# GLACIO-HYDROLOGICAL PARAMETERS OF THE MASS BALANCE OF LEMON GLACIER, JUNEAU ICEFIELD, ALASKA, 1965-67

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ABSTRACT

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MASS BALANCE OF LEMON GLACIER,
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By

Chester R. Zenone

As the initial segment of a ten-year program of glacio-hydrological research, this study covers the years 1965, 1966, and 1967 and has been conducted on the Lemon Glacier on the southwestern periphery of the Juneau Ice-field in the Northern Boundary Range near Juneau, Alaska. The objective was to delineate the role of geomorphological (orographical) and allied meteorological and hydrological factors on the long-term regime (mass balance) of this glacier through systematic recording of basic parameters using standard glaciological and glacio-meteorological techniques. These included measurements on the main accumulation névé at 4000 feet elevation, of temperature, wind, precipitation, cloud cover, duration of sunshine and radiation on a 3-hourly basis during the spring to autumn melting period for comparison with contemporaneous recordings of ablation, transient snow-line and névé-line positions and hydrometric records at a stream gage site near the glacier

terminus. The data are abetted by synoptic weather records at a USWB sea-level station, where continuous data during other months of the year permit extrapolation of the extent of the effective ablation season as it relates to the glacier's liquid water balance.

Good correlation is achieved between hydrometric data and ambient temperatures when atmospheric conditions produce temperatures above 40°F. Below this temperature, correlations tend to break down, although some divergence in pattern can be explained by plotting such influences as wind directions and velocities. Similarly, the propagation of seasonal melt-water is found to be consonant with cumulative ablation and the hydrometric discharge at the glacier's terminus. Anomalies in this correlation are suggested to be the result of runoff propagated by rainfall rather than direct melt and in some cases by the catastrophic self-dumping of ice-dammed water bodies within the glacier system.

A regional cooling, beginning to show significant effects on this glacier by the mid-1960's, is documented by the records of snowfall and glacier stratigraphy. The data are consistent when viewed against the longer-range sequence of records obtained over the quarter century preceding this study, plus data in more recent years obtained from the Lemon Glacier and from other sites on the Juneau Icefield and on the nearby coast. The results support the value of the Lemon Glacier as a regional prototype for monitoring ice mass and hydrological regimes of middle latitude glaciers and the related secular trends in climate which are affecting other glacier watersheds in Alaska and elsewhere in North America.

As this research is being continued through the International Hydrological Decade (1965-74), it will be followed by further reports. The present study and its related data plots have thus been prepared to serve as a baseline for more refined analyses which are planned after addition of subsequent measurements at the same field sites. With respect to the follow-on research, these present efforts have identified marked variations in precipitation from sector to sector in the Northern Boundary Range making it advisable to obtain more detailed comparative measurements in adjacent areas. From this a clearer regional pattern of retained accumulation (net gain) and liquid water discharge (net loss) can be recognized within which the type of data obtained in this study can be most usefully fitted. Another conclusion derived from this investigation is that both in small-scale and large-scale studies of this kind, a total systems approach is quite essential. Therefore, with respect to the Lemon Glacier system, all factors affecting the long-term mass, liquid and heat balance must continue to be taken into account toward a complete understanding of the trends revealed by this preliminary assessment.

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# CHAPTER I

## INTRODUCTION

In recent years it has become increasingly clear that glaciers are indeed unique and useful integrators of climatic change (Ahlmann, 1957). With this in view, observations that would permit a close assessment of the relationships between glacier mass balance and local meteorological and hydrological parameters were made during the period July, 1965 through mid-September, 1967 on Lemon Glacier in Southeastern Alaska.[1] Field operations were continuous from about mid-July through August in 1965, mid-June through mid-September in both 1966 and 1967, in January and February, 1967, and for two weeks in March-April, 1967. At other times in 1966 and 1967, observations were made on a periodic basis--approximately every two to three weeks.

At the outset of this study, it was hoped that the research could be carried out in greater detail than previous

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[1]Lemon Creek Glacier is the name used on U. S. Geological Survey topographic sheets (Juneau B-1 and B-2, 1:63, 360 series). In this presentation, however, the shorter name Lemon Glacier is used, as there are three distinct glaciers serving as the source for Lemon Creek rather than this one alone. The other two are the northern tributary, Thomas Glacier, and the southern tributary, Ptarmigan Glacier (Fig. 2 and pocket map, Fig. 34).

investigations of its type, both on Lemon and other glaciers. To a certain extent, this aim was accomplished on the Lemon Glacier (Miller, 1967). More closely-spaced and more frequently checked observation sites were employed than in the study of this ice mass reported by Heusser and Marcus (1964a&b) and by Marcus (1964). Also observations and collection of data were extended over periods of winter and spring accumulation as well as during the summer ablation season.

When considered in conjunction with a glacio-hydrological study conducted simultaneously on Ptarmigan Glacier, the smaller valley glacier immediately adjacent and west of Lemon Glacier (Fig. 34), the information presented should facilitate historical comparisons and add to the continuing record of data which will be useful in forecasting future water budget trends. On a broader scale, this study provides information on a well-defined and completely self-contained glacier system that is serving as a control location for a larger and longer-term investigation of glacio-climatic relationships on the Juneau Icefield, as well as for other costal glacier systems in Southeastern Alaska.

## Location and Description of Area

Lemon Glacier is a small valley glacier in the Northern Boundary Range of Alaska-Canada, and situated on the southernmost edge of the Juneau Icefield in Southeastern

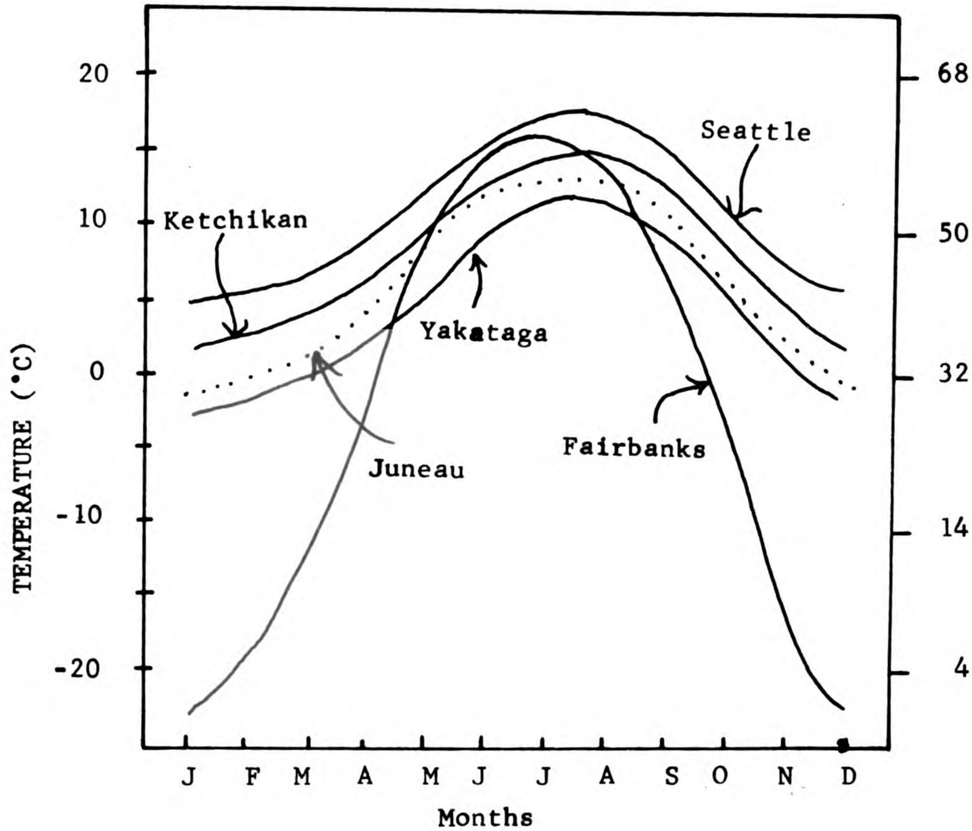
Alaska. It is located about four miles north-northeast of Alaska's capitol city, Juneau (Fig. 1). The glacier's area is well-defined by exposed rock (at the end of summer) and is about four miles long and one and one-half miles across at its broadest point (Figs. 3A and 3B). It flows generally northward, with a westerly turn at an icefall near its terminus (Fig. 3C). Its total surface extends between the elevation of 1500 feet at its terminus and 4900 feet (460-1490 m) on its highest névé. There is a very small area of about one-half square mile which drains southward from a divide at 4000 feet at the southern edge of the glacier. This small portion may be ignored in gross mass budget calculations.

The Lemon Glacier was first selected for special study in 1950 by Dr. Maynard Miller of the Juneau Icefield Research Program because of its accessibility and its simple configuration and size. The plan was for a long-term investigation because these factors would enable field parties to study it most effectively. For a few weeks in the summer of 1950, and again in 1951, the Juneau Icefield Research Program maintained a meteorological station on the nunatak between Thomas and Lemon Glaciers (first designated as Camp 16, later changed to Camp 17-B, as shown on Fig. 2). For reference to the early data see Miller (1954 and 1955a). Besides the regular 5-hour overland foot route to the glacier via Salmon Creek valley, a new and somewhat longer route which was negotiable in winter, was established in the summer of 1966. This route extends upward through timberline from the end of Lemon Creek trail and approaches the glacier from the west via Ptarmigan Glacier (v. Figs. 2 and 34).

## Regional Climatic Environment

The climate in the vicinity of the Lemon Glacier is dominantly controlled by marine influences. Strong differences in topography and elevation cause great changes in local weather over short horizontal distances. The effect of orogrophical winds is especially pronounced. Because U. S. Weather Bureau stations in Southeastern Alaska are all located at or near sea level, year-round climatic summaries for higher areas (i.e. on the Juneau Icefield) must be largely based on extrapolation. Some of this has been faciliated by earlier radiosonde records (Miller, 1963 and Marcus, 1964).

Mild temperatures, heavy precipitation, and generally cloudy conditions are typical factors in the weather of Southeastern Alaska. January temperatures are usually near or only slightly below freezing at sea level, while the summer temperatures are normally between 50 and 60°F (10-15°C). The annual march of temperature at selected stations in Southeastern Alaska (with Seattle and Fairbanks data added for comparison with middle and high latitude positions) is shown on the following graph (after Marcus, 1964, Figure 3, p. 20):




Precipitation ranges between 60 and 200 inches (190 and 508 cm) a year. Snowfall is also heavy along the North Pacific coast, generally increasing with latitude and up to certain levels also with elevation. Under present climatic conditions, at sea level the snow accumulation season extends roughly from early November to mid-April. On the glacier the solid precipitation period extends from late September or early October into early June.

Winds during the summer months are dominantly south to southeast. These winds accompany the low pressure cyclonic storms that frequently pass through the area. When continental high pressure systems build up to dominate the coastal areas between storms, the winds usually shift to a northerly direction.

## Research Facilities and Sponsoring Agencies

The main financial support for this study was provided by the U. S. Department of the Interior, Federal Office of Water Resources Research (Zenone, et al., 1966; Miller, 1967), and by the National Geographic Society through its Alaskan Glacier Commemorative Project administered by the Foundation for Glacier and Environmental Research (Miller, 1969b). Some pilot funds for initiating the study were provided by the College of Natural Science at Michigan State University via the Glaciological and Arctic Sciences Institute. The Institute of Northern Forestry, U.S. Forest Service has provided equipment and personnel assistance. But the main facilities and logistics, plus additional funding, were provided by the Foundation for Glacier and Environmental Research of Seattle, Washington, and its long-term Juneau Icefield Research Program (JIRP). These include six permanent buildings at Camp 17 (elev. 4200 feet) on the Lemon-Ptarmigan Glacier ridge, two at Camp 17A (elev. 2500 feet), a hydrological research station at the terminus of the Ptarmigan Glacier, and a route cabin at 1500 feet elevation above Lemon Creek which proved to be of invaluable use during the summer field season and especially for trail use and emergency occupation on the periodic winter and spring trips up the Lemon Creek trail. Additional temporary camp facilities were installed at Camp 17B on the nunatak between the Lemon and Thomas Glaciers. All these facilities are being expanded for the further field work planned on the total system of the Lemon, Ptarmigan and Thomas Glaciers (Fig. 2). All scientific equipment, oversnow vehicles, radio gear, skis, snow-shoes, extra cold-weather clothing and other equipment for survival and glacier travel were provided by the Foundation.

## CHAPTER II

## PREVIOUS INVESTIGATIONS

A review and analysis of previous work on the Lemon Glacier is presented by Miller (1954), Heusser and Marcus (1964), and by Marcus (1964).

Beginning in 1953, for a period of several years the Juneau Icefield Research Program, supported by the Office of Naval Research, switched some of its emphasis from the much larger Taku Glacier system in the central Juneau Icefield area to the Lemon and Ptarmigan Glaciers. Thereafter special efforts were concentrated on the Lemon Glacier, up through 1958, leading to completion of this early project's final report to the Office of Naval Research in 1958 (JIRP Contract ONR No. 83001). Between 1958 and 1964, annual aerial surveys were made at the end of each summer by Dr. M. M. Miller for JIRP. Detailed ground research on the Lemon Glacier was reactivated in 1965. These studies were again under the aegis of the long-term Juneau Icefield Research Progarm (Bugh, 1965a&b).

From the 1953-58 measurements of annual net accumulation retained in late summer, and the ablation measurements conducted throughout each of these summers, mass budget (balance) figures have been calculated for this early five-year interval. During that period, the mass budgets (balances) were found to be generally negative, except for the 1954-55 mass balance which was strongly positive ($12.6 \times 10^6 m^3$, water equivalent volume). Of the negative budget years, 1957-58 was strongly so ($-8.96 \times 10^6 m^3$). Over the five-year period, the net deficit was determined as $10.32 \times 10^6 m^3$.

Among these early detailed studies carried out on the Lemon Glacier was a micrometeorological program by Hubley (1955, 1957) which considered the surface energy exchange problem during the ablation season. Also a gravimetric determination of ice thickness on the glacier was made by Thiel, et al. (1957). Further geophysical work has been accomplished coincident with the present study (v. Poulter, et al., 1967). A large scale (1:10,000) photogrammetric map of Lemon Glacier, was also produced from aerial photographs taken in September, 1957, and subsequently compiled with a 5-meter contour interval by J. B. Case (1957 and 1959). Another map, surveyed by phototheodolite at the outset of the present study in 1965, at the same scale and with a 10-meter contour interval for volume and topographic comparisons, is in preparation by G. Gloss, G. Konecny, and A. Chrzanowski (1965, also see Konecny, 1966).

# CHAPTER III

## FLUCTUATIONS OF LEMON GLACIER IN HISTORIC TIME

A geobotanical study by Heusser and Marcus (1964) and Marcus (1964) provide an historical framework for useful reference allied with other studies of the Juneau Icefield Research Program on the Lemon Glacier. Down-valley positions of the terminus were recorded on the basis of vegetational changes. These positions were dated using dendrochronological methods also developed on JIRP by Lawrence (1950a).

Though sharp trimlines and well-defined terminal and recessional moraines are not found in Lemon Creek valley, probably due to frequent avalanching from the sides of this narrow, steep valley, the above authors believed sufficient evidence was present to indicate the area into which the glacier advanced, and its fluctuation within that area.

A trimline, presumably representing an eighteenth century position (circa 1750 according to Heusser) is found along a ridge transverse to the valley and marking the most recent ice maximum. Down-valley from this ice maximum, vegetation is composed of old hemlock and spruce with a thick forest litter. Basal peat from a muskeg 375 meters down-valley from this glacial limit was dated by radiocarbon means at 10,300±600 years. This indicates that Lemon Glacier has not advanced more than 375 meters beyond its recent terminal maximum for at least the last 10,000 years.

Dated positions of the terminus since the eighteenth century maximum indicates two episodes of relatively slow wastage followed by more rapid retreat. During the 140 years after the 1750 maximum ice extent, terminal retreat was 675 m. However, from about 1891 to 1902, pronounced loss resulted in another 75 m retreat of the terminus. From then until 1929, slow wastage caused only 150 m retreat. Rapid wastage had been in effect since 1929, causing terminal retreat of about 1000 m. Observations during the period of the present study indicate that the terminal zone continues to experience down-wastage and gradual recession under present climatic conditions. Since the 1750 maximum, Lemon Glacier has lost at least 25 per cent of its area, more than half of which has been lost since 1929. This pattern is characteristic of other small middle-elevation glaciers on the maritime side of the Juneau Icefield.

The behavior of Lemon Glacier also appears to parallel the regime trend of nearby larger valley glaciers since the mid-eighteenth century. Such adjacent glaciers draining the western side of the Juneau Icefield include the Herbert, Eagle, and Mendenhall Glaciers (Lawrence, 1950b, and Lawrence and Elson, 1953).

# CHAPTER IV

## THE PRESENT STUDY

Since the object of this research is to gain a fuller understanding of the parameters affecting glacier mass budget (balance), especially in terms of the local meteorological conditions and relationships, the fundamental meteorological elements were measured which can lead to the establishment of such relationships.

To the above objective, the meteorological program on the Lemon Glacier consisted of basic 3-hourly observations of the pertinent weather elements of temperature, humidity, precipitation, windspeed and direction, cloud cover, duration of sunshine and radiation fluctuations at the observation sites. Daily maximum and minimum thermometer readings were made and the net incoming solar and sky radiation were continuously recorded with a Belfort pyrheliometer. Field measurements of the nature and variation in reflected radiation were also obtained.

The data collected concerning glacier mass balance include daily snow, firn and ice ablation rates, snow-pack and firn-pack density and water equivalence, and net increments of annual accumulation and seasonal névé-line positions on each glacier at the close of the summer ablation season. As well, totalized precipitation data were obtained at the main camp on the Lemon Glacier covering each full year of the 1966-67 period (Fig. 3D; also v. Helmers, 1967).

In the following sections, the individual elements and variations will first be considered and examined, after which any indicated correlations will be discussed. Then brief consideration will be given to the general mass budget problem as it relates to the key meteorological parameters. Before discussing the meteorological factors, the area-elevation relationship is reviewed.

## The Area-Elevation Relationship

As shown in Figure 4, the Lemon Glacier's main accumulation zone lies at elevations well above 3900 feet. This zone, at present the key positive factor in the mass balance of this ice mass, lies above the current mean névé-line (approx. 3500 feet) indicated by records obtained during the three years of this study. Figure 4 also shows that 70 per cent of the glacier's area lies above the mean névé-line (i.e., the average over the preceding 10 years) and thus the glacier as a whole, in spite of the slow down-wasting of its terminal zone, is seen to be in a relatively healthy state.

On Figure 4 is also noted the positions (elevations) of the main test pits for measuring the annual accumulation stratigraphy.

## Meteorological Measurements

Daily and monthly meteorological data from Camp 17 (v. Fig. 2) are given in Appendix A. Representative segments are graphed in figures referenced under each individual element covering periods between 7 July, 1965 and 12 September, 1967. Specific details are as follows.

### Temperature

Temperature readings were obtained with standard mercury (maximum) and alcohol (minimum) thermometers mounted in a U. S. Weather Bureau type of meteorological shelter located on a rock ridge at 4200 feet elevation near Camp 17. The daily maximum, minimum and mean daytime temperatures for the periods of occupation of the station are given in Appendix A. For periods of extended continuous occupation of Camp 17, the data are graphed in Figures 5 and 6. Mean daytime temperature statistics represent the average of six observations, taken at 3-hourly intervals from 0700 to 2200 hours daily. The following table summarizes the mean maximum and minimum and mean daytime temperatures at Camp 17 for those summer months in 1965, 1966, and 1967 for which complete records are available.

Maximum temperature recorded over the several years of this study was 72°F in early June, 1966. However, maximum temperature on cloudless summer days was found generally to reach only into the low 60's. The minimum annual temperature recorded was -15°F, in January and in March of 1967. The nightly minimum temperature during the summer at Camp 17 seldom dropped as low as the freezing point, 32°F (v. Fig. 6).

TABLE 1.--Camp 17 Summer Temperature Summary: 1965 to 1967.*

| | 1965 | 1966 | 1967 |
|---|---|---|---|
| Mean Daily Maximum | | | |
| July | 52 | 48.5 | 45 |
| August | 49 | 43 | 47 |
| Mean Daytime (0700-2200) | | | |
| July | 47 | 44.5 | 41.5 |
| August | 45.5 | 40 | 44 |
| Mean Daily Minimum | | | |
| July | 41 | 40.5 | 36.5 |
| August | 45.5 | 40 | 44 |

*Temperatures in °F.

For comparison of sealevel temperatures with those attained at Camp 17, daily maximum temperatures for both Camp 17 (elevation 4200 feet above m.s.l.) and the U. S. Weather Bureau station at Juneau Airport (elevation 20 feet) are noted in Figure 7, covering most of the summers of 1966 and 1967. The temperature difference between the Juneau Airport station and Camp 17 does not strictly adhere to the normal dry adiabatic lapse rate of 5.4°F/1,000 feet (1°C/100m). Such adherence should not be expected, however, because of the usually high moisture content of the air in this vicinity (release of heat upon condensation of water vapor slows down the rate of cooling), and also because of the strong and locally varied orographic, topographic, and other other geomorphic influences. In Figure 7 it is seen, however, that temperature trends at the Juneau Airport station generally parallel those at Camp 17. This relationship supports the extrapolation of high level meteorological factors in closely adjacent coastal areas of dominant maritimity from data collected at or near sea level. In this case, the Juneau Airport lies but 7 miles map distance from Camp 17.

Precipitation

Rainfall was collected and measured in standard U. S. Weather Bureau type 8-inch rain gages. In addition to the master reference gage near the instrument shelter at Camp 17, a similar gage was monitored in the summer of 1967 near the summit of Vesper Peak (4505 ft.) immediately north of the camp. Also three other standard gages were operated on the ridge immediately west of Ptarmigan Glacier during this same field season. The data from these gages are included in appropriate tables of Appendix A. Mention is also made of the U. S. Weather Bureau gages at Juneau and the totalizing precipitation gage at Camp 17 (Fig. 3D).

For the months of complete record, July through August in 1966 and 1967, August proved to be the wettest month in both years. In July, 1967, there was more than twice the rainfall as in July, 1966, i.e., 15.28 vs 7.24 inches. Rainfall for August was found to be nearly the same in both years (Fig. 8A). The relative rainfall totals, again greater in August than in July, paralleled those at Juneau Airport, at which base station this same pattern has been observed by the U. S. Weather Bureau for at least the last 24 years (Fig. 8B). Average annual precipitation totals, plus those for January and July at the Juneau Airport since 1943, are presented in Fig. 8C. The 24-hour summary of total monthly and annual precipitation, shown in these figures, reveals a general increase in total precipitation from the months of June through September. The established long-term trend at the Juneau Airport was also corroborated at Camp 17 during these same months over the shorter three-year period of this study. This fact suggests that future Juneau Airport precipitation records will be useful in approximating precipitation trends on the Lemon Glacier, a consideration to be discussed in the summary comments at the end of this report. More valuable, however, was installation of the large, totallizing storage precipitation gage near Camp 17 in September, 1966 (Fig. 3D). This gage was installed by A. Helmers of the U. S. Forest Service's Institute of Northern Forestry, in co-operation with the Juneau Icefield Research Program. Ever since it has provided valuable total precipitation data, especially in the late autumn, winter and spring months when the research station could not be easily occupied (Helmers, 1967).

At Camp 17, snowfall during the summer months was found to be light and occurred only during June and in August, with July being exempt. In 1966, a light snowfall was experienced on 11 August at the Camp 17 site (elevation 4200 ft.), but heavier snow was observed on some of the higher surrounding peaks on other occasions in August. On 1-3 September, 1966, however, as much as one foot of new snow fell on the upper névé of the Lemon Glacier at an elevation of 4000 feet, some of which remained when summer operations were suspended on 18 September in that year.

On 28-29 June, 1967, five inches of snow fell at Camp 17. Except for light snows covering peaks above 5000 feet on the 23 August, 1967, no other appreciable solid precipitation was recorded on the Lemon Glacier névé during the summer of 1967, at least through the period of station record to 12 September. Also in this field season, the late season field party reported that no new snow had accumulated at Camp 17 as of the end of summer on 21 September (Miller, personal communication). A trace of new snow fell, however, over the next two weeks, i.e., until 4 October, as recorded by the JIRP aerial photographs taken on that date (v. Fig. 2B). Previous JIRP records, however, have indicated that usually by the end of the third week of September winter snow conditions begin to prevail on the glacier's higher névés and surrounding peaks.

In test pits excavated on the Lemon Glacier in March, 1967, retained winter snow accumulation was measured between 14.5 to 18 feet (4.5 to 5.5 m). Winter test pit data during the period of study are given in Appendix B. Also the seasonal névé-line positions and the lengths of the effective ablation seasons were determined, as discussed later with respect to the mass balance determinations.

A summary of meteorological data for Camp 17 covering the months of July and August 1965 is given in Figures 9A and 9B. These plots compare temperature, precipitation and radiation and duration of sunshine for these summer months.

## Cloud Cover

The records of cloud cover obtained in this study represent tenths of the sky obscured by clouds. These, again, represent the average of six 3-hourly observations each day. Both a complete overcast and a period in which the station was in fog would be recorded as 10/10 cloud cover. At Camp 17, which is the key observation site for such data, a high overcast condition was found to be a rarity during summer months. As a rule this control site enjoys either sunshine, with high broken clouds and unlimited visibility, or it experiences heavy fog at ground level, often reducing visibility to less than 300 feet. The base of these fogs, however, was often observed to rest at less than 200 feet below the station (as seen on ridge flanks on the Ptarmigan Glacier slope).

With respect to periods of extended continuous record over the summer months of the three years of this study, the average daily cloud cover is plotted in Figure 10. The clearest weather (least cloud cover) in the Lemon Glacier area occurs in the late winter and spring months from February to June, which are also often the months of lowest precipitation and coldest weather.

## Duration of Sunshine

Duration of sunshine was recorded with a Campbell-Stokes Duration of Sunshine Recorder. This is a British instrument employing a magnifying glass sphere through which direct sunlight burns a paper strip. The paper burns only when the sun is completely unobstructed by clouds (CAVU). On days with a generally broken cloud condition, or with small patches of fog drifting over the glacier, the record became sporadic and difficult to interpret. For this reason, only days of unquestionable record are included in the plots (e.g., Figs. 9 and 10). These records are most useful when the meteorological condition was CAVU. Such clear days in June and July were found to bring as much as 17 hours of sunshine to the Camp 17 and Lemon Glacier area. As an example the summer of 1966 sun duration data are presented in Figure 11.

## Total Sky and Solar and Reflected Radiation

Incoming total sky and solar radiation were recorded with a pyrheliometer manufactured by the Belfort Instruments

Co. To measure radiation, this instrument employs two bi-metallic stirps, one highly polished and the other blackened. These record a temperature difference which is proportional to incident radiation. The temperature difference creates a weak electric current which drives the recording pen through a series of linkages. The unit value of radiation is gram calories per $cm^2$ per unit time (usually in Langleys, or gm cal/$cm^2$/min). For this study, total daily values were computed (Langleys/day) and are presented on the meteorological data sheets, with the radiation values for July and August, 1965, rated in Figures 9A and 9B.

In these two figures the incoming radiation totals are seen, as expected, to be highest for cloudless days, i.e., days of greatest duration of sunshine. Great differences in radiation values were found to arise between days of complete cloud cover or total fog condition at the base station (Camp 17). These differences are presumed to be the result of substantial variations in relative humidity, as has been discussed by Dobar (1967a).

A brief record of the reflected total sky and solar radiation and calculation of its albedo (reflected coefficient) were also obtained over a few days in August 1965 (Dobar, 1967a) as a preamble to later research on this important topic (v. Gieger, 1966; Wendler and Streten, in Miller, 1971).

Windspeed and Direction

Windspeed was determined with cup-type anemometers. Both a hand-held model and a remote sensing unit with cups mounted on the roof of the science laboratory building at Camp 17 were used. Some of these data for 1966 and 1967 are graphed in Figure 12. The records so plotted represent average ranges of windspeed for the six daytime readings as well as the dominant wind direction over the summers of these years.

Cyclonic low pressure cells lying off the coast of Southeastern Alaska much dominate the summer weather in the Lemon Glacier area. These cellular systems generate an almost constant southeasterly wind which brings the seemingly incessant light to moderate rainfall to the Camp 17 area and the Lemon Glacier névé. Infrequent periods of clear weather during the summer are almost without exception accompanied by light northerly winds. This situation during summer months has been reported in JIRP reports from all of the field stations on the Juneau Icefield over the past 20 years.

## Water Balance Measurements

A complete hydrological (liquid water) analysis of this glacier system over a number of years is being prepared in separate reports by Dr. M. M. Miller and A. E. Helmers, as contributions to the long-term Juneau Icefield Research Program. Therefore, my present emphasis is given to a summary of data collected only in this preliminary phase. Added to this are a few corollary comments and interpretations with respect to the water budget as it allies to the mass (ice) budget (more appropriately termed the water valance vs. mass balance) of this glacier system. These are given in the summary discussion. As background information, the mean monthly Lemon Creek discharge rates during each year from 1951 to 1961 are noted in Figure 25. Appendix E contains a tabulation of daily discharge values for Lemon Creek for the summer months of the present study, June to September 1965, 1966 and 1967. Some of the data are graphed in Figures 26 through 29. These and subsequent records as provided by the U. S. Geological Survey (v. reference list) should be quite helpful in the detailed follow-on analyses noted above.

## Mass Balance Measurements

### Firn Stratigraphy and Test Pit Data

In order to pinpoint the essential measurements for mass balance calculations, that is the water equivalence of the snow-pack and firn-pack, stratigraphic pits were dug every few weeks for comparison at various sites on the Lemon Glacier. The elevations of key pits, as illustrated by the 1966 sites, is noted on the hypsometric curve in Figure 4. The map positions of these test pits both for the 1966 and 1967 field seasons are noted in Figures 14, 15 and 16.

Each test pit was excavated down to the level of the previous summer's ablation surface (v. Miller, 1955). This surface was delineated in almost every pit by a coarse, yellowish dust horizon of granular firn on the pit walls. Occasionally, larger dirt particles could be seen incorporated within this late-summer ablation horizon, as well as undulating ice layers or strata marking the buried position of relict suncups generated by the end of summer.

Measurements in test pits were made following the guidelines of Ostrem and Stanley (1966). Continuous vertical samples, each of 20 centimeters length, were taken using a tube of 500 $cm^3$ volume. The samples were weighed, this weight vs. the known volume giving the water equivalence. Unfortunately this method does not yield information on variations of snow or firn density with depth unless a particular 20 cm. increment contains no ice strata or other diegenetic ice. But by taking the samples in a vertical profile and including the diagenetic lenses and strata, the critical figure of total water equivalence was obtained. Figure 13 illustrates the stratigraphy in a pit on upper Lemon Glacier névé and shows typical values of average density for each 20 cm. sample. It also shows cumulative water equivalences calculated from these densities.

The stratigraphy of key test-pit walls is also given in the tables of Appendix B. Recorded here are the thickness and depth from the surface of all ice strata and horizontal lenses having thicknesses of more than 2 cm. As it is not within the scope or purpose of this study, no attempt is made to trace or discuss the development of such diagenetic ice. Adequate study of this phenomenon has been presented in other JIRP reports (v. Leighton, 1952; Miller, 1963). Suffice it to say that the occurrence of diagenetic structures is highly irregular and that a record of the thickness and number of them at three locations along a single wall of a test pit can result in three very different vertical profiles. Even very thick (5 to 10 cm.) ice strate are not always continuous over the 8- to 10-square meter area covered by a single test pit. Thus interpretive care must be invoked where determinations of annual mass density are desired.

The depth and thickness of the coarse, granular layer of firn marking the previous summer's ablation surface is also noted in the tables of Appendix B. In at least one pit, #4(D) on the upper Lemon Névé, the ablation surface for two previous summers was delineated representive, useful information on retained accumulation over a period of several years.

In test pits excavated during the late-winter operations in March, 1967, the englacial temperature was also measured at regular depth intervals in the snow-pack (v. App. B). Two pits, one each on the Lemon Glacier and on the Ptarmigan Glacier, were dug at locations which were snow- or firn-free at the close of the 1966 summer ablation season. At depth, temperatures in these pits increased from the sub-freezing ambient temperature at the snow surface to a value of -0.5°C. to 0°C., i.e., essentially the freezing point at the buried snow-ice interface. The depths of this interface varied from 3.5 to 5.5 meters (v. App. B; C-10 for Lemon Glacier and C-18 for Ptarmigan Glacier). This is characteristic of glaciothermally temperate conditions generally found on other low and intermediate elevation glaciers along the maritime flank of the Juneau Icefield.

