OBSERVATIONS ON THE NISQUALLY GLACIER AND OTHER GLACIERS IN THE NORTHWESTERN UNITED STATES (1)

by

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Abstract

Observations have been made on the Nisqually Glacier, Mt. Rainier, Washington: Coleman Glacier, Mt. Baker, Washington; Eliot Glacier, Mt. Hood, Oregon; Sperry, Grinnell and Jackson Glaciers in Glacier National Park, Montana.

For the Nisqually Glacier data on terminal recession span almost a full century. The early part of the record is based on historical data while the latter third is based on actual annual observations. Observed data on changes in surface altitudes and rates of movement on various parts of the glacier are available for a period of over 20 years. Maps of the lower part of the glacier have been prepared at 5-year intervals since 1931. Annual photographs have been taken from a series of key points since 1942 and many earlier photographs have been collected.

Observations were started on the Coleman Glacier in 1949 and have shown a definite advance of the terminus since then.

For the Eliot Glacier data on terminal recession have been recorded since 1925 and changes in surface altitudes through the measurement of two profiles across the glacier since 1940.

For the three glaciers in Glacier National Park terminal recession data have been recorded since 1931. Maps have been made at intervals of all three glaciers. Changes in surface altitudes are being recorded by the measurement of profiles. The observations at the Grinnell Glacier include the determination of annual values of precipitation and runoff. Similar data, as far as known, are not available so near any other glacier in the United States.

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This paper describes observations that have been made on the Nisqually Glacier and several other glaciers in the northwestern United States. Its primary purpose is to acquaint the listener (reader) with the factual data that have been obtained for the several glaciers mentioned rather than to make interpretations thereof. It is hoped that this paper will serve to inform those students interested in glaciers of some of the materials available which can serve as a staring point for many interpretative studies.

The observations on the Nisqually Glacier have been more extensive than on any of the other glaciers herein mentioned and consequently the major portion of this paper will be devoted to it.

Nisqually Glacier, Mt. Rainier, Washington

The Nisqually Glacier, which is located on the southwest side of Mt. Rainier in Mt. Rainier National Park in western Washington, has undoubtedly been seen by more pepople than any other glacier in the United States and it is only natural, therefore, that considerable information relating to it has been obtained. Some of this information is from casual observations and random photographs and some from a definite plan of systematic observations and measurements. This paper presents a brief summary of the data that have been obtained and the changes that have occurred on this glacier. This information logically falls under three headings or subjects, viz.; terminal recession, changes in surface elevation and movement.

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Terminal Recession

Information on the recession of the terminus of the Nisqually Glacier now extends back almost a full century. In 1857, Lt. Kautz, who later became Major General Kautz, with a party attempted to climb to the summit of Mt. Rainier. From his diary which describes the terminus of the glacier it has been possible to determine that the location at that time was about 760 feet downstream from the present highway bridge across the Nisqually River. At the present time the terminus is somewhat over 4,000 feet upstream from the bridge. Positions of the terminus in 1885 and 1892 have been based on information obtained from early settlers and according to this information the terminus in 1885 was at the present location of the highway bridge and by 1892 had moved 140 feet upstream from it. The first definite observation on the location of the terminus was made in 1905 by Prof. Le Conte from the University of California. In that year he placed a rock cairn on the left bank of the canyon opposite the terminus and from this point recorded certain reference angles with a transit. This cairn was found in 1951 and, using Prof. Le Conte's notes, it was determined that the terminus in 1905 was 900 feet upstream from the present highway bridge. The Geological Survey map of Mt. Rainier National Park, which was made in 1910, shows the terminus as 1,000 feet upstream from the bridge. The National Park Service has located the position of the terminus annually since 1918. The terminus locations until 1943 were determined by measuring from known points to the front of the glacier, at the point of the outflowing stream. Due to changes in the location of this stream the year-to-year measurements do not always appear to be consistent but the results do well record the over-all change when several years are considered. Starting in 1943 a map has been made of the terminus each year and the recession determined by a comparison of these maps. The available data on terminal recession are given in the following table.

