the GLACIAL chronicles

Ben Linhoff, WHOI

Graduate student Benjamin Linhoff spent several months over the past two summers studying a glacier at a remote camp on the Greenland Ice Sheet. Here are excerpts from his blog describing life and work there.

Leaving home—April 28, 2011

"Do I need a gun?"

"No, polar bears are fairly rare in this part of Greenland."

"*Fairly* rare?"

Dr. Jemma Wadham, one of our expedition leaders, laughed and told me not to worry. They hadn't seen any bears in the past. Aside from the fairly rare massive carnivores, I'm told there will be other hazards—hurricane-force winds, plagues of biting flies and mosquitoes, glacier traverses, and, of course, the daunting task of keeping equipment working in the Arctic for 100 days.

This trip is the result of a lot of planning and preparation. A few weeks ago, I sent 500 pounds of equipment to Greenland, and I really hope it'll be waiting for me when I arrive. The shipment includes everything from radon detectors and solar panels to pounds of peanut butter cups and coffee. I also shipped what my advisor has termed our "Science Tent." There I will set up my laboratory: an amalgamation of car batteries, computers, detectors, and tools. For sleeping, I brought a small four-season tent and a very warm sleeping bag.

About the expedition

On a small spit of land jutting out into the western edge of the Greenland Ice Sheet, our small team of scientists will be living in tents, cooking over a propane stove, and collecting data. Without Internet or cell phones, our contact with other people will consist of a satellite phone, infrequent visits from helicopter pilots, and a few visits to a nearby village, where we will receive email and regular mail and appreciate my favorite local delicacy—musk ox burgers.

Two members of our team will take a helicopter 50 miles from land onto the ice sheet. There they will set up two small tents, and for almost three uninterrupted months, they will live and work on the ice. For them, a nightly satellite phone call or text to our camp at the ice sheet's edge will be their only link to other people.

This blog will be about our team's work, life in the Arctic, climate change, and our inevitable adventures.

Rivers of ice, rivers under ice

Ice melts when things warm up. Since the Industrial Revolution, the concentration of heat-trapping carbon dioxide (CO_2) in our atmosphere has risen to levels about 40 percent higher than the highest concentrations previously experienced by the Greenland Ice Sheet.

In Greenland, glaciers are sliding faster, moving massive quantities of ice from the cold, high altitudes of the ice sheet's interior to the warm subtropical ocean currents that brush up against East Greenland. The increase in glacial meltwater is raising the global sea level, fertilizing the North Atlantic, and may even be changing ocean currents.

We hope our work will elucidate some of the complex dynamics of the Greenland Ice Sheet and perhaps lead to hypotheses, or educated guesses, of the ice sheet's future.

Arrival—May 5, 2011

I set my sleeping tent on top of a large hill overlooking camp. The view was magnificent. I wondered why I was the only one to pick such a beautiful spot. That night I learned why. The wind picked up, and I spent the night listening to and feeling my four-season, hurricane-proof tent violently flap and bend in obscene directions. The next day I moved my tent behind some sand dunes.

Glacial movements

How glaciers melt and move is complex. Forced downhill by gravity, glaciers compress, deform, and slide, while moving and crushing the rocks beneath them. Every summer, lakes of meltwater form on the ice surface, and when the weight of the water becomes too great, the ice splits open to form channels that can drain the lakes in a matter of hours.

These supraglacial lake drainage events are significant, as they transport heat to the base of the ice sheet while lubricating the bedrock. It is hypothesized that this causes the ice sheet to accelerate its march to the ocean.

Early in summer, before efficient meltwater channels develop under the ice, meltwater at the bottom of glaciers can physically lift the entire mass of ice and move it downhill. As this water at the glacier's base rushes beneath a glacier, it slowly breaks down and dissolves rocks and even supports a diverse community of microbial life that lives beneath the ice.