At the end of March, 1967, in pits dug at locations where new snow overlay firn of the previous years, the temperatures at the snow-firn interface were well below freezing, e.g., -3.5°C. in Pits #1 on the upper Lemon Glacier Névé. This indicates that the winter cold wave had penetrated well into the older firn by March 28th in that spring. Sub-freezing conditions, however, are not presumably at great depth in the firn-pack because of the temperate nature of glaciers at this elevation in south coastal Alaska. The temperate character of the Lemon Glacier is further indicated by the only slightly sub-freezing conditions occurring at all measured depths during this study.

Rammsonde Profiles

Rammsonde (Swiss ram penetrometer) profiles were obtained at a number of sites on both the Lemon and Ptarmigan Glaciers. The locations of these sites are also given on the maps of Figures 14, 15, and 16. Most of these profiles were taken during the summer of 1966, although a few were obtained in January and March, 1967, and some check profiles obtained for comparison in the summer of 1967. In the summer of 1965, Bugh (1965b) also obtained late July and late August profiles at the mid-glacier site (3950 ft.) on the Lemon Glacier.

Ram penetrometer profiles are taken to aid in the interpretation of annual firn-pack segments and in time-changes in the firnification process affecting the seasonal snow-pack stratigraphy. The Swiss Federal Institute for Snow and Avalanche Research has developed an equation which relates snow-pack resistances to penetration rates of penetrometer heads and this in turn to the density of snow or firn (Also v. Niedringhaus, 1965; and Waterhouse, 1966). The technique has proved quite useful in other phases of the Juneau Icefield Research Program, especially in delineation of the diagnostic depth-hoar stratum and generally the determination of depths and character of annual firn-packs (v. previous JIRP reports and also Egan, 1966).

The interpretation of ram penetrometer profiles in the Lemon Glacier study is also beyond the purpose of this preliminary report. For reference, however, all of the ram profile records are on file at the Glaciological and Arctic Sciences Institute, Department of Geology, Michigan State University. It is anticipated that their interpretation will be included in the ten-year summary report on this total study over the years 1965-74.

The general location of ram profile sites and the dates of measurement are given in a table of appended data (App. D). Unless thick ice strata prevented it, the profiles were usually extended the full 4-meter depth allowed by the ram tubes.

Ablation Records

Ablation, defined as all losses by the evaporating and melting of snow, firn and ice, insofar as it is expressed by lowering of the glacier surface, was measured employing a network of small diameter wooden stakes and dowels. These were implanted in the glacier surface at locations shown in Figures 14, 15, and 16. Although more sophisticated measurement techniques can be applied if high precision is required, dowels or wands, even if they sometimes must be replaced because of breakage, proved to give sufficiently reliable ablation data for purposes of this study. Stakes were checked at frequent intervals, especially in snow, so that sinking effects (largely due to melting caused by heat conduction downward by the stake itself) could be minimized. To determine if stakes were sinking, adjacent wooden dowels, some with and others without wooden plates nailed to their lower ends, were set into the snow or firn. No measurable sinking of those stakes without attached wooden plates was observed, so most of the data were derived from simple lines of stakes.

In 1966, five cross-glacier ablation profiles were established at five elevation levels on the Lemon Glacier névé. The stakes in each profile were set at approximately the same elevation above m.s.l. During that summer it was found that among stakes on a given profile, no measurable difference in the rate of ablation was calculated over a 3-, 7- or even 14-day period. Therefore, in 1967 the cross-glacier profile network was abandoned and a single down-glacier profile of ablation stakes was used on the glacier's longitudinal axis. The stakes in this profile were close enough together so that at least two stakes could be used to average ablation at any given elevation. This also provided adequate comparison with the 1966 measurements, both daily and cumulative.

No reliable ablation data in bubbley glacier ice from below the Lemon Glacier névé-line were obtained in 1966. An effort was made to use wooden stakes for this purpose, but after a few days, because of excessive ablation rates in this lower glacier sector these were found to be floating in the "melted-out" holes. In 1967, ablation on exposed bubbley glacier ice below the névé-line was more effectively determined by measuring the change in depth of holes drilled into the ice. Measurement of these depths was obtained on the shaft of the ice auger. When making such measurements, it was necessary to assure that the auger tip was at the bottom of the hole and not held up by encrustations of ice along the sides. In previous JIRP studies LaChapelle (1955) found that if the holes are redrilled often enough to keep them approximately two meters deep, melting would not occur at the bottom, allowing it to serve as a reliable reference level.

For the summer of 1967 measurements at three ice-ablation sites (A, B, and C) were located above the icefall at elevations of 3650, 3250, and 3175 feet. Also a line of five ice-ablation holes was established below the terminal icefall at an elevation of approximately 2000 feet and close to the snout of Lemon Glacier (Fig. 3C). The location of these sites is shown in Figure 16. The pertinent ablation records are listed in Appendix C.

## Névé-line Positions, 1965-1967

In 1966 and 1967, ablation of snow and firn on Lemon Glacier produced a distinct end of summer névé-line which trended diagonally and in a southeasterly direction across the glacier from an elevation of about 3600 feet (1100m.) on its western edge to an elevation of 3750 feet (1145m.) on its eastern margin. The névé-lines (more properly termed the transient snowlines if before mid-summer--see glossary) for mid-August, 1948 and for early October, 1967, are distinctly shown in the photographs of Figures 3A and 3B. The 1967 névé-line is also delineated on the map of Figure 17. This position was mapped on 8 September 1967 by A. Pinchek and L. Acker using a Brunton pocket transit and a small altimeter. Also shown are the 1967 seasonal and semi-permanent névé-lines on the Lemon and Ptarmigan Glaciers.

The boundary between these (1965-66 and 1966-67) firn-pack wedges was easily distinguished on the ground by the greater amount of dust and other fine debris producing darker layers in the older firn-pack. The approximate mid-glacier névé-line positions on the Lemon and Ptarmigan Glaciers for the years 1965, 1966, and 1967 are tabulated as follows:

| Year | Seasonal Névé-line | Semi-permanent Névé-line |
|---|---|---|
| Lemon Glacier | | |
| 1967 | 3700' | 3600' |
| 1966 | 3600' | 3600' |
| 1965 | 3400' | 3400' |
| Ptarmigan Glacier | | |
| 1967 | 4000' | 3950' |
| 1966 | 3800' | 3800' |
| 1965 | below 3700' | below 3700' |

The snow-free areas of the Lemon Glacier were about equal at the close of the ablation seasons in both 1966 and 1967. The 1966 and 1967 névé-lines on Lemon Glacier were slightly lower in elevation than the highest recorded in the earlier five-year (1953-58) investigation, as previously discussed. During that earlier study, the highest névé-line recorded was 3950 feet (1200m.) in 1958. The close of the ablation season in 1955 resulted in the lowest névé-line in that same five-year period, at 2875 feet (875m.). (Although this three-year period is too short to draw conclusions from, the névé-line position in 1968 was slightly higher than 1967, indicating a deficit mass balance. But since 1968 there has been a notable lowering of the névé-line, consistent with a regional cooling trend which began to effect the area during the mid-1960's and elsewhere over the Juneau Icefield).

Also from the above we note that on the Ptarmigan Glacier, the 1966 névé-line was roughly at the 3800-foot (1160m.) elevation, and in 1967 the névé-line generally paralleled the 4000-foot (1220m.) contour line. This relatively higher névé-line on the Ptarmigan Glacier, where ablation rates are comparable to those on the Lemon Glacier (v. tables, App. C) is probably related to the narrower geometry of the glacier and the lesser total snow accumulation on the western side of the Lemon-Ptarmigan ridge. The narrow width of the Ptarmigan Glacier also should be expected to result in greater heating effects from radiation and convection off of the enclosing rock walls of this considerably smaller ice mass. The orographical effects, hence local climatic influences on these two glaciers, are also somewhat different.

## Duration of Annual Ablation Seasons, 1965-67

In any attempt to calculate the mass budget of a glacier from data which do not span the entire ablation season (which is the case here), an extrapolation must be made of the duration of that ablation season. To derive such information, three techniques have been invoked in this study: interpretation of aerial photographs taken on dates near the critical times of beginning and end of an ablation season, evaluation of spot field observations by JIRP personnel, and by reference to the U. S. Weather Bureau meteorological records at the Juneau Airport over periods when the field camps were not occupied.

A note of explanation is necessary with respect to the Juneau Airport records. Using an average lapse rate of 4°F/1000 ft, as a guideline (lying between the wet- and dry-adiabatic rates), temperatures at the 4000-foot level were extrapolated from the Juneau Airport data. Thus it was judged when mean daily temperatures at the airport remained generally above approximately 48°F., that above freezing (hence melting) conditions would obtain on the main névé of the upper Lemon Glacier at approximately 4000 feet.

Table 2, page 34, gives estimated dates of the beginning and end of the annual melt season and the effective ablation seasons (v. Glossary). The approximate duration of the effective ablation season in months in each of these three years is also indicated. Later this information will be shown to be significant with respect to the annual periods of runoff indicated in Figures 26 through 29.

TABLE 2.--Lemon Glacier Ablation Periods, 1965-1967.

| Year | Estimate of Annual Melt Period* | Extrapolated Effective Ablation Season** | |
|---|---|---|---|
| | | Period | Duration |
| 1967 | after 4 April to 26 September | ca. 1 May to 10 Oct. | 5.3 mos. |
| 1966 | 1 May (?) to 22 September | late May to 10 Oct. | 4.4 mos. |
| 1965 | ca. 9 April to 28 September | May 15-20 to 12 Oct. | 4.9 mos. |

*Based on aerial and ground observations. These estimates are with respect to conditions over the whole range of elevations on the névé.

**Based on analysis of Juneau Airport and Camp 17 weather records.

# CHAPTER V

## ANALYSIS OF HYDRO-METEOROLOGICAL AND MASS BALANCE DATA

As the present investigation is a principles study, with a chief aim to establish and define the basic relationships between meteorological parameters and mass balance on this typical middle-elevation maritime glacier, it also relates to seasonal and longer-term shifts in the North Pacific Low which have such fundamental influence on the climate of this coast. To this end, it is important that this three-year study has involved considerably more observation sites than the previous investigations of the Lemon Glacier. Although sufficient areal coverage was obtained to permit the calculation of short-term mass balances, this culminating analysis is reserved for the more detailed follow-on reports covering many more years. Even the gross total mass balance statistics for the Lemon Glacier over the five-year interval 1953-58 (Heusser and Marcus, and Marcus, op. cit.) will be added to the continuing accrual of data to round out the consecutive sequence of measurements made by various JIRP personnel covering not only the International Hydrological Decade, 1965-74, but a significantly longer period, 1953-74. This longer-term analysis is also planned because of the need for important supplementary micrometeorological measurements.

Thus, in the following pages which concern mainly the 1965-67 data, attention is primarily given to the basic relationships between the meteorological, hydrological, and mass balance measurements obtained over the shorter period of record covered by this particular study.

## Ablation Rates and the Interdependence of Meteorological Factors

With respect to those periods over which synoptic meteorological data and simultaneous mass balance values were obtained, Figures 18, 19, and 20 portray the 1965, 1966, and 1967 summer ablation rates on snow and firn surfaces of the Lemon Glacier. These are plotted for comparison with the corresponding summer trends of meteorological conditions which have been described. A pertinent illustration of such comparison is given in Figure 22, showing ablation rates on five transects across the Lemon Glacier Névé plotted against changes in temperature and cloud cover over the summer of 1966. Here these parameters are seen rather neatly to parallel each other.

The method of presentation of the meteorological parameters for more refined interpretation needs to be discussed. It is recognized that direct plottings do not always reveal such close agreement and also that the running mean smoothing technique may introduce spurious fluctuations with respect to true variations on a smoothed curve. This is why a liner regression analysis is in order for some of these data. However, even a careful plotting of raw data, especially short period and annual running means, can reveal the major trends in some particular parameters. Such is graphically illustrated in Figure 23, which shows good correlations between temperature and ablation data covering the whole summers of 1966 and 1967, when the temperatures are graphed on 7-day, 11-day, and 15-day running means. This is not to say that for refined interpretations, the regression analyses will not be additionally helpful in the subsequent and more detailed interpretations which are to follow this preliminary report.

At this juncture, the apparent correlations indicate ambient temperatures to be most representative of incoming solar energy, and hence this is assumed to be a dominant factor influencing ablation. This conclusion is supported by reconsideration and comparison of the data presented in Figures 5 and 21. These plots show that higher average monthly temperatures in summer at the Camp 17 station parallel higher total ablation on the Lemon Glacier. Accepting the average temperature as a dominant factor influencing the average of ablation, it would appear (Fig. 23) that the 11-day running mean of daily temperature gives the best fit to the ablation trend. This has also been documented at the same elevation at a slightly more continental location on the upper Taku Glacier (Camp 10) about 30 miles to the northeast (Miller, 1963, Figs. 46 and 47). For comparison, the other meteorological parameters measured at Camp 17 between 1965 and 1967 have also been graphed in this manner, i.e., all based on 11-day running means.

In each of the integrated figures (18, 19 and 20), the daily trends of temperature, incident radiation, and average cloud cover show excellent correlation and so are assumed to be closely interrelated parameters. Again, it is noted that a later regression analysis of these and other data given in Appendix A will attempt to refine the more precise degree of this interrelation. Also graphed in Figures 18 to 20 are the daily windspeed means which show less obvious correlation with the other parameters. In those days, however, which were characterized by relatively severe southeasterly storms (e.g., early September, 1966, and again in September, 1967), a fairly direct correlation is demonstrated between increased wind velocity, increased cloud cover, and decreased radiation and temperature. The specific relationship of ablation to wind is considered in the turbulent heat transfer discussion below.

For the mass balance considerations in Figure 24 cumulative ablation curves for the Lemon Glacier's main névé zone at 3850 to 3950 feet (1140-1240m.) are also plotted for the summers of 1966 and 1967. In this the last two summers of this study are shown to be quite comparable in terms of melt-water propagation affecting runoff, at least during July and August. This aspect, too, will be reconsidered in the summary discussion.

Temperature vs. Ablation Rate

Recorded temperatures represent the basic measure of heat available and used in melting snow, firn and ice at a glacier's surface. On temperate glaciers, therefore, it can be anticipated that the higher the temperature over a given period, the higher the rate of ablation over the same period. For such direct and simple correlation, however, all other factors would have to be equal, which situation does not often pertain in nature.

Further examination of Figures 18 to 20 reveals that, in general, as the smoothed temperature curve rises and falls, the rate of ablation generally increases and decreases. Perfect agreement does not exist over some periods, however, and this also must be explained. To illustrate the situation, we can refer to Figure 19 for 1966 in which there is generally a close correlation, i.e., the period 15 July to 3 August displaying an ablation rate of 6.2 cm/day; the period 3 August to 18 August a much lower rate of ablation (4.5 cm/day); and the period 18 August to 2 September a return to slightly higher rates (4.8 cm/day).

In fact over this total 50-day interval of relatively stormy summer weather, the 11-day running mean curve of daily temperature reveals a general decrease, representing a cooling toward autumn conditions. Yet superimposed on this downward temperature trend is a slight temperature rise associated with increased ablation rates for the period 18 August to 2 September. Similar patterns are seen in Figures 18 and 20.

A different situation is indicated, however, by analysis of the 1967 summer curves in Figure 20. It is particularly of interest that here too, we are dealing with a relatively stormy interval over the period 5-30 August, one in which increasing ablation corresponded with decreasing temperature. These temperatures, however, as opposed to those measured in late August and early September 1966, were between 41° and 45°F, which is 5° or so warmer than in the comparable late summer period of 1966. It is significant that the ablation trends in these two periods are quite opposite, even though the temperature trends are the same. This illustrates the kind of situation where detailed micrometeorological measurements can help. The available basic data, however, are adequate for the purposes of the current study as long as a total systems analysis is applied through which the effects of other key meteorological factors are recognized. This situation is well illustrated by the discussion next below.

## Windspeed, Turbulent Heat Transfer and Ablation Rates

In the foregoing consideration which points up some opposing correlations in temperature and ablation during two comparable stormy periods, and in the light of not having detailed heat balance information at the ice surface, it is suggested that a basic explanation lies in the difference in magnitude of temperatures involved, i.e., in the difference in energy intensities represented. In Figures 19 and 20 the trends and magnitude of temperature curves for the pertinent intervals in 1966 and 1967 are compared. It has been shown in earlier glacio-meteorological research on this icefield (Leighton, 1952) that ambient temperatures below 40°F. exert negligible affect on ablation. In the present consideration with respect to our 1967 meteorological records the decreasing temperatures of late summer are seen to be accompanied by significant increases in wind velocities. Therefore, the crux of the inverse ablation correlation appears, at least in part, to be related to much higher than usual summer wind velocities as well as the seasonal ambient temperatures recorded in the late summer of 1967.

The foregoing suggestion has corroboration in the study of heat energy exchanges at the surface of Lemon Glacier carried out by Hubley in the mid-1950's (1957). In that study it was concluded that turbulent heat transfer was the most important single factor in ablation. Increased surface air turbulence at the glacier surface is obviously associated with the stronger winds that accompany summer storms passing over Lemon Glacier. Hubley was cautious, however, in pointing out that this explanation is but a very general one and that more refined and complete heat balance research is yet needed. The data presented in this present study also suggest that the relationships are not simple nor always obvious between the factors of windspeed and turbulence alone, and that there are many "anomalies" that will require explanation through more detailed research on the other glacio-meteorological parameters involved (v. Streten and Wendler, 1968).

Incident Radiation and Cloud Cover
vs. Ablation Rates

The comparison of curves of incident radiation with those of average daily cloud cover, as given in Figures 18-20, reveal that in general, the lesser the cloud cover at an observation site, the greater is the incident radiation at the surface at the same site. Here again some of the correlation appears simple and direct, and indeed on clear days solar radiation should be expected to reach the surface relatively unimpeded, except for minor atmospheric scattering related to abnormal water vapor conditions or dust or smoke components which may develop. Also when high overcast or low fog conditions exist, back scatter by minute water particles greatly reduces the amount of radiation reaching the ground. This is borne out by the Lemon Glacier field and laboratory observations of Dobar (1967a) who, during the 1965 summer, found that variations in ground fog density, presumably representing differences in relative humidity, seemed to have pronounced influence on the amount of solar radiation reaching the glacier surface.

Hubley (1957) also demonstrated that on the Lemon Glacier, the albedo or reflective ability of the snow/ice surface increases with increasing cloudiness. Thus absorbed insolation on overcast days is only about 50 per cent of that absorbed on clear days, with the result that notably higher daily ablation rates should be expected to be associated with lesser proportions of average cloud cover, which situation this current study bears out. Hubley also found that daily insolation on horizontal surfaces under overcast skies was 60 per cent of that received under clear skies. All of this verifies and corroborates the direct correlations suggested by plotted records of cloud cover and ablation in this 1965 through 1967 study.

Simple calculations, based on the above percentages of absorbed incident radiation under the two extreme sky conditions, reveal that on overcast days the amount of energy available to melt snow, firn or ice is only about 30 per cent that available on clear days. This conclusion is also well illustrated and substantiated by the plotted curves. It is cautioned, however, that the albedo under these two conditions (clear sky vs. high overcast or low fog) cannot always be compared simply because it also varies with the sun angle and hence the time of day (Dobar, 1967a; Miller, 1971). The albedo is expressed as a total energy flux, i.e., as a Total Flux Reflected/Total Flux Incident. From the nature of this expression, it will always be greater on overcast days.

Because only incoming radiation could be measured in the 1966-67 seasons, no further evaluation is warranted. This does not mean that the radiation balance measurements are assigned a secondary role. Instead they are considered absolutely essential for the more refined measurements and analyses planned for later phases of this project. In fact, specific research on this aspect was conducted in connection with a micro-metrological program on the Lemon Glacier during the summer of 1968 (Miller, 1971).

## Lemon Creek Runoff and Glacier Mass Balance Considerations

In Figure 26 daily hydrometric discharge rates are shown for Lemon Creek over extended periods of the summers of 1965, 1966 and 1967 (also v. App. E). These hydrological data are from the U. S. Geological Survey Surface Water Records of Alaska (1965-67) and represent records from the USGS stream gage on Lemon Creek (Fig. 2). It is mentioned also that in 1967 a gaging station and a recording ground water well was installed on the tributary Ptarmigan Creek for comparison of runoff from Ptarmigan Glacier (also v. Fig. 2 and Miller, 1969a).

When compared with ablation rates and trends during the summers of 1965, 1966, and 1967 the Lemon Creek hydrometric information suggests that the general trends of curves of daily discharge down Lemon Creek (Figs. 27, 28, and 29) in these same summers show fair correlation with trends of ablation on the glacier over corresponding periods. It can be specifically shown that the high point on the discharge curve, in late July, 1966 (Fig. 28), corresponds to a high point on the ablation rate curve during the same interval. The narrow peaks superimposed on the gross curve seemingly reflect the high and oftimes sudden precipitation of stormy periods. These peaks are accentuated as the ablation season progresses. This is not only because of increased storminess as autumn approaches (v. Fig. 8B), but is also a result of the greater area of exposed ice in late summer, i.e., that over which water propagated by rainfall produces direct runoff instead of percolating to depth. As such water drains off with minimal response-time lag at the terminus, it is quickly reflected in the stage recorder of the outlet stream.

Some of the peaks of discharge shown after midsummer, 1967, have been suggested by Miller (1969a) to relate to observed sudden lowerings of an ice-impounded marginal lake on the southwestern margin of the Lemon Glacier Névé. This phenomenon has been reported as "glacier bursts" (Jokulhlaups) on Icelandic glaciers and the causal relationship may be similar here. These so-called Jokulhlaups are self-dumping catastropic releases of water impounded in and on the glacier. The dates of their suspected occurrence are noted in Figure 29. Because of the environmental hazard which outbursts of glacier-dammed water could represent, they are worthy of detailed consideration. A special investigation of this aspect of the hydrological regime of this glacier was initiated in 1968 (Miller, 1971; Smithsonian Institution, 1971).

Further to the analysis of the hydrometric records at least in the broadest sense, the 4.9, 4.4, and 5.3 month periods of the effective ablation season in 1965, 1966, and 1967 which have been previously discussed are commensurate with extrapolated limits of the main period of intensive hydrological discharge shown in Figures 28 and 29. This emphasizes only the months of excessive melting and runoff and not the early season and late season weeks when but minor flow is involved. That such a relationship exists between runoff maxima and melting firn maxima has been corroborated by the studies of Andress (1962), Miller (1963, Figs. 48 and 50, 1971) and Helmers (1967).

Although it may appear obvious that the greater the total melt on a glacier, the greater should be the discharge of its runoff stream, there are complications in the correlations because of rainfall as opposed to strictly melt-water effects. Thus it is difficult precisely to relate discharge rates and total runoff volumes to changes in a glacier's mass balance without complete, reliable and consecutive precipitation data over the full melting season. Such is planned in even more detail for subsequent phases of this research program, using where possible instrumented precipitation recorders. In this it will have to be kept in mind that unusually high total annual runoff values associated with high ablation rates might still parallel a highly positive mass balance if that year's net accumulation were indeed excessive.

Specific at-site accumulation on the Lemon and Ptarmigan Glaciers is, of course, a highly variable factor because of orographic effects, wind drift deposits, and so forth. To establish a significant total mass balance relationship which is truly meaningful to long-range glacier budget predictions, maps of accumulation thickness over the total glacier for a period of a number of years should also be constructed. These maps should then be compared with the corresponding melt-season runoff values and cumulative ablation totals for Lemon Glacier. In the meantime, selective late spring and end-of-summer stratigraphy measurements at a few representative sites on the flattest névé areas can provide a fair estimate of trends. To this end, the test pit measurements obtained can serve as a useful index for the 1965-67 period.

# CHAPTER VI

## GLACIO-CLIMATIC TRENDS AND SUMMARY COMMENTS

A review of the total array of meteorological parameters and their influence on accumulation and ablation of Lemon Glacier has revealed some direct and useful correlations. It has been shown that the trend of any one parameter can often provide a guide to what the trend of other parameters should be. In effect, by looking at details of one factor in this study to date, the others have been approximated. It is anticipated that the more refined and continuous year-around hydrological measurements and analyses of related meteorological information which have subsequently been obtained by A. E. Helmers, Dr. J. Bugh, and Dr. M. M. Miller, as part of the long-range acquisition of data for this and allied projects, will support and enlarge the basic correlations presented here. The integration of earlier records obtained by Miller, Egan, Andress, and other researchers on the Juneau Icefield Research Program will also add long-term depth and further reliability to the interpretations.

Substantial examples of the above are given by the main Juneau Icefield névé-line and retained accumulation sequence for 1946 to 1965 presented in Figure 30, and the snowfall record to date in Figure 31. Respectively, these two figures illustrate the pre-1965 accumulation and névé-line trends on the adjacent Taku Glacier of the Juneau Icefield, and the annual winter season snowfall at the Juneau Airport station for the period 1943-71, thus extending this part of the regional record backward several decades prior to this study and forward to the present. The current conditions that have been discussed and which are leading to a healthier regime on the Lemon Glacier are well corroborated by the changes revealed by incorporation of these preceding and subsequent data. And they add credence to the interpretaion of pronounced warming during the 1940's and 1950's, significantly followed by the secular cooling trend which has been recognized in this study and indeed by other research (v. Hamilton, 1965). This current trend is particularly well documented by the 5-year running mean plot in Figure 31.

A provisional map of district variations in annual precipitation given in Figure 33 (pocket) also provides a working model for future reference. This map is from regional estimates made in connection with some forest hydrology studies by Dan Bishop of the Institute of Northern Forestry at the U. S. Forest Service in Juneau, Alaska (Miller, personal communication). In 1966-67, Mr. Bishop assisted in field measurements on our Lemon Glacier project and so is familiar with the Juneau Icefield Research Program statistics. Although it is clear that some of his referenced data are only gross values based on selected site measurements and hence are not precise figures, the map's significance lies in recognition of pronounced differences in annual total precipitation which do occur in different sectors or local watersheds of the Northern Boundary Range as a result of marked variation in the parameters of geographical position and elevation. Exemplifying this is the 100 inches (254 cm.) of water equivalent precipitation per year known for the Juneau and Douglas Island area, as opposed to the 140 inches (356 cm.) recorded down Gastineau Channel from Thane; the 60 to 80 inches (203 cm.) recorded up-channel in the lower Mendenhall Valley and Juneau Airport sector; the 150 inches (381 cm.) per year indicated for the Mt. Juneau ridge area; the 200 inches (508 cm.) per year extrapolated from JIRP data for the south maritime flank of the main Juneau Icefield, including the Lemon Glacier; and the 180 inches (457 cm.) recorded at JIRP camps in the high maritime interior and southeastern sectors of the Juneau Icefield. On the north continental flank of the range, annual precipitation is recorded at little more than 10 inches (25.4 cm.w.e.) per year at Atlin. In the future, regime trends on the "prototype" Lemon Glacier, when compared with measured glacio-hydrologic trends in other areas in this part of Alaska and the adjoining inland sectors of Canada will have to take into account this distribution and gradient precipitation. All of this points up the need for further and more complete regional data of the type this study has identified. In this context, plans are underway for synoptic studies of a comparable-sized inland and more continental climate glacier in the Atlin region as noted in Figures 1 and 33. For such comparative future research the facilities at Camp 17 on the Lemon Glacier provide an excellent base of field operations (Fig. 32).

Thus the continuing accrual of detailed field measurements on the liquid and mass budgets not only on this glacier but on others in the region can have important environmental value. New emphasis on the Lemon Glacier's heat budget up through 1971 (Miller, 1971) has already provided significant additional information towards understanding the state of health of this particular glacier and has as well borne out some of the main conclusions suggested in this study. Although there are now five years of fairly consecutive and detailed records ready for analysis, it is anticipated that the ten-year record up through the International Hydrological Decade (1965-74) will be of considerably greater interpretive significance. It is out of this approach that the total regime of the Lemon Glacier system will eventually be understood. It is hoped that the information, plotted data, records, ideas and maps presented in this format, although covering only the initial several years of a much larger study, will nevertheless serve as a useful baseline for the more refined and larger objectives.

The analyses to date at least substantiate the value of using the Lemon Glacier system (v. large-scale map in pocket, Fig. 34) as a prototype for long-range glacio-hydrometric measurements which, once the differences in climatic character of the various sectors are delineated for the region as a whole, may serve as a representative model for much of the Alaskan Panhandle and adjoining areas of Canada (Ostrem, 1966). This should also then add significantly to the comparative monitoring and evaluation of mass and liquid water balances on other representative glaciers in the middle and high latitudes of North America.

# GLOSSARY*

Annual Melt-Period

Includes those intervals of time in which air temperature at the snow surface is persistently above the freezing point. This condition can pertain in late spring and early autumn, even when englacial temperatures within the snow or firn-pack may be sub-freezing.

Effective Ablation Season

That part of the annual melt-period when the snowpack of the previous winter's accumulation is fully isothermal at 0°C., i.e., the glaciothermally temperate condition over essentially the summer melting period, in which the englacial percolation of liquid water is not impeded by freezing.

Snow

Defined by age, i.e., density; new snow density 0.1 to 0.3; old snow density, 0.3 to 0.45. Firn is a density of 0.45 to 0.74; firn-ice is a density of 0.74 to 0.85. Greater densities represent glacier ice.

Firn

Derived from the German adjective fern, meaning material retained "from last year." It most usually refers to old glacier snow metamorphosed to a density of 0.45 or above (up to 0.74 above which density there are no longer interconnected air spaces), and which has survived at least one ablation season.

Bubbley Glacier Ice

Defined by age, i.e., density of 0.85 to 0.91 (mean 0.90); aerated white-appearing ice below the névé-line. Ice of greater than 0.91 is referred to as dense glacier ice.

Diagenetic Ice

That formed by refreezing of percolating melt-water usually found in firn-packs as part of the stratigraphy, i.e., ice strata, ice lenses, ice columns, etc.

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*All terms are as defined in Taku Glacier Evaluation Study, Foundation for Glacier Research, M. M. Miller (1963); also v. Miller (1955b).

Névé

Used here as a geographical term having an areal connotation; refers only to the glacier's accumulation area covered by perennial firn, i.e., that lying entirely within the zone of accumulation (again, as noted above, firn refers to the substance of the material itself; neve to the area in which firn is found).

Névé-line

A general reference term only. More specifically, the most stable position of the névé-line over a period of several years is referred to as the semi-permanent névé-line. It may lie at a lower elevation than the seasonal névé-line noted below.

Transient Snow-Line

The outer limit of the retained winter snow cover (density less than 0.45) in the névé. Its final elevation at the end of the annual ablation season becomes the seasonal névé-line which may be either above or below (hence burying) the semi-permanent névé-line.

