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Natural Resource Stewardship and Science

Glacier Monitoring in Denali and Wrangell-St. Elias National Park and Preserve, 2022-2024

Inventory and Monitoring Program, Central Alaska Network

ON THE COVER

USGS Benchmark Glacier Program scientist Louis Sass (right) and CAKN Glaciers PI Michael Loso (left) measuring snowpack thickness and density at Kahiltna Pass with the West Buttress of Denali visible in the background. September 25, 2023. (NPS Photo)

Glacier Monitoring in Denali and Wrangell-St. Elias National Park and Preserve, 2022-2024

Inventory and Monitoring Program, Central Alaska Network

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Abstract

This report summarizes glacier monitoring activities that occurred during the years 2022-2024 in the glacierized Central Alaska Network parks: Denali National Park & Preserve and Wrangell-St. Elias National Park & Preserve. Work completed in both parks is described with an emphasis on activities, logistics, and accomplishments. Preliminary results from the monitoring work are described briefly but are not the focus of this paper. Final results will be presented separately, with appropriate error analysis and interpretation, in peer-reviewed technical report(s) and/or scholarly publications.

Glacier monitoring has occurred in Central Alaska Network since 1991, and is based upon monitoring protocols initiated by Larry Mayo at that time (Mayo, 2001) and updated in 2011 by Rob Burrows (Burrows, 2011). Work during that period and until 2015 was focused on the Kahiltna and Traleika Glaciers in Denali. The principal investigator and program structure of the glacier monitoring program both changed in 2016. In 2016, Michael Loso took over as glaciers PI and adjusted the program objectives to include a major glacier in Wrangell-St. Elias (Kennicott Glacier) and to discontinue monitoring of the Traleika Glacier. Monitoring efforts on Kahiltna and Kennicott Glacier comprise the bulk of the glacier monitoring activity described here, but this report also describes ancillary work and accomplishments.

Introduction

This report summarizes glacier monitoring activities that occurred during the years 2022-2024 in the glacierized Central Alaska Network parks: Denali National Park & Preserve and Wrangell-St. Elias National Park & Preserve. Work completed in both parks is described with an emphasis on fieldwork, logistics, and accomplishments. Preliminary results from the monitoring work are described briefly but are not the focus of this paper. Final results will be presented separately, with appropriate error analysis and interpretation, in peer-reviewed technical report(s) and/or scholarly publications.

Glaciers Vital Sign: Monitoring Objectives

Glaciers and glacier systems are dominant and dynamic physical features of two of the three parks (Denali, Wrangell-St. Elias) in the Central Alaska Network and are a driver of landform and ecosystem change in them. Glaciers are inextricably tied to climate and the hydrological cycle. Because glacier systems are regulated primarily by climate fluctuations, they provide a reliable record of long-term climate change that has already occurred. Upper elevation climate is nearly impossible to measure directly and can be well represented by glacier dynamics. Glaciers provide significant hydrologic base flow to major rivers in Central Alaska national parks.

Mass balance (snow accumulation and snow/ice melt) is the primary variable monitored on an annual basis in Denali and Wrangell-St. Elias. In Denali, mass balance has been measured twice annually (spring and fall) on Traleika and Kahiltna glaciers since 1991. Measurements on Kahiltna are ongoing, while measurements on Traleika were discontinued in 2016. In Wrangell-St. Elias, mass balance is measured twice annually on Kennicott Glacier, and is ongoing. Glacier mapping is completed for the parks using aerial and/or satellite imagery every decade or so. In addition, repeated measurements of surface elevation are taken on a subset of glaciers by collaborators through the NASA-funded Operation Icebridge or, in the future, from other means likely including satellite data. These data are analyzed roughly once per decade.

The objectives, methods, and standard operating procedures associated with the CAKN glacier monitoring program are described more thoroughly in a Protocol Narrative and associate Data Quality Standards and SOPs. These documents have been periodically revised since inception of the protocol in 1991 and the most recent major revision was submitted for peer review October 2022. That protocol document package was returned with comments in December 2024, and is now undergoing revisions in anticipation of being published and posted in IRMA.

Structure of This Report

The bulk of the report is focused on describing the protocol-based mass balance monitoring sites and the activities conducted therein, organized by glacier and then by year. There is a short description of how we manage the collected data. Following that, I present some very brief preliminary results from these monitoring sites. I then report on progress towards our quasi-decadal glacier mapping and surface elevation work. Finally, the report concludes with a brief overview of other glacier monitoring activities conducted by the PI and colleagues during the 2022-2024 period.

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Kahiltna Glacier Monitoring Sites and Activities

Overview

Historically, the Kahiltna Glacier work began with direct measurements at an index site located roughly where the Kah6300 stake (**Figure 1**) is now located. Additional lower altitude stakes were sporadically measured over the years between 1991 and 2015 but beginning in 2016 we have routinely measured accumulation and ablation at Kah3600, Kah6300, and (when possible) Kah10,000. We added Kah7100 and Kah14,200 as measurement sites in 2018, specifically by adding year-round telemetered weather stations. Efforts were made several times to install and maintain a weather station at Kahiltna Pass (Kah10,000), but accumulation rates there (even in summer) have been determined to be too high to successfully obtain weather data there. In 2024 we added a new mid-elevation measurement site at Kah8700.

As of 2024, the full suite of ongoing measurements at Kahiltna Glacier (Figure 1) includes (with nominal elevations shown in parentheses):

- Kah3600 (formerly “K53”, 1113 m): Ablation stake and snowpit-based accumulation measurements
- Kah6300 (formerly “K17”, 1933 m): Ablation stake and snowpit/snowcore-based accumulation measurements
- Kah7100 (formerly “BaseCamp”, 2163 m): Year-round weather station with hourly measurements of snow accumulation and ablation, augmented by a neighboring ablation stake
- Kah8700 (2660 m): Ablation stake and snowpit/snowcore-based accumulation measurements
- Kah10,000 (formerly “KahiltnaPass”, 3055 m): Net accumulation measurements, via snowpit/snowcore in spring and fall, with no stakes or weather stations
- Kah14,200 (formerly “14Camp”, 4346 m): Year-round weather station with hourly measurements of snow accumulation and ablation

Glacier monitoring work at Kahiltna Glacier has evolved to emphasize high altitude measurements that are uniquely possible because of the support of the Talkeetna rangers and their exclusive use rescue helicopter. On any glacier, measurements of mass balance are most difficult in the accumulation zone, but that is particularly true on large high-altitude glaciers like the Kahiltna. The operations of the Talkeetna (“South District”) rangers, in support of climbing activities on Denali, provide infrastructure, safety and travel expertise, aviation capacity, and an independent need for real-time weather data that has led to a productive collaboration.

The logistics of all work on Kahiltna Glacier are based in Talkeetna. The South District Ranger (presently Tucker Chenoweth) functions as a primary point of contact for the work conducted, with backup support from other rangers. The support of the Talkeetna rangers includes aviation (the A-Star B3e and an exclusive use NPS fuel cache), temporary use of a staging area in the loading bay of the ranger station, personnel support for fieldwork, and other items. Equipment is no longer stored behind the ranger residence now that USGS has taken over primary fieldwork responsibilities.

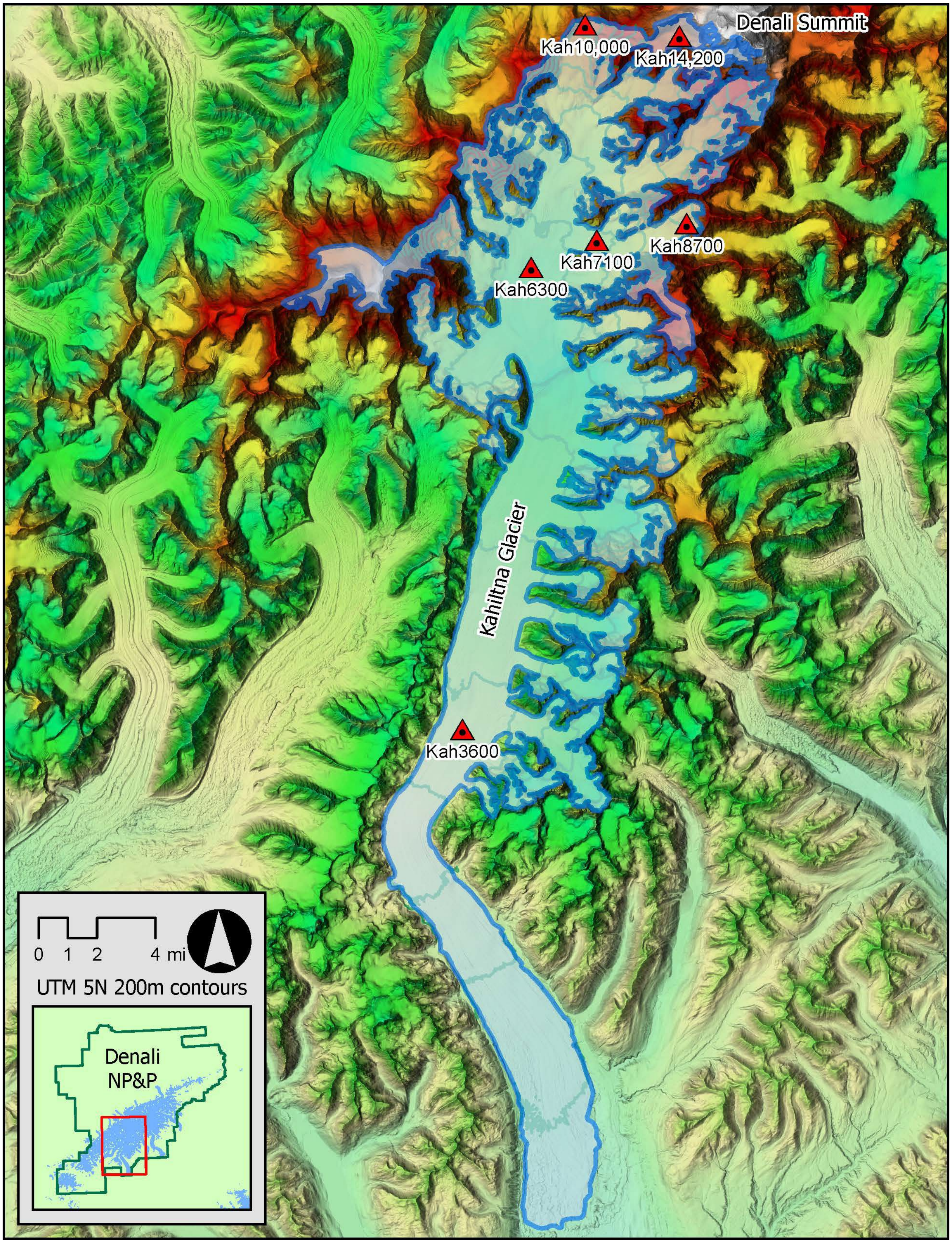

Figure 1. Stake monitoring sites on Kahiltna Glacier. The glacier is outlined in semi-transparent gray using the RGI 6.0 boundary.

