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RECENT MONTANA GLACIER AND CLIMATE TRENDS

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ABSTRACT

Glaciers of Glacier National Park, Mont., the program for their measurement, and findings from measurements and mappings are discussed. Recent trends in temperature and precipitation in Montana are analyzed and their relation to glacier changes are noted. The growth of Glacier Park glaciers in recent years, after over 40 years of recession, appears to be related to the recent cool and relatively wet years in the northern Rocky Mountain Region. It is pointed out that this trend toward cool, wet weather coincides with Willett's tentative forecast [6] based on extrapolation of sunspot–climate relationships.

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INTRODUCTION

There is evidence to show that there are critical points in climatic variations affecting glacier growth or ablation. When such points are reached, the effects on temperate and polar climates can become very large [1, 2]. Many authors (notably Tannehill [3], Kincer [4], Ahlmann [5], among others) have described the world-wide increase in average temperatures which, with only minor fluctuations has occurred during the last 100 years. This gradual temperature increase has coincided fairly well with world-wide (with a few local exceptions) glacier decrease in both area and volume.

Since the relationship of glacier behavior to climatic variations and fluctuations has been established [2], it is the purpose of this paper to discuss the most recent fluctuations in Montana climate in the light of glacier behavior in Glacier National Park in the northwestern part of the State. While the study is limited both in period and area covered, the results appear to agree quite well with Willett's recent extrapolations [6].

Glacier behavior in Glacier National Park has been described by Beatty and Johnson [7]. Grinnell Glacier appears to have followed very well the pattern of decrease in glacier size observed over the world in general for the last 70 to 80 years. In particular, however, Beatty refers to the rapid glacier recession which accompanied the very warm years of the 1930–39 decade, and points out that Grinnell Glacier lost over half its 1902 volume in the succeeding 48 years. However, in their 1951 annual report on Glacier National Park glacier studies, Beatty and Johnson describe the first sizable increase in the size of Grinnell Glacier in 40 years—an increase of the order of 5 feet in depth near the front, with greater depth increases probably farther back from the front. They also reported, at the same time, an average advance of 10 to 25 feet of the front edge of this glacier. A comparison of the behavior of this glacier with weather records for Montana, including meager information about precipitation in the glacier area, furnishes some interesting results which are presented in the following sections.

GLACIERS OF GLACIER NATIONAL PARK

GEOGRAPHY AND GEOLOGY

Glacier National Park lies astride the Continental Divide in the Rocky Mountains of northwestern Montana adjoining the international boundary between Canada and the United States. The park was established by act of Congress in 1910 and comprises close to one million acres of federally owned land.

It is essentially a land of rugged mountains formed by great earth forces. Here is found one of the classic examples of faulting—the Lewis Overthrust, where a section of the earth's crust was uplifted along a gigantic break and then pushed northeastward for a distance of some eighteen miles. More recently Ice Age glaciers played their part in sculpturing the landscape which in general appearance today is said to resemble that of the Swiss and Italian Alps.

In this magnificent mountain setting are more than 200 lakes, mostly of glacial origin, and 50 small glaciers of the cirque or cliff type. These glaciers are not considered remnants of the large Ice Age valley glaciers which in some instances extended out on the Great Plains to coalesce with the Continental Ice Sheet. Evidence indicates that the present glaciers are of a more recent origin.

EARLY RECORDS OF PARK GLACIERS

The first scientist to see and record the presence of a glacier in the area that is now Glacier National Park was Professor Raphael Pumpelly, who journeyed over Cut Bank Pass in 1883 and saw the glacier now named in his honor. George Bird Grinnell, an editor of *Forest and Stream* magazine and a prominent sportsman and conservationist, visited the area in the early eighties and mapped much of the area on the east side of the Divide. It was Grinnell who, in 1887, first visited the glacier now bearing his name. Other scientists such as Dr. Lyman B. Sperry and Professor L. W. Chaney, Jr., followed in the nineties and likewise discovered and visited the ice bodies now named for them.

