Surface Velocity Changes on the Taku Glacier System – 1993 to 2007

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JIRP OPEN FILE SURVEY REPORT—2007

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Abstract

Surface velocities on the Juneau Icefield, Alaska have been measured every summer since 1993 with survey-grade, real-time differential GPS by the Juneau Icefield Research Program. From 1993 through 2006, surface velocities at transverse profiles throughout the Taku Glacier system remained steady. During the summer of 2007, eight of these profiles were re-surveyed. **For the first time since JIRP began monitoring these profiles, significant velocity changes were observed.** The velocity at four profiles increased, three profiles showed no significant change, and the velocity at one profile decreased. The increased velocities may ultimately contribute to further advancement of the Taku Glacier.

Introduction

The Juneau Icefield Research Program (JIRP) is an interdisciplinary research and educational program operating on the Juneau Icefield in southeast Alaska. Founded in 1946, JIRP, through the support of its parent foundation, the Foundation for Glacier and Environmental Research, conducts glaciological, geological, meteorological, and geophysical research on the Juneau Icefield in order to construct the past physical history of the area and to quantify future changes.

One of the primary objectives is to determine the surface velocities, direction of movement, and surface elevation changes of the numerous glaciers of the Juneau Icefield. Traditionally, this was accomplished using terrestrial-based instruments and methods – theodolites and electronic distance measuring devices. With the development of the Global Positioning System, JIRP began utilizing survey-grade, dual-frequency GPS in 1993. The survey network now encompasses the entire Taku Glacier system and includes nearly 60 individual transverse and longitudinal profiles.

Study Area

The Juneau Icefield is located in southeast Alaska, just north of the capital city of Juneau. Covering some 3,900 km^2 (~1,500 mi.^{2}), it straddles the Coast Mountain range in a triangular region between the towns of Juneau and Skagway in Alaska, and the small town of Atlin in British Columbia, Canada. The Taku Glacier and its tributaries comprise the largest glacial system on the Juneau Icefield, at 1,000 km^2 (386 mi.^{2}). Approximately 95% of the Taku system is within Alaska. The remaining 5% is on the Canadian side of the Icefield.

Eight transverse profiles on the Taku system were surveyed during the summer of 2007. Two of these are located on the main trunk of the Taku Glacier, while the other six are on various tributaries – one profile on the Demorest Glacier, one on the Northwest Branch, three on the Matthes Glacier, and one on the Vaughan Lewis Glacier (see Figure 1).

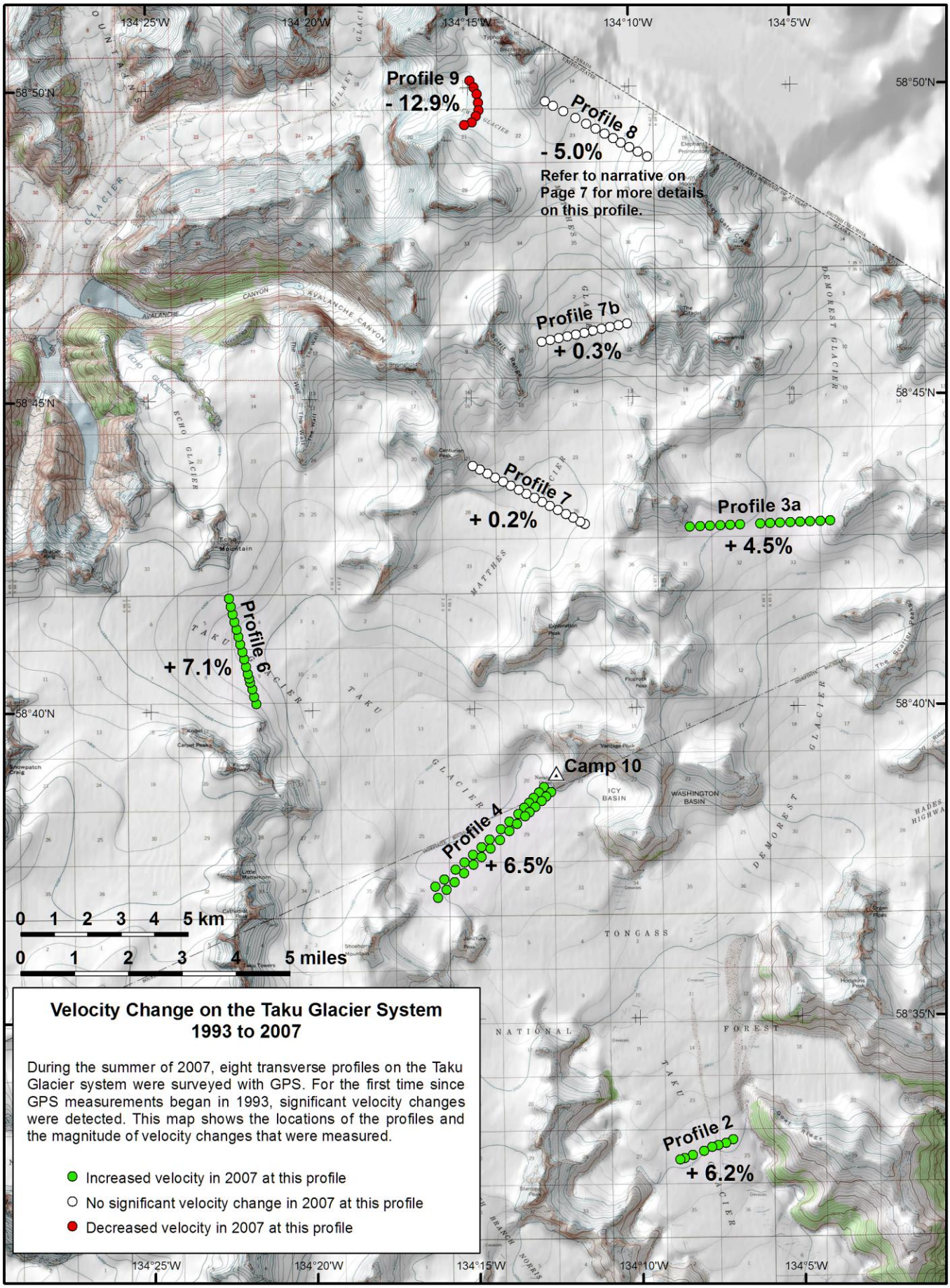

Figure 1: Location of transverse profiles surveyed in 2007 and percentage velocity change compared with GPS surveys prior to 2007.

