UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

THE NISQUALLY GLACIER, MOUNT RAINIER, WASHINGTON, 1857 - 1979: A SUMMARY OF THE LONG-TERM OBSERVATIONS AND A COMPREHENSIVE BIBLIOGRAPHY

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U.S. GEOLOGICAL SURVEY

OPEN-FILE REPORT 83-541

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Tacoma, WA
1984

UNITED STATES DEPARTMENT OF THE INTERIOR

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ABSTRACT

Nisqually Glacier on Mount Rainier, Washington has a long record of terminus position observations and ice-surface altitude measurements along specific profiles, and has been the topic of numerous scientific studies. From the earliest observations in 1857 to the present many individuals and several different organizations have been involved in data collection at the glacier. All long-term data on the glacier was assembled and reduced to a standard format for this report. A comprehensive bibliography of scientific publications relating to the glacier is included. Between 1857 and 1979, Nisqually Glacier receded a total of 1,945 meters and advanced a total of 294 meters. Advances occurred from 1963-68 and from 1974-79. Ice-surface altitude changes of as much as 25 meters occurred between 1944 and 1955.

INTRODUCTION

The Nisqually Glacier on Mount Rainier, Washington (pl. 1A), has an unusually long and complete history of recorded observations. The first description of the terminus was made in 1857, and in 1918 the National Park Service began to record terminus recession annually. In 1931 the U.S. Geological Survey and Tacoma City Light, a local power company, began a cooperative research effort that included surveying transverse ice-surface altitude profiles to record changes in the ice thickness. Following a lapse between 1933 and 1941, the Geological Survey has resurveyed three transverse profiles almost every year.

Nisqually Glacier has been mapped at approximately 5-year intervals since 1931, and has been photographed extensively since the early 1900's. The glacier has also been the site for numerous short-term research projects.

This report is part of an effort to archive all the Nisqually Glacier data at the Geological Survey Water Resources Division Project Office - Glaciology in Tacoma, Washington. Over the years, many of the original data were lost as the responsibility for the Nisqually Glacier research program was passed from one person or agency to the next. In order to insure against further loss, and to provide a guide to the existing information on Nisqually Glacier,

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this report includes the following: (1) a brief history of scientific observations at Nisqually Glacier, with references to the resulting data, publications, and photographs; (2) a summary of the results of two long-term programs; the annual terminus-position measurements and the annual survey of ice-surface altitude profiles; and (3) a comprehensive bibliography of all publications known to pertain to Nisqually Glacier.

ACKNOWLEDGEMENTS

From 1941 through 1952, Arthur Johnson supervised the profile surveying on Nisqually Glacier. Art's enthusiasm provided the momentum which has kept the program going for nearly 40 years. His coauthors wish to thank him for his helpfulness in searching his memory and files for missing data. We also want to acknowledge a heavy debt to his unpublished manuscript, "Nisqually Glacier--1857-1970, Mount Rainier National Park, Washington", which in many cases was the only source for the information included in this report.

HISTORY OF LONG-TERM SCIENTIFIC OBSERVATIONS AT NISQUALLY GLACIER

A list of significant dates follows:

1857 The first recorded observation of the Nisqually terminus was made by Lt. August V. Kautz, who climbed over the glacier during his unsuccessful attempt to ascend Mount Rainier (Kautz, 1857, p. 393-403).

1870 Samuel F. Emmons toured the Mount Rainier area as a member of the Geological Survey's "Exploration of the 40th Parallel", and wrote a letter to Clarence King which included a description of Nisqually Glacier (King, 1871, p. 162-163).

1884 The earliest known photograph of Nisqually Glacier was taken near the terminus by Allen C. Mason (Veatch, 1969, p. 4).

1885 James Longmire, an early settler in the area, recorded the position of the terminus (Veatch, 1969, p. 4).

1896 A party from the Geological Survey, headed by Israel C. Russell, spent two weeks exploring the glaciers on Mount Rainier (Russell, 1898, p. 355-409).

1904-1912 Asahel Curtis, a Seattle photographer, took many pictures of Mount Rainier, including a number of Nisqually Glacier. A collection of his photographs and negatives is now at the Washington State Historical Society Museum in Tacoma, Washington.

