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Fifty Years of McCall Glacier Research: From the International Geophysical Year 1957–58 to the International Polar Year 2007–08

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INTRODUCTION

McCall Glacier, located in the eastern Brooks Range of northern Alaska (Fig. 1), has the longest and most complete history of scientific research of any glacier in the U.S. Arctic. Spanning the period from the International Geophysical Year (IGY) in 1957–58 to the Fourth International Polar Year (IPY) in 2007–08, this research has resulted in perhaps the best record of recent climate change and its impacts in this region of the Arctic. Creation of this record played a major role in the lives of numerous people associated with the Arctic Institute of North America and the Universities of Alaska and Washington. This essay attempts to document the history of research on the glacier, as well as the evolution of research logistics there, through personal anecdotes from some of the scientists involved.

McCall Glacier today is about 6.5 km^2 in area and faces mostly north, towards the tundra and the Arctic Ocean coast near Barter Island, Alaska, not far from the Yukon border. *The Dictionary of Alaska Place Names* (Orth, 1967:607) lists the glacier as follows:

> McCall Glacier: *glacier*, heads on Mt. Hubley in Romanzov Mts., trends N 5 mi. to its terminus at head of McCall Creek, 10 mi. E of Mt. Michelson, Brooks Ra.; 69°20′ N; 143°49′ W.
>
> Named in 1956 by R.C. Hubley for John Gill McCall, glaciologist, University of Alaska, who died in 1954.

John Gill McCall, a World War II veteran, earned his bachelor's degree in geology at the University of Alaska in 1949 and the first PhD in glaciology ever awarded by Cambridge University four years later. In the fall of 1953, he returned to Alaska to head the Geology Department at University of Alaska Fairbanks (UAF). Known as a glacier expert, he became involved in the rescue of a mountaineering party that had completed the first traverse of Mount McKinley from the southeast side across the peak and down the Muldrow Glacier to Wonder Lake. On the descent, the roped-up party fell on a steep ice slope of the

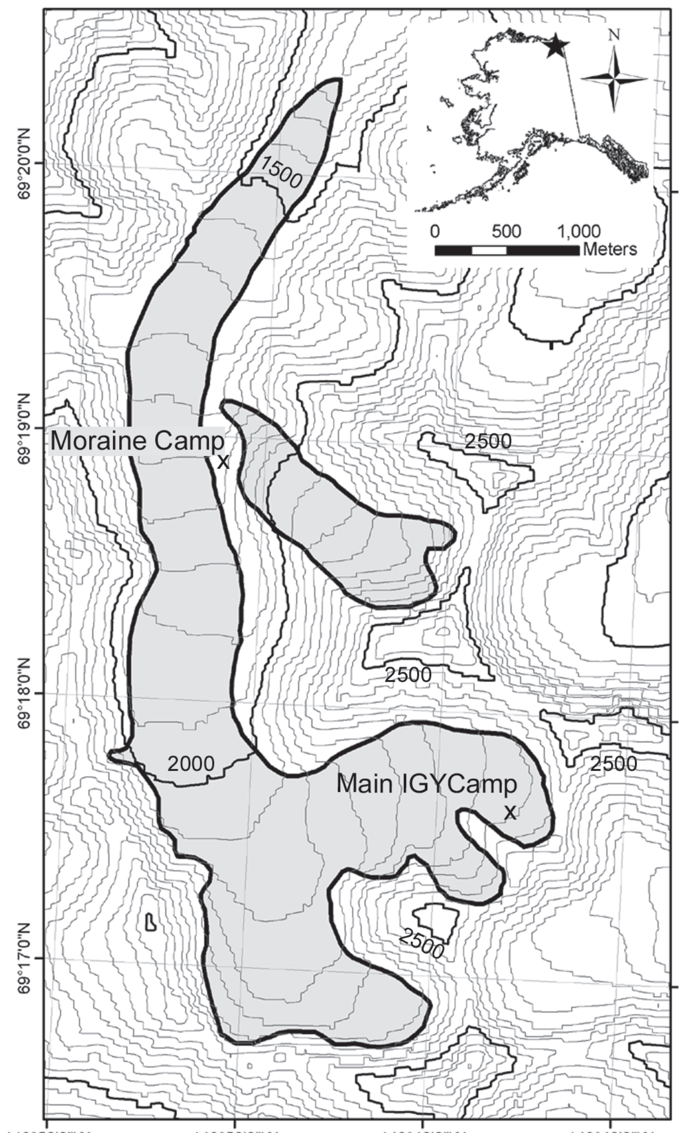

FIG. 1 Map showing McCall Glacier and its location in the Brooks Range. Map contours are in meters, based on the 1956 U.S. Geological Survey map.

