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Mount Rainier National Park Geology Program Report

Surficial Velocities of the Nisqually Glacier, Mount Rainier National Park, 2011 and 2012

Mount Rainier National Park Geology Program Report 2019

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Laura Walkup and Eric McPherren travel across crevasses while surveying the Nisqually Glacier.
Photograph by: Paul Kennard, Mount Rainier National Park

ON THE COVER
Paul Kennard and Jeff Fortner survey a rock in a crevasse
Photograph by: Laura Walkup, Mount Rainier National Park

Surficial Velocities of the Nisqually Glacier, Mount Rainier National Park, 2011 and 2012

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Abstract

Mount Rainier, Washington is the tallest of multiple glacier-clad volcanic peaks within the Cascade Range and it contains the most glacial ice. Glaciers are the headwaters for numerous rivers emanating from Mount Rainier, many of which flow into the Puget Sound approximately 60 km (37 mi) away. Glaciers on Mount Rainier have unleashed damaging outburst floods (jökulhlaups) in the past, often without warning. Previous observations indicate an empiric link between changing glacial velocities and glacial outburst flood hazards.

This study explores whether the surficial velocity field of the Nisqually glacier is changing and whether ice velocity fluctuations indicate a change in glacial outburst flood potential. Numerous sites on the lower Nisqually glacier were surveyed weekly during late summer/early fall of 2011 and 2012. The surficial velocity field of the lower 1 km^2 (0.4 mi^2) of the glacier was calculated from repeated measurements. Between 2011 and 2012, observed velocities in the upper portions of the study area increased while the lower portions of the glacier slowed or remained the same. Shortly after the on-glacier study concluded, a small glacial outburst flood was released from the glacier during a minor rain event.

Our work contributes to the understanding of glacial outburst floods and provides evidence that changing ice velocities precede outburst floods. Further study of glacial velocity fields could provide a predictive methodology for glacial outburst floods in similar terrain. These results are critical for employee, visitor, and infrastructure protection in dynamic environments such as that at Mount Rainier.

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Introduction

Mount Rainier, an active volcano located within Mount Rainier National Park (MORA) in Washington State, is the tallest of a number of glacier-clad volcanic peaks within the Cascade Range. Standing at 4,392 m (14,411 ft) and having 29 named glaciers (Beason 2017a), it contains approximately 4.4 km^3 (1 mi^3) of ice ─ more glacial ice than any other single peak in the continental United States (Driedger and Kennard, 1986), and more than all the other Cascade volcanos combined.

Glaciers are the headwaters for a number of rivers emanating from Mount Rainier, and most flow into the Puget Sound approximately 60 km (37 mi) away. Glaciers on Mount Rainier have unleashed damaging outburst floods (jökulhlaups) in the past, often without warning. The Nisqually Glacier is the largest south-facing glacier on Mount Rainier and it is the source for the Nisqually River, which parallels much of the main access road into the Park. Longmire, the principal worker and visitor center within the park, is also immediately adjacent to the Nisqually River. Park management is concerned with flooding risks, including glacier outburst floods to both the road and to Longmire.

The Nisqually Glacier has one of the longest histories of scientific examination of any glacier in the United States (Heliker and others, 1984), in part due to its proximity to park roads and trails. The 1st recorded observation of the glacier terminus was in 1857, and since then numerous research efforts have maintained the continuity of long-term records. For example, measurements of ice-surface elevations started in 1931, and continue to this day (Stevens and others 2016). The Nisqually glacier is of particular interest to the park due to its influence on the Nisqually River.

For hazard purposes, the park has sought to identify the watersheds susceptible to glacier outburst flooding, and the physical and climatic controls to jökulhlaup initiation. To this end, the park has done internal studies, collaborated with area universities (University of Washington, Portland State University, and Oregon State University) on multiple projects, and tracked other independent university analyses. These projects are listed in the Further Research section of this report.

As part of the larger hazard project, this subject project examines glacier velocity and outburst flood hazards at the park. In it, we measured the surficial velocity of the lower 1 km^2 (0.4 mi^2) of the Nisqually Glacier (Figure 1) during two summers (2011 and 2012) in an attempt to identify whether the ice was changing in velocity and whether or not a potential, measurable fluctuation in velocity could be used as a predictor for glacial outburst flood hazard. Paul Kennard is the principal investigator for this project, and Laura Walkup is project manager.

At Mount Rainier, there is an empirical correlation between retreating glaciers and stagnant ice with glacier outburst floods. Specifically, the lower portions of the glaciers were often stagnant when outburst floods occurred. The connection between stagnant ice and jökulhlaups is seen most clearly with South Tahoma glacier and Tahoma Creek. Of the 32 debris flows and outburst floods that have occurred there since 1967 (compiled in Beason, 2019), almost all originated as glacier outburst floods (Walder and Driedger 1995). In fact, the initial massive 1967 jökulhlaup exited from glacier at about 7,000 feet elevation, and physically severed the upper glacier from the lower half, which then became stagnant (National Park Service 2018). Additionally, a significant mechanism facilitating the bulking up of jökulhlaups and transforming into debris flows is entrainment of sediment as the flows incised stagnant ice (Walder and Driedger 1994).

However, the stagnant ice – outburst flood relationship is not clear with the Nisqually glacier. Skloven-Gill and Fountain (2015) found “no obvious correlation” with stagnant ice and outburst floods. To investigate this, they used ice elevation measurements (Heliker and others 1984) as a surrogate for ice activity. They attributed the difficulty in making a definitive determination either way on the relationship of stagnant ice and outburst flooding on insufficient data. In particular, they noted a lack of information on the extent and duration of dead ice; and an incomplete record of outburst floods on the Nisqually (Skloven-Gill and Fountain 2015). Skloven-Gill and Fountain (2015) did note that the largest and most destructive outburst flood (1955) on the Nisqually, discussed below, occurred during a period of documented stagnant ice (USGS 1978).

Past research indicates that the lower Nisqually glacier has displayed a range of seasonal velocities throughout its measurement history (Table 1). Seasonal velocity variations are most likely attributed to alterations in glacier sliding, driven by englacial and subglacial hydrology changes (Fountain and Walder 1998, Hodge 1978, and Allstadt and others 2015).
As discussed earlier, empiric evidence suggests that glacial outburst floods or jökulhlaups at Mount Rainier tend to occur when large amounts of stagnant ice are present in the lower glacier. Additionally, Hodge (1974) found that the summer ice velocity of the Nisqually glacier increased measurably in the vicinity of the equilibrium line altitude (ELA), while slowing occurred toward the terminus relative to the previous summer just prior to the 1970 glacier outburst flood. He proposed that observed variations in ice velocity were correlated with the amount of liquid water temporarily stored within the glacier. This suggests that the presence of englacial water leads to faster ice velocities and a higher potential for outburst floods, while the absence of large quantities of englacial water is associated with slower glacial flow and fewer outburst floods. Long-term annually-repeating glacial velocity measurements of the lower glacier could prove to be a powerful tool in the prediction of potentially devastating glacial outburst floods.

Several major, damaging glacial outburst floods have been released from the Nisqually Glacier since the 1920’s, along with many smaller outburst events (e.g. figure 2b). The floods of 1926 and 1934 damaged the bridge below the glacial terminus, and the floods in 1932 and 1955 destroyed it (Hodge, 1972). The largest recorded outburst flood on the Nisqually occurred in 1955. This was the largest known Nisqually glacier discharge (Nelson 1987), and the only time the historic work and visitor center at Longmire was inundated with flood waters (figure 2c). In addition, much of the main access road, which is also the park’s only year-around road, parallels the Nisqually River, putting park access and anyone on the road at risk in the event of a major glacial outburst flood from the Nisqually Glacier (e.g. figure 2d).

Historic accounts of glacial outburst floods include observations that the outburst can occur above the terminus of the glacier (Richardson, 1968) (figure 2a). This is consistent with an origination point at the interface between active and stagnant ice. This style of outburst flood has been known to sweep the surface glacial ice clean of debris.

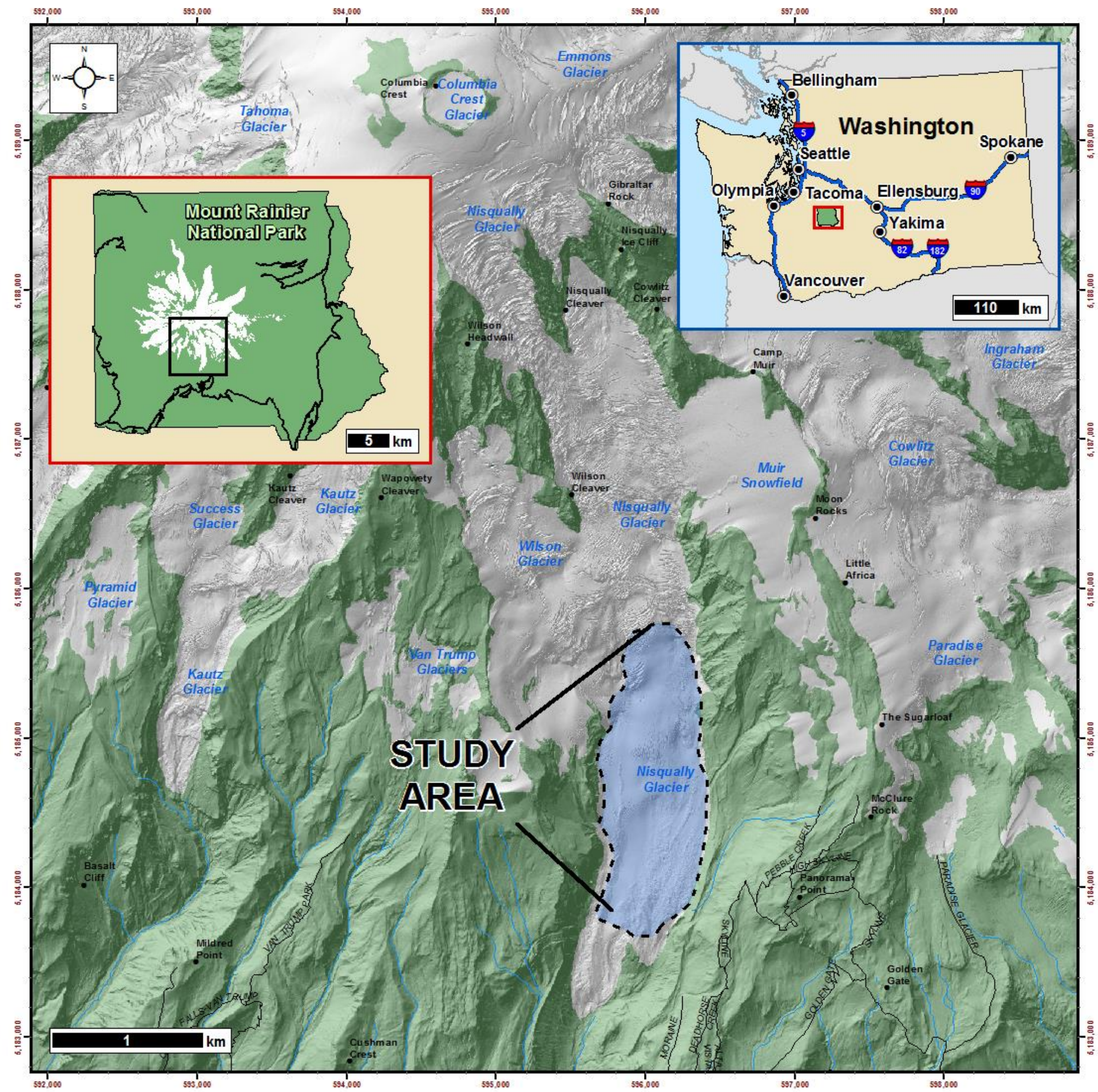

Figure 1. Location map showing the study area extent. The Nisqually Glacier is the largest south-facing glacier on Mount Rainier. The study area extends from just above the 2011-2012 terminus, approximately 1,580 m (5,180 ft), up to about 2,190 m (7,180 ft), well above the seasonal ELA. The area surveyed is approximately 1.0 km^2 (0.4 mi^2).

Our work contributes to the understanding of glacial outburst floods and provides an additional line of evidence that changing ice velocities precede outburst floods. Further study of glacial velocity fields could provide a predictive methodology for glacial outburst floods in similar terrain. These results are critical for employee, visitor, and infrastructure protection in dynamic environments such as that at Mount Rainier.

Table 1. Historic velocity data for the Nisqually Glacier.

Survey Interval	Location on Glacier	Maximum Measured Velocity (mm/day)	Minimum Measured Velocity (mm/day)	Data Source
June 2012	1,900 m	500	–	Allstadt and others, 2015
Nov. 2012	1,900 m	260	–	
June 2012	Near Terminus	2	–	Allstadt and others, 2015
Nov. 2012	Near Terminus	1	–	
June-Sept 1968	Near ELA	380	210	Hodge, 1974
	Near Terminus	146	88	Hodge, 1974
May – Sept 1969	Near ELA	460	340	Hodge, 1974
	Near Terminus	130	68	Hodge, 1974
May 1970	Near ELA	740	660	Hodge, 1974
	Near Terminus	77	68	Hodge, 1974

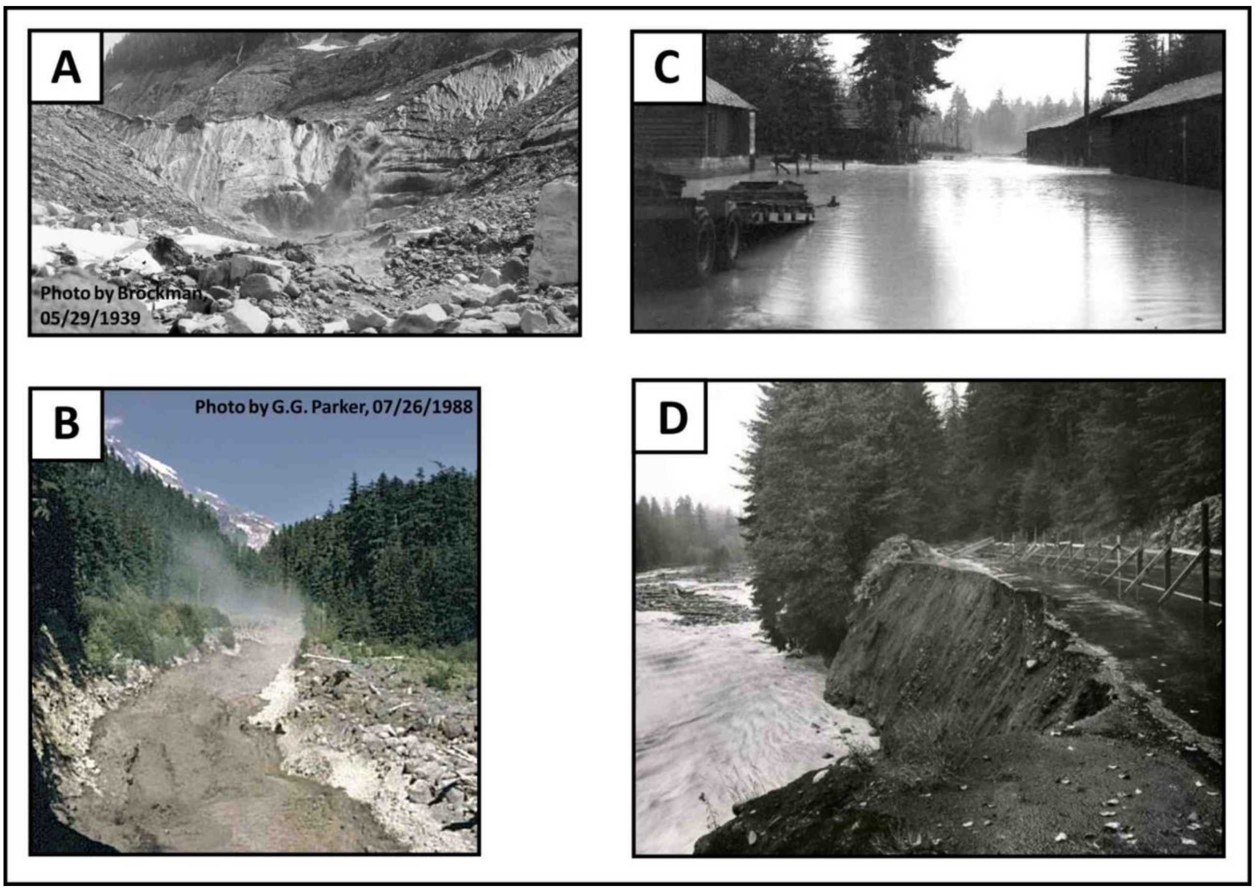

Figure 2. Historic Outburst Flood photos. A (top left): Photo taken in 1939 showing a “surge” of water pouring over the face of the Nisqually Glacier. B (bottom left): Photo of a debris flow initiated by a glacial outburst flood on Tahoma Creek, Mount Rainier National Park. C (top right): Photo of the Longmire maintenance area inundated during a glacial outburst flood in 1955. D (bottom right): Photo showing

some of the impacts of the 1955 outburst flood to the riverbank and park road between the main park entrance and Longmire.

Methods

The movement of rocks and ablation stakes was used as a proxy of the surficial velocity of the glacier. The geographic position of many individual rocks and several ablation stakes were surveyed in August and September of 2011 and again from July through October 2012. The positions were differenced to estimate the surface velocity of the lower Nisqually glacier. Measurements were conducted on the same day weekly, weather permitting. Surveying occurred from just above the terminus (figure 3), at approximately 1580 m (5,184 ft), up to about the 2190 m (7,185 ft) level. The area covered was approximately 1 km^2 (0.4 mi^2).

Surveying was conducted with a Topcon GPT-3105W 5-second electronic total station and Topcon FC-250 hand held data collector with Top Surv software using standard surveying practices (Topcon, 2008). The total station was occupied at two points with known locations: (1) on the left lateral moraine of the Nisqually Glacier and (2) above the moraine at Glacier Vista. Each location was back sighted to a known point when occupied. Positions for this study were recorded in the North American Datum (NAD) of 1983 Washington State Plane South Zone coordinate system (FIPS = 4602), with positions measured in meters. Vertical elevation control was obtained from benchmarks placed along the left lateral moraine by surveys conducted by Hodge (1972) and later modified as needed (due to moraine erosion) by Parametrix, Inc. of Lacey (later Puyallup), WA. These controls were originally used for annual ice elevation surveys conducted yearly on the Nisqually Glacier, starting in 1931 (Heliker and others 1984, Stevens and others 2016).

The rocks used as velocity data points were located on top of, or entrained within, the glacial ice. They were chosen as survey points based on their on-glacier location, and the estimated likelihood of staying in place on ice. Rocks chosen as survey points were assigned and labeled with a unique identification number (figure 4a). Individual survey teams were composed of two to four members supplied with personal protective and glacier-travel equipment, and radios. Two or three teams were present on the glacier during each survey.

Rocks were surveyed by placing the point of a survey rod and prism on the surface of the ice directly adjacent to the farthest down-slope portion of the rock (figure 4b). In the rare instances where it was impossible to measure the down-slope point on a target, the alternate placement was marked to insure repeatability, reducing measurement error. A small surveying flag labeled with the rock number (figure 4a) was also placed into the ice at the survey point to provide a point of reference in case the rocks rolled or slid between successive measurements. The location of the flag and survey point was recorded in a field notebook and photographed each with each measurement.

In addition to the total station surveying, Global Positioning System (GPS) positions of the rocks were measured weekly using a handheld Garmin GPSMap 78. This information was used to help find the rocks in subsequent surveys, and provides a basis for future method comparison if we wish to do a similar survey in the future using only handheld GPS units. GPS-only surveys would be less accurate, but could be accomplished using fewer people, in less time, and in lower visibility conditions.

Teams photographed each surveyed rock every field day in order to note any changes in rock orientation. At least two photos per rock were taken at each measurement site; one close-up and one zoomed out for context. At most locations, the rod position and flag position were in one or both photos. Printed field guides were created and updated weekly with the photographs and GPS positions of the rocks. These were used in the field to assist with re-identification of specific target rocks by the survey teams.

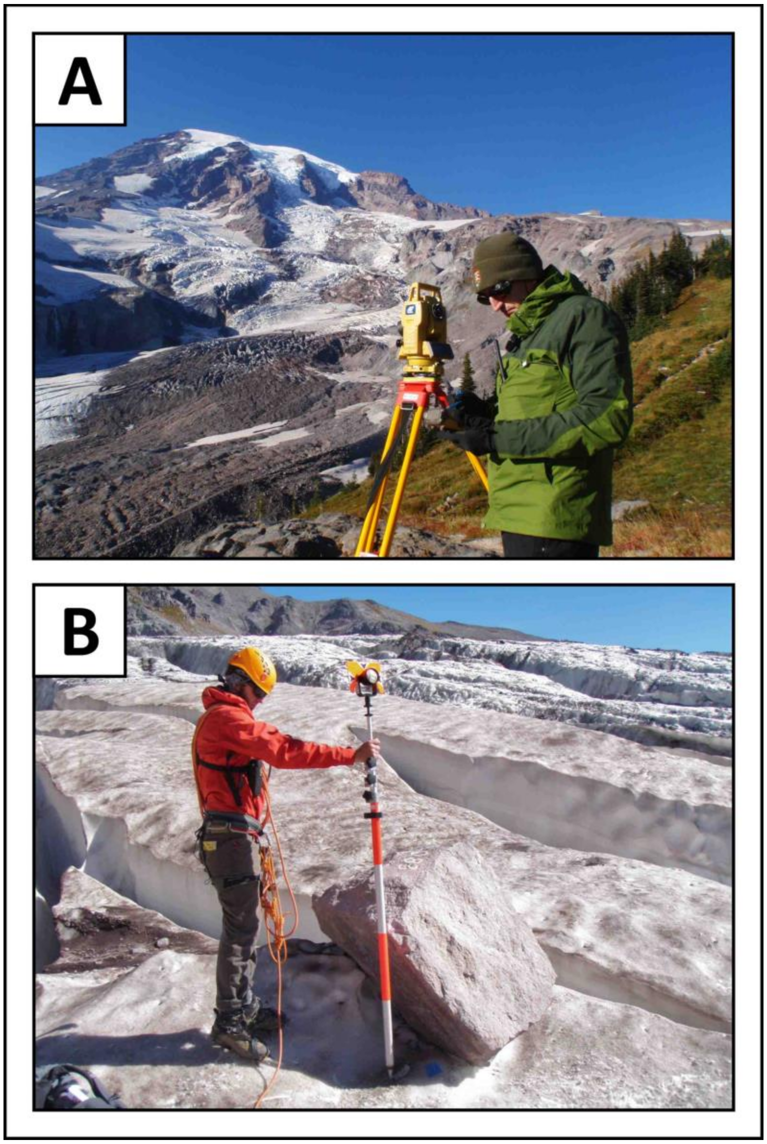

Figure 3. Survey Methods. A (top): The total station was placed at a known position off-glacier and back sighted to a known point (Photo: Scott Beason, photo by Paul Kennard). B (bottom): Survey rods were placed adjacent to rocks of interest and used in conjunction with the total station to gain rock positions weekly (Photo: Justin Ohlschlager, photo by Jeff Fortner).

