DISTRIBUTION AND VARIATIONS OF GLACIERS IN THE UNITED STATES EXCLUSIVE OF ALASKA

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SUMMARY

A cooperative program of investigations of the distribution of existing glaciers in the United States south of Alaska and the variations of these glaciers was instituted during the International Geophysical Year. Approximately 1,000 glaciers were found to exist; 77 percent of the glacier area occurs in the State of Washington. The total glacierized area is 513 km². Quantitative data on surface rise, advance of terminus, gross accumulation, late summer ablation rate, and measured precipitation were obtained for seven glaciers, and qualitative data were obtained on the condition of many other glaciers. These data indicate that during 1957 glaciers were generally thickening and advancing in Washington and perhaps in Oregon, were thinning slightly in Montana, and were retreating in California. The summer of 1958 was one of exceptional ablation and caused a marked volume reduction in all glaciers measured as well as a decrease in the numbers of glaciers advancing. The 1958-59 budget year was slightly favorable for the growth of glaciers but there is no indication that a cycle of advancing glaciers has resumed.

The existence of glaciers in the United States south of Alaska has been known for nearly a hundred years. However, an accurate count of the total amount of glacier ice has not been possible until recent years because of the large amount that occurs in relatively inaccessible and seldom-visited areas. Several attempts at a glacier census have been made (Russell, 1858; Wentworth and Delo, 1931). More recently, Field and others (1958) summarized existing knowledge on the subject.

With the advent of the International Geophysical Year, it seemed appropriate to (1) learn more exactly how much glacier ice presently exists and where it is located and (2) determine the present condition of these glaciers. A cooperative program to obtain this information was authorized by the Technical Panel on Glaciology of the U.S. National Committee for the International Geophysical Year. Several government agencies and universities cooperated by undertaking new projects or modifying existing projects so that the data could be interrelated. This article represents a preliminary summary of the results obtained during the International Geophysical Year, 1957-58, and the year following, known as International Geophysical Cooperation 1958-59. The objective of this article is to summarize the pertinent data that were obtained so they can be related with other results collected during the IGY-IGC observation period. No attempt is made to present a detailed analysis of these data.

This report could not have been possible without the excellent cooperation of several organizations and persons, who are mentioned as their data are presented.

1. DISTRIBUTION OF GLACIERS

New maps plotted by the Forest Service and the Geological Survey, new aerial photography by the Geological Survey, the Forest Service, and the University of Washington, and especially a study of the Northern Cascades by A.S. Post of the University of Washington, and the Geological Survey permitted compilation by the author of data on glacier sizes, numbers, and distribution. Data gathered by Dyson (1952) and Phillips on Rocky Mountain and Oregon glaciers, respectively, added greatly to this compilation. The sizes of all larger glaciers and more than half of the

smaller glaciers were measured by planimeter on the new maps. In order to portray the size-distribution of glaciers and to permit the more rapid sizing of the remaining unmeasured glaciers, an arbitrary scale of glacier sizes was defined. The average area of glaciers within each class was determined from a sample of 264 measured glaciers. The class limits and the measured average areas are given in table 1.

TABLE 1

Glacier size class limits and average areas

Class	Glacier area limits km²	Average area within each class km²
I	Less than 0.5	0.169
II	0.5 - 1	.73
III	1 - 2	1.42
IV	2 - 4	2.97
V	4 - 8	5.11
VI	More than 8	9.48

For each glacierized area in the United States south of Alaska, data are presented on numbers, sizes, and total areas of glaciers in table 2. Geographic variation in the mean altitudes of glaciers lends insight into the variations in climatic environment. However, in any given region it was found that the mean altitude of a group of glaciers was a direct function of the average size of the glaciers in that group. Because all glacierized regions contain Class I glaciers, mean altitudes of these smallest glaciers only are given in table 2. The locations of the glacierized areas are presented in figure 1. The latitudinal variation of mean altitude along the Cascade Mountains-Sierra Nevada system and the Rocky Mountain system are shown in figure 2. Locations of glaciers and geographic variations in mean elevation of the glaciers in Washington State are given in figure 3.

The total number of glaciers listed in table 2 is nearly 1,000, and they cover an area of more than 500 km². About 77 percent of this ice-covered area occurs in the State of Washington. By estimating reasonable average thicknesses for glaciers in each of the size classes and summing, we estimate a total volume of ice of 65 km³ (53×10^6 acre-feet). Assuming that the average yearly ablation is 4 m of water, these glaciers contribute about $2{,}000 \times 10^6$ m³ (1.7×10^6 acre-feet) of water to streamflow in the West during the summer months.

