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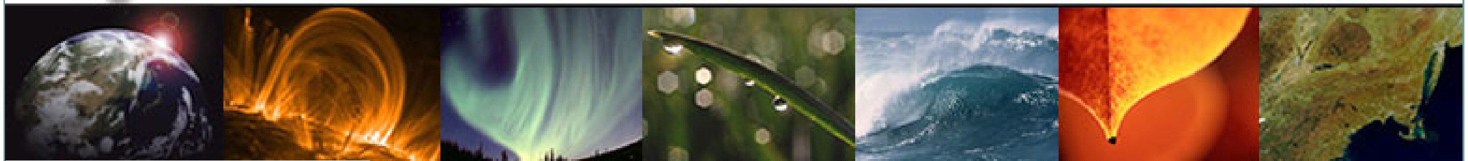

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Director: Harlan Spence
Assoc. Dir.: David S. Bartlett
Editor: David Sims
Designer: Kristi Donahue
Circulation: Laurie Pinciak

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Winter 2011

Earth Systems Science

EOS in Greenland

IN THE UPCOMING MONTHS, scientists from the UNH Institute for the Study of Earth, Oceans, and Space (EOS) continue long-term research efforts on the Greenland ice sheet.

Glaciology in a Warming World

FIVE FIELD SEASONS ago at the Jakobshavn Isbrae glacier in western Greenland, glaciologist Mark Fahnestock was “simply” trying to measure the speed with which the vast river of ice was racing towards the sea. Read More…

A Score and More at the Summit

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Earth Systems Science

Ebullient Science

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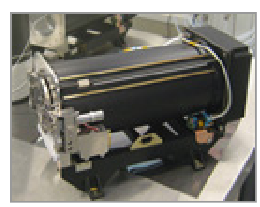
Ocean Science

Sentinel at Sea

FOR THE PAST FIVE YEARS, a sentinel buoy has bobbed about in waters northeast of Appledore Island in the Gulf of Maine taking hourly readings of both atmospheric and oceanic carbon dioxide. It is one of just half-a-dozen such buoys nationwide making a crucial measurement… Read More…

Space Science

From Drawing Board to Onboard



ONE YEAR AGO, these pages reported that Space Science Center scientists, engineers, and machinists had pulled off something of an eleventh-hour miracle by rescuing a mission-critical or "Level 1 science" instrument for NASA's MMS mission. Read More…

Around the Hall

News and Notes

- Faculty, Staff, and Student News Read More…
- From the Director: Inherit the Earth Read more…

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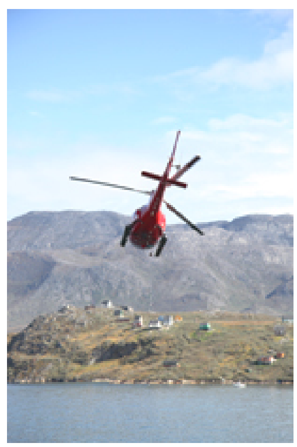
Glaciology in a Warming World

In just half a dozen years, Mark Fahnestock has watched Greenland's glaciers go from bad to worse

FIVE FIELD SEASONS ago at the Jakobshavn Isbrae glacier in western Greenland, glaciologist Mark Fahnestock of the Complex Systems Research Center was "simply" trying to measure the speed with which the vast river of ice was racing towards the sea. Jakobshavn had doubled its pace in five years and scientists didn't know why.

So Fahnestock and colleagues made two annual, month-long pilgrimages to Jakobshavn where they deployed Global Positioning System (GPS) receivers that rode Jakobshavn six months at a time as the behemoth gave new meaning to the saying "moving at a glacial pace."



A helicopter ride from the town of Kapisillit in Southwest Greenland takes researchers and supplies into their camp next to the glacier Kangiata Nunata Sermia. Photo by Mark Fahnestock.

Since then, the researchers have had to move camp more than a kilometer "upstream" to keep near the terminus as the glacier backed up and disappeared around the corner.

Today, it requires a much bigger toolbox and a lot more scientists to adequately investigate the extent of what's happening on the 100,000-year-old ice sheet – a process Fahnestock, exaggerating for clarity, calls "learning how to watch an ice sheet come apart."

The greening of Greenland may be disconcerting in most respects, but these are indeed interesting times to be a glaciologist.

A Focus on Fjords

LAST WINTER, the time-lapse cameras Mark Fahnestock and colleagues deploy year-round at the Jakobshavn Isbrae glacier captured a surprising nighttime image near its terminus – lights from fishing boats bobbing about in the fjord's icy waters.

That fishing boats are able to get well into the fjord in winter is a recent historical first but is perhaps not so surprising in light of other firsts that occurred in the 2009-10 season: there was no wintertime advance of the glacier itself as it uncharacteristically shed, or "calved" icebergs all year long; Disko Bay, which feeds Jakobshavn's fjord, was almost completely free of sea ice, and conditions in the fjord itself were unusual.

Notes Fahnestock, "The ice cover in the inner fjord didn't stay stiff. It was unconsolidated, and so as it comes apart the ice moves and instead of shutting down calving for most of the winter as is normal the glacier keeps calving icebergs."

To get a better handle on what might be fueling these changes, master's student Ryan Cassotto and Fahnestock are compiling a decade's worth of sea surface temperature records from NASA's Moderate Resolution Imaging Spectroradiometer (MODIS) aboard the Terra satellite. From this they will derive the first comprehensive record of daily changes in fjord ice surface temperatures and conditions.

For his thesis work, Cassotto, whose background is in electromagnetic compatibility engineering and remote sensing, has taken ten years of MODIS

"…the tools and techniques that can now be applied to investigating a big, changing system like an ice sheet have evolved in scope and sophistication…"

Home for three weeks while studying Kangiata Nunata Sermia. The glacier was 1,600 feet thicker and filled this fjord to the line visible at the top of the ridge 200 years ago. Photo by Mark Fahnestock.

"Six years ago we knew Jakobshavn's speed had changed but we had just begun to grapple with trying to understand why. We've made progress with that problem but at this point the ice sheet is changing so much and so fast that we're having a hard time keeping up. There are a lot of interesting problems to consider," Fahnestock says.

Fortunately, in the last 15 to 20 years the tools and techniques that can now be applied to investigating a big, changing system like an ice sheet have evolved in scope and sophistication to help scientists wrestle with those problems. Indeed, back in the early 1990s it was a challenge to compile even a rudimentary map of the ice sheet's basic features and flow rates to assist scientists in keeping a languid eye on a more-or-less steadfast system. Glaciology back then was the study of ice on Earth as it was at the time – known to change over thousands and hundreds of years but not on an annual basis.

Now, with scores of scientists scrambling to understand what's driving big changes on a variety fronts, an array of instruments are being deployed year-round. Time-lapse cameras, seismometers, GPS receivers, radar, satellites and aircraft armed with lasers, and even old steel-hulled boats capable of navigating fjords choked with icebergs in an effort to probe the increasingly important ocean-side of the equation.

Says Fahnestock, "The urgency for getting better at measuring what the ice sheet is up to has come from watching it change over so short a period. In the last fifteen to twenty years the field of glaciology has gone from trying to understand why a glacier flowed the way it did to now trying to understand why the whole system is changing and how vulnerable it is to continued acceleration in a warmer climate. We need to do this to understand what the flow of the ice out of the ice sheet will look like in the future, which is ultimately driven by our need to know as best as we can just how much sea level rise is possible."

An Ocean of Change

Scientists now know the ocean itself is having a profound influence on the changing glaciers in Greenland – in particular, tidewater outlet glaciers like Jakobshavn that terminate in fjords, and so they are looking more closely at the ice sheet in its ocean setting.