Muldrow Glacier, where one climber was killed and another badly injured. McCall helped in the evacuation of the wounded person, who was left in a tent on the glacier. John McCall died of polio in 1954, shortly after this event.

RESEARCH STARTS DURING THE INTERNATIONAL GEOPHYSICAL YEAR

As a contribution to the IGY, the Arctic Institute of North America, with support from the U.S. Air Force, planned an 18-month study of McCall Glacier. The idea for this came from Richard Hubley and Walter Wood of the U.S. IGY Glaciological Panel. Hubley was a graduate of the University of Washington, having received his PhD in 1956 in the Atmospheric Sciences Department, only the second PhD awarded by the department. Before going to McCall Glacier, Hubley had served as planner and coordinator for the U.S.-IGY Glaciology program in the Northern Hemisphere, working at the National Science Foundation (NSF) in Washington, D.C. The initial team on the glacier included Richard C. Hubley as chief scientist (until his death in October 1957), John Sater as junior scientist and chief surveyor, Charles Keeler as assistant scientist, and Robert Mason as logistics officer and scientific assistant.

None of the original IGY team members were available to contribute to this story, but Norbert Untersteiner helped with the construction of the glacier camps. In April 1957, reconnaissance flights of the U.S. Air Force Alaska Command had located an ice floe 1000 km north of Point Barrow that was deemed suitable for the establishment of IGY Drifting Station Alpha. The teams of scientists from Columbia University, the University of Washington, and the U.S. Weather Bureau, including Untersteiner, waited at the former Ladd Air Force Base (now Fort Wainwright) near Fairbanks while a crew of four civilian construction workers and Air Force personnel was preparing the camp for occupancy. At the same time, Walter Wood and his son Peter were also at Ladd AFB, on behalf of the Arctic Institute of North America (AINA), to coordinate the deployment of two small camps for Richard Hubley's IGY project on McCall Glacier.

As a person with experience working in the mountains, Untersteiner was given the chance to help in this glacier deployment. The planes used for this mission were the legendary twin-engined C-119 "flying boxcars," with ample cargo space and a cockpit mounted between two slender fuselages. In brilliant weather, they made two flights from Ladd AFB over the snow-covered Brooks Range to the glacier, where they pushed boxes with camp and scientific gear out the huge cargo door. In total, more than 30 tons of fuel and 18 tons of supplies dropped onto the glacier during the IGY deployment. On the last return flight on 10 May, the party landed at Barter Island, where the scientists remained while the C-119 returned to Fairbanks. On the same afternoon, John Sater and Charles Keeler (AINA), Art Rich (Martin-Marietta), and Untersteiner were flown to McCall Glacier in a small Cessna by Al Wright, a renowned bush pilot who looked like Spencer Tracy. After a smooth landing on the lower, gently sloping part of the glacier, they pitched a tent for the night before making the hike up the glacier to visit Hubley and Mason, who were already established at the upper station. Hubley seemed full of energy and enthusiasm and ready to brave the prospect of many months of work in this remote region.

The next day was spent collecting all the scattered crates dropped from the air. On the third day, Sater and Untersteiner built a rock platform for a truncated Jamesway hut on the lateral moraine near the lower camp. (Little did they realize that this base would be re-used in the late 1960s to erect a plywood hut, which survives there to this day.) The main camp, comprising five half-units of Jamesway huts, was established on the uppermost of the three cirques of the glacier, with the lower moraine camp as a secondary location in the ablation area. An emergency retreat camp, another Jamesway hut, was erected on the shores of Jago Lake in the foothills, about 15 km from the terminus. All of these camps played a role in subsequent expeditions. On 13 May, Untersteiner returned to Barter Island with Al Wright because he had received word that the ice camp in the Beaufort Sea was ready for occupancy. His brief excursion to McCall Glacier was a fortunate and memorable event of initiation for a novice to the Arctic.

In the summer of 1957, Walter Sullivan, the leading science writer of *The New York Times*, visited McCall Glacier to collect material for his book on the IGY, in which he describes his experiences there (Sullivan, 1961:275–279). He and Dick Hubley discussed the goals and history of the project. Sullivan found Hubley to be quiet and, in retrospect, perhaps somewhat preoccupied, but there was no evidence of the deep-seated trouble that later led to tragedy. Sullivan even helped with dropping supplies on the glacier from a Cessna-180.

