desirable.

Oceanographic Data Assimilation Scientist
We seek an ocean scientist to contribute to a major project in Earth System Data Assimilation, including leadership of the ocean group in the Global Modeling and Assimilation Office. The incumbent will be expected to lead advances in the data assimilation techniques for the ocean, in the context of using multiple satellite observations of the physical and biological ocean state in high-resolution computer models. Experience in more than one of the areas of high-resolution ocean modeling, high-performance computing, development of observation operators for complex ocean-observing instruments, and Kalman-filter assimilation techniques is essential. The incumbent will also be expected to liase closely with NASA and other science teams, in order to effectively support their missions, use their observations, and plan for future observational types.

Seasonal Prediction Scientist
We seek an Earth scientist with expertise in numerical modeling of physical processes to contribute to the continued development and refinement of the coupled GEOS-5 Earth System Model. The incumbent will be expected to lead research projects that isolate impacts of different forcing mechanisms on the sub-seasonal to seasonal time frame. The incumbent will contribute to the GMAO's participation in NASA current missions, including GPM and SMAP, and to the planning and execution of future missions. Experience is essential in studies of physical forcing processes in the Earth System, including cloud-aerosol-radiative forcing, polar processes, or tropical ocean-atmosphere coupling. Experience in numerical simulation using high-performance computing environments is essential.

The above positions are intended for civil servant hiring for U.S. citizens. A PhD or equivalent experience in Earth sciences or related discipline is highly desirable for all positions. Interested scientists should send a cover letter, curriculum vitae, statements of research interests and names and contact information for three professional references to Michele.r.ben-gera@nasa.gov by September 30, 2015. A subsequent job application process will be conducted through USAJOBS (www.usajobs.gov). NASA GSFC is an Equal Opportunity Employer.

Postcards from the Field

Greetings from the High Cascades!

My collaborator (and molecular microbiologist extraordinaire) Dr. Trinity Hamilton snapped this picture of me harvesting snow algae from the surface of Collier Glacier on the flank of the North Sister in Central Oregon.

In the background (looking north, from left to right) you can see Belknap Crater, Mt. Washington, and Three Fingered Jack. In the distance we could also see other Cascade stratovolcanoes (Mt. Jefferson, Mt. Hood, and the very top of Mt. Adams on the hazy horizon), giving us a breathtaking scene as we sampled.

Not a bad way to start the morning collecting geochemical and microbiological samples!

Wish you were here (especially to help filter water and carry out rocks)!

—Jeff R. Havig, Ph.D.
University of Cincinnati

View the full image and other postcards at *http://americangeophysicalunion.tumblr.com/tagged/postcards-from-the-field.*

EARTH & SPACE SCIENCE

virtual poster showcase

Students Can Now Share Their Research—From Anywhere!

This is a new opportunity that allows undergraduate and graduate students to present their research virtually, without any need to travel.

3 Opportunities to Participate in Fall 2015

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Virtual Poster Showcase #2
For Undergraduate Students

Virtual Poster Showcase #3
For Graduate Students

Advantages of Virtual Presentations Over In-person Meetings

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Lower Cost

More Flexible Scheduling

Students

- **Share** your research
- **Practice** your presentation skills
- **Review** the posters of your peers
- **Receive** quality feedback from peers and experts in your field
- **Build** your credibility

Faculty

- **Help students** develop their presentation skills and ability to evaluate science
- **Impact more students** with the funds you have
- **Incorporate Virtual Poster Showcases** in a capstone course

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2016

OCEAN SCIENCES MEETING

21—26 February • New Orleans, Louisiana, USA

AGU • ASLO • The Oceanography Society

Submit an Abstract for Presentation

Abstract Submission Deadline:
23 September 2015

The theme for the 2016 Ocean Sciences Meeting is **Ocean Sciences at the Interface**. Complex interactions often occur at interfaces. Interactions at these interfaces occur on a wide range of spatial and temporal scales, and these interactions are critical for understanding the world around us and implementing informed policies in a global society. The meeting will highlight processes at interfaces and how the work at such interfaces pervades the study of ocean sciences and shapes the impact of our research on society.

osm.agu.org