They've discovered that rapid changes in the glaciers themselves very quickly follow changing conditions in the fjords, including a lowering in sea ice cover and warmer water off the coast – the latter which is being measured by oceanographers who are seeing pulses of warm water entering the fjords from the open ocean.

thermal imagery for the larger Disko Bay region and remapped it at a one-kilometer resolution to see specifically and in greater detail what has been occurring in the fjord itself. He can then compare the thermal record with both seismic records and time-lapse imagery over the same period to better ascertain how changes in the fjord are affecting what the glacier itself is doing far inland.

Ryan Cassotto conducts a GPS survey to profile a lateral moraine above the researcher's camp at Kangiata Nunata Sermia. The moraine (debris in foreground) represents the maximum extent of the last major glacial advance during the Little Ice Age. Photo by Mark Fahnestock.

"I should be able to verify that the fjord is really mobile during these periods where we have calving in conjunction with these warmer water temperatures," Cassotto says. Adds Fahnestock, "We're just beginning to develop a picture of some of the ocean controls on the glacier that are not as simple as melting at its front."

But, of course, rarely in so large and complex a system as an ice sheet are there one-size-fits-all answers, and Fahnestock notes that even in the same fjord system glaciers can be surprisingly out of sync with respect to changing environmental conditions.

In a fjord near Greenland's capital of Nuuk, Fahnestock and company are looking at two distinctly different glaciers –one that has maintained itself since the Little Ice Age (a period of cooling that began around 1250 A.D. with the coldest periods during the 16th and 17th centuries) and is only now starting to thin while another neighboring glacier has been in retreat for some time.

"So now you've got the question of why would glaciers in different parts of the same fjord not respond synchronously. It's a

"Currently, if the melting of

all the Greenland glaciers, those in the Canadian ice caps, Alaska, and some from Norway is added together it represents roughly a third of the present rate of sea level rise…"

"What you want to do then is connect that warming water to increased rates of flow from the ice sheet, which has several possible mechanisms behind it," Fahnestock says. But getting at those mechanisms requires looking at a variety of phenomena simultaneously, which can be difficult.

really interesting question, and we have some theories."

For example, to understand how much energy from the warming water in the fjord ends up melting ice at the front of the glacier, measurements need to be made in an area that is typically choked with ice and enormous icebergs that have ripped away from the glacier – a process known as "calving" – and that produce equally enormous waves. Notes Fahnestock, "It's a really tough place to make any observations, it's difficult to access, and dangerous."

Two collaborators from the University of Alaska Fairbanks at the terminus of the glacier. Also pictured are a solar panel and battery bank that power year-round GPS observations, used by the researchers to measure uplift of the area in response to the loss of ice. Photo by Mark Fahnestock.

Dangerous indeed. In 2009, Fahnestock and colleagues were lucky enough to catch the calving of an iceberg at Jakobshavn on film. A kilometer distant from the video camera, the berg that breaks off the front of the glacier and cascades into the rubble of ice in the fjord is so large that its disintegration and end-over-end rollover appears to happen in slow motion.

Another way to look at Jakobshavn's ice output is like this: the glacier calves roughly 40 gigatons (40 billion metric tons) of ice per year. The CSX rail freight company claims to move a million tons of freight per day, which means it would take them roughly 1,000 days to move the icebergs from a typical (not large) calving event from this glacier and a century to move the ice Jakobshavn puts in the ocean in one year.

With numbers like that from one, albeit large, glacier on a planet with a rising thermostat, it's fairly easy to envision waves lapping ever higher at the world's coastlines.

Currently, if the melting of all the Greenland glaciers, those in the Canadian ice caps, Alaska, and some from Norway is added together it represents roughly a third of the present rate of sea level rise, which is about a foot per century.

But notes Fahnestock, "If you take the present rate as a foot in a hundred years, based on what we know from the last decade or decades, and project that forward given what we know about changes occurring now, I don't think a meter (3.2 feet) over 100 years can be taken off the table yet. It's hard to imagine the rate staying as low as one foot." He adds, "The Antarctic is not heavily involved in putting ice in the ocean right now, in a warmer climate it almost certainly will be."

by David Sims, Science Writer, Institute for the Study of Earth, Oceans, and Space.

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"Finally, …we stuck the probe right into the snow

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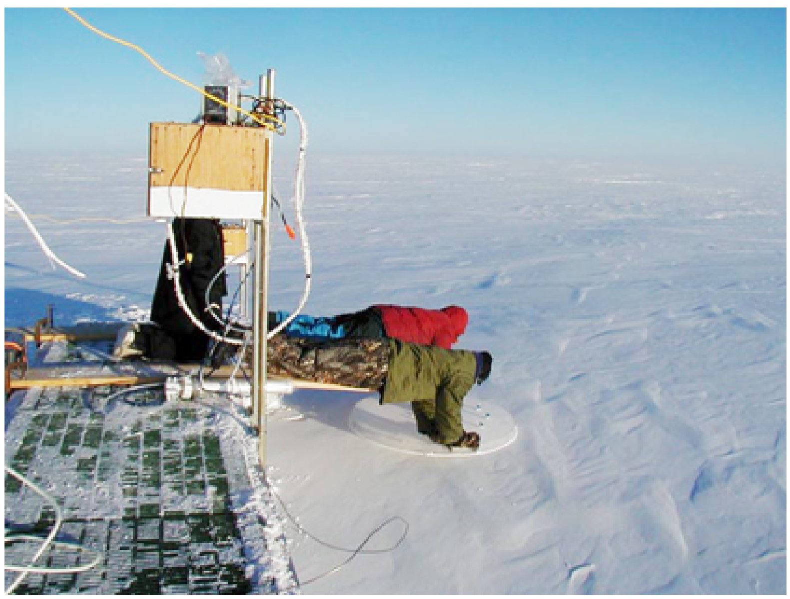
A Score and More at the Summit

This spring, atmospheric chemist Jack Dibb celebrates 24 years of continuous research at Greenland's Summit Station Observatory where he's helped keep the lights on

BACK IN 1998 at the National Science Foundation's Summit Station Observatory in Greenland, a multi-institutional team of researchers led by atmospheric chemist Jack Dibb of the Complex Systems Research Center stumbled upon a surprising chemical process that subsequently launched an entirely new branch of scientific investigation – snow photochemistry.

Located at the peak of the Greenland ice cap, Summit is a pristine Arctic outpost and relatively free of local influences from pollutant chemicals. So when the scientists discovered the equivalent of urban air hovering above the snow they were baffled.



Jack Dibb and Eddie Galbavy of UC Davis lower the bonnet for the group firn-air sampler to the snow surface. The sampler allows six different instruments to simultaneously sample the air filling pores in the snowpack at a given depth, while the bonnet limits the amount of surface air pulled down into the snowpack by the sampling pumps.
Photo courtesy of Barry Lefer, NCAR.

Expecting to find but scant amounts of nitrogen oxides, reactive gases which, among other things, play an important role in the formation of ground-level ozone or smog, they instead took readings eight meters (26 feet) above the snow that were surprisingly high and readings closer to the snow surface even higher. "Finally," recalls Dibb, "we stuck the probe right into the snow and the numbers were astronomical."

This discovery, and a similar, serendipitous find by a different team at the South Pole later that year, opened up the new avenue of scientific inquiry that seeks to understand the complex, small-scale chemical processes that occur when sunlight strikes the surface of snow.

