“Wow,” Elsie Sunderland recalls thinking, “that’s what I need to be doing.” Sunderland’s imagination had been caught by a satellite that trained its instruments not on the stars, but back on Earth. She had been working at the Environmental Protection Agency in Washington, D.C. and listening to an MIT scientist talk about atmospheric chemistry and the broader insights gained by coupling his detailed, well-understood local measurements with the regional and global data streaming back from Earth-observing satellites.

That years-ago flash of inspiration is bearing fruit in Sunderland’s current career as an academic scientist. Now the Cabot Associate Professor of Environmental Science and Engineering at Harvard, Sunderland recently found that Canada’s plans to develop more hydropower, however well-intentioned and climate-friendly, could wind up poisoning native populations with mercury. “Satellite data is essential to making any kind of spatial interpretation,” Sunderland said. “Typically, our approach is to obtain field measurements, which allow you to say something about the area you studied … then use satellite data to extend that over larger spatial scales. Our approach using this method is not perfect, but [it shows] when we should be concerned about human health impacts.”

Sunderland isn’t alone in her inspiration. All around the world, scientists like Sunderland rely on a steady stream of Earth-observing satellites and other instruments serve as a powerful magnifier for scientists’ work.

By Alvin Powell

Many systems are used to piece together Earth’s climate data. Above (clockwise from top left): A 1,000-foot tower measures atmospheric conditions high above the Brazilian rainforest; an image of Earth taken from one million miles away by a NASA camera on the Deep Space Climate Observatory; a self-contained Argo float gathers ocean data; the Copernicus satellite, a joint venture of the European Commission; and a NASA plane studies the climate effects of smoke on clouds.
Dear Friends:

It’s time to get busy. Spring has arrived, classes are over, and the academic year is coming to a close. But this spring feels different in Cambridge. With the uproar in Washington, particularly around environmental issues, there is urgency in the air. Here at the Center for the Environment, we have an opportunity to provide intellectual leadership, deploying the wide range of expertise available to us from across the University—and we cannot delay.

This year, we launched the “Harvard Speaks on Climate Change” website, offering perspectives from our faculty on one of the world’s most challenging problems. And much more is in the wings. Our move last fall into gorgeous new space above the public collections of the Natural History Museum has allowed us to expand our programs for undergraduates, graduate students and faculty. We are hosting new programs, including the exciting work done by the Planetary Health Alliance and a launch of the Solar Geo-engineering Research Program. But most of all, the Center is continuing to foster a community of scholars who can turn their knowledge into practice in the real world. The interactions between faculty members, students, and researchers are crucial to providing guidance to businesses and governments, and to training a new generation of leaders who will take on the grand environmental challenges that will persist. Spring is a time of renewal—and for me, it is a time to renew my commitment to put my shoulder to the wheel.

I wish you a happy and productive summer. Let’s keep moving forward.

Daniel Schrag
Director, Harvard University Center for the Environment

Dear Friends:

Operating a particle accelerator is sometimes likened to studying how a watch works by throwing it against a wall and seeing how the pieces fly apart. Closely observing the pieces is, of course, an important part of the work. For purposes of understanding how the climate system ticks, we have an analogous situation where human activities are impacting our environment, and it behooves us to watch the consequences, especially insomuch as pieces come undone.

The feature article in this issue describes how scientists at Harvard observe and interpret our environment using everything from satellite measurements of smoke to seismometer indications of soil moisture. Most of these Earth observations have been supported by U.S. programs and international collaborations that deploy impressive technology but are often in jeopardy of winking out.

One goal would be to develop a dedicated Earth observation program like that used for weather prediction, but with the mission of monitoring long-term changes, extending forecast horizons, and testing climate models. It would seem negligent on a global scale to drive environmental change without charting where we are going. Of course, it is unclear when such a program could be set-up given current politics... so in the meantime we’ll be breaking watches without learning much about what made them tick.

Sincerely,

Peter Huybers
Co-Director, Harvard University Center for the Environment

Letters from the Directors
works, and the U.S. is the largest among them.

A 2014 report by the U.S. Office of Science and Technology Policy identified 325 different observing systems spanning 11 federal departments. It defined 145 of those systems as “high impact” and identified benefits to society in everything from agriculture to transportation, weather forecasting to climate change, and human health to the environment.

The programs cost $2.5 billion for satellite-based observations and another $1 billion for Earth-observing systems on land, sea and air. But that expenditure pays for itself many times over, the report said, estimating that the programs add $30 billion to the U.S. economy annually and are “vital national infrastructure.”

“The satellite observations have become such a mainstay, and we rely so much on satellite measurements in understanding the Earth system, it’s essential,” said Frank Keutsch, Stonington Professor of Engineering and Atmospheric Science, who uses satellite observations in his work on atmospheric chemistry. “People think it’s just chemistry and climate, and that’s not true. Think about weather and weather predictions, we need a variety of information for that. Satellite instruments focused on the oceans are also a growing need.”

John Holdren, the Heinz Professor of Environmental Policy at the Harvard Kennedy School and Professor of Environmental Science and Policy in the Department of Earth and Planetary Sciences, served until January as Assistant to President Obama for Science and Technology and as Director of the Office of Science and Technology Policy. While in the administration, Holdren worked to boost the priority of such Earth-observing systems in the NASA budget, and helped untangle conflicting priorities between the National Oceanic and Atmospheric Administration (NOAA)—responsible for weather forecasting—and the Defense Department around weather satellites in polar orbit.

Weather forecasting is an obvious priority for Earth-observing satellites, Holdren said, and the ability to forecast weather more than 48 hours in advance depends on a small group of satellites in polar orbit, maintained and operated by NOAA.

In describing the scope of Earth observations today, Holdren rapidly reeled off a long list, including vegetation and land use change, deforestation and reforestation, fisheries and shellfish production, agricultural production, natural disasters, and the Earth’s water cycle.

“We’re using sophisticated gravitational instruments to understand aquifers,” Holdren said. “Some people think water is the next energy in terms of potential for crisis regionally.”

This Earth-observing network is at once robust and providing more data than ever before, but also fragile, reliant on aging platforms, the advocacy of influential individuals and groups, and on fickle, cash-strapped governments to continue their operation and finance replacements.

All that has scientists casting worried looks at Washington, D.C. The politicization of science in general—and climate science in particular—has created the prospect of government becoming hostile not only to economically costly solutions, but also to the very information that
The politicization of science in general—and climate science in particular—has created the prospect of government becoming hostile not only to economically costly solutions, but to the very information that underlies the science.

underlies the science. In March, Mick Mulvaney, the budget director for President Donald Trump—who’s called climate change “a hoax”—said simply of climate change: “We’re not spending money on that anymore.”

The president’s proposed 2018 NASA budget, which would go into effect on Oct. 1, would cut $108 million for Earth science and end four missions in development, including OCO-3, which would make measurements of atmospheric carbon dioxide, and CLARREO Pathfinder, which would test technologies to measure the Earth’s energy absorption and radiation for use in climate science.

Those cancellations still need Congressional approval to take effect, and Congress sent a hopeful signal in late April, when it reached a bipartisan budget agreement to keep the government operating for the remainder of the 2017 fiscal year, which ends Sept. 30. That agreement, which President Trump is expected to sign, would spare key parts of the Earth-observing budget. It would boost NASA’s budget by 1.9 percent over 2016 and continue funding for NASA Earth science programs at last year’s levels. And, while the NOAA budget would decrease overall by 1 percent, its office that supports climate change research around the country would see a 3.5 percent increase, to $478 million.

Even given the administration’s opposition, Steven Wofsy, Rotch Professor of Atmospheric and Environmental Science, said the fragile state of Earth-observing systems today can’t be laid solely at the door of the current administration. Earth science has always had to scratch and claw for its piece of the budgetary pie, a task made more difficult for satellite-mounted instruments, Wofsy said, because NASA is viewed by many as an exploration agency, defined more by moon landings and missions to Mars than measurements of the planet that we live on and are, in many ways, intimately familiar with.

Daniel Schrag, Director of the Harvard University Center for the Environment, the Hooper Professor of Geol-
human impacts, to devise strategies for conservation of natural resources and of biodiversity, and to create systems of all sorts that are environmentally sustainable, we need more measurements, more observations, better algorithms, more computing power, and more understanding.

“We have to [keep] what we have, and we need more,” Sunderland said. “We really do have big gaps in observations that we’re making. What we want to do is build on what we’ve done successfully and [cover] the rest of the world…. You just wouldn’t be able to begin unless you had these satellite data products.”

To Holdren, the need is not only to expand observations to places where they’re not, but to get better observations of places at which we’re already looking.

