ROX Newsletter

The Department of Earth Sciences at Dartmouth College

SUMMER - 2022

Photo Credit: Maggie Lonergan

In This Issue:

earthsciences.dartmouth.edu

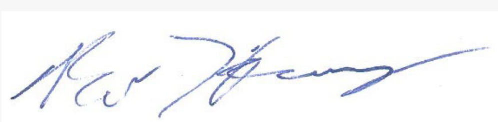
Greetings from Greenland

Greetings and welcome to the revitalized EARS department newsletter! Like every organization, the pandemic has challenged Dartmouth and EARS, and we continue to find new and creative ways to safely complete our teaching and research missions. As I write this I am in quarantine on the way to a remote research station in Greenland, which has managed a record of zero infections to date. But COVID has not been the only thing happening over the past couple of years – our department has grown with new faculty at both junior and senior levels, and our existing faculty, students, and staff continue to break new ground in teaching and research.

In addition to welcoming new (and not-so-new) faculty in this newsletter, I'd like to highlight a couple of other achievements by some of our more familiar faculty. First, Associate Professor Justin Strauss was newly promoted to Associate Professor with tenure; in the process also winning the Karen Wetterhahn Memorial Award for Distinguished Creative or Scholarly Achievement. Justin is just back from an extended field excursion mapping remote parts of British Columbia and Alaska. Second, Professor Meredith Kelly was promoted to Full Professor, and was the winner of the John M. Manley Huntington Award for newly promoted faculty. Meredith continues her research on past climates on four continents and the world's largest island, Greenland. Finally, Professor Mukul Sharma won a highly competitive Guggenheim Fellowship from the John Simon Guggenheim Memorial Foundation, recognizing Mukul's innovative and promising approaches to carbon sequestration. This fellowship and other foundation grants will allow Mukul to devote his full-time effort during the 2022-2023 academic year to helping find solutions for the drawdown of carbon in the atmosphere.

As chair I would like to take the opportunity to thank the entire EARS community, current and past, for all of the hard work you do each day to keep this department a vibrant place. Each person who works and studies here adds to the richness of our community, and we are grateful to have you. Stay in touch, let us know what you've been up to, and where you have taken your EARS experience.

Sincerely,



Bob Hawley, Professor and Chair

Photo Credit: Bob Hawley

Celebrating in Plaid Style: L to R foreground, Justin Strauss, Bob Hawley, Meredith Kelly (photo credit Kristin Williams)

Photo Credit: Maggie Lonergan

In the News

New(ish) EARS Members Dr. C. Brenhin Keller, Dr. Sarah Slotznick and Dr. Mathieu Morlighem are highlighted in this newsletter. Read more about their work!

"Something removed a whole lot of rock, resulting in a whole lot of missing time." Dr. C. Brenhin Keller discusses new research suggesting ancient ice action may be responsible for massive erosion of rock across the planet that lead to the "Great Unconformity". Read more about this research: "*Study Links Glaciers to Earth's 'Great Unconformity*". See also page 6-7 for Q/A with Dr. Keller.

Recent research by Dr. Sarah Slotznick challenges the view that scientists proposed in 2007 of a "whiff" of oxygen present before the Great Oxygenation Event more than 2 billion years ago. Read more about this research in a Cosmos article: "*Rock sample re-writes Earth's early atmospheric history - again*". See also page 8-9 for Q/A with Dr. Slotznick.

Working with colleagues at France's Institute of Environmental Geosciences (IGE), Dr. Mathieu Morlighem and IGE's Romain Millan measured the velocity and depth of more than 250,000 mountain glaciers, revising the global estimate for glacial ice volume. Read more about this research: "*New Atlas Says Most Glaciers Hold Less Ice Than Thought*". See also page 10-12 for Q/A with Dr. Morlighem.

Fall 2021 Graduate Student Cohort:

Josephine G. Benson (M.S.) [Dr. Sarah Slotznick]
Christian M. Erikson (M.S.) [Dr. Carl Renshaw]
George R. Geier (M.S.) [Dr. Justin Strauss]
Victoria E. Halvorson (M.S.) [Dr. Meredith Kelly]
Jiawen Li (Ph.D.) [Dr. Wil Leavitt]
Matthew T. Maclay (M.S.) [Dr. Marisa Palucis]
Eliza H. Malakoff (M.S.) [Dr. Carl Renshaw]
Noemi A. Ortega Dominguez (M.S.) [Dr. Marisa Palucis]
Derek J. Pickell (M.S.) [Dr. Robert Hawley]
Alexander C. Ronan (M.S.) [Dr. Mukul Sharma]
Debbie F. Sulca (M.S.) [Dr. Carl Renshaw]
Joel A. Wilner (Ph.D.) [Dr. Mathieu Morlighem]

Visit our *People Page* for a complete list of students.
Fall 2022 Students will be covered in our Winter edition.

Alumni Update:

Dr. Erich U. Petersen (Dartmouth M.S. 1979) was recognized by the Society of Economic Geologists (SEG) at its 100th Anniversary Meeting in Whistler, B.C. Canada with the 2021 Ralph W. Marsden Award. Dr. Petersen worked with Dr. Half Zantop while at Dartmouth. Check out his image above left.

ONE DAY ON THE STRETCH

By Eric Lee, Undergraduate in Earth Sciences, class of 2023

After a Covid-19 related hiatus, the Stretch is back up and running and we couldn't be happier about that! This one-of-a-kind immersive experience is truly vital to our Earth Science curriculum both for undergraduate students and graduate student TAs. This past year we ran the Stretch both during the Fall 2021 and Spring 2022 term. We sought out an undergraduate to give us his perspective as a student on the Stretch from the Fall 2021 trip. The article has been edited for clarity. It reminds me of a quote by Samuel Beckett: "Ever Tried. Ever Failed. No matter. Try again. Fail better".

"Depending on one's definition," Carl Renshaw says, "there has never been a successful river restoration."