But importantly, all the support provided by the rangers is secondary to their primary mission of ensuring safety and SAR preparedness for the public, especially during the climbing season. Clear communications between the Glacier Monitoring PI (Loso) and the South District Ranger are therefore critical for the smooth functioning of the program, and the Glaciers PI must approach all activities on the Kahiltna with clear prior statements of goals and expectations, but also with a frank and humble understanding of the always present possibility that the South District support could be withdrawn at any time for more pressing needs. A good "plan B" is always smart, and the most critical components of that backup planning would include consideration of alternate dates (weather plays in here too), planning for backup support personnel if the ranger staff are unavailable, and planning for backup aviation if the A-Star is unavailable.

Aviation costs for the Kahiltna Glacier portion of the Glacier Monitoring Program are managed jointly by the Program and by the South District Rangers. This is because both the tool (the helicopter) and one of the primary program objectives (real-time measurement of weather conditions) are shared between the Program and the rangers. Most spring/early summer glacier monitoring work is based from the exclusive use A-Star, and that helicopter is frequently utilized by the rangers for on-mountain activities ranging from camp maintenance to search and rescue, so it is commonly the case that a given day of glacier monitoring work will share use of the helicopter with other ranger-focused activities. That makes it difficult to bill the Glacier Monitoring Program's use of the helicopter in the standard hourly-plus-availability payment format. But equally importantly, the Program's weather stations were developed jointly with the rangers and contribute substantially and directly to their own safety and operations. Because of these shared costs and objectives, the Glacier Monitoring Program PI works jointly with the South District Ranger each spring to determine a flat rate cost that will be borne by the Monitoring Program for all needed aviation. Depending on the amount of flying done each year, that cost provides a substantial but variable cost-savings to the Monitoring Program and simplifies planning and logistics for the rangers. The flat rate varies from year to year but is typically $5-8000. Commonly, the A-Star is unavailable for fall/late summer visits and the Program is required to use a vendor helicopter. Costs for fall visits, if completed in a single day, are typically $7-9000.

With all those contingencies in mind, a typical season of work on the Kahiltna would consist of two visits, one in spring and one in fall. A spring visit will occur in mid-late May or at the latest early June and will consist of a minimum of one day flying but often more, depending especially on the need for weather station maintenance. The mission will utilize the A-Star and will start with preparation of gear at least a day prior to the flight, so that gear and personnel are ready for a briefing at the ranger station the morning of the trip. One day is typically enough for stake and snowpit/snow core measurements, but if significant work is needed on one or both weather stations, more days are added as needed, and may occur in the context of multiple flights (while sleeping in Talkeetna) or in the context of a ranger patrol (while camping on the mountain), depending on details. In the fall, the work is typically completed in a single day in late August or early September. The exclusive use contract for the A-Star end typically ends sometime in mid-summer, with quite a bit of variability, so we typically use a vendor helicopter may be needed if the work occurs after the contract ends. If a vendor is used, an R66 or A-Star B-2 are the minimum aircraft for the higher altitude work on the

Kahiltna—an R44 is not adequate. Note that the 14Camp weather station maintenance is often excluded from this regular seasonal schedule because of the complication of work at such high altitudes. The program is working towards a goal of having the Talkeetna rangers trained and prepared to do all weather station work at that site (since ranger teams regularly travel up there in an acclimatized fashion), but sporadic trips to 14Camp by unacclimatized glacier monitoring staff are only sometimes accomplished—when a combination of factors (weather, team strength, logistics, etc.) are in place to support the safety of that objective. In any case, all these components vary each year, and I therefore summarize below the activities that specifically occurred each year since 2022.

2022

We visited Kahiltna Glacier three times in 2022. The first visit occurred June 1-2, and included Michael Loso and Scientist in the Park (SIP) Shane Scoggin and benefitted from contributions by two Denali Volunteer-in-Parks (VIPS): Leo and Eric. The second visit occurred September 18 and included Michael Loso, SIP Shane Scoggin, and South District Ranger Chelsea Bomba. The final visit occurred October 14 and involved Loso and South District Ranger Galen Dossin. The spring aviation was completed with the Denali A-star B3e 0AE for about $4750, while the fall aviation was conducted via a vendor (Alpine Air) R66. Those two fall round-trips cost $18,289.

We were able to make standard measurements at all sites in the spring (except for Kah8700, which was new in 2024, and Kah14,200). That spring work included digging up/removing the existing Base Camp (Kah7100) weather station and re-installing it further upglacier. We camped one night at Base Camp to complete the spring work, and while there SIP Scoggin also made measurements and took photos to document a potential Cultural Landscape nomination for the Base Camp area. In the fall, we re-visited Kah3600, Kah6300, and Kah7100 and found that the anchors for the Base Camp weather station had melted out and the station had fallen over. We tried to repair it during the 9/18/22 day trip but did not have sufficient time. Deciding that it was impractical to rebuild the station that late in the fall, during the second fall trip on 10/14/2022 we collected all the station materials and returned them to Talkeetna for the winter, leaving no station out in the field. On that trip we also visited Kah10,000 and revisited Kah6300.

2023

We visited Kahiltna Glacier three times in 2023. The first visit occurred May 12-16 and included Michael Loso and USGS Benchmark Glacier Program scientist Louis Sass. We camped at Base Camp during this time and received significant assistance from VIPs Wendy Wagner and John Davis. The second visit occurred as a day trip May 19 and included Loso and USGS Benchmark Glacier Program scientist Emily Baker. We (Loso and Sass) did the fall visit September 25. The spring aviation was completed with the Denali A-star B3e 0AE for about $5332 while the fall aviation was conducted via a vendor (Alpine Air) R66 at a cost of $7519.

During the first multi-day trip we installed the new Base Camp weather station and made measurements associate with that site (Kah7100) but were unable to visit other sites due to weather. We returned for the single day on 5/19 to do measurements at Kah3600, Kah6300, and Kah10,000. During the fall trip we visited all sites except for Kah8700, which was new in 2024, and Kah14,200. Separately, South District Rangers led by Galen Dossin reset the 14Camp weather station (dug it up,

rebuilt it at a site slightly upstream) around May 22. USGS Benchmark Glacier Program scientists were included in every trip in 2023 for the purpose of orienting them to the program in anticipation of taking over fieldwork responsibilities in 2024.

2024

We visited Kahiltna Glacier four times in 2024. All trips were run by USGS Glacier Program scientists. The first visit occurred May 25-26, and included Louis Sass and Katherine Bollen from USGS, and benefitted from assistance by South District Rangers Joe Reichert (on May 25th) and Kakiko Ramos-Leon (May 26th). The second spring visit occurred June 28 and included Sass and Emily Baker from USGS, again benefitting from assistance by Reichert. The first fall visit involved Sass and Baker, and was attempted on August 30, but aborted due to weather. We made a second attempt on September 30, and were successful. The May and June trips were completed with the Denali A-star B3e 0AE for $6339, while the fall aviation was conducted via a vendor (Alpine Air) R66. The fall round-trips cost $11,840, due to the need to revisit the site a second time.

We were able to make standard measurements at Kah3600, Kah6300, Kah7100, Kah8700, and Kah10,000 in the spring. We camped one night at Base Camp to complete that work. On the June trip we installed a new weather station on bedrock at an elevation of 7,800’ on the Southeast Spur of Mt. Foraker. That station is envisioned and permitted as a semi-permanent weather station for a long-term meteorological record, and after a several-month period of overlap with the older on-glacier station at Base Camp (Kah7100), we will permanently remove the Kah7100 station. Near real-time data from the new station is publicly accessible through USGS NWIS (https://waterdata.usgs.gov/monitoring-location/625632151172901) or through NWS (https://www.weather.gov/wrh/timeseries?site=FKRA2). In the fall, we re-visited Kah3600, Kah6300, Kah7100, and Kah8700 and made all the standard measurements. The helicopter was unable to land at Kah10000, but we were able to land at Kah9,800 and make comparable measurements. At Kah7100, the older Base Camp weather station was found leaning approximately 25 degrees. We were able to re-set anchors and partially straighten the station to an approximately 20-degree lean, hopefully stabilizing it for the coming winter.

Kennicott Glacier Monitoring Sites and Activities

Overview

Kennicott Glacier work began in 2016, over a decade after the Kahiltna Glacier monitoring work, in recognition of the importance of including a comparable mass balance program in the country's most heavily glacierized NPS unit. Initial measurement sites evolved slightly over the ensuing years in response to logistical and safety constraints that emerged in the early years. We are now routinely measuring accumulation and ablation at fix sites on Kennicott Glacier (including the Gates Glacier tributary), as listed below. The sixth, highest altitude, site was added in 2024.

As of 2024, the full suite of ongoing measurements at Kennicott Glacier (Figure 2) includes (with nominal elevations shown in parentheses):

- Kenn2700 (806 m): Ablation stake and snowpit-based accumulation measurements
- Kenn3100 (932 m): Ablation stake and snowpit-based accumulation measurements
- Gates3600 (1083 m): Ablation stake and snowpit-based accumulation measurements
- Kenn6100 (1833 m): Ablation stake and snowpit/snowcore-based accumulation measurements
- Gates7200 (2173 m): Ablation stake and snowpit/snowcore-based accumulation measurements
- Kenn8600 (2620 m): Net accumulation measurements, via snowpit/snowcore in spring and fall, with no stakes or weather stations

In contrast with the Kahiltna Glacier, glacier monitoring at Kennicott Glacier is focused more on lower elevation phenomena. We do have two sites in the accumulation zone (Gates7200 and Kenn6100) and augmented those in 2024 with a new station at about 2620 m ("Kenn8600"), but we lack any good measurements at the higher elevations of this large glacier (max glacier elevation is >4800 m, at the summit of Mt. Blackburn). Terrain above 2620 m is quite steep and subject to avalanches/heavy crevassing, and we are unlikely to install stations any higher in the future. Kennicott Glacier provides an excellent opportunity, however, to better understand the mass balance processes typical of a large Alaskan glacier's ablation zone: melt on both clean ice and on debris-covered ice, and also interaction (calving, sublacustrine melt) with a growing proglacial lake. Our work on Kennicott Glacier also benefits from a high degree of interest from outside collaborators, and our stake network is presently augmented by additional data from stakes and temporary weather stations installed by collaborators at University of Alaska Fairbanks and the Chinese Academy of Science. I do not focus on those measurements in this document, but they will be utilized in our subsequent analyses and were recently submitted, along with the NPS mass balance records reported here, to *Geoscience Data Journal*. Finally, the Glacier Monitoring program does not maintain a permanent year-round weather station on Kennicott Glacier, but we do benefit from a long-term Automated Weather Station (AWS) maintained on the Goat Hair Ridge nunatak by the NPS/CAKN Climate Monitoring Program.

