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Gulkana Glacier, Alaska—Mass Balance, Meteorology, and Water Measurements, 1997–2001

Scientific Investigations Report 2011–5046

U.S. Department of the Interior
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Cover: Photograph looking at the mostly debris-covered Gulkana Glacier terminus from just downstream of Phelan Creek USGS streamflow-gaging station No. 15478040, September 12, 2001. The station site is about 1 kilometer downstream of the present glacier terminus. Dennis Trabant, USGS retired, is standing at the edge of the creek in the center of the photograph. The channel bed is composed of typical ground moraine material—poorly sorted gravel and small boulders—which is subject to frequent changes during high flows. The mean discharge for September 12, 2001, was about 0.8 cubic meters per second (daily runoff of about 5.5 millimeters), a value about 40 percent of normal for this time time of year. The unmanned cableway (faintly visible) and southeast bank tower shown are used for making discharge measurements when the flow is too deep and fast for wading. The instrumentation and satellite telemetry shelter for the gaging station lie just beyond of the right edge of the photograph. A recent new fall snowfall is apparent at higher elevations. Photograph by Rod March.

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By Rod S. March and Shad O’Neel

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U.S. Department of the Interior
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Conversion Factors, Datums, and Abbreviations and Acronyms

Conversion Factors

Multiply	By	To obtain
	Length	
centimeter (cm)	0.3937	inch (in.)
millimeter (mm)	0.03937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
kilometer (km)	0.5400	mile, nautical (nmi)
meter (m)	1.094	yard (yd)
	Area	
square kilometer (km^2)	247.1	acre
square kilometer (km^2)	0.3861	square mile (mi^2)
	Volume	
cubic meter (m^3)	6.290	barrel (petroleum, 1 barrel = 42 gal)
cubic meter (m^3)	264.2	gallon (gal)
cubic meter (m^3)	0.0002642	million gallons (Mgal)
cubic meter (m^3)	35.31	cubic foot (ft^3)
cubic meter (m^3)	1.308	cubic yard (yd^3)
cubic meter (m^3)	0.0008107	acre-foot (acre-ft)
cubic kilometer (km^3)	0.2399	cubic mile (mi^3)
liter (L)	33.81	ounce, fluid (fl. oz)
liter (L)	2.113	pint (pt)
liter (L)	1.057	quart (qt)
liter (L)	0.2642	gallon (gal)
	Flow rate	
cubic meter per second (m^3/s)	70.05	acre-foot per day (acre-ft/d)
cubic meter per second (m^3/s)	35.31	cubic foot per second (ft^3/s)
meter per second (m/s)	3.281	foot per second (ft/s)
meter per year (m/yr)	3.281	foot per year (ft/yr)
millimeter per day (mm/d)	0.03937	inch per day (in/d)
	Mass	
kilogram (kg)	2.205	pound avoirdupois (lb)
	Density	
kilogram per liter (kg/L)	62.43	pound avoirdupois per per cubic foot (lb/ft^3)
	Plane angle	
grad	0.9	degree

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F=(1.8×°C)+32.$$

Conversion Factors, Datums, and Abbreviations and Acronyms—Continued

The water year, or hydrologic year, is the interval between October 1 and the end of the following September and provides a framework for a fixed-date or annual mass balance estimate. Each estimate is designated by the calendar year in which it ends; for example, B98 represents the glacier-wide balance for the interval October 1, 1997–September 30, 1998). The terms "this year" and "current year" are used interchangeably in this report for balance year and water year, depending on the data being discussed.

All balance values are reported in meters weq. The density of water is 1 kg/L, and that of glacier ice is assumed to be 0.9 kg/L. We report density in kilograms per liter, which numerically is equivalent to the unitless relative density (the decimal fraction of the density of water).

Positions are given in a local horizontal reference frame (values 0–10,000 m), Universal Transverse Mercator (UTM), and geographic coordinates (latitude, longitude). Horizontal coordinates in the local system (a sea-level-scale network based on UTM with the positive Y-axis approximately true north) may be converted to UTM zone 6 coordinates (NAD 83 datum) as described in appendix 1. NAD 83 datum coordinates are approximately equal to WGS 84 datum coordinates.

Vertical coordinates are referenced to the NGVD 29 datum. Within the basin and nearby region, these may be converted to the NAVD 88 datum or NAD 83 ellipsoid heights (approximately the same as WGS 84 ellipsoid heights) as described in appendix 1.

Abbreviations and Acronyms

AAD	area-altitude distribution
AAR	accumulation-area ratio
DD	degree day
DRG	digital raster graphic
ELA	equilibrium line altitude
LIA	Little Ice Age
mweq	meters water equivalent
PPS	Precise Positioning Service
USGS	U.S. Geological Survey
UTM	Universal Transverse Mercator
WGMS	World Glacier Monitoring Service

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Abstract

The measured winter snow, maximum winter snow, net, and annual balances for 1997–2001 in the Gulkana Glacier basin are determined at specific points and over the entire glacier area using the meteorological, hydrological, and glaciological data. We provide descriptions of glacier geometry to aid in estimation of conventional and reference surface mass balances and descriptions of ice motion to aid in the understanding of the glacier's response to its changing geometry. These data provide annual estimates for area altitude distribution, equilibrium line altitude, and accumulation area ratio during the study interval. New determinations of historical area altitude distributions are given for 1900 and annually from 1966 to 2001. As original weather instrumentation is nearing the end of its deployment lifespan, we provide new estimates of overlap comparisons and precipitation catch efficiency.

During 1997–2001, Gulkana Glacier showed a continued and accelerated negative mass balance trend, especially below the equilibrium line altitude where thinning was pronounced. Ice motion also slowed, which combined with the negative mass balance, resulted in glacier retreat under a warming climate. Average annual runoff augmentation by glacier shrinkage for 1997–2001 was 25 percent compared to the previous average of 13 percent, in accordance with the measured glacier volume reductions.

Introduction

The U.S. Geological Survey (USGS) operates a long-term program to monitor glacier mass balance, geometry, motion and runoff while simultaneously monitoring local climate. Research aims include improved quantitative estimates of water resources, glacier-related hazards, and glacier response to global climate change (Fountain and others, 1997). These goals require making glaciological point measurements alongside continuous observations of local meteorology and runoff thereby facilitating glacier-wide balance estimates.

The purpose of this study is to establish long-term mass balance monitoring programs at three widely spaced index glaciers in the United States that sample different climate-glacier-runoff regimes. This report focuses on Gulkana Glacier, one of the index glaciers located in interior Alaska. Other reports document the programs at Wolverine Glacier in south-central Alaska (e.g. Mayo and others, 2004) and South Cascade Glacier in Washington (e.g. Bidlake and others, 2007). This report contains the glaciological mass balance, geometry, ice dynamics, meteorological, and water budget measurements made at Gulkana Glacier for the 1997–2001 balance years (fig. 1).

History

Measurements began on Gulkana Glacier during the early 1960s with the University of Alaska Gulkana Glacier Project (Péwé and Reger, 1983). For several years this project measured the energy budget, mass balance, meteorology, foliation, flow, and glacier-bottom topography at Gulkana Glacier. In 1966, USGS initiated a suite of continuous measurements as part of the United States contribution to the International Hydrologic Decade study of glacier mass balance. After a decade of dense spatial sampling, the number of glacier measurement sites was reduced to three representative index sites, at which ice-motion and surface-altitude observations (for determining glacier-volume change) began. The Gulkana Glacier record (36 years of balance data, 35 years of meteorology) now exceeds the 30-year criterion to provide statistics with sufficient confidence that can be used in the selection of stations for international exchange through the Global Telecommunications Service for global climate monitoring (Karl and others, 1989).

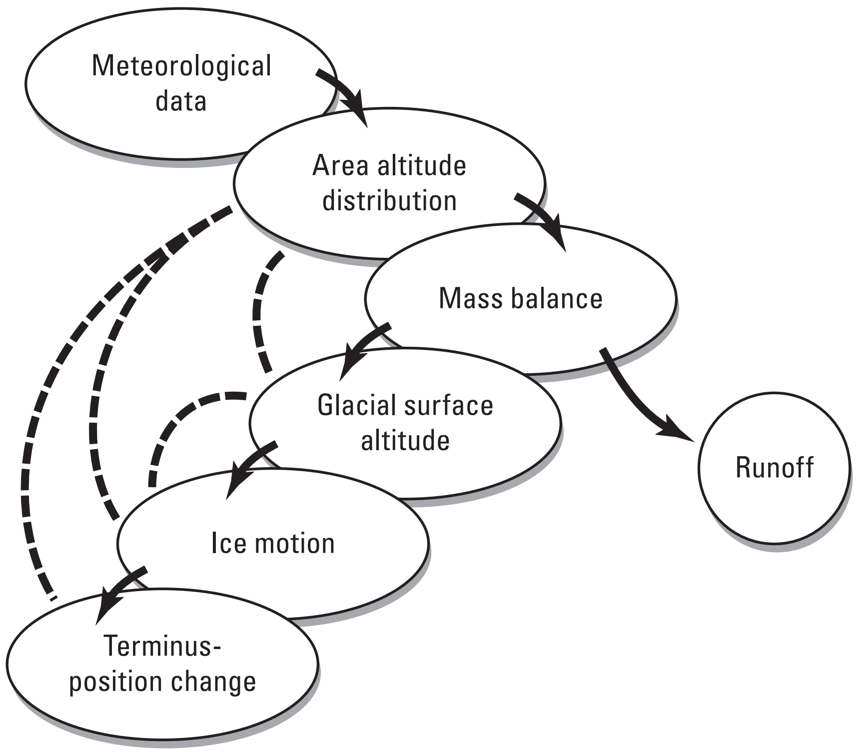

Figure 1. Cause and effect relationships for data presented in this report (modified from Meier, 1965; and Fountain and others, 1997).

Program results are documented in numerous reports: Meier and others (1971) and Tangborn and others (1977) give detailed results for 1966 and 1967, respectively. The series of balance estimates for 1966–77 are reported by Meier and others (1980). Since 1966, the Gulkana Glacier data set has been published by the World Glacier Monitoring Service (http://www.geo.unizh.ch/wgms/) in a 5-year *Fluctuations of Glaciers* series (Kasser, 1967; Muller, 1977; Haeberli, 1985; Haeberli and Müller, 1988; Haeberli and Hoelzle, 1993; Haeberli and others, 1998) and in a 2-year *Glacier Mass Balance Bulletin* series (Haeberli and Herren, 1991; Haeberli and others, 1993, 1994, 1996, 1999). March and Trabant (1996, 1997) and March (1998, 2000, 2003) describe the program for intervals between 1992 and 1996. Trabant and March (1999) published the basic balance series through 1998. Select references, data, maps, and photographs from Gulkana Glacier are available at http://ak.water.usgs.gov/glaciology/.

Interpretations of regional climate-glacier relations using Gulkana Glacier data include papers by Fahl (1973), Letréguilly and Reynaud (1989), Walters and Meier (1989), Dowdeswell and others (1997), Hodge and others (1998), Trabant and others (1998), Bitz and Battisti (1999), Elsberg and others (2001), Rasmussen and Conway (2004), and Josberger and others (2006, 2007). The validity of long-term cumulative mass balance at Gulkana Glacier has been verified recently by a comparison of the geodetic (photogrammetry) and glaciological mass-balance techniques in Cox (2002), and Cox and March (2004).

Theory

Classical glaciological mass balance methodology is well described in the literature, including concise theoretical descriptions (e.g. Mayo and others, 1972; Patterson, 1994) and glaciological field methods (Østrem and Brugman, 1991). We give a minimal framework for understanding the measurements and interpretation presented herein. We follow the terminology established by Mayo and others (1972), for the combined mass balance system, which relates point measurements to time-transgressive stratigraphic horizons, or summer surfaces.

Mass balance is measured at markers drilled into the glacier surface at predetermined locations (index sites), then extrapolated over the entire glacier area. We refer to point measurements as local, or site balances, b, representing glacier thickness changes at a marker in water equivalent (weq) units. Mass is lost from the glacier system through ablation ($b<0$) and subsequent runoff. Ablation can occur at the surface from climatic forcing (old firn and ice melt, $b(i)$)

or from frictional, strain or geothermal heat transfer at the bed or by water transport, which we refer to as internal ablation (*b(j)*). Mass is gained (*b*>0) through snowfall and wind and avalanche transport (*b(f)*) or by refreezing of meltwater below the summer surface in old firn (*b(k)*), which is called internal accumulation. Seasonal measurement intervals provide enough information to evaluate net, seasonal, and annual mass budgets.

Net balance, b_n, is the change in snow, firn, and ice storage between times of minimum mass and is not referenced to fixed dates. Direct stake, pit, core, and probe measurements give the net balance at each index site. The timing of this mass minimum occurs asynchronously on different parts of the glacier (earlier high on the glacier and later low on the glacier, as summer melting usually ends earlier on the upper glacier than the lower glacier). Integrating local balance minimums over the glacier area, as is done by some researchers, yields a close approximation to the glacier average net balance, but unlike the true area-averaged, net balance it is not defined with regard to time and does not represent the actual balance on the glacier at any moment. Here we take the extra step to calculate the true glacier averaged net balance that is defined in time and which represents the actual balance on the glacier. Interpretations of net balance often are generalized conceptually to represent the changes for a glacier on a so-called ‘yearly’ basis even though the net balance period is different each year and may differ substantially from a full year.

Mayo and others (1972) defined winter balance as changes in mass from minimum mass to maximum mass in a season. Measured winter balance, $b_m(s)$, is evaluated during late winter or spring, typically mid-April, to quantify the average snow thickness above the previous summer surface near the time of the maximum winter snow balance. This value differs from the maximum winter snow balance, $b_w(s)$, which quantifies the maximum snow mass during the balance year and may occur either before or after the measured winter snow balance. All values may be evaluated as glacier-wide averages as denoted with a bar as in $\bar{b}_m(s)$. The World Glacier Monitoring Service (WGMS) publishes a winter balance that is not identified clearly as any of these and may vary from glacier to glacier. The glacier-wide averaged measured winter snow balance, $\bar{b}_m(s)$, is probably the most common winter balance value reported by WGMS.

Summer balance, b_s, was defined by UNESCO (1970) as the mass loss from the maximum mass state to minimum mass state in a given season. The summer balance can be determined from difference between the maximum winter balance, $b_w(s)$, and the net (yearly) balance, b_n.

$$b_s = b_n - b_w(s)\,. \qquad (1)$$

Annual mass balance, b_a, is the change in snow, firn, and ice storage for the balance year (same as water year), the period between October 1 of any year and September 30 of the following year. Evaluation of the annual balance requires model estimates of initial snow balance, $b_0(s)$, and initial ice balance, $b_0(i)$, at the beginning of the water year and the final late snow balance, $b_1(ls)$, and final ice balance, $b_1(i)$, at the end of the water year for each index site (Mayo and others, 1972):

$$b_a = b_n - b_0(s) + b_0(i) + b_1(ls) - b_1(i)\,. \qquad (2)$$

Regardless of the measurement time interval (summer, winter, annual or net), local mass balances allow determination of glacier-wide mass balance, *B*, by integrating over the glacier surface area, *A*:

$$B = \int b dA \cdot \qquad (3)$$

A more useful value for comparison between glaciers is obtained by scaling by the glacier surface area, for an area-average balance:

$$\bar{b} = \int \frac{bdA}{A} \cdot \qquad (4)$$

This number represents an average thickness change in meters water equivalent (mweq) for the glacier allowing direct comparison between the changes of glaciers with different areas. Care must be taken, however, because for some purposes using of the volumetric balance will give the correct result and using area-average balance will give a different and incorrect result.

In practice, we often use a description of mass balance as a function of altitude, *b(z)* so that interpolated values can be scaled by the map-derived, area altitude distribution, γ(z). Integrating this product over the glacier altitude range yields the conventional glacier-wide average balance, which can also be scaled by the glacier area:

$$\bar{b} = \int b(z)\frac{\gamma(z)}{A}dz \cdot \qquad (5)$$

Equation 5 can be corrected for glacier-averaged values of internal ablation:-

$$\bar{b} = \int b(z)\frac{\gamma(z)}{A}dz + \bar{b}(j) \cdot \qquad (6)$$

In practice, equation 5 is estimated by integrating a stepwise-constant balance function. Values of area and balance are measured or interpolated at regular elevation intervals (often 50–100 m) depending on the size of glacier and measurement density. For each interval, the contribution to the integral is the product of the median altitude balance (interpolated from the balance-altitude distribution) and the fraction of the total glacier area within the interval.

Cumulative balances, β, are estimated by summing glacier-wide balances over balance years i=1, 2, . . . , N:

$$\beta = \sum_{i=1}^{N} B_i , \qquad (7)$$

to describe whether a glacier is growing (β>0) or shrinking (β<0) in time.

When glacier-climate interactions are the focus of the program, the reference surface balance (Elsberg and others, 2001) is calculated, where the glacier geometry is fixed in its initial state (Elsberg and others, 2001; Harrison and others, 2005). If the hydrologic budget is the focus of the measurement program, the conventional mass balance should be calculated which requires an updated geometry (surface area and area-altitude distribution) each year. Comparison of the two balances can highlight glacier dynamics (Harrison and others, 2009). Although the theory of the reference surface balance is relatively new in glaciology, it has actually been calculated unknowingly far more often than conventional balance due to the time consuming and expensive nature updating the glacier geometry on an annual basis, as is necessary for correctly determining conventional balance.

Gulkana Glacier Basin and its Climate

Gulkana Glacier (figs. 2 and 3; 63°16’ N, 145°25’ W) is located in a 31.5-km^2 basin on the south flank of the eastern Alaska Range. This basin is drained by Phelan Creek. The accumulation area consists of four adjacent cirques with east, south, and west exposures that reach altitudes as high as 2,470 m. About 60 percent of the glacier is accumulation area. The 1966–2001 average equilibrium line altitude (ELA) is 1,770 m, about 50 m higher than the expected ELA in steady state. The ablation area flows south-southwestward, and the

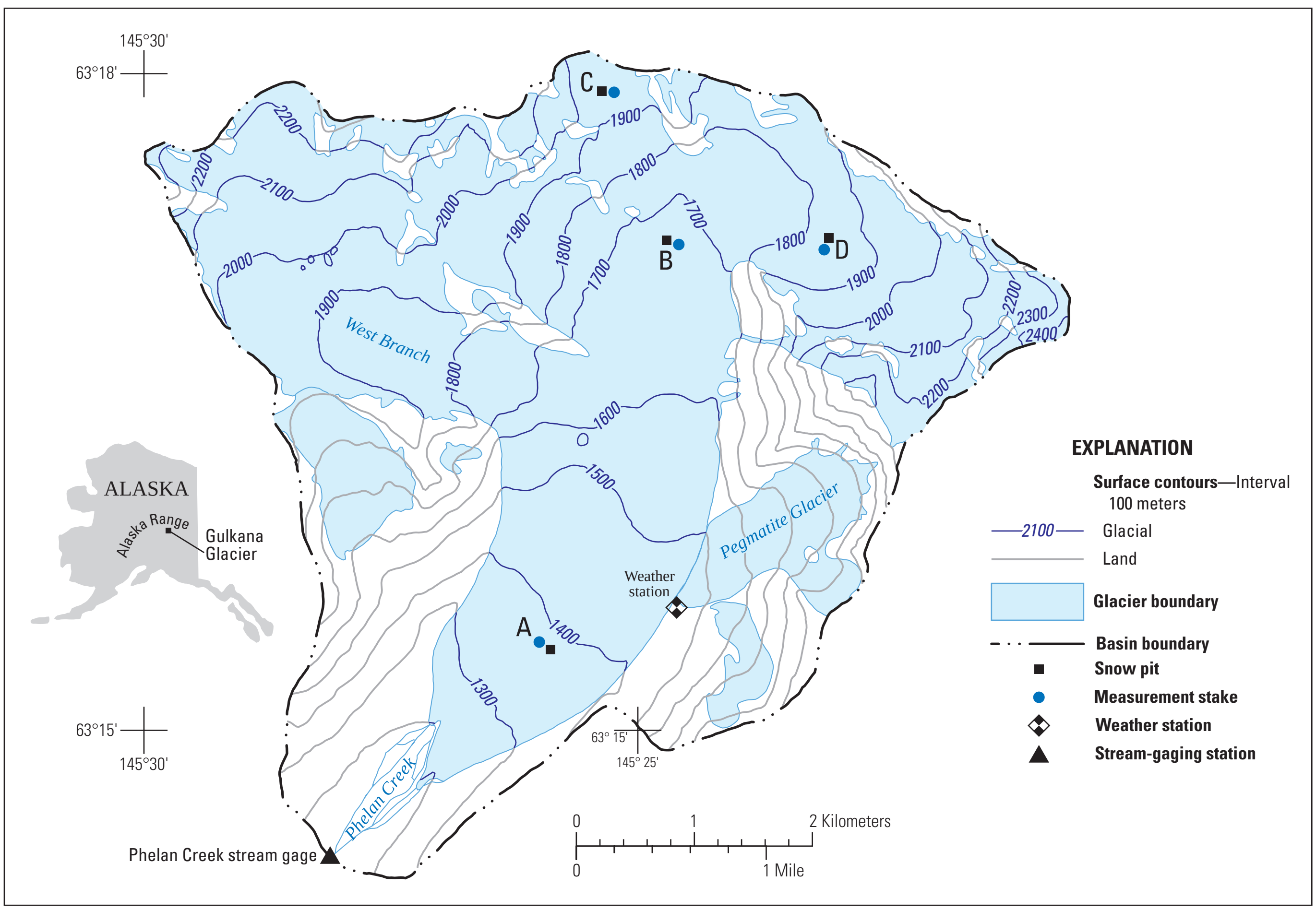

Figure 2. Index measurement sites A, B, and D, glacier surface altitudes, weather and stream-gaging stations, and boundary of Gulkana Glacier, Alaska (horizontal datum, NAD 27; vertical datum, NGVD 1929).

terminus is lightly covered with rock debris (fig. 3) below 1,160 m. Slightly contorted moraines near the terminus (fig. 3) suggest that Gulkana Glacier may have surged in the past, but no flow instabilities have been detected since the early 1960s. The most recent period of advance ended around 1900 with the termination of the Little Ice Age (LIA; Péwé and Reger, 1983). Total recession since then is about 3 km. During our monitoring program the glacierized surface area of the 31.5 km^2 basin decreased about 20 percent from 19.5 km^2 to less than 17 km^2.

The climate in this part of Alaska is best described as continental. Daily mean temperatures display large variability, ranging from -35 °C to 15 °C. The mean annual air temperature at the weather station adjacent to the middle of the glacier's ablation zone is -3 °C; at the ELA the mean annual air temperature is -5 °C assuming a lapse rate of -6.6 °C/km (air cools with increasing altitude). The average annual precipitation gage catch at the weather station is about 1 mweq. Catch efficiency of the gage averages about 60 percent, so annual average precipitation is about 1.6 m. The basin average runoff since the measurement program began is 1.9 m indicating that runoff exceeds precipitation by about 16 percent as a result of the glacier losing mass.

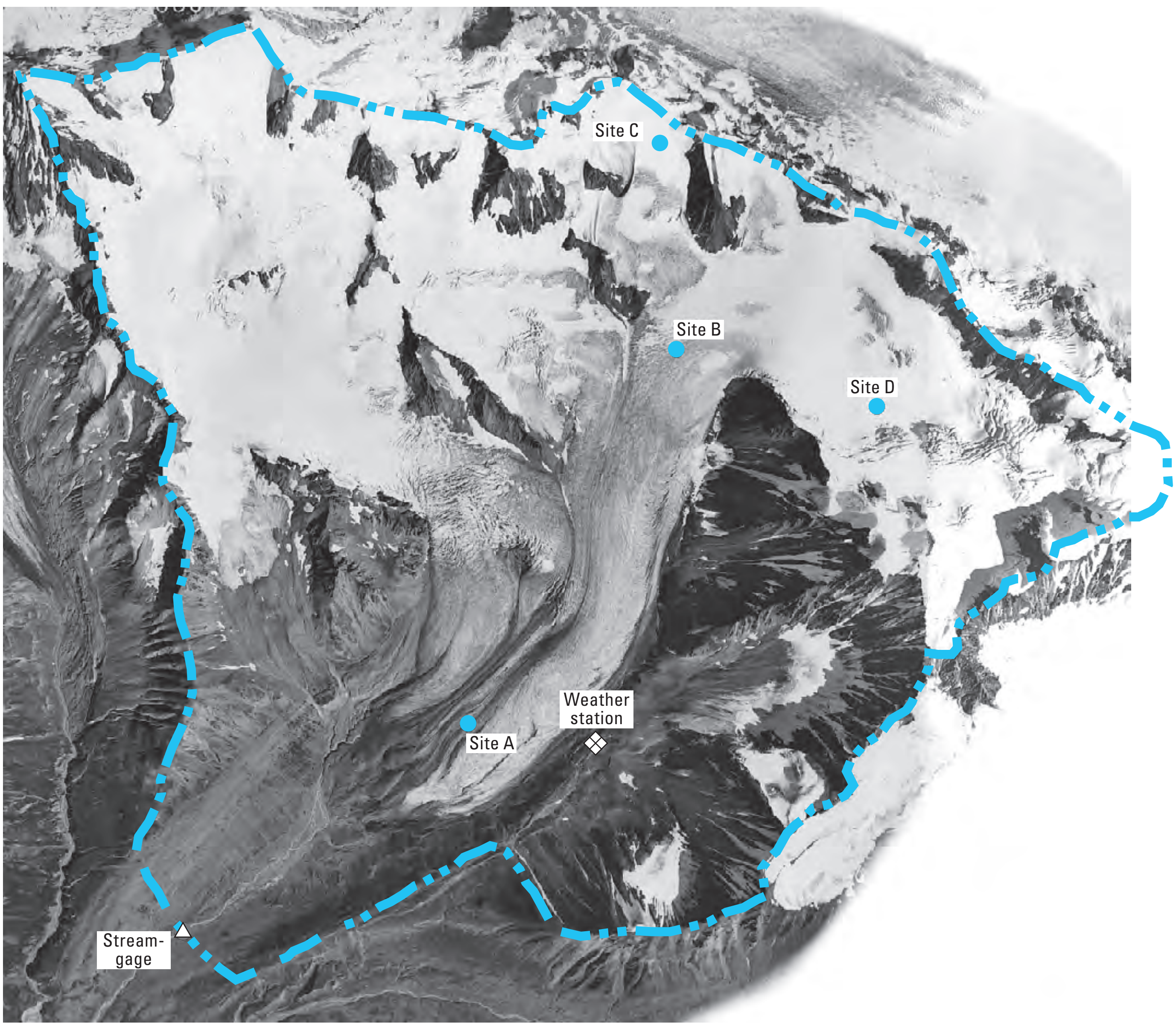

Figure 3. Index measurement sites, stream-gaging station, weather station, and basin boundary, Gulkana Glacier, Alaska, July 11, 1993 (photographs Gulkana GI 1 no. 5 and Gulkana GI 2 no. 4 by AeroMetric, Inc.). A, B, and D are index measurement sites for mass balance, ice motion, and surface altitude. Dash-dot-dot-dash line indicates basin boundary.

Methods

The core of the Gulkana Glacier monitoring program consists of surface mass balance, surface altitude, and ice motion. Measurements were made at three fixed index sites (A, B, and C or D; figs. 2 and 3, table 1). Sites A and B are in the ablation zone; site B is the higher of the two and is near the ELA; site C and D are in the accumulation zone. Site C was used as the high site through 1975; Site D has been used as the high site since then. Streamflow and weather observations are critical to interpret the mass balance measurements with respect to basin-wide water balance and climate. Weather observations also are critical in accurately extrapolating end-of-season point values from the time of seasonal observations, which seldom coincide exactly with the end of each season.

Glacier Mass Balance

We provide data using the terminology described above, largely following Mayo and others (1972). We include point estimates of internal accumulation as outlined in Trabant and Mayo (1985) and glacier-average corrections for internal ablation as described by March and Trabant (1997). Our results include estimates of net (stratigraphic) and annual (fixed-date) balances as well as modeled adjustment parameters required for these calculations.

Stake observations are made in early spring and late autumn in attempts to coincide with mass balance extremes while facilitating fieldwork. In addition to measuring the near-maximum balance, observations during the spring add redundancy to summer surface measurements made during the previous autumn. Because little or no melt of the summer surface occurs between these two measurements, the stake height of the surface should be the same. This height is seldom the same, however, because of variable snow depths, surface roughness, and measurement error; hence, the redundancy supports an assessment of stake-measurement errors.

Site Balances

Although mass-balance measurement locations commonly are referred to as points on a glacier, they are treated as small areas 25–75 m in radius, centered on each index site. Snow depth measurements are made throughout this area to average out surface irregularities. Likewise, stake readings are made to best represent the intersection of the average glacier surface with the stake.

Stake positions were adjusted to correct for lean and bending (b'), which are common after the initial near-vertical installation of the stakes (March, 2000). These corrections also improve the precision of ice motion estimates. When possible, we make redundant stake measurements; although this often delays assignment of final balance values by one or two seasons, it averages local surface roughness and reduces balance errors (March, 2000).

Temporal extrapolations between measurements are necessary to estimate balances such as the maximum winter balance, glacier-averaged net balance, and annual balance. We used a two-parameter linear model that relates the air temperature and precipitation catch recorded at the weather station to each local site balance. The temperature was lapsed from the recorder altitude to each of the index-site altitudes using the wet-adiabatic lapse rate of -6.6 °C/km. Model ablation rates ranged between 3.5 mm and 5 mm water equivalent per positive degree day for snow and twice that when the surface was ice or firn. (Positive degree days is the sum of average daily air temperatures that are above freezing.) This range of values agrees closely with those common in the literature (Braithwaite and Olesen, 1985, 1993; Braithwaite, 1995; Jóhannesson and others, 1995). Modeled accumulation rates are 1.5–4.0 times the precipitation catch for lapsed temperature below 1.8 °C.

Table 1. Coordinates of index sites A, B, C, and D.

[**UTM**, Universal Transverse Mercator projection. **X, Y**, Easting, Northing in meters; latitude, longitude in decimal degrees. **Abbreviations**: NAD 83, North American Datum 1983; m, meter; dec.deg., decimal degrees]

Name	Datum	Local coordinates		Sea level to UTM scale factor	UTM zone	UTM Easting (m)	UTM Northing (m)	North latitude (dec.deg.)	West longitude (dec.deg.)
		X (m)	Y (m)						
Site A	NAD 83	3,825.10	4,447.27	0.9996730	6	578,823.85	7,015,445.82	63.2593085	145.4297726
Site B	NAD 83	4,728.61	7,391.17	0.9996738	6	579,727.07	7,018,388.76	63.2855115	145.4103356
Site C,1966	NAD 83	4,165.61	8,887.93	0.9996733	6	579,164.25	7,019,885.03	63.2990600	145.4208180
Site C,1967	NAD 83	6,731.24	6,870.36	0.9996758	6	581,729.06	7,017,868.13	63.2803900	145.3707010
Site C,1968-75	NAD 83	4,165.61	8,887.93	0.9996733	6	579,164.25	7,019,885.03	63.2990600	145.4208180
Site D, 1976-2001	NAD 83	5,999.01	7,353.57	0.9996751	6	580,997.06	7,018,351.18	63.2848897	145.3850443

Ablation rate and the precipitation-catch multipliers are not fixed in this model. Separate values are determined for each measurement period at each index site to equate simulated and measured balances. Thus, the model serves only to distribute measured balances over each measurement interval enabling estimates of annual and net balances. During the autumn-to-spring measurement period, no ablation usually occurs, so the model is reduced to a one-parameter model dependent only on precipitation. During the spring-to-autumn measurement period, little or no accumulation occurs, so the model again is reduced to a one-parameter model dependent only on temperature. Small quantities of accumulation early in the spring-to-autumn measurement period are modeled using the precipitation-catch multiplier determined for the previous winter. Small quantities of accumulation near the end of the spring-to-autumn measurement period are modeled by adjusting a separate precipitation-catch multiplier until the measured late snow balance is matched. These calculated site balances differ from the tabulated net balances by small increments, b_{n0} and b_{nl}.

Area-Averaged Balances

Although mass balance is measured at only three sites at Gulkana Glacier, March and Trabant (1996) showed that the balance gradient is strongly nonlinear. Therefore, the concern that the limited number of index sites introduces substantial error in glacier-wide balance is warranted. For this reason, the index site concept has undergone rigorous scrutiny. Extensive balance networks measured in 1966 and 1967 were used to select a reduced site distribution (March and Trabant, 1996). We purposefully structured the program with only three altitude intervals whose boundaries are exactly one-half way between the index sites. With this system at Gulkana Glacier, the average balance value in each altitude interval equals the measured site balance value. No interpolation or extrapolation was necessary, and site measurements become the average balance for each altitude interval. No guarantee exists that this approach will work on other glaciers. For added security, we compared our mass balance estimates (called glaciological balances) to geodetic (photogrammetric) balance estimates. The two types of estimates agreed at the 1-m level and the glaciological estimates did not have systematic error propagation issues (Cox and March, 2004). Over the duration of the program, we determined the error in the yearly glaciological glacier-averaged balances to be ±0.2 m (March and Trabant, 1996). The current index sites may not yield high-quality results indefinitely, however, and continued checks between the glaciological and geodetic balances are essential.

In estimates of glacier-averaged mass balance, we include glacier-averaged internal ablation, $b(j)$. This term is derived from three internal and subglacial energy sources: (1) the geothermal heat at the bed of the glacier, (2) the potential energy loss from ice motion, and (3) the potential energy loss from water flowing through the glacier and along the bed of the glacier (Mayo, 1992; March and Trabant, 1997). These terms are quite small annually, but if neglected, would accumulate as a bias error over time.

Equilibrium Line Altitude and Accumulation Area Ratio

The ELA is the average altitude where the net mass balance is zero and separates the accumulation area from the ablation area (where more material is lost during the year through ablation than gained by accumulation). Sometimes the ELA corresponds to the highest transient snow or firn line reached in the melt season, but the ELA commonly is lower on the glacier because of internal accumulation in firn or the presence of superimposed ice. When superimposed ice is exposed at the surface, its lower boundary defines the ELA. Superimposed ice may form in the spring as snowmelt percolates down to the impermeable and cold old ice surface and refreezes, and is considered as part of the current year's snow. At Gulkana Glacier, the ELA can be extremely complicated, seldom crossing the glacier along a single altitude contour. Accurate estimation requires well-timed vertical or high-angle oblique aerial photography over the whole glacier, a rare occurrence. Instead, for reliability, linear interpolation from the balance-altitude curve of the three index sites is used to estimate the ELA.

The accumulation area ratio (AAR) is the fraction of the glacier area over which accumulation or net mass gain occurs. It includes areas of new firn, superimposed ice, and areas of old firn below the snowline where internal accumulation exceeds old firn loss.

Glacier Geometry

Area Altitude Distribution

The area altitude distribution (AAD) most completely describes the history of glacier geometry. An original AAD from 1967 has been used to calculate and report all glacier-averaged balances prior to this publication. As such, previous balances have not been conventional net mass balances, but have been reference surface net balances (Elsberg and others, 2001).

For the first time, we are reporting the time varying AAD for Gulkana Glacier (fig. 4, table 2), so that a true hydrologic balance can be estimated. Four new AADs are introduced (1900, 1974, 1993, and 1999), and from the five complete descriptions of AAD we estimate an annual value using linear interpolation or extrapolation. We estimate an AAD for the Little Ice Age (LIA) maximum, circa 1900, by using the LIA trim lines as the glacier edge and preserving the modern surface curvature. At about the modern ELA, where trim lines disappear, the paleosurface was "feathered" into the 1974 surface and the LIA surface is estimated to be the same as the 1974 surface above the ELA. The original 1967 AAD (Tangborn and others, 1977) is based on a 100-m contour topographic map produced by examination of the USGS 1950s aerial photography and resultant 1:63,360-scale topographic maps (Mt. Hayes A–3 [1950] and B–3 [1955]), and more recent oblique aerial photography (dates unknown) taken by Austin Post and Larry Mayo (part of the USGS Ice and Climate Project Photography Collection, GeoData Center, Fairbanks, Alaska, available at http://www.gi.alaska.edu/services/geodata/). Higher quality estimates of glacier area derive from photogrammetric analysis of vertical aerial photography acquired September 4, 1974; August 11, 1993; and August 18, 1999 (Cox and March, 2004).

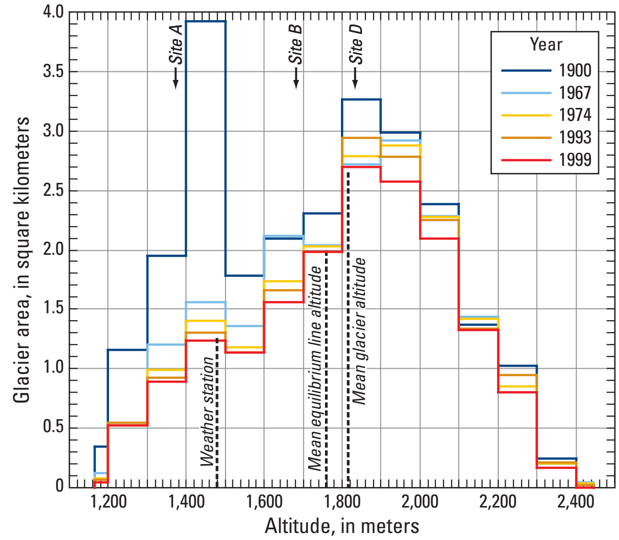

Figure 4. Area altitude distribution of Gulkana Glacier, Alaska, in 1900, 1967, 1974, 1993, and 1999 for 100-meter altitude bins. Altitudes of index sites, the weather station, the mean equilibrium line, and mean altitude of the glacier are shown.