Nisqually Glacier, Recession of Terminus

Period or Year	Recession (feet)	Total recession since 1857 (feet)	Period 1 or Year	Recession (feet)	Total recession since 1857 (feet)
1857 *a*)		---	1932-1933	44	3,219
1857-1885 *a*)	760	760	1933-1934	155	3,374
1885-1892 *a*)	140	900	1934-1935	54	3,428
1892-1905 *b*)	760	1,660	1935-1936	65	3,493
1905-1910 *c*)	140	1,800	1936-1937	55	3,548
1910-1918 *d*)	410	2,210	1937-1938	90	3,638
1918-1919	59	2,269	1938-1939	85	3,723
1919-1920	46	2,315	1939-1940	70	3,793
1920-1921	106	2,421	1940-1941	125	3,918
1921-1922	67	2,488	1941-1942	56	3,974
1922-1923	44	2,532	1942-1943	79	4,053
1923-1924	83	2,615	1943-1944	79	4,132
1924-1925	73	2,688	1944-1945	68	4,200
1925-1926	86	2,744	1945-1946	45	4,245
1926-1927	43	2,817	1946-1947	112	4,357
1927-1928	89	2,906	1947-1948	88	4,445
1928-1929	52	2,958	1948-1949	126	4,571
1929-1930	118	3,076	1949-1950	65	4,636
1930-1931	49	3,125	1950-1951	72	4,708
1931-1932	50	3,175	1951-1952	76	4,784
			1952-1953	50	4,834

a) Position of terminus in these years determined from historical records and photographs.

b) From marker set by Prof. J. N. LeConte in 1905 which was found in 1951.

c) From topographic map of Mt. Rainier National Park.

d) Annual measurements started by National Park Service and made annually since then.

The above data when shown graphically indicate that during the latter part of the 1890 decade there was a definite change in trend in the rate of recession, the rate being greater since then.

It has been the general belief that the terminal recession has been continuous and the above table has been compiled in accordance with that thought. However, recent studies by Prof. A. E. Harrison, of the University of Washington, indicate that there may actually have been some advance of the terminus during the period 1900 to 1910.

Changes in surface elevation

Attention of the casual observer, and the public as a whole, has been focused on the recession of the terminus while pronounced changes occuring in the surface eltitude of the glacier have been largely overlooked. Definite information on these ahanges has now been obtained over a period of more than 20 years by the measurement of several profiles across the glacier. Four profiles have been measured, at locations 0.5, 1.0, 1.4 and 1.7 miles above the present terminus. The approximate mean altitudes of the individual profiles are 5,200, 6,000, 6,400 and 6,800 feet respectively. The first two were established and first measured in 1931 and remeasured in 1932 and 1933 and then discontinued. Measurements were resumed in 1941 and have been made annually (with some omissions) since then. The uppermost profile, altitude 6,800 feet, was first measured in 1942 and has been measured annually since then, with the exception of 1950. The profile at altitude 6,400 feet was established in 1948 and has been measured annually since then, except in 1950.

The results of these profile measurements are summarized in the following paragraphs, starting with the uppermost one and continuing down the glacier.

The measurements at the uppermost profile showed that the surface was much the same in 1942, 1943 and 1944. Starting with 1945 a very definite raising of the surface was indicated which continued through 1951. The maximum increase from 1944 to 1951 was over 200 feet in a section near the west edge and the average increase across the entire glacier was 83 feet. The 1952 surface was definitely lower than the 1951 surface by an average amount of 18 feet. The decrease continued from 1952 to 1953 at about the same rate as in the preceding year. The measurements at this profile indicate that a wave, which first became apparent in 1945, has been moving down from the higher parts of the glacier. The crest of this wave passed this profile between 1950 and 1951 as shown by the lowering of the surface elevation since then.

The second profile in downstream order (1.4 miles above the terminus) was established in 1948 in order to obtain further information on the increasing surface altitude which was at that time being recorded at the uppermost profile. The measurements at this profile showed an increase in surface altitude through 1951, with the 9152 surface being much the same as in 1951. The 1953 measurements show a decrease since 1952, indicating that the crest of the wave has also passed this profile.

The third profile downstream (1.0 mile above the terminus) was first measured in 1931. No measurements were made durign the years 1934 to 1940. Measurements were resumed in 1941. These showed a continuous decrease in surface elevation through 1948 at which time the surface averaged 63 feet lower than in 1931. The 1949 measurements showed that a reversal had occurred and the surface altitude was increasing. This has continued each year through 1953. The change from 1952 to 1953, however, is not quite as pronounced as in the preceding years, indicating that the crest of the wave is now at or approaching this profile. The change from 1948 to 1952 averaged 58 feet, bringing the 1952 surface almost to the same altitude as it was in 1931.

The lowermost profile (0.5 mile above the terminus) was also first measured in 1931 but not measured during the 1934-40 period. Measurements were resumed in

1941 and, with a few exceptions, have been made annually since then. The available data show that this profile at a point near the center of the glacier was over 200 feet lower in 1953 than it was in 1931. Near both edges there was a lowering of 50 to 75 feet. This profile has shown a continued decrease in surface altitude even though the next profile above (only 1/2 mile upstream) has been showing an increase each year since 1949. Measurements at this profile will be watched with interest during the next few years to determine if the wave that has been moving down the higher parts of the glacier will eventually be reflected at this location and possibly even result in an advance of the terminus.