“Coverage is important, geographically. The density of observations is important, the continuity of observations is important, resolution is important when talking about satellite imagery, depending on application,” said Holdren.

That means that we need not only fund these programs, but seek partnerships with other governments to help fill the holes that remain, Holdren said.

“All of that means international collaboration is important because if you’re interested in Earth observations you need ground truthing: ocean-based, land-based, atmosphere-based measurements, in addition to satellite measurements. In order to get the coverage … you need international collaboration,” Holdren said. “Even in terms of space-based [observations], international collaboration is important. The budget for Earth observations—instruments and satellites—is limited and the capabilities of other countries complement ours.”

Should such Earth-focused data gathering be interrupted—whether by a hostile political climate or more mundane federal budget austerity—researchers say the loss of continuity in measurements actually represents a dual loss. Not only is the data left uncollected lost, but also lost is the continuous trend over time, which allows better interpretation of the data at hand.

“Without continuity, if you just came and went every once in a while for a short time period, if you saw a change, ...
you can’t tell if it’s a fluke or a trend,” said J. William Munger, Senior Research Fellow in Atmospheric Chemistry and principal investigator for a long-running project to measure exchanges of gases, such as climate-warming carbon dioxide, between the atmosphere and Petersham-based Harvard Forest. “Because there’s so much variability in climate and the forests’ response to it, without long records you don’t have the trend.”

Carl Wunsch, Visiting Professor of Physical Oceanography and Climate in Harvard’s Department of Earth and Planetary Sciences and Emeritus Professor of Physical Oceanography at MIT, said that continuity is nearly as important as the data itself.

“Gaps are a real problem, we have a lot of gapped records. They’re extremely hard to use because we don’t know what happened in between,” Wunsch said. “What if there was a big ENSO (El Niño) in there and we see a lot of rainfall, and then it’s gapped again because a mooring broke or a satellite failed. These are hard scientific problems that require a long-range view, and we don’t have the infrastructure for coping with them. Understanding rainfall variations without a 50-year record means that you are mainly dealing with weather noise. If a theory is delayed by five years, it’s still an appropriate theory, but if nobody measures the deep Indian Ocean in 2017, it’s gone forever.”

In an ideal world, not only would there be no gaps in data, new instruments would overlap in time with old ones, Wofsy said. That would allow researchers to compare new and old measurements to understand how data gathered from different instruments should be adjusted so they are truly comparable and researchers don’t inadvertently compare apples to oranges.

The fight to ensure that data gathering is continuous is an old one, Wunsch said, and involves some of the best known research of the modern era. Charles Keeling, whose observations of atmospheric carbon dioxide from the top of a Hawaiian volcano allowed him to draw the now famous Keeling Curve illustrating rising atmospheric carbon dioxide concentrations, regularly faced funding problems. Keeling, Wunsch said, was able to overcome them with a personality that Wunsch described as a “tour-de-force … obnoxious enough to keep it going.” While climate science benefited from Keeling’s don’t-take-no-for-an-answer attitude, Wunsch said that not all those studying important questions can replicate his doggedness.

“It’s basic science, which you should do even though you have no idea what the outcome could be,” Wunsch said. “The first geologist couldn’t have predicted the basic science would result in the mining industry as we know it. There are endless examples where basic science, unplanned, turned into something extremely valuable.”

Making the models

One important use of Earth observations is to build better computer models of complex physical processes.

Kaighin McColl, a Ziff Environmental Fellow at the Harvard University Center for the Environment, is working with McKay Professor of Atmospheric and Environmental Science Zhiming Khuang to better understand interactions between the water cycle on land and in the atmosphere.

McColl is relying on soil moisture measurements from NASA’s SMAP (Soil Moisture Active Passive) satellite to help with this work. Because the interactions between moisture in the air and on land are poorly understood, many models split the two apart and deal with them separately, McColl said. Surface hydrologists oversimplify how water behaves in the atmosphere, and those studying the atmosphere oversimplify the water cycle on land. That’s a problem, McColl said, because it has become clear that feedbacks exist between the air and land that affect the behavior of each.
“The way the land and atmosphere behave when coupled to each other is different from how they behave alone,” McColl said. “In models, you can get these feedbacks between land and atmosphere that won’t happen if they’re modelled separately.”

Getting the coupled model right is important, McColl said, because soil moisture can have an impact on rainfall. All else being equal, solar radiation first goes to work evaporating water in the soil. If the soil is wet, moisture evaporates into the atmosphere, cooling the air and forming clouds to produce rain. Dry soil, by contrast, results in the air heating up more quickly, which further dries the land, increasing the chance a drought will persist.

“You get a feedback loop that can alter the persistence of droughts, floods, etc. That’s what we can see that we won’t if we don’t study it as a coupled system,” McColl said.

The oversimplification of the land-atmosphere feedback is present in climate models as well, McColl said, and, because this feedback operates most strongly on a regional scale, it’s thought to be a factor in the poor performance of climate models as they zoom in.

“Climate models are very good at looking at global mean properties, but if you want to know how temperature in Boston will vary over time, climate models struggle with regional estimates,” McColl said.

The trouble is partly due to the complexity and messiness of the land surface, with mountains and buildings and forests and fields, McColl said. Each of those affect surface fluxes differently and add enough complexity that it has only been recently that enough computing power has become available to model it, McColl said.

“The atmosphere that we live in—the bottom 100 meters—is highly turbulent. You can think of the air as a fluid with lots of whirling motions of different sizes mixing it up a lot,” McColl said. “The soil moisture changes the heat pumped into the atmosphere, which changes the turbulence too. It’s hard to model that.”

With the help of SMAP, which can measure moisture in the top five centimeters of soil over 40 square kilometers, McColl is zeroing in on convection over land, the relatively small-scale interaction of air, land and moisture that is the driving force behind summer thunderstorms.

“I think they’re essential,” McColl said of the satellite observations. “We’ve been stonewalled for a long time, struggling to make progress without them.”

**Think globally, research locally**

Since Sunderland left the EPA for Harvard, she’s been investigating how pollutants travel through the environment and wind up in the human body. She’s studying PCBs, which persist in the environment despite being banned, selenium, and an organic form of mercury, called methylmercury, that can impair the development of the brain in fetuses and has been traced to cardiovascular problems in adults.

She’s also studying highly fluorinated compounds, or PFASs, whose properties as a surfactant have made them widely used since the 1950s. Today, they’re found in everything from rain gear to dental floss to food packaging. More recently, they’ve also been found concentrated in the flesh of Arctic polar bears, thousands of miles from the nearest factory; in the drinking water of 6 million Americans at levels exceeding federal guidelines; and at detectable levels in 98 percent of the rest of us.

PFASs have a potent impact on the immune system, according to a Faroe Islands study, Sunderland said, with each doubling of their concentration in islanders correlating to a 50 percent decline in immune function.

Her 2016 study of methylmercury in Canadian hydropower development shows how Earth-observing data can be coupled with intensive, localized study to draw broader conclusions. Methylmercury forms naturally through the action of microbes when soil containing mercury and
methane is flooded. The new compound is transported through the food web, where it is concentrated as it moves from prey to predator to larger predator. This poses a potential hazard to Inuit communities that eat a lot of fish and live near the hydropower sites.

Sunderland and colleagues examined native communities and their environment near a facility that is scheduled to be completed in 2017. They measured individuals’ current mercury exposure and modeled their exposure to methylmercury once the project is complete, finding that mean exposure could double, and that concentrations in women of childbearing age and in young children would exceed U.S. EPA guidelines. Using Earth-observing data of 21 other proposed hydropower sites, they then forecast Inuit exposures, finding that methylmercury concentrations at 11 would be comparable or greater than the original site.

“We used satellite data on soil carbon reservoirs to extend that to planned expansion sites, across the country, to understand the potential human health impacts of hydroelectric power development in those different regions,” Sunderland said.

A similar approach has resulted in a better understanding of the exchange of climate-warming carbon dioxide and other gases between the world’s forests and the atmosphere.

In 1991, Harvard’s Wofsy erected a thin metal tower at Harvard Forest. The tower was laden with instruments to measure how much carbon dioxide was taken in and given off by the forest. The work turned into the first long-term such project in the world, and has helped fill in the picture of how trees, shrubs, soil and other components of the forest contribute to the makeup of the atmosphere.

“The original goal was to be the first ones to actually measure, at the scale of a whole forest, the net exchange of CO₂ up and down,” Wofsy said. “Nobody had done these measurements before. We had a device at the top of the tower that measures wind speed 10 times a second, and that measures CO₂ concentrations at about the same [interval].”