Most (79 percent) of the glaciers are tiny (less than 0.5 km²) masses of ice nestled in protected cirques. These smallest glaciers aggregate 26 percent of the total area of ice, and but 10 percent of the estimated total volume of ice. Only in the Olympic Mountains, the Northern Cascade Mountains, on Mt. Rainier and Mt. Adams in Washington, and in the Wind River Range of Wyoming do glaciers larger than 2 km² in area occur. Most of these larger glaciers are of the valley type, but large cirque glaciers are not uncommon. The largest single glacier is Emmons, on Mt. Rainier, which is 6.9 km long and 10.7 km² in area. However, it is exceeded in size by the Carbon-Russell Glacier system (essentially a single trunk glacier fed by two tributaries) which is 9.7 km long and 13.0 km² in area, and is also on Mt. Rainier.

The geographic variation in mean altitudes shows a good qualitative relation to precipitation and latitude. Glaciers occur at the lowest altitudes in northwestern Washington State, where huge yearly precipitation totals (more than 5 m) are occa-

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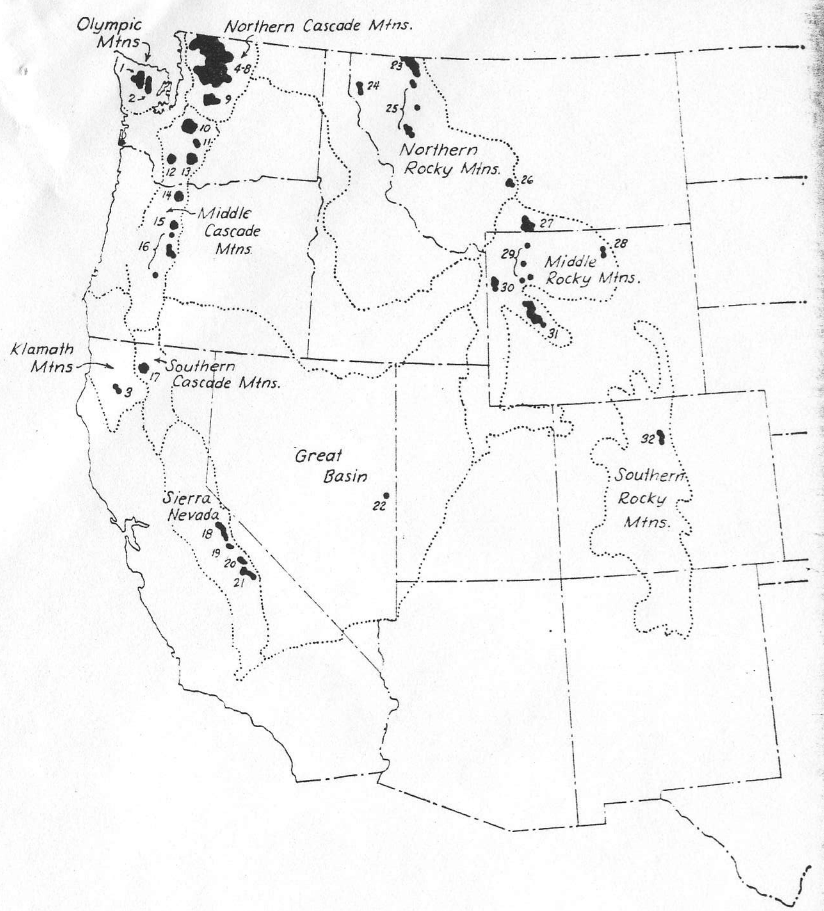
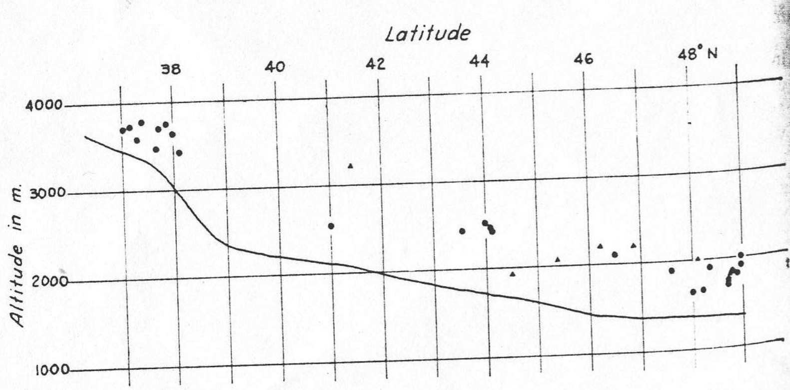


Fig. 1 — Map of Western United States, showing locations of glacierized areas. Dotted lines enclose those physiographic provinces which contain glaciers. Numbers are keyed to the glacier areas listed in table 2.



