Geodetic Activities During the 1996 Juneau Icefield Research Program Field Season

Edited and Compiled By

Scott R. McGee

With NSF REU Student Contributions By

Adam Hobson
Dustin Holcomb
Craig Isenberg
Jeff Kaloustian
Darren Smith
Nathan Stephenson

And JIRP Staff Contributions By

Prof. Dr.-Ing. Walter Welsch
Dipl.-Ing. Martin Lang
Universität der Bundeswehr, München
and
Scott R. McGee
Foundation for Glacier and Environmental Research

Foundation for Glacier and Environmental Research
Juneau Icefield Research Program
Seattle, Washington
and
Glaciological and Arctic Sciences Institute
University of Idaho
Moscow, Idaho

JIRP Open File Survey Report—1996

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Scott McGee, Editor

Foundation for Glacier and Environmental Research
Juneau Icefield Research Program
514 East 1st Street
Moscow, Idaho 83843
USA

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FOUNDATION FOR GLACIER AND ENVIRONMENTAL RESEARCH,
JUNEAU ICEFIELD RESEARCH PROGRAM,
SEATTLE, WASHINGTON

SUMMARY

GPS surveys were conducted at nine established sites on the Juneau Icefield, Alaska to determine movement vectors. Surface elevation, local mass balance, strain rate, and ablation data were also collected. A longitudinal movement profile at the Matthes Glacier/Llewellyn Glacier divide, first established in 1995, was extended 5 km down the Llewellyn Glacier from the divide. Additionally, the berm sequence correlation of the Taku B and Shoehorn Peak ridges was investigated and survey support was provided for the geophysics and meteorology programs.

Results of the movement surveys indicate that the flow regime of the Taku Glacier system has remained relatively stable during the past 4 years. The maximum daily movement of the various profiles surveyed in 1996 is nearly identical with previous surveys. Changes in the surface elevations however, have been more pronounced. All profiles have undergone a net lowering of the glacier surface since the implementation of GPS survey techniques in 1992.

1. INTRODUCTION

The surveying of the Juneau Icefield marked a significant milestone with the 1996 Juneau Icefield Research Program field season; that being the fiftieth consecutive year of conducting glacier movement studies. This represents one of the longest continuous studies of glacier movement in North America, and one which has greatly contributed to an increased understanding of the glaciodynamics of the Juneau Icefield and its broader implications for climate change worldwide.

This year, as in the past, the major focus of the surveying program was the annual resurvey of the standard movement profiles across the Taku/Llewellyn glacier system. These range from the Demorest Glacier, at an elevation of 1,026 meters to the Matthes/Llewellyn Divide profile at an elevation of 1,880 meters, a distance of approximately 40 kilometers. The long-term annual survey of these profiles allows a detailed analysis of the temporal flow regime of the Taku system and may help to predict future advance or retreat of the Taku Glacier.

In addition to surveying the standard movement profiles, several other special survey projects were conducted during the 1996 field season. Continuing a detailed study of Profile 4 that was initiated in 1993, strain rate and annual local mass balance data were once again collected and analyzed. Surveys were also conducted in support of the geophysics and meteorology teams. This included determining the easting, northing, and height coordinates of seismic shot points and mobile meteorological stations. The survey program also provided support for a study of the berm sequence correlation between the Taku B and Shoehorn Peak ridges. Figure 1 shows the greater Juneau Icefield region and the locations of this year's survey projects. These surveys were comprised of 12 profiles and a total of 186 discrete points. When also considering the Epoch 0 and Epoch 1 surveys of the standard movement profiles, 344 total points were surveyed this summer (see Table 1).

The surveying techniques employed on the Juneau Icefield continue to evolve and improve. For the first time, all survey work was completed using GPS equipment. Most significantly, the use of real-time GPS techniques, first initiated in 1995, allowed for efficient and highly accurate relocation of survey points from previous seasons. With the ability to reoccupy positions to within several centimeters, even in whiteout conditions, the establishment and standardization of movement profiles was greatly enhanced. The continued use of real-time GPS in subsequent years will allow for much more precise evaluations of annual movement and surface elevation changes.

As in previous years, a continuing aspect of the survey program was to provide training to students in the various theodolite, EDM, and GPS survey techniques and the methods of data reduction, analysis, and presentation. This was continued in 1996, however the major focus was on GPS methods rather than on terrestrial-based theodolite and EDM techniques. This shift away from traditional methods is due to the great advantage that GPS provides and it is foreseeable that terrestrial techniques will become obsolete in the near future.

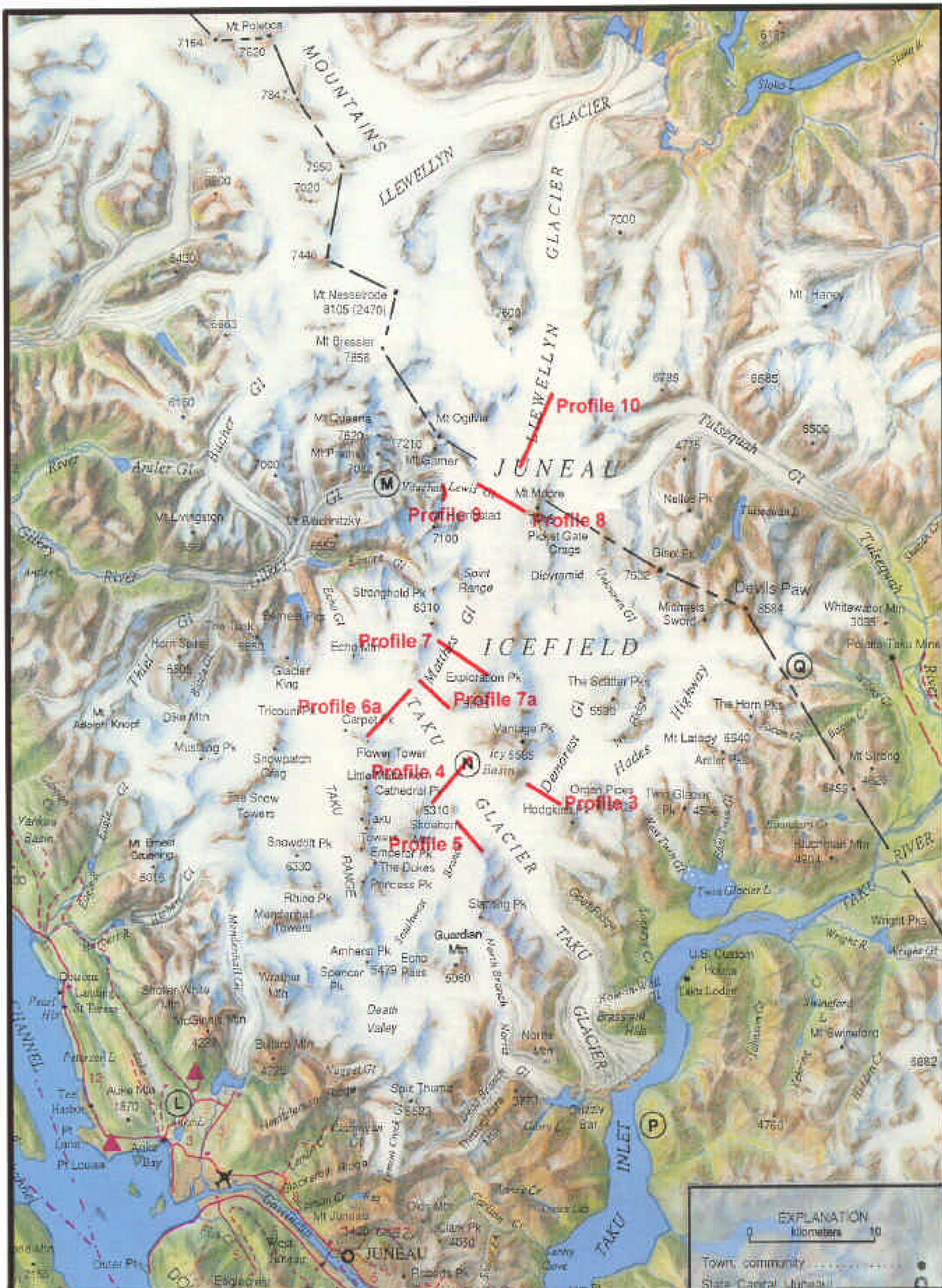


Figure 1: Map of the Juneau Icefield (Molenaar, 1990) showing the locations of profiles surveyed in 1996.

PROFILE	LOCATION	SURVEY DATES	DATA COLLECTED	SURVEY METHOD	# OF FLAGS
Profile 3	Demorest Glacier	July 27, 1996 August 5, 1996	MV AB	DGPS DGPS	11 8
Profile 4	Taku Glacier	July 28, 1996 August 6, 1996	MV, AB SR, MB, HC	RT-DGPS RT-DGPS	31 31
Profile 5	Southwest Branch	July 30, 1996 August 5, 1996	MV AB	RT-DGPS RT-DGPS	12 12
Profile 6a	Northwest Branch	July 29, 1996 August 7, 1996	MV AB	RT-DGPS RT-DGPS	14 14
Profile 7	Matthes Glacier	July 29, 1996 August 6, 1996	MV AB	DGPS DGPS	16 16
Profile 7a	Matthes Glacier	July 31, 1996 August 7, 1996	MV AB	RT-DGPS RT-DGPS	14 14
Profile 8	Matthes Glacier	August 2, 1996 August 10, 1996	MV, AB HC	RT-DGPS RT-DGPS	12 12
Profile 9	Vaughan Lewis Glacier	August 3, 1996 August 9, 1996	MV, AB HC	RT-DGPS RT-DGPS	8 8
Profile 10	Matthes/Llewellyn Divide	August 4, 1996 August 10, 1996	MV AB	RT-DGPS RT-DGPS	13 13
Taku B Ridge	Taku B @ C-10	August 7, 1996	POS	RT-DGPS	21
Shoehorn Peak Ridge	Shoehorn Peak	August 6, 1996	POS	RT-DGPS	25
Upper Demorest Seismic Line	Demorest Glacier	July 27, 1996	POS	DGPS	6
Profile 6a Seismic Center	Northwest Branch	July 29, 1996	POS	RT-DGPS	1
Profile 7a Seismic Center	Matthes Glacier	July 31, 1996	POS	RT-DGPS	1
Crest Met. Station	Taku-Llewellyn Divide	August 4, 1996	POS	RT-DGPS	1

EXPLANATION OF CODES		
Data Collected:	AB = Ablation HC = Height comparison MB = Mass balance	MV = Movement POS = Position SR = Strain rates
Survey Method:	DGPS = Rapid static differential GPS RT-DGPS = Real time differential GPS	

Table 1: Surveys conducted during the 1996 JIRP field season.

2. SURVEY METHODS

For the first time on the Juneau Icefield, all survey work was completed with GPS. Theodolite and EDM methods were not employed in the survey work in 1996, however training was provided in its use to the students in general and the survey crew in particular.

As in the past several years, standard rapid static and real-time differential GPS methods were used for the 1996 surveys. A brief description of the methodology employed will be given here so as to document the procedures used and to provide evidence of the quality and validity of the data collected.

2.1 ESTABLISHMENT OF PROFILES

One of the main goals of the surveying program is to collect data which allows quantitative comparison of surface movement from year to year. In order to ensure the consistency of year-to-year movement data, all profiles were located in roughly the same general area as in past years. See Appendix 1 for the locations of the profiles.

Two methods were used to establish the profiles; estimation and surveying-in via real-time differential GPS. The flags for all profiles, except Profiles 4, 8, and the Upper Vaughan Lewis, were placed by estimating where they were located in previous years. Additionally, all profiles had the same number of flags as in the past several years.

For those profiles that were established by estimation, the specific flag placement was determined by local landmarks, the distance across the glacier, the number of flags, and the track length of the Thiokol that was used to set the profile. For example, Profile 5 is located on the lower Southwest Branch, approximately 900 meters up-glacier from its confluence with the main Taku Glacier, between Juncture Peak and the northern spur of Peak 4066. The glacier is 2,700 meters across at this location, within which 12 flags were placed. The beginning and ending flags were approximately 250 meters from bedrock, so this equates to a flag spacing of approximately 200 meters. Since Thiokol support was used to establish this profile, the length of the Thiokol tracks was used to provide an easy way of measuring approximate distances. The track diameter of the particular Thiokol used in setting Profile 5 was 5.65 meters, so by simply counting the track revolutions and placing a flag every 33.4 revolutions, an approximate and fairly consistent flag spacing of 200 meters was maintained.

The year-to-year positional accuracy of flags placed in this manner is estimated to be approximately 30-40 meters. One advantage of this method is that, given a known profile bearing and the location of its first flag, the profile can be set in complete whiteout conditions. Naturally, this only works in those areas which are relatively crevasse-free, and which can be safely navigated by vehicle. In areas where vehicle support cannot be utilized, it is necessary to count paces in order to estimate the flag spacing. Appendix 1 details the profile bearings, number of flags, flag spacing, and other information useful for establishing each movement profile via the estimation method.

The flags for Profiles 4, 8, the Upper Vaughan Lewis, and Flag 16 of the Matthes/Llewellyn divide profile were placed with the aid of real-time differential GPS methods. The easting and northing coordinates of the 1995 Epoch 0 flag positions for these flags was programmed into the controller of the roving receiver, allowing the operator to navigate to the exact location where the flags were placed the previous year. Using this method, the flags were placed within an average of 8 centimeters from their 1995 Epoch 0 positions. An analysis of the year-to-year flag placement using this method is presented in Appendix 2.

Profile 4 has been the site of an ongoing localized surface mass balance project since July 1993. One requirement of this project is that the flags must be placed as closely as possible to their location from previous years. Because 1993 was the first year of this project, the flag locations from Epoch 0 (July 20) of that year serve as the basis for all future flag locations. The establishment of the flags in 1994 and 1995 was accomplished via classical theodolite and EDM techniques using the horizontal bearings and slope distances of the 1993 Epoch 0 theodolite/EDM survey, while the flag placement in 1996 was done via real-time differential GPS and was based on the GPS easting and northing coordinates of the 1995 Epoch 0 survey. The placement accuracy from 1993 to 1996 for Profile 4 is shown in Appendix 3. As expected, flag placement via GPS is much more precise than with theodolite/EDM techniques. Recognizing this, and the fact that real-time GPS will continue to be widely used on the Juneau Icefield, the GPS-derived easting and northing coordinates from the 1993 Epoch 0 survey now serve as the basis for the establishment of Profile 4.

2.2 GPS Survey Methods

Standard rapid-static and real-time differential GPS methods were employed for all survey work during the 1996 field season. For a complete description of the techniques used, refer to the discussion by Lang (1993) and McGee (1994). However, recognizing that these references may be unavailable to the reader of this report, an overview of the methodology used for the 1996 survey work will be given here.

After establishment of the survey profiles was completed, each profile was surveyed two times, with the time differential between the surveys ranging from 6 days to 9 days. The survey timeline is shown in Appendix 4. For all surveys, a reference receiver was centered and leveled on a tripod over an appropriate bedrock benchmark (a tabulation of GPS benchmarks is presented in Appendix 14). Concurrently, a roving receiver was placed at each flag of a movement profile, and both the reference and roving receivers collected coincident GPS data simultaneously. The antenna of the roving receiver was mounted on an aluminum monopole, which was placed in the same hole from which the survey flag was extracted. The height of the antenna above the snow surface was measured and noted. For rapid-static work, the roving receiver collected readings at 15 second intervals for 10 to 20 minutes at each flag. Real-time methods required only enough time at each flag sufficient to obtain a position fix from the reference receiver.

At the completion of a survey all data was downloaded from the roving and reference receivers for post-processing. Coordinates were then transformed from a geocentric coordinate system to one based on the JIRP projection. This is a Transverse Mercator projection centered on the Juneau Icefield. The parameters of the projection are shown in Table 2.

PARAMETER	VALUE	PROJECTION FILE
Projection	Transverse Mercator	projection transverse units meters datum wgs84 spheroid wgs84 parameters 1 /*Scale of central meridian -134 00 00 /*Longitude of origin 00 00 00 /*Latitude of origin 500000 /*False easting 0 /*False northing
Units	Meters	
Central Meridian	134° 00' 00" West	
Latitude of Origin	0° 00' 00" North	
Zone Width	3° 00' 00"	
Central Meridian Scale	1.000000	
False Easting	500,000 meters	
False Northing	0 meters	

Table 2: Parameters of the JIRP projection. The column "Projection File" lists the parameters required to transform from the JIRP projection to a different projection via Arc/Info.

3. SURVEY PROJECTS

As in past years, the major focus of the survey program was to continue the annual surveys of the standard movement profiles on the Taku Glacier and its main tributaries. Additional projects focussed on the local surface mass balance of Profile 4, surface height comparisons, and the surveying of a transect from the Taku B/Camp 10 ridge across the Taku Glacier and up the northeast ridge of Shoehorn Peak.

3.1 MOVEMENT SURVEYS

The 1996 movement surveys concentrated mainly on the Taku Glacier and were limited to previously established profiles. These ranged from Profile 3 at the junction of the Demorest and Taku Glaciers to Profile 8 on the plateau between the Storm Range and Mt. Moore. A longitudinal profile running roughly parallel to the Matthes/Llewellyn divide was established in 1995. This profile was extended north approximately 5 kilometers across the flow divide in 1996.

The adoption of GPS surveying on the Icefield has resulted in the acquisition of high accuracy data. These data are, unfortunately, not directly comparable to data collected before 1992 when lower accuracy traditional survey methods were employed. Additionally, prior to the use of real-time GPS, the somewhat random nature of flag placement in the general area of the profiles limited the accuracy with which analyses of temporal and spatial changes could be made. Simply put, rigid, quantitative year-to-year comparisons of GPS acquired data with non-GPS acquired data can not be made because the flags were never in the same exact spot from one year to the next. Because of this limitation, all statements in this report relating to surface movement and surface elevations will be limited to data collected with GPS only.

The characteristics and mode of flow of the profiles in 1996 are, in general, consistent with that found in the past several years. Movement surveys in 1996 did not reveal any unusual results. Summary statistics of the profiles are presented in Table 3. The survey timeline is shown in Appendix 4. Flag coordinates are shown in Appendix 5 and surface movement data are presented in Appendix 6.

Profile	Movement (cm^day)				Height Change (cm^day)		Mean Surface Height of Profile @ Epoch 0 (m)
	Minimum	Maximum	Mean	Standard Deviation	Mean	Standard Deviation	
3	12.4	33.0	24.4	6.2	-3.3	0.9	1028.700
4	0.9	60.1	33.9	23.1	-4.4	0.9	1127.479
5	0.9	10.9	7.1	3.7	-4.0	0.6	1074.872
6a	3.0	31.3	21.0	9.5	-4.4	1.1	1280.856
7	0.9	33.5	19.4	13.5	-3.4	0.7	1422.103
7a	17.6	42.1	35.6	7.2	-4.9	0.6	1310.228
8	3.8	15.8	11.4	3.8	-0.6*	0.4	1810.776
9	5.7	12.9	9.9	2.3	-0.5*	0.5	1745.726
M/L Divide	4.7	7.2	6.1	0.7	+0.9*	0.5	1858.008

* Accumulation due to snowstorm during survey period offset normal ablation.

Table 3: Summary statistics of surface movement surveys performed in 1996.

3.1.1 Profile 3

This profile was located on the Demorest Glacier approximately 1 kilometer up-glacier from its convergence with the main Taku Glacier. It was established by estimation in roughly the same area as it was located in 1993, 1994, and 1995, however the northwest end of the profile was unfortunately placed approximately 500 meters further down-glacier this year than previously. The number of flags at Profile 3 has also varied – 12 flags were placed in 1993 and 1994, 10 flags in 1995, and 11 flags this year. Because of these inconsistencies, only broad statements can be made about the temporal flow regime at this profile.

While 11 flags were established at this profile, movement data was collected for only nine of those. Flag 1 was not accessible at the time of resurvey due to the opening of numerous crevasses. Despite being placed deeply enough to come in contact with solid ice beneath a thin layer of firn, Flags 10 and 11 were found to have ablated out and fallen over at the time of the second survey. Thus movement data was obtained for only Flags 2-9. A plot of the surface velocity versus cross-glacier distance is shown in Figure 2. A plot showing

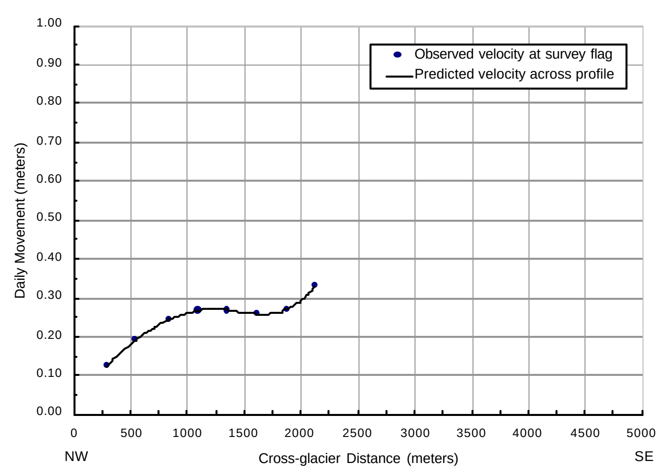


Fig. 2: Profile 3 surface velocity versus cross-glacier distance.

the movement vectors in relation to the surrounding terrain is shown in Appendix 7.

Given the somewhat limited number of flags observed at both epochs, the results indicate a mode of flow consistent with that seen in 1994 and 1995. This profile experiences a moderate magnitude of flow, placing it somewhere between true parabolic and rectilinear flow. While there are well-defined crevasse zones at the edges of the profile, they are not significant enough to indicate pure rectilinear flow. Velocities within the central crevasse-free portion of the profile attain a maximum movement of 33 cm^{day}, while the minimum movement at the edges is on the order of 12.4 cm^{day}. It should be noted however, that Flag 2 was approximately 600 meters from the edge of the glacier at Taku A, and Flag 9 was located 1 kilometer from the southeast edge of the glacier. Therefore the minimum movement reported here does not represent the true minimum movement. In the future, this profile should be established so as to include flags closer to the margins, enabling a much clearer examination of the surface velocities across the entire Demorest Glacier.

The mean short-term height change for Profile 3 during the survey period was -3.3 cm^{day}. The mean surface elevation, at Epoch 0, was 1028.70 meters.

3.1.2 Profile 4

Profile 4 was again located on the main Taku Glacier between C-10 and Shoehorn Peak. It was established by the use of real-time GPS and all flags were placed at their 1995 Epoch 0 positions. The reference point used for the survey was “Scott” at C-10. The accuracy of the flag placement is shown in Appendix 2. As in the past, this profile was composed of 31 flags arranged in two parallel transverse lines. The up-glacier line contained 15 flags and the down-glacier line had 16. The two lines were offset to produce a series of triangles between them.

The mode of flow of Profile 4 is mildly rectilinear with some streaming parabolic flow at the margins. This is consistent with that reported by McGee (1994) and Lang (1995). Figure 3 shows the surface velocity plot. Refer to Appendix 7 for a plot of the movement vectors. The maximum velocity observed in 1996 was 60 cm^{day} at Flag 18. Flag 21, with an apparent velocity of 63.5 cm^{day}, is an outlier and should be neglected. The velocity at Flag 27, while agreeing reasonably well with the adjacent flags, is also suspect due to the anomalous movement vector shown in Appendix 7. Data obtained for all other flags of this profile agree well with previous surveys and exhibit no unusual characteristics. Flag 1 – adjacent to the Camp10 nunatak – and Flag 31 adjacent to Shoehorn Peak show movement vectors deviating

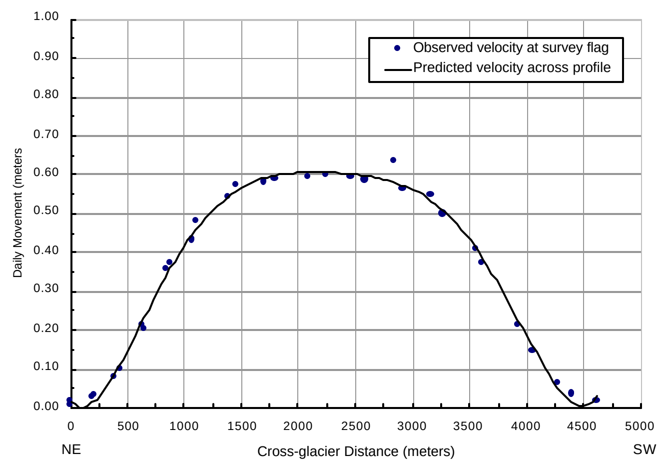


Fig. 3: Profile 4 surface velocity versus cross-glacier distance.

from the mean trend of the rest of the profile. This is normal for these flags and indicates the local flow regime at these specific locations. The movement of Flag 1 is to the east-northeast, toward C-10. This is due to its placement on the slope of a small hill at the base of the nunatak. Flag 31 is actually located at the mouth of a small tributary glacier as it enters the flow of the main Taku Glacier. The northeast trending movement vector at this flag represents the flow of the tributary as it enters the Taku.

The mean surface elevation for Profile 4, at Epoch 0, was 1127.479 meters. The mean short-term height change during the survey period was -4.4 cm^{day}.

3.1.3 Profile 5

This profile was located on the lower Southwest Branch approximately 1 kilometer up-glacier from its confluence with the main Taku Glacier. Because real-time GPS was not available at the time when the profile was established, all 12 flags were set by estimation. However, the profile was surveyed with real-time GPS at both survey epochs. Station "Scott" served as the reference point for the surveys.

This profile experiences true parabolic flow, as evidenced by the movement surveys conducted in 1993 (Lang), 1994 (McGee), and 1995 (Lang). Unfortunately, the flow profile revealed by the 1996 surveys is inconsistent with parabolic flow. Figure 4 presents the velocity profile as a function of cross-glacier distance. The vector plot is presented in Appendix 7. As can be seen, the movement vectors for Flags 2 and 3 are obviously erroneous. This was most likely due to the improper placement of the GPS receiver at either of the two survey epochs. Thus the observed movement for these two flags should be ignored. The results for Flags 9, 10, and 11 also reveal some inconsistencies, although to a much lesser degree than do Flags 2 and 3. Again, this is due to poor placement of the GPS receiver rather than reflecting the true glacier surface movement at these locations. Results for Flags 3-9 and 12 are in agreement with those of previous surveys, with the maximum movement observed being 10.9 cm^{day} at Flag 5.