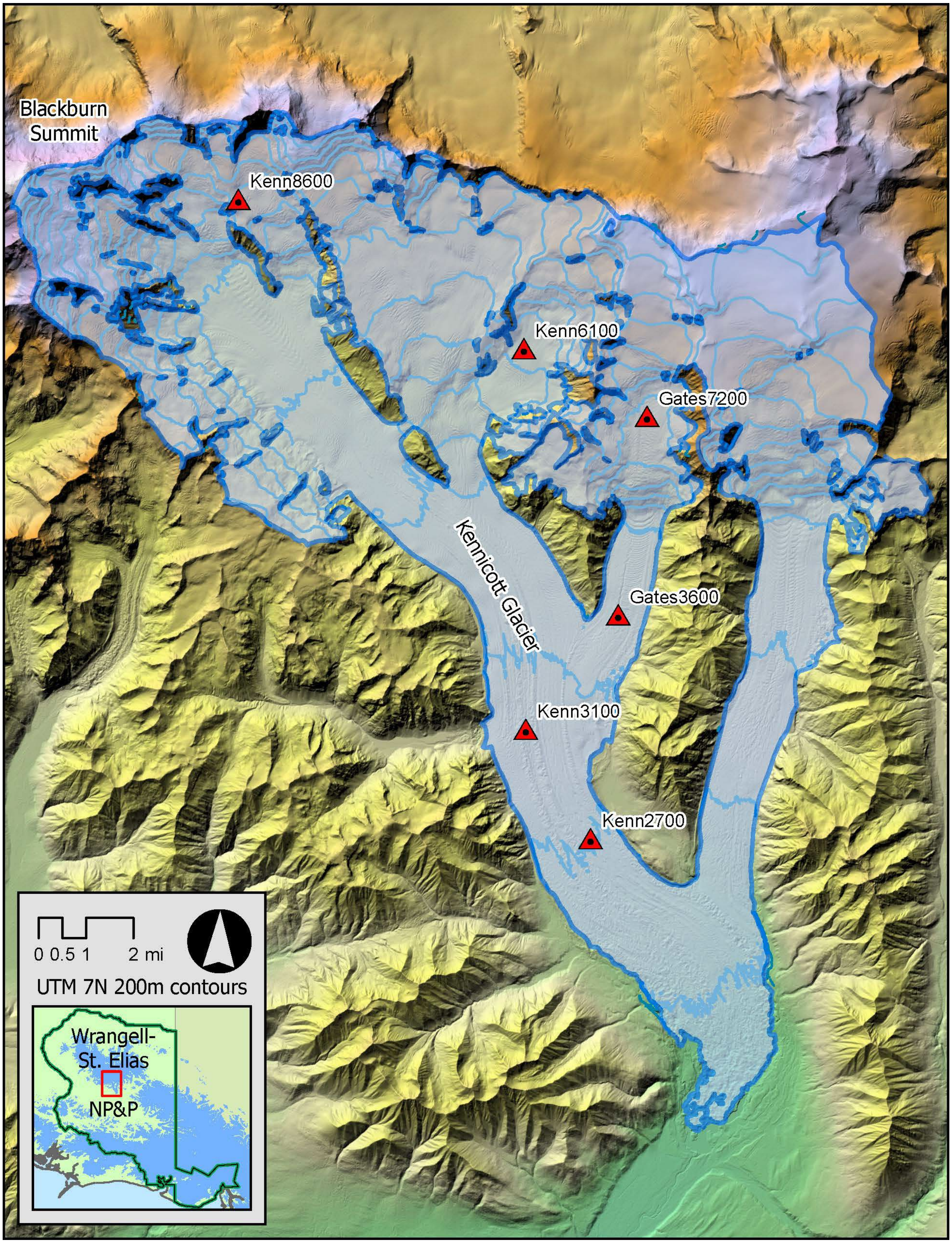

Figure 2. Stake monitoring sites on Kennicott Glacier. The glacier is outlined in semi-transparent gray using the RGI 6.0 boundary.

The logistics of all work on Kennicott Glacier are based in the McCarthy/Kennicott area. The PI (Loso) maintains an office in the Kennecott Mines NHL and most equipment is stored there. Most aviation is based out of the primary DOT-maintained McCarthy airstrip. On occasion, usually at the preference of pilots, we will instead utilize the Rowcon-maintained Fireweed airstrip on the west side of the Kennicott River. Avgas and JetA are available at both sites. No helicopter vendors operate out of the McCarthy/Kennicott area, so the program typically relies on either the exclusive use WAFM Firepro helicopter or a vendor, either of which would have to ferry to the McCarthy airstrip from other locations. Over the years the program has transitioned towards less reliance on the Firepro helicopter, largely because timing (to take advantage of weather windows) is so critical, and scheduling the Firepro ship is difficult with the possibility that it can be diverted to missions in other parks with short notice. As of 2024, most fieldwork is slated to be completed by scientists from the USGS Benchmark Glaciers Program, commonly utilizing an R66 hired from Vertical Solutions.

Aviation costs for the Kennicott Glacier portion of the Glacier Monitoring Program are managed directly by the Program PI. Uncommonly, the PI will take opportunistic advantage of options to share helicopter time with other users (VRP, maintenance, non-NPS users), with the advantage of being able to share ferry and/or availability costs, but it is more typical that the entire cost of the helicopter mission is borne by the Program, including ferry time, availability, fuel, hourly flight time, and (rarely) per diem for multi-day visits. Importantly, these costs can vary significantly based on many factors, and the cost of the fall visit is borne by the Program very close to the end of the fiscal year, so careful planning is required to ensure that the overall Program remains within budget. Costs per mission (spring or fall) have varied through the years but typically amount to $7-8000 per mission. We seek opportunities to share the helicopter with other programs, often achieving significant cost savings from doing this.

A typical season of work on the Kennicott Glacier consists of two visits, one in spring and one in fall. Both spring and fall visits can each typically be conducted in a single day of work, and the PI endeavors to keep the scope of work simple enough to maintain that schedule since the jump to a 2-day mission would require a substantial step increase in aviation costs. Because there are no weather stations to maintain, and because Kennicott Glacier is so much closer to the airstrip than Kahiltna Glacier, the logistics of fieldwork on Kennicott Glacier are in general much simpler. The helicopter, if not already in the Kennicott Valley (sometimes the Firepro ship is already present for other work), will ferry to the McCarthy airstrip early in the morning, where USGS scientists will meet it with all gear prepped and weighed. All the sites are close to each other and to the McCarthy airstrip, so the flying consists of very short hops and the helicopter/pilot wait on site while work is conducted. The most time-consuming portion of the work is often steam-drilling of 6-10 m deep holes ablation stakes on the lower glacier, and good planning is required to ensure that enough time is available at the end of the day to complete these holes. If the crew ran out of time, it would be critical to prioritize helicopter time to complete work at the upper sites, which are strictly accessible only by helicopter. The two lowest sites could, with difficulty, be accessed later on foot if needed. Below, I summarize the activities that specifically occurred each year since 2022.

2022

We visited Kennicott Glacier twice in 2022. The first visit occurred May 25 and included Michael Loso, Scientist in the Park (SIP) Shane Scoggin, and NPS fire program helicopter manager Chad Leshuk. Spring aviation was completed with the EAFM Fire Protection A-Star B2. The second visit occurred September 16 and included Michael Loso and SIP Scoggin. We flex with a Vertical Solutions (vendor) R66. Spring aviation cost about $2500 (because the fire program covers helicopter availability) and fall aviation cost $6287.

We were able to visit all sites in the spring except for Gates7200 (due to poor visibility) and Kenn8600 (which wasn't installed until 2024). We visited all the extant sites in the fall, including Gates7200 which allowed us to retrieve a full year net balance from that site.

2023

We visited Kennicott Glacier twice again in 2023, on June 4 and August 18. Both trips included Michael Loso and a USGS Benchmark Glacier Program scientist: Chris McNeil in the spring and Louis Sass in the fall. Both visits were accomplished with an Alpine Air R66 at a cost of $6489 in the spring and $6989 in the fall. The USGS Benchmark Glacier Program scientists were included in every trip in 2023 for the purpose of orienting them to the program in anticipation of taking over fieldwork responsibilities in 2024. We were able to conduct standard measurements at all the extant sites during both visits in 2023, and during the fall 2023 visit we conducted an overflight of the upper glacier in search of a suitable location for adding a higher elevation site. That reconnaissance led to the successful establishment of Kenn8600 in fall 2024.

2024

We visited Kennicott Glacier twice again in 2024, on May 30 and September 29. Both trips were run by USGS Glacier Program scientists: Chris McNeil and Emily Baker in the spring, and Emily Baker and Louis Sass in the fall. The spring visit was accomplished with a Vertical Solutions R66 that was in McCarthy for other projects. That helicopter support therefore cost the program only $1044 due to cost-sharing. USGS staff drove to McCarthy. The fall visit was accomplished with an Alpine Air R66 from Merrill field at a cost of $6840. We were able to conduct standard measurements at all the extant sites in the spring, and repeat those measurements in the fall, and make measurements at a new higher site scouted in fall 2023, Kenn8600.

Mass Balance Data Management

Data from the glacier monitoring work described above are managed and archived in accordance with National Inventory and Monitoring Program standards. Here I present an overview of the workflow associated with that process; details and SOPs can be found elsewhere. The flow of data can be best visualized as consisting of three components: field data, working archives, and the glaciers database. I describe each in order.

Field Data

Field data consist typically of five products. Each is expected to be archived digitally in at least two locations within 2 days of completion of fieldwork.

