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Historical and Climatological Study of Grinnell Glacier, Montana

R. A. DIGHTMAN

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A western Indian symbol for rain. It also symbolizes man's dependence on weather and environment in the West.

U. S. DEPARTMENT OF COMMERCE
ENVIRONMENTAL SCIENCE SERVICES ADMINISTRATION
WEATHER BUREAU

Weather Bureau Technical Memorandum WR-24

HISTORICAL AND CLIMATOLOGICAL STUDY OF GRINNELL GLACIER, MONTANA

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WESTERN REGION
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GRINNELL GLACIER, MONTANA

I. INTRODUCTION

Insofar as it has a bearing on the glacier activity being studied in Glacier National Park, northern Rocky Mountain climatic history may be divided into three periods, only the most recent portion permitting approach of some refinement. The first period is that for which no specific data are available and includes all but the last century or so prior to George Bird Grinnell's 1887 visit to the glacier which now bears his name. The second period is from about 1880 to 1925, during which some climatic records were started in Montana--records which may represent, in a general sense, the climatic variations in the area around the edges of the Park. The third period dates from about 1925 to the present and represents a period of improving climatic measurements and definition, culminating during the most recent 17 years in actual hydrologic and related climatic observations in the Grinnell Glacier drainage basin.

Information prior to the first part of the 19th century is almost entirely of geological nature, or is largely inferred from meager knowledge of climate in general during about the last thousand years. In 1948 Ahlmann (1) said that results of excavations in south Greenland seemed to justify a conclusion that at no time since the year 1400 had the climate been so favorable (warm) as it had been since the 1920's.

Before 1400 all information on climate is highly subjective and is largely based upon inferences drawn from historical events or periods such as the early Viking voyages in the north Atlantic, the Battle of

Hastings, colonization of Iceland and Greenland, etc. The range of error may be large in climatic assumptions made in this way. Pleistocene glaciation history is fairly well established if errors of hundreds of thousands of years can be tolerated. There is evidence, according to Richmond (10), of at least three stages of Wisconsin glaciation which resulted in merging of Wisconsin advances with the valley glaciers of Glacier National Park. His evidence indicates connections between late Pinedale glaciation and Glacier National Park glaciers much of the time from about 10,000 to 6,500 years ago, but also makes it quite clear that the valley glaciers probably were in existence before the late Wisconsin Pinedale stage (about 25,000 years ago). During the earlier stages of the Wisconsin, glaciation appears to have extended farther westward into Glacier National Park, serving to "back up" Park glaciers to elevations a thousand or more feet higher than at present. According to Lemke, et al (11), roughly the northern third of Montana was involved in the Wisconsin ice age.

We can infer, then, that Glacier National Park glaciers must have an ancient history of their own. We are limited to those portions of the history that geologists can deduce from the deep and sharply carved valleys in the park which are mute but eloquent evidence of large cirque-type and valley glaciers. These glaciers, six to ten thousand years ago, must have been much larger than those currently being studied--they had to be much larger in order to carve the rocky park area into its present complex topographic formations and to extend 25 miles eastward from the mountains as described by Richmond (op. cit.). About the limit of fairly reliable deduction here is that, prior to recorded history in the area, for long periods of time the climate over Glacier National Park had to be more favorable for glaciation than it has been during the last few centuries.

II. TEMPERATURE HISTORY

Archeological studies indicate that there was a quite well-developed agriculture in south Greenland around the 13th or 14th centuries, A.D. The subsequent overrunning of farms and implements by advancing glaciers (which in the last 50 to 80 years receded to uncover such evidence) is itself a basis for concluding that at least parts of the northern hemisphere's climate was favorable for glaciation (but much less extensive than late Wisconsin ice) during substantial parts of the following five centuries (2). Long-period reliable precipitation records are nonexistent for many reasons, including unrecorded methodology, lack of standards, too much subjectivity, or even more important, lack of measurements of any kind. But at least as important as precipitation in the growth of a glacier is temperature. For New Haven, Connecticut, there is a reliable temperature record dating from 1780 -- over 180 years--for which 10-year moving averages are plotted in Figure 1. From year to year the average temperature at any point varies considerably around any computed "normal", but averages over periods of from 10 to 30 years tend to smooth out these annual differences. We may assume the New Haven curve to be the best available approximation of northern U. S. mean temperature conditions since 1780. In any case it is apparent that the portion of the curve prior to about 1900 would represent conditions more favorable to glaciation than the section subsequent to about 1910. And we know (3,4) that the period 1920-1945 was one of rapid ablation for most Continental United States glaciers.

It remains to match the New Haven temperature curve with records from a point or two in Montana near the glacier area plotted on the same time-temperature moving average scale in order to determine if a degree of compatability can be found. Two Montana curves (Kalispell and West Glacier) have been plotted in relation to the New Haven record (Figure 2). Both are 10 year moving averages. More recently Mitchell (9, 1963) has averaged world-wide temperatures on a pentad basis beginning with the 1880-84 period. This period was the first for which all latitude bands except the polar extremities were represented by some data. His world mean temperature trend curve appears in Figure 2 as departures from the 1880-84 pentad average. The curve is area-weighted to improve its statistical significance. The degree of similarity between these curves is remarkable, and appears to support the conclusion, shared by most investigators, that the early 20th century and late 19th century warming was world-wide and real. The curves also support a conclusion that between 1940 and 1960 there has been a global trend toward cooler temperatures amounting to about -0.3°F. Similarly, the warming and subsequent cooling has been experienced by the Glacier National Park area. Some discussion of the possibility of development of a cooling trend was mentioned in 1956 by Dightman (5).