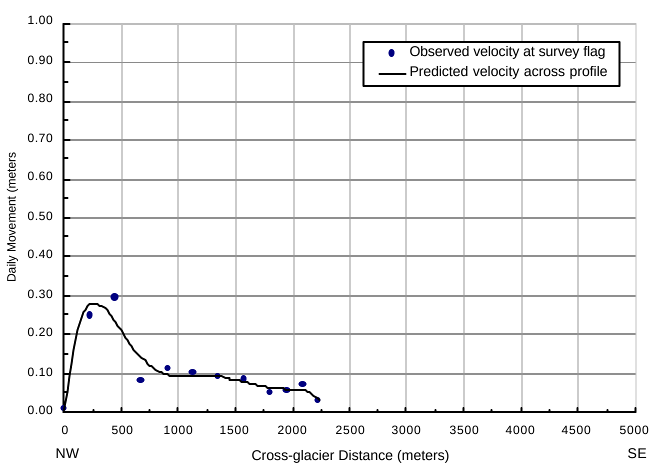


Fig. 4: Profile 5 surface velocity versus cross-glacier distance.

Crevassing at this profile is minimal, with only a few very minor crevasses present at the northwest margin near the base of Juncture Peak. There was however, a very significant and extensive crevasse zone just down-glacier from the profile where the Southwest Branch merges with the flow of the main Taku Glacier. In conjunction with a low amount of retained snow from the previous winter, the crevasses here were much more extensive than had been seen in previous years. Extensive crevasses extending across the entire width of the Southwest

Branch prevented access to the profile with Thiokol support, forcing all survey work to be performed on skis. This year was the first time that this situation was encountered on the Southwest Branch.

The mean surface elevation of Profile 5, at Epoch 0, was 1074.872 meters, and the mean short-term height change was –4.0 cm^{day}.

3.1.4 Profile 6a

Profile 6a was located on the Taku Glacier between Taku D and Taku Northwest Point. This profile was identified as Profile 6 in the 1994 and 1995 survey reports. It has been re-designated as Profile 6a because, historically, the original Profile 6 was located between Taku Northwest Point and Echo Mountain. The profile described here, trending northeast/southwest between Taku Northwest Point and Taku D should in the future be identified as Profile 6a, and should contain 16 flags, rather than the 14 flags that were placed in 1996. This profile was both established and surveyed with real-time GPS, using the Taku Northwest Point USGS benchmark as the reference.

All statements made by McGee (1994) relating to the mode of flow remain consistent with the data collected in 1996. This profile is characterized by parabolic flow, with the zone of maximum velocity occurring within the southwest two-thirds of the profile. This is most likely due to the extension of the southwest ridge of Taku D beneath the glacier at the northeast margin of the profile. This is revealed in the surface velocity plot in Figure 5 and the movement vector plot in Appendix 7. The observed velocity and vector of Flag 1 is erroneous and should not be considered. Data for all other flags however, is reliable. The maximum daily movement was 31.3 cm^{day} in 1996. This is nearly identical to the maximum daily movement observed in 1993, 1994, and 1995.

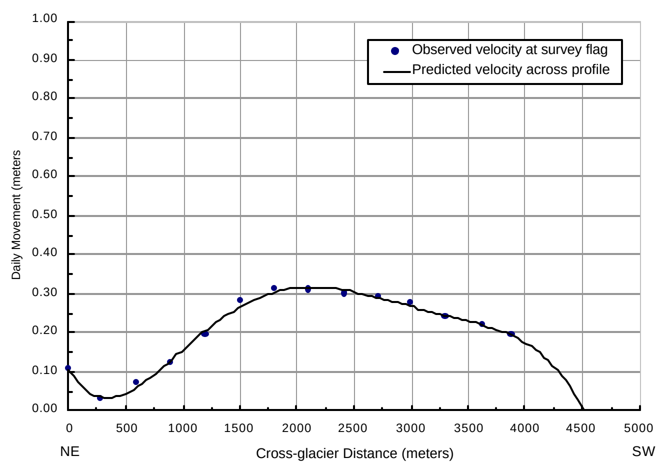


Fig. 5: Profile 6a surface velocity versus cross-glacier distance.

The occurrence of crevasses at this profile is minimal, as would be expected from parabolic flow. Only a few minor crevasses exist along the margins, with none in the central area. The mean short-term height change was -4.4 cm^{day} and the average surface elevation at the time of the Epoch 0 survey was 1280.856 meters. Seismic depth sounding was performed at this profile in 1996. The location of the central blast point was surveyed via GPS and is indicated on the movement vector plot in Appendix 7.

3.1.5 Profile 7

This profile was located on the middle Matthes Glacier west of Camp 9. Starting with Flag 1 at the base of the C-9 nunatak on the southeast margin of the glacier, and ending at the northwest margin near the base of Centurian Peak, the profile contained 16 flags in 1996.

Profile 7 was established by line-of-sight, with the flag spacing determined by counting Thiokol track revolutions. This was necessary because this profile was not previously surveyed via GPS, and the flag placement from earlier theodolite surveys was highly inconsistent. Thus the 1996 flag positions will become the permanent positions for future GPS surveys. The benchmark used for the real-time GPS surveys in 1996 was a bolt fixed into bedrock near the C-9 meteorological shelter. Visibility from this position is such that real-time GPS surveys on the Matthes Glacier may be conducted 8 kilometers both up-glacier and down-glacier from C-9.

Like Profile 5, this profile demonstrates a parabolic flow profile, as shown in Figure 6. Refer to Appendix 7 for a plot of the movement vectors. As can be seen in the vector plot, all flags in the profile show a high degree of accordance, in both velocity and direction, with what is expected from parabolic flow. Flags 1 through 4 were located on the slope of the hill leading up to C-9, explaining why the vectors for these flags are oriented primarily west, toward the middle of the glacier. This reflects the local downslope movement at the eastern margin of the Matthes Glacier rather than that of the Matthes proper. Surface velocities and vectors at the extreme northwest end of the profile are uncertain, and in fact were not measured, due to the fact that the last flag in the profile was located some 700 meters from the base of Centurian Peak. Future surveys of Profile 7 should include two additional flags beyond Flag 16.

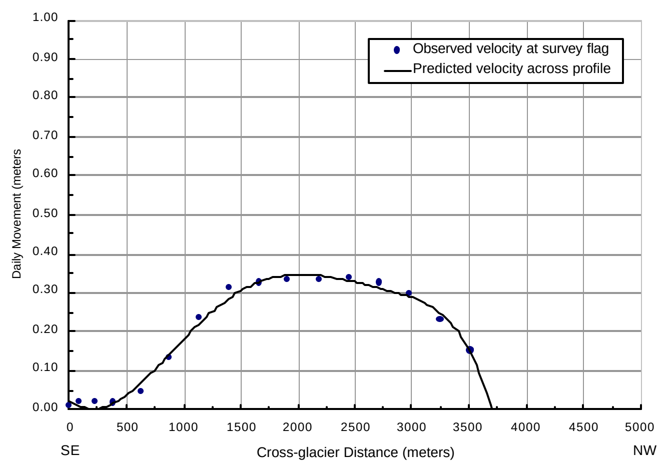


Fig. 6: Profile 7 surface velocity versus cross-glacier distance.

The maximum velocity measured was 33.5 cm^{day} at Flag 12. The mean short-term height changes was -3.4 cm^{day}, and the mean surface elevation at the time of the Epoch 0 survey (disregarding Flags 1-3) was 1422.103 meters.

3.1.6 Profile 7a

This profile was located on the Lower Matthes Glacier, approximately 1 kilometer up-glacier from its junction with the Taku Glacier. It was established by the estimation method because the real-time GPS equipment had not yet arrived on the Icefield at the time the flags were placed. The actual surveys however, did utilize real-time GPS to determine the flag locations at both survey epochs. The benchmark utilized by the GPS reference station was the USGS marker on Taku Northwest Point. This profile consisted of 14 flags in 1996, with Flag 1 being located at the northwest margin near the base of Taku D, and Flag 14 being on the opposite side of the glacier adjacent to Taku C.

The mode of flow at this profile is somewhere between parabolic and rectilinear, as discussed in the 1994 JIRP Survey Report. Surface velocities, as shown in Figure 7, are higher along the southeast two-thirds of the profile. This can also be seen in the movement vector plot in Appendix 7. This velocity curve may be related to the presence of thicker ice in this area. In fact, a vertical cross-section reveals that the surface elevation is approximately 23 meters higher in this area than on the northwest third of the profile. This, coupled with the possibility of a deeper bedrock channel on the southeast side of the Matthes Glacier, would explain the higher surface velocities found here.

As seen in Figure 7 and Appendix 7, the data for all surveyed flags is highly consistent; there are no outliers present in the data set. Unfortunately, the first and last flags of the profile were placed approximately 500 meters from the actual glacier margins at the bases of Taku C and Taku D. Because of this, the velocity curve for these unsurveyed areas along the margins is predicted based on a 6th order polynomial regression analysis of the 14 surveyed flags. In the future, one or two additional flags should be placed between Flag 1 and the base of Taku D. The significant crevasse zone between Flag 14 and Taku C however, may make it too difficult to place additional flags.

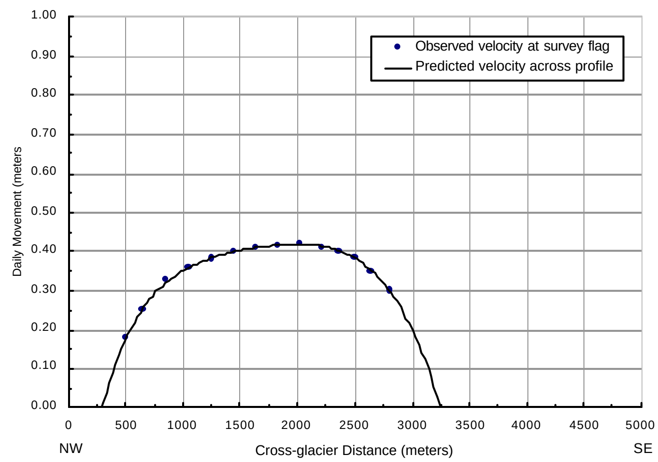


Fig. 7: Profile 7a surface velocity versus cross-glacier distance.

The maximum movement observed in 1996 was 42.1 cm^{day} at Flag 9. The mean short-term height change was -4.9 cm^{day} and the mean surface elevation of the profile at the time of the Epoch 0 survey was 1310.228 meters. Additionally, seismic depth sounding was performed at this profile in 1996. The location of the central blast point was surveyed via GPS and is indicated on the movement vector plot in Appendix 7.

3.1.7 Profile 8

Profile 8 was located on the Matthes Glacier between Blizzard Peak and Camp 8. It was established via the use of real-time GPS, with the flags being placed at the 1995 Epoch 0 coordinates. Flag 1 was located on the southeast end of the profile, while Flag 12 was located at the northwest margin near the south ridge of Blizzard Peak. All flags were surveyed via real-time GPS at both survey epochs. FFGR 39 served as the reference point for the surveys.

Results of the 1996 surveys show no significant deviation in the surface movement from that of 1993 and 1995 (1994 data is not considered because this profile was surveyed with theodolite/EDM methods in that year). In both 1993 and 1995, the maximum observed movement was 16 cm^{day}, which is nearly identical to the maximum of 15.8 cm^{day} that was observed in 1996.

The surface velocity curve for Profile 8 is shown in Figure 8; the movement vector plot is shown in Appendix 7. The calculated movement for Flag 12, at the northwest end of the profile, is erroneous and should not be considered in any analyses of the surface movement. Data for all other flags is, however, reliable. The movement vectors for Flag 11, and to a lesser extent Flag 10, reflect the local downslope movement of the hill upon which these flags were located. Profile 8 is one of the few established profiles on the Juneau Icefield which does not encompass any crevasses. Thus this profile, with its relatively small magnitude of movement, has a true parabolic mode of flow. This is expected due to its location only 4 kilometers down-glacier from the crestal divide between the Matthes and Llewellyn Glaciers. The width of the Matthes Glacier at Profile 8, at approximately 4 kilometers, also contributes to the relatively low surface velocities.

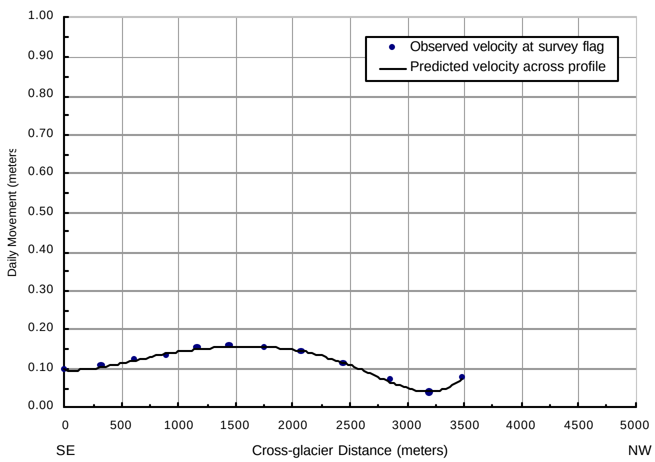


Fig. 8: Profile 8 surface velocity versus cross-glacier distance.

The mean short-term height change between the two survey epochs was +0.6 cm^{day}. This figure is unusual, especially when compared to short-term height changes for the other profiles described above. This is because a snowstorm on August 8th and 9th offset the ablation between August 3, when the profile was first surveyed, and the 8th.

3.1.8 Profile 9

Profile 9 was located on the Vaughan Lewis Glacier approximately 1.8 kilometers east of Camp 18. This profile is at the head of the Vaughan Lewis Icefall and follows the crescentic trend of the crevasses. Eight flags were placed in 1996, with Flag 1 being the farthest north and Flag 8 being located near the base of the northeast ridge of Mammary Peak. The profile was established via real-time GPS at the coordinates of the 1995 Epoch 0 survey. Benchmark N-1 at C-18 served as the reference point for the GPS base station.

This profile is located in a zone of extending flow approximately 1 kilometer east of the point at which the Vaughan Lewis Glacier begins its plunge down the icefall. The movement vectors for this profile reveal radial flow toward the center of the glacier. This is expected due to the bedrock morphology of this area – the profile is at the head of a hanging valley above the Gilkey Trench. Thus, the flow of ice from the north, east, and south converges near the longitudinal center of the valley and becomes redirected toward the west, where it enters the icefall proper. This is graphically seen in the movement vector plot in Appendix 7. Figure 9 presents a plot of the surface velocities across the extent of the profile. It is important to note that the velocity curve does not represent, in the case of Profile 9, a linear transverse profile. Rather it depicts the velocity from one side of the crescentic trend of the profile to the other.

The maximum movement observed in 1996 was 12.9 cm^{day}. This is in sharp contrast to that seen in 1995, when the maximum was 36 cm^{day}. The reason for this apparent significant velocity reduction is unclear at this point, but may be due to the fact that the 1995 Epoch 0 survey was accomplished with theodolite/EDM methods, while the 1995 Epoch 1 and both 1996 surveys were done with real-time GPS. Additionally, the 1995 movement data was determined from a survey period of 5 days; the 1996 data is based on a time period of 6 days between surveys. It appears unlikely that the velocity at this profile in 1996 would be up to 72% less than the magnitude of what it was the previous year, especially in light of the fact that the velocities of all other profiles surveyed in 1996 were essentially unchanged from the previous several years. One thing is certain–the difference in velocity between 1995 and 1996 is not related to the flag placement; real-time GPS was used in 1996 to place the flags in the 1995 Epoch 0 positions. The positions of the flags in 1996 deviated, on average, only 94.1 cm from the 1995 positions. This deviation is not significant enough to explain the apparent velocity decrease. To illustrate the differences between the 1995 and 1996 Profile 9 data, Table 4 presents the daily movement at Profile 9 in each year, as well as the accuracy with which the 1996 flags were placed relative to their 1995 positions.

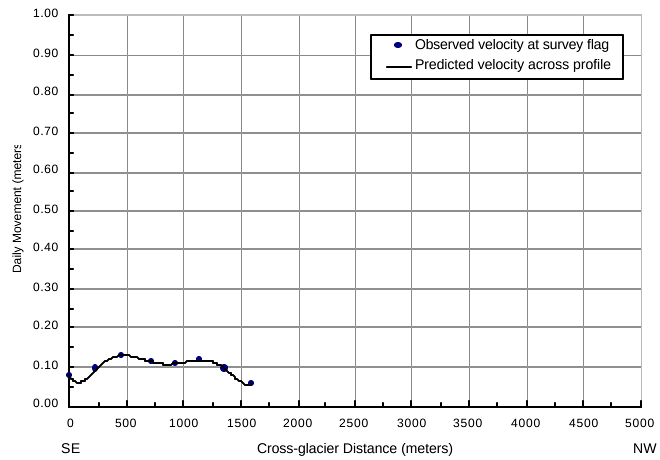


Fig. 9: Profile 9 surface velocity versus cross-glacier distance.

Flag	1995		1996		% Velocity Decrease 1995 to 1996	1996 Placement Error (cm)
	Movement/Day (cm)	Direction (gons)	Movement/Day (cm)	Direction (gons)		
1	11.5	242.8352	7.8	256.9355	32.2	2.8
2	11.5	266.7457	9.5	294.8309	17.4	81.1
3	28.2	300.7138	12.9	315.4936	54.2	212.5
4	27.1	312.0042	11.4	335.1381	57.9	97.8
5	36.2	320.0038	10.6	351.0863	70.7	92.7
6	35.7	329.1892	11.9	358.9421	66.7	74.3
7	33.3	335.9332	9.5	374.7348	71.5	106.9
8	*	*	5.7	394.0905	*	85.0
Minimum	11.5		7.8		17.4	2.8
Maximum	36.2		12.9		71.5	212.5
Mean	26.2		10.5		52.9	94.1

* 1995 Epoch 1 flag coordinates were not obtained. Movement data cannot be calculated.

Table 4: Movement and flag placement data for Profile 9. The 1996 placement error is with respect to the 1995 Epoch 0 flag positions. It is uncertain if the apparent velocity decrease is valid.

The mean short-term height change at Profile 9 in 1996 was +0.5 cm^{day} and the mean surface elevation was 1745.726 meters. As with Profile 8, ablation was offset by accumulation due to the snowstorm between August 8^{th} and 9^{th}.

3.1.9 Profile 10

This profile was located roughly along the longitudinal axis of the Matthes and Llewellyn Glaciers. The work done here in 1996 was an extension of the same profile that was first established in 1995. The objective in establishing the profile was to determine the exact flow divide between the south-flowing Matthes Glacier and the north-flowing Llewellyn Glacier, with the ultimate goal being to locate the area of minimum movement at the crestal divide. This would then allow for the future acquisition of an ice core.

This profile contained 16 flags in 1995, with all but one flag being placed on the southern side of the flow divide. Only Flag 16 revealed a movement vector directed toward the Llewellyn Glacier. Unfortunately, this was not sufficient to provide a detailed picture of the surface flow from the Matthes Glacier, across the crestal divide, and down the Llewellyn side.

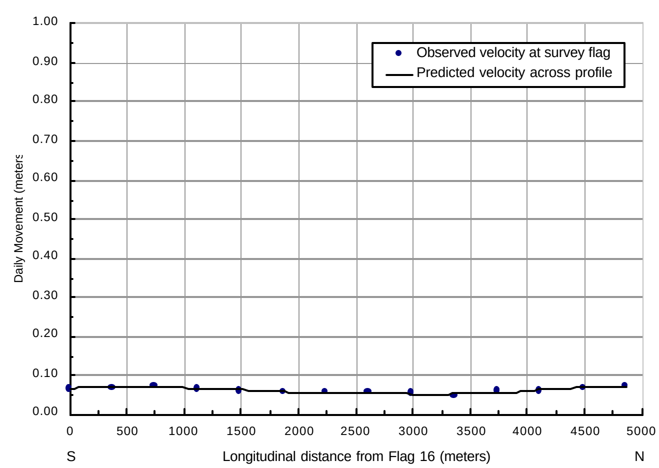


Fig. 10: Profile 10 surface velocity versus longitudinal distance.

Accordingly, the profile was extended approximately 5 kilometers farther north in 1996, bringing the total number of flags in the composite (1995 and 1996) profile to 29. All flags placed in 1996 were established via real-time GPS, with FFGR 39 (Blizzard) serving as the real-time reference point. For the 1996 survey, Flag 16 from the 1995 survey was re-established in the Epoch 0 position; Flags 17-29 were new in 1996. The total longitudinal distance between Flags 1 and 29 is approximately 10 kilometers.

Because this was a longitudinal profile, a determination of the mode of flow can not be made. For this, a transverse profile is necessary. It can be inferred however, that this area experiences parabolic flow. This inference is based on the observed surface velocities at Profile 8, on the Matthes Glacier, and Profile 10a on the Llewellyn Glacier. Both of these profiles are located roughly 4 kilometers down-glacier on either side of divide. The mode of flow at these locations is parabolic.

Examining the movement vectors for the entire profile, one can readily identify the location of the flow divide. This occurs between Flags 15 and 16. Appendix 7 shows the movement vectors for Flags 7-29; Figure 10 details the surface velocities as a function of the longitudinal distance for Flags 16-29. As revealed in Figure 10, the daily movement of the Llewellyn Glacier along this 5 kilometer line, from Flag 16 to Flag 29, varies little. The minimum movement observed was 4.7 cm^{day} and the maximum was 7.2 cm^{day}. The mean movement was 6.1 cm^{day}. The plot of the vectors in Appendix 7 reveals that the ice at the crestal divide is moving toward the east. This is a manifestation of the ice moving down from the Mt. Ogilvie plateau into the crestal divide area between the Matthes and Llewellyn Glaciers. With increasing distance from the crestal divide, between Flags 15 and 16, the movement vectors become directed increasingly down-glacier; to the south on the Matthes, and to the north on the Llewellyn. The maximum observed elevation at the crestal divide in 1996 was 1880.363 meters. Ths short-term height change was +0.9 cm^{day}.

3.2 Profile 4 Surface Mass Balance

Continuing a project that was first initiated during the 1993 JIRP field season, an analysis of the local surface mass balance at Profile 4 was again conducted in 1996. The purpose of this project is to quantify the temporal changes and spatial distribution of mass across the extent of Profile 4. The mass distribution is evaluated with respect to changes in the surface height at each movement flag from year to year. The goal is to determine the magnitude of surface lowering or rising, and to determine the spatial distribution of surface height changes within the area of the profile. Conducting this analysis on a long-term annual basis will provide important information regarding the accumulation, ablation, and flow regime of the Taku Glacier at this particular location.

Traditional glacier mass balance and equilibrium studies are based on an analysis of the net annual balance of an entire glacier system, which is typically comprised of both the accumulation and ablation areas. This requires determining the annual net balance (b_n) by subtracting the mass lost to annual ablation (a_a) from the mass gained by annual accumulation (c_a). The result, in water equivalent, quantifies the volume of mass gained or lost during the previous balance year. Data for this type of analysis requires field studies across the extent of the glacier system within both the accumulation and ablation areas, and in both summer and winter seasons to determine the magnitude of winter accumulation versus summer ablation. Conversely, local surface mass balance or equilibrium studies, such as the one conducted at Profile 4, simply determine the annual net balance as a function of the change in surface height (Paterson, 1981), as measured annually on a specific date. The concept is simple; if the mean surface height is higher than it was the previous year, then the net mass of the glacier within the extent of the measured profile has increased. Likewise, if the surface height is lower, the net mass has decreased. It must be cautioned however, that apparent increases or decreases in the mass as determined by this method must be further investigated to determine the true cause of the change. For example, an increase in the mass may be due to the passage of a kinematic wave through the area of the profile, rather than to a true net increase in the mass of the entire glacier system. Cross-correlation of GPS-derived surface mass balance data with annual firn depth and stratigraphy data can assist in determining if observed mass changes are due to actual increases or decreases of accumulation. Since this project is currently being conducted at only one profile it is not appropriate to extrapolate conclusions, based exclusively on GPS survey data, regarding the mass balance of the entire Taku Glacier system. The only statement that can be made is that there is a greater or lesser amount of ice and firn at the location of Profile 4 than in previous years.

Quantifying the local surface mass balance requires a method whereby the exact same area can be re-measured on an annual basis. Since 1993 this has been accomplished by placing movement stakes in two parallel transects across the Taku Glacier from the Camp 10 nunatak to the northeast ridge of Shoehorn Peak. These transects are offset so as to form a series of triangles between 16 stakes in the down-glacier line and 15 stakes in the up-glacier line. These triangles also provide the proper geometry for the analysis of strain rates within Profile 4. The easting and northing coordinates, as well as the elevation of all stakes at the glacier surface, are then determined via differential GPS methods. Stake placement in 1994 and 1995 was accomplished by surveying in the flags with theodolite and EDM, while placement in 1996 was done with real-time differential GPS methods. The placement accuracy of all stakes from 1994 to 1996, relative to the 1993 Epoch 0 positions, averages 2.727 meters (see Appendix 3 for further details regarding the flag placement error from 1993 to 1996). This is a larger placement error than what might be expected when employing differential GPS. The reason for this is that all flags were originally placed, in 1993, by line of sight without the aid of GPS. The flags were then surveyed via traditional theodolite/EDM methods and the bearings and distances within a local coordinate system to each flag were recorded. Following the placement of the flags in 1993 they were surveyed with rapid static differential GPS methods. Placement of the flags in 1994 and 1995 was again accomplished via theodolite/EDM using the bearings and distances recorded from the 1993 Epoch 0 GPS survey. The theodolite/EDM method was used in 1994 and 1995 only to set the flags; rapid-static differential GPS was then used to determine the easting, northing, and height of each flag. All flags in the profile were established by differential GPS in 1996, using the 1995 Epoch 0 coordinates as the reference. Table 5 below summarizes the history of flag placement at Profile 4 from 1993 to 1996. In the future all Profile 4 flags should be established using the 1993 Epoch 0 GPS coordinates. These coordinates are listed in Appendix 3.

As originally established in 1993, the profile had 27 flags. This was not enough to extend all the way across the Taku Glacier to Shoehorn Peak. Consequently, a determination of surface movement and elevation changes could not be made along the southwestern-most 750 meters of the profile. This was resolved in 1994 with the addition of four flags, bringing the total number in Profile 4 to 31. Because Flags 28-31 were not present in 1993, observed surface elevations for these flags in 1993 do not exist. However, predicted surface elevations for 1993 were calculated via linear regression analysis. This analysis was based on the normalized heights at the flags in 1994, 1995, and 1996.