1. Field notebooks kept by the PI and by other project participants are a primary repository of detailed measurements and other information, some of which provide redundancy for other digital products. These notebooks are scanned and saved as pdfs.
2. GPS data using a mapping-grade or survey-grade receiver. These data are downloaded to a workstation, post-processed using Pathfinder Office or other post-processing software and archived as both raw and corrected files.
3. Stake and snowpit/snowcore measurements are entered into a structured excel spreadsheet that standardizes terminology, units, nomenclature, etc.
4. Downloaded weather station data (from stations directly managed by the Glacier Monitoring Program—this does not apply to stations managed by collaborators) are archived directly as .csv or .xlsx files.
5. All field photos are organized and stored in a labelled subdirectory.

Working Archives

Field data described above, plus all other program files (including historic files, reports, administrative content, and data from ancillary projects) are maintained in well-organized directories on the PI's workstation. These directories are mirrored (and thus backed up) regularly to a network drive (the 'G' drive) at the Alaska Regional Office in Anchorage. That drive is mapped as \\INPAKROVMIM\cakn\Monitoring. That is the authoritative repository for all the "other" program files.

The data files specifically produced under the monitoring protocol (essentially, the archived field data) are further uploaded once per year, in the fall, to the IRMA Project #2216228 ("Glacier Monitoring in the Central Alaska Network of National Parks"). These annual data (Table 1) are uploaded as a single .zip file and contain the updated and complete data from ALL years, except that field photos are not included—to minimize the total size of the archive. The most recently uploaded archive is always the most authoritative and updated record for the entire archive and supersedes earlier data uploads. Those older uploads are maintained on IRMA for archival purposes. The data files uploaded to IRMA are internally viewable.

Table 1. IRMA data records associated with the CAKN Glacier Monitoring Program through 2024. Note that all datasets include all prior years, so the indicated "Data Year" is only the most *recent* year in a given dataset.

Data Year	IRMA Code	Title	Upload Date
2017	2248211	CAKN Glacier Protocol Datasets 2017	December 29, 2017
2018	2258495	CAKN Glacier Protocol Datasets 2018	December 19, 2018
2019	2274312	CAKN Glacier Protocol Datasets 2019	June 1, 2020
2020	2278743	CAKN Glacier Protocol Datasets 2020	September 20, 2020
2021	2287576	CAKN Glacier Protocol Datasets 2021	October 5, 2021
2022	2295364	CAKN Glacier Protocol Datasets 2022	November 23, 2022
2023	2300927	CAKN Glacier Protocol Datasets 2023	September 29, 2023
2024	Pending QC	CAKN Glacier Protocol Datasets 2024	Before January 1, 2025

Glaciers Database

The CAKN_Glaciers database, which is housed at <inpyugamsvm01\nuna_dev> and accessed through the Microsoft SQL Server Management Studio, is oriented around two distinct time periods. The first is all pre-2016 glacier monitoring data, primarily from Denali. These data, collected by a variety of investigators using multiple techniques, were QC'd and homogenized under a Focused Condition Assessment project and are now entered into the database as <dbo.Stakes_pre2016>. Data from 2016 forward are stored in two separate tables. Stake measurements are stored in <dbo.Stakes> and snow measurements are stored in <dbo.Snow>. These tables are updated each year as new data are collected and are entered via a scripted upload directly from the structured excel spreadsheets. Weather station measurements are not yet entered into the database but a new table for those measurements will be added in 2025.

Mass Balance Preliminary Results

Here we present a subset of results from the quality-controlled, certified datasets collected between 2016 and 2023, including not-yet certified data from 2024. Complete results and detailed analyses are not included here. These data are presented with an important caveat, described below. The significance of this caveat is that time-series of accumulation and melt presented here should not be interpreted as indicative of inter-annual changes.

These results describe *measured* changes (ablation and/or accumulation) at the various sampling sites, which are functions not only of actual mass balance patterns but also of sampling dates. Seasonal totals for accumulation (in winter) and ablation (in summer) are the most important fundamental objective for this program, but measurement dates in spring and fall never coincide exactly with the start or end, respectively, of the accumulation and ablation seasons. Measurements must therefore be augmented by modeled changes that occur between the measurement dates and the actual mass maxima/minima dates. That is the primary reason that we rely on weather station data to augment our stake measurements—so that we may model these unmeasured changes with a reasonable degree of accuracy. The complete results await that analysis and inclusion in a more complete research paper. The following results are therefore considered to be high-quality and reliable, but not amenable for interpretation of climatic trends.

Summer Balances

Ablation (and rarely, at high elevation, accumulation) is measured over the course of the summer melt season through measurement and re-measurement of aluminum stakes inserted into holes on the glacier surface. As the snow/ice melts, more of the pole is exposed, yielding a cumulative measurement of melt. Combined with measurements or estimates of the densities of melted strata (900 kg/m^3 for ice, variable between 50-600 kg/m^3 for snow), we have an estimate of ablation in units of meters snow water equivalent (m SWE).

- Summer balances at each site on Kahiltna and Kennicott Glacier are broadly consistent from year to year (Figure 3). Note that dashed lines connecting the points are not meant to reflect accumulation trends in between measurement dates, but rather are presented only to visually connect the measurements from each site. The subtle year-to-year variability of ablation at these sites is important because it reflects the direct role of climate (specifically temperature) on melt. These measurements have not yet been extended to include the entire melt season, and thus the variability in these plots is due partly to variability in the timing of measurements as well as to the variability in summer temperatures. As an example, note the generally high (less negative, as in less melt) values of ablation at sites measured in fall 2020. This is primarily because we made our "spring" measurements late that year—due to covid delays—thus resulting in measurement of a shortened melt season Kahiltna. Finally, note that where measured summer balances are positive (Kah10,000 and Kah14,300 on Kahiltna Glacier), these reflect net summer accumulation at those sites. This does not imply that ablation did not occur—only that accumulation during the measurement period exceeded ablation.

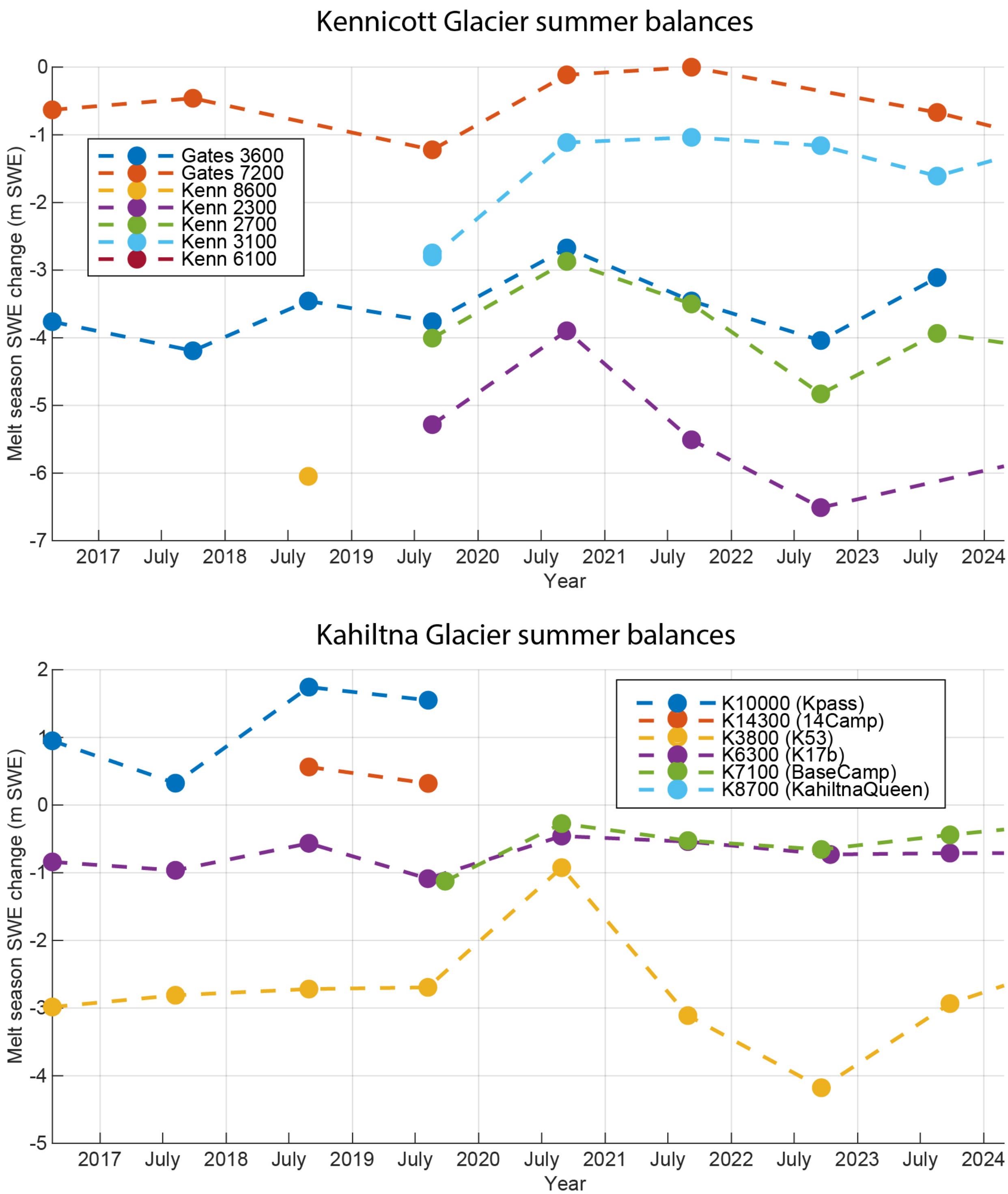

Figure 3. Measurements of ablation, in units of meters snow water equivalent (m SWE), at multiple sites on Kennicott (above) and Kahiltna (below) glaciers. Note that ablation is for the measured time interval only--see text for details.

Winter Balances

Snow accumulation over the winter season is measured each spring through a combination of snowpits, snow cores, probes, and stake measurements. Where the snowpack is reasonably shallow (<~1.5 m), a snowpit is sufficient to measure snow depth and the density of distinct stratigraphic layers. Where the snow is deeper, a shallow snowpit is augmented by measurements of deeper layers in core sections collected with a Kovacs or FELICS corer. Measurements of the ablation stake are used to corroborate these measurements but are rarely used as the primary indicator of snow accumulation because an unknown amount of surface melt may have occurred after the prior fall's measurement. And in cases where the surface underlying the new snow is rough (most common in the ablation zone), we augment the snowpit/core measurements with 10 probed measurements of snow depth in the surrounding area, using the average probe depth to adjust the single value found in the pit/core. Snow thickness and density are used to derive a final estimate of accumulation in units of meters snow water equivalent (m SWE).