The secular temperature trends discussed above may be associated with Grinnell and Sperry Glacier behavior by noting that the coldest part of the 1880-1960 period was at the beginning, when photographs of Grinnell show that the ice volume was much greater than in the recent 20 years or so. In fact, if we trace the New Haven record back to

1780, we find that fluctuations for the century ending in 1880 were small. The warming trend, well established by 1920, is obviously associated with the rapid recession of glaciers in Glacier National Park noted by many observers during the 20 years or so preceding 1940 (6,7). Equally important is the indication that recession slowed markedly 1940-50, according to actual glacier surveys, and that most Park glaciers have about held their own 1950-65. This period, of course, coincides with a period of gradual global cooling, and suggests that the cooling may have reached a point where the glaciers are able to maintain themselves, with losses about equaling gains on the average.

III. PRECIPITATION HISTORY

Variations in precipitation as well as temperature affect the "health" of glaciers and in some cases are more important. Unfortunately, however, variations in precipitation with time and space are much larger than variations in temperature, and a precipitation history can be developed only with assumptions of a nature similar to those discussed under temperature. Some of these conjectures may not be tenable in the long run, so the following comments will be limited to more recent and therefore more certain observations. We know that precipitation had to be adequate for Grinnell Glacier to acquire the size observed first by George Grinnell in 1887, and we also know that temperature variations (as shown by the New Haven curve) during the 107 years prior to 1887 were small and irregular. In Figure 3 some 10 year moving averages of precipitation in the general glacier area have been plotted. Unfortunately, these go back only as far as the beginning of reliable records at Kalispell in 1897, but the Kalispell curve (A, Figure 3) shows a rather persistent trend toward dry 10-year periods beginning with the decade centered near 1913. About 30 years later, recovery from this dry period appears to have started, but it should be noted (Table 1) that both dry and wet periods included an occasional wet or dry year. Wet years have, however, outnumbered dry after 1948. The warmer peaks of the 10-year moving average temperatures (Figure 2) will be seen to coincide very well with low points of these phenomena coincide closely with observations of rapid glacier shrinkage during the 1930's and early 1940's (Dyson, Beatty, Johnson, 3,6). We may conclude that this rapid glacier shrinkage was a direct result of abnormally dry and warm conditions observed about 1920-40.

IV. RECENT CLIMATIC MEASUREMENTS

1. Precipitation. The first step in obtaining actual data on the climate of the Grinnell Glacier area was taken in 1949 with the installation, late in August, of a 16-foot storage precipitation gage (#1 site on USGS 1950-1960 Glacier Plan Sheet). This gage produced reliable seasonable precipitation measurements until it suffered some damage because of lateral movement of the snowpack during the winter of 1953-54. The following summer (1955) the gage was rebuilt, with a new base and a storage section was added to make the gage height 21 feet. The increase in height was deemed necessary in order to insure that the gage orifice would not be overtopped during the snow season. At the same time a second 21-foot storage gage was erected at another site about 2,500 feet southeast of gage #1 at very nearly the same elevation (El. #1-6227 ft., #2-6113).

These gages, mounted on reinforced concrete bases, are of 12-inch diameter steel pipe in 5-foot sections bolted together with the top section 6 feet in length. The top one foot of the top section is a truncated cone, 12-inch diameter at the base welded to the assembly, and 8-inch diameter at the orifice (catch ring). Both gages have performed well since their erection in 1955. They have both been serviced annually in July or August. Each gage, at the time of servicing, has been charged with an equivalent (by weight) of 100.50 inches of precipitation in the form of an antifreeze solution made up of calcium chloride, water, and enough oil to prevent evaporation losses from the water surface. Through a drain assembly the combination precipitation catch and charge have been weighed out each year. Subtracting charge weight from total weight at the end of the season yielded the seasonal total precipitation at each check-out time.

2. Temperature. The difficulties surrounding the attempt to obtain temperature records under glacial conditions are many and obvious. Long term recorders (6 months or more) that are able to operate in such areas simply were not available. Even if such recorders were available, the problem of suitable exposure during the heavy snow season would be extremely difficult. However, some temperature records during the peak melting season have been obtained; 1951-52, and 1957-66 for parts of July and all Augusts at Grinnell #1, and 1960-66 at Sperry Chalet (el. 6754 ft.) several miles to the southwest on the west side of the Continental Divide. The equipment is standard: medium Weather Bureau shelter, maximum and minimum thermometers, and thermographs. At Sperry, records (including precipitation) have been fairly complete for both July and

August; at Grinnell, August is the only full month of record in all years. Without the help of the Sperry Chalet concessioners and naturalists at Grinnell, neither record would have been possible. Plates 1 and 2 show the installations at Grinnell #1 and at Sperry Chalet, respectively.

