

VARIATION IN SURFACE ELEVATION OF THE NISQUALLY GLACIER MT. RAINIER, WASHINGTON

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ABSTRACT

Variation in surface elevations of the Nisqually Glacier has been recorded since 1942 by the annual measurement of three profiles across the glacier, designated as nos. 1, 2, and 3, located 0.5, 1.0, and 1.7 miles respectively from the terminus, at approximate mean elevations of 5,250, 6,000, and 6,800 feet. A fourth profile, 2-A, located 1.4 miles from the terminus at an approximate mean elevation of 6,450 was measured from 1948 to 1954. These profiles cross the glacier approximately normal to the direction of flow. Additional data are available from measurements made at profiles no. 1 and no. 2 in 1931, 1932 and 1941. The results of these measurements show that a wave or surge has been moving down the glacier.

The mean elevation at profile no. 3 began to increase in 1945 and continued through 1951 when it was 83 feet higher than in 1944. The general trend from 1952 to 1959 has been a decrease in elevation with a net change of 30 feet since 1951. The surface elevation at profile no. 2 continued to decrease through 1948, but began to increase in 1949 and continued to do so through 1957 in which year the mean elevation was 102 feet higher than in 1948. The wave became apparent at profile no. 1 in 1954 or 9 years after it first became evident at profile no. 3. The mean elevation has continued to increase and in 1959 was 70 feet higher than in 1954. The increase in surface elevation has been accompanied by a pronounced increase in rate of movement of the glacier.

A program of mapping the Nisqually Glacier at 5 year intervals was initiated by Lewellyn Evans, Superintendent, Tacoma City Light Department and G. L. Parker, District Engineer, U. S. Geological Survey in 1931 as a means of recording changes in the glacier. The 5 year mapping program has been carried out. A map of the glacier in 1951 and 1956 has recently been published. In 1931, along with setting markers for the determination of movement, two profiles were measured across the glacier, referred to in this paper as profile no.1 and no. 2. These are located 0.5 and 1.0 miles respectively from the terminus (1956 position). These profiles were remeasured in 1932 and 1933 after which measurements were discontinued. The author, in 1941, while mapping the glacier resumed measurement of these two profiles. In 1942 a third profile, no.3, and in 1948 a fourth, no. 2-A, was established. These are located 1.7 and 1.4 miles respectively upglacier from the terminus. The location of the four profiles is shown in the inset on figure 1. The measurements of these profiles have provided a record of pronounced variations in the surface elevation of the glacier and have also provided a record of a wave or surge that has been moving down the glacier. This paper will be devoted primarily to a description of the growth and movement of this wave. Before starting this discussion, a brief description of the glacier is in order.

The Nisqually Glacier is located on the southwest flank of Mt. Rainier. It is one of over 20 glaciers on the mountain and one of 6 that radiate from the summit of the mountain like the arms of a starfish. From the summit of the mountain to the terminus (1956 position) it has a length of $4\frac{1}{2}$ miles, in which distance it has a range in elevation of 10,000 feet. The terminus, as shown on the 1956 map, was at an elevation of 4,400 feet. It is a valley glacier and its greatest width does not exceed one-half mile. The Wilson Glacier, a cirque glacier with its upper limits at about an elevation of 10,000 feet, is tributary to the Nisqually Glacier on its

right or west side, between the elevations of 7,200 and 8,600 feet. The observations on the Nisqually Glacier on which this paper is based are downglacier from the confluence with the Wilson Glacier. The Nisqually Glacier, as measured on the 1956 map (and partly on the map of Mt. Rainier National Park) has an area of 1070 acres and the Wilson Glacier an area of 340 acres or a total of 1410 acres, 2.2 square miles. The distribution of area in relation to elevation is tabulated below.

Section	Area, Acres	Percent of Total	Cumulative Percentage
Above 12,000	160	11.4	11.4
10,000 to 12,000	195	13.8	25.2
8,000 to 10,000	450	31.8	57.0
6,000 to 8,000	460	32.6	89.6
4,000 to 6,000	145	10.4	100.0
Total	1410		

The above figures show that about one-fourth of the area is above 10,000 and over one-half above 8,000 feet in elevation. The median elevation is approximately 8,400 feet.