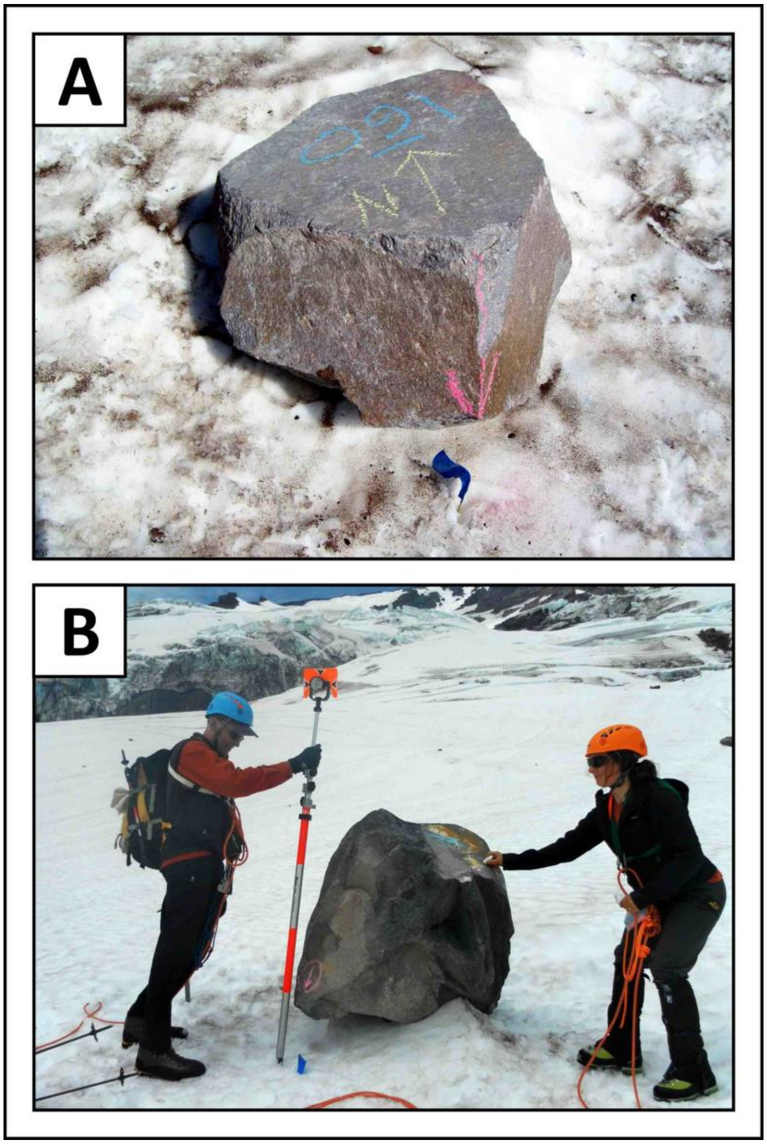

Figure 4. Survey Methods. A (top): Rocks were marked in chalk with the rock number, a North arrow, and the survey point – which is the point at which the survey rod was touching the rock in each survey. Different colors of chalk were used for each label. The blue flag is also labeled with the rock number and marks the point on the ice where the tip of the survey rod was resting (Photo by Laura Walkup). B (bottom): One of the rocks used as a velocity data point. Note position of survey rod and the small blue flag marking the surveyed position (Photo: Paul Kennard (left) and Laura German (right), photo by Laura Walkup).

Rocks that were determined to have rolled or slid independent of glacier movement were surveyed where they were found. The distance and direction of roll was measured using a tape measure, and a compass relative to the location of the survey flag (which nearly always stayed in position, since it was emplaced into firn or ice), or from photographic evidence from the last measurement, usually a week before. Rocks that had rolled were flagged in the database since the measurement error likely would be greater. The roll amount and direction were used to correct the total movement of those rocks so that rock motion independent of ice motion did not skew the data.

Annually, ablation stakes are placed on the Nisqually glacier for a mass balance study (Riedel and Larrabee, 2015). Ice ablation stakes present on the Lower Nisqually during the surveys were occupied, measured, photographed, and surveyed as well. These provided an excellent frame of reference since they could not roll or slide independent of the ice (Figure 5), though they occasionally melted out rendering them unusable. Additionally, one stake emplaced in 2011 survived the winter and was re-measured in 2012, allowing for annual and multi-year velocity measurement.

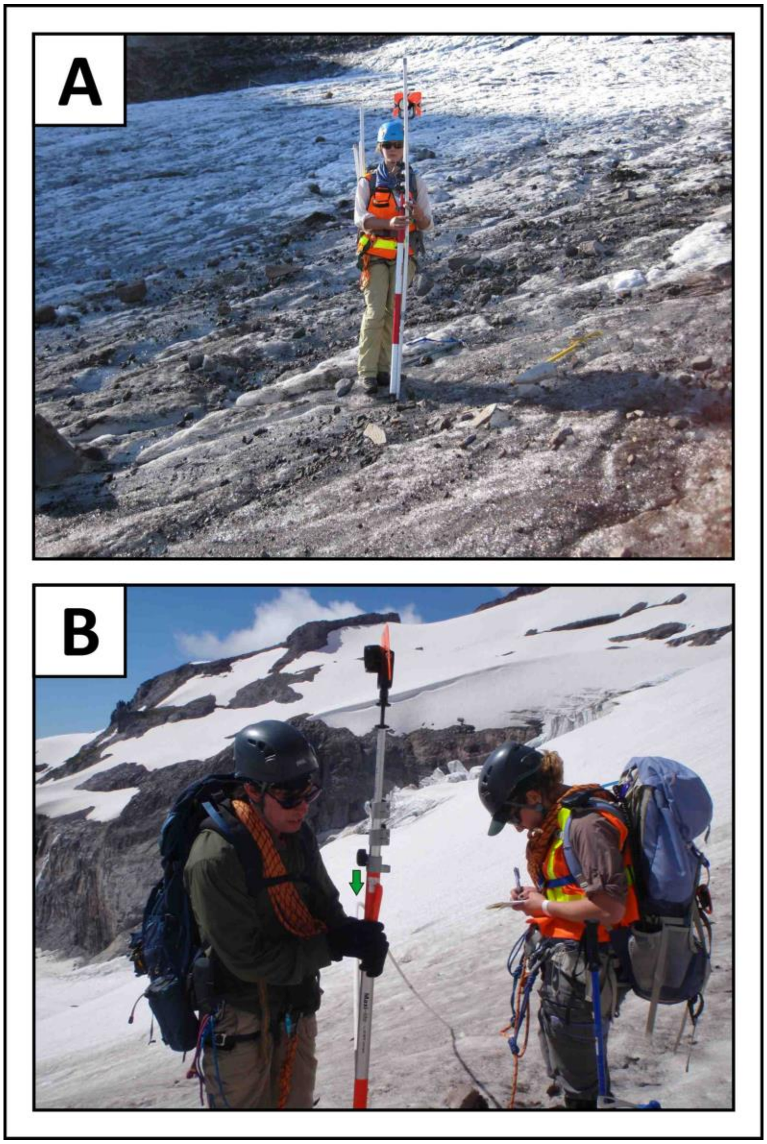

Figure 5. Survey Methods. A (top): Surveying of an ice ablation stake (the white pipe) in the middle of the study area (Photo: Anna Stifter, photo by Justin Ohlschlager). B (bottom): This ablation stake has melted out a tremendous amount – see green arrow pointing to bend in stake. The position where the stake meets the ice is what is surveyed, so the amount that the stake is melted out is not a factor in this survey. (Photo: Bryce Limón (left) and Laura Walkup (right), photo by Paul Kennard).

Survey Error

The magnitude of probable accuracy and error in Total Station surveys is related to the error of measuring individual components in the rock and stake displacements on the glacier. The total error is calculated as the square root of the sum of squares of individual error components, a method used by Czuba and others (2010) to define error in surveys (specifically, Dally et al., 1984 *in* Czuba et al., 2010). Error may be introduced as systematic or random errors. Sources of systematic error can include errors in calibration of the measurement instrument, incorrect measurement technique, or bias of the surveyor. Random errors arise from fluctuations that are most easily observed by making multiple trials of a given experiment. Random errors can include uncontrollable fluctuations in measurements, limitations imposed by the precision of the measurement device, and lack of precise definition of the quantity being measured.

Total survey measurement error in this study comes from 3 sources: (1) Total Station equipment error, (2) survey variability, which includes the precision of rod placements (rod placement and tilt), and (3) target location. Target location errors arise from rock displacements independent of the ice. Total station error is stated by the manufacturer as 0.15 cm (0.06 ft) (Topcon, 2008). Survey variability is based on the location where individual points are taken on the glacier, which may change depending on the surveyor, even in the same year. Survey variability is estimated at 7.6 cm (3 in) (C. Magirl, Personal Communication, 2013).

rock movement

Rock rolling or sliding independent of the ice movement was potentially the largest error factor, and we used a procedure (discussed earlier) to significantly constrain these errors. This practice included placement of marker flags into the ice at the measurement point. These flags rarely melted out between measurements, and generally stayed in place with minimum movement. Even in the cases where ice melt was sufficient to completely melt out the flag, the shape of the flags was such that they tended to just fall over and not roll, so the tip of the flag stayed in place. Rock roll/slide was corrected for by measuring the direction and distance from the marker flag to the displaced rock. Slide distance was measured using a measuring tape. If the measuring tape used was not held level, additional distance error was introduced. If the rock had slid farther than one person’s arm-span, two people stretched the measuring tape between them and the third team member ensured that the tape remained level during the measurement. The direction of movement was determined along the line of the measuring tape, using a leveled compass. Overall corrected rock movement error was estimated to be a maximum of 10 cm (4 in) for the impacted rocks. Of the total 1006 rock and stake measurements, 131 involved rocks that rolled and/or slid (13%). The average rock movement measurement error was 1.3 cm (0.5 in).

total error

The cumulative error from surveying, survey variability, and rock movement is 7.7 cm (3 in). The magnitude of error approaches the measured daily displacements on the lower glacier, but is much less significant on the upper glacier, where glacier movement greatly exceeded rock roll/slide, due to higher velocities. The lower glacier error is somewhat mitigated by the fact that great care was taken to keep the survey rod level on lower glacier measurements, minimizing rod tilt errors. Additionally, most of the lower glacier was significantly less steep than the upper, and rock roll/slide was less prevalent.

Allstadt and others (2015) concluded for our study (from Walkup 2013) that while "measurement errors (e.g., cobble rolling/sliding) for these observations are difficult to document, the large sample size and relatively long measurement intervals allow for accurate surface velocity estimates."

Results

Nisqually Glacial Velocity

To facilitate comparison of the data, glacial velocity fields for the entire study area were calculated using the measured data points. Additionally, the velocity field from 2011 was subtracted from that of 2012 to obtain the change in velocity.

Measured data were post-processed and analyzed on a geographic information system (GIS) using ESRI ArcGIS 10.1 and a Microsoft Excel spreadsheet. The spreadsheet was designed to calculate direction of movement and positions of rocks that rolled and/or slid using field-measured values. Resultant data were imported into ArcGIS and used to create maps showing direction and magnitude of individual survey points on the glacier (figures 6 and 8), as well as interpolated velocity fields in the survey area (figures 7 and 9). Average velocity data for 2011 is given in Table 2 and data for 2012 is given in Table 3. Details of weekly velocity measurements can be found in Appendix A (2011), Appendix B (2012), and Appendix C (rocks and stakes surveyed in both 2011 and 2012).

Graphical representation of individual point velocities, for both years, is shown in figure 6. Average velocity fields for both years and the interannual differences are shown in figure 7. The velocity field from 2011 was subtracted from that of 2012 to obtain the interannual change in velocity (figure 7). In general, the upper portions of the study area showed an increase in glacial velocity in 2012, and the lower portions either showed a decrease or no change in velocity between 2012 and 2011.

The periods of record were different for the 2 measurement years with the 2012 field season starting earlier in the summer and ending later in the fall. To eliminate any potential effects of the different lengths of time on glacier velocities, the 2012 data was limited to include only those data measured between August 2012 and September 2012, corresponding with the same time interval measured in 2011 (Figure 8). While the velocities differ slightly in the time-limited data series (Figure 8) compared with the full record (Figure 6), the same velocity patterns emerge for the normalized measurement time periods (figure 9), as the original measurement time intervals (figure 6), with the upper reaches of the study area were moving faster in 2012 than they were in 2011, and the lower areas slowing.

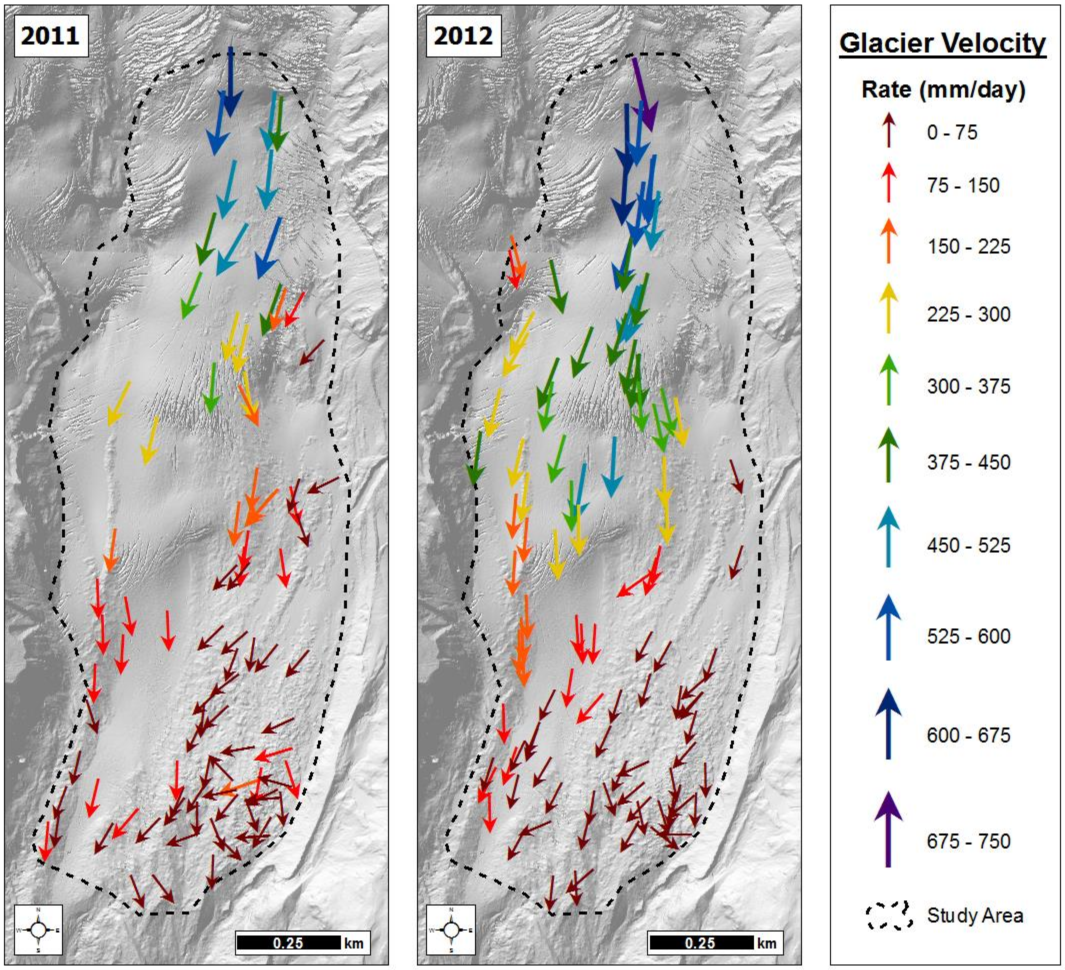

Figure 6. Glacier velocities as measured on individual points during 2011 and 2012, respectively. In the above maps, each arrow represents the average velocity over the survey period of one measured point on the glacier. The 2011 surveys occurred weekly from August 2011 through September 2011. The 2012 surveys occurred weekly from July 2012 through October 2012.

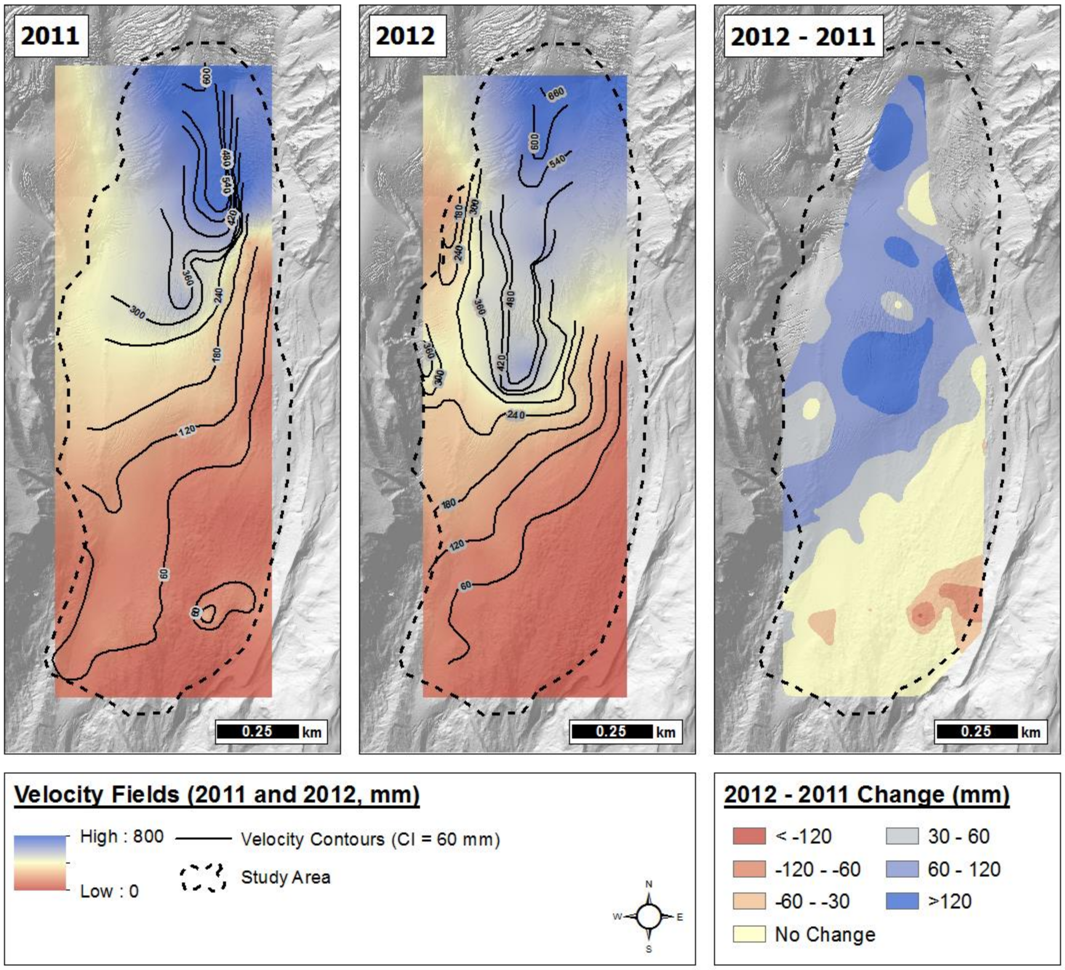

Figure 7. Average glacial velocity fields during the survey periods in 2011 and 2012, respectively, and the calculated difference between the two. In general, the upper portions of the study area showed an increase in glacial velocity in 2012, and the lower portions either showed a decrease or no change in velocity between 2012 and 2011.

Table 2: Nisqually glacier surficial velocity, summer 2011.

Rock ID	Measurement Date		Days Surveyed	Average Elevation	Distance Moved	Average Direction	Average Rate
	Start	End		Meters	Meters	Degrees	mm/day
1_001	08/18/11	09/08/11	21	2036.22	7.75	185	369
1_002	08/18/11	09/08/11	21	2056.63	6.20	193	295
1_003	08/18/11	09/08/11	21	2081.71	8.66	199	412
1_004	08/18/11	09/08/11	21	2081.64	4.63	198	220
1_005	08/18/11	09/08/11	21	2022.35	5.43	170	258
1_006	08/18/11	09/08/11	21	2013.84	4.23	155	201
1_007	08/25/11	09/08/11	14	2047.91	0.98	223	70
1_008	08/25/11	09/08/11	14	2080.26	1.78	208	127
1_009	08/25/11	09/08/11	14	2122.60	7.76	199	555
1_010	08/25/11	09/08/11	14	2169.28	6.41	186	458
1_011	08/25/11	09/08/11	14	2203.71	5.56	185	397
1_012	08/25/11	09/08/11	14	2203.00	6.33	187	452
1_013	08/25/11	09/08/11	14	2270.51	8.86	180	633
1_014	08/25/11	09/08/11	14	2161.31	6.50	192	464
1_015	08/25/11	09/08/11	14	2119.19	7.13	210	509
1_016	08/25/11	09/08/11	14	2085.65	4.71	201	336
1_017	09/01/11	09/08/11	7	2217.91	3.87	188	552
1_018	09/01/11	09/08/11	7	2114.98	2.74	196	391
1_019	09/01/11	09/08/11	7	2064.69	2.06	195	294
1_020	09/08/11	09/08/11	1	2268.40			
1_021	09/08/11	09/08/11	1	2061.18			
2_001	08/16/11	09/08/11	23	1838.31	1.08	226	48
2_002	08/16/11	09/08/11	23	1859.34	0.73	200	30
2_003	08/16/11	09/08/11	23	1882.50	1.49	223	71
2_004	08/16/11	09/08/11	23	1900.28	1.83	186	81
2_005	08/16/11	09/08/11	23	1914.77	2.57	188	114
2_006	08/16/11	09/08/11	23	1962.48	4.02	189	176
2_007	08/16/11	09/08/11	23	1938.00	1.89	168	77
2_008	08/16/11	09/08/11	23	1921.72	1.13	161	47
2_009	08/16/11	08/18/11	2	1896.70	0.22	171	111
2_010	08/18/11	09/08/11	21	1834.73	2.08	162	99

Table 2: Nisqually glacier surficial velocity, summer 2011 (continued).