V. DISCUSSION OF CLIMATIC DATA

1. Precipitation. Tables 2-6 present, in summary form, weather data actually observed in the Glacier area (including Sperry Chalet) as well as some objective estimates of Glacier area weather during the rapid ablation years of 1925 to about 1940. Several points appear worthy of comment:

a) The relationships between catches in gages #1 and #2 have been remarkably steady during all 11 years--catches in #2 have averaged about 150% of #1, ranging from 134 per cent in 1960-61 to 161 per cent in 1964-65. The two sets of data are comparable, and indicate that orographic and wind effects--which certainly exist in this rugged glacial mountain area--must be quite persistent and stable.

b) From comparative precipitation observations for a simultaneous 9 years period (1948-58), a regression equation was developed between Grinnell #1 (y) and the regular climate station at Summit (x) (35 miles to the SSE). This relationship was $y=2.483x$ with a standard error of 14.1 inches.

c) From Table No. 2, it can be seen that all of the seven water years with less than 80 inches of precipitation (estimated) at Grinnell #1 occurred in the 11 years prior to 1946-47. Ten of the twelve water years with more than 100 inches occurred after

1949. It is apparent from the Table that there are much wetter years beginning in 1946 or 1947.

d) Water year runoff data (USGS). If we could be certain that Grinnell #1 (or #2 for that matter) precipitation samplings were accurate volume measurements of water available for runoff, a simple hydrologic budget calculation would be possible, with allowances for evapotranspiration, seepage, etc.; losses which in this cirque would have to be small. However, chances are remote that the samplings are adequate for such a use. We can, however, use them as indices and assume that years in which precipitation exceeds runoff by a large margin (cf. 1953-54) will be less likely to have loss of glacial volume than years when the runoff exceeds precipitation (cf. 1961-62).

2. Temperature. Tables 4, 5, and 6 carry summary temperature data for Sperry Chalet and Grinnell #1, along with comparisons with nearby regular climatic stations. The following points are worth noting:

a) The variability of August mean temperature at both Sperry Chalet and Grinnell #1 is notably greater than at lower level stations. This suggests that high level free air temperature variations have a more pronounced effect on the glacier than in the valley bottoms. Daily records show that minimums are, as a rule, warmer on the glacier than in nearby valley bottoms during warm Augusts, but they are colder than in the valleys during stormy Augusts (which also are cool). Maximums in August invariably are cooler than at lower levels. Grinnell average temperature in August has varied nearly 13 degrees from 48.9° in 1951 to 61.7° in 1961 (records for 1951-52 and 1957-66). For the same years the widest range in August average temperature at lower level stations is less than 11° suggesting a wider difference between cold and warm regimes in the glacier cirque. Seven years of Sperry Chalet (July and August) temperatures show similar characteristics, indicating the possibility of larger climatic variations on the glacier than at lower levels. These larger variations would, of course, be more easily detectable.

b) One or two months a year, of course, provide a limited sample. But August is one of the primary melting months, and is the month during which the lower glacier snow has disappeared in most years. A warm August, as in 1961, would be expected to cause more melting than a cold August, as in 1951; this effect may be included in the Table 2, 94 and 83 per cent runoff volumes for those years. It is apparent, however, that temperature measurements for at least the warmer six months of the year are needed if actual temperature effects on melting of glacier ice are to be determined with any certainty.

VI. SUMMARY AND CONCLUSIONS

Some of the ice which formed in the firn area of Grinnell Glacier in 1887, when George Bird Grinnell first explored the glacier, no doubt is still a part of the ice mass. Even if fairly detailed glacial climate studies, of the kind described herein, had been started then, we would still be many years away from a full cycle in the life of the glacier. But the climatic studies--partial though they may be--were started only in 1950, and by extrapolation and comparison (Table 1, Figures 1, 2, for example) have been extended backward in time only to the early 1930's with any degree of reliability. While we know that the glacier was much larger in 1887 than it was in 1950, we still know little of the northern Rocky Mountain climate details that built the glacier to the 1887 size--except that it had to be a climate favorable for glaciation. Assuming that the weather responsible for the 1887 size had prevailed most of the time for at least a century before that year--we still can know very little about Glacier National Park climate details before about 1930.

Richmond (op. cit., p. 228) states that, "If present free-air temperature gradients are applicable, mean summer temperatures during late Pleistocene glacial maxima (Wisconsin) were about ... 17.5°F. colder than at present in the northern Rocky Mountains. It is likely that winter temperatures then were much the same as at present". This could be classed as one of the gross hypothetical estimates mentioned by Meier (12), and under several circumstances such as higher glacier elevation than now, heavier precipitation, different radiation patterns, etc., temperatures so much colder probably would not have been required for extensive glaciation. It is a matter of record that the 1930's in most of the Continental United States were famous for heat and drought. Available observations indicate that the drought was associated with the rapid ablation of Grinnell Glacier noted during that decade--the period during which Dyson (6) started a simple program of measurements. Climatic records show that a period of cooler and wetter years began about 1945, and measurements a few years later began to show little change in the Glacier's ice volume. In fact, in 1960 the survey of Grinnell showed increases in elevation over the 1950 measurements at 4 out of 5 mapped grid points (Table 7). Most suggestive of renewed glaciation is the fact that in 1960 the maximum firn elevation was about 17 feet higher than 10 years earlier. However, from 1960 to 1966, conditions have not been either as cool or as wet as during the 1951-60 decade, but neither have they been so dry or as warm as the 1930 decade drought period. And of course recent conditions have been far from as cold as described by Richmond (op. cit.) for the Wisconsin age.