Terminus Position

The terminus is the fastest changing region of the glacier, and surveying the ice margin provides the best description of changes to the length and lower area of the glacier. We made late-summer, hand-held GPS terminus surveys each year between 1997 and 2001 by walking about 4 km of the lower glacier margin (fig. 5, tables 3–9). We used a Collins Rockwell Precision Lightweight GPS Receiver, which is a single-frequency (L1) encrypted P(Y) code receiver capable of Precise Positioning Service (PPS) operation. This receiver provided single-station, mapping grade solutions PPS, prior to the removal of the selective availability encryption in 2000. Wilson and others (1999) estimated errors of 4.5 and 6 m in the horizontal and vertical directions, respectively, with improvement to 5 m vertical resolution after 1999. Our own assessment of the errors showed repeat capability averaging 3 m at a known benchmark (Péwé; fig. 5). Software-derived error estimates averaged 5–6 m (5 percent greater than10 m; maximum error 20 m) for about 180 terminus locations surveyed in 1999 and 2000; thus, an average error in the terminus data of 6 m was assumed.

A coarse optical survey from 1985 and photogrammetrically derived terminus locations from vertical aerial photography acquired July 11, 1993 predate GPS measurements (fig. 5, table 4). We estimated the accuracy of optically surveyed positions at 0.1 m and photogrammetrically derived positions at less than 1 m. However, debris covers much of the terminus (fig. 3), and the transition from clean glacier ice to debris-covered ice to ice-cored moraine and till is gradual and indistinct, adding many meters of uncertainty to the terminus definition in some areas, regardless of survey method. This uncertainty is largest along a 0.5-km stretch of the southwest terminus where the error may be as much as 200 m.

Table 2. Gulkana Glacier area altitude distribution, from Little Ice Age (LIA) maximum, about 1900, to 2001.

[1990 estimated AAD is from reconstruction (see text). 1967 estimate is from Tangborn and others (1977). Area in square kilometers; altitude in meters. **Abbreviation**: km^2, square kilometer]

Year	Gulkana Glacier area, in square kilometers, by 100-meter altitude zones															Total Gulkana area	Area change per year (km^2)	Method
	Zone Top / Bottom	1,200 / 1,100	1,300 / 1,200	1,400 / 1,300	1,500 / 1,400	1,600 / 1,500	1,700 / 1,600	1,800 / 1,700	1,900 / 1,800	2,000 / 1,900	2,100 / 2,000	2,200 / 2,100	2,300 / 2,200	2,400 / 2,300	2,473 / 2,400			
1900 ± 15		0.35	1.16	1.95	3.92	1.78	2.09	2.31	3.26	2.99	2.38	1.37	1.03	0.25	0.02	24.86		Estimate
1966		0.13	0.52	1.23	1.58	1.38	2.17	2.04	2.71	2.93	2.28	1.44	0.79	0.20	0.04	19.46	-0.08	Extrapolation
1967		0.12	0.52	1.20	1.56	1.36	2.12	2.04	2.72	2.92	2.28	1.44	0.80	0.20	0.04	19.32	-0.14	Estimate
1968		0.11	0.52	1.17	1.54	1.34	2.07	2.04	2.73	2.91	2.28	1.44	0.81	0.20	0.04	19.18	-0.14	Interpolation
1969		0.11	0.52	1.14	1.52	1.31	2.01	2.04	2.74	2.91	2.28	1.43	0.81	0.20	0.04	19.05	-0.14	Interpolation
1970		0.10	0.52	1.11	1.49	1.29	1.96	2.03	2.75	2.90	2.28	1.43	0.82	0.20	0.04	18.91	-0.14	Interpolation
1971		0.09	0.52	1.08	1.47	1.26	1.90	2.03	2.76	2.90	2.28	1.42	0.83	0.20	0.04	18.78	-0.14	Interpolation
1972		0.09	0.52	1.05	1.45	1.24	1.85	2.03	2.77	2.89	2.27	1.42	0.83	0.20	0.04	18.64	-0.14	Interpolation
1973		0.08	0.52	1.02	1.43	1.21	1.79	2.03	2.77	2.88	2.27	1.42	0.84	0.20	0.03	18.50	-0.14	Interpolation
1974		0.07	0.52	0.99	1.40	1.19	1.74	2.02	2.78	2.88	2.27	1.41	0.85	0.20	0.03	18.37	-0.14	Photogrammetry
1975		0.07	0.52	0.99	1.40	1.18	1.73	2.02	2.79	2.87	2.27	1.41	0.85	0.20	0.03	18.35	-0.01	Interpolation
1976		0.07	0.52	0.98	1.39	1.18	1.73	2.02	2.80	2.87	2.27	1.40	0.86	0.21	0.03	18.34	-0.01	Interpolation
1977		0.07	0.53	0.98	1.39	1.18	1.72	2.02	2.81	2.86	2.27	1.40	0.86	0.21	0.03	18.33	-0.01	Interpolation
1978		0.07	0.53	0.98	1.38	1.18	1.72	2.02	2.82	2.86	2.27	1.40	0.87	0.21	0.03	18.31	-0.01	Interpolation
1979		0.07	0.53	0.97	1.38	1.17	1.71	2.01	2.82	2.85	2.27	1.39	0.87	0.21	0.03	18.30	-0.01	Interpolation
1980		0.07	0.53	0.97	1.37	1.17	1.71	2.01	2.83	2.85	2.26	1.39	0.88	0.21	0.03	18.28	-0.01	Interpolation
1981		0.07	0.53	0.97	1.37	1.17	1.71	2.01	2.84	2.84	2.26	1.39	0.88	0.21	0.03	18.27	-0.01	Interpolation
1982		0.07	0.53	0.96	1.36	1.17	1.70	2.01	2.85	2.84	2.26	1.38	0.89	0.21	0.03	18.26	-0.01	Interpolation
1983		0.07	0.53	0.96	1.36	1.16	1.70	2.00	2.86	2.83	2.26	1.38	0.90	0.21	0.03	18.24	-0.01	Interpolation
1984		0.07	0.53	0.95	1.35	1.16	1.69	2.00	2.86	2.83	2.26	1.37	0.90	0.21	0.03	18.23	-0.01	Interpolation
1985		0.07	0.53	0.95	1.35	1.16	1.69	2.00	2.87	2.82	2.26	1.37	0.91	0.21	0.02	18.22	-0.01	Interpolation
1986		0.07	0.53	0.95	1.34	1.16	1.68	2.00	2.88	2.82	2.26	1.37	0.91	0.21	0.02	18.20	-0.01	Interpolation
1987		0.07	0.53	0.94	1.34	1.15	1.68	2.00	2.89	2.81	2.26	1.36	0.92	0.21	0.02	18.19	-0.01	Interpolation
1988		0.07	0.54	0.94	1.33	1.15	1.68	1.99	2.90	2.81	2.26	1.36	0.92	0.21	0.02	18.18	-0.01	Interpolation
1989		0.07	0.54	0.94	1.32	1.15	1.67	1.99	2.90	2.80	2.25	1.36	0.93	0.21	0.02	18.16	-0.01	Interpolation
1990		0.07	0.54	0.93	1.32	1.15	1.67	1.99	2.91	2.80	2.25	1.35	0.94	0.21	0.02	18.15	-0.01	Interpolation
1991		0.07	0.54	0.93	1.31	1.14	1.66	1.99	2.92	2.79	2.25	1.35	0.94	0.21	0.02	18.14	-0.01	Interpolation
1992		0.07	0.54	0.92	1.31	1.14	1.66	1.98	2.93	2.79	2.25	1.35	0.95	0.21	0.02	18.12	-0.01	Interpolation
1993		0.07	0.54	0.92	1.30	1.14	1.66	1.98	2.94	2.78	2.25	1.34	0.95	0.21	0.02	18.11	-0.01	Photogrammetry
1994		0.07	0.54	0.92	1.29	1.14	1.64	1.98	2.90	2.75	2.22	1.34	0.93	0.21	0.02	17.93	-0.18	Interpolation
1995		0.06	0.53	0.91	1.28	1.14	1.62	1.98	2.86	2.71	2.20	1.34	0.90	0.20	0.01	17.75	-0.18	Interpolation
1996		0.06	0.53	0.91	1.27	1.14	1.61	1.98	2.82	2.68	2.17	1.34	0.88	0.19	0.01	17.58	-0.18	Interpolation
1997		0.05	0.53	0.91	1.26	1.14	1.59	1.98	2.78	2.64	2.15	1.33	0.85	0.18	0.01	17.40	-0.18	Interpolation
1998		0.05	0.52	0.90	1.25	1.14	1.58	1.98	2.74	2.61	2.12	1.33	0.83	0.18	0.01	17.22	-0.18	Interpolation
1999		0.04	0.52	0.90	1.24	1.14	1.56	1.98	2.70	2.57	2.09	1.33	0.80	0.17	0.01	17.05	-0.18	Photogrammetry
2000		0.04	0.52	0.89	1.23	1.13	1.55	1.98	2.66	2.54	2.07	1.33	0.78	0.16	0.00	16.87	-0.18	Extrapolation
2001		0.03	0.51	0.89	1.22	1.13	1.53	1.98	2.62	2.50	2.04	1.33	0.75	0.15	0.00	16.69	-0.18	Extrapolation

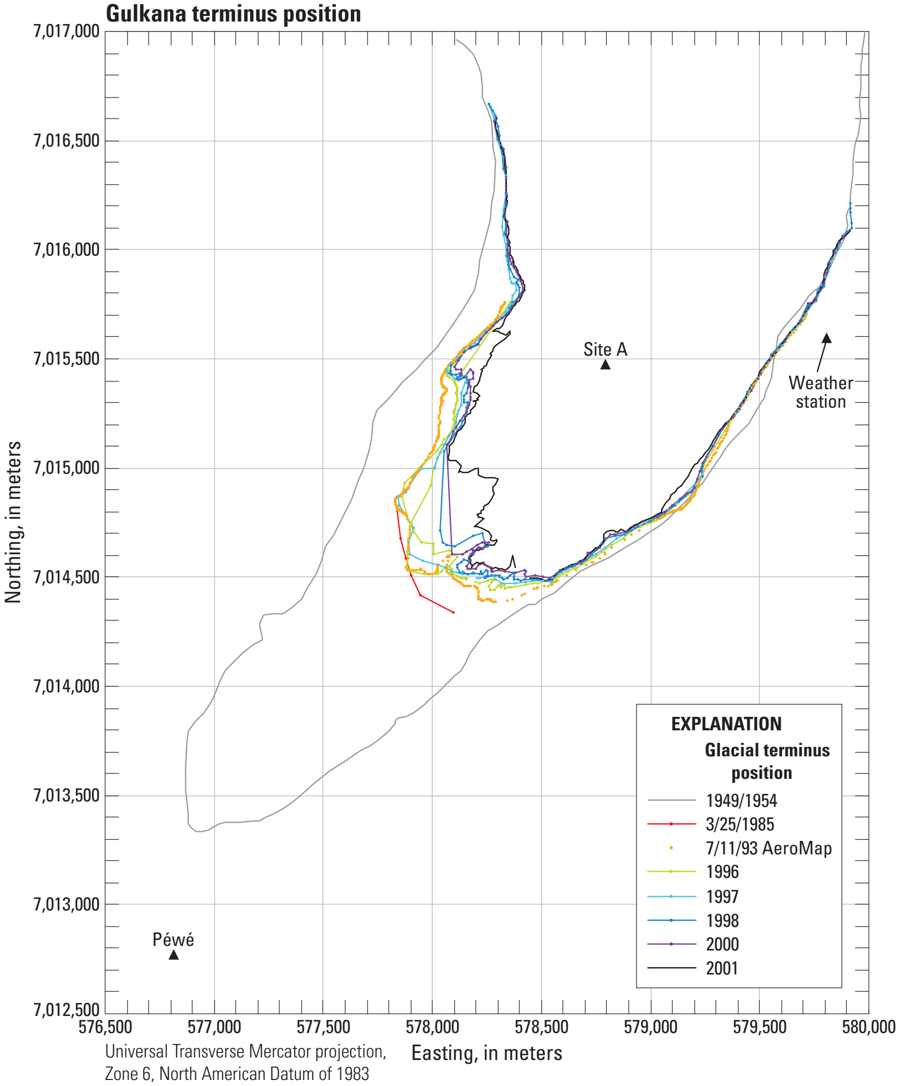

Figure 5. Glacier terminus positions from Global Positioning System surveys at Gulkana Glacier, Alaska, in 1996 (previously published in March [2003]), 1997, 1998, 1999, 2000, and 2001. From U.S. Geological Survey 1:63,360-scale Mt. Hayes A–3 quadrangle (1949 photography; area south of about 7,014,200 m Northing) and B–3 quadrangle (1954 photography; area north of about 7,014,200 m Northing) digital raster graphic (DRG) files; from optical survey in 1985 and photogrammetry in 1993.

Table 3. Optical surveys of terminus position, Gulkana Glacier, March 25, 1985.

[**Abbreviations:** UTM, Universal Transverse Mercator; NAD 83, North American Datum of 1983; NGVD 29, National Geodetic Vertical Datum of 1929]

UTM (zone 6) - NAD 83		NGVD 29
Easting	Northing	Altitude
(meters)		(meters)
Terminus positions		
577,833	7,014,822	1,195
577,854	7,014,676	1,180
577,881	7,014,588	1,171
577,900	7,014,511	1,166
577,947	7,014,415	1,162
578,096	7,014,341	1,183

Table 4. Photogrametric surveys of terminus positions, Gulkana Glacier, July 11, 1993.

[Universal Transverse Mercator Coordinates (UTM) are in UTM zone 6. m, meters. Easting and northing measurements are in meters and North American Datum of 1983 (NAD 83)]

Easting	Northing	Easting	Northing	Easting	Northing	Easting	Northing	Easting	Northing	Easting	Northing
579,715	7,015,704	579,349	7,015,170	579,136	7,014,812	578,548	7,014,467	578,105	7,014,489	577,888	7,014,588
579,712	7,015,699	579,348	7,015,164	579,134	7,014,811	578,543	7,014,464	578,099	7,014,492	577,890	7,014,605
579,709	7,015,696	579,345	7,015,157	579,129	7,014,809	578,533	7,014,461	578,095	7,014,495	577,891	7,014,621
579,708	7,015,693	579,341	7,015,149	579,124	7,014,808	578,515	7,014,457	578,090	7,014,506	577,892	7,014,633
579,706	7,015,690	579,335	7,015,138	579,120	7,014,807	578,480	7,014,452	578,087	7,014,511	577,891	7,014,644
579,704	7,015,687	579,328	7,015,128	579,117	7,014,806	578,474	7,014,450	578,083	7,014,513	577,890	7,014,650
579,703	7,015,685	579,323	7,015,119	579,114	7,014,805	578,466	7,014,446	578,076	7,014,516	577,889	7,014,659
579,702	7,015,683	579,319	7,015,114	579,111	7,014,804	578,424	7,014,424	578,071	7,014,520	577,889	7,014,666
579,701	7,015,681	579,317	7,015,109	579,106	7,014,803	578,409	7,014,416	578,069	7,014,524	577,889	7,014,671
579,699	7,015,679	579,315	7,015,104	579,102	7,014,802	578,371	7,014,401	578,067	7,014,529	577,892	7,014,680
579,696	7,015,675	579,311	7,015,095	579,098	7,014,801	578,344	7,014,394	578,065	7,014,536	577,896	7,014,692
579,692	7,015,668	579,307	7,015,086	579,096	7,014,800	578,290	7,014,385	578,065	7,014,543	577,898	7,014,703
579,685	7,015,660	579,301	7,015,071	579,094	7,014,799	578,287	7,014,385	578,065	7,014,551	577,899	7,014,711
579,677	7,015,649	579,301	7,015,071	579,090	7,014,797	578,283	7,014,386	578,068	7,014,559	577,898	7,014,720
579,666	7,015,636	579,300	7,015,070	579,084	7,014,794	578,278	7,014,389	578,073	7,014,576	577,894	7,014,735
579,656	7,015,622	579,299	7,015,068	579,078	7,014,791	578,271	7,014,393	578,077	7,014,591	577,887	7,014,768
579,645	7,015,608	579,295	7,015,063	579,072	7,014,788	578,267	7,014,395	578,076	7,014,595	577,882	7,014,783
579,633	7,015,594	579,290	7,015,056	579,068	7,014,786	578,263	7,014,397	578,076	7,014,596	577,881	7,014,785
579,620	7,015,578	579,282	7,015,047	579,066	7,014,785	578,260	7,014,397	578,074	7,014,597	577,880	7,014,786
579,604	7,015,561	579,275	7,015,037	579,065	7,014,785	578,256	7,014,398	578,069	7,014,596	577,879	7,014,787
579,588	7,015,541	579,267	7,015,027	579,064	7,014,784	578,251	7,014,398	578,065	7,014,593	577,877	7,014,789
579,571	7,015,521	579,261	7,015,018	579,062	7,014,783	578,247	7,014,397	578,046	7,014,577	577,876	7,014,790
579,555	7,015,501	579,255	7,015,008	579,059	7,014,781	578,232	7,014,395	578,028	7,014,557	577,874	7,014,791
579,542	7,015,483	579,251	7,014,998	579,054	7,014,778	578,228	7,014,395	578,024	7,014,549	577,871	7,014,792
579,532	7,015,470	579,246	7,014,986	579,049	7,014,774	578,225	7,014,396	578,023	7,014,546	577,869	7,014,793
579,527	7,015,462	579,241	7,014,972	579,044	7,014,771	578,220	7,014,397	578,024	7,014,540	577,867	7,014,794
579,523	7,015,456	579,235	7,014,956	579,040	7,014,768	578,216	7,014,399	578,024	7,014,536	577,865	7,014,795
579,518	7,015,450	579,228	7,014,941	579,038	7,014,767	578,213	7,014,402	578,025	7,014,532	577,862	7,014,797
579,511	7,015,440	579,222	7,014,929	579,034	7,014,765	578,212	7,014,405	578,024	7,014,530	577,858	7,014,799
579,502	7,015,428	579,219	7,014,923	579,030	7,014,763	578,210	7,014,411	578,023	7,014,528	577,854	7,014,802
579,493	7,015,415	579,218	7,014,918	579,024	7,014,760	578,210	7,014,418	578,018	7,014,523	577,849	7,014,805
579,485	7,015,403	579,216	7,014,914	579,016	7,014,757	578,210	7,014,429	578,009	7,014,520	577,845	7,014,809
579,478	7,015,393	579,212	7,014,906	579,004	7,014,751	578,209	7,014,437	577,997	7,014,517	577,842	7,014,813
579,473	7,015,386	579,209	7,014,896	579,002	7,014,750	578,207	7,014,445	577,990	7,014,516	577,839	7,014,816
579,470	7,015,381	579,205	7,014,887	578,987	7,014,743	578,206	7,014,449	577,985	7,014,515	577,838	7,014,818
579,468	7,015,377	579,202	7,014,880	578,946	7,014,713	578,205	7,014,452	577,979	7,014,516	577,837	7,014,820
579,465	7,015,371	579,199	7,014,876	578,912	7,014,697	578,202	7,014,454	577,971	7,014,520	577,836	7,014,824
579,459	7,015,360	579,198	7,014,873	578,910	7,014,695	578,198	7,014,456	577,960	7,014,529	577,834	7,014,830
579,452	7,015,347	579,196	7,014,871	578,880	7,014,671	578,195	7,014,457	577,952	7,014,534	577,833	7,014,837
579,444	7,015,331	579,194	7,014,869	578,819	7,014,633	578,191	7,014,458	577,946	7,014,536	577,831	7,014,843
579,435	7,015,315	579,191	7,014,865	578,792	7,014,610	578,175	7,014,459	577,943	7,014,535	577,830	7,014,846
579,426	7,015,300	579,187	7,014,860	578,790	7,014,607	578,171	7,014,459	577,937	7,014,534	577,830	7,014,849
579,417	7,015,286	579,182	7,014,855	578,767	7,014,588	578,163	7,014,458	577,928	7,014,532	577,831	7,014,851
579,409	7,015,273	579,178	7,014,850	578,734	7,014,570	578,159	7,014,457	577,914	7,014,530	577,831	7,014,855
579,400	7,015,262	579,176	7,014,847	578,731	7,014,568	578,154	7,014,458	577,903	7,014,530	577,832	7,014,859
579,392	7,015,250	579,174	7,014,845	578,705	7,014,555	578,151	7,014,458	577,894	7,014,531	577,833	7,014,862
579,383	7,015,238	579,172	7,014,842	578,658	7,014,531	578,148	7,014,460	577,888	7,014,532	577,834	7,014,864
579,375	7,015,226	579,169	7,014,838	578,614	7,014,509	578,142	7,014,462	577,885	7,014,533	577,835	7,014,865
579,367	7,015,213	579,164	7,014,833	578,614	7,014,509	578,139	7,014,464	577,883	7,014,535	577,836	7,014,866
579,361	7,015,201	579,158	7,014,827	578,571	7,014,486	578,137	7,014,467	577,882	7,014,539	577,839	7,014,868
579,357	7,015,190	579,152	7,014,822	578,570	7,014,485	578,130	7,014,471	577,881	7,014,542	577,842	7,014,869
579,353	7,015,182	579,146	7,014,818	578,559	7,014,477	578,125	7,014,476	577,881	7,014,546	577,845	7,014,871
579,352	7,015,177	579,142	7,014,815	578,558	7,014,476	578,121	7,014,479	577,881	7,014,550	577,849	7,014,872
579,350	7,015,173	579,139	7,014,813	578,552	7,014,469	578,116	7,014,483	577,883	7,014,559	577,852	7,014,874

Table 4. Photogrametric surveys of terminus positions, Gulkana Glacier, July 11, 1993.—Continued

[Universal Transverse Mercator Coordinates (UTM) are in UTM zone 6. m, meters. Easting and northing measurements are in meters and North American Datum of 1983 (NAD 83)]

Easting	Northing	Easting	Northing	Easting	Northing	Easting	Northing	Easting	Northing	Easting	Northing
577,856	7,014,876	577,922	7,014,970	578,031	7,015,170	578,058	7,015,343	578,086	7,015,481	578,218	7,015,608
577,859	7,014,879	577,925	7,014,973	578,031	7,015,174	578,060	7,015,346	578,091	7,015,485	578,223	7,015,612
577,861	7,014,882	577,927	7,014,975	578,031	7,015,181	578,062	7,015,350	578,093	7,015,487	578,228	7,015,619
577,863	7,014,884	577,928	7,014,977	578,032	7,015,190	578,063	7,015,354	578,095	7,015,489	578,234	7,015,625
577,864	7,014,886	577,930	7,014,980	578,032	7,015,197	578,064	7,015,357	578,096	7,015,491	578,240	7,015,632
577,865	7,014,888	577,932	7,014,984	578,033	7,015,203	578,064	7,015,360	578,099	7,015,495	578,246	7,015,638
577,866	7,014,889	577,936	7,014,991	578,033	7,015,207	578,063	7,015,362	578,102	7,015,501	578,252	7,015,643
577,866	7,014,891	577,942	7,014,999	578,033	7,015,215	578,061	7,015,364	578,107	7,015,507	578,257	7,015,648
577,867	7,014,893	577,947	7,015,006	578,032	7,015,226	578,059	7,015,367	578,113	7,015,513	578,263	7,015,652
577,868	7,014,895	577,952	7,015,013	578,032	7,015,239	578,056	7,015,368	578,118	7,015,518	578,267	7,015,654
577,868	7,014,896	577,957	7,015,018	578,033	7,015,254	578,054	7,015,370	578,123	7,015,523	578,270	7,015,656
577,868	7,014,896	577,962	7,015,024	578,034	7,015,267	578,052	7,015,371	578,127	7,015,528	578,272	7,015,658
577,869	7,014,897	577,967	7,015,032	578,036	7,015,277	578,050	7,015,372	578,131	7,015,532	578,275	7,015,661
577,871	7,014,897	577,973	7,015,042	578,038	7,015,285	578,049	7,015,372	578,134	7,015,536	578,279	7,015,666
577,873	7,014,899	577,980	7,015,052	578,039	7,015,290	578,048	7,015,374	578,138	7,015,540	578,284	7,015,671
577,875	7,014,900	577,987	7,015,062	578,040	7,015,292	578,046	7,015,377	578,142	7,015,544	578,288	7,015,676
577,878	7,014,901	577,994	7,015,072	578,041	7,015,294	578,045	7,015,382	578,147	7,015,548	578,291	7,015,679
577,881	7,014,902	578,000	7,015,079	578,042	7,015,297	578,043	7,015,386	578,152	7,015,552	578,292	7,015,681
577,884	7,014,902	578,003	7,015,084	578,043	7,015,300	578,042	7,015,391	578,158	7,015,557	578,294	7,015,684
577,885	7,014,903	578,005	7,015,087	578,044	7,015,302	578,041	7,015,396	578,163	7,015,561	578,297	7,015,689
577,887	7,014,905	578,006	7,015,090	578,044	7,015,304	578,041	7,015,399	578,168	7,015,566	578,300	7,015,695
577,889	7,014,909	578,008	7,015,095	578,045	7,015,306	578,041	7,015,402	578,172	7,015,570	578,304	7,015,702
577,892	7,014,915	578,010	7,015,101	578,044	7,015,307	578,041	7,015,404	578,175	7,015,573	578,307	7,015,711
577,895	7,014,923	578,013	7,015,108	578,044	7,015,309	578,041	7,015,406	578,177	7,015,575	578,309	7,015,719
577,899	7,014,931	578,016	7,015,116	578,044	7,015,311	578,041	7,015,408	578,178	7,015,576	578,311	7,015,725
577,903	7,014,940	578,019	7,015,123	578,044	7,015,313	578,042	7,015,412	578,178	7,015,576	578,312	7,015,729
577,906	7,014,947	578,022	7,015,130	578,043	7,015,315	578,044	7,015,417	578,179	7,015,577	578,313	7,015,731
577,908	7,014,952	578,024	7,015,135	578,043	7,015,316	578,047	7,015,424	578,181	7,015,578	578,315	7,015,733
577,910	7,014,956	578,025	7,015,138	578,043	7,015,316	578,050	7,015,430	578,184	7,015,580	578,318	7,015,737
577,911	7,014,958	578,026	7,015,140	578,043	7,015,317	578,053	7,015,435	578,188	7,015,582	578,321	7,015,741
577,912	7,014,959	578,027	7,015,142	578,043	7,015,319	578,055	7,015,439	578,194	7,015,586	578,325	7,015,747
577,913	7,014,961	578,027	7,015,144	578,044	7,015,321	578,056	7,015,441	578,199	7,015,590	578,329	7,015,754
577,915	7,014,962	578,028	7,015,147	578,044	7,015,325	578,059	7,015,445	578,204	7,015,594	578,331	7,015,759
577,916	7,014,964	578,028	7,015,152	578,046	7,015,330	578,063	7,015,452	578,208	7,015,598		
577,917	7,014,965	578,029	7,015,158	578,048	7,015,335	578,068	7,015,460	578,211	7,015,600		
577,918	7,014,966	578,030	7,015,163	578,051	7,015,338	578,074	7,015,468	578,213	7,015,602		
577,920	7,014,968	578,030	7,015,167	578,055	7,015,341	578,080	7,015,475	578,215	7,015,604		

Table 5. Global Positioning System terminus position surveys, Gulkana Glacier, September 3, 1997.

[Universal Transverse Mercator (UTM) coordinates are in UTM zone 6. Easting and northing measurements are in meters and NAD 83, North American Datum of 1983; NGVD 29, National Geodetic Vertical Datum of 1929]

Easting	Northing	Altitude
(NAD 83)		(NGVD 29)
Péwé		
576,813	7,012,778	1,154
576,814	7,012,778	1,154
576,814	7,012,777	1,154
Terminus positions		
578,193	7,014,513	1,175
578,166	7,014,514	1,177
578,139	7,014,516	1,175
578,141	7,014,525	1,176
578,133	7,014,523	1,177
578,120	7,014,522	1,177
578,092	7,014,527	1,175
578,062	7,014,545	1,174
578,025	7,014,557	1,175
577,959	7,014,573	1,168
577,896	7,014,603	1,170
577,892	7,014,661	1,168
577,913	7,014,729	1,178
577,849	7,014,828	1,197
577,843	7,014,870	1,202
577,877	7,014,888	1,208
577,919	7,014,962	1,220
577,953	7,015,001	1,226
578,012	7,014,999	1,228
578,013	7,015,003	1,228
578,026	7,015,044	1,227
578,038	7,015,068	1,227
578,053	7,015,110	1,227
578,076	7,015,148	1,228
578,101	7,015,178	1,230
578,107	7,015,181	1,230
578,106	7,015,208	1,225
578,106	7,015,207	1,225
Terminus positions		
578,116	7,015,245	1,226
578,121	7,015,264	1,230
578,131	7,015,289	1,233
578,133	7,015,342	1,244
578,151	7,015,389	1,245
578,154	7,015,399	1,245
578,156	7,015,420	1,245
578,136	7,015,419	1,236
578,125	7,015,413	1,235
578,109	7,015,407	1,232
578,102	7,015,412	1,232
578,083	7,015,427	1,240
578,064	7,015,440	1,245
578,064	7,015,452	1,245
578,083	7,015,479	1,256
578,114	7,015,507	1,262
578,146	7,015,547	1,269
578,195	7,015,575	1,272
578,217	7,015,596	1,277
578,242	7,015,629	1,284
578,330	7,015,713	1,317
578,349	7,015,735	1,323
578,352	7,015,743	1,326
578,361	7,015,757	1,331
578,370	7,015,793	1,339
578,388	7,015,814	1,351
578,379	7,015,846	1,355
578,367	7,015,847	1,356
578,363	7,015,850	1,355
578,357	7,015,871	1,361
578,348	7,015,910	1,365
578,335	7,015,974	1,377
578,336	7,016,017	1,388
Terminus positions		
578,327	7,016,070	1,393
578,320	7,016,107	1,400
578,328	7,016,183	1,411
578,337	7,016,254	1,426
578,335	7,016,343	1,446
578,323	7,016,424	1,468
578,297	7,016,513	1,487
578,281	7,016,601	1,509
578,261	7,016,667	1,536
578,258	7,016,668	1,525
579,851	7,015,996	1,448
579,825	7,015,946	1,443
579,818	7,015,923	1,441
579,800	7,015,877	1,438
579,783	7,015,838	1,437
579,763	7,015,815	1,437
579,765	7,015,785	1,417
579,709	7,015,708	1,414
579,698	7,015,685	1,411
579,684	7,015,672	1,410
579,672	7,015,654	1,409
579,648	7,015,626	1,407
579,632	7,015,606	1,405
579,600	7,015,562	1,404
579,581	7,015,545	1,409
579,554	7,015,506	1,394
579,525	7,015,461	1,389
579,494	7,015,416	1,383
579,453	7,015,356	1,374
579,421	7,015,295	1,364
579,399	7,015,258	1,358
579,330	7,015,182	1,348
579,289	7,015,107	1,340
Terminus positions		
579,241	7,015,022	1,328
579,237	7,014,972	1,322
579,204	7,014,927	1,313
579,124	7,014,846	1,307
579,082	7,014,810	1,299
578,976	7,014,752	1,290
578,888	7,014,701	1,281
578,847	7,014,679	1,273
578,791	7,014,636	1,273
578,749	7,014,606	1,272
578,673	7,014,561	1,254
578,655	7,014,552	1,250
578,625	7,014,538	1,247
578,609	7,014,530	1,245
578,557	7,014,496	1,238
578,548	7,014,487	1,232
578,544	7,014,480	1,227
578,505	7,014,482	1,211
578,473	7,014,484	1,205
578,430	7,014,481	1,199
578,378	7,014,469	1,197
578,317	7,014,471	1,187
578,291	7,014,490	1,179
578,277	7,014,506	1,181
578,216	7,014,494	1,180
578,205	7,014,499	1,174
Péwé		
576,814	7,012,775	1,149
576,814	7,012,775	1,149
(576,814)	(7,012,775)	1,149

Table 6. Global Positioning System terminus position surveys, Gulkana Glacier, September 9, 1998.

[Universal Transverse Mercator (UTM) coordinates are in UTM zone 6. Easting and northing measurements are in meters. NAD 83, North American Datum of 1983; NGVD 29, National Geodetic Vertical Datum of 1929]

Easting (NAD 83)	Northing (NAD 83)	Altitude (NGVD 29)
Péwé		
576,817	7,012,767	1,150
576,816	7,012,765	1,152
576,815	7,012,765	1,154
Terminus positions		
578,246	7,014,501	1,171
578,254	7,014,508	1,172
578,255	7,014,527	1,171
578,248	7,014,531	1,171
578,231	7,014,517	1,195
578,225	7,014,525	1,182
578,214	7,014,512	1,181
578,185	7,014,520	1,182
578,165	7,014,516	1,181
578,146	7,014,520	1,179
578,128	7,014,522	1,178
578,111	7,014,542	1,179
578,111	7,014,557	1,180
578,133	7,014,566	1,182
578,143	7,014,578	1,185
578,161	7,014,573	1,186
578,177	7,014,605	1,188
578,189	7,014,619	1,192
578,208	7,014,635	1,197
578,235	7,014,636	1,199
578,251	7,014,644	1,198
578,242	7,014,652	1,197
578,227	7,014,700	1,203
578,185	7,014,691	1,202
578,103	7,014,641	1,198
578,066	7,014,648	1,196
578,048	7,014,658	1,198
578,036	7,014,712	1,203
578,056	7,015,075	1,228
578,103	7,015,154	1,232
578,128	7,015,184	1,231
578,132	7,015,193	1,232
578,139	7,015,214	1,229
578,156	7,015,239	1,231
578,157	7,015,261	1,232
578,155	7,015,274	1,232
578,165	7,015,301	1,231
578,165	7,015,303	1,232
578,165	7,015,300	1,234
578,146	7,015,299	1,235
578,144	7,015,312	1,236
578,145	7,015,329	1,238
578,157	7,015,341	1,241
578,160	7,015,366	1,254
578,160	7,015,394	1,252
578,154	7,015,413	1,248
Terminus positions		
578,135	7,015,410	1,248
578,120	7,015,406	1,242
578,115	7,015,410	1,245
578,113	7,015,415	1,246
578,127	7,015,424	1,251
578,125	7,015,431	1,254
578,107	7,015,430	1,258
578,089	7,015,428	1,254
578,083	7,015,433	1,256
578,078	7,015,434	1,254
578,086	7,015,446	1,262
578,086	7,015,471	1,270
578,125	7,015,507	1,278
578,149	7,015,535	1,283
578,177	7,015,549	1,284
578,198	7,015,560	1,284
578,211	7,015,567	1,284
578,219	7,015,586	1,292
578,248	7,015,621	1,297
578,277	7,015,651	1,308
578,288	7,015,661	1,312
578,320	7,015,690	1,322
578,343	7,015,712	1,330
578,357	7,015,728	1,335
578,357	7,015,728	1,334
578,356	7,015,728	1,334
578,367	7,015,760	1,342
578,389	7,015,775	1,349
578,399	7,015,794	1,357
578,400	7,015,826	1,362
578,394	7,015,841	1,365
578,388	7,015,850	1,368
578,390	7,015,864	1,369
578,375	7,015,876	1,373
578,357	7,015,914	1,380
578,352	7,015,932	1,382
578,350	7,015,947	1,385
578,344	7,015,972	1,391
578,344	7,015,997	1,393
578,342	7,016,028	1,402
578,342	7,016,046	1,406
578,334	7,016,074	1,409
578,339	7,016,118	1,418
578,331	7,016,155	1,420
578,336	7,016,194	1,432
578,339	7,016,213	1,432
578,340	7,016,248	1,434
578,336	7,016,336	1,435
578,328	7,016,372	1,441
578,319	7,016,441	1,444
578,316	7,016,477	1,494
Terminus positions		
578,308	7,016,496	1,497
578,306	7,016,523	1,503
578,300	7,016,563	1,512
578,288	7,016,595	1,516
578,288	7,016,612	1,521
578,276	7,016,635	1,527
578,267	7,016,653	1,526
578,261	7,016,667	1,529
579,918	7,016,212	1,466
579,914	7,016,191	1,463
579,915	7,016,173	1,461
579,919	7,016,125	1,455
579,921	7,016,101	1,452
579,897	7,016,079	1,450
579,881	7,016,062	1,446
579,869	7,016,034	1,446
579,855	7,016,004	1,444
579,844	7,015,983	1,442
579,833	7,015,959	1,441
579,819	7,015,924	1,435
579,810	7,015,898	1,432
579,797	7,015,842	1,424
579,795	7,015,834	1,421
579,765	7,015,788	1,417
579,759	7,015,774	1,413
579,757	7,015,766	1,413
579,744	7,015,760	1,404
579,730	7,015,751	1,405
579,724	7,015,743	1,405
579,715	7,015,725	1,405
579,705	7,015,703	1,407
579,693	7,015,678	1,408
579,683	7,015,667	1,408
579,656	7,015,641	1,402
579,624	7,015,604	1,405
579,597	7,015,566	1,400
579,567	7,015,528	1,396
579,534	7,015,489	1,393
579,514	7,015,457	1,390
579,502	7,015,434	1,386
579,462	7,015,378	1,378
579,443	7,015,347	1,374
579,432	7,015,318	1,369
579,416	7,015,296	1,366
579,395	7,015,260	1,360
579,384	7,015,241	1,356
579,355	7,015,211	1,351
579,318	7,015,162	1,343
579,284	7,015,100	1,333
579,260	7,015,066	1,328
579,236	7,015,013	1,321
Terminus positions		
579,231	7,014,985	1,317
579,236	7,014,961	1,324
579,201	7,014,910	1,316
579,184	7,014,888	1,313
579,131	7,014,847	1,308
579,109	7,014,827	1,304
579,064	7,014,793	1,295
579,031	7,014,776	1,292
578,995	7,014,758	1,290
578,945	7,014,733	1,285
578,913	7,014,715	1,280
578,882	7,014,694	1,277
578,837	7,014,691	1,271
578,790	7,014,677	1,268
578,751	7,014,626	1,263
578,733	7,014,607	1,262
578,707	7,014,583	1,262
578,685	7,014,565	1,258
578,653	7,014,558	1,244
578,632	7,014,549	1,240
578,608	7,014,538	1,237
578,588	7,014,527	1,233
578,573	7,014,518	1,230
578,547	7,014,489	1,215
578,528	7,014,486	1,209
578,480	7,014,488	1,209
578,461	7,014,492	1,194
578,425	7,014,491	1,191
578,402	7,014,485	1,187
578,394	7,014,491	1,188
578,375	7,014,491	1,186
578,374	7,014,502	1,186
578,375	7,014,518	1,187
578,373	7,014,521	1,187
578,356	7,014,509	1,185
578,344	7,014,493	1,186
578,323	7,014,489	1,185
578,317	7,014,497	1,184
578,305	7,014,500	1,182
578,306	7,014,511	1,181
578,292	7,014,509	1,179
578,273	7,014,509	1,179
578,241	7,014,495	1,180
578,243	7,014,503	1,176
578,251	7,014,510	1,175
Péwé		
576,816	7,012,769	1,152
576,816	7,012,769	1,151
576,817	7,012,770	1,151

Table 7. Global Positioning System terminus-position surveys, Gulkana Glacier, September 16, 1999.