Over-all changes in the surface of the glacier have been recorded through the medium of mapping at periodic intervals. In 1931 a plan of mapping the glacier at 5-year intervals was initiated which has been continued. The mapping in 1931, 1936, 1941 and 1946 was by ground methods using a plane table. For the 1951 mapping aerial photographs were obtained and a map compiled from these by photogrammetric methods. This map is now in course of preparation for publication. These maps serve to give a picture of the over-all changes. For specific comparisons the profiles above described are more effective.

The information shown by the above described profile measurements clearly indicates that terminal recession measurements alone by no means give a reliable picture of what is occurring on the glacier as a whole.

Movement

In addition to the profile measurements, information has also been obtained on the movement of the glacier. The first observations on the rate of movement of the Nisqually Glacier were made by Prof. Le Conte, from the University of California, in 1905. His observations extended through a 10-day period in July of that year. He found a mean rate of movement of 16 inches per day, but this varied from 13 to 22 inches during the period of observation.

Evans and Parker [1] in 1931 set a series of markers at or near the alignments of the two lowermost profiles. These were observed again in 1932 and 1933. The results of these observations showed that the maximum movement at or near the lowest profile was from 70 to 75 feet per year with movement near the edges of less than 10 feet. At the next profile upstream a maximum movement of approximately 160 feet per year, with movement near the left or east edge of only about 10 feet, was observed.

In 1943 the author and Mr. Howard R. Stagner, who at that time was the park naturalist in Mt. Rainier National Park, marked a number of boulders along or near the alignments for the two lower profiles, 0.5 and 1.0 miles above the terminus. Many of these are still being found, and additional ones have been marked to replace those that have become lost. Location of these rocks in subsequent years shows that at the lower profile during the period 1943 to 1948 the maximum movement was in the magnitude of 30 to 40 feet per year. This has decreased, appreciably in recent yeras, and measurements now indiacte that the maximum movement is less than 10 feet per year at this profile.

At the second profile (1.0 mile from terminus) during the period 1943 to 1947 the maximum movement was 50 to 60 feet per year. This was in the right or west half of the glacier with very little movement near the east edge. With the increase in surface altitude in this part of the glacier a distinct increase in the rate of movement has been observed. As previously stated,for the period 1943 to 1947 the maximum rate was from 50 to 60 feet per year, essentially the same each year. By 1951 this had increased to a maximum rate of over 250 feet per year and from 1951 to 1952 this maximum reached 300 feet.

It has not been possible to obtain much information on movement near the uppermost profile (1.7 miles from terminus) as marked rocks in that area are quite apt to roll or slide or become lost in one of the many crevasses and consequently are not reliable indicators of movement. Some information, however, was obtained in 1945 from a series of markers which had been placed during the previous season. The results of this single year's observations indicate a maximum

(1) Lewelyn Evans, Supt., Tacoma City Light Dept. and G. L. Parker, District Engineer, U. S. Geological Survey.

movement of 250 feet for that particular year. It is of interest to note that during the same year the maximum rate of movement at the second profile located 3,500 feet downstream (1.0 mile above terminus) was only a matter of 50 to 60 feet per year.

In addition to the observations described above, a very valuable fund of information has been accumulated through a collection of pictures. Pictures from various sources, going back to the early 1900's, have been collected. Starting in 1942 a series of key points was selected from which photographs habe been taken periodically since then, most of them annually. These pictures provide a most valuable record of the changes that have occurred on this glacier.

In brief, data are now available relative to the recession of the terminus for almost a full century and for over 20 years on the variations in surface altitudes and rates of movement of the glacier. The early part of the terminal recession record is based only on historical records but the latter one-third is based on annual observations. These data provide a valuable fund of factual information which can serve as a base for studies of many kinds by those interested in the subject of glacier behavior.

Coleman Glacier, Mt. Baker, Washington

The Coleman Glacier is located on the west slope of Mt. Baker, Washington. Observations were initiated on this glacier in 1949 when several permanent reference marks were established, part of the terminus mapped, two profile alignments selected and measured, and a number of photographs obtained. Observations were repeated in 1950, 1952 and 1953. Due to the nature of the surface of the glacier these observations have not been as detailed as those that have been made on the Nisqually Glacier. The observations to date indicate that a wave has been moving down this glacier also. There has been a very definite and pronounced advance of the terminus, in places exceeding 200 feet, during the 4-year period 1949-1953. This, as far as known, is the only glacier where factual data are actually available to show that a terminal advance is in progress. More detailed and continuing observations on this glacier are particularly desirable in view of the marked changes that have already been recorded. These data could be readily obtained by the application of photogrammetric techniques, using terrestrial photographs.