It appears that we have recently (1945-60) witnessed, and documented in some ways, a marked slowing or reversal of the rapid ablation of Grinnell Glacier experienced prior to 1940 for many years. Also documented, at least in part, are some of the climatic features associated with both periods. However, much remains to be done. On the scale of geological time, the period of study is very short indeed. Meier (12) describes some of the difficulties associated with any attempt to trace back changes in climate from glacier variations except in a gross way. Historical details of climate, as Meier describes the problem, may vary widely while producing similar glacier responses. To link climate changes to related responses of Grinnell Glacier (or any glacier, for that matter) many more years of "glacier watching" will be needed, following the ice mass through periods of change, with continuous year-to-year measurements. Improved techniques of measuring the glacial climatic environment should be sought, while maintaining--for the sake of continuity--those measurements already under way. For example, the elevation of the top of firn, shown as glacial mass on the U.S.G.S. 1950 and 1960 maps, measured as a part of surveys at 10-year intervals, might be valuable decennial bits of information. It seems certain that opportunities for refinement of the studies, or adding to them, will present themselves as the glacier responds to its total environment, and possibilities for using glaciers for climatic indices may then develop.

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NEW HAVEN, CONNECTICUT; SECULAR TREND OF TEMPERATURE

LONGEST UNINTERRUPTED RECORD IN THE U.S. (1780–1965)

Mean values for each 10-year period plotted at the midpoint of the decade and connected by a smoothed curve.

Width of line shows uncertainty because of changes in location of station and in observational procedures.

Plot 1785–1955 from Department of Commerce, Weather Bureau, L.S. 5903, Feb. 1959. Plot through 1961 carried forward using data published in New Haven 1965 Annual Local Climatological Data. The period from about 1910 to 1940 was one of rapid glacier ablation in Glacier National Park, but during the 10 years (approximately) centered on about 1955, these same glaciers appear to have stopped shrinking.

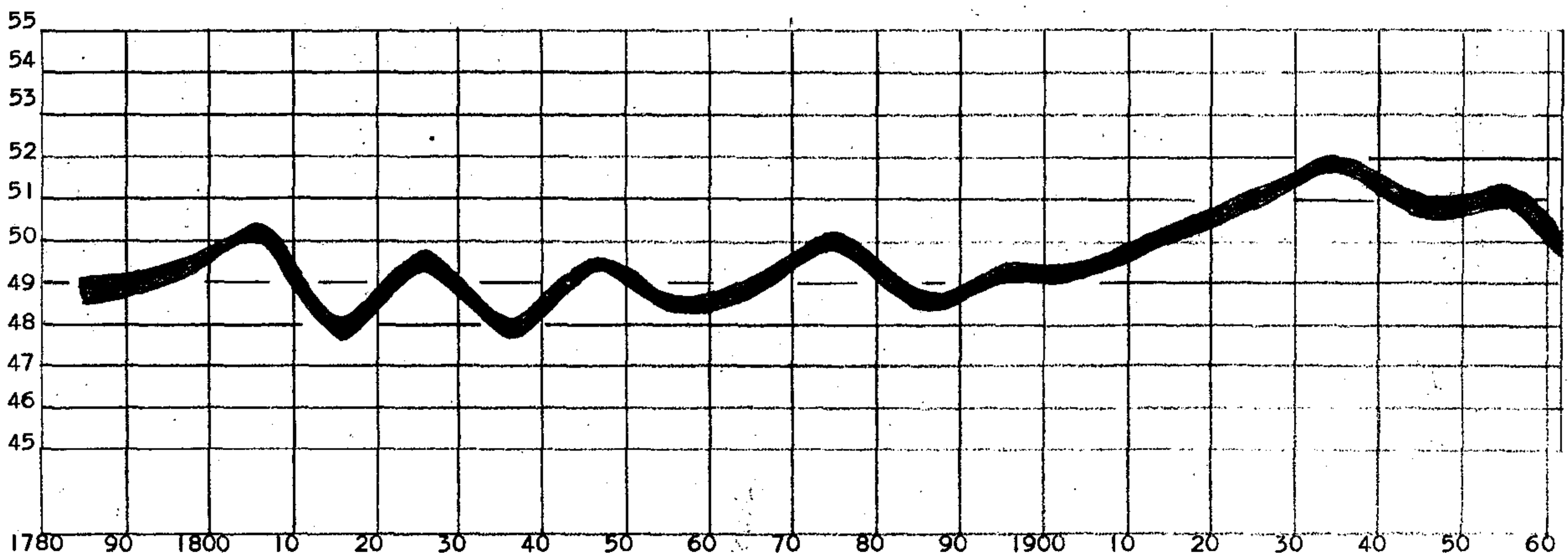

FIGURE I.