The project was launched as awareness and concern about climate change was rising, and—because living trees lock up carbon in their wood while dead ones give it off as they decompose—there were questions about what role mid-latitude forests were playing in the broader climate change picture.

In 1993, Wofsy reported that Harvard Forest, though it appeared mature, was still growing, absorbing two tons of carbon dioxide per hectare each year. Munger, who is principal investigator for the project today, said the work has thrown into question whether such forests ever reach a steady, “mature” state of development.

“We thought the forest at some point would become carbon neutral, and we changed our ideas about when a forest gets to that point,” Munger said. “When I look at data I don’t see any signs it’s approaching a steady state. It may be that it will keep on growing and accumulate carbon in trees and deadwood and keep doing it until some disturbance comes.”

In the years since, other researchers have erected similar “eddy flux towers” around the world. But as many sites as there are, Wofsy said their coverage isn’t broad enough to be able to make general statements about the world’s forests without large-scale Earth observations.

“You can’t characterize the world’s forests with eddy flux sites,” Wofsy said. “You can try to get as representative a set of measurements as you can, then combine them with remote sensing that covers the whole globe and really understand what’s going on.”

Wofsy uses several satellites in his work, including OCO-2, which measures total column carbon dioxide in the atmosphere and solar-induced florescence in trees’ leaves, an indication of the activity going on inside the plant. Others include Landsat, which measures land use change, and data from the MODIS instrument, flown aboard two satellites, which measures greenness at high temporal and spatial resolution, Wofsy said.

“They synergize,” Wofsy said of the tower and satellite measurements. “The whole is greater than the sum of the parts no matter which you’re looking at.”

**A research continuum**

To Keutsch, Stonington Professor of Engineering and Atmospheric Sciences, large-scale Earth observations are an irreplaceable part of a research continuum that extends from a laboratory’s tightly controlled experiments, through local instrument observations, to atmospheric satellite measurements.

Keutsch’s work on atmospheric chemistry has revealed something of a bright spot in efforts to lessen humankind’s impact on the environment. It shows that over the U.S. Southeast, the atmosphere has returned to pre-industrial conditions in at least one respect.

His work explores different atmospheric “regimes” that favor the conversion of methane to either formaldehyde or hydroperoxide. Formaldehyde regimes, he said, are found in industrial air and promoted by the release of nitrogen oxides in fossil fuel burning. His research group is exploring the tipping points from one regime to another and the human influences that push the atmosphere toward those tipping points.
A change in air over the U.S. has occurred over the last 20 years, Keutsch said. Before that, the air was clearly in the formaldehyde regime, but parts of the country had been getting cleaner, in particular the U.S. Southeast, Keutsch said. Because the conversion of methane to formaldehyde occurs on a much shorter time scale than carbon dioxide's cycling, which takes millennia to clear from the atmosphere, the change is observable today.

“It really is remarkable,” Keutsch said, “and a direct impact of the reduction in nitrogen oxides from power-generating industries.”

Keutsch’s research occurs over a range of scales. He conducts tightly controlled laboratory experiments that allow researchers to zoom in on chemical reactions they believe are occurring in the atmosphere.

They also take localized measurements from aircraft and satellites to see what’s going on in the atmosphere and broaden the geographic range.

“The question is how well does the model predict aircraft measurements and then satellite measurements,” Keutsch said. “We do lab studies on one component in great detail, and we can understand everything very well because we can control it well. We take the mechanism and put it in the model, then compare it to the real atmosphere and see if we understand the atmosphere. You have to have these field measurements of this system.

“Regional variability we can only get by satellite…The critical thing in understanding the system is we have observations around you to draw inferences about how that world works and then making conclusions that are relevant for policy and people’s everyday lives—and that grounding in empirical evidence really appealed to me.” After earning his masters degree in statistics and his Ph.D. in economics at Berkeley, he began his career at the Harvard Kennedy School in 1983 as an assistant professor of public policy, beginning what has become a 32-year career at Harvard (briefly interrupted by a two-year stint at Berkeley.)

In 2014, Stock took his climate experience to the President’s Council of Economic Advisors—though his initial appointment wasn’t focused on environmental efforts. “There was, at the time, a particular interest in bringing some forecasting expertise to the Council,” he says. “But there was also a great deal of interest in the White House in moving forward in the climate arena.” With strong personal feelings about the issue and relevant previous work, that part of the portfolio fell to him.

Among the issues that Stock was tasked with investigating on the Council was federal coal policy, a topic he has continued to focus on over the past few years. While he admits that the landscape has shifted under the Trump Administration, with Obama-era reform efforts now shelved, “federal coal policy remains a really important aspect of the climate area that is, I think, underappreciated.” He offers supporting data: coal mined on federal lands, Stock says, accounts for 40% of the coal that we use to generate electricity and burning that coal amounts to 13% of energy-related U.S. greenhouse gas emissions. “The challenge, then, is to think about how we can align our position as the biggest single seller of coal to the U.S. market with our federal climate goals,” he says. And while he notes that the current White House has shown no interest in those climate goals, he doesn’t expect that stance to last beyond this administration. “We want to have a better understanding of how policy can work in this space available to us when we are in a policy-making environment that is not as extreme as the current one.”

— Dan Morell
from very local to satellite observations. These satellite observations are very important for this because the idea that we can make these point measurements everywhere, that is just not feasible.”

**Water and earth**

Not all of the large, Earth-observing networks look down from space. Some of the oldest examine the seas, according to Carl Wunsch. And, though our understanding of the ocean as a large, turbulent body may seem obvious today, it wasn’t always so. The shift in our thinking about the ocean is an illustration of the power of Earth observations to transform our understanding.

As recently as the late 1970s and early 1980s, Wunsch said, detailed knowledge of the oceans was lacking. Unlike the atmosphere, the ocean is hard to see through, so its depths were still largely unknown.

Oceanic surveys began in the 1870s, and scientists aboard oceangoing vessels were able to discern deep layers formed by variations in temperature and salinity, Wunsch said.

Oceanographers understood that this static picture was incomplete, but their work was limited by the difficulty and expense of their primary tool: ship-board surveys. Additional observations gathered as commercial mariners traversed the world’s oceans helped, but Wunsch pointed out they tend to avoid some places of obvious scientific interest, like hurricanes and the high latitudes in winter.

“People began to understand that [the ocean] is changing, but didn’t know what to do with that insight. To some extent it was ignored. A way had to be found to leave instruments at sea,” Wunsch said. “It awaited the integrated circuit.”

In the 1970s, technology permitted the development of self-contained instruments that could be set afloat. Understanding began to grow of the ocean as a swirling turbulent system “much like the atmosphere but without weather,” Wunsch said.

Despite that early work, climate models still lacked a realistic depiction of the oceans.

“Meteorologists were making climate models in which the ocean was treated as a swamp—immobile and doesn’t do anything—because that’s what they’d been taught,” Wunsch said. “So you start to think about how the devil do you measure a global fluid, because climate is global and we knew from these ancient charts that it was interconnected. What happened in the North Atlantic has consequences for the deep Pacific Ocean decades or centuries later.”

Oceanography verged on irrelevancy, Wunsch said. That spurred planning for a major international effort, the World Ocean Circulation Experiment, in which Wunsch played a leading role. Years in the making, it ran from 1990 to 2002 and employed everything from traditional ship-based observations to instruments drifting on floats, moored on buoys, or borne aloft on satellites. What emerged from that effort was a new understanding of the ocean as a dynamic part of the Earth-ocean-atmosphere system.

Today, Wunsch said, our knowledge of the oceans is on par with that of the atmosphere, and scientists have a better understanding of the challenges they face in making additional observations.

“This is an extraordinarily complicated observational problem and an extraordinarily complicated theoretical problem to understand it. But without the observations, you’re sort of dead,” Wunsch said.

The latest generation of ocean observing...
floats, called Argo, represent an evolution of the technology used in the World Ocean Circulation Experiment. Some 3,800 advanced, self-contained Argo floats have been deployed in the world’s oceans, Wunsch said. They descend to a “parking level” 1,000 or 2,000 meters down, take measurements as they drift and then rise every 10 days and send their location and other data to a satellite overhead.

“At any given time, we have measurements of 3,000 plus of these things, all over the ocean,” Wunsch said. “In some sense it’s been revolutionary, because we’ve finally broken away from the ship as the major instrument of in situ measurements.”

Wunsch said the Argo program allows expensive ship-based observations to be deployed where they’re most needed. Instead of being the primary way to gather data, they can fill in where the Argo floats cannot, like collecting data from the deep ocean beyond the depths Argo floats are designed to go.

“If you’re interested in climate, you must know what the deep ocean is doing and has been doing. Developments are underway to take Argo to the bottom,” Wunsch said.