An isotopic medley—May 29, 2011

My work will focus on the chemistry of meltwater discharging from Leverett Glacier, and my goal is to determine where the meltwater comes from and where it's been. I'm taking samples of the glacial meltwater river next to our camp at all hours of the day and night.

My job is to measure three radioactive isotopes: radon, beryllium, and radium. The radon I'm looking for is the same as the radon you may have worried was building up in your basement. Radon enters the base of the glacier the same way it enters a basement—that is, through the radioactive decay of the uranium naturally found in rocks. Radon coming out of the glacier's portal can tell us the proportion of meltwater that has traveled along the glacier's base. Similar to radon, radium should track basal water and is produced through the radioactive decay of uranium found in the rocks under the glacier.

To get at the component of meltwater derived from melting snow on top of the ice sheet, I'm analyzing beryllium-7. It is formed in the upper atmosphere by cosmogenic rays coming from the sun. This isotope of beryllium undergoes radioactive decay and, due to its short half-life, we can assume any beryllium measured is derived from last year's snowmelt. Finally, isotopes of oxygen and hydrogen will be used to quantify the component of meltwater derived from melted ice.

We've also deployed a hefty arsenal of detectors, probes, and instruments into the river to monitor things like pH and electrical conductivity 24 hours a day. Extremely accurate global positioning system (GPS) stations have been installed across the glacier and the Greenland Ice Sheet to monitor when and how Leverett Glacier moves.

Lindsey MacKay, University of Edinburgh

Ben Linhoff chronicled his experiences in a blog called *Following the Ice.*

Read the Blog:
http://followingtheice.blogspot.com

It's laundry day (above left) at an isolated research camp near the front of the Leverett Glacier in Greenland, where MIT/WHOI graduate student Ben Linhoff spent 181 days during the summers of 2011 and 2012.

The front of the Leverett Glacier looms before Ben Linhoff (right) and Jon Telling of the University of Bristol (UK).

Outburst—July 11, 2011

This year, we've had only one major drainage event—at the beginning of June when it appears that every supraglacial lake between the ice sheet margin and 24 miles up the ice sheet drained at once. We think that one large lake drained and sent cracks in many directions, draining other lakes, making more cracks, and so on.

When this happened, our sensors indicated that the river rose more than 6 feet in 13 hours and another 2 feet the following day. This shattered the river's 5-foot-thick covering of ice in an afternoon. In a day, the river changed from a highway of ice to a raging torrent of class IV rapids full of icebergs. There were 7-foot-tall wave trains, deep holes, and icebergs and boulders slamming through the 32°F water. The day before, we had walked on river ice up to the glacier's portal.

For about a week, the river ran wild. It became turbid and opaque, obscuring massive boulders we could hear thundering downriver. The riverbank disintegrated rapidly and became a high steep slope of loose boulders and dust. Falling in could have been deadly, so we set up a harness and climbing rope so we could collect samples safely.

For three nights in a row, I sampled the river every hour all night. I spent my days moving equipment up the eroding bank, taking samples for my research, and helping make discharge measurements. Sleep happened in short bursts, and exhaustion took hold. I'm proud to say that through the entire outburst event, our probes remained in the water and our computerized data loggers stayed dry. We succeeded in capturing the chemical nature of the massive supraglacial lake drainage event from its start to its finish.

'Frankensteining'—July 18, 2011

The Arctic is a terrible place for equipment. Sand and cold seem to destroy everything from zippers to computers. Electronics seem to have a short half-life. Inverters, converters, battery chargers, cameras, and computers have all either needed fixing or have been destroyed.

Because getting replacements is impossible, we attempt to fix everything that breaks. We use the term "Frankensteined" to describe building new versions of broken equipment using parts of other equipment. The Frankensteining I'm most proud of was building a new fluorometer (an instrument that measures light absorption in water) using a boat battery, an inverter, a cell phone charger, and a voltmeter. And yes, it worked!