1905 J. N. LeConte made the first attempt to record the glacier's motion, by setting stakes in the ice about 900 m above the 1905 terminus (LeConte, 1907, p. 108-114).

1908 The terminus was surveyed for the first time by Ray C. Kautz, an inspector on the road being built to Paradise (Potts, 1954, p. 3-4).

1910-1911 Francois E. Matthes mapped Mount Rainier, and photographed the area during the same period (Matthes, 1915, p. 61-65; Arthur Johnson, 1973, p. 18). Many of his negatives are archived at the World Data Center-A, Glaciology, Boulder, Colorado, and some of the prints are on file at the Project Office - Glaciology, Tacoma, Washington.

1918 F. W. Schmoe, a park naturalist, began annual measurements of the Nisqually terminus (Arthur Johnson, 1973, p. 37). The measurements were continued by the National Park Service until 1960.

1930 Llewellyn Evans, of Tacoma City Light, initiated research on Nisqually Glacier. Tacoma City Light wanted to know how the continued recession of

Nisqually Glacier would affect the discharge of the Nisqually River, and consequently their hydroelectric plants (Arthur Johnson, 1973, p. 9).

1931 Evans and G. L. Parker, of the Geological Survey, set two transverse lines of stakes in the glacier, and determined the ice-surface altitude by surveying the lines. The original lines were resurveyed in 1932 and 1933. Nisqually Glacier was also mapped in 1931, in a joint effort by Tacoma City Light, the Geological Survey, and the National Park Service (Arthur Johnson, 1973, p. 9).

1941 Arthur Johnson, of the Geological Survey Conservation Division in Tacoma, resumed measurement of the 1931-33 ice-surface altitude profiles, which were designated Profiles 1 and 2 (Arthur Johnson, 1973, p. 53).

1942 A third profile, higher on the glacier, was added (Arthur Johnson, 1973, p. 53). Fred M. Veatch, of the Geological Survey Water Resources Division in Tacoma, began to photograph the glacier each year from fixed points (Veatch, 1969, p. 1-52). His program has been continued to the present. The negatives and prints are on file at the Project Office - Glaciology, Tacoma, Washington.

1960 The Conservation Division took over the annual survey of the terminus from the Park Service in 1960.

1966 The Conservation Division turned over all the Nisqually Glacier studies to the Project Office - Glaciology, Tacoma, Washington, which continues them today.

1975 The Geological Survey began to locate the terminus position by aerial photography, rather than ground measurements. The negatives and prints are on file at the Project Office - Glaciology, Tacoma, Washington.

1976 The annual survey of the ice-surface altitude profiles was switched from fall to spring to avoid crevasse problems. The profiles were relocated slightly and are now termed A, B, and C to distinguish them from the old profiles 1, 2, and 3.

TERMINUS RECESSION

The distance from the Nisqually Glacier terminus to the site of the former highway bridge (which spanned the Nisqually River from 1936-1955) from 1840 to 1979 is tabulated in Table 1. For each time interval, the recession, cumulative recession, and source of the data are listed.

The terminus receded continuously from the time it was first observed in 1857 (the 1840 position is estimated from tree ring data[4]) through 1963, with the exception of a slight advance sometime between 1905 and 1908 (Harrison, 1951b; A. Johnson, 1973, p. 45). However, by 1951 the terminus was an inactive tongue of debris-covered ice, and measurements of its recession did not reflect the general health of the glacier. During the same period that the terminus was stagnating, the glacier had been thickening at the level of the highest transverse profile, and an active ice front eventually overrode the lower glacier (Veatch, 1969, p. 28-33). By 1964 the stagnant ice was gone, and the terminus had begun a 5-year advance. In 1969 Nisqually Glacier was again retreating, but since 1975 the glacier has been gaining ground.

Since 1857 Nisqually Glacier has retreated a total of 1,945 m, and advanced 294 m.

[4]As a glacier retreats, trees begin to grow on the uncovered terrain; the age of the trees, obtained by counting the annual growth rings, is the approximate date the ice last occupied that position.