Rock ID	Measurement Date		Days Surveyed	Average Elevation	Distance Moved	Average Direction	Average Rate
	Start	End		Meters	Meters	Degrees	mm/day
2_010	08/18/11	09/08/11	21	1834.73	2.08	162	99
2_011	08/18/11	09/08/11	21	1833.43	0.57	286	27
2_012	08/18/11	09/08/11	21	1843.69	2.00	253	95
2_013	08/18/11	09/08/11	21	1852.74	0.94	245	45
2_014	08/18/11	09/08/11	21	1849.34	1.17	233	56
2_015	08/18/11	09/08/11	21	1871.59	0.48	220	23
2_016	08/18/11	09/08/11	21	1865.13	0.89	189	42
2_017	08/18/11	09/08/11	21	1864.58	0.51	219	24
2_018	08/18/11	09/08/11	21	1875.31	2.29	170	109
2_019	08/18/11	09/08/11	21	1939.52	3.16	187	150
2_020	08/18/11	09/08/11	21	1857.17	1.76	178	84
2_021	08/18/11	09/08/11	21	1844.96	2.56	183	122
2_022	08/18/11	09/08/11	21	1874.38	2.22	178	106
2_023	08/25/11	09/08/11	14	1950.27	0.55	244	39
2_024	08/25/11	09/08/11	14	1945.06	1.04	197	74
2_025	08/25/11	09/08/11	14	1947.13	2.42	221	173
2_026	08/25/11	09/08/11	14	1940.92	2.38	221	170
2_027	08/25/11	09/08/11	14	1926.80	2.52	188	180
2_028	08/25/11	09/08/11	14	1990.41	3.43	194	245
2_029	08/25/11	09/08/11	14	1890.27	0.89	218	64
2_030	08/25/11	09/08/11	14	1898.77	1.83	178	131
2_031	08/25/11	09/08/11	14	1857.36	0.63	226	45
2_032	08/25/11	09/08/11	14	1864.13	0.74	229	53
2_033	09/01/11	09/08/11	7	2003.41	1.91	205	273
2_034	09/08/11	09/08/11	1	1988.53			
3_001	08/16/11	09/01/11	16	1826.21	0.61	174	39
3_002	08/16/11	09/01/11	16	1827.74	0.45	244	41
3_003	08/16/11	09/01/11	16	1823.67	3.45	251	170
3_004	08/16/11	09/01/11	16	1822.41	0.82	205	56
3_005	08/18/11	09/01/11	14	1830.62	0.53	227	38
3_006	08/18/11	09/01/11	14	1827.18	0.36	265	26
3_007	08/18/11	09/01/11	14	1829.61	0.67	186	48

Table 2: Nisqually glacier surficial velocity, summer 2011 (continued).

Rock ID	Measurement Date		Days Surveyed	Average Elevation	Distance Moved	Average Direction	Average Rate
	Start	End		Meters	Meters	Degrees	mm/day
3_008	08/18/11	09/01/11	14	1806.87	0.31	266	22
3_009	08/18/11	09/01/11	14	1769.96	0.21	182	15
3_010	08/18/11	09/08/11	21	1747.51	0.58	143	28
3_011	08/18/11	09/01/11	14	1759.76	0.75	210	53
3_012	08/18/11	09/01/11	14	1802.23	0.90	216	64
3_013	08/18/11	09/01/11	14	1815.58	0.75	191	54
3_014	08/18/11	09/01/11	14	1808.66	0.45	210	32
3_015	08/18/11	09/01/11	14	1829.55	1.34	190	96
3_016	08/18/11	09/01/11	14	1812.90	0.29	258	21
3_017	08/18/11	09/01/11	14	1807.69	0.47	213	33
3_018	08/18/11	09/01/11	14	1808.20	1.07	182	76
3_019	08/18/11	09/01/11	14	1776.64	0.40	224	28
3_020	08/18/11	09/01/11	14	1770.89	1.41	220	101
3_021	08/18/11	09/01/11	14	1748.31	0.91	188	65
3_022	08/18/11	09/08/11	21	1745.04	1.61	185	77
3_023	08/18/11	09/01/11	14	1764.75	0.81	200	58
3_024	08/18/11	09/01/11	14	1781.96	0.81	194	58
3_025	08/18/11	09/01/11	14	1809.79	0.68	162	49
3_026	08/18/11	09/01/11	14	1831.55	1.10	182	79
3_027	08/25/11	09/01/11	7	1821.38	0.09	316	13
3_028	08/25/11	09/01/11	7	1827.74	0.23	260	33
3_029	08/25/11	09/01/11	7	1803.69	0.37	202	53
3_030	08/25/11	09/01/11	7	1791.73	0.26	180	38
3_031	08/25/11	09/01/11	7	1791.95	0.09	158	13
3_032	08/25/11	09/01/11	7	1812.47	0.20	219	28
3_033	08/25/11	09/01/11	7	1817.36	0.31	160	44
3_034	08/25/11	09/01/11	7	1792.14	0.16	134	24
3_035	08/25/11	09/01/11	7	1775.66	0.18	250	25
3_036	08/25/11	09/01/11	7	1745.54	0.16	159	23
3_037	09/01/11	09/08/11	7	1762.46	0.58	193	83
3_038	09/08/11	09/08/11	1	1682.14			
3_039	09/08/11	09/08/11	1	1608.62			

Table 3: Nisqually glacier surficial velocity, summer and fall 2012.

Rock ID	Measurement Date		Days Surveyed	Average Elevation	Distance Moved	Average Direction	Average Rate
	Start	End		Meters	Meters	Degrees	mm/day
001	07/19/12	09/20/12	63	1,833.99	1.01	179	17
002	07/19/12	10/04/12	77	1,825.40	0.54	182	9
003	07/19/12	10/04/12	77	1,821.73	0.94	229	23
004	07/19/12	08/30/12	42	1,842.63	0.67	221	14
005	07/19/12	10/04/12	77	1,824.41	0.71	197	10
006	07/19/12	08/30/12	42	1,851.60	0.85	196	18
007	07/19/12	10/04/12	77	1,818.62	1.12	188	21
008	07/19/12	10/04/12	77	1,814.91	1.65	163	24
009	07/19/12	08/30/12	42	1,855.21	1.00	219	23
010	07/19/12	10/04/12	77	1,831.08	1.50	169	26
011	07/19/12	08/30/12	42	1,861.58	1.12	229	26
012	07/19/12	09/06/12	49	1,870.35	1.06	199	20
013	07/19/12	08/30/12	42	1,863.13	1.92	209	48
014	07/19/12	10/04/12	77	1,808.00	1.20	167	18
015	07/19/12	09/06/12	49	1,790.27	1.17	210	24
016	07/19/12	09/27/12	70	1,799.63	3.07	189	51
017	07/19/12	08/30/12	42	1,862.33	2.74	207	69
018	07/19/12	09/13/12	56	1,785.60	1.57	194	31
019	07/19/12	10/04/12	77	1,880.47	8.82	235	117
020	07/19/12	10/11/12	84	2,150.78	45.21	188	525
021	07/19/12	08/30/12	42	1,898.42	5.17	196	120
022	07/19/12	08/09/12	21	1,744.40	0.38	177	18
023	07/19/12	07/19/12	1	2,181.14			
024	07/19/12	10/04/12	77	1,909.09	9.73	192	132
025	07/19/12	10/04/12	77	1,743.90	1.66	186	24
026	07/19/12	10/04/12	77	1,946.17	19.10	178	273
027	07/19/12	09/13/12	56	1,753.22	2.57	209	48
028	07/19/12	07/19/12	1	2,198.94			
029	07/19/12	10/04/12	77	1,749.00	10.93	179	103
030	07/19/12	09/27/12	70	1,767.88	7.53	206	107

Table 3: Nisqually glacier surficial velocity, summer and fall 2012 (continued).

Rock ID	Measurement Date		Days btw Surveys	Elevation	Distance	Direction	Rate
	Start	End		Meters	Meters	Degrees	mm/day
031	07/19/12	09/27/12	70	1,778.14	4.66	198	72
032	07/19/12	10/11/12	84	2,222.73	54.41	179	644
033	07/19/12	09/20/12	63	1,805.18	5.06	178	88
034	07/19/12	08/30/12	42	1,986.73	20.11	183	504
035	07/19/12	08/09/12	21	2,264.60	15.19	166	723
036	07/19/12	10/04/12	77	1,767.47	4.69	247	65
037	07/19/12	08/16/12	28	1,961.66	15.05	189	483
038	07/19/12	09/27/12	70	1,784.87	3.45	207	54
039	07/19/12	10/11/12	84	1,893.54	15.71	178	198
040	07/19/12	09/27/12	70	1,811.42	1.42	230	19
041	07/19/12	08/30/12	42	1,872.15	7.64	176	184
042	07/19/12	10/11/12	84	2,179.27	53.07	184	637
043	07/19/12	10/04/12	77	1,813.74	1.98	205	29
044	07/19/12	10/04/12	77	1,819.93	3.88	204	52
045	07/19/12	10/04/12	77	1,865.20	12.01	180	163
046	07/19/12	10/04/12	77	1,819.09	1.30	245	16
047	07/19/12	10/11/12	84	2,115.29	46.61	197	527
048	07/19/12	10/04/12	77	1,849.53	12.22	177	168
049	07/26/12	10/11/12	77	1,986.92	25.72	196	358
050	07/26/12	10/11/12	77	2,021.45	17.26	210	236
051	07/26/12	10/11/12	77	2,072.10	30.06	167	421
052	07/26/12	10/11/12	77	2,102.74	11.66	165	157
053	07/26/12	10/11/12	77	2,099.95	10.02	169	139
054	07/26/12	10/11/12	77	2,031.56	18.29	209	251
055	07/26/12	09/06/12	42	1,999.49	10.02	194	248
056	07/26/12	09/13/12	49	1,974.90	20.56	188	399
057	07/26/12	10/11/12	77	1,971.20	22.11	193	288
058	07/26/12	10/11/12	77	1,917.84	16.11	184	201
059	07/26/12	10/11/12	77	1,861.31	9.92	176	132
060	08/02/12	10/04/12	63	1,855.84	1.16	223	18

Table 3: Nisqually glacier surficial velocity, summer and fall 2012 (continued).

Rock ID	Measurement Date		Days btw Surveys	Elevation	Distance	Direction	Rate
	Start	End		Meters	Meters	Degrees	mm/day
061	08/02/12	10/04/12	63	1,810.24	0.85	224	12
062	08/02/12	09/06/12	35	1,993.42	8.43	170	244
063	08/02/12	09/06/12	35	2,010.43	11.33	166	323
064	08/02/12	10/11/12	70	1,823.27	8.26	221	88
065	08/02/12	08/30/12	28	2,007.86	10.78	168	371
066	08/02/12	08/09/12	7	2,042.40	2.69	176	385
067	08/09/12	09/06/12	28	1,954.70	0.94	162	30
068	08/09/12	10/04/12	56	1,849.60	1.38	189	26
069	08/09/12	10/04/12	56	1,806.17	0.51	270	9
070	08/09/12	08/09/12	1	2,044.08			
071	08/09/12	10/04/12	56	1,804.45	0.71	129	11
072	08/09/12	10/11/12	63	2,054.30	25.84	191	406
073	08/09/12	10/04/12	56	1,805.02	1.49	161	20
074	08/09/12	09/13/12	35	2,087.54	16.67	195	482
075	08/09/12	10/04/12	56	1,752.69	0.74	229	13
076	08/09/12	10/11/12	63	2,171.53	36.71	184	562
077	08/09/12	10/11/12	63	1,853.50	6.87	178	112
078	08/09/12	10/04/12	56	1,784.57	3.48	205	64
079	08/09/12	10/04/12	56	1,794.07	3.51	199	61
080	08/09/12	10/11/12	63	1,825.96	7.88	189	118
081	08/09/12	10/04/12	56	1,850.14	1.67	196	32
082	08/09/12	10/04/12	56	1,836.19	2.10	197	39
083	08/09/12	10/11/12	63	2,026.94	25.01	201	404
084	08/09/12	10/11/12	63	2,016.61	21.60	191	340
085	08/16/12	10/04/12	49	1,905.82	1.62	198	32
086	08/16/12	10/04/12	49	1,976.21	11.61	180	241
087	08/16/12	10/11/12	56	1,937.28	12.80	179	233
088	08/16/12	10/11/12	56	1,929.81	13.81	177	244
089	08/16/12	10/11/12	56	1,936.83	12.54	185	221
090	08/16/12	10/11/12	56	1,942.69	11.84	185	209

Table 3: Nisqually glacier surficial velocity, summer and fall 2012 (continued).

Rock ID	Measurement Date		Days btw Surveys	Elevation	Distance	Direction	Rate
	Start	End		Meters	Meters	Degrees	mm/day
091	08/16/12	10/11/12	56	1,953.65	13.99	188	247
092	08/16/12	10/11/12	56	2,054.78	21.41	200	385
093	08/30/12	09/20/12	21	2,027.95	6.72	175	320
094	08/30/12	10/11/12	42	1,953.80	11.90	180	302
095	08/30/12	10/11/12	42	1,849.59	3.15	184	76
096	09/06/12	09/13/12	7	2,041.45	2.73	189	389
097	09/06/12	10/11/12	35	2,094.22	15.01	194	431
098	09/06/12	10/11/12	35	2,144.52	17.43	188	519
099	09/06/12	10/11/12	35	2,215.99	20.08	184	598
100	09/06/12	10/04/12	28	1,777.31	2.67	199	96
101	09/13/12	10/11/12	28	2,067.65	11.37	198	413
102	09/06/12	10/11/12	35	2,167.21	18.75	189	552
103	09/13/12	10/11/12	28	2,107.04	11.77	189	420
104	09/20/12	10/04/12	14	1,795.53	1.05	202	75
105	09/20/12	10/11/12	21	2,083.55	10.42	198	496
106	09/27/12	10/04/12	7	1,764.54	0.18	194	26
107	09/27/12	10/04/12	7	1,785.82	0.33	210	47
108	09/27/12	10/11/12	14	1,813.12	0.73	206	52
109	10/11/12	10/11/12	1	2,082.99			
110	10/11/12	10/11/12	1	2,163.82			
111	10/11/12	10/11/12	1	2,166.74			
112	10/11/12	10/11/12	1	2,081.82			

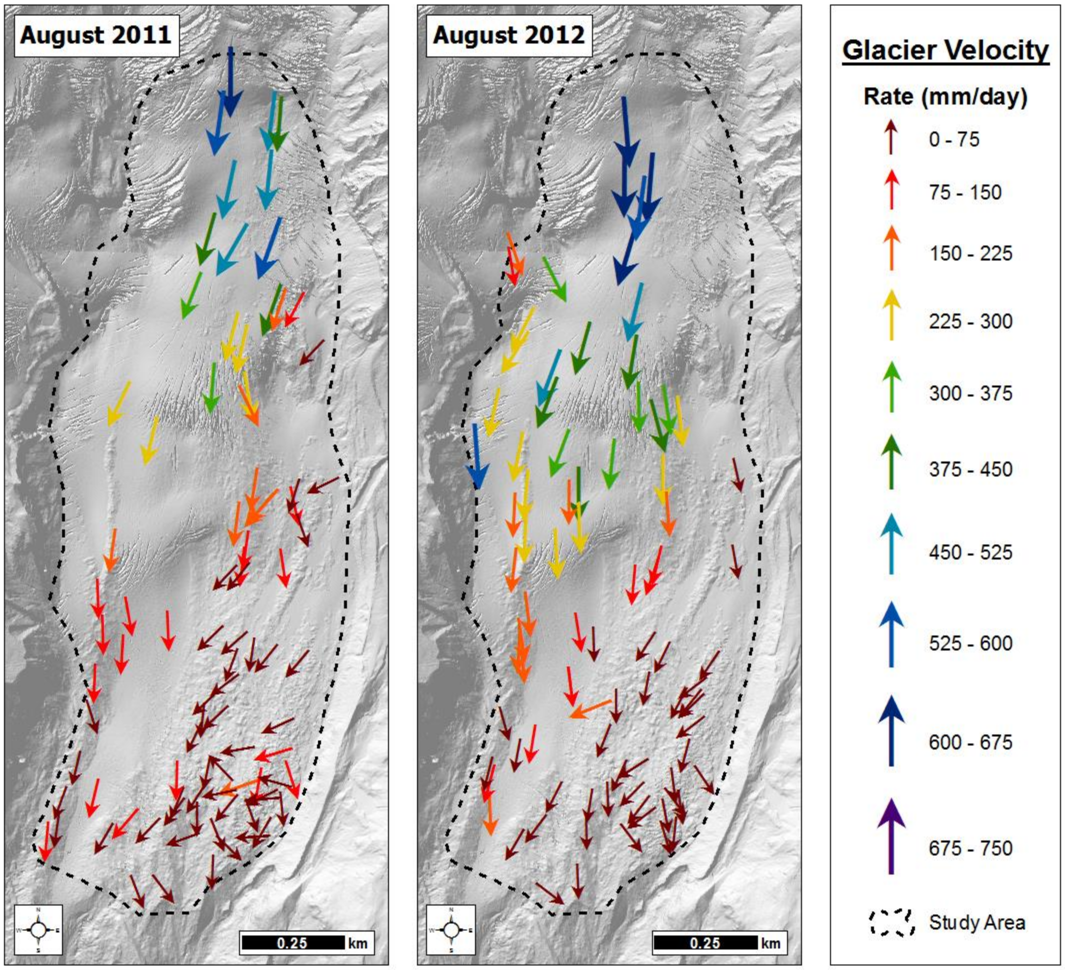

Figure 8. Comparison of glacial velocity between similar time intervals in 2011 and 2012, respectively. As in Figure 6, each arrow represents the average velocity of a single data point. However, in this map, the 2012 data was limited to only include the measurements taken between the end of July and the beginning of September to correspond with the period of record from 2011. The scale is exactly the same as that in the earlier map (Figure 6) showing the entire record. This was done to directly compare data so as to determine that velocity differences between the two years were not solely due to the longer period of record in 2012.

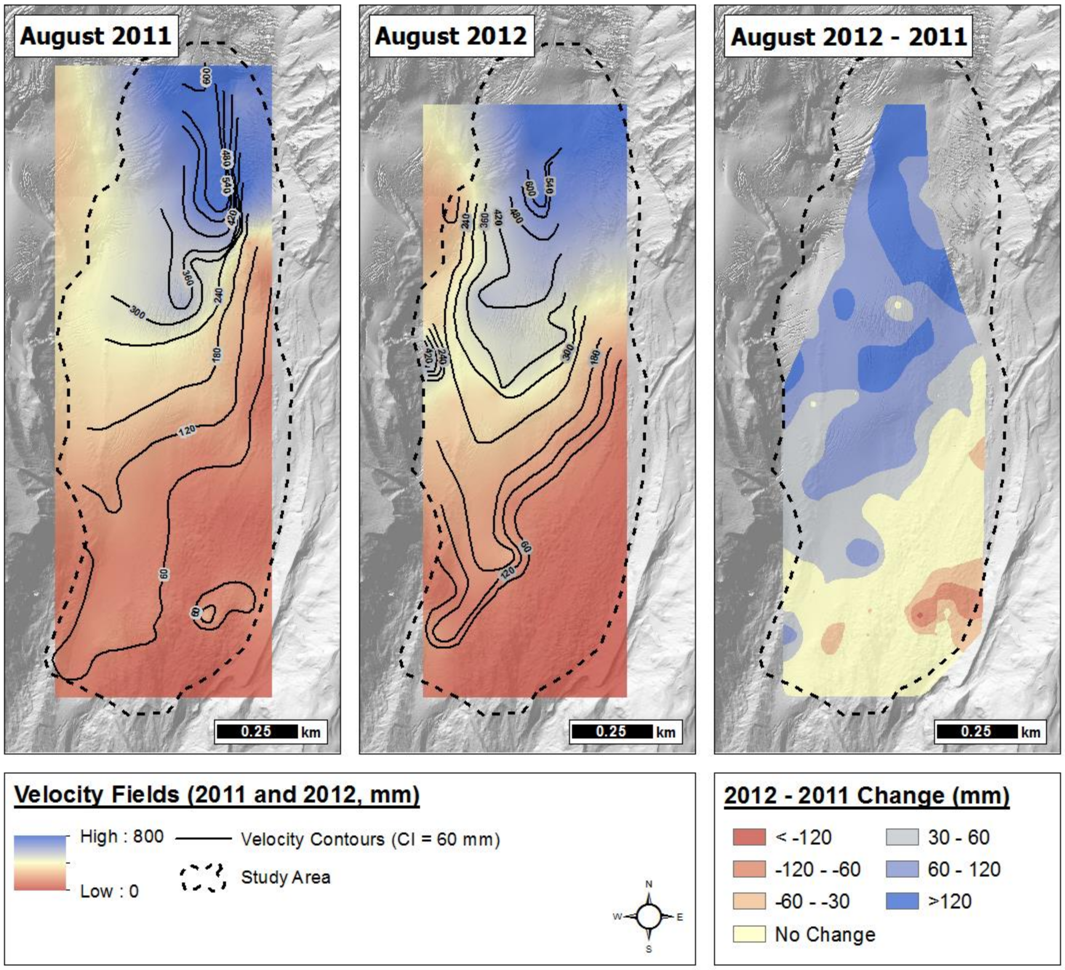

Figure 9. Average glacial velocity fields during similar time intervals in 2011 and 2012, respectively, and the calculated difference between the two. Despite slight differences between the full and time-limited 2012 velocity values, the overall pattern remains the same. In general, the upper portions of the study area showed an increase in glacial velocity in 2012, and the lower portions either showed a decrease or no change in velocity between 2012 and 2011, similar to the comparison between the full records (Figure 7).

Observed Outburst Flood

On October 27, 2012, a relatively small storm, with a recurrence interval of 1.04 years occurred at Mount Rainier, dropping 7.98 cm (3.14 in) of rain. Between 4:00 PM – 7:00 PM, rainfall intensity was between 0.6 – 1.0 cm/hr (0.24 – 0.40 in/hr). At 8:00 PM, a stream gage in Longmire recorded a dramatic and anomalous rise in stream stage, from 0.51 m (1.66 ft) to 1.47 m (4.81 ft). A peak of approximately 50 cubic meters per sec (1,780 ft^3/sec) occurred at 9:45 PM (Figure 10) (Beason 2017b). Employees living near the river reported hearing loud rushing water sounds from the river and the sound of boulders rolling and hitting one another at about that time. Within 15 minutes, the stream stage dropped back to near 0.6 m (2 ft). This 0.96 m (3.15 ft) rise in river level was not noted in other gaged rivers draining Mount Rainier. Additionally, stream temperature dipped noticeably during the peak discharge, consistent with a glacial source for the surge. The hydrograph from the October 2012 event resembles an outburst flood hydrograph from Hodge (1974). Both hydrographs are shown in figure 10.