Eliot Glacier, Mt. Hood, Oregon

Eliot Glacier is located on the northeast slope of Mt. Hood, Oregon. The Research Committee of the Mazamas has made annual measurements (with few omissions) since 1925. The terminus has shown a gradual and continued recession, totaling 136 feet in the period 1925 to 1938. Measurements of terminal recession in recenty years have been somewhat uncertain due to the presence of a perennial snowdrift. Indications are that there has been very little, if any, recession.

In 1940 two profiles were established across the lower part of the glacier, one about 500 feet above the terminus and the other a half mile farther up the glacier. These have been measured almost every year since then. The results of these measurements show a continued lowering of the surface of the glacier from year to year. This lowering is least pronounced on the profile nearest the terminus, due to the protective mantle of debris on this part of the glacier. The maximum change on the lower profile during the 12-year period 1940 to 1952 was 30 feet whereas the maximum change on the upper profile during the same period was 80 feet. The 1953 measurements showed continued ablation at the lower profile whereas at the upper profile a possible thickening was indicated. This, however, should not be accepted as a fact until and unless confirmed by observations in the next few years.

Glaciers in Glacier National Park, Montana

There are over 50 named glaciers within Glacier National Park. Definite measurements and observations have been made on three of the larger ones, viz., Sperry, Jackson and Grinnell. Each of these originates in a cirque rimmed by the Continental Divide. Sperry Glacier drains to the Pacific Ocean whereas the Jackson and Grinnel Glaciers drain to the Hudson Bay.

Measurements of terminal recession of these three glaciers was started in 1931 by the National Park Service. The first determinations ware based on several linear measurements from previously marked points to the ice front. Starting in

1945 the Park Service and the Geological Survey, working togheter, initiated a system for mapping the entire fronts, working from a series of permanently marked points. Periodic successive mapping of the ice fronts has afforded a convenient way of determining terminal changes.

Profile lines were established on the Sperry and Grinnell Glaciers in 1949 and 1950, respectively, for the purpose of obtaining a definite measure of changes in surface elevations.

The Grinnell, Sperry and Jackson Glaciers were mapped by ground methods in 1937, 1938 and 1939, respectively, by the National Park Service. The Grinell and a portion of the Sperry Glacier were remapped in 1946. Aerial photographs were obtained of most of the known glaciers in the park in 1950 through the cooperative efforts of the National Park Service, the U. S. Forest Service, the Glacier National Park Historical Association, and the American Geographical Society. Maps of the Grinnell and Sperry Glaciers were compiled from these photographs and have been published by the U. S. Geological Survey. A map of the Jeakson Glacier has been compiled from the photographs by the U. S. Forest Service but has not been prepared for publication.

The investigations in connection with the Grinnell Glacier have included the measurements of annual precipitation and runoff. In 1949 a storage precipitation gage was installed near the end of the horse trail which is only about 1/3 mile from the glacier. This installation was made through the copperative efforts of the National Park Service and the U. S. Weather Bureau. In the same year a stream flow measuring station was established by the U. S. Geological Survey on Grinnell Creek just below the outlet of Grinnell Lake and about 1-1/2 miles from the glacier. This station measures the runoff from the glacier and its enclosing cirque. The records that have been obtained to date are tabulated below.

Precipitation in inches at storage precipitation gage 1/3 mile from Grinnell Glacier, approximate altitude 6,200 feet

Inclusive dates	Number of days	Precipitation (inches)
Aug. 27 1949 to July 20, 1950	327	125.1
July 21, 1950 to July 24, 1951	369	117.5
July 25, 1951 to July 15, 1952	356	108.3
July 16, 1952 to July 31, 1953	382	106.9

Runoff in inches at gaging station on Grinnell Creek below outlet of Grinnell Lake, approximate altitude 5,000 feet

Year	Runoff (inches)
Oct. 1, 1949 - Sept. 30, 1950	106.5
Oct. 1, 1950 - Sept. 30, 1951	105.0
Oct. 1, 1951 - Sept. 30, 1952	89.6
Oct. 1, 1952 - Sept. 30, 1953	97.2

The above records show a remarkable consistency and give very valuable information on precipitation and runoff in the higher altitudes of this section of the Rocky Mountains. The stream flow measuring station on Grinnell Creek (about 1-1/2 miles from the glacier) is believed to be nearer to a glacier than any other such station in the United States, suggesting that its record is the most representative of the runoff from a glacier and its immediate surrounding area that is now available. This record is a most significant contribution to the study of meteorology in a glacier area.

The aerial and terrestrial photographs that have been obtained in recent years, the maps that have been compiled, and the field measurements of terminal recession, surface changes, and movement of the ice, in addition to the information that has been obtained from other sources, provide a store of basic data for studies of various kinds. The data recently obtained will become even more valuable as observations are continued from year to year.