Field parties of the United States Geological Survey mapped the greater portion of the area between 1900 and 1904, and the present topographic map of the park shows the glaciers as they then existed. Dr. William C. Alden [8], of the United States Geological Survey, made the first comprehensive study of the geology and the glaciers during the summers of 1911–13 and estimated that there were about 90 small glaciers ranging in size from Blackfoot Glacier (included Jackson Glacier, which is now separate and distinct), with its 3 square miles of ice, down to masses but a few acres in extent yet exhibiting the characteristics of true glaciers.

Dr. James L. Dyson [9] computed the areas of some of the major glaciers at the time they were first mapped by the United States Geological Survey from the topographic sheets and from early day photographs which showed the approximate locations of the glacier borders. Several of these individual glaciers at that time apparently had surface areas exceeding 1 square mile. From photographs taken during that period, it appears that these glaciers abutted their terminal and lateral moraines, indicating they were near their maximum size. The size of the moraines in turn would indicate that the maximum stage carried back into the late 1800's, probably reaching a peak around 1890.

PRESENT DAY GLACIERS

Of the 50 small glaciers existing today in the park, only 1 has a surface area of nearly one-half square mile and not more than 7 others are over one-fourth square mile in area. These glaciers are to be found in shaded locations on east- or north-facing slopes at elevations between 6,000 and 9,000 feet, well below the regional snowline.

During the 60-year period following the first written or photographic records of these glaciers, all have been rapidly depleted in both area and volume. Many of the glaciers shown on the topographic map of the park (completed in 1914) are no longer in existence, and others are either inactive or too small to be considered true glaciers. Agassiz Glacier, for example, when first mapped by the United States Geological Survey in 1902, had an area of about 1.4 square miles, and for several decades was considered to be the largest in the park. By 1940 it had shrunk to a position of relative unimportance with a surface area of less than 0.3 square mile, and to all intents, was inactive. Several glaciers in the park occupying similar terrain have likewise wasted away much more rapidly than those occupying normal cirques.

PROGRAM OF MEASURING PARK GLACIERS

Since 1931 the National Park Service has carried on a program of glacier measurement studies in a number of the western national parks in cooperation with the Committee on Glaciers of the American Geophysical Union. These studies, as applied to Glacier National Park, have consisted of marking the fronts of four of the larger glaciers each year to determine the advance or recession of the ice fronts and, more recently, the surface mapping of these glaciers to determine volume loss and rate of movement.

From 1932 to 1944 inclusive, recession of the fronts was determined by direct measurements from fixed points adjacent to the glacier or from paint marks indicating the location of the front in previous years. In addition, Dr. James L. Dyson, serving as a seasonal ranger naturalist in the park, undertook the job of mapping the surface areas of Grinnell Glacier (1937), Sperry Glacier (1938), and Jackson Glacier (1939) by means of a plane table, telescopic alidade, and stadia rod. From these maps Dyson was able to determine the approximate loss in surface area since they were first mapped by the United States Geological Survey. By extending profiles from the terminal moraines he was also able to estimate the loss of volume in the ice mass itself during the same period. Results of these studies indicated that all glaciers of the park had lost more than 50 percent of both area and volume in the period from 1900 to 1940.

Starting in 1945 a change in the method of measuring the ice fronts was put into effect by the new park naturalist, M. E. Beatty, with the assistance of Arthur Johnson, of the United States Geological Survey, Water Resources Branch, Tacoma, Wash. This method was to map the entire front of the Grinnell, Sperry, and Jackson glaciers by plane table and stadia rod, thus giving a better and more accurate average than could be obtained from one or two fixed points which might not be representative of the entire glacier.

In addition to mapping the fronts, profiles were run across the glaciers to determine changes in the surface level of the ice, and large boulders were located to give some indication as to the rate and direction of movement of the ice. Plans called for the complete surface mapping of these glaciers at 5-year intervals, but lack of funds, personnel, and favorable weather conditions have hampered the program.