We are standing outside Fisher Creek, downstream from the New World Mining District in southwestern Montana. It is the first day of a hydrology-focused segment of the Stretch, and the nineteen assembled students are about to learn about river restoration from the college's resident hydrologist.

After a brief lecture, we go down to Fischer Creek to take pH samples. Upstream, Fischer Creek has been impacted by mining which has lowered the pH. We are measuring the pH at a downstream location far enough removed to act as a control. Downstream, the pH is between 6 and 7.

Later, we are sitting near the headwaters of the creek, next to some rusted-out mining equipment. My group just measured this part of the river's pH to be a dismal 3.53—far too acidic to host any notable organisms. The river's surface lacks even a water crawler. We discuss the extent to which this was caused by mining, as opposed to the natural erosion of sulfide minerals, which similarly lowers pH. Carl and Jordan Fields, a graduate student TA, tell us about various river remediation techniques.

Jordan recalls his past work elsewhere with a river restoration firm. Attempting to return enough sediment to a river for salmon to make nests, the firm dumped "two million dollars' worth of gravel" into the Lower American River, just below a dam outside Sacramento. Every year, the sediment washes away, and every year another two million dollars of gravel is added to the river. The firm essentially does the job of natural erosion, which the presence of the dam has made impossible, as the sediment accumulates behind the dam. The only way to return the system to equilibrium, Jordan says, would be to remove the dam. Until then, the Sisyphean task must continue, year after year.

However, Carl interjects, if the dam is removed, three and a half million people will have no source of drinking water. So, we can either spend two million taxpayer dollars per year dumping gravel into a river, a seemingly absurd activity that various pundits would cite as a humorous example of government waste or deprive a state capital of water by removing a dam. There is a third option, left unspoken: we could let the river's ecosystem die. Of course, in the long-term a dead river isn't always a great source of drinking water.

We are earth scientists in training: it is not our job to let rivers die. It is our job to keep them alive for their sake and for ours, to balance ecosystem function and human expansion. We aren't quite sure how to yet. Neither, it seems, are our instructors.

The last stop is Soda Butte Creek, the first river that the State of Montana deemed sufficiently remediated to remove from the Impaired Rivers List. The water's pH sits just above 7: a clear success from a chemistry standpoint.

Above: Students titrating river water to find calcium carbonate concentrations. Photo by Jack Kreisler.

However, Jordan isn't quite satisfied: The river's banks are too rigidly built to be dynamic; there are no shady pools with which to harbor trout. It is an engineer's computer-generated idea of what a river could be, not an earth scientist's understanding. It doesn't restore major ecosystem functions. This restoration failed in a thousand ways.

However, Carl notes, the restorers didn't care about trout habitat complexity, nor with maintaining a naturally dynamic streambed that could shift with time and storms. In fact, they were not focused on this stretch of river at all. They were instead solely focused on keeping toxins out of Yellowstone National Park, less than five miles downstream. To do that, they had one goal: raising the pH enough so that heavy metals toxic to fish, such as copper, would be bound to molecules in the river instead of floating freely.

By this metric, they succeeded spectacularly. The river is decidedly not acidic and can certainly host life in Yellowstone. Jordan notes that the river "is better off" with this failed attempt. "There is potential for restoration," Jordan says. "The way we've been doing it isn't the best, but that doesn't mean it's not worth doing."

River restoration, and environmental policy more broadly, is an exercise in choosing how to fail. It's also clear from this lesson that restoration outcomes are tied to priorities, and that we must adapt our approach based on data from past experiences. Policymakers must balance the needs of ecosystem and animal life with the increasing demands of large-scale human settlement in the drying American West; often humans come first and sometimes at the expense of everything else.

> ***Jordan notes that the river "is better off" with this failed attempt. "There is potential for restoration," Jordan says. "The way we've been doing it isn't the best, but that doesn't mean it's not worth doing."***

This marks a turning point in the Stretch. Previously, we had undertaken difficult but achievable projects: describe the environmental history of an area using only stratigraphic clues in the bedrock; construct bedrock maps with a compass and a level; find gold in three days. Measuring the pH in the river is an achievable task. Imagining how earth science can inform better policy and restoration initiatives is a more arduous one.

Today and for much of the rest of the Stretch, we examine acidic rivers and drying lake beds, silently learning that we must prepare to grapple with problems far larger than any we have tackled before. These are the tasks of our generation. After graduation, our assignments will get much harder. We are told that we must try to solve problems far too big to solve completely or at once, that we must fail and fail and fail again. We know our projects will be failures, but they will be failures worth doing. Our experience on the Stretch has left us more keenly aware of why we should still try. I am confident that the skills learned on the Stretch will prepare us to rise to the occasion.

Photo Credit: Maggie Lonergan

Q & A with Dr. Brenhin Keller

By Kristin Williams

Dr. C. Brenhin Keller is an Assistant Professor in Earth Sciences. I saw him around the office because of the espresso machine that he maintains in the kitchen. He also coordinated the Department seminar for 2021-22. I caught up with Brenhin this winter to ask him a few questions about his work.

When did you first join Dartmouth and what brought you here?

I joined the Department in March of 2019, with a position in geoinformatics -- or as I might perhaps call it, "Computational Geology." I'm interested in the solid Earth from the mantle to the crust, and particularly how the solid Earth interacts with the rest of the Earth system over geologic timescales. A lot of the work I do involves some elements of igneous petrology (the study of rocks formed from magma) and uranium-lead zircon geochronology (one of the most precise ways of dating igneous rocks). In my Ph.D., I worked in a lab at Princeton that specializes in high-precision U-Pb geochronology, but I ended up doing a lot of computational work as a side project, and that eventually evolved into a focus of my research.

Since you mention computational work, and I noticed on your website your GitHub link, I'm curious how much of your work is on computers vs. in the field or lab?

Probably about half of my work is computational, and about half of it is field and lab work. Though it's been almost all computational during the pandemic! At some point though, you still have to get out to do field work to stay grounded in my view.