YEAR	FLAGS SET BY	COORDINATES WHICH WERE USED FOR SETTING FLAGS	PLACEMENT ERROR IN METERS (RELATIVE TO)
1993	Line-of-sight	Straight line between C-10 & Shoehorn Pk.	––
1994	Theodolite/EDM	1993 Epoch 0 bearings & distances	2.732 (1993 Epoch 0)
1995	Theodolite/EDM	1993 Epoch 0 GPS easting & northing	2.723 (1993 Epoch 0)
1996	Real-time GPS	1995 Epoch 0 GPS easting & northing	0.093 (1995 Epoch 0)

Table 5: Summary of flag placement at Profile 4 from 1993 to 1996.

The GPS coordinates obtained during the annual surveys form the basis for the local surface mass balance analysis. McGee (1995) describes one methodology, referred to as the interpolation method, employed for this analysis. Briefly, this method centers on the construction of surface elevation models of the profile for each annual survey that was performed. The difference in surface elevation of the models between consecutive years is then calculated. This represents the magnitude of height change from year to year. Finally, calculations are done to determine the annual change in volume and mean surface elevation change. The interpolation method is an indirect method, in that derived surface elevations across the entire extent of the profile are determined, based on the observed surface elevations of the flags. A second method, referred to as the normalized heights method, is a direct surface height change analysis because it uses the flag elevations directly; it does not rely on interpolation to “fill in the gaps”. The normalized heights method instead is based solely on the observed surface elevation at each flag in conjunction with the observed ablation during the survey period. The raw, observed surface elevations are then adjusted up or down, as appropriate, based on the mean daily ablation rate and the number of days between the surface elevation observations and July 25th. For the purposes of the Profile 4 mass balance project, July 25th was chosen as the annual comparison date because it nearly always coincides with the time period with which the C-10 area surveys occur. For example, suppose that Profile 4 was surveyed on July 20, with the resurvey occurring on July 30. Assume he ablation rate during this time period was 5 cm^{day}. Therefore, the surface elevations at the flags, as observed at the first survey, must be adjusted down by 25 cm. This then gives the approximate surface elevation at each flag had they been surveyed on July 25, the annual comparison date.

3.2.1 The Surface Mass Balance at Profile 4 (1993–1996)

All data presented in this report relating to the surface mass balance of Profile 4 are based on a mean of the interpolation and normalized heights methods. This seems a reasonable approach given the advantages and disadvantages of each, particularly in light of the fact that the two methods give results within approximately 2% of each other. Table 6 summarizes the results of both methods for the cumulative time period 1993 to 1996, while Figure 11 graphs the mean year to year elevation changes for the profile as a whole. Figure 12 shows the magnitude of surface elevation changes at each flag on a year to year basis, as well as the cumulative change at each flag for the time period of 1993 to 1996. Detailed year to year data for both the interpolation and normalized heights methods are presented in Appendix 8.

Time Period 1993–1996	Analysis Method		Mean	Standard Deviation
	Interpolation	Normalized Heights		
Height Change (m)	-1.928	-1.885	-1.907	0.030

Table 6: Summary of mean surface elevation change at Profile 4 for the cumulative time period July 25, 1993 to July 25, 1996. All values are in units of meters. Assuming an annual surface firn density of 0.55 g/cm^3, the mean value equates to a water equivalent loss of 1.049 m^3/m^2.

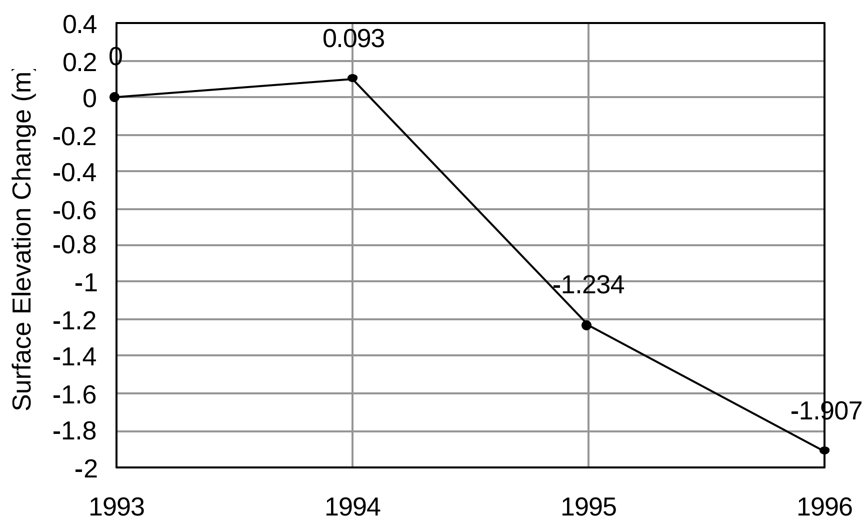


Figure 11: Graph showing the mean surface height change at Profile 4 from year to year, relative to a baseline height of zero on July 25, 1993. The profile had a positive balance from 1993 to 1994. The balance was negative in both 1995 and 1996.

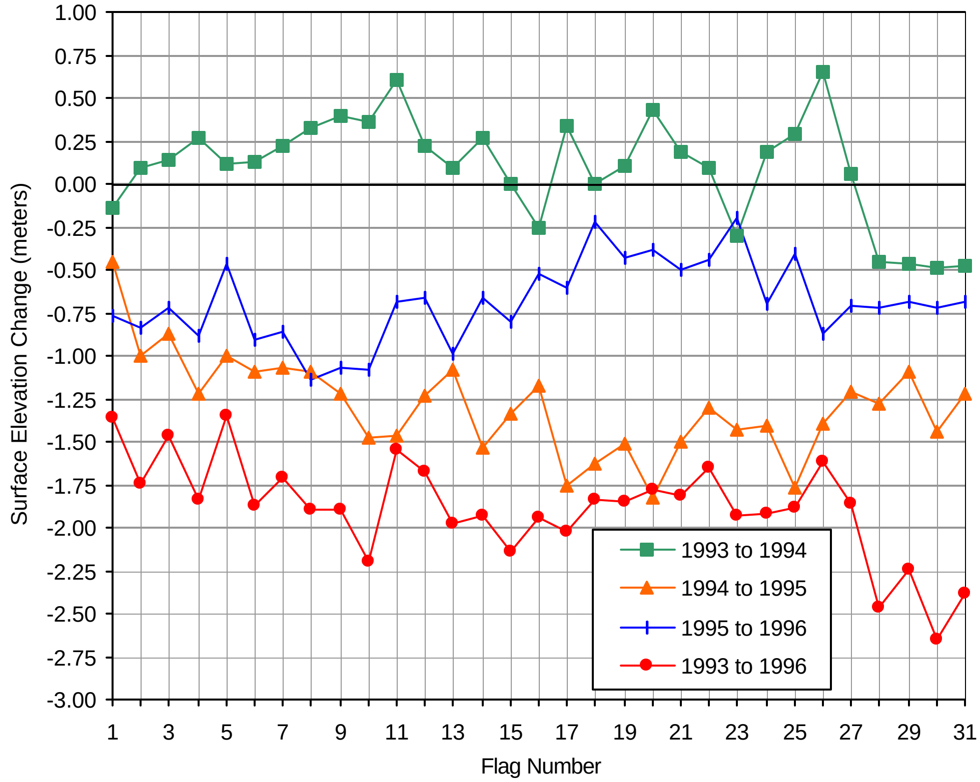


Figure 12: Graph showing the relative surface height change at each flag for each annual time period. The baseline elevation of zero references the initiation of the project in 1993. The cumulative change from 1993 to 1996 at each flag is also shown.

3.2.2 July 25, 1993 to July 25, 1994

One of the objectives of the surface mass balance project at Profile 4 is to determine the extent and magnitude of changes in the temporal and spatial mass distribution. The data presented in Table 6, Figure 11, and Appendix 8 quantify the mean surface elevation and mass changes across the extent of the profile. This information does not however, provide an insight into the spatial distribution and magnitude of the changes. The surface plots shown in Figures 13, 14, 15, and 16 address this issue. These plots show, as a series of contour intervals, the change in height of the surveyed flags from one year to the next. For example, Figure 13 reveals that the surface elevation at Flag 11 was approximately 0.6 meter higher in 1994 than in 1993. Green shades represent an increase in surface elevation while red shades indicate a lowering of the surface elevation, thus giving a visual means of determining the spatial distribution of the changes.

Since this project began in 1993, the balance regime of Profile 4 has been positive in only one year; from 1993 to 1994. The balance has been negative in all other years. As seen in Figure 13, the majority of the profile had a net increase in surface elevation during the preceding measurement year. The surface elevation decreased at 8 flags, while the surface elevation at all other flags increased. The magnitude of the elevation decrease at Flags 28-31, relative to that along the rest of the profile, seems to be greater. In other words, is seems that the surface elevation here decreased more than at the other flags. This may not actually reflect the true conditions, but may rather be an artifact of the linear regression that was done to predict the surface elevations at these flags in 1993. Therefore, the surface elevation change at Flags 28-31 between 1993 and 1994 is subject to some speculation. The remainder of the flags in the profile do not share this uncertainty because they were surveyed in both 1993 and 1994. Not considering Flags 28-31, the maximum increase in elevation of 0.654 meter, was observed at Flag 26. The maximum decrease in elevation of 0.307 meter was seen at Flag 23. The mean surface elevation increase across the entire profile, taking into account both the interpolation and normalized heights methods, was 0.093 meter.

3.2.3 July 25, 1994 to July 25, 1995

Compared to the 1993 to 1994 time period, results from the 1994 to 1995 measurement year reveal a very strong negative balance. The surface elevation at all flags decreased during this time period. The maximum decrease was 1.829 meters at Flag 20 and the least was 0.454 meter at Flag 1, near the base of the C-10 nunatak. The average surface lowering was 1.327 meters. The middle portion of the profile underwent more lowering and mass loss than did the margins. And of the marginal areas, the northeast end of the profile near the C-10 nunatak experienced the least amount of surface lowering. A contour plot of the surface elevation changes is shown in Figure 14.

The surface also became somewhat flatter during the 1994-1995 period. In other words, the magnitude of the amplitude differences between the highest portions of the profile and the lowest portions was less in 1995. This is revealed by the standard deviation of the surface height changes at each flag. The standard deviation of height changes for the 1993-1994 period was 0.303 meter. It was 0.285 meter for the 1994-1995 time period.

3.2.4 July 25, 1995 to July 25, 1996

The 1995-1996 measurement year reflected a smaller magnitude of surface lowering than the previous measurement year. However, the balance regime remained entirely negative for the second year in a row. The surface elevations decreased at all flags, with the minimum being 0.200 meter at Flag 23. The maximum elevation change was at Flag 8, where the surface was 1.138 meters lower than in 1995. The mean surface elevation lowering, encompassing both analysis methods, was 0.672 meter. This is roughly one-half of the mean surface lowering observed during the previous measurement year.

Looking at Figure 15, it can be seen that the central sector of the profile experienced less change with respect to the margins. This is in contrast to the 1994-1995 period when the marginal areas subsided the least. Figure 12 shows that, while surface elevations in the central portion decreased the most (relative to the margins) in the 1994-1995 period, they did the inverse in 1995-1996. During this time period, the central portion, with respect to the margins, experienced the least amount of surface lowering. The profile also became flatter this year as evidenced by a height change standard deviation of 0.236 meter, compared to a standard deviation of 0.285 meter for the 1994-1995 time period.

3.2.5 Cumulative Change from July 25, 1993 to July 25, 1996

With one year of only minor increases in surface elevation and two years of significant decrease, it is no surprise that the cumulative effects at Profile 4 have resulted in a significant lowering of the surface. This is true for the surface at all flags within the profile. The maximum magnitude of lowering was 2.651 meters at Flag 30, with the least being 1.354 meters at Flag 5. The mean surface elevation drop, across the entire profile and as calculated from the interpolation and normalized heights methods, was 1.907 meters. Assuming a density of the surface firn of 0.55 g/cm^3, this equates to a water equivalent loss of 1.049 m^3/m^2. With a profile surface area of 1,124,880 m^2, and assuming that the loss was not retained as internal accumulation, this means that the mass lost at Profile 4 from 1993 to 1996 was nearly 1,180,000 m^3 water equivalent.

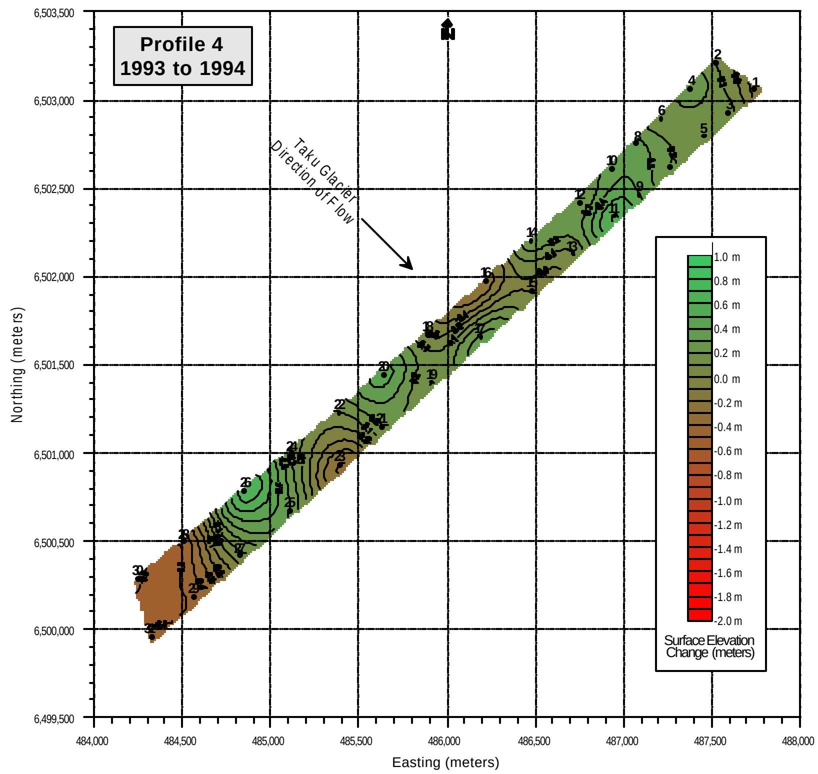


Figure 13: Surface height change between July 25, 1993 and July 25, 1994.

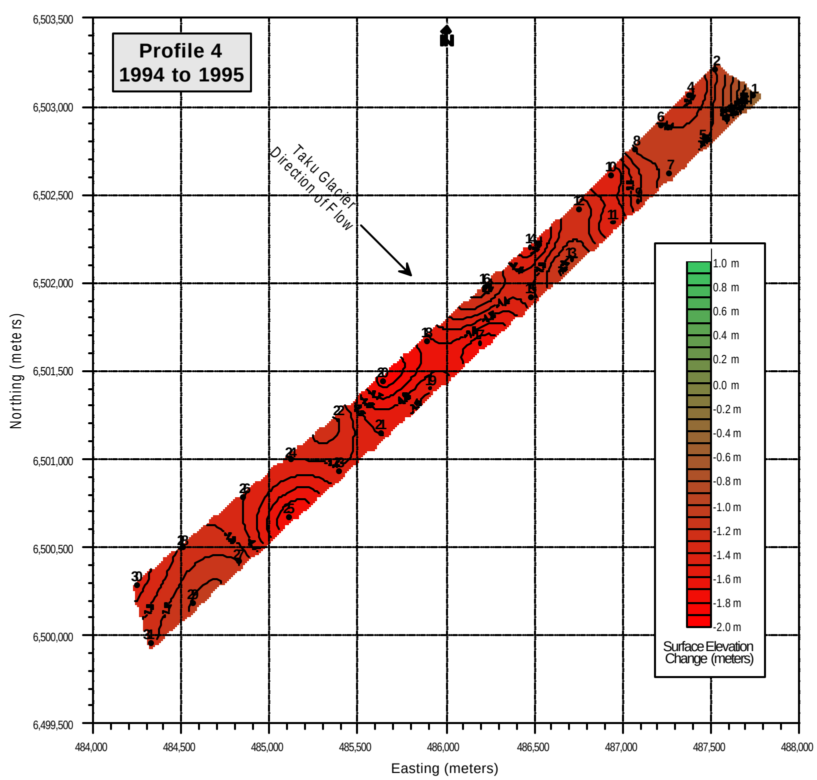


Figure 14: Surface height change between July 25, 1994 and July 25, 1995.

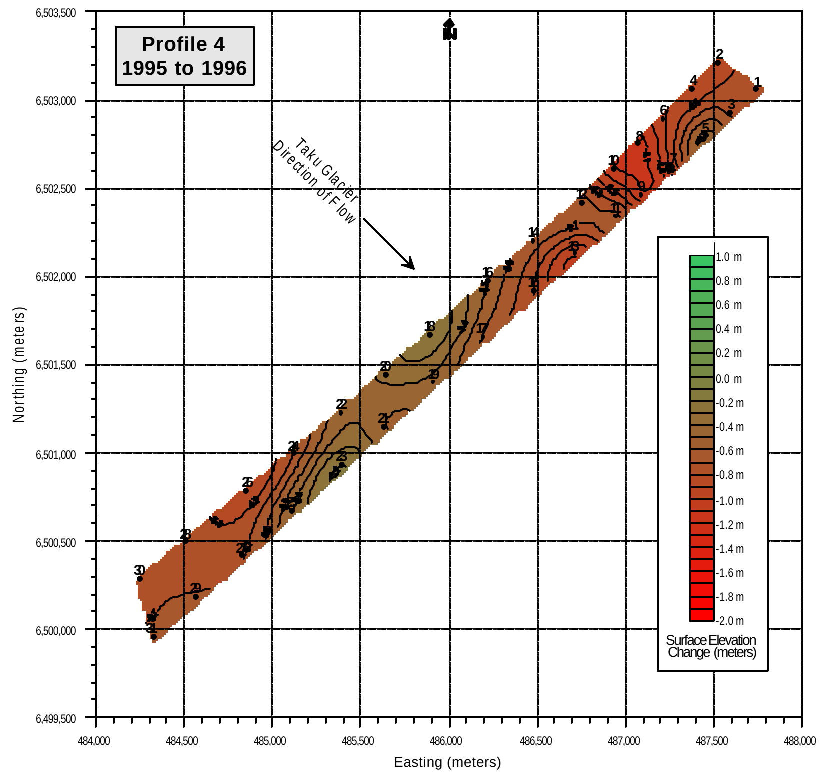


Figure 15: Surface height change between July 25, 1995 and July 25, 1996.

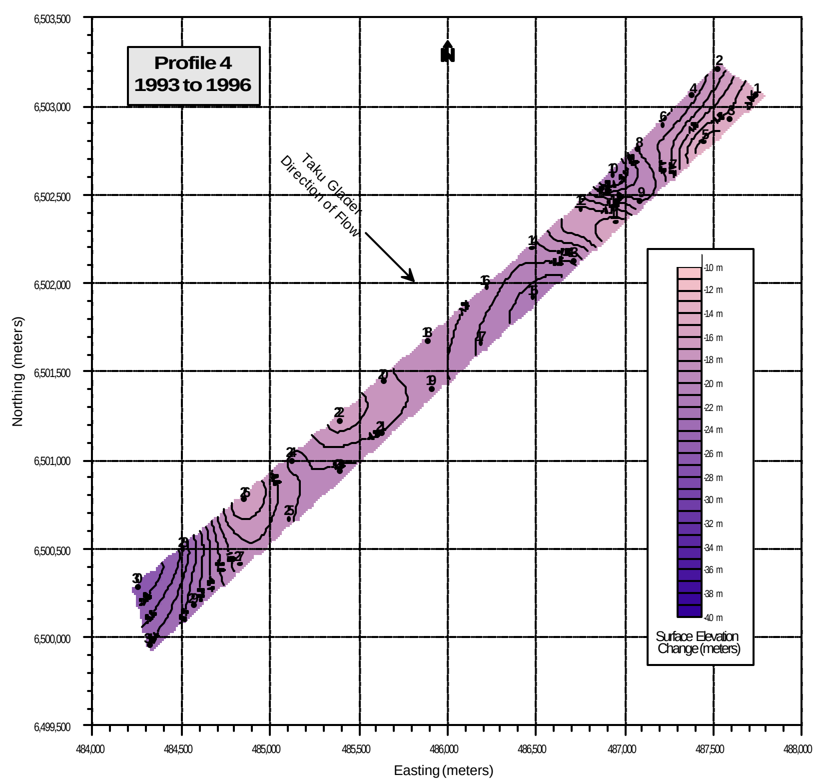


Figure 16: Cumulative surface height change from July 25, 1993 to July 25, 1996.

3.3 PROFILE 4 STRAIN RATE ANALYSIS

Strain rates provide important information regarding the internal stress and resultant deformation of glaciers. Surface movement is one manifestation of strain. A more important indicator of strain, and one which has implications on conducting research in glacial areas safely, is the formation of crevasses. One may therefore gain a qualitative understanding of the stress/strain relationship by simply observing the crevasse patterns in a particular area. However, to quantify the magnitude of, and temporal changes in, the strain regime, a more detailed study must be conducted.

In conjunction with the surface mass balance study at Profile 4, an on-going strain rate analysis project has also been conducted from 1993 to the present. This project was continued in 1996 with the surveys of Profile 4 on July 28 and August 6. The configuration of this profile, with a double line of offset flags, provides the proper geometry for the determination of strain rates via a series of 29 triangles. Triangle 1 is comprised of Flags 1-3, Triangle 2 of Flags 2-4, Triangle 3 of Flags 3-5, and so on. With Triangle 1 at the base of the Taku A/Camp 10 ridge and Triangle 29 near the base of Shoehorn Peak, this allows for an examination of the strain across the entire extent of the main Taku Glacier.

Strain is defined as the change in length of a line divided by its original length, and can be extensional (E_1) or compressional (E_2). Calculation of the strain ellipse at each triangle is based on the easting and northing coordinates of the flags at each of two survey epochs. Changes in the side lengths and interior angles of the triangles define the shape and orientation of the strain ellipse. The calculations employed in this analysis follow the method outlined by Welsch (1987).

The strain regime at Profile 4 has remained relatively stable for the past several years. As such, the results from the 1996 surveys show no startling or unusual characteristics. The location of the maximum extensional and compressional strains correlate well with the marginal shear zones, as evidenced by the numerous crevasses in these areas. The surface movement shown in Figure 3 also corroborates the observed strains, including the crevasse-free central zone which undergoes minimal strain. The maximum observed compressional strain in 1996 was 671 $\mu strain^{day}$ at Triangle 26. The maximum extensional strain was 456 $\mu strain^{day}$ at Triangle 27. Application of the strain relation $E_1 + E_2 + E_3 = 0$ reveals the vertical component of movement (E_3) at each of the triangles, shown in Figure 17. A plot of the strain ellipses is shown in Figure 18. The calculated strains for each triangle and the triangle geometry are presented in Appendix 9.

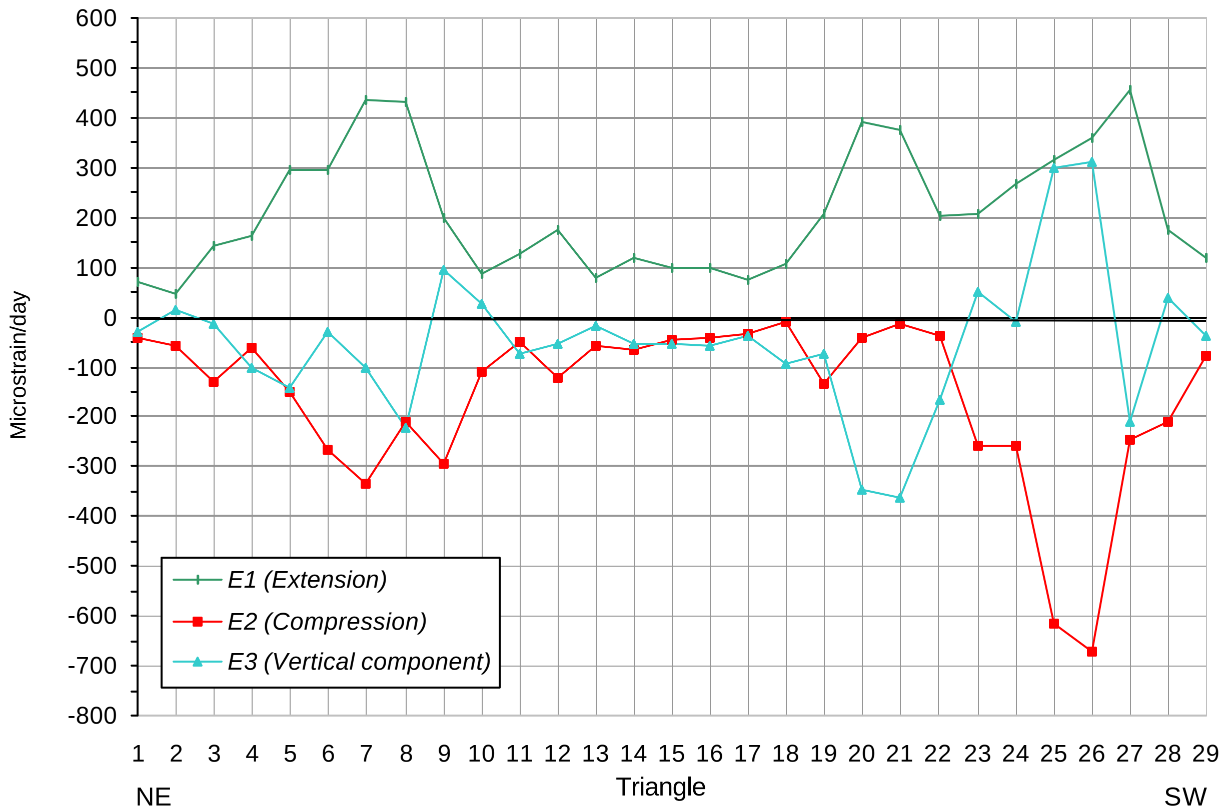


Figure 17: Principal components of strain at each triangle of Profile 4 in 1996. The vertical component (E_3) indicates the magnitude of surface lowering or rising due to the strain regime. Positive values for E_3 indicate that the surface is rising, while negative values represent a lowering of the surface. These elevation changes are minute with respect to those due to mass balance changes. Thus mass balance changes are the dominant factor in controlling surface elevations, rather than the strain regime.

