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1 MARCH 2016
VOLUME 97, ISSUE 5

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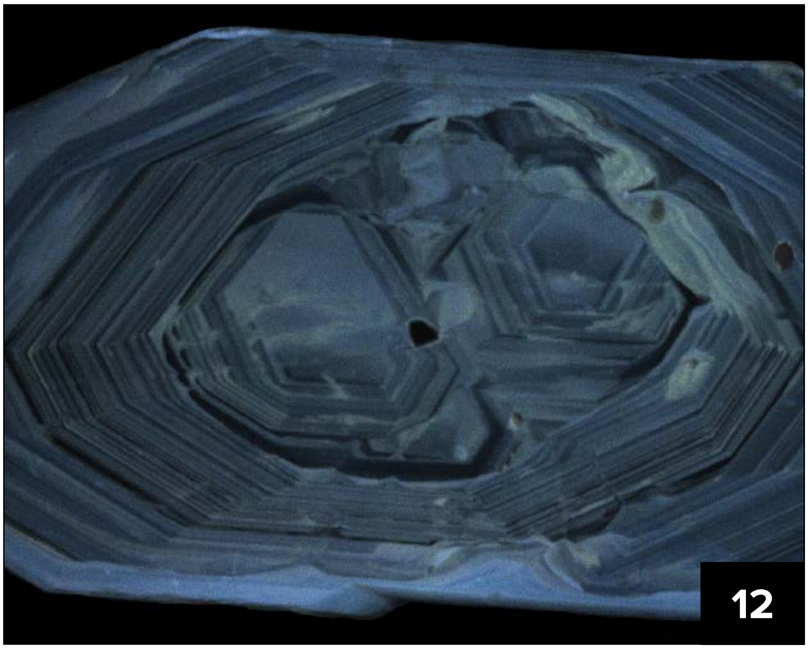






# Eos®





*Eos* (ISSN 0096-3941) is published semi-monthly, on the 1st and 15th of the month 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.

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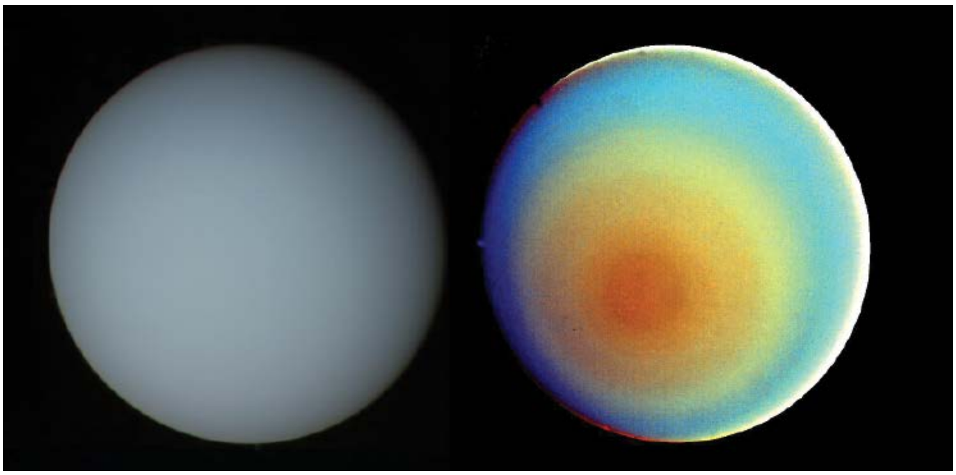
# What Caused the Sudden Heating of Uranus's Atmosphere?



NASA/JPL

*The Voyager 2 spacecraft snapped these (left) true-color and (right) false-color images of Uranus in 1986.*

Models of Jupiter, Saturn, Uranus, and Neptune predict that the temperatures of their upper atmospheres—the zones of dilute gases far above the planets' frigid cloud tops—should be around 200 kelvins, or −73°C. However, when the two Voyager spacecraft zipped by those gas giants in the late 1980s, scientists discovered that the planets' outermost atmospheres were much hotter than expected—nearing 1000 kelvins, or more than 700°C.

Scientists have had trouble coming up with a mechanism to explain these searing temperatures. Now, after decades of observation, they might be closer to an answer.

Although close monitoring has shown that Uranus's upper atmosphere underwent consistent cooling over the past 20 years, measurements since 2014 by University of Leicester's Henrik Melin and colleagues revealed a reversal toward heating.

During this time, other observers detected a storm in the planet's lower atmosphere. Could the two phenomena be related?

"The fact that this turbulent weather phenomenon in the lower atmosphere occurs at the same time as there is significant heating in the upper atmosphere suggests that [the storm] is an important mechanism" in that heating process, Melin said.

Melin suspects that the recently spotted Uranian storm (see http://bit.ly/U-storm) could have generated enough heat to reverse the 20-year cooling trend in the upper atmosphere of the planet. Also, because storms occur all the time on Jupiter and Saturn, the disturbances might have a hand in maintaining high temperatures in their upper atmospheres, he suggested.

Melin presented the data on the Uranian heating last December at the 2015 AGU Fall Meeting in San Francisco, Calif. (see http://bit.ly/FM15-abstract).

### Turning Up the Heat

During the past 20 Earth years, the upper atmosphere of Uranus cooled from 750 to 550 kelvins, but since 2013, it has heated by about 50 kelvins per Earth year, Melin said. A Uranus year is 84 Earth years, so small variations in Uranus's atmospheric temperature while the planet orbits the Sun should take place gradually. That the reversal happened relatively quickly means that "something dramatic has changed," Melin said.

Several mechanisms can heat a planet, but none solve the mystery of the gas giants' so-called "energy crisis," Melin explained. The Sun warms the gas giants, but because those planets are so large and far away, scientists know that solar photons don't supply enough energy to heat their upper atmospheres to current temperatures.

Scientific evidence suggests that Jupiter and Saturn hold extremely hot cores left over from their formation about 4.5 billion years ago, but the core of Uranus generates relatively little heat. Also, the process that creates auroras on Earth—high-energy solar particles interacting with the planet's magnetic field—can cause heating. However, because the gas giants are so huge and rotate so fast, this heat circles the poles without spreading globally, so it wouldn't account for the global upper atmospheric heating that's been observed, Melin said.

Given the storm in Uranus's lower atmosphere, Melin suspects that another factor could be at work: low-amplitude "acoustic waves"—also known as gravity waves—generated by huge, turbulent storms. These waves originate from disturbances, like ripples in a pond. On Earth, gravity waves come from violent thunderstorms or when wind blows over a mountain. On the gas giants, storms in the lower altitudes create these waves, which propagate toward the higher altitudes and generate heat, Melin said.

"Uranus is unique in that it has remained so very quiet [stormwise] for so long and that the appearance of these storms in 2014 correlates so well with the abrupt heating of the upper atmosphere," Melin said.

### Stormy Waves

Astronomers have seen a similar effect before on Saturn, said Leigh Fletcher, a planetary scientist who is also at the University of Leicester in the United Kingdom but wasn't involved in the research by Melin and his colleagues. In 2010, a huge storm erupted in Saturn's lower atmosphere, and scientists witnessed the evolution of a region of hot gases that rose into the upper atmosphere (see http://bit.ly/Saturn-Storm).

"Connecting this middle-atmospheric activity to the tropospheric storms is very challenging, but it's also possible that waves can transfer their energy all the way up to the top of the atmosphere, where Dr. Melin has been working," Fletcher continued.

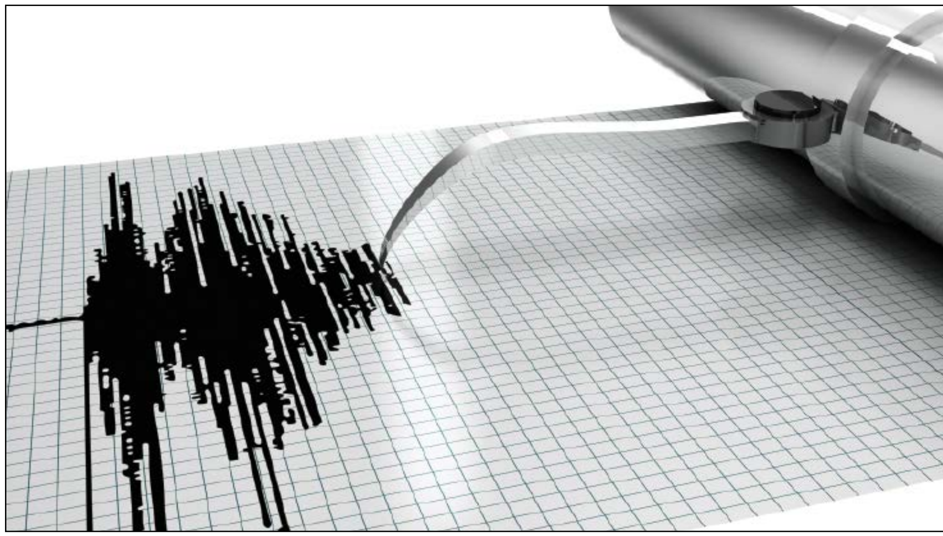
However, scientists remain unclear as to how these planets' lower atmospheres interact with their upper atmospheres. "The apparent increase in storminess of Uranus over the past few years might just be an observational bias, as our observing techniques continue to improve," Fletcher said. "Only a long-term campaign of Uranus storm tracking can accurately tell us the statistics of Uranian storms, although the [2014] storms do appear to have been bigger and brighter than anything we've seen before."

By **JoAnna Wendel,** Staff Writer

# Quake or Bomb? Seismic Waves Speak Truth, Even If Nations Don't

Early this year, North Korea tested what it claimed to be a hydrogen bomb, or as the North Korean government declared in its official statement, an "H-Bomb of justice." However, it's not likely that North Korea actually developed a hydrogen bomb and successfully tested it on 6 January local time as announced. The U.S. Geological Survey recorded the subsequent seismic event as having a 5.1 magnitude, which is much lower than would be expected from such a powerful weapon.

But even if North Korea or anyone else conducting a clandestine nuclear test makes no announcement, seismologists can still figure out if an underground bomb test or an earthquake took place by analyzing how energy propagates from the seismic event in question.



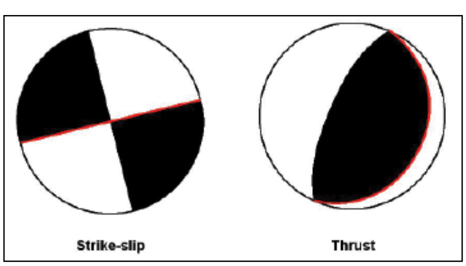


*Even if a country doesn't announce an underground nuclear test, seismologists can distinguish a subterranean bomb blast or other explosion from an earthquake by examining the event's seismic waveforms. As shown here, a seismograph translates seismic waves into a graph called a seismogram, which researchers can then evaluate.*

### Explosions Send Compression Waves in All Directions

*P* waves are the fastest-moving type of seismic waves. They alternately compress and dilate the material they move through. When an explosion, such as a nuclear test, occurs within the Earth, all of the force of the blast strikes the surrounding material.

"As the bomb is detonating, it's compressing the rock immediately adjacent to it, and that propagates out to the recording stations" as *P* waves, said Douglas Dreger, a seismologist at the University of California, Berkeley. The first wave to reach the seismometer generates an "up" signal. Seismologists use the term "up" because the ground actually moves up when the compression phase of a *P* wave arrives and the squeezed underground rock and soil juts upward at the surface.






*When an earthquake strikes, seismologists use diagrams called focal mechanism plots to determine what type of faults moved. Each type generates a different pattern, with both black and white regions. Earthquake faults of different configurations, such as strike-slip or thrust faults, yield distinctive plot patterns when earthquakes occur along them. However, all regions of the diagram go dark if the jolt is caused by an explosion.*

Seismologists then plot the up signals from *P* wave compressions and down signals from dilations on black-and-white diagrams called focal mechanism plots. They divide these diagrams into four regions representing directions in which seismic waves travel from a shock. A focal mechanism plot would appear completely white before an earthquake and then be shaded black in some spots once seismic detectors register an up signal in a region.

Each type of earthquake generates a different plot pattern in which there are some black and some white regions. By contrast, concussive signals propagating in all directions from an explosion would shade the entire plot black. Dreger's focal mechanism plot for the North Korean nuclear test is entirely shaded.

### Bigger Interior Waves Suggest an Explosion

The relative amplitudes of an event's seismic waves, which zip through the Earth's interior, when compared to the amplitudes of its surface waves, which radiate more slowly from the shock, can also indicate if an explosion or earthquake triggered the event. Explosions produce larger internally propagating waves than surface waves, whereas an earthquake doesn't cause the same discrepancy.

Looking at only the waveforms from the North Korean test, Dreger said, "It's very obviously an explosion." So even if a less outspoken country tried to secretly test an atomic or hydrogen bomb, scientists could still uncover the truth.

### Seismology Alone Can't Determine What Type of Bomb Detonated

Once scientists know an underground explosion or bomb test occurred and they know the magnitude of the seismic event it caused, they can calculate the explosive force that caused that quake. This latest test, registering at 5.1, most likely falls below the magnitude a hydrogen bomb would produce, said Brian Stump, a seismologist at Southern Methodist University in Dallas, Texas.

But, Stump said, drawing a firm conclusion concerning what type of bomb was detonated requires radionuclide measurements that specially designed aircraft can make. Some news media outlets reported shortly after the North Korean announcement that U.S. Air Force planes would sample the air near the test area to determine what radioactive material, if any, leaked out of the underground blast site (see http://bit.ly/Sniffer).