"The whole issue wasn't even on anybody's radar screen before the late '90s. The thinking was that when it rained or snowed these reactive gases were taken out of the atmosphere and that was the end of the story," says Dibb.

But obviously the story didn't end there and the mystery has sparked ongoing and expanding investigation. Researchers are now trying to decipher what chemical compounds might be exerting an outside influence in the creation of these reactive gases that shouldn't be there.

Specifically, scientists are measuring for ubiquitous halogen compounds, such as bromine, which they hypothesize may be a large player in the mismatch between modeled processes in the snow and processes that are measured.

To that end, Dibb will return to Summit in May to continue working on collaborative snow photochemistry research with Brown University and Georgia Tech scientists looking into how bromine may play a role in the recycling of nitrate – a precursor to the mysterious nitrogen oxide showing up in *and the numbers were astronomical."*

the snow.

Says Dibb, “Very small amounts of bromine in the atmosphere can really modify how the ozone chemistry works, how the nitrogen oxide chemistry works.”

Among other reasons, the work Dibb and colleagues are doing in the field of snow photochemistry is critical if scientists are to feel confident in their interpretation of ice core records. Notes Dibb, “Ice cores may be the best place to get past, atmospheric composition information but there are all these open questions about the accuracy, resolution, and fidelity with which snow records the composition of the air above it.”

The House that Jack Helped Build

Summit Station was the site of the Greenland Ice Sheet Project 2 (GISP2) beginning in 1989, and GISP2-related activities were eventually what took Dibb up to Summit after his arrival at UNH in 1988. But when the project hit bedrock in 1993 and closed operations, there was some question as to what the station’s future might hold.

Dibb was a key player in convincing the National Science Foundation to not only keep the lights on but to make Summit Station a year-round scientific observatory. “I helped convince NSF to let us keep doing projects after the drilling ended and to expand operations year-round as we had no idea of what was happening during the wintertime from a scientific perspective,” Dibb says.

The main building or "Big House" at Summit Station. The dome houses the antenna for the satellite link to the outside world. Photo courtesy of John Burkhart, The Norwegian Institute for Air Research, Kjeller, Norway

The effort was successful, and it was Dibb himself who tried the first year-round experiment in 1997. Today, there is a long-term commitment to keep Summit Station operating full-time as the only year-round, dedicated, staffed observatory in the high-altitude Arctic. The location is relatively free of local influences that could corrupt climatic records, and captures rare phenomena that can represent climatic trends and help scientists understand the impacts of climate change. The observatory is situated ideally for studies aimed at identifying and understanding long-range, intercontinental transport and its influences on air and snow chemistry and "albedo" or reflectivity.

"… there is a long-term commitment to keep Summit Station operating full-time as the only year-round, dedicated, staffed observatory in the high-altitude Arctic. "

“So now Summit hosts one of six National Oceanic and Atmospheric Administration (NOAA) Global Atmospheric Baseline Observatories where NOAA can make the same suite of measurements of climatically relevant gases and aerosols at a select few places on the planet,” says Dibb. “This is a service they provide to the whole science community, especially modelers.”

The Summit “berthing module” or sleeping quarters, which is the equivalent of three, combined office trailers with thickened walls to withstand the polar environment. Photo courtesy of John Burkhart.

The NOAA baseline stations are located strategically in an effort to get a global, average signal in both the northern and southern hemispheres. Explains Dibb, “So they’ve tried to locate their stations where there’s very little local influence. Barrow, Alaska, where they’ve been making observations for nearly half a century, used to be like that. But then the Prudhoe Bay oil fields went in and as more and more ice melts in the Arctic, and shipping, exploration, and drilling increases, the chances are good that Barrow is going to increasingly give you a regional signal.”

In addition to continuing his decades-long research efforts at the observatory, Dibb, along with CSRC’s Mark Twickler who heads up the NSF Science Coordination Office, are active in plans for the redevelopment of Summit Station, which will help it fulfill its mission as a sentinel, scientific outpost in a fast-changing Arctic landscape.

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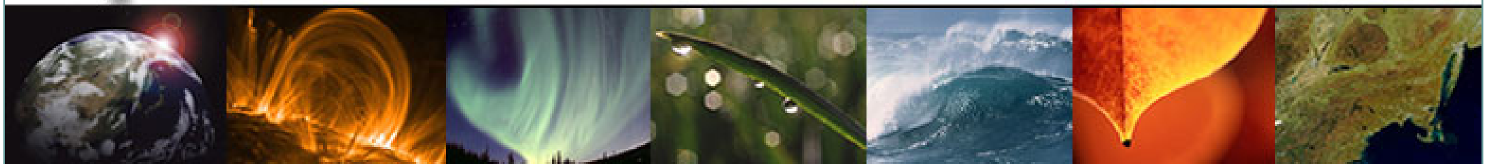

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Ebullient Science

A novel means of obtaining key data in the climate change puzzle bubbles to the surface

A CHANCE ENCOUNTER next to the Complex Systems Research Center mailboxes led to a pre-eureka moment for Ruth Varner.

Early last year her CSRC colleague, tropical ecologist and sound technologist/musician Michael Palace, was opening a package he had just received when Varner passed by. “Guess what I got?” Palace asked Varner, whom he knew was interested in field recordings he’d done during research projects in tropical forests. “A hydrophone,” he answered.

Palace had purchased the underwater microphone to record waves and dolphins in the Caribbean, but in Varner’s mind a different thought quickly surfaced. “Do you think we could hear bubbles with that, bubbles of methane from peatlands?” “Let’s find out,” replied Palace.

With no peat readily available, the two grabbed a couple of paper coffee cups, a few little stirrer-straws with which to blow bubbles, and headed to Palace’s office. They plugged the hydrophone into the requisite electronic gadgetry he had on hand, plunged it into a coffee cup filled with water, and commenced to blow bubbles. Eureka!

This photograph taken at Stordalen mire in Abisko,Sweden shows a permafrost collapse feature of permafrost palsa (permanently frozen ice lenses) at the right and the collapse "pond" in the center.
Photo by Ruth Varner, UNH-EOS.

Some months and a lot of front-end work later, Varner and Palace received a pilot grant of $50,000 from the U.S. Geological Survey to further develop and field test instrumentation that could listen for methane and, potentially, help provide insight into one of the biggest unknowns in the climate change puzzle: the global methane budget. Specifically, Varner and Palace’s unique effort will attempt to nail down the methane that is emitted to the atmosphere through the process of “ebullition” or bubbling.

Wetlands are the planet’s largest natural source of methane and ebullition is perhaps the dominant pathway for its release.

Extending the Reach of Research

LAST SUMMER, Ruth Varner was funded by the UNH Center for International Education to visit a research site in Sweden and work with former Complex Systems Research Center scientist Patrick Crill, now at Stockholm University and an affiliate professor with CSRC. Crill studies aspects of northern peatland ecosystems, including the process of methane ebullition. Varner used the opportunity to build some collaborative research opportunities between UNH scientists and students and Swedish counterparts around themes of Earth systems science and the impact of climate change on northern ecosystems.

The effort has resulted in recommended funding for a four-year National Science Foundation Research Experience for Undergraduates (REU) grant. The project, which Varner will begin in 2012 after a summer of preparatory fieldwork in Sweden this year, will bring eight undergraduates from other universities and colleges to UNH to conduct research here and abroad during a 10-week summer session. As part of the experience, students will be involved in various aspects of Varner’s methane ebullition work.

“Last summer’s visit to the Swedish site was an important step in securing funding for the REU project,” says Varner. “From that experience it was clear that I knew the logistics involved, and taking eight students to a foreign country for a month of scientific research is a pretty big undertaking.”

methane and ebullition is perhaps the dominant pathway for its release."