A change in the weather—July 23, 2011

Summer seems to have ended. The wind has been blowing for two weeks straight, and it's cold enough to need long underwear

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and down jackets. Rain, wind, and clouds are the new normal.

The sound of tents flapping is the new soundtrack of camp. We have to yell in the mess tent to be heard. Anything that isn't in a latched container or held down by a rock has the potential to take flight and whiz through camp.

The end of Year 1—Aug. 9, 2011

I rose from my bed, left my tent, and walked to the river. It was well past midnight, a full moon had risen over the glacier, and in the twilight of the Arctic summer night, I could make out a herd of musk ox grazing nearby. My hair had gotten long, my beard now changed the shape of my face, and my clothes were sewn, patched, and soaked in dirt.

A few steps from the riverbank, I slung a climbing rope around my waist and checked the knot at other end, secured to a boulder. Then, with one hand on the rope and sampling bottles in the other, I eased my way down the steep riverbank to the water's edge.

As I approached, the temperature dropped, and I could see bear-size icebergs bumping through a train of rapids. So powerful was the river that I could feel the thunder of boulders bumping over the river bottom through my boots.

I had long ago given up wearing waterproof gloves to sample the freezing water, so I plunged my hands in and waited for the first bottle to fill. By now, the sun was coming up. The brief Arctic night was over. Back in my tent, I tied a bandanna around

Red boxes show the location of the camp where researchers are studying the complex movements of the Greenland Ice Sheet. Glaciers are sliding faster, moving ice from the ice sheet's interior to the ocean.

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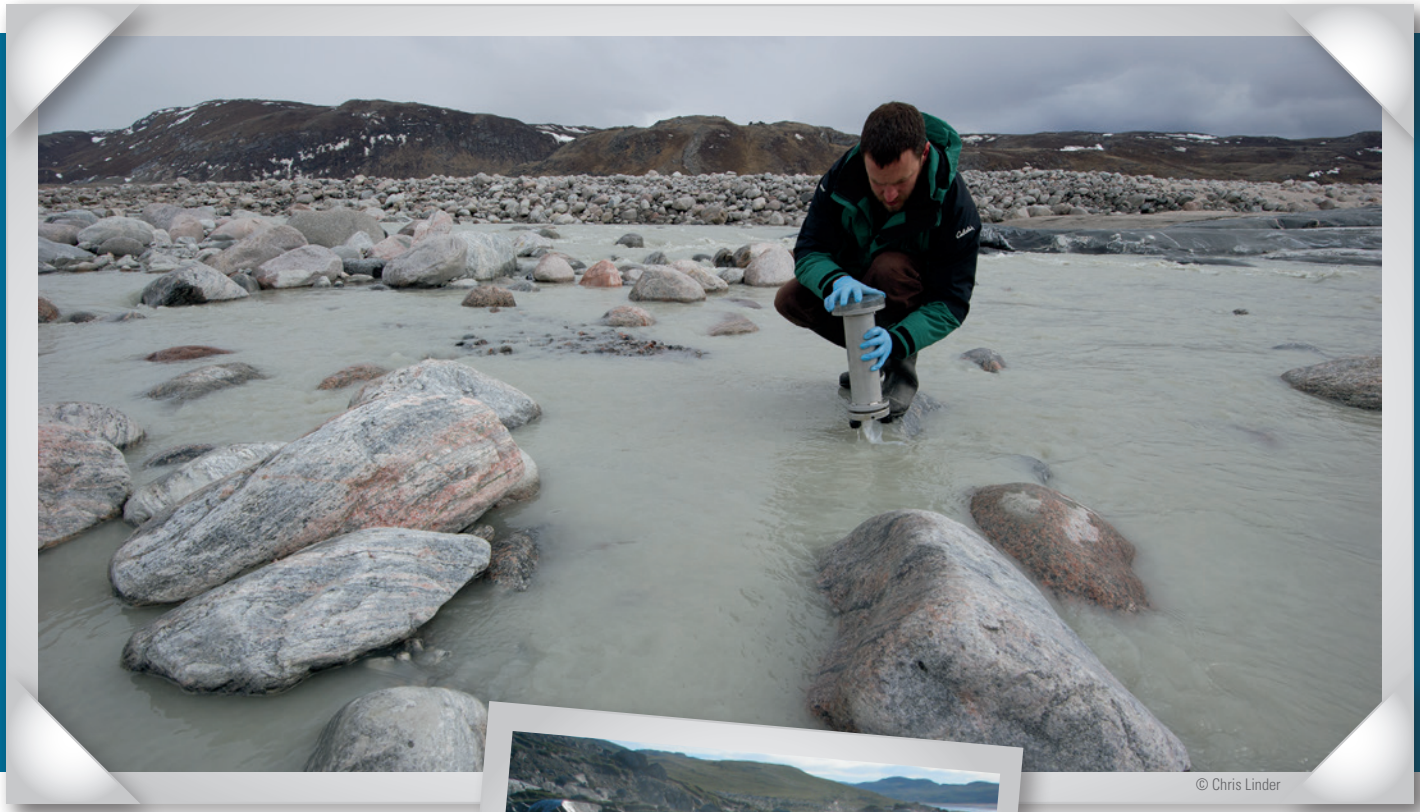