Is your work focused on one location or across the globe? Do you have other collaborators?

My work is pretty widely spread across the globe. For one current project on the origin of the Great Unconformity, we're currently interested in samples from basically anywhere there are cratons (old, stable crust). For that project, we're currently looking at samples from the Western U.S., the Canadian shield, Australia, and Africa. Some of that work involves us traveling, but we also collaborate with researchers who send us samples. Since I arrived at Dartmouth, I've also started collaborating in the field with Justin Strauss, mostly on projects in northwest Canada.

You're mentoring students and post-docs right now, what are they working on?

One big focus of my work recently is on the Great Unconformity, which has been the subject of some debate –and is still a bit of an unknown in geology. It's sometimes described as a break or gap in the geological record – which isn't rare, except that this one seems to be quite widespread, with a similar pattern on just about all continents. In the most typical case, you have layers from the Cambrian Period (say ~540 million years ago – think "Cambrian Explosion"), and then below that you have much older igneous or metamorphic rocks that formed, say, billion or more years ago. We are interested in finding new ways to measure what happened to make this pattern so widespread. We hypothesize that the cause of these missing layers may be glacial erosion related to the global "Snowball Earth" glaciations. [Brenhin later sent me some links which I've included below]. This is a problem that I've been thinking about for a while and is currently a main focus of my work with postdoctoral fellow Kalin McDannell here at Dartmouth.

Another major focus is the relationship between mass extinctions and solid-earth processes like flood-basalt volcanism. Theo Green, an undergraduate in Earth Science, recently finished up [has graduated as of 2021] a really great Senior Fellowship project on the statistical correlation between mass extinctions and continental Large Igneous Provinces, which we're hoping will be in print soon. Alexander Cox, an MS student in my group, has been studying more specifically the K-Pg boundary (Cretaceous-Paleogene, though perhaps more famous under the older name "K-T boundary", the one that killed off the dinosaurs). This is a relatively unique mass extinction in that we have both a Large Igneous Province (the Deccan Traps in India) and a large meteorite impact (the Chicxulub impact). Alex is modeling the effects of CO_2 and SO_2 emissions under different scenarios, estimating what changes in temperature and planktic and benthic carbon isotope changes would have occurred under those scenarios. Then he is comparing those computational model outputs to measured data from field and lab geology, and using that to ultimately "invert" for the best-fit degassing history.

Gailin Pease, an M.S. student, who defended in November 2021 (graduated in 2022), was looking at thermodynamic calculations of what minerals should be stable for a given composition at depth, and using that to help estimate the composition of deep crust from seismic properties. Graham Edwards, an NSF post-doctoral fellow,

The Ignacio Sandstone (of contested age, though likely Cambrian) unconformably overlies the Mesoproterozoic (1.433 Ga) Eolus Granite in the Needle Mountains, Colorado. Credit: Brenhin Keller - Visit his lab website for more photos: https://brenhinkeller.github.io/fieldwork/

is examining the composition and ages of meteorites in a few different ways, which can provide a record of planetary and solar system evolution. And Ke Gao, a visiting student, has been working on the volcanic-plutonic connections. All of these may be considered igneous petrology in some form, but with very different applications.

Of the work that you are doing, what makes you most excited?

What excites me the most is researching the connections between the solid Earth, the deep solid Earth, life, and the biosphere. Why did the transition from the Ediacaran (late Proterozoic) and the Cambrian Explosion take place? The erosion of the continental crust provides a lot of key nutrients, like phosphorus, for life on Earth, so thinking about the processes that produce the crust and ultimately provide these nutrients is relevant when thinking about the long-term evolution and diversification of life on Earth. Continental crust is quite necessary to have life on Earth – the silicate weathering thermostat is what makes Earth habitable on billion-year timescales.

Growing up, what got you interested in geology?

My family would often "rock hound" when we were on trips when I was a kid. A trip to the Great Unconformity at the Grand Canyon certainly made a lasting impression on me. For a while I thought I wanted to be a chemist, but then I eventually learned that I could study chemistry in the context of rocks -- which brought me to geochemistry and petrology!

Covid has affected us all and we've all been learning how to adapt. Have you had to adapt any of your research or teaching approaches right now, and is there anything positive that came out of that?

Well, I am happy to be back to in-person classes, but Covid certainly has meant that it's been a good time to do computational work. In fact, I've noticed more people may be branching out into it right now, so that's perhaps a silver lining. But I was certainly happy when the Stretch came back this school year (Fall 2021). I went out for one section that Justin Strauss led, and then I co-taught a section with Ed Meyer, both of which were great. The Stretch is a unique program and it is one thing that I really like about this department and our undergraduate program. And it usually ends near the Grand Canyon, so they see the unconformity a few times!

You like espresso.... Tell me about that.

I developed my coffee habits relatively late in life... While I was a post-doc at Berkeley, they had a coffee machine just outside the door of my office, and I became an addict!

Lastly, when you are not at work, what do you like to do for fun?

Well, I guess typical outdoorsy stuff – downhill skiing, hiking, backpacking (aside from fieldwork). The Upper Valley is a pretty good place for doing these.

Do you have a memorable backpacking trip?

Packrafting for a week through the Bob Marshall Wilderness (Western Montana) probably stands out the most. But I've had a lot of good ones over the years!

Learn more about Brenhin's work:

Lab Github:
https://brenhinkeller.github.io/fieldwork/

National Geographic Article:
https://www.nationalgeographic.com/science/article/part-earths-crust-went-missing-glaciers-may-be-why-geology

PBS Eons short video:
https://youtu.be/6R_NAV8Ieuo

Q & A with Sarah Slotznick

By Kristin Williams

Dr. Sarah Slotznick is an Assistant Professor in Earth Sciences. I sat down with her in May to learn more about her work. I was particularly curious to understand what drew her to magnetics and what applications there are for that work.

When did you first join Dartmouth and what brought you here?