Methodology

All survey work on the Juneau Icefield utilized survey-grade, dual-frequency, real-time kinematic GPS. Systems included the Leica System 300, Leica System 530, and Trimble 5700 units. Standard GPS procedures were used for all surveys. This included minimizing the baseline length between the reference GPS and the roving GPS, utilizing measurements only when the PDOP was 6 or less, and setting an elevation mask of 15°. The average baseline length was 5 kilometers, while the longest baseline was 8.5 kilometers.

All profiles were established in the standard positions, with the same number of flags and with the same flag spacing as defined in the JIRP Stake-Out Coordinate tables. These coordinates specify the exact easting and northing positions for each flag of each profile on the Juneau Icefield. The coordinates were loaded into the roving GPS unit and the operator navigated to within 0.5 meter of the stake-out coordinates. The navigated position was then recorded and a bamboo wand was inserted into the snow in the same location where the rover's range pole was positioned for the measurement. A second survey was done 5 to 10 days later. The coordinates of the first and second surveys were then analyzed to determine the surface velocity and direction of movement.

After calculating the summer 2007 velocities, a comparison was made with the velocities from previous summers. See Tables 1 through 9 for details on the years each profile was surveyed and the measured velocities at each flag.

Results

Comparison of the results of the 2007 surveys with previous surveys reveals an obvious increase in velocity on the main trunk of the Taku Glacier and its Northwest Branch accumulation zone. A smaller velocity increase is seen on the Demorest Glacier. The Matthes Glacier, a major tributary of the Taku, showed no significant velocity change. We observed decreased velocity on the Vaughan Lewis Glacier.

Between 1993, when GPS surveys were first conducted on the Juneau Icefield, and 2006, the velocity at all transverse profiles on the Juneau Icefield was, for the most part, constant. Year to year variations in the average velocity across each individual profile were remarkably consistent and insignificant. The graphs in Figure 2 present the flow profiles for each of the eight transverse profiles that were surveyed in 2007 (there are nine graphs because Profile 4 is composed of two parallel survey lines; an up-glacier line and a down-glacier line). The black lines show the transverse flow profile for surveys done between 1993 and 2006. The red line shows the results of the 2007 surveys. As can be seen by the black lines, velocities from 1993 to 2006 show little variation from year to year. Velocity increases in 2007 are evident for the Taku Glacier, the Demorest Glacier, and the Northwest Branch.

Taku Glacier at Profile 2: 6.2% Velocity Increase

Profile 2 is located on the main trunk of the Taku Glacier at Goat Ridge, 12 kilometers down glacier from Camp 10. Profile 2 is down-glacier from the confluence of all tributaries to the Taku Glacier, and therefore all flow of the entire Taku system passes through this profile. The glacier width at this location is 3.2 kilometers and the mean surface elevation on July 17, 2007 was 822 meters (reference datum and ellipsoid for all profiles: WGS84). This profile was previously surveyed in 1994 and 2000. The average velocity across the profile in 1994 was 0.864 meter/day. Six years later, in 2000, the average velocity was 0.863 meter/day. A velocity variation of about 1 mm/day is considered insignificant and confirms the steady state of the Taku Glacier at this profile from 1994

to 2000. The average velocity in 2007 was 0.917 meter/day, a 6.2% increase. Additionally, the maximum velocity in 1994 and 2000 was 0.930 meter/day. This increased to 0.989 meter/day in 2007, a 6.3% increase.

Demorest Glacier at Profile 3a: 4.5% Velocity Increase

Profile 3 is midway between the head of the Demorest Glacier and its confluence with the main trunk of the Taku Glacier. The mean surface elevation on August 4, 2007 was 1,355 meters. The glacier width is 4 kilometers at this profile. This profile was surveyed in 1998, 1999, and 2007. The average velocity in 1998 was 0.096 m/day and it was 0.097 m/day in 1999. In summer 2007, this increased to 0.101 m/day, for a 4.5% velocity increase.

Taku Glacier at Profile 4: 6.5% Velocity Increase

Profile 4 is located on the main trunk of the Taku Glacier at Camp 10, in the center of the Juneau Icefield. The profile is composed of two parallel transverse lines; one down-glacier line and the second line approximately 250 meters up-glacier. The flags on each line are laterally offset with respect to the other line so as to form a series of 29 triangles across the glacier. This allows for strain analysis. The average surface elevation of Profile 4 on July 25, 2007 was 1,127 meters. The width of the Taku Glacier at this profile is 5.3 kilometers.

This profile has the most continuous record of GPS surveys of all the profiles on the Juneau Icefield. It was first established in the early 1950's and has been surveyed in its present configuration every year since 1993, with surveys typically being conducted between July 20 and July 28. The average velocity of the down-glacier line from 1993 to 2006 was 0.337 m/day, increasing to 0.358 m/day in 2007, for a 6.2% increase. The average velocity of the up-glacier line from 1993 to 2006 was 0.348 m/day, increasing to 0.371 m/day in 2007, for a 6.8% increase. With a distance of only 250 meters between the two parallel lines, it may seem odd that the percentage of velocity increase of the two lines is not the same. This is explained by the fact that the down-glacier line has 16 flags while the up-glacier line has 15 flags. This results in an additional flag on either end of the down-glacier line being placed closer to the margins of the glacier, where the velocity is least. The minimal movement at these two marginal flags contributes to the lower apparent velocity increase for the down-glacier line. To negate this effect, the velocity of all 31 flags of Profile 4 was averaged for the 1993 to 2006 time period and for 2007, without breaking it out by up-glacier or down-glacier line. This gives an average velocity from 1993 to 2006 of 0.343 m/day, and an average velocity in 2007 of 0.365 m/day, an increase of 6.5%.