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ILLUSTRATIONS AND FIGURES

## THE NORTHERN BOUNDARY RANGE

### ALASKA - CANADA

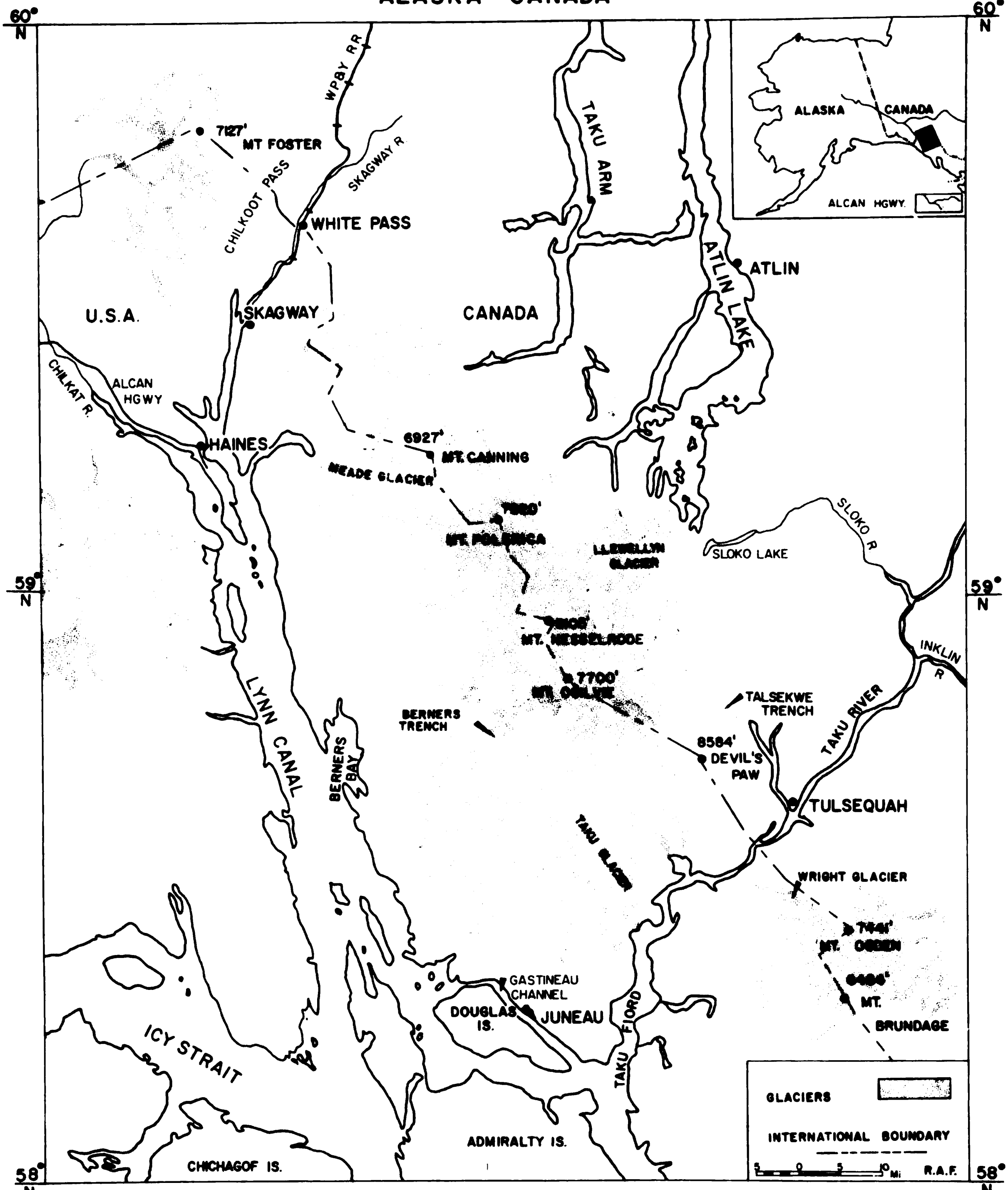



FIG. I

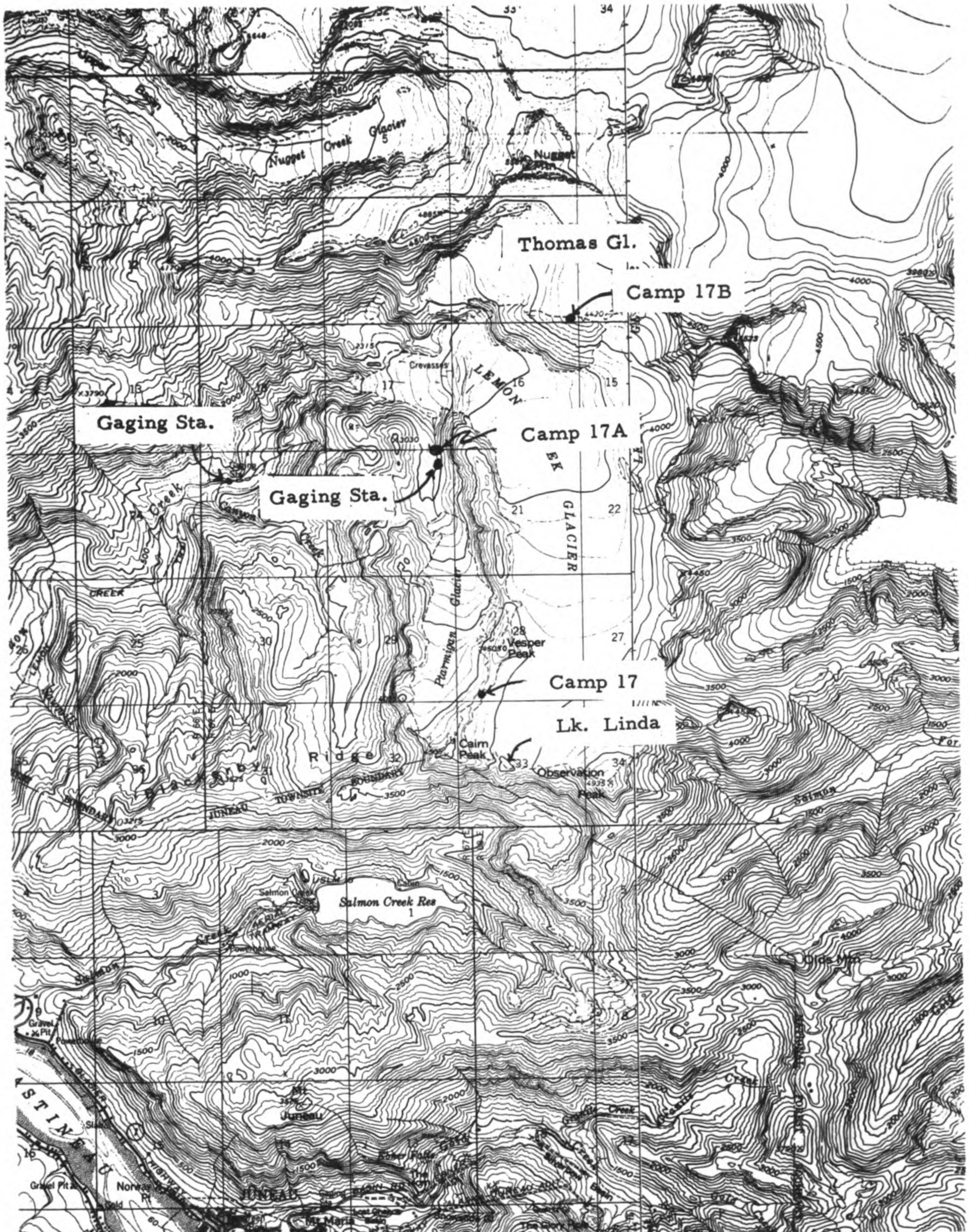



FIGURE 2 MAP OF SOUTHERN TIP OF JUNEAU ICEFIELD SHOWING LOCATION OF LEMON AND PTARMIGAN GLACIERS AND CAMPS 17, 17A AND 17B. SCALE 1:63:360

FIG. 3A.--Lemon-Ptarmigan Glacier System, 13 August 1948 (Photography by M. M. Miller).


FIG. 3B.--Lemon Glacier, 4 October 1967 (Photography by A. E. Helmers).

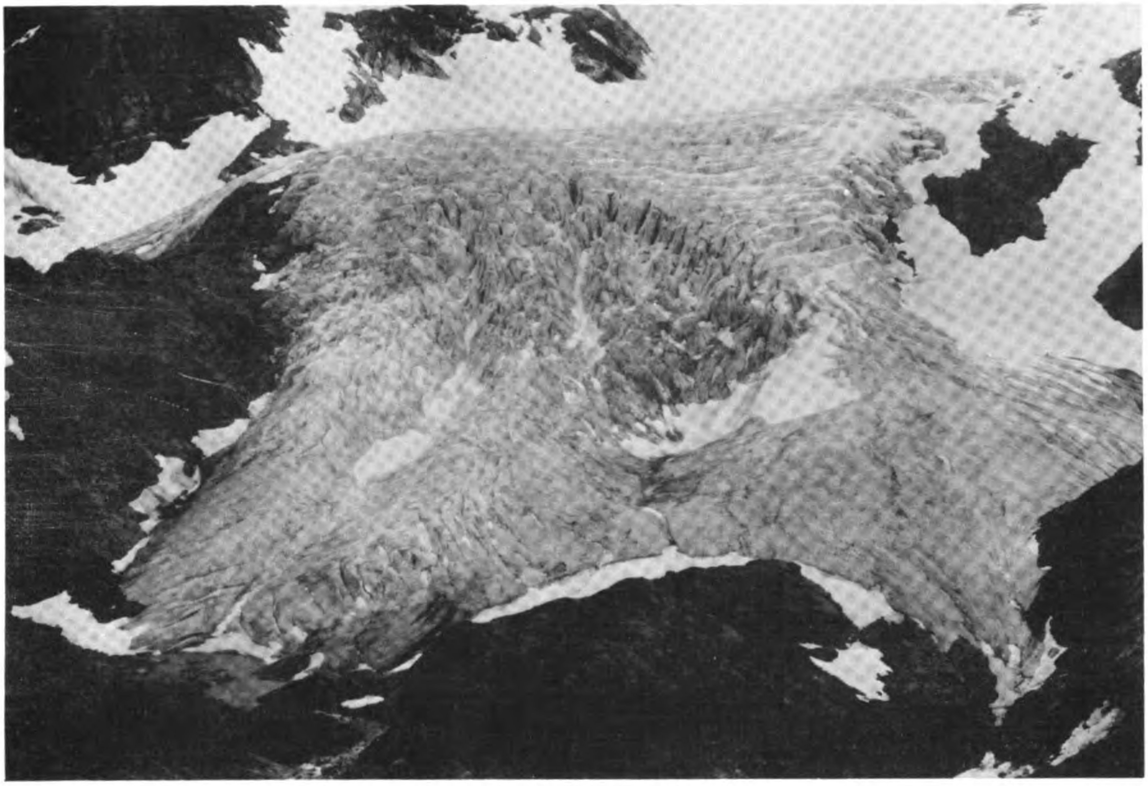
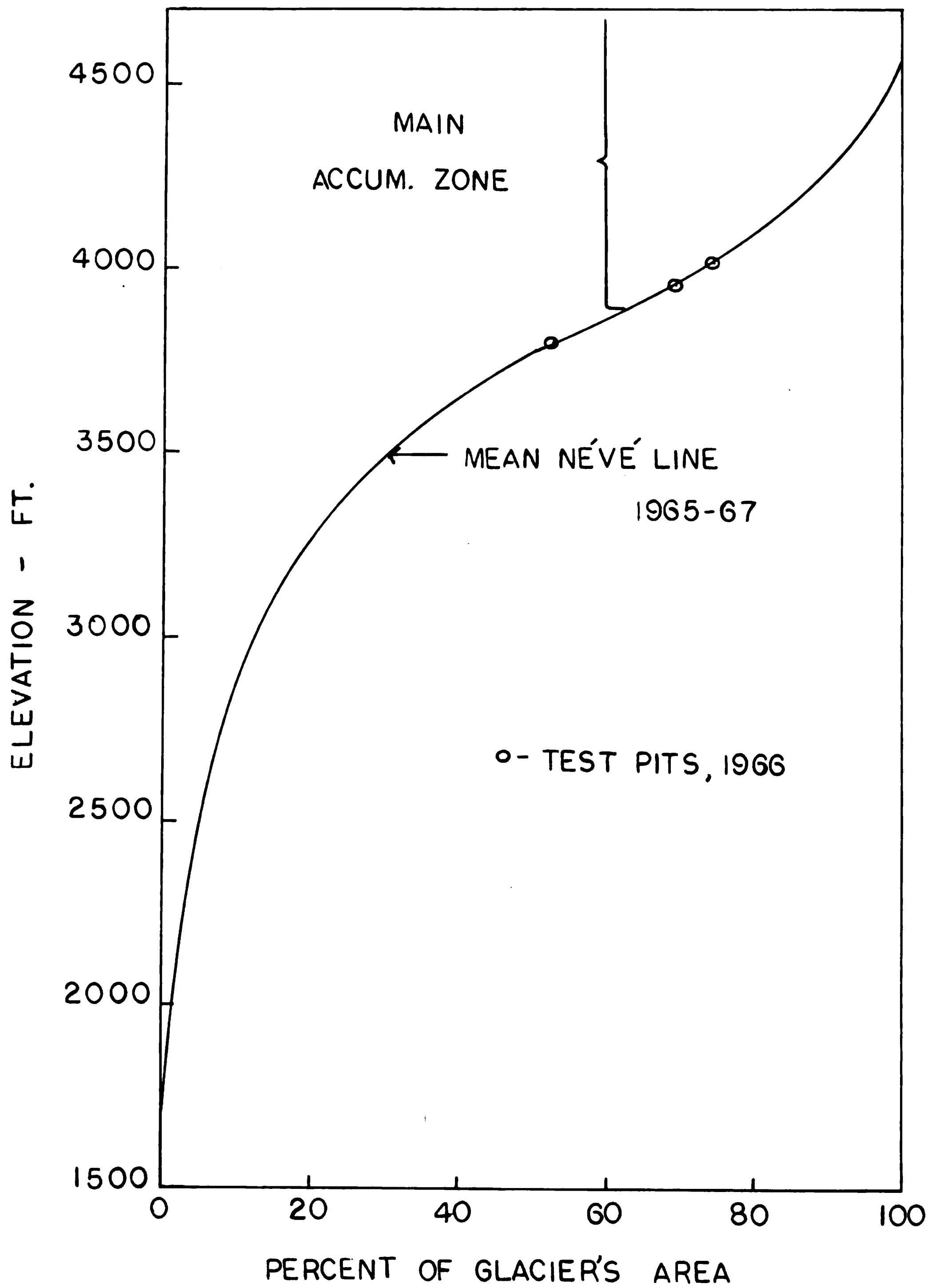


FIG. 3C.--Lemon Glacier Icefall and Terminus, July 1966 (Photograph by M. M. Miller).

FIG. 3D.--Storage Precipitation Gage (on Lemon-Ptarmigan Ridge ) near Camp 17 (Photograph by M. M. Miller).

FIG. 4 - AREA-ELEVATION RELATIONSHIPS,
LEMON GLACIER



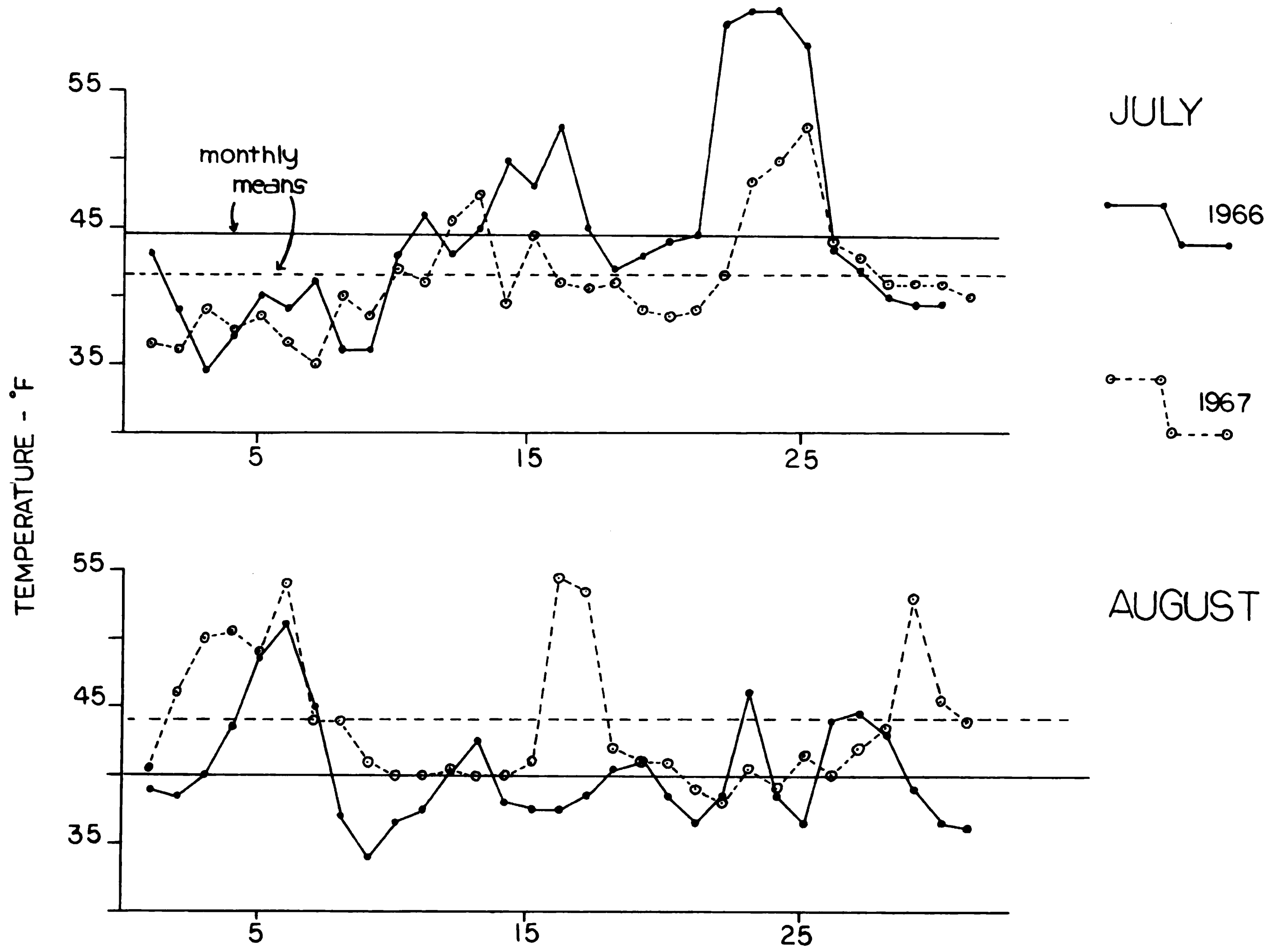



FIGURE 5: MEAN DAYTIME TEMPERATURE RECORD, CAMP 17, ELEVATION 4200 FEET, JULY AND AUGUST, 1966 AND 1967

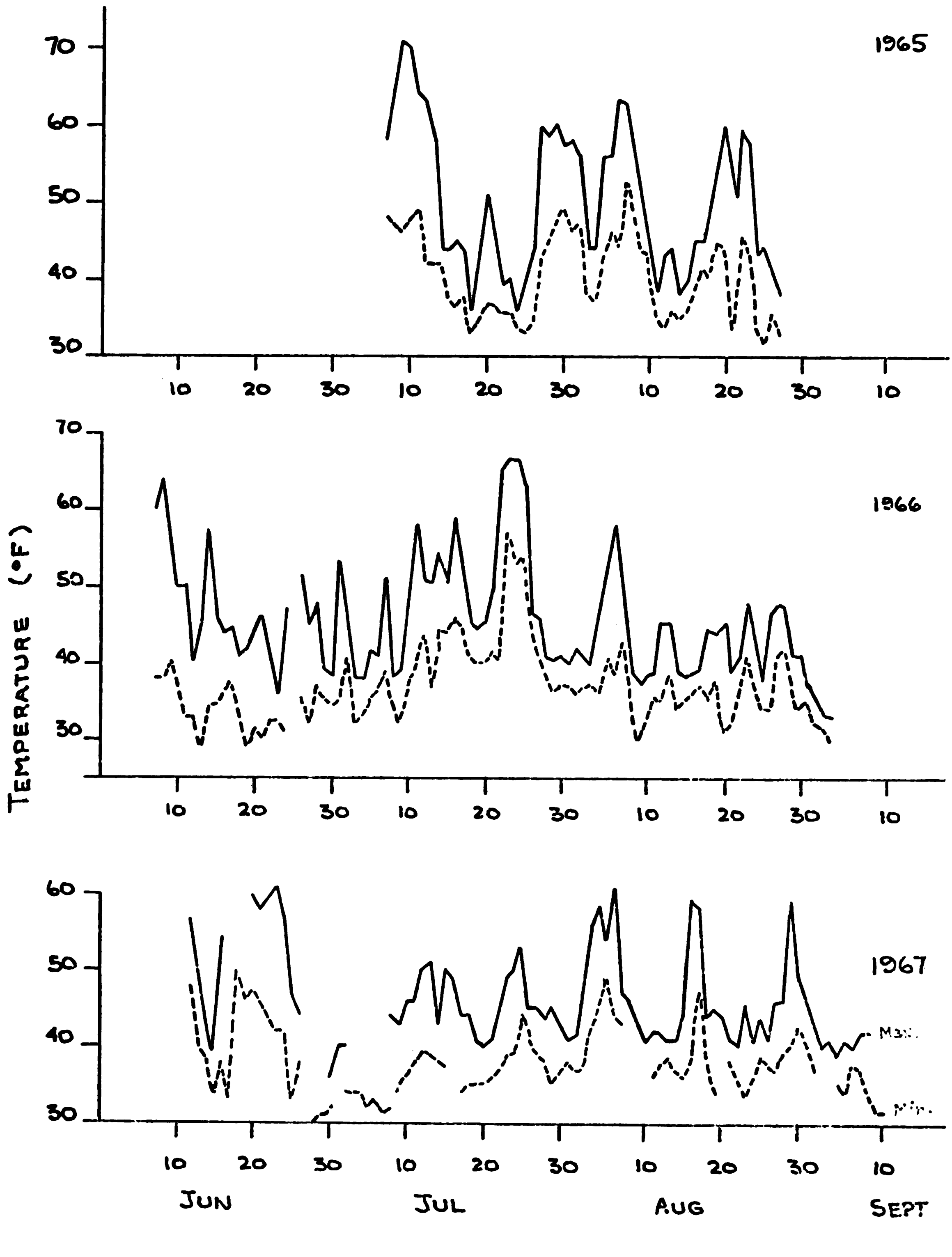



Fig. 6 - Daily Maximum and Minimum Temperatures at C-17

——— Max. - - - - - Min.

FIG. 7 - MAXIMUM DAILY TEMPERATURES : JUNEAU AIRPORT vs C-17

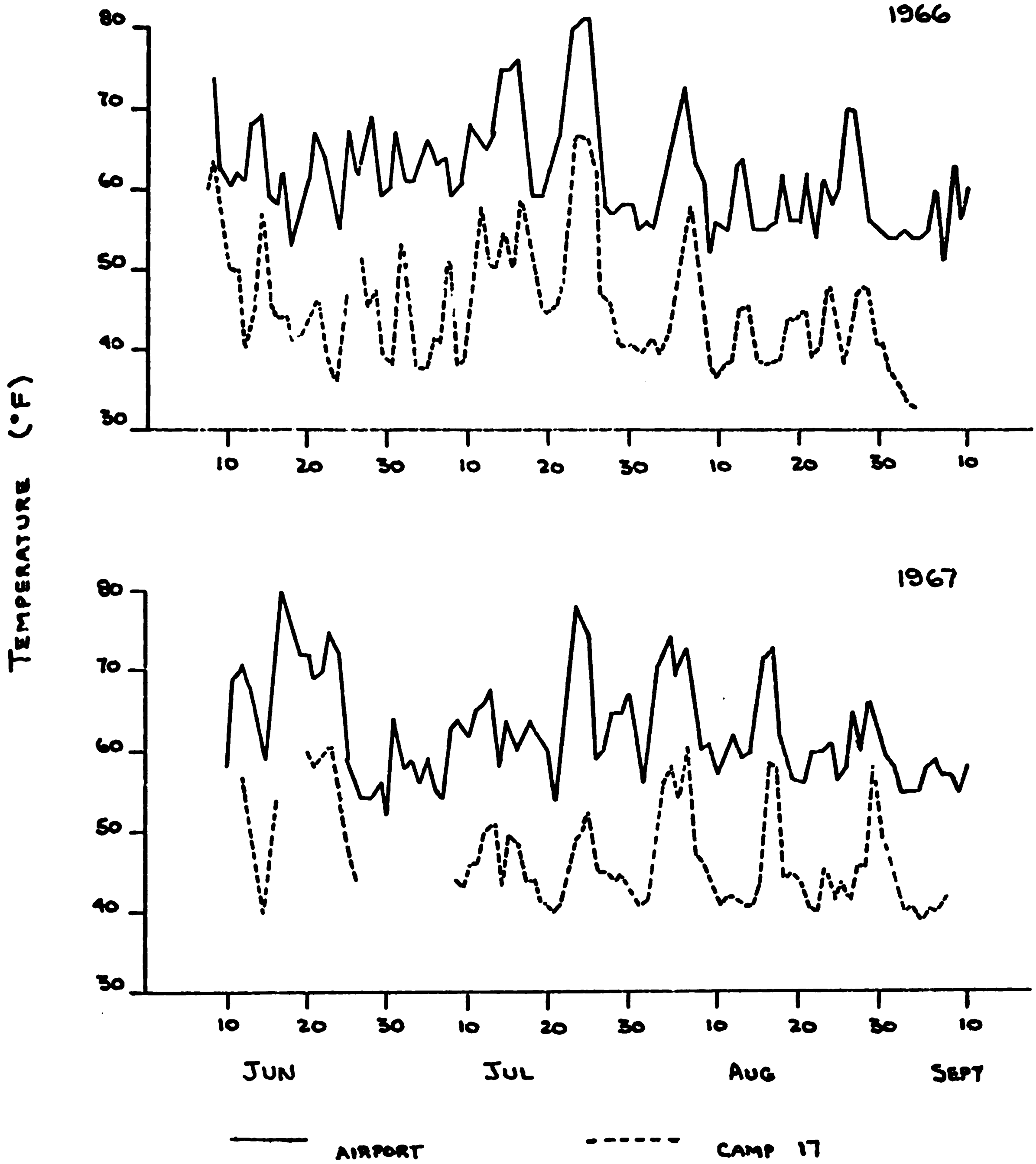


Fig. 8A - Total Precipitation: Camp 17 vs Juneau Airport

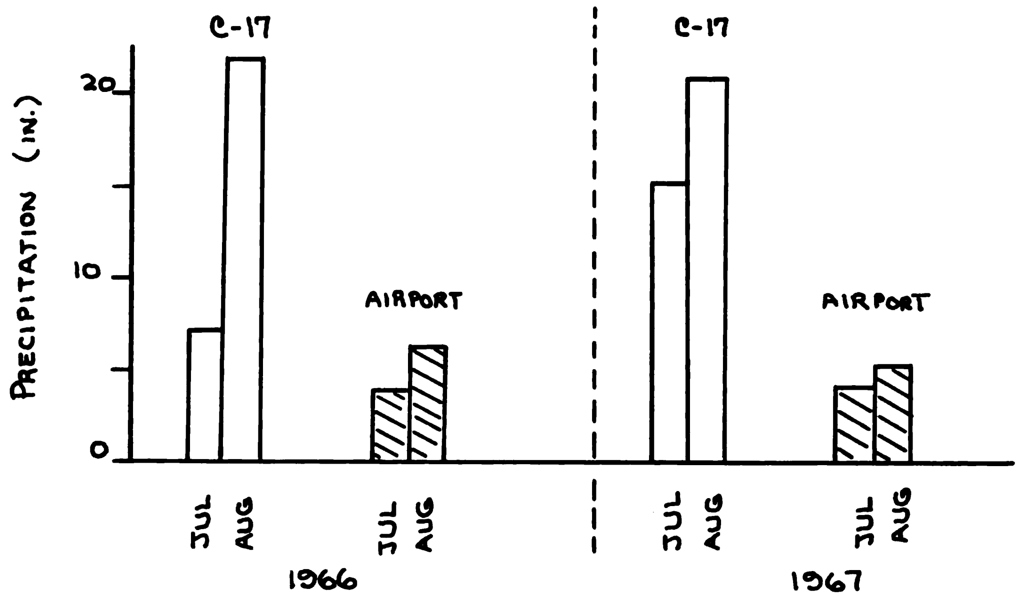



Fig. 8B - Mean Monthly Precipitation at Juneau Airport, 1943-66

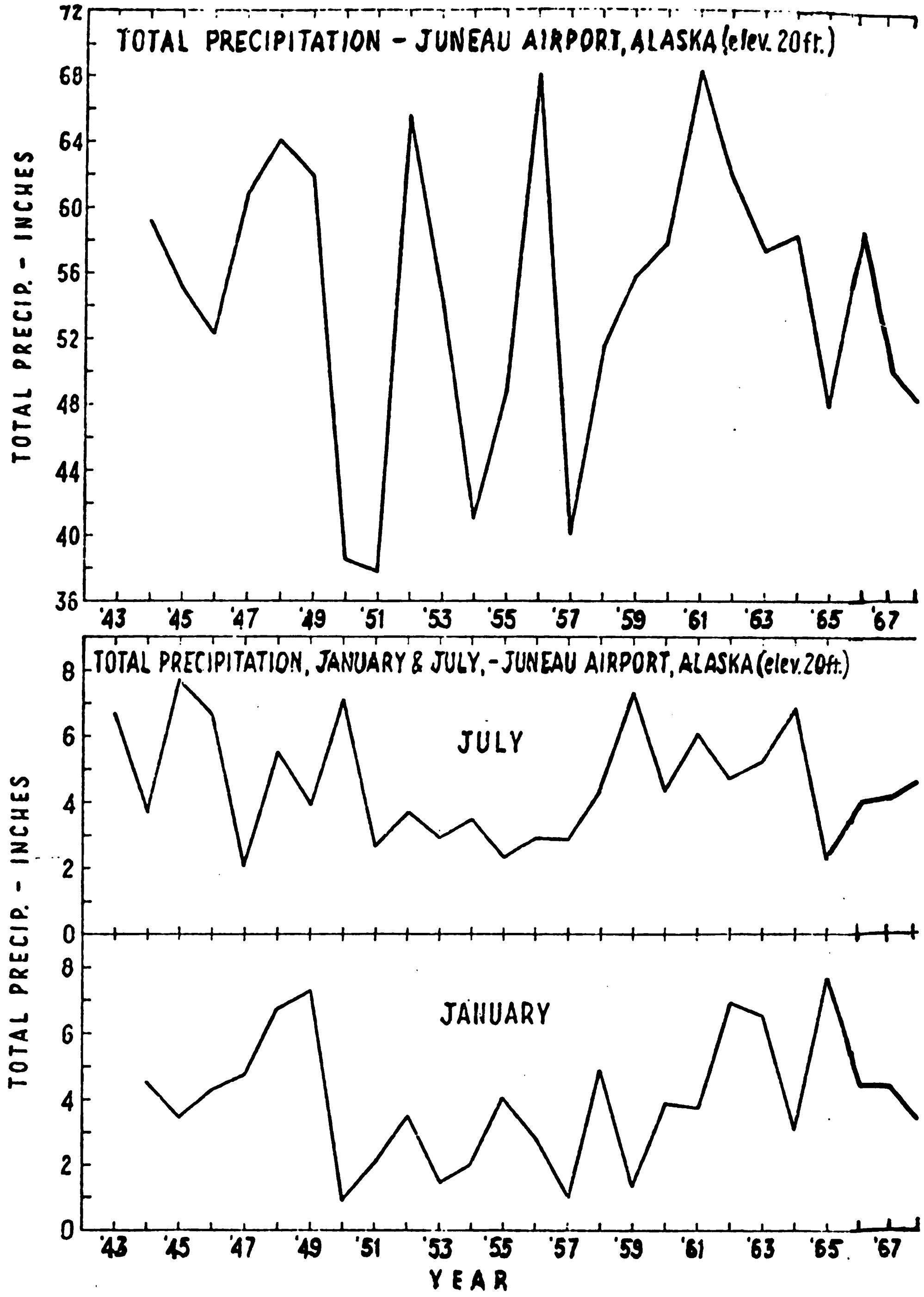



FIG. 8C 1943-68 TEMPERATURE & PRECIPITATION TRENDS AT THE JUNEAU AIRPORT, ALASKA.