Table 1.--Terminus position of Nisqually Glacier, 1857-1979

Year	Recession in meters from former highway bridge.[5] For period	Cumulative	
1840-57	210	---	1840 position estimated from tree ages (Sigafoos and Hendricks, 1961, p. 8-10). 1957 position from A. V. Kautz's observations (Kautz, 1875; Schmoe, 1925, p. 4; Arthur Johnson, 1973, p. 28).
1857-85	232	0	In 1885 the terminus was at the approximate position of the former highway bridge (Reid, 1913, p. 749-750; Brockman, 1938, p. 770; Arthur Johnson, 1973, p. 33-34).
1885-92	43	43	From Len Longmire (Brockman, 1938, p. 770).
1892-1905	232	275	LeConte's measurement (LeConte, 1907, p. 108-114; Arthur Johnson, 1973, p. 35).
1905-08	-2	273	Terminus advanced. From Ray Kautz (Potts, 1954, p. 3-4; Arthur Johnson, 1973, p. 35-36).
1908-10	33	306	From first map of Mount Rainier National Park, 1910.
1910-18	137	443	
1918-19	18	461	
1919-20	14	475	
1920-21	32	507	Data for 1918-1960 from National Park Service measurements
1921-22	20	527	
1922-23	13	540	

Table 1.--Terminus position of Nisqually Glacier, 1857-1979--Continued.

Year	Recession in meters from former highway bridge.[5] For period	Cumulative
1923-24	25	565
1924-25	22	587
1925-26	26	613
1926-27	13	626
1927-28	27	653
1928-29	16	669
1929-30	36	705
1930-31	15	720
1931-32	15	735
1932-33	13	748
1933-34	47	795
1934-35	16	811
1935-36	20	831
1936-37	17	848
1937-38	27	875
1938-39	26	901
1939-40	21	922
1940-41	38	960
1941-42	17	977
1942-43	24	1001
1943-44	24	1025

Table 1.--Terminus position of Nisqually Glacier, 1857-1979--Continued.

Year	Recession in meters from former highway bridge.[5]		
	For period	Cumulative	
1944-45	21	1046	
1945-46	14	1060	
1946-47	34	1094	
1947-48	27	1121	
1948-49	38	1159	
1949-50	20	1179	
1950-51	22	1201	From 1951-1963 the measurements were to the stagnant ice front. An active ice front began moving down the glacier in the early 1950's and overrode the stagnant terminus by 1964.
1951-52	23	1224	
1952-53	15	1239	
1953-54	14	1253	
1954-55	24	1277	
1955-56	20	1297	
1956-57	23	1320	
1957-58	24	1344	
1958-59	38	1382	
1959-60	38	1420	
1960-61	165	1585	Geological Survey took over measurements from the National Park Service.
1961-62	9	1594	
1962-63	46	1640	
1963-64	-17	1623	Terminus advancing.
1964-65	-52	1571	

Table 1.--Terminus position of Nisqually Glacier, 1857-1979--Continued.

Year	Recession in meters from former highway bridge.[5] For period	Cumulative	
1965-66	-44	1527	
1966-67	-25	1502	
1967-68	-8	1494	
1968-69	10	1504	Terminus in retreat.
1969-70	6	1510	
1970-71	11	1521	1971 position estimated.
1971-72	15	1536	
1972-73	22	1558	
1973-74	8	1566	
1974-75	-4	1562	Terminus advancing. Due to the hazards created by rockfalls from the advancing terminus, aerial photography replaced ground surveys in 1975. Photographs of the terminus were not obtained in 1977.
1975-76	-30	1532	
1976-78	-91	1441	
1978-79	-22	1419	

[5]The former highway bridge (1936-55) has traditionally been used as the reference from which recession is measured. In the interests of consistency, the same reference is used here. The present bridge is 198 m downstream from the site of the former bridge.

ICE-SURFACE ALTITUDE PROFILES

Profiles 1, 2, and 3 are 550 m, 1,300 m, and 2,370 m respectively upglacier from the 1976 terminus, which was 1,532 m from the old bridge (pl. 1A). Since 1941, all three profiles have been surveyed nearly every year, and Profiles 1 and 2 were also measured from 1931-1933. A fourth profile, 2A, was surveyed from 1948 until 1954, when it was abandoned because of crevasses. The data from 2A are not included here because the measurements cover a short period, and are unlikely to be resumed.