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Ben Linhoff, WHOI

Linhoff (above) took water samples at all hours of the Arctic day and night from the river of glacial meltwater flowing from the glacier's front. By analyzing the water's chemistry, he can trace its sources and pathways. In 2012, melting was unusually high: 98 percent of the ice sheet's surface area melted for several days, sending torrents of meltwater (left) to the glacier's front. Rising meltwaters and icebergs tore apart the riverbank, making sampling difficult and dangerous.

my eyes and went back to sleep. It was my hundredth day in camp.

A second summer on ice—June 20, 2012

It had been a very windy night, and the sound of nylon tents flapping in the wind had kept everyone awake. When it's light out 24 hours a day, a person's circadian cycle becomes sensitive to light levels, and when cloudy days come, everyone gets sleepy and walks around in a haze. And when low clouds make the sky unusually dark, the camp is in low spirits.

I saw myself in the mirror today for the first time in about three weeks. I was greeted by a tanner, hairier, and noticeably thinner version of myself. My beard looks almost like the lead singer of Iron and Wine, my face is dark brown, and my nose is red.

I'm tired. I don't know if it's the 24 hours of light and wind that makes it hard to sleep, the lack of any days off, or the canned-food diet. I hate to say it, but in the past few weeks my energy has been slowly siphoned off. No matter how much I eat, meals don't seem to give me any energy. Recently I've caught myself hiking in a daze—head down, shuffling over rocks and hills, trying to clear the cobwebs from my head.

I'm still happy, and the team is in good spirits. We're having fun, and I'm still very excited to be here. The work hasn't slowed.

I'm about halfway through my field season. Six-and-a-half weeks left. I called my dad on the satellite phone last night. He said, "Keep the faith and get it done."

A few minutes ago, I bought an entire caribou leg off a hunter to bring back to camp. I'm not sure how we're going to cook it, but I do know that it was one of my best ideas ever.

Is this global warming?—July 12, 2012

More meltwater is spilling out from beneath Leverett Glacier than we've ever seen. What's more, the river has spilled over its banks and is now eroding a glacial moraine near our camp that was likely pushed there in the 1700s during the Little Ice Age. It's only June and the river is still rising.

Can we say this year's warm weather is because of global warming? It's not for certain, and it's important not to ascribe one especially warm season or year to global warming.

Global warming refers to increases in average temperature over the entire globe over a period of decades, not in one location or

"The problem with having a scientific breakthrough is that no awesome music starts up like in the movies. It's just you and your friend, sitting in a tent late at night dunking chocolate bars in mugs of warm powdered milk."

Water at the glacier's edge may have originated far atop the ice sheet and traveled through cracks and along bedrock at the base of the ice.