Winter accumulation measurements at each site on Kahiltna and Kennicott Glacier are shown in Figure 4. Note that dashed lines connecting the points are not meant to reflect accumulation trends in between measurement dates, but rather are presented only to visually connect the measurements from each site. As with the ablation measurements, we caution that these trends have not been corrected for length of measurement period and thus are biased by variability in sampling date. On Kennicott Glacier, where there are more low-elevation measurement sites, it is also worth noting that many of these sites have already lost their shallow snowpack before we typically arrive in the spring. These "zero accumulation" measurements are common and reflective of low winter snowpacks at those sites, but do not imply a complete absence of winter snowpack at these areas. Shared trends among the sites are relatively high snowpacks in winters 2012-22 and 2022-23, and also the significant (perhaps greater than expected) impact of elevation on snowfall at both glaciers.

Geodetic Balances

Glacier mass balances acquired through stake measurements of the sort described above must periodically be calibrated with geodetic balances that are calculated from sequential pairs of digital elevation models. Such an analysis is underway with significant support from our partners at the USGS Benchmark Glacier Program. We acquired stereo satellite imagery (WorldView) at both Kennicott and Kahiltna Glaciers coincident with both spring and fall mass balance campaigns in 2024. We produced DEMs from those satellite images as well as imagery acquired in September 2018. We coregistered and differenced those DEMs with the state-wide IfSAR DEM which was collected in 2010 at Kahiltna and in 2012 at Kennicott Glacier. Total volume change was -5.18 km^3 at Kahiltna Glacier and -1.92 km^3 at Kennicott Glacier. Converting these to geodetic mass balance rates (m w.e. a^{-1}) requires us to account for the mid-summer acquisition dates of the IfSAR DEMs and to account for changes in glacier area between the DEM acquisitions. We have an established workflow to account for those changes using the methods of O'Neel et al (2019) and are working toward assembling the glaciological and meteorological data required for that workflow.

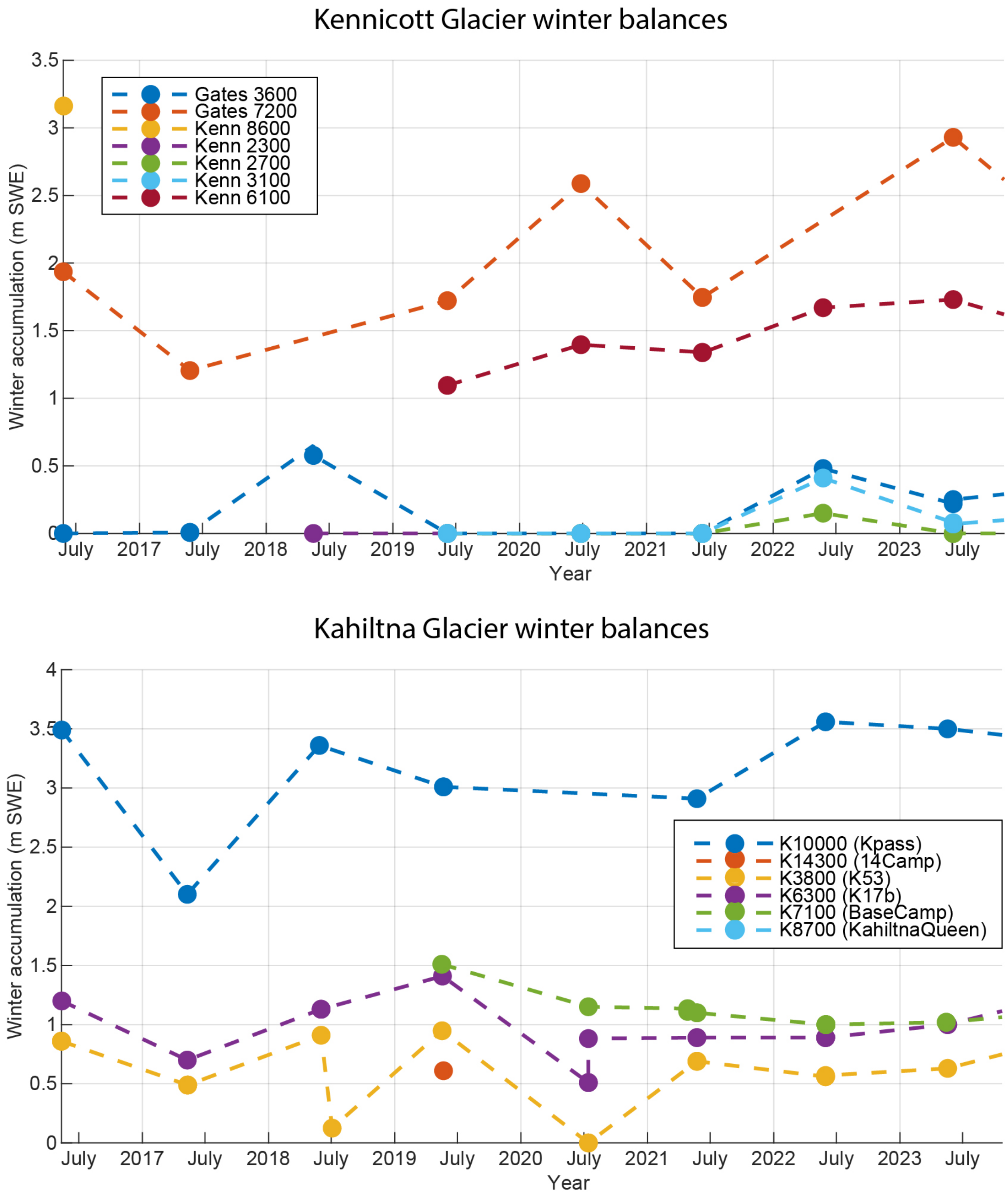

Figure 4. Measurements of snow accumulation, in units of meters snow water equivalent (m SWE), at multiple sites on Kennicott (above) and Kahiltna (below) glaciers. Note that accumulation is for the measured time interval only--see text for details.

Weather and Climate

The Glacier Monitoring Program typically maintains two year-round weather stations on Kahiltna Glacier. These telemetered stations provide real-time access to a variety of weather products, but for the purpose of glacier monitoring they are most valuable for their direct measurements of air temperature and snow thickness, which reflects the combination of accumulation, melt, compaction, and wind. Snapshots of measurements-to-date are shown in Figure 5 and Figure **6**.

Since first installing on-glacier weather stations in 2018, we have learned through trial and error what works and what does not. A station installed at Kahiltna Pass (Kah10,000), for example, was removed after 2 years because snow accumulation there is too rapid to keep the station from becoming completely buried overwinter. The station at the 14,200’ Camp (Kah14,200) has, surprisingly, been fairly resilient and has survived most winters without significant trouble. The station at Base Camp (Kah 7100), in contrast, has been very difficult to keep functional. Shade from Mount Hunter, to the south, has routinely caused the station to failure (for lack of solar power) in mid-winter, the high-amplitude swings in snow depth between winter and summer have created challenges for keeping the station upright, and because of rapid glacier flow the station has required resetting (moving to a new location upstream) more often than anticipated—typically every year.

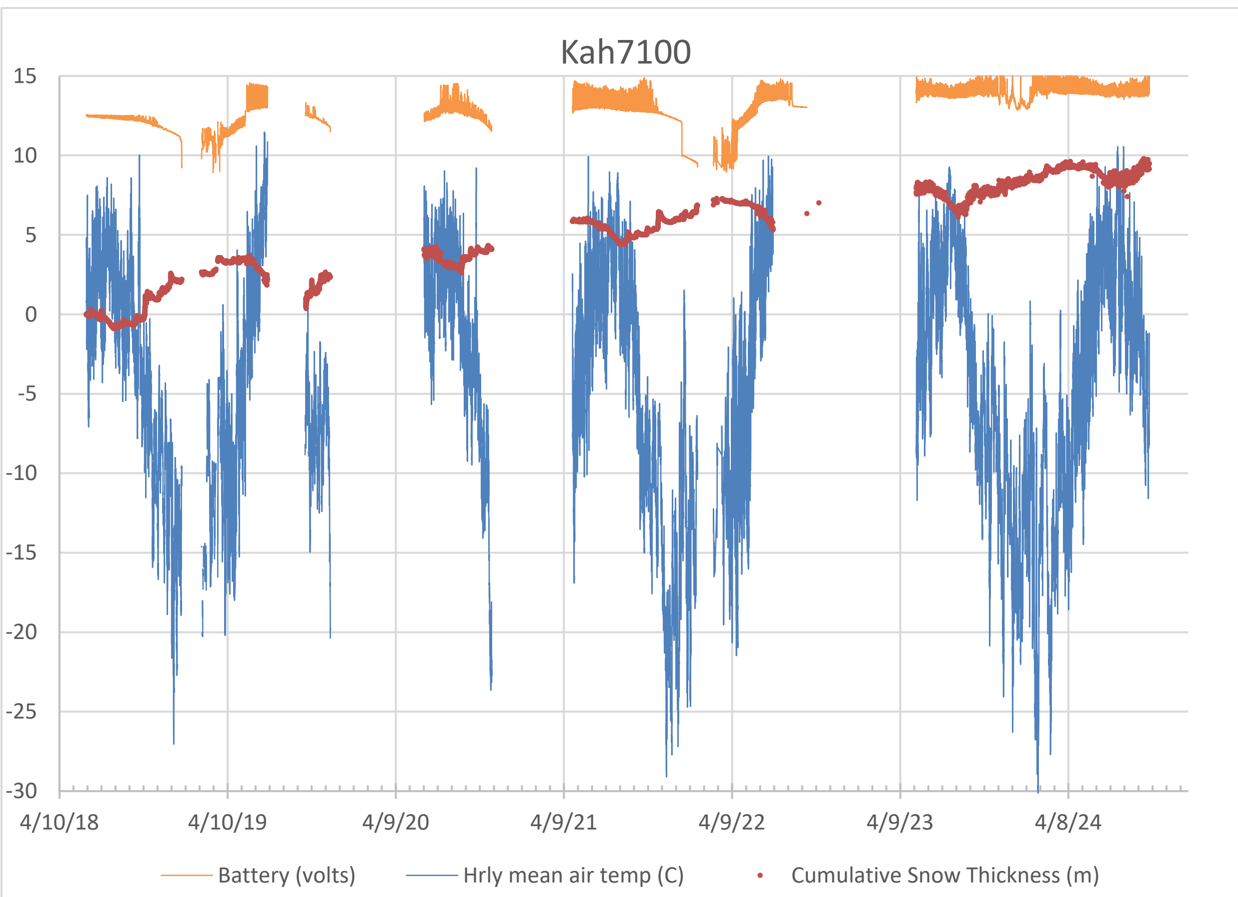

Figure 5. Snapshot of key data (temperature, snow depth, and battery voltage) from Kah7100. Gaps reflect periods when the station failed, typically due to lack of power.