Schrag and graduate student Lauren Kuntz are among those very much interested in climate. Argo data from the upper ocean is helping them formulate a new theory that explains the seeming periodicity in global temperature rise.

“You need to know more, and observations are really the only way you can get that level of detail and get that level of understanding,” Kuntz said. “I think everyone would agree that we want to know where we’ve been and where we’re going, in terms of climate.”

Measurements of global temperatures have marked several periods of relatively rapid warming, separated by periods of relative stability. Temperatures remained fairly stable from the mid-1940s to the mid-1970s, then rose sharply through the late 1990s, when they stabilized again until a couple of years ago.

“The question is why, that is what we’re trying to understand,” Schrag said.

The dominant theory, Schrag said, is that atmospheric particles called aerosols, generated in volcanic explosions and industrial emissions, reflected enough solar radiation to interrupt warming during those periods. But Schrag and Kuntz aren’t so sure. They’re looking at an entirely different process.

When Schrag arrived at Harvard in 1998, he wrote a paper about the possibility that the ocean waters in the tropical Pacific played a role in the oscillations in global temperature change but, he says today, the data back then were so sparse, it was little more than speculation.

Now, using data from the Argo floats, Schrag and Kuntz are tracking fluctuations in the thickness of layers in the tropical Pacific made up of water that is a constant density—called “isopycnal layers” that they believe are linked to the “fits and starts” of global temperature rise.

“We had no idea it existed there, but what we’ve observed is that the upper layers of the ocean are changing their thickness … in a pattern that’s led us to new insights,” Schrag said. “The theory was required to explain the observations that we made from Argo. It was Argo that

Naomi Oreskes

When Naomi Oreskes was working on her Ph.D. in geology at Stanford, she stumbled across a class called “Growth of Scientific Knowledge.” Determined to be a broad-minded scientist and take advantage of all that Stanford had to offer, she enrolled.

A young assistant professor named Peter Galison—now Pellegrino University Professor in History of Science and Physics at Harvard—taught the course. “He was teaching in the philosophy department, but what he was teaching was really history,” says Oreskes. “And that was my eureka moment where I thought, ‘Oh, this is my field.’” Not only did it combine her interests, but it also meant that all of the enjoyable pursuits she had come to think of as distractions—like her interest in writing and the humanities—were now considered strengths.

Oreskes’s science interest came early. She collected bugs and rocks as a child, encouraged by her father, a biochemist, but eventually discovered during her undergraduate studies that there were only two disciplines that would allow her to spend time outdoors: geology and biology. “I took a field biology class where the professor was a dragonfly expert, and we actually went out in the field counting dragonflies. I have to say, it didn’t seem that exciting,” she says. “But it also meant that all of the enjoyable pursuits she had come to think of as distractions—like her interest in writing and the humanities—were now considered strengths.

After her Ph.D., she began to focus on epis- temological questions about scientific knowledge: “How do we know what we know? And what does it take for scientists to say, ‘Yes, we have enough evidence to say that this is so?’” She took deep dives into the research histories behind plate tectonics and continental drift, which would eventually result in her first two books. In the early 1990s, as she started work on a book on oceanography, she came across a research team from the Scripps Institution of Oceanography that had started working on climate change in the 1950s. “The climate science piece kind of took over the project,” says Oreskes. “And then it took over my life.”

In 2004, she published a paper in Science titled “The Scientific Consensus on Climate Change,” the result of a survey of more than 900 research papers—the first of what would become a groundswell of similar analyses. The subsequent attacks from dissenters made her curious: why were people denying well-demonstrated science conducted by respected scientists? “What I really didn’t understand at the time was why were people denying well-demonstrated science conducted by respected scientists? And then it took over my life.”

Denolle’s research seeks to understand how water affects the movement of seismic waves and, ultimately, inform changes to building codes in major cities. She’s seeking clues about how pollutants move from the Atlantic to the Arctic oceans and whether that is changing as sea levels rise. “I think this is going to be very exciting,” Sunderland said. “We’re borrowing the approach from Earth sciences. We’re using the same tools, assimilated Earth observations, to drive our understanding of how the compounds distribute in the global environment and then how they accumulate in food webs.”

**Open science, open data**

In addition to the steady stream of new observations, these observing networks also archive data that can be accessed by researchers who are exploring similar questions or historical trends. Marine Denolle, Assistant Professor of Earth and Planetary Sciences at Harvard, is exploring the nature of earthquakes and how seismic waves travel through the ground. To conduct her work, she deploys her own networks of seismometers, but also accesses data from past research held by the National Science Foundation (NSF).

“The NSF funds a lot of data collection. There’s an incredible amount of data already collected that is terribly underused,” Denolle said. “There’s terabytes and terabytes of seismometer data unused.”

Denolle’s research seeks to understand how earthquakes and groundwater can alert us to this going on.”

Another scientist eagerly examining Argo data is Sunderland, who wants to see how it can benefit her work on pollutants moving through the environment. She’s seeking clues about how pollutants move from the Atlantic to the Arctic oceans and whether that is changing as sea levels rise and currents shift.
Though we don’t understand precisely how the world is changing, the fact that we know it is and that some of those changes will impact people, perhaps dramatically, argues that Earth observing should continue.

“We still need to know more,” Holdren said. “In particular, we need better observations to get more accurate regional disaggregation of ways that the climate is changing and ways it’s likely to change going forward so communities, farmers, fishermen can plan and make investment in preparedness, resilience and adaptation. Climate is a global system, but all of its impacts are local.”

Beyond pressing, short-term concerns lie broader issues related to the mismatch between the time scales of scientific research and the processes that we’re trying to understand, Wunsch said. Many key processes involved in climate science occur over decades, centuries, even millennia, while human scientists’ funding is measured in years.

“In a system [such as the oceans] that we know is responding to events thousands of years ago, the instrumental record is decades old, at best,” Wunsch said. “I date it to 1992—call it 30 years. Anything older than that, we don’t know whether you’re seeing [a response due to] something from long ago or due to modern atmospheric climate. There just aren’t enough observations. You look at the problem of climate and say the need is for records that are long enough to make sense of them, and not just in the ocean.”

The scientific establishment, Wunsch said, needs to think hard about the best way to study such long-term phenomena, which he termed intergenerational scientific problems.

“If I wrote a proposal to NSF saying I need 25 years of funding to get longer records to really say something, I’d be laughed out of the room,” Wunsch said. “Nobody funds that sort of thing.”

That’s a real problem.

One positive trend, Holdren said, is the development of a new generation of small, inexpensive satellites. These “small sats,” are enabled by the abundance of off-the-shelf parts that are driving costs down and make it increasingly possible for other players to step in—like wealthy individuals, foundations and even states.

“We’re better and better at miniaturization now,” Holdren said. “Companies make small sats using cellphone parts and other commercially available components. It’s possible, with the help of lowered costs, you’ll see some states getting involved—Governor Brown said California will put up its own—as Earth observing gets cheaper.”

Though we don’t understand precisely how the world is changing, the fact that we know it is and that some of those changes will impact people, perhaps dramatically, argues that Earth observing should continue, Wunsch said.

“We don’t have so many years [of data that] we can afford to give anything up,” Wunsch said. “At the end of the day, the basic science of the Earth is too important to let it lapse for one or 10 years.”
John Holdren is the Heinz Professor of Environmental Policy at the Harvard Kennedy School; Co-Director of the Program on Science, Technology, and Public Policy in the Kennedy School’s Belfer Center for Science and International Affairs; and Professor of Environmental Science and Policy in the Department of Earth and Planetary Sciences. From January 2009 to January 2017, he was President Obama’s Science Advisor and Director of the White House Office of Science and Technology Policy (OSTP), as well as Co-Chair of the President’s Council of Advisors on Science and Technology (PCAST), on which HUCE Director Dan Schrag also served. What follows is an edited excerpt of their conversation.

A Harvard Homecoming

John Holdren returns to campus after eight years in Washington

Dan Schrag: John, welcome back. What is it like to be back at Harvard after eight years away?
John Holdren: Well, it’s terrific to be back and to see a lot of my former colleagues, who are still here. I enjoyed being here for the 13 years I spent on the Harvard faculty before going to Washington, and I’m enjoying being back. I had a wonderful time in Washington—but I’m glad I’m not there now.

Schrag: Washington has certainly changed in the last three months. You arrived in Washington at a unique time in history, following the financial crisis and the opportunities that it offered in terms of investment in energy and other areas. You had an opportunity to work incredibly closely with the President for all eight years on environmental issues, and while the environment seemed to be very high up on his agenda from the beginning, his messaging on it seemed to get louder and clearer over time. Was this the same perspective from the inside?