As previously mentioned, two profile lines were established in 1931, a third one in 1942 and a fourth one in 1948. The results of the measurements of these four profiles will be summarized in the following paragraphs, starting with the uppermost and moving downglacier. Profiles for selected years are shown graphically in figure 1.

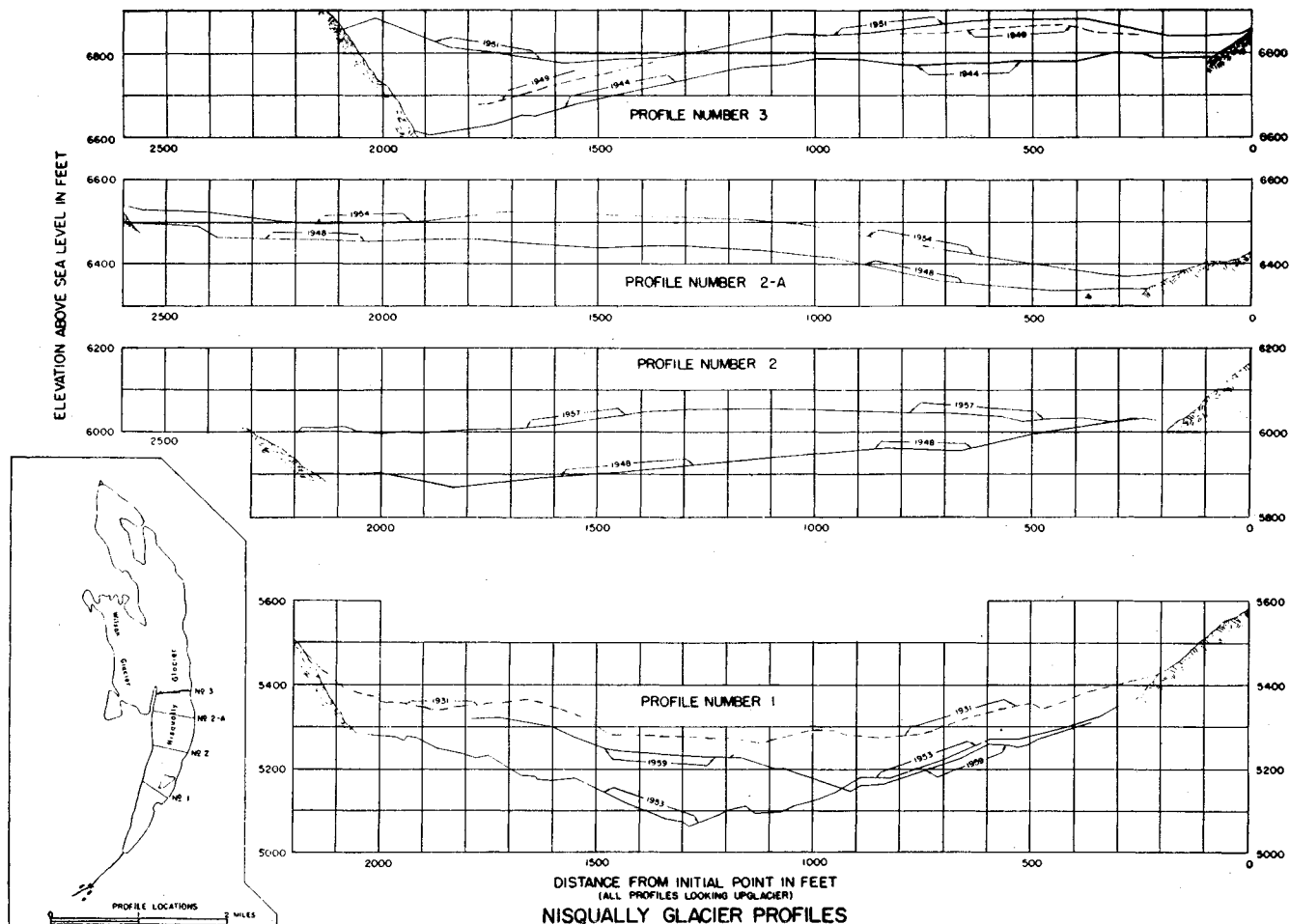
The uppermost profile, no. 3, is located 1.7 miles from the terminus at an approximate mean elevation of 6,800 feet, a short distance below the confluence of the Wilson and Nisqually Glaciers. As reported in a letter, dated June 7, 1943 to Francois Matthes, who was then Chairman, Committee on Glaciers, American Geophysical Union,