The weather and climate of the glacier were major topics of the research. Both are influenced by the Brooks Range, which provides a topographic barrier between the extreme continental climate of interior Alaska and the polar climate of the Arctic Basin, with both regimes influencing the local glacier climate. The glacier lies above the prevailing summer stratus cloud decks that cover the Arctic Ocean and extend into the foothills of the Brooks Range. It was found that the glacier's weather was influenced mainly by storms moving over the ocean north of the glacier. Storm winds were westerlies but were considerably modified by local topography in the lower sections of the glacier. Glacier and katabatic winds characterized the meso-scale circulation between storm periods.

Even during the last glacial maximum, glaciation in the Brooks Range was never very extensive, since precipitation is relatively low (ca. 500 mm of water, falling largely as snow in spring and fall) and summer temperatures are high. Keeler (1959) documented five distinctive advances of McCall Glacier. The farthest of these advances gave the

FIG 2. A) A supercub unloads people and supplies in the upper cirque of McCall Glacier, with the IGY camp in the background. B) Main IGY camp on McCall Glacier after a blizzard. Photos by A. Post, AINA.

glacier a length of approximately 20 km where it joined a glacier that used to fill the Jago River valley, compared with its 1957 length of about 8 km. Mason studied ice temperatures and heat flux in the upper cirque of McCall Glacier, in a borehole drilled down to 90 m. While the upper 15 m showed strong seasonal variations, below that level the temperature was fairly constant, with a value close to -1˚C, because of surface meltwater that percolated into the cold firn and refroze, releasing its latent heat. Keeler also reported on the ablation on the lower McCall for the summer of 1957. He provided an ablation map for the glacier and discussed the snow cover and superimposed ice. He found that the ablation rates were 2–3 cm/day: surprisingly, not much less than on the Blue Glacier in Washington State. These began the first comprehensive measurements of ablation on a glacier in the U.S. Arctic, although there was work on a small glacier on nearby Mt. Michelson at the same time, and Leffingwell had studied Okpilak Glacier briefly in 1906.

The work on the glacier proceeded well, but in October a tragic event occurred: Hubley committed suicide, following severe depression. *Arctic* (1957:187) published the following announcement:

> Richard Carleton Hubley, 1926–1957
>
> On October 29, 1957, word was received by the Institute of the death of Richard Hubley while leading the International Geophysical Year glaciological program on McCall Glacier, Brooks Range, Alaska.
>
> Dr. Hubley's death has come at a time when he has assumed national—and even international—leadership in his chosen field. North American science has been slow in building a coterie of scientists in the field of glaciology. Of those we have, Richard Hubley was one of the most distinguished. Science can as ill afford his loss as can we who knew him as a companion in the office and among the high snows.

It was a sad ending after such a promising start. The field station was closed in October but reactivated in late February 1958 by Keeler, Mason, and Sater, with Svenn Orvig of McGill University as the new scientific leader of the project. Austin Post, who considered Dick Hubley his best friend at the time, also returned with the scientific party out of respect for Hubley. Post helped to finish the project by leading the surveying and other measurements, including photo documentation. His photos are perhaps the most lasting and often used legacy of the IGY project (see Figs. 2 and 6). The stations were occupied from June to October 1957 and from February to August 1958, when they were abandoned in place. In the following years, a peak overlooking McCall Glacier and an adjacent glacier were named after Hubley to honor his contributions to science. Three reports on the McCall Glacier project (Keeler, 1959; Mason, 1959; Sater, 1959) were published in the June 1959 issue of *Arctic*. The meteorological observations made on the glacier, typically every one to six hours, were later edited and published by Orvig (1961), but without Dick Hubley around to analyze them, they remained unanalyzed glaciologically for another 45 years.

UNIVERSITY OF ALASKA RESEARCHERS RETURN TO THE GLACIER, 1969–72

In 1969, the National Science Foundation awarded a grant to researchers at the University of Alaska Fairbanks to resume the study of McCall Glacier. These researchers

FIG. 3. The IGY sign for the moraine camp, found in 1969 and held in the photo by Gunter Weller (left) and Charlie Fahl (right). Photo by G. Wendler.

argued that the glacier was of special importance since it lies at the intersection of two glacier "chains" recommended for intensive study in the International Hydrological Decade (IHD): the Arctic Circle and the American chains. They stated that since it had been studied during the IGY, McCall Glacier had a useful past data base and that the United States should study at least one Arctic glacier on its own territory. McCall Glacier was indeed the only Arctic glacier studied by the United States for some time. The goal of the research was to conduct a comprehensive investigation of the heat, ice, and water balance of the glacier under the auspices of the IHD.