In 1950 a program of aerial mapping by photogrammetric methods was instituted as a result of donations by the American Geographical Society of New York and the Glacier Natural History Association, supplemented by Glacier National Park funds. Arrangements were made with the United States Forest Service in Missoula to take the aerial photographs and put in the necessary ground controls on a repayment basis. Funds were sufficient to have photographs taken of over 30 park glaciers, put in ground controls for 3, and to prepare a surface map of Jackson Glacier. Unsuitable weather prevented continuation of this program in 1951, but the United States Geological Survey in Washington offered to prepare surface maps of the other two glaciers having ground controls, using aerial photographs taken in 1950.

SUMMARY OF FINDINGS FROM MEASUREMENTS AND MAPPING

All glaciers experienced rapid recession of fronts and shrinkage in area and volume between 1902 and 1940, with only moderate recession and area loss between 1945 and 1950.

Table 1.—*Summary of measurements and mappings of Sperry and Grinnell Glaciers*

	Sperry Glacier	Grinnell Glacier
First measured (year)	1935	1932.
Last measured (year)	1950	1951.[3]
Net recession during period	about 800 feet in 15 years	about 610 feet in 19 years.
Average yearly recession	53 feet per year	32 feet per year.
Area in 1900–02 [1]	840 acres (approximate)	600 acres (approximate).
Area in 1950 [2]	300 acres (approximate)	
Area in 1951 [2]		270 acres (approximate).

[1] Computed from Chief Mt. Quad., U. S. Geological Survey.
[2] Estimated from surface mapping.
[3] Ice front showed an advance for first time in 1951.

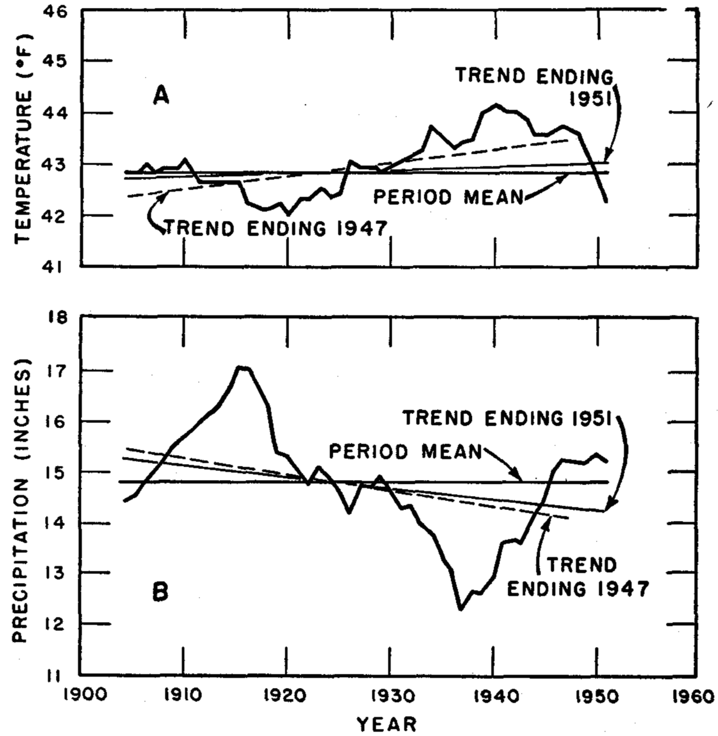

Figure 1.—Montana temperature (A) and precipitation (B). Ten-year moving averages (irregular solid curve) ending with year indicated by abscissa, mean for the period (horizontal solid line), straight line trend ending 1947 (dashed line), straight line trend ending 1951 (thin solid line).

Movement of ice mass (rate of motion) was found extremely variable based on measurement of movement of rocks imbedded in ice surface. The maximum rate is considered to be about 40 feet per year.

All glaciers lost at least 50 percent of their surface area in the 50-year period following the turn of the present century; some lost as much as 80 percent, and several disappeared entirely.