I joined Dartmouth in January of 2020. I was attracted by Dartmouth's emphasis on undergraduate education and lab research. I was also really excited about the people in the Earth Sciences department, who create a supportive and collaborative environment including many with a similar research focus on Earth History.

What brought you to specifically study iron and Earth's magnetism?

As an undergraduate at MIT, I focused in geophysics and conducted my senior thesis on magnetics of meteorites and planetary formation. I even got to "touch" (with gloves) moon samples while working in Houston. Even though I decided not to pursue planetary science, I liked the concept of applying the principles of physics to material things that you could actually hold. For my Ph.D., I decided to study Geobiology, which is this synergy of geology and biology and in that way seemed to me to be a unique science. Geobiology was still pretty new as a discipline when I was in graduate school. As I created my PhD, I figured out a way to merge magnetics and Earth History through a focus on iron. As the most abundant transition metal in the Earth's crust, iron is used by nearly all life, being a key player in oxidation-reduction reactions.

Your research was recently highlighted in Cosmos, discussing when "whiffs" of oxygen first appear in the geological record. Can you first discuss why it was originally such a surprising finding in 2007 to suggest that oxygen appeared much earlier than previously thought?

The Great Oxygenation Event (GOE), which became solidified in the 1990s, is the recognition that early Earth's atmosphere had very low levels of oxygen prior to about 2.4 billion years ago. Across this transition, we see evidence of iron and sulfide minerals changing from reduced to oxidized states. Pyrite detrital cobbles (pyrite is an iron sulfide mineral) appear in the sedimentary rock record before this time. However, today pyrite weathers quickly due to higher oxygen levels. After the GOE, sedimentary beds of sulfate and iron oxides appear, so-called "red beds" because oxidized iron creates the red color. Banded iron formations are lost in the geological record, suggesting that oxygen levels had increased. Also, sulfur isotope signals present before the GOE disappear, which suggest that an early atmosphere did not contain much UV-shielding oxygen. There are several lines of evidence for the GOE as being the period when oxygen first increased in the Earth's atmosphere.

Your research challenges those conclusions that "whiffs" of oxygen appear in the atmosphere before the Great Oxygenation Event. Can you describe how you arrive at a different conclusion than the 2007 findings and what the implications are?

This is research I started during my Ph.D. Our results are based on how we analyzed the samples. Previous research relied on grinding up bulk samples and analyzing them for signatures of oxygen. Instead, we made thin sections and utilized high-resolution techniques using synchrotron spectroscopy and secondary ion mass spectrometry (SIMS) to make isotopic measurements spatially and map element distributions. These analyses kept the sample intact, meaning that we were able to identify that oxygen signatures were post-depositional from fluid flow several million up to 1 billion years later. These results are in keeping with the original GOE timeline.

What other work are you engaged in right now? My work is focused on the Proterozoic, specifically from 2.5 billion to 1 billion years ago when eukaryotes, the domain of life containing most macroscopic life including animals, were evolving and diversifying. I'm interested in what the oxygen levels were and what life was doing during this period. Eukaryotes had evolved but they don't become multicellular for a billion years, and the question is why? Was the limiting factor some biological phenomena or was the environment constraining the evolution of life?

I have been conducting research on an ancient lake, looking at sedimentary rocks and iron minerals deposited over a billion years ago in what is now Michigan and Wisconsin. We are working with paleobiologists to connect the redox information stored in these iron minerals directly to the microscopic fossils found in the rocks to understand the environments in which they lived.

You're mentoring students and post-docs right now, what are they working on?

Theo Green '21 and Jack Kreisler '22 are undergraduates who worked in my lab. Theo was looking at improving


Photo Credit: Sarah Slotznick

chronology near the Late Devonian mass extinction and Jack is looking at iron oxide minerals deposited in modern sediments to understand their fate before the sediments are turned into rocks.

Current graduate student Josie Benson, who is also co-advised with Wil Leavitt, is looking at iron sulfide formation in lakes in NH. These are meromictic lakes (water columns do not mix), with oxygen in the top, but bottom layers that do not contain oxygen and instead have sulfide. Very few had been noted previously – we are now finding and confirming the existence of these lakes. We hope to study these lakes to learn how the mineral pyrite forms. There are two potential paths, one of which has a magnetic precursor. We want to understand pyrite formation as it will allow us to make better interpretations of environmental conditions and provide context for the geological record.

NSF Post-Doc Joe Biasi is examining the timescales of volcanic eruptions – he is developing a new approach using magnetics and thermodynamic modeling. Together we are focused on applying this to volcanic events connected to large-scale climate changes in Earth History; volcanic gases like CO_2 and SO_2 can affect the climate so understanding eruption duration will improve paleoclimate models.

What makes you most excited or keeps you going in your work?

Two things broadly. First, the search for knowledge especially new applications of magnetic tools. The meromictic lakes project is a great example of applying this research approach to questions that haven't been asked before, and bringing new perspectives to old questions. Secondly, mentoring both graduates and undergraduate students, and seeing those "Aha" moments, which honestly is really a repeated continuous process. I like helping students to go beyond what they think they can do and see them work through stumbling blocks.

Growing up, what got you interested in geology?

When I was a kid, I did have a rock collection, but I loved math in elementary school and then I became interested in physics. My interest in geology came from my interest in physics in college, and searching for an application of it. I enjoy the outdoors and doing fieldwork, but it wasn't what initially drew me to geology. I really enjoyed the active learning of lab-based courses and the ability to physically hold and touch specimens. Plus, I realized that I liked how geology mixed qualitative as well as quantitative knowledge. In my research, we spend about one month in the field for a year of work in the lab.

Lastly, when you are not at work, what do you like to do for fun?

I enjoy reading, particularly fiction – Sci-Fi and fantasy. Also, I enjoy hiking and ice skating. In non-pandemic times I enjoyed attending musical theater. I'm also a big fan of board games.

What are some of your favorite board games?