Holdren: I would say, first of all—since you mentioned the economic crisis and the fact that every crisis in a sense provides also some opportunity—that the American Recovery and Reinvestment Act, which was one of the first things that we got done in the Obama Administration, had $80 billion dollars in it for clean and efficient energy. I think that’s the biggest increase in government support for clean energy in the history of the country. And a lot of good was done with that money.

Secondly, although a lot of people say that President Obama didn’t get really interested in the energy and climate change challenge until the second term, that’s actually not right. What happened initially was, of course, the Waxman-Markey bill, which would have produced a cap-and-trade approach to reducing greenhouse gas emissions in the United States. It passed the House, but never got a vote in the Senate.

Schrag: And it was Carol Browner’s main focus for the first couple years.
Holdren: It was! And Carol Browner was the head of the Office of Energy and Climate Change in the White House. It was the first time that had been a separate office there, headed by an Assistant to the President. That in itself underscored the priority the President was putting on energy and climate change.

But after Waxman-Markey failed and the 2010 midterm elections changed the composition of the Congress, it became apparent that most of what we would be able to get done in the energy and climate space would have to be done with executive authority, rather than with the help of the Congress.

And what we were able to do included the first ever combined CO₂/fuel-economy standards for light-duty vehicles, the extension of those to heavy-duty vehicles, a whole raft of new efficiency standards for buildings and appliances; and the first-ever interagency task force on climate change, adaptation, preparedness and resilience. There was actually a lot done on energy and climate in the first term!

Of course, one of the reasons that it receded somewhat from the evident public priority list was the fact that health care, and the struggle over health care reform, took so much of the oxygen out of the room. You know, an administration can fight only so many really major battles at one time.

But the President never lost his personal interest in and priority on the energy and climate challenge. We talked about it a
lot in private. Throughout the first term, there was something called “The Green Cabinet,” which included the Cabinet secretaries with responsibilities related to energy and environment, as well as, within the White House, Carol Browner, me, and Nancy Sutley, the Chair of the Council on Environmental Quality. It included Energy Secretary Steve Chu, EPA Administrator Lisa Jackson, Interior Secretary Ken Salazar, Transportation Secretary Ray LaHood, and Secretary of Commerce Gary Locke.

Because of the importance of the issue and the President’s interest in it, people kept trying to add themselves. Pretty soon it was half the cabinet that met frequently, as well as periodically with the President.

So there was never any real lag in the President’s interest and determination, but it really was not until the second term that we were able to develop the more comprehensive approach represented in the President’s Climate Action Plan, which he rolled out in June 2013 on a very hot day at Georgetown University in an outdoor presentation. I still have a photograph of the President giving the speech and wiping the sweat off his brow in the middle of his remarks.

Schrag: I’ve heard President Obama credit you with continuing to make climate change present in policy discussions. He credits you with bringing new observations, new information, new studies to him on a regular basis.

Holdren: Well, I did, although in fairness he’s a little too generous, in that he was already thoroughly committed to the proposition that the energy-climate challenge is going to prove to be one of the great challenges of the 21st century, and that it was going to require a major effort by the United States and other countries to address. I didn’t have to persuade him of that in my role as a science advisor, but what I did do, as you note, and as he noted, is I kept him abreast of developments in climate science, including, of course, the ongoing observations of how the climate is changing and what the impacts are.

There is, as you know, a tendency of climate change contrarians to say, “Well, the models aren’t reliable, so we don’t know anything.” And, of course, the models are not perfect—although they have been getting better and better. But a lot of what we know is based on observations and measurements, including—again, in your own domain—paleoclimatological measurements that enable us to understand how different the current situation is from the fluctuations and changes in climate that have occurred over the millennia.

And what I did is continuously provide the President with summaries and analyses of the latest observations, including paleo observations and current observations, and the ways in which these meshed with what basic physical science analyses and models were telling us about what the effects of the measured increases in greenhouse gases in the atmosphere are predicted to be.

And one of the things I think that the contrarians prefer to ignore is the multiple lines of evidence that have converged to produce the current understanding of what’s happening in the climate, and what’s likely to happen going forward.

The President being, as you know, something of a science wonk, was extremely interested in these details, and he would ask very intelligent questions about them, and then he would come back and he would use facts from these briefings I had provided to him in his wider conversations, and he always got it right!

Schrag: It was clear that this was somebody who really was curious, and truly took an interest in the details. In the past, the science advisor, the person in your role, is really the only trained scientist in the room with the President and the Cabinet.

How important was it to have other people like Steve Chu, or Ernie Moniz, or Jane Lubchenco, or Lisa Jackson, with a chemical engineering degree, or Gina McCarthy, with a public health degree?

Holdren: Well, it was very helpful. Again, this President was extraordinary in many respects, including his successful effort to recruit science and technology talent into government. And the first tranche of appointments, including his appointments to PCAST, which included you, had five
Nobel laureates in science and some 25 members of the National Academies of Science, Engineering, and Medicine—really extraordinary!

And one of the great pleasures, besides having such a science-savvy President, was that so many of the people populating the relevant positions—the Energy Secretary, the EPA Administrator, the NOAA Administrator, the NIH Director, the NSF Director, the heads of the institutes in the NIH—knew each other already. Most of us had been colleagues in one way or another for decades. It was just an amazing team.

I suspect that there were fewer territorial battles in this administration than typical in past administrations, where different departments and agencies are in competition over who is talking to the President and who really owns a particular subject matter. Those kinds of struggles are almost inevitable at any level of policy, but they were very rare in this administration because there was not only a long set of relationships that had already existed among the key folks in science and technology and the administration, but a lot of mutual respect.

Schrag: It helps a lot. One of the things that I noticed, just being on PCAST, was how much the President empowered us, and also, frankly, was able to get a group of mostly very busy, overcommitted people to work extraordinarily hard.

Holdren: People were working their tails off, but they were happy to do it. Because, again, they knew they were working for a President who was going to pay attention to the results, and who was going to embrace the best ideas that emerged. I think we probably had the most engaged and productive PCAST in history. All of these folks had very demanding day jobs. The only PCAST member of course, who doesn’t have a day job outside of government is the President’s science advisor, but all the rest of you were incredibly generous with your time, producing 39 reports that the President requested from PCAST on a huge range of topics. And again, all of this was made possible and was enabled by the fact that we had a President who understood how and why science and technology and innovation matter to all the other aspects of his agenda.

Schrag: And actually was receptive to our recommendations.

Holdren: One of the stories that I like to tell about the President is there has been this very long-standing rule of thumb in the White House that you never give the President of the United States a memo longer than two single-spaced pages on anything. The notion is: presidents just don’t have the time to read a lot of detail. They want a summary and synthesis of the memo that’s better than the memo itself.

And the Chief of Staff let you get away with it!

Holdren: Well, and in fact there were occasional conversations about this. It was actually the Staff Secretary who was most appalled by the length of these memos. The Staff Secretary is the person in the White House who controls the paper flow to the President. And he or she is invariably a very capable person who looks at these memos and comes back and says, “You don’t need eight pages for this. You could have said this in five, rewrite it.” Or, “This is too opaque. Nobody can figure out what you mean.”

So I had a big argument with the Staff Secretary over my 13.5-page memo, and finally prevailed. I said, “Look, I know the President. I know what he wants to know about this issue, I know what he needs to know about this issue. Please don’t make me cut it.”

So the Staff Secretary let it through. And the next day the President was telling everybody he ran into in the West Wing...
what a fabulous memo he had gotten from OSTP on this topic [laughter].

Schrag: What a pleasure. A literate President, wow.
Holdren: A literate President, and one who actually wants to understand the details. He really wants to understand, and so he wants to be provided with the depth that he thinks he needs. And that just made the job a delight.

Schrag: So now let’s fast forward. So here we are leaving the White House with the kind of intensity that you had for eight years, the regular access to the President, and more importantly, the regular engagement on dozens of everyday issues that were vitally important to this country, not just on the environment, but all aspects of science and technology. But given that withdrawal, do you sometimes feel like you’re missing a limb or two?
Holdren: [Laughter.] You know, everybody who leaves the White House in these positions observes afterwards that there’s a withdrawal issue, and that it’s harder than one thinks. I don’t think I would have found that to be so true, except for the characteristics of the Administration that has followed. They seem at best to be uninterested in science and technology. And as a result, most of the top positions in science and technology have not been filled at all [as of May 2017].

There is no OSTP Director, and none of the four Associate Directors of OSTP, which are Senate confirmed positions, have been named. There is no NOAA Administrator, no NASA Administrator, no Director of the US Geological Survey. Most of the assistant secretary and under secretary positions that deal with science and technology are also vacant.