«This profile was established with the thought in mind that changes observed here might indicate future changes to be expected on the lower glacier and also give some information on the relation between changes in the various altitude zones».

The data obtained at this profile in subsequent years has proved to be far more important than was envisioned at the time.

Profile no. 3 was first measured on August 21, 1942. The first remeasurement in 1943 showed an average increase in elevation of approximately 5 feet. The lowest point of the profile was the same elevation in both years, and was near the right or west side. The 1944 measurement showed a decrease in elevation of 8 feet. This measurement, however, was one month later than the 1943 measurement. If it had been made at the same time of year, the difference would have probably been about 4 or 5 feet instead of 8 feet. The surface as recorded by the 1944 measurements was the lowest observed during the observations that have been made at this location. Successive measurements at this profile showed a rise each year through 1951. Measurements were not made in 1950 as the east edge of the glacier had raised to such an extent that the reference point was covered with ice. In reviewing the changes from year to year, the most significant difference noted was the pronounced filling in near the right side during the two year period 1949 to 1951. As shown on figure 1, the filling in along this section of the profile was well over 100 feet during the 1949-51 interval. Much of the ice that filled in this area very likely originated from the Wilson Glacier, as reference to the map shows that an extension of the center line of the Wilson Glacier would come through this section of the profile. The surface, as measured in 1951, was at the highest point recorded in the current series of observations. Reference to photographs indicates that the surface in 1950 may have been equally as high or even higher. In the absence

Fig. 1



of definite information to the contrary, 1951 is therefore being considered as the highest year. The results since 1951 have fluctuated. Both 1952 and 1953 showed a decrease each year whereas 1954 showed a slight increase; 1955 was a year of slight decrease, and 1956 a pronounced increase; 1957 and 1958 both showed marked decreases with an increase in 1959. The largest increase, 21 feet, was between the years 1955 and 1956, and the most pronounced decrease, 29 feet, between 1957 and 1958. The mean elevation in 1951 was 83 feet higher than in 1944 and in 1959 was 30 feet lower than in 1951 or 53 feet higher than the low of 1944. The maximum difference between 1944 and 1951 was 225 feet.

In view of the continuing rise in the surface elevation noted at profile no. 3, an additional profile, located 1.4 miles from the terminus roughly mid-way between no. 2 and no. 3, designated as no. 2-A, was established in 1948. It is at an approximate mean elevation of 6450. This was measured annually, except 1950, from 1948 through 1954; and only partially measured in 1950 and 1955 as the glacier was so badly broken up that it was impracticable to cross the glacier on the profile alignment. No further attempts have been made to measure this profile since 1955. During the six years of available record, there was a net increase in the average elevation of 56 feet; 51 feet occurring during the three year interval 1948 to 1951. The years 1952 and 1953 both showed a slight decrease with 1954 showing an increase which more than offset the loss in 1952 and 1953.