Dominion, Wing Span, and Betrayal at the House on the Hill. Topically related, Terraforming Mars is a good one.

Learn more about Sarah's work:

Lab Website: *https://dartmouthmaglab.github.io/index.html*

Cosmos Article: *https://cosmosmagazine.com/earth/earth-sciences/rock-sample-rewrites-atmospheric-history/*

Ancient Lake article (second paper currently in review): *https://www.pnas.org/doi/10.1073/pnas.1813493115*

Photo Credit: Wil Leavitt


Q & A with Dr. Mathieu Morlighem

By Kristin Williams

Dr. Mathieu Morlighem is an Evans Family Distinguished Professor in Earth Sciences and a Faculty member of Dartmouth's academic cluster Changing Polar Regions. He is the newest faculty member of EARS. Fun fact, Mathieu led research that found a new Guinness World Record (2020) for the deepest point on land, which was under the Denman Glacier, in East Antarctica. I sat down with him this March to discuss his work.

When did you first join Dartmouth and what brought you here?

July 1, 2021, in the middle of the pandemic. Previously, I was a professor at the University of California Irvine in the Department of Earth System Science, and my wife was a scientist at NASA's Jet Propulsion Laboratory, where I had also previously worked. We loved our jobs, but after 13 years in California, we were looking for a change and the possibility of moving East. With California's droughts and wildfires increasing in frequency and severity, the climate of New England was an attraction along with NH being closer to France, where we are from. I had heard that Dartmouth had been looking for a glaciologist for a few years, and Bob [Robert] Hawley caught up with me at the 2019 American Geophysical Union's fall meeting and told me that they were still looking for someone. As a numerical modeler, my work is very multi-disciplinary, and so being able to lead a cluster dedicated to polar regions with the Thayer School of Engineering was particularly attractive. My wife was also offered a faculty position, and we visited here in December 2020 with our two young children. We really enjoyed the area and the atmosphere, and decided to take the job.

Your background is in physics and engineering. How did you get interested specifically in glaciers and ice sheets? Were you always interested in geology as well, or did that evolve?

Engineering schools in France are multidisciplinary and expose students to a breadth of topics. I was particularly interested in aerospace engineering and one of my professors told me she knew of someone doing that work at NASA's Jet Propulsion Lab. As it turned out, they were not doing any aerospace engineering but were using satellite data to better understand how Greenland and Antarctica are changing, and they were looking for someone to develop a new ice sheet flow numerical model

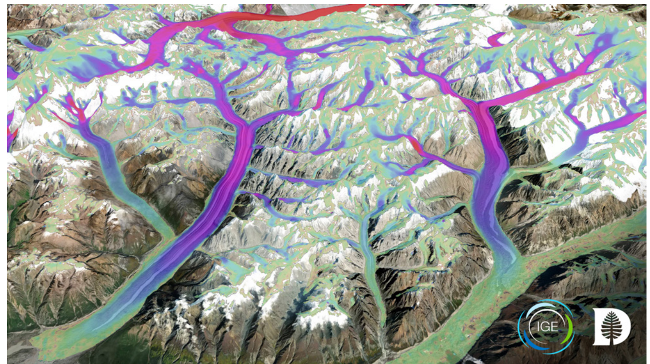


Photo Credit: Mathieu Morlighem

to better understand what they were observing. I became excited about that work and have been working in this field ever since. It was a bit of a happy accident that brought me, and my wife, there.

Lay people may think of engineering as a study for "building things". Can you describe how engineering is used in glacier modeling?

We are building something: a computer model! I see engineering as a science that brings multiple disciplines together to solve complex problems. My work involves applied math, physics, and software engineering. We use fluid and solid mechanics, and physics principles such as the conservation of mass or energy, which are applied to the movement of ice sheets. In short, we can describe the behavior of the ice sheets through a set of partial differential equations and use mathematical methods and computer science to solve them efficiently on supercomputers.

If a student is interested in glaciology, would you recommend they also study physics or engineering in addition to studying Earth Sciences/geology?

If a student is specifically interested in modeling to develop future projections, then math, physics and programming will all be useful or necessary skills. If a student is interested in the past stability of ice sheets as a basis for predicting the future, then geology would be the right focus.

Describe your international collaboration. Is most of your work remote when doing modeling or do you do field work?

Our work uses a lot of satellite imagery to initialize and validate our ice sheet numerical models. Ice sheet modeling is a relatively new field of research and has grown quickly since about the 2010s. There are only a handful of modelers in the world doing this kind of work; we are a very tight-knit community. We all realize the urgency of our work, and the complexity of the task in front of us, so we are all working together instead of competing. Outside of the US, I work closely with scientists in Canada, Denmark, Norway, France, Germany, the UK, Australia, New Zealand, South Korea and Japan.

What differs between model approaches? Does your work contribute to the IPCC projections?

We absolutely need more than one model. The models differ in computational methods, the physical processes they include, or how they are initialized for example. For IPCC reports, the scientific community compares all the models as they have different strengths, and this leads to more robust predictions and a simple way to quantify uncertainty. I provide one of the many model projections for the future mass balance of Greenland and Antarctica that are included in the 6th assessment report of the IPCC.

In the recent news about your research, you and colleagues estimated there is less water stored in glacial ice worldwide than previously thought. Can you explain this research briefly? What are the potential implications of this on projections like IPCC sea level rise or drought in areas that depend on glaciers?

I should mention that this was a bit of a pet project and not the main focus of my work. In this study, we mapped the flow speed of all 250,000+ mountain glaciers around the world from space, and used simple physical principles to infer their volume. Our estimates suggest that mountain glaciers have the potential to raise sea level by about 10 inches, 3 inches less than previous estimates. This will have an impact on local communities: millions of people rely on glaciers for drinking water, agriculture, and power generation. But overall, it is not changing predictions of sea level rise. The ice sheets hold a lot more ice than mountain glaciers and are now the primary contributors to sea level.