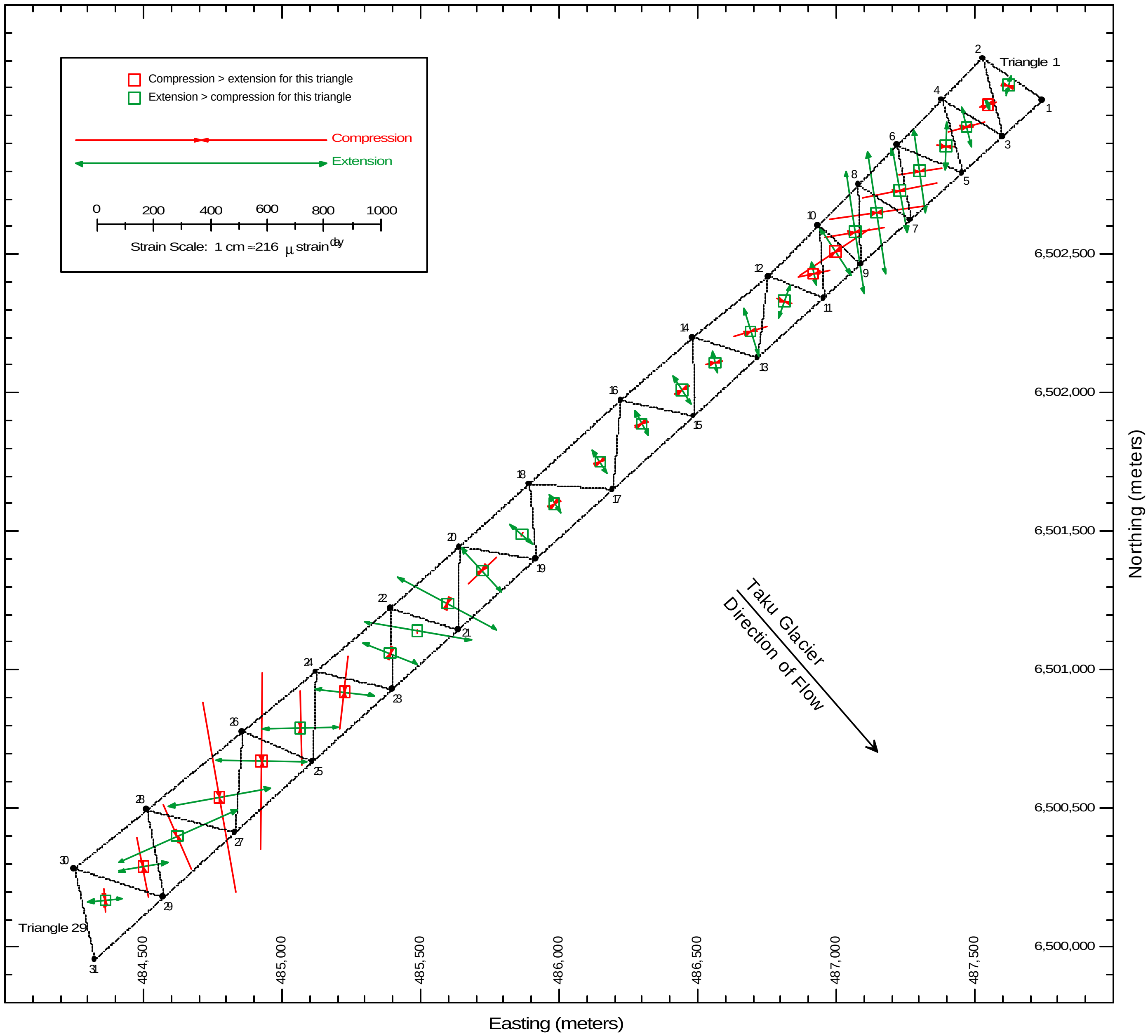


Figure 18: Strain rates at Profile 4 between July 28 and August 6, 1996. Orientation of the extensional strain correlates well with the orientation of marginal shear crevasses. The majority of the profile is subject to extensional strain. Only 7 of 29 triangles exhibit compressional strain. Surface elevations at triangles with net extensional strain decrease due to the overall stretching of the triangle. The reverse is true at triangles with net compressional strain – the surface elevation increases due to the squeezing of the triangle. The magnitude of surface elevation changes due to strain is reflected by the calculated values of E_3. Refer to Appendix 9 for strain values, triangle dimensions, and identification scheme.

3.4 LONG-TERM HEIGHT CHANGE

Historically, one of the most difficult aspects of surveying in a glacial environment, such at the Juneau Icefield, has been the acquisition of accurate surface elevations. Traditional terrestrial methods relied on optical and infrared based instruments such as theodolites and EDMs. Unfortunately, the effects of atmospheric refraction made trigonometric height determinations subject to a wide margin of error. The adoption of differential GPS techniques on the Juneau Icefield has now made it possible to determine precise surface elevations – typically to within approximately 5 cm. This, combined with the added benefits of real-time GPS, allows for highly accurate annual comparisons of surface elevations at the standard profiles.

During the 1996 field season, Profiles 4, 8, and 9 were established at the same locations in which they were located in 1995. These profiles were set with the aid of real-time differential GPS and typically had a mean placement error of approximately 30 cm. Analysis of the annual surface height change and its implications on mass balance at Profile 4 is discussed in Section 3.2 and will therefore not be discussed here. Because Profiles 8 and 9 each consist of a single transverse line of stakes, as opposed to a double line at Profile 4, a spatial analysis of height changes is not possible. Rather, only the annual change in height at each flag can be examined. This long-term height change should not be confused with the project at Profile 4. The long-term height change analysis is simply an examination of the year-to-year surface height fluctuations at each flag of the subject profiles.

As with the Profile 4 surface mass balance project, comparing surface height changes annually requires that the observed surface heights be normalized to a 365 day measurement period. The dates of the surveys each year usually overlap with each other, making it a simple matter to use the observed mean daily ablation to adjust the observed surface heights of one of the years either up or down. This gives the predicted surface height of the year that was adjusted based on a time period of exactly one year.

3.4.1 Profile 8

On average, the surface at Profile 8 was 0.926 meter lower in 1996 than it was at the same time in 1995. Figure 19 shows the surface height change at each flag. Additional data concerning the analysis are shown in Appendix 10. The surface at Flag 10 experienced the least amount of lowering, at –0.658 meter. Flag 6 had the most, at –1.234 meters.

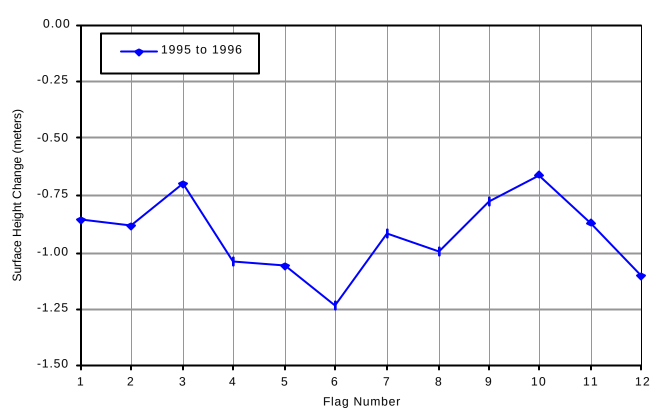


Fig. 19: Surface height change at Profile 8 (1995 to 1996).

Since the Epoch 1 surveys of this profile in 1995 and 1996 were performed on August 10, adjustment of the surface heights was not necessary for Profile 8. Thus, the surface heights employed in the analysis are the actual observed heights for a period of exactly one year.

3.4.2 Profile 9

This profile experienced slightly more annual surface elevation change than did Profile 8. This is expected due to its lower elevation just above the Vaughan Lewis Icefall. The mean annual change was –1.084 meters. The minimum loss was at Flag 6, with a decrease in the surface height of -0.640 meter. The surface at Flag 1 decreased the most, at –1.519 meters. Figure 20 graphs the surface height changes for all flags in the profile. Appendix 10 gives additional details about the profile.

Observed surface heights for the 1996 Epoch 0 survey were decreased by 2 cm to account for 4 days of ablation. The data in Appendix 10 reflect the height adjustment. This adjustment reflects the surface height changes between August 7, 1995 and August 7, 1996.

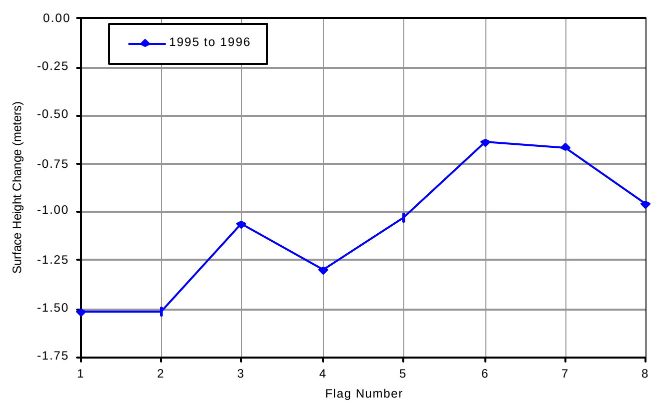


Fig. 20: Surface height change at Profile 9 (1995 to 1996).

3.5 SHORT-TERM HEIGHT CHANGE

For the purposes of this report, short-term height change is defined as the change in surface elevation between the initial (Epoch 0) survey and the resurvey (Epoch 1) in a given year. It considers elevation change only within a period of typically one or two weeks during the summer field season. This is in contrast to the long-term height change analysis described in Section 3.4, in which annual elevation changes are determined.

Short-term height change is a composite of three main factors – ablation (which reflects the prevailing atmospheric conditions), the downslope movement of a survey stake during the survey period, and the vertical component of three-dimensional movement. Figure 21 shows a plot of short-term height change versus surface elevation. At first glance, one might expect an inverse relationship between elevation and height change. As can be seen, this is not always the case. To understand why the observed data shown in Figure 21 do not portray an obvious relationship between height change and elevation, the three composite factors must be examined to determine the relative contribution of each to the observed overall height change.

Theoretically, ablation should decrease with an increase in elevation. Atmospheric conditions over different portions of the Juneau Icefield may be quite different at the same point in time. In other words, heavy rain may be falling at the higher elevations while there may be only cloudy conditions lower down. This could have the effect of producing more ablation at the higher elevations than at the lower elevations – the opposite of what might logically be expected. Thus, the magnitude of ablation is more tightly linked to meteorological conditions than to elevation alone.

The second factor which influences short-term height change is the effect of the surface slope at a survey stake. Unlike height change due to ablation, there is a direct relationship between height change due to surface slope and the magnitude of the change. Steeper slopes result in a greater proportion of the height change being attributable to the downslope movement, rather than to other factors. Similarly, gentler slopes contribute to a smaller proportion. Because surface slopes on the Juneau Icefield at the locations of the survey profiles are typically only 1° to 2°, and the total horizontal movement less than 6 meters over 7-10 days, this means that the height change due to downslope movement is only 1-2 cm^{day} or less. Given the inherent error in determining the exact surface of the glacier (due to suncups

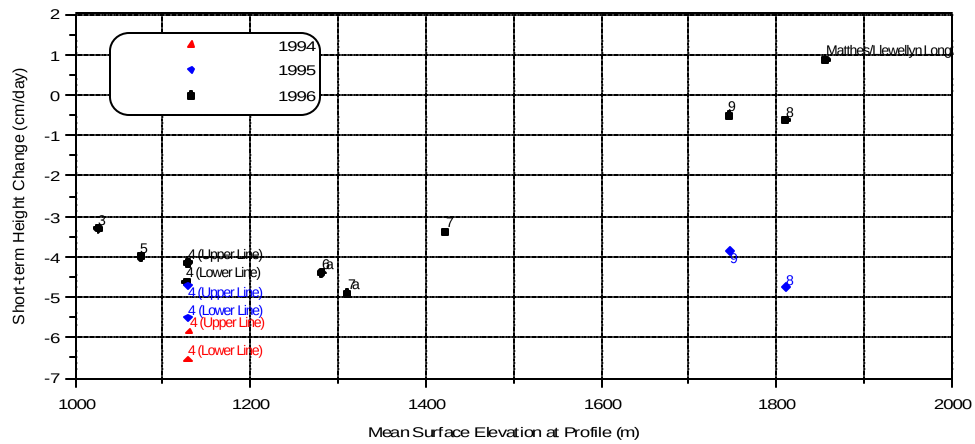


Figure 21: Short-term height change versus profile elevation at several profiles in 1994, 1995, and 1996. Height change is not controlled primarily by elevation, but rather by a combination of ablation, surface slope, submergence or emergence velocity, strain rate, and firn compaction.

and other surface irregularities), elevation changes due to downslope movement are insignificant with respect to the daily ablation, which averages roughly 5 cm^{day}. Nevertheless, since the magnitude of the downslope movement is not directly measured on the Juneau Icefield, and therefore cannot be quantified separately, the analysis of short-term height change must incorporate the downslope component, however slight that may be.

The third factor involved in short-term height change is the vertical component of movement. Vertical movement is a result of three factors – the emergence/submergence velocity, the local strain regime, and the gradual compaction of the firn layer. Because a glacier system is constantly seeking to balance accumulation and wastage, movement vectors in the accumulation area have a downward component of vertical motion, termed the submergence velocity, whereas vectors in the ablation area have an upward orientation referred to as the emergence velocity. An additional complication arises from the fact that the strain regime also influences the vertical movement component. Net compressive strain directs movement vectors upward, resulting in an increase of the surface elevation. Conversely, net extensional strain produces a lowering of the surface. And finally, the firn layer itself is subject to constant and gradual compaction, the degree of which is controlled in large part by meteorological conditions.

Collectively, the effects of ablation, surface slope, and the vertical component of movement determine the magnitude of short-term height change. These effects are seen in Figure 21. Because each of the controlling mechanisms may change in magnitude with respect to each other, and through time, a clear and predictable relationship linking short-term height change and elevation cannot be deduced. However, tracking these changes over time may in the future allow a relationship to be seen.

Cross-sections through the profiles, and the magnitude of short-term height change at each flag, are shown in Appendix 11.

3.6 Taku B / Shoehorn Ridge Cross-section Survey

In support of other scientific activities, the survey program assisted in the investigation of berm sequence correlation. The principle investigator of this study was Robert Burrows, one of the graduate students in 1996. The objective of the study was to determine if a correlation existed between the southwest ridge of Taku B (the C-10 ridge) and the long northeast ridge of Shoehorn Peak. Correlation between the two, as defined by the cross-sectional profile and elevations of steep sections and benches, would possibly help to determine the past regime of the Taku Glacier. It is beyond the scope if this report to provide an analysis of the project. Rather, only the results of the surveys are presented.

Rapid static GPS surveys were conducted on the Taku B and Shoehorn ridges to determine surface elevations along transects from the surface of the Taku Glacier and up the ridges. The 1996 Epoch 0 survey of Profile 4 provided the cross-glacier data. The GPS survey data are presented in Appendix 12. Figure 22 shows a cross-section through the Taku Glacier and the morphology of the Taku Glacier valley. Surveyed elevations on the Taku Glacier and the Taku B and Shoehorn Peak ridges are accurate to approximately 5 cm. Subsurface bedrock topography was derived from seismic refraction studies conducted by Sprenke and Adema, et al (1994, 1995). Subsurface topography is an approximation and is subject to refinement.

There appears to be a strong elevational correlation of two sets of berms on both Taku B and Shoehorn Peak ridges. These are at elevations of 1200 and 1300 meters. An additional bench at an elevation of 1450 meters was surveyed on Shoehorn Peak. Its corollary is present on the Taku B ridge but was not surveyed with GPS. Although the subglacial topography is accurate to only about 10-20 meters, it nevertheless reveals the possibility of a bench at about 400 meters above sea level.

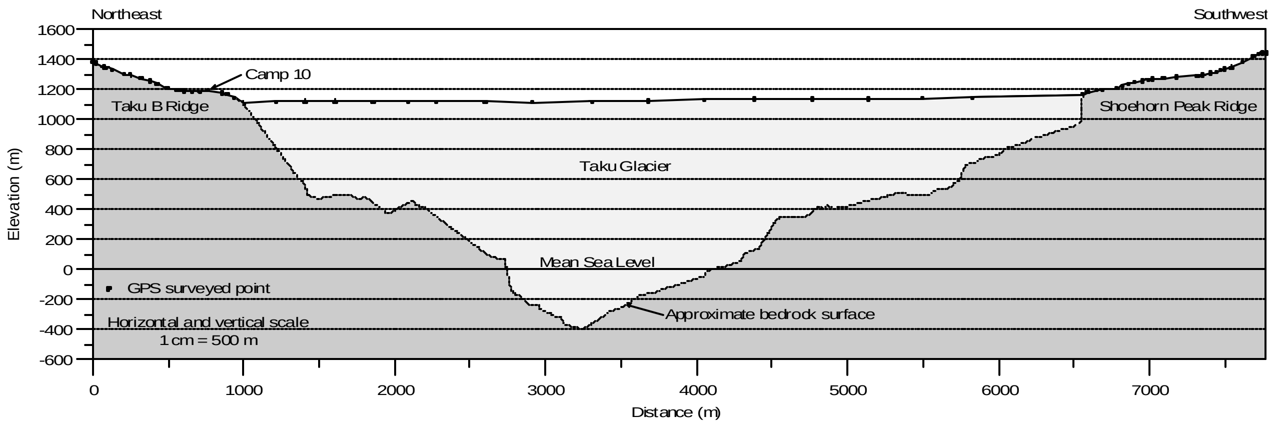


Figure 22: Cross-section through the Taku Glacier along a transect from Taku B to Shoehorn Peak. GPS surveys of the Taku B and Shoehorn Peak ridges confirm the existence of benches at elevations of 1200 and 1300 meters on both ridges. Shoehorn Peak has an additional bench at 1450 meters. A corresponding bench, at roughly the same elevation, exists on Taku B but was not surveyed. Approximate bedrock topography was derived from seismic refraction studies and is subject to further refinement.

3.7 Miscellaneous Surveys

In addition to the movement, strain-rate, and local surface mass balance surveys, the survey program also provided support for the geophysics and meteorological teams. This support consisted of rapid static and real-time GPS surveys of the locations of blast points employed by the ongoing seismic refraction studies. A new seismic profile on the Demorest Glacier, approximately 3 kilometers upglacier from Profile 3, was established by the geophysics team. This profile consisted of 9 flags, 5 of which were surveyed. Additionally, a remote meteorology station was placed at the divide of the Matthes and Llewellyn glaciers. The position of the station was established by real-time GPS. All coordinates and surface heights of these miscellaneous surveys are presented in Appendix 13.

4. Future Survey Work / Projects

In evaluating the survey data collected in 1996, several areas of concern must be addressed in the upcoming field seasons. Chief among these is the need to develop a consistent, reliable method of measuring the GPS antenna height above the glacier surface. This is necessary to calculate and apply the proper offset to the heights obtained by GPS. Suncups and other surface irregularities at the base of the survey stakes make it difficult to determine the mean surface at the stakes. Inconsistent antenna height measurements for the Epoch 0 and Epoch 1 surveys impact the accuracy of the short-term height change calculations. Outliers are the result of such inconsistencies. A method to accurately and consistently determine the mean surface at the base of the stakes is therefore needed.

With the increasing use of real-time GPS on the Juneau Icefield, exact comparisons of year-to-year movement and height changes is possible. This can only be accomplished if the survey stakes are placed in the same exact spot every year. At this time, it is a cumbersome process to do this, as the profile coordinates are listed in numerous survey reports, some of which may not be available at the time the profiles are established. A comprehensive booklet of profile coordinate tables should be compiled. All coordinates for all profiles would then be in one document, making it much easier to reset the profiles in their proper locations every year.

Annual monitoring of the standard movement profiles is well established. The data show that the movement regime of the Taku Glacier system has been stable, making the annual survey of all standard profiles less necessary. Therefore, future survey work should continue to expand the network of profiles into new, unsurveyed areas such as the middle and upper Demorest Glacier, Hades Highway, and the western accumulation area of the Taku Glacier west of the Taku Towers. In addition to monitoring the majority of the standard profiles, one or two new profiles should be established each season to accomplish this goal.

Pearce, Khan, and Pelto, et al (1989) developed a numerical flow model of the Taku Glacier. One of the primary assumptions inherent in the model is the surface velocity field of the Taku Glacier system. Because it is based on the observed surface velocity at only 8 transects, the model could be greatly refined if more surface velocity data are available. Thus an interesting project, and one which would provide an enormous amount of movement data, would be to conduct a longitudinal movement survey from the terminus of the Taku Glacier to the crest of the divide between the Matthes and Llewellyn glaciers. The profile could even extend down the Llewellyn Glacier to the north end of F-10 Peak. Placing flags every 500 meters would provide a detailed analysis of the centerline movement of the entire Taku Glacier. This data could then be used in the development of new flow models for the Taku Glacier or the refinement of existing ones.

ACKNOWLEDGEMENTS

As usual, the survey field work and the compilation of this report could not have been accomplished without the financial and logistical support of the Foundation for Glacier and Environmental Research, Juneau Icefield Research Program. Continued thanks to Dr. Maynard Miller and his wife Joan for the enormous amount of work they do to organize, raise funds, select students, plan logistics, and attend to the hundreds of other details necessary for a successful field season. Prof. Dr.-Ing. Walter Welsch and Dipl.-Ing. Martin Lang, Universistät der Bundeswehr, Munich, Germany contributed invaluable support for the survey field work by providing the necessary equipment and technical expertise. Thanks also to the numerous students involved in the survey work for the great amount of physical labor and assistance they provided. The help of these students could not have been utilized without the generous financial support of the National Science Foundation’s Research Experience for Undergraduates program. Many thanks also to Rebecca and Morgan Dayton for the endless logistical details they performed in keeping everyone on the Icefield supplied and well fed.

REFERENCES

Lang, Martin (1993) Geodetic Activities of the 1993 Juneau Icefield Research Program Field Season. Open File Survey Report, Foundation for Glacier and Environmental Research, Moscow, Idaho. 35 pp.

Lang, Martin (1995) Geodetic Activities of the 1995 Juneau Icefield Research Program Field Season. Open File Survey Report, Foundation for Glacier and Environmental Research, Moscow, Idaho. 64 pp.

McGee, Scott (1994) Geodetic Activities of the 1994 Juneau Icefield Research Program Field Season. Open File Survey Report, Foundation for Glacier and Environmental Research, Moscow, Idaho. 88 pp.

McGee, Scott (1995) Using GPS to Determine Local Surface Mass Balance: A Case Study on the Taku Glacier, Alaska, 1993–1995. Open File Survey Report, Foundation for Glacier and Environmental Research, Moscow, Idaho. 22 pp.

McGee, Scott (1996) Computer Procedures for Interpolation of Glacier Surface Models and Local Surface Mass Balance. Open File Survey Report, Foundation for Glacier and Environmental Research, Moscow, Idaho. 10 pp.

Molenaar, D. (1990) Pictorial Landform Map: Glacier Bay – Juneau Icefield Region. Molenaar Maps. Burley, Washington.

Paterson, W.S.B. (1981) The Physics of Glaciers. Pergamon Press, Oxford, England. p. 72.

Pearce, B.R., L.A. Khan, M.S. Pelto, P.S. Sucsy, V.G. Panchang, M.M. Miller (1989) A Numerical Flow Model of the Taku Glacier, Alaska. University of Maine, Sea Grant College Program. Orono, Maine. 199 pp.

Sprenke, Ken and Guy Adema, et al (1994, 1995) Seismic Refraction Studies on the Juneau Icefield, Alaska. Unpublished data. Foundation for Glacier and Environmental Research, Moscow, Idaho.

Welsch, W.M. (1987) Computing Principal Strains from the Changes of the Elements of a Triangle. Open File Survey Report, Foundation for Glacier and Environmental Research, Moscow, Idaho and Universität der Bundeswehr, München. 6 pp.

APPENDICES

APPENDIX 1

1996 MOVEMENT PROFILE LOCATIONS

Profile	Number of Flags	Flag Spacing (meters)	Bearing From First Flag to Landmarks* (degrees)	Bearing From Last Flag to Landmarks* (degrees)	Bearing of Profile From First Flag to Last Flag (degrees)
Profile 3 (Demorest Glacier)	11	253	Taku A: 313 Taku SW: 219	Taku A: 304 Taku SW: 240	121
Profile 4 [1] (Camp 10)	31	311**	Taku C: 333 Shoehorn Pk.: 228	Taku C: 12 Shoehorn Pk.: 232	227
Profile 5 (Southwest Branch)	12	203	Taku A: 52 Taku SW: 134	Taku A: 32 Taku SW: 110	137
Profile 6a (Northwest Branch)	14	299	Taku B: 122 Taku D: 37	Taku B: 96 Taku D: 38	219
Profile 7 (Camp 9)	16	234	Taku D: 261 Exploration Pk.: 206	Taku D: 228 Exploration Pk.: 160	292
Profile 7a (Taku C to Taku D)	14	177	Taku C: 137 Centurian Pk.: 10	Taku C: 169 Centurian Pk.: 348	126
Profile 8 [1] (Camp 8)	12	317	Mt. Moore: 111 Mammary Pk.: 262	Mt. Moore: 117 Mammary Pk.: 246	299
Upper Vaughan Lewis (C-18)	8	229	Typhoon Pk.: 44 Mammary Pk.: 206	Typhoon Pk.: 28 Mammary Pk.: 228	Profile parallels trend of crevasses
Matthes-Llewellyn Divide Profile [1]	14	374	Blizzard Pk: 246 Mt. Moore: 163	Blizzard Pk: 219 Mt. Moore: 179	18

* All bearings are to the summits of the noted mountains and are referenced to true north.

** Profile 4 is composed of two parallel lines of flags. The up-glacier line has 15 flags and the down-glacier line has 16 flags. The average spacing of flags on each line is approximately 311 meters.

[1] Profiles 4, 8, the Upper Vaughan Lewis, and Flag 16 of the Matthes-Llewellyn Divide profile were placed in their 1995 Epoch 0 positions via real-time differential GPS.