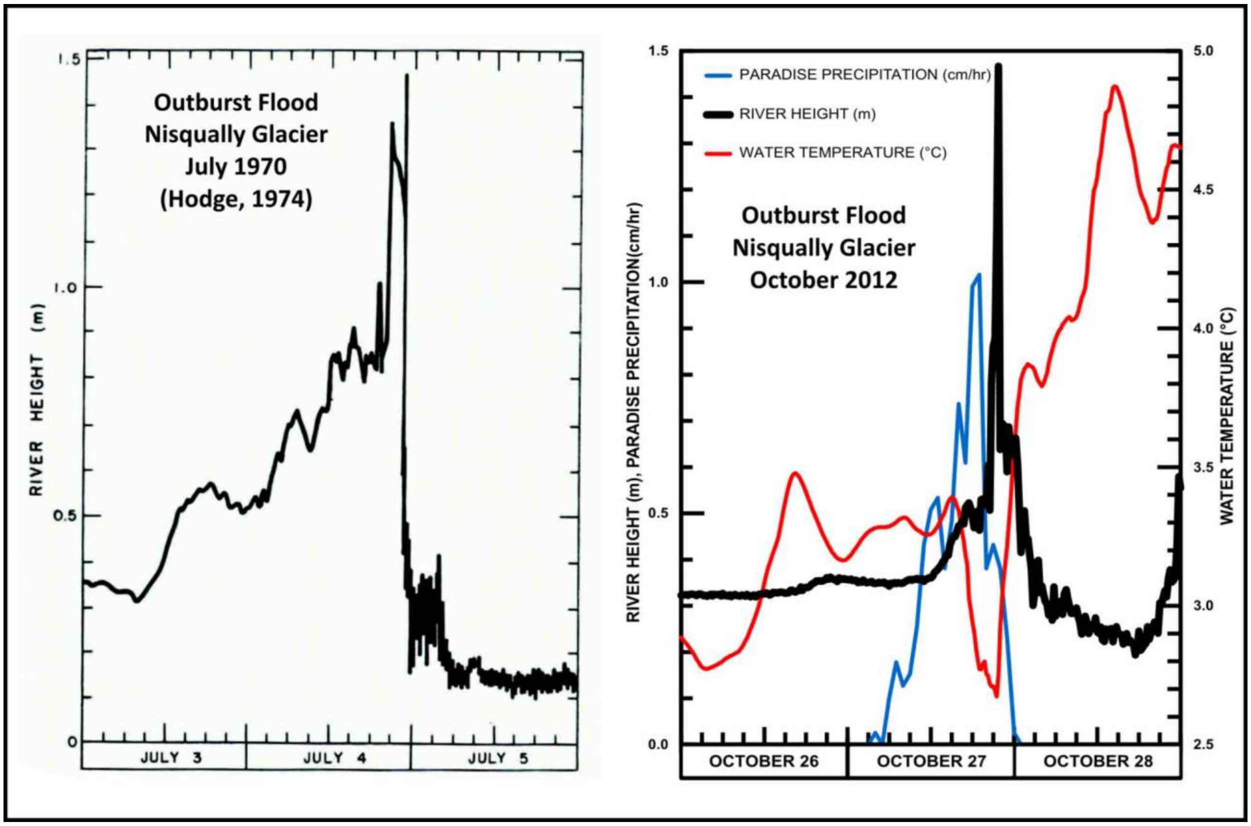

Figure 10. Hydrographs from an outburst flood recorded by Hodge in 1970 (left), and a small outburst flood recorded in October 2012 at Longmire (right). The corresponding dip in water temperature occurs at about the same time as the peak in flow.

Shortly after the October 2012 outburst flood was recognized in stream gage records, field reconnaissance was undertaken to look for evidence of the event. A prominent trim line (figure 11a) was noted approximately 1 m (3 ft) above the "normal" flow of the Nisqually River near Cougar Rock, 5.3 km (3.3 mi) downstream from the glacier, and just upstream of the confluence of Van Trump Creek with the Nisqually River. More evidence of trim lines (figure 11b) was noted in Longmire, farther downstream, and at several other locations on the Nisqually River. A corresponding trim line was not seen in any of the sampled tributaries, leading into the Nisqually River.

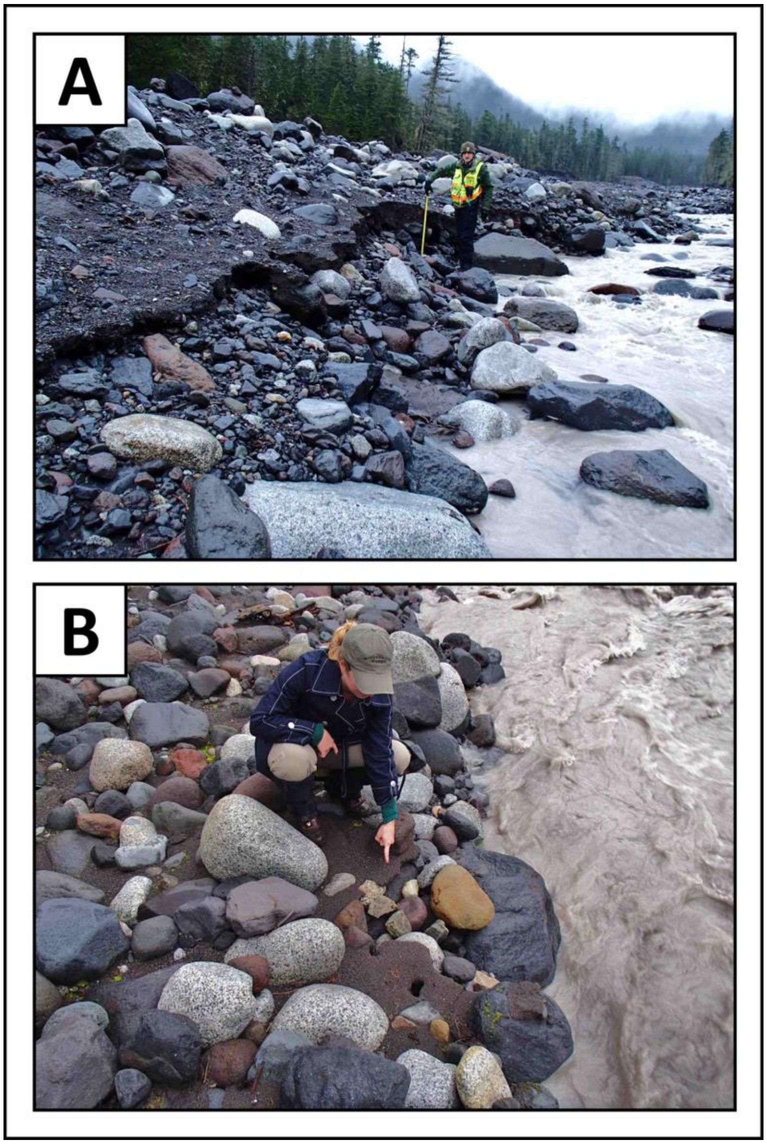

Figure 11. High-water mark (trim line) observed in the Nisqually riverbed shortly after the outburst flood was recognized in the stream gage record. A: Trim line at Cougar Rock. (Photo: Scott Beason, photo by Laura Walkup). B: Trim line farther downstream at Longmire (downstream from stream gage). (Photo: Laura Walkup, photo by Scott Beason).

The exact location where the outburst flood exited the Nisqually Glacier was not found. However, images of the Nisqually Glacier shortly before (Figure 12A) and after (Figure 12B) the event show a band of ice that appears to have been "washed" by the event. The band begins just downstream of the confluence of the Wilson and Nisqually Glacier (figure 1) and continues down to the terminus of the Nisqually. Inclement weather precluded a comprehensive on-glacier search for the source, however, it appears that the event was sourced on top of the glacier in the vicinity of the boundary between active, fast moving glacial ice and stagnating ice, as determined by the 2011 and 2012 Nisqually glacier ice-surface elevation surveys (Stevens and others 2015). This is consistent with historical accounts indicating that portions of the glacier were "swept clean" during outburst flood events (Richardson, 1968).

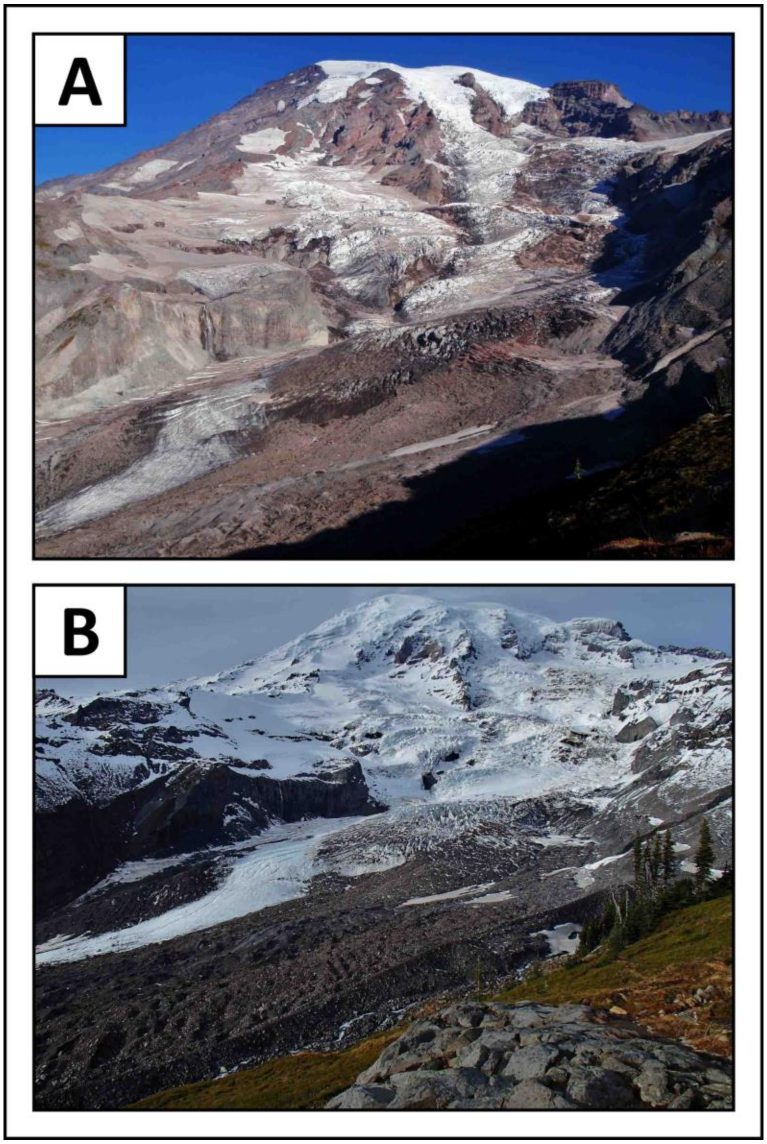

Figure 12. Photo evidence of the glacier before (A) and after (B) the outburst flood event. Note the band of ice in the center-left of the photo that appears to have been washed clean of debris.

Discussion

Allstadt and others (2015) produced glacier surface velocity maps for several Mount Rainier glaciers, including the Nisqually. The velocities were derived from repeat terrestrial radar interferometry (TRI) measurements taken in the summer and fall of 2012. Their measurement technique allowed them to measure the entire glacier, an advantage over previous glacier velocity studies. They report velocity uncertainties as low as 0:02–0.08 m per day. They document a significant decrease in seasonal velocity of 25% to 50% from July to November for most of the glacier, with the exception of the icefall.

Allstadt and others (2015) compared their TRI results with ours for an overlapping time period. Velocity vector attributes were compared. For the velocity magnitudes, they found them to be “similar”, and that our mean measurements were “slightly higher on average”. They concluded this is an expected result for mean velocities collected during the same time periods.

They also found the velocity directions were “relatively consistent, with a median angular difference of 12°.” Overall, they concluded that “(i)n general, the two techniques provide similar results and offer complementary data validation.” They noted the spatial limitations of our study, which did not include “icefalls, and other hazardous dynamic areas generally higher on the mountain.”

They attributed the observed seasonal velocity changes (mentioned earlier) to variations in glacier sliding driven by evolving englacial and subglacial hydrology, citing Fountain and Walder (1998). Earlier (Nisqually Glacial Velocity subsection), the differences of the measurement periods for 2011 and 2012 for our study were discussed. The similarity with the Allstadt and others (2015) summer velocities, confirms that our measurements are emblematic of the summer season.

Allstadt and others (2015) also compared their data to Hodge (1972, 1974), who measured Nisqually glacier surface velocities from 1968-1970, using a series of centerline stakes. Specifically, they compared the July and November 1969 velocity data upper stakes (corresponding to the up-glacier half of our study area), and lower stakes (conforming to the lower, stagnating portion of our study area).

For the upper area, the fall surface velocities were “almost identical” to theirs. This was despite significant terminus retreat, and glacier ice loss (Sisson and others 2011). In contrast, Hodge’s upper stake July 1969 measurements were 8 to 33% faster than Allstadt and others (2015). By analogy, the Hodge fall velocities are similar to ours, and the July results, faster than ours.

As discussed earlier, our study found that summer velocities increased in the central part of the glacier, relative to the lower glacier, in 2012 relative to 2011 (figures 7 and 9). Hodge’s (1974) interannual measurements showed surface velocities increased measurably in the vicinity of the equilibrium line altitude (ELA), while slowing occurred toward the terminus relative to the previous summer just prior to the 1970 glacier outburst flood. He proposed that observed variations in ice velocity were correlated with the amount of liquid water temporarily stored within the glacier. This suggests that the presence of englacial water leads to faster ice velocities and a higher potential for outburst floods, while the absence of large quantities of englacial water is associated with slower glacial flow and fewer outburst floods. The 2012 Nisqually glacier outburst flood (described in the glacier outburst flood section above) is consistent with Hodge’s findings.

These 2 cases suggest that long-term annually-repeating glacial velocity measurements of the lower and central glacier could be a powerful tool in the prediction of potentially devastating glacial outburst flood.

Further Research

A primary motivation for this ice velocity study was to identify the Nisqually glacier's current susceptibility to glacier outburst flooding. In general, the park is interested in identifying the outburst flood hazards in all its watersheds, and the physical and climatic controls to jökulhlaup initiation.

To this end, the park has done internal studies, collaborated with area universities (University of Washington, Portland State University, and Oregon State University) on multiple projects, and tracked other independent scholarly analyses.

Multiple research approaches are employed in this on-going effort, which include investigating the following factors in the context of outburst flood hazards:

- the influence of kinematic waves (Stevens and others 2016, Skloven-Gill and Fountain 2015);
- the relationship with glacier surface velocities, both field measured (Wilson and Fountain 2013, this study) and remotely sensed (Allstadt and others 2015, Shean and others 2017);
- the governing physical factors (Lindsey 2015, Legg and others 2014);
- and weather and climatic triggers (Legg 2014 and 2015, Haskins 2016, and Beason and others 2019).

The park is continuing its outburst flood research as time and resources allow, with a current emphasis on developing useful and accurate forecasting methods, building particularly on the work of Legg 2015, and Beason and others 2019. However, many questions remain, that future research could address.

In the previous section, we noted the utility of continued repeat (annual) surface ice velocity surveys to help better estimate Nisqually glacier outburst flood potential. The target areas should include the lower and central areas of the glacier, below the icefalls. The methods of this study could be used, or similar surveys could employ only handheld GPS units. GPS-only surveys could be accomplished using fewer people, in less time, and in lower visibility conditions, but may be less accurate. As mentioned earlier (Methods section), the GPS positions of the velocity indicators recorded for this study (rocks ablation stakes) could be used to estimate the accuracy of surveys conducts using only handheld GPS units. The GPS data of this study may be useful in locating the rocks used in the study, for future efforts.

Additional techniques for determining glacier velocities include remotely sensed techniques, such as TRI (Allstadt and others 2015) or using satellite data (Shean and others 2017). Both of these techniques may ultimately prove to be more efficient ways to get glacier velocities.

Other identified, priority information needs include installing a stream gauge and turbidity meter close to the terminus of the Nisqually glacier. This would be useful to monitor fluctuations in glacial discharge, and could provide the additional advantage of allowing for the detection small outburst floods that might be less noticeable on stream gauges farther downstream. Additionally, real-time monitoring of stream levels just below the terminus of the glacier would alert staff if an abrupt rise occurs, and potentially provide short-term outburst flood warning.

As storage of englacial water is most likely the driver of outburst floods. A real-time GPS installed on the lower glacier would not only provide velocity data, but will also record glacier elevation changes. Immediately before an outburst flood event, the glacier is literally floated by trapped subsurface melt water. Detecting this sudden vertical change would allow for a short-term outburst flood warning. State-of-the-art, high resolution kinematic GPS units are capable of recording centimeter movements every second, and the data is instantly available (it requires no post-processing), by radio transmission.

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Appendix A

Appendix A, Table 1: 2011 Nisqually Glacier measured velocity data.

Rock ID	Measurement Date		Roll		Starting Position			Ending Position			Distance	Direction	Rate
	First	Second	Deg	Dist (m)	X (m)	Y (m)	Z (m)	X (m)	Y (m)	Z (m)	m	Degrees	mm/day
1_001	08/18/11	08/25/11			405,311.72	165,236.50	2,037.80	405,311.51	165,234.10	2,036.59	2.40	185	343
	08/25/11	09/01/11			405,311.51	165,234.10	2,036.59	405,311.54	165,231.68	2,035.70	2.43	179	347
	09/01/11	09/08/11			405,311.54	165,231.68	2,035.70	405,311.05	165,228.80	2,034.65	2.92	190	417
1_002	08/18/11	08/25/11			405,386.35	165,329.36	2,058.40	405,386.02	165,327.05	2,057.02	2.33	188	333
	08/25/11	09/01/11			405,386.02	165,327.05	2,057.02	405,385.59	165,325.10	2,055.99	2.00	192	286
	09/01/11	09/08/11			405,385.59	165,325.10	2,055.99	405,385.00	165,323.33	2,054.86	1.86	199	266
1_003	08/18/11	08/25/11			405,461.73	165,429.83	2,083.80	405,461.42	165,428.18	2,083.13	1.68	191	240
	08/25/11	09/01/11	45	0.30	405,461.42	165,428.18	2,083.13	405,459.17	165,424.93	2,081.17	3.96	215	566
	09/01/11	09/08/11	15	0.91	405,458.95	165,424.71	2,081.17	405,458.28	165,421.77	2,079.62	3.02	193	432
1_004	08/18/11	08/25/11			405,476.15	165,424.37	2,082.36	405,475.67	165,422.90	2,081.95	1.54	198	220
	08/25/11	09/01/11			405,475.67	165,422.90	2,081.95	405,474.98	165,421.36	2,081.49	1.69	204	241
	09/01/11	09/08/11			405,474.98	165,421.36	2,081.49	405,474.72	165,419.99	2,080.93	1.40	191	200
1_005	08/18/11	08/25/11			405,393.76	165,209.09	2,024.47	405,394.06	165,207.35	2,023.86	1.76	170	252
	08/25/11	09/01/11	237	4.11	405,394.06	165,207.35	2,023.86	405,394.45	165,205.22	2,021.10	2.17	170	310
	09/01/11	09/08/11			405,397.90	165,207.46	2,021.10	405,398.13	165,205.98	2,020.24	1.50	171	214
1_006	08/18/11	08/25/11			405,400.86	165,188.34	2,015.26	405,401.59	165,187.21	2,014.08	1.35	147	192
	08/25/11	09/01/11			405,401.59	165,187.21	2,014.08	405,402.70	165,185.92	2,013.14	1.70	139	243
	09/01/11	09/08/11			405,402.70	165,185.92	2,013.14	405,402.74	165,184.74	2,012.41	1.18	178	169
1_007	08/25/11	09/01/11			405,557.22	165,316.06	2,048.06	405,556.92	165,315.62	2,047.78	0.54	214	77
	09/01/11	09/08/11			405,556.92	165,315.62	2,047.78	405,556.57	165,315.35	2,047.75	0.44	233	63

Appendix A, Table 1: 2011 Nisqually Glacier measured velocity data (continued).

Rock ID	Measurement Date		Roll		Starting Position			Ending Position			Distance	Direction	Rate
	First	Second	Deg	Dist (m)	X (m)	Y (m)	Z (m)	X (m)	Y (m)	Z (m)	m	Degrees	mm/day
1_008	08/25/11	09/01/11			405,513.43	165,419.43	2,080.65	405,513.14	165,418.44	2,080.18	1.03	196	147
	09/01/11	09/08/11			405,513.14	165,418.44	2,080.18	405,512.67	165,417.86	2,079.87	0.75	220	107
1_009	08/25/11	09/01/11			405,453.53	165,578.89	2,125.16	405,452.27	165,575.39	2,123.53	3.72	200	532
	09/01/11	09/08/11	2	4.27	405,452.27	165,575.39	2,123.53	405,450.94	165,571.57	2,120.05	4.04	199	577
1_010	08/25/11	09/01/11			405,448.85	165,739.76	2,170.77	405,448.28	165,736.50	2,169.24	3.30	190	472
	09/01/11	09/08/11			405,448.28	165,736.50	2,169.24	405,448.18	165,733.40	2,167.78	3.11	182	444
1_011	08/25/11	09/01/11			405,475.30	165,875.47	2,205.21	405,474.74	165,872.61	2,203.69	2.91	191	416
	09/01/11	09/08/11			405,474.74	165,872.61	2,203.69	405,474.83	165,869.96	2,202.20	2.65	178	378
1_012	08/25/11	09/01/11			405,454.32	165,881.16	2,204.68	405,453.92	165,878.05	2,202.92	3.13	187	448
	09/01/11	09/08/11	345	0.30	405,453.92	165,878.05	2,202.92	405,453.58	165,874.87	2,201.33	3.20	186	457
1_013	08/25/11	09/01/11			405,355.48	165,979.73	2,273.56	405,355.54	165,975.16	2,270.12	4.57	179	653
	09/01/11	09/08/11	225	0.61	405,355.54	165,975.16	2,270.12	405,355.46	165,970.87	2,267.45	4.29	181	613
1_014	08/25/11	09/01/11			405,355.23	165,716.19	2,163.16	405,353.97	165,713.07	2,161.46	3.37	202	482
	09/01/11	09/08/11			405,353.97	165,713.07	2,161.46	405,353.85	165,709.94	2,159.47	3.13	182	447
1_015	08/25/11	09/01/11			405,363.47	165,572.87	2,120.93	405,361.73	165,569.78	2,119.41	3.55	209	507
	09/01/11	09/08/11	350	2.13	405,361.73	165,569.78	2,119.41	405,359.88	165,566.72	2,117.45	3.58	211	511
1_016	08/25/11	09/01/11	65	0.61	405,265.03	165,459.06	2,086.90	405,264.09	165,456.89	2,085.41	2.37	203	338
	09/01/11	09/08/11			405,263.54	165,456.63	2,085.41	405,262.79	165,454.41	2,084.40	2.34	199	335
1_017	09/01/11	09/08/11	315	1.68	405,326.94	165,875.38	2,219.33	405,326.40	165,871.55	2,216.49	3.87	188	552
1_018	09/01/11	09/08/11			405,303.36	165,592.03	2,115.55	405,302.62	165,589.40	2,114.41	2.74	196	391
1_019	09/01/11	09/08/11			405,360.31	165,356.85	2,064.99	405,359.77	165,354.86	2,064.38	2.06	195	294
1_020	09/08/11				405,353.21	165,973.72	2,268.40						
1_021	09/08/11				405,280.56	165,346.85	2,061.18						

Appendix A, Table 1: 2011 Nisqually Glacier measured velocity data (continued).