Why would scientists have over-estimated it previously (accelerated melting, less precise models)? Previous estimates were based on very simple approaches, like how large they were – larger glaciers being deeper. Here we had access to high-resolution ice speed for the first time and could use a much more sophisticated approach.

You're mentoring students and post-docs right now, what are they working on?

I have students in Irvine CA, New Zealand and at Dartmouth. I am still an adjunct for a year at UCI and I am an Honorary Research Associate at Victoria University of Wellington in NZ.

At Irvine, Shivani Ehrenfeucht is looking at subglacial hydrology in Northern Greenland. We are getting increasingly more meltwater at the surface of the ice sheet every summer, and this water ultimately reaches the bottom of the ice. This affects the pressure of the water at the ice base and can lead to significant accelerations of ice flow, and hence ice discharge into the ocean. In NZ, Francesca Baldacchino is looking at the Ross Ice Shelf in Antarctica. Her research includes fieldwork at GPS stations to examine daily/weekly velocity variations. Finally, Joel Wilner at Dartmouth is looking at the calving of icebergs and will use machine learning to develop a "calving law". Also, I have a postdoctoral fellow who is developing and improving a model of Helheim Glacier in East Greenland. He is specifically looking at how this glacier has been changing over the past 20 years, and whether we can explain its variability by the ocean temperature changes in the fjord.

"What keeps me inspired is that this work has direct implications for societies to plan for the future. This work is humbling ..."

What makes you most excited or inspired to keep doing research?

It's a relatively new field of research and there is a lot of work to do. In order to understand and predict the future mass balance of the ice sheets, we must understand how they interact with the rest of the climate system. Much research and knowledge has been gained in a relatively short period of time, but there are still some physical processes that are poorly represented or missing in numerical models. We still have surprises about how quickly these massive systems can respond to perturbations, especially when they come from the ocean.

To explain this phenomenon: With climate change, wind patterns have changed in both hemispheres, and this affects ocean currents. We have always had deep and relatively warmer water around Antarctica, for example, but it used to stay away from the coast. With stronger winds, these waters now upwell into the ice shelves (floating extensions of the ice sheet).

What keeps me inspired is that this work has direct implications for societies to plan for the future. This work is humbling because we want to make sure that we provide accurate numbers to policymakers. Also, the ice sheets are incredibly beautiful and fragile places, and in some ways still unexplored. You could say it is poetic. Some folks ask if it is depressing studying the ice sheets, and I don't think so. Even if they are losing mass quickly, the ice sheets will still be around in our lifetimes.

Interview continues on next page.

Q & A with Mathieu Morlighem Continued from pg. 9

Lastly, when you are not at work, what do you like to do for fun?

My wife and I both really enjoy classical music. I play the flute and she plays the piano. Although, to be honest we haven't had a lot of time for it now that we are raising two children. I like to listen to classical music while doing my work though.

Learn more about Mathieu's work:

Dartmouth Feature Articles:
https://earthsciences.dartmouth.edu/news/2022/02/new-atlas-says-most-glaciers-hold-less-ice-thought

https://earthsciences.dartmouth.edu/news/2021/08/glaciologist-joins-arctic-engineering-cluster

Lab website: *https://icefuture.org/*

Academic Clusters: *https://provost.dartmouth.edu/initiatives/academic-clusters*

NASA Jet Propulsion Lab Ice-Sheet and Sea-Level System Model: *https://issm.jpl.nasa.gov/*

Select publications from EARS 2021-2022:

Busch, J. F., Hodgin, E. B., Ahm, A. S. C., Husson, J. M., Macdonald, F. A., Bergmann, K. D., ... & Strauss, J. V. (2022). Global and local drivers of the Ediacaran Shuram carbon isotope excursion. Earth and Planetary Science Letters, 579, 117368. *https://doi.org/10.1016/j.epsl.2022.117368*

Cheng, G., Morlighem, M., Mouginot, J., & Cheng, D. (2022). Helheim Glacier's Terminus Position Controls Its Seasonal and Inter-Annual Ice Flow Variability. *Geophysical Research Letters*, 49(5), e2021GL097085. *https://doi.org/10.1029/2021GL097085*

Dethier, E. N., Renshaw, C. E., & Magilligan, F. J. (2022). Rapid changes to global river suspended sediment flux by humans. Science, 376(6600), 1447-1452. *https://doi.org/10.1126/science.abn7980*

Check out EARS members latest publications listings online
earthsciences.dartmouth.edu

Harris, C. M., Maclay, M. T., Lutz, K. A., Nathan, V., Ortega Dominguez, N. A., Leavitt, W. D., & Palucis, M. C. (2022). Remote and in-Situ Characterization of Mars Analogs: Coupling Scales to Improve the Search for Microbial Signatures on Mars. *Frontiers in Astronomy and Space Sciences*, 9, 849078. *https://doi:10.3389/fspas.2022.849078*

Huang, H., Patricola, C. M., Winter, J. M., Osterberg, E. C., & Mankin, J. S. (2021). Rise in Northeast US extreme precipitation caused by Atlantic variability and climate change. Weather and Climate Extremes, 33, 100351. *https://doi.org/10.1016/j.wace.2021.100351*

Lowell TV, Kelly MA, Howley JA, Fisher TG, Barnett PJ, Schwartz R, Zimmerman SRH, Norris N, Malone AGO, 2021. Near-constant retreat rate of a terrestrial margin of the Laurentide Ice Sheet during the last deglaciation: *Geology* 49, 1511-1515. *https://doi.org/10.1130/G49081.1*

McDannell, K. T., Keller, C. B., Guenthner, W. R., Zeitler, P. K., & Shuster, D. L. (2022). Thermochronologic constraints on the origin of the Great Unconformity. *Proceedings of the National Academy of Sciences*, 119(5), e2118682119. *https://doi.org/10.1073/pnas.2118682119*

Slotznick, S. P., Johnson, J. E., Rasmussen, B., Raub, T. D., Webb, S. M., Zi, J. W., ... & Fischer, W. W. (2022). Reexamination of 2.5-Ga "whiff" of oxygen interval points to anoxic ocean before GOE. *Science Advances*, 8(1), eabj7190. *https://doi.org/10.1126/sciadv.abj7190*

EARS Alumni News:

David Bieler, AM '74, has been named Professor Emeritus of Geology on his retirement from 34 years on the faculty of Centenary College in Shreveport, Louisiana. On retirement David is moving back up into the hills, lakes, waterfalls, and wineries of the Finger Lakes region of Upstate New York to continue some research projects and spend time with family and old friends.