And the partial proposed budget for 2018 that the White House released in March reflects the absence of advice on the Federal government’s role in science and technology.

As a result, I’ve spent a fair amount of my time since leaving the government writing op-eds and doing interviews and giving speeches about what that role is and why it’s a terrible mistake not to have scientists and engineers in government to help get it right.

Schrag: I think many of us have been trying to find a silver lining, or at least say that things may not be quite as dark as they seem in terms of it being more difficult to undo some of the EPA regulations, or that maybe the Trump administration will not be as hostile as the rhetoric sounds, or that Congress will protect the various science budgets that relate to earth science and climate.

But the reality is that the lack of momentum—the lack of support from on high is pretty profound. What do you think about that?
Holdren: Well, it is pretty profound, and one sees this right up to the present with the EPA removing web pages that were simply informational, like the pages that explain that emissions from fossil-fuel burning and from land-use change are changing the climate. It has taken down even such innocuous pages as how consumers can improve the energy efficiency of their residences. We’ve had a Director of the Office of Management and Budget who has said publicly, “We’re not going to spend any more money on climate change. We think it’s a waste of your—that is, the

2017 Undergraduate Summer Research Award Winners

Each year, the Center for the Environment’s Undergraduate Summer Research Fund provides scholarships for students to complete research across a variety of disciplines. This year, the Center offered seven assistantships for research with Harvard faculty and 10 awards for independent research to undergraduate concentrators in Chemical Sciences, Economics, Environmental Science and Public Policy, History, Integrative Biology, Mathematics, Mechanical Engineering, and Physics. Summer research opportunities are made possible by the generous support of Bertram Cohn ’47.

- Naomi Asimow ’18, “Iron Hydride Porphyrins as Nucleophiles for Carbon Dioxide Reduction,” with Professor Dan Nocera.
- Hannah Byrne ’18, “An Investigation into the Nature of Induced Seismicity in Tectonically Active Regions; A Case Study in the Los Angeles Basin, California,” with Professor John Shaw.
- Katherine Culbertson ’18, “Invasion, Competition, and Niche Evolution: An Investigation of Inter-Specific Interactions of Anolis carolinensis and Anoles sager,” with Professor Jonathan Losos.
- Sabrina Devereaux ’18, “Assessing the Effectiveness of Fisheries Management Regimes in Rural Madagascar,” with Professor James McCarthy.
- Beverly Ge ’20, “Using Feather Archives to Explore Past Exposure of Songbirds to Methyl Mercury,” with Professor Elsie Sunderland.
- Catherine Le ’18, “Green Buildings and Health,” with Professor Joseph Allen.
- Briana Matalle ’18, “The Effect of Full-Scale Bivalve Aquaculture on the Benthic Community in the Narragansett Bay,” with Professor Cameron Hebert.
- Alexander Moore ’18, “Analysis of Recent Global Data on Carbonyl Sulfide (OCS) and Other Atmospheric Gases,” with Professor Steve Wofsy.
- Barra Peak ’18, “Ice Age Sea Level in the Red Sea Region,” with Professor Jerry Mitrovica.
- Daniel Um ’19, “The Conversion of PET, Polyurethane and Styrene into Valuable Biomolecules by Engineered Pseudomonas Putida,” with Professor Peter Girguis.
- Tiffany Zhang ’19, “Environmental Clearances in India,” with Professor Rohini Pande.
taxpayers’—money.”

That same OMB Director has said, “It’s not clear to me why the government needs to support research and development at all.” President Trump has said, when criticized about all the vacant positions: “Well, I’m not sure we need to fill all those positions. I don’t know what all those people do.” I’m sure it’s true that he doesn’t know what all those people do, but that’s not a reason to fail to fill those positions. The government is not going to be able to function effectively as the government that the people expect.

The people expect their government to protect the safety of their water supply. They expect the government to be limiting the amount of toxic air pollutants that they have to breathe. And without these positions filled, the government is not going to do that — [especially] at the EPA, where the overall cut proposed for fiscal year 2018 in the Trump White House partial budget is 31%. And the cut for the EPA’s R&D in that budget is about 50%.

I said for attribution, in an interview that was printed by the AP; that this is beginning to look like a know-nothing trifecta; people who don’t know anything are proud of not knowing anything, and who don’t want anyone else to know anything. And the not wanting anyone else to know anything is evident in taking these websites down, and in going after the budgets that support the sources of data and insight about environmental change. And again, not to restrict it to climate change, it appears that the Trump administration also wants to roll back the administration’s initiatives with respect to the oceans. As you well know, President Obama announced the first ever National Ocean policy in July of 2010—created a National Ocean Council to implement it, focused among many other things, on using integrated coastal and marine planning to support the multiple uses of the ocean and coastline while protecting these resources for posterity.

Schrag: As well as creating some national monument areas.

Holdren: He expanded immensely the marine national monuments, and so far it looks like the Trump administration would like to roll those back. President Obama put substantial amounts of our offshore territorial waters off limits to oil drilling. I think for very good reasons. He put a big chunk of the Arctic waters off limits, in part because there is no reason to believe that a major spill in oil operations in the Arctic could be successfully managed.

Schrag: And by the way, you can just ask Shell about their experience.

Holdren: Exactly. So you have a situation where the administration seems intent on rolling back much of what President Obama and his team accomplished—not just with respect to climate change, but with respect to the emissions and the new source performance standards for coal-burning power plants, with respect to mountaintop removal coal mining, with respect to protection of wilderness. I don’t think they’re going to be able to do it all. I think they’re going to be hung up in the courts on a lot of this. It’s not clear they have the authority to roll back all of the things that they’re trying to roll back.

One of the more perverse examples of what the Trump administration is trying to do is their attempt to reverse Obama’s executive orders on climate change preparedness, resilience, and adaptation. The kinds of things Obama did in this domain—flood-risk standards, wildfire-risk management, and so on—are things that would make sense even if climate change weren’t making these kinds of risks bigger than they used to be.

Schrag: Sure. Being prepared for disaster is just a good thing.

Holdren: Being prepared for floods, being prepared for wildfires, being prepared for droughts…these are win-win strategies. They are things that would make sense to do even if the climate were not changing.

Schrag: So here we are back at Harvard now as Harvard faculty, and I think we’re probably all scratching our heads and saying, “What do we do with this energy, with this commitment? How do we proceed to continue to further the issues that we think are so important? Especially climate preparedness, climate and energy—but all of the other related issues. Can I just probe your thoughts on how do you keep the fight going?”

Holdren: Well, I think there are a lot of ways to keep it going. I think that the whole science community, not just the climate science community or the environmental science community, has to speak up for the importance of science, technology, and innovation in our society; for the importance of the symbiosis we’ve had between the academic sector, the private sector, the public sector, and civil society.

In virtually every area of priority in the Obama administration, we tried to move the needle through partnerships. And we were quite successful at it. That was true in the climate area, where we had the American Business Acts on Climate consortium with a large number of the most important corporations in the country stepping up and saying, “Here’s what we’re going to do to reduce our emissions. Here’s what we’re going to get done in the next X years. Here’s why it’s important for society to work together to do this.”

We had those kinds of partnerships in the advanced-manufacturing domain, we had them in the health initiatives, the Precision Medicine Initiative, the Brain Initiative and so on. That community, involving all of those sectors, now has to stand up and explain that our well-being rests both on a healthy economy and on a healthy environment, that you need to nurture both, and that it’s possible with modern technology to nurture both. It is possible to have the reliable and affordable energy that society needs obtained in ways that are not wrecking the climate.

I’m not sure explanations to President Trump will do a lot of good, but I think we have to rely on the Congress now to rein in some of the more extreme tendencies that have become apparent in the Trump administration. We’ve got to bring some Republican members of Congress along. I think there are quite a few Republican members of Congress who are persuadable; particularly, again, since this is not inherently—and should not be—a partisan issue.
Schrag: And it’s perfectly appropriate to have arguments about strategy, about regulation versus fiscal policy.

Holdren: Right—the argument shouldn’t be about whether we need to protect the environment, but about how to protect the environment and the economy at the same time. The whole notion that anything done to protect the environment is a job killer is a fundamentally bankrupt notion.

Schrag: You and I are here at the Kennedy School, where you’re going to be teaching students, many of whom are going to go off to positions in public service. Long ago, when I first arrived at Harvard, you inspired me in my interest in public service, and so what do you think about how to pass that experience along to the generations of students you’re going to see in this next phase of your career?