Northwest Branch at Profile 6: 7.1% Velocity Increase

Profile 6 is located between Taku Northwest Point and Echo Mountain at the junction of the Northwest Branch with the main trunk of the Taku Glacier. The mean surface elevation on July 19, 2007 was 1,334 meters. The width of the glacier at this profile is 4.7 kilometers. The average velocity in 1998 was 0.220 m/day and was nearly identical in 1999 at 0.219 m/day. This increased to an average velocity of 0.235 m/day in 2007, a 7.1% increase.

Matthes Glacier at Profile 7: 0.2% Velocity Increase

Profile 7 is located on the Matthes Glacier between Camp 9 and Centurian Peak. The glacier is 4.5 kilometers wide at this profile, and the mean surface elevation on July 24, 2007 was 1,423 meters. This profile has been surveyed six times between 1996 and 2006. The average velocity for these surveys is 0.220 m/day. The average velocity in 2007 was nearly identical at 0.221 m/day. This apparent velocity increase is not significant and we conclude that there was no velocity change at this profile in 2007.

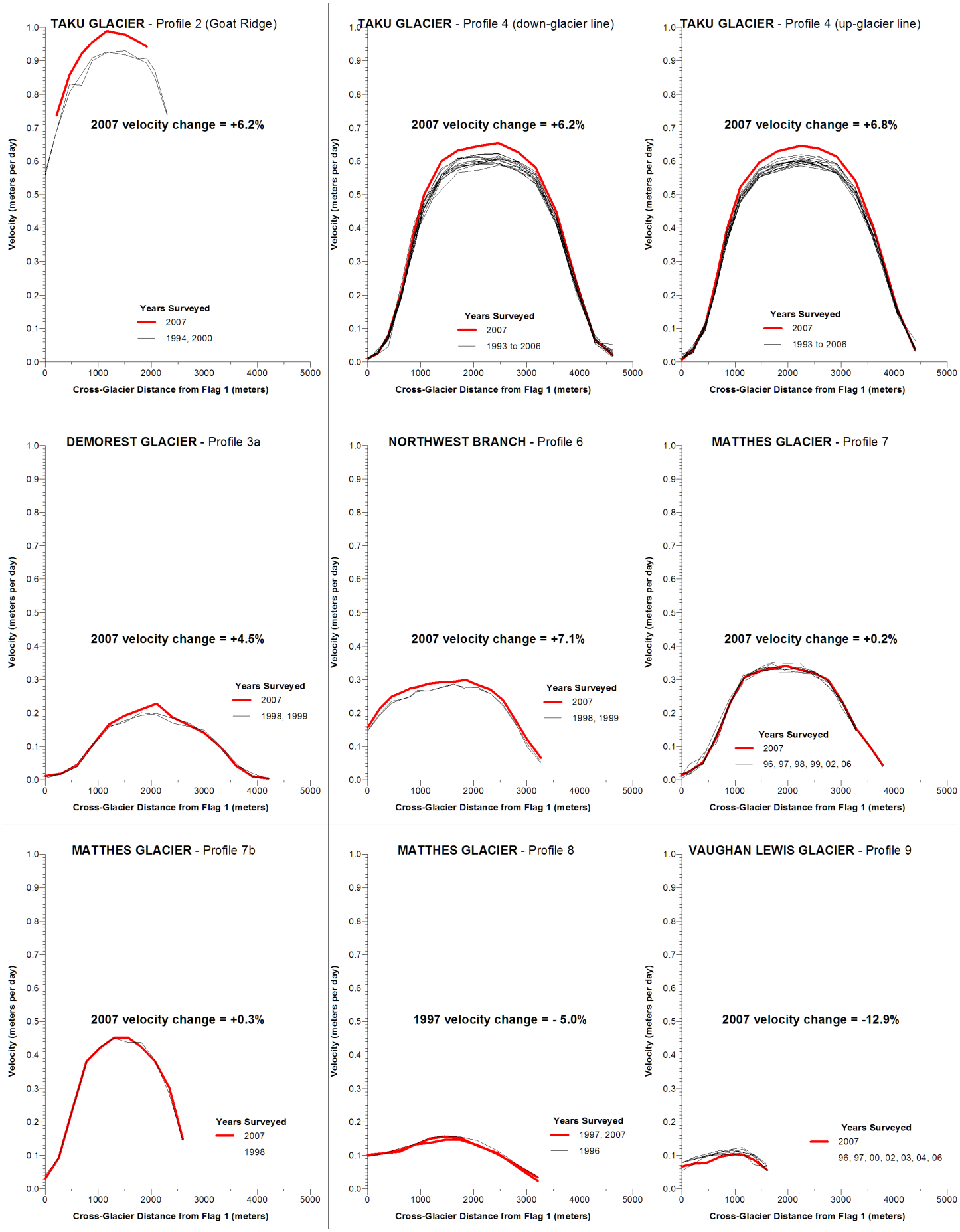

Figure 2: Comparison of transverse velocities in 2007 with previous surveys. Black lines indicate surveys from 1993 to 2006. Bold red line represents the results of the 2007 surveys.

