1

BEGINNINGS

Turning points in life are seldom recognized until they have already passed. In my case, that turning point was in 1981. After a series of aimless years, I finally landed on a track toward a bachelor's degree from the University of Massachusetts Amherst in physical geography. I'd started out in 1978 as an astronomy and physics major, but for a number of reasons, none of which bear especially close scrutiny, I decided to go in a different direction. On the plus side, it was clear that a bachelor's in geography was better than no degree at all. On the minus side, I hadn't yet learned enough hard science to be employable, only enough to be irritating to my friends.

Lucky for me, the decision panned out. I ended up being in the right place at the right time to seize an opportunity and see part of the world where, at the time, few had ventured. Six months later, I found myself in a ski-equipped Twin Otter headed to northeastern Ellesmere Island in the Canadian High Arctic to begin a detailed study of two little ice caps. I became enchanted with the North and decided to become an Arctic climatologist. By 2016, those ice caps had almost completely melted away, victims of the Arctic meltdown. I could never have imagined this at the time. I could not have known that in becoming a climate scientist, I was to earn a front-row seat to observe how, in fits and starts, it first began to be noticed that the Arctic was changing. Nor could I have known that I'd also become part of the growing cadre of scientists who first struggled with conflicting evidence to try and make sense of what was happening, then finally had no recourse but to yield to the conclusion that a radical transformation was underway. I could not have foreseen that Arctic climate research, once the domain of a small community of scientists with love for snow and ice, would become a centerpiece in the quest to understand the impacts of global climate change that would involve collaboration between thousands of scientists from around the world.

CHARTING A COURSE

It was a rainy afternoon when I learned that Dr. Raymond Bradley, an associate professor at the Department of Geology and Geography, was teaching upper-division courses in both climatology and paleoclimatology—climates of the past.[1] This sounded like interesting stuff, so I signed up for both.

Since elementary school, I had been aware that the earth's climate had varied in the past, but until taking Ray's courses I had no real idea how these variations related to things like periodic changes in earth-orbital configuration, atmospheric greenhouse gas composition, volcanic eruptions, solar variability, and climate feedbacks. Ray drew in part from his own research, which focused on the past and present-day climate of the Arctic. Ray wrote his first research paper in 1972 while still a graduate student.[2] He found that a global warming trend starting in the 1880s, particularly notable during the winter season and in the Arctic, changed to a cooling trend in the 1940s. He later documented a rather abrupt further cooling in the Canadian High Arctic starting right around 1963/1964, which he suspected might relate to a massive injection of dust into the upper atmosphere from the 1963/1964 eruption of Mount Agung, a rather ill-tempered and still active volcano located in Bali, Indonesia.[3] The cooling noted by Ray and others turned out to be a temporary thing, but for a time it helped to foster speculation, greatly overstated by the media, that the planet might be entering a long-term cooling phase. Reflecting my fondness for big snowstorms and seeing commerce grind to a halt, I found the idea of a cooling planet quite appealing. While part of the climate class also covered the already quickly growing counterpoint that because of the observed rise in carbon dioxide levels in the atmosphere, as measured at the Mauna Loa Observatory, the planet should start to warm up, and most strongly in the polar regions, deep down I was hoping for an ice age.

I was friendly with Mike Moughan, a fellow a few years older than me who was one of Ray's graduate students. Making full use of the university's CDC Cyber Systems mainframe computer, Mike was processing temperature and precipitation data from weather stations across the Canadian Arctic (with enchanting names like "Resolute Bay," "Alert," and "Eureka") to better understand variability and recent trends in the region's climate. His work doing real climate research seemed so cool, and he looked so scientific walking down the hall of the Morrill Science Center with computer printouts or toward the Computing Center carrying a 9-track magnetic tape of valuable data.

I wanted to be part of it. The opportunity came when Mike decided that he was not up for graduate school. This left Ray in a lurch. Upon Mike's suggestion, Ray agreed to take me on as an hourly student, at a seemingly princely wage of five dollars per hour, to finish the work that Mike had started. Mike showed me how to log onto the CDC Cyber Systems mainframe, and how to edit the SPSS routines that he had been using. After climbing a steep learning curve, I became competent enough to supply Ray with data plots. Now I was the cool dude walking down the hall and to and from the Computing Center.