Undergraduate Student Projects

Virgil S. Alfred: *"Where do New England Stream Channels Begin?"* (Advisors: Carl E. Renshaw, Evan N. Dethier, Jordan F. Fields)

Öykü Z. Mete: *"Barium in Seawater: Global Distribution Relationship to Silicate, and Barite Saturation State"* (Advisors: William D. Leavitt – Dartmouth, Tristan J. Horner – Woods Hole Oceanographic Institute)

Kate E. Boydston: *"Developing a probabilistic model for solifluction processes in the Richardson Mountains, Canada"* (Advisor: Marisa C. Palucis)

Peter A. Kannam: *"Changing Host Phases of Sedimentary Mercury in the Road River Group of Yukon, Canada"* (Advisor: Justin V. Strauss)

EARS AWARDS

Undergraduate Awards:

John A. Ebers 1961 Memorial Award (outstanding undergraduate major): **Öykü Z. Mete**
Estwing Award (outstanding Geology student): **Madeline M. Duhnoski & Jack E. Kreisler**
Earle S. Lenker 1956 Undergraduate Award (outstanding Junior Earth Sciences major, field work excellence): **Amanda N. Calhoun & Eric C. Youth**
Doug Bangs Award (best overall student in Stretch program): **Dylan P. Davis**

Graduate Awards:

Gary B. Malone 1970 Memorial Award (outstanding graudate student): **Karol Faehnrich & Jordan Herbert**
Earth Sciences Dept Gift Award (academic excellence through outstanding publication): **Carolynn M. Harris & Matthew T. Maclay**
Earle S. Lenker 1956 Graduate Award (outstanding academic achievement): **James Busch**
John A. Ebers 1961 Memorial Award (outstanding graduate student TA): **Tianran Zhang**

Post-Doc or any level:

Elizabeth L. Drake Award for Oustanding Dept. Service: **Joseph A. Biasi**
A. Lincoln Washburn Award for Outstanding Mentoring: **Michelle A. Fame**

Thesis defenses between Spring 2021 and Spring 2022:

- **Charlotte Cockburn**, MS - *"Drivers of Contemporary and Future Streamflow Changes across the Northeastern United States"*, April 2021
- **Rebecca Rossi**, MS - *"Impacts of Channel Reach Morphology and Seasonal Flow History on Particle Initiation and Transport"*, June 2021
- **Trevor Partridge**, PhD - *"Climate and Agricultural Interactions Through the Lens of a Globally Anomalous Cooling Trend"*, July 2021
- **Ji-Hye Seo**, PhD - *"Search for Volcanic and Cosmic Signals in Ice Cores Using Osmium Isotopes and Platinum Metals"*, August 2021
- **Gailin Pease**, MS - *"Estimating the Composition of the Continental Crust from its Seismic Properties"*, Nov. 2021
- **Danielle Niu**, PhD - *"The Role of Organo-Clay Composites on Organic Carbon Preservation in Overmature Black Shale"*, December 2021
- **James Busch**, PhD - *"Stratigraphic Expression of the Ediacaran Shuram Carbon Isotope Excursion in Northwest Canada"*, April 2022
- **Laura Blum**, MS - *"Archaeal membrane lipid cyclization genes in terrestrial thermal springs"*, May, 2022

Pets who kept us sane during the pandemic

(Right) Gigi (Prof. Sarah Slotznick) was a junior TA for EARS1. Here she's absorbing material from *Essentials of Geology (6th Edition)* by Stephen Marshak.

(Above) Winnie (Evan Dethier) likes fetch and zoom bombing

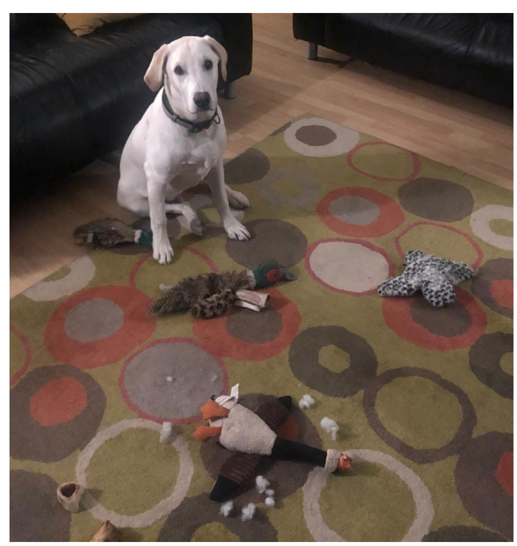
(Above) Annie (James Busch), 4.5 year old golden retriever, would be delighted if you stop by the 4th floor of Fairchild to say hi.

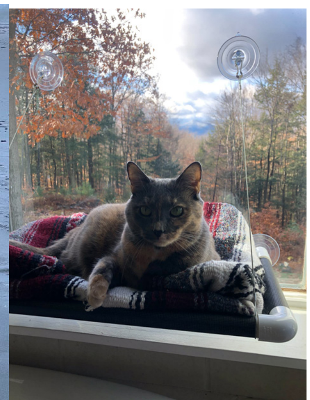
(Right) Wendell (Jordan Fields) seen here at 9 months old, has been a lab tech in-training in Carl Renshaw's Fluvial Research lab since he was 8 weeks old. Wendell is a "super mutt" extraordinaire, which allows him to thrive in diverse environments and take on myriad tasks such as: sleeping on the lab floor, wagging his tail so hard his whole body wiggles every time he sees another graduate student or professor, chewing on cardboard boxes to help accelerate the recycling process, and helping Jordan to locate RFID- tagged sediments ("radio rocks") in streams around New England.