(*a*)
Fig. 2

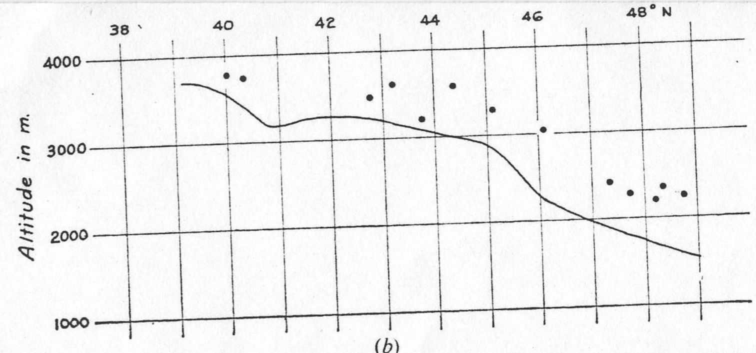


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Fig. 2 — Graphs showing mean altitudes of Class I glaciers as a function of latitude in the Cascade Mountains and the Sierra Nevada (*a*) and Rocky Mountains (*b*). Each dot or triangle represents the average altitude of a group of from 2 to 63 glaciers. Glaciers on the seven major Cascade Volcanoes are indicated by triangles, other glacier areas are indicated by dots. The solid line indicates the altitude of Pleistocene cirque floors, taken from Flint (1957, p. 309).

sionally recorded. Glaciers occur at higher elevations further south and further inland. In general present-day small glaciers occur at altitudes from 300 to 600 m above the altitudes of Pleistocene cirque floors. If the mean annual precipitation had not changed, this would imply that the present-day summer climate is of the order of 2-4 °C warmer than during the Ice Ages. Present-day glaciers occur only slightly above the Pleistocene cirque floors in the most southerly latitudes.

The vertical gradient in net accumulation (Shumskii, 1947) has been measured on only three glaciers in the conterminous United States. Values range from 15×10^{-3} (South Cascade Glacier, Washington) to 11×10^{-3} (Dinwoody Glacier, Wind River Range, Wyoming). These values indicate a relatively maritime climate. With the possible exception of glaciers in the Sierra Nevada, there is reason to believe that no highly continental-type glaciers occur in the conterminous United States.

2. Variations in the glaciers, 1956-59

Detailed regimen studies were made during the International Geophysical Year on Blue Glacier (La Chapelle, 1959) and South Cascade Glacier, both in Washington. Repeated topographic surveys provide data on the growth or shrinkage of four additional glaciers during the period 1956-59. Additional incomplete quantitative or qualitative data have been obtained on a large number of glaciers. Pertinent quantitative data are summarized in table 3.

An attempt has been made in table 3 to compare the relative intensity of ablation processes from glacier to glacier, by listing the measured or computed surface ablation rate in late summer. This was not measured on Nisqually, Grinnell, or Sperry Glacier, but the rate of lowering of the ice surface relative to sea level was measured. Ablation (V_a), lowering or raising of the ice surface (V_s) and the flow of ice normal to the surface (V_d) are related as follows (Meier, 1960) :

$$V_a = V_s - V_d$$

In this equation all components can be resolved either perpendicular to the surface or in a vertical direction, and velocities directed upward are considered positive. We assume that these glaciers were nearly in equilibrium ($V_s = 0$ over one budget year) and that V_d for one month was equal to $1/12\ V_d$ for one year. The total yearly