APPENDIX 2

FLAG PLACEMENT ACCURACY OF PROFILES ESTABLISHED VIA GPS (1996 VS. 1995)

PROFILE	FLAG	1995 EPOCH 0 POSITION		1996 EPOCH 0 POSITION		PLACEMENT ERROR (M)*
		EASTING(M)	NORTHING(M)	EASTING(M)	NORTHING(M)	
4	1	487,743.545	6,503,056.139	487,743.285	6,503,056.315	0.314
	2	487,528.410	6,503,206.257	487,528.442	6,503,206.253	0.032
	3	487,602.073	6,502,925.201	487,602.164	6,502,925.232	0.096
	4	487,379.731	6,503,057.231	487,379.730	6,503,057.159	0.072
	5	487,453.688	6,502,792.801	487,453.571	6,502,792.800	0.117
	6	487,221.996	6,502,890.742	487,221.959	6,502,890.762	0.042
	7	487,267.134	6,502,623.699	487,266.974	6,502,623.637	0.172
	8	487,085.967	6,502,746.552	487,085.981	6,502,746.546	0.015
	9	487,091.299	6,502,466.818	487,091.221	6,502,466.751	0.103
	10	486,936.638	6,502,602.233	486,936.671	6,502,602.239	0.034
	11	486,957.200	6,502,341.183	486,956.992	6,502,341.320	0.249
	12	486,756.726	6,502,417.719	486,756.744	6,502,417.685	0.038
	13	486,716.328	6,502,123.843	486,716.259	6,502,123.805	0.079
	14	486,484.475	6,502,197.607	486,484.468	6,502,197.630	0.024
	15	486,483.743	6,501,913.898	486,483.711	6,501,913.877	0.038
	16	486,223.460	6,501,969.995	486,223.435	6,501,969.963	0.041
	17	486,195.813	6,501,649.160	486,195.710	6,501,649.155	0.103
	18	485,892.972	6,501,668.947	485,892.985	6,501,668.963	0.021
	19	485,918.786	6,501,396.568	485,918.793	6,501,396.576	0.011
	20	485,641.421	6,501,439.734	485,641.481	6,501,439.749	0.062
	21	485,640.910	6,501,145.929	485,640.790	6,501,145.925	0.120
	22	485,392.602	6,501,217.948	485,392.649	6,501,217.978	0.056
	23	485,397.041	6,500,926.534	485,396.995	6,500,926.425	0.118
	24	485,125.776	6,500,988.688	485,125.733	6,500,988.641	0.064
	25	485,111.782	6,500,666.605	485,111.799	6,500,666.460	0.146
	26	484,860.761	6,500,776.902	484,860.729	6,500,776.842	0.068
	27	484,836.495	6,500,415.009	484,836.392	6,500,414.973	0.109
	28	484,511.799	6,500,494.136	484,511.955	6,500,494.122	0.157
	29	484,572.945	6,500,178.523	484,572.821	6,500,178.540	0.125
	30	484,251.322	6,500,281.146	484,251.425	6,500,281.250	0.146
	31	484,324.050	6,499,953.280	484,324.148	6,499,953.240	0.106
					Mean	**0.093**
					Standard deviation	**0.068**

* Relative to 1995 Epoch 0 position.

PROFILE	FLAG	1995 EPOCH 0 POSITION		1996 EPOCH 0 POSITION		PLACEMENT ERROR (M)*
		EASTING(M)	NORTHING(M)	EASTING(M)	NORTHING(M)	
8	1	490903.021	6522004.866	490,903.010	6,522,004.830	0.038
	2	490613.420	6522169.266	490,613.399	6,522,169.252	0.025
	3	490366.204	6522305.920	490,366.266	6,522,305.853	0.091
	4	490119.216	6522443.514	490,119.212	6,522,443.505	0.010
	5	489885.040	6522574.352	489,884.940	6,522,574.352	0.100
	6	489636.881	6522711.678	489,636.913	6,522,711.650	0.043
	7	489366.448	6522858.938	489,366.498	6,522,858.879	0.077
	8	489089.149	6523015.443	489,089.161	6,523,015.397	0.048
	9	488765.920	6523197.618	488,765.898	6,523,197.604	0.026
	10	488415.469	6523396.533	488,415.370	6,523,396.517	0.100
	11	488105.722	6523570.894	488,105.788	6,523,570.860	0.074
	12	487864.179	6523706.811	487,864.222	6,523,706.860	0.065
					Mean	**0.058**
					Standard Deviation	**0.031**

Upper Vaughan Lewis	1	485620.483	6524358.071	485,620.495	6,524,358.046	0.028
	2	485747.180	6524153.872	485,747.248	6,524,154.680	0.811
	3	485830.159	6523948.108	485,831.279	6,523,946.302	2.125
	4	485874.313	6523693.866	485,874.017	6,523,692.934	0.978
	5	485877.331	6523472.567	485,876.768	6,523,471.830	0.927
	6	485794.830	6523293.130	485,795.341	6,523,292.591	0.743
	7	485670.263	6523113.673	485,669.197	6,523,112.756	1.406
	8	485441.790	6523028.187	485,441.358	6,523,027.455	0.850
					Mean	**0.983**
					Standard Deviation	**0.598**

M/L Divide	16	490913.452	6526854.310	490,913.518	6,526,854.324	**0.067**

* Relative to 1995 Epoch 0 position

APPENDIX 3

FLAG PLACEMENT ACCURACY FOR PROFILE 4 – 1993 TO 1996

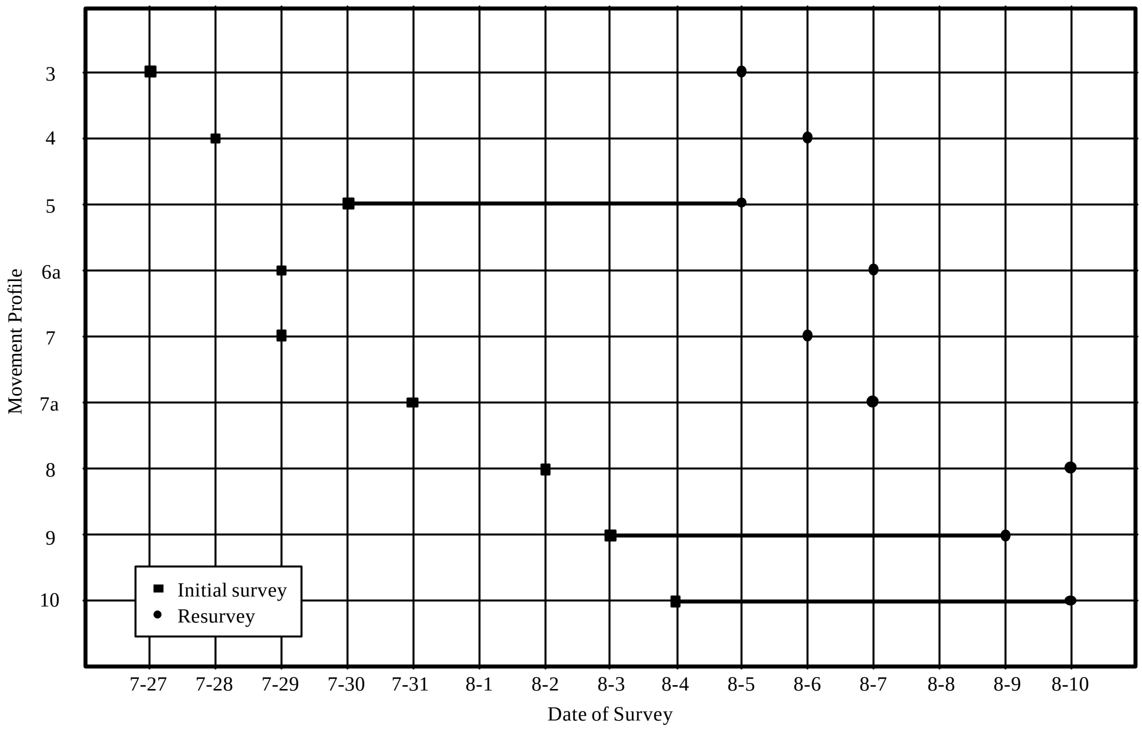
FLAG	1993 EPOCH 0 POSITION		PLACEMENT ERROR – RELATIVE TO 1993 EPOCH 0 (M)		
	EASTING(M)	NORTHING(M)	1994	1995	1996
1	487,744.558	6,503,055.271	6.039	1.334	1.646
2	487,527.414	6,503,206.819	3.375	1.144	1.174
3	487,601.279	6,502,925.736	3.459	0.957	1.018
4	487,380.242	6,503,056.891	2.244	0.614	0.578
5	487,454.297	6,502,792.822	3.077	0.609	0.726
6	487,219.219	6,502,892.955	1.952	3.551	3.510
7	487,266.743	6,502,623.410	2.445	0.486	0.324
8	487,079.493	6,502,750.063	1.996	7.365	7.380
9	487,088.983	6,502,462.428	2.223	4.963	4.868
10	486,936.245	6,502,604.403	2.445	2.205	2.206
11	486,955.346	6,502,341.581	2.511	1.896	1.667
12	486,755.083	6,502,418.956	2.405	2.057	2.091
13	486,716.641	6,502,124.995	2.423	1.194	1.250
14	486,483.751	6,502,199.046	2.811	1.611	1.587
15	486,484.695	6,501,915.579	2.568	1.932	1.966
16	486,222.777	6,501,971.820	2.869	1.949	1.970
17	486,193.390	6,501,651.586	2.408	3.429	3.360
18	485,891.842	6,501,670.771	2.672	2.146	2.139
19	485,916.025	6,501,399.690	2.701	4.168	4.166
20	485,639.949	6,501,442.829	2.658	3.427	3.440
21	485,636.642	6,501,145.952	3.029	4.268	4.148
22	485,391.514	6,501,220.810	3.056	3.062	3.051
23	485,397.765	6,500,929.198	101.253**	2.761	2.878
24	485,121.571	6,500,992.813	2.642	5.890	5.893
25	485,110.387	6,500,667.968	2.649	1.950	2.066
26	484,859.271	6,500,778.014	2.222	1.859	1.871
27	484,829.919	6,500,413.740	2.151	6.697	6.589
		Mean	**2.732**	**2.723**	**2.725**
		Standard Deviation	**0.775**	**1.840**	**1.816**

Note: The 1993 easting and northing coordinates shown here were adjusted to correspond with the GPS coordinate system that was established in 1995. The original GPS surveyed 1993 easting coordinates were decreased by 14.58 meters and the northing coordinates were decreased by 3.409 meters. The adjusted 1993 coordinates are shown here. The placement accuracy of Flags 28-31 is not shown because these flags were not established until 1994.

** Gross placement error; excluded from mean and standard deviation calculations.

APPENDIX 4

1996 SURVEY TIMELINE



This chart shows the timeline of the surveys completed during the summer of 1996. The first survey took place on July 27 and the last to be completed was on August 10.

APPENDIX 5

MOVEMENT PROFILE FLAG COORDINATES

PROFILE 3 (DEMOREST GLACIER) — EPOCH 0					
FLAG	EASTING (M)	NORTHING (M)	HEIGHT (M)	DATE	TIME
1	491,382.417	6,500,862.571	1,010.728	07-27-96	12:54
2	491,622.284	6,500,706.575	1,014.411	07-27-96	13:33
3	491,838.290	6,500,570.261	1,018.679	07-27-96	14:08
4	492,084.713	6,500,413.642	1,024.120	07-27-96	14:40
5	492,303.589	6,500,277.524	1,024.814	07-27-96	15:10
6	492,521.819	6,500,139.106	1,023.507	07-27-96	15:36
7	492,744.868	6,500,000.974	1,026.530	07-27-96	16:06
8	492,974.773	6,499,866.198	1,035.525	07-27-96	16:32
9	493,183.574	6,499,745.080	1,043.749	07-27-96	16:58
10	493,364.930	6,499,632.874	1,046.728	07-27-96	17:24
11	493,531.096	6,499,525.528	1,046.912	07-27-96	18:01

PROFILE 3 (DEMOREST GLACIER) — EPOCH 1					
FLAG	EASTING (M)	NORTHING (M)	HEIGHT (M)	DATE	TIME
1[1]	—	—	—	—	—
2	491,621.434	6,500,705.860	1,014.195	08-05-96	12:16
3	491,836.954	6,500,569.198	1,018.357	08-05-96	12:44
4	492,083.018	6,500,412.280	1,023.856	08-05-96	13:13
5	492,301.691	6,500,276.079	1,024.504	08-05-96	13:38
6	492,519.890	6,500,137.687	1,023.208	08-05-96	14:04
7	492,742.963	6,499,999.652	1,026.077	08-05-96	14:32
8	492,972.723	6,499,864.919	1,035.323	08-05-96	15:00
9	493,181.528	6,499,742.954	1,044.081	08-05-96	15:26
10[2]	—	—	—	—	—
11[2]	—	—	—	—	—

[1] Flag was not accessible at time of resurvey due to crevasses.
[2] Flag ablated out and fell over before it could be resurveyed.

PROFILE 4 (TAKU GLACIER @ C-10) — EPOCH 0					
FLAG	**EASTING (M)**	**NORTHING (M)**	**HEIGHT (M)**	**DATE**	**TIME**
1	487,743.285	6,503,056.315	1,118.360	07-28-96	14:44
2	487,528.442	6,503,206.253	1,125.042	07-28-96	20:34
3	487,602.164	6,502,925.232	1,121.239	07-28-96	15:02
4	487,379.730	6,503,057.159	1,123.917	07-28-96	20:28
5	487,453.571	6,502,792.800	1,121.364	07-28-96	15:18
6	487,221.959	6,502,890.762	1,121.481	07-28-96	20:22
7	487,266.974	6,502,623.637	1,118.815	07-28-96	15:32
8	487,085.981	6,502,746.546	1,120.513	07-28-96	20:14
9	487,091.221	6,502,466.751	1,119.179	07-28-96	15:48
10	486,936.671	6,502,602.239	1,120.070	07-28-96	20:02
11	486,956.992	6,502,341.320	1,119.977	07-28-96	16:09
12	486,756.744	6,502,417.685	1,119.874	07-28-96	19:54
13	486,716.259	6,502,123.805	1,119.458	07-28-96	16:20
14	486,484.468	6,502,197.630	1,121.318	07-28-96	19:43
15	486,483.711	6,501,913.877	1,115.671	07-28-96	16:28
16	486,223.435	6,501,969.963	1,120.396	07-28-96	19:35
17	486,195.710	6,501,649.155	1,119.745	07-28-96	16:36
18	485,892.985	6,501,668.963	1,126.359	07-28-96	19:25
19	485,918.793	6,501,396.576	1,126.323	07-28-96	16:44
20	485,641.481	6,501,439.749	1,132.354	07-28-96	19:18
21	485,640.790	6,501,145.925	1,132.736	07-28-96	16:57
22	485,392.649	6,501,217.978	1,136.813	07-28-96	19:10
23	485,396.995	6,500,926.425	1,134.871	07-28-96	17:05
24	485,125.733	6,500,988.641	1,137.286	07-28-96	19:02
25	485,111.799	6,500,666.460	1,136.717	07-28-96	17:35
26	484,860.729	6,500,776.842	1,139.092	07-28-96	18:52
27	484,836.392	6,500,414.973	1,137.358	07-28-96	17:59
28	484,511.955	6,500,494.122	1,139.020	07-28-96	18:38
29	484,572.821	6,500,178.540	1,140.990	07-28-96	18:11
30	484,251.425	6,500,281.250	1,140.354	07-28-96	18:30
31	484,324.148	6,499,953.240	1,145.156	07-28-96	18:21

PROFILE 4 (TAKU GLACIER @ C-10) — EPOCH 1					
FLAG	EASTING (M)	NORTHING (M)	HEIGHT (M)	DATE	TIME
1	487,743.368	6,503,056.335	1,117.996	08-06-96	19:17
2	487,528.500	6,503,206.127	1,124.750	08-06-96	11:55
3	487,602.367	6,502,925.025	1,120.879	08-06-96	19:01
4	487,379.945	6,503,056.986	1,123.631	08-06-96	12:10
5	487,454.145	6,502,792.360	1,120.886	08-06-96	18:58
6	487,222.512	6,502,890.091	1,121.148	08-06-96	12:18
7	487,268.335	6,502,622.374	1,118.475	08-06-96	18:51
8	487,087.328	6,502,745.307	1,120.164	08-06-96	12:23
9	487,093.770	6,502,464.473	1,118.805	08-06-96	18:46
10	486,938.908	6,502,600.066	1,119.785	08-06-96	12:32
11	486,960.185	6,502,339.032	1,118.497	08-06-96	18:41
12	486,759.836	6,502,414.856	1,119.575	08-06-96	12:38
13	486,719.983	6,502,120.567	1,119.032	08-06-96	18:35
14	486,488.239	6,502,194.376	1,120.895	08-06-96	12:45
15	486,487.716	6,501,910.445	1,115.169	08-06-96	18:30
16	486,227.433	6,501,966.728	1,119.910	08-06-96	12:50
17	486,199.871	6,501,645.760	1,119.218	08-06-96	18:24
18	485,897.144	6,501,665.762	1,125.906	08-06-96	13:03
19	485,923.033	6,501,393.262	1,125.785	08-06-96	18:17
20	485,645.571	6,501,436.668	1,131.925	08-06-96	13:10
21	485,645.550	6,501,142.702	1,134.425	08-06-96	18:09
22	485,396.587	6,501,215.023	1,136.363	08-06-96	13:16
23	485,400.967	6,500,923.478	1,134.381	08-06-96	8:04
24	485,129.277	6,500,986.064	1,136.894	08-06-96	13:22
25	485,114.996	6,500,664.640	1,135.020	08-06-96	17:56
26	484,863.431	6,500,774.958	1,138.758	08-06-96	13:29
27	484,838.314	6,500,415.149	1,131.490	08-06-96	17:48
28	484,513.075	6,500,493.447	1,138.684	08-06-96	13:39
29	484,573.374	6,500,178.379	1,140.677	08-06-96	17:31
30	484,251.726	6,500,281.163	1,140.069	08-06-96	13:45
31	484,324.251	6,499,953.349	1,144.831	08-06-96	17:24

PROFILE 5 (SOUTHWEST BRANCH) — EPOCH 0					
FLAG	EASTING (M)	NORTHING (M)	HEIGHT (M)	DATE	TIME
1	485,618.931	6,497,859.218	1,066.490	07-30-96	15:28
2	485,771.848	6,497,694.166	1,066.987	07-30-96	15:37
3	485,926.748	6,497,531.066	1,069.646	07-30-96	15:41
4	486,082.024	6,497,366.493	1,069.175	07-30-96	15:46
5	486,235.983	6,497,193.249	1,068.130	07-30-96	15:56
6	486,386.191	6,497,025.998	1,069.418	07-30-96	16:02
7	486,534.089	6,496,857.611	1,074.534	07-30-96	16:08
8	486,681.372	6,496,687.025	1,079.493	07-30-96	16:13
9	486,827.602	6,496,515.077	1,081.470	07-30-96	16:20
10	486,922.862	6,496,403.596	1,082.474	07-30-96	16:24
11	487,014.746	6,496,295.533	1,084.485	07-30-96	16:27
12	487,103.902	6,496,195.399	1,086.165	07-30-96	16:32

PROFILE 5 (SOUTHWEST BRANCH) — EPOCH 1					
FLAG	EASTING (M)	NORTHING (M)	HEIGHT (M)	DATE	TIME
1	485,618.974	6,497,859.254	1,066.274	08-05-96	14:27
2	485,773.152	6,497,694.836	1,066.983	08-05-96	14:24
3	485,928.234	6,497,531.979	1,069.134	08-05-96	14:19
4	486,082.322	6,497,366.869	1,069.253	08-05-96	14:15
5	486,236.290	6,497,193.816	1,068.236	08-05-96	14:03
6	486,386.452	6,497,026.518	1,069.193	08-05-96	13:53
7	486,534.414	6,496,858.033	1,074.245	08-05-96	13:49
8	486,681.626	6,496,687.439	1,079.232	08-05-96	13:44
9	486,827.714	6,496,515.353	1,081.247	08-05-96	13:40
10	486,922.965	6,496,403.907	1,082.290	08-05-96	13:36
11	487,015.004	6,496,295.850	1,083.783	08-05-96	13:33
12	487,103.989	6,496,195.541	1,085.909	08-05-96	13:26

PROFILE 6A (NORTHWEST BRANCH) — EPOCH 0					
FLAG	EASTING (M)	NORTHING (M)	HEIGHT (M)	DATE	TIME
1	482,127.340	6,508,768.430	1,287.049	07-29-96	18:14
2	481,950.496	6,508,541.222	1,278.565	07-29-96	18:09
3	481,761.196	6,508,302.150	1,275.017	07-29-96	18:05
4	481,575.845	6,508,070.166	1,273.681	07-29-96	18:00
5	481,381.921	6,507,826.928	1,272.628	07-29-96	17:55
6	481,185.845	6,507,582.155	1,275.002	07-29-96	17:50
7	481,005.849	6,507,353.613	1,278.359	07-29-96	17:43
8	480,819.777	6,507,117.220	1,280.795	07-29-96	17:34
9	480,623.311	6,506,868.078	1,283.028	07-29-96	17:27
10	480,438.272	6,506,638.979	1,285.352	07-29-96	16:46
11	480,264.789	6,506,421.617	1,287.214	07-29-96	16:33
12	480,075.297	6,506,177.619	1,286.660	07-29-96	16:17
13	479,882.140	6,505,925.117	1,285.463	07-29-96	16:08
14	479,715.376	6,505,720.952	1,285.221	07-29-96	16:01
Seismic Center	480,772.415	6,506,668.084	1,278.810	07-29-96	17:20

PROFILE 6A (NORTHWEST BRANCH) — EPOCH 1					
FLAG	EASTING (M)	NORTHING (M)	HEIGHT (M)	DATE	TIME
1	482,126.408	6,508,768.345	1,286.845	08-07-96	14:34
2	481,950.701	6,508,541.055	1,278.235	08-07-96	14:28
3	481,761.685	6,508,301.802	1,274.721	08-07-96	14:28
4	481,576.780	6,508,069.625	1,273.371	08-07-96	14:24
5	481,383.460	6,507,826.172	1,272.290	08-07-96	14:20
6	481,187.953	6,507,580.881	1,274.670	08-07-96	14:17
7	481,008.274	6,507,352.265	1,277.999	08-07-96	14:13
8	480,822.286	6,507,116.129	1,280.388	08-07-96	14:09
9	480,625.772	6,506,867.080	1,282.554	08-07-96	14:06
10	480,440.696	6,506,638.091	1,284.942	08-07-96	14:02
11	480,267.125	6,506,420.838	1,286.765	08-07-96	13:59
12	480,077.232	6,506,176.748	1,286.171	08-07-96	13:54
13	479,883.978	6,505,924.449	1,284.935	08-07-96	13:50
14	479,717.006	6,505,720.430	1,284.690	08-07-96	13:45

PROFILE 7 (MATTHES GLACIER @ C-9) — EPOCH 0					
FLAG	EASTING (M)	NORTHING (M)	HEIGHT (M)	DATE	TIME
1	489,081.757	6,510,948.605	1,467.189	07-27-96	14:18
2	489,007.100	6,510,989.085	1,454.019	07-27-96	14:56
3	488,875.592	6,511,059.338	1,439.970	07-27-96	15:24
4	488,742.074	6,511,131.090	1,431.028	07-27-96	15:54
5	488,520.946	6,511,249.391	1,426.715	07-27-96	16:24
6	488,305.846	6,511,364.044	1,427.461	07-27-96	16:54
7	488,075.242	6,511,486.361	1,426.766	07-27-96	17:24
8	487,839.931	6,511,611.351	1,424.963	07-27-96	18:00
9	487,614.252	6,511,731.625	1,423.971	07-27-96	18:33
10	487,386.393	6,511,854.294	1,416.701	07-27-96	19:04
11	487,147.445	6,511,982.425	1,410.517	07-27-96	19:38
12	486,912.734	6,512,107.861	1,414.868	07-27-96	20:10
13	486,677.872	6,512,231.641	1,422.322	07-27-96	20:45
14	486,445.849	6,512,351.114	1,418.572	07-27-96	21:18
15	486,214.448	6,512,478.148	1,418.034	07-27-96	21:50
16	485,980.542	6,512,606.285	1,425.427	07-27-96	22:19

PROFILE 7 (MATTHES GLACIER @ C-10) — EPOCH 1					
FLAG	EASTING (M)	NORTHING (M)	HEIGHT (M)	DATE	TIME
1	489,081.684	6,510,948.629	1,466.916	08-06-96	18:08
2	489,006.955	6,510,989.121	1,453.771	08-06-96	17:52
3	488,875.437	6,511,059.345	1,439.733	08-06-96	17:34
4	488,741.937	6,511,131.062	1,430.814	08-06-96	17:18
5	488,520.633	6,511,249.187	1,426.522	08-06-96	17:02
6	488,305.153	6,511,363.228	1,427.236	08-06-96	16:44
7	488,074.086	6,511,484.885	1,426.487	08-06-96	16:28
8	487,838.438	6,511,609.394	1,424.658	08-06-96	16:08
9	487,612.686	6,511,729.599	1,423.656	08-06-96	15:50
10	487,384.895	6,511,852.192	1,416.324	08-06-96	15:00
11	487,146.011	6,511,980.290	1,410.188	08-06-96	14:44
12	486,911.331	6,512,105.671	1,414.621	08-06-96	14:23
13	486,676.538	6,512,229.517	1,422.013	08-06-96	14:04
14	486,444.707	6,512,349.155	1,418.295	08-06-96	13:46
15	486,213.739	6,512,476.543	1,417.799	08-06-96	13:28
16	485,980.249	6,512,605.189	1,425.222	08-06-96	13:04