By **Cody Sullivan,** Writer Intern

# Human Activities Account for Less Than a Third of Ocean Nitrogen

Tony Webster, CC BY-SA 2.0 (http://bit.ly/ccbysa2-0)

*Smokestacks like these emit nitrogen oxides, which are converted to nitrate in the atmosphere.*

Since the Industrial Revolution, humans have been releasing nitrogen into the atmosphere and, from there, into the ocean, where it acts as a nutrient but also poses dangers to aquatic ecosystems in high quantities. Now new research finds that far less human-generated nitrogen is reaching the open ocean than previously thought.

Although atmospheric models suggest that up to 80% of the ocean's reactive nitrogen—that is, nitrogen that can be used by organisms—comes from anthropogenic sources, such as livestock production, agriculture, and coal-fired power plants, a recent series of observational studies indicates that only 27% can be traced to human activities.

The results may lead to future research that could alter how scientists view fundamental interactions between the ocean and the air. "We're lacking important understandings of the nitrogen cycle because the traditional idea is that nitrogen coming in via rain and aerosol deposition is really anthropogenic in origin," said Meredith Hastings, an associate professor of Earth, environmental, and planetary sciences at Brown University in Providence, R.I. "If it's not, and the ocean is playing a significant role in recycling, then that's something that's been totally missing in our thinking."

### A Rigorous Analysis

Hastings participated in the new research, which was led by Katye Altieri, a senior researcher at the University of Cape Town in South Africa. At the time of the studies, Altieri worked as a National Oceanic and Atmospheric Administration postdoc jointly appointed between Brown University and Princeton University.

The researchers spent 18 months collecting aerosol and precipitation samples from a National Science Foundation atmospheric sampling tower in Bermuda that rises 65 meters above sea level. Because the island is at times "downstream" from winds that blow over the North American continent, it has proven useful for atmospheric sampling in the past.

During its warm season, Bermuda receives air masses only from farther out in the ocean, whereas its cool season brings an influx of air masses directly from North America in addition to marine ones. Using weather modeling, the team could be sure where each air mass came from.

To gather rainwater, the team used a precipitation collector—basically a glorified bucket equipped with a sensor that opened its lid to collect new samples whenever it began to drizzle. Low-lying aerosol particles that hang from the air regardless of rain were pumped through filters. The samples were later analyzed for nitrate, ammonium, and organic nitrogen in what chemical oceanographer Angela Knapp of Florida State University in Tallahassee, who was not involved in the study, called "one of the most rigorous analytical studies of atmospheric deposition that's been done." The researchers scaled up their results to represent the world as a whole so they could compare their findings with previous models.

> "The ammonium seems to all be coming from the ocean itself."

### Revisiting the Nitrogen Cycle

Human activities produce nitrogen mainly as ammonia, nitrogen oxides, and organic nitrogen-containing compounds. In the atmosphere, chemical reactions convert ammonia to ammonium and nitrogen oxides to nitrate. A lack of data about the fates of nitrogen compounds motivated the research, Hastings said, particularly with regard to ammonium and organic nitrogen deposition.

She and her colleagues found that approximately 60% of nitrate in their samples hails from human sources. The ammonium came entirely from evaporated seawater, although the researchers were able to use only precipitation, not aerosol, data for that compound. Although the nitrate data aligned with results Hastings had seen before, the ammonium data were unprecedented. "We would have thought we would've seen significant agriculture or industrial activity influence, but the ammonium seems to all be coming from the ocean itself," she said. "That was a particularly big surprise." The results of the researchers' analyses for these nitrogen sources were published in the *Journal of Geophysical Research: Atmospheres* in 2013 (see http://bit.ly/JGR_paper) and *Global Biogeochemical Cycles* in 2014 (see http://bit.ly/Global_BioGeo), respectively.

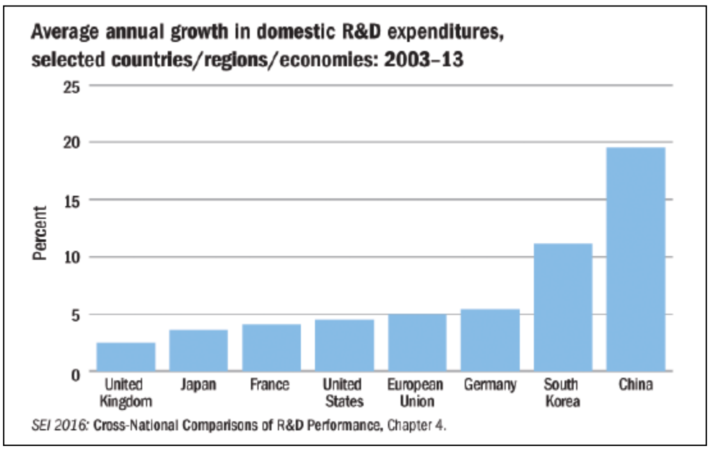
In a third study using the same samples, which was published on 6 January in the *Proceedings of the National Academy of Sciences* (see http://bit.ly/PNAS-paper), the team found that only about 17% of the organic nitrogen originated from anthropogenic activities. Hastings said she would have expected a significant portion of it to be generated by humans, as with nitrate. "This is the most organic nitrogen data that really anyone has ever had for this type of data set over the ocean," she said.

In this final study, the team also pooled the data for all three nitrogen sources extracted from the precipitation and aerosol samples. They found that only about 27% of the total nitrogen deposition was anthropogenic in origin. Although Knapp considers the results somewhat surprising, she suspects that the discrepancy between the team's results and past findings could be due to a paucity of research.

"This is a data-limited field and there just aren't a lot of atmospheric deposition measurements," said Knapp. "I don't think it's overturning a paradigm. I think it's more that this is a new piece in the puzzle."

By **Shannon Kelleher,** Writer Intern

# United States Still First in Science, Tech Research Spending




National Science Foundation

*Between 2003 and 2013, China's research and development (R&D) expanded more rapidly than that of any other country, accounting for about one third of total global growth in science and engineering R&D during that decade, according to "Science and Engineering Indicators 2016," a report issued in January by the U.S. National Science Board.*

The United States continues to lead the world in expenditures for research and development, but the number 2 spender, China, is increasing its investment in those areas at the fastest pace of any nation, states the newest issue of a recently released biennial report. China is strengthening its research enterprise in other ways as well, such as making huge strides in graduating science and engineering degree recipients, according to the report, which relies mostly on data through 2013.

The United States accounted for 27% of global research and development (R&D) spending in 2013, and China accounted for 20%, according to the report, which states that global R&D expenditures in 2013 were nearly $1.7 trillion, up from $836 billion a decade earlier.

A "multipolar world" for science and engineering "is emerging after many decades of leadership by the United States, the European Union, and Japan," states the report, entitled "Science and Engineering Indicators 2016," which is a biennial analysis issued by the U.S. National Science Board (NSB). The report (see http://bit.ly/SandE-Indics) provides key information about how the United States compares with other nations in the areas of research and development; science, technology, engineering, and math (STEM) education; and workforce development. The report also surveys public attitudes toward science.

## Increased International Competition

"While international competition is growing, [U.S.] federal support for R&D is wavering," said NSB vice-chair Kelvin Droegemeier, vice president for research at the University of Oklahoma in Norman, during a 19 January briefing to release the report.

"There is plenty of room for lots of [international] players," he said. "It's really about U.S. competitiveness and making sure that we remain competitive. We have to continue investing, [but] not at the same rate. We've got to continue speeding up and accelerating our investments and upping our game."

There is "continuing evidence" of budget pressures on total R&D, particularly in the past 3–5 years, and "total federal R&D investments have not kept up with inflation," said NSB chair Dan Arvizu, director of the U.S. Department of Energy's National Renewable Energy Laboratory in Golden, Colo.

In 2013, U.S. R&D expenditures totaled $456 billion, with the private sector accounting for more than two thirds of that amount; 80% of U.S. R&D funding went to development and applied research, and 18% went to basic research, according to the report. About 40% of the U.S. gross domestic product derives from high-technology manufacturing and "knowledge-intensive service industries," the report continues.

> "There is plenty of room for lots of players. It's really about U.S. competitiveness and making sure that we remain competitive."

The report also focuses on the increased cost of attending public research universities. Net tuition and fees for full-time students rose 80% between 1999 and 2012 in the most research-intensive public universities while state and local appropriations fell 36% per student, according to the report. "We see now that budget constraints have substantially affected federally funded higher education R&D," Droegemeier said.

Although the report does not delve too specifically into funding trends for the Earth and space sciences, Droegemeier said that "the lack of predictability in funding is, I think, more important an issue than the actual amounts." He said, "Those areas in particular that are heavily dependent on observing systems that are very expensive really would benefit from having more predictability in their funding cycle."

## Public Attitudes Toward Science

The report details public attitudes toward science, showing that the public has more confidence in the scientific community than in any other institutions surveyed aside from the military and that about 55% of Americans worry "a great deal" or a "fair amount" about global warming or climate change.

In an interview with *Eos*, Arvizu said that responses about climate change often depend on what question is asked and on other factors such as the economy. "If unemployment is low, people have more interest in the environment. When unemployment is high, they have less interest in the environment."

Arvizu said he was surprised by the results of a survey question that show that 51% of Americans believe that science makes life change too quickly, a percentage that is up about one third from a decade ago.

"What we found is those with less education and less income were more likely to express worry about the pace of change," Arvizu said. Leaders in the scientific community "definitely need to be worried" about this perception, he added, because the nation needs a science- and technology-savvy population to thrive in today's advanced society and to maintain its research and development leadership.

"We can't leave large portions of our society underserved, and education is the key," he said. "We have all this technology that is driving the pace of change. Simply to be competitive, I think we need a much more literate general population."

By **Randy Showstack,** Staff Writer

# New Step Toward Finding Earth 2.0

Astronomers have developed a more accurate way to estimate the masses of exoplanets, an important step toward the ultimate goal of finding Earth's twin among the orbs circling nearby Sun-like stars.

They'll need something like this, exoplanet seekers say, if they hope to ultimately find what's popularly dubbed Earth 2.0—an Earth-mass planet orbiting a Sun-like star at a distance similar to Earth's orbit. Researchers described the new work earlier this year at the winter meeting of the American Astronomical Society in Kissimmee, Fla.

## Measuring an Exoplanet's Mass

Astronomers typically calculate the mass of an exoplanet by using a method known as radial velocity (see http://bit.ly/RadialV). The method relies on tracking the motion of a star that moves slightly back and forth, or wobbles, due to the tug of an orbiting planet. As seen by a distant observer, the forward motion shifts the color of starlight toward the blue end of the spectrum, and the backward motion shifts the light toward the red, an effect known as the Doppler shift. Knowing the magnitude of the wobble and how frequently it recurs allows scientists to measure the planet's mass as well as how far the planet's orbit lies from the star.

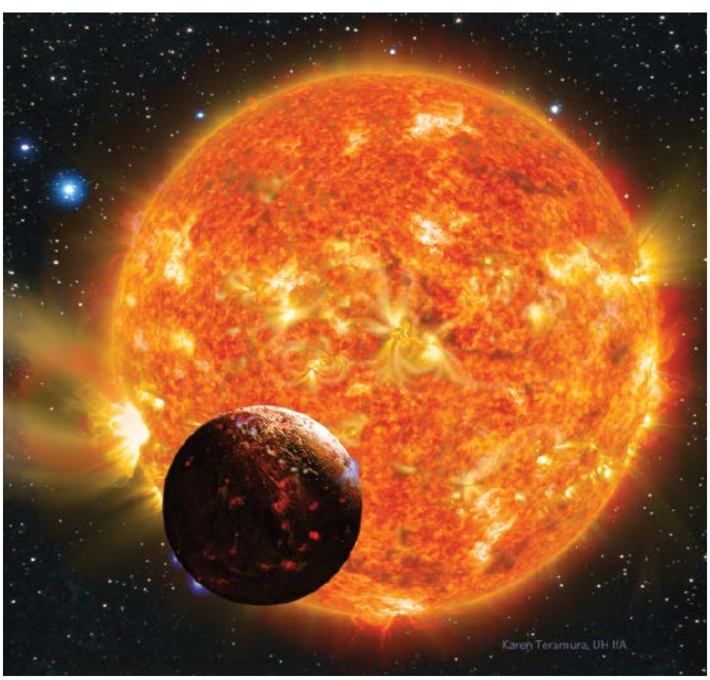
## Confounding Star Spots

Although the radial velocity method has been used to detect more than 500 of the roughly 2000 known exoplanets, a common feature on the surface of stars can confound the results.

Just as dark blemishes called sunspots dot our Sun, star spots fleck the surfaces of stars. As a star spot rotates with its star's surface, it moves toward an observer then recedes, inducing a Doppler shift that can mimic the shift caused by the wobble of a star due to an orbiting planet.

Stars wobble significantly enough from heavy planets orbiting close to them that the additional color shift due to star spots poses little challenge to exoplanet observers. However, in the quest to find the much smaller shift caused by a less massive, Earth-like planet at a much greater distance—like Earth's—from the star, the interfering signals from these dark blemishes loom large, said astronomer Samuel Grunblatt of the University of Hawai'i at Mānoa in Honolulu.