Profile no. 2 is located 1.0 miles from the terminus at an approximate mean elevation of 6,000 feet. This profile was first measured in 1931 in connection with the establishment of a line of markers for measuring movement. It was remeasured in 1932 and 1933 after which measurements were discontinued. When remeasured in 1932, it showed an average increase of 18 feet. Further comparable data is not available until 1936, in which year a map was made of the lower portion of the glacier. A profile, as developed from this map, shows an increase of 23 feet since 1932. Measurements of this profile were resumed in 1941, in which year the mean elevation was 53 feet lower than in 1936. Whether or not a higher elevation was reached between 1932 and 1941 than shown on the 1936 map is not known. Measurements at this profile showed a continuous annual decrease in elevation through 1948, total for the seven year period 1941-1948 amounting to 51 feet. The increasing thickness of the ice or increased surface elevation noted at profile no. 3 since 1945 became apparent at profile no. 2 in 1949. In that year the west or right half of the glacier showed an appreciable increase in elevation whereas the left half continued to decrease. By 1950 the entire profile showed an increase in elevation. This increase continued each year through 1957, at which time the mean elevation for the entire profile was 102 feet higher than in 1948 with a maximum difference of 135 feet. The surface in 1958 was 9 feet lower than in 1957 and in 1959 was essentially the same as in 1958. It would appear, therefore, that the crest of the wave reached profile no. 2 in 1957; and the trend since then has been a decrease in elevation. The 1960 observations will probably show a more pronounced decrease at this location.

Profile no. 1, located 0.5 miles from the terminus at an approximate mean elevation of 5250 feet, was also first measured in 1931 in connection with setting a line of markers to determine rates of movement. A measurement in 1932 showed a decrease in elevation of 4 feet. No further comparable measurements were made until 1941. A profile as developed from the 1936 map, showed a decrease of 9 feet since 1931. It is of interest to note that during this same five year interval, 1931-36, there was an increase of 41 feet in mean elevation at profile no. 2. Measurements at profile no. 1 in 1941 showed that during the five year interval from 1936 to 1941 there was an average decrease in elevation of 37 feet. If the rise in surface elevation at profile no. 2 between 1931 and 1936 extended down to profile no. 1, it occurred sometime between 1936 and 1941. It seems doubtful that any rise did occur. The surface along this profile continued to lower in elevation each year through 1954, except for a short section near the right edge which showed a slight increase since 1953 but the mean elevation for the entire profile decreased. The net change from 1931 to 1954 amounted to an average of 136 feet, and since 1941 an average of 90 feet. The change in elevation along this profile was much less pronounced in the left or east one-third than in the right or west two-thirds. Although the decrease in average elevation for the period

1931 to 1954 was 136 feet, the maximum difference as shown by figure 1 exceeded 200 feet. The first indication of an increase in surface elevation at this profile appeared in 1954 when a portion near the right edge showed an increase, whereas most of the rest of the profile showed a decrease. Considering the entire profile, the net change was a decrease of 2 feet from 1953 to 1954 although in the section 1,600 to 2,000 feet from the reference point there was an average net increase of 4 feet. The east or left one-third of profile no. 1 has continued to decrease a matter of a few feet per year, whereas the right or west two-thirds has shown a pronounced increase starting in 1954. During the five year period 1954 through 1959 for the section 900 to 1,600 feet from the reference point, the average increase in surface elevation was 111 feet and for the section between 1,600 and 2,000 the average increase in elevation was 77 feet. The elevation of the approximate west two-thirds of this profile will undoubtedly continue to increase for the next few years. Inasmuch as the crest of the wave has apparently passed profile no. 2, the left one-third of profile no. 1 will probably not be affected and will continue to decrease in elevation.

The foregoing paragraphs have briefly discussed the changes that have been observed at the four profiles. The data provided by these profile measurements indicate that a wave or surge has been moving down the glacier. The course of this wave can best be visualized by reference to figure 2 which shows the annual mean elevation for the four profiles. At profile no. 3 there was a continual increase in the mean surface elevation from 1944 to 1951. Thereafter the general