PROFILE 7A (MATTHES GLACIER @ TAKU 'D') — EPOCH 0					
FLAG	EASTING (M)	NORTHING (M)	HEIGHT (M)	DATE	TIME
1	483,727.039	6,509,199.381	1,301.255	07-31-96	16:20
2	483,850.028	6,509,107.958	1,300.448	07-31-96	16:27
3	484,016.982	6,508,983.974	1,300.950	07-31-96	16:30
4	484,171.491	6,508,870.349	1,300.794	07-31-96	16:34
5	484,330.132	6,508,753.317	1,300.477	07-31-96	16:38
6	484,487.932	6,508,636.987	1,299.780	07-31-96	16:41
7	484,646.112	6,508,520.767	1,301.034	07-31-96	16:48
8	484,802.055	6,508,406.687	1,308.304	07-31-96	16:51
9	484,954.874	6,508,294.649	1,316.774	07-31-96	16:57
10	485,116.199	6,508,176.452	1,320.892	07-31-96	17:00
11	485,229.884	6,508,093.214	1,321.566	07-31-96	17:02
12	485,343.470	6,508,009.811	1,323.313	07-31-96	17:05
13	485,455.581	6,507,927.800	1,323.925	07-31-96	17:09
14	485,584.783	6,507,833.634	1,323.675	07-31-96	17:12
Seismic Center	484,560.289	6,508,580.075	1,299.696	07-31-96	16:44

PROFILE 7A (MATTHES GLACIER @ TAKU 'D') — EPOCH 1					
FLAG	EASTING (M)	NORTHING (M)	HEIGHT (M)	DATE	TIME
1	483,726.264	6,509,198.426	1,300.956	08-07-96	15:56
2	483,848.892	6,509,106.619	1,300.118	08-07-96	15:53
3	484,015.479	6,508,982.256	1,300.549	08-07-96	15:49
4	484,169.809	6,508,868.521	1,300.423	08-07-96	15:46
5	484,328.280	6,508,751.406	1,300.109	08-07-96	15:43
6	484,485.996	6,508,634.987	1,299.457	08-07-96	15:40
7	484,644.113	6,508,518.715	1,300.629	08-07-96	15:37
8	484,799.997	6,508,404.643	1,307.916	08-07-96	15:34
9	484,952.798	6,508,292.597	1,316.437	08-07-96	15:31
10	485,114.171	6,508,174.444	1,320.568	08-07-96	15:28
11	485,227.893	6,508,091.268	1,321.265	08-07-96	15:22
12	485,341.583	6,508,007.942	1,323.012	08-07-96	15:19
13	485,453.860	6,507,926.104	1,323.599	08-07-96	15:12
14	485,583.296	6,507,832.202	1,323.386	08-07-96	15:08

PROFILE 8 (MATTHES GLACIER @ C-8) — EPOCH 0					
FLAG	EASTING (M)	NORTHING (M)	HEIGHT (M)	DATE	TIME
1	490,903.010	6,522,004.830	1,831.317	08-02-96	16:58
2	490,613.399	6,522,169.252	1,819.905	08-02-96	16:50
3	490,366.266	6,522,305.853	1,796.065	08-02-96	16:41
4	490,119.212	6,522,443.505	1,790.617	08-02-96	16:32
5	489,884.940	6,522,574.352	1,791.698	08-02-96	16:24
6	489,636.913	6,522,711.650	1,795.140	08-02-96	16:08
7	489,366.498	6,522,858.879	1,800.354	08-02-96	15:59
8	489,089.161	6,523,015.397	1,803.682	08-02-96	15:49
9	488,765.898	6,523,197.604	1,808.396	08-02-96	15:40
10	488,415.370	6,523,396.517	1,814.112	08-02-96	15:26
11	488,105.788	6,523,570.860	1,828.391	08-02-96	15:12
12	487,864.222	6,523,706.860	1,849.640	08-02-96	14:57

PROFILE 8 (MATTHES GLACIER @ C-8) — EPOCH 1					
FLAG	EASTING (M)	NORTHING (M)	HEIGHT (M)	DATE	TIME
1	490,902.290	6,522,004.558	1,831.274	08-10-96	16:14
2	490,612.653	6,522,168.859	1,819.865	08-10-96	16:08
3	490,365.589	6,522,305.164	1,795.960	08-10-96	16:03
4	490,118.760	6,522,442.536	1,790.200	08-10-96	15:51
5	489,884.532	6,522,573.201	1,791.276	08-10-96	15:48
6	489,636.563	6,522,710.439	1,794.743	08-10-96	15:45
7	489,366.141	6,522,857.691	1,800.330	08-10-96	15:40
8	489,088.862	6,523,014.290	1,803.653	08-10-96	15:36
9	488,765.744	6,523,196.708	1,808.367	08-10-96	15:32
10	488,415.435	6,523,395.959	1,814.038	08-10-96	15:28
11	488,106.030	6,523,570.675	1,827.949	08-10-96	15:24
12	487,863.668	6,523,707.123	1,849.754	08-10-96	15:18

Profile 9 (Upper Vaughan Lewis Glacier) — Epoch 0					
Flag	Easting (m)	Northing (m)	Height (m)	Date	Time
1	485,620.495	6,524,358.046	1,732.081	08-03-96	18:30
2	485,747.248	6,524,154.680	1,733.318	08-03-96	18:49
3	485,831.279	6,523,946.302	1,737.022	08-03-96	18:59
4	485,874.017	6,523,692.934	1,741.869	08-03-96	19:06
5	485,876.768	6,523,471.830	1,747.106	08-03-96	19:16
6	485,795.341	6,523,292.591	1,751.470	08-03-96	19:29
7	485,669.197	6,523,112.756	1,756.061	08-03-96	19:35
8	485,441.358	6,523,027.455	1,766.882	08-03-96	19:42

Profile 9 (Upper Vaughan Lewis Glacier) — Epoch 1					
Flag	Easting (m)	Northing (m)	Height (m)	Date	Time
1	485,620.140	6,524,357.761	1,732.030	08-09-96	15:13
2	485,746.695	6,524,154.635	1,733.313	08-09-96	15:21
3	485,830.546	6,523,946.484	1,736.801	08-09-96	15:26
4	485,873.447	6,523,693.285	1,741.810	08-09-96	15:35
5	485,876.336	6,523,472.277	1,747.065	08-09-96	15:42
6	485,794.922	6,523,293.148	1,751.486	08-09-96	15:49
7	485,668.982	6,523,113.269	1,756.026	08-09-96	15:54
8	485,441.327	6,523,027.788	1,767.037	08-09-96	16:00

PROFILE 10 (MATTHES-LLEWELLYN DIVIDE PROFILE) — EPOCH 0					
FLAG	EASTING (M)	NORTHING (M)	HEIGHT (M)	DATE	TIME
16	490,913.518	6,526,854.324	1,878.212	08-04-96	13:13
17	491,022.767	6,527,209.109	1,880.363	08-04-96	13:28
18	491,139.601	6,527,561.943	1,878.869	08-04-96	13:36
19	491,251.410	6,527,917.401	1,874.578	08-04-96	13:42
20	491,363.041	6,528,270.706	1,869.479	08-04-96	13:49
21	491,477.384	6,528,633.059	1,865.750	08-04-96	13:56
22	491,588.604	6,528,985.070	1,861.971	08-04-96	14:01
23	491,701.993	6,529,342.783	1,857.528	08-04-96	14:18
24	491,815.634	6,529,701.109	1,853.073	08-04-96	14:25
25	491,929.387	6,530,058.155	1,847.074	08-04-96	14:31
26	492,043.911	6,530,415.667	1,838.807	08-04-96	14:43
27	492,158.401	6,530,773.036	1,831.498	08-04-96	14:49
28	492,271.425	6,531,125.263	1,827.323	08-04-96	14:56
29	492,386.016	6,531,482.149	1,822.468	08-04-96	15:02
Met. Station	490,312.901	6,526,716.996	1,883.129	08-04-96	12:18

PROFILE 10 (MATTHES-LLEWELLYN DIVIDE PROFILE) — EPOCH 1					
FLAG	EASTING (M)	NORTHING (M)	HEIGHT (M)	DATE	TIME
16	490,913.901	6,526,854.332	1,878.308	08-10-96	13:31
17	491,023.176	6,527,209.172	1,880.433	08-10-96	13:37
18	491,140.017	6,527,562.051	1,878.929	08-10-96	13:40
19	491,251.771	6,527,917.564	1,874.671	08-10-96	13:45
20	491,363.375	6,528,270.831	1,869.528	08-10-96	13:49
21	491,477.691	6,528,633.210	1,865.800	08-10-96	13:52
22	491,588.889	6,528,985.252	1,862.018	08-10-96	13:55
23	491,702.230	6,529,343.019	1,857.571	08-10-96	13:59
24	491,815.850	6,529,701.351	1,853.137	08-10-96	14:02
25	491,929.506	6,530,058.411	1,847.137	08-10-96	14:05
26	492,044.094	6,530,415.974	1,838.805	08-10-96	14:08
27	492,158.578	6,530,773.347	1,831.517	08-10-96	14:11
28	492,271.607	6,531,125.624	1,827.401	08-10-96	14:14
29	492,386.214	6,531,482.510	1,822.470	08-10-96	14:17

APPENDIX 6

MOVEMENT VECTORS AND SHORT-TERM HEIGHT CHANGE

PROFILE 3 (DEMOREST GLACIER) JULY 27 → AUGUST 5, 1996							
FLAG	FLAG DISTANCES		FLAG MOVEMENT			SURFACE HEIGHT CHANGE	
	FLAG TO FLAG (M)	SUM (M)	TOTAL (M)	DAILY (M)	BEARING (GONS)	TOTAL (CM)	DAILY (CM)
1[1]	0.000	0.000	—	—	—	—	—
2	286.131	286.131	1.111	0.124	255.4780	-21.6	-2.4
3	255.421	541.552	1.707	0.191	257.2135	-32.2	-3.6
4	291.983	833.535	2.174	0.243	256.9075	-26.4	-3.0
5	257.750	1,091.285	2.385	0.267	258.5744	-31.0	-3.5
6	258.426	1,349.711	2.395	0.268	259.6236	-29.9	-3.3
7	262.357	1,612.068	2.319	0.260	261.3786	-45.3	-5.1
8	266.497	1,878.565	2.416	0.270	264.4887	-20.2	-2.3
9	241.386	2,119.951	2.951	0.330	248.7794	33.2[2]	3.7[2]
10[1]	213.261	2,333.212	—	—	—	—	—
11[1]	197.824	2,531.036	—	—	—	—	—
Mean	**253.104**	**—**	**2.182**	**0.244**	**257.8055**	**-29.5**	**-3.3**
St. Dev.	**29.256**	**—**	**0.551**	**0.062**	**4.6194**	**8.3**	**0.9**

[1] Movement and height data not available.
[2] Data unreliable. Not used in calculation of mean and standard deviation.

Profile 4 — Lower Line (Taku Glacier @ C-10) July 28 → August 6, 1996							
Flag	Flag Distances		Flag Movement			Surface Height Change	
	Flag to Flag (m)	Sum (m)	Total (m)	Daily (m)	Bearing (gons)	Total (cm)	Daily (cm)
1	0.000	0.000	0.085	0.009	84.9467	-36.4	-4.0
3	192.608	192.608	0.290	0.032	150.6211	-36.0	-3.9
5	199.043	391.651	0.723	0.079	141.6355	-47.8	-5.2
7	251.862	643.513	1.857	0.203	147.6235	-34.0	-3.7
9	235.589	879.102	3.419	0.375	146.4296	-37.4	-4.1
11	183.713	1,062.815	3.928	0.431	139.5824	-148.0[1]	-16.3[1]
13	324.446	1,387.261	4.935	0.543	145.5631	-42.6	-4.7
15	313.286	1,700.547	5.274	0.581	145.1047	-50.2	-5.5
17	391.181	2,091.728	5.370	0.592	143.5682	-52.7	-5.8
19	374.806	2,466.534	5.381	0.594	142.2348	-53.8	-5.9
21	374.315	2,840.849	5.749	0.635	137.8911	168.9[1]	18.7[1]
23	328.049	3,168.898	4.946	0.547	140.6370	-49.0	-5.4
25	385.900	3,554.798	3.679	0.408	132.9468	-169.7[1]	-18.8[1]
27	372.954	3,927.752	1.930	0.215	94.1866	-586.8[1]	-65.3[1]
29	354.077	4,281.829	0.576	0.064	118.0359	-31.3	-3.5
31	335.557	4,617.386	0.150	0.017	48.1987	-32.5	-3.6
Mean	**307.826**	**—**	**3.018**	**0.334**	**128.7004**	**-42.0**	**-4.6**
St. Dev.	**74.966**	**—**	**2.168**	**0.241**	**28.6835**	**8.3**	**0.9**

[1] Data unreliable. Not used in calculation of mean and standard deviation.

Profile 4 — Upper Line (Taku Glacier @ C-10) July 28 → August 6, 1996							
Flag	**Flag Distances**		**Flag Movement**			**Surface Height Change**	
	Flag to Flag (m)	**Sum (m)**	**Total (m)**	**Daily (m)**	**Bearing (gons)**	**Total (cm)**	**Daily (cm)**
2	0.000	0.000	0.139	0.016	172.5362	-29.2	-3.4
4	210.581	210.581	0.276	0.032	143.1355	-28.6	-3.3
6	229.303	439.884	0.870	0.100	156.1184	-33.3	-3.8
8	198.213	638.097	1.830	0.211	147.3428	-34.9	-4.0
10	207.649	845.746	3.119	0.359	149.0762	-28.5	-3.3
12	257.748	1,103.494	4.191	0.482	147.1741	-29.9	-3.4
14	350.083	1,453.577	4.981	0.572	145.3233	-42.3	-4.9
16	346.368	1,799.945	5.143	0.590	143.3091	-48.6	-5.6
18	446.988	2,246.933	5.248	0.601	141.7599	-45.3	-5.2
20	340.284	2,587.217	5.121	0.586	141.1008	-42.9	-4.9
22	333.316	2,920.533	4.923	0.562	140.9821	-45.0	-5.1
24	351.909	3,272.442	4.382	0.500	140.0251	-39.2	-4.5
26	339.243	3,611.685	3.294	0.375	138.7629	-33.4	-3.8
28	448.970	4,060.655	1.308	0.149	134.5294	-33.6	-3.8
30	336.438	4,397.093	0.313	0.036	117.9125	-28.5	-3.2
Mean	**314.078**	**—**	**3.009**	**0.345**	**143.9392**	**-36.2**	**-4.1**
St. Dev.	**82.109**	**—**	**2.014**	**0.231**	**11.4864**	**7.0**	**0.8**

Profile 5 (Southwest Branch) July 30 → August 5, 1996							
Flag	Flag Distances		Flag Movement			Surface Height Change	
	Flag to Flag (m)	Sum (m)	Total (m)	Daily (m)	Bearing (gons)	Total (cm)	Daily (cm)
1	0.000	0.000	0.056	0.009	55.6262	-21.6	-3.6
2	225.002	225.002	1.466[1]	0.246[1]	69.7841[1]	-0.4[1]	-0.1[1]
3	224.935	449.937	1.744[1]	0.293[1]	64.9260[1]	-51.2[1]	-8.6[1]
4	226.263	676.200	0.480	0.081	42.6652	7.8[1]	1.3[1]
5	231.769	907.969	0.645	0.109	31.5924	10.6[1]	1.8[1]
6	224.801	1,132.770	0.582	0.098	29.6146	-22.5	-3.8
7	224.116	1,356.886	0.533	0.090	41.7793	-28.9	-4.9
8	225.371	1,582.257	0.486	0.082	35.0336	-26.1	-4.4
9	225.720	1,807.977	0.298	0.051	24.5413	-22.3	-3.8
10	146.637	1,954.614	0.328	0.056	20.3604	-18.4	-3.1
11	141.846	2,096.460	0.409	0.070	43.4905	-70.2[1]	-11.9[1]
12	134.073	2,230.533	0.167	0.028	34.9942	-25.6	-4.4
Mean	**202.776**	**—**	**0.398**	**0.067**	**35.9698**	**-23.6**	**-4.0**
St. Dev.	**39.924**	**—**	**0.186**	**0.032**	**10.3126**	**3.5**	**0.6**

[1] Data unreliable. Not used in calculation of mean and standard deviation.

Profile 6A (Northwest Branch) July 29 → August 7, 1996							
Flag	Flag Distances		Flag Movement			Surface Height Change	
	Flag to Flag (m)	Sum (m)	Total (m)	Daily (m)	Bearing (gons)	Total (cm)	Daily (cm)
1	0.000	0.000	0.936[1]	0.106[1]	294.2099[1]	-20.4[1]	-2.3[1]
2	287.919	287.919	0.264	0.030	143.5194	-33.0	-3.7
3	304.942	592.861	0.600	0.068	139.3753	-29.6	-3.3
4	296.937	889.798	1.080	0.122	133.3934	-31.0	-3.5
5	311.081	1,200.879	1.715	0.194	129.0684	-33.8	-3.8
6	313.623	1,514.502	2.463	0.278	134.6081	-33.2	-3.8
7	290.912	1,805.414	2.774	0.313	132.2985	-36.0	-4.1
8	300.840	2,106.254	2.736	0.309	126.1123	-40.7	-4.6
9	317.286	2,423.540	2.656	0.300	124.5265	-47.4	-5.3
10	294.492	2,718.032	2.582	0.291	122.3551	-41.0	-4.6
11	278.105	2,996.137	2.462	0.277	120.4915	-44.9	-5.0
12	308.937	3,305.074	2.122	0.238	126.9266	-48.9	-5.5
13	317.910	3,622.984	1.956	0.220	122.1923	-52.8	-5.9
14	263.616	3,886.600	1.712	0.192	119.7305	-53.1	-6.0
Mean	**298.969**	—	**1.932**	**0.218**	**128.8152**	**-40.4**	**-4.5**
St. Dev.	**16.048**	—	**0.831**	**0.094**	**7.4225**	**8.3**	**0.9**

[1] Data unreliable. Not used in calculation of mean and standard deviation.

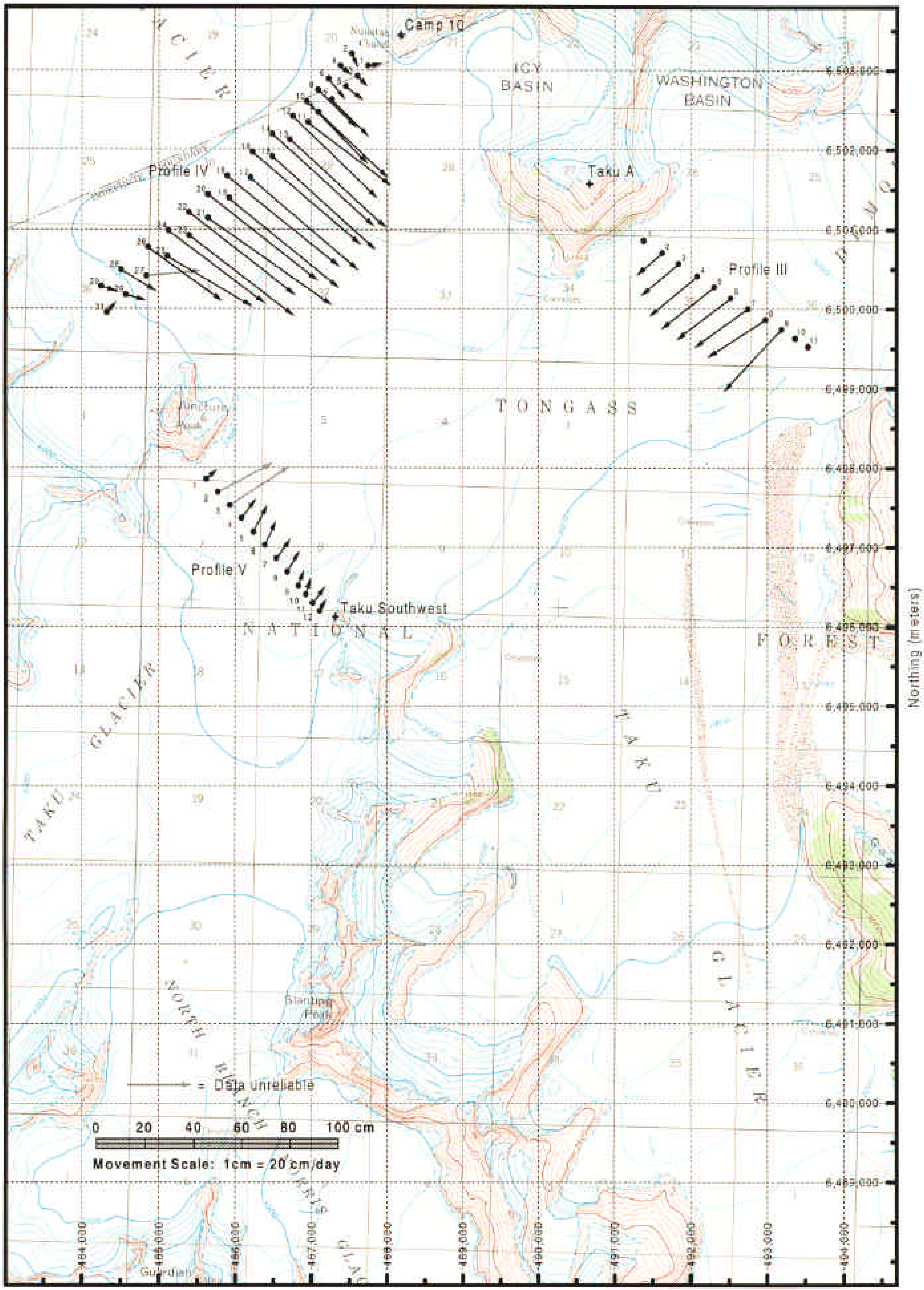
Profile 7A (Matthes Glacier @ Taku 'D') July 31 → August 7, 1996							
Flag	Flag Distances		Flag Movement			Surface Height Change	
	Flag to Flag (m)	Sum (m)	Total (m)	Daily (m)	Bearing (gons)	Total (cm)	Daily (cm)
1	0.000	0.000	1.230	0.176	243.4000	-29.9	-4.3
2	153.246	153.246	1.756	0.252	244.7901	-33.0	-4.7
3	207.956	361.202	2.283	0.327	245.7569	-40.1	-5.8
4	191.791	552.993	2.484	0.357	247.3535	-37.1	-5.3
5	197.138	750.131	2.661	0.382	249.0019	-36.8	-5.3
6	196.045	946.176	2.784	0.400	248.9649	-32.3	-4.6
7	196.286	1,142.462	2.865	0.412	249.1671	-40.5	-5.8
8	193.216	1,335.678	2.901	0.418	250.2173	-38.8	-5.6
9	189.489	1,525.167	2.919	0.421	250.3701	-33.7	-4.9
10	199.991	1,725.158	2.854	0.411	250.3155	-32.4	-4.7
11	140.900	1,866.058	2.784	0.402	250.7276	-30.1	-4.3
12	140.918	2,006.976	2.656	0.383	250.3051	-30.1	-4.3
13	138.905	2,145.881	2.416	0.349	250.4658	-32.6	-4.7
14	159.876	2,305.757	2.064	0.299	251.1994	-28.9	-4.2
Mean	**177.366**	**—**	**2.476**	**0.356**	**248.7168**	**-34.0**	**-4.9**
St. Dev.	**26.104**	**—**	**0.497**	**0.072**	**2.4492**	**3.9**	**0.6**

Profile 7 (Matthes Glacier @ C-9) July 29 → August 6, 1996							
Flag	Flag Distances		Flag Movement			Surface Height Change	
	Flag to Flag (m)	Sum (m)	Total (m)	Daily (m)	Bearing (gons)	Total (cm)	Daily (cm)
1	0.000	0.000	0.077	0.008	320.2213	-27.3	-2.7
2	84.925	84.925	0.149	0.015	315.4925	-24.8	-2.5
3	149.097	234.022	0.155	0.015	302.8731	-23.7	-2.3
4	151.576	385.598	0.140	0.014	287.1655	-21.4	-2.1
5	250.784	636.382	0.374	0.037	263.2282	-19.3	-1.9
6	243.748	880.130	1.071	0.107	244.8223	-22.5	-2.3
7	261.036	1,141.166	1.875	0.188	242.2977	-27.9	-2.8
8	266.447	1,407.613	2.461	0.248	241.4890	-30.5	-3.1
9	255.728	1,663.341	2.561	0.259	241.8914	-31.5	-3.2
10	258.781	1,922.122	2.581	0.263	239.4175	-37.7	-3.8
11	271.134	2,193.256	2.572	0.263	237.6531	-32.9	-3.4
12	266.127	2,459.383	2.601	0.267	236.2725	-24.7	-2.5
13	265.484	2,724.867	2.508	0.258	235.7014	-30.9	-3.2
14	260.976	2,985.843	2.268	0.234	233.6001	-27.7	-2.9
15	263.977	3,249.820	1.755	0.182	226.4813	-23.5	-2.4
16	266.704	3,516.524	1.134	0.118	216.6302	-20.5	-2.1
Mean	**234.435**	**—**	**1.518**	**0.155**	**255.3273**	**-26.7**	**-2.7**
St. Dev.	**57.051**	**—**	**1.048**	**0.107**	**32.5938**	**5.1**	**0.5**

Profile 8 (Matthes Glacier @ C-8) August 2 → August 10, 1996							
Flag	Flag Distances		Flag Movement			Surface Height Change	
	Flag to Flag (m)	Sum (m)	Total (m)	Daily (m)	Bearing (gons)	Total (cm)	Daily (cm)
1	0.000	0.000	0.770	0.097	277.0051	-4.3	-0.5
2	333.030	333.030	0.843	0.106	269.1326	-4.0	-0.5
3	282.373	615.403	0.966	0.121	249.4408	-10.5	-1.3
4	282.814	898.217	1.069	0.134	227.7858	-41.7	-5.2
5	268.336	1,166.553	1.221	0.153	221.6868	-42.2	-5.3
6	283.493	1,450.046	1.261	0.158	217.9113	-39.7	-5.0
7	307.897	1,757.943	1.240	0.155	218.5842	-2.4	-0.3
8	318.455	2,076.398	1.147	0.143	216.7943	-2.9	-0.4
9	371.077	2,447.475	0.909	0.114	210.8360	-2.9	-0.4
10	403.034	2,850.509	0.562	0.070	192.6175	-7.4	-0.9
11	355.298	3,205.807	0.305	0.038	141.5517	-44.2	-5.5
12	277.219	3,483.026	0.613	0.077	328.2167	+11.4	+1.4
Mean	**316.639**	—	**0.909**	**0.114**	**230.9636**	**-15.9**	**-1.2**
St. Dev.	**44.243**	—	**0.303**	**0.038**	**46.5802**	**19.9**	**2.5**