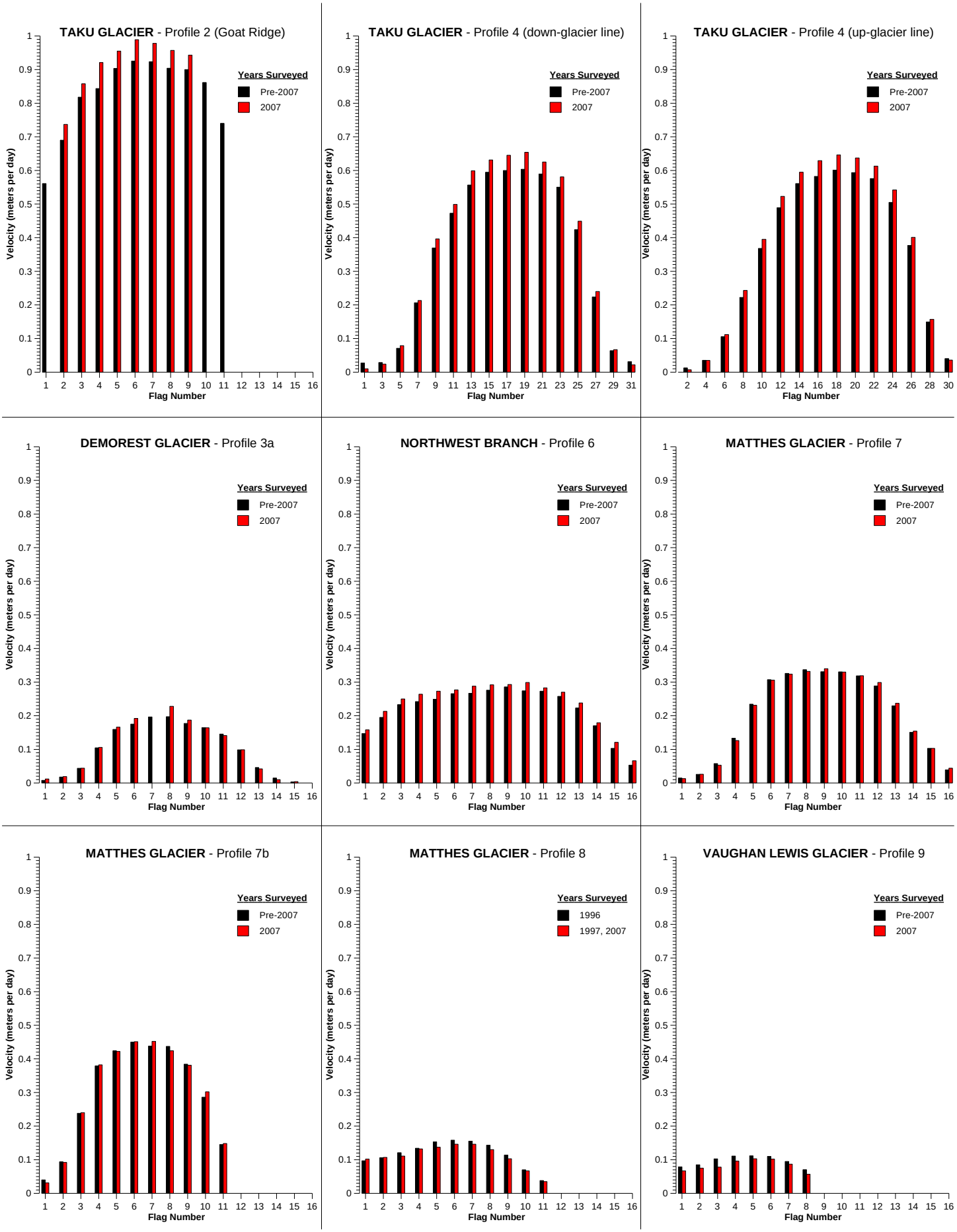

Figure 3: Comparison of transverse velocities in 2007 with previous surveys. Black bars show the average velocity of surveys prior to 2007. Red bars represent the results of the 2007 surveys.

Matthes Glacier at Profile 7b: 0.3% Velocity Increase

Profile 7b is located on the Matthes Glacier 5.5 kilometers up-glacier from Profile 7. This profile is midway up the steepest section of the Matthes Glacier where the surface slope averages 5°. By comparison, the surface slope of majority of the Taku Glacier and its tributaries averages between 1° and 2°. The width of the glacier at this profile is 3 kilometers, the narrowest of the Taku system transverse profiles. The mean surface elevation on August 3, 2007 was 1,567 meters. The only previous survey of Profile 7b was in 1998. The average velocity at that time was 0.301 m/day. In 2007, this was measured at 0.302 m/day. As with the results seen at Profile 7, we conclude that there was no significant velocity increase at this profile in 2007.

Matthes Glacier at Profile 8: 5.0% Velocity Decrease

Profile 8 is situated between Blizzard Peak and Mt. Moore, approximately 6.5 kilometers up-glacier from Profile 7b. The profile is roughly 3 kilometers down-glacier from the crest of the divide between the Matthes Glacier and the Llewellyn Glacier. The surface elevation of the divide area is approximately 1,870 meters. The mean surface elevation at Profile 8 on July 31, 2007 was only a few tens of meters lower at 1,808 meters. This profile was previously surveyed in 1996 and 1997, with average velocities of 0.117 m/day and 0.112 m/day respectively. The average velocity in 2007 was 0.111 m/day. This apparently reveals a velocity decrease that took place in 1997, while 10 years later the velocity was nearly identical to that in 1997. Averaging the 1997 and 2007 gives a velocity decrease of 5.0% when compared to the average 1996 velocity. This is the only transverse profile of the eight surveyed in 2007 that shows a velocity change prior to 2007. However, given the low average magnitude of movement compared to the inherent horizontal accuracy of the GPS measurements (roughly 1 to 2 cm), it is difficult to state unequivocally that the computed velocity decrease is significant. For this reason, we consider Profile 8 to show no significant change.