However, measuring the bubbling process is so challenging that its estimated contribution to the global budget runs the gamut from zero to 60 percent as gauged by a handful of field studies.

"It's a really hard number to get at," Varner says, "there have been a number of estimates but the error bars are really large because ebullition happens both spatially and temporarily in a very heterogeneous way."

It is difficult, in other words, to know where and when a methane bubble is going to burst. And, one wonders, even if it's possible to take measure of a single bubble by sound, how do you to gauge its frequency, volume, and density to derive how much methane is trapped inside before it adds its two cents worth to the global picture?

That is, in fact, precisely what Varner, Palace, and master's student Jillian Lennartz have figured out how to do, and they are currently in the process of bringing the technique to fruition. Field tests were conducted last fall and an array of instruments will be deployed this summer in wetlands locally, in Alaska, and in Sweden (see related story "Extending the Reach of Research").

Martin Wik, a graduate student at Stockholm University, installs bubble sensors in Mellan Harrsjön, a lake adjacent to Stordalen mire.
Photo by Ruth Varner, UNH-EOS.

Lennartz is currently conducting rigorous calibration testing in the lab so that the scientists can be assured next season's field data is spot-on, and Palace is working on the sound-side of things writing computer code that will aid in the accurate and efficient interpretation of a methane bubble's sound signature vis-à-vis the minute details of the gas itself.

One Size Does Not Fit All

Using what's known as an autochamber technique, Varner has been tracking methane emissions at a 9,000-year-old wetland area known as Sallie's Fen in Barrington, N.H. since 2009 and UNH scientists have a record of methane emissions from the fen going back 22 years. (A fen is a peat-forming, groundwater-fed wetland thick in vegetation. Autochambers open and close automatically to take precise measurements of the buildup of gaseous emissions over a specified period of time.)

Although she and graduate student Jordan Goodrich have been using the autochambers to measure total methane emissions via diffusion from soil, water, and plants, they began to suspect that ebullition was occurring because data repeatedly showed abrupt spikes in methane levels.

Says Varner, "We'd see a rapid increase in methane concentration in a short period of time, which indicated a large amount was being released during an 'event.' So we realized ebullition was not as episodic as we originally thought, but actually happens pretty frequently and at a regular rate."

Varner also realized they couldn't deploy an army of the large, expensive autochambers to capture tiny bubbles, so the arrival of Palace's hydrophone in Morse Hall was fortuitous indeed.

Another bit of serendipity was Lennartz showing up at Varner's office door in search of a master's project. With a background in chemistry and computers, Lennartz was a good match for Varner's nascent ebullition research/instrument development,

Varner notes that she recently received a $10K grant from the NH Space Grant Consortium to provide additional support for her graduate student, Jillian Lennartz, to participate in the REU program's work on methane ebullition. The NHSGC funds will also help support work Varner plans on doing with NASA Goddard Space Flight Center scientists on the issue of "scaling up" the ebullition data to the global scale.

Varner will go back to Sweden this summer with two students, graduate Research and Discover student Kaitlyn Steele (who is actually spending five months in Sweden working on her thesis project) and undergraduate Jacki Amante, to firm up the details for next year and deploy more methane ebullition sensors to further the calibration and field test efforts

The intent of the REU program is to provide an opportunity for undergraduates whose home institutions don't necessarily have research programs of their own. By giving the students a rich, hands-on research experience it is hoped they will carry what they've learned forward to graduate school and possible careers as research scientists. Eight different students will participate each summer of the four-year program.

Students will spend their first four weeks at UNH learning fundamentals of Earth system science and climate change impacts on northern ecosystems, and get basic training in laboratory and field techniques, including conducting fieldwork at Sallie's Fen where Varner does her methane emissions field studies. They will then travel to the Abisko Scientific Research Station in a permafrost region of northern Sweden for four weeks of hands-on research and data collection investigating how climate warming is affecting geochemical, hydrological, and biological cycles. The final two weeks of the program will be spent back at UNH where they will summarize and present their findings to research peers and mentors, and prepare to submit their research for presentation at an international scientific meeting.

and the fact that she had a mechanical engineering background “by proxy,” as she puts it, made her a shoe-in for the project.

“My father has two degrees in engineering and a machine shop at home. I grew up with spare robotics parts scattered around the house. He was always trying to make a robot that would serve drinks or do some other mundane task,” she says.

Other UNH faculty involved in the REU grant are Erik Hobbie (CSRC), Julie Bryce (Earth Science), and Sertia Frey (Natural Resources and the Environment).

For her master’s thesis work, Lennartz was tasked to build and test out a variety of designs for hearing and analyzing bubbles of methane. The plan was to find an inexpensive and practical way of conducting the science. With input from Varner and Palace she built one gadget using a funnel stuffed with vibration-sensitive material. Another attempt was made using a stethoscope that had been gutted and replaced with a tiny, inexpensive microphone that Palace had made previously to record the hundreds of little “footsteps” of centipedes in Amazonian rainforests. (The miniscule and affordable technology is the same often used by performance artists to incorporate sound with body movements.)

Undergraduate Jacki Amante (left) and Jillian Lennartz conduct calibration tests on the hydrophone-based ebullition instrument invented at UNH.
Photo by David Sims, UNH-EOS.

The first recorder didn’t produce a strong enough bubble signal, while the latter tuned in a riot of extraneous noise. So in the end the group came full circle, back to the original hydrophone-based instrument that Palace and Varner had tested in his office half a year earlier.

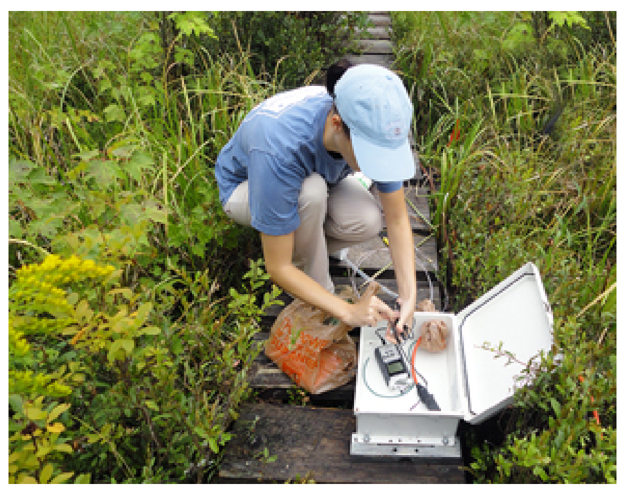
After going through several iterations Lennartz ended up with an instrument comprised of a side-hinged PVC pipe that, when opened, exposes two, small offset funnels – one containing the hydrophone itself, and one off to the other side and higher up that captures the bubble after it hits the hydrophone. Completing its journey, the bubble rises up a tube into a “gas trap.”

Explains Lennartz, “Periodically we’ll collect the gas in the trap, put it in a vial, and look at the concentration of methane and its the isotopic signature so we can tell something about how the methane is being produced. The deeper, older methane will be heavier, the stuff closer to the surface, lighter. We’ll do the analysis in the isotopic lab here at UNH.”

" The great thing is that when the bubble is recorded, we'll know if it occurred at night or during the day, and under what meteorological conditions."

Lennartz notes that the method the team came up with to sample methane ebullition allows them to accurately measure the when, where, and how of the process.

“The great thing is that when the bubble is recorded we’ll know if it occurred at night or during the day, and under what meteorological conditions. It’s a relatively complete understanding of the entire process – where it’s produced, how it’s released, and what causes it to be released.”