[Universal Transverse Mercator (UTM) coordinates are in UTM zone 6. Easting and northing measurements are in meters. NAD 83, North American Datum of 1983; NGVD 29, National Geodetic Vertical Datum of 1929]

Easting (NAD 83)	Northing (NAD 83)	Altitude (NGVD 29)
Péwé		
576,813	7,012,768	1,155
576,813	7,012,769	1,155
Terminus positions		
578,261	7,014,519	1,164
578,260	7,014,535	1,169
578,256	7,014,538	1,166
578,231	7,014,542	1,166
578,213	7,014,539	1,164
578,195	7,014,537	1,159
578,173	7,014,528	1,158
578,153	7,014,526	1,160
578,150	7,014,532	1,160
578,134	7,014,531	1,157
578,143	7,014,544	1,160
578,164	7,014,566	1,161
578,189	7,014,619	1,168
578,217	7,014,634	1,174
578,235	7,014,634	1,179
578,234	7,014,638	1,179
578,245	7,014,648	1,181
578,244	7,014,673	1,185
578,212	7,014,704	1,187
578,193	7,014,708	1,189
578,157	7,014,688	1,188
578,131	7,014,695	1,191
578,118	7,014,721	1,194
578,112	7,014,735	1,196
578,184	7,014,787	1,205
578,209	7,014,815	1,211
578,230	7,014,825	1,210
578,248	7,014,849	1,213
578,252	7,014,858	1,216
578,256	7,014,877	1,217
578,260	7,014,891	1,219
578,268	7,014,920	1,226
578,279	7,014,934	1,228
578,266	7,014,938	1,224
578,238	7,014,924	1,222
578,207	7,014,942	1,224
578,186	7,014,967	1,227
578,144	7,014,950	1,225
578,123	7,014,956	1,226
578,052	7,015,078	1,223
578,079	7,015,126	1,220
578,114	7,015,163	1,225
578,128	7,015,192	1,225
578,131	7,015,218	1,221

Easting (NAD 83)	Northing (NAD 83)	Altitude (NGVD 29)
Terminus positions		
578,144	7,015,247	1,222
578,148	7,015,267	1,223
578,151	7,015,279	1,225
578,159	7,015,296	1,226
578,160	7,015,308	1,226
578,151	7,015,321	1,229
578,168	7,015,350	1,239
578,178	7,015,369	1,241
578,195	7,015,384	1,244
578,201	7,015,407	1,245
578,209	7,015,435	1,245
578,214	7,015,452	1,244
578,221	7,015,485	1,245
578,192	7,015,469	1,243
578,176	7,015,454	1,242
578,159	7,015,424	1,236
578,143	7,015,414	1,236
578,136	7,015,414	1,236
578,128	7,015,429	1,241
578,106	7,015,452	1,252
578,138	7,015,520	1,264
578,151	7,015,531	1,268
578,178	7,015,550	1,270
578,221	7,015,584	1,277
578,246	7,015,616	1,284
578,256	7,015,622	1,287
578,273	7,015,642	1,291
578,295	7,015,661	1,300
578,321	7,015,686	1,308
578,346	7,015,711	1,318
578,362	7,015,735	1,322
578,367	7,015,751	1,326
578,374	7,015,765	1,329
578,392	7,015,770	1,334
578,403	7,015,788	1,340
578,409	7,015,812	1,345
578,397	7,015,846	1,349
578,386	7,015,882	1,357
578,366	7,015,900	1,358
578,353	7,015,942	1,365
578,343	7,015,969	1,372
578,344	7,016,007	1,373
578,336	7,016,044	1,374
578,463	7,016,019	1,381
578,337	7,016,077	1,409
578,337	7,016,097	1,413
578,335	7,016,185	1,429
578,342	7,016,249	1,444

Easting (NAD 83)	Northing (NAD 83)	Altitude (NGVD 29)
Terminus positions		
578,343	7,016,328	1,461
578,335	7,016,412	1,482
578,327	7,016,456	1,494
578,306	7,016,507	1,507
578,295	7,016,568	1,520
578,279	7,016,628	1,537
578,271	7,016,659	1,546
579,936	7,016,379	1,484
579,925	7,016,339	1,481
579,924	7,016,327	1,480
579,931	7,016,296	1,480
579,928	7,016,275	1,477
579,918	7,016,238	1,472
579,922	7,016,204	1,470
579,921	7,016,166	1,464
579,930	7,016,134	1,461
579,930	7,016,127	1,463
579,889	7,016,058	1,446
579,870	7,016,040	1,447
579,849	7,015,994	1,443
579,826	7,015,941	1,438
579,801	7,015,880	1,438
579,787	7,015,836	1,436
579,765	7,015,808	1,436
579,769	7,015,789	1,416
579,766	7,015,770	1,411
579,759	7,015,769	1,410
579,746	7,015,764	1,409
579,729	7,015,745	1,409
579,705	7,015,699	1,408
579,692	7,015,677	1,408
579,645	7,015,621	1,403
579,624	7,015,590	1,400
579,588	7,015,543	1,394
579,545	7,015,494	1,389
579,511	7,015,436	1,383
579,449	7,015,337	1,366
579,418	7,015,283	1,357
579,390	7,015,241	1,351
579,376	7,015,224	1,350
579,353	7,015,206	1,346
579,332	7,015,183	1,341
579,309	7,015,142	1,334
579,286	7,015,105	1,327
579,267	7,015,076	1,323
579,266	7,015,077	1,324
579,227	7,014,992	1,323
579,234	7,014,979	1,320

Easting (NAD 83)	Northing (NAD 83)	Altitude (NGVD 29)
Terminus positions		
579,226	7,014,958	1,317
579,208	7,014,930	1,313
579,186	7,014,901	1,309
579,156	7,014,877	1,305
579,102	7,014,829	1,298
579,066	7,014,801	1,292
579,012	7,014,771	1,285
578,978	7,014,758	1,285
578,929	7,014,734	1,281
578,890	7,014,708	1,275
578,837	7,014,698	1,267
578,810	7,014,701	1,263
578,782	7,014,669	1,263
578,745	7,014,631	1,258
578,726	7,014,611	1,255
578,701	7,014,581	1,250
578,680	7,014,566	1,242
578,658	7,014,557	1,238
578,625	7,014,543	1,233
578,588	7,014,521	1,225
578,572	7,014,510	1,221
578,539	7,014,489	1,224
578,522	7,014,490	1,229
578,499	7,014,493	1,229
578,484	7,014,499	1,226
578,459	7,014,496	1,225
578,417	7,014,489	1,225
578,414	7,014,494	1,224
578,394	7,014,497	1,224
578,402	7,014,520	1,163
578,414	7,014,529	1,163
578,406	7,014,540	1,164
578,388	7,014,533	1,160
578,362	7,014,521	1,158
578,345	7,014,521	1,154
578,341	7,014,524	1,156
578,354	7,014,540	1,157
578,323	7,014,529	1,155
578,315	7,014,526	1,154
578,298	7,014,532	1,151
578,283	7,014,530	1,150
578,273	7,014,531	1,151
Péwé		
576,817	7,012,773	1,151
576,818	7,012,774	1,151
576,818	7,012,774	1,153

Table 8. Global Positioning System terminus-position surveys, Gulkana Glacier, October 2, 2000.

[Universal Transverse Mercator (UTM) coordinates are in UTM zone 6. Easting and northing measurements are in meters. NAD 83, North American Datum of 1983; NGVD 29, National Geodetic Vertical Datum of 1929]

Easting	Northing	Altitude
(NAD 83)		(NGVD 29)
Péwé		
576,810	7,012,771	1,158
576,811	7,012,771	1,158
Terminus positions		
578,274	7,014,529	1,174
578,265	7,014,543	1,174
578,250	7,014,551	1,174
578,240	7,014,555	1,175
578,232	7,014,564	1,178
578,210	7,014,557	1,173
578,200	7,014,541	1,170
578,172	7,014,539	1,169
578,163	7,014,538	1,170
578,154	7,014,552	1,170
578,173	7,014,573	1,172
578,169	7,014,590	1,175
578,188	7,014,605	1,180
578,184	7,014,613	1,181
578,189	7,014,620	1,181
578,195	7,014,619	1,182
578,207	7,014,629	1,184
578,217	7,014,637	1,186
578,231	7,014,631	1,186
578,242	7,014,642	1,186
578,259	7,014,662	1,189
578,243	7,014,661	1,187
578,226	7,014,662	1,187
578,202	7,014,646	1,185
578,179	7,014,631	1,181
578,159	7,014,618	1,178
578,138	7,014,606	1,177
578,090	7,014,606	1,175
578,065	7,015,105	1,223
578,081	7,015,132	1,223
578,098	7,015,165	1,225
578,108	7,015,187	1,222
578,128	7,015,214	1,223
578,143	7,015,237	1,223
578,154	7,015,258	1,227
578,160	7,015,278	1,228
578,170	7,015,291	1,233
Terminus positions		
578,176	7,015,311	1,233
578,176	7,015,324	1,232
578,172	7,015,344	1,235
578,177	7,015,373	1,240
578,169	7,015,380	1,240
578,167	7,015,393	1,242
578,168	7,015,402	1,242
578,186	7,015,407	1,246
578,189	7,015,435	1,247
578,188	7,015,442	1,242
578,173	7,015,452	1,239
578,145	7,015,417	1,236
578,134	7,015,426	1,237
578,132	7,015,435	1,237
578,133	7,015,453	1,246
578,110	7,015,454	1,246
578,102	7,015,465	1,252
578,121	7,015,491	1,256
578,142	7,015,529	1,265
578,176	7,015,554	1,270
578,205	7,015,565	1,270
578,221	7,015,591	1,276
578,248	7,015,621	1,284
578,279	7,015,649	1,293
578,297	7,015,668	1,299
578,322	7,015,686	1,306
578,355	7,015,718	1,318
578,365	7,015,740	1,321
578,398	7,015,782	1,335
578,416	7,015,818	1,340
578,412	7,015,842	1,346
578,402	7,015,859	1,348
578,391	7,015,886	1,353
578,385	7,015,902	1,356
578,371	7,015,918	1,361
578,359	7,015,938	1,365
578,355	7,015,959	1,369
578,348	7,015,972	1,370
578,350	7,015,986	1,370
578,346	7,016,004	1,370
578,349	7,016,034	1,381
Terminus positions		
578,335	7,016,068	1,385
578,341	7,016,130	1,391
578,331	7,016,150	1,396
578,330	7,016,169	1,402
578,336	7,016,222	1,414
578,337	7,016,263	1,423
578,337	7,016,291	1,432
578,338	7,016,325	1,442
578,336	7,016,376	1,450
578,329	7,016,427	1,465
578,323	7,016,460	1,468
578,304	7,016,507	1,481
578,291	7,016,557	1,493
578,285	7,016,587	1,498
579,884	7,016,057	1,461
579,863	7,016,035	1,460
579,843	7,015,991	1,454
579,819	7,015,939	1,447
579,805	7,015,896	1,442
579,795	7,015,846	1,433
579,779	7,015,816	1,428
579,763	7,015,794	1,426
579,758	7,015,777	1,423
579,749	7,015,762	1,422
579,723	7,015,752	1,421
579,685	7,015,678	1,419
579,633	7,015,611	1,408
579,614	7,015,581	1,406
579,588	7,015,553	1,401
579,553	7,015,518	1,395
579,544	7,015,496	1,397
579,525	7,015,465	1,394
579,507	7,015,431	1,388
579,491	7,015,407	1,386
579,459	7,015,356	1,378
579,425	7,015,298	1,367
579,407	7,015,269	1,363
579,378	7,015,231	1,356
579,329	7,015,178	1,348
579,284	7,015,103	1,335
579,254	7,015,051	1,326
Terminus positions		
579,240	7,015,020	1,325
579,229	7,014,984	1,321
579,216	7,014,947	1,312
579,188	7,014,895	1,305
579,164	7,014,881	1,302
579,135	7,014,856	1,299
579,101	7,014,827	1,294
579,063	7,014,800	1,287
579,027	7,014,779	1,282
578,965	7,014,754	1,280
578,927	7,014,733	1,275
578,885	7,014,708	1,268
578,832	7,014,696	1,262
578,815	7,014,698	1,260
578,780	7,014,652	1,257
578,769	7,014,636	1,254
578,752	7,014,630	1,253
578,718	7,014,609	1,254
578,712	7,014,610	1,248
578,711	7,014,606	1,251
578,686	7,014,576	1,245
578,665	7,014,565	1,241
578,640	7,014,552	1,244
578,614	7,014,545	1,226
578,588	7,014,530	1,221
578,567	7,014,513	1,216
578,535	7,014,496	1,200
578,506	7,014,503	1,193
578,472	7,014,509	1,188
578,429	7,014,504	1,184
578,425	7,014,513	1,182
578,428	7,014,526	1,182
578,420	7,014,535	1,180
578,379	7,014,522	1,180
578,333	7,014,527	1,176
578,302	7,014,534	1,173
578,276	7,014,528	1,172
578,270	7,014,533	1,173
Péwé		
576,817	7,012,771	1,147

Table 9. Global Positioning System terminus-position surveys, Gulkana Glacier, August 23, 2001.

[Universal Transverse Mercator (UTM) coordinates are in UTM zone 6. Easting and northing measurements are in meters. NAD 83, North American Datum of 1983; NGVD 29, National Geodetic Vertical Datum of 1929]

Easting (NAD 83)	Northing (NAD 83)	Altitude (NGVD 29)
Péwé		
576,817	7,012,770	1,158
576,818	7,012,770	1,158
576,818	7,012,771	1,158
576,817	7,012,771	1,158
Terminus positions		
578,377	7,014,543	1,181
578,369	7,014,599	1,181
578,354	7,014,548	1,181
578,345	7,014,539	1,181
578,329	7,014,535	1,184
578,317	7,014,539	1,185
578,309	7,014,537	1,184
578,291	7,014,543	1,183
578,274	7,014,539	1,181
578,272	7,014,541	1,181
578,269	7,014,542	1,180
578,265	7,014,543	1,180
578,242	7,014,556	1,183
578,232	7,014,567	1,185
578,217	7,014,565	1,182
578,206	7,014,570	1,184
578,187	7,014,559	1,182
578,182	7,014,547	1,180
578,180	7,014,557	1,180
578,177	7,014,563	1,181
578,175	7,014,578	1,185
578,168	7,014,589	1,184
578,180	7,014,598	1,186
578,187	7,014,604	1,185
578,187	7,014,615	1,188
578,196	7,014,623	1,189
578,209	7,014,626	1,191
578,221	7,014,627	1,191
578,230	7,014,630	1,190
578,239	7,014,641	1,192
578,247	7,014,646	1,195
578,253	7,014,649	1,194
578,264	7,014,646	1,195
578,283	7,014,650	1,194
578,294	7,014,666	1,195
578,293	7,014,674	1,194
578,278	7,014,665	1,194
578,266	7,014,673	1,194
578,270	7,014,687	1,194
578,268	7,014,696	1,194
578,259	7,014,705	1,194
578,247	7,014,714	1,194
578,235	7,014,718	1,194
578,222	7,014,727	1,203
578,204	7,014,731	1,205

Easting (NAD 83)	Northing (NAD 83)	Altitude (NGVD 29)
Terminus positions		
578,194	7,014,731	1,206
578,233	7,014,766	1,214
578,234	7,014,770	1,215
578,221	7,014,772	1,217
578,211	7,014,775	1,218
578,209	7,014,782	1,219
578,206	7,014,786	1,217
578,216	7,014,790	1,221
578,225	7,014,795	1,221
578,224	7,014,803	1,221
578,232	7,014,812	1,223
578,236	7,014,822	1,221
578,241	7,014,826	1,224
578,254	7,014,834	1,223
578,260	7,014,843	1,223
578,269	7,014,859	1,224
578,281	7,014,884	1,224
578,280	7,014,895	1,224
578,275	7,014,913	1,224
578,289	7,014,926	1,224
578,300	7,014,949	1,225
578,281	7,014,955	1,223
578,265	7,014,953	1,223
578,243	7,014,954	1,223
578,223	7,014,960	1,224
578,210	7,014,970	1,225
578,208	7,014,982	1,225
578,208	7,014,997	1,226
578,198	7,014,997	1,225
578,186	7,014,992	1,226
578,175	7,014,986	1,226
578,165	7,014,982	1,225
578,139	7,014,982	1,225
578,128	7,014,983	1,226
578,123	7,014,978	1,234
578,132	7,015,011	1,246
578,126	7,015,017	1,241
578,119	7,015,024	1,243
578,112	7,015,030	1,241
578,105	7,015,033	1,239
578,095	7,015,037	1,235
578,078	7,015,036	1,241
578,074	7,015,048	1,240
578,076	7,015,068	1,239
578,075	7,015,082	1,235
578,080	7,015,099	1,239
578,093	7,015,121	1,238
578,099	7,015,135	1,241
578,107	7,015,149	1,238
578,113	7,015,165	1,239
578,132	7,015,182	1,239

Easting (NAD 83)	Northing (NAD 83)	Altitude (NGVD 29)
Terminus positions		
578,143	7,015,199	1,234
578,153	7,015,212	1,235
578,152	7,015,231	1,235
578,165	7,015,245	1,235
578,174	7,015,254	1,239
578,176	7,015,266	1,237
578,185	7,015,276	1,239
578,195	7,015,285	1,242
578,200	7,015,293	1,240
578,201	7,015,305	1,241
578,189	7,015,308	1,239
578,211	7,015,313	1,236
578,203	7,015,317	1,236
578,215	7,015,331	1,245
578,213	7,015,337	1,242
578,203	7,015,340	1,245
578,187	7,015,347	1,245
578,195	7,015,372	1,245
578,204	7,015,379	1,245
578,213	7,015,391	1,246
578,215	7,015,405	1,248
578,217	7,015,411	1,250
578,225	7,015,426	1,251
578,220	7,015,436	1,251
578,226	7,015,443	1,251
578,224	7,015,450	1,248
578,232	7,015,456	1,250
578,236	7,015,462	1,252
578,245	7,015,468	1,252
578,254	7,015,489	1,253
578,267	7,015,504	1,258
578,274	7,015,519	1,260
578,267	7,015,524	1,258
578,275	7,015,537	1,263
578,279	7,015,544	1,260
578,281	7,015,553	1,260
578,290	7,015,560	1,269
578,316	7,015,580	1,279
578,330	7,015,590	1,283
578,335	7,015,598	1,283
578,353	7,015,617	1,289
578,355	7,015,627	1,292
578,336	7,015,610	1,286
578,305	7,015,619	1,298
578,301	7,015,627	1,298
578,280	7,015,630	1,294
578,297	7,015,640	1,294
578,309	7,015,641	1,302
578,318	7,015,652	1,306
578,323	7,015,663	1,307
578,331	7,015,679	1,310

Easting (NAD 83)	Northing (NAD 83)	Altitude (NGVD 29)
Terminus positions		
578,339	7,015,693	1,313
578,342	7,015,700	1,314
578,350	7,015,707	1,321
578,364	7,015,721	1,325
578,366	7,015,737	1,325
578,372	7,015,744	1,324
578,381	7,015,750	1,327
578,386	7,015,759	1,331
578,396	7,015,768	1,335
578,410	7,015,792	1,341
578,413	7,015,799	1,342
578,424	7,015,813	1,342
578,424	7,015,813	1,342
578,422	7,015,815	1,345
578,421	7,015,828	1,346
578,423	7,015,841	1,351
578,419	7,015,847	1,351
578,417	7,015,857	1,351
578,411	7,015,862	1,353
578,405	7,015,871	1,353
578,404	7,015,878	1,354
578,397	7,015,885	1,358
578,394	7,015,892	1,359
578,390	7,015,904	1,362
578,387	7,015,910	1,362
578,384	7,015,919	1,363
578,376	7,015,932	1,365
578,370	7,015,945	1,368
578,372	7,015,943	1,368
578,367	7,015,958	1,370
578,364	7,015,969	1,370
578,358	7,015,975	1,371
578,358	7,015,991	1,376
578,356	7,016,004	1,377
578,353	7,016,014	1,379
578,352	7,016,021	1,380
578,353	7,016,032	1,384
578,351	7,016,042	1,386
578,345	7,016,056	1,388
578,348	7,016,077	1,392
578,350	7,016,098	1,396
578,342	7,016,115	1,399
578,335	7,016,126	1,400
578,279	7,015,544	1,260
578,281	7,015,553	1,260
578,290	7,015,560	1,269
578,316	7,015,580	1,279
578,330	7,015,590	1,283
578,335	7,015,598	1,283
578,353	7,015,617	1,289
578,355	7,015,627	1,292

Table 9. Global Positioning System terminus-position surveys, Gulkana Glacier, August 23, 2001.—Continued

[Universal Transverse Mercator (UTM) coordinates are in UTM zone 6. Easting and northing measurements are in meters. NAD 83, North American Datum of 1983; NGVD 29, National Geodetic Vertical Datum of 1929]

Easting (NAD 83)	Northing (NAD 83)	Altitude (NGVD 29)
Terminus positions		
578,336	7,015,610	1,286
578,305	7,015,619	1,298
578,301	7,015,627	1,298
578,338	7,016,324	1,441
578,338	7,016,344	1,445
578,336	7,016,360	1,449
578,333	7,016,377	1,453
578,329	7,016,392	1,460
578,331	7,016,403	1,459
578,330	7,016,415	1,463
578,329	7,016,425	1,465
578,328	7,016,436	1,467
578,327	7,016,449	1,469
578,322	7,016,463	1,474
578,314	7,016,469	1,476
578,311	7,016,486	1,479
578,306	7,016,499	1,483
578,303	7,016,515	1,487
578,300	7,016,524	1,489
578,296	7,016,544	1,495
578,292	7,016,559	1,496
578,291	7,016,590	1,506
578,295	7,016,599	1,508
578,291	7,016,610	1,508
578,289	7,016,626	1,513
579,914	7,016,088	1,451
579,903	7,016,076	1,450
579,891	7,016,062	1,450
579,875	7,016,051	1,453
579,860	7,016,037	1,453
579,858	7,016,034	1,453
579,853	7,016,024	1,451
579,849	7,016,007	1,450
579,839	7,015,993	1,449
579,836	7,015,980	1,448
579,830	7,015,968	1,446
579,826	7,015,957	1,445
579,823	7,015,952	1,445
579,820	7,015,946	1,444
579,814	7,015,936	1,442
579,811	7,015,925	1,441
579,803	7,015,905	1,439
579,796	7,015,885	1,439
579,793	7,015,869	1,437
579,792	7,015,860	1,436
579,788	7,015,850	1,435
579,786	7,015,841	1,433
579,784	7,015,833	1,431
579,778	7,015,821	1,430
579,772	7,015,812	1,430
579,767	7,015,805	1,428
579,762	7,015,795	1,426
579,757	7,015,784	1,424
579,702	7,015,703	1,420
579,683	7,015,670	1,419
579,664	7,015,646	1,405
579,640	7,015,620	1,401
579,617	7,015,589	1,401
579,598	7,015,560	1,398
579,576	7,015,533	1,395
579,551	7,015,507	1,391
579,534	7,015,488	1,390
579,514	7,015,461	1,391
579,499	7,015,440	1,388
579,490	7,015,417	1,385
579,468	7,015,386	1,380
579,457	7,015,367	1,378
579,446	7,015,350	1,375
579,435	7,015,324	1,371
579,432	7,015,316	1,370
579,421	7,015,301	1,366
579,406	7,015,281	1,365
579,391	7,015,259	1,361
579,374	7,015,234	1,361
579,363	7,015,220	1,357
579,342	7,015,203	1,352
579,326	7,015,187	1,348
579,318	7,015,176	1,352
579,306	7,015,156	1,348
579,306	7,015,155	1,348
579,299	7,015,142	1,347
579,289	7,015,125	1,345
579,277	7,015,101	1,340
579,260	7,015,083	1,333
579,252	7,015,068	1,332
579,238	7,015,053	1,331
579,225	7,015,043	1,333
579,214	7,015,025	1,325
579,203	7,015,014	1,324
579,192	7,014,998	1,325
579,186	7,014,985	1,322
579,171	7,014,964	1,321
579,151	7,014,936	1,312
579,139	7,014,920	1,313
579,122	7,014,905	1,313
579,111	7,014,889	1,313
579,096	7,014,875	1,313
579,087	7,014,856	1,312
579,072	7,014,838	1,309
579,052	7,014,812	1,289
579,049	7,014,797	1,289
579,027	7,014,788	1,283
579,008	7,014,774	1,282
578,980	7,014,763	1,280
578,963	7,014,759	1,278
578,943	7,014,744	1,272
578,927	7,014,737	1,274
578,908	7,014,724	1,271
578,897	7,014,717	1,270
578,887	7,014,710	1,269
578,876	7,014,713	1,268
578,866	7,014,718	1,268
578,850	7,014,710	1,261
578,839	7,014,710	1,262
578,835	7,014,711	1,262
578,815	7,014,711	1,262
578,795	7,014,707	1,262
578,786	7,014,697	1,265
578,783	7,014,681	1,266
578,782	7,014,667	1,265
578,786	7,014,657	1,266
578,777	7,014,656	1,265
578,763	7,014,637	1,258
578,747	7,014,633	1,253
578,742	7,014,627	1,254
578,726	7,014,611	1,252
578,714	7,014,599	1,252
578,693	7,014,583	1,247
578,679	7,014,573	1,240
578,668	7,014,567	1,238
578,656	7,014,563	1,236
578,631	7,014,555	1,232
578,614	7,014,547	1,226
578,600	7,014,539	1,228
578,584	7,014,525	1,228
578,562	7,014,507	1,228
578,547	7,014,486	1,228
578,537	7,014,487	1,220
578,521	7,014,485	1,226
578,504	7,014,485	1,224
578,505	7,014,492	1,225
578,481	7,014,494	1,225
578,465	7,014,496	1,219
578,447	7,014,497	1,222
Péwé		
576,814	7,012,770	1,152
576,814	7,012,770	1,151
576,813	7,012,771	1,151
576,813	7,012,771	1,152

Glacier Surface Altitude

Change in surface altitude along a profile down the glacier is often the best way to intuitively grasp how a glacier's geometry is changing over time. For example, Mayo and Trabant (1986) used this parameter alone to estimate growth of Gulkana Glacier from 1975 to 1984.

The glacier surface altitude and the uppermost glacier summer surface at each index site were measured during each onsite visit (fig. 6, table 10). We estimated the surface topography of the glacier by establishing a 75-m plane defining local topography around each index site by surveying at least three local surface points. The index-site altitude was taken as the altitude of this plane at the position of the index site (Mayo and Trabant, 1982). Surveyed glacier-surface points typically have an altitude uncertainty of about 0.05 m.

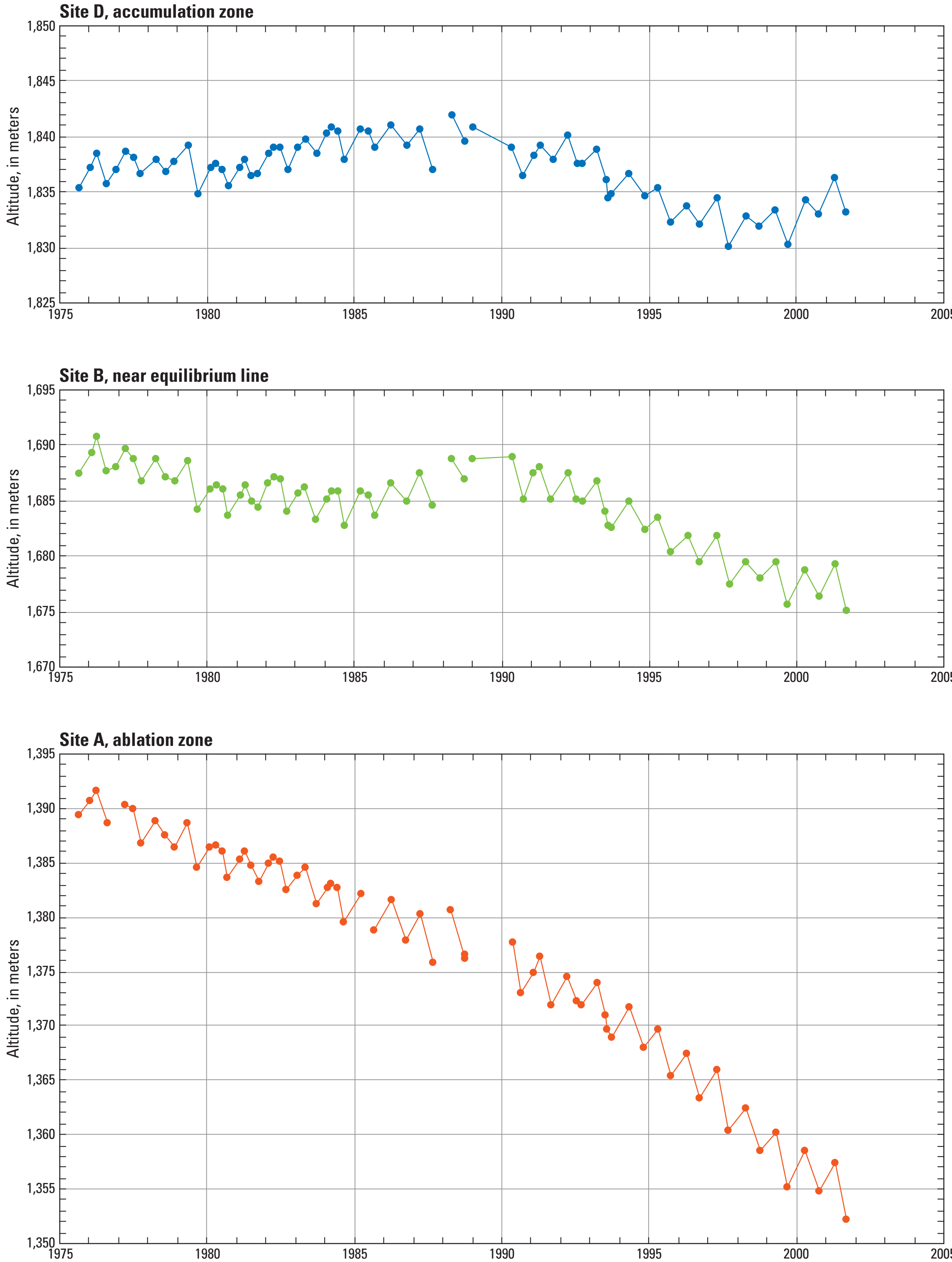

Figure 6. Surface altitudes at index sites A, B, and D, Gulkana Glacier, Alaska.

Table 10. Gulkana Glacier glacier-surface altitudes at index sites A, B, and D.

[An unresolved datum shift exists between the 1975–87 data and the 1988–96 data. Altitude, in meters; NGVD 29, National Geodetic Vertical Datum of 1929. **Abbreviation**: mm-dd-yy, month-day-year]

Date (mm-dd-yy)	Site A (meters)	Site B (meters)	Site D (meters)
08-25-75	1,389.48	1,687.48	1,835.44
01-20-76	1,390.65	1,689.37	1,837.25
04-05-76	1,391.73	1,690.77	1,838.41
08-06-76	1,388.59	1,687.62	1,835.69
11-22-76		1,688.10	1,837.01
03-30-77	1,390.34	1,689.72	1,838.71
06-25-77	1,389.93	1,688.86	1,838.09
10-03-77	1,386.90	1,686.87	1,836.65
03-27-78	1,388.90	1,688.74	1,838.05
08-04-78	1,387.60	1,687.19	1,836.90
11-18-78	1,386.46	1,686.79	1,837.78
05-04-79	1,388.71	1,688.57	1,839.20
08-31-79	1,384.65	1,684.24	1,834.85
02-06-80	1,386.38	1,686.10	1,837.26
04-15-80	1,386.68	1,686.47	1,837.63
07-04-80	1,386.06	1,686.08	1,837.08
09-16-80	1,383.65	1,683.69	1,835.64
02-19-81	1,385.40	1,685.49	1,837.18
04-17-81	1,386.16	1,686.47	1,837.89
07-10-81	1,384.76	1,684.92	1,836.57
10-01-81	1,383.33	1,684.45	1,836.66
01-27-82	1,384.89	1,686.55	1,838.45
04-12-82	1,385.56	1,687.08	1,839.14
06-19-82	1,385.13	1,686.92	1,839.13
09-13-82	1,382.45	1,684.03	1,836.98
02-03-83	1,383.82	1,685.72	1,839.12
05-04-83	1,384.59	1,686.25	1,839.80
09-23-83	1,381.21	1,683.39	1,838.53
01-28-84	1,382.77	1,685.21	1,840.31
03-22-84	1,383.14	1,685.88	1,840.89
06-08-84	1,382.77	1,685.82	1,840.53
08-29-84	1,379.64	1,682.82	1,838.02
03-23-85	1,382.23	1,685.83	1,840.72
06-28-85		1,685.46	1,840.55
09-04-85	1,378.82	1,683.76	1,838.99
03-30-86	1,381.66	1,686.68	1,841.11
10-07-86	1,377.98	1,684.95	1,839.18
03-24-87	1,380.32	1,687.60	1,840.68
08-28-87	1,375.80	1,684.60	1,837.13
04-15-88	1,380.67	1,688.85	1,841.93
09-25-88	1,376.29	1,686.91	1,839.66
09-25-88	1,376.59		
01-06-89		1,688.80	1,840.81
05-18-90	1,377.70	1,689.04	1,839.11
08-17-90	1,373.13	1,685.11	1,836.56
02-02-91	1,374.87	1,687.44	1,838.31
04-18-91	1,376.35	1,688.14	1,839.23
09-06-91	1,371.94	1,685.16	1,837.94
03-26-92	1,374.56	1,687.49	1,840.13
07-22-92	1,372.29	1,685.19	1,837.54
09-22-92	1,371.91	1,684.94	1,837.60
03-31-93	1,374.08	1,686.85	1,838.86
07-12-93	1,371.07	1,683.97	1,836.13
08-03-93	1,369.64	1,682.83	1,834.56
09-22-93	1,368.97	1,682.53	1,834.79
04-28-94	1,371.84	1,685.01	1,836.75
10-31-94	1,368.01	1,682.32	1,834.66
04-19-95	1,369.64	1,683.54	1,835.37
09-26-95	1,365.46	1,680.41	1,832.29
04-18-96	1,367.50	1,681.81	1,833.71
09-16-96	1,363.39	1,679.52	1,832.08
04-19-97	1,365.92	1,681.86	1,834.44
09-15-97	1,360.39	1,677.40	1,830.12
04-17-98	1,362.38	1,679.46	1,832.89
10-02-98	1,358.63	1,677.97	1,831.89
04-20-99	1,360.26	1,679.40	1,833.48
09-14-99	1,355.27	1,675.65	1,830.36
04-20-00	1,358.54	1,678.70	1,834.23
10-01-00	1,354.76	1,676.40	1,833.04
04-19-01	1,357.49	1,679.30	1,836.32
09-10-01	1,352.22	1,675.15	1,833.18

Additionally, the locations used to define the plane of the glacier surface may not be representative of the average glacier surface; hence, extrapolating along this plane to the index site may introduce further error. The glacier-surface orientation and slope determinations have a small random variability that is used to assess the magnitude of this error. Because this error is site specific, depending largely on the local surface roughness of the glacier, an average glacier-surface slope error of 0.5 grad was applied to the distance between the closest surveyed point and the index site. This error, combined with the surveying error, yielded an average error of 0.15 m for the index-site altitudes.

Ice Motion

Surface displacement at index sites was measured by optical surveying of balance stakes. Figure 7 shows 1996–2001 stake locations and displacements at site B. The stakes were kept within about 1 year's displacement of the index site (usually less than 80 m) to maximize the year-to-year comparability of the motion (Mayo and others, 1979; Mayo and Trabant, 1982) and were replaced as necessary. Reported stake locations (tables 11–13) have been corrected for changes in stake geometry including bends, bows and leans (March, 2000). Leaning stakes are most commonly observed at Gulkana Glacier, and when a bend or bow does occur, it is generally at or above the most-recent summer surface. Aside from changes in stake geometry, location uncertainty is largely a result of the survey-control net errors (GPS for horizontal and optical surveying for vertical) and resection errors. Resection was conducted by surveying four or five backsight targets, instead of the minimum of three backsight targets, to allow error evaluation. The net and resection errors combined yield position errors of about 0.15 m in the horizontal and 0.05 m in the vertical. The error of extrapolating to the bottom of the stake is estimated to be 0.15 m, resulting in a total horizontal error for stake-bottom positions of 0.2 m. Vertical errors are significantly less, about 0.05 m. Hence, reported displacements have errors of about 0.3 m.