Using our own star as an example, he noted that sunspot activity generates a Doppler shift that's between 10 and 100 times more than the shift caused by Earth's tug. In effect, our sunspot activity drowns out the wobbles that Earth induces on the Sun.




Karen Teramura, UHIfA

*This close-orbiting exoplanet found in 2013 is known as the Hell planet because of its nearness to its star, Kepler-78.*

## Model for Star Wobble

Although instruments aren't yet sensitive enough to record the stellar wobble induced by Earth 2.0, Grunblatt and his colleagues are gearing up for such a detection and have developed a model that can more accurately account for the confounding star spot signal than earlier attempts.

Previous strategies have usually assumed that at any given time, the signal due to a star spot can be known exactly. But that didn't sit well with Grunblatt and his colleagues.

"If we don't know what [Earth's] sunspot activity is going to be tomorrow, how can we assume that we can know what [activity on] an unresolved star hundreds of light-years away is going to look like in a month?" he explained. Because star spots come and go and change shape over time, the team modeled them as having somewhat unpredictable traits instead of assuming they evolve in an entirely predictable manner.

The team applied its model to a test case—a previously detected Earth-mass planet, dubbed the Hell planet because it lies within roasting distance of its star, Kepler-78. The researchers found that their model yielded a mass estimate slightly more precise than previous results.

In addition to presenting the new technique at the Florida meeting , Grunblatt and his colleagues described the work in the 1 August 2015 issue of *The Astrophysical Journal* (see http://bit.ly/ApJ-paper).

"The power of their method is that it can be applied to Earth-size planets in longer period orbits," said exoplanet astronomer Artie Hatzes of the Thüringian State Observatory in Tautenburg, Germany, who did not participate in the study.

## Other Approaches

A team that includes astronomer Suzanne Aigrain at the University of Oxford in England has worked on a similar model. The researchers reported their findings in the 21 September 2015 issue of *Monthly Notices of the Royal Astronomical Society* (see http://bit.ly/Rajpaul_et_al).

Aigrain said that she and her collaborators incorporate other information in their model, such as the activity of the star's chromosphere, the layer that sits above a star's visible surface. In contrast, Grunblatt and his colleagues adopted a more basic strategy, using only radial velocity information and the rotation period of the star to eliminate the star spot signal.

During a stellar observation, "if [our] approach was found not to work well, then Grunblatt's more basic approach would be a pretty robust one to fall back on," said Aigrain.

Methods like these "will become more and more important in the search for smaller and cooler planets," she added.

By **Ron Cowen,** Freelance Science Journalist; email: roncowen@msn.com

# Claudia Joan Alexander (1959–2015)

Courtesy of NASA/JPL-Caltech

*Claudia Alexander*

Claudia Alexander, who oversaw the dramatic conclusion of the Galileo mission to Jupiter and was the NASA project scientist for the international comet-chasing Rosetta project, died of breast cancer on 11 July 2015. She was 56.

Claudia was born in Vancouver, British Columbia, Canada, on 30 May 1959. The family moved to Northern California when she was 1 year old, and she grew up in Santa Clara. Her father, Harold Alexander, was a social worker, and her mother, Gaynelle, was a corporate librarian for chipmaker Intel.

**Early Life as a Space Science Student**

Claudia wanted to study journalism at the University of California, Berkeley (UC Berkeley), but her parents "would only agree to pay for it if I majored in something 'useful,' like engineering," she once said in an interview. During college, she became an engineering intern at NASA's Ames Research Center. She found herself drawn to the space facility and visited it as often as she could. Her supervisor eventually arranged for her to intern in the space science division. She went on to earn a bachelor's degree in geophysics at UC Berkeley in 1983 and a master's in geophysics and space physics at UC Los Angeles in 1985. After earning her master's degree, she joined NASA's Jet Propulsion Laboratory (JPL) as an instrument representative for the Near Infrared Mapping Spectrometer of the Galileo mission.

In 1988, Claudia enrolled in the doctoral program in space and planetary physics at the University of Michigan, Ann Arbor, where she worked on thermophysical modeling of cometary nuclei under my guidance. In 1993, she defended her Ph.D. thesis and returned to JPL, where she continued her research on comets and the early history of the solar system.

In her spare time, Claudia wrote two books on science for children and mentored young people, especially African American girls.

**Role Model for Young Women Scientists**

At Michigan, Claudia was also very active in student life. She was lighthearted, an instigator of many jokes, and had great success imitating my heavy Hungarian accent. In her more serious moments, she initiated high-impact outreach efforts to underprivileged and underrepresented groups. She worked extensively with inner city students in Detroit and helped many young women to finish school. Some were motivated enough by Claudia to attend institutions of higher learning. She was particularly enthusiastic about working with young women of color and becoming a role model for the next generation.

Her efforts were recognized and appreciated at Michigan. In 1992, Claudia was named University of Michigan Woman of the Year in Human Relations. She continued to have a strong relationship with the university over the years, and in 2002, she earned the Department of Atmospheric, Oceanic and Space Sciences (AOSS) Alumni Merit Award. She also served on the AOSS National Advisory Board. In 2007, her uncle, Jiles Williams, established the Claudia Alexander Scholarship for undergraduate students at Michigan.

**Leading the Galileo and Rosetta Missions**

During her 3 decades at NASA JPL, Claudia served as the last project manager of Galileo, one of the most successful missions for exploring the distant reaches of the solar system. She was leading the mission when scientists orchestrated its death dive into Jupiter's dense atmosphere in 2003, when the spacecraft finally ran out of fuel after 8 years orbiting the giant planet. Her leadership resulted in major new discoveries about the upper layers of Jupiter's atmosphere, including its composition and dynamics.

Beginning in 1998, she was Rosetta's U.S. project scientist, and for an extended period of time, she also served as project manager, coordinating with the European Space Agency on the orbiter's journey to rendezvous with the 67P/Churyumov-Gerasimenko comet as it circled the Sun. She played a critical role in integrating the disparate science team into a coherent science enterprise, and she led the effort to relate Rosetta's observations to our understanding of the formation of our solar system.

In her spare time, Claudia wrote two books on science for children and mentored young people, especially African American girls. On the U.S. Rosetta mission's webpage, she wrote, "Throughout school I was one of few women in class and didn't feel very feminine talking my way through engineering applications like dam or bridge building. At that time there were few female role models to give me a vision of myself as a professional engineer. I wasn't feeling very validated, which played hugely into my self-esteem at the time. But I stuck with it. When I was a senior in undergraduate school, a professor nudged me into a senior project on Earth's carbon cycle. It turned out great. He was really pleased and pretty much got me into graduate school. It was a case of a professor believing in me. Fifteen years later, I was chosen to be the project scientist on Rosetta, a lifelong dream, and my life has never been the same!"

We mourn the loss of Dr. Claudia Alexander, a dedicated scientist, inspiring role model, and one of the nicest people I ever had the pleasure of working with.

By **Tamas I. Gombosi,** University of Michigan, Ann Arbor; email: tamas@umich.edu

# The Impact of African Dust on Air Quality in the Caribbean Basin

**Symposium on Airborne Dust, Climate Change, and Human Health**
Miami, Florida, 19–21 May 2015

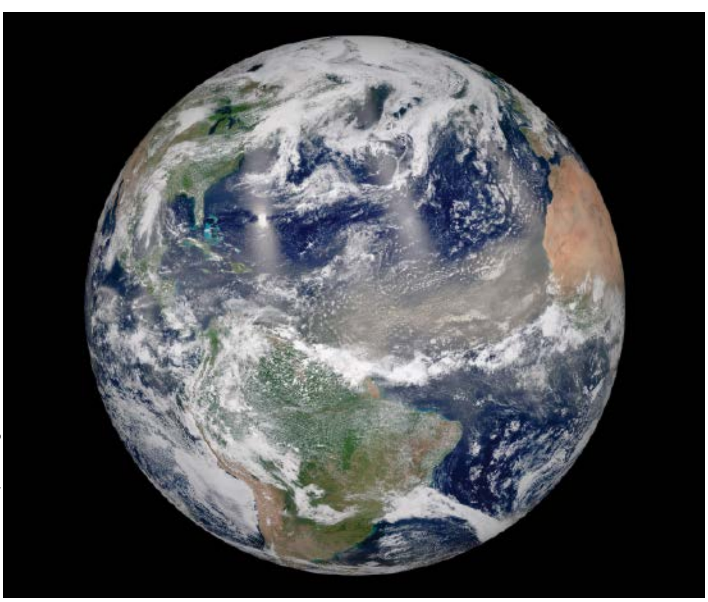
Large quantities of African dust are carried to the Caribbean Basin every year, causing concerns about the impact on human health. Because of dust, the concentration of airborne particulate matter in the region frequently exceeds the World Health Organization guideline for particles measuring less than 10 micrometers in diameter. Further, the shifting global climate could exacerbate the problem.

To address these concerns, 48 scientists engaged in Caribbean studies met for a symposium last May at the University of Miami in Miami, Fla. Participants included researchers, atmospheric modelers, climatologists, and representatives from the public health community.

Although African dust is widely believed to be linked to the high incidence of asthma in the Caribbean, there have been few regional studies of asthma or other aerosol-related health issues. Epidemiological studies were presented at the meeting, but the results were inconclusive or contradictory. Participants agreed that there is a need for better data on cardiovascular and other respiratory illnesses, in addition to asthma.

There is also a need for more widespread air quality measurements, which are currently made only in Barbados, Puerto Rico, Guadeloupe, Martinique, and Cayenne. Participants agreed to implement an ad hoc federated network to enable accurate tracking and quantifying of African dust outbreaks and the transport of this dust across the Caribbean to the coastline of the southern United States. NASA solar tracking photometers and micropulse lidars are located at a number of sites, and participants discussed increasing the number of sites. As an outcome of the meeting, a website (currently in beta testing) will integrate these observations in real time with Moderate Resolution Imaging Spectroradiometer (MODIS) satellite products and aerosol model forecasts.

Plans were also made to develop a dust warning capability linked to public health services in the region so that alerts could be issued to susceptible populations. The Caribbean effort will be coordinated with the World Meteorological Organization Sand and Dust Storm Warning Advisory and Assessment System, which currently focuses on African dust and its impact on Europe and the Middle East.



NASA Goddard Space Flight Center

*A Suomi National Polar-Orbiting Partnership (NPP) satellite composite image of the Trans-Atlantic African dust plume on 16 June 2015, during the second of two major dust outbreaks that occurred in rapid succession. The tail end of the first, which emerged from Africa on 6 June, can be seen over the western Caribbean and Gulf of Mexico. Note that the canted, vertically oriented, light-toned areas seen over the midlatitude North Atlantic are artifacts caused by Sun glint on the ocean surface.*

There is widespread concern about the effects of climate change on dust transport and health in the region. The 50-year Barbados dust record shows significant changes linked to climate, most notably the intense droughts in the 1970s and 1980s.

Plans were also made to develop a dust warning capability linked to public health services.

Discussions focused on the considerable research that has gone into dust-climate linkages on scales ranging from regional (e.g., changes in rainfall, vegetation, land use, wind conditions in Africa) to planetary teleconnections (e.g., El Niño, the Atlantic Multidecadal Oscillation). Although this work has yielded promising results, large uncertainties still exist, exemplified in the Intergovernmental Panel on Climate Change projections for Africa, which are indefinite for the two most critical dust-related parameters, soil moisture and wind fields.

Symposium participants concluded that a coordinated study of air quality and the health impacts across the Caribbean Basin could serve as a test bed for evaluating dust-climate models and the consequent dust-health effects. Because the Caribbean is relatively unaffected by major aerosol sources other than dust, health impacts could be more directly linked to dust. The information gained from these studies could provide insights on possible health impacts in other dusty regions of the world where 2.1 billion people live and where there is little research on aerosol-health issues.

The symposium was supported by the National Integrated Drought Information System of the National Oceanic and Atmospheric Administration.

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# Understanding Ecosystem Services from a Geosciences Perspective

Human societies depend greatly on the natural environment in many ways: for food production, water supplies, erosion and flood control, and recreational opportunities, for example. However, the linkages between human societies and these benefits they derive from the environment have not always been considered explicitly when managing natural resources. To understand these linkages so that benefits from the environment can be more effectively managed, the framework of "ecosystem services" has emerged as a useful approach.

The benefits that society derives from the environment have been described in many ways, with ecosystem services initially classified into four distinct categories [*Millennium Ecosystem Assessment,* 2005]:

- Provisioning services are material benefits to humans, such as fiber, food, or timber.
- Regulating services are processes such as pollination, flood control, and disease control.
- Supporting services include nutrient cycling and soil formation.
- Cultural services are those aspects of species and ecosystems that provide humans with recreational, spiritual, or religious experiences.

P. D. Brooks

*West Maroon Creek is fed by high elevation snowfall in the Elk Mountains of Colorado. These mountains typify the high elevation water sources that feed the major rivers of Western North America and serve as the primary water sources for more than 70 million people in the United States. Recent work shows that most of this meltwater infiltrates soils and recharges groundwater before becoming streamflow and feeding downstream reservoirs. Here studies of the critical zone related to groundwater supply focus on how large the groundwater stores are, how these storage zones vary over space and time, and how they can buffer or exacerbate regional drought.*

An example of an ecosystem service critical to society is provision of water of sufficient quantity, timing, and quality for drinking and other human requirements. A traditional ecosystem services perspective focuses on relating active vegetation management (e.g., forest thinning) or vegetation change due to disturbance (e.g., fire, insect, or drought mortality) to water resources, often emphasizing precipitation, soil moisture, and surface water flows while not necessarily considering other influential processes [e.g., *Alila et al.,* 2009].