In early 1982, Ray inquired about my future plans and said that if I was up for it, he needed a field assistant for the upcoming summer's work in the Arctic. I enthusiastically volunteered. He also emphasized that I ought to apply to graduate school and take Mike's place. I applied.

Ray's project was to reconstruct the past glacial history of the Queen Elizabeth Islands, which is a part of the Canadian Arctic Archipelago. At the time, this area was a part of the Northwest Territories; it is now part of Nunavut. The project involved recovering and analyzing sediment cores from Arctic lakes, including a series of small freshwater bodies called the Beaufort Lakes, near the northeastern coast of Ellesmere Island. Ray had been coordinating his research with Dr. John England from the University of Edmonton.

Via a well-written proposal, Ray convinced the U.S. National Science Foundation (NSF) to support a modest additional project on and around a pair of nearby small, stagnant ice caps at about 1000 m elevation on the Hazen Plateau (fig. 1). The NSF, as I quickly learned, is the key federal agency supporting fundamental research and education in the non-medical fields of science and engineering; its counterpart in medical fields is the National Institutes of Health.

The objective of this side project was to shed light on an idea advanced in 1975 by Jack Ives of the University of Colorado Boulder regarding how the great continental ice sheets of the Pleistocene might have formed.[4] It had long been known that the past 2 million years or so had seen a series of major ice ages, separated by warm

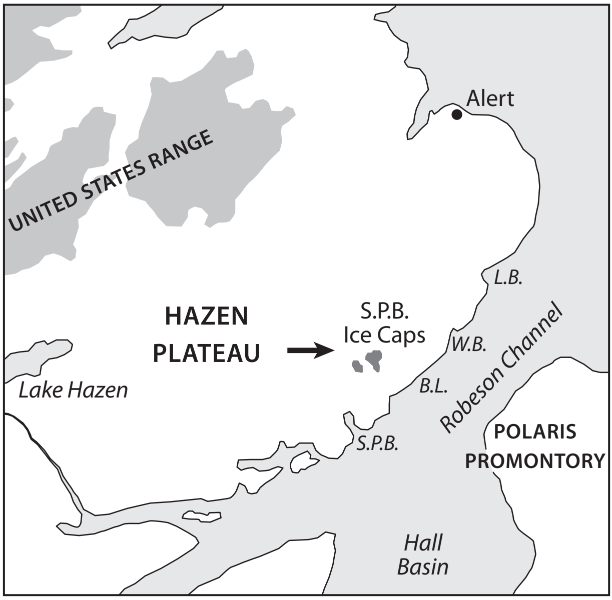

FIGURE 1: Northeastern Ellesmere Island and the location of the St. Patrick Bay ice caps on the Hazen Plateau, near St. Patrick Bay (S.P.B.) and the Beaufort Lakes (B.L.). Source: Bradley, R., & Serreze, M.(1987), "Topoclimatic Studies of a High Arctic Plateau Ice Cap." *Journal of Glaciology*, 33(114), 149-158.

interglacials, like the one we live in today. Ives's thinking was that the past great ice sheets of North America, the most recent being the Laurentide Ice Sheet, at its biggest about 25,000 years ago, initially formed through the accumulation of snow on the extensive Labrador-Ungava plateau of Canada. If the climate cooled for some reason, then the snow line would drop below the altitude of much of the plateau surface. Temperatures tend to decrease the higher one goes in altitude, and above a certain altitude, it is cold enough that the snow that falls during winter survives the summer melt season. This elevation determines the snow line.

The drop in the elevation of the snow line below the level of the plateau surface would raise the reflectivity of the surface (that is, its albedo), reducing how much of the sun's energy is absorbed, further cooling the climate over the plateau, fostering the survival of even more high-albedo snow the next summer, and so on. The snow would eventually compress into ice, forming glaciers that would then coalesce, eventually growing to an ice sheet. Because the initial snow cover would quickly expand via this albedo feedback mechanism, the process was dubbed, with considerable exaggeration, instantaneous glacierization. As early as 1875, James Croll, in his book *Climate and Time in Their Geological Relations: A Theory of Secular Change of the Earth's Climate*, had recognized albedo feedback as an important climate process. He saw that the whole thing could work in reverse as well—warm conditions lead to less snow and ice, lowering the albedo and favoring more warming.

