Measuring Arctic Waters:

Searching for Secrets of Climatic Change

Kelly Falkner is associate professor of Chemical Oceanography in the College of Oceanic and Atmospheric Sciences at Oregon State University. Her research interests involve the application of inorganic elemental and isotopic measurements to the understanding of aqueous geochemical issues. Falkner's laboratory group conducts state-of-art analyses of media as diverse as snow and ice; river, lake and sea waters; and associated solid phases. In doing so, they have explored topics ranging from the recent history of lead pollution in the atmosphere, to factors controlling the chemical composition of the world's largest lake (Baikal), to large-scale perturbations to chemical cycling in the Black Sea. Much of Falkner's present effort is directed toward tracking the fate of river waters and other water types in the Arctic and sub-polar oceans. All of her projects involve extensive inter-disciplinary collaboration.

Most of your work is focused on the Arctic?

Yes, that's where my current funding is. I've been predominantly focused there for about a decade. Basically, I'm an inorganic chemist and apply inorganic chemistry to aqueous geochemical problems.

How did you first get involved?

I got involved in the Arctic because I was out on Lake Baikal (East Siberia) with a physical oceanographer, Ed Carmack. We were there with several other researchers, but their equipment didn't come in—it was quarantined in Moscow. Ed and I had what we needed in duffle bags, so we sailed together for two weeks. I was sampling rivers entering into the lake and he had a CTD (conductivity, temperature, and density equipment) to sample physical properties of the lake.

Dr. Kelly Falkner labeling sample containers in the Twin Otter aircraft May 2002. Photo by pilot Jim Haffey.

Ed had focused a lot of his career on Arctic oceanography. Since he had no one else to speak to for a couple of weeks, I learned a lot about that interest of his. At one point he was watching me sample river waters and asked, "Do you think there is anything you could measure in the Arctic that would let you say whether a river water contribution in the ocean came from one river or another?" Being young, I answered, "Absolutely. I don't know what that would be. I'd have to test a range of things, but I have some ideas."

Out of that conversation sprang a proposal to the Office of Naval Research for a Young Investigator Award to test that idea. At the same time, unknown to me, the Russians had revealed that during the Soviet era they had dumped nuclear waste in the Arctic. A good deal of funding was diverted in that direction to see whether that waste had implications for Alaskan or Norwegian fisheries and other resources.

The funding aligned with my interests and topic; that catapulted me into what I'm doing now.

Did you succeed in identifying chemical constituents that would allow you to distinguish contributions from different rivers?

The short story is that indeed we found such constituents.

Most of the people who are trying to figure out where waters come from in the oceans rely largely upon temperature and salinity. But in the Arctic, the salinity signal is confounded by the fact that freshening could be due either to ice melt or river water. Sorting these out is an issue. Researchers already knew how to do that when I started working on the problem.

The question then was, could we sort out the rivers from each other? Was a river contribution coming from North America? Was it coming from Eurasia? One of my graduate students, Chris Guay, focused his thesis on these questions and came up with some answers.

In the process of studying these chemicals, we determined their utility not only for tracking river water but for other circulation-related questions. Our laboratory group has put together an arsenal of these chemical tracers that we use to look at the disposition of various types of water in the Arctic.

Was the Arctic always a focal point of ocean research?

At the time I started studying the Arctic, it was regarded as a quiescent, predictable ocean environment. The Arctic Ocean was covered with ice. Not a lot of wind energy got through to the water beneath, and researchers expected things to be more or less the same whenever they went up there.

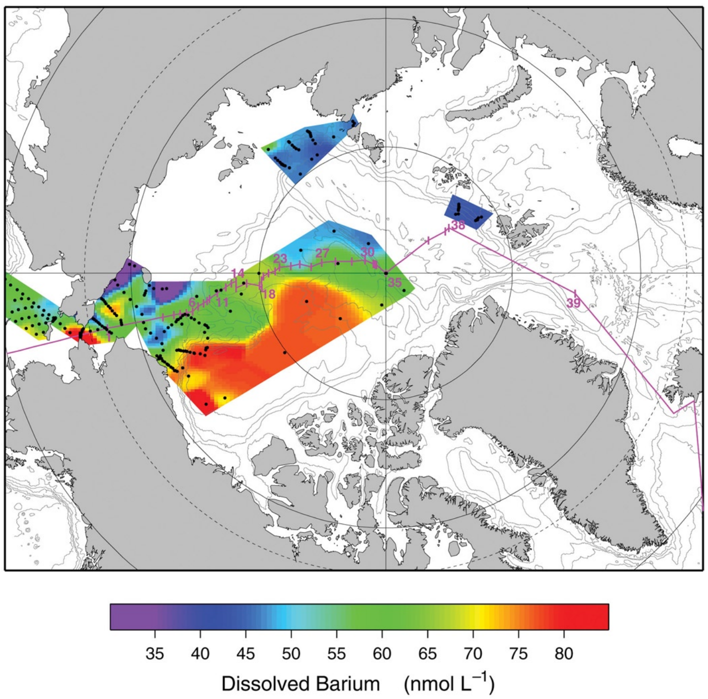
Suddenly, in the early 1990s scientists were saying of the Arctic, "Whoops! It's not behaving like it did before!" Very significant changes appeared to be underway. It was an exciting time to become involved in Arctic Ocean research because the paradigms of how its circulation worked were evolving very rapidly.