Vaughan Lewis Glacier at Profile 9: 12.9% Velocity Decrease

Profile 9 is located at the head of the Vaughan Lewis Icefall on the Vaughan Lewis Glacier. This glacier does not contribute to the Taku Glacier system, as it flows westerly into the Gilkey Trench, away from the Taku system. It is approximately 3 kilometers west of Profile 8, and is oriented parallel to the crescentic trend of the crevasses in the area. The mean surface elevation on August 5, 2007 was 1,743 meters. The width of the glacier at this profile is 1.6 kilometers. The profile has been surveyed seven times between 1996 and 2006. The average velocity for these years was 0.095 m/day. This decreased to an average of 0.083 m/day in 2007. This equates to a 12.9% decrease in velocity.

Validity of Results

JIRP has been utilizing survey-grade, centimeter-level GPS for monitoring the surface velocities on the Juneau Icefield since 1993. Throughout the past 15 years we have observed no significant year-to-year variations in the surface velocities. This is despite the fact that the Taku Glacier continues to slowly advance into Taku Inlet. Thus, the velocity changes measured in 2007 came as a surprise, and with some skepticism. To address this, we examined all aspects of the surveys in order to identify any possible systematic errors or blunders. Possibilities included GPS system configuration, staking-out and surveying the profiles, and post-survey data reduction.

From 1993 to 2006 we used Leica System 300 and Leica System 530 GPS units. In 2007 we used Trimble 5700 systems. Our initial thought upon seeing the velocity changes was that we had inadvertently configured the Trimble systems incorrectly. Double, triple, and quadruple checking

the configuration files used in the reference receivers revealed no errors. Likewise, the settings used in the roving receivers were correct. Parameters checked and confirmed as correct included the reference station coordinates, the coordinate system and datum, confirming that no datum transformation was specified (we employ a Transverse Mercator coordinate system that utilizes the WGS84 datum, thus a datum transformation between the GPS-based coordinate system and our system is not required). The elevation mask was set at 15° to eliminate satellites near the horizon, and we employed a minimum PDOP of 6.

The procedures used in staking-out and surveying the profiles were also examined. In order to accurately quantify velocity and height changes we must ensure that we are measuring the same exact locations from year to year. We accomplish this using standardized stake-out coordinates and two independent GPS systems. The stake-out coordinates serve as the master coordinates which permanently fix the location of each flag of each profile. These coordinates are published in the JIRP Stake-Out coordinate tables and are also loaded into a Magellan Meridian Platinum handheld GPS and the survey-grade systems (Leica and Trimble). The Magellan GPS utilizes WAAS differential corrections to enable navigation to within 1 meter of the established stake-out coordinates. This is possible due to the close proximity of the Juneau Icefield to the nearest WAAS ground station at the Juneau airport. The Juneau WAAS ground station computes the necessary error corrections for the area surrounding Juneau and transmits these corrections to the WAAS satellites, which in turn broadcast the corrections to all WAAS-capable receivers. We have repeatedly tested the accuracy of the Magellan GPS by keying in the coordinates of several benchmarks on the Icefield. We then place the Magellan on the benchmark and observe the GPS-derived, WAAS-corrected coordinates. Often, the GPS coordinates are within as little as 30 centimeters of the stake-out coordinates, and nearly always no greater than 1 to 1.5 meters. Thus, we are confident that using the Magellan GPS gives the accuracy and repeatability that is required in staking-out the profiles.

Upon navigating to within approximately one meter of the stake-out coordinates, the survey-grade systems (Leica and Trimble) were used to further navigate to within 50 centimeters of the stake-out coordinates. It is possible to get to within one or two centimeters of the exact position, however this level of placement for the first survey is not necessary due to the low surface slope (typically around 1°) of the glacier and the surface roughness due to suncups. Once the desired location is occupied with the Trimble GPS we level the range pole, making sure it is vertical, and take a reading. A bamboo wand is placed in the exact location occupied by the rover's range pole. The wand is placed deeply enough into the firn to ensure that it does not ablate out and fall over during the time interval between the first survey and the subsequent resurvey 5 to 10 days later. The resurvey employs the same techniques as the first survey – the bamboo wand is removed and the range pole is placed in the exact spot occupied by the wand. The range pole is held vertical with the aid of a circular bubble level on the pole, and a GPS measurement is recorded. These procedures were rigidly followed for all surveys, not only in 2007, but also in all previous years. We have high confidence that our survey methods are consistent from year to year and are free of blunders and systematic errors.

This leaves post-survey data reduction as the remaining factor in determining if the suspected velocity changes are indeed valid. The close correlation of the survey data for 1993 to 2006 confirms that our data reduction using the Leica SKI software and velocity computations using Excel is error-free. Post-processing with the Trimble Office software was negligible, due to the fact that we utilized real-time differential systems. Items checked and confirmed included ensuring the antenna heights of the reference and rover receivers were correct, as verified by our field notes. We also confirmed that the correct coordinates were assigned to the reference receiver at both the first survey and the resurvey. In 2007 we simply copied the 2006 Excel worksheets and substituted the

2006 data with the 2007 data. In all cases the formulas remained unchanged. After exhaustive investigation we could find no systematic errors or blunders in any of our GPS configuration, survey, or post-processing methodology.

Examining the velocity graphs in Figure 2 and the bar charts in Figure 3 rules out systematic errors and blunders. Systematic errors would be seen as a consistent trend in the data. For example, the velocity graphs would show all increases, all decreases, or no significant change. Likewise, the bar graphs would show all increases, all decreases, or no significant change for each flag of each profile. The bar charts, in particular, reveal this is not the case as they show velocity increases, decreases, and no significant change both within individual profiles and across all eight of the profiles. Blunders would manifest as uncharacteristic spikes or dips in the data. The graphs and charts reveal no such significant spikes or dips.