Profile 9 (Upper Vaughan Lewis) August 3 → August 9, 1996							
Flag	Flag Distances		Flag Movement			Surface Height Change	
	Flag to Flag (m)	Sum (m)	Total (m)	Daily (m)	Bearing (gons)	Total (cm)	Daily (cm)
1	0.000	0.000	0.455	0.078	256.9355	-5.1	-0.9
2	239.633	239.633	0.555	0.095	294.8309	-0.5	-0.1
3	224.683	463.316	0.755	0.129	315.4936	-22.1	-3.8
4	256.947	721.263	0.669	0.114	335.1381	-5.9	-1.0
5	221.121	942.384	0.622	0.106	351.0863	-4.1	-0.7
6	196.868	1,139.252	0.697	0.119	358.9421	+1.6	+0.3
7	219.666	1,358.918	0.556	0.095	374.7348	-3.5	-0.6
8	243.284	1,602.202	0.334	0.057	394.0905	+15.5	+2.7
Mean	**228.886**	—	**0.580**	**0.099**	**335.1565**	**-3.0**	**-0.5**
St. Dev.	**19.572**	—	**0.137**	**0.023**	**44.7062**	**10.3**	**1.8**

PROFILE 10 (MATTHES – LLEWELLYN DIVIDE) AUGUST 4 → AUGUST 10, 1996							
FLAG	FLAG DISTANCES		FLAG MOVEMENT			SURFACE HEIGHT CHANGE	
	FLAG TO FLAG (M)	SUM (M)	TOTAL (M)	DAILY (M)	BEARING (GONS)	TOTAL (CM)	DAILY (CM)
16	0.000	0.000	0.383	0.064	98.6704	+9.6	+1.6
17	371.225	371.225	0.414	0.069	90.2703	+7.0	+1.2
18	371.675	742.900	0.430	0.072	83.8294	+6.0	+1.0
19	372.628	1,115.528	0.396	0.066	72.9997	+9.3	+1.5
20	370.521	1,486.049	0.357	0.059	77.2017	+4.9	+0.8
21	379.966	1,866.015	0.342	0.057	70.8994	+5.0	+0.8
22	369.163	2,235.178	0.338	0.056	63.8198	+4.7	+0.8
23	375.254	2,610.432	0.334	0.056	50.1346	+4.3	+0.7
24	375.915	2,986.347	0.324	0.054	46.3899	+6.4	+1.1
25	374.729	3,361.076	0.282	0.047	27.7012	+6.3	+1.1
26	375.407	3,736.483	0.357	0.060	34.2209	-0.2	0
27	375.261	4,111.744	0.358	0.060	32.9395	+1.9	+0.3
28	369.917	4,481.661	0.404	0.068	29.7280	+7.8	+1.3
29	374.832	4,856.493	0.412	0.069	31.9375	+0.2	0
Mean	**373.576**	**—**	**0.367**	**0.061**	**57.9102**	**+5.2**	**+0.9**
St. Dev.	**3.034**	**—**	**0.042**	**0.007**	**24.7187**	**3.0**	**0.5**


Camp 10
ICY BASIN
WASHINGTON BASIN
Profile IV
Taku A
Profile III
TONGASS
Profile V
Taku Southwest
NATIONAL
FOREST
TAKU GLACIER
TAKU GLACIER
NORTH BRANCH NORRIS GLACIER
Slanting Peak
= Data unreliable
0 20 40 60 80 100 cm
Movement Scale: 1cm = 20 cm/day
6,503,000
6,502,000
6,501,000
6,500,000
6,499,000
6,498,000
6,497,000
6,496,000
6,495,000
6,494,000
6,493,000
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6,489,000
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488,000
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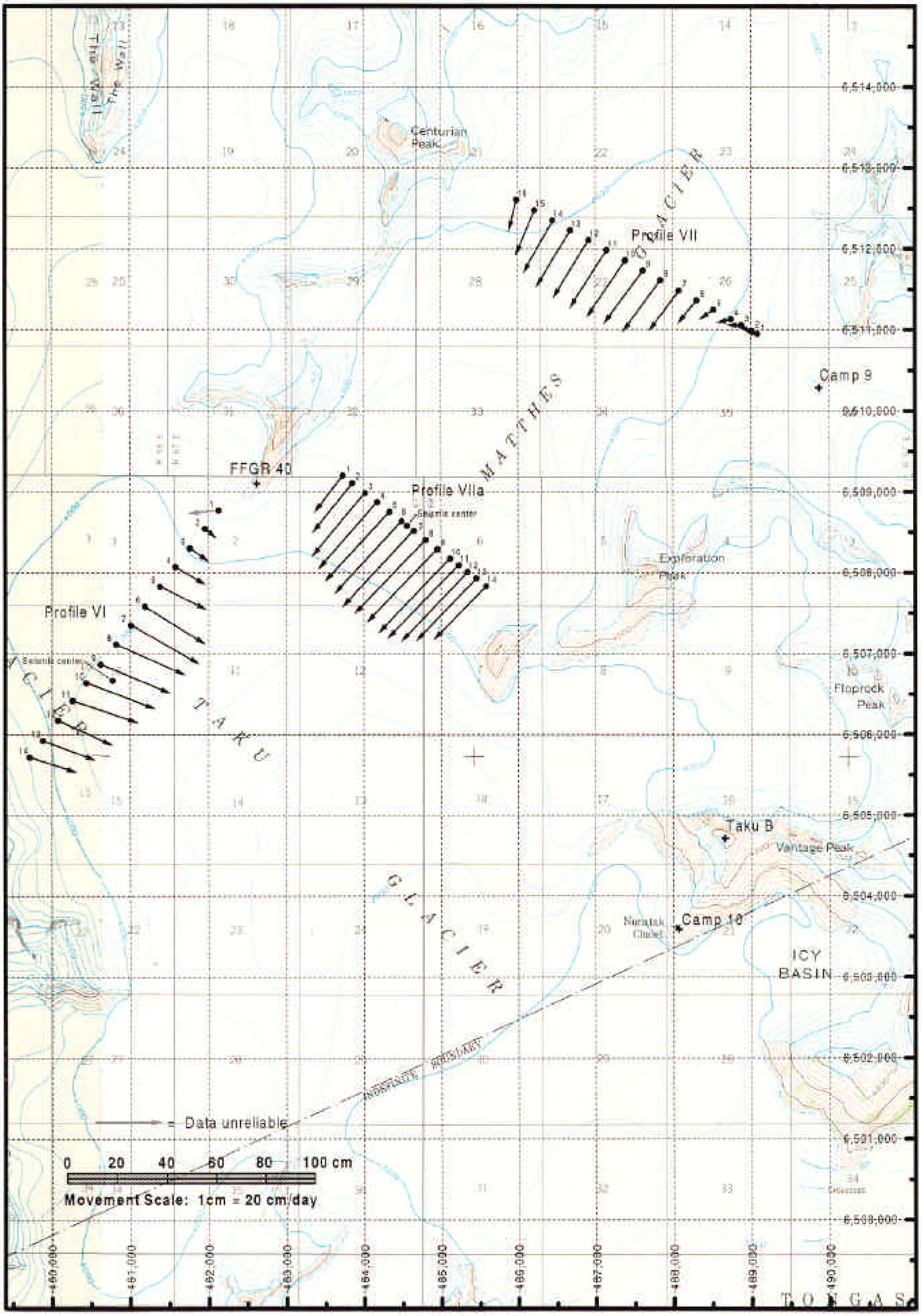
491,000
492,000
493,000
494,000
Northing (meters)
Easting (meters)



The Wall
Centurian Peak
Profile VII
MATTHES GLACIER
Camp 9
FFGR 40
Profile VIIa
Seismic center
Exploration Peak
Profile VI
Seismic center
TAKU GLACIER
Floprock Peak
Taku B
Vantage Peak
Nunatak Chalet
Camp 10
ICY BASIN
INTERNATIONAL BOUNDARY
= Data unreliable
0 20 40 60 80 100 cm
Movement Scale: 1cm = 20 cm/day
Northing (meters)
Easting (meters)
6,514,000
6,513,000
6,512,000
6,511,000
6,510,000
6,509,000
6,508,000
6,507,000
6,506,000
6,505,000
6,504,000
6,503,000
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6,500,000
480,000
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482,000
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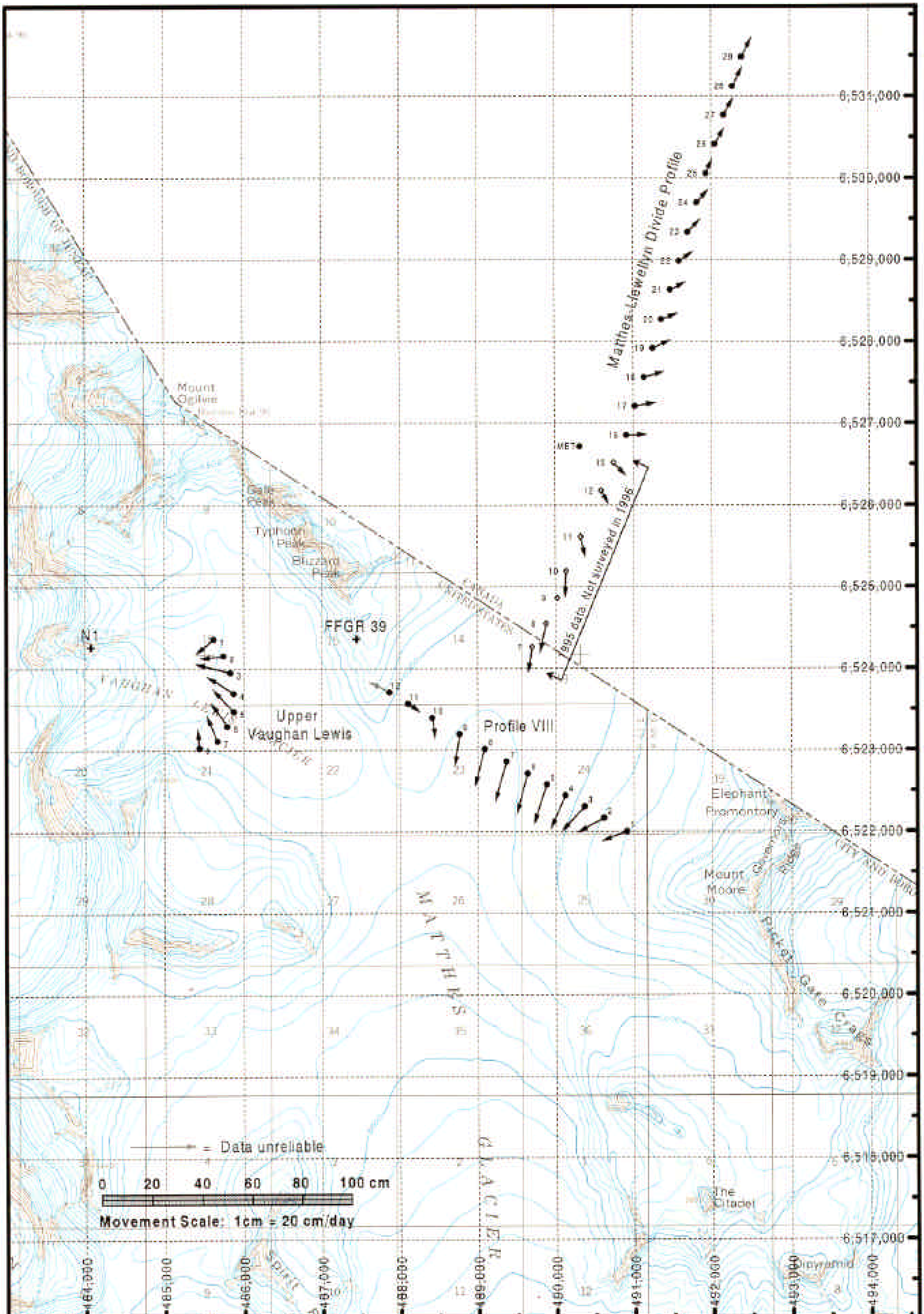
484,000
485,000
486,000
487,000
488,000
489,000
490,000
TONGASS


Mathes-Llewellyn Divide Profile
1995 data. Not surveyed in 1996
Mount Ogilvie
Gale Peak
Typhoon Peak
Blizzard Peak
FFGR 39
N1
Upper Vaughan Lewis
Profile VIII
Elephant Promontory
Mount Moore
Pack of Gale Crags
The Citadel
Dipyramid
MATTHES GLACIER
CANADA
UNITED STATES
MET
Data unreliable
0 20 40 60 80 100 cm
Movement Scale: 1cm = 20 cm/day
Northing (meters)
Easting (meters)
6,531,000
6,530,000
6,529,000
6,528,000
6,527,000
6,526,000
6,525,000
6,524,000
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494,000

APPENDIX 8

VOLUME AND SURFACE HEIGHT CHANGES AT PROFILE 4

July 25, 1993 to July 25, 1996

The following data shows the volume and surface height changes of Profile 4 from the first survey in 1993 to the present. It is divided into three sections.

Section 1 shows the volume and height changes as determined by the interpolated grids method. This method determines the change in height based on the volume between an interpolated surface and a baseline planar elevation of 1100 meters. This methodology is fully documented by McGee (1996).

Section 2 shows the change in height based on the normalized surface heights. In other words, the surveyed heights are adjusted up or down, based on the daily ablation at Profile 4 between the two survey epochs, so that the normalized heights represent what they would be on July 25.

Section 3 is simply a mean of the two different methods and is the figure to be used as the final determination of height change for Profile 4. As the profile is surveyed every year, the calculated data should be added to the data shown below.

Section 1: Change in volume and surface height as calculated from interpolated grids

Year	Volume (m^3)	Surface Area (m^2)
1993	35,101,700	1,124,880
1994	35,202,367	1,124,880
1995	33,672,933	1,124,880
1996	32,933,367	1,124,880

Time Period	Volume Change (m^3)	Height Change* (m)
1993 to 1994	+100,667	+0.089
1994 to 1995	-1,529,434	-1.360
1995 to 1996	-739,566	-0.657
1993 to 1996	-2,168,333	-1.928

$$\text{* Height Change} = \frac{\text{Volume Change}}{\text{Surface Area}}$$

Section 2: Change in height as calculated directly from normalized heights

Year	Mean Normalized Height (m)
1993	1,129.496
1994	1,129.592
1995	1,128.298
1996	1,127.611

Time Period	Height Change (m)
1993 to 1994	+0.096
1994 to 1995	-1.294
1995 to 1996	-0.687
1993 to 1996	-1.885

Section 3: Height Change in meters (mean of Sections 1 and 2)

Time Period	Interpolated Grids	Normalized Heights	Mean	St. Dev
1993 to 1994	+0.089	+0.096	+0.093	0.005
1994 to 1995	-1.360	-1.294	-1.327	-0.047
1995 to 1996	-0.657	-0.687	-0.672	0.021
1993 to 1996	-1.928	-1.885	**-1.907**	0.030

Between July 25, 1993 and July 25, 1996 the mean surface elevation of Profile 4 *decreased* by 1.907 meters. Assuming an annual surface firn density of 0.55 g/cm^3, this equates to a water equivalent loss of 1.049 m^3/m^2.

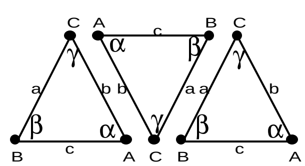
APPENDIX 9

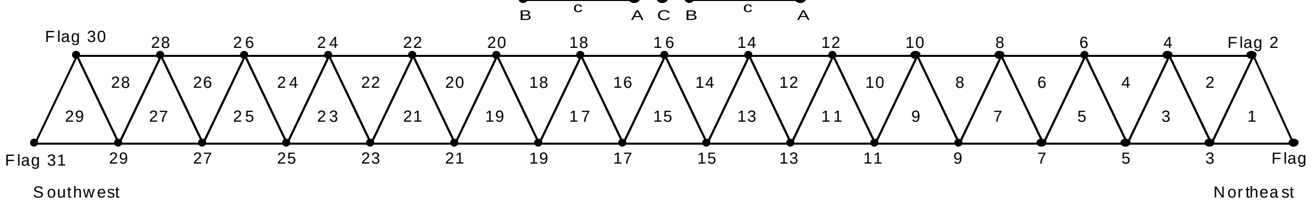
PROFILE 4 STRAIN RATES AND TRIANGLE GEOMETRY

Triangle	E_1 (extension)	E_2 (compression)	E_3 (vertical)	θ (gons)
1	70.5001	-40.0362	-30.4639	16.1871
2	44.8547	-59.7483	14.8936	177.7293
3	143.6668	-129.2414	-14.4254	185.0825
4	162.4790	-61.0278	-101.4512	1.6578
5	295.1747	-151.3092	-143.8655	190.7809
6	295.3609	-266.9877	-28.3732	188.1708
7	433.9756	-333.7572	-100.2184	191.1207
8	433.1974	-210.4488	-222.7486	190.5951
9	197.6411	-292.9651	95.3240	162.6214
10	85.2566	-111.6648	26.4082	185.6384
11	125.8773	-51.0158	-74.8615	20.7382
12	174.4215	-121.7885	-52.6330	180.4257
13	76.9349	-59.0719	-17.8630	185.0592
14	117.7489	-64.6369	-53.1120	165.7379
15	98.7249	-46.1160	-52.6089	166.1766
16	98.5960	-40.3672	-58.2288	165.2444
17	73.9226	-35.7520	-38.1706	162.1911
18	105.0297	-11.5448	-93.4849	145.0610
19	207.2285	-132.5762	-74.6523	153.1509
20	390.0370	-41.3541	-348.6829	131.1841
21	376.9416	-15.3225	-361.6191	110.6477
22	204.6173	-36.9704	-167.6469	123.5872
23	206.3079	-257.0982	50.7903	106.7697
24	267.0381	-257.2369	-9.8012	98.5551
25	316.1758	-615.5078	299.3320	100.7693
26	358.9509	-671.5886	312.6377	88.8494
27	456.1959	-247.4011	-208.7948	73.2361
28	174.2199	-211.4230	37.2031	87.9854
29	118.9857	-79.8377	-39.1480	93.1138

Note: E_1, E_2, and E_3 are given in units of μstrain^{day}. Theta (θ) is the orientation of the E_1 axis clockwise from north. E_2 is perpendicular to E_1. E_3 is the vertical component of strain as derived from the relation $E_1 + E_2 + E_3 = 0$.

GEOMETRY OF PROFILE 4 TRIANGLES (JULY 28, 1996)							
TRIANGLE	SURVEY FLAGS	LENGTH OF SIDES (M)			INTERIOR ANGLES (GONS)		
	(A B C)	a	b	c	α	β	γ
1	1 3 2	290.530	261.990	192.608	86.4434	68.6794	44.8772
2	4 2 3	290.530	258.615	210.581	84.1622	66.2512	49.5867
3	3 5 4	274.478	258.615	199.043	80.4235	70.9972	48.5793
4	6 4 5	274.478	251.477	229.303	77.1673	65.6465	57.1862
5	5 7 6	270.891	251.477	251.862	72.3564	63.7455	63.8981
6	8 6 7	270.891	218.781	198.213	89.8486	58.7571	51.3943
7	7 9 8	279.844	218.781	235.589	84.3705	54.7991	60.8304
8	10 8 9	279.844	205.530	207.649	94.7373	52.2768	52.9859
9	9 11 10	261.709	205.530	183.713	93.6658	57.1044	49.2299
10	12 10 11	261.709	214.315	257.748	74.0020	54.1400	71.8580
11	11 13 12	296.656	214.315	324.446	69.9710	44.5076	85.5214
12	14 12 13	296.656	243.264	350.083	62.9021	48.0122	89.0857
13	13 15 14	283.754	243.264	313.286	66.3779	53.0818	80.5403
14	16 14 15	283.754	266.250	346.368	59.1719	54.1700	86.6581
15	15 17 16	322.004	266.250	391.181	60.8320	47.1915	91.9765
16	18 16 17	322.004	303.372	446.988	51.1927	47.4788	101.3286
17	17 19 18	273.607	303.372	374.806	51.2355	58.9380	89.8265
18	20 18 19	273.607	280.653	340.284	56.8824	58.9636	84.1539
19	19 21 20	293.825	280.653	374.315	56.5413	53.1412	90.3175
20	22 20 21	293.825	258.390	333.316	64.3342	53.5070	82.1588
21	21 23 22	291.585	258.390	328.049	64.6555	54.2843	81.0602
22	24 22 23	291.585	278.305	351.909	59.5415	55.7606	84.6980
23	23 25 24	322.482	278.305	385.900	61.4088	50.1927	88.3985
24	26 24 25	322.482	274.263	339.243	69.2949	54.3230	76.3821
25	25 27 26	362.686	274.263	372.954	73.4813	48.6131	77.9056
26	28 26 27	362.686	333.952	448.970	58.5984	52.3598	89.0418
27	27 29 28	321.398	333.952	354.077	61.7814	65.5814	72.6372
28	30 28 29	321.398	337.409	336.438	63.3043	68.5169	68.1788
29	29 31 30	335.975	337.409	335.557	66.5549	67.0266	66.4185





GEOMETRY OF PROFILE 4 TRIANGLES (AUGUST 6, 1996)							
TRIANGLE	SURVEY FLAGS (A B C)	LENGTH OF SIDES (M)			INTERIOR ANGLES (GONS)		
		a	b	c	α	β	γ
1	1 3 2	290.645	261.927	192.675	86.4928	68.6237	44.8835
2	4 2 3	290.645	258.622	210.503	84.2145	66.2337	49.5518
3	3 5 4	274.832	258.622	198.921	80.5669	70.9260	48.5072
4	6 4 5	274.832	251.406	229.432	77.2745	65.5469	57.1786
5	5 7 6	271.610	251.406	251.834	72.5882	63.6214	63.7903
6	8 6 7	271.610	218.806	198.084	90.1630	58.6098	51.2271
7	7 9 8	280.908	218.806	235.384	84.7927	54.6483	60.5590
8	10 8 9	280.908	205.834	207.662	95.0937	52.1492	52.7571
9	9 11 10	261.900	205.834	183.250	93.7819	57.1786	49.0395
10	12 10 11	261.900	214.217	257.623	74.1055	54.1051	71.7894
11	11 13 12	296.975	214.217	324.691	70.0181	44.4457	85.5361
12	14 12 13	296.975	243.214	349.823	63.0397	48.0205	88.9398
13	13 15 14	283.931	243.214	313.208	66.4452	53.0669	80.4880
14	16 14 15	283.931	266.299	346.184	59.2424	54.1977	86.5599
15	15 17 16	322.149	266.299	391.041	60.8905	47.2135	91.8960
16	18 16 17	322.149	303.387	446.846	51.2451	47.5017	101.2532
17	17 19 18	273.727	303.387	374.693	51.2750	58.9554	89.7697
18	20 18 19	273.727	280.837	340.254	56.9041	59.0052	84.0907
19	19 21 20	293.966	280.837	373.868	56.6361	53.2385	90.1254
20	22 20 21	293.966	259.255	333.346	64.3038	53.6894	82.0068
21	21 23 22	291.578	259.255	328.451	64.5205	54.4337	81.0459
22	24 22 23	291.578	278.805	351.961	59.5037	55.8663	84.6300
23	23 25 24	321.741	278.805	385.716	61.2457	50.3413	88.4131
24	26 24 25	321.741	274.691	339.470	69.0350	54.4480	76.5170
25	25 27 26	360.685	274.691	372.557	73.0228	48.8501	78.1271
26	28 26 27	360.685	334.531	449.442	58.1308	52.4722	89.3970
27	27 29 28	320.786	334.531	355.321	61.4691	65.6091	72.9219
28	30 28 29	320.786	337.671	336.701	63.1191	68.6098	68.2711
29	29 31 30	335.741	337.671	335.709	66.4585	67.0932	66.4483

APPENDIX 10
LONG-TERM HEIGHT CHANGE

Profile 8 – Comparison Time Period
August 10, 1995 to August 10, 1996

Survey Dates
1995: Aug. 6 and Aug. 10
1996: Aug. 2 and Aug. 10

Surface Height Adjustment
None required. 1995 and 1996 Epoch 1 surveys were both on August 10

Profile 8 (Blizzard Peak to C-8)			
Flag	Height Change 1995 to 1996 (Raw)	Ablation (cm)	1995 to 1996 (Adjusted)
1	-0.862	Adjustment not needed	-0.862
2	-0.883	Adjustment not needed	-0.883
3	-0.697	Adjustment not needed	-0.697
4	-1.041	Adjustment not needed	-1.041
5	-1.062	Adjustment not needed	-1.062
6	-1.234	Adjustment not needed	-1.234
7	-0.921	Adjustment not needed	-0.921
8	-0.999	Adjustment not needed	-0.999
9	-0.776	Adjustment not needed	-0.776
10	-0.658	Adjustment not needed	-0.658
11	-0.870	Adjustment not needed	-0.870
12	-1.106	Adjustment not needed	-1.106
		Minimum	**-0.658**
		Maximum	**-1.234**
		Standard deviation	**0.171**
		Mean	**-0.926**

Profile 9 – Comparison Time Period
August 7, 1995 to August 7, 1996

Survey Dates
1995: Aug. 7 and Aug. 12
1996: Aug. 3 and Aug. 9

Surface Height Adjustment
Year: 1996
Mean Daily Ablation: 0.5 cm
Days of Adjustment: 4 (Aug. 3 to Aug 7)
Total Adjustment: -2.0 cm

PROFILE 9 (UPPER VAUGHAN LEWIS GLACIER)			
Flag	**Height Change 1995 to 1996 (Raw)**	**Ablation (m)**	**1995 to 1996 (Adjusted)**
1	-1.499	-0.020	-1.519
2	-1.492	-0.020	-1.512
3	-1.038	-0.020	-1.058
4	-1.281	-0.020	-1.301
5	-1.004	-0.020	-1.024
6	-0.620	-0.020	-0.640
7	-0.639	-0.020	-0.659
8	-0.938	-0.020	-0.958
		Minimum	**-0.640**
		Maximum	**-1.519**
		Standard Deviation	**0.342**
		Mean	**-1.084**

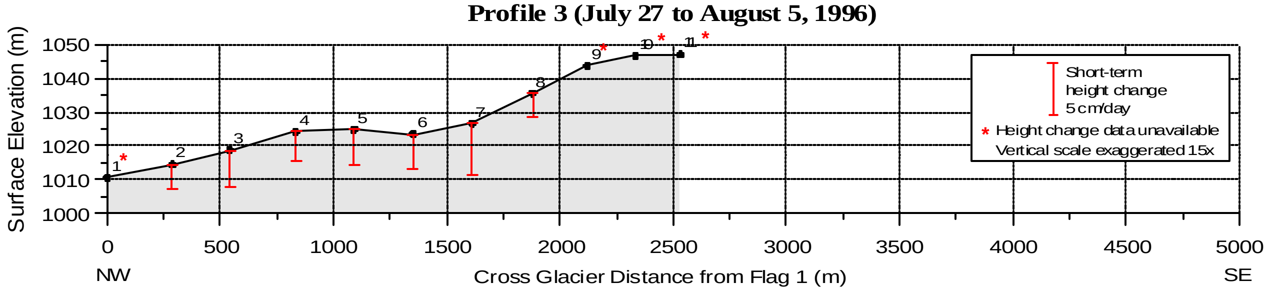
APPENDIX 11

SHORT-TERM HEIGHT CHANGE

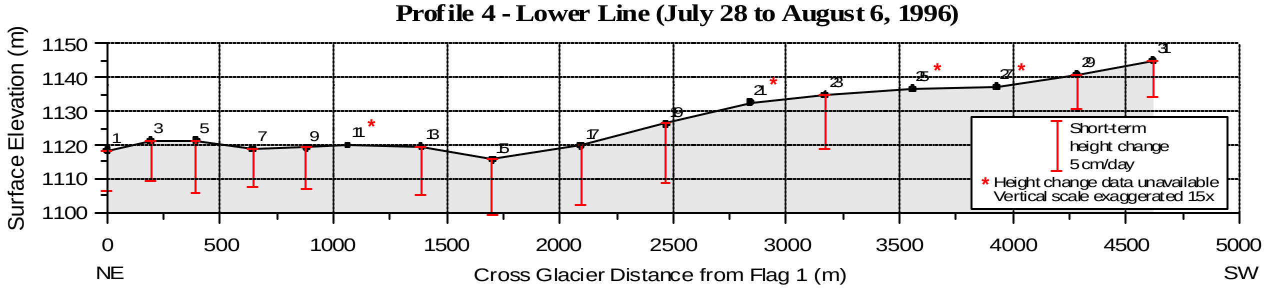
The following graphs depict vertical cross-sections through the survey profiles in 1996. Distances along the profile, referenced to Flag 1 of the profile, are plotted on the X-axis. The surface elevation of each flag within the profile at the time of the Epoch 0 survey is plotted on the Y-axis. Red bars represent the magnitude of short-term height change at each flag, in centimeters per day. Flags without an accompanying red bar indicate that either the height change information for those flags was not obtained, or that it was calculated but was an outlier, and therefore rejected. Surface elevation and height change data for these graphs were obtained from Appendices 5 and 6.