Traditionally the surveying was done in late August or September, but the upper and lower profiles became increasingly difficult to cross at that time of year due to crevasses. In 1976 the surveying was switched to early May to reduce the field-work hazards. The profiles were relocated slightly in order to use instrument stations that are snow free in the spring. (A list of past and present instrument stations and their UTM coordinates is presented in table 2.) The new profiles are referred to as A, B, and C, and their locations relative to the old profiles are shown on plate 1A.

During spring surveying the winter snow depth is probed at each observed point on the profile and subtracted from the altitude of the spring surface. This method measures the altitude of the ice surface at the end of the previous summer's ablation and also provides winter snow-accumulation data.

The ice-surface altitude profiles for each year are plotted on plates 2, 3, and 4. The only year in which the glacier was surveyed, but for which the data are missing, is 1966.

The annual mean ice-surface altitudes for each profile are listed in tables 3, 4, and 5, and are plotted on plate 1B. The sudden jump in the mean altitudes in 1976 is due in part to the relocation of the profiles, and in part to the shift from a fall survey to a spring survey. The change in mean altitude due to relocating the profile is defined in the case of profiles 2 and B, since both were surveyed in the fall of 1976. However, it is still difficult to compare the profiles surveyed in the spring with those surveyed in the fall because an unknown amount of emergence flow occurred between September and May.

The ice-surface altitude data have provided a unique record of kinematic waves propagating through glacier ice. Examination of plate 1B shows that two waves have moved down Nisqually Glacier causing a substantial rise and fall in the ice-surface altitude as the waves passed each of the profiles.

The first and largest wave was detected when the mean altitude at Profile 3 rose by 25 m between 1944 and 1951. The bulge propagated downglacier at velocities 2 to 6 times greater than the average surface velocity of the ice (Arthur Johnson, 1960, p. 59-60; Meier and J. N. Johnson, 1962, p. 886). The wave crest reached Profile 2 in 1957, Profile 1 in 1958, and the terminus in 1964. The maximum amplitude of the wave was 31 m at Profile 2. A second, smaller wave crested at Profile 3 in 1956, reached Profile 2 in 1963, and Profile 1 in 1965.

Both waves traveled from Profile 3 to Profile 2 in 6-7 years, at an approximate rate of 157-180 m/year; and from Profile 2 to Profile 1 in 1-2 years, at a rate of 380-760 m/year (Arthur Johnson, 1973, p. 63-64).

NOTES ON THE SURVEYING

Until the late 1960's, the profiles were surveyed with a transit and stadia rod. The accuracy of this method is estimated to be ±0.3 m. The surveying is now done by triangulation using one-second theodolites. The vertical accuracy at 1.7 km, the maximum distance sighted, is ±0.03 m. A much more significant source of error is the estimation of the local average surface. In spring surveys the ice-surface roughness is sampled a discreet number of times by means of snow-thickness probes. A large number of individual probings may be averaged to give an approximation of snow thickness. This thickness, subtracted from the surveyed snow-surface altitude, is the ice-surface altitude. It must be assumed that the probes are stopped by the summer surface rather than ice layers within the seasonal snowpack. The standared deviation of probe readings local to individual targets ranges from ±0.10 to ±0.80 m, with an average of ±0.25 m for all of the profiles. In the fall surveys the summer surface is sampled an infinite number of times in the process of the rod person's subjective determination of the best "average" point at which to establish the station. This error is comparable to that of the spring error, ±0.25 m.