After repeated investigations into the various procedures and methods used for the GPS surveys and finding no systematic errors or blunders, we conclude that the velocity changes shown in Figures 2 and 3 and Tables 1 through 9 indeed truly reveal the first velocity changes we have observed on the Juneau Icefield in the past 15 years.

Appendices

Tables 1-9: Annual GPS Survey Data

Profile 2 Daily Movement (meters)			
Flag	**1994**	**2000**	**2007**
1	0.565	0.557	No data
2	0.690	0.690	0.737
3	0.830	0.806	0.858
4	0.827	0.860	0.921
5	0.899	0.908	0.955
6	0.924	0.927	0.989
7	0.930	0.917	0.978
8	0.905	0.903	0.957
9	0.907	0.893	0.943
10	0.871	0.852	No data
11	0.741	0.739	No data
Average	**0.864**	**0.863**	**0.917**

Average velocity for 1994 and 2000 (flags 2-9)	0.864
Average velocity for 2007 (flags 2-9)	0.917
Minimum velocity for 1994 and 2000 (flags 2-9)	0.690
Minimum velocity for 2007 (flags 2-9)	0.737
Maximum velocity for 1994 and 2000 (flags 2-9)	0.930
Maximum velocity for 2007 (flags 2-9)	0.989
Average velocity increased by	6.2%
Minimum velocity increased by	6.8%
Maximum velocity increased by	6.3%
Average velocity increase for Profile 2:	**6.2%**

Table 1: Measured surface velocity at Profile 2, located on the Taku Glacier at Goat Ridge. Units are meters per day, as measured during the summer. Figures in light gray are not used in the calculations.

PROFILE 4, DOWN-GLACIER LINE – Daily Movement (meters)

Flag	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
1	0.013	0.013	0.029	0.009	0.013	0.005	0.003	0.012	0.010	0.013	0.007	0.007	0.011	**0.011**	0.010
3	0.027	0.031	0.033	0.032	0.023	0.026	0.038	0.026	0.026	0.031	0.031	0.024	0.026	0.027	0.024
5	0.076	0.066	0.075	0.079	0.073	0.069	0.069	0.079	0.076	0.068	0.070	0.045	0.065	0.084	0.079
7	0.201	0.239	0.199	0.203	0.201	0.196	0.207	0.211	0.212	0.203	0.197	0.213	0.194	0.213	0.213
9	0.372	0.419	0.366	0.375	0.357	0.372	0.346	0.379	0.382	0.370	0.357	0.344	0.361	0.375	0.396
11	0.469	0.588	0.462	0.431	0.462	0.459	0.482	0.483	0.480	0.460	0.458	0.461	0.445	0.478	0.499
13	0.556	0.561	0.549	0.543	0.556	0.547	0.558	0.573	0.577	0.551	0.558	0.558	0.549	0.558	0.599
15	0.591	0.588	0.606	0.581	0.601	0.578	0.633	0.607	0.603	0.585	0.565	0.581	**0.594**	0.609	0.631
17	0.606	0.598	0.615	0.592	0.598	0.597	0.591	0.620	0.620	0.590	0.573	0.596	0.591	0.610	0.645
19	0.601	0.605	0.590	0.594	0.606	0.594	0.608	0.622	0.621	0.612	0.588	0.616	0.588	0.606	0.654
21	0.584	0.580	0.575	0.635	0.598	0.568	0.588	0.598	0.598	0.589	0.583	0.592	0.571	0.596	0.625
23	0.544	0.559	0.560	0.547	0.546	0.534	0.557	0.562	0.569	0.540	0.542	0.563	0.532	0.550	0.581
25	0.428	0.428	0.437	0.408	0.414	0.420	0.415	0.438	0.439	0.416	0.429	0.415	0.411	0.435	0.449
27	0.226	0.218	0.235	0.215	0.217	0.227	0.218	0.232	0.245	0.222	0.237	0.206	0.213	0.222	0.240
29	**0.064**	0.053	0.071	0.064	0.067	0.055	0.059	0.068	0.076	0.060	0.055	0.066	0.058	0.080	0.067
31	**0.031**	0.022	0.019	0.017	0.036	0.014	0.052	0.031	0.027	0.029	0.081	0.034	0.026	0.020	0.022
Average	**0.337**	**0.348**	**0.339**	**0.333**	**0.336**	**0.329**	**0.339**	**0.346**	**0.348**	**0.334**	**0.333**	**0.333**	**0.327**	**0.342**	**0.358**

Average velocity for 1993 through 2006	0.337
Average velocity for 2007	0.358
Minimum velocity for 1993 through 2006	0.003
Minimum velocity for 2007	0.010
Maximum velocity for 1993 through 2006	0.635
Maximum velocity for 2007	0.654
Average velocity increased by	6.2%
Minimum velocity increased by	233.3%
Maximum velocity increased by	3.0%

Average velocity increase for down-glacier line:	**6.2%**
Average velocity increase for both lines:	**6.5%**

Table 2: Measured surface velocity at the down-glacier line of Profile 4, located on the main trunk of the Taku Glacier at Camp 10. Units are meters per day, as measured during the summer. Figures in red indicate that no data was collected that year for that flag. The figure shown is the average of the daily velocity for all other years through 2006. The minimum velocity increase should be disregarded, as the magnitude of minimum movement is within the error range of the GPS measurements.