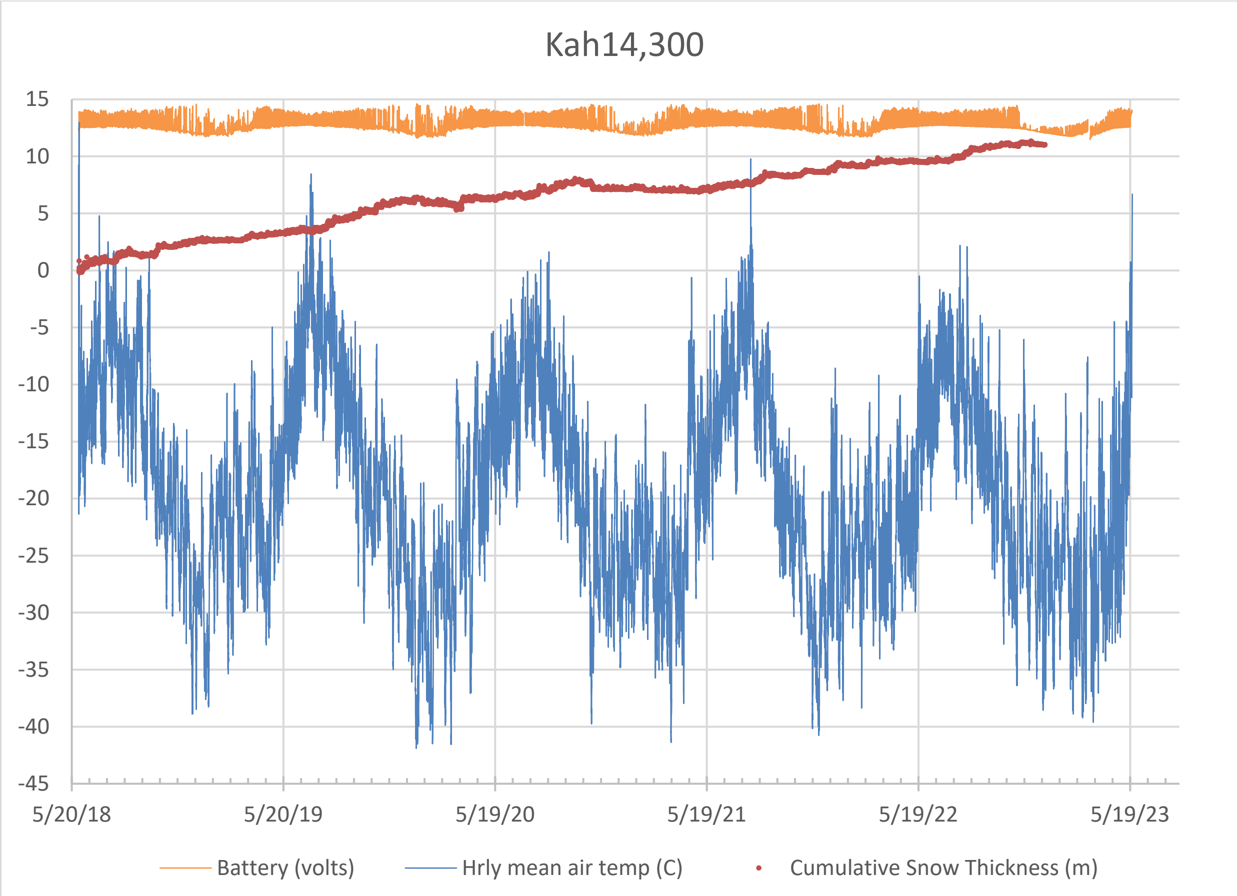

Figure 6. Snapshot of key data (temperature, snow depth, and battery voltage) from Kah14,300. Gaps reflect periods when the station failed, typically due to lack of power.

Because of the challenges with Kah7100, we decided in the last year to replace that station with an off-glacier station on Sultana/Mt. Foraker (Figure 7). Though this station will not provide granular details about on-glacier climate, it has the advantage of being more durable, better powered (because of its solar exposure), and importantly, it will require less frequent maintenance and hence be more affordable. The station was installed June 28, 2024 and the data can be viewed online at https://waterdata.usgs.gov/monitoring-location/625632151172901. In order to determine a stable statistical relationship between the data at the new and old sites, we have left the existing Kah7100 station standing and intend to remove it in summer 2025.

An overview of data collected thus far by the Glacier Monitoring Protocol is provided in Table 2.

Figure 7. New Sultana weather station being installed in June 2024 on the south ridge of Mt. Foraker. This station will become the permanent replacement for the "Base Camp" weather station at Kah7100.

Table 2. Summary of successful climate data collection by CAKN Glacier Monitoring Program weather stations. Periods of operation/non-operation noted here may not include brief interruptions to operation.

Station	From	To	Status at end of period
Sultana (new)	6/28/2024	This writing	Still running
	6/7/2018	12/31/2018	Lost power
	3/26/2019	7/25/2019	Mast broke
	9/26/2019	11/18/2019	Lost power
Kah7100	6/9/2020	11/3/2020	Lost power
	4/27/2021	1/23/2022	Lost power
	2/27/2022	7/7/2022	Melted out
	5/13/2023	This writing	Still running
Kah10,000	5/24/2018	12/6/2018	Buried, removed
Kah14,200	6/1/2018	5/22/2023	Electronic failure, still on glacier

Glacier Outline Mapping Activities

Overview

The CAKN Glacier Monitoring Protocol calls for periodic (quasi-decadal) mapping of glacier boundaries statewide. The first such effort culminated in 2014 (Loso et al. 2014), and a second effort was completed in 2022 as part of the Glacier Status and Trends 2.0 project. Roberts-Pierel et al. (2022) led an effort, with significant contributions from NPS/SWAN scientist Peter Kirchner, to develop and implement an automated deep-learning-method for measuring glacier boundaries over a 35-year time period (1985-2020) using Landsat imagery. This project included all statewide glaciers but, unlike the 2014 effort, excluded glacier ice in adjacent Canada (that is often grouped with “Alaskan glaciers” as part of RGI region 6.

Their project found consistent declines in glacier cover, along with consistent increases in debris-covered glacier area, for most of the state (Figure 8). Only the Brooks Range region showed a period of sustained increase in glacier cover, but the authors concluded that their automated classification system performed poorly in the small, shaded, heavily debris-covered glaciers of that particular region. In contrast, their technique provided results in the rest of the state that were largely comparable to studies using other techniques. The time-series of glacier outlines is available at the online NSIDC repository for this paper.

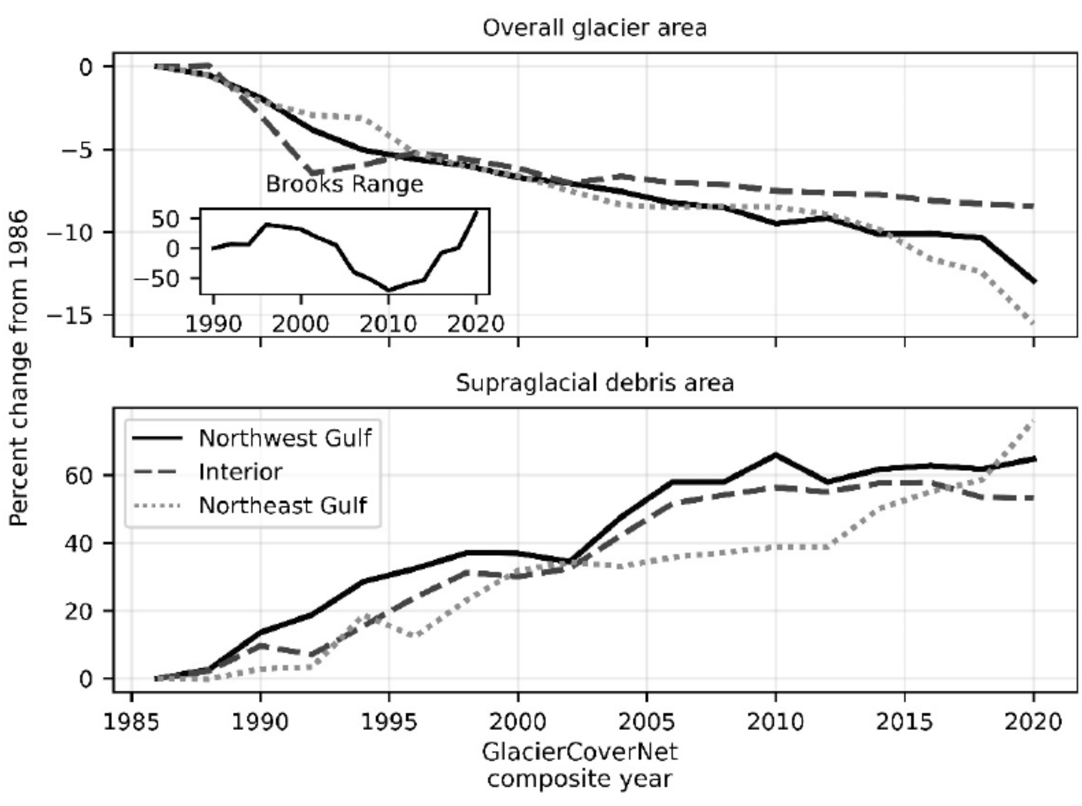

Figure 8. Percentage change in supraglacial glacier cover (top panel) and debris covered ice (bottom panel) for Alaskan glaciers. Inset in top panel shows results for the Brooks Range (including GAAR), while all other curves are stratified by regions in southern/southeast Alaska.