The principal investigator of the research project was Prof. Gerd Wendler, a PhD graduate of the University of Innsbruck who had done research on glaciers in the Austrian Alps. Prof. Carl Benson, with a PhD from the California Institute of Technology (Caltech), was a senior glaciologist at the Geophysical Institute. He had conducted pioneering snow research on traverses across Greenland, under the auspices of SIPRE (Snow Ice Permafrost Research Establishment), now CRREL (Cold Regions Research and Engineering Laboratory), of the U.S. Army. Benson and Prof. Gunter Weller were the two main scientists participating in the studies with Wendler. Weller, with a PhD from the University of Melbourne, Australia, had worked on heat and mass balance studies in Antarctica before joining the UAF faculty.

On 1 April 1969, Wendler and Weller, in a Cessna 180 flown by Fairbanks pilot Tom Classen, made a reconnaissance flight from Fairbanks up to the Brooks Range to locate the glacier and any remains of the IGY camps. Circling over the glacier after a long flight, they could detect no sign of past human occupation on the ice. It later turned out that the upper cirque camp had been completely buried by snow, and no sign remained of it. The glacier surface appeared to be very rough, and although the scientists were prepared to land, the pilot was reluctant to do so. They returned home, refueling the plane at Arctic Village on the southern slopes of the Brooks Range, after landing on the ice of the frozen east fork of the Chandalar River. The entire flight in excellent weather took six and a half hours.

At the end of April, the party organized an overland trip by snowmobile from the village of Kaktovik on Barter Island, located about 100 km from the glacier. Wendler, Weller, and graduate student Charlie Fahl set out with three snowmobiles. They were led by two Inuit guides from Kaktovik, one accompanied by his wife, who cooked for them. They drove up the Jago River valley, over ripe snow and partly broken-up river ice, and got fairly wet in the process. Wendler shot a few ptarmigan and they had a good meal in the evening, each fishing out a whole bird—by hand—from the broth in a big cooking pot. They reached the glacier in two days and managed to get their own Ski-Doo up the steep frozen waterfalls and aufeis fields that form each winter below the glacier's terminus. They found the moraine camp completely ruined, but retrieved from the rubble the original camp sign—with the still legible words: "Moraine Camp, McCall Glacier Project, AINA"—which remains at the camp to this day (Fig. 3). A meteorological instrument shelter was set up on the moraine, as well as a big corrugated standpipe for the water level recorder in McCall Creek. Several accumulation/ablation stakes were drilled into the glacier ice, and an airstrip 3000 feet long was laid out and marked with stakes and surveyor tape. Leaving their Ski-Doo and other equipment on the glacier, the party returned with the three Kaktovik villagers on their snowmobiles.

Logistical support for the glacier research turned out to be difficult. In June, a first attempt was made to land a Cessna 180 on the glacier. Al Wright, the same pilot who had flown Untersteiner to the glacier during the IGY, landed to bring some gear and Eldon Thomson, an engineer at UAF's Geophysical Institute, who was to do a quick survey of the site for the building to be constructed. When they did not return after six hours, and since there was no radio communication, the Naval Arctic Research Lab (NARL) at Barrow was alerted and sent a rescue plane, which reported that the two on the glacier were safe but could not take off because of the rough glacier surface and strong down-glacier katabatic winds. After 10 hours of compacting the snow surface with the Ski-Doo, Wright and Thomson flew out to Barter Island, where the rest of the glacier team was waiting. Al Wright reported that it was too dangerous at that time for small aircraft to land on the glacier.

With help from the Office of Naval Research and NARL, then directed by Dr. Max Brewer, the project was able to continue. NARL chartered a large Huey helicopter that brought in building materials for a new moraine camp in five separate flights from Barter Island. The floorboards of the old Jamesway hut on the moraine were still useful for constructing the building, but everything else had to be flown in. Later NARL provided parachute airdrops of food

FIG. 4. Parachutes dropped from a NARL R4D supplied the researchers on the glacier with food and fuel in the 1970s. Photo by G. Wendler.

and fuel from their R4D aircraft during the four-year operation of the project (Fig. 4), and Cessna flights to take people in and out from the glacier, usually by floatplane from Jago Lake, when it was not possible to land on the glacier itself.