10-YEAR MOVING TEMPERATURE AVERAGES

CENTERED AT DECADE MID-POINT

THROUGH 1965

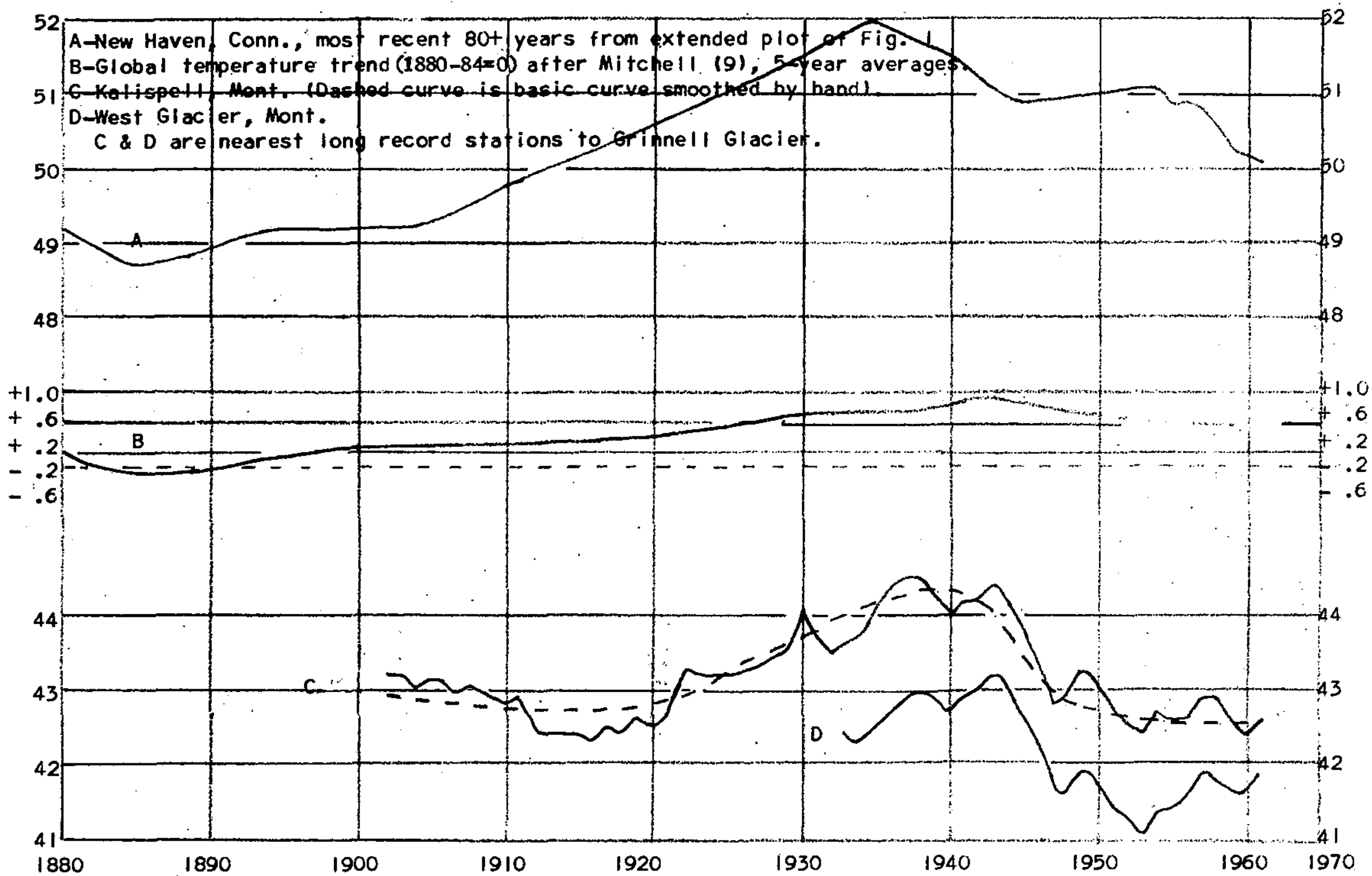

FIGURE 2.