Explicitly expanding assessment of the service of water provision to include geosciences perspectives would in many cases lead to more robust understanding of relevant environmental processes and how to manage them for the benefit of society [*Field et al.,* 2015]. For example, geosciences perspectives on water resources explicitly bring into consideration other key processes such as water quantity as affected by groundwater interactions with surface water, water timing as affected by subsurface flow transit times, and water quality as affected by rate-limiting biogeochemical processes [*Chorover et al.,* 2011; *Brooks et al.*, 2015]. This perspective is consistent with the original definition of ecosystems as one physical system [*Richter and Billings,* 2015].

To further highlight the utility of incorporating geosciences perspectives into considerations of ecosystem services, we discuss an example focusing on integration of biological, physical, and chemical processes associated with evolution of the "critical zone" (CZ, extending from groundwater level to the top of the vegetation canopy) and their relevance to society in the context of ecosystem services.

## The Critical Zone Perspective

The societal relevance of processes occurring at CZ scales comes primarily from their fundamental role in regulating ecosystem processes and their effects on associated services. There is growing concern that human disturbance, including intensive management for agriculture, is altering the CZ's potential to provide essential services, to the extent that it transforms the CZ into a less active regulator of nutrients, carbon, and water.

The long-term evolution of the CZ from its bedrock source is driven by climate-sensitive ecosystems [*Rasmussen et al.,* 2011], and the evolved structure of porous soil and bedrock, in turn, affects how an ecosystem responds to perturbation [*Lin,* 2010]. However, CZ development occurs over longer time scales (thousands to millions of years) than ecosystem succession (tens to hundreds of years) [e.g., *Chadwick et al.,* 1999]. Services deriving from CZ processes, such as water purification and carbon stabilization, are sensitive to how variations in climate or rock formation characteristics (lithology) affect the long-term evolution of regolith, the surface soil and deeper rocky material that covers unweathered bedrock.

Hence, a CZ perspective of ecosystem services (Figure 1) expands the scope to include processes at time scales often not considered in ecosystem services, such as nutrient release from rock to bioavailable form based on lithology, substrate age, atmospheric deposition, nutrient retention, and loss mediated by soil development, weathering-induced carbon sequestration, aspect-induced variation in subsurface water storage, and landscape-scale water dynamics affecting plant-available water [*Field et al.,* 2015].

CZ science seeks to understand these larger-scale and longer-term processes associated with evolution of the weathering profile and their effects on regulating climate, nourishing ecosystems, and controlling water quality and quantity. Such biotic-geologic couplings are particularly relevant for the assessment of regulating and supporting ecosystem services. Incorporating a broader perspective that includes couplings of biotic and geologic processes that influence the production of natural resources, such as soils, that are "nonrenewable" on human time scales can help enhance ecosystem service assessments, particularly for regulating and supporting services.

Recent developments in CZ science have revealed the importance of ecological, geomorphic, geochemical, and hydrologic pro-

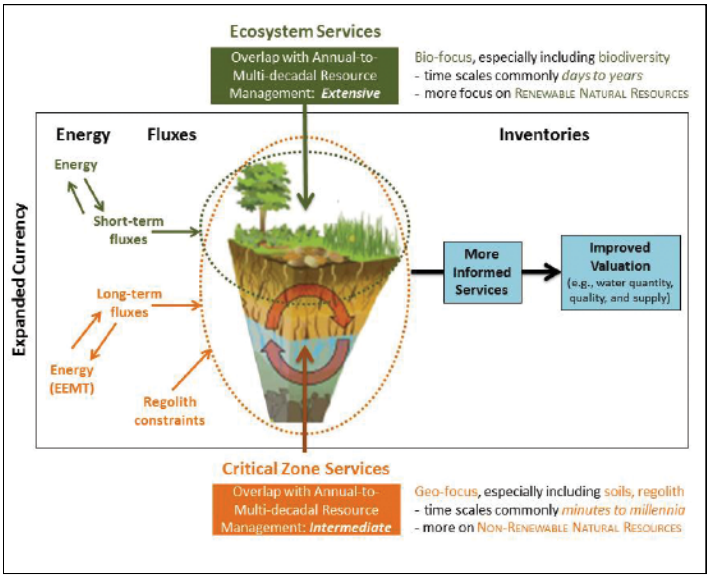


*Fig. 1. Critical zone services provide context, constraints, and currency that enable more effective management and valuation of ecosystem services. From* Field et al. *[2015].*

cesses that affect the relevant supply of services and act over larger temporal and spatial scales than those generally accounted for in the ecosystem services community ("supply chains" [*Field et al.*, 2015]). Many ecosystem successions occur over the mean residence time of a single regolith. This regolith is therefore the primary source of lithogenic nutrients for many successions of plants and animals, even on tectonically active hillslopes. CZ evolution rates therefore clearly affect ecosystem function and the supply of services.

Conceptualization of CZ processes expands the context of ecosystem services temporally and spatially, providing constraints on ecosystem services associated with rate-limiting processes such as soil formation and hydrological partitioning. This conceptualization also advances the assessment and valuation of ecosystem services by providing integrated currencies that quantify the energy flux available to do thermodynamic work on the CZ [*Field et al.*, 2015].

By incorporating CZ processes into the ecosystem services framework, society gains a broader perspective on ecosystem services and hence more refined tools to value societal benefits. We have highlighted CZ processes as an example, but the concept applies more generally to linking geosciences perspectives to ecosystem services.

## Improving Valuation with Geosciences Perspectives

Geosciences perspectives expand both spatial and temporal scales of consideration affecting ecosystem services. For example, ecologists who focus on the services provided by vegetation and reefs in reducing impacts of coastal hazards could benefit from geosciences input on how geomorphology, elevation, and coastline configuration interact with the living organisms to deliver those services.

Time scales associated with plant community succession provide a more detailed example of how ecosystems services assessments can be improved through geosciences. The succession after a disturbance such as forest blowdown (high winds that topple trees) usually occurs in tens to hundreds of years, after initial colonization by short-lived species, followed by longer-lived species.

However, geosciences perspectives also consider the conversion of rock to soil and the long-term evolution of the soil profile and are on the order of thousands to millions of years. For instance, the long-term evolution of Hawaiian tropical forest ecosystems occurs on lava flows that range in age from hundreds of years on the big island of Hawaii to about 4.1 million years on Kauai [*Chadwick et al.*, 1999].

The regolith profiles support ecosystems comprising the same forest vegetation species, but they differ dramatically in their physical-chemical properties as a result of long-term weathering processes. A core aspect of ecosystem services is to provide a means for valuing the services they provide.A geosciences perspective could prove valuable in estimating the cost of recovering lost services, for example, if we lost both types of forests and their services due to disturbances like blowdown or lava flow. In this case, we would need to consider the contrast in rate-limiting soil production processes for these two forest types.

## Geoscientists' Perspectives Needed

In summary, we need geosciences perspectives—focused over a broader range of temporal and spatial scales than is typically studied by terrestrial ecosystem scientists—to infuse our knowledge of ecological processes with geophysical and biophysical mechanisms that support them. We encourage geoscientists to partner with ecologists, economists, and social scientists to bring these larger spatial-scale and longer temporal-scale perspectives when working with stakeholders, decision makers, and policy makers.

These groups will be well served by explicitly linking geosciences with ecosystem services, building upon advances in both communities to quantify the time scales required to replenish services following a disturbance. A geosciences context enables broader perspectives for managers, policy makers, and stakeholders to effectively understand the expanded temporal and spatial scales of Earth processes required to provision ecosystem services to society.


## Acknowledgment

This work was supported by a grant from the National Science Foundation (NSF EAR-1331408).


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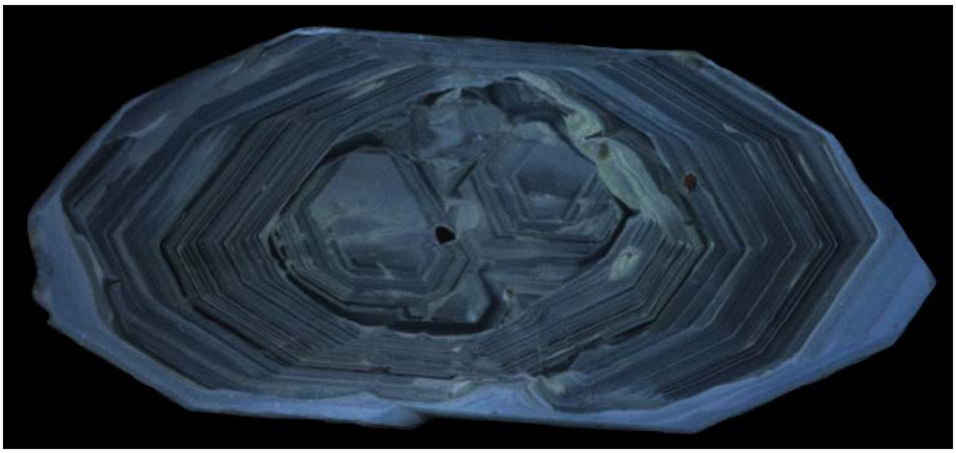
# Geochronology: It's About Time



George Gehrels

*A zircon crystal (approximately 0.2 millimeter long) from the Coast Mountains in western Canada shows zonation that records multiple stages of crystallization. The ages from this sample range from more than 116 million years old at their cores to 58 million years old for outer rims. Zircon plays an important role in radiometric dating because it is a common mineral in crustal rocks; it contains trace amounts of uranium and thorium, which decay to lead with reasonably well-constrained half-lives; and it preserves a record of geological processes despite younger metamorphism.*

Time is at the heart of Earth sciences; every significant advance in geochronology has produced a paradigm-shifting breakthrough in our understanding of Earth's history. Without quantitative knowledge of absolute and relative time, no modern discipline with a historical focus could function.

However, when we conducted a broad consultation with geochronology experts and researchers who rely upon geochronological data, we found a strong sense that the field has been orphaned by the national science support structure and weakened by the widespread view that it is a "tool" rather than a scientific challenge.

Every discipline that benefits from geochronology should participate in the stewardship and development of this field, including scientific efforts and financial support. In return, geochronologists must address the research priorities of the disciplines they support and provide enhanced user access to data.

### Radical Changes in Perception

In one instance after another, geochronology has provided information that drastically changes our understanding of natural phenomena. The earliest mineral dates, determined more than 100 years ago, catapulted Earth's estimated age from 10 million to 100 million years into billions of years. The ability to date young basalts revealed a geomagnetic timescale that led directly to the plate tectonic revolution.

The development of high-precision uranium-lead (U-Pb) zircon dating is currently revolutionizing our understanding of magmatic timescales as well as the tempo of sediment accumulation and biologic change. In situ U-Pb dating challenges our assumption that early Earth was an arid world that was hostile to life. The recognition that major extinction events are coeval with the formation of large igneous provinces and asteroid impacts is changing our understanding of the processes of species evolution and highlights the dependency of Earth's living systems on extraterrestrial inputs.

> Geochronology has provided information that drastically changes our understanding of natural phenomena.

By quantifying variations in rock temperature and depth through time, application of the potassium-argon (K-Ar) and uranium-thorium/helium (U-Th/He) methods to rocks and minerals has advanced our understanding of the pace of tectonic processes. Together with studies of nuclides produced by cosmic rays, this understanding has revolutionized the study of landscape evolution.

The advent of carbon-14 dating radically altered our understanding of prehistoric human migration. However, this isotope's 5700-year half-life led to an apparent concentration of events 30,000 to 40,000 years ago. This pileup only relaxed to include much older ages after the development of optically stimulated luminescence dating, which brought quantitative chronologies to systems that were historically difficult to date. Coupled with enormous advances in uranium series dating, these techniques focused on the Pleistocene have been essential for calibrating glacial-interglacial cycles from climate records.

### Taking Stock: Where Are We Now?

A visionary program (EarthScope, http://www.earthscope.org) begun in 2002 has been spectacularly successful in revealing the three-dimensional structure within the North American continent. However, fulfilling its goal of understanding the evolution of the North American continent will require a major effort led by geochronologists.

The *National Research Council* [2012] report *New Research Opportunities in the Earth Sciences* recognized the central role that geochronology plays in the geosciences (Figure 1) and identified pressing instrumentation and facilities needs for fostering research and education. In response, with the support of the National Science Foundation, we led a yearlong consultation with consumers and producers of geochronology to understand their aspirations and the challenges they face.

We surveyed nearly 300 U.S.-based geochronology producers on their views regarding the role of geochronology in innovation, transformative science, facility support, synergistic research, and the status of decay constants. With these results as a guide, we hosted meetings at the 2014 Goldschmidt Conference, the 14th International Conference on Thermochronology, and the 2014 Geological Society of America Annual Meeting. The conclusions drawn from these interactions were recently published in the report "It's About Time: Opportunities and Challenges for U.S. Geochronology" [*Harrison et al.*, 2015].

### Data Disconnect

Our field has changed dramatically over the past 20 years. Many scientists now focus on dating youthful features at or near Earth's surface using measurement methods that didn't exist a generation ago. In situ methods have produced massive amounts of new data for those interested in deeper time or deeper Earth, whereas traditional methods have gained an exquisite degree of precision as they have matured.