What appears to be an unusually low magnitude of height change at Profiles 8 and 9, and the Matthes/Llewellyn Longitudinal Profile, is a result of a snowstorm on August 8th and 9th. Accumulation from the storm offset the normal daily ablation that occurred between the Epoch 0 surveys and the onset of the storm.

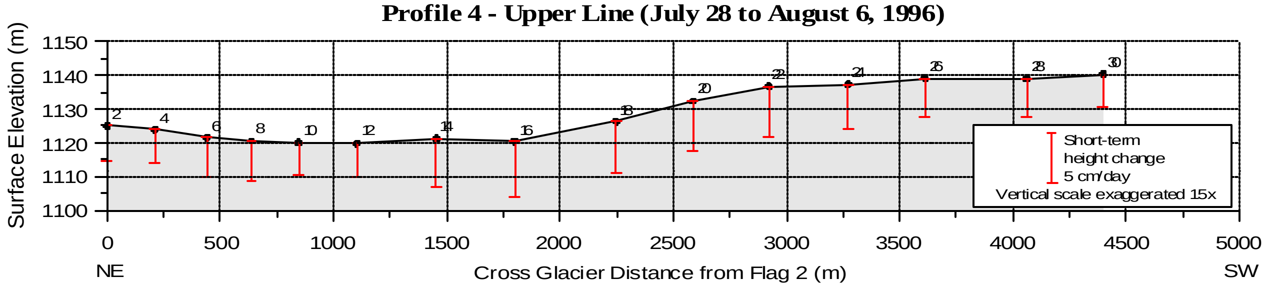
Profile 3 (July 27 to August 5, 1996)



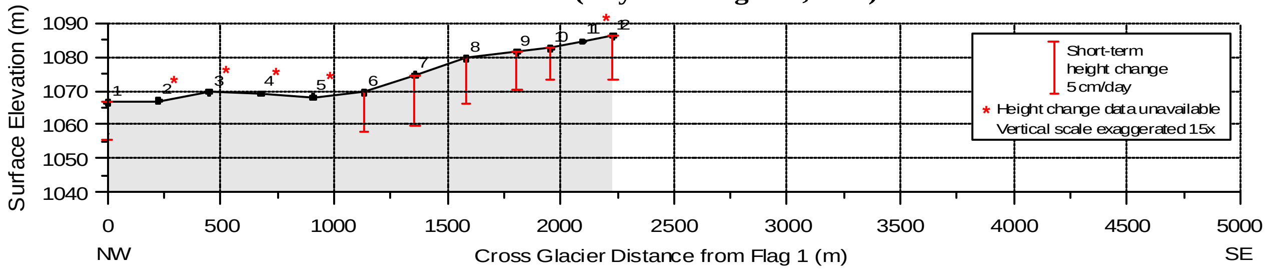
Profile 4 - Lower Line (July 28 to August 6, 1996)



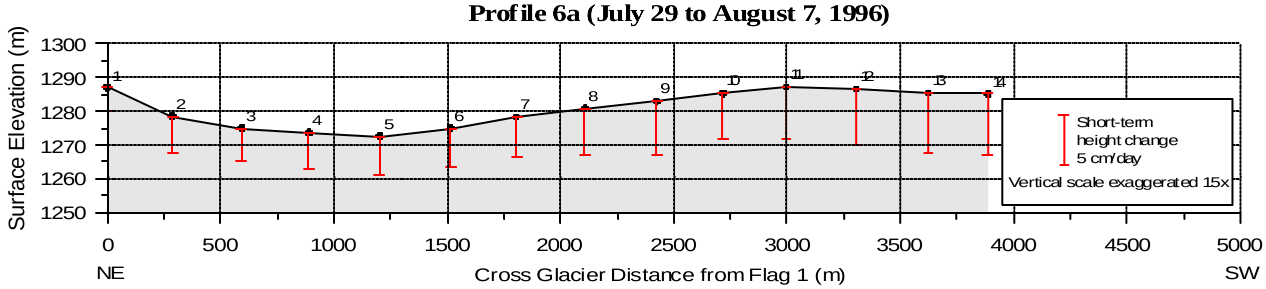
Profile 4 - Upper Line (July 28 to August 6, 1996)



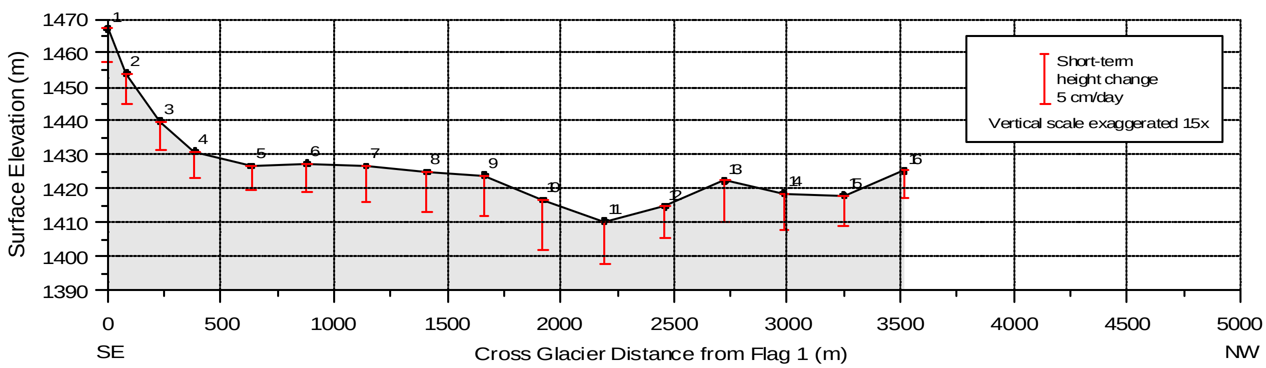
Profile 5 (July 30 to August 5, 1996)



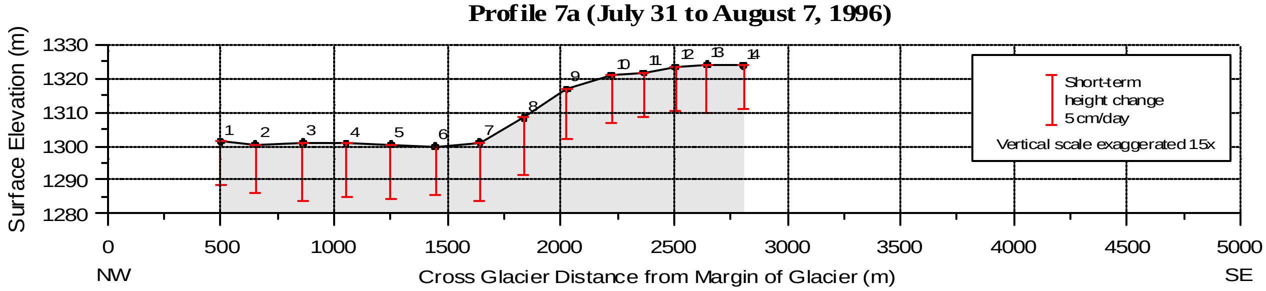
Profile 6a (July 29 to August 7, 1996)

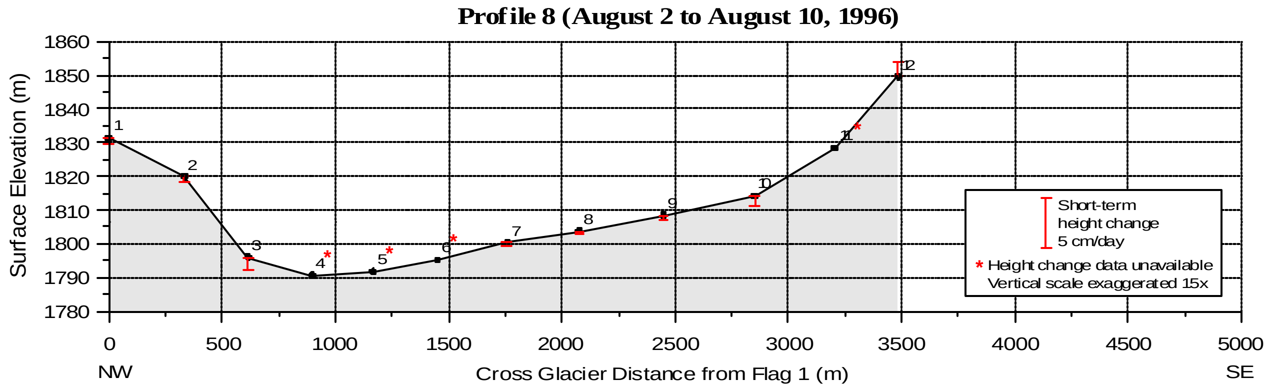


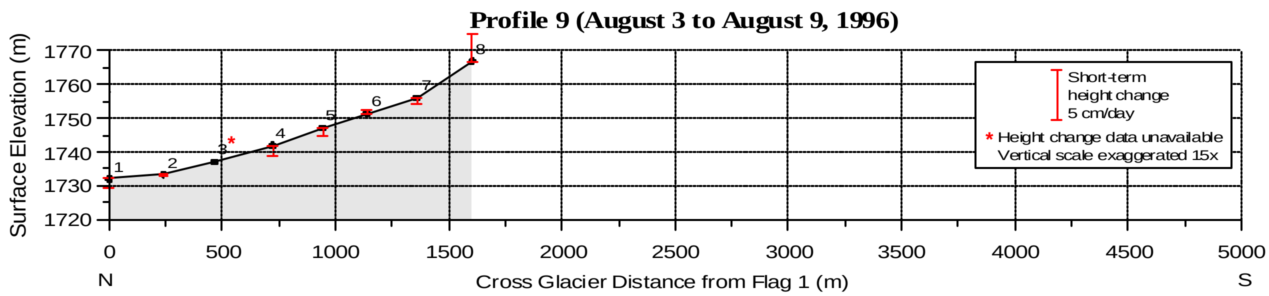
Profile 7 (July 29 to August 6, 1996)

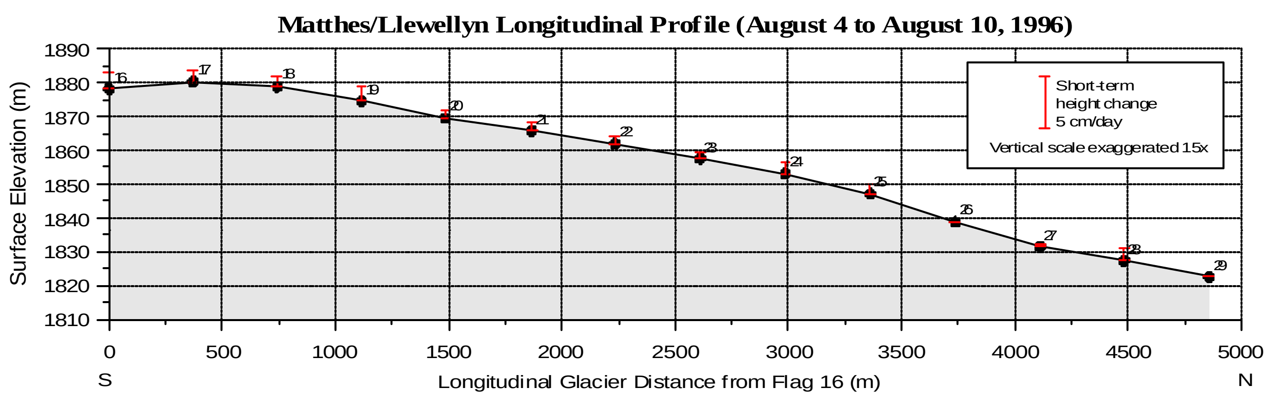


Profile 7a (July 31 to August 7, 1996)




Profile 8 (August 2 to August 10, 1996)
Surface Elevation (m)
Cross Glacier Distance from Flag 1 (m)
NW
SE
Short-term height change 5 cm/day
* Height change data unavailable
Vertical scale exaggerated 15x


Profile 9 (August 3 to August 9, 1996)
Surface Elevation (m)
Cross Glacier Distance from Flag 1 (m)
N
S
Short-term height change 5 cm/day
* Height change data unavailable
Vertical scale exaggerated 15x


Matthes/Llewellyn Longitudinal Profile (August 4 to August 10, 1996)
Surface Elevation (m)
Longitudinal Glacier Distance from Flag 16 (m)
S
N
Short-term height change 5 cm/day
Vertical scale exaggerated 15x

APPENDIX 12

TAKU B AND SHOEHORN PEAK SURVEY DATA

TAKU B RIDGE (SURVEYED AUGUST 7, 1996)						
Point*	Flag to Flag Distance	Cumulative Distance	Easting	Northing	Height	Time
1	0.000	0.000	487,895.913	6,503,211.350	1,109.779	8:14
2	58.531	58.531	487,937.916	6,503,252.113	1,144.975	8:35
3	47.700	106.231	487,957.312	6,503,295.691	1,168.215	8:42
4	31.665	137.895	487,970.234	6,503,324.599	1,177.819	8:44
5	91.177	229.072	488,023.917	6,503,398.297	1,194.553	8:49
6	59.689	288.762	488,068.806	6,503,437.639	1,184.521	8:51
7	50.485	339.247	488,101.936	6,503,475.733	1,185.500	8:53
8	47.973	387.220	488,128.448	6,503,515.715	1,188.390	8:55
9	22.581	409.801	488,144.995	6,503,531.080	1,195.438	8:57
10	27.182	436.983	488,160.114	6,503,553.669	1,200.492	9:01
11	64.986	501.968	488,189.201	6,503,611.782	1,206.992	9:04
12	65.637	567.605	488,223.627	6,503,667.666	1,239.211	9:09
13	46.655	614.260	488,260.497	6,503,696.254	1,254.366	9:12
14	61.813	676.073	488,299.846	6,503,743.925	1,273.016	9:15
15	69.545	745.618	488,357.794	6,503,782.376	1,299.391	9:19
16	41.915	787.533	488,371.865	6,503,821.859	1,300.664	9:21
17	79.876	867.409	488,412.268	6,503,890.763	1,331.379	9:28
18	36.810	904.219	488,437.474	6,503,917.589	1,345.368	9:30
19	20.478	924.697	488,455.738	6,503,926.851	1,350.303	9:31
20	50.259	974.957	488,503.495	6,503,942.512	1,378.975	9:36
21	21.019	995.975	488,521.811	6,503,952.823	1,384.599	9:37

* Point 1 was located on the Taku Glacier at the base of the Taku B ridge. Point 21 was at the end of the transect northeast of C-10.

SHOEHORN PEAK RIDGE (SURVEYED AUGUST 6, 1996)						
Point*	**Flag to Flag Distance**	**Cumulative Distance**	**Easting**	**Northing**	**Height**	**Time**
1	0.000	0.000	483,673.378	6,499,628.851	1,169.630	14:03
2	30.000	30.000	483,649.190	6,499,611.104	1,182.263	14:41
3	58.065	88.065	483,606.603	6,499,571.634	1,194.510	14:45
4	42.978	131.044	483,578.916	6,499,538.762	1,199.436	14:47
5	93.829	224.873	483,530.455	6,499,458.416	1,209.414	14:50
6	37.727	262.600	483,516.568	6,499,423.338	1,225.607	14:55
7	42.270	304.870	483,482.667	6,499,398.090	1,238.254	14:58
8	36.423	341.292	483,451.471	6,499,379.290	1,247.255	15:00
9	50.915	392.207	483,405.634	6,499,357.125	1,258.287	15:02
10	38.990	431.198	483,380.656	6,499,327.186	1,265.935	15:04
11	24.849	456.047	483,361.513	6,499,311.342	1,269.932	15:05
12	79.411	535.458	483,301.016	6,499,259.901	1,276.031	15:09
13	84.618	620.076	483,232.948	6,499,209.632	1,283.021	15:13
14	138.847	758.923	483,118.795	6,499,130.590	1,290.250	15:17
15	37.951	796.874	483,081.506	6,499,123.530	1,297.125	15:20
16	48.495	845.370	483,039.115	6,499,099.976	1,307.222	15:21
17	37.637	883.007	483,007.922	6,499,078.915	1,316.451	15:23
18	26.669	909.676	482,984.422	6,499,066.305	1,327.422	15:29
19	32.865	942.541	482,959.886	6,499,044.440	1,336.581	15:31
20	42.237	984.779	482,923.871	6,499,022.374	1,347.155	15:33
21	71.249	1,056.027	482,865.687	6,498,981.252	1,381.049	15:42
22	73.384	1,129.411	482,805.283	6,498,939.580	1,421.432	15:55
23	38.107	1,167.518	482,770.103	6,498,924.935	1,440.031	15:58
24	17.692	1,185.210	482,752.913	6,498,920.751	1,444.366	16:00
25	29.662	1,214.872	482,725.490	6,498,909.445	1,442.188	16:01

* Point 1 was located on the Taku Glacier at the base of the Shoehorn Peak ridge. Point 25 was at the end of the transect southwest of the base of the ridge.

APPENDIX 13
MISCELLANEOUS SURVEY DATA

SEISMIC REFRACTION SHOT POINTS AND DEMOREST SEISMIC PROFILE					
Location	**Easting**	**Northing**	**Height**	**Date**	**Time**
Demorest Seismic Flag 1	496,239.762	6,500,744.466	1,087.531	7/27/96	19:48
Demorest Seismic Flag 2	496,050.914	6,500,906.532	1,089.375	7/27/96	20:09
Demorest Seismic Flag 3	495,906.687	6,501,030.032	1,089.931	7/27/96	20:26
Demorest Seismic Flag 4	495,817.541	6,501,106.615	1,090.613	7/27/96	20:48
Demorest Seismic Flag 6	495,073.237	6,501,789.736	1,086.887	7/27/96	21:37
Demorest Seismic Center	495,477.378	6,501,399.638	1,091.217	7/27/96	21:14
Profile 6a Seismic Center	480,772.415	6,506,668.084	1,278.810	7/29/96	17:20
Profile 7a Seismic Center	484,560.289	6,508,580.075	1,299.696	7/31/96	16:44

REMOTE METEOROLOGICAL STATION LOCATION					
Location	**Easting**	**Northing**	**Height**	**Date**	**Time**
Matthes/Llewellyn Divide	490,312.901	6,526,716.996	1,883.129	8/4/96	12:18

APPENDIX 14
JUNEAU ICEFIELD GPS BENCHMARKS

GPS BENCHMARKS (JIRP PROJECTION COORDINATES)			
BENCHMARK	EASTING (M)	NORTHING (M)	HEIGHT (M)
FFGR 1 (C-17)	478,573.838	6,472,234.227	1,301.709
FFGR 6 (Cleaver)	483,309.746	6,524,118.094	1,388.753
FFGR 12 (C-19)	482,221.820	6,522,621.728	1,292.865
FFGR 19 (C-10)	488,001.820	6,503,290.614	1,180.836
FFGR 19C (C-10)	487,983.651	6,503,410.033	1,198.000
FFGR 24 (C-18 Hill)	484,189.635	6,524,371.872	1,733.416
FFGR 31 (C-8)	492,136.624	6,521,147.773	2,051.576
FFGR 31 (Cleaver)	483,705.534	6,524,279.606	1,623.548
FFGR 34 (C-18 Hill)	484,554.464	6,524,402.905	1,734.890
FFGR 39 (Blizzard)	487,443.145	6,524,360.975	1,984.385
FFGR 43 (Cleaver)	483,990.101	6,524,352.738	1,703.762
FFGR 44 (Cleaver)	483,834.598	6,524,280.382	1,669.527
FFGR 45 (C-18 Hill)	484,309.150	6,524,412.394	1,746.191
FFGR 53 (C-19)	482,195.157	6,522,670.922	1,277.773
FFGR 62 (F10)	492,497.562	6,535,469.195	1,860.563
FFGR 63 (C-18 Hill)	484,315.335	6,524,309.996	1,723.699
FFGR 64 (C-18 Hill)	484,219.214	6,524,334.390	1,727.783
FFGR 65 (Taku D)	482,942.072	6,509,779.956	1,774.109
FFGR 68 (C-18 Hill)	484,425.554	6,524,412.335	1,751.611
C-9 Bolt	489,442.431	6,510,665.042	1,554.938
C-10A	489,181.351	6,501,882.011	1,105.758
Lupine (Sunday Pt.)	490,263.717	6,500,621.560	1,080.574
N1 (C-18)	484,073.444	6,524,262.764	1,698.457
N2 (Cleaver)	483,956.314	6,524,239.526	1,682.217
Scott (C-10)	487,963.303	6,503,372.111	1,189.740
SW Taku Pt.	487,320.590	6,495,968.917	1,133.488
Taku D Lower	482,601.539	6,509,092.743	1,399.213
Taku NW Pt (USGS)	479,186.763	6,505,147.716	1,402.060
Taku NW (UniBm)	479,188.345	6,505,144.633	1,402.149
Vista (C-9 East)	489,873.478	6,510,298.945	1,564.057

GPS BENCHMARKS (GEOGRAPHIC COORDINATES)			
BENCHMARK	WEST LONGITUDE	NORTH LATITUDE	HEIGHT (M)
FFGR 1 (C-17)	134 21 57.942684	58 22 1.732978	1,301.709
FFGR 6 (Cleaver)	134 17 20.377172	58 49 59.308553	1,388.753
FFGR 12 (C-19)	134 18 27.762700	58 49 10.792606	1,292.865
FFGR 19 (C-10)	134 12 23.899681	58 38 46.758278	1,180.836
FFGR 19C (C-10)	134 12 25.049008	58 38 50.615966	1,198.000
FFGR 24 (C-18 Hill)	134 16 25.595230	58 50 7.629607	1,733.416
FFGR 31 (C-8)	134 8 9.785576	58 48 24.218727	2,051.576
FFGR 31 (Cleaver)	134 16 55.748732	58 50 4.582822	1,623.548
FFGR 34 (C-18 Hill)	134 16 2.860336	58 50 8.680180	1,734.890
FFGR 39 (Blizzard)	134 13 2.775834	58 50 7.663122	1,984.385
FFGR 43 (Cleaver)	134 16 38.028785	58 50 6.984705	1,703.762
FFGR 44 (Cleaver)	134 16 47.703578	58 50 4.625407	1,669.527
FFGR 45 (C-18 Hill)	134 16 18.155186	58 50 8.954924	1,746.191
FFGR 53 (C-19)	134 18 29.438155	58 49 12.378488	1,277.773
FFGR 62 (F10)	134 7 49.040300	58 56 7.080992	1,860.563
FFGR 63 (C-18 Hill)	134 16 17.743731	58 50 5.646451	1,723.699
FFGR 64 (C-18 Hill)	134 16 23.741807	58 50 6.422174	1,727.783
FFGR 65 (Taku D)	134 17 39.370491	58 42 15.874914	1,774.109
FFGR 68 (C-18 Hill)	134 16 10.898731	58 50 8.968227	1,751.611
C-9 Bolt	134 10 55.822743	58 42 45.226060	1,554.938
C-10A	134 11 10.525565	58 38 1.345224	1,105.758
Lupine (Sunday Pt.)	134 10 3.247227	58 37 20.700786	1,080.574
N1 (C-18)	134 16 32.810299	58 50 4.088062	1,698.457
N2 (Cleaver)	134 16 40.105698	58 50 3.321412	1,682.217
Scott (C-10)	134 12 26.303369	58 38 49.388336	1,189.740
SW Taku Pt.	134 13 4.662101	58 34 50.057832	1,133.488
Taku D Lower	134 18 0.327718	58 41 53.616470	1,399.213
Taku NW Pt (USGS)	134 21 31.048187	58 39 45.577275	1,402.060
Taku NW (UniBm)	134 21 30.949035	58 39 45.477910	1,402.149
Vista (C-9 East)	134 10 28.987537	58 42 33.431361	1,564.057