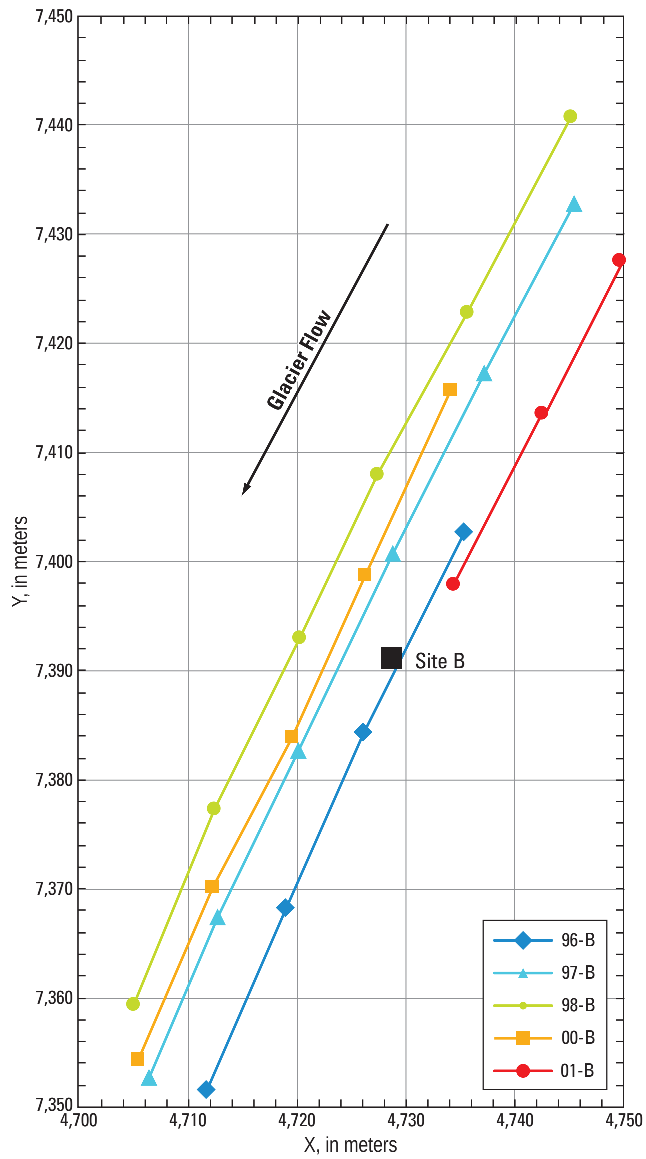

Figure 7. Locations of stakes at site B, Gulkana Glacier, Alaska, shown as an example. First two characters of stake name represent the last two digits of the year the stake was installed. Two locations for stake 96-B are from previous report (March, 2003).

Table 11. Glacier surface slope, stake bottom locations, and stake motion determined from optical surveys, Site A, 1996–2001.

[Stake name: The first two digits represent the year the stake was installed; letters (A, B, D) represent the index site on the glacier (fig. 2); and a number following the letter is used to differentiate multiple stakes installed at the same site in 1 year. θ is the downdip direction with zero east and positive counterclockwise. φ is the dip angle with zero horizontal and positive angles up. X_S, Y_S, Z_S, stake bottom location. ΔXYZ is the total three-dimensional displacement of the stake bottom between measurements. Horizontal displacement angle is measured positive counterclockwise; zero is east. Vertical displacement angle is measured positive up from horizontal. Seasonal speed is the stake displacement divided by the measurement period in years. Annual speed is the stake displacement divided by the measurement period in years for two or more measurement periods, so that the period is close to a year. Grad is a unit of measure for a plane angle and is equal to the plane angle in degrees multiplied by (100/90). **Abbreviations**: mm-dd-yy, month-day-year; m, meter; m/yr, meter per year]

Date (mm-dd-yy)	Stake name	Glacier surface		Stake bottom			Period (days)	ΔXYZ (m)	Displacement angles		Seasonal speed (m/yr)	Annual speed (m/yr)
		θ_g	ϕ_g	X_S	Y_S	Z_S			Horizontal	Vertical		
		(grad)		(m)					(grad)			
04-17-96	96-A	-154.95	– 7.06	3,802.06	4,477.24	1,358.14						
09-16-96	96-A	-144.50	– 7.20	3,796.46	4,471.07	1,358.40	152	8.34	-146.92	1.93	20.03	
04-18-97	96-A	-149.37	– 7.16	3,791.09	4,465.10	1,358.51	214	8.03	-146.65	0.86	13.70	16.3
04-17-96	96-A1	-154.95	– 7.06	3,810.54	4,470.37	1,358.42						
09-16-96	96-A1	-144.50	– 7.20	3,804.79	4,464.43	1,358.66	152	8.27	-148.95	1.88	19.86	
04-18-97	96-A1	-149.37	– 7.16	3,799.60	4,458.51	1,358.76	214	7.88	-145.86	0.84	13.44	16.1
04-18-97	97-A	-149.37	– 7.16	3,805.05	4,465.16	1,355.31						
09-15-97	97-A	-144.67	– 6.79	3,799.58	4,459.88	1,355.59	150	7.60	-151.17	2.33	18.49	
04-17-98	97-A	-146.96	– 6.68	3,794.58	4,454.87	1,355.71	214	7.08	-149.89	1.09	12.08	14.7
04-18-97	97-AA	-149.37	– 7.16	3,832.08	4,466.73	1,357.48						
09-15-97	97-AA	-144.67	– 6.79	3,826.76	4,460.95	1,357.74	150	7.86	-147.39	2.07	19.13	
04-17-98	97-AA	-146.96	– 6.68	3,821.70	4,455.69	1,357.84	214	7.30	-148.76	0.92	12.45	15.2
04-17-98	98-A	-146.96	– 6.68	3,830.84	4,455.99	1,353.46						
09-23-98	98-A	-160.52	– 7.20	3,825.90	4,450.60	1,353.66	159	7.31	-147.21	1.79	16.78	
04-22-99	98-A	-149.20	– 7.99	3,821.43	4,445.90	1,353.80	211	6.49	-148.40	1.32	11.23	13.6
04-17-98	98-A2	-146.96	– 6.68	3,824.76	4,461.74	1,353.55						
09-23-98	98-A2	-160.52	– 7.20	3,819.96	4,456.54	1,353.77	159	7.08	-147.42	1.97	16.25	
04-22-99	98-A2	-149.20	– 7.99	3,815.48	4,451.96	1,353.90	211	6.41	-149.29	1.26	11.09	13.3
04-22-99	99-A	-149.20	– 7.99	3,839.34	4,458.94	1,352.45						
09-14-99	99-A	-168.66	– 8.80	3,835.30	4,454.87	1,352.55	145	5.73	-149.79	1.12	14.42	
04-21-00	99-A	-154.01	– 7.76	3,830.93	4,450.37	1,352.81	220	6.28	-149.02	2.64	10.42	12.0
04-22-99	99-A1	-149.20	– 7.99	3,832.55	4,465.45	1,352.41						
09-14-99	99-A1	-168.66	– 8.80	3,828.80	4,461.15	1,352.56	145	5.71	-145.74	1.68	14.37	
04-21-00	99-A1	-154.01	– 7.76	3,825.29	4,456.63	1,353.00	220	5.74	-142.01	4.81	9.52	11.4
04-21-00	00-A	-154.01	– 7.76	3,834.76	4,454.07	1,349.10						
10-01-00	00-A	-152.47	– 7.31	3,830.48	4,449.27	1,349.38	163	6.44	-146.38	2.75	14.42	
04-20-01	00-A	-159.65	– 6.96	3,826.60	4,445.00	1,349.61	201	5.77	-146.97	2.50	10.48	12.2
09-10-01	00-A	-159.63	– 6.89	3,822.71	4,440.44	1,349.80	143	5.99	-144.91	2.04	15.29	
04-21-00	00-A1	-154.01	– 7.76	3,827.74	4,461.17	1,348.89						
10-01-00	00-A1	-152.47	– 7.31	3,823.00	4,456.73	,1349.18	163	6.50	-152.08	2.83	14.56	
04-20-01	00-A1	-159.65	– 6.96	3,819.31	4,452.98	1,349.45	201	5.27	-149.48	3.23	9.57	11.8
09-10-01	00-A1	-159.63	– 6.89	3,815.18	4,447.92	1,349.58	143	6.54	-143.55	1.33	16.69	
04-20-01	01-A	-159.65	– 6.96	3,835.35	4,455.43	1,348.98						
09-10-01	01-A	-159.63	– 6.89	3,831.31	4,451.27	1,349.28	143	5.81	-148.99	3.28	14.83	
Average		-153.16	– 7.31					6.76	-147.69	2.02	14.31	13.68
Standard deviation		6.56	0.56					0.93	2.35	0.96	3.20	1.82

Table 12. Glacier surface slope, stake bottom locations, and stake motion determined from optical surveys, Site B, 1996–2001.

[Stake name: The first two digits represent the year the stake was installed; letters (A, B, D) represent the index site on the glacier (fig. 2); and a number following the letter is used to differentiate multiple stakes installed at the same site in 1 year. θ is the downdip direction with zero east and positive counterclockwise. φ is the dip angle with zero horizontal and positive angles up. X_s, Y_s, Z_s, stake bottom location. ΔXYZ is the total three-dimensional displacement of the stake bottom between measurements. Horizontal displacement angle is measured positive counterclockwise; zero is east. Vertical displacement angle is measured positive up from horizontal. Seasonal speed is the stake displacement divided by the measurement period in years. Annual speed is the stake displacement divided by the measurement period in years for two or more measurement periods, so that the period is close to a year. Grad is a unit of measure for a plane angle and is equal to the plane angle in degrees multiplied by (100/90). **Abbreviations**: mm-dd-yy, month-day-year; m, meter; m/yr, meter per year]

Date (mm-dd-yy)	Stake name	Glacier surface			Stake bottom			Period (days)	ΔXYZ (m)	Displacement angles		Seasonal speed (m/yr)	Annual speed (m/yr)
		θ_g		ϕ_g	X_S	Y_S	Z_S			Horizontal	Vertical		
		(grad)			(m)					(grad)			
09-16-96	96-B	-128.30	–	6.15	4,735.27	7,402.66	1,674.06						
04-19-97	96-B	-135.63	–	6.19	4,726.06	7,384.38	1,672.55	215	20.52	-129.70	-4.69	34.84	40.5
09-15-97	96-B	-133.11	–	6.75	4,718.94	7,368.27	1,670.80	149	17.70	-126.47	-6.29	43.36	
04-17-98	96-B	-127.90	–	6.28	4,711.75	7,351.54	1,669.39	214	18.27	-125.85	-4.93	31.16	36.2
04-19-97	97-B	-135.63	–	6.19	4,745.38	7,432.80	1,677.28						
09-15-97	97-B	-133.11	–	6.75	4,737.10	7,417.29	1,675.55	149	17.66	-131.25	-6.27	43.26	
04-17-98	97-B	-127.90	–	6.28	4,728.76	7,400.75	1,674.08	214	18.58	-129.70	-5.02	31.69	36.4
10-02-98	97-B	-136.12	–	6.34	4,720.07	7,382.66	1,672.07	168	20.17	-128.53	-6.36	43.82	
04-20-99	97-B	-132.33	–	6.33	4,712.69	7,367.30	1,670.77	200	17.09	-128.51	-4.86	31.19	37.0
09-14-99	97-B	-134.27	–	6.49	4,706.40	7,352.64	1,669.01	147	16.05	-125.81	-6.98	39.85	
04-17-98	98-B	-127.90	–	6.28	4,745.12	7,440.75	1,674.42						
10-02-98	98-B	-136.12	–	6.34	4,735.62	7,422.90	1,672.42	168	20.32	-131.13	-6.29	44.15	
04-20-99	98-B	-132.33	–	6.33	4,727.43	7,407.96	1,671.08	200	17.09	-131.93	-4.98	31.19	37.1
09-14-99	98-B	-134.27	–	6.49	4,720.22	7,393.01	1,669.25	147	16.70	-128.60	-6.99	41.47	
04-20-00	98-B	-139.66	–	6.53	4,712.39	7,377.29	1,667.83	219	17.62	-129.44	-5.15	29.37	34.2
10-01-00	98-B	-131.84	–	6.35	4,705.00	7,359.39	1,666.03	164	19.45	-124.92	-5.91	43.29	
04-20-00	00-B	-139.66	–	6.53	4,734.07	7,415.68	1,671.38						
10-01-00	00-B	-131.84	–	6.35	4,726.19	7,398.76	1,669.69	164	18.74	-127.75	-5.75	41.71	
04-20-01	00-B	-123.89	–	6.48	4,719.52	7,383.89	1,668.27	201	16.36	-126.86	-5.56	29.71	35.1
09-10-01	00-B	-131.53	–	6.33	4,712.23	7,370.20	1,666.73	143	15.58	-131.13	-6.27	39.77	
04-16-02	00-B	-131.42	–	6.11	4,705.44	7,354.29	1,665.21	218	17.37	-125.66	-5.59	29.08	33.3
04-20-01	01-B	-123.89	–	6.48	4,749.56	7,427.57	1,673.52						
09-10-01	01-B	-131.53	–	6.33	4,742.42	7,413.58	1,672.00	143	15.78	-130.05	-6.12	40.28	
Average		-132.18	–	6.38						-128.52	-5.78	37.18	36.22
Standard deviation		4.19		0.17						2.19	0.72	5.91	2.18

Table 13. Glacier surface slope, stake bottom locations, and stake motion determined from optical surveys, Site D, 1996–2001.

[Stake name: The first two digits represent the year the stake was installed; letters (A, B, D) represent the index site on the glacier (fig. 2); and a number following the letter is used to differentiate multiple stakes installed at the same site in 1 year. θ is the downdip direction with zero east and positive counterclockwise. ϕ is the dip angle with zero horizontal and positive angles up. X_S, Y_S, Z_S, stake bottom location. ΔXYZ is the total three-dimensional displacement of the stake bottom between measurements. Horizontal displacement angle is measured positive counterclockwise; zero is east. Vertical displacement angle is measured positive up from horizontal. Seasonal speed is the stake displacement divided by the measurement period in years. Annual speed is the stake displacement divided by the measurement period in years for two or more measurement periods, so that the period is close to a year. Grad is a unit of measure for a plane angle and is equal to the plane angle in degrees multiplied by (100/90). **Abbreviations:** mm-dd-yy, month-day-year m, meter; m/yr, meter per year]

Date (mm-dd-yy)	Stake name	Glacier surface			Stake bottom			Period (days)	ΔXYZ (m)	Displacement angles		Seasonal speed (m/yr)	Annual speed (m/yr)
		θ_g		ϕ_g	X_S	Y_S	Z_S			Horizontal	Vertical		
		(grad)			(m)					(grad)			
04-18-96	94-D	182.80	–	6.22	5,959.1	7,379.8	1,819.4						
09-16-96	94-D	-196.20	–	6.93	5,940.7	7,390.6	1,817.0	151	21.5	166.4	-7.1	51.9	
04-19-97	94-D	-197.11	–	8.10	5,916.8	7,404.5	1,814.4	215	27.8	166.4	-5.9	47.2	49.1
04-18-96	96-D	182.80	–	6.22	6,020.5	7,339.7	1,826.8						
09-16-96	96-D	-196.20	–	6.93	6,002.4	7,350.6	1,824.2	151	21.2	165.5	-7.7	51.3	
04-19-97	96-D	-197.11	–	8.10	5,978.2	7,364.3	1,821.2	215	28.0	167.3	-6.7	47.5	49.1
09-15-97	96-D	183.30	–	6.85	5,962.2	7,374.1	1,819.2	149	18.9	164.8	-7.0	46.2	
04-15-98	96-D	196.96	–	8.10	5,944.4	7,384.9	1,817.1	212	20.9	165.5	-6.3	36.1	40.2
04-19-97	97-D	-197.11	–	8.10	6,023.5	7,336.2	1,827.5						
09-15-97	97-D	183.30	–	6.85	6,007.3	7,345.7	1,825.3	149	19.0	166.5	-7.7	46.5	
04-15-98	97-D	196.96	–	8.10	5,989.2	7,356.6	1,823.1	212	21.2	165.3	-6.6	36.4	40.6
10-02-98	97-D	196.72	–	8.06	5,971.7	7,367.4	1,820.4	170	20.8	164.7	-8.2	44.7	
04-20-99	97-D	167.38	–	7.00	5,954.5	7,378.1	1,818.3	200	20.4	164.6	-6.7	37.2	40.7
09-14-99	97-D	171.97	–	7.13	5,939.6	7,387.0	1,816.4	147	17.4	165.8	-6.7	43.2	
04-15-98	98-D	196.96	–	8.10	6,031.1	7,329.9	1,827.2						
10-02-98	98-D	196.72	–	8.06	6,013.3	7,340.6	1,824.4	170	21.0	165.5	-8.7	45.1	
04-20-99	98-D	167.38	–	7.00	5,996.1	7,351.2	1,822.1	200	20.3	164.8	-6.9	37.1	40.8
09-14-99	98-D	171.97	–	7.13	5,981.2	7,360.2	1,820.2	147	17.5	165.5	-7.0	43.4	
04-20-00	98-D	181.74	–	7.48	5,962.3	7,371.3	1,818.0	219	22.1	166.0	-6.4	36.8	39.4
04-20-00	00-D	181.74	–	7.48	6,019.9	7,333.9	1,827.2						
10-01-00	00-D	177.11	–	7.92	6,002.9	7,344.9	1,825.1	164	20.3	163.7	-6.9	45.2	
04-19-01	00-D	182.01	–	6.74	5,984.4	7,355.9	1,823.1	200	21.7	165.6	-5.7	39.5	42.1
09-10-01	00-D	190.73	–	7.12	5,969.7	7,364.2	1,821.3	144	17.1	167.4	-6.8	43.2	
04-19-01	01-D	182.01	–	6.74	6,040.1	7,325.8	1,831.6						
09-10-01	01-D	190.73		7.12	6,025.3	7,334.5	1,829.7	144	17.3	165.9	-6.8	43.9	
Average		107.90	–	7.34					20.7	165.7	-6.9	43.3	42.7
Standard deviation		155.71		0.62					3.0	0.9	0.7	4.9	4.0

Meteorology

Since October 1967, a weather station has operated at 1,480 m on the eastern ice-cored moraine of Gulkana Glacier (figs. 2 and 3; Kennedy and others, 1997) to measure air temperature and precipitation, a location representative of the glacier area meteorology. Since October 1996, wind speed has also been measured.

A radiation-shielded digital temperature sensor with an accuracy of 0.1 °C and time constant of 10 seconds in air was installed in 1996. The sensor brand is the same as the logger, so we assume the sensor specification is not invalidated by the analog to digital conversion in the logger. The radiation shield is open on the bottom and there is likely some temperature error due to upward radiation when snow is on the ground and/or there is little wind. This is a known problem with virtually all passive radiation shields. This air temperature sensor was sampled every minute and the 15-minute averages were logged and used to determine the daily averages shown in figures 8–12 and listed in tables 14–18. Following the National Climatic Data Center (1996) convention, monthly mean temperatures were calculated for months with nine or fewer missing daily values.

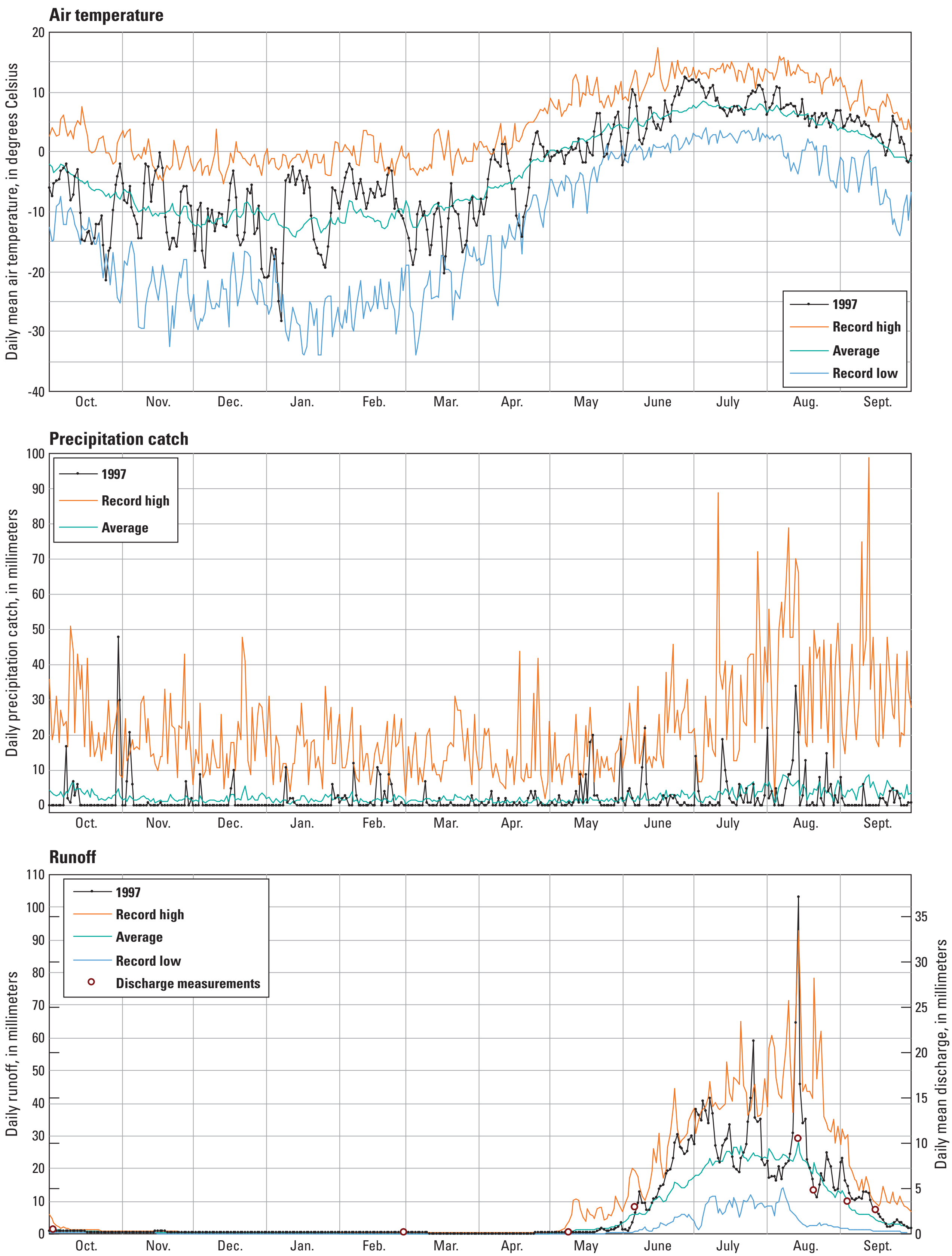

Figure 8. Daily values of mean air temperature, precipitation catch, and daily runoff at Phelan Creek, Alaska, water year 1997.

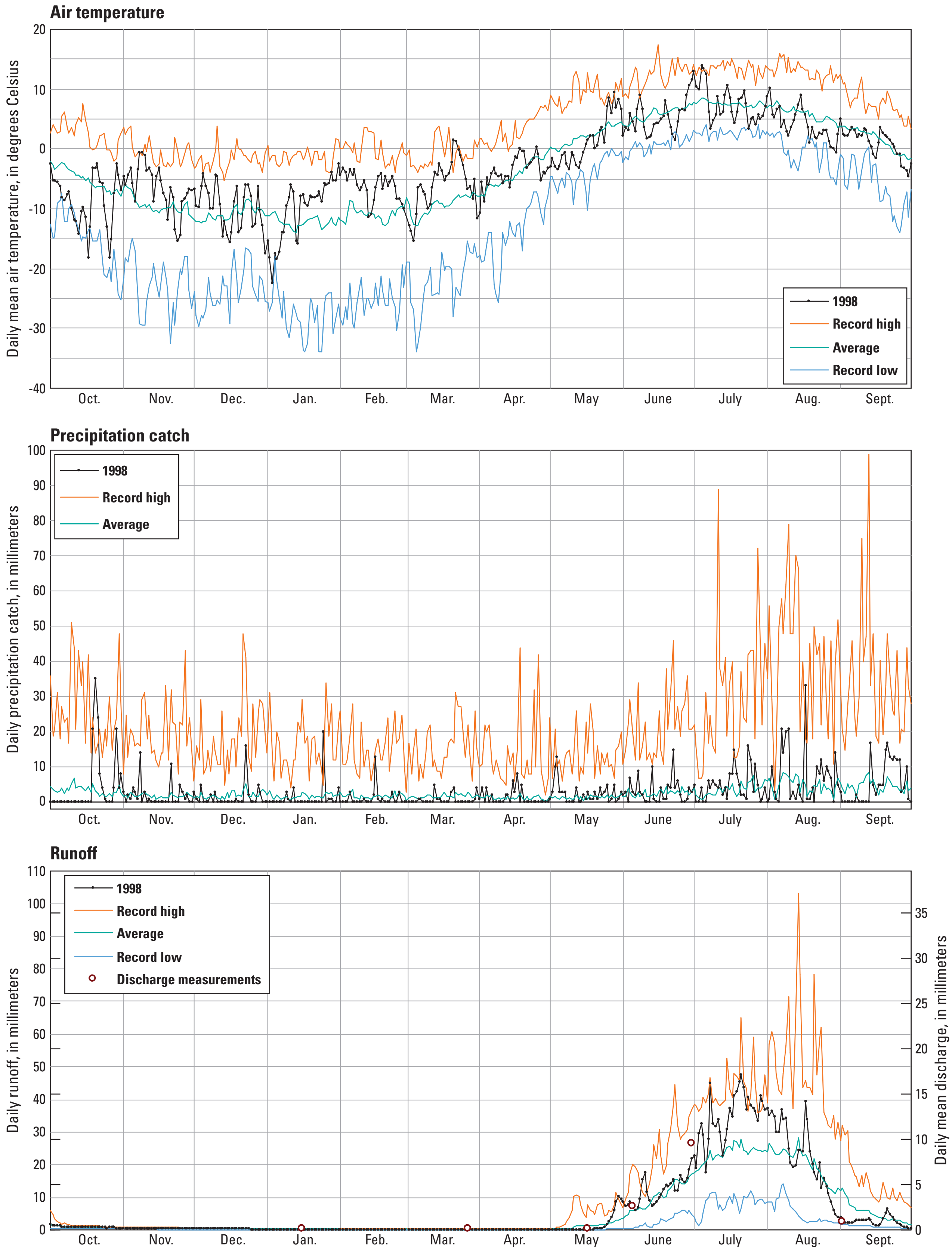

Figure 9. Daily values of mean air temperature, precipitation catch, and daily runoff at Phelan Creek, Alaska, water year 1998.

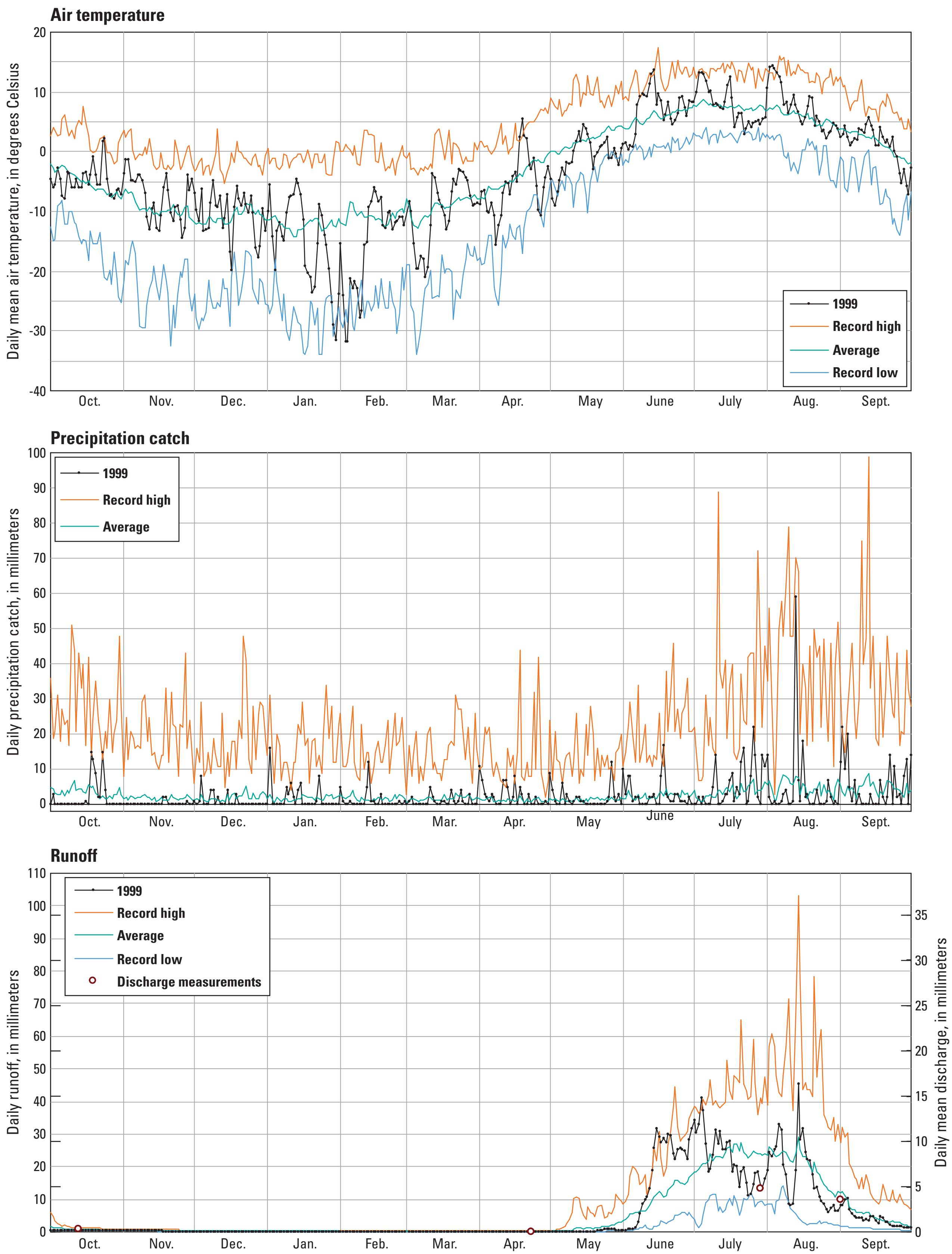

Figure 10. Daily values of mean air temperature, precipitation catch, and daily runoff at Phelan Creek, Alaska, water year 1999.

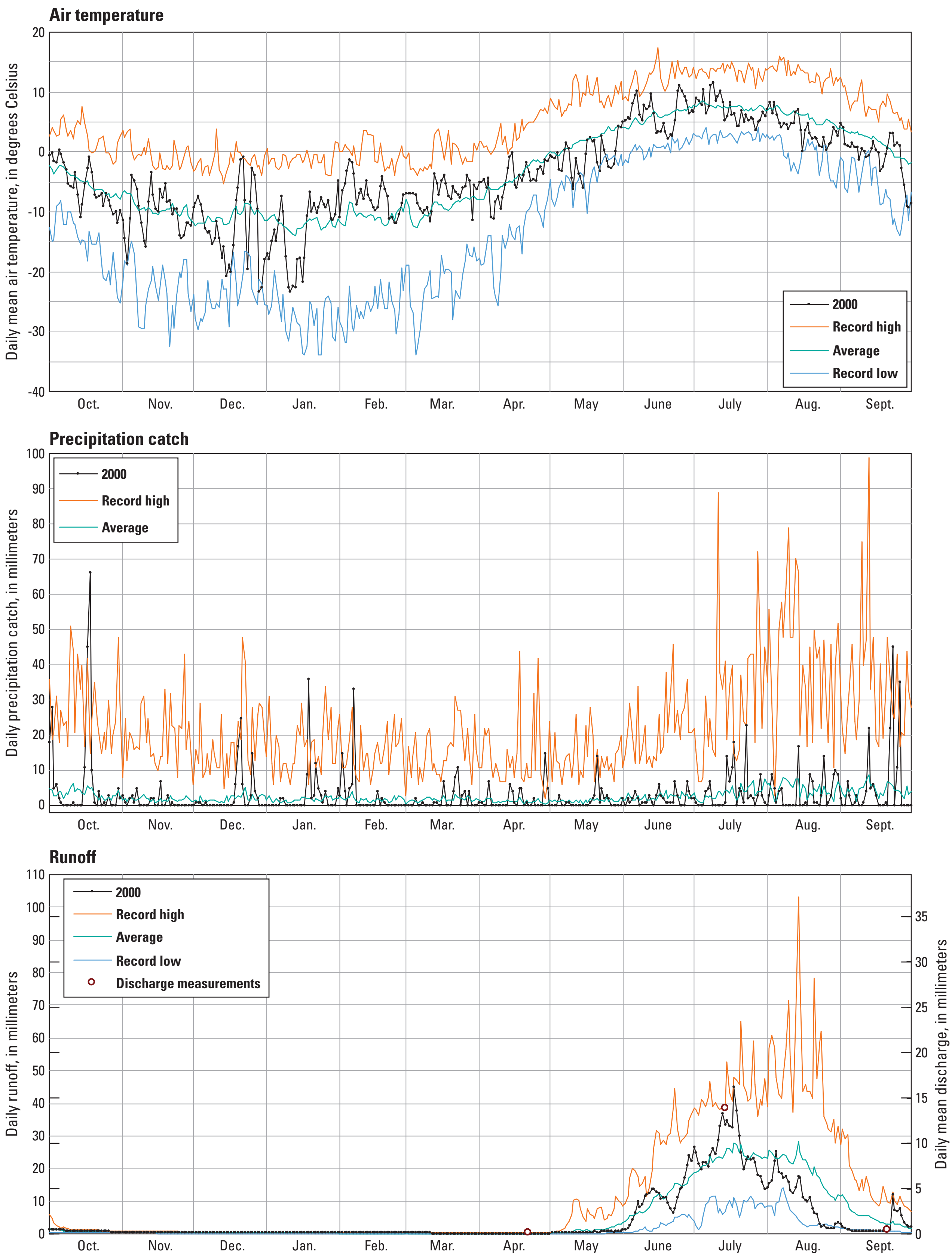

Figure 11. Daily values of mean air temperature, precipitation catch, and daily runoff at Phelan Creek, Alaska, water year 2000

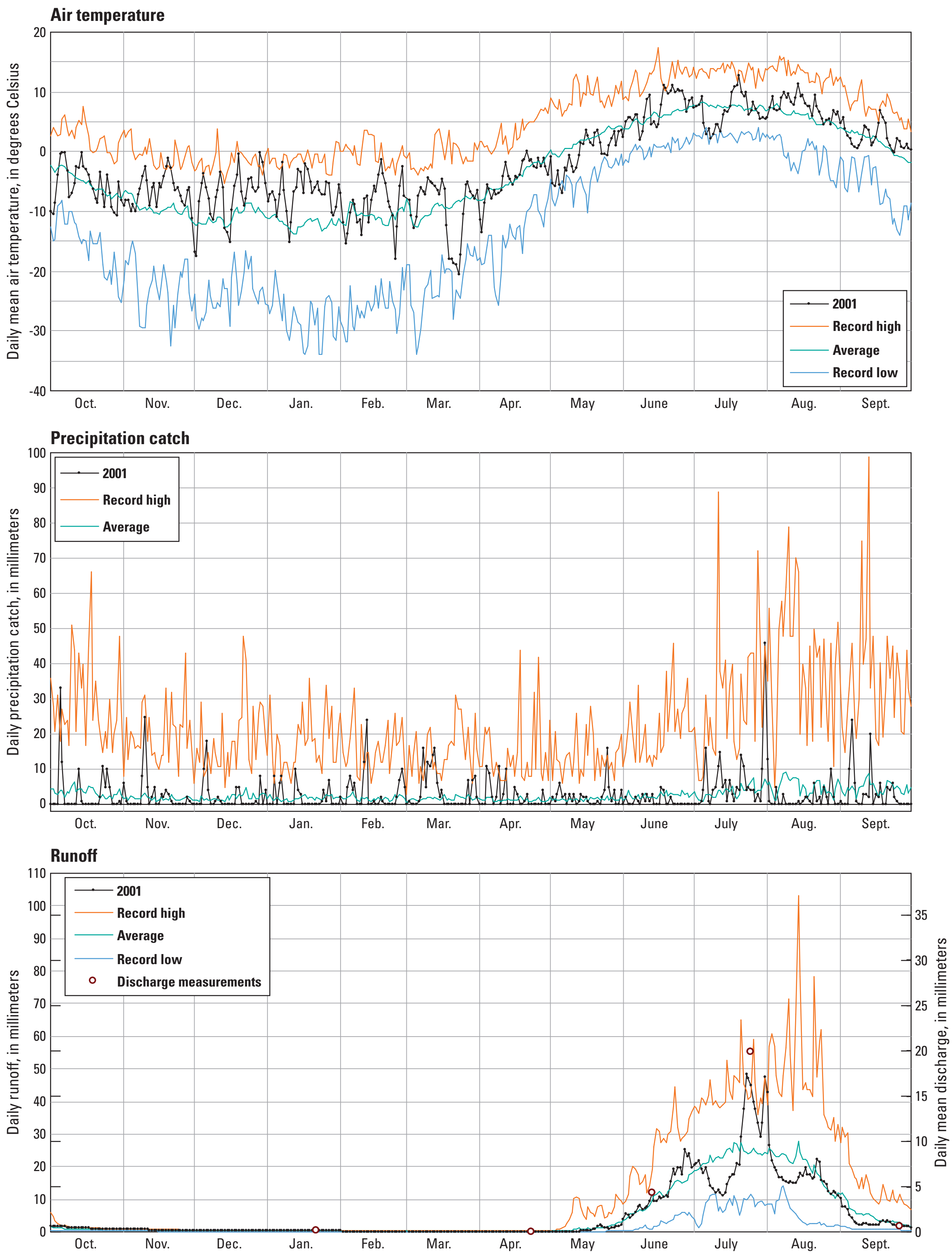

Figure 12. Daily values of mean air temperature, precipitation catch, and daily runoff at Phelan Creek, Alaska, water year 2001.

Table 14. Daily, monthly, and annual average air temperature from analog sensor at 1,480 meters altitude, Gulkana Glacier basin, 1997 hydrologic year.