Airdrops were an interesting experience, both for those in harness on the aircraft, who pushed out crates and drums through the cargo doors, and for those on the ground, who watched the drops. On one occasion, Benson and Weller watched free-falling 55-gallon drums that had separated from their parachutes come hurtling towards them, producing large impact craters and big splashes of diesel and gasoline fuel on the glacier surface. Whoever was on the glacier, however, did appreciate the steaks, eggs, and other good things that came raining from the sky. Graduate students Charlie Fahl and Dennis Trabant were the first to spend several weeks on the glacier, and it was almost continuously occupied by at least two people for most of the summers. An automated weather station was supposed to give year-round climate records, but it functioned only intermittently. Several researchers from the Institute of Low Temperature Science of Hokkaido University, Japan, also conducted research on snow and ice properties on McCall.

Getting back to civilization sometimes proved to be a challenge. On one occasion in 1969, Benson and Weller camped in the ruins of the IGY Jago Lake camp, which showed evidence of grizzly bear visits, including tufts of bear hair that had been ripped out by projecting nails. Waiting through almost a week of bad weather to be picked up by floatplane, they ran out of food, but found old IGY military C-rations scattered over the tundra. Some showed marks of bear teeth in the tin cans, but many still had edible contents, such as baked beans and even bread, which were very welcome.

Attempts were also made to visit the glacier in winter. On one trip in November 1969, Weller and Fahl were flown to McCall Glacier to check out the malfunctioning automated weather station. Pilot Claude O'Donovan flew them in a Hiller FH-1100 helicopter from Fairbanks via Livengood, Bettles, and Anaktuvuk Pass to the pipeline construction camp at Sagwon. After staying overnight at Sagwon, they were flown to the glacier, but with very low temperatures and drifting snow high up on the exposed ridge of the upper part of the glacier, they were unable to revive the station.

The results of the glacier study were published in 14 journal articles and several other publications (e.g., Fahl, 1973; Wendler and Ishikawa, 1974; Wendler and Weller, 1974; Weller et al., 1975). The heat balance studies showed that radiation is the most important factor influencing snow and ice melt, contributing about 60% of the energy from all sources. On the other hand, the magnitude of the radiation balance in summer was only about half that of the tundra north of the Brooks Range at Barrow. High surface albedo—and to a lesser degree, the screening of the sun by the mountains surrounding the glacier, which reduces the duration of sunshine on the glacier surface by a mean of 39% in summer—combined to give a low radiation balance, favorable to the continued existence of the glacier. The mass balance of the glacier was negative during each of the four years of intensive monitoring (1969–72). The mass balance surveys were conducted by placing numerous accumulation/ablation stakes on the glacier, by measuring several cross-flow profiles by theodolite, and by the hydrological method of measuring precipitation and runoff from the glacier. Two stakes from the IGY research were still in place in the middle reaches of the glacier, at an altitude of 2065 m, in 1969. Runoff from the glacier occurred all year long. From September to early June, this runoff, in the form of groundwater, re-froze to form large perennial aufeis deposits below the glacier, which were repeatedly surveyed. A study of the physical characteristics of the snow, by examining its stratigraphy, showed a hard, wind-packed snow layer underlain by a thick layer of depth-hoar. The depth-hoar was destroyed during the summer at all points on the glacier and served as a site for localization of ice lenses, which form in the firn by refreezing of percolating meltwater. When Trabant and UAF Professor Will Harrison drilled a deep thermocouple string into the glacier near the moraine camp, they found ice temperatures of about –10˚C near the surface and near melting at the bottom, indicating that the ice may not be frozen to its bed everywhere beneath the glacier.

In 1971 a photogrammetric flight was conducted, repeating one first carried out in 1958. This flight allowed

FIG. 5. GPS surveying on the glacier can be carried out in nearly any weather, which is both good news and bad news. Photo by M. Nolan (May 2006) of Thomas Nylen of UNAVCO and Jason Geck of UAF heading out to survey as the clouds descend.

another method of calculating the total mass loss of the glacier for the period 1958–71. In addition to the photogrammetric method, changes in the mean height of the equilibrium line and a hydrological method were used to calculate the mass balance of the glacier. All three methods gave mean values on the order of -100 to -200 mm water equivalent annually (Dorrer and Wendler, 1976).

NEW RESEARCH TEAMS AND METHODS, 1993 TO THE PRESENT

Research on the glacier did not begin again in earnest until 1993, when Keith Echelmeyer (UAF) was awarded an NSF grant. Echelmeyer, who had earned his own PhD from Caltech, was supervising that of Bernhard Rabus at UAF, and together they led the scientific efforts from 1993 to 1997. A major part of this PhD involved the rescue of surveying and mapping data from the 1950s and 1970s. The original field books were scoured and the calculations were double-checked to ensure accuracy. Many of the locations for the new mass balance and ice velocity stakes were based on former locations.