PROFILE 4, UP-GLACIER LINE – Daily Movement (meters)

Flag	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
2	0.013	0.014	0.012	0.016	0.014	0.012	0.007	0.006	0.010	0.024	0.011	0.010	0.006	0.020	0.007
4	0.025	0.027	0.046	0.032	0.031	0.029	0.038	0.030	0.040	0.036	0.042	0.050	0.033	0.037	0.035
6	0.109	0.114	0.117	0.100	0.103	0.109	0.110	0.107	0.112	0.097	0.101	0.103	0.103	0.094	0.112
8	0.228	0.225	0.212	0.211	0.225	0.221	0.228	0.231	0.227	0.221	0.220	0.217	0.219	0.227	0.243
10	0.372	0.368	0.378	0.359	0.352	0.358	0.372	0.372	0.384	0.368	0.394	0.356	0.355	0.365	0.395
12	0.489	0.496	0.506	0.482	0.499	0.482	0.494	0.497	0.500	0.479	0.489	0.480	0.476	0.480	0.523
14	0.564	0.557	0.577	0.572	0.562	0.552	0.551	0.572	0.574	0.557	0.553	0.551	0.551	0.560	0.595
16	0.585	0.593	0.591	0.590	0.583	0.583	0.577	0.599	0.608	0.576	0.531	0.570	0.577	0.588	0.629
18	0.610	0.603	0.603	0.601	0.600	0.599	0.594	0.614	0.619	0.599	0.588	0.593	0.585	0.605	0.646
20	0.595	0.594	0.585	0.586	0.588	0.585	0.616	0.604	0.611	0.593	0.596	0.582	0.577	0.597	0.637
22	0.570	0.574	0.590	0.562	0.587	0.565	0.571	0.592	0.593	0.568	0.566	0.564	0.566	0.593	0.613
24	0.510	0.507	0.520	0.500	0.486	0.505	0.510	0.515	0.519	0.508	0.505	0.483	0.498	0.506	0.542
26	0.373	0.372	0.361	0.375	0.375	0.368	0.381	0.393	0.397	0.376	0.380	0.364	0.398	0.363	0.401
28	**0.150**	0.151	0.150	0.149	0.150	0.139	0.160	0.149	0.157	0.155	0.143	0.147	0.146	0.148	0.157
30	**0.040**	0.041	0.037	0.036	0.044	0.042	0.036	0.037	0.039	0.036	0.064	0.039	0.041	0.031	0.036
Average	**0.349**	**0.349**	**0.352**	**0.345**	**0.347**	**0.343**	**0.350**	**0.355**	**0.359**	**0.346**	**0.346**	**0.341**	**0.342**	**0.348**	**0.371**

Average velocity for 1993 through 2006	0.348
Average velocity for 2007	0.371
Minimum velocity for 1993 through 2006	0.006
Minimum velocity for 2007	0.007
Maximum velocity for 1993 through 2006	0.619
Maximum velocity for 2007	0.646
Average velocity increased by	6.8%
Minimum velocity increased by	16.7%
Maximum velocity increased by	4.4%

Average velocity increase for down-glacier line:	**6.8%**
Average velocity increase for both lines:	**6.5%**

Table 3: Measured surface velocity at the up-glacier line of Profile 4, located on the main trunk of the Taku Glacier at Camp 10. Units are meters per day, as measured during the summer. Figures in red indicate that no data was collected that year for that flag. The figure shown is the average of the daily velocity for all other years through 2006.

Flag	Profile 3a Daily Movement (meters)		
	1998	1999	2007
1	0.010	0.005	0.012
2	0.018	0.017	0.019
3	0.048	0.039	0.044
4	0.107	0.102	0.106
5	0.161	0.158	0.166
6	0.172	0.178	0.192
7	0.201	0.192	No data
8	0.194	0.200	0.228
9	0.170	0.184	0.187
10	0.159	0.170	0.164
11	0.149	0.142	0.141
12	0.102	0.095	0.099
13	0.047	0.045	0.042
14	0.009	0.020	0.010
15	0.003	0.003	0.004
Average	**0.096**	**0.097**	**0.101**

Average velocity for 1998 and 1999	0.097
Average velocity for 2007	0.101
Minimum velocity for 1998 and 1999	0.003
Minimum velocity for 2007	0.004
Maximum velocity for 1998 and 1999	0.200
Maximum velocity for 2007	0.228
Average velocity increased by	4.5%
Minimum velocity increased by	33.3%
Maximum velocity increased by	14.0%
Average velocity increase for Profile 3a:	**4.5%**

Table 4: Measured surface velocity at Profile 3a, located on the Demorest Glacier east of Camp 9. Units are meters per day, as measured during the summer.

Flag	Profile 6 Daily Movement (meters)		
	1998	1999	2007
1	0.148	0.146	0.158
2	0.196	0.194	0.213
3	0.236	0.230	0.250
4	0.241	0.243	0.264
5	0.248	0.250	0.273
6	0.264	0.267	0.277
7	0.267	0.266	0.288
8	0.276	0.276	0.292
9	0.285	0.286	0.293
10	0.276	0.272	0.299
11	0.275	0.271	0.283
12	0.257	0.258	0.270
13	0.221	0.225	0.238
14	0.168	0.172	0.179
15	0.108	0.098	0.121
16	0.055	0.051	0.066
Average	**0.220**	**0.219**	**0.235**

Average velocity for 1998 and 1999	0.220
Average velocity for 2007	0.235
Minimum velocity for 1998 and 1999	0.051
Minimum velocity for 2007	0.066
Maximum velocity for 1998 and 1999	0.286
Maximum velocity for 2007	0.299
Average velocity increased by	7.1%
Minimum velocity increased by	29.4%
Maximum velocity increased by	4.5%
Average velocity increase for Profile 6:	**7.1%**

Table 5: Measured surface velocity at Profile 6, located on the Northwest Branch of the Taku Glacier. Units are meters per day, as measured during the summer.