After you could identify the particular river contribution by its constituents, what did you look at?

Once we had a basic idea of the ocean basin scale picture, we naturally moved to answering questions of variability of circulation. That's what I'm involved in now, to a large extent, in my contribution to the North Pole Environmental Observatory. It's run for four years; we're going into our fifth year this season and our research has been extended through at least 2008. It is designed to track at the boundaries of the major water masses.

If the ocean is covered by ice, how do you study its circulation?

We go out onto the ice and occupy key sections of stations much like "spokes on a wheel." We land on the ice with an aircraft, drill a hole, and then lower our CTD and water sampling equipment from a cable mounted on a small winch in the plane. I cover the chemistry component; my colleague Jamie Morrison covers the physics. We work together to try to define where Pacific water meets Atlantic water and how the boundaries between those water types change with geography and with time.



Distribution of dissolved barium is the surface mixed layer of the Arctic Ocean in summer 1993. Black dots indicate ship station locations from a composite of cruises. The track of Arctic Ocean Crossing of 1994 is also superimposed in magenta. Figure from Guay and Falkner (1997) Deep-Sea Research II, 44:8:1543-1569.

I've put an oxygen sensor onto the CTD package so we have continuous profiles of oxygen. We're the first people to really make that work from aircraft deployments in the Arctic and have found that the water mass tracking potential of a continuous readout (as opposed to discrete bottle samples) is phenomenal.

Each Spring, we go out to determine the location of major water masses. You have to go out when the sunlight has returned, yet hasn't been back long enough to cause melt ponds to occur on the ice. That gives you the April–May time frame as a working window.

As a result of changes within the Arctic, we've seen impacts downstream in the ocean and probably the whole climate system. One of the big issues is that the outpouring of freshwater into the Arctic Ocean is an important component of global circulation. The freshwater input and its impact on downstream circulation has been observed to be highly variable in the last couple of decades.

Researchers have been looking at the North Atlantic since oceanography began, again thinking that the deep water properties and its formation processes were relatively constant. All of a sudden in the early 1970s, people noticed they were seeing measurable changes. They noticed "a great salinity anomaly" passing through the North Atlantic— it was as if someone had suddenly dumped a whole bunch of fresh water into that system.

We now understand that the fresh water came from a pulse out of the Arctic. Internationally, researchers are collaborating to try and understand the variability of that output and what controls it. The North Atlantic is one of the predominant sites for the formation of deep water. In order for deep water to form, there needs to be water at the surface dense enough that it can sink to depth and then push along waters at depth. If there is too much freshwater near the surface, that will change the process. Surface water won't become dense enough to sink to the same depths, or sink at all. If this cold-freshened water doesn't sink, where does it go and how does it affect the surface circulation? These are the concerns.

Could you say a few words about what deep water does and why it is important?

Deep water formation drives the circulation of global oceans. On time scales of short duration, for instance seasonal, solar heating and winds on our rotating earth are what move water around. On a longer time scale, the sinking process drives the deep ocean around. It is the interplay between these things that determines our climate, so we really have to understand the whole system.

So researchers are now measuring these Arctic fluxes of fresh water?

There is a big international push to observe and understand freshwater fluxes at all the gateways of the Arctic (Arctic Subarctic Ocean Fluxes or ASOF program). Europeans have invested an unprecedented amount of effort to the east of Greenland and continue to monitor and measure fluxes there.

Our own research was funded three years ago and is focused on gateways to the west of Greenland in the Canadian Archipelago. Three main gateways connect through the archipelago to Baffin Bay and Labrador Sea. The Labrador Sea is another area where Atlantic-intermediate to deep waters form. If freshwater is coming out of the Arctic from those passages, it is going to impact global circulation.

It has been harder to work in that part of the world, so people have generally focused efforts east of Greenland. But our data makes clear that this part of the world is important at the same time that the larger science community is reporting major changes in North Atlantic intermediate water properties and spreading.

What are the difficulties of studying the gateways west of Greenland? Sea ice?

There are many reasons why it has been impractical to work in this remote region.

Magnetic forces are one challenge. As you are very close to magnetic north, you can't use standard compasses for determining direction. Typically researchers use compasses with current measuring devices to tell the direction of the currents. You have to devise more clever ways to measure direction.