Watch the 'Following the Ice' Video:
www.whoi.edu/main/images-multimedia

over one year. I don't think this point can be made often enough. While we cannot say one warm season is the result of global warming, I think the fact that our ice-melt-fed river is spilling out of its banks and eroding things that have clearly been there for centuries seems worth noting.

Climate change feedback loops—July 12, 2012

Surprisingly, glaciers may also play an important role in driving photosynthesis in the world's oceans. Glacial meltwater, icebergs, and wind-blown dust from glaciated landscapes can all carry essential nutrients (especially iron) to nutrient-starved regions of the ocean. These glacial nutrient sources can fertilize the ocean, stimulate photosynthesis, and ultimately cause the consumption of atmospheric CO_2.

If you are scratching your head thinking, "So more glaciers can lead to more CO_2 taken out of the atmosphere, which would cool the planet, grow glaciers, cause more icebergs, more CO_2 consumed, more cooling," then you're on the right track and have identified something called a feedback loop.

Consider permafrost. Permafrost is a thick layer of subsurface soil in polar regions that remains frozen year-round. You may not have realized that permafrost contains vast quantities of carbon that was frozen in place thousands of years ago. As the planet warms, and permafrost melts, this ancient carbon becomes food for microbes that transform that carbon into CO_2 gas and methane (CH_4), which warm the planet, melt more permafrost, and produce more CO_2 and CH_4.

Ice cores taken from the Antarctic Ice Sheet give us a datable record of the atmospheric CO_2 concentrations through time. These records tell us that ice ages were often ended by sharp, fast upswings in CO_2. Those upswings could very well be the release of CO_2 from melting permafrost.

There are many CO_2 feedback loops; glaciers and permafrost are just part of a few of them. Serious accounting skills are required to understand the delicate balance between all of the world's CO_2 feedback loops, as well as all the sources and sinks for CO_2.

Eureka moment—July 20, 2012

If this were a movie, the music would be tense and building; this was the moment of truth. It was late in the evening. Andrew Tedstone, a graduate student at Edinburgh University, and I were huddled over our laptops, the orange glow of the mess tent in the low sun lighting our faces. Chocolate bars and mugs of steaming hot powdered milk were spread out on the big metal box that serves as our dining table.

Andrew's lab group specializes in deploying extremely accurate GPSs on glaciers and the Greenland Ice Sheet. How, why, when, and how much glaciers move are surprisingly complex questions, and scientists have spent decades looking into these problems.

Last season, I deployed a new type of water chemistry probe designed to measure the fraction of glacial meltwater that had been "delayed," or stored at the base of the ice sheet, before it flowed out of the glacier's front. This delayed water is hypothesized to be responsible for daily cycles in glacial uplift and in seasonal surges in the movement of glaciers. However, proving this has been difficult, as the delayed water doesn't seem to have a reliable chemical or physical signal to differentiate it from the rest of the meltwater. We hoped my new water probe would be able to detect this delayed water in a way that no other method could.

"Let me check," Andrew said. "O.K., July 16, the GPS stations recorded a major glacial uplift followed by one of the biggest accelerations of the season."

"Wow, you're kidding!" I said. "That was the biggest peak my water probe recorded too! O.K., let's check June 15, what time of day was the glacier moving fastest?"

"On June 15, the glacier accelerated fastest at 2:15 p.m," Andrew said.

"That's exactly what my water probe predicted!"

I couldn't believe it: Every day, the ice sheet was being lifted up, moved slightly forward, and set back down as this delayed flow water passed beneath it. The water probe my lab had developed was telling us in real time when the glacier was physically moving. It was as if we'd stuck a magic wand into the river coming out from beneath the glacier, and it told us what time of day the glacier was moving and, in relative terms, by how much.

The problem with having a scientific breakthrough is that no awesome music starts up like in the movies. It's just you and your friend, sitting in a tent late at night dunking chocolate bars in mugs of warm powdered milk.