Flag	Profile 7 Daily Movement (meters)						
	1996	1997	1998	1999	2002	2006	2007
1	0.019	0.017	0.016	0.005	0.016	0.015	0.013
2	0.017	0.016	0.028	0.020	0.023	0.049	0.026
3	0.047	0.079	0.050	0.054	0.048	0.068	0.053
4	0.134	0.109	0.137	0.127	0.134	0.157	0.126
5	0.235	0.232	0.230	0.228	0.234	0.247	0.231
6	0.311	0.319	0.294	0.312	0.305	0.302	0.306
7	0.325	0.317	0.319	0.329	0.333	0.332	0.324
8	0.330	0.348	0.319	0.336	0.337	0.351	0.332
9	0.330	0.326	0.321	**0.331**	0.329	0.348	0.340
10	0.335	0.321	0.319	0.326	0.333	0.349	0.330
11	0.325	0.324	0.316	0.317	0.321	0.309	0.319
12	0.295	0.296	0.280	0.278	0.292	0.291	0.299
13	0.229	0.215	0.228	0.239	0.228	0.237	0.237
14	0.149	0.154	0.145	0.150	0.146	0.158	0.154
15	No data	No data	No data	0.103	No data	No data	0.103
16	No data	No data	No data	0.039	No data	No data	0.044
Average	**0.220**	**0.220**	**0.214**	**0.218**	**0.220**	**0.230**	**0.221**

Average velocity for 1996 through 2006	0.220
Average velocity for 2007	0.221
Minimum velocity for 1996 through 2006	0.005
Minimum velocity for 2007	0.013
Maximum velocity for 1996 through 2006	0.351
Maximum velocity for 2007	0.340
Average velocity increased by	0.2%
Minimum velocity increased by	160.0%
Maximum velocity increased by	-3.1%
Average velocity increase for Profile 7:	**0.2%**

Table 6: Measured surface velocity at Profile 7, located on the Matthes Glacier at Camp 9. Units are meters per day, as measured during the summer. Figure in red indicates that no data was collected that year for that flag. The figure shown is the average of the daily velocity for all other years through 2006. The minimum velocity increase should be disregarded, as the magnitude of minimum movement is within the error range of the GPS measurements.

Flag	Profile 7b Daily Movement (meters)	
	1998	2007
1	0.040	0.031
2	0.094	0.092
3	0.238	0.240
4	0.379	0.382
5	0.424	0.422
6	0.450	0.451
7	0.438	0.452
8	0.437	0.424
9	0.384	0.381
10	0.286	0.302
11	0.145	0.148
Average	**0.301**	**0.302**

Average velocity for 1998	0.301
Average velocity for 2007	0.302
Minimum velocity for 1998	0.040
Minimum velocity for 2007	0.031
Maximum velocity for 1998	0.450
Maximum velocity for 2007	0.452
Average velocity increased by	0.3%
Minimum velocity increased by	-22.5%
Maximum velocity increased by	0.4%
Average velocity increase for Profile 7b:	**0.3%**

Table 7: Measured surface velocity at Profile 7b, located on the Matthes Glacier 5.5 kilometers up-glacier from Profile 7. Units are meters per day, as measured during the summer. The minimum velocity increase should be disregarded, as the magnitude of minimum movement is within the error range of the GPS measurements.

Flag	Profile 8 Daily Movement (meters)		
	1996	1997	2007
1	0.097	0.099	0.102
2	0.106	0.107	0.107
3	0.121	0.116	0.111
4	0.134	0.132	0.132
5	0.153	0.149	0.137
6	0.158	0.156	0.146
7	0.155	0.151	0.146
8	0.143	0.129	0.130
9	0.114	0.107	0.103
10	0.070	0.062	0.067
11	0.038	0.025	0.035
12	0.077	0.011	0.021
Average	**0.117**	**0.112**	**0.111**

Average velocity for 1996	0.117
Average velocity for 1997	0.112
Average velocity for 2007	0.111
Minimum velocity for 1996	0.038
Minimum velocity for 1997	0.011
Minimum velocity for 2007	0.021
Maximum velocity for 1996	0.158
Maximum velocity for 1997	0.156
Maximum velocity for 2007	0.146
Average velocity for 1997 and 2007	0.111
Average velocity decrease (1996 to 1997 & 2007 average)	**-5.0%**

Table 8: Measured surface velocity at Profile 8, located on the Matthes Glacier between Blizzard Peak and Mt. Moore. Units are meters per day, as measured during the summer. Data for Flag 12 are not included in the computations due to the obvious outlier value for 1996.

Flag	Profile 9 Daily Movement (meters)							
	1996	**1997**	**2000**	**2002**	**2003**	**2004**	**2006**	**2007**
1	0.078	0.079	0.077	0.078	0.047	0.139	0.054	0.067
2	0.095	0.087	0.089	0.092	0.089	0.067	0.076	0.075
3	0.129	0.100	0.120	0.096	0.096	0.077	0.100	0.078
4	0.114	0.098	0.110	0.111	0.108	0.132	0.102	0.096
5	0.106	0.118	0.113	0.118	0.099	0.123	0.104	0.103
6	0.119	0.124	0.110	0.110	0.111	0.097	0.098	0.102
7	0.095	0.100	0.099	0.101	0.072	0.095	0.103	0.087
8	0.057	0.069	0.053	0.069	0.066	0.104	0.074	0.057
Average	**0.099**	**0.097**	**0.096**	**0.097**	**0.086**	**0.104**	**0.089**	**0.083**

Average velocity for 1996 through 2006	0.095
Average velocity for 2007	0.083
Minimum velocity for 1996 through 2006	0.047
Minimum velocity for 2007	0.057
Maximum velocity for 1996 through 2006	0.139
Maximum velocity for 2007	0.103
Average velocity increased by	-12.9%
Minimum velocity increased by	21.3%
Maximum velocity increased by	-25.9%
Average velocity decrease for Profile 9:	**-12.9%**

Table 9: Measured surface velocity at Profile 9, located above the icefall on the Vaughan Lewis Glacier near Camp 18. Units are meters per day, as measured during the summer. The minimum velocity increase should be disregarded, as the magnitude of minimum movement is within the error range of the GPS measurements.