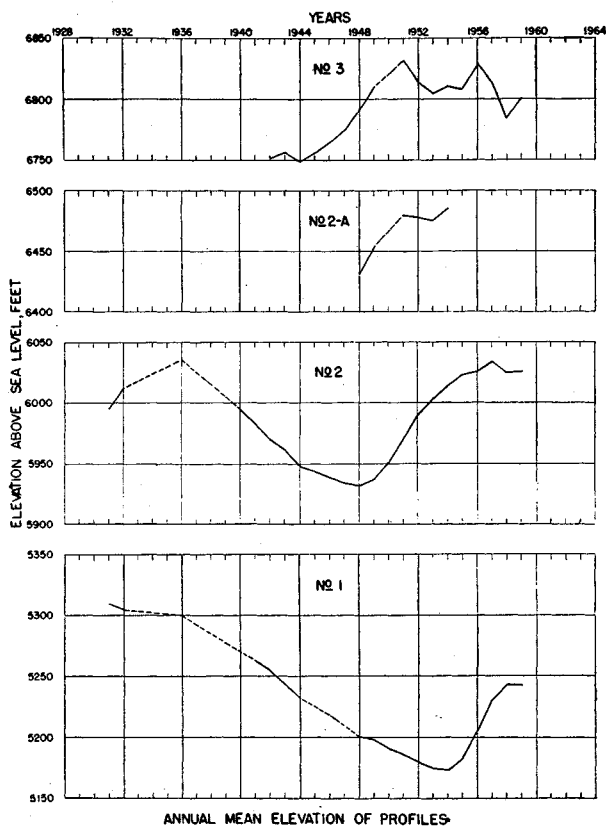


Fig. 2

trend has been a decrease in elevation but with annual fluctuations. At profile no. 2 there was an increase from 1931 to 1936. Sometime between 1936 and 1941 this trend was reversed as the 1941 surface was 53 feet below that in 1936. This decrease continued through 1948. Starting with 1949 the surface elevation increased continually through 1957 and has been fluctuating both up and down since then. At profile no. 1 there was a continual decrease in surface elevations from 1931 through 1953. In 1954 a section of the profile near the right sided showed an increase in elevation even though the mean elevation for the entire profile was less than in 1953.

The increase in surface elevation which first became apparent at profile no. 3 in 1945 became evident at profile no. 2 in 1949 or four years later, and at profile no. 1 in 1954 or nine years later. The distance from profile no. 3 to no. 2 is 3,500 feet. The wave, therefore, was moving down the glacier at an average rate of almost 900 feet per year in this area during the four year period 1945-1949. The distance from profile no. 2 to no. 1 along the main ice stream is about 2,200 feet. The wave moved forward in this area at a rate of about 440 feet per year.

The rate of movement of this wave is of particular interest when considered along with the known data on the rate of movement of marked boulders on the glacier surface. The rate of movement at profile no. 3 has only been determined for one year. Several markers set near the alignment of profile no. 3 in 1944 were relocated on 1945 and showed a maximum movement of 250 feet for the year interval. During the same year the maximum movement at profile no. 2, 3,500 feet downglacier, was only a matter of 50 to 60 feet or only about one-fifth to one-fourth of the movement at profile no. 3. Considerable information has been obtained on the rate of movement near profile no. 2. During the period 1943-47 the average maximum rate of movement was found to be about 50 to 60 feet per year. Following the increase in surface elevation first observed in 1949, there was an increase in the rate of annual movement of marked boulders