The roughly cyclical timing of past ice ages and interglacials implied a climate force that was itself cyclic. Using ocean core records, in 1976, James Hays, John Imbrie and Nick Shackleton presented convincing evidence that the major ice ages and interglacials of the Pleistocene had been "paced" by variations in earth orbital geometry called Milankovitch cycles.[5] Named after the Serbian geophysicist and astronomer Milutin Milankovitch, these cycles refer to variations in the earth's orbital eccentricity (departure from circular), its obliquity (tilt), and the timing of the equinoxes (precession) that affect how much solar energy reaches the top of the atmosphere at different latitudes and at different times of the year. Although astronomical theories to explain climate change had been around since the 19th century, they had not been verified by observation. The view of Milankovitch cycles as a pacemaker also recognized that orbital conditions favoring ice sheet onset (in particular, cool summers over the higher latitudes of the Northern Hemisphere) would then kick in various climate feedbacks to hasten the cooling, albedo feedback being but one of them. It is now known that carbon feedback is a biggie—as it cools, carbon dioxide comes out of the atmosphere and is stored in the oceans, and further cools the climate.

While Milankovitch effects had nothing to do with the temporary change toward Arctic cooling that Ray discussed in his 1972 paper, the cooling, through its potential link with albedo feedback, was one of the key science themes driving the ice cap study. "How misguided that looks nowadays," recalls Ray regarding the cooling phase, "though at the time it was pretty accurate—cooler and wetter winters on Baffin Island, and colder summers, so upland snow cover was indeed expanding."

The strategy of the NSF-sponsored ice cap study was to set up a weather station on top of the bigger of the two ice caps to measure air temperature, solar energy fluxes, albedo, and other variables. We would compare these to other measurements collected at stations set up at different distances beyond the edge of the ice cap at a similar elevation. Looking at the differences would tell us how the ice cap was affecting the local climate and how far the effects extended beyond its margins. It amounted to a local evaluation of some of the ideas encapsulated in instantaneous glacierization. In the spring of 1982, I invested a lot of time testing the instruments and the state-of-the art data loggers (called Microloggers) from the Campbell Scientific company.

OFF TO THE ARCTIC

We left for Ellesmere Island in May 1982. Beforehand, we'd shipped the major equipment to Resolute Bay in the care of the able government-run Polar Continental Shelf Program that handles logistics in the Canadian far north, directed for many years by Canadian scientist George D. Hobson.[6] I left first, accompanied by Mike Retelle, another of Ray's graduate students, and his assistant, Dick Friend, who would be staying with Mike at Beaufort Lakes for the coring work. We flew from Bradley Field outside of Hartford, Connecticut, to Montreal, and boarded a lumbering 737-200 to Edmonton, Alberta, operated by Pacific Western ("Piggly-Wiggly") airlines. We spent two boozy nights in Edmonton with one of John England's graduate students; we spent days visiting various stores, getting last-minute supplies together. Ray flew into Edmonton a day or so later. He informed me that although I had forgotten to ship the portable generator, a rather severe oversight, I had been accepted into the graduate school.

The next morning, we boarded the twice-weekly Piggly-Wiggly flight to Resolute Bay with a stop in Yellowknife. The specially equipped 737-200 C landed at Resolute Bay in a cloud of dust and gravel. The plan was to be ensconced for a few days at the ugly yet functional Polar Continental Shelf Program building, then head to Beaufort Lakes and the ice caps in a ski-equipped Twin Otter. Aircraft time is expensive. To save money, we would coordinate logistics with John England's group from Edmonton; they would be doing work on and around Polaris Promontory, Greenland, just across the Robeson Channel, which is the narrow ocean channel separating northeastern Ellesmere Island from northwestern Greenland (fig. 1).

Because of bad weather, a few days at Resolute Bay turned into almost a week. We spent the days eating, reading, eating, reading, eating, and moseying down to the weather station to look at the forecasts. We spent evenings at the Resolute Bay Bar. The bar, patronized by the local Inuit, base personnel, civilian and military pilots (Royal Canadian Air Force), and whoever else was around, was something right out of a Robert Service poem—dingy, dark, smoky, raucous, sexist, and not entirely safe.