Table 1 summarizes findings from measurements and mappings of the Sperry and Grinnell Glaciers.

RECENT TRENDS IN MONTANA CLIMATE

The last 57 years of Montana average temperature and precipitation records have been used for comparison with glacier measurements. The records for the whole State area of about 147,000 square miles are used to minimize local effects. In figure 1 are plotted 10-year moving temperature and precipitation averages for Montana, ending with the year indicated by the abscissa. Means for the period of record are shown. By the method of least squares (see Croxton and Cowden [10]), straight line trends were computed for the period ending with 1947 and for the period ending with 1951. These trend lines also are shown in figure 1.

It will be noted that the temperature trend line slope decreased to an insignificant value from 1947 to 1951, while the slope in the precipitation trend line changed in the opposite direction, but by a lesser amount. The curve of 10-year moving averages is similar to like-period plots of Tannehill [4] and Kincer [5] for areas with longer records. This shows that the 10-year moving averages for Montana are in reasonable agreement with at least some of those for other Northern Hemisphere areas.

A few other items may be noted. First, the decrease in the 10-year moving temperature averages, which started in 1951 and has increased in tempo the last 5 years, appears much larger and more persistent than the previous decrease from 1910 to 1920. In fact, the most nearly comparable trend the authors have found is the decrease in the 20-year moving temperature averages at New Haven, Conn., beginning about 1810 (Tannehill [4]). This reversal of moving averages which started about 1940 in the area surrounding Glacier Park appears to be having an effect on glaciation, as will be described later.

Willett [6] comments on several apparent relationships between sunspot activity periods and changes in climate. Pointing out that we are apparently headed for a period of sunspot inactivity, he also mentions that transition from warm, dry conditions in middle latitudes to cool and wet conditions appears more closely related to sunspot activity than the emergence from cool wet to warm dry conditions. It was Willett's suggestion that the rainfall increase associated with such a change has already appeared in the western United States, and it is considered possible that the expected accompanying temperature change may also be at hand, in view of the trends shown for Montana. The evidence certainly shows that Montana has tended toward wetter and colder climate now for several years, but the persistence of such a trend remains impossible to predict in spite of the fact that it appears established. Moreover, in climatic trends of many years which are available for study, an occasional year has been encountered which was an exception to the general pattern. Paramount, of course, is the fact that our historical knowledge of most of the factors is very limited. In his work, Willett pointed out that sunspot activity records may be used roughly from about 1750, but have become fully reliable only during the last 100 years. Climate records are of similar quality but when we consider records of 100 to 200 years against climate history as a whole, our basis for study is limited indeed. We know there was agricultural activity in Greenland in the years around 1300 or 1400 A. D. [5], but direct observations of sunspot activity, precipitation, temperatures, etc., are missing.

At any rate, Montana has for about 11 years been riding a trend toward a comparatively cool wet climate. Where this trend will lead or when it may be reversed are matters apparently undeterminable at this time. Willett, however, has made a tentative forecast which ties in well with the observed Montana trends, and indicates the trend may last for several decades. While such a trend has not definitely appeared in some parts of the Northern Hemisphere, Willett mentioned a probable lag of several years in some European and Asiatic areas. Brooks [2] also indicates the strong likelihood that we are now in a period of climatic change which may have far-reaching effects upon civilization. The complete change may take thousands of years, however, if glacier research and the history of the earth have been interpreted correctly.