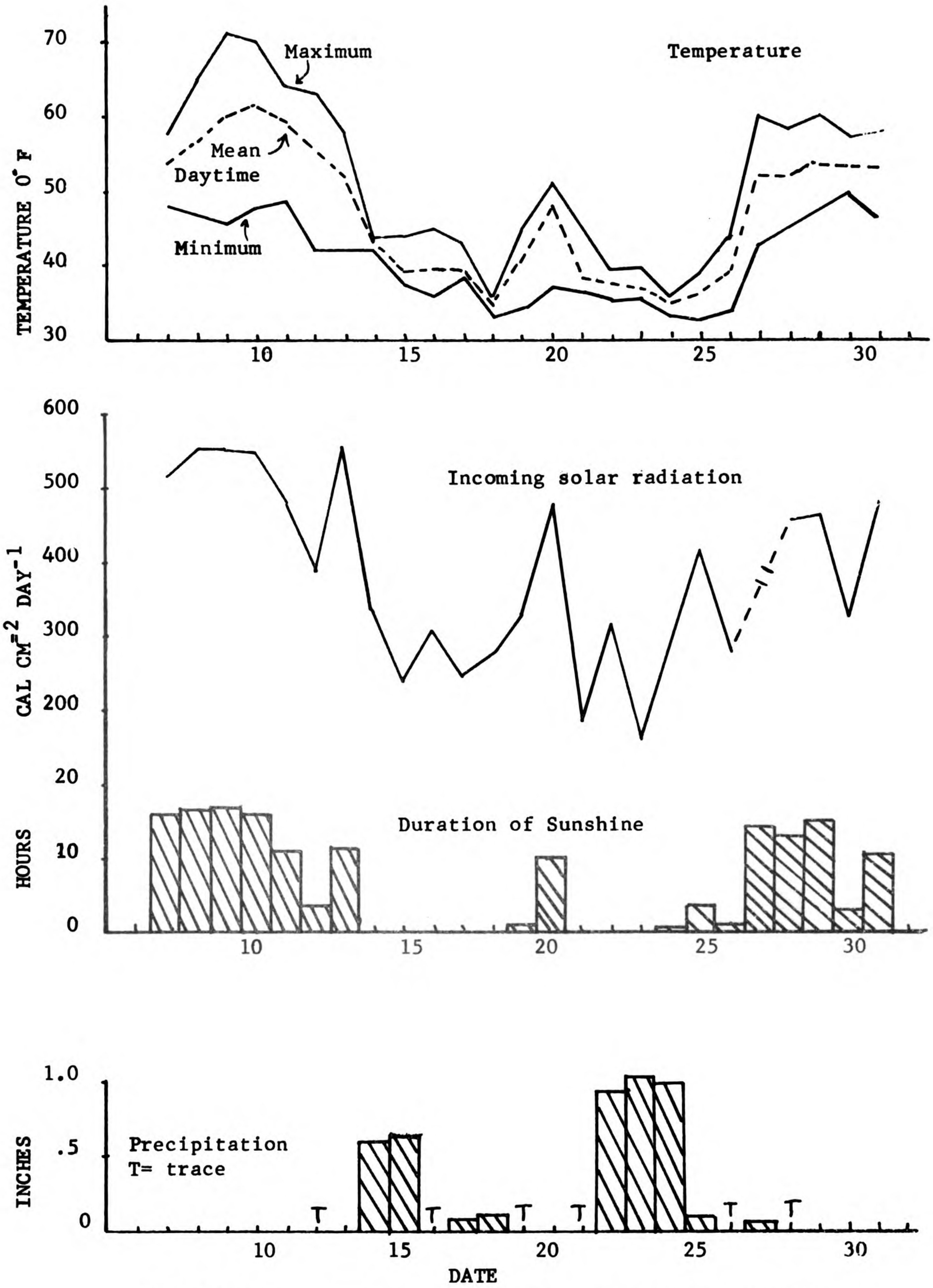



FIGURE 9 A: METEOROLOGICAL DATA - JULY, 1965 - CAMP 17

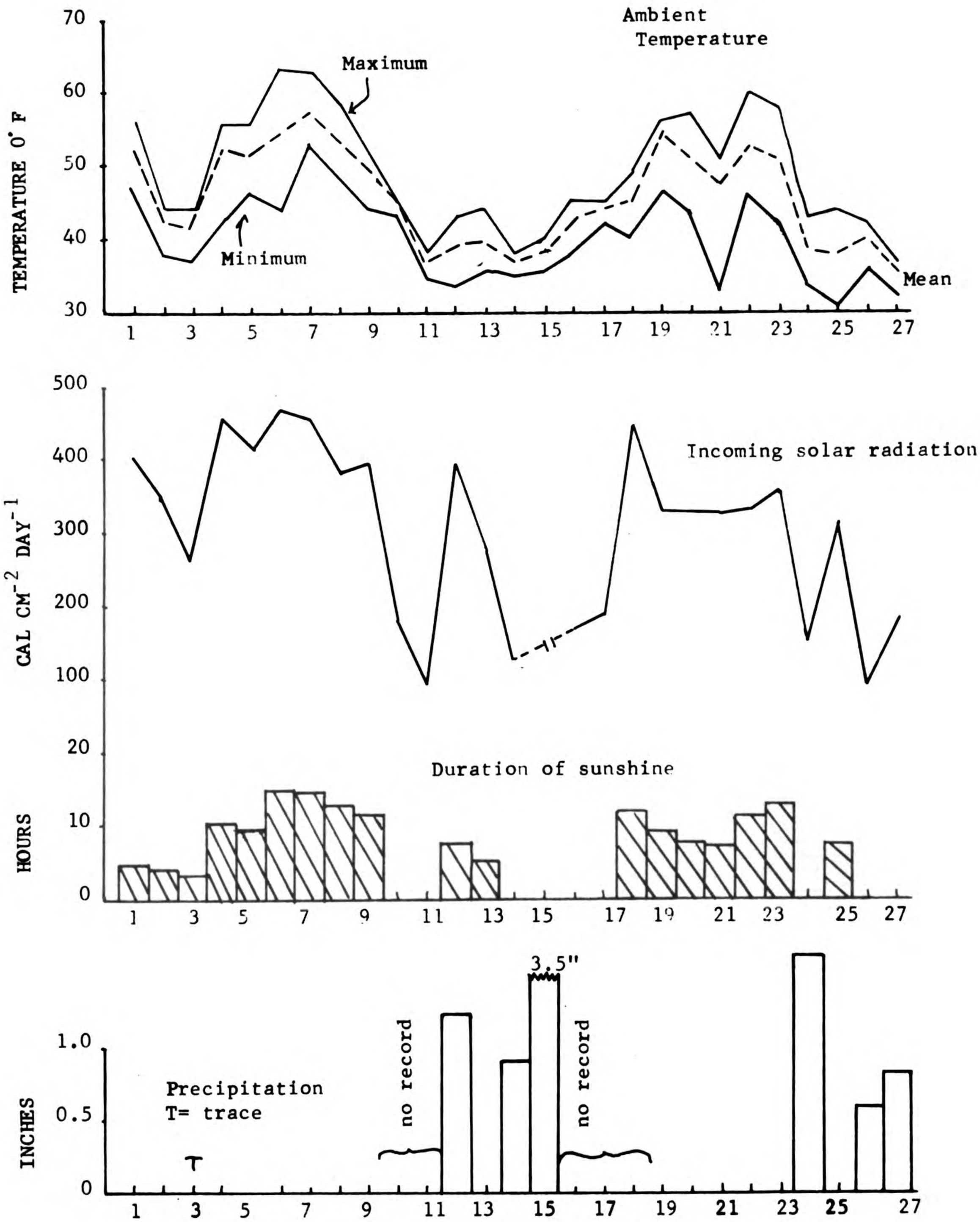



FIGURE 9 B: METEOROLOGICAL DATA - AUGUST, 1965 - CAMP 17

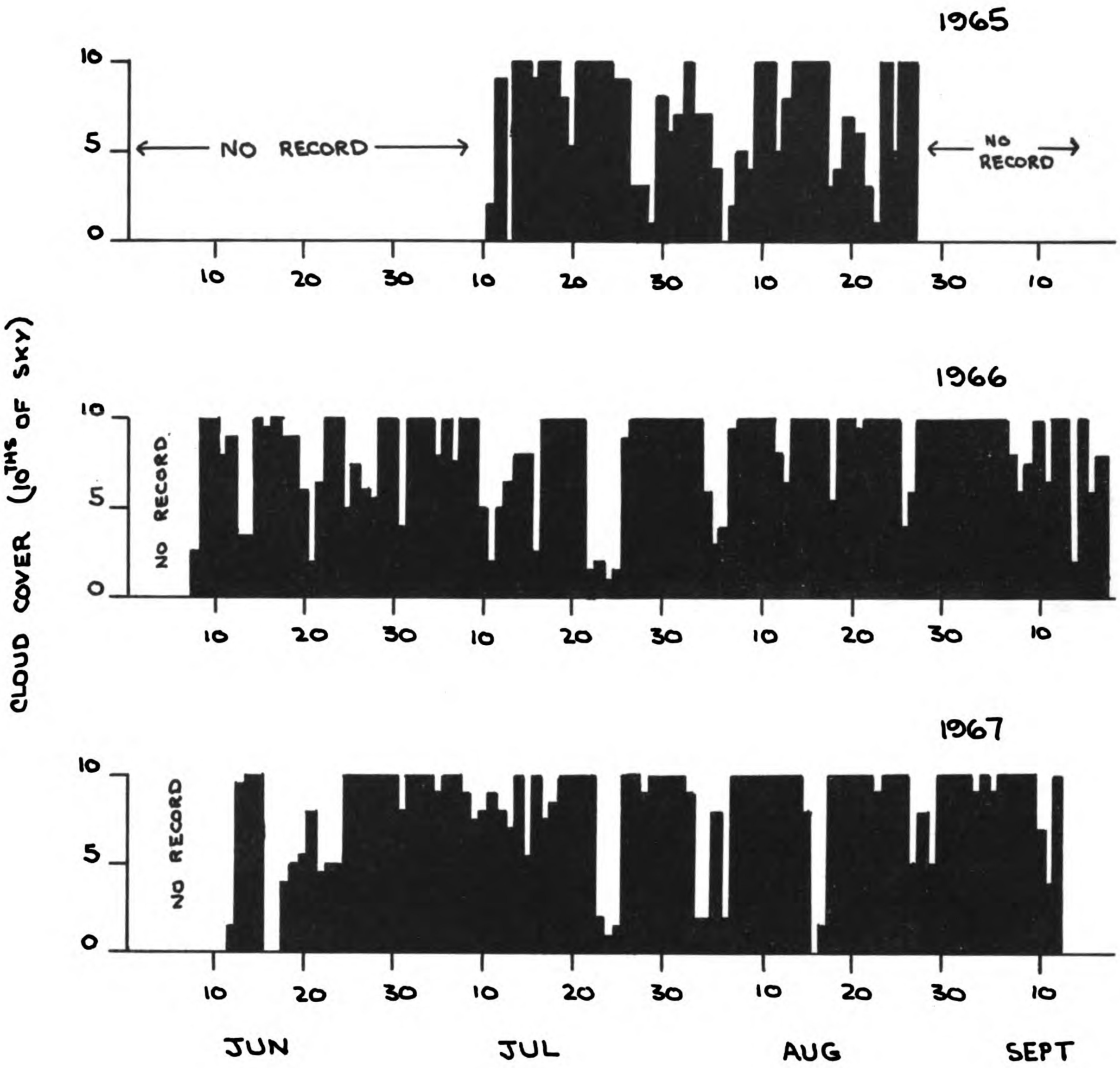



FIGURE 10 AVERAGE DAILY CLOUD COVER, CAMP 17, JUNE-SEPTEMBER, 1965-1967

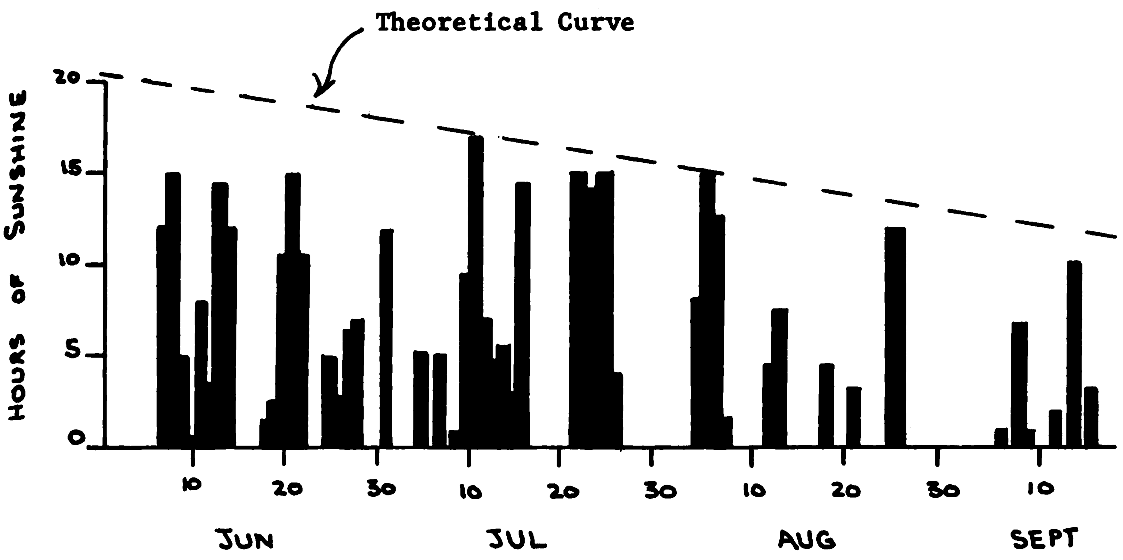



FIGURE 11 DURATION OF SUNSHINE, CAMP 17, 1966

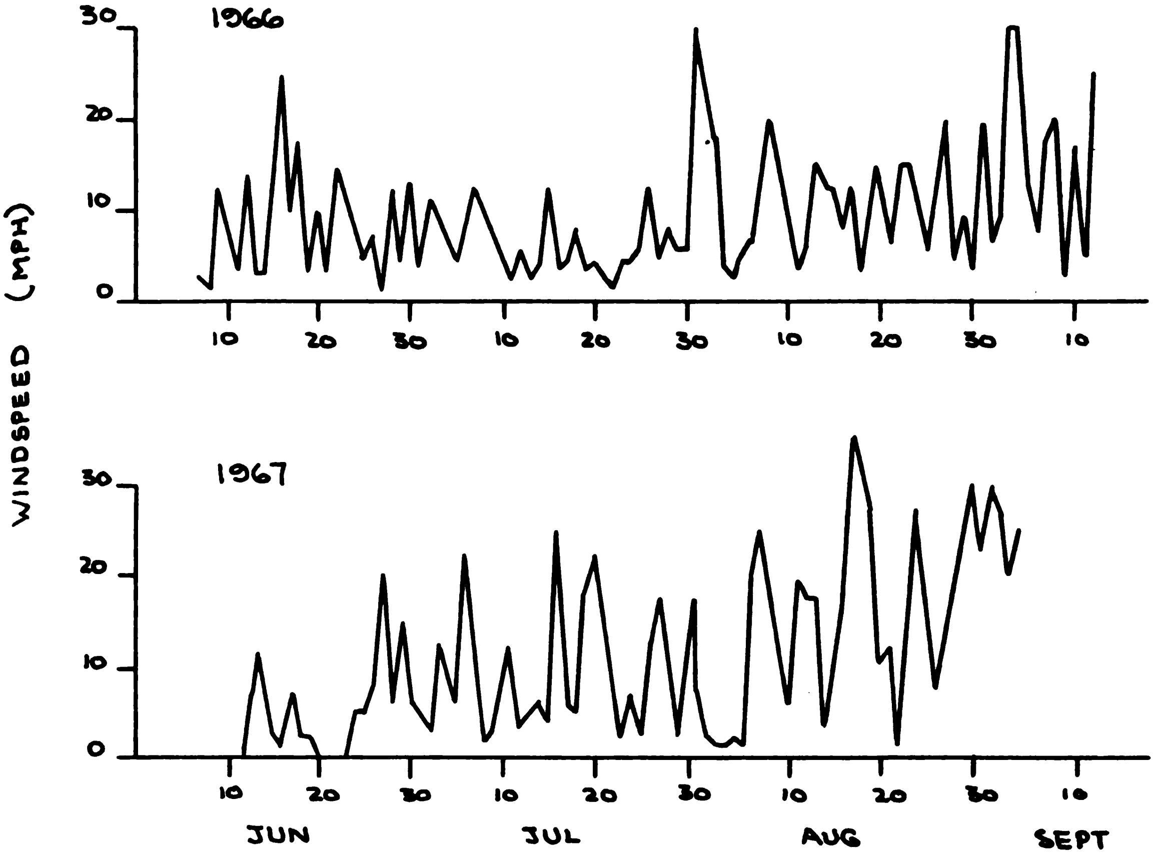



FIGURE 12 AVERAGE DAYTIME WINDSPEED AT CAMP 17, 1966 AND 1967

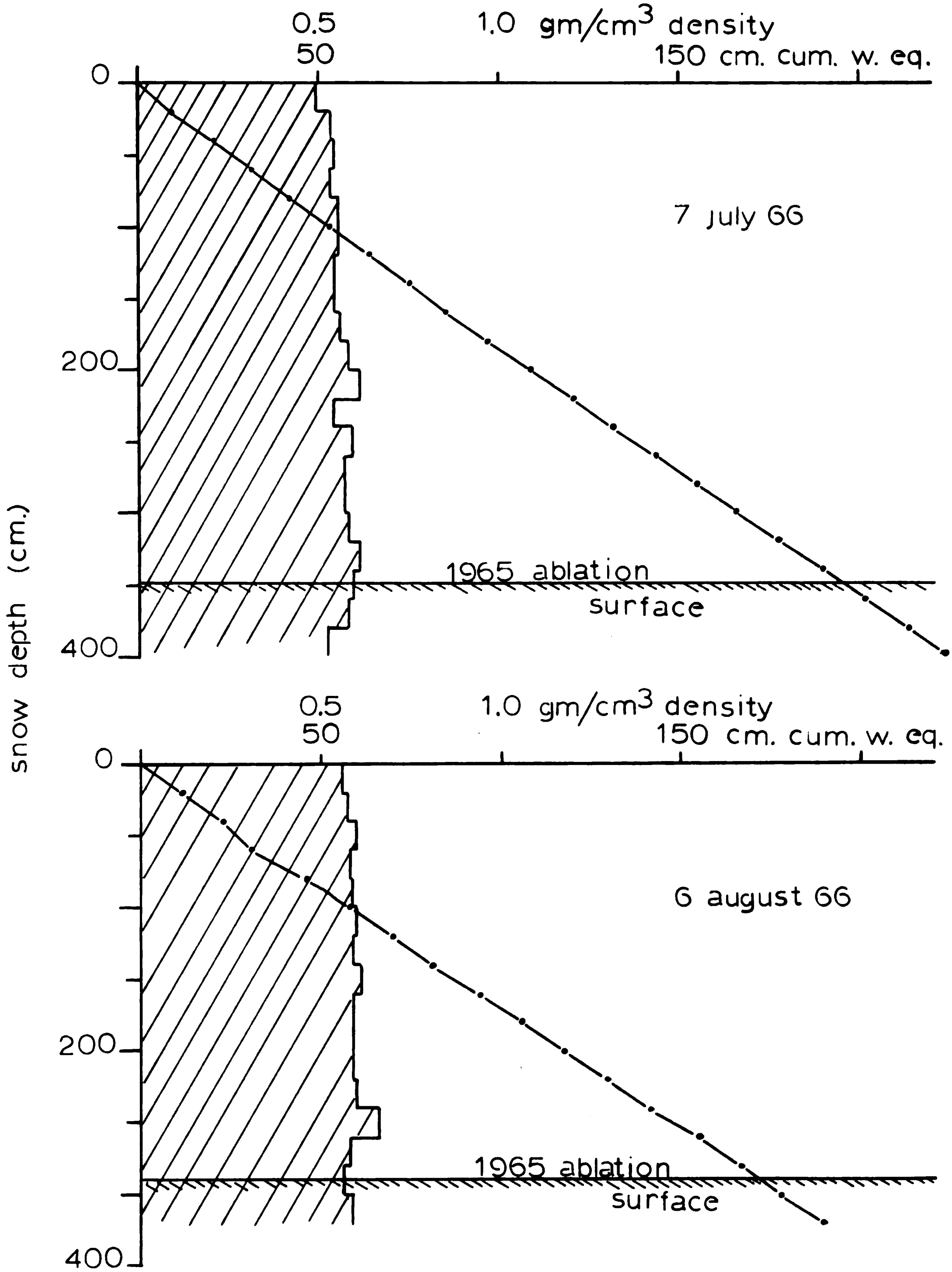



FIGURE 13 DENSITY AND WATER EQUIVALENCE OF TEST-PIT N° 2B ON LEMON GLACIER

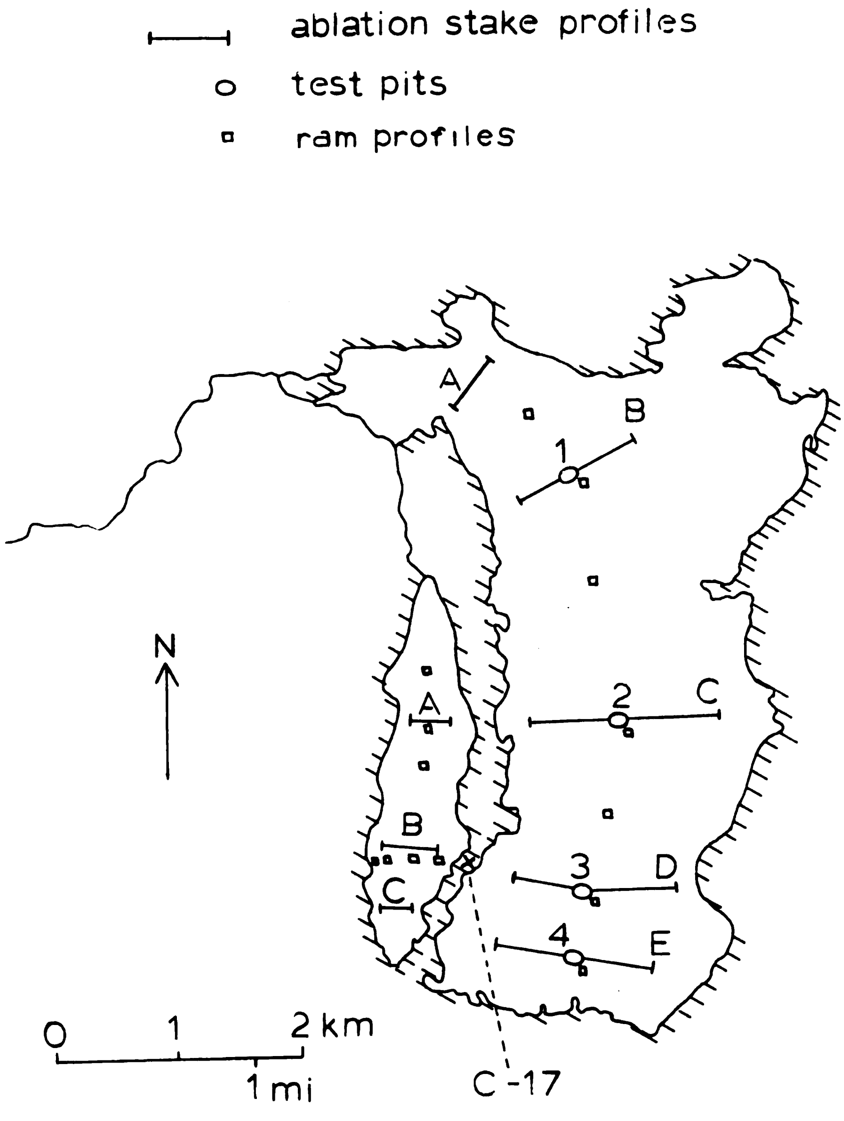



FIGURE 14 LEMON AND PTARMIGAN GLACIER OBSERVATION SITES, SUMMER, 1966

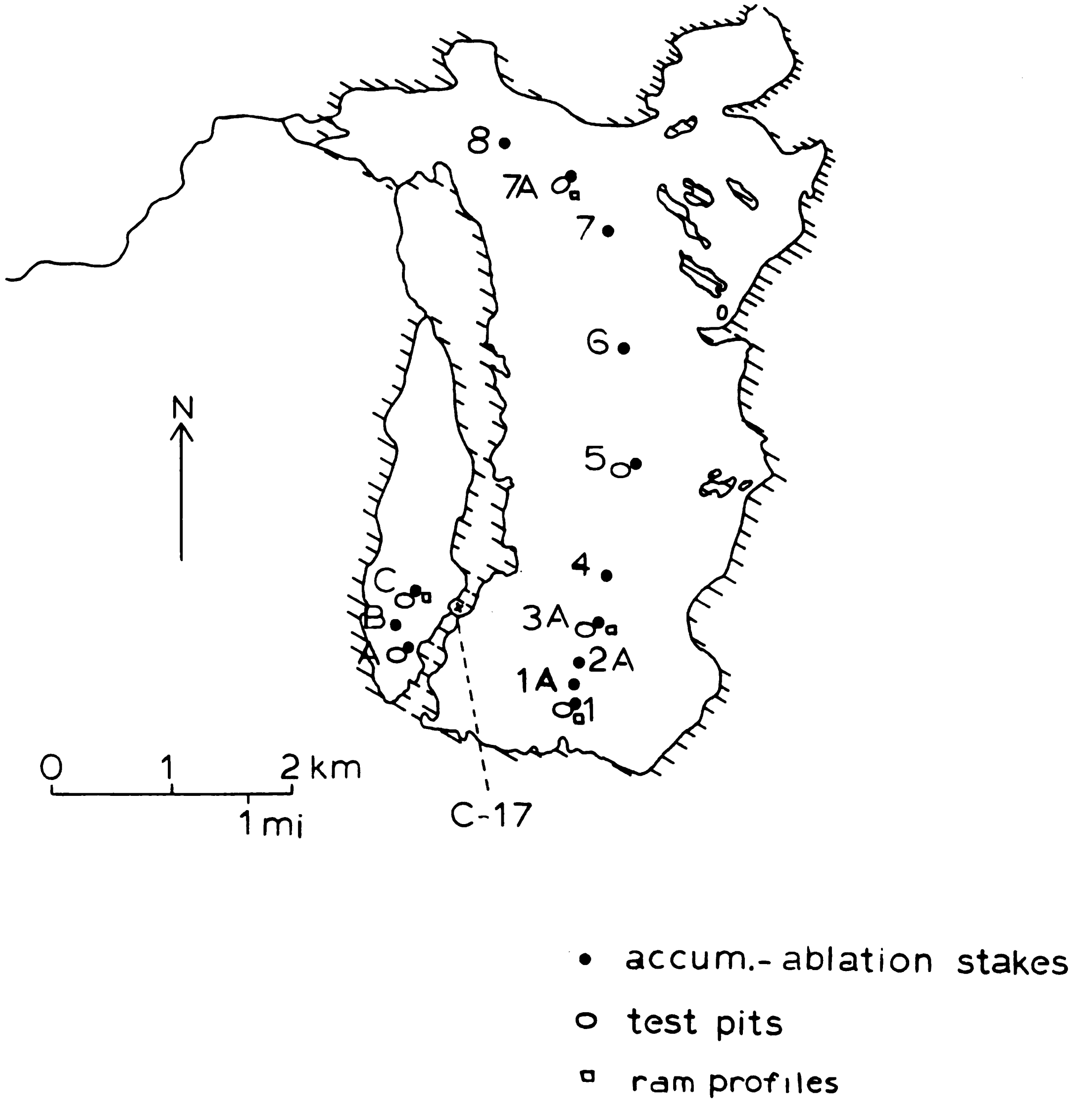



FIGURE 15 LEMON AND PTARMIGAN GLACIER OBSERVATION SITES, WINTER, 1967

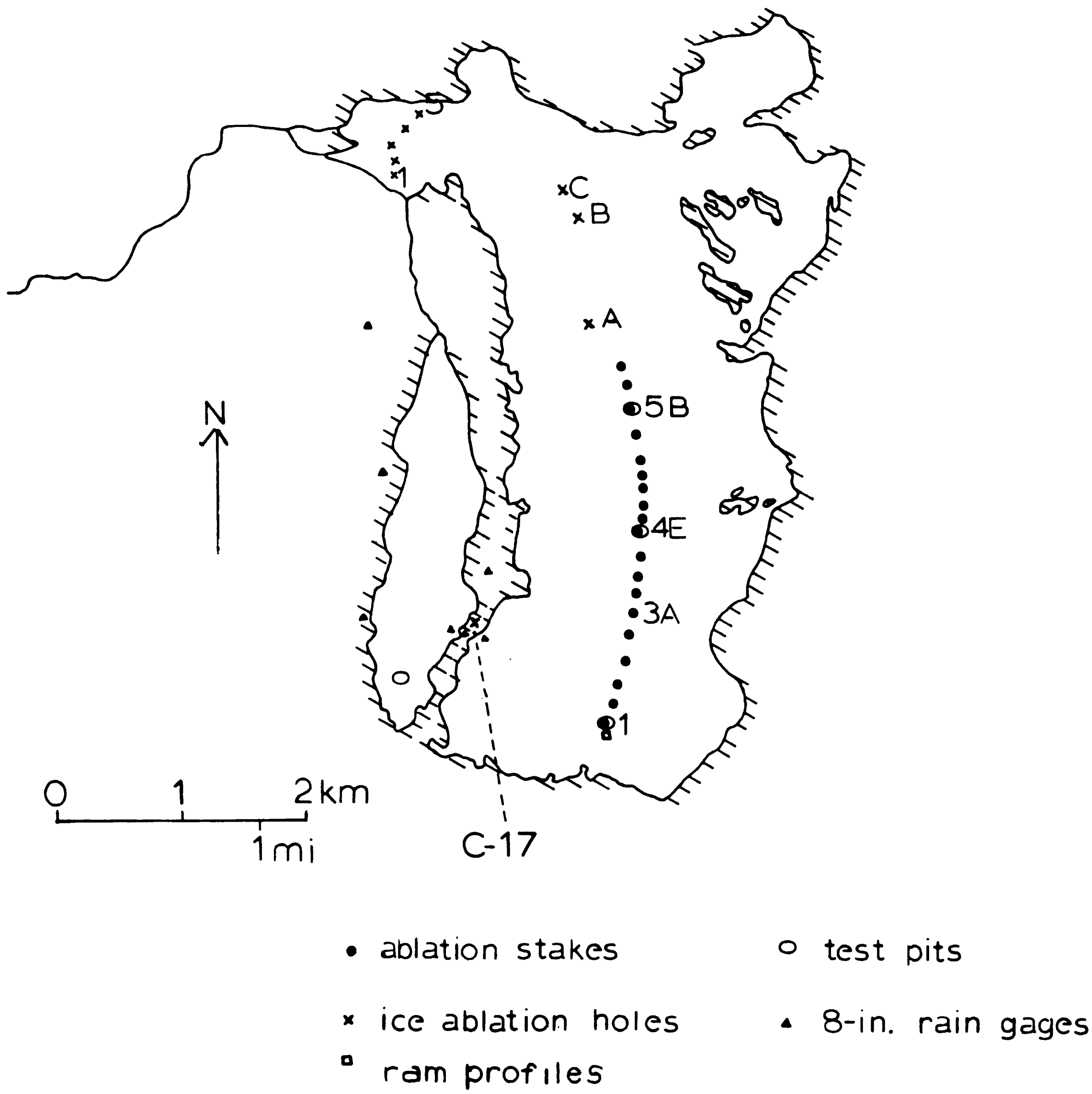



FIGURE 16 LEMON AND PTARMIGAN GLACIER OBSERVATION SITES, SUMMER, 1967

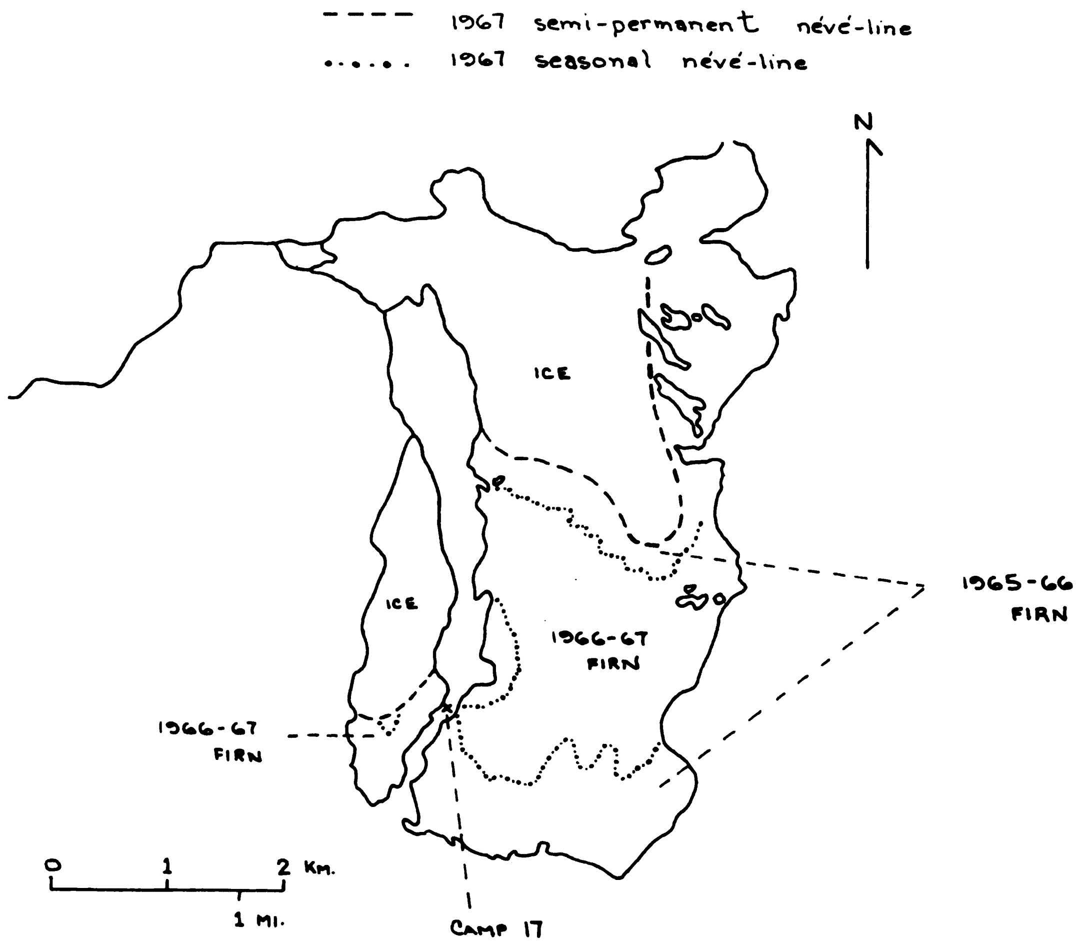



FIGURE 17 LEMON AND PTARMIGAN GLACIER NÉVÉ-LINE POSITIONS, 1967

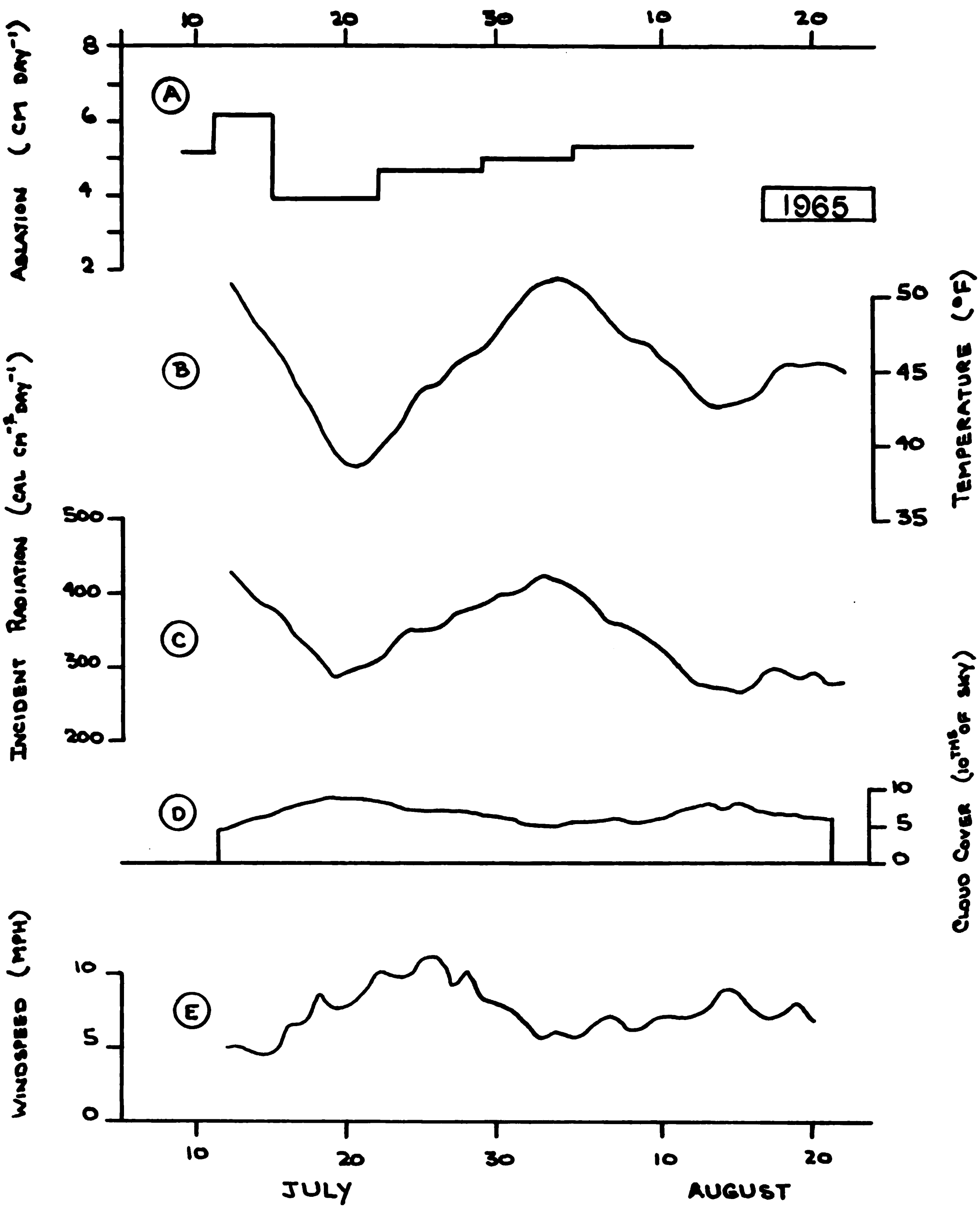



FIG. 18 - ABLATION RATES ON LEMON GLACIER vs TRENDS OF METEOROLOGICAL PARAMETERS AT CAMP 17

(B, C, D & E BASED ON 11-DAY RUNNING MEANS)