Finally, the weather started looking better, and we headed out. Twin Otters fly low and slow, and we were looking at about three hours to our destination. However, the weather shut down again, and we diverted to Eureka, lying to the west. The routine over the next few days was pretty much the same as that at Resolute Bay, including nightly visits to the somewhat more upscale RCAF bar. A rule at the RCAF bar was that anyone caught wearing a hat, as I unwittingly did when first entering, was required to buy a round of drinks for everyone. Only by repeatedly pleading ignorance as an American civilian did I escape the sentence, which was very fortunate, given my limited bankroll.

The weather settled again, and Ray and I flew out ahead of the rest of the team. The Twin Otter landed on the ice cover of the largest of the Beaufort Lakes (a pond, really), and the gear was unloaded in short order. The plane headed back to Eureka, picked up Mike and Dick and the rest of the gear, and safely landed on the ice-covered lake a second time. We spent the next two days setting up camp for the Beaufort Lakes party and organizing. The weather continued to hold. The same Twin Otter returned from Eureka, picked up Ray and me with our gear, and made the short hop to the Hazen Plateau and the larger of the two ice caps. It was a rare cloudless, windless day. The temperature was probably 5°F or so, and the fresh snow on the plateau sparkled. The pilot dropped us off with our food, gear, white gas for the stove, regular gas for the generator, and a two-way radio, and then roared off.

It took about a week to set up camp and the weather stations. We had a large aluminum-framed igloo-style tent for sitting and cooking, and a couple of smaller tents for sleeping (fig. 2). A Coleman stove in the igloo tent served for cooking and melting snow for drinking water, and as a source of heat. Potential death by carbon monoxide poisoning never entered our minds. The sleeping tents were unheated, but we had warm sleeping bags.

Once everything was up and running, attention turned to a detailed survey of snow conditions on the ice cap. The Hazen Plateau, like almost all of the Canadian Arctic Archipelago, is a very dry environment, classified as a polar desert. The average total annual precipitation is on the order of only 20 centimeters (less than 8 inches), but because it is such a cold environment, evaporation is also quite low. Hence, in summer, it can be an oddly damp desert. Snow depths on the ice cap were typically in the range of 30–50 cm, representing almost all of the precipitation that had fallen since the end of the previous summer. Every so often, we measured the water equivalent of the snowpack. This required sticking a snow-coring tube through the snowpack to its base, recording the depth of the snow, extracting the coring tube along with its sample of snow, dumping the snow sample in a plastic bag, and then weighing the bag of snow. Knowing the snow depth and cross-sectional area of the tube, we could determine the snow volume. By measuring the weight (more properly, the mass), we could also get the snow density and water equivalent of the snow—that is, how much actual water is contained in

FIGURE 2. Camp at the edge of the ice cap, early June 1982, with a full snow cover. Courtesy of the author.

the snow. These numbers told us how much accumulation there had been on the ice cap through the previous autumn and winter.

The next step was to insert a series of aluminum stakes into the ice, using a hand-powered ice drill. By measuring the distance from the ice surface to the top of the stakes during spring (before melt starts) and then again at the end of summer, and combining this with information from the snow surveys, we could determine how much melt had occurred during the summer. The difference between the autumn/winter mass gain and the summer snow and ice loss represented the annual mass balance of the ice cap. A positive mass balance meant a growing ice cap (because of more autumn/winter accumulation than summer melt); a negative balance (more summer melt than autumn/winter accumulation) meant a shrinking ice cap.

Back in 1972, Canadian scientists Harold Serson and J. A. Morrison, despite foul weather, managed to insert eight aluminum stakes in transect partway across the ice cap—the start of a stake network. Late in that same summer, by which time the melt season had pretty much ended, the ice cap was again visited by Geoffrey Hattersley-Smith and A. Davidson. They found the ice cap and surrounding plateau to be completely snow-covered, pointing to a positive mass balance for that year.[7] This was very different from the situation in 1959, when high-altitude air photographs showed the ice caps to be free of snow, with exposed dirt layers standing out sharply against the dark tundra, pointing to a negative mass balance for that year.