The biggest campaign occurred in 1993, when several UAF researchers spent the summer on the glacier to make intensive measurements of ice velocity, mass balance, and ice temperatures. Dennis Trabant joined the field party for a few days in June 1993 to help relocate the survey benchmarks from the 1970s, some of which were old IGY benchmark locations. He also helped with ice radar measurements to construct the first bedrock map of McCall Glacier. Ice thicknesses typically ranged from 120 to 200 m.

An innovative way of measuring the surface elevation of glaciers, developed by Keith Echelmeyer and Will Harrison, involved an airborne laser altimeter coupled with a high-accuracy Global Positioning System that could measure the elevation every 1.5 m along glaciers with an accuracy of 30 cm. This new system, installed in a small aircraft that Echelmeyer flew along one or more tracks down a glacier, allowed a detailed and accurate profiling of the glacier's surface. Profiles were flown on about 110 glaciers in Alaska and northwest Canada during 1993–2002, and these profiles were then compared to U.S. Geological Survey and Canadian topographic maps made 30–45 years earlier. Eleven glaciers in the northeastern Brooks Range, including McCall, were profiled, both by this system and by researchers on foot or on skis (Fig. 5). These comparisons yielded elevation, volume, and area changes between 1956 and 1993–94. Profiles were also compared with the 1972 IHD McCall Glacier maps. These comparisons showed that all of the measured Brooks Range glaciers have been thinning at rapid rates. This rapid thinning has been observed on most of the Alaskan glaciers thus studied. Such changes in glaciers must be related to changes in climate.

Echelmeyer's aircraft had frequently had problems getting stuck in rotten snow in July 1993, so the next McCall Glacier field season was started earlier, during an unusual cold spell in the spring of 1994. Nevertheless, with internal melt setting in just after the field party left in early July, 1994 still became a record negative melt year, and several mass balance poles were unexpectedly lost on the lower glacier. The neighboring Hubley, Bravo, and Gooseneck glaciers were also surveyed with kinematic GPS during this campaign. As on previous expeditions, leaving the glacier sometimes proved to be a challenge. In 1994, Echelmeyer and Rabus, waiting for better weather at the Jago Lake camp, also ran out of food, but found that nothing was left at this camp except some loose debris. They later accused Benson and Weller of having consumed everything edible in 1969. In 1995, two field campaigns were carried out, one in late winter. The 1996 campaign was already outside the official three-year life of the project; nonetheless, Echelmeyer and Rabus carried out two brief (1–2 day) campaigns to measure the mass balance poles and read the data loggers.

Four significant papers resulted from this research (Rabus et al., 1995; Rabus and Echelmeyer, 1997, 1998, 2002). The mass balance of the glacier was found to be negative, or nearly so, in every year of measurement, and volume change measurements made by laser altimeter confirmed and quantified this further, indicating that the rates of ice loss had nearly doubled in 20 years. Ice temperatures were re-analyzed at the same locations as in the 1970s and found to be significantly warmer, indicating, after all other factors had been accounted for, that an air temperature increase of at least 1.2˚C had occurred in the previous two decades. One region of the glacier, near the hut established on top of the old IGY Jamesway base, was found to be sliding significantly. Through modeling, this sliding area was found to be at least a kilometer long, and the modeling suggested that basal motion accounted for over 50% of the annual surface motion there.

After the NSF grant expired, the mass balance program was maintained primarily through the efforts of Echelmeyer, who used his own plane and resources to keep a reduced stake network functional. At this point, it had become clear to the scientists that long-term measurements of the glacier were not only fruitful, but vital. In 1999, Echelmeyer and his students installed a number of new poles in traditional locations that had been surveyed in the past. In 2000 and 2001, these locations were resurveyed by Echelmeyer and his graduate students, who came in by foot from airstrips several days' hike away. They typically spent only one or two nights on the glacier before hiking back to the airstrip for their ride back to Fairbanks.

The next major phase of McCall Glacier research began in 2003, after a one-year gap in field efforts. The NSF funded a large grant to UAF Professors Larry Hinzman and Matt Nolan for a multi-component study of changes in the freshwater flux to the Arctic Ocean in Alaska and the western Arctic. Nolan led the glacier aspect of the study, and selected McCall Glacier as the best location to study the role of Arctic polythermal glaciers in the hydrological cycle and climate change in this region. The choice of McCall Glacier was largely due to its history of prior research and the wealth of expertise to draw on among local UAF faculty. One fact Nolan learned at the onset of the project was that because McCall Glacier is now in what is known as the Designated Wilderness Area of the Arctic National Wildlife Refuge, new long-term glacier research projects would be impossible to start there or elsewhere in the refuge. The only reason the U.S. Fish and Wildlife Service continues to grant permits to continue work on McCall Glacier is that research efforts there pre-dated the formation of this refuge and the wilderness area within it—a fortuitous, unexpected benefit derived from the original IGY project.