Glacier Surface Elevations Activities

Overview

The CAKN Glacier Monitoring Protocol calls for periodic (quasi-decadal) mapping of glacier surface elevations statewide. The first such effort culminated in 2014 (Loso et al. 2014), and a second effort is presently underway as part of the Glacier Status and Trends 2.0 project. PI Loso is working with glaciology collaborators from the University of Alaska Fairbanks (Mark Fahnestock and Chris Larsen) to document a complete analysis of the data collected under NASA's Operation Icebridge (OIB). OIB was a program of airborne glacier LIDAR measurements conducted from the early 1990s to 2022. In this program, midline surface elevations of 206 large glaciers in Alaska and adjacent Canada were surveyed periodically (typically every 3-4 years) to measure changes in glacier volume. The project included 93 glaciers within AK National Parks; those glaciers collectively represent 70% of the glacier covered area in the parks (Figure 9). As a part of this project, all the historic lidar data from OIB (some of which has been published previously, including in Loso et al. 2014) has been reprocessed to a common reference frame and analyzed using a new technique. That analysis is complete, and the results will be published in a paper being prepared at the time of this writing. Examples of the final processed dataset are shown for two CAKN glaciers (Kennicott and Kahiltna) in Figure 10.

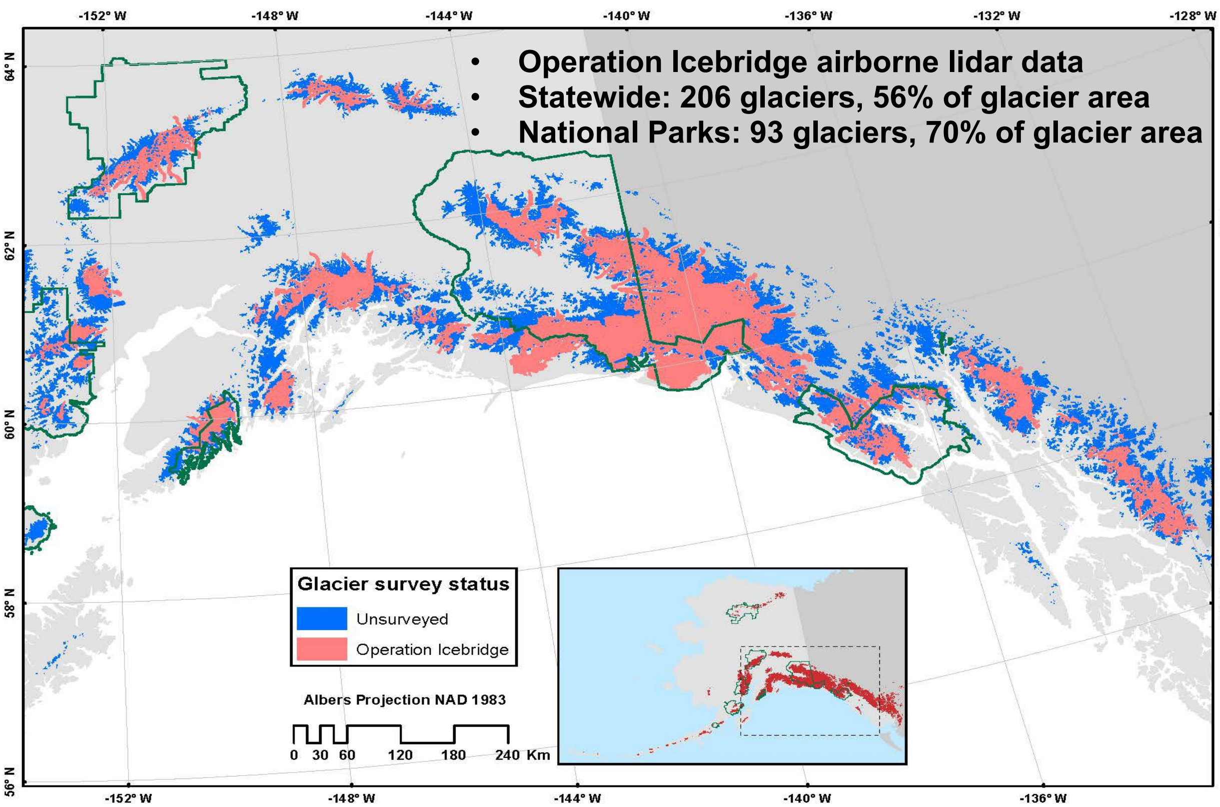

Figure 9. Glaciers (in red) surveyed by Operation Icebridge. Glaciers in blue were not surveyed.

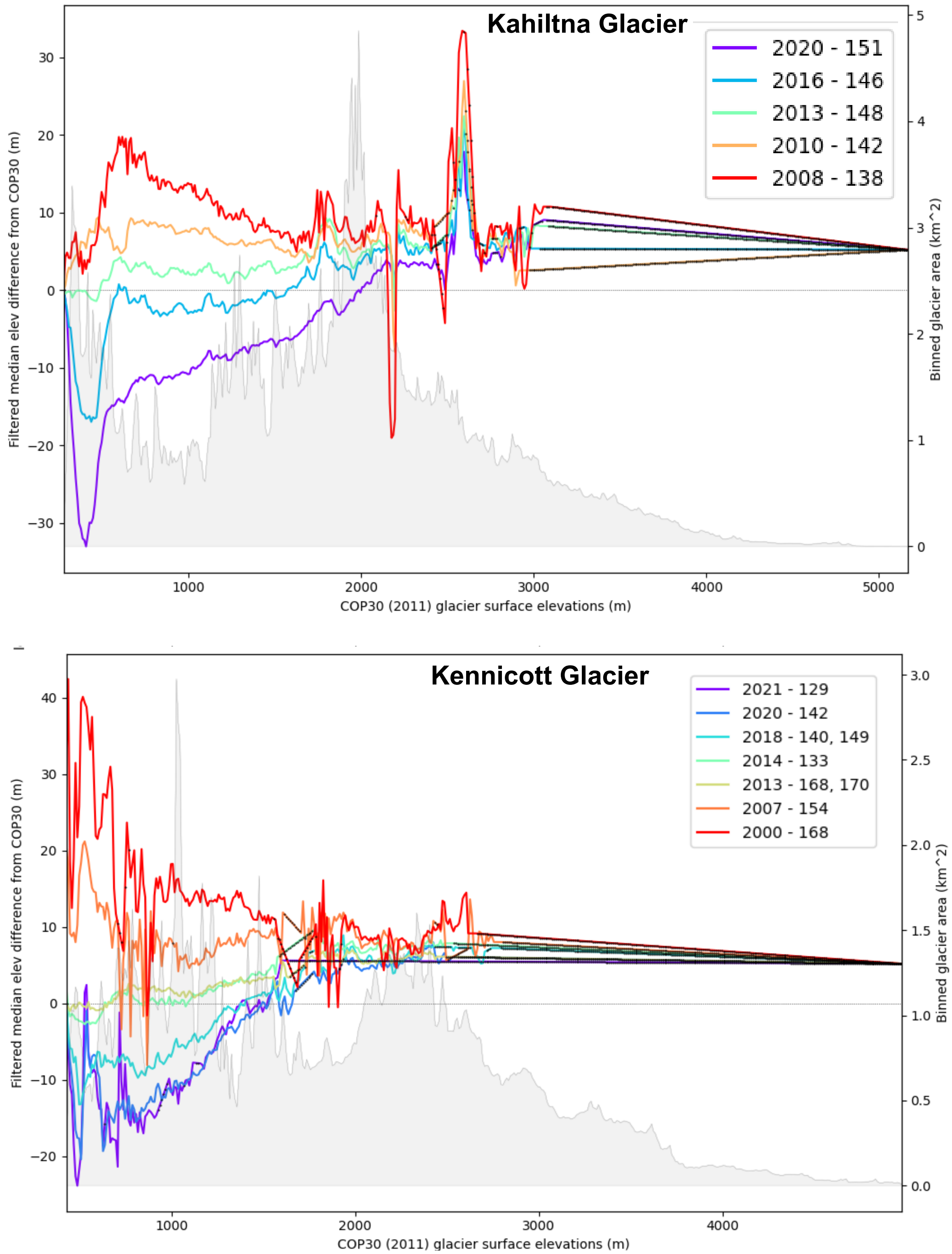

Figure 10. Surface elevation changes for Kahiltna (top panel) and Kennicott (bottom) Glaciers.

Other Glacier Monitoring Activities

Overview

Glacier monitoring in the Central Alaska Network is focused on the mass balance measurements described in the bulk of this report. These measurements are guided by protocols and maintained with long-term intentions. But these measurements describe only two glaciers, and the Central Alaska Network is home to over 4000 individual glaciers. This substantial glacier cover, and the impacts it has upon the ecosystems around it, provides an opportunity—and at times a requirement—that the monitoring program pay attention to phenomena outside the strict bounds of the protocol-based work. Here I describe very briefly some of the other projects that have, with substantial assistance from numerous collaborators inside and outside NPS, been undertaken in the last several years.

Outreach and Interpretation

Education of visitors and management about park phenomena is one important goal for I&M monitoring work, along with an emphasis on detecting and understanding geohazards. Several projects were completed, and others are underway towards accomplishing this goal.

- Two physical models of WRST glaciers were built of precision cut plywood and epoxy and placed in visitor centers. One, showing change in Icy Bay's Tyndall Glacier (also the site of a major landslide), was placed in the headquarters visitor center in Copper Center. The other, of Kennicott Glacier, was placed in the visitor center in the Kennecott Mines National Historic Landmark.

- An article about consequences of human waste disposal on Kahiltna Glacier was published in *Alaska Park Science*. Another, about consequences of climate change for glaciers and other ecosystem components, was separately published in the same journal.

- A storymap about Alaska's Shrinking Glaciers (https://www.nps.gov/maps/stories/alaskas-shrinking-glaciers.html) was published online.

- A new exhibit about the dynamics and anatomy of glaciers is being fabricated at this writing for placement at the Kennecott Mines NHL visitor center.

- Talks about glacier change were given to lay audiences in Anchorage, Gustavus, Juneau, Talkeetna, Kennicott, and Copper Center. Numerous other talks were given to scientific audiences at the American Geophysical Union and other meetings.

Statewide Glacier Change Forecast

With funding primarily from the Southeast Alaska I&M Network (SEAN), NPS is collaborating with researchers at Carnegie Mellon University to produce a new forecast of Alaska glacier change through the year 2100. I conceived of this project after watching a talk given by David Rounce, of CMU, who was summarizing work he and colleagues recently published in Science (Rounce et al.