Once our initial survey was done, things settled into a satisfying routine, with odd hours because of the 24 hours of sunlight. With the arrival of summer, snow started to melt off the surrounding tundra, and later off the ice cap. The data from the weather stations showed that the ice cap was having a strong impact on the local climate, which meant that I would have something to write about for my master's thesis. We conducted further surveys and explored the surrounding area, including the smaller of the two ice caps.

I was totally into it and took great pride in my measurements and in providing precise weather reports to the Polar Continental Shelf Project base, with impeccable radio etiquette. Passion bordered on the disturbing, such as one day when, despite a complete whiteout, with visibility of perhaps 100 feet and, of course, no GPS, Ray and I tried to hike out to download data from the Microloggers. After half an hour, we came upon footprints in the snow. We were shocked. Who else could possibly be out here? Russian spies? But the footprints were ours! We had walked in a circle.

In the evenings under the midnight sun, nursing valuable rations of scotch, Ray related stories of the age of early Arctic exploration. There were stories of scientific triumph, such as Fridtjof Nansen's idea of freezing his stout little ship, the *Fram*, into Arctic Ocean pack ice off the coast of the New Siberian Islands, letting it drift with the currents to determine the basic circulation of the ocean. But many were of tragedy. Ray, being British, was enamored with the disappearance of Sir John Franklin's ships, the *Erebus* and the *Terror*, which set out in 1845 to conquer the fabled Northwest Passage—the shortcut between the Atlantic and Pacific Oceans through the channels of the Canadian Arctic Archipelago—but failed to emerge in the Pacific, and the later discovery of relics from the expedition and gravesites on Beechey Island, where it appears that the crew of originally 129 men over-wintered in 1845/1846. There was evidence that as the end neared, some of the men resorted to cannibalism, shocking Victorian England. During the 1903–1906 voyage of the *Gjøa*, Roald Amundsen finally conquered the Northwest Passage with six companions, but it took them two and a half years to navigate the ice-choked channels. Ray was adamant in his belief that Robert Peary never made it to the North Pole, but Frederick Cook's claim of being the first to the pole a year earlier than Peary, in April 1908, seemed at least equally dubious.

Most fascinating to me as an aspiring scientist (or "cub scientist," as Ray would say), was the story of Lt. Adolphus Greely's Lady Franklin Bay expedition to Discovery Harbor, Ellesmere Island, as part of the First International Polar Year (IPY). The IPY, which took place in 1882/1883, was the first major international effort to collect data to better understand the Arctic environment. Twelve scientific stations were established, including Fort Conger at Discovery Harbor, just down the coast from St. Patrick Bay. While Greely is known to have explored much of the area around Fort Conger, he never mentioned the ice caps. Perhaps the extensive snow cover over the plateau during the colder conditions of the late 19th century—the tail end of the Little Ice Age—masked their presence. The Fort Conger site had actually first been used as a wintering site by the crew of the *HMS Discovery* during the British Arctic Expedition of 1875, led by George Nares. The expedition was an attempt to reach the North Pole via Smith Sound. Although it failed to reach the pole, the *HMS Discovery*, along with a second ship, the *HMS Alert*,

FIGURE 3. Members of the Lady Franklin Bay expedition. Greely is sitting in the bottom row, fourth from the left. Courtesy of National Archives, photo no. 200-LFB-134.

explored large parts of the coasts of both Greenland and Ellesmere Island.

The order given to Greely was that if relief ships failed to reach him, he was to retreat with his men southward down the coast. While his party would have been able to make it through winter quite well at Fort Conger, given the plentiful game in the area, Greely carried out his orders. They retreated, and winter overtook the party. Of the original expedition members (fig. 3), only seven, including Greely, lived to meet the relief ship in June 1884. Some of the meteorological records nevertheless survived.