Over the five-year project, Nolan and his teams of students, technicians, family members, and visiting faculty installed and maintained a network of mass balance and velocity stakes, all largely at locations used in the 1970s and 1990s, to facilitate long-term comparisons. They also installed over a dozen automated weather stations, some on former sites, and four of which telemetered data hourly to the Internet. An interesting challenge they had to face was the conversion to using GPS for all of their surveying, as the geographic projections and datums change between theodolite and satellite triangulations. On the first expedition of this five-year effort, the others on the trip listened patiently while Nolan, Bernhard Rabus (who had finished his PhD in 1997) and Bjorn Johns of UNAVCO spent seemingly endless hours in the cook tent trying to convince themselves that they had not made some blunder in these conversions. In the end, judging by the re-occupation of bedrock benchmarks still in place since the IGY, they think they got it right. Modern Real-Time Kinematic (RTK) GPS methods also permitted them to re-occupy the airborne laser transects of Keith Echelemeyer. Several of the stakes installed in the 1990s were found still upright in the glacier, and many of the stakes and thermocouple wires from the 1970s were found fallen over, often making a trail leading back to where their modern counterparts are now located.

Nolan and colleagues were able to verify and expand on many of the prior studies through a time-series analysis made possible after 50 years of measurements. The rate of ice loss continues to increase over time (Nolan et al., 2006) and the annual mass balance trend continues to grow more negative, indicating that local climate is continuing to change and become less conducive to glacier growth. Since no long-term weather stations exist in the entire Brooks Range, loss of glacier ice is one of our few indications of long-term climate trends here. One particularly ominous example of this change was the discovery that the terminus had retreated past the lowest survey transect established in 1969—the ice is completely gone there! Finite-difference thermomechanical modeling, led by Dr. Frank Pattyn and graduate student Charlotte Delcourt in Belgium, has indicated that if current climate trends continue, McCall Glacier will continue to retreat up into the highest cirque and possibly disappear within the next 100–200 years. Such modeling is made possible only by long-term records of ice velocities, ice temperatures, and mass balance, as well as a bedrock map that continues to be improved through new radar studies.

Nolan, like others before him, has collaborated on this project with numerous national and international colleagues, both in the field and in the office, but his collaboration with Austin Post is especially appropriate to relate here. It was only by chance that Nolan learned of Post's presence on the glacier in 1958, as it was not documented in the scientific literature. After several e-mail exchanges between them, a shoebox arrived in the mail the day before Nolan's second expedition to the glacier in August 2003. Inside this shoebox were hundreds of medium-format negatives of McCall Glacier from 1958 that Post had never printed, and which had miraculously survived a house fire. At 2:00 a.m. the night before the trip, Nolan held each negative up to his window, in the dim glow of the late-summer night, to see if there were any shots that might be good to repeat. Several candidates were found, scanned, and printed out to take into the field. The best among them was a photo of the terminus. As things went in the field, it was a busy trip and there was not much time for hikes down past the terminus. On a reasonably nice evening at about 6:00 p.m., however, Nolan and his wife Kristin had finished maintenance on a weather station on the ice near the old moraine camp and decided to try to repeat the terminus photo. After several hours of hiking and hunting for Post's photo location, they finally found it and took the picture. Part of the delay was Nolan's mistake in scrambling up the wrong gullies, forgetting that the terminus had retreated substantially so that Austin's viewpoint was much farther down-glacier than the terminus he was looking at that night. But back at camp by about 3:00 a.m., they had accomplished what is likely to be the most lasting and

FIG. 6. Comparison of the McCall Glacier terminus in 1958 (photo by A. Post) and in 2003 (photo by M. Nolan).

often used public legacy of their project—the second photo of the pair shown in Figure 6, which has been reproduced widely and is becoming an icon of Arctic climate change.

CLEANUP

During the IGY and IHD efforts, most supplies were brought in with air drops, and over the next 30 years various efforts were made to clean up the glacier, now located in an environmentally and politically sensitive wildlife refuge. Carl Benson tried to find a way to entice military helicopters to come for a "training" mission on the glacier and backhaul this debris out, but without success. To start the process, however, in July 1987 Benson and Weller were flown from Kaktovik to the glacier in a Fish and Wildlife helicopter. Accompanied by Larry Sweet and graduate student Eric Breitenberger, they collected parachutes and other debris scattered over the glacier, made an inventory of all the major pieces, including fuel drums, a broken-down snowmobile, and generators, and waited for good weather to have everything flown out. Bad weather defeated them, and after waiting for two weeks they had to return without having achieved much cleanup. In 1993, Bernhard Rabus, Keith Echelmeyer, and colleagues spent much of the summer consolidating the debris located around the hut, but also lacked the resources to remove it.