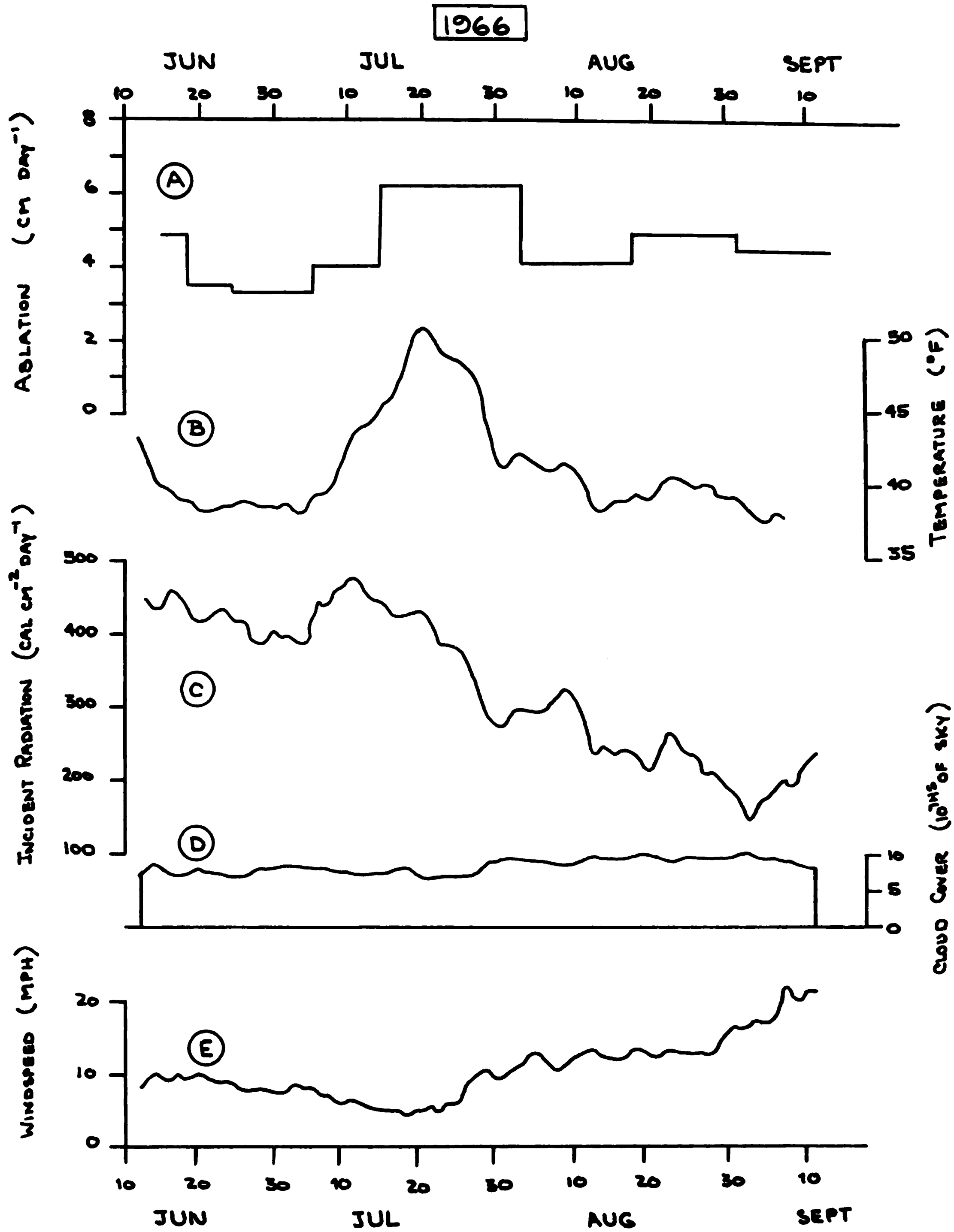



FIG. 19 - ABLATION RATES ON LEMON GLACIER vs TRENDS OF METEOROLOGICAL PARAMETERS AT CAMP 17

(B, C, D & E BASED ON 11-DAY RUNNING MEANS)

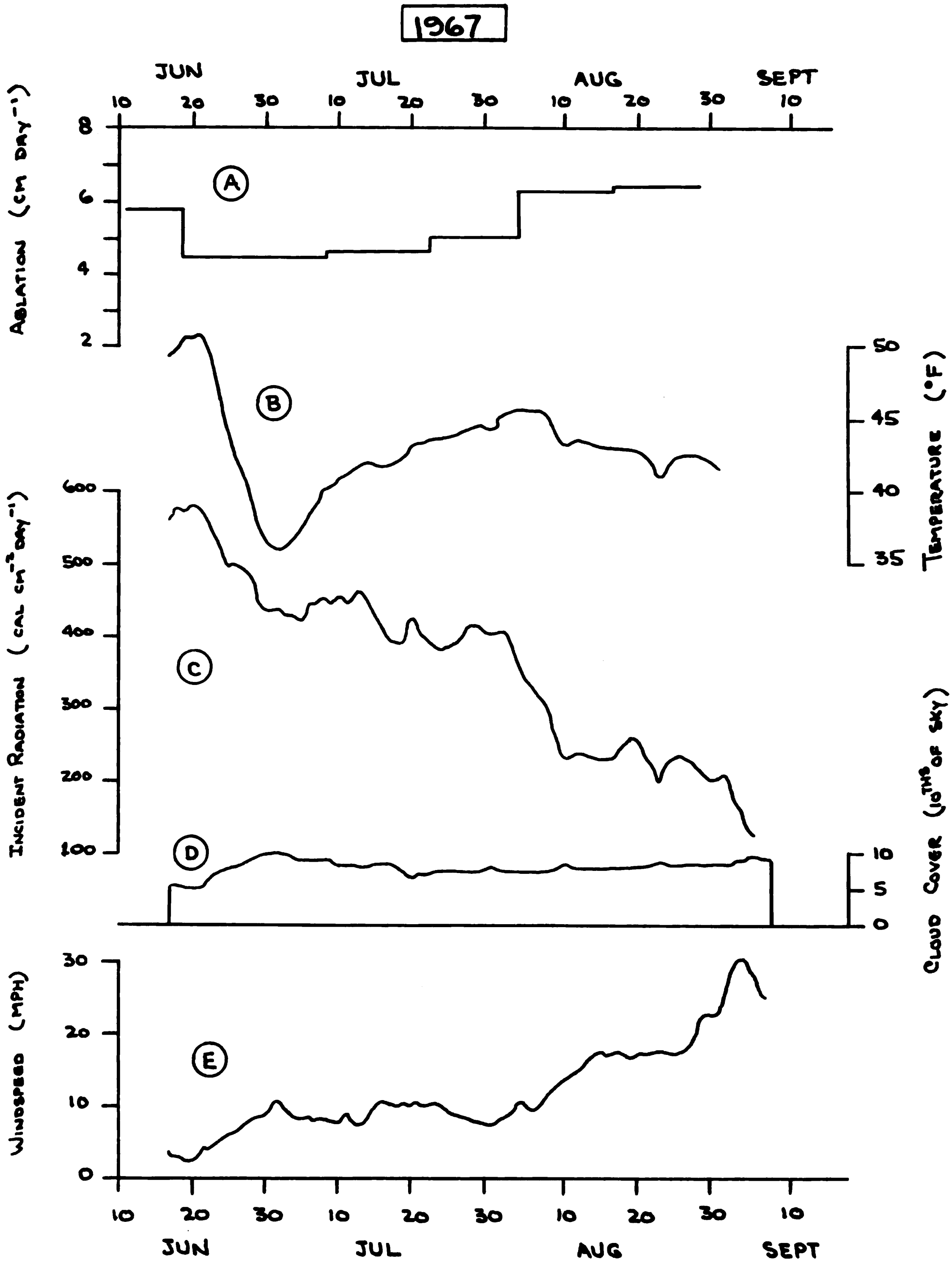
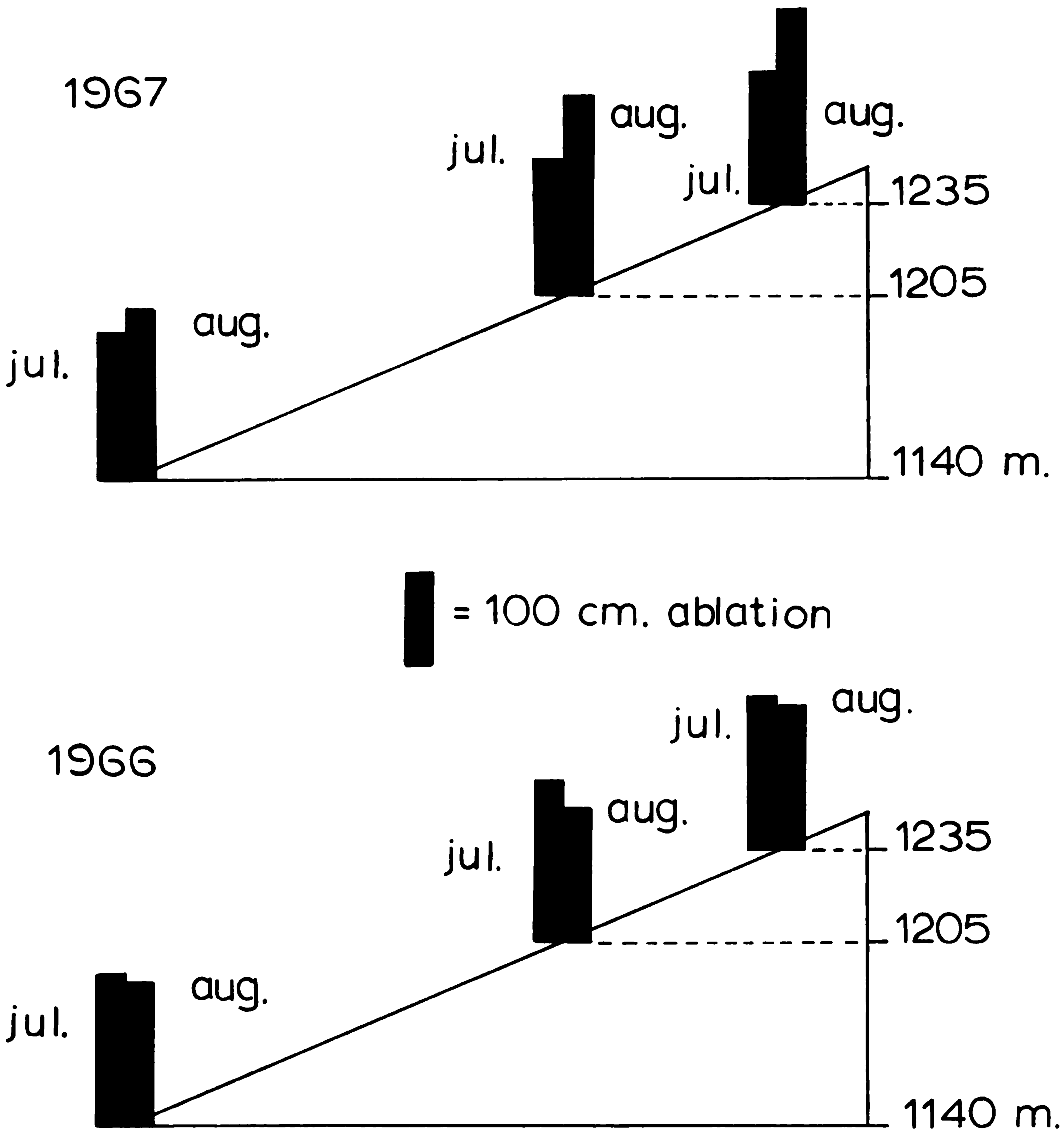



FIG. 20 - ABLATION RATES ON LEMON GLACIER vs TRENDS OF METEOROLOGICAL PARAMETERS AT CAMP 17 (Ⓑ, Ⓒ, Ⓓ & Ⓔ BASED ON 11-DAY RUNNING MEANS)

FIG. 21 - SNOW ABLATION ON LEMON GLACIER



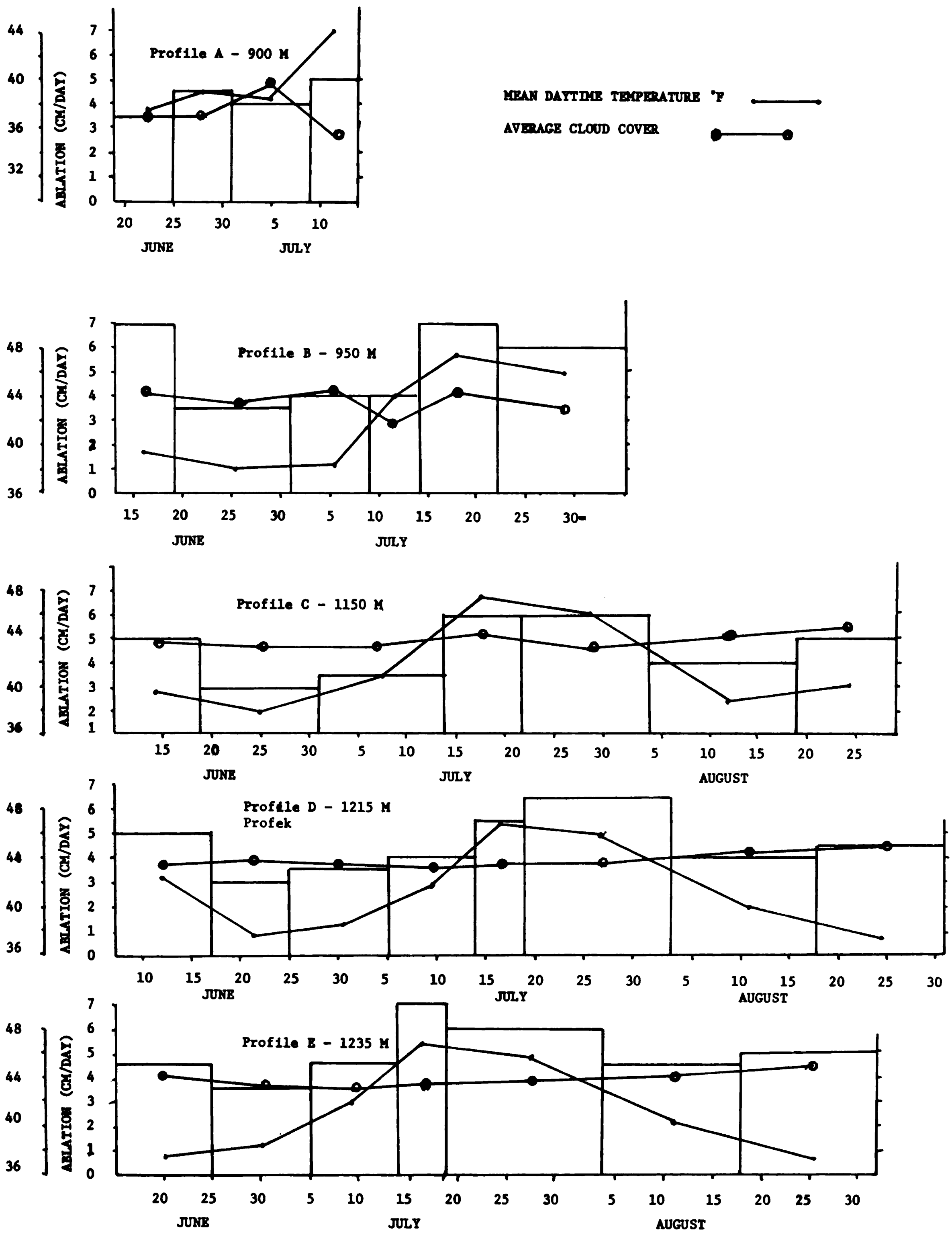



FIGURE 22 LEMON GLACIER ABLATION RATES ON FIVE TRANSECTS IN NÉVÉ ZONE vs. CHANGES IN CLOUD COVER, SUMMER, 1966.

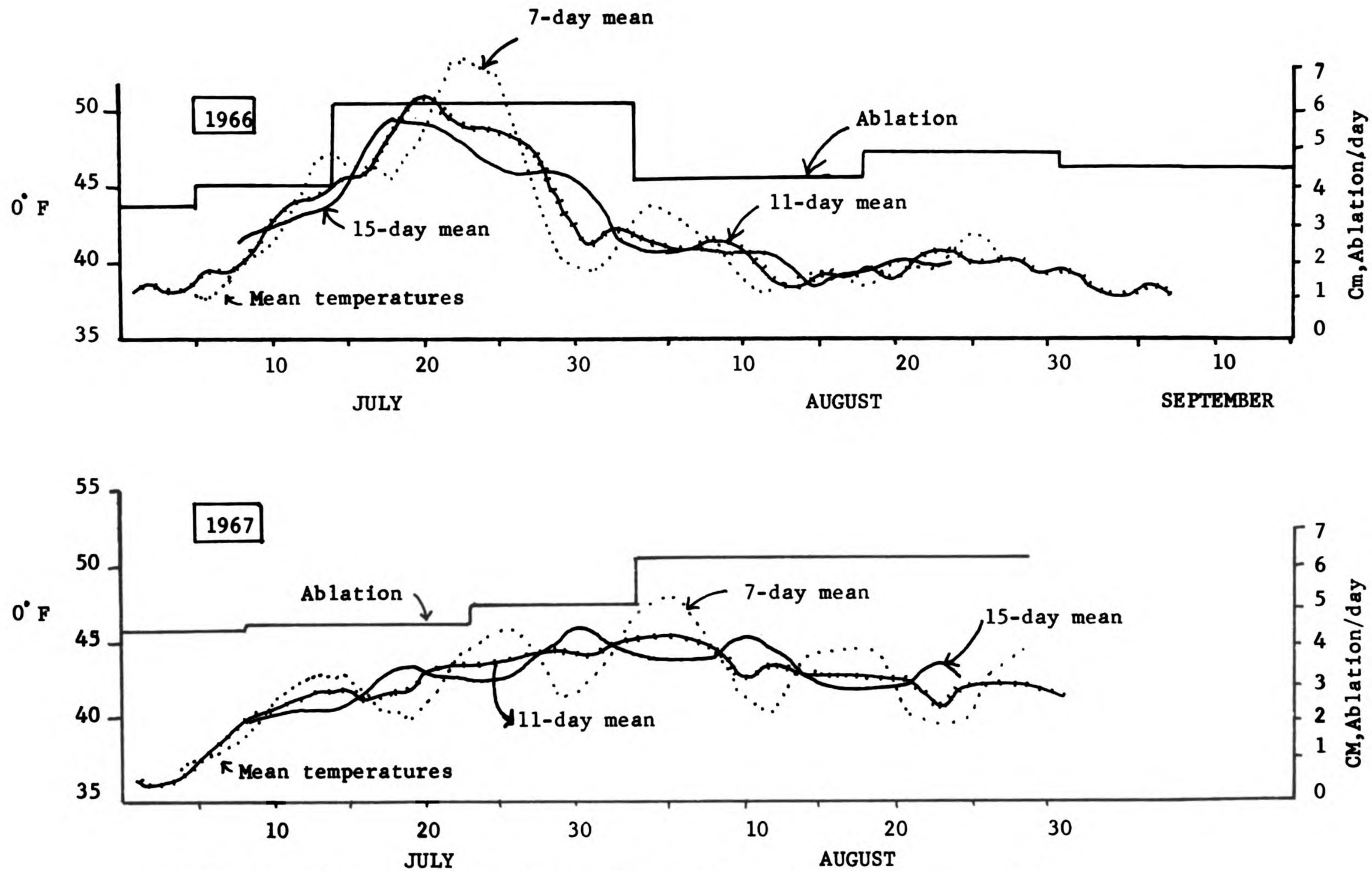



FIGURE 23 COMPARATIVE MEAN TEMPERATURES (0° F) AT CAMP 17 vs. ABLATION RATES (CM/DAY) ON LEMON GLACIER IN JULY - AUGUST, 1966, 1967. (AVERAGE ABLATION RATE BETWEEN 3750 - 4050 FT. (1140 - 1235 M).

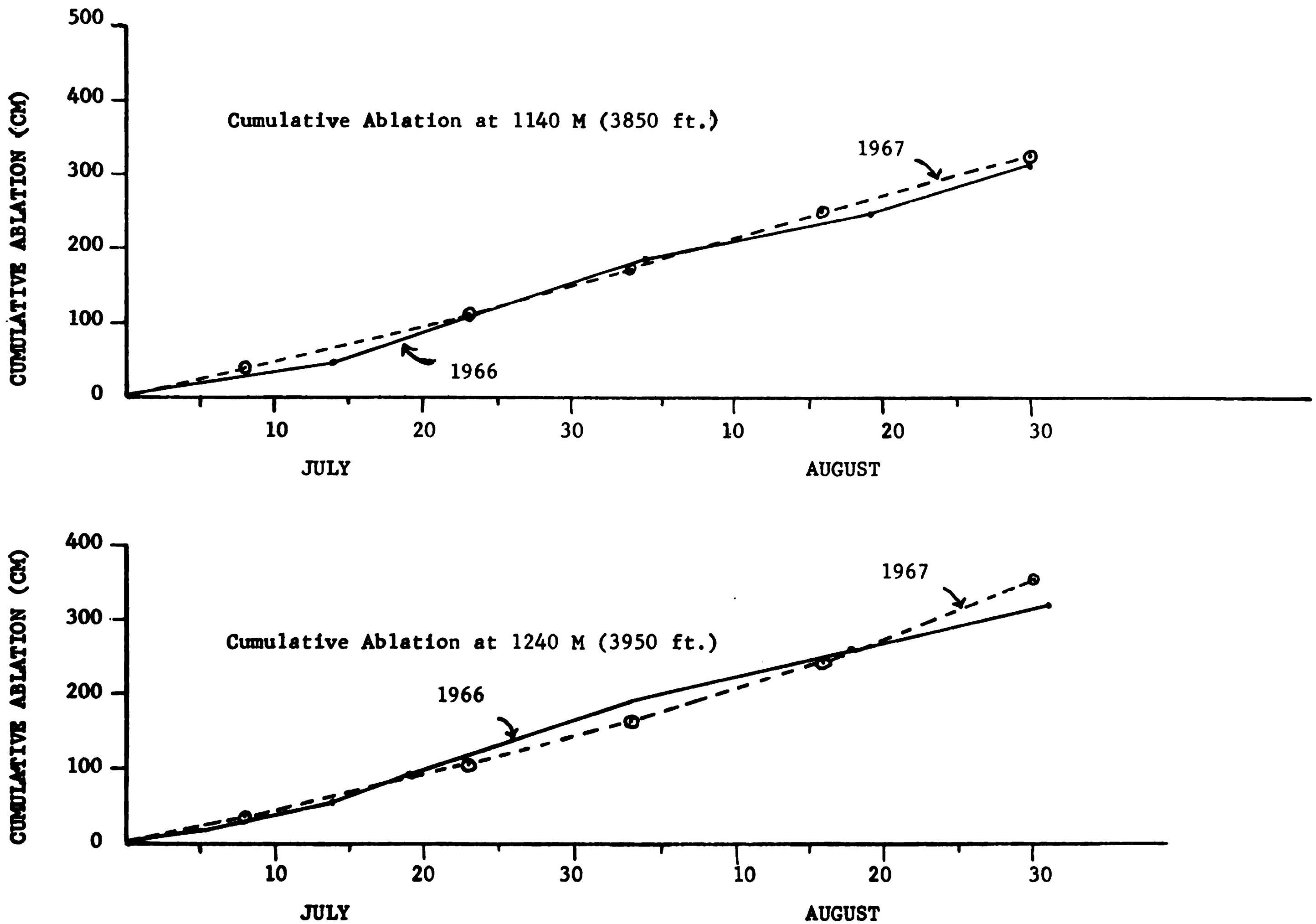



FIGURE 24 CUMULATIVE ABLATION CURVES ON LEMON GLACIER IN JULY - AUGUST, 1966, 1967, BETWEEN 3850 - 3950 FT. (1140 - 1240 M).