Analog sensor													
Day	Air temperature, in degrees Celsius												Annual
	1996			1997									
	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	July	Aug.	Sept.	
1	- 6.5	- 5.8	-14.9	-22.1	-10.3	-15.7	- 9.6	- 1.0	- 1.5	10.5	5.9	2.9	
2	- 8.0	- 8.7	-17.2	-21.4	- 7.8	-17.1	-11.6	- 1.2	2.3	10.6	6.7	3.1	
3	- 6.0	- 9.8	-10.9	-17.2	- 5.6	-19.4	- 8.5	- 1.6	6.6	9.5	8.5	4.2	
4	- 5.1	- 6.6	- 9.8	-18.7	- 4.4	-17.0	- 4.9	- 1.5	9.3	9.5	9.6	5.5	
5	- 4.5	- 9.7	-17.2	-17.4	- 2.9	-10.4	- 1.9	- 1.2	8.9	7.4	9.2	3.7	
6	- 3.9	-11.2	-20.3	-25.9	- 3.8	- 8.9	- 0.2	- 3.8	6.5	8.6	5.2	3.6	
7	- 3.7	-12.6	-10.9	-28.8	- 6.4	-11.5	- 1.9	- 1.6	0.6	9.4	7.2	4.6	
8	- 3.0	-15.3	-12.5	-18.2	- 9.2	-10.8	- 2.0	- 0.7	- 0.1	9.7	6.5	4.2	
9	- 4.3	-15.1	-10.8	- 5.2	- 5.9	-13.9	- 2.8	0.2	0.5	6.8	6.1	2.9	
10	- 8.9	- 5.9	-14.1	- 4.8	- 6.0	-18.4	1.8	- 1.1	2.5	7.6	6.8	3.4	
11	- 8.4	- 2.8	-13.3	- 6.1	- 8.6	-15.9	0.5	- 0.7	6.4	5.4	6.1	3.3	
12	- 4.9	- 2.7	-11.0	- 3.5	-10.3	-10.3	- 2.0	1.5	6.3	5.6	6.1	3.4	
13	- 3.7	- 9.2	-11.3	- 6.8	- 9.1	- 9.9	- 3.5	- 0.9	3.7	5.4	4.8	1.1	
14	-11.9	- 6.4	-12.9	- 5.2	- 6.7	- 9.1	- 6.9	- 2.9	2.7	4.5	4.9	1.6	
15	-15.5	- 4.4	-13.2	- 4.4	- 8.2	-14.3	- 6.7	- 3.5	3.4	5.5	7.3	1.5	
16	-15.3	- 3.3	- 9.1	- 6.1	- 7.7	-21.6	-12.3	- 0.1	2.4	5.4	4.6	1.7	
17	-14.4	- 1.6	- 6.7	- 7.8	- 6.0	-17.8	-12.2	- 1.6	4.2	6.4	4.5	0.8	
18	-14.1	- 3.5	- 3.7	- 5.2	- 7.1	-11.0	-12.6	- 0.8	7.6	5.9	3.1	- 0.6	
19	-15.6	-12.2	- 9.0	- 7.0	- 7.8	- 6.2	-11.7	1.3	5.4	5.5	4.9	- 1.9	
20	-14.6	-14.4	-15.1	-12.0	- 8.0	- 9.9	- 9.1	6.0	3.4	5.6	5.0	- 1.5	
21	-12.7	-16.9	-16.5	-15.4	- 4.5	-10.3	- 7.1	5.6	6.6	4.7	2.4	0.4	
22	-12.6	-15.3	-16.0	-17.0	- 4.0	-11.0	- 2.2	1.2	7.8	6.0	4.2	4.8	
23	-11.4	-15.6	-15.1	-17.6	- 4.8	-14.3	0.2	- 2.1	9.8	7.6	5.5	3.6	
24	-16.6	-16.7	- 7.2	-18.4	-10.1	-17.5	2.7	- 1.7	8.0	8.1	5.0	2.5	
25	-21.9	-13.0	- 7.9	-19.7	- 8.8	-15.8	2.6	- 0.1	9.4	8.8	4.7	- 0.3	
26	-16.7	- 7.8	- 6.8	-19.6	-10.6	-14.8	0.5	1.6	10.9	8.6	3.1	1.4	
27	-16.6	- 6.9	-15.0	-16.3	-11.0	- 9.3	- 0.2	3.7	10.8	9.6	2.6	- 0.4	
28	-10.7	- 6.6	-13.6	-11.3	-11.2	- 8.3	- 0.9	4.5	10.5	9.9	3.7	- 3.4	
29	- 6.6	- 9.4	- 9.9	- 6.3		-11.4	- 0.7	5.7	10.7	9.3	6.1	- 2.7	
30	- 4.9	- 9.9	-21.2	- 7.7		-12.0	- 1.9	1.0	10.5	7.3	5.4	- 2.2	
31	- 2.6	-14.9	-21.6	-10.2		-10.7		- 3.6		4.8	5.2		
Monthly average	- 9.9	- 9.5	-12.7	-13.0	- 7.4	-13.0	- 4.2	0.0	5.9	7.4	5.5	1.7	- 4.1

Table 14. Daily, monthly, and annual average air temperature from digital sensor at 1,480 meters altitude, Gulkana Glacier basin, 1997 hydrologic year.—Continued

Digital sensor													
Day	Air temperature, in degrees Celsius												Annual
	1996			1997									
	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	
1	- 6.1	- 5.3	-13.7	-21.1	- 9.6	-14.4	- 8.0	- 0.9	- 0.5	11.6	7.3	4.1	
2	- 7.3	- 8.0	-16.5	-20.7	- 6.6	-16.5	-10.6	- 0.5	3.0	12.0	8.1	4.3	
3	- 5.3	- 8.7	- 9.7	-16.2	- 4.3	-19.0	- 7.5	- 0.0	7.2	10.9	9.6	5.6	
4	- 5.0	- 5.7	- 8.6	-18.1	- 3.5	-16.3	- 4.6	- 0.2	10.3	10.6	10.9	6.2	
5	- 4.5	- 9.2	-16.5	-16.4	- 2.1	-10.5	- 1.3	0.1	9.5	9.0	10.5	5.1	
6	- 3.3	-10.7	-19.5	-25.1	- 2.9	- 8.3	0.3	- 2.1	7.6	10.0	7.0	5.0	
7	- 2.8	-12.1	- 9.6	-28.2	- 5.2	-10.7	- 1.4	- 0.6	1.9	10.7	7.3	5.8	
8	- 2.1	-14.5	-11.7	-18.6	- 8.0	-10.0	- 1.8	- 0.3	1.2	11.0	7.8	5.6	
9	- 3.4	-14.4	- 9.7	- 5.0	- 5.4	-13.0	- 2.5	0.8	2.1	8.5	7.8	4.4	
10	- 8.2	- 5.2	-13.2	- 4.0	- 4.7	-17.2	1.2	0.4	3.8	9.0	8.0	4.9	
11	- 7.2	- 2.1	-12.1	- 5.2	- 7.0	-15.6	1.2	0.6	7.4	7.3	7.6	4.6	
12	- 4.1	- 2.5	-10.2	- 2.4	- 9.6	-10.5	- 2.0	2.2	7.4	7.0	7.7	4.4	
13	- 3.0	- 8.3	-10.4	- 5.5	- 8.5	- 9.6	- 3.2	0.1	4.9	6.8	5.9	2.9	
14	-10.3	- 5.6	-12.3	- 4.6	- 6.1	- 8.6	- 6.1	- 1.7	3.7	5.9	6.6	2.8	
15	-14.6	- 3.2	-12.5	- 3.3	- 7.1	-12.5	- 6.2	- 1.9	4.4	7.0	8.7	2.5	
16	-15.0	- 2.4	- 8.2	- 4.9	- 7.6	-20.3	-10.6	1.4	3.6	6.7	5.5	2.6	
17	-13.6	- 0.1	- 5.4	- 7.0	- 5.1	-17.4	-12.3	- 0.2	5.6	7.6	5.9	2.8	
18	-13.2	- 2.8	- 3.1	- 4.1	- 6.2	-11.3	-14.2	- 0.5	8.5	7.6	4.4	1.4	
19	-15.3	-11.0	- 7.8	- 6.1	- 7.4	- 5.2	-10.9	3.4	6.5	6.8	5.9	- 0.6	
20	-14.4	-13.6	-14.0	-10.7	- 7.2	- 9.0	- 9.2	6.3	5.1	7.1	6.4	0.1	
21	-12.2	-16.3	-15.6	-14.6	- 3.8	-10.0	- 6.0	6.3	7.9	6.2	4.0	2.0	
22	-12.0	-14.4	-14.8	-16.0	- 2.8	-10.5	- 1.4	2.9	9.2	7.3	5.8	6.0	
23	-10.7	-14.5	-13.6	-17.1	- 3.3	-12.9	1.3	- 0.8	10.8	9.1	6.4	5.1	
24	-15.6	-15.8	- 6.3	-17.4	- 9.6	-16.9	3.2	- 0.4	9.5	9.7	6.0	4.2	
25	-21.4	-11.8	- 6.9	-18.9	- 7.9	-15.7	3.5	1.2	10.6	10.2	6.3	1.4	
26	-16.5	- 6.8	- 5.6	-19.3	-10.0	-15.0	1.3	2.9	12.5	9.8	4.7	2.5	
27	-16.1	- 5.8	-13.7	-15.8	-10.8	- 8.7	0.7	4.4	12.3	11.0	4.0	1.3	
28	- 9.7	- 5.7	-12.8	-10.2	-11.2	- 7.8	- 0.9	5.6	11.7	11.0	5.1	- 1.5	
29	- 5.6	- 8.5	- 9.1	- 5.9		-11.1	0.2	6.7	12.1	10.4	6.8	- 1.7	
30	- 4.2	- 9.1	-19.6	- 6.4		-12.4	- 1.6	1.8	12.0	8.4	6.9	- 0.7	
31	- 2.0	-13.7	-21.0	- 8.7		-10.1		- 2.4		6.2	6.9		
Monthly average	- 9.2	- 8.6	-11.7	-12.2	- 6.6	-12.5	- 3.6	1.1	7.1	8.8	6.8	3.1	- 3.1
Departure from normal	- 4.2	0.3	- 1.0	- 0.4	4.1	- 2.9	0.5	- 0.9	1.1	1.2	1.0	1.6	- 0.1
Standardized value	- 1.9	0.1	- 0.4	- 0.1	1.2	- 1.2	0.2	- 0.6	0.9	1.2	0.6	1.1	- 0.1

Table 15. Daily, monthly, and annual average air temperature from analog sensor at 1,480 meters altitude, Gulkana Glacier basin, 1998 hydrologic year.

Analog sensor													
Day	Air temperature, in degrees Celsius												Annual
	1997			1998									
	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	
1	- 4.3	- 6.0	- 8.3	-17.1	- 5.6	-14.0	- 6.8	- 2.4	2.6	8.8	9.1	0.9	
2	- 7.1	- 7.7	-11.1	-20.0	- 4.9	-15.1	-10.3	- 4.2	1.9	8.7	4.5	1.2	
3	- 6.7	- 5.8	-11.3	-22.9	- 5.2	-16.4	- 6.1	- 4.5	5.2	13.2	3.9	0.7	
4	- 6.8	- 4.6	- 7.7	-19.0	- 6.5	-12.0	- 7.7	- 3.7	2.5	12.7	5.7	1.9	
5	- 7.0	- 7.2	- 5.6	-19.5	- 4.9	- 7.5	- 5.2	- 2.2	1.3	11.7	5.8	1.9	
6	- 9.0	-10.6	- 7.6	-17.9	- 5.6	- 6.8	- 4.9	- 1.6	5.3	4.9	2.6	2.0	
7	- 9.9	- 5.4	- 9.6	-15.6	- 4.8	- 8.6	- 4.9	- 3.6	7.6	1.8	3.4	0.3	
8	- 8.8	- 2.3	-11.6	-15.5	- 7.8	- 8.9	- 5.8	- 4.8	5.5	3.5	1.7	1.0	
9	- 8.8	- 2.2	-11.2	-11.1	- 8.7	-11.4	- 5.2	- 2.0	2.5	4.3	1.0	2.8	
10	-11.5	- 2.4	- 5.8	- 9.8	- 8.2	- 9.6	- 7.1	- 1.9	0.3	7.2	2.6	2.3	
11	-12.5	- 5.2	- 5.8	- 7.7	- 6.7	- 7.9	- 5.8	- 3.7	0.9	4.5	3.7	2.0	
12	-13.4	- 4.9	-10.7	- 8.8	- 8.5	- 6.0	- 5.7	- 3.7	1.2	4.8	4.8	0.3	
13	-15.6	- 5.8	-16.1	-16.9	-12.5	- 5.2	- 8.0	- 3.7	2.8	7.7	6.2	- 0.9	
14	-11.8	-10.1	-14.1	-16.7	-12.2	- 3.7	- 4.5	- 1.8	2.5	9.6	8.1	- 2.4	
15	-10.8	- 6.0	-16.0	- 9.6	-10.1	- 4.8	- 2.6	- 0.9	3.3	7.1	5.2	- 2.8	
16	-13.0	- 4.6	-17.1	-10.3	- 7.7	- 6.8	- 2.7	- 0.1	3.7	5.2	4.1	- 0.3	
17	-19.3	- 6.7	-15.4	-10.6	- 6.1	- 5.8	- 2.4	1.4	4.4	2.9	2.1	2.2	
18	-14.1	- 8.7	-10.7	-10.8	- 6.2	- 5.8	- 1.0	2.2	7.0	4.8	- 0.3	0.7	
19	- 4.6	-10.5	- 8.0	- 9.5	- 7.6	- 2.9	- 0.9	- 0.8	4.1	6.9	2.0	0.1	
20	- 4.7	-13.0	-15.1	- 9.5	- 5.9	0.4	- 4.1	- 0.5	2.4	7.1	0.7	- 0.1	
21	- 3.9	- 8.0	-14.6	- 9.7	- 7.3	0.3	- 3.4	2.1	0.9	8.3	0.4	- 0.1	
22	- 7.0	- 9.8	- 9.9	- 9.1	- 6.1	- 1.1	- 3.1	2.3	- 0.3	5.9	1.8	- 1.0	
23	- 7.0	-14.9	- 7.5	- 8.8	- 5.8	- 2.1	- 2.8	0.3	3.1	1.7	0.9	- 1.1	
24	-10.7	-16.4	- 7.8	-10.7	- 7.7	- 4.2	- 0.1	6.4	5.7	3.7	1.7	- 2.3	
25	-15.1	-16.1	- 9.8	- 7.4	- 9.8	- 6.0	- 2.0	6.6	5.8	3.8	1.9	- 2.4	
26	-19.6	-10.2	-14.6	- 7.6	- 9.9	- 8.1	- 5.9	4.7	5.4	2.7	0.0	- 4.7	
27	-16.4	- 9.7	-13.9	- 7.5	-10.4	- 7.5	- 5.4	8.2	7.9	4.0	- 0.8	- 4.3	
28	- 9.2	- 8.9	- 7.7	- 5.1	-11.2	-10.1	- 6.0	5.3	9.9	3.7	- 1.7	- 5.2	
29	- 3.8	- 8.5	-11.8	- 6.6		- 6.2	- 4.8	7.3	10.2	3.9	- 2.3	- 6.3	
30	- 5.8	- 7.9	-14.3	- 7.1		-13.4	- 4.5	4.4	11.7	6.2	1.2	- 3.8	
31	- 8.7		-19.0	- 4.1		-12.6		1.2		7.8	3.3		
Monthly average	- 9.9	- 8.0	-11.3	-11.7	- 7.6	- 7.4	- 4.7	0.2	4.2	6.1	2.7	- 0.6	- 4.0

Table 15. Daily, monthly, and annual average air temperature from digital sensor at 1,480 meters altitude, Gulkana Glacier basin, 1998 hydrologic year.—Continued

Digital sensor													
Day	Daily air temperature, in degrees Celsius												Annual
	1997			1998									
	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	
1	- 2.5	- 4.7	- 6.8	-15.3	- 4.3	-12.9	- 5.5	- 1.5	3.5	10.4	10.1	2.5	
2	- 5.4	- 6.1	- 9.6	-18.2	- 3.3	-13.8	- 8.8	- 3.0	3.2	10.0	5.6	2.3	
3	- 5.3	- 4.4	- 9.7	-22.4	- 3.8	-15.4	- 4.8	- 3.4	5.9	13.9	5.2	2.1	
4	- 5.6	- 3.2	- 6.3	-17.6	- 5.3	-11.0	- 6.1	- 3.0	4.6	13.5	6.6	3.1	
5	- 6.2	- 5.7	- 4.1	-18.4	- 3.4	- 6.6	- 4.2	- 1.2	3.0	12.5	7.1	3.6	
6	- 8.2	- 8.8	- 6.2	-17.2	- 4.4	- 5.9	- 3.2	- 0.6	6.7	6.2	3.6	3.1	
7	- 8.6	- 3.5	- 7.5	-14.1	- 3.5	- 7.1	- 4.1	- 2.5	8.9	3.4	4.7	2.0	
8	- 7.7	- 0.7	-10.0	-14.1	- 6.1	- 7.6	- 4.6	- 3.5	6.7	4.7	3.0	2.4	
9	- 7.3	- 0.7	- 9.9	- 9.5	- 7.0	-10.0	- 4.4	- 0.7	3.7	5.7	2.3	2.2	
10	- 9.9	- 1.0	- 4.4	- 8.2	- 6.5	- 9.2	- 5.8	- 1.0	1.7	8.7	3.7	3.4	
11	-11.8	- 3.7	- 4.7	- 6.1	- 5.3	- 6.4	- 4.5	- 2.8	1.9	5.8	4.7	3.2	
12	-12.1	- 3.3	- 9.2	- 7.1	- 7.0	- 4.0	- 4.6	- 3.2	2.2	6.2	5.6	1.3	
13	-14.2	- 4.3	-14.7	-15.5	-11.3	- 4.4	- 6.5	- 2.3	4.0	8.9	7.4	0.3	
14	-10.4	- 8.8	-12.0	-15.9	-10.9	- 2.4	- 2.7	- 0.6	4.3	10.7	9.1	- 0.8	
15	- 9.7	- 4.5	-14.4	- 7.9	- 8.6	- 3.7	- 1.4	0.8	4.4	8.5	6.7	- 1.5	
16	-11.5	- 3.2	-15.7	- 7.7	- 6.4	- 5.3	- 1.5	1.5	5.1	6.2	5.7	0.9	
17	-18.1	- 5.2	-14.0	- 9.1	- 4.6	- 4.5	0.0	2.2	5.5	4.2	3.5	3.6	
18	-13.1	- 7.5	- 8.8	- 9.5	- 4.2	- 4.2	- 0.4	2.2	8.1	6.2	0.9	2.6	
19	- 3.2	- 8.7	- 6.3	- 7.8	- 6.7	- 2.3	- 0.4	0.1	5.6	8.2	3.5	2.1	
20	- 3.2	-11.9	-13.9	- 8.2	- 4.7	1.4	- 3.3	0.5	3.7	8.5	2.0	2.0	
21	- 2.4	- 6.5	-13.3	- 8.2	- 6.3	1.2	- 2.4	3.1	2.4	9.8	1.8	1.4	
22	- 5.6	- 8.2	- 8.1	- 7.8	- 5.6	- 0.2	- 2.2	3.7	1.5	7.5	2.7	0.8	
23	- 5.8	-13.4	- 6.1	- 7.1	- 4.7	- 1.1	- 1.5	1.1	4.5	3.4	2.5	0.2	
24	- 9.5	-15.3	- 6.0	- 8.8	- 6.3	- 2.7	0.3	7.1	6.4	5.1	3.2	- 0.8	
25	-13.1	-14.5	- 7.9	- 5.8	- 8.3	- 5.1	- 0.9	8.5	6.6	5.2	3.2	- 0.8	
26	-18.1	- 8.8	-13.0	- 5.9	- 8.4	- 6.7	- 5.3	5.9	6.5	4.0	1.3	- 3.0	
27	-15.1	- 8.3	-12.6	- 5.8	- 9.4	- 6.3	- 3.8	9.5	8.9	5.6	0.4	- 3.1	
28	- 7.5	- 7.4	- 6.3	- 3.9	-10.1	- 8.3	- 4.1	6.9	10.7	5.0	0.1	- 3.6	
29	- 2.4	- 6.7	-10.3	- 5.3		- 5.1	- 3.1	8.2	11.5	5.4	- 0.6	- 4.6	
30	- 4.4	- 6.9	-12.7	- 5.4		-11.7	- 3.0	6.6	12.9	7.1	2.5	- 2.5	
31	- 7.0	- 6.8	-17.6	- 2.6		-10.7		2.2		8.8	5.1		
Monthly average	- 8.5	- 6.5	- 9.7	-10.2	- 6.3	- 6.2	- 3.4	1.3	5.5	7.4	4.0	0.8	- 2.7
Departure from normal	- 3.6	2.4	1.0	1.6	4.3	3.4	0.7	- 0.7	- 0.5	- 0.1	- 1.8	- 0.7	0.4
Standardized value	- 1.6	0.9	0.4	0.4	1.3	1.3	0.3	- 0.5	- 0.4	- 0.1	- 1.1	- 0.5	0.4

Table 16. Daily, monthly, and annual average air temperature from digital sensor at 1,480 meters altitude, Gulkana Glacier basin, 1999 hydrologic year.

Day	Air temperature, in degrees Celsius												Annual
	1998			1999									
	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	
1	- 4.7	- 3.7	- 6.9	-10.1	-15.5	- 8.4	- 6.7	- 7.8	1.6	9.9	14.2	2.9	
2	- 6.0	- 1.3	- 9.7	- 5.6	-24.0	-10.1	- 6.5	- 9.0	0.3	13.2	14.3	4.3	
3	- 5.6	- 1.4	-11.7	-14.2	-31.8	-15.4	-10.0	- 6.7	1.1	13.3	14.0	2.4	
4	- 2.7	- 4.8	- 6.3	-19.8	-31.7	-19.6	-10.3	- 4.9	0.7	12.9	13.1	1.0	
5	- 4.6	- 4.9	-13.3	-13.3	-21.2	-19.7	- 8.5	- 2.8	2.8	11.8	12.5	1.4	
6	- 7.5	- 5.1	-13.1	-11.8	-23.0	-17.4	-10.7	- 3.8	7.9	9.9	11.5	2.2	
7	- 7.9	- 3.9	-12.8	-14.2	-21.8	-18.0	-15.6	- 1.7	9.2	10.2	7.8	2.0	
8	- 3.4	- 4.0	- 8.6	-14.9	-22.8	-21.0	-12.3	- 2.0	9.7	7.9	8.3	3.8	
9	- 3.6	- 4.8	- 4.9	-10.2	-27.9	-19.4	-10.7	- 1.8	9.4	8.0	6.3	3.6	
10	- 5.9	- 6.9	- 9.0	- 7.7	-26.6	-12.4	- 7.0	0.1	9.2	7.8	7.7	3.2	
11	- 6.0	-11.0	- 9.4	- 7.5	-15.6	- 3.7	- 5.1	1.8	11.4	7.3	9.5	4.6	
12	- 4.7	-13.1	- 7.4	- 7.3	-15.1	- 4.4	- 5.4	3.3	12.9	7.2	7.9	5.7	
13	- 6.0	- 9.6	-12.8	- 4.7	- 9.3	- 7.0	- 7.1	1.8	13.6	8.2	6.6	4.3	
14	- 5.9	- 8.6	-11.1	- 5.3	- 8.4	- 8.1	- 4.2	4.5	7.8	11.2	5.1	3.5	
15	- 3.6	-12.8	- 7.3	- 7.3	- 5.9	- 9.3	- 3.4	3.9	9.6	12.5	4.5	1.0	
16	- 3.5	-13.2	-16.7	-11.4	- 6.8	-10.6	- 5.1	3.0	8.5	8.9	5.7	1.0	
17	- 5.5	-10.6	-19.9	-19.2	- 8.3	-13.0	2.5	1.6	5.3	4.1	7.6	4.0	
18	- 3.9	- 5.9	- 9.4	-20.3	- 7.6	-11.6	5.4	- 2.9	6.2	5.8	9.2	2.4	
19	- 0.9	- 3.7	- 5.7	-21.1	-12.3	- 6.8	2.7	- 0.8	8.2	6.4	9.1	1.5	
20	- 3.9	- 6.5	- 8.0	-23.6	-12.8	- 4.7	2.1	- 0.1	5.5	6.3	4.4	2.0	
21	- 5.6	-10.3	- 9.1	-22.6	-10.3	- 5.6	- 2.3	0.8	4.6	3.0	5.9	0.8	
22	- 5.6	-11.7	- 6.9	-15.5	-10.0	- 3.0	- 2.9	1.0	5.2	3.8	4.9	2.5	
23	1.8	- 9.3	- 8.9	- 8.8	-13.0	- 3.3	- 1.0	1.6	6.4	5.1	3.3	0.1	
24	2.2	- 9.1	-10.2	-10.8	-11.9	- 3.5	- 5.7	2.5	8.9	4.1	3.5	- 0.9	
25	- 4.7	-11.5	- 7.5	-14.1	-11.7	- 4.3	- 9.8	- 1.1	9.2	4.8	2.3	- 3.7	
26	- 7.4	-14.5	-10.3	-15.6	-10.9	- 4.9	-10.6	- 1.1	7.4	4.9	3.2	- 5.4	
27	- 7.2	-12.8	-16.0	-19.6	-10.9	- 7.4	- 6.1	0.5	5.9	5.3	3.3	- 3.0	
28	- 8.0	- 4.0	-17.8	-25.3	-12.3	- 9.1	- 4.3	- 0.4	8.4	4.5	4.7	- 5.8	
29	- 6.5	- 6.4	-15.8	-28.9		- 8.8	- 2.4	- 2.2	8.2	5.4	4.2	- 7.2	
30	- 6.3	- 4.6	- 9.6	-31.5		- 8.6	- 4.5	0.6	8.2	5.7	3.8	- 2.7	
31	- 7.1	- 6.9	-13.2	-23.9		- 8.9		1.3		10.6	2.5		
Monthly average	- 4.8	- 7.6	-10.6	-15.0	-15.7	- 9.9	- 5.5	- 0.7	7.1	7.7	7.1	1.1	- 3.9
Departure from normal	0.1	1.3	0.2	- 3.2	- 5.1	- 0.4	- 1.4	- 2.7	1.1	0.2	1.3	- 0.4	- 0.8
Standardized value	0.0	0.5	0.1	- 0.8	- 1.5	- 0.1	- 0.6	- 1.7	0.9	0.2	0.8	- 0.3	- 0.8

Table 17. Daily, monthly, and annual average air temperature from digital sensor at 1,480 meters altitude, Gulkana Glacier basin, 2000 hydrologic year.

Day	Air temperature, in degrees Celsius												Annual
	1999			2000									
	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	
1	- 0.7	-11.4	- 9.3	-17.1	-11.0	- 7.0	- 5.0	- 0.9	5.3	8.9	8.3	4.0	
2	- 0.2	-14.5	- 8.7	-18.0	- 6.6	- 6.9	- 4.6	- 1.0	5.7	8.5	6.4	1.3	
3	- 1.5	-18.6	- 7.4	-14.9	- 5.3	- 7.0	- 5.9	- 0.1	5.5	7.7	8.2	0.9	
4	- 1.7	-11.1	- 8.9	-13.1	- 3.3	- 7.2	- 4.3	- 3.0	8.0	10.3	6.2	0.8	
5	0.2	- 3.8	-10.0	-14.9	- 1.3	- 8.5	-11.0	- 3.3	9.5	6.5	4.7	1.4	
6	- 0.5	- 4.8	-12.8	-11.4	- 1.8	- 9.5	-11.1	0.4	10.2	7.5	4.0	0.8	
7	- 1.7	- 6.2	-13.6	- 7.5	- 3.6	-10.2	- 8.4	1.5	6.2	11.2	4.8	0.8	
8	- 3.0	- 9.1	-13.2	-10.1	- 8.9	- 9.7	- 7.5	0.6	5.2	11.5	4.6	- 1.3	
9	- 5.2	-11.8	-15.5	-17.6	- 6.9	- 9.2	- 9.6	- 4.4	7.9	8.5	3.8	0.5	
10	- 5.8	-14.9	-14.4	-22.6	- 6.2	-11.7	- 7.7	- 6.3	7.2	9.2	4.8	0.0	
11	- 5.9	-15.8	-11.6	-23.4	- 8.0	- 9.9	- 5.5	- 1.2	7.5	10.1	4.8	- 0.9	
12	- 3.5	- 8.3	-14.5	-22.4	- 4.8	- 3.7	- 2.8	- 3.6	9.7	8.2	6.6	- 0.7	
13	- 7.1	- 3.5	-17.7	-22.6	- 7.2	- 5.4	- 0.9	- 4.1	6.5	5.2	7.2	0.5	
14	-10.9	- 7.3	-15.8	-18.0	- 8.1	- 7.3	- 0.1	- 6.0	3.1	6.0	3.5	1.7	
15	- 8.9	- 9.5	-20.8	-17.8	- 9.2	- 4.9	- 5.5	- 0.3	3.4	8.3	0.1	0.4	
16	- 5.4	-10.1	-18.9	-21.7	- 9.8	- 4.0	- 6.0	2.0	3.3	6.1	3.7	- 0.2	
17	- 2.8	- 6.2	-20.1	-17.7	- 9.3	- 5.4	- 3.9	2.5	4.7	6.3	4.8	- 3.3	
18	- 0.9	- 7.7	-15.6	-10.7	- 5.8	- 7.5	- 4.9	1.7	3.4	4.4	3.1	- 2.6	
19	- 3.4	- 5.3	- 8.2	- 6.7	- 4.2	- 7.9	- 3.8	1.9	2.3	4.3	2.3	- 0.3	
20	- 7.2	- 8.3	- 6.0	-10.1	- 6.3	- 5.7	- 1.7	- 1.7	3.0	6.8	2.5	0.5	
21	- 7.7	- 8.1	- 1.3	- 8.6	- 7.5	- 6.7	- 3.4	- 3.1	2.7	5.0	2.2	3.1	
22	- 7.4	-10.4	- 0.8	-10.3	-11.1	- 7.2	- 4.9	2.6	5.3	6.1	0.9	3.2	
23	- 7.0	- 9.6	- 8.2	- 9.2	-11.0	- 7.7	- 4.7	0.4	10.2	5.3	0.7	0.9	
24	- 9.0	- 9.6	-19.6	- 7.7	-11.8	- 6.0	- 4.9	- 1.6	11.0	5.7	2.4	1.4	
25	- 7.0	-14.0	- 8.4	- 8.8	-11.8	- 5.8	- 3.0	- 2.6	10.2	5.5	0.4	1.1	
26	- 8.2	-14.5	- 2.7	- 9.3	-10.5	- 3.8	- 2.5	- 2.7	9.2	3.6	1.3	- 2.7	
27	- 9.0	-13.9	- 4.0	- 8.1	- 8.7	- 4.8	- 3.6	- 2.1	8.5	5.0	1.5	- 5.6	
28	-10.4	-11.8	- 9.6	-11.1	- 7.2	-11.5	- 1.3	0.0	6.3	5.3	4.0	- 9.0	
29	-10.1	-11.9	-23.3	-11.4	- 6.9	- 5.5	- 1.5	4.3	6.9	6.7	3.3	- 9.2	
30	-11.8	-12.3	-22.7	-10.4		- 6.2	- 0.7	4.0	6.6	6.0	2.7	- 8.5	
31	- 9.8	- 9.3	-17.9	- 4.8		- 5.1		5.0		7.2	4.8		
Monthly average	- 5.6	-10.1	-12.3	-13.5	- 7.4	- 7.1	- 4.7	- 0.7	6.5	7.0	3.8	- 0.7	- 3.7
Departure from normal	- 0.7	- 1.2	- 1.5	- 1.7	3.2	2.5	- 0.5	- 2.7	0.5	- 0.5	- 2.0	- 2.2	- 0.7
Standardized value	- 0.3	- 0.4	- 0.6	- 0.4	0.9	1.0	- 0.2	- 1.7	0.4	- 0.5	- 1.2	- 1.5	- 0.7

Table 18. Daily, monthly, and annual average air temperature from digital sensor at 1,480 meters altitude, Gulkana Glacier basin, 2001 hydrologic year.

Day	Air temperature, in degrees Celsius												Annual
	2000			2001									
	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	
1	-10.1	- 9.0	-16.7	- 8.4	- 6.9	- 8.2	-13.4	- 5.3	4.9	7.5	7.3	5.6	
2	-10.5	- 8.1	-17.6	- 7.2	-11.9	-10.8	- 8.6	- 5.7	5.6	7.9	9.2	3.9	
3	- 8.7	- 8.2	- 8.3	- 6.7	-15.4	-12.8	- 5.6	- 3.3	5.8	9.2	7.2	2.6	
4	- 4.0	-10.1	- 5.2	- 8.2	-13.8	-10.9	- 6.3	- 5.5	5.3	4.7	6.9	2.1	
5	- 0.4	- 8.8	- 3.7	-10.9	-10.3	- 7.5	- 7.8	- 6.9	6.2	3.0	7.0	1.3	
6	- 0.1	-10.1	- 5.9	- 7.2	- 8.1	- 5.9	- 6.6	- 2.8	6.2	3.8	9.1	0.8	
7	- 0.2	- 7.1	- 7.8	- 1.7	- 8.8	- 6.8	- 7.1	- 3.1	2.0	2.1	9.9	0.6	
8	- 3.1	- 6.3	-10.4	- 6.6	-11.9	- 7.1	- 6.9	- 0.7	3.4	3.0	9.0	1.1	
9	- 7.6	- 4.2	-11.5	-10.1	-11.4	- 4.3	- 6.4	- 2.4	5.6	4.5	9.6	2.0	
10	- 6.9	- 2.6	- 7.6	-15.1	-13.9	- 5.0	- 4.2	- 3.4	8.7	4.5	8.3	4.3	
11	- 5.3	- 4.9	- 6.4	-11.9	- 7.8	- 5.4	- 1.7	- 2.8	9.4	3.3	7.9	4.0	
12	- 2.4	- 9.1	- 3.5	- 6.8	- 7.5	- 5.8	- 4.2	- 0.7	4.5	6.2	8.9	3.5	
13	- 2.8	- 6.0	- 6.0	- 5.9	-11.9	- 6.6	- 4.7	1.5	5.0	6.8	11.3	1.1	
14	- 0.2	- 5.2	-12.9	- 3.0	- 8.1	- 7.2	- 5.5	1.3	4.1	6.7	9.3	1.5	
15	- 2.6	- 9.4	-13.4	- 3.4	- 5.8	- 4.7	- 4.1	3.7	4.6	7.5	9.4	2.5	
16	- 2.9	- 5.4	-15.2	- 7.0	- 6.8	- 6.3	- 4.3	2.7	7.8	10.0	8.0	4.8	
17	- 3.9	- 6.1	- 9.8	- 2.0	- 4.0	-12.3	- 4.0	1.4	11.0	10.9	7.6	6.8	
18	- 5.0	- 4.1	- 5.8	- 3.0	- 1.4	-17.9	- 1.5	0.9	10.6	11.1	7.5	5.8	
19	- 6.2	- 2.5	- 3.8	- 5.1	- 3.6	-17.9	- 1.3	3.2	9.8	12.7	6.0	4.7	
20	- 7.8	- 1.1	- 0.4	- 6.9	- 5.2	-18.6	0.1	3.6	10.2	9.9	9.4	2.3	
21	- 8.6	- 2.8	- 6.7	- 6.0	- 8.4	-18.8	- 1.6	1.4	11.1	9.3	7.6	1.0	
22	- 3.5	- 5.4	- 9.1	- 5.0	- 9.2	-20.6	- 1.4	- 0.4	10.0	9.9	6.6	0.1	
23	- 7.2	- 6.5	- 8.0	- 6.4	-10.6	-17.2	- 2.5	- 0.5	10.3	6.1	5.6	- 0.1	
24	- 9.2	- 6.0	- 4.6	- 7.2	-17.9	-10.5	- 2.7	- 0.7	10.1	6.9	4.6	2.2	
25	- 3.8	- 7.4	- 4.4	- 7.1	-12.6	- 5.6	- 1.2	1.1	10.1	8.2	5.3	1.7	
26	- 6.9	- 8.3	- 6.0	- 5.0	- 5.8	- 5.1	- 2.6	2.2	8.7	7.2	5.4	0.7	
27	- 9.3	- 9.1	- 6.7	- 5.4	- 2.5	- 6.8	- 1.1	3.4	6.6	6.5	4.6	0.6	
28	-10.3	- 6.6	- 5.9	-10.3	- 7.4	- 7.4	- 2.4	1.0	8.6	5.5	6.9	1.3	
29	-10.6	- 5.9	- 0.1	-10.8		- 8.0	- 3.8	3.4	8.9	5.8	6.3	0.6	
30	- 5.1	-11.2	- 1.8	- 9.3		- 6.4	- 0.9	3.7	7.4	5.5	6.6	0.2	
31	- 8.1	-16.7	- 5.4	- 5.5		-11.5		2.5		5.8	4.7		
Monthly average	- 5.6	- 6.9	- 7.4	- 6.9	- 8.9	- 9.7	- 4.1	- 0.2	7.4	6.8	7.5	2.3	- 2.1
Departure from normal	- 0.6	2.0	3.3	4.9	1.7	- 0.1	0.0	- 2.3	1.4	- 0.7	1.7	0.8	0.9
Standardized value	- 0.3	0.7	1.3	1.2	0.5	- 0.0	0.0	- 1.4	1.2	- 0.7	1.0	0.6	1.0

An analog temperature recorder with a slow time response and an accuracy of 1.0 °C (Kennedy and others, 1997) has operated in its current configuration since the beginning of record in October 1967. After a 3-year overlap period, analysis of analog temperatures terminated in 1998, although data collection continued until spring 2007 as a backup. We expect differences between the analog sensor and the digital sensor due to the large difference in their time constants; a bias analysis for 1996–98 is shown in figure 13.

A storage-type precipitation gage with a modified Nipher wind shield (Kennedy and others, 1997) catches part of the total precipitation that falls at the weather-station site (tables 19–23). Daily precipitation catch has an estimated accuracy of 0.001 m and cumulative precipitation catch an accuracy of 0.002 m per month (Mayo and others, 1992; Kennedy, 1995).