Despite these advances, our consultations revealed several troubling paradoxes. Although more instruments than ever are being employed for Earth science research in the United States, the geochronologic community still has enormous demand for more data. Individual laboratories produce more, and higher quality, data than ever, but many interested parties feel that costs are prohibitive or that bottlenecks in the process preclude their participation. The techniques and instruments in use today are far more sophisticated than those in the recent past, but many are concerned by the lack of progress in putting proven advances in geochronologic instrumentation to use.

Our consultations point to a lack of optimization between geochronology producers and consumers. We believe this mismatch is driven by misdirected incentives in combination with a pervasive view that geochronology is merely a tool rather than a discipline in its own right.

Looking back, it is easy to see how this occurred. To address the specific needs of a particular Earth sciences discipline, geochronologists developed novel methods to address their challenging scientific problems. In the process, individual geochronologists became experts in an increasing diversity of specialized fields. This specialization, in turn, has separated the providers of geochronologic information from those who apply this information: In some cases, these information consumers have never actually participated in the analyses that provide them with their data.

Even within geochronology, researchers perceive different issues facing them. For example, some researchers are frustrated by the low accuracy with which decay constants are known; others would not be significantly affected by an improvement as large as an order of magnitude.

## No Simple Solutions

There is not a simple solution to the challenges the geochronology community faces, but perhaps the first step is a better understanding of the landscape we live in. The most salient feature is that virtually every geochronologist operates within a different disciplinary home because no federal science program has sustaining geochronology infrastructure and innovation as its core mission.

The reasons for this are partly historical and partly due to the expansion of the field into disciplines that require different constraints on timing and rates. As geochronology spread into these emerging fields, it often failed to become firmly rooted within those cultures. Routine analyses could be supported through existing programmatic funding, but new fields lacked the tradition of sustaining the development of geochronologic protocols.

For our community to truly prosper, we must make the case across the geosciences that stewardship of geochronology is the responsibility of all disciplines that use its products. This stewardship includes the need to support high-risk research and development of equipment, methods, and applications. In return, the geochronology community needs the analytical and staffing resources to address the research priorities of supportive disciplines and to provide enhanced user access to data.

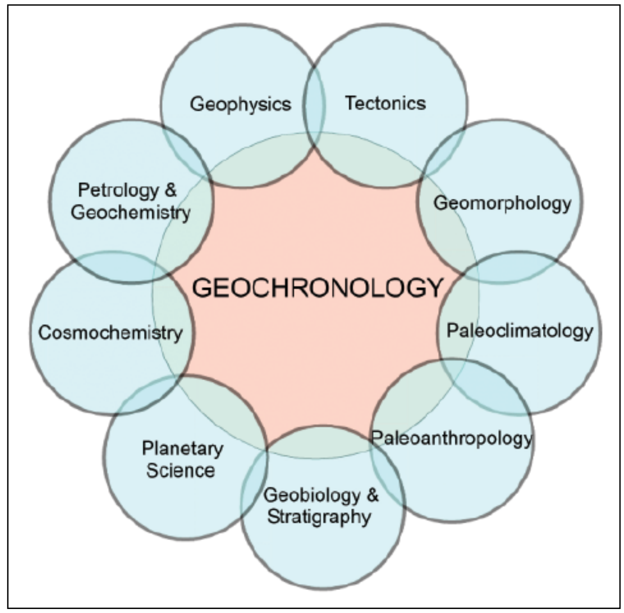



*Fig. 1. Geochronology plays a central role in all historical aspects of the Earth and planetary sciences but has no disciplinary home within the federal funding umbrella.*

## Grand Challenges

Geochronology is poised to make unprecedented leaps in its capacity to stimulate transformative research. We envision four grand challenges for the coming decade:

- age precision and accuracy of ±0.01% from the Cenozoic to the Hadean, which requires creating methods and mass analyzers of unprecedented sensitivity and resolution with vastly improved decay constants
- continuous temporal coverage throughout the Quaternary—from 1 week to 1 million years—of processes key to today's societal security, including climate change, critical zone management, volcanic hazards, and paleoseismology
- measuring the denudation of the Earth's surface with submillimeter per year accuracy using thermochronometers, for timescales as short as 10,000 years, to place geodetic deformation rates in context with long-term geologic trends
- coverage of thermal conditions ranging from Earth's cryosphere through to the mantle to provide the deep time dimension to structures imaged by the USArray seismic observatory network

These ambitions are more than simply honing a tool; they touch on the great, unanswered scientific questions of our time (e.g., when life began on Earth) and would permit the goal of EarthScope—to understand the four-dimensional structure of North America—to be fully realized.

Our report points to the need to support foundational and potentially high-risk development of new geochronological methods, the need for greater cooperation among existing laboratories, and cooperative interactions with allied scientists. We invite you to download a copy of our report (http://bit.ly/Geochron_rpt) and join the conversation on the future of U.S. geochronology at http://bit.ly/Geochron_feedback.

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K. Gavahan

# DRONES IN A COLD CLIMATE

By Guy D. Williams, Alexander D. Fraser, Arko Lucieer, Darren Turner, Eva Cougnon, Peter Kimball, Takenobu Toyota, Ted Maksym, Hanumant Singh, Frank Nitsche, and Matt Paget

At the ends of the Earth, climate change is altering the polar landscape and seascape faster than ever in recorded history. In the Arctic, a drastic decline in sea ice is unlocking trade routes and a new theater for the world's navies. In Antarctica, a collapse of the western ice sheet could raise global sea levels and inundate the world's coasts. Monitoring the state of sea ice is crucial.

Satellite observations drive the numerical models and forecasts, but to verify them, scientists need in situ measurements from the freezing seas themselves—at resolutions and coverages that match the ever-improving models and the extent of satellite coverage. Imagery taken from airplanes or helicopters is one option, but these missions are very expensive and logistically challenging.

In the face of these obstacles, polar researchers are beginning to explore the use of unmanned aerial vehicles (UAVs), more commonly known as drones. As technology develops, new advanced sensors that can launch from icebreakers and survey the surrounding ice promise to provide a valuable new tool in the arsenal of seagoing scientists.

Drone pilots face challenging and extreme conditions in the Antarctic: high winds, temperatures well below freezing, and landing on a moving ship, to name a few. To gather operational experience, we conducted a pilot study of drones launching from the U.S. icebreaker *Nathaniel B. Palmer* in April 2015 while en route to the ice shelves of East Antarctica (Figure 1).

Using two off-the-shelf models of multirotor drones, we successfully captured high-resolution aerial imagery of Antarctic sea ice. We also learned about some of the drones' limitations, and we can give recommendations for how other teams might overcome them.

## Sea Ice: The Canary in the Coal Mine

Sea ice is often referred to as the "canary in the coal mine" when it comes to monitoring the effects of climate change at the poles. Sea ice, a relatively thin layer (meters thick, in contrast to the kilometers-thick continental ice sheets) that forms each winter at the surface of the freezing polar oceans, is a dynamic and complex medium. It reacts to many different atmospheric and oceanic processes, making it a valuable area of study to scientists. The key area is the marginal ice zone (MIZ), where the open ocean meets the sea ice and a complex interaction between wind and waves controls seasonal advance and retreat.

Arctic sea ice is declining dramatically, but paradoxically, mean Antarctic sea ice extent is increasing slightly

*The Spreading Wings S1000 eight-rotor unmanned aerial vehicle (UAV) successfully operated in the polar environment. Imagery obtained using its attached Panasonic Lumix GH4 camera helped to determine sea ice floe size distribution.*

[*Maksym et al.*, 2012]. Antarctic sea ice is bounded on all sides by a MIZ and the Southern Ocean. In contrast, the Arctic has previously been totally covered by ice and is bounded by continents. Sea ice is very effective at damping waves, so as the Arctic ice decreases, models predict that the open water at its edges will allow more powerful waves to break up ice on the boundaries, forming MIZs, similar to processes in the Antarctic regions.

### The Need for Ship-Based UAVs in Sea Ice Research

Aerial observations provide valuable assistance in studying these complex environments: They provide situational awareness and spatial context for surface-based measurements from the ship and can aid ships navigating treacherous ice fields. However, helicopters cannot land on the sparse sea ice field of an MIZ, and this introduces additional safety constraints to operating helicopters over these regions.

Enter drones. Scientists have long deployed autonomous submersibles to survey below the sea ice [*Williams et al.*, 2014]. Now aerial drones offer scientists the possibility to gain remote bird's-eye views of the ice as well [*Maslanik et al.*, 2002; *Cassano et al.*, 2010]. The images they collect can be a valuable addition to existing observational data sets of sea ice from satellites, ships, and aircraft.

In particular, global climate models lack information on how waves and sea ice interact. One key indicator of the annual advance and retreat of sea ice is the size distribution of the ice floes in the MIZ [*Zhang et al.*, 2015]—we attempted to collect these data with our drone pilot study.

### Ready for Takeoff—But Are You Certified?

UAVs are not new, and many geospatial surveying groups have developed and built their own platforms. (See "Drone Squadron to Take Earth Monitoring to New Heights," http://bit.ly/Drone_Squadron, for more on scientific studies using unmanned aircraft.) However, they required significant work and pilot skill to operate. In the past couple of years, the industry has exploded with an incredible pace of development, seeing new platforms emerge on a near-monthly basis. As multirotor drones have become ubiquitous, they have become dramatically easier to fly, which allows the end user to focus more on integrating instruments and collecting data.

Although the regulations surrounding these products have struggled to keep pace, they are now catching up. Most national aviation bodies now enforce strict flying rules for hobbyists and set up formal licensing for those operating UAVs for commercial gain, which in some countries includes academic research.

In addition to pilot certification, specific approval for UAV operations is becoming mandatory, tailored to the operational environment and inherent risks, liability, and environmental impacts. For this study, the National Science Foundation (NSF) performed a special review of pilot competency, vehicle specifications, and operational procedures to permit the flights from the R/V *Nathaniel B. Palmer.*

The unfortunate prospect of harming the pristine Antarctic environment heightens the risk involved. For now, in general, the U.S. Antarctic Program (USAP) prohibits the use of drones by program personnel without specific authorization while it develops a policy on the safe and environmentally sound use of UAVs. This model will also provide guidance for other national Antarctic programs to adopt.

For this mission, the principal scientist, Guy Williams, was the pilot in command for all flights. He was trained by the TerraLuma group at the University of Tasmania in Australia and certified by Australia's Civil Aviation Safety Authority. He had 15 months' experience prior to the mission and completed more than 10 hours on each platform.

### Flight Testing in the Antarctic

Our pilot program, overseen by the NSF on a voyage of the USAP, was centered on multirotor UAV operations developed by the TerraLuma UAV facility at the University of Tasmania.

Alexander Fraser

*Fig. 1. The Phantom 2 Vision+ UAV is launched from the U.S. icebreaker* Nathaniel B. Palmer *on 13 April 2015.*

For testing, we chose two off-the-shelf models manufactured by DJI Ltd.: the popular Phantom 2 Vision+ quadcopter and the more advanced eight-rotor Spreading Wings S1000. Both models successfully operated in the polar environment and retrieved imagery for the determination of sea ice floe size distribution.

The team scheduled UAV operations around the primary science schedule and could fly only when wind speeds were 15 knots or less with plenty of daylight. As such, we completed nine flights on three separate occasions.

### Flight Log

On day 1, the ship was idle but drifting with the winds and currents. We performed basic hover

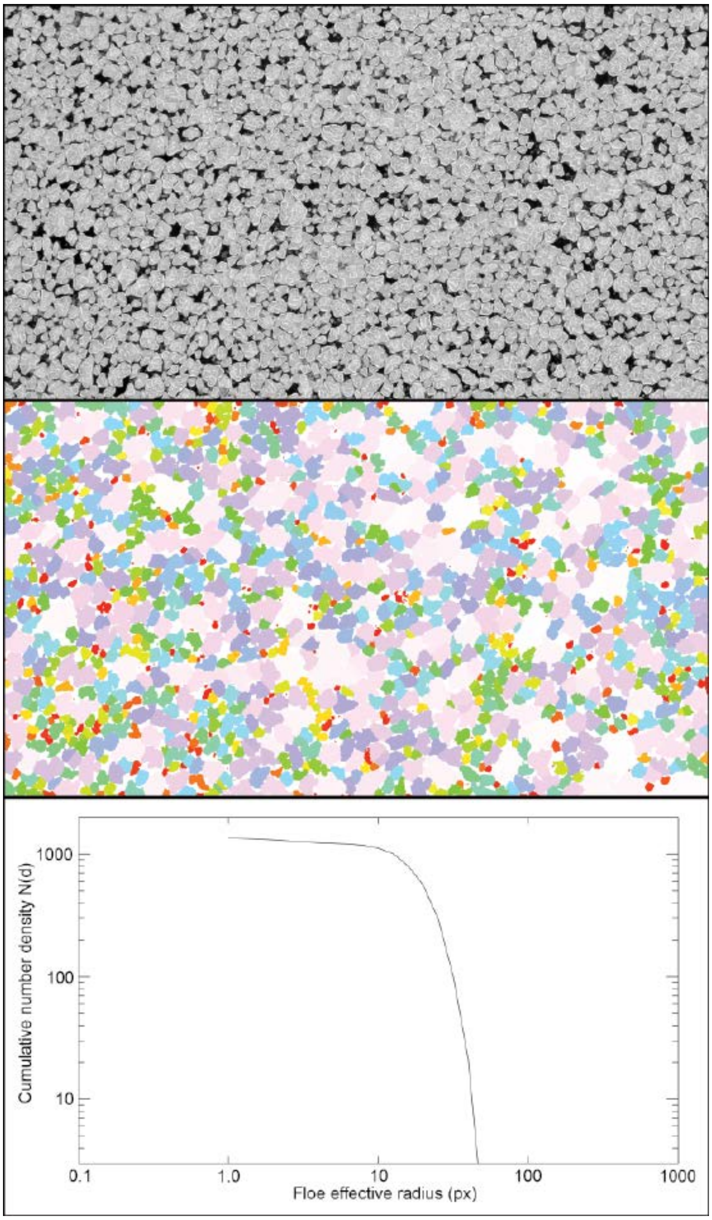


*Fig. 2. (top) Aerial image of pancake field, taken by the S1000 UAV on 9 April (day 2). (middle) Floe segmentation based on mathematical morphology for the aerial image (following* Paget et al. *[2001]). (bottom) Probability distribution function of floe size distribution.*

testing over the ship's helideck to introduce the crew to the operational protocols. This introduction included going over emergency responses to drones crashing into the ship or personnel or going over the side and needing recovery.