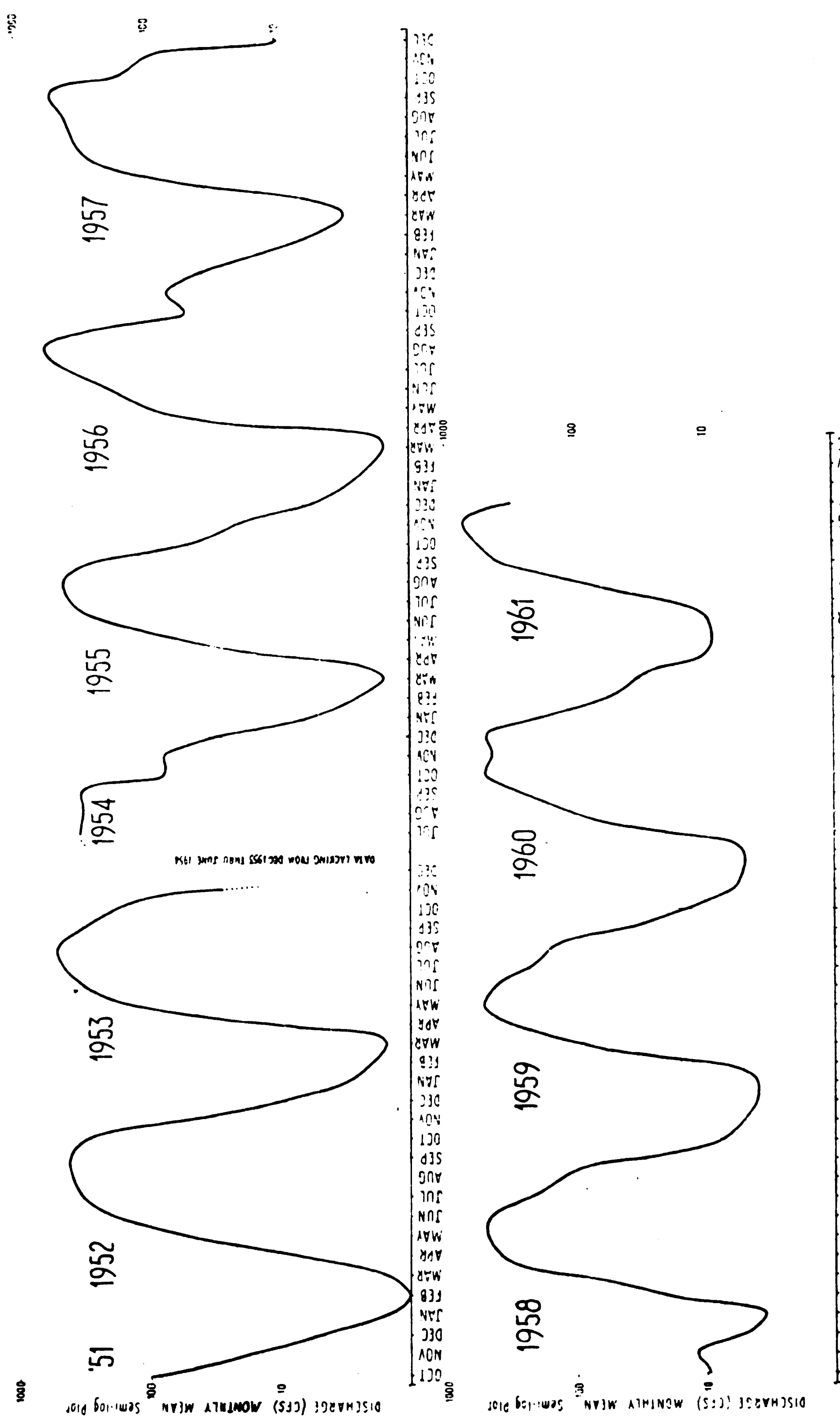



FIGURE 25 MEAN DISCHARGE RATES AT LEMON CREEK STREAM GAGE SITE, 1951 - 1961

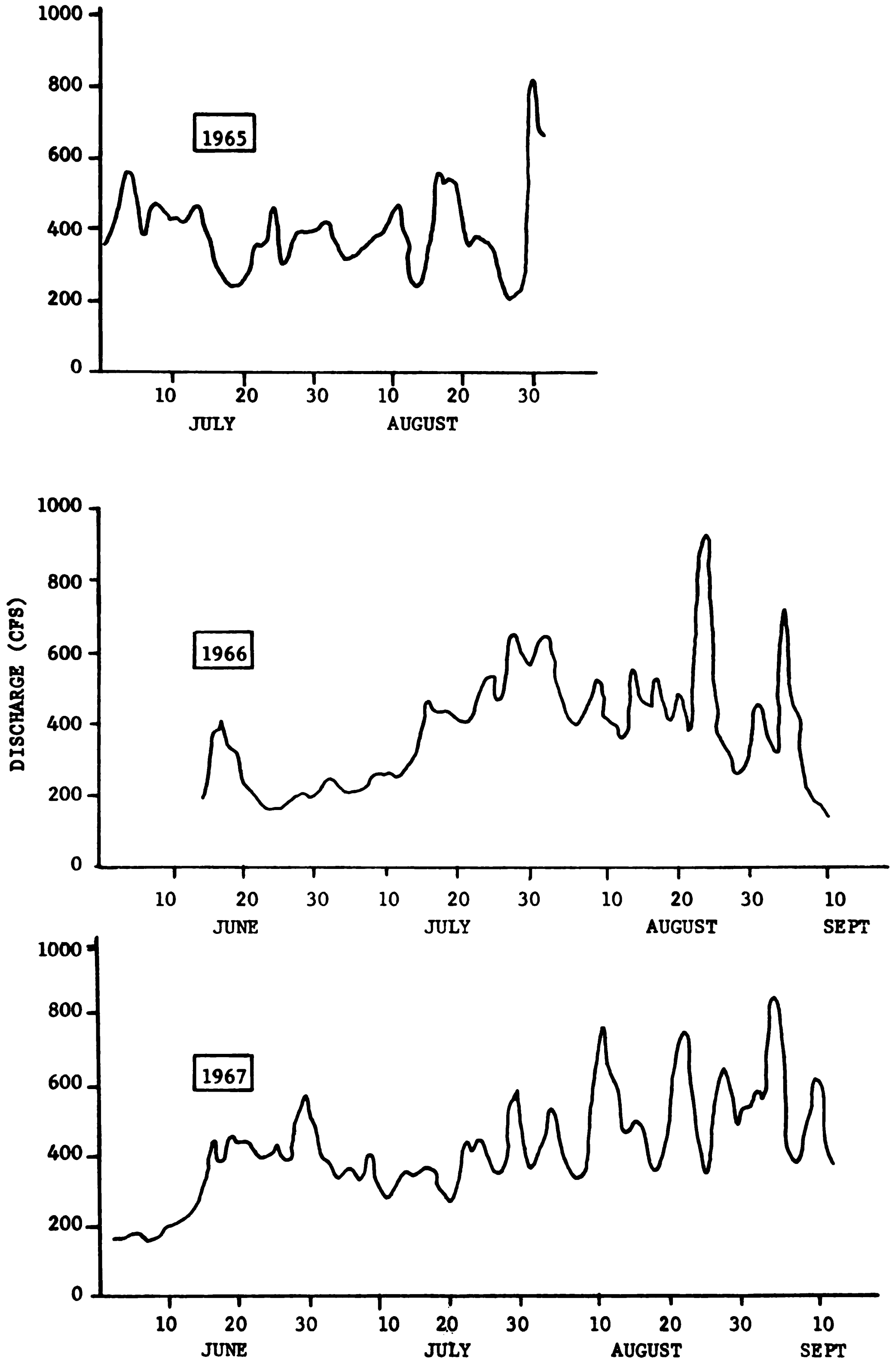
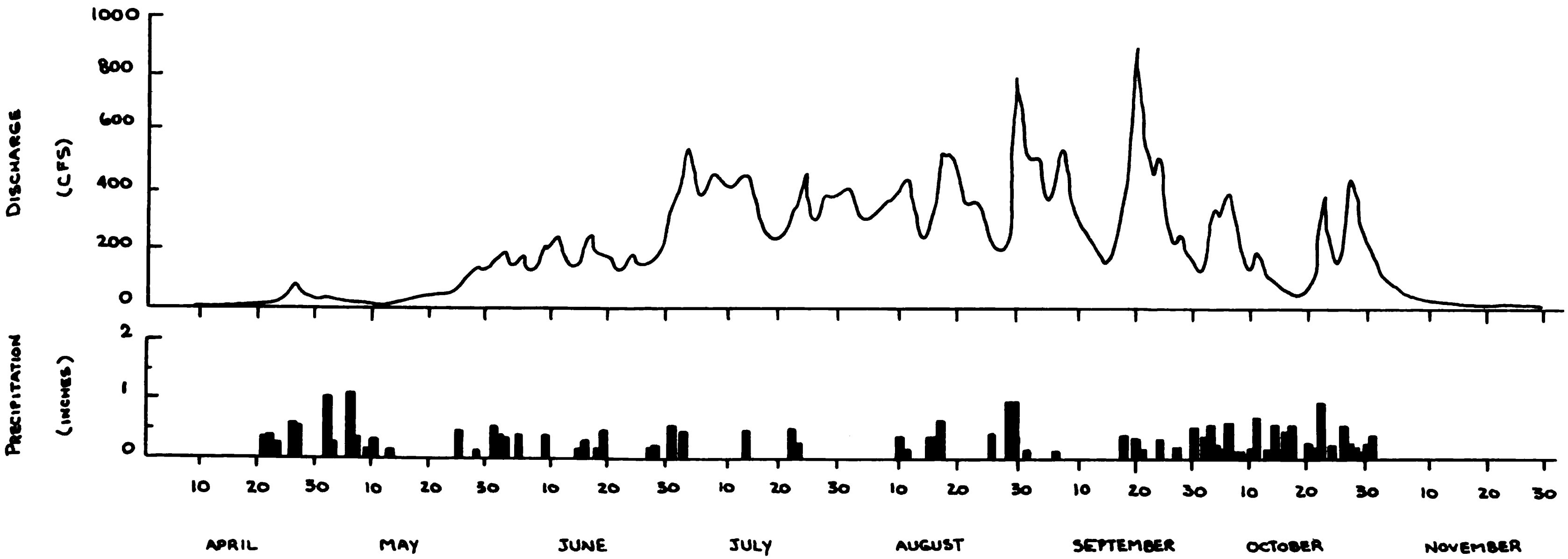


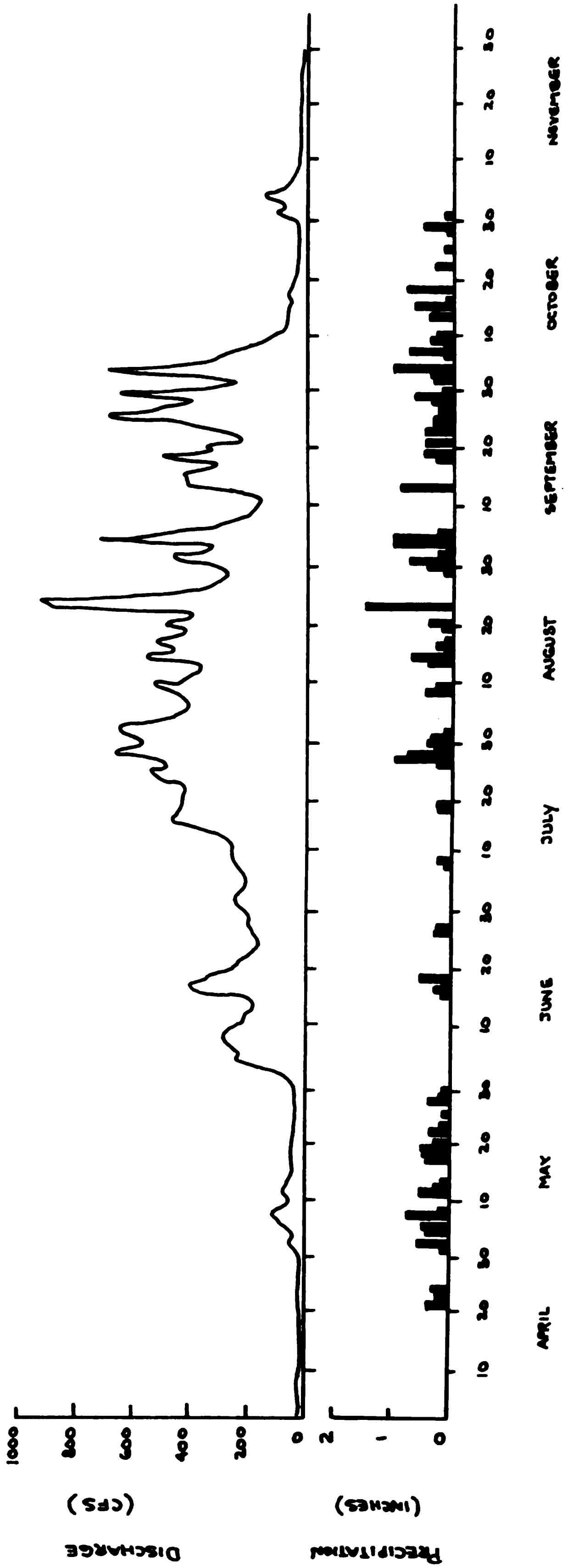

FIGURE 26 SUMMER DAILY DISCHARGE RATES ON LEMON CREEK, 1965-1967

FIG. 27 DAILY DISCHARGE OF LEMON CREEK - 1965




DAILY PRECIPITATION (≥ 0.1") AT JUNEAU AIRPORT - 1965

Fig 28 Daily Discharge of Lemon Creek - 1966




Daily Precipitation (≥0.1") at Juneau Airport - 1966

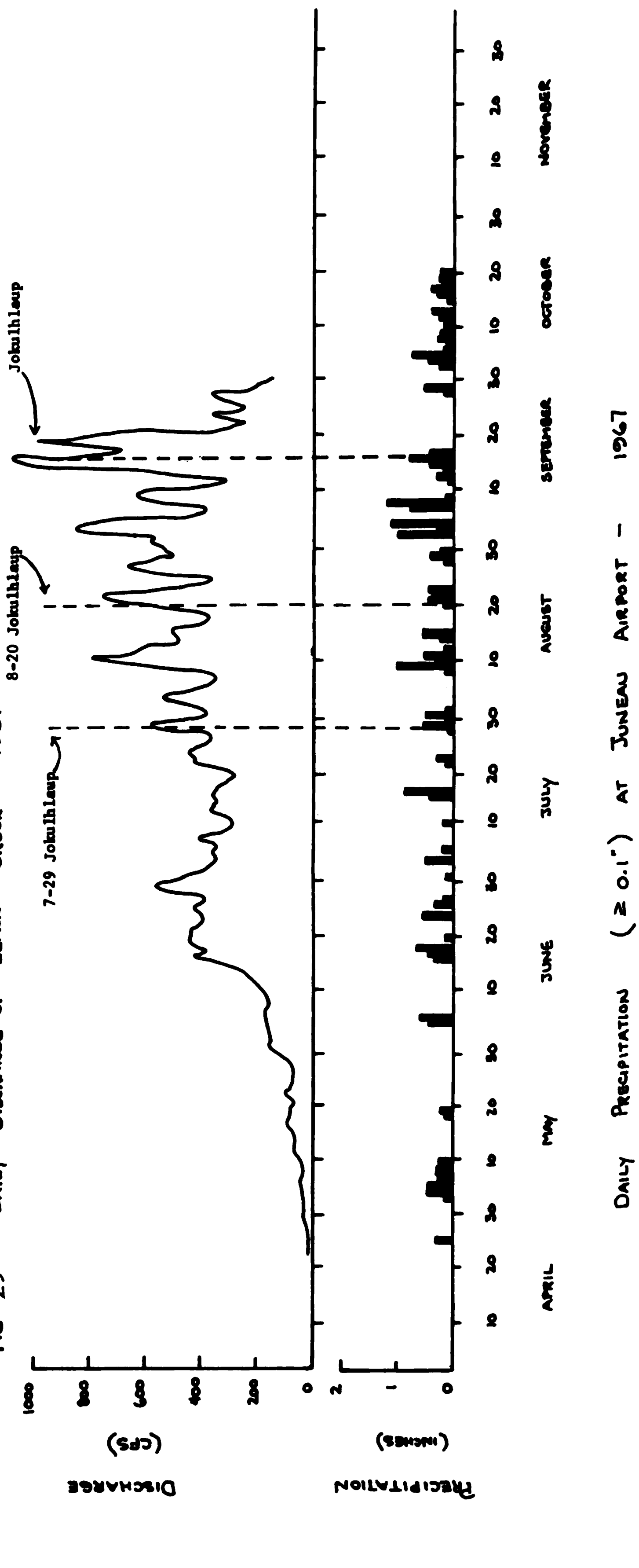



Fig 29 Daily Discharge of Lemon Creek - 1967

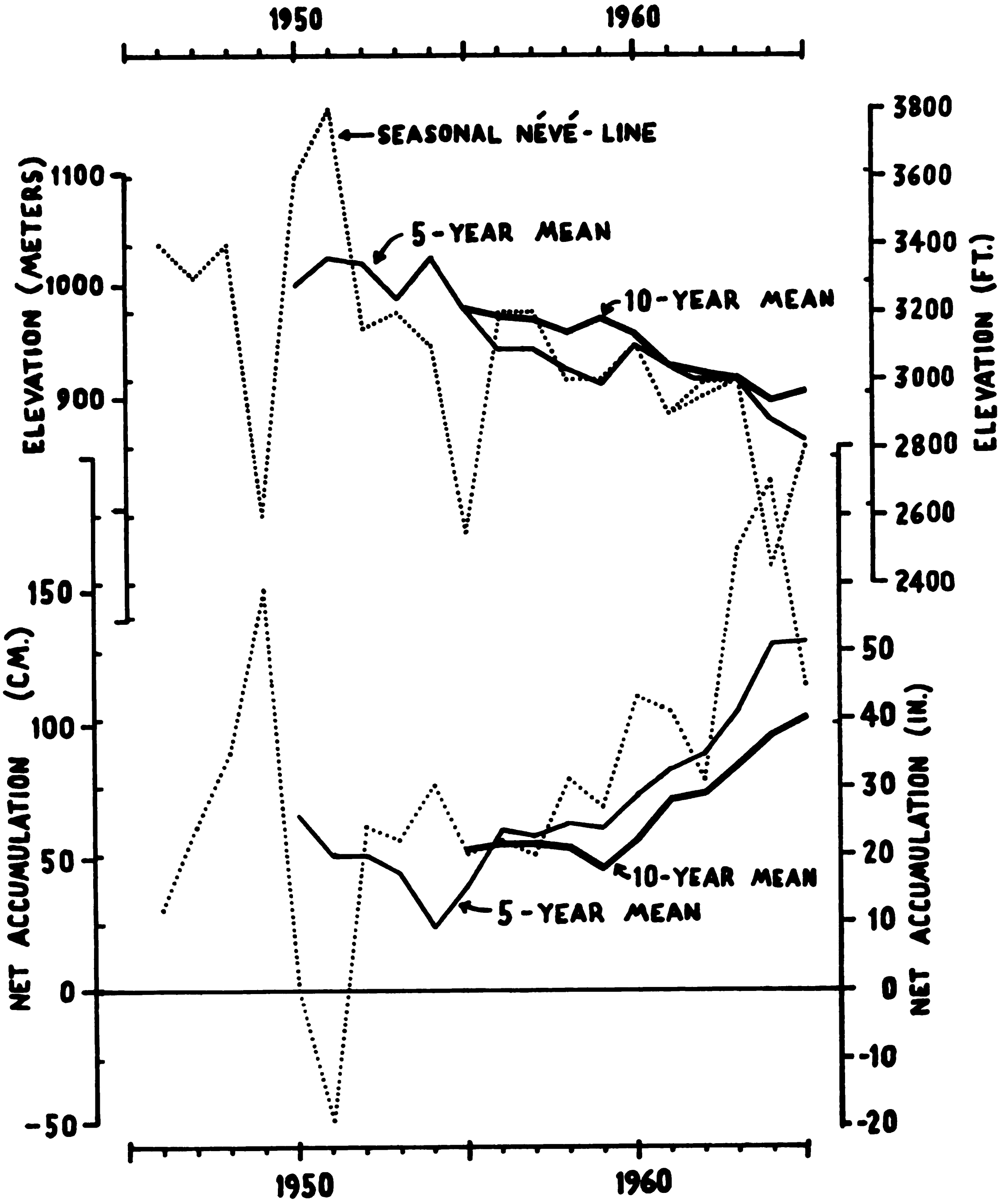



FIGURE 30 COMPARATIVE NÉVÉ-LINE AND NET ACCUMULATION TRENDS ON THE TAKU GLACIER, 1946-1965

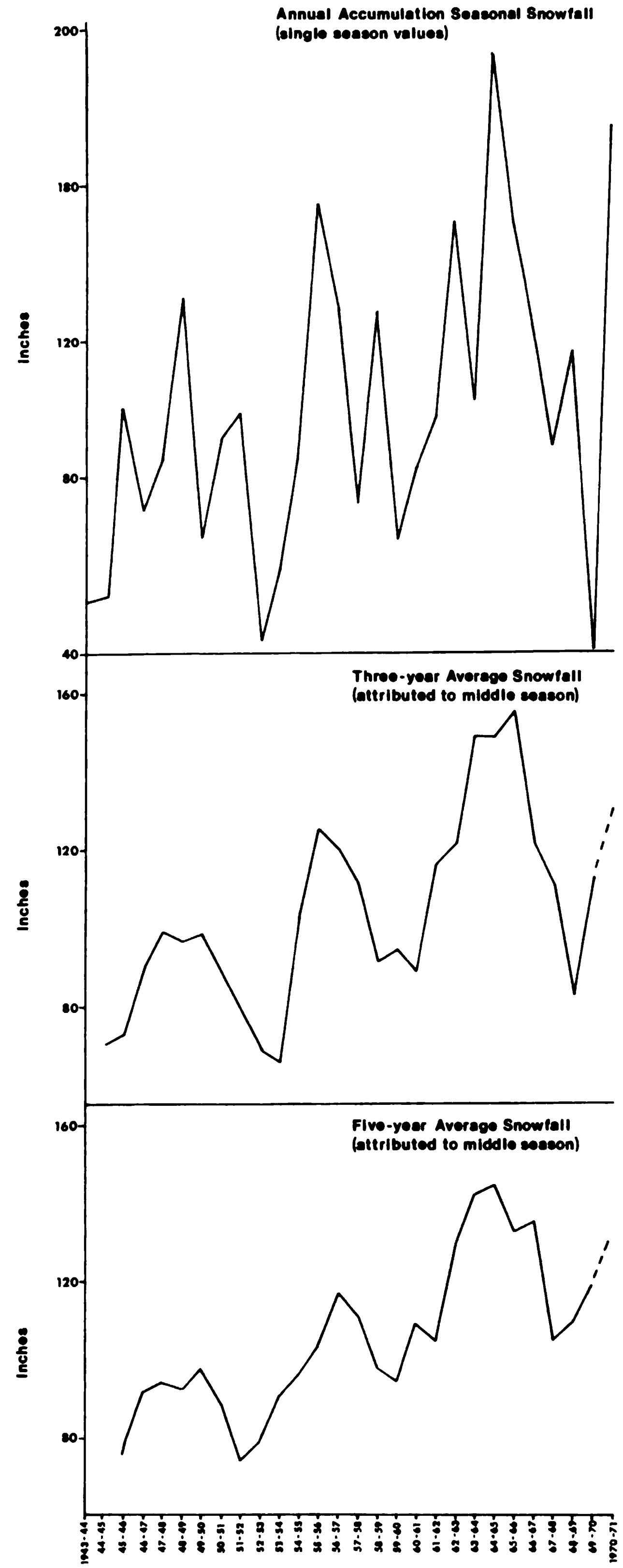



FIG. 31.--Seasonal Snowfall Trends, Juneau Airport, Alaska 1943-71, based on 1-year, 3-year and 5-year averages.

FIG. 32.--View of Camp 17 Research Station, Base Camp for the Long-term Glacio-hydrological Research Program, 1965-74 (F.G.E.R. photo).

APPENDICIES

RECORDS AND FIELD DATA:

Lemon and Ptarmigan Glaciers
1965-1967

# APPENDIX A

# METEOROLOGICAL DATA

# JUNEAU ICEFIELD RESEARCH PROGRAM

MONTHLY SUMMARY WEATHER FORM

SITE OR CAMP No. 17 DATE JULY 1965 ELEVATION 4185'

| Date | Max. Temp. °F | Min. Temp. °F | Mean Temp. (0700 - 2200) °F | Average Clouds (10ths) | Total Precip. -Rain- (inches) | Total Snow (in.) | Av. Wind Speed Day (MPH) | Av. Wind Direction | Duration Sunshine (hours) | Radiation (cal/cm² day) |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | | | | | | | | | |
| 2 | | | | | | | | | | |
| 3 | | | | | | | | | | |
| 4 | | | | | | | | | | |
| 5 | | | | | | | | | | |
| 6 | | | | | | | | | | |
| 7 | 58 | 48 | 53.5 | 0 | 0 | | 8-10 | N | 16 1/2 | 516 |
| 8 | 65 | 47 | 56.5 | 0 | 0 | | 7-10 | E | 16 3/4 | 557 |
| 9 | 71 | 46 | 60 | 0 | 0 | | 3-4 | NW | 17 | 555 |
| 10 | 70 | 48 | 61.5 | 0 | 0 | | CALM | - | 16 | 547 |
| 11 | 64 | 49 | 59.5 | 2 | 0 | | 1-2 | SE | 12 | 481 |
| 12 | 63 | 42 | 56 | 9 | TR | | 1-3 | SE | 3 1/2 | 386 |
| 13 | 58 | 42 | 52.5 | 0 | 0 | | 12-16 | SE | 11 1/2 | 555 |
| 14 | 44 | 42 | 43.5 | 10 | 0.6 | | 5-8 | SE | < 1/4 | 332 |
| 15 | 44 | 37.5 | 39 | 10 | 0.64 | | 5-6 | W | 0 | 241 |
| 16 | 45 | 36 | 39.5 | 9 | 0.02 | | 0-1 | W | 0 | 308 |
| 17 | 43 | 38 | 39 | 10 | 0.06 | | 3-5 | NW | 0 | 244 |
| 18 | 36 | 33 | 35 | 10 | 0.08 | | 7-12 | SE | 0 | 271 |
| 19 | 44.5 | 34.5 | 40.5 | 8 | 0.02 | | 3-5 | NNW | 1 | 328 |
| 20 | 51.5 | 37 | 48 | 5 | 0 | | 2-3 | NW | 10 | 475 |
| 21 | 46 | 36.5 | 38 | 10 | 0.03 | | 15-25 | SE | 0 | 181 |
| 22 | 39.5 | 35.5 | 37.5 | 10 | 0.96 | | 2-3 | S | 0 | 313 |
| 23 | 40 | 35.5 | 37 | 10 | 1.01 | | 18-30 | SE | 0 | 160 |
| 24 | 36 | 33.5 | 35 | 10 | 1.00 | TR | 5-6 | SW | 1/2 | 290 |
| 25 | 39 | 33 | 36.5 | 9 | 0.08 | | 6-8 | SE | 3 1/2 | 420 |
| 26 | 44 | 34 | 39.5 | 9 | 0.02 | | 12-17 | E | 3/4 | 281 |
| 27 | 60 | 43 | 52 | 3 | 0.05 | | 13-19 | E | 14 | - |
| 28 | 58.5 | 45 | 52 | 3 | 0.03 | | 0-2 | S | 12 3/4 | 457 |
| 29 | 60 | 47.5 | 53.5 | 1 | 0 | | 7-12 | E | 15 | 464 |
| 30 | 57.5 | 49.5 | 53.5 | 8 | 0 | | 14-19 | E | 3 | 328 |
| 31 | 58 | 46.5 | 52 | 6 | 0 | | 3-5 | SE | 10 | 480 |
| Cum | | | | | | | | | | |
| Mean | | | | | | | | | | |

# JUNEAU ICEFIELD RESEARCH PROGRAM

MONTHLY SUMMARY WEATHER FORM

SITE OR CAMP No. 17 DATE AUG 1965 ELEVATION 4185′

| Date | Max. Temp. °F | Min. Temp. °F | Mean Temp. (0700-2200) °F | Average Clouds 10ths | Total Precip. -Rain- Inches | Total Snow In. | Av. Wind Speed Day MPH | Av. Wind Direction | Duration Sunshine Hours | Radiation Cal/cm² Day |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 56 | 47 | 52.5 | 7 | 0 | | 1-2 | SW | 4½ | 403 |
| 2 | 44 | 38 | 42.5 | 10 | 0 | | 11-14 | W | 4 | 348 |
| 3 | 44 | 37 | 41.5 | 7 | TR | | 2-3 | SW | 3 | 268 |
| 4 | 56 | 42 | 52.5 | 7 | 0 | | 2-3 | S | 10½ | 457 |
| 5 | 56 | 46 | 51.5 | 4 | 0 | | 3-4 | W | 9¼ | 411 |
| 6 | 63.5 | 44 | 54.5 | 0 | 0 | | 2-3 | SE | 14¾ | 470 |
| 7 | 63 | 53 | 57 | 2 | 0 | | | S | 14¾ | 455 |
| 8 | 59 | 48 | 53.5 | 5 | 0 | | | W | 12½ | 381 |
| 9 | 52 | 44 | 49 | 4 | 0 | | | W | 11½ | 397 |
| 10 | 45.5 | 43 | 44.5 | 10 | TR | | | SE | ¼ | 185 |
| 11 | 38 | 35 | 37 | 10 | TR | | | W | 0 | 93 |
| 12 | 43 | 33.5 | 39 | 5 | 1.20 | | | N | 7¾ | 391 |
| 13 | 44 | 36 | 39.5 | 8 | 0 | | | W | 5½ | 275 |
| 14 | 38 | 35 | 37 | 10 | 0.90 | | | W | 0 | 125 |
| 15 | 40 | 35.5 | 38 | 10 | 3.50 | | | S | 0 | – |
| 16 | 45 | 38 | 42.5 | 10 | – | | | S | 0 | 169 |
| 17 | 45 | 41.5 | 44 | 10 | – | | | SW | 0 | 188 |
| 18 | 49 | 40 | 45 | 3 | – | | | E | 12¼ | 446 |
| 19 | 56 | 46 | 54 | 4 | 0 | | | NE | 9½ | 327 |
| 20 | 57 | 43 | 50.5 | 7 | 0 | | | SE | 7½ | 328 |
| 21 | 51 | 33 | 47 | 6 | 0 | | 5-6 | ENE | 7½ | 322 |
| 22 | 60 | 46 | 52.5 | 3 | 0 | | 10-11 | SE | 11½ | 330 |
| 23 | 58 | 42 | 50.5 | 1 | 0 | | 3-4 | WSW | 13¼ | 353 |
| 24 | 43 | 34 | 38.5 | 10 | 1.60 | | 12-13 | W | 0 | 153 |
| 25 | 44 | 31 | 38 | ·5 | 0 | | 4-5 | NE | 7½ | 313 |
| 26 | 42 | 36 | 40 | 10 | 0.59 | TR | CALM | – | 0 | 91 |
| 27 | 37 | 32 | 35.5 | 10 | 0.82 | TR | 7-8 | W | 0 | 182 |
| 28 | | | | | | | | | | |
| 29 | | | | | | | | | | |
| 30 | | | | | | | | | | |
| 31 | | | | | | | | | | |
| Cum | | | | | | | | | | |
| Mean | | | | | | | | | | |

# JUNEAU ICEFIELD RESEARCH PROGRAM

MONTHLY SUMMARY WEATHER FORM

SITE OR CAMP No. 17 DATE JUNE 1966 ELEVATION 4185'

| DATE | °F MAX. TEMP. | °F MIN. TEMP. | °F MEAN TEMP. (0700-2200) | 10THS AVERAGE CLOUDS | INCHES TOTAL PRECIP. -RAIN- | IN. TOTAL SNOW | MPH AV. WIND SPEED DAY | AV. WIND DIRECTION | HOURS DURATION SUNSHINE | CAL/CM² DAY RADIATION |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | | | | | | | | | |
| 2 | | | | | | | | | | |
| 3 | | | | | | | | | | |
| 4 | | | | | | | | | | |
| 5 | | | | | | | | | | |
| 6 | | | | | | | | | | |
| * 7 | 60 | 38 | 53 | 0 | 0 | | 0-5 | NE | 12 | — |
| 8 | 64 | 38 | 55 | 3 | 0 | | 0-3 | NE | 15 | 591 |
| 9 | 56 | 40 | 44 | 10 | TR | | 5-20 | SE | 5 | 426 |
| 10 | 50 | 37 | 40.5 | 10 | TR | | 5-10 | SE | ½ | 348 |
| 11 | 50 | 33 | 41.5 | 8 | 0.06 | | 0-7 | ESE | 8 | 548 |
| 12 | 40 | 33 | 38.5 | 9 | 0.17 | | 10-18 | ESE | 3½ | 402 |
| 13 | 45 | 29 | 39.5 | 3 | 0 | | 0-7 | W | 14½ | 651 |
| 14 | 57.5 | 34.5 | 48.5 | 3 | 0 | | 2-4 | SW | 12 | 540 |
| 15 | 46 | 34.5 | 39.5 | 10 | 0.36 | | 10-25 | SE | 0 | 342 |
| 16 | 44 | 36 | 37 | 10 | 0.64 | | 20-30 | SE | 0 | 270 |
| 17 | 44.5 | 37.5 | 39.5 | 10 | 0.29 | | 5-15 | SE | 0 | 410 |
| 18 | 41 | 33.5 | 36 | 9 | 0.51 | TR | 15-20 | SE | 1½ | 402 |
| 19 | 42 | 28.5 | 37.5 | 9 | 0 | | 2-4 | SW | 2½ | 390 |
| 20 | 44 | 32 | 37 | 6 | 0.05 | TR | 5-15 | SE | 10½ | 474 |
| 21 | 46 | 30 | 42 | 2 | 0 | | 2-5 | SW | 15 | 633 |
| 22 | 39.5 | 32.5 | 37 | 6 | 0 | | 5-25 | SW | 10½ | 509 |
| 23 | 36 | 32.5 | 35 | 10 | TR | | 5-15 | SW | 0 | 291 |
| 24 | 47 | 31 | — | 10 | | | | | | 327 |
| 25 | | | | | | | | | | 531 |
| •26 | 51.5 | 35.5 | 39.5 | 8 | 0.08 | | 5-10 | SE | 2¾ | 366 |
| 27 | 45 | 32 | 37.5 | 6 | TR | | 0-2 | SE | 6½ | 402 |
| 28 | 48 | 36 | 41 | 5 | 0 | | 10-15 | SE | 7 | 459 |
| 29 | 39.5 | 35 | 37 | 10 | TR | | 4-5 | SW | 0 | 252 |
| 30 | 38 | 34.5 | 36.5 | 10 | 0.06 | | 10-15 | SW | 0 | 276 |
| 31 | | | | | | | | | | |
| CUM | | | | | | | | | | |
| MEAN | | | | | | | | | | |

*C-17 opened for summer

# JUNEAU ICEFIELD RESEARCH PROGRAM

## MONTHLY SUMMARY WEATHER FORM

SITE OR CAMP No. 17 DATE JULY 1966 ELEVATION 4185'

| Date | Max. Temp. °F | Min. Temp. °F | Mean Temp. (0700-2200) °F | Average Clouds 10THS | Total Precip. -Rain- Inches | Total Snow In. | Av. Wind Speed Day MPH | Av. Wind Direction | Duration Sunshine Hours | Radiation Cal/cm² Day |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 53.5 | 35 | 43 | 4 | TR | | 4-5 | SE | 12 | 558 |
| 2 | 43.5 | 40.5 | 39 | 10 | TR | | 10-12 | S | 0 | 297 |
| 3 | 38 | 32 | 34.5 | 10 | 0.07 | TR | 9-10 | NW | 0 | 459 |
| 4 | 38 | 33 | 37 | 10 | 0 | | 7-8 | W | 0 | 360 |
| 5 | 42 | 35 | 40 | 8 | TR | | 4-5 | SW | 5¼ | 474 |
| 6 | 41 | 36.5 | 39 | 10 | TR | | 7-8 | W | 0 | 429 |
| 7 | 51 | 38 | 41 | 8 | TR | | 12-13 | W | 5 | 420 |
| 8 | 38 | 34 | 36 | 10 | 0.19 | | 8-9 | W | 0 | 294 |
| 9 | 39 | 32 | 36 | 10 | 0.36 | TR | 6-7 | SW | ¾ | 420 |
| 10 | 48 | 37 | 43 | 5 | 0 | | 4-5 | NW | 9½ | 570 |
| 11 | 56.5 | 40 | 46 | 2 | 0 | | 2-3 | S | 17 | 570 |
| 12 | 51 | 43.5 | 43 | 5 | 0 | | 5-6 | SW | 7 | 519 |
| 13 | 50.5 | 36.5 | 45 | 7 | 0 | | 2-3 | W | 4¾ | 531 |
| 14 | 54.5 | 44.5 | 50 | 8 | 0 | | 4-5 | SE | 5½ | 498 |
| 15 | 50.5 | 44 | 48 | 8 | 0 | | 12-13 | SE | 3 | 429 |
| 16 | 59 | 46 | 52.5 | 2 | 0 | | 3-4 | SW | 14½ | 597 |
| 17 | 51 | 44.5 | 45 | 10 | TR | | 4-5 | S | 0 | 255 |
| 18 | 45 | 41 | 42 | 10 | 0.14 | | 8-9 | W | 0 | 237 |
| 19 | 44.5 | 40 | 43 | 10 | 0.30 | | 3-4 | W | 0 | 276 |
| 20 | 45.5 | 40 | 44 | 10 | 0.06 | | 4-5 | SW | 0 | 369 |
| 21 | 49.5 | 41.5 | 44.5 | 10 | TR | | 2-3 | W | 0 | 390 |
| 22 | 65 | 40 | 60 | 2 | 0 | | 1-2 | NW | 15 | 573 |
| 23 | 67 | 57 | 61 | 2 | 0 | | 4-5 | N | 14 | 522 |
| 24 | 66.5 | 53 | 61 | 1 | 0 | | 45 | NE | 14¼ | 546 |
| 25 | 63.5 | 53.5 | 58.5 | 2 | 0 | | 5-6 | NW | 15 | 561 |
| 26 | 46.5 | 45 | 43.5 | 9 | 0.16 | | 12-13 | SE | 4 | 282 |
| 27 | 45.5 | 41 | 42 | 10 | 0.93 | | 4-5 | SE | 0 | 189 |
| 28 | 41 | 38.5 | 40 | 10 | 1.38 | | 8-9 | SW | 0 | 273 |
| 29 | 40.5 | 36 | 39.5 | 10 | 1.14 | | 5-6 | SE | 0 | 219 |
| 30 | 41 | 37.5 | 39.5 | 10 | 1.02 | | 5-6 | SE | 0 | 279 |
| 31 | 40 | 37 | 39 | 10 | 1.49 | | 20-40 | SE | 0 | 132 |
| Cum | | | | | 7.24 | | | | | |
| Mean | 48.5 | 40.5 | 44.5 | | | | | | | |