Holdren: Well, you know, even in the last phase, when I was at Harvard for the 13 years preceding going into the Obama administration, I was teaching science and technology policy and environmental science for policy. Now, with the last eight years under my belt, I have a new perspective, and I have some new experiences and some new insights to draw on.

Just to give you one example of what I’m going to be doing: before I went into the administration, I taught a course called, “Introduction to Science and Technology Policy.” And that was taken by a relatively small group of Kennedy School students and others drawn from other departments around the campus who were really interested in science and technology policy per se.

And now, in place of that course, I’m going to teach “Science and Technology in Domestic and Foreign Policy.” It’s going to focus on how science and technology are relevant across all these policy domains, and how students that are planning to go into any of them need to know something about how science and technology influence their policy space, how policies relating to science and technology feed back into the tools that they will have available to make progress in their space.

Schrag: I suspect that we’re going to have a lot of students from our own graduate consortium, which brings together students from across the University, interested in taking this course.

Holdren: The other thing I’m going to do is continue to speak out publicly and continue to write op-ed pieces, and continue to do interviews that, basically, try to propagate and underscore the idea that science and technology matter to all of society.

That this is not just a matter of scientists and technologists wanting to be left alone and do their own thing; if we slash the government’s support for science and technology, and slash the government’s use of insights on science and technology in its own decision making, all of society will be the loser. And that’s a message I think that we all need to take on board.

Harvard Climate Week 2017

In late April, HUCE and partners across campus hosted a weeklong series of events organized to examine the many dimensions of the climate change challenge, including: climate policy and defense of climate scientists; the impacts of climate change on human health and on agriculture and ecosystems; adaptation to climate change in Boston; and Harvard’s investment decisions and science-based climate goals. The full schedule and videos from the talks are on the HUCE website: www.environment.harvard.edu

Photos (clockwise from top left): Gina McCarthy, former Administrator of the Environmental Protection Agency; Bud Ris, Co-Chair, Climate Preparedness Working Group, Boston Green Ribbon Commission, and Senior Climate Advisor, Barr Foundation; David Doniger, Director, Climate and Clean Air Program, NRDC; Lauren Kurtz, Executive Director, Climate Science Legal Defense Fund, and Naomi Oreskes, Professor, History of Science, Harvard University; David Lobell, Associate Professor of Earth System Science, Stanford University.

Photos by Alex Griswold, HUCE
In late August 2016, HUCE moved in to newly-renovated space on the fourth floor of the Museum complex. Designed by Perry and Radford Architects, the new space—approximately three times larger—features two large seminar rooms, an expansive central lounge area and smaller gathering spaces, and offices for faculty, students, staff, and affiliated programs like the Planetary Health Alliance and Harvard Solar Geo-engineering Program. The Center was also fortunate to exhibit Whale Bay, Antarctica no. 4, a 7’x12’ pastel drawing by Zaria Forman on loan from Seattle gallery Winston Wachter Fine Art, as well as an additional work by Forman, Greenland, no. 62, on loan from a private collector. If you haven’t already, please come visit us at 26 Oxford Street in the Museum of Comparative Zoology.

Photos by Perry and Radford Architects and Alex Griswold
Harvard Speaks on Climate Change

Video project channels wide range of climate change knowledge

By Alvin Powell, reproduced from the Harvard Gazette

The Harvard University Center for the Environment has unveiled its latest multimedia project, “Harvard Speaks on Climate Change.” Thirty-five videos, featuring Harvard experts in science, business, law, health, economics, engineering, public policy, design, and the arts, have been assembled over the last year and a half as a resource for members of the public who want to learn more about climate change.

The project is the brainchild of Center Director Daniel Schrag, the Hooper Professor of Geology and Professor of Environmental Science and Engineering. The videos, which went live in Fall 2016, are paired with explanatory and background material.

The breadth of perspectives that Harvard faculty members bring to climate change has impressed Schrag in his years working on the problem. He wanted to share those perspectives with the public. “It’s a way of giving the broader community—not just Harvard, but really the whole world—access to the amazing intellectual community that I get to interact with every day,” he said. “We have incredible depth of perspective and unbelievable depth of knowledge on all sorts of things, from aspects of the climate system to detailed understanding of carbon pricing and economics to legal, regulatory systems, and aspects of climate and literature.”

The issue’s head-spinning complexity demands engagement by institutions like Harvard, with broad-based experience in engineering, public policy, business, medicine, public health, education, religion, and the arts and humanities, Schrag said. “Part of my point was to actually encourage people to see that all of these perspectives are needed to solve this problem,” he said.

Schrag identified candidates for the videos and worked with multimedia producer Alex Griswold to pull them together. Griswold met with each for an introductory interview and then for a recorded interview in which they talked about their work or an aspect of it related to climate change.

The interviews were edited from roughly an hour of raw footage to five minutes, and supplemented with graphs, charts and other elements that help explain subjects ranging from atmospheric chemistry to public policy. The site went live in September with 30 interviews. Five have been added since.

“My job was to try to make a short video, accessible to a wide audience, to really talk about the central issues Harvard climate researchers are working on,” Griswold said. “For me it was such a great learning experience.”

At a time when leaders in Washington appear unlikely to take action on climate change, said Schrag, it becomes more important that knowledgeable voices be heard.

“This will require the best minds at Harvard and elsewhere to solve,” he said. “This is one of the great challenges of our time.”

To access the videos, visit: climatechange.environment.harvard.edu
Introducing the 2017-19 Environmental Fellows

The Center for the Environment extends a warm welcome to its incoming cohort of Environmental Fellows, who will begin their research appointments at the Center this fall. Fellows work for two years with Harvard faculty members to advance research on a wide variety of environmental topics and strengthen connections across the University’s academic disciplines. Fellows also meet twice a month for Fellows dinners, which bring them together with a large, diverse group of Harvard faculty for discussions on environmental issues. Visit our website, www.environment.harvard.edu, to learn more about the Environmental Fellows program or to apply to join the 2018-20 cohort.

Kelvin Bates is an atmospheric chemist who investigates the interactions between biogenic and anthropogenic emissions and their contributions to smog formation. Kelvin earned his B.S. in chemistry and economics from Davidson College in 2012 and his Ph.D. in chemistry from Caltech in 2017. During his graduate work, Kelvin used a combination of laboratory experiments, chemical transport modeling, and field measurements to study the gas-phase oxidation mechanisms of isoprene, a volatile hydrocarbon emitted by plants, and the ways in which isoprene can influence trace gas budgets, ozone formation, and organic aerosol production in the atmosphere. As an Environmental Fellow, Kelvin will continue this work with Professor Daniel Jacob of the Paulson School of Engineering and Applied Sciences to incorporate a detailed mechanism of isoprene oxidation into GEOS-Chem, a global chemical transport model. Comparisons with ongoing field measurements will enable him to examine isoprene’s effects on oxidant cycling on a global scale and provide insights into how isoprene oxidation affects our climate. Kelvin will also collaborate with Professor Frank Keutsch (also of the Paulson School) to perform targeted experiments on the oxidation products of biogenic trace gases.

Michael Ford is an engineering and public policy scholar who examines the challenges and opportunities for nuclear energy in contributing to a low-carbon energy future. Mike earned his Ph.D. in Engineering and Public Policy from Carnegie Mellon University in 2017. Prior to his doctoral studies, Mike completed a distinguished career in the United States Navy, where he served as commanding officer of a cruiser and a destroyer, and held sub-specialties in nuclear engineering, finance, and operations analysis. He is a past Fellow in the MIT Center for International Studies Seminar XXI program. In his research at CMU, Mike examined the potential for nuclear energy to play a role in decarbonizing the energy sector. He explored the history of advanced reactor research and development in the U.S., the potential for broader nuclear development worldwide, and also studied issues surrounding novel nuclear deployment options such as floating nuclear power plants. As an Environmental Fellow, Mike will work with Dan Schrag, Sturgis Hooper Professor of Geology, Professor of Environmental Science and Engineering, and HUCE Director, on challenges and opportunities for nuclear energy. Mike will examine the technological limitations, market constraints, and regulatory/policy structures that impact the potential of nuclear fission to play a significant role in a future low-carbon energy mix.