Both types of UAV were launched in attitude mode (ATTI), in which the drone automatically maintains orientation but not position. In general, the drones were unable to operate in GPS mode, where the drone automatically maintains both orientation and position. The inability to use GPS mode is a known issue that previous teams working with multirotor UAVs in polar regions have reported. The problem is the poor performance of the drone's magnetometer close to the magnetic poles, which combines with its GPS to provide attitude and position.

On day 2, four flights were undertaken with the S1000s flying astern of the ship. Again, they couldn't achieve a GPS hold, and this prevented autonomous waypoint navigation for structured aerial mapping.

There was also some erratic behavior (the cause was never fully resolved) during manual piloting of the S1000s and the Zenmuse Z15 gimbal system that provided pivoting support to a Panasonic Lumix GH4 camera (with an Olympus M.Zuiko 12mm f/2.0 Micro Four Thirds Lens) mounted to it. Winds were also stronger and gusting more than 20 knots, which increased the challenge of flying and landing in ATTI mode. Nonetheless, the drone was able to acquire aerial imagery (16.1 megapixels), facing both down (Figure 2) and toward the horizon.

Day 3 flights were in the early evening: We had our first successful operation of the Phantom 2 in GPS mode, allowing it to carry out a preprogrammed flight plan, gathering images (14 megapixels) and 1080p video (HDTV high definition) around the ship at flying heights greater than 100 meters for more than 12 minutes (Figure 3).

The final flight with the S1000 did not achieve GPS hold, and the gimbal was no longer oriented correctly when it was in ATTI mode. After we returned home, we resolved this using a firmware upgrade to the Zenmuse Z15 gimbal that had become available during the voyage to address a specific balance issue affecting the A2 controller in ATTI mode.

## 256 Shades of Gray (and Beyond)

Sea ice image analysis is often completed in gray scale, given the lack of color in detecting white sea ice on a dark ocean. Sea ice researchers joke that their line of work involves "256 shades of gray." Nevertheless, these shades of gray provide a wealth of valuable information.

Both the S1000 and the Phantom 2 proved capable of taking basic aerial imagery suitable for determining floe size distribution (Figure 2), with a basic correction using PTLens applied to the latter to remove the pin-barrel distortion of its mounted GoPro camera. The Phantom internally geotagged the images, and we used an external GPS logger for the images collected by the S1000. In both cases, the geotagged images will allow us to perform future analysis and create mosaics.

Ultimately, more sophisticated flight patterns are required for sufficient image overlap, either in autonomous or manual modes, to exploit this photogrammetry further. There may be a limit to what can be achieved in the dynamic sea ice field of the MIZ, as waves jostle the position of small floes between images. However, optimized mapping surveys over large continuous floes sampled

*Fig. 3. The Phantom 2 Vision+ UAV took this image of the U.S. icebreaker* Nathaniel B. Palmer *on 13 April 2015 (day 3) during an assessment of floe size distribution conducted en route to the ice shelves near East Antarctica.*

during "ice station"-type voyages, where the ship moors against the floes and scientists can leave the ship to conduct experiments on the ice itself, promise to return much greater detail in the surface morphology.

Natural extensions of this work include lidar laser scanning systems to map the three-dimensional structure and hyperspectral imaging to measure biological productivity [*Wallace et al.,* 2012; *Lucieer et al.*, 2014; *Turner et al.,* 2014]. However, these instruments are heavier and pricier—and therefore riskier. Deploying drones and underwater vehicles in concert to take simultaneous measurements from above and below sea ice may become feasible in the near future, presenting another exciting prospect.

## Onward and Upward

This pilot study successfully proved the concept of rapid deployment of multirotor UAVs for aerial sea ice imaging. The operations were conducted safely, with greatly reduced risk and cost compared to helicopter operations, and did not interfere with the primary scientific objectives of the voyage.

We learned some important lessons:

- The purchase price of an off-the-shelf drone is only a quarter of the total expense. The final project cost for a research voyage also includes spares, cases, training, and certification.
- Current consumer-grade multirotor UAVs are best suited to gaining a quick bird's-eye view of the ship and surrounding ice. True aerial mapping with multirotor drones will require more sophisticated models with better performance. An alternative is to use fixed-wing drone airplanes, but that brings the added challenge of landing and retrieving them on the ship.
- Pilot experience, certification, and operational background are critical to handle the challenge of polar operations. Pilots must also have extensive training in maintenance (modifications, sensor distribution, firmware updates). In particular, pilots must be trained in ATTI mode in 15- to 20-knot wind speeds and limited-area takeoffs and landings.

Nonetheless, what was impossible several years ago is now possible, and this theme will continue as unmanned aerial platforms develop in response to the urgent need for expanded in situ observations of sea ice.

## Observations over the Beaufort Sea

In late 2015, we completed UAV operations over the Arctic MIZ in the Beaufort Sea from the R/V *Sikuliaq*. Using the DJI Phantom 3 Advanced UAV, the team achieved 5 hours of flights with GPS hold, attaining a maximum range and altitude of 500 meters (for a drone's-eye view video, see http://bit.ly/Drone_Video). Initial calibration on the ice, away from the ship, proved helpful.

We also deployed a fixed-wing UAV, which used a 3DR Pixhawk autopilot and successfully operated autonomously to produce a photo mosaic of the sea ice field at each ice station while an autonomous underwater vehicle surveyed the sea ice from below. We were able to use a net effectively to recover the fixed-wing UAV when we needed to take off and land back on the ship.


### Acknowledgments

This project was funded by the Australian Research Council and supported by the Australian Cooperative Research Centre program and by Grant-in-Aids for Scientific Research 25·03748 of the Ministry of Education, Culture, Sports, Science and Technology in Japan. Research voyage NBP15-03 was conducted on board the R/V *Nathaniel B. Palmer* and supported by the USAP. Antarctic UAV operations were overseen and planned in coordination between NSF and USAP.


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# ARCTIC RESEARCH ON THIN ICE

## Consequences of Arctic Sea Ice Loss

By Mats A. Granskog,
Philipp Assmy,
Sebastian Gerland,
Gunnar Spreen,
Harald Steen,
and Lars H. Smedsrud

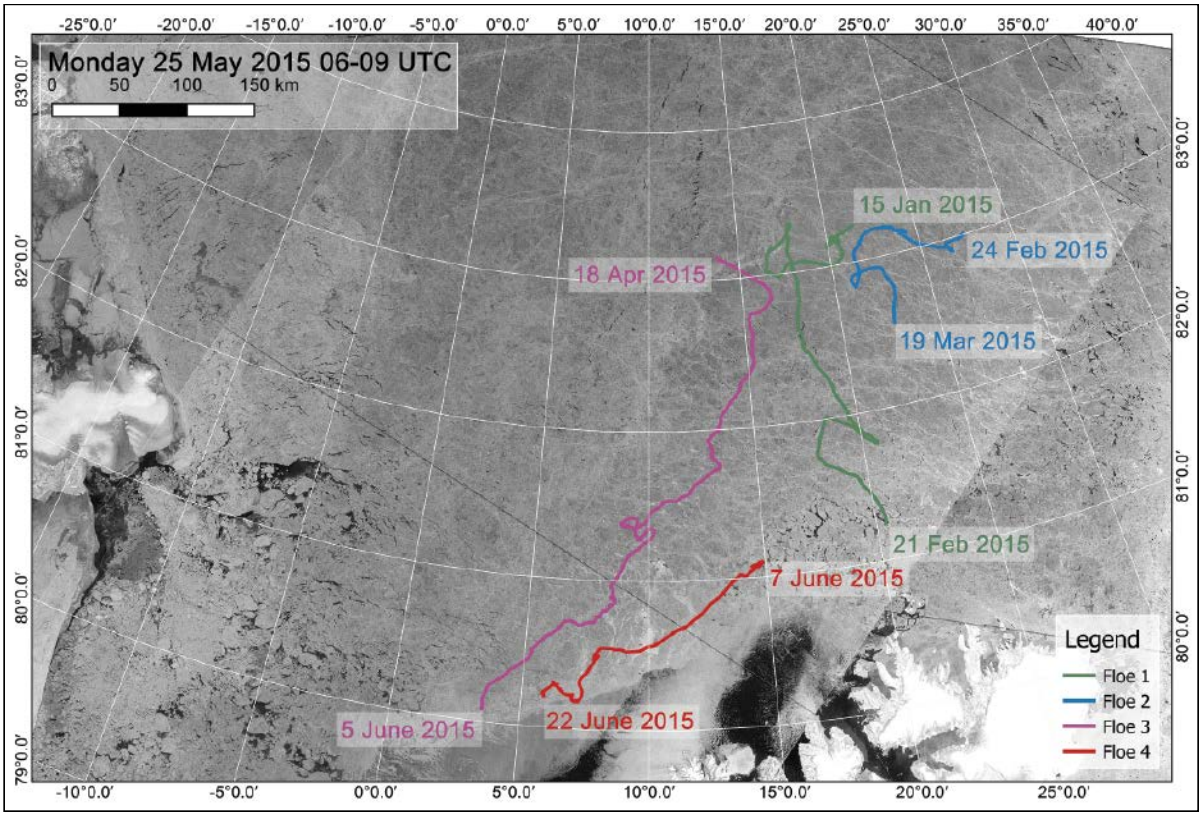

Paul Dodd, Norwegian Polar Institute

**Scientists embarked on a 6-month expedition in the Arctic Ocean to study the thinning sea ice cover, improve our understanding of sea ice loss effects, and help predict future changes.**

In February and March 2015, scientists studying the highly dynamic, thinning Arctic drift ice north of Svalbard were forced to evacuate their ice camp several times as ice floes broke up under their feet. Although they never knew exactly when it would happen, they had come to expect and prepare for ice breakups, which have become more common in recent years. During their work as part of the Norwegian-led research project Norwegian Young Sea Ice Cruise (N-ICE2015), an expedition launched to observe Arctic sea ice conditions, they were accustomed to watching for danger signs and moving quickly to salvage their gear and instruments when the ice broke up.

The Arctic Ocean is shifting to a new regime: A younger and thinner ice pack is replacing older, thicker sea ice [*Meier et al.*, 2014]. Large areas of the ocean that were previously covered by sea ice year round are now ice free for parts of the summer. This will have consequences locally and in a much wider area around the

*The Norwegian research vessel* Lance *froze into the Arctic ice pack during the polar night in January 2015. Scientists used the ship as a research platform for studying the atmosphere, snow, sea ice, ocean, and marine ecosystem throughout the Arctic winter and spring.*




*Drift tracks of research vessel Lance in winter and spring 2015 in the region north of Svalbard. Ice camps were set up three times on ice floes near 83°N, then evacuated and reestablished when ice broke up near the ice edge. The Norwegian Young Sea Ice Cruise (N-ICE2015) field campaign ended in late June 2015 with a shorter 2-week drift along the ice edge. Credit: RADARSAT-2 images provided by NSC/KSAT under the Norwegian-Canadian RADARSAT agreement. RADARSAT-2 Data and Products © MacDonald, Dettwiler and Associates Ltd (2013). All Rights Reserved. RADARSAT is an official mark of the Canadian Space Agency. Map created by the Norwegian Polar Institute / Max König*

Arctic. Much of our current knowledge of Arctic sea ice stems from the former old-ice regime, and we need new knowledge to understand the system in its current thinner state and to improve our capacity to predict its future.

From the midst of the polar night to early summer (January to June 2015), the N-ICE2015 crew allowed the Arctic waters to freeze around the Norwegian Polar Institute's research vessel *Lance* to help provide this new knowledge. The concept of N-ICE2015 followed the precedent of many previous expeditions, including the *Fram* expedition by Fridtjof Nansen, Russian drifting stations, the Surface Heat Budget of the Arctic Ocean campaign in 1998–1999 [*Perovich et al.,* 1999], and the *Tara* drift during International Polar Year 2007–2008 [*Gascard et al.,* 2008]. However, all of these expeditions were conducted in a thicker ice regime.

*Lance*, adrift in the ice, provided a base for 100 scientists and engineers who spent 3 to 6 weeks on board the vessel studying air-snow-ice-ocean interactions in a region with thinner sea ice. The scientists also investigated how the marine ecosystem responds to these new conditions. Interdisciplinary work was an integral part of N-ICE2015, as physical oceanographers, sea ice physicists, atmospheric scientists, and marine biogeochemists worked successfully side by side.