Jillian Lennartz installs a recording device for an ebullition sensor at Sallie's Fen in Barrington, N.H.
Photo by Olivia Varner.

With such a fundamental data set in hand the trick will then be to figure out what it all might mean in terms of filling in the blanks with respect to global methane sources, which is the ultimate goal of the project and will be the particular focus of future funding that Varner and Palace are pursuing.

Says Varner, “That’s actually something we’ll be addressing, How do you scale these data up and generalize what this instrument can do in an array in one specific location to derive an estimate for methane ebullition for the entire globe?”

It will be a key question to answer; methane’s role in the climate change puzzle could increase significantly in years to come as areas of permafrost thaw and peatlands degrade to potentially release much more of the potent climate-forcing gas.

by David Sims, Science Writer, Institute for the Study of Earth, Oceans, and Space.

Institute for the Study of Earth, Oceans, and Space

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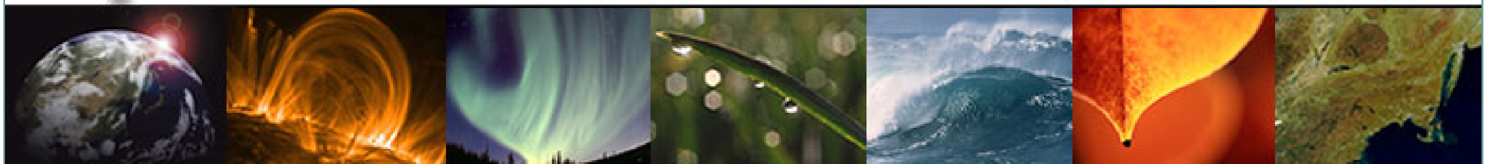

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Sentinel at Sea

UNH ocean scientists are in the vanguard of NOAA's efforts to monitor ocean acidification remotely around the clock

FOR THE PAST FIVE YEARS, a sentinel buoy has bobbed about in waters northeast of Appledore Island in the Gulf of Maine taking hourly readings of both atmospheric and oceanic CO_2. It is one of just half a dozen such buoys nationwide making a crucial measurement to help scientists know how much carbon the ocean is taking up globally as atmospheric CO_2 levels continue to rise.

More specifically, the Gulf of Maine buoy measurements are aimed at better understanding the role complex coastal waters play in the increasing acidification of the global ocean.

Oceanographer Joe Salisbury with the UNH CO_2 buoy being deployed from the R/V Gulf Challenger.
Photo courtesy of James Irish, UNH

"We're trying to understand how much carbon the ocean is taking up globally," says research associate professor Doug Vandemark of the Ocean Process Analysis Laboratory and principal investigator on the CO_2 buoy. He adds, "And one of the big questions is, If we don't make measurements along our coasts, are we missing a big part of the picture?"

In a word, yes. Unlike open ocean waters, which have been monitored for CO_2 levels much more extensively, coastal ocean waters are a complicated mix of intense, seasonal biological activity and inflowing river waters that flush nutrients, sediments, and pollutants directly into the sea. In addition, short-term events like storms, large spring snowmelts, flooding, and even seasonal air pollution plumes can have an influence on the uptake of CO_2 in coastal oceans.

In a word, yes. Unlike open ocean waters, which have been monitored for CO_2 levels much more extensively, coastal ocean waters are a complicated mix of intense, seasonal biological activity and inflowing river waters that flush nutrients, sediments, and pollutants directly into the sea. In addition, short-term events like storms, large spring snowmelts, flooding, and even seasonal air pollution plumes can have an influence on the uptake of CO_2 in coastal oceans.

And because there is so much mixing that goes on in coastal ocean waters, taking accurate readings of CO_2 levels is much more challenging than in pelagic seas.

"The coastal ocean mixes faster than we can monitor using traditional shipboard sampling," says Vandemark. "With a ship we might go out once a week at best, and it's a lot of effort, a lot of time and expense. So having a buoy out there making hourly measurements helps us to deal with these issues in a pragmatic way."

Not that the buoy didn't require tremendous effort and skill to get up and running, improve, and keep maintained. Vandemark notes that without the engineering expertise of Jim Irish, former OPAL faculty and now a research professor in the UNH Center for Ocean Engineering, the technical prowess of OPAL research scientist Shawn Shellito, and the skill of the crew on the UNH Research Vessel *Gulf*

Challenger, the buoy would never have gotten off the ground, literally.

Increasing the buoy's effectiveness was the recent addition of a pH sensor that will make a direct measurement of ocean acidity/alkalinity levels. In tandem with the CO_2 readings this makes the buoy a more complete, long-term ocean acidification monitoring platform, which aligns well with NOAA's future plans. Current funding for the buoy comes from the National Science Foundation and NOAA.

Jim Irish of Ocean Engineering (left) and Doug Vandemark of the Ocean Process Analysis Laboratory onboard the Gulf Challenger.
Photo courtesy of James Irish, UNH

When the buoy "got wet" five years ago in May, NOAA's Pacific Marine Environmental Laboratory, which built the $60,000 CO_2 instrument on the UNH buoy, had a target of some 60 such buoys scattered around to gauge global CO_2 levels. But with the issue of ocean acidification coming to the fore in the interim, the emphasis is now on establishing a network of ocean acidification buoys with the hope they will be reading the waters for the next decade and beyond.

"…because there is so much mixing that goes on in coastal ocean waters, taking accurate readings of CO_2 levels is much more challenging than in pelagic seas."

Says Vandemark, "The issue of ocean acidification is certainly saturating our field of ocean sciences. It's a very pressing topic and one that has chemists, biologists, and fisheries people very concerned."

One of the chief concerns is the impact acidic ocean water has on depleting naturally occurring, calcium carbonate minerals that both buffer the acidity (i.e., make the water more alkaline, or think of eating some Rolaids to relieve heartburn) and serve as the building blocks for shell making.

Shellfish larvae, including those of clams, mussels, and scallops, begin their lives in shallow coastal waters where they must begin building their protective shells immediately. They do so by pulling calcium carbonate out of seawater. But as seawater becomes more acidic the critical ingredient is in shorter supply as it is used to buffer the water itself. Indeed, if the acidity level exceeds a certain threshold the process goes in reverse and shells begin to disintegrate.

Research assistant professor Joe Salisbury is co-investigator on the CO_2 buoy and is specifically investigating how biological activities – the seasonal burst in the birth and growth of critters from phytoplankton to fish and shellfish – are affecting the carbon fluxes of coastal waters.

"In addition to the atmosphere's influence on oceanic carbon levels, there is this biological perturbation that I'm interested in and that we don't know much about," Salisbury says. "But we do know that it's extremely variable near the coast."

It is also known that the Gulf of Maine's coastal waters are cold and relatively poorly buffered and, thus, could be particularly vulnerable to the effects of increased acidification.

"So these coastal waters could be more sensitive than, say, adjacent regions to the northeast or south, which are similar but tend to be better buffered," Salisbury notes.

One, Two, Three Equals Buffering Capacity

The Gulf of Maine buoy, particularly with the recent addition of the pH sensor, is a critical tool for getting a complete picture of these coastal waters vis-à-vis increased ocean acidification. By adding the pH sensor the scientists can now determine – hourly, 24/7 – what the precise buffering capacity of the waters is. It's as simple as one, two, three.

"The question the scientific community is trying to refine, and which models will help answer is, How much atmospheric carbon dioxide is the ocean taking up in general and, if that uptake rate changing, is it weakening?"