Anthony Medrano is a historian of the Asian marine environment who studies the interplay between people and fish, science and society, and technology and nature. Anthony earned a B.A. in political science from Humboldt State University, an M.A. from the University of Hawaii, and a Ph.D. in history from the University of Wisconsin-Madison. He has also studied at the University of Indonesia and the National University of Malaysia, and held visiting fellowships at the University of Malaysia-Sabah and the Royal Netherlands Institute of Southeast Asian and Caribbean Studies. Based on two years of fieldwork in Indonesia, Singapore, the Philippines, Malaysia, Japan, The Netherlands, and the United Kingdom, Anthony’s dissertation explains why fish and the people who studied them were central to the emergence of modern Asia. He combines archival material with ethnographic research to show how science and industry opened the Southeast Asian shelf, thereby producing a protein boom that fed and fueled the rise of urban society, plantation agriculture, and imperial expansion in the interwar period. As an Environmental Fellow, Anthony will work with Sunil Amrith from the Department of History. He plans to revise his dissertation for publication and commence a second project on the edible ocean in the age of climate change. Looking specifically at how Southeast Asian publics adapted their food cultures to shifting supplies of ocean produce, Anthony hopes to historicize local understandings of and responses to marine environmental change in the long twentieth century.

HUCE Environmental Fellow Joins Harvard Faculty

Congratulations to Prineha Narang, an applied physicist and materials scientist currently at HUCE as a Ziff Environmental Fellow with Professor Alán Aspuru-Guzik (Department of Chemistry and Chemical Biology). Prineha recently accepted a position as Assistant Professor of Computational Materials Science at the Paulson School of Engineering and Applied Sciences. In addition to teaching, Prineha will continue her research on the theoretical fundamentals of nanoscale energy transfer for the design of next-generation light-harvesting and energy conversion devices.
Rebecca Musgrave is a chemist and materials scientist interested in the synthesis of highly magnetic metal-containing polymers. Rebecca received her undergraduate M. Chem degree from the University of Oxford (UK), and earned her Ph.D. at the University of Bristol (UK). Her doctoral thesis was based on the synthesis of polymeric materials and related nanomaterials, which combine the functionality of metal centers (i.e., electronic and magnetic properties) with the processing advantages of conventional polymers, for use in a variety of biological and physical applications. As an Environmental Fellow, Rebecca will work with Ted Betley from the Department of Chemistry and Chemical Biology. She will research novel materials derived from the linking of highly magnetic and redox-active metal clusters into a number of dimensional arrays. The applications of these materials will be investigated, focusing specifically on the areas of energy storage, magnetic memory technology, electrocatalytic reduction of carbon dioxide, and the energy-efficient separation of gases. Rebecca’s work will be supported by a Marie Curie Fellowship from the E.U.

Jisung Park is an economist studying how climate change impacts economic productivity and human health. Jisung earned a B.A. in economics and political science from Columbia University, M.Sc. degrees in development economics and environmental policy from Oxford University, and a Ph.D. in economics from Harvard University. Jisung’s doctoral work in environmental economics examined the economic effects of climate change from a variety of perspectives: from how heat affects student test scores to how daily heat shocks affect local labor productivity. Jisung received a Climate Change Solutions Fund grant to support his research while he was a graduate student at Harvard. As an Environmental Fellow, Jisung will work with faculty in the Department of Economics and the Chan School of Public Health to explore the potential for long-run climate adaptation and the possible mechanisms through which such adaptation is likely to occur, namely: structural investments (e.g., air conditioning); physiology and personal behavior; and new cultural norms in the workplace.

Environment @ Harvard
A sampling of the academic year’s events

Ongoing Series
The Future of Food: Climate, Crops, and Consequences
This new series, convened in Spring 2017 by HUCE Co-Director Peter Huybers, explores the interactions between agriculture and climate, and their consequences for health and stability.

The series kicked off with a lecture on the compounding effects of climate change on the global food supply and strategies to meet the needs of a growing population with the International Food Policy Research Institute (IFPRI)’s Director General, Shenggen Fan.

The next installment of the series welcomed Michael K. Stern, Chief Executive Officer and President of The Climate Corporation, for a discussion touting big data and how it can help farmers make better, more strategic decisions in order to increase crop yields.

David Lobell, William Wrigley Fellow at the Freeman Spogli Institute for International Studies and Stanford Woods Institute for the Environment; Associate Professor of Earth System Science; and Deputy Director of the Center on Food Security and the Environment at Stanford University, visited Harvard during Climate Week to discuss “Improving Agriculture in a Warmer World.”

The debut series closed with Lisa Ainsworth, Associate Professor of Plant Biology and Adjunct Assistant Professor of Crop Sciences at the University of Illinois at Urbana-Champaign, who discussed the challenges and opportunities that climate change presents for genetic and biotechnological improvement of crop yield and food supply.

Ecological Systems in the Anthropocene
Hosted by HUCE and organized by HUCE faculty associate Elizabeth Wolkovich, Assistant Professor of Organismic and Evolutionary Biology and Faculty Fellow at the Arnold Arboretum, this series, now in its second year, explores the future of ecological systems in a world heavily impacted by humans.

The fall installment of the series hosted a panel discussion on conservation strategies that both protect biodiversity and encourage economic development. The panelists were Jon Hoekstra, Executive Director of the Mountains to Sound Greenway Trust; Peter Kareiva, Director of the Institute of the Environment and Sustainability at UCLA; and M. Sanjayan, Executive Vice President and Senior Scientist at Conservation International.

The spring semester opened with HUCE visiting scholar Christopher B. Barrett, Deputy Dean and Dean of Academic Affairs, College of Business; Stephen B. & Janice G. Ashley Professor of Applied Economics and Management and International Professor of Agriculture, Charles H. Dyson School of Applied Economics and Management; and Faculty Fellow, David R. Atkinson Center for a Sustainable Future, Cornell University, who discussed “Poverty Traps, Resilience, and Coupled Human-Natural Systems.”

The latest and final installment of the academic year took place during Climate Week. Sandra Diaz (Córdoba National University, Argentine National Research Council); Kate Jones (Centre for Biodiversity and Environmental Research, University College London); Michael Donoghue (Yale University); and Ana Rodriguez (The French National Center for Scientific Research), discussed how climate change, habitat loss, and overexploitation are driving species declines and extinctions across the globe. The discussion was moderated by Jonathan Davies (McGill University).

Science & Democracy
This series, co-sponsored with the Harvard Kennedy School Program on Science,
This series features panel discussions moderated by Sheila Jasanoff, Pforzheimer Professor of Science and Technology Studies at the Harvard Kennedy School.

**HUCE Special Lecture**

Challenges for the New President
Bob Perciasepe, President of the Center for Climate and Energy Solutions (C2ES) and former Deputy EPA Administrator in the Obama Administration, visited Harvard in the fall to discuss environmental policy at the federal level and nonpartisan opportunities to reduce carbon emissions from the U.S. energy supply.

**Climate Change and the Developing World Symposium**

In November, the Harvard Global Institute and HUCE convened a remarkably diverse group of faculty from across the University to discuss the global dimensions of the climate change challenge. After a welcome and introductory remarks by President Drew Faust, faculty moderators Rebecca Henderson, McArthur University Professor; Jennifer Leaning, Bagnoud Professor of the Practice of Health and Human Rights; and Daniel Schrag, Hooper Professor of Geology and Professor of Environmental Science and Engineering, led interdisciplinary panel discussions on urbanization and adaptation, food and water security, and the role of technology and policy in identifying solutions.

“Stillness and Momentum through Climate Change” with Zaria Forman Artist Zaria Forman shared the inspiration behind her drawings and the role they play in communicating the urgency of climate change and connecting people to the beauty of remote landscapes. Two pieces of her work, *Whale Bay, Antarctica* no. 04 and *Greenland* no. 62, are showcased in HUCE’s new space.

**Inaugural Planetary Health/Geo Health Annual Meeting**

The Planetary Health Alliance, a program housed at HUCE, along with the American Geophysical Union, the Ecological Society of America, and The Lancet, hosted the Inaugural Planetary Health/GeoHealth Annual Meeting in April. The symposium brought together a diverse group of students, investigators, instructors, and policy makers to showcase the extraordinary momentum taking place around the world in the field of planetary health and highlight institutional developments, new directions in research, and applications to policy-making and natural resource management.

**HUCE Film Screenings**

*Before the Flood*

HUCE opened the academic year with a film screening of *Before the Flood*, a documentary by Academy Award®-winning filmmaker Fisher Stevens and Academy Award-winning actor, environmental activist and U.N. Messenger of Peace Leonardo DiCaprio. The film shares a riveting account of the dramatic changes now occurring around the world due to climate change, as well as the actions we as individuals and as a society can take to prevent catastrophic disruption of life on our planet. Small group discussions followed the screening with students and Harvard faculty.

**The Age of Consequences**

In January, HUCE hosted a film screening and discussion of *The Age of Consequences*. Directed by Jared P. Scott, the film investigates the impacts of climate change, resource scarcity, migration, and conflict through the lens of U.S. national security and global stability. Executive producer Sophie Robinson led a discussion with attendees following the screening.