## What Provides the Heat to Melt the Ice?

What causes the sea ice in this region to melt? This was one of the key questions during the field campaign. Is it caused by the 1°C warming since the 1980s of the Atlantic water (currently, a relatively warm 3.0°C) that flows into the Arctic Ocean west of Svalbard [*Onarheim et al.,* 2014]? Is the heat in the warm water mixed toward the surface to melt the ice in the deep basin? Or is the ice melt solely triggered by the return of the Sun and solar heating of the ice and ocean? How do storms affect the ice pack and the mixing of ocean heat to the surface? How does the freezing during the previous winter affect the conditions during spring?

To answer these questions, the team was primarily interested in observing the ocean heat content, vertical mixing of the ocean heat toward the sea ice, and how sunlight penetrated the ice and snow and contributed to melting of the thinner ice pack. Dozens of autonomous buoys deployed on the sea ice as far as 20 kilometers away from the vessel measured the growth and melting of sea ice to give indications of ocean heat flux on a larger scale.

## Is the Thinner Ice Pack More Susceptible to Atmospheric Forcing?

Signs that the movement (dynamics) of the ice pack has changed have appeared as the ice pack has grown thinner.

Tor Ivan Karlsen, Norwegian Polar Institute

*The photo shows research vessel* Lance *following Norwegian Coast Guard vessel* KV Svalbard *in late February as it breaks a passage through the ice.* KV Svalbard *was assisting* Lance *up to 83N to redeploy the research camp on the ice after the first floe had broken up.*

The ice is moving faster [*Spreen et al.*, 2011], and the thinner ice may be more sensitive to breakup due to storms and waves.

Understanding the dynamics of the ice pack is one of the key challenges for climate models. To this aim, the N-ICE2015 campaign (see http://bit.ly/N-ICE2015) and partners deployed two arrays of autonomous buoys on the sea ice several tens of kilometers away from *Lance*. Ski patrols using snow machines deployed the buoys during the cold of the polar night. Later in spring, buoys were deployed by helicopter. These buoys sent their positions and measurements via satellite in near-real time to track the movement and deformation of the ice pack, providing valuable data on ice dynamics for use in improving climate models and satellite products.

Because the thinner ice pack might be more vulnerable to storms than the thicker ice decades ago [*Parkinson and Comiso*, 2013], the role of Arctic storms in sea ice loss has received attention recently. N-ICE2015 scientists monitored interactions of the thinner ice pack with storms using a combination of buoys that measured wave action in the ice pack and satellite observations.

## How Does the Ecosystem Respond to Thinner Ice?

The biologists involved were interested in finding out how organisms living in the sea ice and the underlying water column adapt to the thinner ice cover. Will under-ice phytoplankton blooms become more widespread in the new ice regime, as has been suggested by observations in other parts of the Arctic [*Arrigo et al.*, 2012]? Or are ice algal blooms likely to experience negative effects from later freeze-up, earlier melt-out, and possibly detrimentally high light levels transmitted through thinner ice?

Scientists were keen to find out how ice algae cope under the new ice regime. Changes in the timing and magnitude of the ice algal and phytoplankton blooms would have downstream effects on the organisms that eat algae and phytoplankton and, eventually, the entire ice-associated ecosystem.

## Collaboration, Coverage, and Outreach

Research during N-ICE2015 was truly international and reflected the current interest in the Arctic. Scientists from institutions in several countries, including Canada, Denmark, Finland, France, Germany, Japan, Korea, Norway, Russia, the United Kingdom, and the United States, participated, and the crew came from many more nations. This unique opportunity brought together many experts in their respective fields to contribute to a better understanding of the Arctic.

The N-ICE2015 research campaign also benefited from social media. Accounts on Instagram, Facebook, and Twitter showcased the research to a wide general audience on a regular basis (search for hashtag #NICE2015Arctic on Twitter and Instagram).

Traditional media outlets, including news teams from National Geographic and BBC, were invited on board the research vessel, which brought wider attention to the research and the ongoing changes in the Arctic. The Norwegian national broadcaster NRK used the opportunity to educate the audience about climate change in the Arctic through *Oppdrag Nansen*, a television program that documented how four 13-year-olds followed the footsteps of Nansen by staying on board *Lance* for a week to study the ice and snow with the scientists on board.

## Work for Years to Come

Although the field campaign from January to June 2015 was a key component of the project, work is far from over. In the months and years to come, the scientists will analyze the various observations to make sense of it all. New understanding of the thinner ice regime in the Arctic will help reduce the uncertainty in predictions of how the ice conditions evolve. Core data sets will be made available to the broader scientific community, which can make use of them in developing and evaluating process and regional and global climate models.

## Acknowledgments

This work was supported by the Centre of Ice, Climate and Ecosystems at the Norwegian Polar Institute and the Ministry of Climate and Environment and the Ministry of Foreign Affairs of Norway. This work was also supported, in part, by funding from the Ice, Climate, Economics–Arctic Research on Change (ICE-ARC) project from the European Union 7th Framework Programme, grant 603887, the Norwegian Research Council, and the European Space Agency. Many participating institutions also provided support.

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# Early Agriculture Has Kept Earth Warm for Millennia

AP Photo/Xinhua, Yu Xiangquan

*Farmers work on a rice paddy terrace in southern China. Mounting evidence suggests that early agriculture may have contributed to preindustrial warming of Earth's climate.*

Modern human activity is known to drive climate change, but global temperatures were already affected by farmers millennia before the Industrial Revolution. For years, scientists have been debating about the size of preindustrial warming effects caused by human activities. Now, according to *Ruddiman et al.*, new evidence confirms that early agricultural greenhouse gas emissions had a large warming effect that slowed a natural cooling trend.

Earth's climate has cycled between warmer interglacial and cooler glacial periods for 2.75 million years as a result of cyclic variations in the Earth's orbit. The current Holocene epoch, which began about 11,700 years ago, is an interglacial period.

In an earlier study, Ruddiman compared Holocene trends with data from previous interglacial periods over the past 350,000 years. Instead of slowly decreasing—as observed early in previous interglacial periods—carbon dioxide levels began to rise 8000 years ago, and methane levels started increasing 5000 years ago. These increases correspond with the onset of early agriculture, which, Ruddiman hypothesized, may have produced enough greenhouse gases to slow the normal cooling trend.

Now Ruddiman and 11 colleagues have more thoroughly compared the Holocene with past interglacial periods. They assessed ice core records from Antarctica, which provide a record of greenhouse gas levels and temperature-sensitive geochemical indices going back 800,000 years. If preindustrial warming were due to natural causes, the Holocene trends should fit the patterns of past interglacial periods.

Instead, the team found that Holocene patterns deviate from the norm—suggesting human influence. The comparisons confirmed that gas trends during the past few millennia have been anomalous and thus anthropogenic. An interglacial period near 800,000 years ago is the best analogue to the Holocene in terms of natural orbital variations. Toward the end of this analogous period, carbon dioxide ($CO_2$) levels had decreased by 17 parts per million (ppm), but by the same point in the preindustrial Holocene, the $CO_2$ levels had risen by 20 ppm. The anthropogenic greenhouse gas emissions necessary to explain this 37-ppm difference is very close to the 40-ppm amount originally hypothesized by Ruddiman in 2003.

The team also reviewed archaeological and paleoecological evidence. Studies show that the spread of rice irrigation is likely responsible for much of the increase in atmospheric methane between 5000 and 1000 years ago. The spread of livestock across Asia, Africa, and Europe—as well as other agricultural activities like burning weeds and crop residues—contributed as well.

Deforestation that accompanied early agriculture could be responsible for the carbon dioxide increase that began nearly 7000 years ago. New pollen data from Europe reveal mainly preindustrial deforestation, and archaeological data from north central China suggest major forest loss as well.

More research is needed to reveal exactly how much carbon dioxide and methane was produced by these early agricultural practices, the scientists say. It seems, however, that the argument of whether early farming emitted enough preindustrial gas to keep Earth warm has been largely put to rest. (*Reviews of Geophysics,* doi:10.1002/2015RG000503, 2015)

**—Sarah Stanley, Freelance Writer**

# Oklahoma's Dormant Faults Hide Huge Seismic Risk Potential

In October of 2014, two earthquakes sent shivers down the spine of Cushing, Okla., home to the world's largest crude oil storage facility as well as operational sections of the Keystone pipeline. At magnitudes 4.0 and 4.3, the quakes were more than enough to make authorities nervous; known ties between wastewater injection and induced seismicity prompted decision makers to shut down several injection wells.

Here *McNamara et al.* looked at seismic data from the 2014 Cushing earthquake sequence to better understand earthquake hazards and their potential impact on the local energy infrastructure.

The researchers used continuous data from seismic stations around the epicenter to spot aftershocks of the Cushing sequence. They identified eight quakes, which were relatively shallow (less than 6 kilometers) and aligned along the 5-kilometer-long, northwest oriented "Cushing fault."

The 2014 earthquakes showed increased static stress in the Cushing fault and nearby Wilzetta-Whitetail fault zone. Using the U.S. Geological Survey (USGS) Prompt Assessment of Global Earthquakes for Response (PAGER) model, the researchers found that this slow increase in stress could be unleashed in an earthquake as large as the one that hit nearby Prague, Okla., in 2011 with magnitude 5.6.

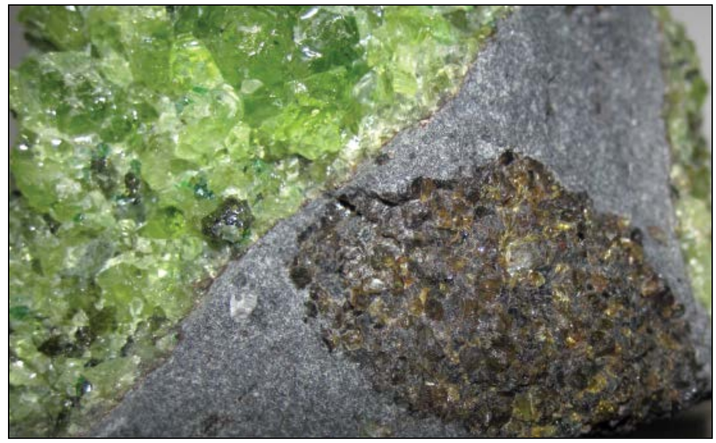
The results suggest that the Cushing community and its costly energy infrastructure are at high risk for damage in future quakes. The researchers also emphasize the need to better understand the relationship between local seismicity and the practice of wastewater injection. The USGS is now working to include induced seismicity in its National Seismic Hazard Model; without it, decision makers in Oklahoma could easily underestimate the risk.

Brian Sherrod, USGS

*Bricks cascade from a chimney damaged after the 2011 earthquake near Prague, Okla. U.S. Geological Survey geophysicists attributed the quake to wastewater injection into deep disposal wells in the Wilzetta North field.*

The team advises that the oil and gas industry take measures to reduce induced seismicity risk, including distributing wells over a larger area and avoiding injections into active faults. Incidentally, the Cushing sequence reactivated in October 2015—the same week this research was published—and as a result, the Oklahoma Corporation Commission moved to limit wastewater disposal in the area to avoid a large earthquake. This demonstrates the significance of studies like this as resources for local leaders. Further work in seismology and stress analysis is a stepping-stone to better earthquake forecasting and safer communities. (*Geophysical Research Letters*, doi:10.1002/2015GL064669, 2015) **—Lily Strelich, Freelance Writer**

# *P* Wave Amplitude Decay Offers a Glimpse of Earth's Structure



James St. John, CC BY 2.0 (http://bit.ly/ccby2-0)

*A peridotite mantle xenolith glitters bright green. Mantle xenoliths are inclusions that occur when mantle fragments are caught up and included in eruptions, revealing a relic of the upper mantle where seismic waves scatter due to irregularities in mantle structure.*

The amplitude and traveltime of seismic waves can reveal vital information about the structure of the planet. Here *Cafferky and Schmandt* look at the amplitude of teleseismic *P* waves and map variations in the upper mantle across the United States to gain a better understanding of how seismic waves lose energy as they propagate.

Seismic amplitudes decrease as waves travel through the mantle, and this decay behaves differently in material that is elastic or slightly anelastic. Elastic attenuation refers to energy becoming less concentrated as it spreads through increasingly large volumes of Earth, and anelastic attenuation refers to wave energy lost by conversion to heat. A form of elastic attenuation known as scattering occurs when nonuniformities in the mantle material cause seismic waves to deviate from their trajectory.

To analyze these differences, the researchers looked at USArray measurements of teleseismic *P* wave amplitude spectra from deep earthquakes. The data were inverted in order to map variations in the upper mantle attenuation parameter called $\Delta t^*$ across the contiguous United States.

The team found relatively high $\Delta t^*$ in the south Rocky Mountains, Appalachian margin, and American southwest and low $\Delta t^*$ across the older, more stable interior. Where changes in $\Delta t^*$ magnitudes varied, the variation was dramatic: roughly 2 to 7 times more than models of mantle temperature predicted.