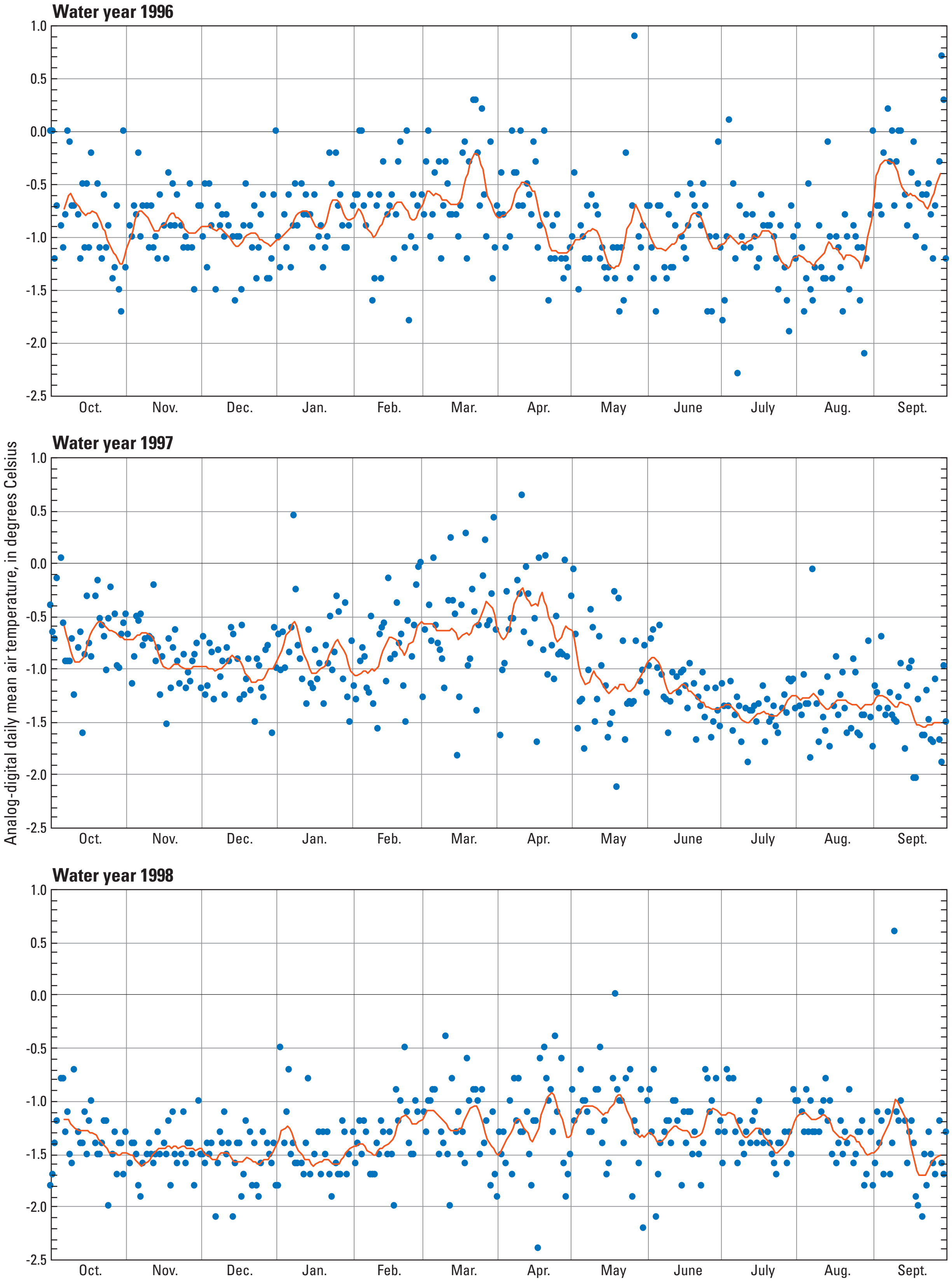

Figure 13. Difference between analog and digital temperature sensors at 1,480 meters altitude, Gulkana Glacier, Alaska, water years 1996–98. Red line is an inverse distance weighted smoothing of data with an 11-day window.

Table 19. Daily, monthly, and annual precipitation catch recorded at 1,480 meters altitude, Gulkana Glacier basin, 1997 hydrologic year.

Day	Precipitation, in millimeters												Annual
	1996			1997									
	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	
1	0	0	0	0	1	0	1	1	0	14	2	2	
2	0	0	0	0	2	0	0	0	4	4	4	0	
3	0	7	0	0	3	0	0	0	5	0	0	0	
4	0	21	9	0	2	0	1	3	2	0	5	0	
5	0	6	0	0	0	0	4	0	0	0	0	0	
6	0	0	0	0	0	0	0	0	0	0	0	0	
7	0	0	0	0	12	0	0	0	0	1	0	0	
8	17	0	0	0	3	7	2	1	11	0	5	0	
9	2	0	0	11	0	1	0	0	22	0	9	0	
10	1	0	0	1	0	0	0	1	6	1	9	6	
11	7	0	0	2	0	0	2	4	0	0	13	0	
12	3	1	0	2	0	0	0	1	0	19	34	0	
13	6	0	0	1	0	0	0	9	0	10	21	0	
14	0	0	0	0	1	2	0	1	0	7	0	0	
15	0	0	0	0	0	0	1	9	0	2	3	0	
16	0	0	0	0	0	0	0	1	1	1	13	0	
17	0	1	5	0	11	0	1	18	3	1	0	2	
18	0	0	10	0	9	0	0	20	2	0	0	2	
19	0	0	0	0	0	1	0	3	0	6	1	1	
20	0	0	0	0	4	0	0	3	3	3	0	0	
21	0	0	0	0	1	0	2	1	2	1	0	4	
22	0	0	0	0	9	0	4	0	3	5	8	5	
23	0	0	0	0	6	0	2	0	1	1	2	1	
24	0	0	0	0	0	0	4	0	0	1	0	4	
25	0	0	0	0	0	0	0	0	0	6	15	2	
26	0	0	0	0	0	0	1	0	1	0	4	0	
27	0	0	0	0	1	0	0	0	0	2	6	0	
28	0	7	0	0	0	3	0	2	0	0	0	0	
29	0	0	0	6		0	0	1	0	0	3	1	
30	48	2	0	2		0	0	19	0	3	1	1	
31	30	0	0	3		0		2		22	8		
Total	114	45	24	28	65	14	25	100	66	110	166	31	788
Departure from normal	3	- 13	- 42	- 29	11	- 46	- 17	52	- 16	- 10	18	-107	-195
Standardized value	0.1	- 0.3	- 1.0	- 1.0	0.3	- 1.2	- 0.7	2.2	- 0.4	- 0.1	0.2	- 1.3	- 0.8

Table 20. Daily, monthly, and annual precipitation catch recorded at 1,480 meters altitude, Gulkana Glacier basin, 1998 hydrologic year.

Day	Precipitation, in millimeters												Annual
	1997			1998									
	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	
1	0	3	3	0	0	0	4	3	3	0	1	0	
2	0	0	1	0	0	0	0	10	0	0	10	0	
3	0	2	0	0	0	0	4	13	7	4	3	0	
4	0	1	5	0	0	0	0	3	3	0	1	0	
5	0	4	0	0	3	1	2	3	2	0	0	0	
6	0	3	0	0	0	1	0	3	9	6	21	0	
7	0	1	0	0	0	0	0	0	3	4	14	2	
8	0	14	2	0	0	0	0	0	2	6	20	0	
9	0	0	0	3	0	0	0	0	0	5	21	0	
10	0	3	3	1	0	0	0	0	0	4	1	0	
11	0	0	0	0	1	0	2	4	0	6	3	0	
12	0	1	0	4	0	5	2	0	10	2	1	0	
13	0	0	0	0	0	1	0	0	1	4	5	17	
14	0	0	0	0	0	1	6	2	0	1	2	5	
15	0	0	0	0	2	0	3	1	0	8	0	2	
16	0	0	0	0	13	0	8	3	4	8	33	5	
17	0	0	0	0	1	0	0	1	1	15	1	5	
18	0	0	0	0	0	0	5	1	1	8	1	5	
19	21	0	1	0	1	3	0	3	5	5	4	15	
20	35	0	0	0	0	4	0	1	4	2	0	17	
21	24	11	0	0	0	0	0	4	15	2	10	13	
22	8	0	0	0	0	0	0	2	4	1	8	12	
23	4	0	16	0	3	0	0	3	6	16	12	13	
24	1	0	2	0	0	0	0	5	2	12	6	12	
25	0	5	0	20	0	0	0	0	0	3	10	12	
26	0	3	0	0	3	0	0	1	0	11	9	3	
27	0	1	0	1	0	0	0	5	1	5	7	4	
28	4	2	5	1	0	0	0	0	4	0	0	10	
29	21	0	3	0		1	0	1	3	1	14	1	
30	4	0	0	0		4	1	3	5	4	5	0	
31	8	3	0	4		1		2		0	3		
Total	130	57	41	34	27	22	37	77	95	143	226	153	1,042
Departure from normal	19	- 1	- 25	- 23	- 27	- 38	- 5	29	13	23	78	15	59
Standardized value	0.3	- 0.0	- 0.6	- 0.8	- 0.8	- 1.0	- 0.2	1.2	0.3	0.3	0.8	0.2	0.2

Table 21. Daily, monthly, and annual precipitation catch recorded at 1,480 meters altitude, Gulkana Glacier basin, 1999 hydrologic year.

Day	Precipitation, in millimeters												Annual
	1998			1999									
	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	
1	0	0	1	0	5	1	7	4	3	0	2	22	
2	3	0	0	16	1	2	3	1	8	2	0	10	
3	0	0	1	0	0	0	2	0	8	0	1	20	
4	0	0	8	0	0	0	1	0	1	2	0	5	
5	0	0	0	0	1	0	3	6	2	0	0	1	
6	0	0	0	0	0	0	2	0	2	0	1	7	
7	0	0	0	0	0	0	0	3	0	0	3	0	
8	0	0	4	0	0	0	0	1	0	5	4	3	
9	0	0	4	5	0	0	0	0	0	14	0	0	
10	0	0	0	3	0	5	7	1	0	0	0	0	
11	0	0	2	6	0	2	7	2	2	0	1	0	
12	0	0	0	2	5	1	5	2	2	1	59	0	
13	0	0	0	0	12	0	0	1	3	3	7	3	
14	0	0	0	4	1	0	2	1	0	3	1	0	
15	0	0	4	6	1	1	8	0	0	7	18	0	
16	1	0	0	0	0	1	0	0	8	9	2	0	
17	0	0	0	0	0	0	5	0	17	1	3	7	
18	15	2	0	0	3	0	3	0	3	5	0	2	
19	13	2	3	0	0	4	0	0	2	3	0	0	
20	9	0	0	0	0	1	0	0	1	12	0	2	
21	2	0	0	0	0	0	3	0	1	16	4	14	
22	2	0	0	1	0	1	0	0	3	0	0	0	
23	15	0	0	8	0	4	0	0	3	1	0	11	
24	4	0	0	0	0	1	2	1	1	8	0	2	
25	0	0	0	0	0	0	0	2	1	22	1	3	
26	0	0	0	0	1	0	0	12	1	14	7	0	
27	0	0	0	0	0	3	0	2	0	2	2	8	
28	0	1	0	0	1	0	1	1	2	0	0	13	
29	0	0	0	0		0	0	3	0	14	1	0	
30	0	0	0	0		0	9	0	0	11	0	14	
31	0	1	0	0		11		10		14	12		
Total	64	6	27	51	31	38	70	53	74	169	129	147	859
Departure from normal	- 47	- 52	- 39	- 6	- 23	- 22	28	5	- 8	49	- 19	9	-124
Standardized value	- 0.8	- 1.2	- 1.0	- 0.2	- 0.7	- 0.6	1.2	0.2	- 0.2	0.6	- 0.2	0.1	- 0.5

Table 22. Daily, monthly, and annual precipitation catch recorded at 1,480 meters altitude, Gulkana Glacier basin, 2000 hydrologic year.

Day	Precipitation, in millimeters												Annual
	1999			2000									
	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	
1	18	3	0	0	3	0	1	0	0	1	3	0	
2	28	1	1	0	15	0	0	0	2	0	9	0	
3	5	0	1	0	4	0	0	0	1	0	5	7	
4	6	2	1	0	0	2	7	3	2	0	1	3	
5	2	3	0	0	5	0	0	0	4	4	4	0	
6	1	1	1	0	6	0	0	0	2	5	5	1	
7	0	5	0	2	33	1	0	1	0	7	0	3	
8	0	0	0	2	0	0	0	1	1	0	0	0	
9	0	0	0	0	0	0	0	0	1	0	0	0	
10	0	0	0	0	0	0	0	0	1	0	0	1	
11	1	0	0	0	0	0	0	0	3	0	0	4	
12	0	0	0	0	0	1	0	0	1	0	0	22	
13	0	2	0	0	0	1	6	0	0	1	17	5	
14	0	2	0	0	0	0	4	0	3	14	0	6	
15	0	0	0	0	0	0	1	0	6	7	0	3	
16	11	0	0	0	0	7	0	0	3	11	1	0	
17	45	7	0	0	4	0	5	1	2	18	0	0	
18	66	0	1	9	0	0	5	2	1	0	9	0	
19	10	0	6	36	2	0	0	3	1	5	7	1	
20	1	3	17	2	1	4	1	14	1	4	1	0	
21	0	0	25	3	0	8	0	1	1	1	1	22	
22	4	1	6	12	0	11	0	5	7	23	0	45	
23	0	0	0	5	0	0	2	2	3	2	3	0	
24	1	0	0	3	0	3	0	3	0	3	14	11	
25	0	0	3	1	0	4	0	2	0	2	0	35	
26	3	0	15	4	0	0	0	0	0	0	1	0	
27	0	0	4	0	0	4	0	0	7	3	3	0	
28	0	0	2	0	0	0	15	0	4	9	9	0	
29	0	0	0	0	0	0	5	0	2	3	10	0	
30	5	0	0	0		0	0	0	2	1	9	0	
31	2	0	0	5		1		2		0	2		
Total	209	30	83	84	73	47	52	40	61	124	114	169	1,086
Departure from normal	98	- 28	17	27	19	- 13	10	- 8	- 21	4	- 34	31	103
Standardized value	1.7	- 0.6	0.4	0.9	0.6	- 0.3	0.4	- 0.4	- 0.5	0.0	- 0.4	0.4	0.4

Table 23. Daily, monthly, and annual precipitation catch recorded at 1,480 meters altitude, Gulkana Glacier basin, 2001 hydrologic year.

Day	Precipitation, in millimeters												Annual
	2000			2001									
	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	
1	0	6	0	0	2	1	0	2	2	0	1	0	
2	0	1	0	0	0	0	0	1	0	0	0	0	
3	0	0	0	0	0	0	11	3	0	1	0	0	
4	0	0	0	8	5	0	9	6	0	4	5	10	
5	33	0	10	0	8	1	2	2	2	16	0	24	
6	12	0	18	6	4	2	0	3	1	1	0	6	
7	0	0	4	8	6	16	2	0	0	0	3	1	
8	0	0	0	0	0	5	11	3	3	4	0	0	
9	0	8	0	0	0	12	0	1	1	5	0	0	
10	0	25	1	0	0	11	3	3	3	11	0	3	
11	0	5	2	0	12	14	10	0	1	15	0	3	
12	0	0	1	0	24	16	0	1	3	5	0	2	
13	10	2	0	10	0	6	0	3	0	7	1	20	
14	1	5	0	4	0	2	0	2	0	1	0	0	
15	0	0	0	3	1	4	5	2	0	7	1	3	
16	0	0	0	0	0	0	3	1	5	3	2	2	
17	0	3	0	0	0	0	0	0	4	1	2	6	
18	0	2	0	0	2	0	0	0	0	5	1	0	
19	0	4	5	0	1	0	1	0	0	4	0	0	
20	0	3	5	0	0	0	3	1	2	14	6	5	
21	0	1	0	0	0	0	0	0	0	11	1	4	
22	2	0	0	0	0	0	0	2	0	4	2	6	
23	11	0	0	0	0	0	0	4	0	5	0	2	
24	5	0	0	1	0	0	0	16	0	4	5	1	
25	10	0	0	4	2	0	0	5	0	4	2	0	
26	5	0	0	1	7	7	0	1	0	1	0	0	
27	0	0	1	7	10	0	4	4	0	3	10	0	
28	0	2	0	0	5	7	0	0	0	1	2	0	
29	0	1	8	0		8	0	0	0	10	0	0	
30	1	0	0	0		2	0	4	0	46	0	0	
31	0	0	4	0		0		0		13	1		
Total	90	68	59	52	89	114	64	70	27	206	45	98	982
Departure from normal	- 21	10	- 7	- 5	35	54	22	22	- 55	86	-103	- 40	- 1
Standardized value	- 0.4	0.2	- 0.2	- 0.2	1.1	1.3	0.9	0.9	- 1.3	1.0	- 1.1	- 0.5	- 0.0

Prior to 1996, precipitation catch data were processed with a temperature and water-concentration dependent density correction. However, analysis that was not possible at the beginning of the monitoring program indicates that the density correction is incomplete and actually increases the measurement error rather than reducing it. Hence, the density correction was not applied to data after 1995. Comparison of density-corrected data to non-density-corrected data for earlier years shows monthly and annual differences of several percent. These differences are judged to be minor compared to other errors. Daily value differences can be greater, with precipitation occasionally shifted from 1 day to an adjacent day.

A Taylor Scientific Engineering WS-3 rotor anemometer, designed for a very windy, rugged mountain environment, records 3-m height wind speeds. The threshold wind speed is 1.34 m/s and it has an accuracy of about 0.5 m/s. The time constant for a step increase in wind speed is 7–8 seconds and 19–20 seconds for a step decrease. Fifteen-minute Average wind speeds are recorded (fig. 14, tables 24–28).

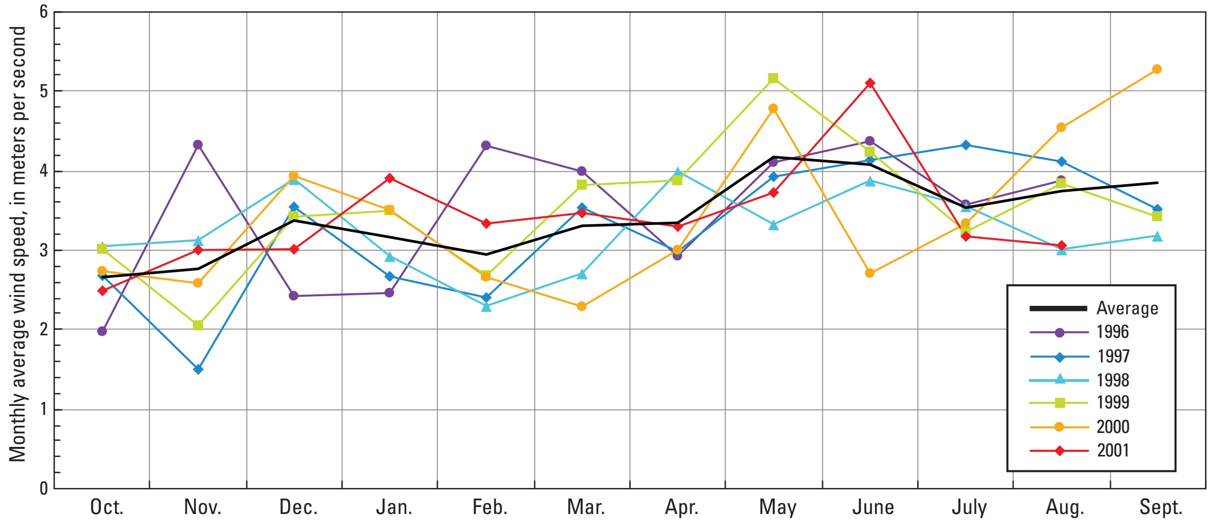

Figure 14. Monthly average wind speed at 1,480 meters altitude, Gulkana Glacier basin, Alaska, water years 1997–2001.

Table 24. Daily, monthly, and annual average wind speed at 1,480 meters altitude, Gulkana Glacier basin, 1997 hydrologic year.

Day	Wind speed, in meters per second												Annual
	1996			1997									
	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	
1	1.5	0.5	2.5	1.8	2.9	7.9	10.8	1.9	2.7	4.9	2.4	4.0	
2	10.7	.4	1.8	1.8	6.2	5.6	14.1	1.9	2.3	4.8	4.0	3.0	
3	10.3	.8	1.5	.6	3.7	1.2	1.7	6.3	3.5	5.8	2.6	6.4	
4	3.6	1.4	.5	.5	4.5	2.1	1.7	5.0	5.1	4.7	5.4	2.1	
5	1.6	.2	8.3	1.6	3.0	1.3	2.3	8.2	3.0	3.8	4.6	1.7	
6	3.4	.1	2.1	3.0	2.5	1.9	2.6	7.5	4.8	5.0	3.3	2.0	
7	.9	3.0	3.2	2.3	1.3	.5	2.2	2.1	1.0	6.6	2.7	3.1	
8	2.4	2.7	5.1	1.4	3.4	.0	2.6	1.9	.6	5.8	2.6	4.7	
9	3.5	1.5	2.6	2.7	1.8	5.4	2.7	2.2	1.7	2.9	2.7	1.8	
10	2.1	1.5	1.7	7.6	1.9	15.1	1.4	3.1	2.0	3.0	3.9	4.2	
11	1.4	1.6	.5	2.5	.8	5.6	1.4	4.0	2.7	2.9	7.0	8.0	
12	.3	.7	2.2	1.6	.5	4.1	1.3	2.6	2.0	1.7	7.0	6.2	
13	2.6	1.0	3.0	4.9	1.8	2.7	1.4	3.2	2.8	2.1	4.8	7.1	
14	7.9	1.4	2.0	2.7	1.2	3.3	2.2	3.3	3.6	2.7	2.5	2.3	
15	3.2	1.3	1.7	2.4	4.2	8.6	1.2	4.4	2.6	3.1	2.1	2.2	
16	.8	1.2	1.8	3.7	.8	13.5	7.4	1.6	3.1	3.1	4.0	3.2	
17	1.0	1.6	.5	1.0	.1	3.2	4.4	2.8	7.6	3.3	3.4	5.5	
18	2.7	1.4	3.6	.5	.3	1.0	2.6	5.0	5.8	3.0	7.6	6.4	
19	1.4	2.4	10.5	1.8	2.3	1.8	1.7	2.1	3.2	2.0	2.1	3.2	
20	1.3	1.3	9.1	0.8	2.5	1.8	1.3	1.6	1.9	3.7	1.9	3.7	
21	1.2	.6	7.7	3.2	3.7	1.5	1.8	2.2	5.8	2.3	1.4	2.0	
22	1.8	.4	3.3	1.3	6.1	.8	1.7	6.9	9.3	3.3	6.5	2.0	
23	1.5	1.3	5.2	1.8	5.7	5.2	2.6	9.2	6.0	6.8	11.0	3.0	
24	3.5	.9	2.9	1.6	1.9	5.0	2.2	4.9	5.5	8.2	4.6	4.4	
25	2.0	1.6	1.7	4.3	1.0	1.4	2.5	4.7	3.5	9.7	6.3	4.2	
26	1.9	1.5	5.6	10.2	1.2	1.8	3.6	5.7	7.0	5.2	3.1	2.8	
27	1.2	1.5	4.2	2.1	.0	1.4	2.4	2.9	7.3	6.3	2.6	1.5	
28	1.7	3.7	1.9	2.1	1.8	.8	2.2	3.2	6.3	6.6	2.1	1.2	
29	2.5	4.1	8.2	3.1		1.5	2.7	3.2	5.7	5.2	1.6	1.7	
30	1.4	3.3	3.7	4.3		1.5	1.2	1.3	5.7	3.1	3.9	2.2	
31	1.8	2.5	1.4	4.0		2.2		6.7		2.6	7.9		
Monthly average	2.7	1.5	3.5	2.7	2.4	3.5	3.0	3.9	4.1	4.3	4.1	3.5	3.3
Departure from normal	.0	- 1.2	.2	- .5	- .5	.2	- .4	- .2	.1	.8	.4	- .3	- .1
Standardized value	.1	- 1.3	.3	- .8	- .7	.3	- .8	- .4	.1	1.9	.6	- .3	-1.3

Table 25. Daily, monthly, and annual average wind speed at 1,480 meters altitude, Gulkana Glacier basin, 1998 hydrologic year.

Day	Wind speed, in meters per second												Annual
	1997			1998									
	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	
1	4.4	2.6	5.7	0.5	3.1	1.8	2.7	1.3	2.9	3.3	2.9	4.5	
2	6.0	2.7	5.0	3.7	1.8	1.6	5.0	2.9	1.6	3.9	2.5	2.3	
3	3.0	2.8	2.2	12.1	1.7	1.8	5.7	5.6	2.5	3.3	1.3	2.6	
4	1.5	2.0	7.4	9.6	2.9	1.3	5.0	5.8	1.9	3.6	1.7	1.7	
5	4.1	4.6	5.1	2.2	2.1	1.5	2.4	3.0	2.4	3.4	1.9	4.1	
6	8.3	3.5	2.2	1.6	1.4	1.5	2.4	3.5	3.0	2.0	2.7	6.5	
7	10.9	3.6	3.2	1.3	1.3	1.7	2.5	3.0	4.2	2.1	4.9	1.8	
8	1.4	2.8	3.3	1.3	2.5	1.0	2.5	6.3	4.3	2.2	4.2	1.8	
9	3.2	2.4	3.9	0.7	1.8	0.6	2.1	4.4	2.8	2.3	0.4	2.0	
10	4.9	4.8	4.4	1.1	2.2	1.0	3.8	3.8	1.6	7.8	1.0	3.1	
11	1.9	3.5	4.2	0.9	3.0	1.1	1.0	2.3	3.1	3.0	2.0	1.5	
12	2.2	3.4	4.3	6.7	4.6	1.3	0.6	2.0	2.0	2.7	2.0	0.5	
13	3.2	2.8	2.2	12.2	1.4	1.9	4.1	4.2	4.0	4.8	1.9	0.2	
14	0.8	3.7	2.4	1.2	2.7	2.6	5.9	4.3	10.6	4.2	2.3	0.2	
15	0.3	1.4	2.0	2.4	1.0	2.8	5.3	5.4	5.5	2.7	2.0	0.2	
16	1.4	1.6	2.0	3.5	0.4	4.0	2.1	4.0	3.6	2.9	5.7	0.5	
17	7.3	2.2	3.8	1.3	0.9	3.8	2.7	2.9	6.1	1.1	4.6	2.9	
18	1.5	1.2	6.5	1.7	1.8	6.3	1.9	2.4	3.6	2.6	5.7	7.0	
19	1.1	2.4	2.4	1.6	1.8	2.7	2.0	2.2	3.3	4.4	3.7	6.8	
20	1.7	1.3	5.6	1.9	3.1	2.2	2.9	2.3	2.7	2.6	3.6	5.2	
21	0.1	4.3	2.4	1.8	2.0	1.9	4.3	3.0	2.6	2.2	1.0	0.6	
22	0.6	3.7	1.2	2.2	1.8	2.3	2.4	2.4	1.5	2.6	2.7	3.3	
23	1.3	6.8	5.1	1.6	3.6	2.1	2.8	2.8	6.9	1.3	4.5	3.7	
24	1.6	6.2	10.9	1.3	3.0	5.2	3.0	1.8	10.1	2.1	1.6	4.3	
25	7.5	0.8	7.9	1.7	2.7	1.9	6.3	2.4	4.0	6.7	3.7	6.3	
26	10.6	2.6	0.4	0.8	3.7	6.5	7.2	3.6	2.0	1.7	1.1	2.6	
27	1.3	1.8	1.6	2.6	3.3	2.3	11.1	3.3	3.6	3.5	2.9	0.8	
28	1.9	3.9	2.1	2.9	3.0	7.1	7.7	3.5	4.5	6.2	6.4	1.3	
29	0.1	3.4	4.8	1.9		2.1	7.0	3.1	5.2	5.8	5.2	5.4	
30	0.6	4.6	5.1	2.7		8.7	5.2	4.5	4.5	8.2	4.5	12.0	
31	0.1	5.7	1.5	4.0		1.4		1.4		4.8	2.9		
Total	3.1	3.2	3.9	2.9	2.3	2.7	4.0	3.3	3.9	3.6	3.0	3.2	3.3
Departure from normal	0.4	0.4	0.5	- 0.2	- 0.5	- 0.6	0.7	- 0.8	- 0.2	0.0	- 0.6	- 0.6	-0.2
Standardized value	1.0	0.5	0.9	- 0.3	- 0.8	- 0.9	1.3	- 1.2	- 0.3	0.0	- 0.8	- 0.7	-1.6

Table 26. Daily, monthly, and annual average wind speed at 1,480 meters altitude, Gulkana Glacier basin, 1999 hydrologic year.

Day	Wind speed, in meters per second												Annual
	1998			1999									
	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	
1	1.4	2.7	2.2	2.6	6.6	1.5	7.4	12.9	3.2	4.6	3.2	3.6	
2	0.9	2.9	2.5	0.4	1.6	0.1	1.5	13.1	2.6	5.7	4.3	3.9	
3	1.5	2.1	1.6	0.1	0.8	6.0	1.5	15.2	1.4	6.7	5.4	5.5	
4	2.2	1.6	2.8	2.0	1.1	10.3	3.1	2.7	10.1	4.6	5.9	0.6	
5	6.5	1.3	6.2	1.3	15.3	11.9	1.3	1.2	12.2	3.9	4.6	6.0	
6	6.2	1.3	2.5	1.0	1.5	7.2	5.0	8.2	2.6	2.8	4.0	5.5	
7	5.7	1.4	1.1	2.2	2.6	4.6	7.6	1.3	2.3	3.0	1.9	5.3	
8	2.8	1.4	2.6	0.4	1.0	5.8	1.0	2.0	3.1	2.3	2.9	8.6	
9	1.5	1.1	4.5	0.4	0.5	0.7	1.7	2.8	2.9	3.5	2.0	4.9	
10	1.2	1.4	2.2	0.1	0.4	3.3	1.1	2.3	3.9	2.9	2.5	2.3	
11	2.0	1.7	4.2	1.7	5.9	4.0	2.1	2.1	3.2	2.4	2.5	2.3	
12	2.3	1.2	2.5	4.1	1.3	2.6	2.3	3.0	3.5	3.0	4.1	1.9	
13	1.9	1.7	4.0	2.7	0.3	2.9	7.4	6.8	4.9	3.2	8.1	4.1	
14	1.6	0.8	2.6	2.2	4.7	4.8	4.0	6.3	3.7	3.0	3.0	4.3	
15	2.4	0.8	1.8	4.1	2.9	2.8	4.1	5.0	3.2	4.5	5.7	2.3	
16	2.7	0.9	4.5	4.0	1.6	3.7	5.9	5.8	2.9	3.0	10.3	2.0	
17	2.2	0.9	1.6	1.7	0.5	3.3	2.4	5.8	2.2	1.5	7.9	3.7	
18	2.4	0.9	1.0	2.0	3.8	3.9	1.8	9.9	2.7	1.3	2.7	6.4	
19	3.5	3.0	1.4	2.5	2.4	2.8	1.6	4.1	7.2	2.1	2.7	3.1	
20	7.6	8.0	1.5	2.1	2.2	3.0	1.5	5.2	4.7	3.5	3.2	3.7	
21	5.4	3.2	1.1	1.6	3.1	2.7	1.0	2.6	2.4	5.2	2.1	2.6	
22	2.3	1.3	1.7	3.7	2.7	1.7	2.1	2.0	1.8	3.8	2.8	6.3	
23	3.9	1.3	9.8	8.4	1.3	2.2	1.3	5.1	6.4	1.7	2.6	1.5	
24	5.8	2.6	8.2	1.9	1.6	3.6	9.9	4.1	3.8	0.9	3.6	0.6	
25	6.2	2.0	2.3	0.4	1.7	2.6	14.0	1.8	3.3	0.7	1.0	3.4	
26	2.2	1.4	2.0	6.4	2.6	1.4	9.0	3.2	2.5	1.1	1.5	0.8	
27	2.4	4.6	14.2	18.1	3.6	3.1	2.7	2.3	2.1	4.0	3.7	0.5	
28	1.4	2.3	5.0	16.8	1.4	3.5	3.1	4.8	7.1	6.5	9.6	5.3	
29	2.0	2.6	1.5	4.3		3.9	2.8	5.5	7.0	3.0	1.7	1.1	
30	2.0	3.1	4.8	7.5		3.7	6.0	5.0	8.3	2.6	2.1	0.6	
31	1.4	2.2	2.2	1.7		5.0		7.9		3.4	1.4		
Total	3.0	2.1	3.4	3.5	2.7	3.8	3.9	5.2	4.2	3.2	3.8	3.4	3.5
Departure from normal	0.4	- 0.7	0.1	0.4	- 0.2	0.5	0.6	1.0	0.2	- 0.3	0.2	- 0.3	0.1
Standardized value	0.9	- 0.7	0.1	0.6	- 0.2	0.8	1.1	1.4	0.2	- 0.7	0.3	- 0.4	1.1

Table 27. Daily, monthly, and annual average wind speed at 1,480 meters altitude, Gulkana Glacier basin, 2000 hydrologic year.

Day	Wind speed, in meters per second												Annual
	1999			2000									
	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	
1	0.1	5.5	2.5	6.9	6.0	3.0	1.9	2.6	0.7	2.3	3.6	2.8	
2	0.0	4.6	2.3	2.3	12.7	2.2	1.2	4.2	1.2	1.3	3.8	6.3	
3	0.1	1.4	3.3	2.7	7.4	2.8	1.1	7.4	1.6	2.6	6.6	1.0	
4	0.9	0.3	0.7	1.7	2.7	0.8	0.9	6.5	1.9	3.4	2.1	4.9	
5	2.4	2.6	2.3	1.4	3.2	0.0	5.0	4.5	2.5	2.4	1.5	4.8	
6	1.7	1.6	4.4	0.9	1.8	1.9	1.2	1.9	3.6	2.7	4.2	7.6	
7	2.1	2.0	1.9	2.1	1.1	2.1	0.9	2.2	4.0	3.8	3.9	6.5	
8	1.4	1.9	0.9	6.8	0.5	1.3	1.2	2.0	2.1	2.6	8.8	9.0	
9	2.1	4.4	0.6	2.4	1.8	1.1	2.0	12.0	3.0	2.2	9.1	4.5	
10	2.2	1.3	1.0	3.7	1.0	1.1	2.2	10.5	2.8	6.3	1.8	2.5	
11	2.6	1.2	1.4	6.4	1.7	1.3	1.7	4.5	2.3	5.5	2.0	0.7	
12	1.0	2.4	1.7	6.8	1.9	0.6	1.4	10.8	3.4	8.3	2.8	5.6	
13	7.3	2.4	1.3	1.3	1.2	1.7	1.6	6.0	2.2	2.3	3.1	3.6	
14	7.2	2.5	1.7	0.8	1.5	1.4	3.1	10.8	0.9	1.1	10.8	4.5	
15	1.7	3.9	1.6	2.1	2.4	2.6	7.8	1.2	1.3	2.3	15.6	1.0	
16	0.9	2.3	1.2	1.2	3.2	1.8	1.2	1.4	5.6	4.0	2.8	7.4	
17	4.2	3.8	1.6	0.8	0.2	1.9	0.1	1.0	5.5	3.7	1.5	13.9	
18	1.5	3.3	2.4	0.2	2.5	1.0	4.1	1.9	1.1	3.8	1.2	3.8	
19	6.1	2.0	4.1	2.4	3.3	4.6	5.2	1.0	4.1	2.4	3.4	1.8	
20	0.6	1.3	8.7	0.7	3.9	2.3	4.9	4.2	2.9	2.5	4.8	2.2	
21	11.6	2.3	10.6	4.0	0.9	0.9	5.4	7.1	1.3	1.5	5.3	4.4	
22	2.9	2.5	13.8	2.4	1.6	1.4	3.0	0.6	3.5	2.8	9.4	4.7	
23	2.5	2.6	9.7	5.2	2.1	3.1	2.3	2.1	2.7	2.0	1.4	0.5	
24	2.5	9.7	4.3	8.6	2.2	2.4	3.0	4.8	2.8	2.9	1.6	0.7	
25	2.0	0.8	4.6	5.3	2.3	5.2	3.1	7.6	2.5	5.2	8.6	1.7	
26	4.2	1.9	9.1	5.5	1.8	3.3	6.1	11.3	2.6	8.0	3.9	5.7	
27	3.2	1.7	9.1	6.4	2.2	3.0	7.4	7.8	2.2	2.4	1.4	15.9	
28	1.6	2.0	6.8	6.6	2.4	3.8	7.5	6.1	2.0	4.5	2.5	16.3	
29	1.5	1.1	2.1	5.5	1.6	4.2	1.6	1.7	3.1	2.6	2.0	8.1	
30	3.1	2.1	2.0	2.0		5.7	2.1	1.7	5.9	2.2	8.4	5.7	
31	3.7	2.5	4.4	3.6		2.6		0.9		3.9	3.1		
Total	2.7	2.6	3.9	3.5	2.7	2.3	3.0	4.8	2.7	3.3	4.5	5.3	3.4
Departure from normal	0.1	- 0.2	0.6	0.4	- 0.2	- 1.0	- 0.3	0.6	- 1.4	- 0.2	0.9	1.5	0.0
Standardized value	0.2	- 0.2	1.0	0.6	- 0.3	- 1.5	- 0.6	0.9	- 1.7	- 0.5	1.2	1.8	0.3

Table 28. Daily, monthly, and annual average wind speed at 1,480 meters altitude, Gulkana Glacier basin, 2001 hydrologic year.