Rock ID	Measurement Date		Roll		Starting Position			Ending Position			Distance	Direction	Rate
	First	Second	Deg	Dist (m)	X (m)	Y (m)	Z (m)	X (m)	Y (m)	Z (m)	m	Degrees	mm/day
2_001	08/16/11	08/18/11			405,297.42	164,466.18	1,838.39	405,297.33	164,466.12	1,838.36	0.11	235	55
	08/18/11	08/25/11			405,297.33	164,466.12	1,838.36	405,297.29	164,465.99	1,838.33	0.13	199	19
	08/25/11	09/01/11			405,297.29	164,465.99	1,838.33	405,297.05	164,465.75	1,838.23	0.34	224	49
	09/01/11	09/08/11			405,297.05	164,465.75	1,838.23	405,296.59	164,465.56	1,838.23	0.49	247	70
2_002	08/16/11	08/18/11			405,360.14	164,556.11	1,859.42	405,360.16	164,556.07	1,859.42	0.04	147	20
	08/18/11	08/25/11			405,360.16	164,556.07	1,859.42	405,360.12	164,555.95	1,859.42	0.13	196	19
	08/25/11	09/01/11			405,360.12	164,555.95	1,859.42	405,359.91	164,555.86	1,859.35	0.23	248	33
	09/01/11	09/08/11			405,359.91	164,555.86	1,859.35	405,359.74	164,555.58	1,859.25	0.33	210	47
2_003	08/16/11	08/18/11			405,344.91	164,768.94	1,882.60	405,344.77	164,768.80	1,882.66	0.20	223	102
	08/18/11	08/25/11			405,344.77	164,768.80	1,882.66	405,344.61	164,768.43	1,882.43	0.40	204	58
	08/25/11	09/01/11			405,344.61	164,768.43	1,882.43	405,344.28	164,768.16	1,882.56	0.42	231	60
	09/01/11	09/08/11			405,344.28	164,768.16	1,882.56	405,343.91	164,767.90	1,882.41	0.46	235	65
2_004	08/16/11	08/18/11			405,385.50	164,795.89	1,900.44	405,385.62	164,795.77	1,900.45	0.18	135	88
	08/18/11	08/25/11			405,385.62	164,795.77	1,900.45	405,385.75	164,795.10	1,900.36	0.68	170	96
	08/25/11	09/01/11			405,385.75	164,795.10	1,900.36	405,385.30	164,794.81	1,900.17	0.53	236	76
	09/01/11	09/08/11			405,385.30	164,794.81	1,900.17	405,385.12	164,794.40	1,900.13	0.45	204	64
2_005	08/16/11	08/18/11			405,395.11	164,834.62	1,915.19	405,395.28	164,834.45	1,915.09	0.25	134	123
	08/18/11	08/25/11			405,395.28	164,834.45	1,915.09	405,394.61	164,834.23	1,915.00	0.71	252	101
	08/25/11	09/01/11			405,394.61	164,834.23	1,915.00	405,394.62	164,833.17	1,914.67	1.06	180	151
	09/01/11	09/08/11			405,394.62	164,833.17	1,914.67	405,394.55	164,832.61	1,914.36	0.56	187	81

Appendix A, Table 1: 2011 Nisqually Glacier measured velocity data (continued).

Rock ID	Measurement Date		Roll		Starting Position			Ending Position			Distance	Direction	Rate
	First	Second	Deg	Dist (m)	X (m)	Y (m)	Z (m)	X (m)	Y (m)	Z (m)	m	Degrees	mm/day
2_006	08/16/11	08/18/11			405,410.06	164,984.26	1,963.73	405,410.08	164,983.89	1,963.62	0.36	177	181
	08/18/11	08/25/11			405,410.08	164,983.89	1,963.62	405,409.50	164,982.82	1,963.22	1.22	209	174
	08/25/11	09/01/11			405,409.50	164,982.82	1,963.22	405,409.27	164,981.70	1,962.79	1.14	191	163
	09/01/11	09/08/11	280	3.05	405,409.27	164,981.70	1,962.79	405,409.32	164,980.41	1,961.23	1.30	178	185
2_007	08/16/11	08/18/11			405,514.37	164,944.86	1,939.53	405,514.38	164,944.75	1,939.42	0.11	174	54
	08/18/11	08/25/11	225	0.08	405,514.38	164,944.75	1,939.42	405,514.56	164,944.17	1,939.15	0.61	162	86
	08/25/11	09/01/11	100	0.46	405,514.62	164,944.23	1,939.15	405,514.48	164,943.65	1,938.86	0.59	194	85
	09/01/11	09/08/11	5	4.27	405,514.03	164,943.73	1,938.86	405,514.39	164,943.28	1,936.46	0.58	141	83
2_008	08/16/11	08/18/11	131	0.21	405,530.52	164,883.17	1,922.08	405,530.57	164,883.12	1,922.06	0.07	139	36
	08/18/11	08/25/11	315	0.15	405,530.41	164,883.26	1,922.06	405,530.51	164,883.11	1,922.01	0.18	143	26
	08/25/11	09/01/11			405,530.62	164,883.00	1,922.01	405,530.63	164,882.56	1,921.53	0.45	178	64
	09/01/11	09/08/11	90	0.15	405,530.63	164,882.56	1,921.53	405,530.62	164,882.13	1,921.35	0.43	182	61
2_009	08/16/11	08/18/11	220	0.21	405,487.39	164,787.34	1,896.77	405,487.42	164,787.12	1,896.62	0.22	171	111
2_010	08/18/11	08/25/11	150	1.22	405,507.15	164,276.66	1,835.11	405,507.33	164,276.07	1,833.91	0.62	163	88
	08/25/11	09/01/11			405,506.72	164,277.12	1,833.91	405,506.97	164,276.24	1,834.36	0.92	164	132
	09/01/11	09/08/11	150	0.61	405,506.97	164,276.24	1,834.36	405,507.16	164,275.73	1,834.35	0.54	159	77
2_011	08/18/11	08/25/11			405,465.97	164,271.90	1,833.47	405,465.80	164,271.89	1,833.20	0.17	266	24
	08/25/11	09/01/11			405,465.80	164,271.89	1,833.20	405,465.76	164,271.93	1,833.38	0.06	307	8
	09/01/11	09/08/11			405,465.76	164,271.93	1,833.38	405,465.43	164,272.01	1,833.39	0.34	283	49
2_012	08/18/11	08/25/11			405,460.23	164,338.54	1,843.70	405,460.07	164,338.84	1,843.79	0.34	332	48
	08/25/11	09/01/11			405,460.07	164,338.84	1,843.79	405,460.70	164,338.22	1,843.90	0.88	135	126
	09/01/11	09/08/11			405,460.70	164,338.22	1,843.90	405,459.98	164,338.51	1,843.68	0.78	292	111

Appendix A, Table 1: 2011 Nisqually Glacier measured velocity data (continued).

Rock ID	Measurement Date		Roll		Starting Position			Ending Position			Distance	Direction	Rate
	First	Second	Deg	Dist (m)	X (m)	Y (m)	Z (m)	X (m)	Y (m)	Z (m)	m	Degrees	mm/day
2_013	08/18/11	08/25/11			405,474.60	164,407.53	1,852.79	405,474.50	164,407.66	1,852.79	0.16	323	22
	08/25/11	09/01/11			405,474.50	164,407.66	1,852.79	405,474.74	164,407.37	1,852.77	0.38	140	54
	09/01/11	09/08/11			405,474.74	164,407.37	1,852.77	405,474.34	164,407.37	1,852.68	0.40	271	58
2_014	08/18/11	08/25/11			405,344.10	164,509.06	1,849.50	405,343.57	164,509.09	1,849.28	0.53	272	75
	08/25/11	09/01/11	135	0.24	405,343.57	164,509.09	1,849.28	405,343.55	164,508.66	1,849.14	0.43	184	61
	09/01/11	09/08/11			405,343.37	164,508.83	1,849.14	405,343.18	164,508.73	1,849.18	0.22	242	32
2_015	08/18/11	08/25/11			405,519.51	164,559.31	1,871.73	405,519.46	164,559.20	1,871.51	0.12	208	17
	08/25/11	09/01/11			405,519.46	164,559.20	1,871.51	405,519.34	164,559.10	1,871.49	0.15	230	21
	09/01/11	09/08/11	300	0.70	405,519.34	164,559.10	1,871.49	405,519.20	164,558.95	1,871.45	0.21	221	30
2_016	08/18/11	08/25/11			405,408.56	164,580.83	1,865.27	405,408.56	164,580.62	1,865.19	0.21	180	30
	08/25/11	09/01/11	130	0.58	405,408.56	164,580.62	1,865.19	405,408.47	164,580.26	1,864.94	0.37	194	53
	09/01/11	09/08/11			405,408.03	164,580.63	1,864.94	405,407.96	164,580.33	1,864.99	0.30	192	44
2_017	08/18/11	08/25/11			405,448.31	164,571.36	1,864.65	405,448.18	164,571.29	1,864.64	0.15	242	22
	08/25/11	09/01/11			405,448.18	164,571.29	1,864.64	405,447.90	164,571.20	1,864.51	0.29	252	42
	09/01/11	09/08/11			405,447.90	164,571.20	1,864.51	405,447.92	164,571.14	1,864.50	0.06	162	9
2_018	08/18/11	08/25/11			405,110.70	164,674.15	1,876.07	405,110.82	164,673.37	1,875.76	0.79	171	113
	08/25/11	09/01/11	310	1.22	405,110.82	164,673.37	1,875.76	405,110.90	164,672.68	1,874.70	0.69	174	99
	09/01/11	09/08/11			405,111.83	164,671.90	1,874.70	405,112.03	164,671.12	1,874.54	0.81	165	115
2_019	08/18/11	08/25/11			405,373.03	164,901.06	1,940.18	405,372.57	164,900.32	1,940.09	0.87	212	125
	08/25/11	09/01/11			405,372.57	164,900.32	1,940.09	405,372.39	164,899.16	1,939.44	1.18	189	168
	09/01/11	09/08/11			405,372.39	164,899.16	1,939.44	405,372.75	164,898.11	1,938.87	1.11	161	159

Appendix A, Table 1: 2011 Nisqually Glacier measured velocity data (continued).

Rock ID	Measurement Date		Roll		Starting Position			Ending Position			Distance	Direction	Rate
	First	Second	Deg	Dist (m)	X (m)	Y (m)	Z (m)	X (m)	Y (m)	Z (m)	m	Degrees	mm/day
2_020	08/18/11	08/25/11			405,204.06	164,639.24	1,858.10	405,204.05	164,638.70	1,857.60	0.55	181	78
	08/25/11	09/01/11			405,204.05	164,638.70	1,857.60	405,203.94	164,637.93	1,856.82	0.77	188	110
	09/01/11	09/08/11			405,203.94	164,637.93	1,856.82	405,204.07	164,637.51	1,856.25	0.44	164	63
2_021	08/18/11	08/25/11			405,093.69	164,581.62	1,845.66	405,093.69	164,580.77	1,845.20	0.85	180	122
	08/25/11	09/01/11	280	1.37	405,093.69	164,580.77	1,845.20	405,093.61	164,579.91	1,844.44	0.87	185	124
	09/01/11	09/08/11	135	0.23	405,094.96	164,579.67	1,844.44	405,094.89	164,578.83	1,844.27	0.84	185	120
2_022	08/18/11	08/25/11			405,049.18	164,629.88	1,874.68	405,049.24	164,629.15	1,874.59	0.74	176	105
	08/25/11	09/01/11			405,049.24	164,629.15	1,874.59	405,049.15	164,628.32	1,874.33	0.83	186	118
	09/01/11	09/08/11			405,049.15	164,628.32	1,874.33	405,049.24	164,627.68	1,874.08	0.65	172	93
2_023	08/25/11	09/01/11			405,584.19	164,993.52	1,950.27	405,583.86	164,993.51	1,950.10	0.32	269	46
	09/01/11	09/08/11			405,583.86	164,993.51	1,950.10	405,583.72	164,993.34	1,950.26	0.22	219	31
2_024	08/25/11	09/01/11			405,515.02	164,968.58	1,945.29	405,514.75	164,968.08	1,945.12	0.57	209	82
	09/01/11	09/08/11			405,514.75	164,968.08	1,945.12	405,514.70	164,967.62	1,944.83	0.46	186	66
2_025	08/25/11	09/01/11			405,426.57	164,961.55	1,951.44	405,426.14	164,960.57	1,951.05	1.07	204	152
	09/01/11	09/08/11	330	19.51	405,426.14	164,960.57	1,951.05	405,424.99	164,959.86	1,942.81	1.35	238	193
2_026	08/25/11	09/01/11			405,429.30	164,936.35	1,941.50	405,428.61	164,935.51	1,941.15	1.09	219	156
	09/01/11	09/08/11	310	1.37	405,428.61	164,935.51	1,941.15	405,427.75	164,934.55	1,940.34	1.29	222	184
2_027	08/25/11	09/01/11			405,069.01	164,833.63	1,926.94	405,068.28	164,832.49	1,926.77	1.35	213	193
	09/01/11	09/08/11			405,068.28	164,832.49	1,926.77	405,068.62	164,831.38	1,926.67	1.17	163	167
2_028	08/25/11	09/01/11			405,163.02	165,102.77	1,991.24	405,162.42	165,101.21	1,990.17	1.66	201	237
	09/01/11	09/08/11	275	0.46	405,162.42	165,101.21	1,990.17	405,162.22	165,099.46	1,989.59	1.77	187	252
2_029	08/25/11	09/01/11			405,378.42	164,773.00	1,890.40	405,377.98	164,772.75	1,890.28	0.50	240	71
	09/01/11	09/08/11			405,377.98	164,772.75	1,890.28	405,377.87	164,772.38	1,890.13	0.39	197	56

Appendix A, Table 1: 2011 Nisqually Glacier measured velocity data (continued).

Rock ID	Measurement Date		Roll		Starting Position			Ending Position			Distance	Direction	Rate
	First	Second	Deg	Dist (m)	X (m)	Y (m)	Z (m)	X (m)	Y (m)	Z (m)	m	Degrees	mm/day
2_030	08/25/11	09/01/11			405,036.64	164,717.91	1,898.99	405,036.51	164,716.97	1,898.75	0.95	188	135
	09/01/11	09/08/11			405,036.51	164,716.97	1,898.75	405,036.70	164,716.11	1,898.54	0.88	168	126
2_031	08/25/11	09/01/11			405,309.99	164,621.58	1,857.49	405,309.81	164,621.35	1,857.43	0.29	218	42
	09/01/11	09/08/11			405,309.81	164,621.35	1,857.43	405,309.54	164,621.15	1,857.23	0.33	233	48
2_032	08/25/11	09/01/11			405,363.63	164,609.18	1,864.23	405,363.34	164,608.70	1,864.09	0.56	212	80
	09/01/11	09/08/11			405,363.34	164,608.70	1,864.09	405,363.18	164,608.63	1,864.03	0.17	246	25
2_033	09/01/11	09/08/11			405,088.22	165,191.94	2,004.02	405,087.40	165,190.22	2,002.80	1.91	205	273
2_034	09/08/11				405,132.48	165,110.85	1,988.53						
3_001	08/16/11	08/18/11			405,484.76	164,203.90	1,826.22	405,484.77	164,203.99	1,826.20	0.08	11	42
	08/18/11	08/25/11			405,484.77	164,203.99	1,826.20	405,484.83	164,203.70	1,826.19	0.30	168	42
	08/25/11	09/01/11			405,484.83	164,203.70	1,826.19	405,484.76	164,203.92	1,826.20	0.23	343	33
3_002	08/16/11	08/18/11			405,434.67	164,235.34	1,827.79	405,434.72	164,235.18	1,827.82	0.17	162	83
	08/18/11	08/25/11			405,434.72	164,235.18	1,827.82	405,434.71	164,235.28	1,827.71	0.09	355	13
	08/25/11	09/01/11			405,434.71	164,235.28	1,827.71	405,434.61	164,235.12	1,827.70	0.19	214	28
3_003	08/16/11	08/18/11			405,381.98	164,259.09	1,824.48	405,381.93	164,259.08	1,824.42	0.05	251	23
	08/18/11	08/25/11			405,381.93	164,259.08	1,824.42	405,379.71	164,259.64	1,823.37	2.29	284	328
	08/25/11	09/01/11			405,379.71	164,259.64	1,823.37	405,379.04	164,258.75	1,822.85	1.11	217	159
3_004	08/16/11	08/18/11			405,267.79	164,380.40	1,822.48	405,267.87	164,380.28	1,822.44	0.14	144	70
	08/18/11	08/25/11			405,267.87	164,380.28	1,822.44	405,267.71	164,380.03	1,822.39	0.30	212	43
	08/25/11	09/01/11			405,267.71	164,380.03	1,822.39	405,267.34	164,379.97	1,822.34	0.37	261	54
3_005	08/18/11	08/25/11			405,322.60	164,429.92	1,830.83	405,322.55	164,429.86	1,830.76	0.08	219	11
	08/25/11	09/01/11			405,322.55	164,429.86	1,830.76	405,322.17	164,429.60	1,830.40	0.45	235	65

Appendix A, Table 1: 2011 Nisqually Glacier measured velocity data (continued).

Rock ID	Measurement Date		Roll		Starting Position			Ending Position			Distance	Direction	Rate
	First	Second	Deg	Dist (m)	X (m)	Y (m)	Z (m)	X (m)	Y (m)	Z (m)	m	Degrees	mm/day
3_006	08/18/11	08/25/11			405,435.70	164,228.52	1,827.22	405,435.59	164,228.30	1,827.08	0.25	206	35
	08/25/11	09/01/11			405,435.59	164,228.30	1,827.08	405,435.53	164,228.39	1,827.14	0.11	324	16
3_007	08/18/11	08/25/11			405,291.49	164,421.28	1,829.74	405,291.56	164,421.21	1,829.65	0.10	133	14
	08/25/11	09/01/11			405,291.56	164,421.21	1,829.65	405,291.07	164,420.91	1,829.49	0.58	238	82
3_008	08/18/11	08/25/11			405,412.36	164,140.47	1,806.95	405,412.28	164,140.18	1,806.83	0.29	196	42
	08/25/11	09/01/11			405,412.28	164,140.18	1,806.83	405,412.28	164,140.20	1,806.80	0.02	337	3
3_009	08/18/11	08/25/11			405,312.23	164,052.69	1,770.10	405,312.18	164,052.52	1,769.91	0.17	197	25
	08/25/11	09/01/11			405,312.18	164,052.52	1,769.91	405,312.19	164,052.49	1,769.83	0.04	167	5
3_010	08/18/11	08/25/11			405,193.61	164,013.13	1,748.79	405,193.83	164,013.04	1,747.03	0.23	112	33
	08/25/11	09/01/11			405,193.83	164,013.04	1,747.03	405,193.67	164,012.82	1,746.65	0.27	215	39
	09/01/11	09/08/11			405,193.67	164,012.82	1,746.65	405,193.74	164,012.80	1,746.23	0.08	101	11
3_011	08/18/11	08/25/11			405,052.23	164,131.53	1,760.10	405,052.06	164,131.24	1,759.70	0.34	211	48
	08/25/11	09/01/11			405,052.06	164,131.24	1,759.70	405,051.85	164,130.88	1,759.42	0.41	210	59
3_012	08/18/11	08/25/11			405,217.88	164,198.25	1,802.42	405,217.45	164,198.10	1,802.00	0.46	252	66
	08/25/11	09/01/11			405,217.45	164,198.10	1,802.00	405,217.45	164,197.66	1,802.05	0.44	180	63
3_013	08/18/11	08/25/11			405,302.14	164,292.51	1,815.67	405,302.38	164,292.31	1,815.59	0.31	130	44
	08/25/11	09/01/11			405,302.38	164,292.31	1,815.59	405,301.95	164,292.18	1,815.50	0.45	252	64
3_014	08/18/11	08/25/11			405,435.49	164,146.13	1,808.79	405,435.54	164,145.96	1,808.61	0.17	165	25
	08/25/11	09/01/11			405,435.54	164,145.96	1,808.61	405,435.27	164,145.89	1,808.53	0.27	255	39
3_015	08/18/11	08/25/11	315	0.30	405,420.44	164,256.39	1,830.03	405,420.29	164,255.40	1,829.16	1.00	189	143
	08/25/11	09/01/11	135	0.30	405,420.50	164,255.18	1,829.16	405,420.44	164,254.84	1,829.07	0.34	191	49
3_016	08/18/11	08/25/11			405,328.77	164,244.96	1,813.03	405,328.73	164,244.95	1,812.91	0.04	266	5
	08/25/11	09/01/11			405,328.73	164,244.95	1,812.91	405,328.49	164,244.87	1,812.78	0.26	250	37

Appendix A, Table 1: 2011 Nisqually Glacier measured velocity data (continued).

Rock ID	Measurement Date		Roll		Starting Position			Ending Position			Distance	Direction	Rate
	First	Second	Deg	Dist (m)	X (m)	Y (m)	Z (m)	X (m)	Y (m)	Z (m)	m	Degrees	mm/day
3_017	08/18/11	08/25/11			405,274.84	164,235.69	1,807.84	405,274.63	164,235.50	1,807.71	0.29	229	41
	08/25/11	09/01/11			405,274.63	164,235.50	1,807.71	405,274.57	164,235.32	1,807.54	0.18	197	26
3_018	08/18/11	08/25/11			405,223.28	164,274.50	1,808.37	405,223.77	164,274.01	1,808.06	0.69	134	98
	08/25/11	09/01/11			405,223.77	164,274.01	1,808.06	405,223.49	164,273.76	1,808.03	0.38	229	54
3_019	08/18/11	08/25/11			405,159.49	164,154.89	1,776.72	405,159.42	164,154.79	1,776.55	0.12	215	16
	08/25/11	09/01/11			405,159.42	164,154.79	1,776.55	405,159.20	164,154.62	1,776.56	0.28	232	40
3_020	08/18/11	08/25/11			405,098.79	164,169.94	1,770.98	405,099.14	164,169.20	1,770.88	0.83	154	118
	08/25/11	09/01/11			405,099.14	164,169.20	1,770.88	405,098.58	164,169.36	1,770.79	0.59	286	84
3_021	08/18/11	08/25/11			404,935.64	164,154.61	1,748.60	404,935.55	164,154.31	1,748.31	0.31	198	45
	08/25/11	09/01/11			404,935.55	164,154.31	1,748.31	404,935.56	164,153.72	1,748.01	0.59	178	85
3_022	08/18/11	08/25/11			404,908.78	164,124.25	1,744.59	404,908.77	164,123.92	1,744.20	0.33	181	47
	08/25/11	09/01/11			404,908.77	164,123.92	1,744.20	404,908.69	164,123.26	1,743.93	0.66	187	95
	09/01/11	09/08/11	235	1.83	404,908.69	164,123.26	1,743.93	404,908.61	164,122.65	1,745.49	0.62	187	88
3_023	08/18/11	08/25/11			404,945.49	164,219.95	1,765.04	404,945.46	164,219.76	1,764.74	0.19	190	27
	08/25/11	09/01/11			404,945.46	164,219.76	1,764.74	404,945.15	164,219.23	1,764.46	0.61	210	88
3_024	08/18/11	08/25/11			404,982.25	164,304.62	1,782.20	404,982.21	164,304.15	1,781.91	0.47	184	67
	08/25/11	09/01/11			404,982.21	164,304.15	1,781.91	404,982.08	164,303.84	1,781.72	0.34	203	48
3_025	08/18/11	08/25/11			405,020.81	164,430.47	1,810.00	405,020.85	164,430.35	1,809.67	0.13	161	18
	08/25/11	09/01/11			405,020.85	164,430.35	1,809.67	405,021.00	164,429.82	1,809.58	0.55	164	79
3_026	08/18/11	08/25/11			405,025.83	164,508.71	1,831.86	405,025.90	164,508.21	1,831.44	0.51	172	72
	08/25/11	09/01/11			405,025.90	164,508.21	1,831.44	405,025.77	164,507.63	1,831.25	0.60	192	85
3_027	08/25/11	09/01/11			405,337.33	164,307.26	1,821.40	405,337.26	164,307.33	1,821.36	0.09	316	13
3_028	08/25/11	09/01/11			405,372.69	164,351.77	1,827.75	405,372.46	164,351.73	1,827.73	0.23	260	33

Appendix A, Table 1: 2011 Nisqually Glacier measured velocity data (continued).