2023). That work involved a massive computer model that individually simulated the response of every global glacier to several climate change scenarios. In subsequent discussions, Rounce acknowledged that the model could be better calibrated for Alaska using the OIB lidar elevation dataset described earlier in this report. Now he and postdoctoral researcher Brandon Tober are doing just that, re-calibrating their global model using detailed Alaskan data with a goal of producing a new statewide forecast of glacier change. Analysis is expected to be complete in May 2025.

Kahiltna Glacier Climate

One of the great values of NPS-led science is the opportunity it provides for leveraging additional findings through collaborations with other researchers. Utilizing data described earlier in the section on weather stations, the CAKN Glacier Monitoring Program is contributing to several new scientific papers related to high-altitude/high-latitude climate. One paper, just published, uses our data to help explain the extraordinarily high relief of Denali, North America's largest peak (Matmon et al. 2024). One paper, just submitted to Journal of Glaciology, compares our climate and mass balance data to similar data from Mt. Hunter, Mt. Logan, and Mt. St. Elias to develop a new analysis of Gulf of Alaska climate (Kindstedt et al. submitted). A third paper, still in development, focuses on the role of cold high-elevation arctic air masses in inhibiting snowfall on large mountains like Denali (paper in development, no citation).

Alsek River / Grand Plateau Glacier

Though technically involving a glacier outside the CAKN network (Grand Plateau Glacier in Glacier Bay National Park and Preserve), it is worth mentioning a paper that was published recently with significant implications for park management. Following up on an idea first hatched (reportedly) by Austin Post in the 1980s, we used new data including LIDAR and ice-penetrating radar to assess the likelihood of Alsek River being re-routed by the gradual and imminent dissolution of Grand Plateau Glacier's terminus (Loso et al. 2021). Because the Alsek River mouth is of critical importance for numerous human activities in the Dry Bay portion of Glacier Bay National Preserve, this event could have important effects on numerous stakeholders. We predict the change to be highly likely, with the time less certain but possibly within 1-3 decades. The work was also presented to several lay audiences and stakeholder meetings.

Kennicott Glacier Dynamics

As mentioned above, one of the great values of NPS-led science is the opportunity it provides for leveraging additional findings through collaborations with other researchers. Several examples are underway or completed at Kennicott Glacier. We have been working with a group of researchers from University of Alaska Fairbanks (UAF) and from the Chinese Academy of Science (CAS) on mass balance and glacier dynamics-related work on Kennicott Glacier for several years now. This has allowed us to densify our mass balance stake network and we have just submitted a joint paper that includes both NPS and UAF/CAS mass balance measurements (Petersen et al – Submitted). With the same group we recently completed an article about the dynamics of debris-covered glacier termini (Petersen et al. 2024). Finally, we are in the midst of a large project that grew out of management concerns by the NPS maintenance team and the Department of Transportation. Unexpectedly large glacier outburst floods have occurred in each of the last two years at Mendenhall

Glacier (near Juneau) and have prompted us to revisit the question of whether similar floods on the Kennicott River might unexpectedly grow to threaten road, community, NPS, and/or visitor infrastructure near the community of McCarthy. This past summer we collected new ice penetrating radar data from the glacier, and we are presently developing a new funding proposal to support further modeling and analysis.

WRST and CAKN Resource Summaries

Utilizing data and anecdotal knowledge gathered while running the Glacier Monitoring Program, the glaciers PI is contributing summaries of CAKN glacier status and change to several new publications. One, already published, is the new Resource Stewardship Strategy for Wrangell-St. Elias National Park and Preserve. Another is the just completed but yet unpublished Geological Resource Inventory Report prepared with lead author Amanda Lanik. Finally, we are contributing to the development of a cryosphere chapter for the upcoming CAKN book.

Sit' Tlein (Malaspina Glacier) Collaborative Forecasting Project

Malaspina Glacier, along with the Seward Glacier which feeds it (this is unusual for a single glacier to have two names), is the largest glacier in Alaska. We typically refer to it by the traditional Yakutat Tlingit name: Sit' Tlein. We are working towards completion of a multi-year project that combined NPS and National Science Foundation funding to predict the future evolution of this massive glacier. All fieldwork is now complete. Three publications, including two coauthored by the CAKN Glacier Monitoring PI, now summarize some of our findings (Brinkerhoff et al. 2024, Thompson et al. 2024, Tober et al. 2023). More work is expected to be published in the coming year, including a summary of foreland/proglacial lake dynamics and an analysis of the glacier's surge history.

Reporting

In the context of work described above, the CAKN Glaciers program coauthored 10 peer-reviewed publications and has 5 additional papers submitted and/or in press since the 2022 monitoring status report (Table 3).

Table 3. Peer-reviewed papers completed or submitted since 2021.

Year	Article
submitted	Wells A, Tober BS, Child SF, Rounce DR, **Loso MG**, Hults CP, Truffer M, Holt JW, Christoffersen MS. An 85-year record of glacier change and impacts on future projections for Kennicott and Root Glaciers, Alaska. Submitted to *Nature Communications*.
submitted	Petersen E, Hock R, **Loso MG**, Markovsky C, Guo W, Kang S, Shangguan D, Han H, Yang R. Multi-year glaciological and meteorological observations on debris-covered Kennicott Glacier, Alaska, 2008 - 2023. Submitted to *Geoscience Data Journal*.
submitted	Kindstedt I, Coplan L, Kreutz K, Winski D, Campbell S, Schild K, and **Loso MG**. Snow accumulation at Divide Icefield (St. Elias Mountains, Yukon, Canada) as an indicator of Gulf of Alaska coastal climate. Submitted to *Journal of Glaciology*.
in revisions	**Loso MG.** Glacier monitoring in the Central Alaska Network: Protocol narrative, version 1.0. Final edits underway for publication as a Natural Resource Report. National Park Service, Fort Collins, Colorado.
in press	**Loso MG**, Chenoweth T. Is poop a problem? Insights from decades of human waste research and management on Denali. In press for *Alaska Park Science*.
2024	Thompson AC, **Loso MG**, Mooneyham SA, Tober BS, Larsen CF, Holt JW. Surficial geology and proglacial lake change at Sít' Tlein (recently known as "Malaspina Glacier"), Wrangell-St.

	Elias National Park and Preserve, Alaska. *Natural Resource Report* NPS/WRST/NRR-2024/2620. National Park Service, Fort Collins, Colorado. DOI:10.36967/2301689.
2024	Petersen E, Hock R, **Loso MG**. Stream hydrology controls on ice cliff evolution and survival on debris-covered glaciers. *Earth Surface Dynamics*. DOI:10.5194/esurf-12-727-2024.
2024	Matmon A, Haeussler P, **Loso MG**. Anomalously high relief on Denali, Alaska, caused by tectonic, lithologic, and climatic drivers. *Earth and Planetary Science Letters*. DOI:10.1016/j.epsl.2024.118999.
2024	Brinkerhoff D, Tober B, Daniel M, Devaux-Chupin V, Christofferson M, Holt J, Larsen C, Fahnestock M, **Loso MG**, Timm K, Mitchell R, Truffer M. The demise of the world's largest piedmont glacier: a probabilistic forecast. *The Cryosphere*. DOI:10.5194/egusphere-2024-2354.
2023	Sousanes P, Hill K, Swanson D, O'Donnell J, Kirchner P, Kurtz D, **Loso MG**, and Bliss A. Crossing the Zero-Degree C Threshold. *Alaska Park Science,* 22(1):6-21.
2022	White JT, Aureade H, Kuehn S, **Loso MG**, and Rasic JT. Terminal Pleistocene human occupation of the upper Copper River Basin, southern Alaska: Results of test excavations at *NATAEŁ NA'*. *Quaternary International*. DOI:10.1016/j.quaint.2022.08.012.
2022	Jacquemart M, Welty E, Leopold M, **Loso M**, Lajoie L, Tiampo K. Geomorphic and sedimentary signatures of catastrophic glacier detachments: A first assessment from Flat Creek, Alaska. *Geomorphology*. DOI:10.1016/j.geomorph.2022.108376.
2021	Schiefer E, Geck J, Ostman J, McKay N, Praet N, **Loso MG**, Kaufman D. Fluvial suspended sediment transfer and lacustrine sedimentation of recent flood turbidites in proglacial Eklutna Lake, western Chugach Mountains, Alaska. *Hydrological Processes*. DOI:10.1002/hyp.14375.
2021	**Loso MG**, Larsen CF, Tober B, Fahnestock M, Truffer M, Christoffersen M, Holt J. Quo vadis, Alsek? Climate-driven glacier retreat may change the course of a major river outlet in southern Alaska. *Geomorphology*. DOI:10.1016/j.geomorph.2021.107701.
2021	Geck J, Hock R, **Loso MG**, Ostman J, Dial R. Modeling the impacts of climate change on mass balance and discharge of Eklutna Glacier, Alaska, 1985-2019. *Journal of Glaciology*. DOI:10.1017/jog.2021.41.

Lidar and SfM Acquisitions

Geospatial data is increasingly important for glacier monitoring, and the CAKN Glacier Monitoring Program is taking advantage of opportunities to catalyze or leverage new acquisitions of data using both lidar and Structure-from-Motion (SfM) technologies. This is occurring under the auspices of numerous different projects and funding sources, and the products themselves are listed here (Table 4) for convenience. Ultimate ownership, disposition, and availability of each dataset varies, but many are in the process of being incorporated into the NPS/AKRO Theme Manager and/or the State of Alaska's Division of Geological and Geophysical Surveys Elevation Portal <DGGS Elevation Portal (alaska.gov)>.

Table 4. DEMs acquired by the CAKN Glacier Monitoring Program since 2022.

Location	Park	Source	Date
Iceberg Lake	WRST	Larsen SfM	2022_07_08
Kennicott Glacier	WRST	AKRO Hults SfM	2023_08_01
Malaspina Glacier	WRST	Larsen lidar and SfM	2022_05_30
103 glaciers	All	NASA Operation Icebridge lidar	Multi-epoch since 1990s

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Kindstedt I, Coplan L, Kreutz K, Winski D, Campbell S, Schild K, and Loso MG. (Submitted) Snow accumulation at Divide Icefield (St. Elias Mountains, Yukon, Canada) as an indicator of Gulf of Alaska coastal climate. Submitted to *Journal of Glaciology*.

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Loso MG, Larsen CF, Tober B, Fahnestock M, Truffer M, Christoffersen M, Holt J (2021) Quo vadis, Alsek? Climate-driven glacier retreat may change the course of a major river outlet in southern Alaska. *Geomorphology*. DOI:10.1016/j.geomorph.2021.107701.

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December 2024

National Park Service
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