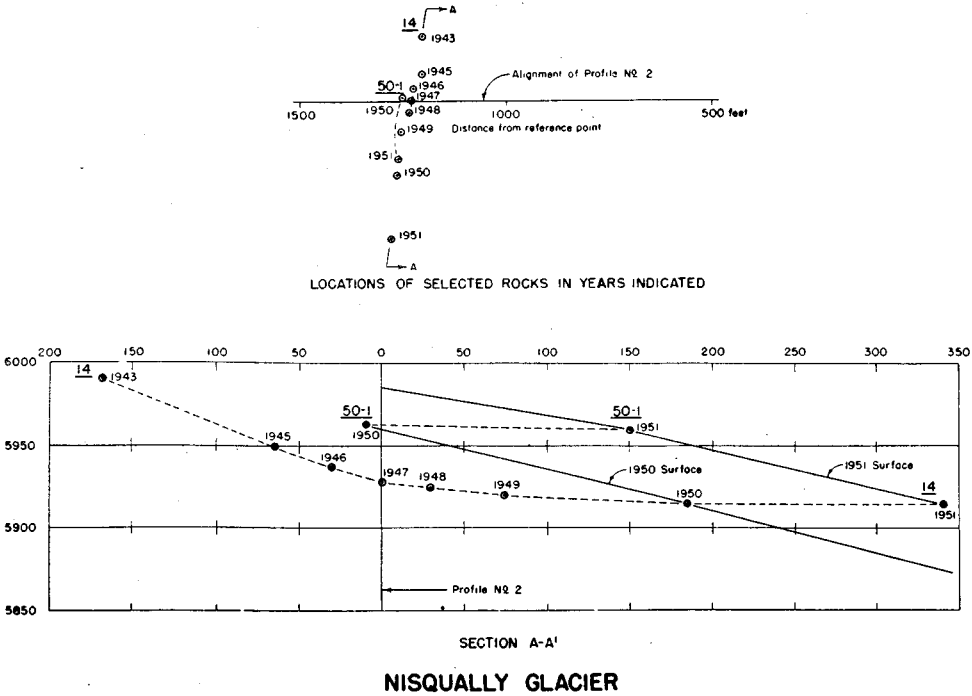


Fig. 3

starting in 1950. This increased each year through 1958, reaching a value of somewhat over 400 feet from 1957 to 1958. The movement from 1958 to 1959 was only about 300 feet, although there was no marked change in the surface elevation in this area. As previously pointed out, the wave first became apparent at profile no. 2 in 1949. The maximum rate of movement observed in 1949 in the vicinity of profile no. 2 was not appreciably different from that observed in previous years, 50 to 60 feet per year. Observations in 1950 showed a maximum of about 150 feet for the preceding year. Observations in 1945 showed that the annual movement near profile no. 3 was four to five times as much as at profile no. 2. If this ratio continued, the movement near profile no. 3 for 1949 to 1950 would have been approximately 700 feet per year.

When the wave first became evident at profile no. 2, the maximum annual movement was about 50 to 60 feet per year. The wave, however, had moved from profile no. 3 to no. 2 at a rate of almost 900 feet per year. It is evident that the wave moves along the glacier at a much faster rate than the ice mass, at least the surface of the ice mass. The velocity below the surface, in this section of the glacier, is evidently much faster than at the surface.

Figure 3 attempts to visualize and represent the actual movement or change in the glacier surface. Two rocks, no. 14 and no. 50-1, as shown in the upper part of figure 3 were essentially on a line normal to the profile alignment but different distances therefrom. The longitudinal section, lower part of figure 3, shows the positions and elevations of these two rocks in 1950 and 1951. From this it is seen that in each case the elevation of the rocks was within two or three feet of the same value each year. The surface, in general, was 30 to 40 feet higher in 1951 than in 1950. This rise in surface elevation is evidently due to the ice moving faster in the lower part of the glacier than near the surface. The path of travel for rock no. 14 for the years 1943-49 has also been indicated. Similar illustrations could be prepared from the available data.

The wave moved from profile no. 2 to no. 1, a distance of 2,200 feet in five years or 440 feet per year. During the five year period, 1949 to 1954 the maximum annual movement near profile no. 2 increased from 50 to 60 feet to over 300 feet per year. The maximum movement observed from 1953 to 1954 was therefore appreciably less than the average annual forward progress of the wave.

The data presented in this paper shows that an increase in the surface elevation of the Nisqually Glacier originating above the 7,000 foot elevation moved downglacier as a wave. The wave travelled a distance of 5,700 feet in a nine year period or an average of over 600 feet per year. The forward advance of this wave was at a much faster rate than the observed rate of surface movement. The forward movement of the wave and the increasing elevation of the glacier surface was accompanied by a pronounced increase in the annual rate of surface movement. Near the 6,000 foot elevation the maximum annual rate of movement increased from about 50 feet per year for the period 1943 through 1947 to a maximum of over 400 feet during the year 1957 to 1958. This increase in surface elevation is presumed due to a higher velocity of ice movement within the glacier than at the surface. The wave has now reached a point within one-half mile of the terminus which has shown a continual recession since 1918 when annual observations were started by the Park Service. From historical data, it appears that recession of the terminus has been continuous since about 1885 and even for some time prior thereto. The data now available emphasizes the fact that changes observed at the terminus of a glacier are not indicative of what is happening to the glacier as a whole.



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