Having both CO_2 *and* pH provides the variables to "solve for the carbonate equilibrium equations," Salisbury explains. In other words, the scientists can now easily gauge the total inorganic carbon concentration of the waters – the buffering capacity – and, in turn, Salisbury can use this to further delve into the mysteries of how the biological processes that occur in coastal waters affect fluxes in ocean acidification.

In the early 1990s it was thought that high productivity coastal areas, such as the Gulf of Maine, should be sinks for CO_2 – that they would sequester CO_2 and that it would be "lost" to deep water for a thousand years.

“But,” says Salisbury, “what we’re finding in the Gulf of Maine is that although the biology is working really hard to take up CO_2 during the spring and summer, the system is not sequestering much carbon. What gets fixed tends to be released back up to the atmosphere, so there’s sort of a no-net gain.”

Which is not good news in the face of rising levels of acidity in global oceans, and which comes back full circle to the UNH-NOAA buoy.

“The reason why these observations are important, and why NOAA is so focused on them, is that we don’t yet have accurate predictive models for how carbon moves between the atmosphere and ocean, and the land and the ocean,” explains Vandemark, whose research interests focus on the study of ocean and atmosphere boundary layer interactions.

A satellite image of the Gulf of Maine showing trillions of calcite (limestone) coated phytoplankton known as coccolithophores.
Photo courtesy of NASA Earth Observatory

One of the next steps for Vandemark and Salisbury is to begin collaborative work with modeling groups around the country in an effort to test and improve the models of carbon uptake in the coastal oceans in the northeast and the Gulf of Maine.

Says Vandemark, “The question the scientific community is trying to refine, and which models will help answer is, How much atmospheric carbon dioxide is the ocean taking up in general and, if that uptake rate changing, is it weakening?”

And, adds Salisbury, while there may be continued debate in some lofty scientific circles over whether or not the increasing ocean acidification is within the bounds of natural variability, the fact remains that isotope research has shown “we haven’t seen this type of change in acidity in 65 million years.”

by David Sims, Science Writer, Institute for the Study of Earth, Oceans, and Space.

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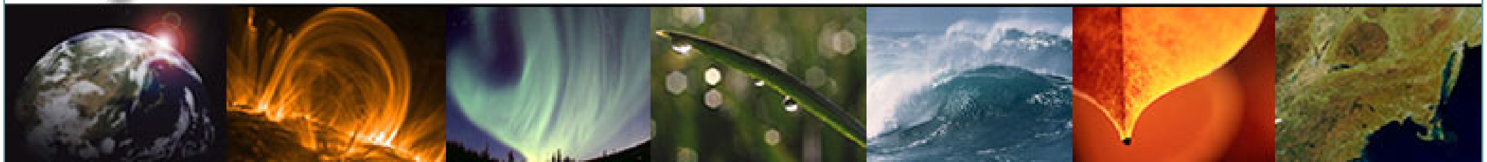

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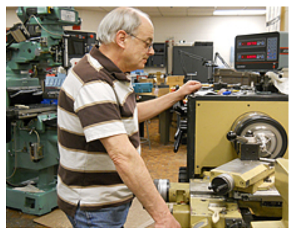
Winter 2011

From Drawing Board to Onboard

Space Science Center personnel open a new window of opportunity to future space instrument work at UNH

ONE YEAR AGO, these pages reported that Space Science Center scientists, engineers, and machinists had pulled off something of an eleventh-hour miracle by rescuing a mission-critical or "Level 1 science" instrument for NASA's ambitious Magnetospheric Multiscale (MMS) mission. That is, without the Spin-plane Double Probe (SDP) the $1 billion mission would not fly or, more precisely, other aspects would need to be "de-scoped" as science goals were scaled back to deal with the loss. But that was not to be.

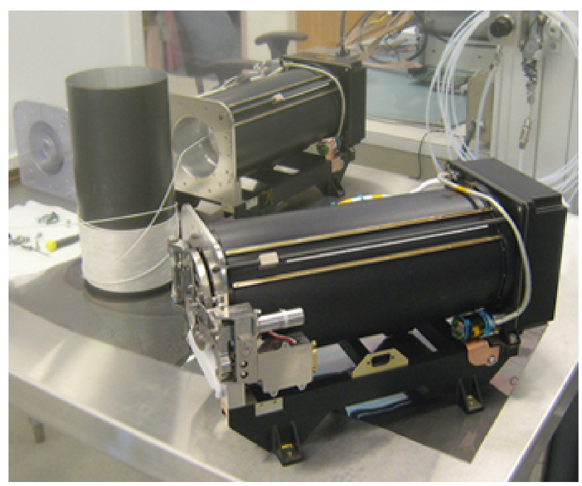


Senior project machinist Phil Demaine.

Senior project machinist and shop supervisor John Levasseur.

Senior project machinist Aaron Bolton.
Photos by David Sims, UNH-EOS.

The UNH team, which was already knee deep in the design and construction of other MMS components, stepped up to the plate and took over an elegant instrument design that had floundered due to a lack of dedicated engineering resources. After two months of nearly round-the-clock effort they created a working model of the SDP deployer and had it ready to roll the night before NASA officials arrived to give a thumbs up or down.



In the foreground is the "engineering qualification model" of the Spin-plane Double Probe, which passed all the rigorous environmental "shake and bake" testing required of space-based scientific instruments.
Photo by Mark Granoff, UNH-EOS.

The thumbs went up, the contract was won, and one year and a whole lot of additional work later, UNH got the go-ahead from NASA to move forward into the "flight fabrication" stage for the 16 probes required for the mission. The team is now in the manufacturing mode, and much of the work is being done in the unassuming, corner machine shop on the first floor of Morse Hall. The shop, manned by John Levasseur, Phil Demaine, and Aaron Bolton, has a long, rich history of machining high-precision parts for the complex space instruments built at UNH for numerous NASA and European Space Agency (ESA) missions.

The four-spacecraft MMS mission will use Earth's magnetosphere – the comet-shaped magnetic shield that protects our planet from solar and cosmic radiation – as a laboratory to study the microphysics of magnetic reconnection, a process in which magnetic fields reconfigure themselves and release enormous amounts of energy. UNH is leading an international team of seven institutions for the "FIELDS" instrument suite. To date, UNH has been awarded over $69 million from NASA for the mission.

The SDP deployer is designed to ever-so-gingerly pay out 60 meters (192 feet) of spaghetti-like, high-tech cable, at the end of which is an orange-sized metallic sphere that will measure electric potential in the vacuum of space. Each of the four MMS spinning spacecraft has four such deployers positioned

90 degrees apart. So, in addition to an already full plate of MMS tasks, the engineers and machinists now have to construct 16 identical deployers (plus two flight spares and an engineering model) each comprised of more than 100 machined parts, many of which have tolerances in the range of 50 microns – less than the thickness of a human hair.

"This has never been done before by UNH, that is, building such a complex mechanism for a space mission."

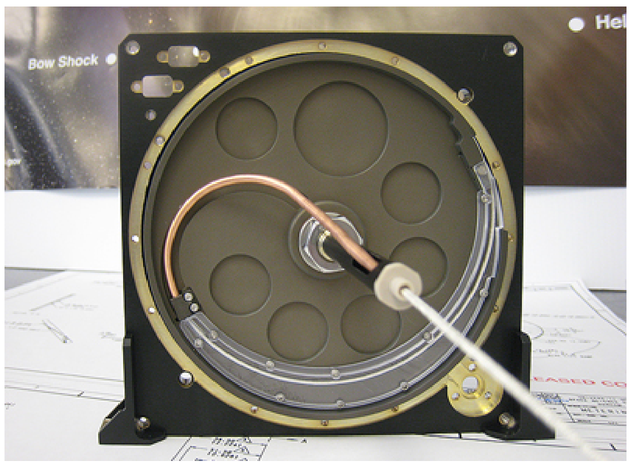
“The biggest challenge is meeting the close tolerances required of the parts,” says John Levasseur, senior project machinist and a 30-year veteran in the machine shop. The first space mission Levasseur worked on beginning in 1981 was the Compton Gamma Ray Observatory – the second of NASA's Great Observatories launched on April 5, 1991 aboard the space shuttle Atlantis – and on which UNH played a vital role.