Drilling through the sea ice in the central Arctic. Co-pilot Dave Hanberg with shovel on left. K. Falker in the middle and Jamie Morison of the Applied Physics Laboratory, University of Washington on the right. Photo by pilot Jim Haffey.

Where we are working in the North, there is calving of icebergs off of Greenland and off of Ellesmere. These bergs can have very deep keels—a couple of hundred meters—that can rip out moored instruments.

In the summer the weather is predominantly foggy, making it difficult to navigate. Ice is an issue in the winter. In fact, ice is an issue in the summer, too, because waterways get locked up in winter into ice bridges and passages. When these bridges break in July–August, then old ridged sea ice is encountered streaming down through Baffin Bay, which makes it extremely difficult to get through with ships.

How do you cover the area?

Under the ASOF-West program, researchers are looking at all these gateways simultaneously. Our group is looking in particular at the passage between Ellesmere and Greenland called Nares Strait which is the deepest one. Our Canadian collaborator, Humfrey Melling, is continuing a program in the adjacent passage of Jones Sound. Another Canadian colleague, Simon Prinsenberg, is looking in Lancaster Sound.

After we complete this program, for the first time we'll have records of information from all the gateways at the same time. We'll be able to say, when the fluxes are higher in one place whether they are lower in another, or are correlated—we don't know this yet. Available models go both ways. For our project we will be able to say how freshwater fluxes relate to wind and sea level pressure fields. Collaborator Andreas Muenchow of the University of Delaware is measuring the relative pressure field and Roger Samelson with Phil Barbour of COAS are determining winds fields from a nested mesco-scale model. There are many additional collaborators and aspect to our program. Putting it all togther will be a major step forward in understanding that freshwater valve.

There is a lot of excitement about what we are seeing. There are still many unanswered questions about how much of Arctic variability is naturally driven versus anthropogenically driven (caused by human activities). I believe that we have crossed over the line and can now unambiguously attribute some of the changes we are seeing to anthropogenic forces.

What do you mean we have "crossed over the line"?

It has been debated since the early 1990s whether we knew enough to say for certain that the warming we are seeing in the Arctic was anthropogenic rather than a natural signal. The warming trend in the Arctic right now is causing a major retreat of the sea-ice in summer. There was also a warming trend of similar magnitude with lesser ice retreat starting in about the 1920s or 1930s through the early 1960s.

The pattern of ice area and temperatures in the Arctic is highly variable. The variability of the previous warming can be produced by our best models today, without allowing for anthropogenic forces. However, the pattern we've been observing since the late 1980s cannot be reproduced by climate models without using greenhouse gas forcing.

So we've "crossed over the line" of debating the causes of the current Arctic warming pattern?

We now know human activities are doing things to the system. Five years ago, I would have said that the most important question to answer is what is the scope of variability and what are we doing as humans to the system. Today, it is still very hard to tease out what part of the changes reflect natural variability and what part of the changes are due to human activity. As we endeavor to do that it seems that climate is headed into a new mode.

The most important questions to focus on now are the implications of what we are seeing—"What does this change portend for the future?" We continue to need to understand how variability functions in the system in order to answer that question.

Are Arctic researchers involved with policy, or is research confined to science and measurement only?

For me personally, the science and the policy are interrelated. There are immediate implications for the population in the Arctic from the changes we are seeing; that is a regional concern. I personally believe that we have responsibilities at other latitudes to attend to the issues. I don't think we can attend to them fast enough to reverse the changes by any means, but we do have a responsibility to help determine what are the likely changes and what can be done to mitigate the worst effects for resident populations that are certainly not responsible for those changes. It is a morass of responsibility.

What interests me about working in the Arctic is that you do have all of science and social science and policy at the table. It is very interdisciplinary. You can't ask a question in an academic sense without having an implication for a local population and then, because of the global climate situation, for all of us.

There are other issues that I am interested in regarding pollutants or contaminants. Again, we're producing them at southern latitudes and they make their way north. That is a whole other topic, but analogous to the climate one in terms of meshing science and policy.

Launching the messenger to trip Niskin bottles in the central Arctic May 2002. Jamie Morison left, Kelly Falkner right. Photo by Jim Haffey.

You work with researchers from several disciplines. Is Arctic research a crossroads for researchers from many disciplines?

Yes, the culture of the Arctic division of NSF reflects this. Certainly the pressure has been increasing on researchers, across the board, to be more accountable to the taxpayer for what we are doing. Especially since the cold war is not a justification anymore.

In addition to that general pressure, the Office of Polar Programs, Arctic Division, moved progressively and proactively in the direction of having physical scientists talk with social scientists before creating major long-term research plans. Not only did these scientists have to talk, they were also to find overlapping interests and look for where they might collaborate.