RECENT GLACIER CHANGES IN RELATION TO CLIMATE

A sizable advance and increase in depth of Grinnell Glacier occurred during the season ending in mid-1951, when an advance from 10 to 25 feet and a depth increase of 5 feet near the front were measured [11]. This was apparently the first sizable increase since 1910, when the park was created, and follows a period of about 3 years during which changes were small. Although actual glacier measurements were started in 1932, attempts to record climate factors did not begin until late in August 1949, when the United States Weather Bureau installed a storage seasonal precipitation gage, and the United States Geological Survey started measuring run-off from the Grinnell Glacier drainage area. Run-off and precipitation data are shown in tables 2 and 3. Run-off values are from 85 to 90 percent of the measured precipitation, assuming precipitation to be reasonably uniform over the basin. Loss from seepage should be small in such a geological formation; therefore, the precipitation which did not run off can be assumed either to have evaporated or to have contributed to glacial growth. That which contributed to glacial growth may show up in run-off excess over precipitation should ablation occur during the period of measurements. In any case, both precipitation and run-off records, when coupled with glacier measurements over many years, should give results of great usefulness in future studies of glacier behavior.

Amounts measured for two seasons, and verified by run-off measurements, indicate precipation in the glacier area to be unusually heavy for an interior North American location at this latitude (48° 46′). At the same time,

TABLE 2.—*Run-off from Grinnell Glacier Basin (3.4 sq. mi.).* *(U. S. Geological Survey)*

Month	Year ending Sept. 30, 1950		Year ending Sept. 30, 1951 [1]	
	Inches	Acre-feet	Inches	Acre-feet
October	3.79	687	10.71	1,940
November	4.17	758	4.23	770
December	1.44	261	2.85	516
January	.34	61	.71	128
February	.31	56	.62	113
March	.48	83	.42	76
April	2.05	373	4.43	803
May	10.44	1,800	16.26	2,950
June	32.02	5,820	19.30	3,500
July	29.74	5,290	24.33	4,410
August	15.10	2,750	11.99	2,160
September	6.66	1,210	9.13	1,650
Water Year	106.54	19,339	104.98	19,016

[1] Unpublished records, subject to revision.

TABLE 3.—*Precipitation totals for Grinnell Glacier, Summit, and Babb, Mont.*

Period	Grinnell	Summit	Babb
	Inches	*Inches*	*Inches*
Aug. 27, 1949–July 20, 1950	125.1	50.2	18.4
July 20, 1950–July 24, 1951	117.5	52.0	28.4
July 24–Sept. 12, 1951	8.7	4.3	7.2

precipitation was unusually heavy at Summit, about 33 miles south-southeast of Grinnell, and at Babb, about 21 miles northeast (see table 3). While low temperature is considered the main element in glaciation by Ahlmann [12], and probably must be assigned the primary role in the over-all history of a glacier, there seems to be some basis for considering the importance of heavy precipitation to glaciation. It would seem that during periods when temperature might remain near or below freezing most of the time, temperature fluctuations might be considered of secondary importance to precipitation. Also to be considered are inherent differences between the so-called maritime glaciers of the Northwestern European Coast and the continental glaciers of North America.

SUMMARY AND CONCLUSIONS

1. After 40 years or more of recession, Glacier Park glaciers seem to have entered a period of growth, probably resulting from the several recent cool and relatively wet years in the northern Rocky Mountain Region.
2. Montana temperatures, at least for the last 11 years through 1951, show a marked downward trend. The average for the 10 years ending with 1939 was 44.1° F., but for the 10 years ending with 1951, this average was only 42.2° F. A similar trend, but in the opposite direction, shows up in precipitation records.
3. Willett's tentative forecast of a trend toward a cool wet cycle in middle latitudes coincides very well with observed conditions in the Northern Rockies during the 2 years following his work. However, there seems to be insufficient basis for concluding that the observed trend will continue, maintain itself at the present level, or reverse.
4. The program of glacier research in Glacier Park has been enhanced by the addition of precipitation and run-off measurements in the Grinnell Glacier basin. More details of glacier behavior will become apparent as more records become available for study. Development of these details will undoubtedly help to cast light upon some of the questions not yet fully answered in studies to date. Of course, these glacier studies will have their impact on the study of long-range climate variations.
5. From Dr. C. E. P. Brooks, [2] we quote a sentence which sums the case quite well: "The problem is not entirely academic, for signs are not wanting that we are even now in a period of climatic change which may have vital, but so far unpredictable, consequences for civilization."

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