[–, daily missing value]

Day	Wind speed, in meters per second												Annual
	2000			2001									
	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	
1	3.8	0.6	2.6	2.4	4.9	3.2	2.8	6.5	12.1	2.7	5.6	10.0	
2	2.6	1.6	1.6	2.3	2.1	2.0	2.2	5.8	6.9	3.4	2.7	2.7	
3	1.8	9.1	4.0	5.6	1.0	1.9	7.6	4.7	1.8	2.4	3.9	0.8	
4	1.3	1.8	2.9	3.7	.7	2.3	5.7	2.5	1.6	2.1	2.9	6.2	
5	.9	1.6	5.4	.7	.0	2.8	5.2	2.9	1.8	2.2	3.0	2.4	
6	3.0	1.7	3.3	3.3	.0	3.4	2.9	3.6	5.2	10.1	2.9	1.8	
7	5.6	1.3	1.6	4.3	8.8	3.0	1.4	6.6	.9	7.2	1.9	6.7	
8	3.3	1.7	1.4	5.6	3.1	2.1	1.7	1.3	3.7	1.7	2.2	2.7	
9	3.1	1.8	2.3	4.2	6.9	.3	2.4	1.9	4.1	2.7	2.0	2.8	
10	1.6	7.4	4.6	3.6	1.8	1.9	3.2	2.5	3.5	2.6	2.0	2.1	
11	4.1	5.1	3.5	4.2	.8	3.8	2.3	1.8	3.6	1.5	2.3	2.4	
12	3.3	2.0	1.8	2.8	6.5	6.5	2.5	1.5	2.4	2.5	2.7	–	
13	4.7	5.2	2.0	1.7	6.9	1.8	1.8	3.1	5.2	1.8	2.5	7.1	
14	2.6	3.2	1.8	4.7	1.6	2.6	3.1	4.9	11.9	5.1	4.1	2.6	
15	1.6	1.1	1.5	10.3	3.2	2.4	5.2	2.5	12.1	3.1	1.5	2.4	
16	2.7	2.8	1.9	4.7	4.1	3.7	2.3	1.3	4.2	4.6	2.5	2.7	
17	2.3	5.2	2.3	3.1	3.0	11.3	2.9	.9	3.3	3.9	2.6	4.8	
18	2.2	5.2	2.0	5.1	2.4	9.6	2.9	3.8	2.5	2.7	2.2	4.9	
19	1.1	4.2	3.7	6.2	1.7	8.9	2.0	1.4	3.0	3.8	2.9	.9	
20	3.3	1.8	5.0	2.8	1.3	2.2	1.6	2.7	3.8	3.9	6.3	.7	
21	2.6	4.1	5.3	3.2	2.0	3.2	2.0	1.7	3.6	3.5	8.1	1.5	
22	1.8	2.6	4.7	2.4	1.2	2.5	3.2	2.0	6.0	2.7	8.2	3.0	
23	1.0	1.5	1.9	5.4	2.8	1.1	2.7	2.4	4.3	1.4	2.3	6.6	
24	2.4	3.3	2.3	5.1	4.3	1.2	6.6	.9	3.1	2.4	1.6	2.4	
25	4.6	2.0	3.6	2.6	3.2	1.1	2.7	1.5	6.4	3.1	2.0	2.9	
26	1.5	2.3	2.7	6.9	6.7	1.1	6.0	3.5	8.8	2.6	1.6	2.5	
27	3.9	.6	2.2	3.6	8.0	3.0	3.5	10.5	11.1	1.9	2.3	3.0	
28	2.1	4.8	3.3	5.0	4.4	.5	3.2	14.6	8.9	2.0	2.2	2.9	
29	1.6	3.1	3.6	1.0		3.2	6.2	1.9	2.5	3.5	3.0	4.9	
30	.8	1.5	5.6	2.3		3.8	1.4	3.1	4.6	3.1	2.1	5.9	
31	.1	2.6	2.9	2.1		11.3		11.4		2.7	2.9		
Monthly average	2.5	3.0	3.0	3.9	3.3	3.5	3.3	3.7	5.1	3.2	3.1	3.5	3.4
Departure from normal	- .2	.2	- .4	.8	.4	.2	.0	- .4	1.0	- .4	- .7	- .3	0.0
Standardized value	- .4	.2	- .6	1.3	.5	.3	- .1	- .6	1.3	- .8	- 1.1	- .3	0.1

Streamflow

The Phelan Creek stream-gaging station (USGS station number 15478040) is part of a large-scale USGS stream-monitoring network in Alaska. Data collection and analysis are conducted by standard techniques developed by the USGS (Wahl and others, 1995). Daily values of discharge are reported along with those for the rest of Alaska in the annual USGS Water-Data Report series (U.S. Geological Survey, 1968–2002; also available at http://ak.water.usgs.gov/glaciology/gulkana/streamflow/). An 11-year gap in the record exists from 1979–1989.

The gaging station is located at an altitude of 1,125 m and about 1 km downstream from the present glacier terminus (figs. 2, 3, and 15). The creekbed consists of poorly sorted gravel and small boulders, and the channel is subject to frequent changes during high flows, making it difficult to monitor accurately. Phelan Creek freezes from early autumn until mid-spring, and runoff must be estimated during this interval. Stream stage is continuously recorded, and discharge measurements are made periodically to determine the relation between stage and discharge at different streamflow levels (including ice covered) and to detect any shifts in the relation due to changes in the creekbed.

Figure 15. The Gulkana Glacier terminus from just downstream of the Phelan Creek stream–gaging station, USGS station 15478040, Alaska, September 1, 1996. The gaging station site is about 1 km downstream of the present glacier terminus. The channel bed is composed of typical ground moraine material, poorly sorted gravel and small boulders, which is subject to frequent changes during high flows. The mean discharge for September 1, 1996, was about 9 cubic meters per second (runoff of about 24 millimeters), a value typical of mid-summer, but high for early September. The cable way and small hand car are used for making discharge measurements when the flow is too deep and fast for safe wading. The round structure to the right of the creek houses instrumentation and satellite telemetry.

Results

Glacier Mass Balance

Winter balance is generally less variable than summer or net balance (standard deviation of the former is about half the latter). The average measured winter balance for 1997–2001 of 1.15 mweq was about equal to the period-of-record average, though 2000 and 2001 were well above average. A linear trend in the 1966–2001 winter balance indicates an increase of 0.03 mweq/decade, which is small and may be insignificant. In most years, the glacier-wide maximum snow balance occurs 4–6 weeks after the measured winter snow balance and generally after the snow balance has peaked and started to decline on the lower glacier. A simple temperature- and precipitation-forced model used to evaluate the difference between measured balance and maximum balance shows that maximum balances are generally 5–15 percent greater than the measured balance.

Net balance values are listed in table 29. The glacier-averaged, net balance year typically starts and ends about the end of August, but can start as early as mid-August or as late as the end of September. Of note, 1997 was the most negative year of record so far with a net balance of -1.71 mweq and the 1997–2001 average net balance of -0.77 mweq was about 2.5 times more negative than the previous 31-year average of -0.30 mweq (fig. 16). The 1966–2001 linear regression trend shows a decreasing net balance by 0.20 mweq/decade. Summer balance shows large changes over the project history. The year 1997 also exhibited the most negative summer balance of -2.71 mweq and furthermore the 1997–2001 average summer balance of -1.92 mweq was almost 1 standard deviation below the previous 31-year average of -1.41 mweq. The 1966–2001 linear regression trend shows a decreasing summer balance by 0.18 mweq/decade.

As previously discussed, the integral in equation (5) was estimated as the sum of the product of site balances b_A, b_B, and b_D (fig. 2), and area weighting coefficients which were determined from maps. As examples, for 1966 the estimation is:

$$\bar{b} = 0.203b_A + 0.270b_B + 0.527b_D + b_{\text{int}} \,, \qquad (8)$$

and for 2001:

$$\bar{b} = 0.157b_A + 0.198b_B + 0.645b_D + \bar{b}_{\text{int}} \,. \qquad (9)$$

These examples show decreased representation of the region represented by site A as the lower glacier thins and retreats. During the same time interval, little change occurred at upper site D, which represents more of the glacier area.

Table 30 lists detailed glacier-wide, reference surface balances (Elsberg and others, 2001, Harrison and others, 2005) for the 5 years of this study and table 31 provides a summary for all years. Reference surface balances are calculated by the same method as the conventional balances except that the AAD is fixed in 1966 at the beginning of the record. Reference surface balances correct the balances by removing the glacier's dynamic response of the glacier from the balance as if its area or altitude had remained invariant. Some find this balance parameter is better suited for climate analysis in long-term studies than the conventional balance. For instance, when climate undergoes a permanent step change, the conventional balance of a glacier initially in equilibrium with the climate undergoes only a temporary step change then slowly reverts back to its equilibrium zero balance, but the reference surface balance, like the climate, will undergo a permanent step change. The correction is large for Gulkana Glacier as shown in figure 17. The cumulative reference surface balance volume for the 36-year period of record is 28 percent more negative than the conventional balance volume.

Estimates of the ELA and AAR are listed in table 29. The 1997–2001 average AAR is about 0.53 compared to the previous 31-year average of 0.60, which represents approximately a 35-m rise in the ELA. Both parameter changes are consistent with the trend towards more negative balances.

Table 29. Index-site and area-integrated conventional balance quantities for Gulkana Glacier and Gulkana Glacier basin, 1997–2001 hydrologic years.

[**Abbreviations**: m, meters; mweq, meters water equivalent; mm-dd-yy, month-day-year; km^2, square kilometers; °C, degrees Celsius]

Parameter / Year of area-altitude distribution determination =	Site, glacier average, or subparameter	Units	Conventional balance 1997	1998	1999	2000	2001
Index-site altitudes	Site A	(m)	1,364	1,362	1,360	1,357	1,355
	Site B	(m)	1,680	1,679	1,679	1,678	1,678
	Site D	(m)	1,833	1,832	1,833	1,833	1,834
Index-site weighting factors	Site A		0.165	0.163	0.161	0.158	0.157
	Site B		0.199	0.198	0.198	0.198	0.198
	Site D		0.636	0.639	0.641	0.644	0.645
b_{n0}, initial net balance	Site A	(mweq)	-0.49	0.00	-0.42	-0.33	-0.44
	Site B	(mweq)	-0.10	0.00	0.00	-0.08	-0.05
	Site D	(mweq)	-0.01	-0.01	0.00	-0.13	0.00
	Glacier average	(mweq)	-0.11	-0.00	-0.07	-0.15	-0.08
$b_0(s)$, initial snow balance	Site A	(mweq)	0.05	0.00	0.09	0.07	0.00
	Site B	(mweq)	0.12	0.00	0.46	0.19	0.32
	Site D	(mweq)	0.37	0.01	0.54	0.40	0.56
	Glacier average	(mweq)	0.27	0.01	0.45	0.30	0.42
$b_m(s)$, measured winter snow balance	Date of measurement	(mm-dd-yy)	04-19-97	04-17-98	04-22-99	04-21-00	04-19-01
	Site A	(mweq)	0.46	0.37	0.37	0.82	0.68
	Site B	(mweq)	0.70	0.58	0.91	1.17	1.33
	Site D	(mweq)	1.24	0.97	1.27	1.69	1.68
	Glacier average	(mweq)	1.00	0.79	1.05	1.45	1.45
$b_w(s)$, maximum winter snow balance	Date of maximum	(mm-dd-yy)	05-18-97	05-23-98	06-05-99	05-25-00	05-25-01
	Site A	(mweq)	0.47	0.36	0.30	0.82	0.66
	Site B	(mweq)	0.84	0.67	0.98	1.25	1.39
	Site D	(mweq)	1.35	1.15	1.49	1.82	1.81
	Glacier average	(mweq)	1.10	0.93	1.19	1.55	1.55
b_{nl}, late net balance	Site A	(mweq)	0.00	0.42	0.33	0.44	0.27
	Site B	(mweq)	0.00	-0.00	0.08	0.05	0.00
	Site D	(mweq)	0.01	0.00	0.13	0.00	0.00
	Glacier average	(mweq)	0.00	0.07	0.15	0.08	0.04
$b_1(ls)$, final late snow balance	Site A	(mweq)	0.00	0.09	0.07	0.00	0.00
	Site B	(mweq)	0.00	0.46	0.19	0.32	0.07
	Site D	(mweq)	0.01	0.54	0.40	0.56	0.18
	Glacier average	(mweq)	0.01	0.45	0.30	0.42	0.13
$b_a(f)$, annual firn balance	Site A	(mweq)	0.00	0.00	0.00	0.00	0.00
	Site B	(mweq)	0.00	0.00	0.00	0.00	0.00
	Site D	(mweq)	0.00	0.26	0.00	0.78	0.22
	Glacier average	(mweq)	0.00	0.17	0.00	0.50	0.14
$b_a(k)$, annual internal accumulation	Site A	(mweq)	0.00	0.00	0.00	0.00	0.00
	Site B	(mweq)	0.00	0.00	0.00	0.00	0.00
	Site D	(mweq)	0.07	0.14	0.16	0.14	0.14
	Glacier average	(mweq)	0.04	0.09	0.10	0.09	0.09

Table 29. Index-site and area-integrated conventional balance quantities for Gulkana Glacier and Gulkana Glacier basin, 1997–2001 hydrologic years.—Continued

[**Abbreviations**: m, meters; mweq, meters water equivalent; mm-dd-yy, month-day-year; km^2, square kilometers; °C, degrees Celsius]

Parameter / Year of area-altitude distribution determination =	Site, glacier average, or subparameter	Units	Conventional balance				
			1997	1998	1999	2000	2001
$b_a(i)$, annual old firn and ice balance	Site A	(mweq)	-4.85	-3.49	-4.35	-2.52	-3.97
	Site B	(mweq)	-2.30	-0.95	-1.35	-0.14	-0.99
	Site D	(mweq)	-0.49	0.00	-0.27	0.00	0.00
	Glacier average	(mweq)	-1.57	-0.76	-1.14	-0.43	-0.82
$b_a(j)$, annual internal ablation (glacier averaged)	From geothermal heat flux	(mweq)	-0.005	-0.005	-0.005	-0.005	-0.005
	From potential energy loss from ice motion	(mweq)	-0.005	-0.005	-0.005	-0.005	-0.005
	From potential energy loss from water flow (estimated)	(mweq)	-0.075	-0.060	-0.054	-0.035	-0.048
	Total	(mweq)	-0.08	-0.07	-0.06	-0.04	-0.06
b_n, net balance	Start of net balance year for glacier average	(mm-dd-yy)	08-25-96	09-28-97	08-21-98	09-03-99	08-18-00
	End of net balance year for glacier average	(mm-dd-yy)	09-27-97	08-20-98	09-02-99	08-17-00	09-03-01
	Site A	(mweq)	-5.34	-3.07	-4.44	-2.41	-4.13
	Site B	(mweq)	-2.39	-0.95	-1.27	-0.17	-1.04
	Site D	(mweq)	-0.43	0.39	0.02	0.79	0.36
	Glacier average (includes $b_a(j)$)	(mweq)	-1.71	-0.51	-1.02	0.06	-0.68
b_a, annual balance (Oct. 1 to Sept. 30)	Site A	(mweq)	-4.90	-3.40	-4.37	-2.59	-3.97
	Site B	(mweq)	-2.41	-0.49	-1.62	-0.01	-1.24
	Site D	(mweq)	-0.78	0.93	-0.25	1.08	-0.02
	Glacier average (includes $b_a(j)$)	(mweq)	-1.86	-0.13	-1.25	0.24	-0.94
ELA, equilibrium-line altitude		(m)	1,867	1,787	1,831	1,705	1,794
Accumulation area		(km^2)	8.08	10.07	8.83	11.41	9.51
Ablation area		(km^2)	10.04	8.06	9.29	6.72	8.61
AAR, accumulation-area ratio			0.45	0.56	0.49	0.63	0.52
Calculated annual precipitation	Basin average	(m)	1.34	1.98	1.22	1.66	1.37
Annual basin runoff	1,125-meter stream gage	(m)	2.54	2.34	1.93	1.62	1.85
Percent of runoff from balance	Basin value	(percent)	47	15	37	-2	26

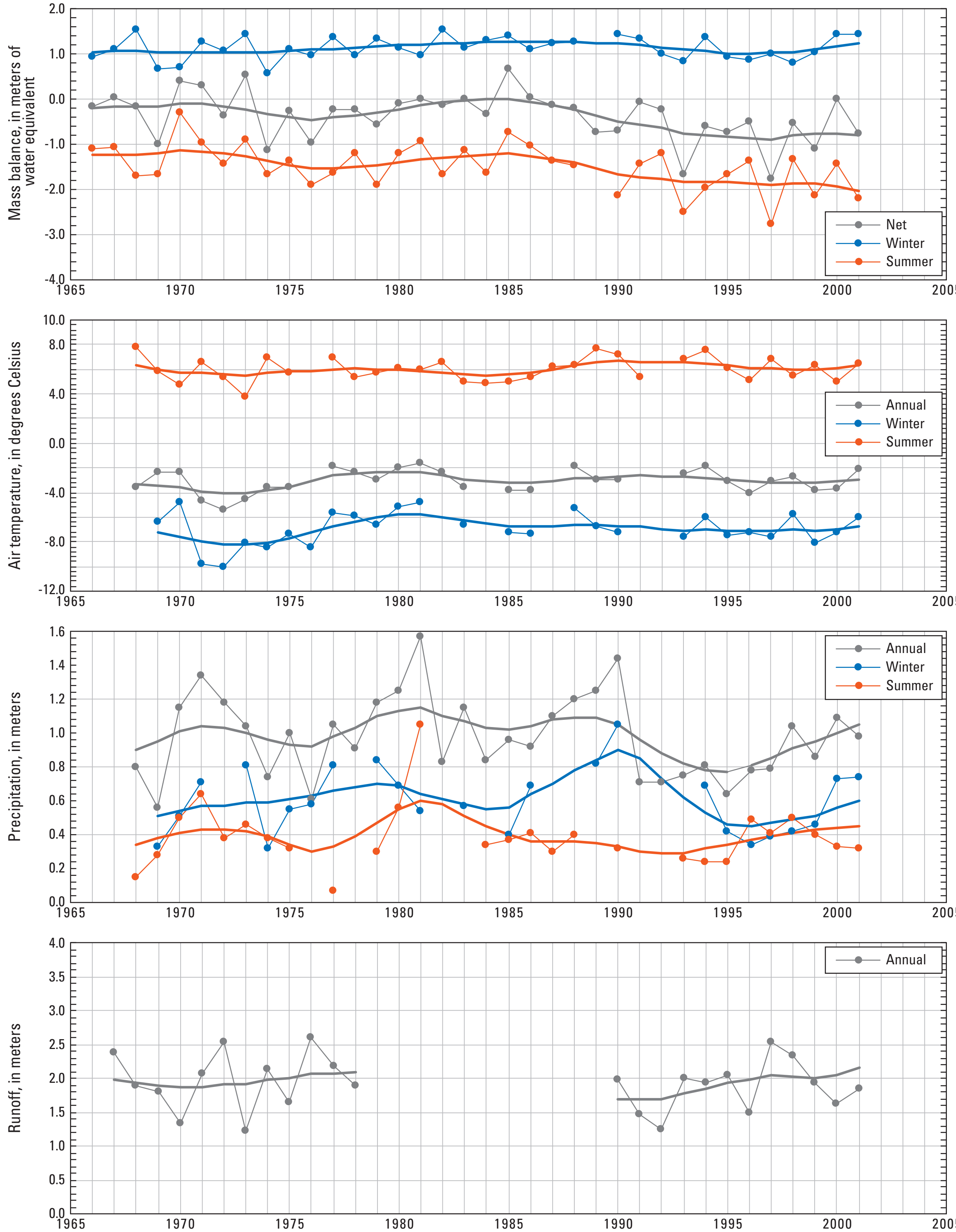

Figure 16. Net, winter, and summer values for mass balance, air temperature, precipitation catch, and runoff, Gulkana Glacier basin, Alaska, water years 1966–2001.

Table 30. Index-site and area-integrated reference surface balance quantities for Gulkana Glacier and Gulkana Glacier Basin, 1997–2001 hydrologic years.

[Reference surface is 1967 area-altitude distribution. **Abbreviations**: m, meters; mweq, meters water equivalent; mm-dd-yy, month-day-year; km^2, square kilometers; °C, degrees Celsius]

Parameter	Site, glacier average, or subparameter	Units	1967 reference-surface balance				
Year of area-altitude distribution determination =			1997	1998	1999	2000	2001
Index-site altitudes	Site A	(m)	1,364	1,362	1,360	1,357	1,355
	Site B	(m)	1,680	1,679	1,679	1,678	1,678
	Site D	(m)	1,833	1,832	1,833	1,833	1,834
Index-site weighting factors	Site A		0.193	0.192	0.192	0.190	0.189
	Site B		0.227	0.227	0.228	0.229	0.230
	Site D		0.580	0.581	0.580	0.581	0.581
b_{n0}, initial net balance	Site A	(mweq)	-0.49	0.00	-0.42	-0.33	-0.44
	Site B	(mweq)	-0.10	0.00	0.00	-0.08	-0.05
	Site D	(mweq)	-0.01	-0.01	0.00	-0.13	0.00
	Glacier average	(mweq)	-0.13	-0.00	-0.08	-0.15	-0.10
$b_0(s)$, initial snow balance	Site A	(mweq)	0.05	0.00	0.09	0.07	0.00
	Site B	(mweq)	0.12	0.00	0.46	0.19	0.32
	Site D	(mweq)	0.37	0.01	0.54	0.40	0.56
	Glacier average	(mweq)	0.25	0.01	0.43	0.29	0.40
$b_m(s)$, measured winter snow balance	Date of measurement	(mm-dd-yy)	04-19-97	04-17-98	04-22-99	04-21-00	04-19-01
	Site A	(mweq)	0.46	0.37	0.37	0.82	0.68
	Site B	(mweq)	0.70	0.58	0.91	1.17	1.33
	Site D	(mweq)	1.24	0.97	1.27	1.69	1.68
	Glacier average	(mweq)	0.97	0.77	1.02	1.41	1.41
$b_w(s)$, maximum winter snow balance	Date of maximum	(mm-dd-yy)	05-18-97	05-23-98	06-05-99	05-25-00	05-25-01
	Site A	(mweq)	0.47	0.36	0.30	0.82	0.66
	Site B	(mweq)	0.84	0.67	0.98	1.25	1.39
	Site D	(mweq)	1.35	1.15	1.49	1.82	1.81
	Glacier average	(mweq)	1.06	0.89	1.14	1.50	1.49
b_{nl}, late net balance	Site A	(mweq)	0.00	0.42	0.33	0.44	0.27
	Site B	(mweq)	0.00	-0.00	0.08	0.05	0.00
	Site D	(mweq)	0.01	0.00	0.13	0.00	0.00
	Glacier average	(mweq)	0.00	0.08	0.16	0.10	0.05
$b_1(ls)$, final late snow balance	Site A	(mweq)	0.00	0.09	0.07	0.00	0.00
	Site B	(mweq)	0.00	0.46	0.19	0.32	0.07
	Site D	(mweq)	0.01	0.54	0.40	0.56	0.18
	Glacier average	(mweq)	0.01	0.43	0.29	0.40	0.12
$b_a(f)$, annual firn balance	Site A	(mweq)	0.00	0.00	0.00	0.00	0.00
	Site B	(mweq)	0.00	0.00	0.00	0.00	0.00
	Site D	(mweq)	0.00	0.26	0.00	0.78	0.22
	Glacier average	(mweq)	0.00	0.15	0.00	0.45	0.13
$b_a(k)$, annual internal accumulation	Site A	(mweq)	0.00	0.00	0.00	0.00	0.00
	Site B	(mweq)	0.00	0.00	0.00	0.00	0.00
	Site D	(mweq)	0.07	0.14	0.16	0.14	0.14
	Glacier average	(mweq)	0.04	0.08	0.09	0.08	0.08

Table 30. Index-site and area-integrated reference surface balance quantities for Gulkana Glacier and Gulkana Glacier Basin, 1997–2001 hydrologic years.—Continued

[Reference surface is 1967 area-altitude distribution. **Abbreviations**: m, meters; mweq, meters water equivalent; mm-dd-yy, month-day-year; km^2, square kilometers; °C, degrees Celsius]

Parameter	Site, glacier average, or subparameter	Units	1967 reference-surface balance				
Year of area-altitude distribution determination =			1997	1998	1999	2000	2001
$b_a(i)$, annual old firn and ice balance	Site A	(mweq)	-4.85	-3.49	-4.35	-2.52	-3.97
	Site B	(mweq)	-2.30	-0.95	-1.35	-0.14	-0.99
	Site D	(mweq)	-0.49	0.00	-0.27	0.00	0.00
	Glacier average	(mweq)	-1.74	-0.89	-1.30	-0.51	-0.98
$b_a(j)$, annual internal ablation (glacier averaged)	From geothermal heat flux	(mweq)	-0.005	-0.005	-0.005	-0.005	-0.005
	From potential energy loss from ice motion	(mweq)	-0.004	-0.004	-0.004	-0.004	-0.004
	From potential energy loss from water flow (estimated)	(mweq)	-0.070	-0.056	-0.050	-0.033	-0.045
	Total	(mweq)	-0.08	-0.06	-0.06	-0.04	-0.05
b_n, net balance	Start of net balance year for glacier average	(mm-dd-yy)	08-25-96	09-28-97	08-21-98	09-03-99	08-18-00
	End of net balance year for glacier average	(mm-dd-yy)	09-27-97	08-20-98	09-02-99	08-17-00	09-03-01
	Site A	(mweq)	-5.34	-3.07	-4.44	-2.41	-4.13
	Site B	(mweq)	-2.39	-0.95	-1.27	-0.17	-1.04
	Site D	(mweq)	-0.43	0.39	0.02	0.79	0.36
	Glacier average (includes $b_a(j)$)	(mweq)	-1.90	-0.64	-1.19	-0.08	-0.86
b_a, annual balance (Oct. 1 to Sept. 30)	Site A	(mweq)	-4.90	-3.40	-4.37	-2.59	-3.97
	Site B	(mweq)	-2.41	-0.49	-1.62	-0.01	-1.24
	Site D	(mweq)	-0.78	0.93	-0.25	1.08	-0.02
	Glacier average (includes $b_a(j)$)	(mweq)	-2.02	-0.29	-1.42	0.09	-1.09
ELA, equilibrium-line altitude		(m)	1,867	1,787	1,831	1,705	1,794
Accumulation area		(km^2)	8.58	10.66	9.56	12.34	10.52
Ablation area		(km^2)	10.88	8.79	9.90	7.12	8.94
AAR, accumulation-area ratio			0.44	0.55	0.49	0.63	0.54
Calculated annual precipitation	Basin average	(m)	1.20	1.89	1.09	1.57	1.24
Annual basin runoff	1,125-meter stream gage	(m)	2.54	2.34	1.93	1.62	1.85
Percent of runoff from balance	Basin value	(percent)	53	19	43	3	33

Table 31. Conventional and reference surface yearly and cumulative net balances and cumulative volume changes.

[**Abbreviations**: mweq, meters water equivalent; km^3 weq, cubic kilometers water equivalent]

Year	Conventional-net balance			Reference-surface net balance		
	Yearly (mweq)	Cumulative (mweq)	Cumulative volume (km^3 weq)	Yearly (mweq)	Cumulative (mweq)	Cumulative volume (km^3 weq)
1966	-0.16	-0.16	-0.003	-0.16	-0.16	-0.003
1967	0.02	-0.14	-0.003	0.01	-0.15	-0.003
1968	-0.17	-0.31	-0.006	-0.18	-0.34	-0.007
1969	-1.00	-1.31	-0.025	-1.03	-1.37	-0.027
1970	0.39	-0.92	-0.018	0.34	-1.03	-0.020
1971	0.29	-0.63	-0.012	0.24	-0.79	-0.015
1972	-0.37	-1.00	-0.019	-0.42	-1.22	-0.024
1973	0.54	-0.46	-0.009	0.46	-0.75	-0.015
1974	-1.12	-1.58	-0.030	-1.21	-1.96	-0.038
1975	-0.25	-1.83	-0.034	-0.34	-2.30	-0.045
1976	-0.96	-2.79	-0.052	-1.05	-3.35	-0.065
1977	-0.24	-3.03	-0.056	-0.36	-3.71	-0.072
1978	-0.22	-3.25	-0.060	-0.33	-4.04	-0.079
1979	-0.56	-3.81	-0.071	-0.67	-4.71	-0.092
1980	-0.09	-3.90	-0.072	-0.20	-4.92	-0.096
1981	0.02	-3.89	-0.072	-0.07	-4.99	-0.097
1982	-0.14	-4.03	-0.075	-0.26	-5.25	-0.102
1983	0.00	-4.03	-0.074	-0.15	-5.39	-0.105
1984	-0.34	-4.36	-0.081	-0.45	-5.84	-0.114
1985	0.66	-3.70	-0.069	0.55	-5.29	-0.103
1986	0.04	-3.65	-0.068	-0.07	-5.36	-0.104
1987	-0.14	-3.79	-0.070	-0.26	-5.62	-0.109
1988	-0.20	-3.99	-0.074	-0.34	-5.96	-0.116
1989	-0.73	-4.73	-0.087	-0.88	-6.85	-0.133
1990	-0.71	-5.44	-0.100	-0.83	-7.68	-0.149
1991	-0.08	-5.52	-0.102	-0.20	-7.88	-0.153
1992	-0.23	-5.74	-0.106	-0.33	-8.21	-0.160
1993	-1.68	-7.42	-0.136	-1.82	-10.03	-0.195
1994	-0.58	-8.00	-0.147	-0.72	-10.75	-0.209
1995	-0.70	-8.70	-0.159	-0.83	-11.58	-0.225
1996	-0.46	-9.17	-0.168	-0.62	-12.20	-0.237
1997	-1.71	-10.88	-0.199	-1.90	-14.10	-0.274
1998	-0.51	-11.38	-0.208	-0.64	-14.74	-0.287
1999	-1.02	-12.40	-0.226	-1.19	-15.93	-0.310
2000	0.06	-12.35	-0.225	-0.08	-16.01	-0.311
2001	-0.68	-13.03	-0.238	-0.86	-16.87	-0.328

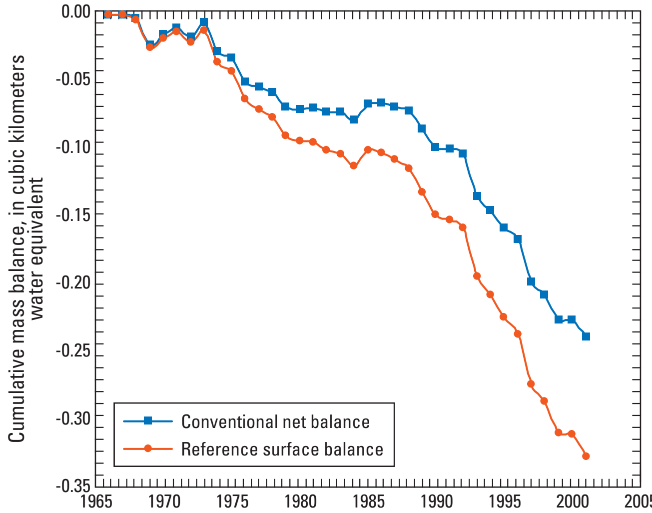

Figure 17. Cumulative conventional net balance and the cumulative reference surface net balance using the reference surface area altitude distribution of 1967, Gulkana Glacier, Alaska. Cumulative reference surface net balance volume is 38 percent more negative than the cumulative conventional net balance volume at the end of this 36-year period.

Glacier Geometry

Measurements of glacier geometry include AADs, terminus position, and glacier surface altitude. Selected AADs are shown in figure 4 and all are given in table 2. Between the LIA maximum and 2001, the area of Gulkana Glacier decreased by 8.2 km² or 33 percent. Between 1966 and 2001, the area decreased by 2.8 km² or 14 percent.

Our research shows that the terminus retreated 1,650 m between 1949 (U.S. Geological Survey 1:63,360-scale Mt. Hayes A–3 quadrangle topographic map) and 1996 at an average retreat rate of 35 m/yr. Since 1996, retreat rates have been 15–20 m/yr along the south margin where the terminus is fed by the main trunk of the glacier. Along the southwest margin, an area not fed directly by the main trunk, retreat is two to three times faster than along the south margin. Faster retreat is expected to continue along the southwest margin as source ice for this area gets cutoff by the thinning of ice coming over the icefall just upstream.

We show the measured glacier surface altitude in figure 6 and table 10. Between 1997 and 2001, the general thinning trend of the 1990s continued. However, between 2000-02, the glacier began to thicken at site D, reversing the thinning of the previous 10–15 years.

Ice Motion

At site A in the ablation zone, we measured speeds between 10–15 m/yr (table 11); higher speeds between 30–40 m/yr occur at site B near the ELA (table 12); motion at site D in the lower accumulation zone ranges between 35–50 m/yr (table 13). Motion varies seasonally with summer speeds 20–30 percent greater than winter speeds. A general slowing trend began in the early 1990s with speeds reduced by almost 40 percent since then. As stated in the methods, stake positions are known to the highest level of accuracy possible, given the leaning and bending of stakes after installation. Taken together, all sources of error yield position estimates accurate to 0.3 m, resulting in well-resolved speed estimates over seasonal and annual time scales.

Meteorology

During 1997–2001, winter, summer, and annual average air temperatures (fig. 16) were all about normal for the 1968–2001 period of record (-7 °C, +6 °C, and -3 °C respectively). Daily and monthly values with statistics are shown in figures 8–12 and tables 14–18. Daily mean temperatures reach +15 °C in summer and -30°C in winter. A small warming trend exists in the data; the annual trend is +0.16 °C/decade, the winter trend is +0.17 °C/decade, and the summer trend is +0.10 °C/decade. We compared temperature data over the 3-year interval of different instrument overlap, which indicates that the digital sensors average 1.0 °C warmer than the analog sensor (fig. 13, tables 14–15). The difference exhibits both seasonal and interannual variability, but the variability from the average of +1.0 °C is within the accuracy threshold of the analog sensor. To remedy the sensor differences or bias, 1.0 °C was added to all values in the analog record (October 1, 1967–September 30, 1998).

Over the 5 years of our study, annual average wind speed was 3.5 m/s. Daily and monthly average and period-of-record average monthly wind speeds are shown in figure 14 and tables 24–28. Seasonal variability was small, and winds were slightly stronger in summer. Maximum daily average wind speed for these years was 18.1 m/s; the maximum 15-minute average wind speed was 32.7 m/s. Wind speeds exceeded the threshold of 5–8 m/s for blowing snow (Barry, 1989) 15–20 percent of the time. Hence, wind entrainment and redeposition of snow is an important process in the mass balance of Gulkana Glacier. Wind-speed data have been collected at Gulkana Glacier only since 1996 prohibiting any analysis of trends.

Precipitation catch (figs. 8–12 and 14, tables 19–23) averages about 1 m/yr, with monthly averages of 5–6 cm from November through June, but is two to three times greater during summer and early autumn. (Note that this apparent seasonal increase in precipitation may be negated by a seasonal change in the catch efficiency; see discussion of catch efficiency later in this section.) During this 5-year study, annual precipitation catch was about equal to the 1968–2001 average. Precipitation shows significant variability at decadal time scales (fig. 16). Linear regression trend analysis for 1968–2001 shows a decrease of about 2–3 percent per decade in the annual and summer values, but no trend in the winter values. The statistical significance of these small trends was not estimated.

Detailed knowledge of the gage efficiency is highly desired, and we have analyzed the relation between gage catch and true basin precipitation. As a starting point, we compared the Gulkana data to the nearest National Weather Service station, in Paxson (station 50709704), 20 km south of the glacier at an altitude of 823 m. Precipitation recorded at Paxson data between 1975–84 and 1986–92 is approximately 50 percent lower than at Gulkana Glacier station. Correlation between the two data sets is with only a moderate Pearson correlation coefficient of 0.62 between the two daily time series. Hence, Paxson precipitation is considered a poor proxy to Gulkana Glacier basin precipitation explaining less than 40 percent of the variability of the Gulkana record.

Gage catch efficiencies vary with wind speed, direction, and the nature of the precipitation. For an identical gage at Wolverine Glacier, which has a windier environment than Gulkana, Mayo and others (1992) determined that the gage-catch efficiency was 0.31 over a 10-year period. Estimates for water years 1968–78 and 1990–2001 at Gulkana Glacier, yielded a long-term average catch efficiency of about 60 percent assuming precipitation variations over the basin, evaporation, condensation, and sublimation are insignificant. Despite the low catch efficiency, precipitation catch is useful as an indicator of true basin precipitation.

In 1996, a complete mockup of our gage and wind shield was sent to Environment Canada's Climate Processes Section, Climate Research Division, Science and Technology Branch, to calibrate the precipitation catch efficiency as a function of wind speed. They analyzed data from winter, 1999, studying 21 precipitation events (5 rain events, 6 mixed precipitation events, and 10 snow events) total. These storms each deposited more than 3 mm of precipitation and ranged in duration between 2 hours and 3 days (fig. 18). The highest average wind speeds for individual events were 6.1 m/s for rain, 5.7 m/s for mixed precipitation, and 4.8 m/s for snow, considerably less than the maximum daily average local wind speeds, but consistent with monthly average wind speeds. True precipitation for the study was estimated from a gage inside a double fenced intercomparison reference shield (DFIR). The DFIR is designated as the standard reference shield by the World Meteorological Organization for collection of true precipitation (Goodison and others, 1998) and the shield is recommended for use in the U.S. Climate Reference Network. For rain events, linear regression analysis suggests the Gulkana Glacier gage collects true precipitation when wind speeds are less than 6 m/s. For mixed rain and snow events, catch efficiency drops by 3 percent for every 1 m/s increase in wind speed, and for pure snow events, catch efficiency is reduced 10 percent for every 1 m/s increase in wind speed. Corrections have not been applied to the data based on these findings, but the statistics reveal patterns present in the data that may not be explained by true precipitation trends. Note that our statistics are weak as only 21 storm events from one winter were analyzed.

Basin Runoff

Typical summer discharge from Phelan Creek ranges from 4 to 20 m^3/s, and exhibits strong diurnal fluctuations. Winter values are more constant and range from 0.04 to 0.1 m^3/s, which is about three to four times the average contribution from geothermal and strain heating forced melt of the glacier bed (March and Trabant, 1997). Record peak discharge is 65 m^3/s (Linn and others, 1997). The 1997–2001 discharge records are described fully with the Alaska water data in the USGS Water-Data Report annual series AK-97-1 to AK-01-1 (U.S. Geological Survey, 1968–2002). The low frequency of discharge measurements coupled with the poor quality of gage-height record and the changeable nature of the creekbed result in a discharge record that was rated as poor, meaning the standard error is greater than ±7.5 percent of the true value (Linn and others, 1997). The standard error of the daily discharge values at Phelan Creek gaging station during summer open-water conditions previously was estimated at 10 percent, except for those periods when discharge was estimated, in which case a 20 percent standard error was assumed (R. Kemnitz, U.S. Geological Survey, oral commun., 1997). These estimates of error are considered generally applicable for the discharge record discussed in this report.

Daily mean discharge data were converted to runoff by dividing the discharge values by the basin area (figs. 8–12, tables 32–36). Runoff is estimated for the frozen period (from about October 1 to May 31) on the basis of air temperature, precipitation, and a few winter discharge measurements. During this time, runoff typically undergoes a gradual decline, referred to as the winter recession, with little interannual variability. From pre-1996 data, we estimate winter runoff standard errors to be less than ±0.2 mm/d with increasing errors up to ±5 mm/d coinciding with the onset of the melt season by early June.