Rock ID	Measurement Date		Roll		Starting Position			Ending Position			Distance	Direction	Rate
	First	Second	Deg	Dist (m)	X (m)	Y (m)	Z (m)	X (m)	Y (m)	Z (m)	m	Degrees	mm/day
3_029	08/25/11	09/01/11			405,229.31	164,219.23	1,803.76	405,229.17	164,218.89	1,803.61	0.37	202	53
3_030	08/25/11	09/01/11			405,278.86	164,181.35	1,791.80	405,278.86	164,181.08	1,791.66	0.26	180	38
3_031	08/25/11	09/01/11			405,326.64	164,140.74	1,791.93	405,326.68	164,140.65	1,791.97	0.09	158	13
3_032	08/25/11	09/01/11			405,349.34	164,207.45	1,812.49	405,349.21	164,207.30	1,812.45	0.20	219	28
3_033	08/25/11	09/01/11			405,409.48	164,189.62	1,817.39	405,409.58	164,189.33	1,817.33	0.31	160	44
3_034	08/25/11	09/01/11			405,354.97	164,111.38	1,792.17	405,355.09	164,111.26	1,792.11	0.16	134	24
3_035	08/25/11	09/01/11			405,242.60	164,131.94	1,775.69	405,242.43	164,131.88	1,775.62	0.18	250	25
3_036	08/25/11	09/01/11			405,130.96	164,005.32	1,745.56	405,131.02	164,005.17	1,745.51	0.16	159	23
3_037	09/01/11	09/08/11	70	2.13	405,026.14	164,234.00	1,762.86	405,026.01	164,233.44	1,762.06	0.58	193	83
3_038	09/08/11				404,857.31	163,938.84	1,682.14						
3_039	09/08/11				404,818.46	163,746.67	1,608.62						

Appendix B

Appendix B, Table 1: 2012 Nisqually Glacier measured velocity data.

Rock ID	Measurement Date		Roll		Starting Position			Ending Position			Distance	Direction	Rate
	First	Second	Deg	Dist (m)	X (m)	Y (m)	Z (m)	X (m)	Y (m)	Z (m)	m	Degrees	mm/day
001	07/19/12	08/02/12			405,506.67	164,276.10	1,834.07	405,506.57	164,275.88	1,834.03	0.24	205	17
	08/02/12	08/09/12			405,506.57	164,275.88	1,834.03	405,506.54	164,275.90	1,834.02	0.04	293	5
	08/09/12	08/16/12			405,506.54	164,275.90	1,834.02	405,506.57	164,275.88	1,833.96	0.03	115	5
	08/16/12	08/30/12			405,506.57	164,275.88	1,833.96	405,506.78	164,275.84	1,834.08	0.22	101	16
	08/30/12	09/06/12			405,506.78	164,275.84	1,834.08	405,506.48	164,275.83	1,833.90	0.30	267	43
	09/06/12	09/20/12			405,506.48	164,275.83	1,833.90	405,506.66	164,275.82	1,833.90	0.18	92	13
002	07/19/12	08/02/12			405,484.30	164,203.72	1,825.62	405,484.23	164,203.56	1,825.72	0.18	202	13
	08/02/12	08/09/12			405,484.23	164,203.56	1,825.72	405,484.19	164,203.57	1,825.64	0.04	281	6
	08/09/12	08/16/12			405,484.19	164,203.57	1,825.64	405,484.21	164,203.64	1,825.54	0.08	13	11
	08/16/12	10/04/12			405,484.21	164,203.64	1,825.54	405,484.01	164,203.49	1,825.17	0.25	232	5
003	07/19/12	08/02/12			405,447.64	164,210.30	1,821.92	405,447.37	164,210.10	1,821.89	0.34	233	24
	08/02/12	08/09/12			405,447.37	164,210.10	1,821.89	405,447.33	164,210.27	1,822.09	0.18	345	25
	08/09/12	08/16/12			405,447.33	164,210.27	1,822.09	405,447.40	164,210.01	1,821.79	0.27	166	39
	08/16/12	10/04/12			405,447.40	164,210.01	1,821.79	405,447.41	164,209.85	1,821.54	0.16	174	3
004	07/19/12	08/02/12			405,458.60	164,337.13	1,842.73	405,458.43	164,336.81	1,842.70	0.36	207	26
	08/02/12	08/09/12			405,458.43	164,336.81	1,842.70	405,458.35	164,336.80	1,842.71	0.08	263	11
	08/09/12	08/16/12			405,458.35	164,336.80	1,842.71	405,458.33	164,336.78	1,842.61	0.03	242	5
	08/16/12	08/30/12			405,458.33	164,336.78	1,842.61	405,458.36	164,336.58	1,842.54	0.20	171	14

Appendix B, Table 1: 2012 Nisqually Glacier measured velocity data (continued).

Rock ID	Measurement Date		Roll		Starting Position			Ending Position			Distance	Direction	Rate
	First	Second	Deg	Dist (m)	X (m)	Y (m)	Z (m)	X (m)	Y (m)	Z (m)	m	Degrees	mm/day
005	07/19/12	08/09/12			405,433.94	164,225.39	1,824.46	405,433.74	164,225.18	1,824.52	0.29	224	14
	08/09/12	08/16/12			405,433.74	164,225.18	1,824.52	405,433.65	164,225.13	1,824.40	0.10	243	14
	08/16/12	09/13/12			405,433.65	164,225.13	1,824.40	405,433.85	164,225.06	1,824.52	0.21	110	7
	09/13/12	10/04/12			405,433.85	164,225.06	1,824.52	405,433.79	164,224.96	1,824.37	0.11	210	5
-006	07/19/12	08/02/12			405,473.19	164,405.43	1,851.83	405,472.79	164,405.18	1,851.73	0.47	237	34
	08/02/12	08/09/12			405,472.79	164,405.18	1,851.73	405,472.84	164,405.19	1,851.66	0.05	74	7
	08/09/12	08/16/12			405,472.84	164,405.19	1,851.66	405,472.75	164,405.16	1,851.54	0.09	251	13
	08/16/12	08/30/12			405,472.75	164,405.16	1,851.54	405,472.59	164,404.99	1,851.38	0.23	223	17
007	07/19/12	08/02/12			405,428.70	164,199.94	1,818.97	405,429.40	164,199.44	1,819.03	0.86	125	61
	08/02/12	08/09/12			405,429.40	164,199.44	1,819.03	405,429.42	164,199.40	1,818.95	0.05	158	6
	08/09/12	08/16/12			405,429.42	164,199.40	1,818.95	405,429.32	164,199.37	1,818.83	0.10	254	15
	08/16/12	10/04/12			405,429.32	164,199.37	1,818.83	405,429.25	164,199.28	1,818.27	0.12	214	2
008	07/19/12	08/02/12			405,408.79	164,188.11	1,816.41	405,408.52	164,187.84	1,815.94	0.38	226	27
	08/02/12	08/09/12			405,408.52	164,187.84	1,815.94	405,408.51	164,187.81	1,815.85	0.03	200	5
	08/09/12	08/16/12	45	8.0	405,408.51	164,187.81	1,815.85	405,408.52	164,188.14	1,814.54	0.33	2	47
	08/16/12	10/04/12			405,406.80	164,186.41	1,814.54	405,406.17	164,185.77	1,813.41	0.90	225	18
009	07/19/12	08/02/12	0	1.5	405,474.63	164,456.56	1,855.77	405,474.23	164,456.33	1,855.12	0.46	240	33
	08/02/12	08/09/12			405,474.23	164,455.87	1,855.12	405,474.25	164,455.82	1,855.00	0.05	167	7
	08/09/12	08/16/12			405,474.25	164,455.82	1,855.00	405,474.02	164,455.79	1,854.81	0.23	262	33
	08/16/12	08/30/12			405,474.02	164,455.79	1,854.81	405,473.90	164,455.56	1,854.65	0.26	208	19

Appendix B, Table 1: 2012 Nisqually Glacier measured velocity data (continued).

Rock ID	Measurement Date		Roll		Starting Position			Ending Position			Distance	Direction	Rate
	First	Second	Deg	Dist (m)	X (m)	Y (m)	Z (m)	X (m)	Y (m)	Z (m)	m	Degrees	mm/day
010	07/19/12	08/09/12			405,432.47	164,262.44	1,831.21	405,432.31	164,262.10	1,831.64	0.38	205	18
	08/09/12	09/13/12			405,432.31	164,262.10	1,831.64	405,431.97	164,262.36	1,831.02	0.43	307	12
	09/13/12	09/20/12			405,431.97	164,262.36	1,831.02	405,432.13	164,262.49	1,830.97	0.20	51	29
	09/20/12	09/27/12			405,432.13	164,262.49	1,830.97	405,431.82	164,262.19	1,830.95	0.43	225	61
	09/27/12	10/04/12			405,431.82	164,262.19	1,830.95	405,431.87	164,262.22	1,830.95	0.06	55	9
011	07/19/12	07/26/12			405,477.03	164,500.52	1,861.80	405,476.90	164,500.34	1,861.79	0.22	216	31
	07/26/12	08/02/12			405,476.90	164,500.34	1,861.79	405,476.72	164,500.26	1,861.74	0.19	246	28
	08/02/12	08/09/12			405,476.72	164,500.26	1,861.74	405,476.67	164,500.22	1,861.68	0.07	231	10
	08/09/12	08/16/12			405,476.67	164,500.22	1,861.68	405,476.58	164,500.01	1,861.49	0.23	202	33
	08/16/12	08/30/12			405,476.58	164,500.01	1,861.49	405,476.20	164,499.85	1,861.36	0.41	248	29
012	07/19/12	08/02/12			405,517.95	164,556.61	1,870.68	405,517.54	164,556.34	1,870.54	0.49	237	35
	08/02/12	08/09/12			405,517.54	164,556.34	1,870.54	405,517.61	164,556.31	1,870.45	0.08	115	11
	08/09/12	08/16/12			405,517.61	164,556.31	1,870.45	405,517.54	164,556.21	1,870.32	0.11	216	16
	08/16/12	08/30/12			405,517.54	164,556.21	1,870.32	405,517.40	164,556.00	1,870.21	0.25	213	18
	08/30/12	09/06/12			405,517.40	164,556.00	1,870.21	405,517.33	164,555.90	1,870.02	0.13	213	19
013	07/19/12	07/26/12			405,405.64	164,574.84	1,863.60	405,405.33	164,574.40	1,863.43	0.54	215	78
	07/26/12	08/02/12			405,405.33	164,574.40	1,863.43	405,405.06	164,574.16	1,863.36	0.35	228	50
	08/02/12	08/09/12			405,405.06	164,574.16	1,863.36	405,405.06	164,573.99	1,863.13	0.17	182	25
	08/09/12	08/16/12			405,405.06	164,573.99	1,863.13	405,404.81	164,573.68	1,863.03	0.40	219	57
	08/16/12	08/30/12			405,404.81	164,573.68	1,863.03	405,404.66	164,573.25	1,862.67	0.46	199	33

Appendix B, Table 1: 2012 Nisqually Glacier measured velocity data (continued).

Rock ID	Measurement Date		Roll		Starting Position			Ending Position			Distance	Direction	Rate
	First	Second	Deg	Dist (m)	X (m)	Y (m)	Z (m)	X (m)	Y (m)	Z (m)	m	Degrees	mm/day
014	07/19/12	08/02/12			405,354.42	164,184.73	1,808.33	405,354.28	164,184.17	1,808.20	0.58	194	41
	08/02/12	08/09/12			405,354.28	164,184.17	1,808.20	405,354.35	164,184.23	1,808.19	0.09	48	13
	08/09/12	09/13/12			405,354.35	164,184.23	1,808.19	405,353.99	164,183.96	1,807.53	0.45	233	13
	09/13/12	10/04/12			405,353.99	164,183.96	1,807.53	405,353.97	164,183.89	1,807.67	0.07	195	4
015	07/19/12	08/02/12			405,325.62	164,137.94	1,790.61	405,325.16	164,137.66	1,790.43	0.53	239	38
	08/02/12	08/09/12			405,325.16	164,137.66	1,790.43	405,325.07	164,137.63	1,790.36	0.10	249	14
	08/09/12	09/06/12			405,325.07	164,137.63	1,790.36	405,325.40	164,137.19	1,789.94	0.55	143	19
016	07/19/12	08/09/12			405,226.32	164,213.77	1,802.27	405,225.91	164,213.21	1,801.91	0.70	216	33
	08/09/12	09/13/12			405,225.91	164,213.21	1,801.91	405,225.73	164,212.05	1,800.71	1.17	189	33
	09/13/12	09/27/12	314	20.0	405,225.73	164,212.05	1,800.71	405,226.10	164,210.91	1,796.98	1.20	162	86
017	07/19/12	07/26/12			405,360.06	164,601.69	1,862.70	405,359.84	164,601.14	1,862.53	0.58	201	84
	07/26/12	08/02/12			405,359.84	164,601.14	1,862.53	405,359.35	164,600.96	1,862.45	0.52	249	75
	08/02/12	08/09/12			405,359.35	164,600.96	1,862.45	405,359.58	164,600.55	1,862.38	0.47	151	67
	08/09/12	08/16/12			405,359.58	164,600.55	1,862.38	405,359.20	164,600.21	1,862.39	0.51	228	72
	08/16/12	08/30/12			405,359.20	164,600.21	1,862.39	405,358.92	164,599.61	1,861.95	0.66	206	47
018	07/19/12	08/09/12			405,218.41	164,149.34	1,786.07	405,217.99	164,148.56	1,785.76	0.88	209	42
	08/09/12	09/13/12			405,217.99	164,148.56	1,785.76	405,218.00	164,147.87	1,785.14	0.69	179	20
019	07/19/12	08/02/12	0	3.5	405,337.91	164,751.28	1,882.20	405,335.87	164,750.82	1,881.72	2.09	257	149
	08/02/12	08/09/12			405,335.87	164,749.75	1,881.72	405,335.83	164,749.23	1,881.53	0.52	184	75
	08/09/12	08/30/12	24	7.8	405,335.83	164,749.23	1,881.53	405,332.84	164,751.05	1,879.71	3.50	301	167
	08/30/12	10/04/12			405,331.87	164,748.88	1,879.71	405,331.09	164,746.29	1,878.74	2.70	197	77

Appendix B, Table 1: 2012 Nisqually Glacier measured velocity data (continued).

Rock ID	Measurement Date		Roll		Starting Position			Ending Position			Distance	Direction	Rate
	First	Second	Deg	Dist (m)	X (m)	Y (m)	Z (m)	X (m)	Y (m)	Z (m)	m	Degrees	mm/day
020	07/19/12	08/09/12			405,351.64	165,692.68	2,162.13	405,349.28	165,679.33	2,155.61	13.56	190	646
	08/09/12	08/30/12			405,349.28	165,679.33	2,155.61	405,347.74	165,667.79	2,149.46	11.64	188	554
	08/30/12	09/06/12			405,347.74	165,667.79	2,149.46	405,347.28	165,664.40	2,147.52	3.42	188	489
	09/06/12	09/13/12			405,347.28	165,664.40	2,147.52	405,346.20	165,660.74	2,145.74	3.82	196	546
	09/13/12	09/20/12			405,346.20	165,660.74	2,145.74	405,346.43	165,657.51	2,143.86	3.23	176	462
	09/20/12	10/11/12			405,346.43	165,657.51	2,143.86	405,344.91	165,648.10	2,139.43	9.54	189	454
021	07/19/12	08/02/12			405,379.56	164,772.90	1,898.75	405,378.75	164,771.14	1,898.48	1.93	205	138
	08/02/12	08/09/12			405,378.75	164,771.14	1,898.48	405,378.68	164,770.42	1,898.48	0.73	185	104
	08/09/12	08/30/12			405,378.68	164,770.42	1,898.48	405,377.89	164,768.04	1,898.09	2.51	198	120
022	07/19/12	08/09/12			405,195.19	164,012.38	1,744.48	405,195.21	164,012.00	1,744.32	0.38	177	18
023	07/19/12				405,371.03	165,738.43	2,181.14						
024	07/19/12	08/02/12			405,390.50	164,804.16	1,910.23	405,389.44	164,802.11	1,909.83	2.30	207	165
	08/02/12	08/09/12			405,389.44	164,802.11	1,909.83	405,389.47	164,801.25	1,908.16	0.86	178	123
	08/09/12	08/30/12			405,389.47	164,801.25	1,908.16	405,388.75	164,798.52	1,909.07	2.83	195	135
	08/30/12	10/04/12			405,388.75	164,798.52	1,909.07	405,388.27	164,794.81	1,907.95	3.74	187	107
025	07/19/12	08/09/12			405,131.38	164,002.53	1,744.38	405,130.61	164,001.83	1,744.27	1.04	228	49
	08/09/12	09/13/12			405,130.61	164,001.83	1,744.27	405,130.88	164,001.63	1,743.86	0.34	127	10
	09/13/12	10/04/12			405,130.88	164,001.63	1,743.86	405,130.77	164,001.37	1,743.42	0.28	204	13

Appendix B, Table 1: 2012 Nisqually Glacier measured velocity data (continued).

Rock ID	Measurement Date		Roll		Starting Position			Ending Position			Distance	Direction	Rate
	First	Second	Deg	Dist (m)	X (m)	Y (m)	Z (m)	X (m)	Y (m)	Z (m)	m	Degrees	mm/day
026	07/19/12	07/26/12			405,416.26	164,930.24	1,950.08	405,416.43	164,928.65	1,949.46	1.59	174	228
	07/26/12	08/02/12			405,416.43	164,928.65	1,949.46	405,416.03	164,926.84	1,948.85	1.86	192	266
	08/02/12	08/09/12			405,416.03	164,926.84	1,948.85	405,416.34	164,922.95	1,947.15	3.90	175	557
	08/09/12	08/16/12			405,416.34	164,922.95	1,947.15	405,416.38	164,921.37	1,946.36	1.57	179	225
	08/16/12	08/30/12			405,416.38	164,921.37	1,946.36	405,417.04	164,918.24	1,945.02	3.20	168	229
	08/30/12	09/06/12			405,417.04	164,918.24	1,945.02	405,416.88	164,916.76	1,944.27	1.49	186	213
	09/06/12	10/04/12			405,416.88	164,916.76	1,944.27	405,417.40	164,911.31	1,942.26	5.48	175	196
027	07/19/12	08/09/12			405,047.45	164,119.85	1,753.90	405,046.90	164,118.76	1,753.43	1.22	207	58
	08/09/12	09/13/12			405,046.90	164,118.76	1,753.43	405,046.22	164,117.60	1,752.53	1.35	210	38
028	07/19/12				405,355.51	165,803.15	2,198.94						
029	07/19/12	09/27/12			404,984.24	164,206.83	1,752.68	404,984.71	164,196.29	1,745.75	10.55	177	151
	09/27/12	10/04/12			404,984.71	164,196.29	1,745.75	404,984.71	164,195.91	1,745.32	0.38	180	55
030	07/19/12	08/02/12			404,982.69	164,269.22	1,771.06	404,981.88	164,267.64	1,770.27	1.77	207	127
	08/02/12	08/09/12			404,981.88	164,267.64	1,770.27	404,981.69	164,266.99	1,769.73	0.68	196	97
	08/09/12	08/16/12			404,981.69	164,266.99	1,769.73	404,981.34	164,266.36	1,769.18	0.72	208	102
	08/16/12	09/27/12	14	6.8	404,981.34	164,266.36	1,769.18	404,979.09	164,262.62	1,764.69	4.36	211	104
031	07/19/12	08/02/12			404,978.58	164,293.87	1,779.24	404,978.07	164,292.53	1,778.80	1.43	201	102
	08/02/12	08/09/12			404,978.07	164,292.53	1,778.80	404,977.87	164,292.19	1,778.58	0.40	210	57
	08/09/12	08/16/12			404,977.87	164,292.19	1,778.58	404,977.84	164,291.68	1,778.34	0.51	183	73
	08/16/12	09/27/12			404,977.84	164,291.68	1,778.34	404,977.12	164,289.47	1,777.05	2.32	198	55

Appendix B, Table 1: 2012 Nisqually Glacier measured velocity data (continued).