CHAPTER 1

GAINING EXPERIENCE

Our plan was that partway through the field season, Ray and I would fly to Polaris Promontory, Greenland. There, Ray would team up with John England. Meanwhile, I would fly to Beaufort Lakes with a fellow named Chris, and then hike back to the ice caps. This plan got delayed by an impressive blizzard that kept us holed up. On July 4, in good weather, we hiked down from the ice caps about 10 miles to a raised proglacial delta near St. Patrick Bay where, by previous agreement established by radio, a Twin Otter would be waiting. The plane arrived as planned, and we clambered on board, flew to Polaris Promontory, and dropped off Ray. Chris and I returned to Beaufort Lakes, spent the night with Mike Retelle and Dick Friend, and then hiked back up to the ice caps. Mike and Dick went part of the way up with us. Along the way, we were attacked by a group of four ill-tempered musk oxen. A shotgun blast over their heads, meant to dissuade them, instead provoked ire, and we were obliged to retreat to the safety of a small, steep hill. Chris and I eventually made it back to the ice cap in good order and took advantage of the half bottle of scotch reserved for the triumphant arrival.

We expanded the stake network and conducted surveys of the snow and ice conditions every week. It seemed that it was to be a negative mass balance year. During our expedition, all of the snow melted off, leaving bare ice with a cryoconite surface. Cryoconite is a powdery, windblown dust, comprised variably of small rock particles, soot, and microbes. It is dark and hence has a much lower albedo than the ice. It tends to clump to create small holes, which in the case of the ice cap, were typically a few centimeters deep and 5–10 centimeters in diameter. I had never seen anything like it. The tents, initially set up right near the edge of the ice cap, became wet and miserable. Eventually, we moved them to a better location. The food selection slowly narrowed to a choice between cans of tuna fish, Kraft macaroni and cheese, and canned French-style green beans. Sanitary conditions were deplorable, but temperatures generally near the freezing point helped in this regard. By the time we left the ice cap at the end of July, with autumn already setting in on the Hazen Plateau, I knew every nook, cranny, elevation change, and mood of the ice cap. I felt a sense of responsibility and ownership.

A helicopter took us down to Fort Conger, where we joined Mike Retelle, Dick Friend, and John England. Waiting for the Twin Otter to land at the short airstrip and take us back to Resolute, we explored the ruins of the fort and the surrounding area. After Greely left on his ill-fated retreat down the coast, Fort Conger stood idle until Robert Peary stopped there during his unsuccessful 1899 expedition to reach the North Pole. Peary again visited Fort Conger in 1905 and 1908. He tore down the original three-room fort and used the wood to construct several smaller buildings better suited to the environment. In later years, other expeditions used the site. A fascinating sight during our several-day stay was the stack of numerous bleached skulls of musk oxen shot for food back in the days of Greely and Peary.

The year rolled by and in April 1983, I gained additional experience as an assistant to the renowned Canadian glaciologist Roy (Fritz) Koerner, doing mass balance measurements on the Devon Ice Cap, on central Ellesmere Island, and on the Meighen Island Ice Cap.[8] A case of frostbite on my nose and face while at the top of the Devon Ice Cap instilled wisdom regarding always having the proper gear. I also briefly visited the Ward Hunt Ice Shelf on the northern end of Ellesmere Island, the likely source of a number of tabular (flat-topped, like a table) icebergs that had been discovered floating around the Arctic Ocean, some of which found use as platforms for scientific observations, such as Hobson's Choice and T3 (also known as Fletcher's Ice Island, named after its discoverer, U.S. Air Force Colonel Joe Fletcher). Ice shelves form when glacial ice flows out into the ocean, forming a flat floating sheet. Tabular icebergs occasionally break off from their seaward edge. While Ward Hunt is tiny compared to the ice shelves surrounding the Antarctic continent (which sometimes produce tabular icebergs the size of Delaware, such as iceberg A68, which calved from the Larsen C ice shelf in summer 2017), it was the largest one in the Arctic. Very little of it is left today.

Ray and I got back to the ice caps in late May 1983, with a new field assistant (yet another Mike) in tow. We set up camp and the weather stations, and awaited the melt season. The data showed that the mass balance of the ice caps in 1982 had indeed been negative, with all the snow melting off and some of the bare ice melting away as well. So maybe the Arctic was warming up, as expected. But by sharp contrast, just like Hattersley-Smith and Serson had experienced in 1972, the snow never melted away in 1983. I felt vindicated, and we jokingly referred to 1983 as the Year of Instantaneous Glacierization. The stake network was further expanded in anticipation of future visits to assess the mass balance (fig. 4), and we collected high-quality weather data. For my master's thesis, I planned to look at the effects of the ice cap on the local climate for two contrasting years. Ray left partway through the summer, and Mike and I finished a productive field season. We packed everything up in late July and, as before, flew by helicopter down to Fort Conger, to await the arrival of the Twin Otter the next day to take us back to Resolute. Again, our food supply was very low. On the last evening, we dined on two cans of French-style green beans, and an Arctic hare illegally and rather messily dispatched with the shotgun.