The team interprets this as evidence that $\Delta t^*$ variations are not only the result of thermal influences. Instead, other drivers of the variations could include partial melt, changes in mantle composition, and scattering, which could be caused by sharp irregular boundaries or mantle fabric developed by past or ongoing strain. They hypothesize that scattering—a form of elastic attenuation—has the potential to obscure the signal of anelastic attenuation. Identifying the relationship between these influences is an important step in improving scientific knowledge of mantle convection and composition. (*Geochemistry, Geophysics, Geosystems*, doi:10.1002/2015GC005993, 2015) **—Lily Strelich, Freelance Writer**

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### Atmospheric Sciences

**Postdoctoral Research Associate**

The Shepson Tropospheric Chemistry Research Group at Purdue University has an opening for a Postdoctoral Research Associate. The position involves work aimed at developing and improving methods for quantification of sources and sinks of greenhouse gases, focusing on aircraft-based methods. This work is part of the Indianapolis Flux Experiment (INFLUX). Depending on interests, there may also be an opportunity to lead, and to work on a number of other problems in atmospheric chemistry, including:

1. Nitrogen cycling in forest environments
2. Aerosol phase photochemistry
3. Arctic halogen chemistry and analytical mass spectrometry

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Prof. Paul B. Shepson
Purdue University
560 Oval Dr.
West Lafayette, IN 47907
765-494-7441
pshepson@purdue.edu

Purdue University is an ADVANCE Institution. Purdue University is an EEO/AA employer fully committed to achieving a diverse work force. A background check will be required for employment in this position.

### Hydrology

**Tenure-Track Assistant Professor Position GROUNDWATER HYDROLOGIST University of Wyoming**

The Department of Civil and Architectural Engineering at the University of Wyoming invites applications for a tenure-track faculty position in Groundwater Hydrology at the Assistant Professor level. We seek a candidate with the interest and abilit y to develop and sustain a nationally competitive research program. The successful candidate must hold an earned doctoral degree in Civil Engineering or in a closely related discipline by the position start date. Registration as a professional engineer or professional hydrologist are desirable but not required. The successful candidate must be able to teach courses in fluid mechanics, hydraulics, hydrology, and water resources engineering. Also, the successful candidate must have the demonstrated ability to develop an externally funded research program in groundwater hydrology.

This position will become part of a major research thrust in water resources at the University of Wyoming. Groundwater resources are of immense impo11ance to societal and ecological needs. Approximately half of Wyoming water resources are from groundwater, and subsurface resources provide critical water to agriculture, oil and gas development, and municipalities. There are tremendous research challenges in groundwater resulting from changing climate signals and human population patterns, and emerging techniques provide outstanding opportunities for groundwater hydrologists to better quantify the fate and transport of water in a changing west. We seek a groundwater hydrologist with experience in laboratory and field approaches for describing complex subsurface processes. Areas of specific interest include, but are not limited to, surface-groundwater interaction, unsaturated flow and contaminant transport.

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

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

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

Applications must include: 1) a letter of application, 2) a curriculum vitae including a list of publications, 3) a statement of research interests, 4) a statement ofteaching interests, and 5) contact information for at least three references. Do not include supplemental information such as off-prints of papers, reference letters, or transcripts. Review of applications will begin 1 5 September 2015 and continue until the position is filled. The preferred start date for the position is January 2016. Submit applications in a single PDF file to: water_search@uwyo.edu.

The University of Wyoming is an Equal Employment Opportunity/Affirmative Action employer. All qualified applicants will receive consideration for employment without regard to race, color, religion, sex, national origin, disability or protected veteran status or any other characteristic protected by law and University policy. Please see: http://www.uwyo.edu/diversity/faimess. We conduct background investigations for all final candidates being considered for employment. Offers of employment are contingent upon the completion of the background check.

**HIGP Hawaiʻi Institute of Geophysics & Planetology**

**Assistant/Associate Researcher in Hydrogeophysics** (Position Numbers 0088474/0088665). The Hawaii Institute Geophysics and Planetology (HIGP) and the Water Resources Research Center (WRRC), University of Hawaii at Mānoa, jointly seek a tenure-track Assistant/Associate Researcher (locus of tenure in HIGP) in hydrogeophysics specializing in geophysical techniques, including electromagnetic and magneto-telluric methods that are applicable to the study of aquifers, subsurface flow dynamics, and geothermal resources. The selectee will report to the HIGP and WRRC Directors. The level of State support will be equivalent to at least 9 months per year, with the remainder to be raised through external funds. The incumbent is expected to work in water research in collaboration with colleagues in HIGP, WRRC, and other Colleges at UH Mānoa (such as Engineering and Social Sciences), and is expected to seek and obtain extramural funding in support of these areas of research, to take an active role in student advising and teaching, and to publish research results in the refereed literature.

Full information on the position description, including minimum and desirable qualifications, can be found at: http://workatuh.hawaii.edu (search on position numbers). All applications must be made electronically to higp-search@higp.hawaii.edu, and limited to 25 Mbyte. Submit a letter of interest to the Chair HIGP/WRRC Search Committee, and include a curriculum vitae, official transcripts (copies acceptable with application, original required upon hire) and the names and contact information (phone and e-mail address) of at least three professional references. Initial review of applications shall begin on April 4th, 2016, and shall continue until the position is filled. The position is available July 1, 2016 or as mutually acceptable. For further information on UHM, visit: http://www.manoa.hawaii.edu/

The University of Hawaiʻi is an equal opportunity/affirmative action institution and is committed to a policy of nondiscrimination on the basis of race, sex, gender identity and expression, age, religion, color, national origin, ancestry, citizenship, disability, genetic information, marital status, breastfeeding, income assignment for child support, arrest and court record (except as permissible under State law), sexual orientation, domestic or sexual violence victim status, national guard absence, or status as a covered veteran.

W.R.R.C.

### Ocean Sciences

**Assistant Professor, Tenure Track.**

The School of Oceanography at the University of Washington invites applications for a full-time (100% FTE) 9-month, multi-year tenure-track Assistant Professor (0116) position. A Ph.D. or foreign equivalent is required on the date of appointment. We welcome applicants who have expertise in trace elements including metals and nutrients and their isotopes. Persons whose research is focused on understanding the distributions, sources, sinks and biological consequences of trace elements in the ocean are encouraged to apply. We expect the successful applicant will enhance the School's existing expertise in global scale biogeochemical cycles, microbial ecology, fluxes across ocean boundaries, and/or paleoceanography.

University of Washington faculty engage in teaching, research and service. The successful applicant will be expected to contribute to the teaching mission of the department at the graduate and undergraduate levels. The University of Washington and the School of Oceanography promote diversity and inclusivity among our students, faculty, staff, and public. Thus, we seek candidates whose research, teaching, and/or service have prepared them to fulfill our commitment to inclusion, and have given them the confidence to fully engage audiences in higher education from a wide spectrum of backgrounds.

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

Applicants should submit A) a cover letter, B) curriculum vitae with publication list, C) statements of research and teaching interests with reference to how their teaching and/or research demonstrate a commitment to diversity and inclusion through scholarship or by improving access to higher education for underrepresented individuals or groups, and D) the names and contact information of four references. Letters of recommendation from references should be sent directly by the referee before the application deadline.

Electronic materials are preferred; please send to oceanjob@uw.edu with "Assistant Professor Elemental Cycling Position" in the subject line. Hard copies can be sent to Ms. Su Tipple, School of Oceanography, University of Washington, Box 357940, Seattle, WA, 98195, USA. Individuals with disabilities desiring accommodations in the application process should notify Su Tipple, School of Oceanography (206-543-5060). Applications, including letters of recommendation, should be received prior to March 6, 2016, to ensure full consideration.

The University of Washington (UW) is located in the greater Seattle metropolitan area, a dynamic, multicultural community of 3.7 million people. The UW serves a diverse population of 80,000 students, faculty and staff, including 25% first-generation college students, over 25% Pell Grant students, and faculty from over 70 countries. The UW provides a wide range of networking, mentoring, and development opportunities for junior faculty.

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

## Interdisciplinary/Other

**CHEMICAL OCEANOGRAPHY - TENURE TRACK POSITION.**

The Department of Chemistry and Biochemistry, at California Polytechnic State University, San Luis Obispo invites applications for a full-time, academic year, tenure track position beginning September 15, 2016. Area of research specialization is in Chemical Oceanography. Appointments are anticipated at the Assistant Professor rank. For details, qualifications, and application instructions (online faculty application required), please visit WWW.CALPOLYJOBS.ORG and search/apply to requisition #103924 Open until filled. Application review begins April 4, 2016. For further information about the Department of Chemistry and Biochemistry see http://www.calpoly.edu/~chem. EEO

**Endowed Open Rank Position in Quantitative Geosciences**

The Department of Geological Sciences at Michigan State University [MSU] invites outstanding candidates to apply for a full-time academic year endowed open rank tenure system position in geosciences starting in Fall 2016. We encourage applications from across a broad spectrum of geoscience research areas from individuals who employ advanced quantitative and computational analysis in their research. We are seeking candidates who will develop a vigorous externally-funded research program, teach and advise undergraduate and graduate students, contribute to a collegial and inclusive environment, and engage in collaborative endeavors.

MSU is committed to achieving excellence through diversity and encourages applications from women, persons of color, veterans, and persons with disabilities, and we endeavor to facilitate employment assistance to spouses or partners of candidates for faculty positions.

Details on how to apply will be found at jobs.msu.edu under posting number 2591. We will begin reviewing applications in March 2016 but the position will remain open until filled. Questions regarding this position can be directed to M. D. Gottfried, Chair of the Search Committee, at gottfrie@msu.edu.

**GDL Foundation Fellowships in Structure and Diagenesis**

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

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

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

## Student Opportunities

**PhD opportunities in ocean-atmosphere interactions emphasizing atmospheric chemistry, School of Marine and Atmospheric Sciences, Stony Brook University, NY.**

Students with strong backgrounds in physics and/or chemistry and math wanted to study the chemical and physical properties of anthropogenic and ocean derived biogenic particles and their effects on ice cloud formation processes. Laboratory and field hands-on experience desirable. For more information contact Daniel Knopf (Daniel.knopf@stonybrook.edu) or Josephine Aller (Josephine.aller@stonybrook.edu).

RUTGERS
Institute of Earth, Ocean, and Atmospheric Sciences

EOAS
EDUCATION. RESEARCH. DISCOVERIES.

## Postdoctoral Fellowships in Earth, Ocean, and Atmospheric Sciences

The Institute of Earth, Ocean, and Atmospheric Sciences at Rutgers University (**eoas.rutgers.edu)** invites applications for three Postdoctoral Fellowships to be awarded in Fall 2016. Our strong research programs include focuses on global climate change, ocean modeling and observations, paleoceanography and Earth history, planetary science, geobiology, marine ecology, molecular ecology, and environmental biophysics. We seek proposals to conduct innovative transdisciplinary research in these subject areas. Some specific areas of need are listed on our web site. Applicants should contact one or more members of the EOAS faculty and develop a three-page research proposal. The application package should include a cover letter, Curriculum Vitae, and a research proposal. Please send to **keng@marine.rutgers.edu** under the heading EOAS Postdoctoral Appointments. Applications will be reviewed beginning in mid-February and will continue until the positions are filled.

Rutgers is an Equal Opportunity/Affirmative Action Employer.

Freie Universität Berlin

Freie Universität Berlin – Department of Earth Sciences
Institute of Meteorology invites applications for a tenured

## Professorship in Weather and Climate Processes

salary grade W 3, **reference code: 24030000**

The successful applicant will cover the area named above in research and teaching. Appointment requirements are governed by Article 100 of the Berlin Higher Education Act (Berliner Hochschulgesetz).

Candidates will have internationally visible experience in the area of modelling weather and climate processes. The successful candidate will have demonstrated the ability to combine modelling, theory, and data in innovative ways to advance understanding of the Earth System. She or he will be expected to pursue research that links different processes within the Earth System and to work with researchers across disciplines. Candidates will have experience acquiring funding for, and carrying out, sponsored research. Additionally, experience is required in the management and implementation of knowledge and technology transfer (such as industry co-operations, inventions/patents and spin-offs). Furthermore, applicants will have demonstrated their ability in inspiring and advising students.

The appointee will address one or several of the following topics:

(i) Seamless approaches to addressing scale interactions;
(ii) Developing and using models to advance understanding of the coupling of processes within or across components of the Earth System;
(iii) The use or development of model-hierarchies to understand past, present, and future climate and its variability.

Furthermore, an ability to clearly articulate and develop links between the appointee's research and existing areas of expertise within the broader Berlin-Brandenburg area research environment is desired.

Applications quoting the **reference code** should include a CV, copies of all certificates of academic qualification, a list of publications, evidence of teaching experience (such as courses previously taught) as well as of involvement in ongoing or planned research endeavors, joint research projects and externally funded projects. If applicable, candidates should also include information on existing or planned industrial co-operations, inventions/patents and spin-offs. All materials, including a private postal and an e-mail address must be received in hard copy **no later than March 29th, 2016** at Freie Universität Berlin, Fachbereich Geowissenschaften, Dekanat, Frau Herm, Malteserstr. 74 – 100, 12249 Berlin, Germany.

Freie Universität Berlin is an equal opportunity employer.

# Postcards from the Field

Hello everyone,

Here I am in the Scottish Highlands. See those three parallel striations about half-way down the picture? They are the Parallel Roads of Glen Roy, a glacial leftover that once baffled scientists. Charles Darwin was here in 1838 and, to his later regret, he published an incorrect theory for their origins. Louis Agassiz eventually figured it out and set the record straight.

Wish you were here—the sheep aren't great conversationalists!

**Paul Williams,** Royal Society Research Fellow at University of Reading, UK

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