Rock ID	Measurement Date		Roll		Starting Position			Ending Position			Distance	Direction	Rate
	First	Second	Deg	Dist (m)	X (m)	Y (m)	Z (m)	X (m)	Y (m)	Z (m)	m	Degrees	mm/day
032	07/19/12	08/09/12	34	5.8	405,317.30	165,889.45	2,236.27	405,317.26	165,873.92	2,226.81	15.53	180	739
	08/09/12	09/06/12	164	2.0	405,316.28	165,872.47	2,226.81	405,317.87	165,853.91	2,217.71	18.63	175	665
	09/06/12	09/13/12	286	7.0	405,317.70	165,854.49	2,217.71	405,315.73	165,848.86	2,215.74	5.96	199	852
	09/13/12	09/20/12	22	4.5	405,317.78	165,848.27	2,215.74	405,318.62	165,845.44	2,213.88	2.96	164	422
	09/20/12	10/11/12			405,318.10	165,844.17	2,213.88	405,318.54	165,832.85	2,209.20	11.33	178	539
033	07/19/12	08/02/12			405,020.86	164,417.48	1,806.28	405,020.17	164,416.13	1,806.33	1.52	207	109
	08/02/12	08/09/12			405,020.17	164,416.13	1,806.33	405,020.33	164,415.54	1,805.69	0.61	164	87
	08/09/12	09/20/12			405,020.33	164,415.54	1,805.69	405,021.13	164,412.72	1,804.08	2.93	164	70
034	07/19/12	07/26/12	120	3.0	405,281.46	165,054.56	1,991.20	405,281.96	165,051.32	1,990.28	3.28	171	468
	07/26/12	08/02/12			405,281.16	165,051.78	1,990.28	405,280.49	165,049.17	1,988.96	2.69	194	385
	08/02/12	08/09/12			405,280.49	165,049.17	1,988.96	405,280.56	165,042.69	1,985.39	6.48	179	926
	08/09/12	08/16/12			405,280.56	165,042.69	1,985.39	405,280.43	165,039.94	1,983.69	2.75	183	393
	08/16/12	08/30/12	180	1.0	405,280.43	165,039.94	1,983.69	405,279.77	165,035.08	1,982.26	4.91	188	351
035	07/19/12	08/09/12	20	45.0	405,355.50	165,967.74	2,273.04	405,359.08	165,952.97	2,256.17	15.19	166	723
036	07/19/12	08/02/12			405,095.73	164,160.92	1,768.61	405,093.58	164,160.65	1,767.98	2.17	263	155
	08/02/12	08/09/12			405,093.58	164,160.65	1,767.98	405,093.50	164,160.68	1,767.92	0.09	288	12
	08/09/12	09/13/12			405,093.50	164,160.68	1,767.92	405,092.72	164,159.62	1,767.20	1.31	217	37
	09/13/12	10/04/12			405,092.72	164,159.62	1,767.20	405,092.01	164,158.74	1,766.32	1.13	219	54
037	07/19/12	08/09/12	360	1.0	405,204.75	164,984.98	1,965.03	405,200.70	164,973.24	1,959.81	12.42	199	591
	08/09/12	08/16/12	135	1.0	405,200.70	164,972.93	1,959.81	405,200.70	164,970.30	1,958.29	2.63	180	375

Appendix B, Table 1: 2012 Nisqually Glacier measured velocity data (continued).

Rock ID	Measurement Date		Roll		Starting Position			Ending Position			Distance	Direction	Rate
	First	Second	Deg	Dist (m)	X (m)	Y (m)	Z (m)	X (m)	Y (m)	Z (m)	m	Degrees	mm/day
038	07/19/12	08/02/12			405,139.83	164,236.30	1,786.07	405,139.42	164,235.43	1,785.77	0.96	205	69
	08/02/12	08/09/12			405,139.42	164,235.43	1,785.77	405,139.10	164,235.07	1,785.63	0.49	221	69
	08/09/12	09/13/12			405,139.10	164,235.07	1,785.63	405,138.40	164,233.68	1,784.11	1.55	207	44
	09/13/12	09/27/12	41	1.5	405,138.40	164,233.68	1,784.11	405,138.28	164,233.24	1,783.68	0.45	195	32
039	07/19/12	07/26/12			405,075.40	164,686.75	1,895.53	405,075.26	164,685.11	1,895.26	1.65	185	236
	07/26/12	08/09/12			405,075.26	164,685.11	1,895.26	405,075.06	164,682.02	1,894.64	3.10	184	221
	08/09/12	08/16/12			405,075.06	164,682.02	1,894.64	405,075.11	164,680.47	1,894.23	1.55	178	221
	08/16/12	08/30/12			405,075.11	164,680.47	1,894.23	405,075.56	164,678.01	1,893.42	2.50	169	179
	08/30/12	09/06/12			405,075.56	164,678.01	1,893.42	405,075.67	164,676.82	1,893.09	1.20	175	171
	09/06/12	10/11/12			405,075.67	164,676.82	1,893.09	405,075.97	164,671.11	1,891.54	5.72	177	163
040	07/19/12	08/02/12			405,326.74	164,242.22	1,811.95	405,326.44	164,241.82	1,811.77	0.50	217	36
	08/02/12	08/09/12			405,326.44	164,241.82	1,811.77	405,326.38	164,241.80	1,811.58	0.06	253	8
	08/09/12	08/16/12			405,326.38	164,241.80	1,811.58	405,326.32	164,241.74	1,811.49	0.09	224	13
	08/16/12	09/27/12			405,326.32	164,241.74	1,811.49	405,325.77	164,241.19	1,810.89	0.77	225	18
041	07/19/12	08/09/12			405,062.66	164,622.44	1,873.19	405,062.51	164,618.36	1,872.47	4.08	182	194
	08/09/12	08/16/12			405,062.51	164,618.36	1,872.47	405,062.50	164,616.93	1,872.07	1.43	181	205
	08/16/12	08/30/12			405,062.50	164,616.93	1,872.07	405,063.00	164,614.86	1,871.10	2.12	166	152
042	07/19/12	08/09/12			405,310.19	165,763.79	2,193.35	405,308.91	165,748.42	2,186.00	15.42	185	734
	08/09/12	09/06/12	3	1.3	405,308.91	165,748.42	2,186.00	405,308.79	165,731.11	2,176.37	17.31	180	618
	09/06/12	09/13/12	330	1.8	405,308.77	165,730.70	2,176.37	405,308.05	165,726.38	2,174.11	4.39	189	627
	09/13/12	10/11/12	342	1.0	405,308.33	165,725.89	2,174.11	405,308.24	165,709.95	2,165.19	15.95	180	569

Appendix B, Table 1: 2012 Nisqually Glacier measured velocity data (continued).

Rock ID	Measurement Date		Roll		Starting Position			Ending Position			Distance	Direction	Rate
	First	Second	Deg	Dist (m)	X (m)	Y (m)	Z (m)	X (m)	Y (m)	Z (m)	m	Degrees	mm/day
043	07/19/12	08/02/12			405,299.30	164,288.09	1,814.31	405,298.92	164,287.54	1,814.12	0.66	215	47
	08/02/12	08/09/12			405,298.92	164,287.54	1,814.12	405,298.87	164,287.43	1,814.08	0.12	203	17
	08/09/12	08/16/12			405,298.87	164,287.43	1,814.08	405,298.81	164,287.21	1,813.92	0.23	196	33
	08/16/12	10/04/12			405,298.81	164,287.21	1,813.92	405,298.36	164,286.35	1,813.18	0.97	208	20
044	07/19/12	08/02/12			405,264.86	164,373.28	1,820.76	405,263.38	164,372.72	1,820.61	1.59	249	113
	08/02/12	08/09/12			405,263.38	164,372.72	1,820.61	405,263.39	164,372.67	1,820.53	0.05	169	7
	08/09/12	08/16/12			405,263.39	164,372.67	1,820.53	405,263.29	164,372.35	1,820.28	0.33	196	48
	08/16/12	10/04/12			405,263.29	164,372.35	1,820.28	405,262.54	164,370.60	1,819.09	1.91	203	39
045	07/19/12	08/09/12			405,053.11	164,599.58	1,867.24	405,053.63	164,595.65	1,866.01	3.97	172	189
	08/09/12	08/16/12			405,053.63	164,595.65	1,866.01	405,053.64	164,594.35	1,865.45	1.30	180	186
	08/16/12	08/30/12			405,053.64	164,594.35	1,865.45	405,053.39	164,592.40	1,864.87	1.96	187	140
	08/30/12	10/04/12			405,053.39	164,592.40	1,864.87	405,053.43	164,587.62	1,863.17	4.79	179	137
046	07/19/12	08/09/12			405,334.63	164,304.09	1,819.99	405,334.20	164,303.64	1,819.51	0.62	223	30
	08/09/12	08/16/12			405,334.20	164,303.64	1,819.51	405,334.16	164,303.66	1,819.29	0.05	293	7
	08/16/12	10/04/12			405,334.16	164,303.66	1,819.29	405,333.76	164,303.17	1,818.20	0.63	219	13
047	07/19/12	08/09/12	246	2.0	405,328.10	165,589.37	2,124.85	405,323.09	165,576.92	2,119.50	13.43	202	639
	08/09/12	08/30/12			405,323.65	165,577.16	2,119.50	405,319.48	165,563.86	2,114.08	13.94	197	664
	08/30/12	09/06/12	10	11.5	405,319.48	165,563.86	2,114.08	405,318.72	165,560.75	2,111.91	3.20	194	457
	09/06/12	09/13/12			405,318.12	165,557.30	2,111.91	405,316.82	165,553.42	2,110.60	4.09	198	585
	09/13/12	09/20/12	350	4.0	405,316.82	165,553.42	2,110.60	405,316.22	165,550.86	2,109.37	2.63	193	376
	09/20/12	10/11/12			405,316.43	165,549.66	2,109.37	405,313.90	165,540.69	2,105.74	9.32	196	444

Appendix B, Table 1: 2012 Nisqually Glacier measured velocity data (continued).

Rock ID	Measurement Date		Roll		Starting Position			Ending Position			Distance	Direction	Rate
	First	Second	Deg	Dist (m)	X (m)	Y (m)	Z (m)	X (m)	Y (m)	Z (m)	m	Degrees	mm/day
048	07/19/12	08/09/12			405,063.02	164,570.79	1,852.28	405,063.05	164,566.80	1,850.86	3.99	180	190
	08/09/12	08/16/12			405,063.05	164,566.80	1,850.86	405,063.12	164,565.44	1,850.06	1.37	177	195
	08/16/12	08/30/12			405,063.12	164,565.44	1,850.06	405,063.32	164,563.30	1,848.83	2.15	175	153
	08/30/12	10/04/12			405,063.32	164,563.30	1,848.83	405,063.58	164,558.59	1,846.79	4.72	177	135
049	07/26/12	08/02/12			405,157.87	165,081.57	1,992.78	405,156.90	165,078.67	1,991.61	3.05	199	436
	08/02/12	08/09/12			405,156.90	165,078.67	1,991.61	405,156.47	165,076.39	1,990.37	2.32	191	332
	08/09/12	08/16/12			405,156.47	165,076.39	1,990.37	405,154.64	165,074.20	1,988.88	2.85	220	407
	08/16/12	09/06/12			405,154.64	165,074.20	1,988.88	405,152.99	165,067.47	1,985.63	6.93	194	330
	09/06/12	09/13/12	68	1.0	405,152.99	165,067.47	1,985.63	405,152.80	165,064.98	1,984.64	2.50	184	357
	09/13/12	10/11/12	0	1.0	405,152.52	165,064.87	1,984.64	405,151.43	165,056.87	1,981.06	8.07	188	288
050	07/26/12	08/09/12			405,051.55	165,323.40	2,026.71	405,049.46	165,320.15	2,024.22	3.86	213	276
	08/09/12	09/06/12	240	1.6	405,049.46	165,320.15	2,024.22	405,045.64	165,314.16	2,020.12	7.10	213	254
	09/06/12	10/11/12			405,046.06	165,314.40	2,020.12	405,043.51	165,308.64	2,016.18	6.29	204	180
051	07/26/12	08/09/12			405,137.73	165,510.19	2,079.10	405,140.82	165,503.17	2,075.69	7.67	156	548
	08/09/12	09/06/12	90	9.0	405,140.82	165,503.17	2,075.69	405,145.53	165,493.85	2,071.20	10.44	153	373
	09/06/12	10/11/12	310	24.5	405,142.78	165,493.85	2,071.20	405,140.25	165,482.17	2,065.10	11.96	192	342
052	07/26/12	08/09/12	338	2.6	405,047.73	165,560.44	2,107.31	405,048.27	165,558.00	2,105.10	2.50	167	179
	08/09/12	09/06/12	328	3.0	405,048.57	165,557.27	2,105.10	405,050.02	165,553.07	2,101.35	4.45	161	159
	09/06/12	10/11/12	350	0.5	405,050.50	165,552.29	2,101.35	405,051.60	165,547.71	2,098.17	4.72	167	135

Appendix B, Table 1: 2012 Nisqually Glacier measured velocity data (continued).

Rock ID	Measurement Date		Roll		Starting Position			Ending Position			Distance	Direction	Rate
	First	Second	Deg	Dist (m)	X (m)	Y (m)	Z (m)	X (m)	Y (m)	Z (m)	m	Degrees	mm/day
053	07/26/12	08/09/12	278	1.7	405,034.84	165,529.75	2,104.75	405,034.86	165,527.33	2,102.68	2.42	179	173
	08/09/12	09/06/12	303	6.0	405,035.36	165,527.26	2,102.68	405,036.00	165,523.55	2,098.84	3.76	170	134
	09/06/12	10/11/12	324	16.0	405,037.54	165,522.56	2,098.84	405,038.98	165,519.00	2,095.15	3.84	158	110
054	07/26/12	08/09/12			405,068.47	165,379.98	2,037.94	405,066.23	165,376.38	2,035.23	4.24	212	303
	08/09/12	09/06/12	14	13.7	405,066.23	165,376.38	2,035.23	405,063.27	165,370.45	2,029.91	6.62	207	237
	09/06/12	10/11/12	150	2.0	405,062.26	165,366.41	2,029.91	405,058.78	165,359.85	2,025.18	7.43	208	212
055	07/26/12	08/02/12			404,997.15	165,174.51	2,001.88	404,996.30	165,172.71	2,001.29	1.99	205	284
	08/02/12	08/09/12			404,996.30	165,172.71	2,001.29	404,995.97	165,171.02	2,000.17	1.73	191	247
	08/09/12	08/16/12			404,995.97	165,171.02	2,000.17	404,995.90	165,169.07	1,999.08	1.94	182	278
	08/16/12	08/30/12	0	0.8	404,995.90	165,169.07	1,999.08	404,995.33	165,166.43	1,997.75	2.70	192	193
	08/30/12	09/06/12	68	0.2	404,995.33	165,166.18	1,997.75	404,994.72	165,164.63	1,997.10	1.66	202	237
056	07/26/12	08/02/12	315	4.0	404,953.21	165,072.00	1,979.21	404,951.81	165,070.84	1,978.02	1.82	230	260
	08/02/12	08/09/12			404,952.67	165,069.98	1,978.02	404,951.89	165,067.76	1,976.65	2.36	199	336
	08/09/12	08/16/12			404,951.89	165,067.76	1,976.65	404,952.52	165,062.32	1,974.34	5.47	173	781
	08/16/12	08/30/12	170	11.3	404,952.52	165,062.32	1,974.34	404,953.70	165,054.82	1,972.07	7.59	171	542
	08/30/12	09/06/12	180	2.3	404,953.11	165,058.20	1,972.07	404,952.85	165,056.21	1,971.31	2.00	187	286
	09/06/12	09/13/12	180	1.8	404,952.85	165,056.92	1,971.31	404,953.19	165,055.65	1,970.59	1.32	165	189

Appendix B, Table 1: 2012 Nisqually Glacier measured velocity data (continued).

Rock ID	Measurement Date		Roll		Starting Position			Ending Position			Distance	Direction	Rate
	First	Second	Deg	Dist (m)	X (m)	Y (m)	Z (m)	X (m)	Y (m)	Z (m)	m	Degrees	mm/day
057	07/26/12	08/02/12	0	1.0	405,053.20	165,076.26	1,978.60	405,052.51	165,074.11	1,977.37	2.26	198	322
	08/02/12	08/09/12			405,052.51	165,073.81	1,977.37	405,051.79	165,071.30	1,975.64	2.61	196	372
	08/09/12	08/16/12			405,051.79	165,071.30	1,975.64	405,051.26	165,069.06	1,973.93	2.30	194	329
	08/16/12	08/30/12	8	1.5	405,051.26	165,069.06	1,973.93	405,050.91	165,064.94	1,971.44	4.13	185	295
	08/30/12	09/06/12	322	4.4	405,050.84	165,064.49	1,971.44	405,050.20	165,062.88	1,970.41	1.74	202	248
	09/06/12	09/13/12	288	1.0	405,051.03	165,061.82	1,970.41	405,051.03	165,060.03	1,969.31	1.79	180	255
	09/13/12	09/20/12	354	18.6	405,051.32	165,059.94	1,969.31	405,050.99	165,058.53	1,966.76	1.44	193	206
	09/20/12	10/11/12	350	6.0	405,051.58	165,052.90	1,966.76	405,049.68	165,047.37	1,963.81	5.84	199	278
058	07/26/12	08/16/12			405,041.59	164,795.04	1,921.90	405,041.79	164,789.61	1,918.86	5.43	178	259
	08/16/12	08/30/12	320	1.5	405,041.79	164,789.61	1,918.86	405,041.14	164,787.03	1,917.29	2.66	194	190
	08/30/12	09/06/12	18	1.5	405,041.44	164,786.68	1,917.29	405,041.44	164,785.56	1,916.56	1.12	180	160
	09/06/12	10/11/12			405,041.30	164,785.13	1,916.56	405,041.03	164,778.23	1,913.77	6.91	182	197
059	07/26/12	08/09/12			405,197.23	164,637.96	1,864.14	405,197.16	164,636.02	1,862.85	1.94	182	138
	08/09/12	08/16/12			405,197.16	164,636.02	1,862.85	405,197.08	164,634.81	1,862.01	1.21	183	173
	08/16/12	08/30/12			405,197.08	164,634.81	1,862.01	405,197.64	164,633.30	1,860.85	1.61	160	115
	08/30/12	09/06/12			405,197.64	164,633.30	1,860.85	405,197.63	164,632.32	1,860.53	0.98	181	140
	09/06/12	09/13/12			405,197.63	164,632.32	1,860.53	405,197.59	164,631.33	1,860.10	0.99	182	141
	09/13/12	09/20/12			405,197.59	164,631.33	1,860.10	405,197.59	164,630.49	1,859.37	0.84	180	119
	09/20/12	10/04/12			405,197.59	164,630.49	1,859.37	405,197.90	164,629.00	1,858.76	1.52	168	109
	10/04/12	10/11/12			405,197.90	164,629.00	1,858.76	405,197.97	164,628.17	1,858.48	0.84	175	119

Appendix B, Table 1: 2012 Nisqually Glacier measured velocity data (continued).

Rock ID	Measurement Date		Roll		Starting Position			Ending Position			Distance	Direction	Rate
	First	Second	Deg	Dist (m)	X (m)	Y (m)	Z (m)	X (m)	Y (m)	Z (m)	m	Degrees	mm/day
060	08/02/12	08/09/12			405,475.70	164,461.77	1,856.40	405,475.67	164,461.84	1,856.21	0.08	341	11
	08/09/12	08/16/12			405,475.67	164,461.84	1,856.21	405,475.62	164,461.63	1,855.94	0.21	193	30
	08/16/12	08/30/12			405,475.62	164,461.63	1,855.94	405,475.35	164,461.52	1,855.90	0.29	248	21
	08/30/12	09/06/12			405,475.35	164,461.52	1,855.90	405,475.34	164,461.40	1,855.64	0.12	187	17
	09/06/12	09/13/12			405,475.34	164,461.40	1,855.64	405,475.30	164,461.42	1,855.54	0.04	301	6
	09/13/12	09/20/12			405,475.30	164,461.42	1,855.54	405,475.38	164,461.50	1,855.41	0.11	45	16
	09/20/12	10/04/12			405,475.38	164,461.50	1,855.41	405,475.10	164,461.37	1,855.28	0.31	245	22
061	08/02/12	08/09/12			405,347.49	164,204.69	1,810.87	405,347.44	164,204.65	1,810.72	0.06	235	8
	08/09/12	09/13/12			405,347.44	164,204.65	1,810.72	405,347.14	164,204.26	1,810.03	0.50	217	14
	09/13/12	10/04/12			405,347.14	164,204.26	1,810.03	405,346.95	164,204.03	1,809.61	0.30	219	14
062	08/02/12	08/09/12			405,447.26	165,152.63	1,994.44	405,447.71	165,150.84	1,993.89	1.84	166	263
	08/09/12	08/30/12			405,447.71	165,150.84	1,993.89	405,448.18	165,145.90	1,992.74	4.96	174	236
	08/30/12	09/06/12			405,448.18	165,145.90	1,992.74	405,448.49	165,144.30	1,992.40	1.63	169	232
063	08/02/12	08/09/12			405,414.32	165,182.22	2,013.09	405,415.07	165,179.89	2,011.99	2.45	162	349
	08/09/12	08/30/12	2	4.3	405,415.07	165,179.89	2,011.99	405,415.78	165,173.10	2,008.59	6.82	174	325
	08/30/12	09/06/12			405,415.74	165,171.81	2,008.59	405,416.36	165,169.85	2,007.78	2.06	162	294
064	08/02/12	08/09/12			405,232.53	164,450.23	1,825.42	405,232.29	164,450.00	1,825.16	0.34	225	48
	08/09/12	09/13/12	240	7.0	405,232.29	164,450.00	1,825.16	405,226.24	164,447.54	1,821.90	6.53	248	187
	09/13/12	10/04/12			405,228.09	164,448.60	1,821.90	405,227.59	164,447.91	1,821.26	0.86	216	41
	10/04/12	10/11/12			405,227.59	164,447.91	1,821.26	405,227.45	164,447.39	1,821.11	0.54	194	76

Appendix B, Table 1: 2012 Nisqually Glacier measured velocity data (continued).

Rock ID	Measurement Date		Roll		Starting Position			Ending Position			Distance	Direction	Rate
	First	Second	Deg	Dist (m)	X (m)	Y (m)	Z (m)	X (m)	Y (m)	Z (m)	m	Degrees	mm/day
065	08/02/12	08/09/12			405,392.59	165,141.34	2,010.15	405,392.99	165,138.97	2,009.23	2.40	170	343
	08/09/12	08/30/12			405,392.99	165,138.97	2,009.23	405,395.16	165,130.88	2,005.58	8.38	165	399
066	08/02/12	08/09/12	0	1.0	405,345.79	165,246.32	2,042.85	405,345.96	165,243.63	2,041.95	2.69	176	385
067	08/09/12	08/30/12	354	3.1	405,585.91	165,018.71	1,956.55	405,586.01	165,017.93	1,954.19	0.79	173	37
	08/30/12	09/06/12	20	10.7	405,586.11	165,016.99	1,954.19	405,586.18	165,016.86	1,952.84	0.15	151	22
068	08/09/12	08/16/12			405,442.63	164,462.98	1,850.39	405,442.36	164,462.81	1,849.88	0.32	238	46
	08/16/12	08/30/12			405,442.36	164,462.81	1,849.88	405,442.39	164,462.58	1,849.54	0.23	172	16
	08/30/12	09/06/12			405,442.39	164,462.58	1,849.54	405,442.28	164,462.53	1,849.43	0.13	247	18
	09/06/12	09/13/12			405,442.28	164,462.53	1,849.43	405,442.32	164,462.40	1,849.19	0.14	164	20
	09/13/12	09/20/12			405,442.32	164,462.40	1,849.19	405,442.51	164,462.42	1,849.07	0.19	82	28
	09/20/12	10/04/12			405,442.51	164,462.42	1,849.07	405,442.23	164,462.18	1,848.82	0.37	229	26
069	08/09/12	09/13/12			405,434.55	164,144.26	1,806.55	405,434.52	164,143.94	1,806.02	0.32	186	9
	09/13/12	10/04/12			405,434.52	164,143.94	1,806.02	405,434.50	164,144.13	1,805.79	0.19	354	9
070	08/09/12				405,356.52	165,260.47	2,044.08						
071	08/09/12	09/13/12			405,410.90	164,138.20	1,804.84	405,411.08	164,137.62	1,804.44	0.61	163	17
	09/13/12	10/04/12			405,411.08	164,137.62	1,804.44	405,411.18	164,137.62	1,804.06	0.10	94	5
072	08/09/12	08/30/12	350	1.0	405,331.86	165,306.77	2,059.14	405,330.10	165,296.96	2,055.02	9.97	190	475
	08/30/12	09/06/12			405,330.15	165,296.65	2,055.02	405,329.83	165,294.11	2,054.00	2.57	187	367
	09/06/12	09/13/12	325	0.8	405,329.83	165,294.11	2,054.00	405,329.00	165,291.35	2,052.71	2.88	197	411
	09/13/12	10/11/12	270	0.5	405,329.14	165,291.15	2,052.71	405,327.08	165,280.92	2,049.45	10.43	191	372

Appendix B, Table 1: 2012 Nisqually Glacier measured velocity data (continued).