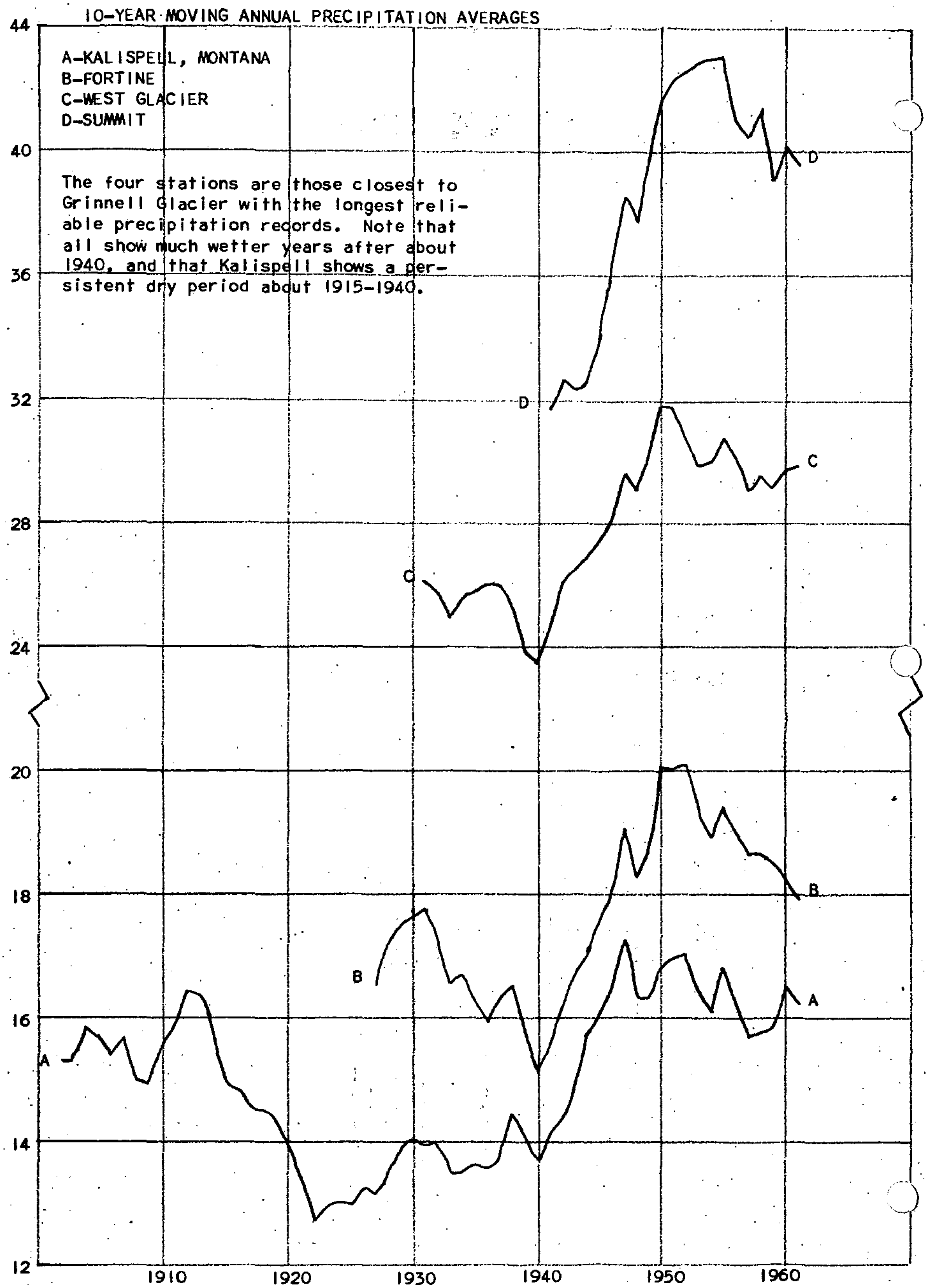
10-YEAR MOVING ANNUAL PRECIPITATION AVERAGES
A-KALISPELL, MONTANA
B-FORTINE
C-WEST GLACIER
D-SUMMIT
The four stations are those closest to Grinnell Glacier with the longest reliable precipitation records. Note that all show much wetter years after about 1940, and that Kalispell shows a persistent dry period about 1915-1940.
44
40
36
32
28
24
20
18
16
14
12
1910
1920
1930
1940
1950
1960
A
B
C
D

FIGURE 3.

TABLE 1.

Kalispell (Curve A in Figures 1 and 2) Annual Precipitation and Annual Average Temperatures 1897-1966 With 10-Year Moving Averages as Plotted. Station moved in 1949 to Airport Location.

Year	Precip.	10-Year Moving Average	Average Temp.	10-Year Moving Average
1897	16.99		42.9	
1898	12.50		44.8	
1899	19.50		41.0	
1900	17.69		44.3	
1901	12.85	15.30	43.3	43.2
1902	19.21	15.29	42.2	43.2
1903	14.63	15.89	42.0	43.0
1904	10.89	15.72	44.6	43.1
1905	15.20	15.37	42.8	43.1
1906	13.50	15.69	44.4	42.9
1907	16.94	14.94	42.1	43.0
1908	18.51	14.87	43.5	42.9
1909	17.80	15.49	41.7	42.8
1910	14.12	15.85	44.4	42.9
1911	16.10	16.46	41.7	42.4
1912	11.70	16.37	42.4	42.4
1913	13.97	15.63	41.2	42.4
1914	17.07	14.97	43.6	42.4
1915	18.75	14.84	43.7	42.3
1916	19.66	14.54	39.2	42.5
1917	16.02	14.47	42.4	42.4
1918	11.15	14.37	43.5	42.6
1919	11.12	13.94	42.2	42.5
1920	12.81	13.32	42.9	42.7
1921	13.13	12.69	43.4	43.3
1922	10.97	12.95	41.7	43.2
1923	12.99	13.03	43.3	43.2
1924	12.83	12.96	42.6	43.2
1925	12.56	13.26	45.8	43.2
1926	13.35		44.9	