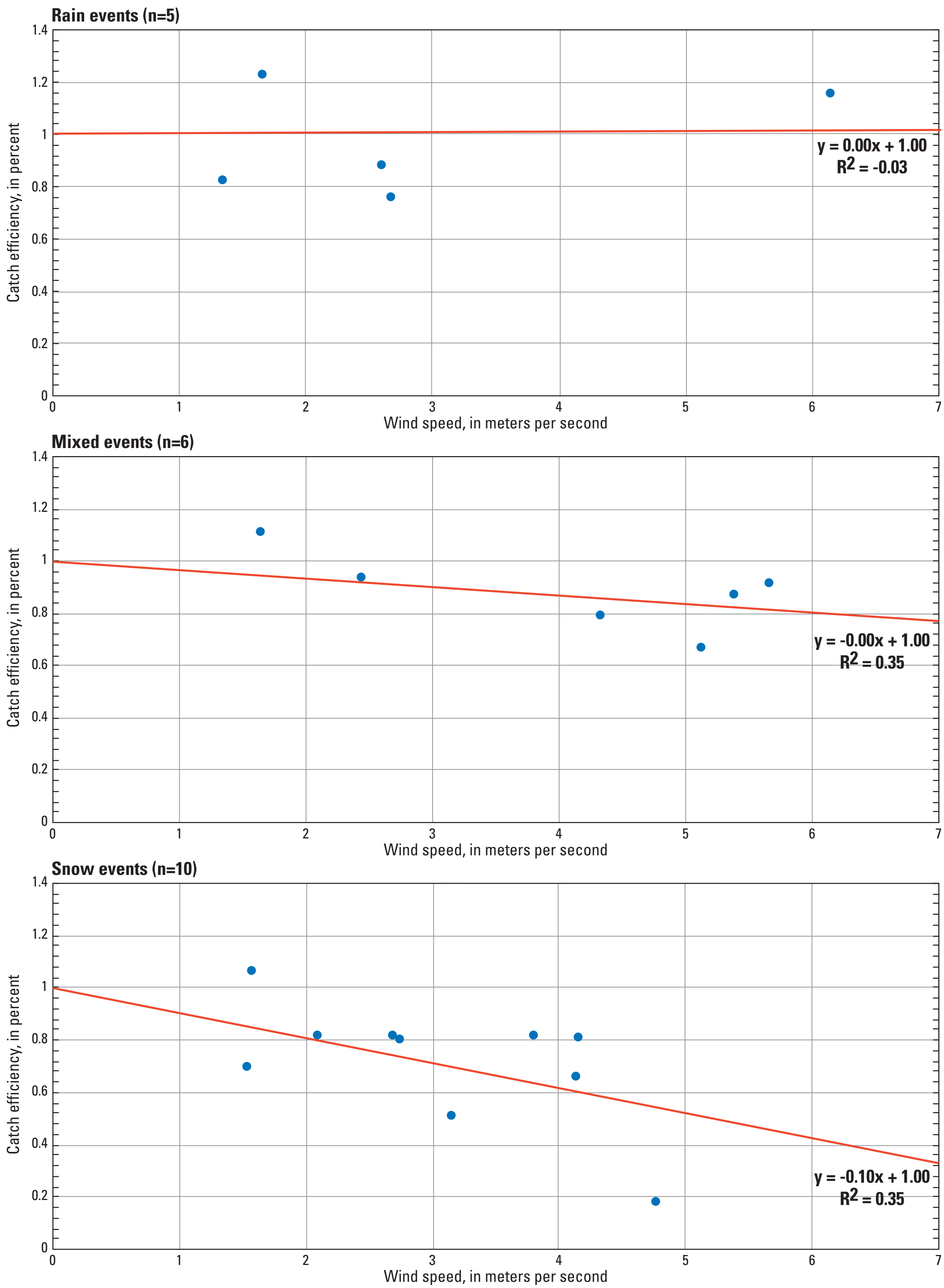

Figure 18. Precipitation gage catch efficiency relative to wind speed of the U.S. Geological Survey gage shield type in the Gulkana Glacier basin, Alaska, compared to the double fenced intercomparison reference shield for precipitation events greater than 3 millimeters during the winter 1997–98 at Toronto, Ontario.

Table 32. Daily mean, monthly, and annual runoff from the Gulkana Glacier Basin, 1997 hydrologic year.

[Values in millimeters, averaged over the basin; except standardized values which are in units of standard deviation. Data in parentheses ( ) indicate value is estimated (see text for explanation)]

Day	1996			1997									Annual
	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	
1	(0.8)	(0.5)	(0.5)	(0.4)	(0.3)	(0.3)	(0.2)	(0.5)	1.2	38.1	17.2	22.9	
2	(0.7)	(0.5)	(0.5)	(0.4)	(0.3)	(0.3)	(0.2)	(0.5)	0.9	36.5	17.4	16.2	
3	(0.7)	(0.5)	(0.5)	(0.4)	(0.3)	(0.3)	(0.2)	(0.5)	1.5	34.6	17.7	14.4	
4	(0.7)	(0.5)	(0.5)	(0.4)	(0.3)	(0.3)	(0.2)	(0.4)	3.3	40.8	16.3	12.3	
5	(0.8)	(0.5)	(0.5)	(0.4)	(0.3)	(0.3)	(0.2)	(0.4)	6.3	37.6	20.7	10.8	
6	(0.8)	(0.5)	(0.5)	(0.4)	(0.3)	(0.3)	(0.2)	(0.4)	9.4	33.9	16.5	10.3	
7	(0.8)	(0.5)	(0.5)	(0.4)	(0.3)	(0.3)	(0.2)	(0.4)	12.9	41.4	20.0	10.6	
8	(0.8)	(0.5)	(0.5)	(0.4)	(0.3)	(0.3)	(0.2)	(0.4)	9.4	36.9	21.4	11.2	
9	(0.7)	(0.5)	(0.5)	(0.4)	(0.3)	(0.3)	(0.2)	(0.5)	9.3	26.9	22.2	10.6	
10	(0.7)	(0.5)	(0.5)	(0.4)	(0.3)	(0.2)	(0.2)	(0.5)	7.1	23.3	24.3	12.9	
11	(0.7)	(0.5)	(0.5)	(0.4)	(0.3)	(0.2)	(0.2)	(0.5)	7.3	21.8	30.9	12.7	
12	(0.7)	(0.6)	(0.5)	(0.4)	(0.3)	(0.2)	(0.2)	(0.5)	9.6	26.8	64.7	12.4	
13	(0.7)	(0.6)	(0.5)	(0.4)	(0.3)	(0.2)	(0.2)	(0.5)	10.6	28.7	103.0	10.3	
14	(0.7)	(0.6)	(0.5)	(0.4)	(0.3)	(0.2)	(0.2)	(0.5)	11.2	29.0	45.6	7.9	
15	(0.7)	(0.7)	(0.5)	(0.4)	(0.3)	(0.2)	(0.2)	(0.5)	13.6	33.4	34.0	7.0	
16	(0.7)	(0.7)	(0.5)	(0.4)	(0.3)	(0.2)	(0.2)	(0.5)	14.4	23.7	34.9	6.1	
17	(0.6)	(0.7)	(0.5)	(0.4)	(0.3)	(0.2)	(0.2)	(0.5)	14.9	20.7	22.5	5.0	
18	(0.6)	(0.7)	(0.5)	(0.4)	(0.3)	(0.2)	(0.2)	(0.6)	18.6	19.7	20.3	4.2	
19	(0.6)	(0.7)	(0.5)	(0.4)	(0.3)	(0.2)	(0.2)	(0.6)	19.3	18.8	16.6	3.0	
20	(0.6)	(0.6)	(0.5)	(0.4)	(0.3)	(0.2)	(0.2)	(0.7)	19.7	23.2	13.0	2.3	
21	(0.6)	(0.6)	(0.5)	(0.4)	(0.3)	(0.2)	(0.2)	(1.2)	23.1	24.7	11.2	2.0	
22	(0.6)	(0.6)	(0.5)	(0.4)	(0.3)	(0.2)	(0.2)	(1.9)	28.0	27.3	14.8	2.6	
23	(0.6)	(0.6)	(0.5)	(0.4)	(0.3)	(0.2)	(0.2)	(1.3)	30.5	34.2	18.4	3.4	
24	(0.6)	(0.6)	(0.5)	(0.4)	(0.3)	(0.2)	(0.3)	1.0	26.4	41.7	16.3	4.4	
25	(0.6)	(0.6)	(0.5)	(0.4)	(0.3)	(0.2)	(0.3)	1.0	26.0	58.9	24.9	3.5	
26	(0.6)	(0.5)	(0.5)	(0.4)	(0.3)	(0.2)	(0.4)	1.2	24.5	35.6	22.8	3.3	
27	(0.6)	(0.5)	(0.5)	(0.3)	(0.3)	(0.2)	(0.4)	1.4	25.2	34.1	20.7	2.6	
28	(0.6)	(0.5)	(0.5)	(0.3)	(0.3)	(0.2)	(0.5)	1.5	28.8	35.2	14.3	2.2	
29	(0.5)	(0.5)	(0.4)	(0.3)		(0.2)	(0.5)	2.2	30.0	22.5	13.2	1.9	
30	(0.5)	(0.5)	(0.4)	(0.3)		(0.2)	(0.5)	3.4	27.3	21.0	13.6	1.7	
31	(0.5)	(0.5)	(0.4)	(0.3)		(0.2)		1.4		22.1	21.8		
Total	20	17	15	12	8	7	8	27	470	953	771	231	2,541
Departure from normal	-6	4	5	4	3	2	2	-14	136	220	172	84	612
Standardized value	-0.8	1.0	1.6	1.5	1.1	0.7	1.2	-0.5	1.3	1.3	0.7	1.0	1.6

Table 33. Daily mean, monthly, and annual runoff from the Gulkana Glacier Basin, 1998 hydrologic year.

[Values in millimeters, averaged over the basin; except standardized values which are in units of standard deviation. Data in parentheses ( ) indicate value is estimated (see text for explanation)]

Day	1997			1998									Annual
	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	
1	1.5	0.6	0.4	(0.2)	(0.2)	(0.2)	(0.2)	(0.2)	(7.4)	19.0	35.2	3.4	
2	(1.3)	0.6	0.4	(0.2)	(0.2)	(0.2)	(0.2)	(0.2)	(7.7)	29.7	36.5	2.2	
3	(1.2)	0.5	0.3	(0.2)	(0.2)	(0.2)	(0.2)	(0.2)	(8.5)	32.6	34.5	2.1	
4	(1.2)	0.5	0.4	(0.2)	(0.2)	(0.2)	(0.2)	(0.2)	7.0	29.1	30.0	2.1	
5	(1.1)	0.5	0.3	(0.2)	(0.2)	(0.2)	(0.2)	(0.2)	6.1	17.6	30.0	2.0	
6	(1.0)	0.5	0.3	(0.2)	(0.2)	(0.2)	(0.2)	(0.2)	6.8	28.0	37.0	2.5	
7	(1.0)	0.5	0.3	(0.2)	(0.2)	(0.2)	(0.2)	(0.2)	9.3	44.8	33.6	2.9	
8	(0.9)	0.5	0.3	(0.2)	(0.2)	(0.2)	(0.2)	(0.2)	15.3	32.7	34.4	3.2	
9	(0.9)	0.5	0.3	(0.2)	(0.2)	(0.2)	(0.2)	(0.2)	17.4	31.7	24.7	3.1	
10	(0.9)	0.5	0.3	(0.2)	(0.2)	(0.2)	(0.2)	(0.2)	11.7	33.7	20.4	3.2	
11	(0.8)	0.5	0.3	(0.2)	(0.2)	(0.2)	(0.2)	(0.2)	8.8	30.0	19.1	2.9	
12	(0.7)	0.5	0.3	(0.2)	(0.2)	(0.2)	(0.2)	(0.2)	7.4	22.6	19.7	3.3	
13	(0.7)	0.5	0.3	(0.2)	(0.2)	(0.2)	(0.2)	(0.2)	7.6	27.6	24.2	3.1	
14	(0.7)	0.5	0.3	(0.2)	(0.2)	(0.2)	(0.2)	(0.2)	8.7	30.7	24.5	1.5	
15	(0.8)	0.5	0.3	(0.2)	(0.2)	(0.2)	(0.2)	(0.2)	10.0	37.2	23.9	1.3	
16	(0.9)	0.5	0.3	(0.2)	(0.2)	(0.2)	(0.2)	(0.2)	10.5	34.8	39.3	1.2	
17	(0.9)	0.4	0.3	(0.2)	(0.2)	(0.2)	(0.2)	(0.2)	12.5	41.1	34.0	1.7	
18	(0.9)	0.4	0.3	(0.2)	(0.2)	(0.2)	(0.2)	(0.2)	13.9	42.4	23.8	3.3	
19	(0.9)	0.4	0.3	(0.2)	(0.2)	(0.2)	(0.2)	(0.3)	13.4	45.5	20.3	5.0	
20	(0.9)	0.4	0.3	(0.2)	(0.2)	(0.2)	(0.2)	(0.3)	14.0	47.4	17.7	6.3	
21	0.8	0.4	0.3	(0.2)	(0.2)	(0.2)	(0.2)	(0.5)	15.5	43.5	15.2	4.5	
22	0.8	0.4	0.3	(0.2)	(0.2)	(0.2)	(0.2)	(0.6)	11.8	36.8	20.5	3.7	
23	0.8	0.4	0.3	(0.2)	(0.2)	(0.2)	(0.2)	(1.0)	11.9	40.7	12.8	2.9	
24	0.8	0.4	0.3	(0.2)	(0.2)	(0.2)	(0.2)	(1.7)	16.5	38.1	15.8	2.0	
25	0.6	0.4	0.2	(0.2)	(0.2)	(0.2)	(0.2)	(2.5)	15.5	37.4	13.2	1.5	
26	0.8	0.4	(0.2)	(0.2)	(0.2)	(0.2)	(0.2)	(3.9)	14.6	36.5	11.2	1.1	
27	0.7	0.4	(0.2)	(0.2)	(0.2)	(0.2)	(0.2)	(6.2)	15.8	33.5	8.6	0.9	
28	0.7	0.4	(0.2)	(0.2)	(0.2)	(0.2)	(0.2)	(8.5)	18.4	41.0	6.1	0.7	
29	0.6	0.4	(0.2)	(0.2)		(0.2)	(0.2)	(10.1)	22.0	39.4	4.8	(0.6)	
30	0.6	0.4	(0.2)	(0.2)		(0.2)	(0.2)	(9.3)	22.5	36.8	3.9	0.6	
31	0.6	0.4	(0.2)	(0.2)		(0.2)		(8.5)		37.3	3.9		
Total	27	14	9	6	6	6	6	57	369	1,079	679	75	2,332
Departure from normal	0	1	-1	-1	-0	1	1	15	34	346	80	-71	404
Standardized value	0.1	0.2	-0.3	-0.5	-0.1	0.3	0.4	0.5	0.3	2.0	0.3	-0.9	1.0

Table 34. Daily mean, monthly, and annual runoff from the Gulkana Glacier Basin, 1999 hydrologic year.

[Values in millimeters, averaged over the basin; except standardized values which are in units of standard deviation. Data in parentheses ( ) indicate value is estimated (see text for explanation)]

Day	1998			1999									Annual
	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	
1	(0.6)	(0.3)	(0.2)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	0.6	30.5	24.3	8.1	
2	(0.6)	(0.3)	(0.2)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.7)	33.0	22.9	9.9	
3	(0.6)	(0.3)	(0.2)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	0.7	40.9	25.1	10.3	
4	(0.5)	(0.3)	(0.2)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	0.7	37.1	26.3	7.0	
5	(0.5)	(0.3)	(0.2)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	1.3	26.8	33.0	5.5	
6	(0.5)	(0.3)	(0.2)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	3.0	18.6	31.4	4.9	
7	(0.5)	(0.3)	(0.2)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	5.4	19.3	20.4	4.1	
8	(0.5)	(0.3)	(0.2)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	8.6	23.6	17.5	4.3	
9	(0.5)	(0.3)	(0.2)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	9.8	31.4	8.7	4.3	
10	(0.5)	(0.3)	(0.2)	(0.1)	(0.1)	(0.1)	(0.1)	(0.2)	10.7	26.8	8.0	3.3	
11	(0.4)	(0.3)	(0.2)	(0.1)	(0.1)	(0.1)	(0.1)	(0.2)	13.3	31.0	8.7	3.9	
12	(0.4)	(0.3)	(0.2)	(0.1)	(0.1)	(0.1)	(0.1)	(0.2)	18.9	25.1	19.0	3.6	
13	(0.4)	(0.3)	(0.2)	(0.1)	(0.1)	(0.1)	(0.1)	(0.2)	25.8	25.1	45.4	4.6	
14	(0.4)	(0.3)	(0.2)	(0.1)	(0.1)	(0.1)	(0.1)	(0.2)	31.6	27.4	28.4	4.5	
15	(0.4)	(0.3)	(0.2)	(0.1)	(0.1)	(0.1)	(0.1)	(0.2)	29.3	27.9	31.5	3.5	
16	(0.4)	(0.3)	(0.2)	(0.1)	(0.1)	(0.1)	(0.1)	(0.2)	27.4	18.6	24.5	2.5	
17	(0.4)	(0.3)	(0.2)	(0.1)	(0.1)	(0.1)	0.1)	(0.2)	28.5	20.6	22.1	4.5	
18	(0.4)	(0.2)	(0.2)	(0.1)	(0.1)	(0.1)	(0.1)	(0.2)	27.5	20.1	22.0	4.2	
19	(0.4)	(0.2)	(0.2)	(0.1)	(0.1)	(0.1)	(0.1)	(0.2)	29.8	13.9	17.7	2.9	
20	(0.4)	(0.2)	(0.2)	(0.1)	(0.1)	(0.1)	(0.1)	(0.3)	29.4	18.5	13.2	3.0	
21	(0.4)	(0.2)	(0.2)	(0.1)	(0.1)	(0.1)	(0.1)	(0.4)	23.8	19.9	13.5	2.0	
22	(0.4)	(0.2)	(0.2)	(0.1)	(0.1)	(0.1)	(0.1)	(0.6)	22.3	14.8	10.7	1.9	
23	(0.4)	(0.2)	(0.2)	(0.1)	(0.1)	(0.1)	(0.1)	(0.8)	25.2	11.1	9.5	1.7	
24	(0.4)	(0.2)	(0.2)	(0.1)	(0.1)	(0.1)	(0.1)	(0.9)	25.6	11.6	8.6	1.7	
25	(0.4)	(0.2)	(0.2)	(0.1)	(0.1)	(0.1)	(0.1)	(0.8)	25.1	14.7	6.7	1.6	
26	(0.4)	(0.2)	(0.2)	(0.1)	(0.1)	(0.1)	(0.1)	(0.8)	24.9	17.9	6.1	1.5	
27	(0.4)	(0.2)	(0.2)	(0.1)	(0.1)	(0.1)	(0.1)	(0.7)	22.3	18.6	7.2	1.4	
28	(0.4)	(0.2)	(0.2)	(0.1)	(0.1)	(0.1)	(0.1)	(0.6)	28.1	14.3	8.2	1.3	
29	(0.4)	(0.2)	(0.2)	(0.1)		(0.1)	(0.1)	(0.6)	31.5	13.3	6.6	(1.3)	
30	(0.4)	(0.2)	(0.2)	(0.1)		(0.1)	(0.1)	(0.6)	34.2	16.2	6.5	(1.2)	
31	(0.4)	(0.2)	(0.1)	(0.1)		(0.1)		(0.6)		19.0	8.3		
Total	14	8	6	3	3	3	3	11	566	688	542	115	1,960
Departure from normal	- 13	- 5	- 4	- 5	- 3	- 2	- 2	- 31	232	- 46	- 57	- 32	32
Standardized value	- 1.6	- 1.3	- 1.2	- 1.6	- 1.3	- 1.1	- 1.1	- 1.0	2.2	- 0.3	- 0.2	- 0.4	0.1

Table 35. Daily mean, monthly, and annual runoff from the Gulkana Glacier Basin, 2000 hydrologic year.

[Values in millimeters, averaged over the basin; except standardized values which are in units of standard deviation. Data in parentheses ( ) indicate value is estimated (see text for explanation)]

Day	1999			2000									Annual
	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	
1	(1.3)	(0.6)	(0.4)	(0.3)	(0.3)	(0.3)	(0.2)	(0.3)	(1.3)	25.0	15.4	2.0	
2	(1.3)	(0.6)	(0.4)	(0.3)	(0.3)	(0.3)	(0.2)	(0.3)	(1.7)	21.2	16.1	1.7	
3	(1.2)	(0.6)	(0.4)	(0.3)	(0.3)	(0.3)	(0.2)	(0.3)	2.6)	19.9	22.3	1.3	
4	(1.1)	(0.6)	(0.4)	(0.3)	(0.3)	(0.3)	(0.2)	(0.3)	4.3	21.7	25.1	1.1	
5	(1.1)	(0.6)	(0.4)	(0.3)	(0.3)	(0.3)	(0.2)	(0.3)	6.6	21.7	19.0	0.9	
6	(1.1)	(0.6)	(0.4)	(0.3)	(0.3)	(0.3)	(0.2)	(0.3)	9.8	20.4	18.3	0.9	
7	(1.1)	(0.5)	(0.4)	(0.3)	(0.3)	(0.3)	(0.2)	(0.4)	8.3	23.8	17.2	0.9	
8	(1.0)	(0.5)	(0.4)	(0.3)	(0.3)	(0.3)	(0.2)	(0.4)	9.2	26.0	17.5	0.9	
9	(0.9)	(0.5)	(0.4)	(0.3)	(0.3)	(0.3)	(0.2)	(0.4)	11.5	24.2	16.0	0.9	
10	(0.9)	(0.5)	(0.4)	(0.3)	(0.3)	(0.3)	(0.2)	(0.4)	12.0	28.8	13.1	0.7	
11	(0.9)	(0.5)	(0.4)	(0.3)	(0.3)	(0.2)	(0.2)	(0.4)	12.6	32.8	12.3	0.7	
12	(0.9)	(0.5)	(0.4)	(0.3)	(0.3)	(0.2)	(0.2)	(0.4)	13.7	36.9	14.0	0.7	
13	(0.9)	(0.5)	(0.4)	(0.3)	(0.3)	(0.2)	(0.2)	(0.4)	13.7	33.4	17.5	0.7	
14	(0.9)	(0.5)	(0.4)	(0.3)	(0.3)	(0.2)	(0.2)	(0.4)	13.0	34.5	17.1	0.7	
15	(0.9)	(0.5)	(0.4)	(0.3)	(0.3)	(0.2)	(0.2)	(0.4)	12.4	32.9	11.0	0.7	
16	(0.8)	(0.5)	(0.4)	(0.3)	(0.3)	(0.2)	(0.2)	(0.4)	10.9	32.7	10.3	0.9	
17	(0.8)	(0.5)	(0.4)	(0.3)	(0.3)	(0.2)	(0.2)	(0.5)	11.3	44.8	9.8	1.0	
18	(0.8)	(0.5)	(0.4)	(0.3)	(0.3)	(0.2)	(0.2)	(0.6)	11.0	37.7	11.1	0.9	
19	(0.8)	(0.5)	(0.4)	(0.3)	(0.3)	(0.2)	(0.2)	(0.7)	9.6	30.0	7.7	0.9	
20	(0.7)	(0.5)	(0.4)	(0.3)	(0.3)	(0.2)	(0.2)	(0.6)	7.6	25.0	6.3	0.9	
21	(0.7)	(0.5)	(0.4)	(0.3)	(0.3)	(0.2)	0.2)	(0.6)	6.5	19.9	5.8	1.2	
22	(0.7)	(0.5)	(0.4)	(0.3)	(0.3)	(0.2)	(0.2)	(0.7)	7.6	22.6	3.2	12.0	
23	(0.7)	(0.4)	(0.4)	(0.3)	(0.3)	(0.2)	(0.2)	(0.8)	11.3	23.6	2.3	7.3	
24	(0.7)	(0.4)	(0.4)	(0.3)	(0.3)	(0.2)	(0.2)	(0.7)	13.5	22.5	2.4	6.8	
25	(0.7)	(0.4)	(0.4)	(0.3)	(0.3)	(0.2)	0.2)	(0.7)	14.0	22.9	1.8	7.8	
26	(0.7)	(0.4)	(0.3)	(0.3)	(0.3)	(0.2)	0.2)	(0.7)	17.2	21.7	1.8	5.6	
27	0.6)	(0.4)	(0.3)	(0.3)	(0.3)	(0.2)	(0.2)	(0.6)	21.1	17.9	1.6	3.4	
28	(0.6)	(0.4)	(0.3)	(0.3)	(0.3)	(0.2)	(0.2)	(0.7)	23.8	17.5	1.9	(2.6)	
29	(0.6)	(0.4)	(0.3)	(0.3)	(0.3)	(0.2)	(0.2)	(0.8)	22.2	15.9	2.8	(2.2)	
30	(0.6)	(0.4)	(0.3)	(0.3)		(0.2)	0.2)	(0.9)	26.5	13.9	3.3	(2.0)	
31	(0.6)	(0.4)	(0.3)	(0.3)		(0.2)		(1.1)		14.1	3.0		
Total	27	15	12	9	9	7	6	17	347	786	327	70	1,631
Departure from normal	0	2	2	2	3	2	1	- 25	13	52	-272	- 76	- 298
Standardized value	0.0	0.4	0.6	0.6	1.2	0.8	0.4	- 0.8	0.1	0.3	- 1.2	- 0.9	- 0.8

Table 36. Daily mean, monthly, and annual runoff from the Gulkana Glacier Basin, 2001 hydrologic year.

[Values in millimeters, averaged over the basin; except standardized values which are in units of standard deviation. Data in parentheses ( ) indicate value is estimated (see text for explanation)]

Day	2000			2001									Annual
	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	
1	1.8	0.8	0.5	0.4	0.3	0.2	0.2	0.2	5.7	20.8	26.6	7.9	
2	1.7	0.8	0.5	0.4	0.2	0.2	0.2	0.2	5.2	21.7	21.8	7.9	
3	1.7	0.8	0.5	0.3	0.2	0.2	0.2	0.2	4.4	19.2	19.7	6.8	
4	1.6	0.8	0.5	0.3	0.2	0.2	0.2	0.2	5.1	17.8	18.7	5.3	
5	1.6	0.8	0.5	0.3	0.2	0.2	0.2	0.2	6.1	19.9	16.5	4.2	
6	1.6	0.7	0.5	0.3	0.2	0.2	0.2	0.2	7.9	16.2	16.5	2.8	
7	1.5	0.7	0.5	0.3	0.2	0.2	0.2	0.2	8.2	14.2	16.0	2.4	
8	1.3	0.7	0.5	0.3	0.2	0.2	0.2	0.2	6.9	13.1	15.4	2.1	
9	1.3	0.7	0.4	0.3	0.2	0.2	0.2	0.2	7.1	11.8	15.0	2.1	
10	1.3	0.7	0.5	0.3	0.2	0.2	0.2	0.2	7.9	12.7	15.6	2.4	
11	1.3	0.7	0.4	0.3	0.2	0.2	0.2	0.2	9.4	12.0	14.9	2.4	
12	1.2	0.6	0.4	0.3	0.2	0.2	0.2	0.2	12.0	11.3	15.0	2.2	
13	1.2	0.6	0.4	0.3	0.2	0.2	0.2	0.3	9.4	12.1	16.8	2.1	
14	1.1	0.6	0.4	0.3	(0.2)	0.2	0.2	0.3	9.6	14.7	18.1	2.0	
15	1.1	0.6	0.4	0.3	0.2	0.2	0.2	0.3	10.6	16.6	17.2	2.0	
16	1.1	0.6	0.4	0.3	0.2	0.2	0.2	0.4	10.1	17.4	19.6	2.0	
17	1.1	0.6	0.4	0.3	0.2	0.2	0.2	0.5	10.6	17.5	17.6	2.8	
18	1.0	0.6	0.4	0.3	0.2	0.2	0.2	0.7	11.0	21.0	17.6	3.3	
19	1.0	0.6	0.4	0.3	0.2	0.2	0.2	1.0	10.9	20.4	16.4	3.1	
20	(1.0)	0.6	0.4	0.3	0.2	0.2	0.2	(1.7)	15.2	29.0	16.9	3.3	
21	(1.0)	0.6	0.4	0.3	0.2	0.2	0.2	(2.2)	19.2	37.5	22.2	3.0	
22	0.9	0.5	0.4	0.3	0.2	0.2	0.2	(1.8)	17.5	48.5	21.2	2.1	
23	0.9	0.5	0.4	0.3	0.2	0.2	0.2	(1.3)	19.9	47.0	15.9	2.0	
24	0.9	0.5	0.4	0.3	0.2	0.2	0.2	(1.1)	19.8	45.1	15.6	1.8	
25	0.9	0.5	0.4	0.3	0.2	0.2	0.2	1.0	17.7	39.7	14.6	1.7	
26	0.9	0.5	0.4	0.3	0.2	0.2	0.2	1.1	25.1	37.5	12.5	1.6	
27	(0.9)	0.5	0.4	0.3	0.2	0.2	0.2	1.3	23.1	33.4	11.6	1.5	
28	(0.9)	0.5	0.4	0.3	0.2	0.2	0.2	1.8	23.8	29.2	12.2	1.5	
29	(0.9)	0.5	0.4	0.3		0.2	0.2	1.9	19.7	33.2	12.0	1.5	
30	0.9	0.5	0.3	0.3		0.2	0.2	2.2	20.4	47.4	11.2	1.3	
31	0.9	0.5	0.4	0.3		0.2		3.7		42.6	10.2		
Total	37	19	13	10	6	6	6	27	380	781	511	87	1,882
Departure from normal	10	6	3	2	- 0	1	1	- 15	45	47	- 88	- 59	- 47
Standardized value	1.2	1.4	1.0	0.6	- 0.0	0.3	0.4	- 0.5	0.4	0.3	- 0.4	- 0.7	- 0.1

Mean annual runoff for the period of record is about 1.9 m (fig. 16). Monthly runoff normally peaks in July (0.7 m) with August a close second (0.6 m), and June a distant third (0.3 m). The cumulative sum of estimated winter runoff represents about 15 percent of the annual runoff. Annual runoff was well above normal in 1997 and 1998, about normal in 1999 and 2001, and well below normal in 2000. The average runoff for the 5-year period (1997–2001) shown in figure 16 is 9 percent greater than the average prior to 1997. We estimate a 12 percent augmentation in runoff attributable to glacier shrinkage when considering all available data. Recent data (1997–2001) demonstrate a larger, 22 percent augmentation of runoff. The augmentation is the ratio of the glacier averaged mass balance (converted to a basin-averaged value) to the basin averaged runoff for similar time periods and expressed as a percent.

Summary

The 1997–2001 measured winter snow, maximum winter snow, summer, net, and annual mass balances in the Gulkana Glacier basin were evaluated on the basis of meteorological, hydrological, and glaciological data. Conventional and reference surface mass balances are reported.

Seasonal values for the mass balance, surface altitude, and ice motion at index measurement sites and the glacier wide mass balance are reported. Winter balance for the 5-year period discussed in this report was about equal to the previous 31-year average (1.1 mweq) and exhibits no overall trend. The 1997–2001 average net balance of -0.77 mweq was about 2.5 times more negative than the previous 31-year average of -0.30 mweq. The trend indicates a decreasing net balance by -0.2 mweq/decade. The 1997 net balance, -1.71 mweq, was the most negative year of record. The 1997–2001 average summer balance of -1.92 mweq was almost 1 standard deviation below the previous 31-year average of -1.41 mweq. The trend indicates a decreasing summer balance by -0.18 mweq/decade. The 1997 summer balance, -2.76 mweq, was the most negative year of record.

Daily values of air temperature, precipitation catch, and wind speed from the Gulkana Glacier weather station are reported. Evaluation of a permanent air temperature sensor change is reported. Mean annual air temperature at an altitude of 1,480 m was about -3.1 °C for the 1968–2001 and indicates a warming trend of +0.16 °C/decade, mostly due to increased winter temperatures. This translates into mean annual temperature at the 1966–2001 average ELA of 5.0° C. Precipitation catch averages 1.0 m for 1968–2001, with a drying trend of 2–3 percent per decade in the annual and summer values, but no trend in the winter values. Catch efficiency of the gage is only 60 percent on average, so true precipitation is about 60 percent greater than the catch, or on average 1.6 m. Gage testing at a facility in Canada showed that the catch efficiency of our wind-shielded gage for solid precipitation is reduced from 100 percent by about 10 percent for every 1 m/s increase in wind speed. Winds average 3.5 m/s but are greater than 5–8 m/s, the threshold for blowing snow, 15–20 percent of the time.

Annual values for the area altitude distribution, equilibrium line altitude, and accumulation area ratio are reported. Additionally, an AAD was reported for 1900 and annually from 1966 to 2001. Annual terminus/lower-glacier position is included plus that for 1985 and 1993. AADs show a decline in area since the peak of the Little Ice Age in 1900. The rate of decline has been faster since 1993. As of 2001, the glacier has lost about 8.2 km² or 33 percent of its area since 1900, and about 2.8 km² or 14 percent of its area since 1966. The 1997–2001 average AAR is 0.53 compared to the previous 31-year average of 0.60. The 1997–2001 average ELA is 35 m higher than the previous 31-year average of 1,760 m. The 1997–2001 glacier surface altitude data demonstrates continued glacier-wide thinning trend of the 1990s, except for site D where recent thickening has been measured.

Ice motion for 1997–2001 was 10–15 m/yr at site A in the ablation zone, 30–40 m/yr at site B in the central reach of the glacier, and 35–50 m/yr at site D in the lower accumulation zone. A general slowing trend occurred through the 1990s with a reduction in speed of about 40 percent since 1990. Motion varies seasonally with summer speeds 20–30 percent greater than winter speeds.

From 1949 to 1996, the terminus retreated about 1,650 m yielding an average retreat rate of 35 m/yr. Since then it has been retreating 15–20 m/yr along the south margin where the terminus is best defined and fed by the main trunk of the glacier and two to three times faster along the southwest margin. Faster retreat is expected to continue along the southwest margin as source ice for this area is cutoff by thinning ice coming over the icefall just upstream.

Runoff for 1997–2001 was 7 percent greater than the previous period of record (1967–78, 1990–96) average, about 1.9 m. Runoff has been augmented by the shrinkage of the glacier in 19 of the total 24 years of runoff measurements. For the period of record prior to 1997, glacier shrinkage made up an average of 13 percent of the runoff. For the 5-year period of this study, 1997–2001, glacier shrinkage contributed an average of 25 percent of the runoff.

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Appendix A. Coordinate Conversions

Horizontal Coordinates

Horizontal coordinates can be converted between the local sea-level-scale system and UTM, NAD 83 datum coordinates by:

$$\text{UTM Easting} = \bar{k}X_L + 575{,}000\,\text{m}, \quad \text{(A1)}$$

and

$$\text{UTM Northing} = \bar{k}Y_L + 7{,}011{,}000\,\text{m}, \quad \text{(A2)}$$

where $\bar{k}$ is the mean horizontal scale factor between the UTM plane and sea level and X_L and Y_L are local coordinates, in meters.

The scale factor, k, at a point is a variable defined by:

$$k = \frac{0.9996}{\sin\left(100 + \frac{500{,}000 - E}{100{,}000}\right)}, \quad \text{(A3)}$$

where E is the UTM Easting of the point and the trigonometric function is evaluated in grad.

The mean scale factor used in equations 1 and 2 is the mean value of the nonlinear distribution of scale factors between the local origin and an observation point. E is approximated by the sum of the UTM Easting of the local origin (575,000 m) and X_L.

$$\bar{k} = \frac{1}{X_L}\int_{(575{,}000)}^{(575{,}000+X_L} k\,dE\,. \quad \text{(A4)}$$

Equation 5 is accurate within about 0.1 part per million of equations from U.S. Departments of the Army and the Air Force (1951, specifically see page 219 and appendixes IV and V) and, hence, yields results accurate at the centimeter level.

The mean scale factor is estimated using Simpson's rule (Cheney and Kincaid, 1980):

$$\bar{k} = \frac{0.9996}{6}\left[\frac{1}{\sin\left(100 + \frac{500{,}000 - 575{,}000}{100{,}000}\right)} + \frac{1}{\sin\left(100 + \frac{500{,}000 - 575{,}000 - ½X_L}{100{,}000}\right)} + \frac{1}{\sin\left(100 + \frac{5000{,}000 - 575{,}000 - X_L}{100{,}000}\right)}\right]. \quad \text{(A5)}$$

Vertical Coordinates

Base on the five nearest National Geodetic Survey (NGS) vertical benchmarks with stability rating of A or B, the local conversion from NGVD 29 to NAVD 88 is a constant equal to 1.64±0.01 m (the later datum being higher).

A series of Geoid models have been developed by NGS to convert between NAD 83 GPS derived ellipsoid heights and NAVD 88 orthometric heights. For Alaska these models include GEOID99 and GEOID06 (accessed June 22, 2009, at http://www.ngs.noaa.gov/TOOLS/program_descriptions.html). GEOID06 is an update of GEOID99 that covers only Alaska. These models have significant errors at Gulkana Glacier. From optical and GPS surveys, the Geoid height is generally 16–17 meters in Gulkana area. Both GEOID models generate geoid heights that typically are 1.5 m too small in the vicinity of Gulkana.

A local geoid model for Gulkana Glacier basin derived from a planar best fit between the seven best quality optical and GPS surveys of off-glacier survey monuments is:

$$\begin{aligned}\text{geoid height, in meters} &= 172.0983 \\ &+ 0.0000372429 * \text{UTM Easting} \\ &+ 0.0000238585 * \text{UTM Northing}, \quad \text{(A6)}\end{aligned}$$

where UTM coordinates are zone 6, NAD 83 datum, and:

$$\begin{aligned}\text{NGVD 29 height} &= \text{NAD 83 ellipsoid height} \\ &- \text{geoid height}\,. \quad \text{(A7)}\end{aligned}$$

The standard error of height estimates from this conversion is ±0.06 m based on measurements at 11 sites. The slope of this locally defined geoid model is similar the slope of the GEOID06.

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