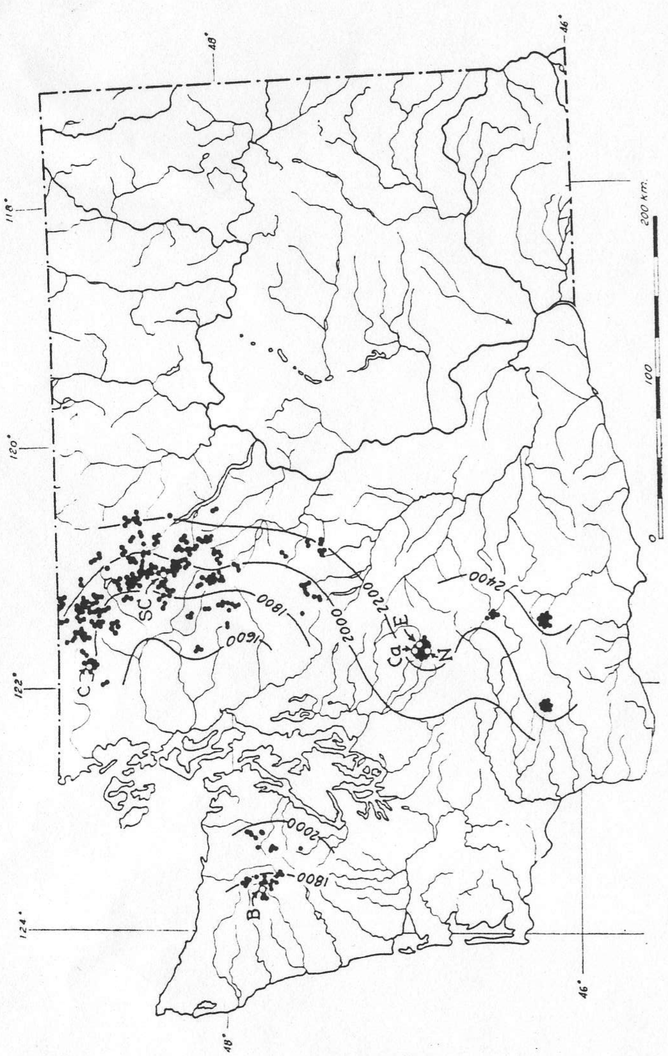

Fig. 3 — Location of glaciers in the State of Washington. Contour lines indicate mean altitude of Class I glaciers. Glaciers identified by letter are as follows:
B Blue Glacier
C Coleman Glacier
Ca Carbon Glacier
E Emmons Glacier
N Nisqually Glacier
SC South Cascade Glacier

ablation for each glacier was estimated, and 1/12 of this value was assumed to represent 1/12 of V_d and was added to the measured V_s during the month August 15 to September 15 in order to obtain V_a for this period. The corrections due to V_d were not large (see Table 3, notes 5 and 6).

TABLE 2

Distribution of glaciers in the conterminous United States, 1958

Location	Latitude	Size Class I	II	III	IV	V	VI	Total number	Total area km²	Altitude Class I glaciers m
1. Western Olympic Mountains	47°50′	22	8	3	1	2		36	27.0	1710
2. Eastern Olympic Mountains	47°50′	23	1	1				25	6.0	1880
3. Salmon-Trinity Mountains	41°00′	2						2	.3	2600*
4. Mt. Baker area	48°47′	17	5	1	1	5	1	30	55.5	1800*
5. Shuksan-Bacon-Challenger-Redoubt area	48°50′	126	11	4	6			147	52.6	1850
6. Dome-Eldorado area	48°25′	94	21	11	2	6		134	82.0	1930
7. Northeastern part, Northern Cascade Mountains	48°40′	39	2	1				42	7.5	1980*
8. Glacier Peak-Bonanza area	48°06′	74	10	7	5			96	39.9	2100
9. Southern part, Northern Cascade Mountains	47°35′	62	7	1				70	14.2	1950*
10. Mt. Rainier	46°52′	18	3	5	7	5	3	41	87.8	2230
11. Goat Rocks area	46°30′	9						9	1.5	2100*
12. Mt. St. Helens	46°12′	17	4					21	7.3	2220
13. Mt. Adams	46°13′	14	4	4		1		23*	16.1*	2500*
14. Mt. Hood	45°22′	4	3	5				12	9.9	2100*
15. Mt. Jefferson	44°41′	2	2	1				5	3.2	?
16. Three Sisters area	44°08′	15	5	1				21	7.6	2440
17. Mt. Shasta	41°25′	3	3	2				8	5.5	3200*
18. Yosemite National Park	38°00′	21						21	3.5	3590