I never returned to the ice caps. I wrote my master's thesis; Ray insisted that it should weigh at least a kilogram, and at over 200 pages on heavy thesis bond paper, it passed muster. We eventually wrote a couple of papers on the mass balance and the energy balance of the ice caps, and then I moved on to eventually earn a PhD

FIGURE 4. Field assistant M. Palecki drilling into the ice during expansion of the stake network in 1983. Courtesy of the author.

at the University of Colorado in geography in 1989 and embark on a career in Arctic climate science.

GOING, GOING, GONE

More than 30 years have passed, and the Arctic I visited back in the early 1980s is fading in the rearview mirror. While I had not forgotten about “my” little ice caps, there was so much going on in the Arctic that I hadn’t really kept up with how they were doing. In the spring of 2016, on a whim, I browsed through online satellite images from the NASA MODIS instrument (Moderate Resolution Imaging Spectroradiometer) to check up on them. I couldn't locate the ice caps, so I walked down the south hallway of the National Snow and Ice Data Center (NSIDC) to the office of my colleague Bruce Raup. Bruce was involved in an international project to map the world's glaciers and ice caps using satellite data at higher spatial resolution (15 m) from a NASA instrument called ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer). I gave him the coordinates, and we looked for a while to find summertime clear-sky images for recent years when the bright ice caps ought to be standing out prominently against the plateau surface. We finally found them, and I could not believe what I was looking at. They had nearly disappeared.

Back in 1959, when aerial photographs were taken, the larger ice cap had an area of 7.48 square kilometers and the smaller one about 2.93 square kilometers. In August 2001, University of Massachusetts scientists Carsten Braun and Doug Hardy, two of Ray Bradley's later generation of graduate students, had returned and conducted a detailed survey of the ice caps. They found some of the aluminum stakes that had been so laboriously drilled into the ice, but all of them had melted out and were lying on the ground. They measured the perimeter of both ice caps using portable GPS. By 2001, the larger and smaller ice cap had already shrunk in area, respectively, to 62% and 59% of their 1959 areas.[9] This I had known. However, the NASA ASTER satellite data showed that as of July 2016, both of the ice caps

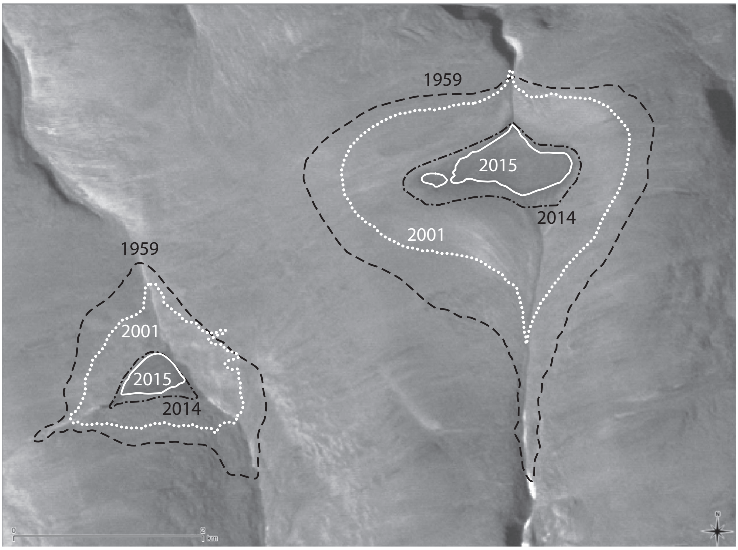

FIGURE 5. The St. Patrick Bay ice caps as seen on August 4, 2015, from ASTER imagery, along with the margins of the ice caps for August 2014 (also from ASTER), 2001 (from GPS surveys by C. Braun and D. Hardy), and 1959 (from aerial photography). Courtesy of the author.

covered only 5% of the areas that they did back in 1959 (fig. 5)! They are just ice patches now—the term “ice cap” is being kind. Quite remarkable is how they noticeably shrank even between 2014 and 2015. This appears to have been in direct response to the especially warm summer of 2015 over northern Ellesmere Island. What remains of the ice caps will likely vanish in only a few years.