Table 2.--Past and present instrument stations on Nisqually Glacier

Present Name	Previous Name(s)	UNIVERSAL TRANSVERSE MERCATOR (UTM) Coordinates (zone 10)		Altitude (meters)	Remarks
		X (meters)	Y (meters)		
Stab[6]	TP1	597037.914	5184686.511	2149.946	
P2002	TP2	596768.404	5184182.306	2001.796	
Fuzzy[6]	TP3	596361.184	5183713.633	1842.330	
Nunatak[6]	TP4, BM5298	595851.500	5183070.549	1615.306	Azimuth reference station for profile A
Cornice[6]	TP5	595724.556	5184655.657	2082.165	
Cheek[6]	TP6, BM6293 BM6295	596548.979	5184238.258	1918.362	Azimuth reference station for profiles 3 and 2A.
P1902	TP7	596515.589	5184158.052	1902.414	
Stoned[6]	TP8	596575.774	5183667.618	1931.332	Azimuth reference station for profile C
Chipmunk[6]	TP9	596860.303	5184189.147	2068.789	Azimuth reference station for profile
Burp[6]	TP10	596156.994	5183181.389	1706.785	Endpoint for profile A.
Toenail[6]		596661.627	5183912.520	1971.567	Endpoint for profile B.
Boomerang[6]		596536.610	5185154.495	2145.157	Endpoint for profile C.
Hangover[6]		595517.549	5184227.453	2115.947	
P2112	BM6903	596499.923	5185147.880	2112.253	

Table 2.--Past and present instrument stations on Nisqually Glacier--Continued

Present Name	Previous Names(s)	UNIVERSAL TRANSVERSE MERCATOR (UTM) Coordinates (zone 10)		Altitude (meters)	Remarks
		X (meters)	Y (meters)		
BM6882		596473.000	5185174.000	2097.500	Endpoint for profile 3, 1954-1957, coordinates approximate.
P2089	BM6853	596463.142	5185173.841	2088.799	Endpoint for profile 3, 1942-1953 and 1958-1971.
P1959	BM6426 BM6428	596564.379	5184662.523	1958.883	Endpoint for profile 2A.
P1879	BM6165	596469.088	5183985.124	1879.253	Endpoint for profile 2.
P1852	BM6074 BM6073	596380.133	5183740.604	1851.531	Azimuth reference station for profile 2.
P1703	BM5587	596138.748	5183144.648	1702.993	Endpoint for profile 1.
P1416	Point A	595609.906	5182871.501	1415.872	Instrument stations P1416, P1429, P1415, P1349, and P1357 used in terminus measurements.
P1429	Point B	595534.957	5182856.104	1428.992	
P1415	Point C	595550.158	5182817.809	1415.362	
P1349	Point D	595507.565	5182528.274	1348.714	
P1357	Point E	595507.575	5182552.989	1357.424	

[6]Official Geological Survey horizontal control station.

Table 3.--Annual mean altitudes for profiles 1 and A.

The mean altitude for profile 1 is calculated from approximately 152 to 610 m west of P1703, the profile endpoint. The mean altitude for profile A is calculated from approximately 225 to 630 m west of Burp, the profile endpoint.

Date	Mean Altitude (meters)	Date	Mean Altitude (meters)
Profile 1		Profile 1 Continued	
1931[7]	1618.2	Oct. 6, 1969	1604.8
1932	1617.0	Sept. 28, 1970	1602.9
1933	1622.4	Sept. 14, 1971	1602.6
1936[7]	1615.4	Sept. 27, 1972	1604.2
Aug. 26, 1941	1604.2	Sept. 13, 1973	1605.3
		Sept. 18, 1974	1608.1
Aug. 21, 1942	1601.7		
Aug. 26, 1943	1598.1		
Sept. 18, 1944	1594.7		
Sept. 11, 1946	1590.4	Profile A	
Sept. 2, 1948	1585.3		
Sept. 22, 1949	1584.4	Sept. 4, 1976	1623.8
Sept. 15, 1950	1582.2	Oct. 18, 1977	1622.3
Sept. 5, 1951	1580.7	May 20, 1978	1627.1
Sept. 9, 1952	1578.9	Oct. 4, 1978	1622.6
Sept. 10, 1953	1577.3	May 15, 1979	1625.4
Sept. 22, 1954	1576.7		
Sept. 22, 1955	1579.8		
Sept. 6, 1956	1586.5		
Sept. 5, 1957	1594.7		
Oct. 3, 1958	1598.1		
Aug. 29, 1959	1598.1		
Sept. 18, 1960	1597.8		
Sept. 26, 1961	1598.1		
Sept. 8, 1962	1605.4		
Aug. 29, 1963	1608.7		
Sept. 13, 1964	1614.2		
Sept. 1, 1965	1615.7		
Aug. 30, 1966	1614.2		
Aug. 30, 1967	1612.7		
Sept. 26, 1968	1608.4		

[7]Mean altitude determined from maps made in 1931 and 1936.