TABLE 2 *(Continued)*

Distribution of glaciers in the conterminous United States, 1958

Location	Latitude	Size Class I	II	III	IV	V	VI	Total number	Total area km²	Altitude Class I glaciers m
19. Ritter-Minarets area	37°40′	4						4	0.7	3530
20. Abbot-Humphreys area	37°20′	8						8	1.4	3730
21. Goethe-Goddard-Palisade area	37°06′	36		1				37	7.5	3730
22. Wheeler Peak	38°59′	1						1	.2	3600?
23. Glacier National Park	48°45′	47	4	2				53	13.8	2280
24. Cabinet Range	48°13′	3						3	.5	2200
25. Flathead-Mission-Swan Ranges	47°40′	7						7*	1.2*	2430*
26. Crazy Mountains	46°05′	3*						3*	.5*	3050*
27. Beartooth Mountains	45°07′	34	5	1				40	10.8	3300
28. Big Horn Mountains	44°23′	2						2	.3	3600*
29. Absaroka Range	44°00′	4*						4*	.7*	?
30. Teton Mountains	43°45′	12						12	2.0	3200
31. Wind River Range	43°10′	45	6	5	5	2		63	44.5	3620
32. Rocky Mountain Park-Front-Range	40°03′	10						10	1.7	3800
Total number		778	104	56	27	21	4	990		
Area, km²		132	77	79	80	107	38	513		
Assumed thickness, m		50	75	100	150	200	300			
Volume, km³		6.6	5.7	8.0	12.0	21.4	11.4	65		

(*) These values represent estimates.

TABLE 3

Quantitative data on the variations of seven glaciers

Glacier	Surface rise in m 1956–57	1957–58	1958–59	Advance of terminus in m 1956–57	1957–58	1958–59	Gross accumulation in m of water 1957–58	1958–59	Ablation rate Aug. 15-Sept. 15 in cm/day of water 1957–58	1958–59	Measured precipitation in mm 1957–58	1958–59	Note
Blue		− 2.1	+ 0.1	Little change			3.5	2.8	3.4	2.0	3780	3560	1
Coleman	+ 0.6	− 7.0	+ 0.3	+ 58	+ 49	0							2
South Cascade		− 2.7	+ 0.8				2.4	3.7	4.4	3.7		5330	3
Carbon				− 4.0	− 5.5	+ 7.9							4
Nisqually	+ 6.1	− 7.9	+ 5.5	+ 39	+ 42	+ 17.3			10.8	3.5	2612	3603	5
Grinnell	− 1.1	− 2.9	+ 1.3	Little change					5.1	2.5	2470	3760	6
Sperry	− 1.2	− 2.9	+ 1.5										7

Notes:

1. Data on gross and net accumulation and ablation rate obtained by E. R. La Chapelle (1959), University of Washington (IGY Project 4.3). Data on terminus advance supplied by the National Park Service (G. D. Gallison, personal communication April 1, 1960), Olympic National Park. Data on surface rise computed from measured net accumulation data assuming an area-averaged density at the surface of 0.8 gms/cm³ at the end of the ablation season. Precipitation measured at 2100 m altitude.

2. Data supplied by A. E. Harrison (personal communications February 1, 1959, and April 1, 1960), University of Washington. Data on surface rise apply only to the area below an altitude of 2400 m, about 58 percent of the total area of the Coleman-Roosevelt Glacier system.

3. Data obtained by the U. S. Geological Survey (M. F. Meier). Data on surface rise computed from net accumulation data assuming an area-averaged density at the surface of 0.8 gms/cm³ at the end of the ablation season. Glacier terminates in a deep lake, and the position of the terminus is controlled mainly by infrequent calving of large blocks. Precipitation measured at 1870 m altitude.

4. Data obtained by the National Park Service, Mt. Rainier National Park (Bender, 1958, 1959).

5. Data obtained by U. S. Geological Survey (Giles, 1958, 1959, 1960) in cooperation with National Park Service. Surface rise data apply only to the area below an altitude of 2100 m, about 17 percent of the total area of the Nisqually-Wilson Glacier system. Advance of terminus data refer to the present active terminus, not the disconnected stagnant ice which lies further downvalley. Ablation rate data computed assuming $V_a = +1.7$ cm/day, from surface rise data obtained on a cross profile at 1840 m altitude. Precipitation measured at 1692 m altitude.

6. Data obtained by U. S. Geological Survey (Johnson, 1958, 1960) in cooperation with National Park Service. Surface rise data measured along three radial profiles extending from terminus to near the headwall. Ablation rate data computed assuming $V_a = +1$ cm/day for 1/3 area and $V_a = 0$ for 2/3 area. Precipitation measured at an altitude of 1881 m.