Matt Nolan, talking with the prior researchers at the start of his project, became aware of the importance and challenges associated with cleaning up the tons of debris on the glacier. With the help and funding of the NSF and the U.S. Fish and Wildlife Service, he was able to develop a successful removal plan. A major unforeseen issue here turned out to be that although on the glacier the debris was just junk, once it was removed it became a hazardous material ("haz-mat") and needed to be handled in a legally rigorous (and potentially expensive) way. Fortunately, the NSF agreed to fund some extra helicopter time as part of the research in May 2004, and the U.S. Fish and Wildlife Service agreed to handle the haz-mat analysis and paperwork once the debris got to Kaktovik village. On two beautiful sunny, calm days in August 2004, Dave Jones in a Bell 407 took out six sling-loads of debris, weighing over two tons in total. Most of this came from the hut, which was gutted, and from its environs. Nolan's biggest regret from this operation was that a case of dated water samples from throughout 1971 was accidentally thrown away. Who knows what scientific value that water might have had? They also took a load of fuel barrels and debris from the upper cirque, where the IGY camp was beginning to melt out of the ice over an icefall. They found a carton of C-rations there, which must have melted out just that day, as the cardboard box was in perfect condition. Nolan kept a few of the cans, but his wife would not let him eat them on the glacier for fear of his sudden demise; a can of "Fruit Cocktail" still sits on the shelf above his desk at the university.

CONCLUSION

What were the conclusions and lessons learned from these studies conducted over half a century? First, they demonstrated the usefulness of long-term, systematic quantitative observations on the ground, particularly observations of complex processes, like those observed and measured on McCall Glacier. Such long-term observations are not that frequent in the Arctic, and in these days of satellite remote sensing are becoming even less so. The information obtained from the studies provided a clear picture of the dramatic changes that have occurred in this region of the Arctic, caused largely by changes in the climate. The studies begun during the IGY have continued, albeit with interruptions, to the present day, and will continue to shed additional light on processes in this fascinating region of the Arctic and the world. Changes in logistics, technology, and permitting have also changed the nature of the fieldwork, though it could be argued not always for the better. For example, these advances in technology and logistics have allowed expeditions to complete in days what it previously took months to do, but it is unsettling to think about all the phenomena and new ideas we miss in those "saved" months of time.

The studies also demonstrated the foresight of their early initiators, the dedication and contributions of the scientists who were involved, and the importance of proper data archival. Richard Hubley should be given great credit for starting the studies. Svenn Orvig, who took over the project after Hubley's death, has also died, but others of the IGY scientists on the glacier are still with us. The scientists from the University of Alaska who restarted the project in 1969 and kept it going through the 1990s and 2000s owe them all a great debt. Those of us who participated in the McCall Glacier enterprise gained much from their earlier work and would not have missed the experience for the world.

There is also another lesson to be learned from this experience. While the McCall Glacier project has at this point turned into a long-term (50-year) study, the record itself was created through the contributions of several short-term projects. These were funded sporadically and resulted in gaps in the record. One of the causes for this is the paucity of federal funding opportunity for long-term glacier research projects. This is a problem not only for glacier research, but for all Arctic research, as long-term studies are the only way to ensure sufficient understanding of important processes such as the climate changes we are experiencing now. The future prospects of obtaining long-term glacier records remains bleak, and the record will likely continue to have gaps. Although modern data loggers for remotely measuring weather, ice melt, and ice motion may help bridge these gaps, it has been and likely will continue to be the initiative, energy, and at some points the personal resources of individual scientists involved that provide a semblance of research continuity.

As glaciers around the world continue to recede, will there still be a McCall Glacier or a McCall Glacier Project at the next IPY in 2057? If the present trends continue, the final chapter in the McCall Glacier story may not be far off (Fig. 7). When it comes, we hope that there will be someone to record it for posterity. In the meantime, from all of us and on behalf of those already departed, we wish these unknown future researchers and colleagues well, and urge them to take good care of McCall Glacier and its long-term record.

FIG. 7. The future of glacier research depends on the next generation of scientists, but will there still be a glacier left here when young Turner Nolan grows up and brings his kids into the field?

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