Camp life—July 25, 2012

Looking around at my dirt-caked companions eagerly tucking into their bowls of expired canned hot dogs and what was left of our rice rations, I noticed an odd smell.

"Did one of you guys take a shower?"

"Oh yeah, I just had a wash!"

We bathe so infrequently that smelling soap is like smelling an overpowering perfume. Fortunately it's usually the only time we can smell each other.

Whether or not to take a bucket shower is often a major conversation during dinner. Will mosquitoes cover me head to toe the second I disrobe? Is it too cold and windy? How bad do I smell, really? Is it just my feet? Would you guys mind if just my feet took a shower?

Our clothes are also washed with a bucket. It takes a few hours, and we rarely have free time, so we try to spread out laundry as much as possible. Other dinner conversations have included: How many days you can go between changing socks? (Answer: three to four for most people.) Does hanging clothes in the sun and wind without a wash makes them smell better? (Answer: yes.) How many mosquitoes have to die in your coffee before you are unwilling to drink it? (Answer: You probably don't want to know.)

It takes a while for people to get accustomed to living in our camp. When people first get here, they'll say, "I don't want to drink pond bugs." Then it's, "I don't want to drink so many pond bugs," which is sometimes followed by, "I feel bad for all the pond bugs we drink." Finally, though, everyone comes around, and it's, "Hey, check out this big crazy-looking bug in my bottle!"

The winds of July—July 25, 2012

Nature here just won't give us a break. After the cold ended in the middle of May, we had a full day-and-a-half of warm weather before zillions of mosquitoes woke up.

July is the month for heavy wind. The wind has been blowing nonstop between 30 and 50 miles per hour for three days. If we weren't living in tents surrounded by sand dunes, this would be easier. I'm coming to the conclusion that there may not be enough shampoo in the whole world to rinse all the sand out of my hair.

Mosquito madness—July 25, 2012

The mosquitoes were swarming in masses I never imagined could exist, and I was completely exposed. I had forgotten my head net and didn't have a mesh jacket or bug spray. I had to breathe through my nose to keep from inhaling the ones swarming around my face. Hundreds went into my ears, eyes, and nose. My arms were tied up in bags so I couldn't shake them off, and I was carrying too much weight to run. There were so many biting my arms, it actually looked and felt like I was wearing a crawling jacket of biting insects. I thought I would go mad.

Epic melting—Aug. 6, 2012

A few days ago, my advisor, Matt Charette, called my satellite phone to let me know that in early July, something like 98 percent of the surface of the Greenland Ice Sheet was melting at once, or, as the media put it, "The entire Greenland Ice Sheet melted." Although the Greenland Ice Sheet is still there, this year's melting will be something to remember.

I've now heard that according to ice-core records, epic melting years like this one seem to occur in Greenland about every 150 years or so. I'm sure back home there will be much debate about whether this year's high melt was part of a natural cycle or if it is yet another symptom of global warming. The answer to that question doesn't actually matter. The fact remains that during this year, like every other year in the past decade, more ice will be lost than created. It's the trend that matters, and this year's melting will accentuate the ice-loss trend. I think it's safe to say that at this point, it would take decades of cold, snowy weather to reverse course in Greenland.

Last day—Aug. 6, 2012

I've lived in this tent for six of the last 15 months, and I've been away from home for seven. When I pull out of camp, I'll have slept here for 181 nights over the past two field seasons (not that I'm counting). It definitely feels like it's time to go home. I've run out of coffee and my peanut butter stash has been gone for a month.

Ben Linhoff's research is funded by the National Science Foundation, the WHOI Coastal Ocean Institute, the WHOI Ocean and Climate Change Arctic Research Initiative, and The Robert H. Cole Endowed Ocean Ventures Fund at WHOI.

Mauro Werder, Simon Fraser University

After three months in the wilderness, Ben Linhoff loads up gear to carry back to civilization at the end of summer.