(Below) Shublik, a red healer, hopes for a cookie (Prof. Justin Strauss). Just look at that adorable face!

(Above) Pippin joined Jordy Herbert in Fall 2021 and resides in Lyme. Seen here petting a pet bear.

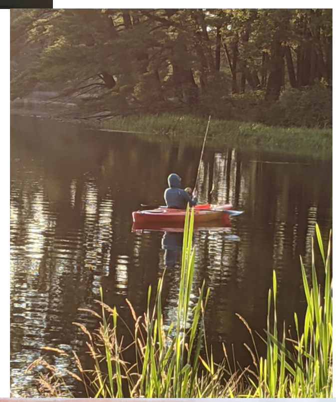
(Below) Percy Jackson (Prof. Brian Jackson), after a productive day hunting game birds.





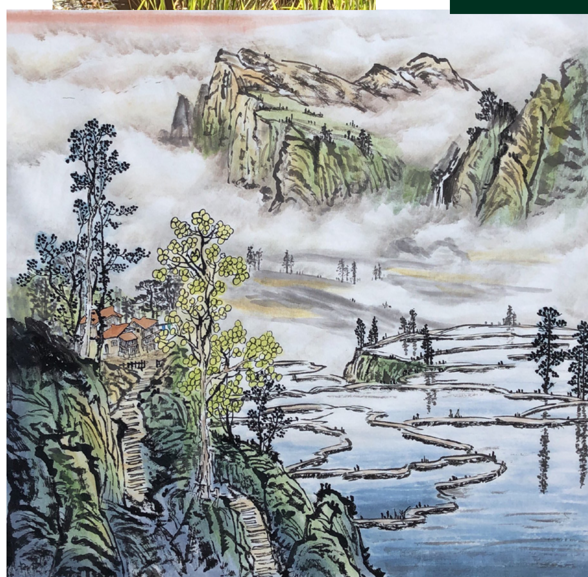
(Right) Koji (Prof. Wil Leavitt) loves accompanying Wil on outdoor adventures, and trying to play with cat friend Nugget. **(Left)** Nugget lounges in front of Mt. Ascutney. **(Below)** Prof Wil Leavit fishing and kayaking.

(Above, left) You might be lucky enough to meet Bailey (Prof. Meredith Kelly) around the department. Here she's summering in Maine, where she learned she probably shouldn't try to drink the ocean.



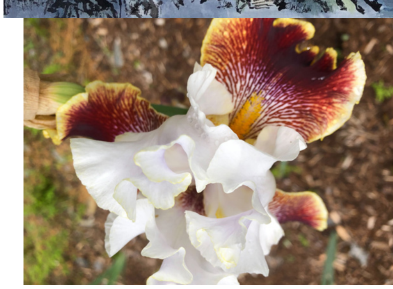
More pets, and some awesome hobbies!

Does building a house count as a hobby when it uses most of your free time? **(Left)** Aurora (AA Kristin Williams) naps on some lumber wrap after a long day helping on the jobsite. **(Left)** Kristin works on screwing in hurricane ties before a threatened hurricane. Said hurricane didn't hit inland after all.



(Left) This stunning painting is from our artist-in-residence, Prof. Xiahong Feng, who picked up Chinese painting during the pandemic.

Prof. Wil Leavitt took in chickens **(left)** and started an iris garden **(right)**.



(Left) Maggie Lonergan has been out ice-swimming! Brrr. **(Right)** Carrie Harris takes on winter canoeing! (Sometimes you run out of water and have to pull the canoe...).

See the last page of the newsletter for more images!

Bob is still at his brewing.

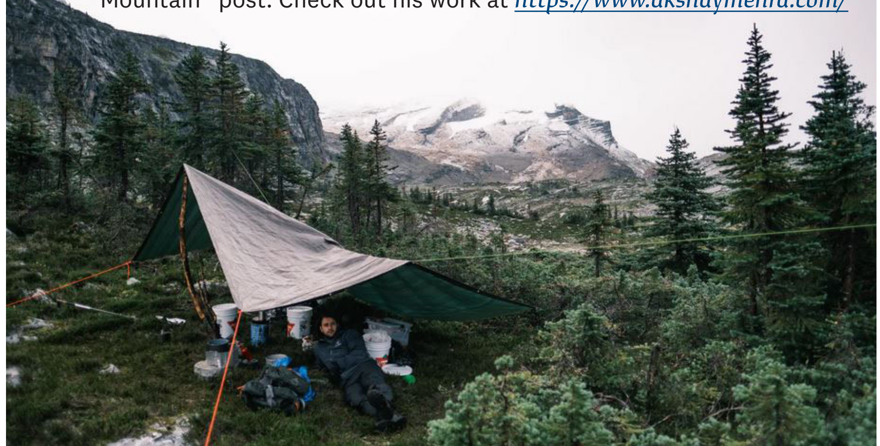
Thank you to all the contributors of the newsletter!

And a special THANK YOU to our alumni for their continued support of the Earth Sciences program at Dartmouth. We hope you are all safe and healthy.

(Above) Welcome to the EARS Family, Babies!

(Above left) Vincent [father Justin Strauss] was born on Jan 5, 2021. Seen here just having turned age one and learning to walk... he was already out on his skis!
(Above right) Rex [mother Marisa Palucis] was born on Dec 8, 2021. He loves snowshoeing, dressing up as a bear, and sleeping through Zoom meetings.

Akshay Mehra, a Nuekom Post-doctoral Fellow who works in C. Brenin Keller's lab has ammased a collection of stunning photographs that capture the process of field studies. This photo is part of his “On Salient Mountain” post. Check out his work at *https://www.akshaymehra.com/*



earthsciences.dartmouth.edu