Although instruments built for scientific experiments conducted in space are by nature complex and unforgiving (that is, once the spacecraft is up there, things can't be fixed), the SDP deployer is a “mechanism” with moving parts, which makes the job that much more challenging.

Notes Levasseur, “This has never been done before by UNH, that is, building such a complex mechanism for a space mission. The close tolerances are required because all the moving parts of the deployer have to do their job precisely and reliably right out of the starting gate. I had to take the prototype apart piece by piece in order to understand the design.”

Uncharted Waters

The instruments on all the numerous space missions SSC scientists, engineers, and machinists have designed and built over the years have been comprised of static (not moving) parts and make measurements “passively.” Such instruments can generally be “tweaked” via ground command to adjust operating parameters and adapt the instrument to the circumstances it encounters in space.



Pictured is the Spin-plane Double Probe's metering wheel (sub-assembly) that is based on the principle of Archimedean screw pump and is the heart of the instrument's singular simplicity. The design allows a 60-meter wire probe to be deployed with very few moving parts. Photo by Mark Granoff, UNH-EOS.

Not so with the deployer, and taking on the SDP project was in a very real sense double jeopardy for UNH.

“We’re in uncharted waters here,” says SSC senior research project engineer Brian King. “Not only has UNH never built a mechanism before but this type of mechanism has never been tried before, it’s never flown in space.”

The novelty of the deployer’s design is its incorporation of an elegantly simple concept purportedly invented by Archimedes of Syracuse in the 3rd century B.C. Unlike, say, a device that spools wire around a canister like a fishing reel, the Archimedean screw pump allows the wire probe to be deployed with very few moving parts making it relatively simple, compact, and less prone to mechanical error.

But moving parts are obviously more prone to error than those that are fixed. So one of the primary tasks of the UNH-SDP team (which also includes Mark Granoff, Pieter Beckman, Ivan Dors, Colin Frost, John Nolin and others) has been to make sure the instrument’s internal torque monitor accurately senses that the deployment of the 60-meter cable is occurring in smooth fashion and at a steady rate of one centimeter per second with no kinks, no twists, no errors. If the monitor detects the least bit of strain, the deployment is halted and operators on the ground can troubleshoot as needed.

"…I think that, in the future, we could propose and pass the raised-eyebrow test for other types of instruments that may have mechanisms."

King and others note that the team’s ultimate success with the substantial challenge presented by the SDP deployer project goes well beyond helping ensure a successful MMS mission; it means that UNH has opened a new window of opportunity in its future work building space instruments – mechanisms.

“There are perhaps half a dozen engineers here at UNH who are now far more qualified for this kind of effort in the future than they were a year ago,” notes project manager John Macri. He adds, “And what I think that means is that, in the future, we could propose and pass the raised-eyebrow test for other types of instruments that may have mechanisms, or other wire boom instruments.”

The SSC deployer team did, in fact, pass a raised-eyebrow test when skeptical NASA officials showed up over a year ago to see how an elegant engineering design had been brought to it’s real-world potential. At that point, UNH was in third place in the competition to win the contract to build the deployer. The other two competitors had loads of experience and heritage building instruments like SDP. But in the end UNH won the day and the ensuing year just carried that success forward.

Notes Macri, “We did remarkably well, but we need to acknowledge the advice we were given by people on the outside, in particular that from NASA Goddard where they do lots of mechanisms, and from our colleagues at the Laboratory for Atmospheric and Space Sciences at the University of Colorado in Boulder where they also do some mechanisms.”

And senior research project engineer Mark Granoff notes that project partners at the Royal Institute of Technology (Kungliga Tekniska Hogskolan or KTH) in Stockholm, Sweden, where the SDP design originated and which is still intimately involved in the mission’s scientific objective, have continued to be strong partners.

Says Granoff, “The project’s been a little tricky, but once we understood all the issues and built our engineering models, conducted extensive operational testing across wide temperature ranges and under vacuum conditions, and demonstrated its robustness in vibration testing, we’ve come to realize it’s quite a reliable approach, just as reliable as any other.”

It is a modest summation of what amounts to the equivalent of three years of labor done in hurry-up fashion, in just one year.

by David Sims, Science Writer, Institute for the Study of Earth, Oceans, and Space.

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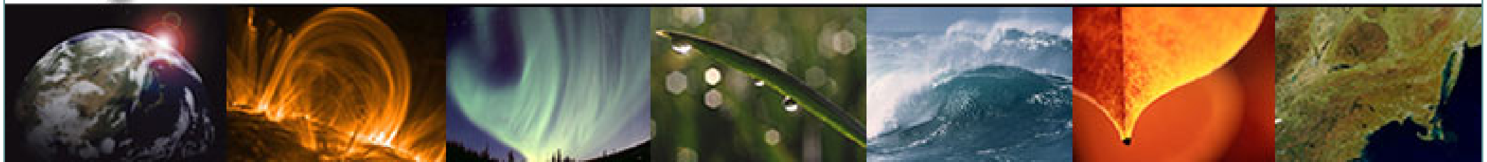

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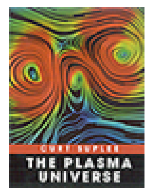
News and Notes

Faculty, Staff, and Student News

Harlan Spence was invited to serve as a member of the National Science Foundation Advisory Committee for Geosciences for a three-year term. The committee covers all of the Geosciences Directorate at NSF, which is one of the agency's seven research arms and whose mission is to support research in the atmospheric, Earth, and ocean sciences.



The Plasma Universe, edited by **Amitava Bhattacharjee** and designed by **Kristi Donahue**, was listed by *Choice* (published by The American Library Association) as one of the Outstanding Academic Titles in Physics for 2010.

Ben Chandran reports that a proposal he and colleagues submitted to NASA's Heliophysics Theory Program was recently selected for funding. The $1.34 million grant will run from 2011 until 2013 and will fund basic theoretical research into the origin of the solar wind. The title of the award is "Turbulence and Kinetic Plasma Physics in the Solar Wind."

Jingfeng Xiao (PI) and **Scott Ollinger** (Co-PI) of CSRC received NSF funding for a proposal they wrote under the agency's new Macrosystems Biology program that deals with issues of regional- to continental-scale ecology – a first for NSF. The successful proposal was titled "Assessing Ecosystem Carbon Dynamics over North America by Integrating Eddy Covariance, MODIS, and New Ecological Data through Upscaling and Model-data Synthesis."

Barkely Sive reports he recently received NSF funding to participate in the Colorado-based Nitrogen, Aerosol Composition, and Halogens on a Tall Tower (NACHTT) campaign, which has involved EOS scientist **Alex Pszenny** and graduate student **Andrew Young**. Sive will investigate and quantify the contribution of monoterpene oxidation to the secondary production of aromatic hydrocarbons and aerosol precursor gases. Such information is essential for improving and developing reliable predictive capabilities for air quality, climate change, and the overall composition of the troposphere.