Year	Precip.	10-Year Moving Average	Average Temp.	10-Year Moving Average
		13.18		43.3
1927	18.61	13.43	42.0	43.5
1928	11.94	13.94	43.3	43.6
1929	10.39	14.03	41.6	44.1
1930	15.85	13.92	4[illegible].2	43.7
1931	12.31	13.99	44.8	43.5
1932	13.43	13.51	43.2	43.6
1933	18.12	13.51	44.3	43.7
1934	13.74	13.65	47.6	44.1
1935	11.47	13.57	42.1	44.4
1936	14.05	13.69	43.1	44.5
1937	13.80	14.43	42.4	44.5
1938	11.94	14.04	45.0	44.3
1939	11.79	13.70	45.4	44.0
1940	15.06	14.15	46.1	44.2
1941	13.53	14.36	45.7	44.2
1942	20.81	14.85	43.0	44.4
1943	14.17	15.75	42.1	44.2
1944	10.42	15.96	44.4	43.8
1945	15.96	16.46	44.4	43.3
1946	16.10	17.29	43.9	42.8
1947	18.73	16.33	44.1	42.9
1948	20.91	16.37	42.4	43.3
1949	13.88	16.86	42.0	43.1
1950	20.08	16.95	41.3	42.7
1951	21.87	17.05	40.8	42.5
1952	11.15	16.42	43.5	42.4
1953	14.62	16.13	45.7	42.7
1954	15.29	16.84	42.7	42.6
1955	16.91	16.26	40.2	42.6
1956	17.07	15.71	42.7	42.9

Year	Precip.	10-Year Moving Average	Average Temp.	10-Year Moving Average
1957	12.44	15.74	42.4	42.9
1958	18.00	15.80	45.5	42.6
1959	20.97	16.51	41.3	42.4
1960	14.26	16.28	41.2	42.6
1961	16.40		44.0	
1962	11.48		42.9	
1963	15.22		43.3	
1964	22.36		40.6	
1965	14.61		41.7	

TABLE 2

Water Year Precipitation, Summit and Grinnell Glacier #1; Grinnell Creek Runoff (in.)

Year	Summit	Grinnell #1	Water Year Runoff-in.	Runoff % of Grinnell Precipitation
1935-36	26.40	ϕ 65.55		
1936-37	29.92	ϕ 74.32		
1937-38	36.51	ϕ 90.65		
1938-39	33.09	ϕ 82.16		
1939-40	26.91	ϕ 66.82		
1940-41	27.21	ϕ 67.56		
1941-42	32.57	ϕ 80.87		
1942-43	41.25	ϕ 102.42		
1943-44	26.04	ϕ 64.66		
1944-45	30.85	ϕ 76.60		
1945-46	30.52	ϕ 75.78		
1946-47	40.23	ϕ 99.89		
1947-48	41.17	ϕ 102.23		
1948-49	36.03	ϕ 89.46		
1949-50	50.79	126.49	106.54	84
1950-51	55.58	126.43	104.98	83
1951-52	34.70	97.27	89.59	92
1952-53	47.99	105.76	97.16	92
1953-54	47.03	144.48	110.74	77
1954-55	33.70	98.83	94.27	95
1955-56	47.57	104.64	102.37	98
1956-57	36.42	85.34	86.87	102
1957-58	37.00	86.31	89.19	103
1958-59	43.26	111.68	104.38	93
1959-60	36.06	114.37 (a)	92.83	81
1960-61	40.98	103.62	97.04	94
1961-62	37.85	83.83	89.88	107
1962-63	35.90	94.20	97.11	103
1963-64	47.04	101.95	100.54	99
1964-65	47.25	104.14 (b)	101.92	98
1965-66	32.15	80.03	97.15	121

ϕ Seasons 1935-36 through 1948-49 estimated by least-squares formula y = 2.48x (See text).

(a) 1960, following 7/21 checkout until 9/30, was wet; therefore adjustment to water year was made on basis of USGS August and September measurements at the Grinnell Creek (lower) gaging station.

(b) 1965, 10/2 dip stick measurement 13.2 used for adjustment to water year for 8/12-9/30 portion; y = 2.48x used for 7/30-9/30 1964 portion.

Table 3
Precipitation measurements Adjacent to Grinnell Glacier
1950-1966

Season ending (year and date)	Gage No. 1, Established 8-27-49 Seasonal total precipitation (in)	Gage No. 2, established 8-15-55 Seasonal total precipitation (in)	#2 Catch in % of #1
1950-July 20	125.05 (11 mo.)		
1951-July 24	117.59		
1952-July 15	109.27		
1953-July 31	106.93		
1954-August 5	138.20		
1955-August 10	108.22		
1956-August 7	100.11	152.83	153
1957-August 7	88.74	137.22	155
1958-July 17	78.89	115.77	147
1959-August 4	111.65	184.64	165
1960-July 21	107.68	166.56	155
1961-August 8	98.28	131.78	134
1962-July 26	87.06	121.45	140
1963-July 18	101.09	157.83	156
1964-July 30	95.50	144.09	151
1965-August 12	101.98	164.00	161
1966-July 28	89.26	140.44	157

Table 4
Temperature (°F.) at Grinnell Glacier (No. 1) 1951-1966

Year	Month	Average Maximum	Average Minimum	Average	Highest	Lowest
1951	August	58.5	39.2	48.9	82	29
1952	August	64.8	43.7	54.3	79	29
1957	August	63.9	42.9	53.4	77	32
1958	August	71.3	50.2	60.8	82	38
1959	August	59.2	42.3	50.8	82	33
1960	August	59.3	42.8	51.1	81	31
1961	August	73.6	49.8	61.7	89	33
1962	August	63.5	45.2	54.5	84	35
1963	August	68.4	45.5	57.5	82	38
1964	August	57.3	40.8	49.1	74	31
1965	August	64.4	44.1	54.3	82	26
1966	August	65.1	41.0	53.1	83	28