From the available evidence, the ice caps probably formed back in the Little Ice Age (about 1650–1850), and at maximum extent they were several times larger than observed in 1959. They have been in an overall state of decline ever since, interrupted by periods of growth. They may have eventually disappeared without our help, but that is a moot point. I've been to a lot of interesting places since 1983, but since looking at the ASTER data, a day has rarely gone by that I haven't thought about my early adventures on those ice caps. As they melt away, part of me is also dying.

UNCHARTED WATERS

The climate records are clear. Surface temperatures over the Arctic as a whole are rising twice as fast compared to the rest of the globe. The Arctic is quickly losing its summer sea-ice cover, and wintertime losses are also starting to become prominent. Permafrost is warming and in some areas is thawing. Arctic glaciers and ice caps and the Greenland ice sheet are all losing mass, contributing to sea-level rise. The Ward Hint ice shelf that I visited back in 1983 is almost gone. Snow arrives later in fall, and melts earlier in spring than it used to. The character of precipitation is changing, with rain-on-snow events leading to massive reindeer mortality episodes.[10] Arctic ecosystems are shifting, and recent years have seen unprecedented heat waves over the Arctic Ocean during autumn and winter. The forces of change seem to be unstoppable. Looking forward, well within this century, perhaps only 20 or 30 years from now, the Arctic Ocean will be essentially free of its floating sea-ice cover in late summer. Sea ice will hence be but a seasonal feature. The two little ice caps near St. Patrick Bay that set me on a path to a career in Arctic climate science will be long gone.

For many people, the Arctic seems like such a faraway place, and given the more immediate challenges that they may be facing, such as putting food on the table and keeping a roof over their head, the changes unfolding in the North may seem unimportant. This is understandable. But there are also those who, for various reasons, choose to ignore what is happening. Then there are those who, largely out of self-interest, are in denial and maintain that it's all part of some natural climate cycle. Some even take the astonishing stand that the scientists are somehow making it all up or blowing it out of proportion. This is foolish.

It can be unpleasant to wake up to reality, but the Arctic is sounding alarm bells that cannot be ignored, and there is no snooze button. What the Arctic is telling us is that climate change is not some vague threat somewhere out in the future that may not even turn out be real, but is rather already here and here in a big way. The meltdown of the North is a clear demonstration that humanity has come to the point where we are geo-engineering our own planet—we have entered the Anthropocene. As we'll learn in coming chapters of this book, even as recently as the early 1990s, the Arctic largely seemed like the Arctic of old, and it took at least a decade for the science community—including myself—to fully come around to the inescapable conclusion that the region was being transformed. And since the dawn of the 21st century, the changes have been coming ever faster and are ever more troubling. The magnitude and scope of the changes that are unfolding have shaken the science community to its roots. We have entered uncharted waters.

If the theme of this book could be summed up in a single word it would be *complexity*. The complexity of the Arctic system is the very reason there are still so many unknowns out there regarding not just the Arctic's future, but impacts beyond its boundaries. Arctic change is certainly affected by what is happening in lower latitudes, but does it go the other way? Will Arctic amplification—the outsized warming of the Arctic compared to the rest of the globe, affect weather patterns in lower latitudes? Has this already happened? Will thawing permafrost lead to a large release of carbon back to the atmosphere, exacerbating the warming not just in the Arctic but for the planet as a whole, and if so, when will this start and how strong will the effect be? Melt of the Greenland ice sheet and of Arctic ice caps and glaciers will certainly continue to contribute to rising global sea levels, but by how much? One pretty sure thing is that as the Arctic continues to become more accessible, it will be a busier place, with less sea ice opening up shipping routes and making rich stores of oil and natural gas under the Arctic seafloor more accessible. Conflicts may arise.

How did we get to this point? To answer this question, it is necessary to first take a close look at the Arctic of today, then step back again in time, to when, in fits and starts, it first began to be noticed that the Arctic was stirring.