# JUNEAU ICEFIELD RESEARCH PROGRAM

MONTHLY SUMMARY WEATHER FORM

SITE OR CAMP NO. 17 DATE AUG. 1966 ELEVATION 4185'

| DATE | Max. Temp. °F | Min. Temp. °F | Mean Temp. (0700-2200) °F | Average Clouds 10THS | Total Precip. -Rain- INCHES | Total Snow IN. | Av. Wind Speed Day MPH | Av. Wind Direction | Duration Sunshine HOURS | Radiation CAL/CM²/DAY |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 42 | 36 | 39 | 10 | 0.45 | | 15-25 | SE | 0 | 156 |
| 2 | 39.5 | 37 | 38.5 | 10 | 1.66 | | 5-15 | SE | 0 | 204 |
| 3 | 42 | 37.5 | 40 | 10 | 0.58 | | 3-4 | W | 0 | 243 |
| 4 | 48 | 36 | 43.5 | 6 | TR | | 2-3 | E | 8¼ | 474 |
| 5 | 52.5 | 40.5 | 48.5 | 3 | 0 | | 5-6 | SE | 15 | 525 |
| 6 | 58 | 38 | 51 | 4 | 0 | | 6-7 | SE | 12¾ | 513 |
| 7 | 51 | 43 | 45 | 9 | 0.08 | | 12-16 | SE | 1½ | 267 |
| 8 | 39 | 36 | 37 | 10 | 0.93 | | 15-25 | E | 0 | 222 |
| 9 | 37 | 30 | 34 | 10 | 1.80 | 1-2 | 12-15 | S | 0 | 198 |
| 10 | 38.5 | 33 | 36.5 | 10 | 0.14 | TR | 7-8 | SW | 0 | 264 |
| 11 | 39 | 36 | 37.5 | 10 | 0.38 | | 3-4 | SE | 0 | 183 |
| 12 | 45.5 | 35 | 40.5 | 8 | TR | | 6-7 | E | 4½ | 357 |
| 13 | 45.5 | 39 | 42.5 | 7 | 0.50 | | 10-20 | E | 7½ | 372 |
| 14 | 39 | 34 | 38 | 10 | 3.05 | | 10-15 | SE | 0 | 207 |
| 15 | 38.5 | 35 | 37.5 | 10 | 0.69 | | 10-15 | E | 0 | 174 |
| 16 | 39 | 36 | 37.5 | 10 | 0.99 | | 6-10 | S | 0 | 162 |
| 17 | 39.5 | 37 | 38.5 | 10 | 0.94 | | 10-15 | W | 0 | 150 |
| 18 | 44.5 | 35.5 | 40.5 | 6 | 0.11 | | 3-4 | SE | 4½ | 435 |
| 19 | 44 | 38 | 41 | 10 | 0.50 | | 10-15 | SE | 0 | 165 |
| 20 | 45 | 31 | 38.5 | 10 | 1.12 | | 12-18 | SW | 0 | 126 |
| 21 | 39 | 32 | 36.5 | 9 | 0.15 | | 6-7 | W | 3¼ | 378 |
| 22 | 41 | 35 | 38.5 | 10 | 0.41 | | 12-18 | SE | 0 | 126 |
| 23 | 48 | 41 | 46 | 10 | 3.32 | | 12-18 | SE | 0 | – |
| 24 | 45 | 37.5 | 38.5 | 10 | 0.81 | | 8-10 | W | 0 | 183 |
| 25 | 37.5 | 34 | 36.5 | 10 | TR | | 5-6 | W | 0 | 189 |
| 26 | 47 | 34 | 44 | 4 | 0 | | 9-12 | NE | 12 | 447 |
| 27 | 48 | 40 | 44.5 | 6 | 0 | | 15-25 | NE | 12 | 489 |
| 28 | 48 | 42.5 | 43 | 10 | TR | | 4-5 | SW | 0 | 150 |
| 29 | 41 | 37.5 | 39 | 10 | 0.20 | | 9-10 | S | 0 | 115 |
| 30 | 41 | 34 | 36.5 | 10 | 0.75 | | 3-4 | SW | 0 | 156 |
| 31 | 37 | 35 | 36 | 10 | 2.41 | | 15-25 | SE | 0 | 87 |
| CUM | | | | | 21.97 | | | | | |
| MEAN | 43 | 36.5 | 40 | | | | | | | |

# JUNEAU ICEFIELD RESEARCH PROGRAM

MONTHLY SUMMARY WEATHER FORM

Site or Camp No. 17 Date SEPT. 1966 Elevation 4185′

| Date | Max. Temp. °F. | Min. Temp. °F. | Mean Temp. (0700-2200) °F | Average Clouds 10THS | Total Precip. -Rain- INCHES | Total Snow IN. | Av. Wind Speed Day MPH | Av. Wind Direction | Duration Sunshine HOURS | Radiation CAL/cm²/DAY |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 36 | 32 | 34 | 10 | 1.49 | TR | 6-7 | SW | 0 | 99 |
| 2 | 33.5 | 31.5 | 32.5 | 10 | 0.45 | 2 | 9-10 | SE | 0 | 168 |
| 3 | 33 | 30 | 31.5 | 10 | — | 2-3 | 25-35 | NE | 0 | 123 |
| 4 * | — | — | 34 | 10 | — | TR | 20-40 | SE | 0 | 63 |
| 5 * | — | — | 34.5 | 10 | — | 1-2 | 10-15 | SE | 0 | 156 |
| 6 * | — | — | 35 | 10 | 0.30 | TR | 7-8 | SE | 1 | 255 |
| 7 * | — | — | 34 | 8 | — | 0 | 10-25 | SE | 0 | 171 |
| 8 * | — | — | 38.5 | 6 | 0 | 0 | 15-25 | NE | 6¾ | 375 |
| 9 * | — | — | 38.5 | 8 | TR | 0 | 0-5 | E | ¾ | 246 |
| 10 | 36 | 35 | 35.5 | 10 | TR | 0 | 15-20 | SW | 0 | 195 |
| 11 | — | 31 | 33 | 7 | TR | 0 | 4-5 | SW | 0 | 279 |
| 12 | — | — | 43 | 10 | 0 | 0 | 20-30 | SE | 2 | 159 |
| 13 | 44 | 40 | 40.5 | 10 | 1.90 | 0 | 40-55 | SE | 0 | 51 |
| 14 | 51 | 42 | 48 | 2 | 0.60 | 0 | 10-20 | SE | 10¼ | 384 |
| 15 | 43 | 41 | 42 | 10 | 0.29 | 0 | 20-40 | SE | 0 | 159 |
| 16 | 42 | 35.5 | 39 | 6 | 0.37 | 0 | 15-30 | E | 3¼ | 264 |
| 17 | 42 | 36.5 | 37.5 | 8 | 0.21 | 0 | 5-15 | SE | 0 | — |
| 18 | CONTINUOUS SUMMER OPERATIONS SUSPENDED | | | | | | | | | |
| 19 | | | | | | | | | | |
| 20 | | | | | | | | | | |
| 21 | | | | | | | | | | |
| 22 | | | | | | | | | | |
| 23 | | | | | | | | | | |
| 24 | | | | | | | | | | |
| 25 | | | | | | | | | | |
| 26 | | | | | | | | | | |
| 27 | | | | | | | | | | |
| 28 | | | | | | | | | | |
| 29 | | | | | | | | | | |
| 30 | | | | | | | | | | |
| 31 | | | | | | | | | | |
| Cum | | | | | | | | | | |
| Mean | | | | | | | | | | |

* INSTRUMENT SHELTER DESTROYED BY WINDS - REACHING 60-100 MPH NIGHT OF SEPT 3-4. (—— DENOTES NO RECORD)

# JUNEAU ICEFIELD RESEARCH PROGRAM

## MONTHLY SUMMARY WEATHER FORM

SITE OR CAMP NO. 17 DATE JAN. 1967 ELEVATION 4185'

| DATE | °F. MAX. TEMP. | °F MIN. TEMP. | °F MEAN TEMP. (0700-2200) | 10THS AVERAGE CLOUDS | INCHES TOTAL PRECIP. -RAIN- | IN. TOTAL SNOW | MPH AV. WIND SPEED DAY | AV. WIND DIRECTION | HOURS DURATION SUNSHINE | CAL/CM² / DAY RADIATION |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | | | | | | | | | |
| 2 | | | | | | | | | | |
| 3 | | | | | | | | | | |
| 4 | | | | | | | | | | |
| 5 | | | | | | | | | | |
| 6 | | | | | | | | | | |
| 7 | | | | | | | | | | |
| 8 | | | | | | | | | | |
| 9 | | | | | | | | | | |
| 10 | | | | | | | | | | |
| 11 | | | | | | | | | | |
| 12 | — | 15 | 17 | — | | 0 | 4-5 | ENE | | |
| 13 | 19 | 15 | 17 | 6 | | 0 | 5-10 | SE | | |
| 14 | 10 | 2 | 6 | 5 | | 0 | 40-50 | E | | |
| 15 | — | 2 | 3 | 8 | | TR | 10-[illegible]0 | E | | |
| 16 | 19 | 4 | 17 | 10 | | 6 | 5-15 | S | | |
| 17 | 20 | 17 | 20 | 8 | | 0 | 5-10 | NE | | |
| 18 | 17 | 12 | 15 | 5 | | TR | 15 | NE | | |
| 19 | 10 | -3 | 4 | 1 | | 0 | 30-50 | NE | | |
| 20 | -7 | -12 | -10 | 2 | | 0 | >60 | NE | | |
| 21 | -9 | -15 | -11 | 2 | | 0 | 40-60+ | NE | | |
| 22 | -3 | -9 | -5 | 2 | | TR | 25-70 | NE | | |
| 23 | 0 | -5 | -2 | 1 | | 0 | 10-30 | NE | | |
| 24 | 21 | -3 | 13 | 1 | | 0 | 10-20 | NE | | |
| 25 | 4 | 0 | 2 | 0 | | 0 | 20-60 | NE | | |
| 26 | 2 | -4 | -1 | 0 | | 0 | 25-50 | NE | | |
| 27 | -5 | -7 | -6 | 0 | | 0 | 15-25 | NE | | |
| 28 | -7 | -9 | -8 | 10 | | 0 | 65-70 | NE | | |
| 29 | | | | | | | | | | |
| 30 | | | | | | | | | | |
| 31 | | | | | | | | | | |
| CUM | | | | | | | | | | |
| MEAN | | | | | | | | | | |

# JUNEAU ICEFIELD RESEARCH PROGRAM

MONTHLY SUMMARY WEATHER FORM

SITE OR CAMP NO. 17 DATE MARCH 1967 ELEVATION 4185'

| DATE | °F. MAX. TEMP. | °F. MIN. TEMP. | °F MEAN TEMP. (0700-2200) | 10THS AVERAGE CLOUDS | INCHES TOTAL PRECIP. -RAIN- | IN. TOTAL SNOW * | MPH AV. WIND SPEED DAY | AV. WIND DIRECTION | HOURS DURATION SUNSHINE | CAL/CM² / DAY RADIATION |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | | | | | | | | | |
| 2 | | | | | | | | | | |
| 3 | | | | | | | | | | |
| 4 | | | | | | | | | | |
| 5 | | | | | | | | | | |
| 6 | | | | | | | | | | |
| 7 | | | | | | | | | | |
| 8 | | | | | | | | | | |
| 9 | | | | | | | | | | |
| 10 | | | | | | | | | | |
| 11 | | | | | | | | | | |
| 12 | | | | | | | | | | |
| 13 | | | | | | | | | | |
| 14 | | | | | | | | | | |
| 15 | | | | | | | | | | |
| 16 | | | | | | | | | | |
| 17 | | | | | | | | | | |
| 18 | — | — | — | 4 | | ✓ | 20-40 | ENE | | — |
| 19 | — | — | — | 3 | | ✓ | 30-50 | ENE | | — |
| 20 | 11 | 9.5 | 10 | 6 | | 0 | 35-50 | NE | | — |
| 21 | 14.5 | 4 | 8 | 4 | | 0 | 10-20 | ENE | | 254 |
| 22 | 9 | 7 | 8 | 8 | | ✓ | 25-40 | ENE | | 258 |
| 23 | -1 | -6 | -3.5 | 9 | | ✓ | 30-40 | ENE | | 306 |
| 24 | -10 | -15 | -11.5 | 0 | | 0 | 25-35 | ENE | | 366 |
| 25 | -5 | -15.5 | -8.5 | 0 | | 0 | 15-25 | ENE | | 374 |
| 26 | 4 | -9.5 | -1 | 0 | | 0 | — | ENE | | 336 |
| 27 | 17 | 0 | 9 | — | | ✓ | 20-25 | ENE | | 290 |
| 28 | 24 | 12 | 16 | — | | ✓ | 5-10 | N | | 276 |
| 29 | 23 | 11 | 13 | 2 | | 0 | 5-15 | NNE | | 379 |
| 30 | 19 | 8 | 13.5 | 0 | | 0 | 10-20 | ENE | | — |
| 31 | | | | | | | | | | |
| CUM | | | | | | | | | | |
| MEAN | | | | | | | | | | |

* DAYS ON WHICH SNOW FELL ARE DENOTED ✓ – DRIFTING MADE MEASUREMENTS INVALID

# JUNEAU ICEFIELD RESEARCH PROGRAM

MONTHLY SUMMARY WEATHER FORM

Site or Camp No. 17 Date JUNE 1967 Elevation 4185'

| Date | Max. Temp. °F | Min. Temp. °F | Mean Temp. (0700 - 2200) °F | Average Clouds 10THS | Total Precip. -Rain- INCHES | Total Snow IN. | Av. Wind Speed Day MPH | Av. Wind Direction | Duration Sunshine HOURS | Radiation CAL/cm² DAY |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | | | | | | | | | |
| 2 | | | | | | | | | | |
| 3 | 55 | 47 | 51 | 0 | 0 | | CALM | — | | — |
| 4 | | | | | | | | | | |
| 5 | | | | | | | | | | |
| 6 | | | | | | | | | | |
| 7 | | | | | | | | | | |
| 8 | | | | | | | | | | |
| 9 | | | | | | | | | | |
| 10 | | | | | | | | | | |
| 11 | | | | | | | | | | |
| 12 | 57 | 48 | 49.5 | 2 | 0 | | | | | — |
| 13 | 48 | 40 | 43 | 9 | 0.17 | | 0-1 | W | | 522 |
| 14 | 42 | 38 | 40.5 | 10 | 0.46 | | 10-14 | SE | | 386 |
| 15 | 39 | 34 | 36.5 | 10 | 1.03 | | 7-8 | SE | | 408 |
| 16 | 54 | 38 | 48 | 0 | 0 | | 2-3 | SE | | 738 |
| 17 | — | 32 | 52 | 0 | 0 | | 0-2 | NE | | 772 |
| 18 | 60 | 50 | 55 | 4 | 0 | | 7-8 | NE | | 660 |
| 19 | — | 46 | 54 | 5 | 0 | | 2-3 | NE | | 570 |
| 20 | 60 | 47 | 56 | 6 | 0 | | 2-3 | NE | | — |
| 21 | 58 | 45 | 53 | 8 | 0 | | CALM | — | | 494 |
| 22 | 60 | 44 | 55.5 | 5 | 0 | | CALM | — | | 563 |
| 23 | 61 | 42 | 54.5 | 5 | 0 | | 0-1 | NE | | 714 |
| 24 | 57 | 42 | 50 | 5 | 0 | | CALM | — | | 486 |
| 25 | 47 | 33 | 41 | 10 | 0.07 | | 5-6 | SE | | 437 |
| 26 | 44 | 38 | 39.5 | 10 | 0.37 | | — | — | | 342 |
| 27 | — | — | 37.5 | 10 | 1.60 | | 6-10 | SE | | — |
| 28 | 32 | 30 | 31 | 10 | 1.12 | 3.0 | 18-22 | SE | | — |
| 29 | — | 31 | 33 | 10 | 0.22 | 2.0 | 4-8 | S | | — |
| 30 | 36 | 31 | 33 | 10 | 0.54 | TR | 10-20 | SSW | | 306 |
| 31 | | | | | | | | | | |
| Cum | | | | | | | | | | |
| Mean | | | | | | | | | | |

# JUNEAU ICEFIELD RESEARCH PROGRAM

MONTHLY SUMMARY WEATHER FORM

SITE OR CAMP No. 17 DATE JULY 1967 ELEVATION 4185'

| DATE | °F MAX. TEMP. | °F MIN. TEMP. | °F MEAN TEMP. (0700-2200) | 10THS AVERAGE CLOUDS | INCHES TOTAL PRECIP. -RAIN- | IN. TOTAL SNOW | MPH AV. WIND SPEED DAY | AV. WIND DIRECTION | HOURS DURATION SUNSHINE | CAL/cm² DAY RADIATION |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 40 | - | 36.5 | 8 | 0.33 | | 4-6 | SW | | 582 |
| 2 | 40 | 34 | 36 | 10 | 0.07 | | 2-4 | SW | | 440 |
| 3 | - | 34 | 39 | 10 | 1.50 | TR | 12-14 | W | | 420 |
| 4 | 38 | 34 | 37.5 | 10 | 0.54 | TR | 8-10 | W | | 242 |
| 5 | 42 | 32 | 38.5 | 9 | 0.42 | | 5-7 | SE | | 426 |
| 6 | - | 33 | 36.5 | 10 | 0.80 | | 20-25 | SE | | — |
| 7 | - | 31.5 | 35 | 10 | 1.57 | | 10-15 | SE | | — |
| 8 | 44 | 32 | 40 | 9 | 0.05 | | 0-3 | S | | 420 |
| 9 | 43 | 35 | 38.5 | 8 | 0 | | 2-4 | SE | | 558 |
| 10 | 46 | 36 | 42 | 8 | 0.16 | | 5-10 | SE | | 418 |
| 11 | 46 | 38 | 41 | 9 | 0.47 | | 10-15 | SE | | 594 |
| 12 | 50 | 39.5 | 45.5 | 8 | 0.23 | | 3-4 | SE | | 550 |
| 13 | 51 | 39 | 47.5 | 7 | 0.07 | | 3-7 | SE | | 570 |
| 14 | 43 | 38 | 39.5 | 10 | 0.57 | | 4-9 | SW | | 264 |
| 15 | 50 | 37.5 | 44.5 | 6 | 0.36 | | 2-6 | E | | — |
| 16 | 49 | — | 41 | 10 | 0.31 | | 20-30 | SE | | 272 |
| 17 | 44 | 34 | 40.5 | 8 | TR | | 4-8 | SE | | 518 |
| 18 | 44 | 35 | 41 | 9 | 0.08 | | 3-7 | SW | | 510 |
| 19 | 41 | 35 | 39 | 10 | 0.11 | | 15-20 | SW | | 269 |
| 20 | 40 | 35 | 38.5 | 10 | 0.37 | | 20-25 | SW | | 264 |
| 21 | 41 | 36 | 39 | 10 | 1.24 | | 10-15 | S | | 290 |
| 22 | 44 | 37 | 41.5 | 10 | 0.34 | | 5-10 | SE | | 342 |
| 23 | 54 | 39 | 48.5 | 2 | 0.15 | | 0-5 | S | | — |
| 24 | 55 | 39.5 | 50 | 1 | 0 | | 5-10 | N | 10½ | 582 |
| 25 | 58 | 44 | 52.5 | 2 | 0 | | 0-5 | SW | 13 | 564 |
| 26 | 45 | 41 | 44 | 10 | 0.58 | | 10-15 | SE | | 262 |
| 27 | 45 | 39 | 43 | 10 | 3.03 | | 15-20 | SE | | 234 |
| 28 | 44 | 38 | 41 | 9 | 0.47 | | 5-15 | SE | | 398 |
| 29 | 45 | 35 | 41 | 10 | 0.14 | | 0-5 | S | | 412 |
| 30 | 43 | 37 | 41 | 10 | 0.07 | | 5-15 | SE | | 320 |
| 31 | 41 | 38 | 40 | 10 | 1.29 | | 15-20 | NW | | — |
| CUM | | | | | 15.28 | | | | | |
| MEAN | 45 | 36.5 | 41.5 | | | | | | | |

# JUNEAU ICEFIELD RESEARCH PROGRAM

[MONTHLY SUMMARY WEATHER FORM]

SITE OR CAMP NO. 17 DATE AUG. 1967 ELEVATION 4185'

| Date | °F Max. Temp. | °F Min. Temp. | °F Mean Temp. (0700-2200) | 10THS Average Clouds | Inches Total Precip. -Rain- | In. Total Snow | MPH Av. Wind Speed Day | Av. Wind Direction | Hours Duration Sunshine | CAL/CM² / DAY Radiation |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 41.5 | 37 | 40.5 | 10 | 1.23 | | 5-10 | SE | | — |
| 2 | 48 | 37.5 | 46 | 9 | 1.00 | | 0-5 | SW | | 360 |
| 3 | 56 | 42.5 | 50 | 2 | 0 | | 0-3 | E | | 548 |
| 4 | 58.5 | 46 | 50.5 | 2 | 0 | | 0-3 | NE | | 534 |
| 5 | 54 | 49 | 49 | 8 | 0 | | 0-5 | NW | 8 | 480 |
| 6 | 61 | 44 | 54 | 2 | 0 | | 0-3 | SE | 14 | 582 |
| 7 | 47 | 43 | 44 | 10 | TR | | 15-25 | SE | ½ | 245 |
| 8 | 46 | — | 44 | 10 | *(3.28) | | 20-30 | SE | | 124 |
| 9 | 43 | 39 | 41 | 10 | | | 15-20 | SE | | — |
| 10 | 41 | — | 40 | 10 | 1.24 | | 5-10 | SE | | 146 |
| 11 | 42 | 36 | 40 | 10 | 0.97 | | 4-8 | SE | | 173 |
| 12 | 42 | 38 | 40.5 | 10 | 0.13 | | 15-25 | NW | | 152 |
| 13 | 41 | 38.5 | 40 | 10 | 0.29 | | 15-20 | NW | | 119 |
| 14 | 41 | 37 | 40 | 10 | 0.20 | | 15-20 | NW | | — |
| 15 | 44 | 36 | 41 | 8 | 0.02 | | 3-4 | NW | | 320 |
| 16 | 59 | 39 | 54.5 | 0 | 0 | | 5-10 | SE | 13½ | 534 |
| 17 | 58 | 48 | 53.5 | 2 | 0 | | 15-20 | SE | 13½ | 600 |
| 18 | 44 | 38 | 42 | 10 | 0.21 | | 30-40 | SE | | 168 |
| 19 | 45 | 34 | 42 | 10 | 2.14 | | 20-40 | SE | | 120 |
| 20 | 44 | — | 41 | 10 | 1.34 | | 25-35 | SE | | 90 |
| 21 | 41 | 38.5 | 39 | 10 | 1.10 | | 5-15 | S | | 158 |
| 22 | 40 | 36 | 38 | 10 | 0.87 | | 10-15 | SE | | 186 |
| 23 | 46 | 33.5 | 40.5 | 9 | 0.21 | | 0-2 | N | | 318 |
| 24 | 41 | 36 | 39 | 10 | 0.37 | | 10-20 | SE | | 260 |
| 25 | 44 | 39 | 41.5 | 10 | 2.06 | | 25-30 | SE | | — |
| 26 | 41 | 37.5 | 40 | 10 | 1.21 | | 10-20 | SE | | 78 |
| 27 | 46 | 37 | 42 | 5 | 0.37 | | 5-10 | SE | | 410 |
| 28 | 46 | 39 | 43.5 | 8 | 0.02 | | 10-20 | SE | | 258 |
| 29 | 59 | 40 | 53 | 5 | TR | | 15-25 | SE | | 470 |
| 30 | 49 | 43 | 45.5 | 10 | 0.32 | | 20-30 | SE | | 180 |
| 31 | 47 | 40 | 44 | 10 | 2.23 | | 20-40 | SE | | 155 |
| CUM | | | | | 20.81 | | | | | |
| MEAN | 47 | 39.5 | 44 | | | | | | | |

* TWO DAY TOTAL

# JUNEAU ICEFIELD RESEARCH PROGRAM

MONTHLY SUMMARY WEATHER FORM

SITE OR CAMP No. 17 DATE SEPT 1967 ELEVATION 4185'

| DATE | °F. MAX. TEMP. | °F MIN. TEMP. | °F MEAN TEMP. (0700-2200) | 10THS AVERAGE CLOUDS | INCHES TOTAL PRECIP. -RAIN- | IN. TOTAL SNOW | MPH AV. WIND SPEED DAY | AV. WIND DIRECTION | HOURS DURATION SUNSHINE | CAL/CM² DAY RADIATION |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 43 | 37 | 39.5 | 10 | 1.18 | | 15-30 | SE | | 96 |
| 2 | 40 | – | 39 | 10 | 3.11 | | 20-40 | SE | | – |
| 3 | 41 | 36 | 36.5 | 9 | 1.66 | | 25-35 | SE | | 162 |
| 4 | 39 | – | 37.5 | 10 | 0.40 | | 15-25 | SE | | 146 |
| 5 | 41 | 35 | 37.5 | 9 | 0.93 | | 20-30 | SE | | 192 |
| 6 | 40 | 34 | 37.5 | 10 | 0.76 | | 35-45 | SE | | 132 |
| 7 | 42 | 38 | 40 | 10 | 0.75 | | 40-60+ | SE | | 90 |
| 8 | 42 | 37 | 39 | 10 | 0.92 | | 20-35 | SE | | 102 |
| 9 | – | 34 | 35 | 10 | 2.04 | TR | 15-20 | SW | | 98 |
| 10 | 41 | 31.5 | 37.5 | 7 | 0.26 | | 5-10 | SE | | – |
| 11 | 47 | 31 | 41 | 4 | 0 | | 0-30 | NE | 1/2 | – |
| 12 | – | 31 | 36.5 | 10 | 1.35 | TR | 45-60+ | SE | | – |
| 13 | | | | | | | | | | |
| 14 | | | | | | | | | | |
| 15 | | | | | | | | | | |
| 16 | | | | | | | | | | |
| 17 | | | | | | | | | | |
| 18 | | | | | | | | | | |
| 19 | | | | | | | | | | |
| 20 | | | | | | | | | | |
| 21 | | | | | | | | | | |
| 22 | | | | | | | | | | |
| 23 | | | | | | | | | | |
| 24 | | | | | | | | | | |
| 25 | | | | | | | | | | |
| 26 | | | | | | | | | | |
| 27 | | | | | | | | | | |
| 28 | | | | | | | | | | |
| 29 | | | | | | | | | | |
| 30 | | | | | | | | | | |
| 31 | | | | | | | | | | |
| CUM | | | | | | | | | | |
| MEAN | | | | | | | | | | |

APPENDIX A-13.--Lemon-Ptarmigan Ridge Precipitation Data, 1967

| Location | Inches of Precipitation | | | Vesper Park (4) |
|---|---|---|---|---|
| | Lemon Glac. (1) | Ptar. Glac. (2) | C-17 (3) | |
| Date | | | | |
| July 2 | Gages buried in snow | | | |
| 8 | 3.23 | 5.01 | 4.88 | |
| 11 | .52 | .65 | .51 | |
| 20 | 2.01 | 2.03 | 2.01 | |
| 22 | 1.22 | 1.38 | 1.71 | |
| 28 | 3.07 | 4.14 | 4.27 | |
| Aug. 1 | 1.20 | 1.17 | 1.95 | |
| 3 | 1.51 | 1.53 | 1.78 | |
| 12 | 5.04 | 7.31 | 5.60 | |
| 23 | 7.74 | 8.83 | 6.39 | 5.93 |
| Sept. 4 | 6.74 | 8.82 | 12.67 | |
| 10 | 4.05 | 6.38 | 6.00 | 4.46 |

Precipitation gages were standard 8-inch USWB rain gages

(1) and (2)--These gages were buried flush with the snow surface and emptied each time precipitation was recorded. Gage (1) on Lemon Glac. was East of the C-17 ridge and Gage (2) on Ptarmigan Glac. West of the ridge. Prevailing summer winds and rainstorms are from the Southeast.

(3)--Located near the Meterological Instrument shelter at C-17. Figures for this gage show total precipitation collected at this site between the two dates when the precipitation at the on-glacier sites was measured.

(4)--Located about 40 m. NW of Vesper Peak, approx. 5 m. below the ridge crest.

APPENDIX A-14.--Lemon-Ptarmigan Glacier Area Precipitation Data, 1967. Gage on Vesper peak installed 1 August; Gages on W. Ptarmigan ridge installed 30 July; Figures in inches of precipitation.

| Location | | Vesper Peak | West Ptarmigan Ridge (S to N) | | |
|---|---|---|---|---|---|
| | | | (1) | (2) | (3) |
| Date | | | | | |
| August | 13 | 5.93 | 6.88 | 6.28 | 4.47 |
| | 23 | 6.43 | 8.01 | 7.61 | 5.82 |
| | 26 | 3.14 | 4.05 | 3.82 | 2.41 |
| Sept. | 4 | 7.25 | 7.24 | 8.22 | 6.11 |
| | 9 | | 5.17 | 5.30 | 3.51 |
| | 10 | 4.46 | | | |

APPENDIX A-15.--Mean Temperatures (°F) at JIRP Camp 17 and at Juneau Airport.

| Date | Camp 17[a] | Juneau Airport[b] |
|---|---|---|
| 1965 | | |
| July 7-13 | 47.0 | 55.4 |
| August 1-27 | 45.5 | 55.1 |
| 1966 | | |
| June 7-30 | 40.5 | 52.4 |
| July | 44.5 | 56.2 |
| August | 40.0 | 52.4 |
| Sept. 1-15 | 37.0 | 50.2 |
| 1967 | | |
| June 12-30 | 45.5 | 54.8 |
| July | 41.5 | 53.8 |
| August | 44.0 | 55.1 |
| Sept. 1-12 | 38.0 | 52.3 |

[a]Elevation approx. 4200 feet.

[b]At sea level on Gastineau Channel.