The **New Hampshire Space Grant Consortium** will celebrate 20 years of inspiring and educating future scientists and engineers on June 2, 2011 with a Morse Hall event. UNH graduate and NASA astronaut Lee Morin has been invited to share his spaceflight experiences. Student robotic demonstrations, research posters, exhibits by NHSGC affiliate organizations, and tours of the institute will also be part

From the Director

Inherit the Earth


Harlan Spence

ERIC HOFFER, noted political scientist and social psychologist, pointed out that "In times of profound change, the learners inherit the Earth, while the learned find themselves beautifully equipped to deal with a world that no longer exists."

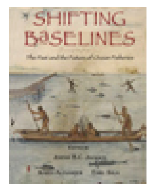
Just one year ago, President Huddleston rolled out the UNH2020 strategic plan, a vision for profound institutional changes over the next ten years motivated in large part by looming and daunting budget pressures and shifting demographics. In order to meet these decadal challenges, he compelled UNH to "reimagine, rebuild, redefine, and reignite." In Hoffer's terms, we must constantly and nimbly learn to prepare for, adapt to, and flourish in a changing landscape rather than barely surviving using obsolete knowledge gleaned from an earlier one.

Over the past year, some of the driving forces of change predicted by Huddleston are upon us. At both federal and state levels, dramatic budget pressures are already producing or threatening to produce changing landscapes – but not without opportunity and positive outcomes resulting from our strengths.

Even against this past year's backdrop of budget pressures, in fiscal year 2010 EOS achieved an all-time record in terms of annual, total external awards at $41.2 million, besting the previous record of $38 million set in FY2008 by 8.5 percent. The commensurate of the event. In addition to celebrating its two decades of work, the gathering will recognize NHSGC founding director **David Bartlett**, who will retire in June as EOS Associate Director, a position he has held for 21 years. The NHSGC event will be held from noon to 3 o'clock. Additional details will be announced in May.

Alex Prusevich and **Gopal Mulukutla** of CSRC are co-authors on a report that will be used for the combined research highlights submitted to Congress from the Earth Sciences Division at NSF. The report is titled "New science and technology lead to breakthroughs in understanding and prediction of fine ash volcanic eruptions that lead to major air traffic and human health hazards."

Joe Salisbury gave the invited talk at the AGU Fall Meeting's session on ocean acidification. The title was "Influence of land - ocean exchange on carbonate mineral saturation state." He was also selected for a 2010 UK-US Collaboration Development Award, which will enable OPAL's coastal carbon group to formally collaborate with researchers at the Plymouth (England) Marine Lab in the area of ocean acidification.



OPAL's **Karen Alexander** reports that the book "Shifting Baselines: the Past and Future of Ocean Fisheries," which she co-authored/edited, will be published this summer by Island Press. Other UNH authors include Andy Rosenberg, Jamie Cournane, Bill Leavenworth, and Jeff Bolster. Additionally, a paper in *the Bulletin of Marine Science* authored by Alexander, Leavenworth, Bolster, and former OPAL researcher Stefan Claesson will be published this summer.

Cameron Wake, director of Carbon Solutions New England, notes that a report issued in February by CSNE provides first-year results from the state's Greenhouse Gas Emissions Reduction Fund (GHGERF) showing grants awarded by the fund generated an energy use reduction of 40,500 BTUs and a savings of $1.5 million to state businesses, communities, and residents in the first year of the program with a projected lifetime savings of $60.6 million in energy costs based on current energy prices. The report can be reviewed at http://www.carbonsolutionsne.org/resources/reports/pdf/GHGERF_Year1_Report_Final.pdf.

Ivan Dors of SSC published a paper in the *Journal of Geophysical Research* with UNH co-author **John McHugh** of the mechanical engineering department. Entitled "Velocity spectra and turbulence using direct detection lidar and comparison with thermosonde measurements," the paper demonstrates the ability to remotely measure atmospheric turbulence from a distance of kilometers using an incoherent LIDAR, which bounces a laser beam off of air molecules to make measurements. The paper also presents an analysis that quantifies the method's effectiveness when applied to any wind-measuring instrument.

scientific results that these funds enable represents both the unchanging core that defines our central essence, and also the new activities that demonstrate we are "learners" confronting the challenge of change with an enterprising spirit.

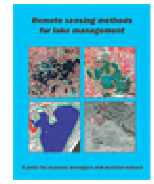
In this issue of *Spheres*, you will discover examples of how EOS researchers are rising to external and internal changes and challenges as we reimagine, rebuild, redefine, and reignite who we are, what we do, and how we do it as an institute. It might be through redefining our research to address the Earth more comprehensively as a system, hence a deep commitment to interdisciplinarity, or it might be through extending our capabilities into whole new realms.

In addition to such representative stories in this issue, another tangible example of EOS reimagining itself is the late-breaking news about the establishment of the Sustainability Research Collaboratory. A future issue of *Spheres* will report on this exciting, transformative effort that has bridged many silos across the university even in its infancy.

It is in these times of change and challenge that I feel rewarded in being surrounded by so many EOS colleagues who are engaged in constantly reinventing their strengths, and seeking out and even creating the rich opportunities that accompany change. Thomas Edison remarked, "Opportunity is missed by most people because it is dressed in overalls and looks like work." EOS researchers, staff, and students are most certainly not "most people."

I am fully confident that EOS is comprised of Hoffer's "learners," and given so, we will continue to inherit not merely the Earth, but also the Oceans and Space.
– Harlan Spence

Wil Wollheim of the Water Systems Analysis Group reports that two NSF projects he proposed were recently funded. The first, under the NSF-EaSM (Earth System Model) program is titled “A Regional Earth System Model of the Northeast Corridor: Analyzing 21st Century Climate and Environment.” This is a collaboration with CCNY (overall lead), the Marine Biological Laboratory, and Rensselaer Polytechnic Institute. The second project under the NSF Macrosystems Biology program is titled, “Stream Consumers and Lotic Ecosystem Rates (SCALER): Scaling from Centimeters to Continents.” Wollheim is a co-investigator with Bill McDowell of Natural Resources and the Environment (UNH lead), and collaborators from Kansas State. Univ. (overall lead), and the universities of Kansas, Alaska Fairbanks, Vermont, and Georgia.



Annette Schloss of CSRC served as a technical editor on a newly published manual titled “Remote sensing methods for lake management: a guide for resource managers and decision-makers.”

Rachel Feeney notes that the Northeast Consortium in conjunction with NH Sea Grant is co-hosting a June 27-78 workshop entitled "Workshop on Reconciling Spatial Scales and Stock Structures for Fisheries Science and Management." The workshop is located at the Sheraton Harborside Hotel in Portsmouth, N.H. For more information and to register, visit http://extension.unh.edu/GISGPS/SpatialScalesWorkshop_001.htm.

Ph.D. student **Katelyn Dolan** was lead author of a paper published in *Remote Sensing Environment* titled “Using ICESat’s Geoscience Laser Altimeter System (GLAS) to assess large-scale forest disturbance caused by hurricane Kartrina.” Says Dolan, “The real unique part of this paper is that no one had used satellite lidar to look at change in forest structure for a disturbance event. We found that we were able to use the lidar directly to assess change in structure over a large expanse of area.”

Eric Kelsey received a Dissertation Year Fellowship awarded by the UNH Graduate School that will provide funding for the 2011-12 academic year as he completes his Ph.D. research. His work involves the reconstruction of Northern Hemisphere sea-level pressure data back to 1000 AD using Arctic ice cores. The research builds off his prior Ph.D. research calibrating Alaskan ice core records with regional atmospheric circulation and temperature patterns.

by David Sims, Science Writer, Institute for the Study of Earth, Oceans, and Space.