7. Data obtained by U. S. Geological Survey (Johnson, 1958, 1960) in cooperation with the National Park Service, along one transverse and two longitudinal profiles from the terminus almost to the head of the glacier.

In the Northwest the 1957-58 budget year was characterized by an early spring and a warm summer that was unusually long. The high ablation rates in August and September are attributed partly to a high incoming energy flux and partly to the abnormally low albedo of the glaciers due to the length of the ablation season.

The 1958-59 budget year was characterized by a relatively heavy winter accumulation of snow, a cool and wet spring, and frequent storms during the summer.

The data in table 3 reveal that during 1956-57 the Coleman and Nisqually tongues grew while the Grinnell and Sperry Glaciers declined slightly. All of the measured glaciers showed an appreciable reduction in volume during the year 1957-58. During 1958-59 all of the glaciers showed slight growth. Note that the data on advance of the termini do not correlate well with the overall volume change data. This is principally because the dynamic adjustment of valley glaciers (e.g. Carbon and Nisqually) to climatic change appears to take place by the development and propagation of kinematic waves (Weertman, 1958). These waves may arrive at the terminus several years after their initiation. There are suggestions in the 1959 survey data that two of these waves (Giles, G.C., personal communication April 18, 1960) may have been in progress on Nisqually Glacier.

It is perhaps surprising that the ablation rate data from the different glaciers are not markedly dissimilar, after allowing for some differences in the locations of sampling points. The similarity of local climatic environment is also suggested by the precipitation data. Thus, Grinnell Glacier appears to be in almost the same type of local climatic environment as Blue Glacier. Blue Glacier is but 52 km from the Pacific Ocean (a principal source of moisture-laden air), and occurs near verdant rain forests. Grinnell Glacier is 800 km from the ocean, and is separated from it by vast expanses of semiarid land.

Qualitative data on the variations of glaciers in the Northern Cascade Mountains, Washington, have been summarized by LaChapelle (1960). He reported on about 26 glaciers. During the 1956-57 budget year, 18 of these were actively advancing and 4 were retreating. During 1957-58, 9 were advancing and 5 were retreating. During 1958-59, only 4 were advancing whereas 12 were retreating.

Only three glaciers on Mt. Rainier, Washington, were observed during this period. Data on two of these are presented in table 3. Emmons Glacier, on the same mountain, advanced continuously from 1956 to 1959. On Mt. St. Helens, one glacier is known to have advanced at least until 1958, another was apparently retreating during this period, and no others have been studied. Few, if any, of the glaciers on Mt. Adams show evidence of reactivation, thickening, or advance; many show evidence of thinning and recession.

The lowest extremity of Eliot Glacier, on Mt. Hood, Oregon, has thinned continuously since before 1956; a profile at a higher elevation showed no appreciable change from 1955 to 1957 but the ice became thicker in 1958 and 1959; and points further up the glacier showed increases since 1957 ranging from 1.5 m to 6 m per year according to K.N. Phillips (personal communication to J.B. Case, September 29, 1959). Several other glaciers, as far south as Three Sisters, showed evidence of renewed activity in 1957.

Lyell Glacier, in Yosemite National Park, California, thinned 0.57 m from 1956 to 1957, according to surveys along a cross profile by personnel of the National Park Service and the Geological Survey (Gallison, et all 1957). Further south in the Sierra Nevada, O. Kehrlein (personal communicated to W.O. Field, December 10, 1959), reported that Palisade and Powell Glaciers also were retreating in 1958, but Howell Glacier was holding its own.

Arapaho Glacier, Colorado, was probably retreating from 1957 to 1959, according to H.A. Waldrop (personal communication February 2, 1960).

It appears that the recent advance of glaciers discussed by Hubley (1956) was largely confined to the States of Washington and Oregon, possibly extending to Mt. Shasta in California (O. Kehrlein, personal communication to W.O. Field, December 10, 1959). Glaciers in the Sierra Nevada have apparently continued to waste away, whereas those in Glacier National Park, Montana, have remained very close to an equilibrium condition. The most spectacular advances occurred in the Cascade Mountains from Mt. Rainier north to the Canadian border, especially on Mt. Baker and on the Eldorado massif.

This advance was slowed appreciably by an abnormally heavy ablation season in 1958. Although conditions slightly favored glacier growth in 1958-59, all indications suggest that the recent cycle of advancing glaciers has not yet resumed and may be near an end.

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