Rock ID	Measurement Date		Roll		Starting Position			Ending Position			Distance	Direction	Rate
	First	Second	Deg	Dist (m)	X (m)	Y (m)	Z (m)	X (m)	Y (m)	Z (m)	m	Degrees	mm/day
073	08/09/12	09/13/12			405,272.28	164,230.30	1,805.67	405,272.33	164,229.17	1,804.77	1.13	178	32
	09/13/12	09/27/12			405,272.33	164,229.17	1,804.77	405,272.22	164,228.86	1,804.46	0.32	198	23
	09/27/12	10/04/12			405,272.22	164,228.86	1,804.46	405,272.26	164,228.85	1,804.36	0.04	106	5
074	08/09/12	08/30/12	16	2.8	405,339.15	165,425.98	2,090.88	405,336.77	165,416.45	2,086.51	9.82	194	468
	08/30/12	09/06/12	192	0.8	405,336.54	165,415.65	2,086.51	405,335.82	165,412.24	2,085.24	3.48	192	498
	09/06/12	09/13/12			405,335.87	165,412.49	2,085.24	405,334.71	165,409.32	2,084.20	3.37	200	481
075	08/09/12	09/06/12			405,200.82	164,031.39	1,753.27	405,200.84	164,031.02	1,752.67	0.37	178	13
	09/06/12	09/13/12			405,200.84	164,031.02	1,752.67	405,200.81	164,031.10	1,752.55	0.09	340	13
	09/13/12	10/04/12			405,200.81	164,031.10	1,752.55	405,200.86	164,030.83	1,752.10	0.28	170	13
076	08/09/12	09/13/12	42	1.1	405,375.48	165,741.67	2,179.90	405,373.74	165,720.10	2,169.99	21.64	185	618
	09/13/12	09/20/12			405,373.52	165,719.85	2,169.99	405,373.64	165,716.18	2,168.04	3.68	178	525
	09/20/12	10/11/12			405,373.64	165,716.18	2,168.04	405,371.98	165,704.91	2,163.17	11.39	188	542
077	08/09/12	08/16/12			405,207.32	164,611.58	1,855.41	405,207.21	164,610.47	1,854.66	1.12	185	160
	08/16/12	08/30/12			405,207.21	164,610.47	1,854.66	405,207.68	164,609.16	1,853.58	1.39	160	99
	08/30/12	09/06/12			405,207.68	164,609.16	1,853.58	405,207.76	164,608.50	1,853.38	0.67	173	95
	09/06/12	09/13/12			405,207.76	164,608.50	1,853.38	405,207.66	164,607.49	1,853.05	1.01	186	144
	09/13/12	09/20/12			405,207.66	164,607.49	1,853.05	405,207.58	164,606.93	1,852.28	0.57	188	81
	09/20/12	10/04/12			405,207.58	164,606.93	1,852.28	405,207.74	164,605.55	1,851.79	1.39	173	99
	10/04/12	10/11/12			405,207.74	164,605.55	1,851.79	405,207.77	164,604.83	1,851.59	0.72	178	103

Appendix B, Table 1: 2012 Nisqually Glacier measured velocity data (continued).

Rock ID	Measurement Date		Roll		Starting Position			Ending Position			Distance	Direction	Rate
	First	Second	Deg	Dist (m)	X (m)	Y (m)	Z (m)	X (m)	Y (m)	Z (m)	m	Degrees	mm/day
078	08/09/12	08/16/12			405,049.64	164,336.06	1,787.35	405,049.42	164,335.49	1,786.35	0.60	201	86
	08/16/12	09/13/12			405,049.42	164,335.49	1,786.35	405,048.75	164,333.96	1,783.51	1.67	204	60
	09/13/12	09/20/12			405,048.75	164,333.96	1,783.51	405,048.52	164,333.42	1,782.75	0.59	204	84
	09/20/12	09/27/12			405,048.52	164,333.42	1,782.75	405,048.43	164,333.22	1,782.26	0.22	203	31
	09/27/12	10/04/12			405,048.43	164,333.22	1,782.26	405,048.21	164,332.90	1,781.79	0.40	215	57
079	08/09/12	08/16/12			405,086.71	164,362.78	1,796.67	405,086.60	164,362.13	1,795.63	0.66	189	94
	08/16/12	09/20/12			405,086.60	164,362.13	1,795.63	405,085.58	164,360.11	1,792.12	2.26	207	65
	09/20/12	09/27/12	210	1.5	405,085.58	164,360.11	1,792.12	405,085.48	164,359.84	1,791.85	0.29	200	41
	09/27/12	10/04/12	0	0.3	405,085.71	164,360.24	1,791.85	405,085.61	164,359.95	1,791.46	0.30	200	43
080	08/09/12	08/30/12	0	12.0	405,180.11	164,509.57	1,829.03	405,180.46	164,506.39	1,825.79	3.20	174	152
	08/30/12	09/06/12	351	1.5	405,180.46	164,502.73	1,825.79	405,180.55	164,502.14	1,825.15	0.60	172	86
	09/06/12	09/13/12			405,180.62	164,501.69	1,825.15	405,180.22	164,500.53	1,824.65	1.23	199	175
	09/13/12	10/04/12	36	1.2	405,180.22	164,500.53	1,824.65	405,179.97	164,498.13	1,823.16	2.41	186	115
	10/04/12	10/11/12	30	2.0	405,179.76	164,497.84	1,823.16	405,179.51	164,497.47	1,822.89	0.44	214	63
081	08/09/12	08/16/12			405,361.96	164,496.35	1,850.56	405,361.89	164,496.05	1,850.42	0.31	194	44
	08/16/12	08/30/12			405,361.89	164,496.05	1,850.42	405,361.90	164,495.71	1,850.14	0.34	177	24
	08/30/12	09/13/12			405,361.90	164,495.71	1,850.14	405,361.65	164,495.34	1,849.83	0.46	214	33
	09/13/12	10/04/12			405,361.65	164,495.34	1,849.83	405,361.45	164,494.81	1,849.72	0.57	200	27
082	08/09/12	08/30/12			405,292.60	164,457.88	1,836.61	405,292.69	164,457.13	1,836.19	0.75	173	36
	08/30/12	09/13/12			405,292.69	164,457.13	1,836.19	405,292.45	164,456.46	1,836.09	0.71	200	51
	09/13/12	10/04/12			405,292.45	164,456.46	1,836.09	405,292.04	164,455.97	1,835.77	0.64	219	30

Appendix B, Table 1: 2012 Nisqually Glacier measured velocity data (continued).

Rock ID	Measurement Date		Roll		Starting Position			Ending Position			Distance	Direction	Rate
	First	Second	Deg	Dist (m)	X (m)	Y (m)	Z (m)	X (m)	Y (m)	Z (m)	m	Degrees	mm/day
083	08/09/12	08/16/12	292	2.6	405,134.51	165,265.53	2,031.71	405,133.42	165,262.72	2,030.35	3.01	201	430
	08/16/12	08/30/12	186	2.4	405,134.15	165,262.43	2,030.35	405,132.01	165,255.87	2,027.64	6.90	198	493
	08/30/12	09/06/12	35	2.4	405,132.09	165,256.60	2,027.64	405,130.97	165,254.14	2,026.47	2.70	204	386
	09/06/12	09/13/12			405,130.55	165,253.54	2,026.47	405,129.84	165,251.15	2,025.78	2.49	197	356
	09/13/12	10/11/12	10	1.5	405,129.84	165,251.15	2,025.78	405,126.04	165,242.00	2,022.16	9.91	203	354
084	08/09/12	08/16/12			405,128.81	165,204.15	2,021.63	405,127.95	165,201.48	2,020.15	2.81	198	401
	08/16/12	08/30/12	251	1.0	405,127.95	165,201.48	2,020.15	405,125.85	165,196.07	2,017.66	5.80	201	414
	08/30/12	09/06/12			405,126.14	165,196.17	2,017.66	405,125.05	165,193.64	2,016.54	2.75	203	393
	09/06/12	09/13/12	27	3.5	405,125.05	165,193.64	2,016.54	405,125.55	165,192.57	2,015.60	1.18	155	169
	09/13/12	10/11/12			405,125.06	165,191.62	2,015.60	405,122.58	165,182.91	2,011.59	9.05	196	323
085	08/16/12	08/30/12			405,582.79	164,806.55	1,907.11	405,583.01	164,806.23	1,905.79	0.39	147	28
	08/30/12	09/06/12			405,583.01	164,806.23	1,905.79	405,582.93	164,806.06	1,905.51	0.19	207	27
	09/06/12	09/20/12			405,582.93	164,806.06	1,905.51	405,582.38	164,806.20	1,904.73	0.56	285	40
	09/20/12	10/04/12	62	3.2	405,582.38	164,806.20	1,904.73	405,582.59	164,805.78	1,904.52	0.47	154	34
086	08/16/12	08/30/12			405,407.45	165,011.67	1,977.61	405,407.41	165,008.16	1,976.82	3.51	181	251
	08/30/12	10/04/12	348	1.8	405,407.41	165,008.16	1,976.82	405,407.62	165,000.07	1,974.81	8.09	178	231
087	08/16/12	08/30/12			405,201.75	164,897.73	1,939.30	405,201.98	164,894.00	1,938.67	3.74	176	267
	08/30/12	09/06/12			405,201.98	164,894.00	1,938.67	405,202.12	164,892.35	1,938.27	1.65	175	236
	09/06/12	09/27/12	306	6.0	405,202.12	164,892.35	1,938.27	405,202.03	164,888.13	1,936.05	4.22	181	201
	09/27/12	10/11/12			405,203.51	164,887.06	1,936.05	405,203.44	164,883.87	1,935.25	3.19	181	228

Appendix B, Table 1: 2012 Nisqually Glacier measured velocity data (continued).

Rock ID	Measurement Date		Roll		Starting Position			Ending Position			Distance	Direction	Rate
	First	Second	Deg	Dist (m)	X (m)	Y (m)	Z (m)	X (m)	Y (m)	Z (m)	m	Degrees	mm/day
088	08/16/12	08/30/12			405,147.04	164,835.75	1,932.32	405,147.40	164,832.10	1,930.86	3.67	174	262
	08/30/12	09/27/12			405,147.40	164,832.10	1,930.86	405,147.54	164,825.02	1,928.09	7.08	179	253
	09/27/12	10/11/12			405,147.54	164,825.02	1,928.09	405,147.71	164,821.96	1,927.30	3.06	177	218
089	08/16/12	08/30/12			405,072.56	164,870.97	1,939.46	405,072.26	164,867.59	1,937.88	3.40	185	243
	08/30/12	09/06/12			405,072.26	164,867.59	1,937.88	405,072.30	164,866.07	1,937.19	1.52	178	217
	09/06/12	09/27/12			405,072.30	164,866.07	1,937.19	405,071.60	164,861.09	1,935.12	5.02	188	239
	09/27/12	10/11/12			405,071.60	164,861.09	1,935.12	405,071.20	164,858.52	1,934.19	2.60	189	186
090	08/16/12	08/30/12			405,045.38	164,928.46	1,943.39	405,045.25	164,925.44	1,943.11	3.02	182	215
	08/30/12	09/27/12			405,045.25	164,925.44	1,943.11	405,044.57	164,919.39	1,942.24	6.10	186	218
	09/27/12	10/11/12			405,044.57	164,919.39	1,942.24	405,044.27	164,916.67	1,941.99	2.73	186	195
091	08/16/12	08/30/12	40	2.5	405,072.96	164,978.07	1,957.22	405,072.45	164,973.96	1,955.19	4.15	187	296
	08/30/12	09/20/12	32	5.0	405,071.96	164,973.37	1,955.19	405,071.38	164,968.24	1,952.52	5.17	186	246
	09/20/12	09/27/12	50	1.5	405,070.57	164,966.94	1,952.52	405,070.40	164,965.38	1,951.53	1.57	186	224
	09/27/12	10/11/12	0	4.0	405,070.05	164,965.09	1,951.53	405,069.36	164,962.07	1,950.07	3.10	193	221
092	08/16/12	08/30/12	28	1.0	405,213.54	165,335.92	2,059.01	405,211.69	165,330.82	2,056.72	5.43	200	388
	08/30/12	09/06/12			405,211.54	165,330.55	2,056.72	405,210.53	165,327.95	2,055.67	2.79	201	399
	09/06/12	09/13/12			405,210.53	165,327.95	2,055.67	405,209.68	165,325.46	2,054.65	2.63	199	376
	09/13/12	09/20/12			405,209.68	165,325.46	2,054.65	405,208.71	165,322.89	2,053.35	2.75	201	392
	09/20/12	10/11/12			405,208.71	165,322.89	2,053.35	405,206.04	165,315.55	2,050.56	7.80	200	372
093	08/30/12	09/20/12	20	2.0	405,348.72	165,189.58	2,029.15	405,349.26	165,182.88	2,026.76	6.72	175	320

Appendix B, Table 1: 2012 Nisqually Glacier measured velocity data (continued).

Rock ID	Measurement Date		Roll		Starting Position			Ending Position			Distance	Direction	Rate
	First	Second	Deg	Dist (m)	X (m)	Y (m)	Z (m)	X (m)	Y (m)	Z (m)	m	Degrees	mm/day
094	08/30/12	09/06/12	314	3.0	405,178.10	164,959.27	1,956.70	405,178.06	164,957.77	1,955.94	1.50	182	214
	09/06/12	09/13/12			405,178.71	164,957.13	1,955.94	405,178.68	164,953.63	1,954.83	3.51	181	501
	09/13/12	09/27/12	337	14.4	405,178.68	164,953.63	1,954.83	405,178.92	164,950.37	1,952.01	3.27	176	233
	09/27/12	10/11/12	270	1.0	405,180.63	164,946.32	1,952.01	405,180.62	164,942.69	1,950.91	3.63	180	259
095	08/30/12	09/06/12			405,237.68	164,608.96	1,850.70	405,237.75	164,608.48	1,850.32	0.48	173	69
	09/06/12	09/13/12			405,237.75	164,608.48	1,850.32	405,237.55	164,607.78	1,849.99	0.73	196	104
	09/13/12	09/20/12			405,237.55	164,607.78	1,849.99	405,237.51	164,607.38	1,849.45	0.41	186	58
	09/20/12	10/04/12			405,237.51	164,607.38	1,849.45	405,237.47	164,606.36	1,848.78	1.02	182	73
	10/04/12	10/11/12			405,237.47	164,606.36	1,848.78	405,237.45	164,605.84	1,848.47	0.52	182	74
096	09/06/12	09/13/12			405,337.56	165,246.85	2,041.72	405,337.13	165,244.16	2,041.18	2.73	189	389
097	09/06/12	09/13/12	17	1.3	405,357.14	165,459.11	2,097.05	405,355.86	165,456.01	2,095.87	3.35	203	479
	09/13/12	09/20/12			405,355.75	165,455.65	2,095.87	405,355.64	165,452.93	2,094.70	2.72	182	388
	09/20/12	10/11/12			405,355.64	165,452.93	2,094.70	405,353.11	165,444.36	2,091.39	8.94	196	426
098	09/06/12	09/13/12			405,384.98	165,653.47	2,148.63	405,383.56	165,649.60	2,146.95	4.13	200	590
	09/13/12	09/20/12	350	2.0	405,383.56	165,649.60	2,146.95	405,383.88	165,646.12	2,145.22	3.49	175	499
	09/20/12	10/11/12	356	4.7	405,383.98	165,645.52	2,145.22	405,382.64	165,635.80	2,140.42	9.81	188	467
099	09/06/12	09/13/12	332	52.0	405,339.20	165,880.00	2,223.97	405,337.45	165,875.75	2,215.50	4.60	202	657
	09/13/12	09/20/12	340	4.0	405,344.89	165,861.75	2,215.50	405,345.41	165,857.60	2,213.03	4.18	173	598
	09/20/12	10/11/12			405,345.83	165,856.46	2,213.03	405,346.28	165,845.17	2,208.01	11.30	178	538

Appendix B, Table 1: 2012 Nisqually Glacier measured velocity data (continued).

Rock ID	Measurement Date		Roll		Starting Position			Ending Position			Distance	Direction	Rate
	First	Second	Deg	Dist (m)	X (m)	Y (m)	Z (m)	X (m)	Y (m)	Z (m)	m	Degrees	mm/day
100	09/06/12	09/13/12	20	2.0	405,036.35	164,313.40	1,778.55	405,036.11	164,313.06	1,777.98	0.41	215	59
	09/13/12	09/20/12			405,035.90	164,312.49	1,777.98	405,034.99	164,311.14	1,776.97	1.63	214	232
	09/20/12	09/27/12			405,034.99	164,311.14	1,776.97	405,034.86	164,310.77	1,776.43	0.40	200	57
	09/27/12	10/04/12	40	1.0	405,034.86	164,310.77	1,776.43	405,034.91	164,310.54	1,776.07	0.24	168	34
101	09/13/12	09/20/12			405,302.95	165,355.32	2,069.22	405,302.05	165,352.48	2,068.34	2.98	198	426
	09/20/12	10/11/12			405,302.05	165,352.48	2,068.34	405,299.50	165,344.49	2,066.07	8.39	198	399
102	09/06/12	09/13/12			405,371.42	165,732.82	2,171.09	405,370.55	165,728.85	2,169.38	4.06	192	580
	09/13/12	10/11/12			405,370.55	165,728.85	2,169.38	405,369.23	165,714.23	2,163.33	14.68	185	524
103	09/13/12	09/20/12			405,321.54	165,539.51	2,109.20	405,321.31	165,536.57	2,107.78	2.94	184	420
	09/20/12	10/11/12			405,321.31	165,536.57	2,107.78	405,319.17	165,528.01	2,104.88	8.82	194	420
104	09/20/12	09/27/12	200	1.0	405,091.86	164,378.89	1,796.05	405,091.61	164,378.35	1,795.41	0.59	204	85
	09/27/12	10/04/12			405,091.72	164,378.64	1,795.41	405,091.57	164,378.21	1,795.01	0.46	199	65
105	09/20/12	10/11/12	70	2.2	405,324.64	165,418.68	2,085.71	405,321.42	165,408.76	2,081.39	10.42	198	496
106	09/27/12	10/04/12			405,044.63	164,249.49	1,764.76	405,044.58	164,249.31	1,764.31	0.18	194	26
107	09/27/12	10/04/12			405,109.64	164,294.59	1,786.03	405,109.48	164,294.31	1,785.60	0.33	210	47
108	09/27/12	10/04/12	0	0.5	405,124.43	164,459.06	1,813.46	405,124.27	164,458.77	1,813.13	0.33	208	47
	10/04/12	10/11/12	0	1.0	405,124.27	164,458.62	1,813.13	405,124.11	164,458.26	1,812.77	0.39	204	56
109	10/11/12				405,422.34	165,422.84	2,082.99						
110	10/11/12				405,365.85	165,719.41	2,163.82						
111	10/11/12				405,361.51	165,725.27	2,166.74						
112	10/11/12				405,259.46	165,433.06	2,081.82						

Appendix C

Appendix 4, Table 1: Rocks and stakes surveyed in both 2011 and 2012.
Note, all are rocks except 1 stake (labeled 5-1-014 and 103-9 below).

Rock ID	Measurement Date	Rock ID	Measurement Date	Time Between Surveys	Velocity Between Surveys	2011 Velocity	2011 Velocity
2011	2011	2012	2012	Days	mm/day	mm/day	mm/day
5_2_010	9/8/2011	001-01	7/19/2012	315	1	99	16
4_3_001	9/1/2011	002-01	7/19/2012	322	2	39	9
5_2_012	9/8/2011	004-01	7/19/2012	315	6	95	14
4_3_006	9/1/2011	005-01	7/19/2012	322	11	26	11
5_2_013	9/8/2011	006-01	7/19/2012	315	7	45	18
5_2_015	9/8/2011	012-01	7/19/2012	315	9	23	20
5_2_016	9/8/2011	013-01	7/19/2012	315	19	42	48
4_3_029	9/1/2011	016-01	7/19/2012	322	18	53	51
5_2_032	9/8/2011	017-01	7/19/2012	315	24	52	69
5_2_003	9/8/2011	019-01	7/19/2012	315	56	71	117
5_2_004	9/8/2011	021-01	7/19/2012	315	70	81	120
5_3_010	9/8/2011	022-01	7/19/2012	315	5	27	18
5_2_005	9/8/2011	024-01	7/19/2012	315	91	114	132
4_3_036	9/1/2011	025-01	7/19/2012	322	8	23	24
5_2_006	9/8/2011	026-01	7/19/2012	315	158	176	273
4_3_011	9/1/2011	027-01	7/19/2012	322	37	53	48
4_3_024	9/1/2011	031-01	7/19/2012	322	33	58	72
4_3_025	9/1/2011	033-01	7/19/2012	322	38	48	88
4_3_016	9/1/2011	040-01	7/19/2012	322	10	21	19
4_3_013	9/1/2011	043-01	7/19/2012	322	15	54	29
4_3_004	9/1/2011	044-01	7/19/2012	322	22	55	52
5_2_022	9/8/2011	045-01	7/19/2012	315	90	105	163
4_3_027	9/1/2011	046-01	7/19/2012	322	13	13	16
5_1_019	9/8/2011	066-03	8/2/2012	329	326	294	385
4_3_014	9/1/2011	069-04	8/9/2012	343	5	32	9
4_3_008	9/1/2011	071-04	8/9/2012	343	7	22	11
4_3_017	9/1/2011	073-04	8/9/2012	343	16	34	20
5_2_020	9/8/2011	077-04	8/9/2012	336	78	84	112
5_2_001	9/8/2011	082-04	8/9/2012	336	26	48	39

Appendix C, Table 1: Rocks and stakes surveyed in both 2011 and 2012 (continued).
Note, all are rocks except 1 stake (labeled 5-1-014 below).

5_1_014	9/8/2011	103-09	9/13/2012	371	468	464	420
5_1_015	9/8/2011	105-10	9/20/2012	378	397	509	496
5_1_009	9/8/2011	109-13	10/11/2012	399	369	555	0
5_1_013	9/8/2011	110-13	10/11/2012	399	632	633	0
5_1_020	9/8/2011	111-13	10/11/2012	399	623	0	0
5_1_018	9/8/2011	112-13	10/11/2012	399	407	391	0