Table 4.--Annual mean altitudes for profiles 2 and B.

The mean altitude for profile 2 is calculated from approximately 122 to 610 west of P1879, the profile endpoint. The mean altitude for profile B is calculated from approximately 300 to 870 west of Toenail, the profile endpoint.

Date	Mean Altitude (meters)	Date	Mean Altitude (meters)
Profile 2		Profile 2 Continued	
1931	1827.3	Aug. 27, 1963	1844.3
Sept. 30, 1932	1832.8	Sept. 12, 1964	1843.1
July 31, 1933	1839.8	Aug. 31, 1965	1841.9
1936[8]	1839.8	Aug. 31, 1966	1839.2
1940[8]	1827.6	Aug. 28, 1967	1837.3
Aug. 26, 1941	1823.6	Sept. 24, 1968	1832.8
Aug. 21, 1942	1820.0	Sept. 15, 1969	1829.1
Aug. 26, 1943	1817.2	Sept. 28, 1970	1828.5
Sept. 24, 1944	1813.0	Sept. 14, 1971	1831.2
Aug. 22, 1945	1811.7	Oct. 4, 1972	1835.8
Aug. 28, 1946	1810.2	May 30, 1973	1836.4
Sept. 11, 1947	1808.7	Sept. 12, 1973	1836.9
Aug. 31, 1948	1808.1	Sept. 18, 1974	1841.6
Aug. 22, 1949	1809.6	Sept. 1, 1976	1847.1
Sept. 14, 1950	1814.2		
Aug. 21, 1951	1820.3	Profile B	
Sept. 5, 1952	1825.8		
Sept. 11, 1953	1829.7		
Sept. 20, 1954	1833.1	Sept. 2, 1976	1841.8
Sept. 19, 1955	1835.8	Oct. 18, 1977	1836.3
		May 20, 1978	1838.6
Aug. 21, 1956[9]	1838.6	Oct. 4, 1978	1839.6
Oct. 7, 1956	1836.7	May 15, 1979	1838.6
July 12, 1957	1841.3		
Sept. 3, 1957[9]	1839.2		
Sept. 27, 1958	1836.4		
Aug. 30, 1959[9]	1837.3		
Oct. 2, 1959	1836.7		
Sept. 16, 1960	1836.1		
Sept. 14, 1961	1838.6		
Sept. 17, 1962	1843.4		

[8]Mean altitude estimated from maps made in 1936 and 1940.
[9]Corresponds to the profile on Plate 3.

Table 5.--Annual Mean Altitudes for Profiles 3 and C.

The mean altitude for profile 3 is calculated from approximately 30 to 550 west of P2089, the profile endpoint. The mean altitude for profile C is calculated from approximately 90 to 615 west of Boomerang, the profile endpoint.

Date	Mean Altitude (meters)	Date	Mean Altitude (meters)
Profile 3		Profile C	
Aug. 24, 1942	2058.0	May 19, 1978	2085.3
Aug. 26, 1943	2059.5	May 14, 1979	2085.5
Sept. 24, 1944	2057.1		
Aug. 22, 1945	2059.2		
Aug. 22, 1946	2062.0		
Sept. 12, 1947	2065.0		
Sept. 1, 1948	2070.2		
Aug. 24, 1949	2076.0		
Aug. 22, 1951	2082.4		
Sept. 4, 1952	2076.9		
Sept. 14, 1953	2074.2		
Sept. 4, 1954	2076.0		
Sept. 23, 1955	2075.1		
Aug. 22, 1956	2081.5		
Sept. 4, 1957	2076.9		
Sept. 27, 1958	2068.1		
Sept. 17, 1959	2073.2		
Sept. 14, 1960	2077.2		
Sept. 19, 1961	2076.9		
Sept. 20, 1962	2075.4		
Aug. 28, 1963	2074.8		
Sept. 10, 1964	2075.1		
Aug. 30, 1965	2076.3		
Sept. 1, 1966	2069.9		
Aug. 29, 1967	2070.2		
Sept. 25, 1968	2065.6		
Sept. 29, 1970	2070.2		
Sept. 13, 1971	2073.6		

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