Table 5

August Mean Temperatures at Nearby Stations Compared with Grinnell No. 1

Year	Sperry Chalet el. 6,754 ft.	Grinnell No. 1 el. 6,238 ft.	Summit el. 5213 ft.	Babb 6 NE el. 4,300	West Glacier el. 3,154	Polebridge el. 3,690	Gaging Station
1951		48.9	53.2	55.1	60.1	57.0	54.2
1952		54.3	54.7	57.0	61.9	58.5	54.6
1957		53.4	55.2	56.0	60.8	56.7	54.8
1958		60.8	59.5	61.5	66.5	63.6	62.9
1959		50.8	52.8	55.7	58.7	56.6	55.1
1960	50.7	51.1	53.9	57.8	57.9	57.8	
1961	61.9	61.7	62.6	64.7	66.4	64.3	
1962	51.0	54.5	53.3	57.8	60.6	57.2	
1963	56.6	57.5	56.8	59.6	63.2	59.5	
1964	45.5	49.1	51.9	55.7	56.7	55.7	
1965	53.4	54.3	54.3	59.3	61.8	60.6	
1966	52.3	53.1	54.0	57.8	60.8	57.6	

TABLE 6

SPERRY CHALET CLIMATIC DATE

Year	Average Max. July	Average Max. Aug.	Average Min. July	Average Min. Aug.	Average July	Average Aug.	Highest July	Highest Aug.	Lowest July	Lowest Aug.	Precipitation July	Precipitation Aug.
1960	73.0	57.6	52.3	43.7	62.7	50.7	84	76	39	30	0.15	3.82
1961	67.8	71.8	48.2	51.9	58.0	61.9	75	90	37	36	3.27	3.30
1962	61.2	58.9	44.5	43.1	52.9	51.0	74	82	32	31	0.76	2.41
1963	62.0	66.5	44.9	46.7	53.5	56.6	76	81	35	36	2.30	1.60
1964	66.4*	56.7	45.7*	42.3	56.1*	45.5	79*	76	37*	33	2.69*	3.52
1965	62.9	59.9	43.8	46.2	53.4	53.1	74	77	34	29	1.98	6.44
1966	64.0	60.5	47.6	44.1	55.8	52.3	76	81	32	32	2.03	2.60

*minus first 3 days of month.

TABLE 7

GRINNELL ICE SURFACE ELEVATIONS (MSL) AT
GRID POINTS, USGS MAP 1950 & 1960

Points are identified by grid line labels, horizontal label first, vertical second.

Point H	Point V	9/1/50 el. (ft.)	9/8/60 el. (ft.)	Change
6000	12000	6798	6826	+28
6000	10000	6802	6807	+ 5
8000	8000	7155	7179	+24
8000	10000	6553	6544	- 9
Highest point of Glacial Firn		7324	7341	+ 17

PLATE 2.

SPERRY CHALET CLIMATE STATION 6/29/60

Standard 8" precipitation gage and medium shelter in center; Chalet dining hall in right background. Sperry Glacier lies just beyond the gap in the mountain structure in the distant background, to the right of the gap. The gap is sometimes called the Sperry Headwall. Exposure of a storage precipitation gage in the Chalet area is not practical, but possible high-level glacier-related locations that have been discussed include Avalanche Creek above Avalanche Lake and Falls, and in the vicinity of Granite Park Chalet.

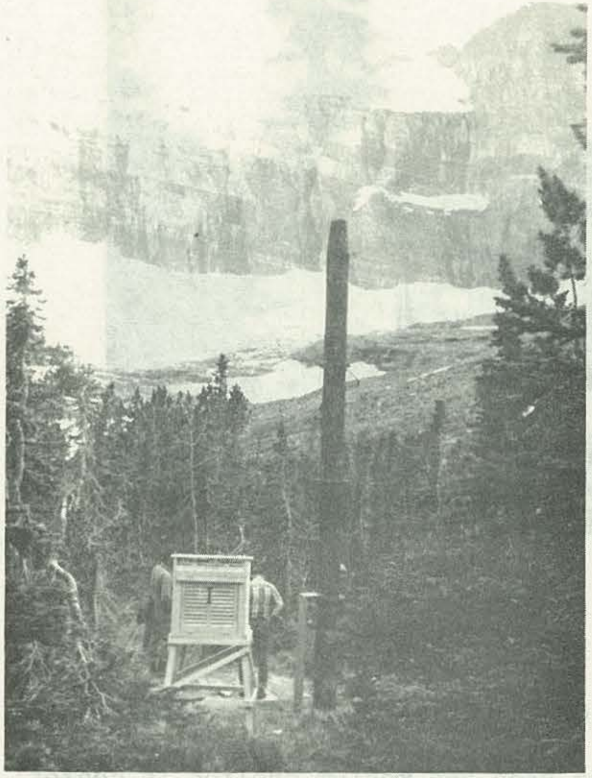

PLATE I.

GRINNELL GLACIER NO. I CLIMATE STATION 7/16/57

The glacier is in middle background, and ice surface is mostly snow-covered. The Continental Divide ridge is in the background, with Gem Glacier at the right of the notch in the center. The thermometer shelter in foreground is used only in August, and for parts of July and September. During the snow season, shelter is wrapped in hardware cloth and stored under trees; instruments are stored at a nearby Ranger Station.