About a decade ago, physical scientists and social scientists were brought to a meeting in Utah. We were all very skeptical—we didn't think the others knew enough about our sub-systems. We thought we couldn't talk to those other scientists, because in many ways we did not share a common language. It was an awkward meeting.

But by the end of that meeting—after three straight days of forcing us to be in the same room with each other—some attitudes had changed. Many of us came away with the understanding that by failing to talk to that group of people, you could design a program at great expense that missed addressing vital issues. We discovered many examples where minor tweaks to research program objectives could address issues very important to local people.

All kinds of research collaborations sprang out of those discussions. That kind of thinking has pushed all of us who get funding from the OPP Arctic division of NSF into more interdisciplinary collaboration.

At the Ocean Sciences division at NSF, which is a larger entity and subdivided into disciplines, there seems to be much more of a barrier to making that kind of crossover happen. Interdisciplinary collaboration is starting to happen across ocean sciences, but not on the same scale or with the same directedness as in Arctic research. Part of the barrier to collaboration is simply that the funding for research comes through a discipline such as chemical oceanography or physical oceanography. And of course the global population is so much larger with divergent issues.

Do Arctic and Antarctic researchers collaborate?

Some scientists work at both poles but I'd say in general there is very little collaboration. In part, this is a political divide. The U.S. would have no claim to Antarctica if we didn't have a science presence there. NSF is our science presence and is responsible at a policy level for adhering to the treaty regarding Antarctica. NFS is always going to have money awarded to do that.

Political pressures on Arctic research are different. Arctic research funding has long been the poorer cousin of the Office of Polar Programs at NSF and other funding agencies. Certain senators from Alaska have been successful in pushing through Congress what would be considered by some "pork" in the form of research dollars for their region.

The NSF Arctic Division has grown dramatically since I started my work. For example, when I started my work, there was no logistics support. You had to figure it out and make it up on your own. For Antarctica, a contracted logistics group is funded to look after your needs; if you go down south they issue you everything you need, they had specific procedures for medical exams, etc.

Displaying a banner for a gradeschool project of a classroom in Maine at the North Pole in May 2002. Jamie Morison, left; Jim Haffey middle and Kelly Falkner right. Photo by co-pilot Dave Hanberg.

We don't have extensive logistics support that the Antarctic side of the house has at this point, but about six years ago NSF did establish an logistics arm with a pot of new money, and those services are now evolving.

What other challenges face Arctic researchers?

A gamut of things can get in the way of what you want to do. One of the challenges to doing research on an ice-covered ocean is that ice.

For example, one of the most exciting things happening in oceanography right now is the use of gliders and Argo floats. These autonomous instruments can go out on their own for months and months, relaying data to satellites and unprecedented coverage of 3-D time series observations that can be put toward improving our understanding of ocean circulation. The gliders, for example, are taking excursions to a depth of a thousand meters all over the ocean. The gliders pop up and send the data—far more data than we could ever hope to get from multiple ship operations. That is exciting for scientists who need lots of data to understand complex systems.

But in the Arctic, you can't use the same technique of popping to the top of the water to send out data signals, because you've got to get through that layer of ice. At this point, we don't have good ways of doing that. There are ideas out there; I've seen lots of things attempted. But if we can get to the point where we have that ability to sail autonomous vehicles around the Arctic, quickly gather information over the large areas, and get it to satellite and to our offices all over the world, then we would move into a new era of Arctic research.

We are not there yet. There are many challenges to getting there. I might see it at the end of my lifetime, but not anytime soon.

What do you tell people about why they should care about the Arctic?

We are seeing the ice cover shrinking dramatically in the Arctic. We have satellite photos and know that data well.

The troublesome thing about losing that ice cover is that ice normally reflects 80–90% of sunlight back into space; it's got a highly reflective surface. When ice cover shrinks, it leaves water in its place. Water only reflects 10–20% of light back into space; it is absorbing the rest of the energy in the form of warming. So, the loss of ice cover results in enhanced warming of the system. In a very simple way of thinking, it's a positive feedback loop.

When it gets to some threshold point, the system is going to become too warm to form the ice again. Scientists now project that somewhere between 2050 and 2070 the summertime Arctic ice cover is going to be gone, with accompanying higher temperatures in the region.

The implications are large—very large for the heat balance of the Earth; large for organisms that are dependant on ice, like polar bears and seals. The tundra will be melted permafrost, which will limit our ability to drive on it or to remove oil. On the other hand, maybe ship navigation through the region will be expedited.

We can expect further dramatic changes. For the Arctic populations used to subsistence living, those changes are going to be phenomenal. There are other social forces changing for those groups as well; it is a complex picture. Just because the Arctic seems remote, it shouldn't be thought of as such. The Arctic is intimately linked in our global climate system, and seems be the "canary in the coal mine."