APPENDIX A-16.--Juneau City, January and Annual Mean Temperatures and Precipitation, 1944-68

| January Mean Temp. °F | Annual Mean Temp. °F |
|---|---|
| 1961 - 34.2 | 1961 - 43.1 |
| 1962 - 29.7 | 1962 - 43.3 |
| 1963 - 29.8 | 1963 - 43.5 |
| 1964 - 30.8 | 1964 - 41.5 |
| 1965 - 26.2 | 1965 - 42.4 |
| 1966 - 18.5 | 1966 - 40.8 |
| 1967 - 26.8 | 1967 - 43.3 |
| 1968 - 24.6 | 1968 - 42.9 |
| 1969 - 14.0 | 1969 - incomplete data |

11 (eleven) Year Running Means - Average Temperature °F

| | | | |
|---|---|---|---|
| 1944-1954 | 47.83 | 1952-1962 | 48.15 |
| 1945-1955 | 47.53 | 1953-1963 | 47.73 |
| 1946-1956 | 47.58 | 1954-1964 | 46.95 |
| 1947-1957 | 47.93 | 1955-1965 | 46.31 |
| 1948-1958 | 48.20 | 1956-1966 | 45.79 |
| 1949-1959 | 48.34 | 1957-1967 | 45.40 |
| 1950-1960 | 48.71 | 1958-1968 | 44.63 |
| 1951-1961 | 48.45 | | |

TOTAL Annual Precipitation--Inches

| | | | |
|---|---|---|---|
| 1950 | 62.06 | 1960 | 100.31 |
| 1951 | 66.63 | 1961 | 120.51 |
| 1952 | 102.64 | 1962 | 100.09 |
| 1953 | 103.68 | 1963 | 99.36 |
| 1954 | 81.73 | 1964 | 106.62 |
| 1955 | 85.20 | 1965 | 79.32 |
| 1956 | 100.46 | 1966 | 96.68 |
| 1957 | 66.75 | 1967 | 83.52 |
| 1958 | 90.52 | 1968 | 82.47 |
| 1959 | 102.93 | | |

APPENDIX A-17.--Juneau Airport, January and Annual Mean Temperatures and Precipitation, 1944-68.

| January Mean Temp. °F | Annual Mean Temp. °F |
|---|---|
| 1961 - 30.5 | 1961 - 40.8 |
| 1962 - 26.7 | 1962 - 40.5 |
| 1963 - 27.7 | 1963 - 41.5 |
| 1964 - 29.3 | 1964 - 40.2 |
| 1965 - 23.1 | 1965 - 39.3 |
| 1966 - 8.6 | 1966 - 37.2 |
| 1967 - 23.1 | 1967 - 39.7 |
| 1968 - 18.6 | 1968 - 39.3 |
| 1969 - 6.8 | 1969 - incomplete data |

11 (eleven) Year Running Means - Average Temperature °F

| | | | |
|---|---|---|---|
| 1944-1954 | 40.17 | 1952-1962 | 40.46 |
| 1945-1955 | 39.76 | 1953-1963 | 40.55 |
| 1946-1956 | 39.57 | 1954-1964 | 40.42 |
| 1947-1957 | 39.61 | 1955-1965 | 40.37 |
| 1948-1958 | 39.66 | 1956-1966 | 40.31 |
| 1949-1959 | 39.76 | 1957-1967 | 40.43 |
| 1950-1960 | 40.00 | 1958-1968 | 40.25 |
| 1951-1961 | 40.28 | | |

| Eleven-Year Running Means-- Annual Precipitation (inches) | | Total Annual Precipitation (inches) | |
|---|---|---|---|
| 1951-1961 | 53.57 | 1960 | 57.77 |
| 1952-1962 | 55.76 | 1961 | 68.11 |
| 1953-1963 | 55.00 | 1962 | 61.83 |
| 1954-1964 | 53.34 | 1963 | 57.39 |
| 1955-1965 | 55.95 | 1964 | 58.28 |
| 1956-1966 | 56.81 | 1965 | 47.88 |
| 1957-1967 | 55.18 | 1966 | 58.30 |
| 1958-1968 | 55.90 | 1967 | 50.07 |
| | | 1968 | 48.02 |

# APPENDIX B

## GLACIOLOGICAL DATA, PART I

### 1966 and 1967 Test--Pit Measurements (Englacial Temperatures and Firn Stratigraphy)

APPENDIX B-1.--Lemon Glacier Data--1966. Test Pit 1: Location--Upper Lemon Névé at approximately 3950 ft. Conditions--11 in. new snow (2.32 w.e.) on packed surface; Ambient Temperature 0°C. Snow-pack temperatures from top of wind packed surface, taken on 3 April 1966.

| Depth | | Temperature | | Density gm/cc |
|---|---|---|---|---|
| feet | cm. | °F | °C | |
| 0.5 | 15 | 29.0 | -1.7 | - |
| 1.0 | 30.5 | 29.0 | -1.7 | 0.217 |
| 1.5 | 46 | 29.0 | -1.7 | - |
| 2.0 | 61 | 29.0 | -1.7 | 0.239 |
| 2.5 | 66 | 29.0 | -1.7 | - |
| 3.0 | 92 | 28.5 | -2 | 0.213 |
| 3.5 | 107 | 27.5 | -2.3 | 0.306 |
| 4.0 | 123 | 27.0 | -2.6 | 0.291 |
| 4.5 | 139 | 25.0 | -4.0 | - |
| 5.0 | 153 | 23.5 | -4.5 | 0.305 |
| 6.0 | 185 | - | - | 0.344 |
| 7.0 | 216 | - | - | 0.366 |
| 8.0 | 247 | - | - | 0.362 |

Re stratigraphy: the snow pack was essentially homogeneous, except for a 1.9 cm. ice lens at a depth of 94 cm. In a shallow pit located 5 meters from the test pit, an ice layer or lens was encountered at this (95 cm) depth. However, the existence of a discontinuous ice stratum was suggested by resistance offered by the snowpack when some of the accumulation stakes were placed in the test pit area.

APPENDIX B-2.--Lemon Glacier Data--1967. Test Pit 1: Location--Upper Lemon névé at approx. 3950 ft. Conditions--15-25 cm. powder snow over wind-packed surface; Ambient Temperature -5°C, Visibility obscured by snow.

Snow-Pack Temperatures (Depths from Top of Wind-Packed Surface)

| Depth (cm | Temperature (°C) |
|---|---|
| 20 | -13.5 |
| 40 | -14.5 |
| 60 | -13.5 |
| 80 | -11.5 |
| 100 | -10 |
| 120 | - 8.5 |
| 140 | - 8 |
| 160 | - 7.5 |
| 180 | - 7 |
| 200 | - 6.5 |
| 220 | - 6 |
| 240 | - 6 |
| 260 | - 5.5 |
| 280 | - 5 |
| 300 | - 4.5 |
| 320 | - 4.5 |
| 340 | - 4.5 |
| 360 | - 4 |
| 380 | - 3.5 |
| 400 | - 3 |
| 420 | - 3.5 |
| 440 | - 2.5 |

Date: 28 March, 1967

APPENDIX B-3.--Lemon Glacier Data, 1967. Test Pit 7A: Location--Lower Lemon névé at approx. 3100 ft. Conditions--Thin ice crust at surface overlying layer of low density snow; Ambient Temperature -9°C; CAVU with light winds.

Snow-Pack Temperatures

| Depth (cm) | Temperature (°C) |
|---|---|
| 20 | -13.5 |
| 40 | -10.5 |
| 60 | - 8.5 |
| 80 | - 7.5 |
| 100 | - 7 |
| 120 | - 6.5 |
| 140 | - 6 |
| 160 | - 5.5 |
| 180 | - 5.5 |
| 200 | - 5.5 |
| 220 | - 5.5 |
| 240 | - 5 |
| 260 | - 5 |
| 280 | - 4.5 |
| 300 | - 4 |
| 320 | - 4 |
| 340 | - 3.5 |
| 460 | - 3 |
| 380 | - 3 |
| 400 | - 2.5 |
| 420 | - 2.5 |
| 440 | - 2 |
| 460 | - 2 |
| 480 | - 2 |
| 500 | - 1.5 |
| 520 | - 1 |
| 535 (in glacier ice) | - 9.5 |

Date: 26 March, 1967

APPENDIX B-4.--Lemon Glacier Data, 1966. Test Pit 2(B): Continuous Vertical Density Profile and Cumulative Water Equivalence; Location--Approx. Elev. 1150 m (3775 ft) on lower névé.

| Depth Interv. (cm) | Density (g/cc) | Cum. $H_2O$ Eq. (cm) |
|---|---|---|
| 0-20 | .49 | 9.8 |
| 20-40 | .53 | 20.4 |
| 40-60 | .54 | 31.2 |
| 60-80 | .53 | 41.8 |
| 80-100 | .55 | 52.8 |
| 100-120 | .55 | 63.8 |
| 120-140 | .54 | 74.6 |
| 140-160 | .54 | 85.4 |
| 160-180 | .56 | 96.6 |
| 180-200 | .58 | 108.2 |
| 200-220 | .61 | 120.4 |
| 220-240 | .54 | 131.2 |
| 240-260 | .59 | 143.0 |
| 260-280 | .57 | 154.4 |
| 280-300 | .57 | 165.8 |
| 300-320 | .58 | 177.4 |
| 320-340 | .61 | 189.6 |
| 340-360 | .59 | 201.4 |
| 360-380 | .58 | 213.0 |
| 380-400 | .52 | 223.4 |

Stratigraphy

| Depth from Surface (cm) | Ice Lens Thickness (cm) |
|---|---|
| 25 | 2 |
| 107 | 2-3 |
| 234 | 3-7 |
| 328 | 1-3 discontinuous |
| 349 | 10 yellowish firn |

Date: 7 July, 1966.

APPENDIX B-5.--Lemon Glacier Data, 1966. Test Pit 2(b): Continuous Vertical Density Profile and Cumulative Water Equivalence; Location: Approx. Elev. 1150 m (3775 ft) on lower névé.

| Depth Interv. (cm) | Density (g/cc) | Cum. $H_2O$ Eq. (cm) |
|---|---|---|
| 0-20 | .56 | 11.2 |
| 20-40 | .57 | 22.6 |
| 40-60 | .60 | 34.6 |
| 60-80 | .58 | 46.3 |
| 80-100 | .59 | 58.0 |
| 100-120 | .60 | 70.0 |
| 120-140 | .59 | 81.8 |
| 140-160 | .61 | 94.0 |
| 160-180 | .59 | 105.8 |
| 180-200 | .59 | 117.6 |
| 200-220 | .59 | 129.4 |
| 220-240 | .60 | 141.4 |
| 240-260 | .66 | 154.6 |
| 260-280 | .58 | 166.2 |
| 280-300 | .56 | 177.4 |
| 300-320 | .59 | 189.2 |

Stratigraphy

| Depth from Surface (cm) | Ice Lens Thickness (cm) | |
|---|---|---|
| 10 | 1-2 | |
| 35 | 5 | discontinuous |
| 66 | 1-5 | interlayered with firn |
| 196 | 1-7 | " " " |
| 224 | 3 | " " " |
| 254 | 2-3 | " " " |
| 292 | 3-4 | yellowish granular firn and ice |

Date: 6 August, 1966

APPENDIX B-6.--Lemon Glacier Data, 1966. Test Pit 3(C): Continuous Vertical Density Profile and Cumulative Water Equivalence; Location: Approx. Elev. 1215 m (3985 ft) on upper névé.

| Depth Interv. (cm) | Density (g/cc) | Cum. $H_2O$ Eq. (cm) |
|---|---|---|
| 0-20 | .48 | 9.6 |
| 20-40 | .52 | 20.0 |
| 40-60 | .50 | 30.0 |
| 60-80 | .50 | 40.0 |
| 80-100 | .53 | 50.6 |
| 100-120 | .60 | 62.6 |
| 120-140 | .53 | 73.2 |
| 140-160 | .57 | 84.6 |
| 160-180 | .56 | 95.8 |
| 180-200 | .55 | 106.8 |
| 200-220 | .57 | 118.2 |
| 220-240 | .62 | 130.6 |
| 240-260 | .56 | 141.8 |
| 260-280 | .58 | 153.4 |
| 280-300 | .57 | 164.8 |
| 300-320 | .58 | 176.4 |
| 320-340 | .58 | 188.0 |
| 340-360 | .56 | 199.2 |
| 360-380 | .57 | 210.6 |

Stratigraphy

| Depth from Surface (cm) | Ice Lens Thickness (cm | |
|---|---|---|
| 22 | 2-3 | |
| 111 | 1-3 | |
| 185 | 1-3 | |
| 200 | 1-5 | |
| 221 | 3-4 | |
| 256 | 6 | Three 1-cm lenses interlayered with firn |
| 277 | 1-3 | |
| 340 | 2-3 | Yellowish, granular firn and ice |

Date: 13 July, 1966

APPENDIX B-7.--Lemon Glacier Data, 1966. Test Pit 3(C): Continuous Vertical Density Profile and Cumulative Water Equivalence; Location: Approx. Elev. 1215 m (3985 ft) on upper névé.

| Depth Interv. (cm) | Density (g/cc) | Cum. $H_2O$ Eq. (cm) |
|---|---|---|
| 0-20 | .59 | 11.8 |
| 20-40 | .60 | 23.8 |
| 40-60 | .59 | 35.6 |
| 60-80 | .66 | 48.8 |
| 80-100 | .57 | 60.2 |
| 100-120 | .56 | 71.4 |
| 120-140 | .60 | 83.4 |
| 140-160 | .59 | 95.2 |
| 160-180 | .61 | 107.4 |
| 180-200 | .62 | 119.8 |
| 200-220 | .59 | 131.6 |
| 220-240 | .56 | 143.4 |

Stratigraphy

| Depth from Surface (cm) | Ice Lens Thickness (cm) | |
|---|---|---|
| 31 | 2 | |
| 39 | 2 | |
| 73 | 4 | |
| 88 | 1-4 | Interlayered with firn |
| 120 | 1-3 | Discontinuous |
| 186 | 2-4 | |
| 203 | 1-4 | Yellowish granular firn with ice lenses |

Date: 5 August, 1966.

APPENDIX B-8.--Lemon Glacier Data, 1966. Test Pit 4(D): Continuous Vertical Density Profile and Cumulative Water Equivalence. Location: Approx. Elev. 1225 m (4020 ft) on upper névé

| Depth Interv. (cm) | Density (g/cc) | Cum. $H_2O$ (cm) |
|---|---|---|
| 0-20 | .56 | 11.2 |
| 20-40 | .54 | 22.0 |
| 40-60 | .56 | 33.2 |
| 60-80 | .57 | 44.6 |
| 80-100 | .56 | 55.8 |
| 100-120 | .58 | 67.4 |
| 120-140 | .60 | 79.4 |
| 140-160 | .60 | 91.4 |
| 160-180 | .60 | 103.4 |
| 180-200 | .63 | 116.0 |
| 200-220 | .61 | 128.0 |
| 220-240 | .58 | 139.8 |
| 240-260 | .59 | 151.6 |
| 260-280 | .60 | 163.6 |
| 280-300 | .61 | 175.8 |
| 300-320 | .61 | 188.0 |
| 320-340 | .65 | 201.0 |
| 340-360 | .61 | 213.2 |

Stratigraphy

| Depth from Surface (cm) | Ice Lens Thickness (cm) | |
|---|---|---|
| 19 | 1-2 | |
| 55 | 1-2 | |
| 98 | 1-2 | |
| 199 | 0-4 | Discontinuous |
| 283 | 1-3 | |
| 304 | 1-5 | |
| 329 | 7 | Yellowish granular firn with 2-3 cm ice lens |

Date: 14 July, 1966

APPENDIX B-9.--Lemon Glacier Data, 1966. Test Pit 4(D): Continuous Vertical Density Profile and Cumulative Water Equivalence. Location: Approx. Elev. 1225 m (4020 ft) on upper névé.

| Depth Interv. (cm) | Density (g/cc) | Cum. $H_2O$ Eq. (cm) |
|---|---|---|
| 0-20 | .54 | 11.8 |
| 20-40 | .60 | 23.8 |
| 40-60 | .63 | 36.4 |
| 60-80 | .57 | 47.8 |
| 80-100 | .58 | 59.4 |
| 100-120 | .56 | 70.6 |
| 120-140 | .60 | 82.6 |
| 140-160 | .61 | 94.8 |
| 160-180 | .57 | 106.2 |
| 180-200 | .58 | 117.8 |
| 200-220 | .55 | 128.8 |
| 220-240 | .58 | 140.4 |
| 240-260 | .55 | 151.4 |

Stratigraphy

| Depth from Surface (cm) | Ice Lens Thickness (cm) | |
|---|---|---|
| 117 | 2 | |
| 133 | 1-3 | |
| 150 | 3-4 | |
| 180 | 3 | Irregular (sun-cupped?) surface; yellowish |
| 208 | 1-2 | |
| 215 | 3 | |
| 252 | 4-5 | Yellowish granular firn (1964 summer ablation surface?) |

Date: 6 August, 1966

APPENDIX B-10.--Lemon Glacier Data, 1967. Test Pit 1: Location: Upper Lemon névé at Approx 3950 ft. Conditions: 15-25 cm. Powder Snow over Wind-Packed Surface; Ambient Temperature -5°C, Visibility Obscured by Snow.

Snow-Pack Temperatures (Depths from Top of Wind-Packed Surface):

| Depth (cm) | Temperature (°C) |
|---|---|
| 20 | - 13.5 |
| 40 | - 14.5 |
| 60 | - 13.5 |
| 80 | - 11.5 |
| 100 | - 10 |
| 120 | - 8.5 |
| 140 | - 8 |
| 160 | - 7.5 |
| 180 | - 7 |
| 200 | - 6.5 |
| 220 | - 6 |
| 240 | - 6 |
| 260 | - 5.5 |
| 280 | - 5 |
| 300 | - 4.5 |
| 320 | - 4.5 |
| 340 | - 4.5 |
| 360 | - 4 |
| 380 | - 3.5 |
| 400 | - 3 |
| 420 | - 3.5 |
| 440 | - 2.5 |

Date: 28 March, 1967

APPENDIX B-11.--Lemon Glacier Data, 1967. Continuous Vertical Density Profile and Cumulative Water Equivalence (Test Pit 1).

| Depth Interval (cm) | Density (g/cc) | Cum. $H_2O$ Eq. (cm) |
|---|---|---|
| 0-20 | .42 | 8.4 |
| 20-40 | .46 | 17.6 |
| 40-60* | .36 | 24.8 |
| 60-80 | .36 | 32.0 |
| 80-100 | .37 | 39.4 |
| 100-120 | .37 | 46.8 |
| 120-140** | .40 | 54.8 |
| 140-160 | .43 | 63.4 |
| 160-180 | .42 | 71.8 |
| 180-200 | .41 | 80.0 |
| 200-220 | .43 | 88.6 |
| 220-240 | .42 | 97.0 |
| 240-260 | .45 | 106.0 |
| 260-280 | .46 | 115.2 |
| 280-300 | .46 | 124.4 |
| 300-320 | .46 | 133.6 |
| 320-340 | .47 | 143.0 |
| 340-360 | .49 | 152.8 |
| 360-380 | .48 | 162.4 |
| 380-400 | .48 | 172.0 |
| 400-420 | .47 | 181.4 |
| 420-440*** | .44 | 190.2 |
| 440-460 | .48 | 199.8 |

*From 52-55 cm. depth--3 to 4 thin ice layers

**At 136 cm. depth--top of 1 cm. ice layer.

***Coarse, granular depth hoar began at depth of 420 cm., extended downward to thin, undulating, slightly yellowish ice layers at approx. 455 cm.

Date: 28 March, 1967

APPENDIX B-12.--Lemon Glacier Data, 1967. Test Pit 3A: Location--Upper Lemon névé at approx. 4000 ft.; Conditions--Wind-Packed Surface; Ambient Temperature at C-17,-12°C, Visibility Obscured by Blowing Snow, Winds 30-40 kts.

| Depth (cm) | Temperature (°C) |
|---|---|
| 30 | -10 |
| 60 | - 9 |
| 90 | - 8 |
| 120 | - 7.5 |
| 150 | - 7 |
| 180 | - 7.5 |
| 210 | - 6 |
| 330 | - 5 |

Test Pit 5: Location--Middle Lemon névé at approx. 3800 ft.; Conditions--Wind-Packed Surface; Ambient Temperature of -31°C at C-17, CAVU, Winds 30-40 kts.

| Depth (cm) | Temperature (°C) |
|---|---|
| 30 | -12.5 |
| 60 | -10.5 |
| 90 | - 9 |
| 120 | - 8 |
| 150 | - 7.5 |
| 180 | - 7.5 |
| 210 | - 7 |
| 240 | - 7 |
| 270 | - 6.5 |
| 300 | - 6.5 |
| 330 | - 6 |
| 360 | - 5.5 |

Also at Test Pit 5:

One (1) centimeter ice layer at depth of 48 cm.

Ram penetrometer encountered impenetrable layer at 450 cm. from the surface (two trials).

Date: 26 March, 1967.

APPENDIX B-13.--Lemon Glacier Data, 1967. Test Pit 7A: Location: Lower Lemon névé at Approx. 3100 ft. Conditions: Thin Ice Crust at Surface Overlying Layer of Low Density Snow; Ambient Temperature -9°C, CAVU with Light Winds.

Snow-Pack Temperatures

| Depth (cm) | Temperature (°C) |
|---|---|
| 20 | - 13.5 |
| 40 | - 10.5 |
| 60 | - 8.5 |
| 80 | - 7.5 |
| 100 | - 7 |
| 120 | - 6.5 |
| 140 | - 6 |
| 160 | - 5.5 |
| 180 | - 5.5 |
| 200 | - 5.5 |
| 220 | - 5.5 |
| 240 | - 5 |
| 260 | - 5 |
| 280 | - 4.5 |
| 300 | - 4 |
| 320 | - 4 |
| 340 | - 3.5 |
| 350 | - 3 |
| 380 | - 3 |
| 400 | - 2.5 |
| 420 | - 2.5 |
| 440 | - 2 |
| 460 | - 2 |
| 480 | - 2 |
| 500 | - 1.5 |
| 520 | - 1 |
| 535 (in glacier ice) | - 0.5 |

Date: 26 March, 1967.

APPENDIX B-14.--Test Pit 7A: Continuous Vertical Density Profile and Cumulative Water Equivalence.

| Depth Interval (cm) | Density (g/cc) | Cum. $H_2O$ Eq. (cm) |
|---|---|---|
| 0-20 | .30 | 6.0 |
| 20-40 | .33 | 12.6 |
| 40-60 | .37 | 20.0 |
| 60-80 | .36 | 27.2 |
| 80-100 | .40 | 35.5 |
| 100-120 | .39 | 43.3 |
| 120-140 | .42 | 51.7 |
| 140-160 | .48 | 61.3 |
| 160-180 | .49 | 71.1 |
| 180-200 | .49 | 80.9 |
| 200-220 | .44 | 89.7 |
| 220-240 | .44 | 98.5 |
| 240-260 | .46 | 107.7 |
| 260-280 | .50 | 117.7 |
| 280-300 | .47 | 127.1 |
| 300-320 | .49 | 136.9 |
| 320-340 | .51 | 147.1 |
| 340-360 | .50 | 157.1 |
| 360-380 | .50 | 167.1 |
| 380-400 | .50 | 177.1 |
| 400-420 | .52 | 187.5 |
| 420-440 | .44 | 196.3 |
| 440-460 | .47 | 205.7 |
| 460-480 | .46 | 214.9 |
| 480-500 | .50 | 224.9 |
| 500-520 | .50 | 234.9 |

A coarse, granular ice occurred from depth of 420 cm. to glacier ice at 535 cm. No "dirty layer" or any other ablation surface indicators were found in the snowpack. Thus, this area was completely snow free at the close of the 1966 ablation season.

This site lies in a zone just below a steeper slope which divides it from a higher, relatively flat névé zone. The site is also in the direct path of northeasterly winds which deflate snow from other higher areas and deposit it here, thus adding to the "true precipitation."

Date: 26 March, 1967.

APPENDIX B-15.--Lemon Glacier Data, 1967. Test Pit 1: Continuous Vertical Density Profile and Cumulative Water Equivalence. Location: Approx. Elev. 4050 ft. at Crest of Glacier.

| Depth Interval (cm) | Density (g/cc) | Cum. $H_2O$ Eq. (cm) |
|---|---|---|
| 0-20 | .57 | 11.4 |
| 20-40 | .57 | 22.8 |
| 40-60 | .57 | 34.2 |
| 60-80 | .58 | 45.8 |
| 80-100 | .55 | 56.8 |
| 100-120 | .58 | 68.4 |
| 120-140 | .57 | 79.8 |
| 140-160 | .57 | 91.2 |
| 160-180 | .57 | 102.6 |
| 180-200 | .57 | 114.0 |
| 200-220 | .59 | 125.8 |
| 220-240 | .59 | 137.6 |
| 240-260 | .56 | 148.8 |
| 260-280 | .58 | 160.4 |
| 280-300 | .62 | 172.8 |
| 300-320 | .57 | 184.2 |
| 320-340 | .62 | 196.6 |
| 340-360 | .72 | 211.0 |
| 360-367 | .90 (ice) | 217.3 |

Stratigraphy: Ice Lenses Generally Thicken Toward the North

| Depth from Surface (cm) | Ice Lens Thickness (cm) |
|---|---|
| 15 | 3 |
| 39 | 1-3 discontinuous |
| 46 | 6 |
| 61 | 2-3 |
| 66 | 2-7 |
| 110-115 | 4 or 5/ 0.5 each |
| 140-150 | 5-7 |
| 340 | 8 |
| 360 | 7 |
| 367 | 5-7 Yellowish granular firn |

Date: 2 July, 1967

APPENDIX B-16.--Lemon Glacier Data, 1967. Test Pit 1: Continuous Vertical Density Profile and Cumulative Water Equivalence. Location: Approx. Elev. 4050 ft. at Crest of Glacier.

| Depth Interval (cm) | Density (g/cc) | Cum $H_2O$ Eq. (cm) |
|---|---|---|
| 0-20 | .64 | 12.8 |
| 20-40 | .57 | 24.2 |
| 40-60 | .62 | 36.6 |
| 60-80 | .57 | 48.0 |
| 80-100 | .56 | 59.2 |
| 100-120 | .53 | 69.8 |
| 120-140 | .58 | 81.4 |
| 140-160 | .60 | 93.4 |
| 160-180 | .61 | 105.6 |
| 180-200 | .63 | 118.2 |
| 200-220 | .58 | 129.8 |
| 220-240 | .59 | |
| 240-260 | .60 | |

Stratigraphy

| Depth from Surface (cm) | Ice Lens Thickness (cm) |
|---|---|
| 189 | 2 |
| 214 | 2 |
| 216 | 6, Yellowish firn (1965-66 surface) |
| 254 | Possible 1964-65 surface? |

Date: 3 August, 1967

APPENDIX B-17.--Lemon Glacier Data, 1967. Test Pit 1: Continuous Vertical Density Profile and Cumulative Water Equivalence; Location: Approx. Elev. 4050 ft. at Crest of Glacier.

| Depth Interval (cm) | Density (g/cc) | Cum. $H_2O$ Eq. (cm) |
|---|---|---|
| 0-20 | .59 | 11.8 |
| 20-40 | .58 | 23.4 |
| 40-60 | .62 | 35.8 |
| 60-74 | .65 | 48.8 |
| 20 cm. spl. from 1965-66 snowpack | .60 | |
| 20 cm. spl. from 1964-65 snowpack | .62 | |

Stratigraphy

| Depth from Surface (cm) | Ice Lens Thickness (cm) |
|---|---|
| 50 | 1-3 |
| 74 | 7 cm. yellowish, granular firn, with 2 cm. ice at 75 cm. depth 1966 Ablation surf. |
| 115 | 2-3 cm. yellowish, granular firn, with 1 cm.ice 1965 Ablation surf. |

Date: 24 August, 1967

APPENDIX B-18.--Lemon Glacier Data, 1967. Test Pit 4(E): Continuous Vertical Density Profile and Cumulative Water Equivalence. Location--Approx. Eleva. 3850 ft. at Intermediate névé of Glacier

| Depth Interval (cm) | Density (g/cc) | Cum. $H_2O$ Eq. (cm) |
|---|---|---|
| 0-20 | .51 | 10.2 |
| 20-40 | .55 | 21.2 |
| 40-60 | .61 | 33.4 |
| 60-80 | .56 | 44.6 |
| 80-100 | .60 | 56.6 |
| 100-120 | .60 | 68.6 |
| 120-140 | .60 | 80.6 |
| 140-160 | .62 | 93.0 |
| 160-180 | .68 | 106.6 |
| 180-200 | .57 | 118.0 |
| 200-220 | .55 | 129.0 |
| 220-240 | .59 | 140.8 |
| 240-260 | .60 | 152.8 |
| 260-280 | .58 | 164.4 |
| 280-300 | .55 | 175.4 |
| 300-320 | .57 | 186.8 |
| 320-340 | .56 | 198.0 |
| 340-360 | .56 | 209.0 |
| 360-380 | .62 | 221.6 |
| 380-400 | .58 | 233.2 |
| 400-420 | .61 | 245.4 |
| 420-440 | .56 | |

Stratigraphy

| Depth from Surface (cm) | Ice Lens Thickness (cm) |
|---|---|
| 50 | 7 |
| 66 | 3 |
| 110 | 1-4 Discontinuous |
| 156 | 3 |
| 223-240 | 3 Lenses of 2 cm |
| 425 | 5-7 cm of yellowish, granular firn |

Date: 12 July, 1967

APPENDIX B-19.--Lemon Glacier Data, 1967. Test Pit 5(B): Continuous Vertical Density Profile and Cumulative Water Equivalence. Location: Approx. Elev. of 3675 ft. on lower névé.

| Depth Inter. (cm) | Density (g/cc) | Cum. $H_2O$ Eq. (cm) |
|---|---|---|
| 0-20 | .54 | 10.8 |
| 20-40 | .55 | 21.8 |
| 40-60 | .56 | 33.0 |
| 60-80 | .56 | 44.2 |
| 80-100 | .58 | 55.8 |
| 100-120 | .62 | 68.2 |
| 120-140 | .58 | 79.8 |
| 140-160 | .52 | 90.2 |
| 160-180 | .56 | 101.4 |
| 180-200 | .55 | 112.4 |
| 200-220 | .60 | 124.4 |
| 220-240 | .56 | 135.6 |
| 240-260 | .58 | 147.2 |
| 260-280 | .56 | 158.4 |
| 280-300 | .57 | |

Stratigraphy

| Depth from Surface (cm) | Ice Lens Thickness (cm) | |
|---|---|---|
| 32 | 1-2 | Discontinuous |
| 92 | 1-4 | |
| 115 | 1-7 | |
| 142 | 1-3 | |
| 211 | 2 | |
| 275 | 10 | Yellowish, granular, firn |

Date: 28 July, 1967

APPENDIX B-20.--Ptarmigan Glacier Data. Test Pit A: Location--Upper Ptarmigan névé at approx. 4000 ft.; Conditions--25 cm. of New Powder Snow above Wind-Packed Surface; Ambient Temp -7 to -9°C: CAVU with Light Wind.

Snow-Pack Temperatures (Depths from Top of Powder Snow Surface);

| Depth (cm) | Temperature (°C) |
|---|---|
| 30 | -14.5 |
| 60 | -14.5 |
| 90 | -13 |
| 120 | -11 |
| 150 | - 9.5 |
| 180 | - 8.5 |
| 210 | - 7.5 |
| 240 | - 7.5 |
| ca. 600* | - 4 |
| ca. 700* | - 3 |

Continuous Vertical Density Profile and Cumulative Water Equivalence:

| Depth Interval (cm) | Density (g/cc) | Cum. $H_2O$ Eq. (cm) |
|---|---|---|
| 0-20** | .43 | 8.6 |
| 20-40 | .41 | 16.8 |
| 40-60 | .34 | 23.6 |
| 60-80*** | .34 | 30.4 |
| 80-100 | .36 | 37.6 |
| 100-120 | .38 | 45.2 |
| 120-140 | .37 | 52.6 |
| 140-160 | .41 | 60.8 |
| 160-180 | .41 | 69.0 |
| 180-200 | .43 | 77.6 |
| 200-220 | .49 | 87.4 |
| ca. 620-650**** | .49 | -- |

*These temperatures were measured in 7.62 cm (3 in.) hand augered cores immediately after they were brought to the surface.

**Measured from top of wind-packed surface.

***A 1 cm. ice lens occurred at a depth of 66 cm.

****Determined from a core obtained by hand augering. The core contained three 1-cm. ice lenses.

Further notes on Site A:

A 2-3 cm. "dirty layer" was found in a coarse-granular snow-ice core recovered from an approximate depth of 620-650 cm. below the wind-packed surface. This dirty layer is believed to mark the 1966 summer ablation surface.

An accumulation stake with 220 cm. above the surface was placed near the test-pit (Stake marked "A").

Date collected: 29 March, 1967.

APPENDIX B-21.--Ptarmigan Glacier Data. Test Pit C--Location: Upper Ptarmigan névé at approx. 3800 ft. Conditions: Wind-Packed Surface; Ambient Temperature -19°C, CAVU with 15-20 kt. Winds.

Snow-Pack Temperatures

| Depth (cm) | Temperature (°C) |
|---|---|
| 20 | - 14 |
| 40 | - 10 |
| 60 | - 9 |
| 80 | - 8 |
| 100 | - 6.5 |
| 120 | - 6 |
| 140 | - 5.5 |
| 160 | - 5 |
| 180 | - 4.5 |
| 200 | - 4.5 |
| 220 | - 4 |
| 240 | - 4 |
| 260 | - 3.5 |
| 280 | - 3 |
| 300 | - 3 |
| 320 | - 2.5 |
| 340 | - 2 |
| 360 | - 2 |
| 369 (glacier ice) | - 1.5 |

Further Notes on Site C:

At approx. 5 meters south of Test Pit C, a Swiss Ram Penetrometer encountered glacier ice at a depth of 364 cm. Ice was also recovered from a core obtained with a hand driven 7.62 cm (3 in.) S.I.P.R.E. corer.

Data collected: 25 March, 1967

S.I.P.R.E. Coring Results: 30 March, 1967

(1) Location--200 meters west of Test Pit C, 3750 ft. elev. Ice encountered in core @ 380-400 cm. from wind-packed surface (20-25 cm. powder snow above that surface)

(2) Location--200 to 250 meters east of Test Pit C, 3850 ft. elev. Greater than 4.5 meters of snow since beginning of 1966-67 accumulation season (drilling terminated because of difficulty lifting equipment back to surface). Fifteen cm. of new powder snow at this site.

APPENDIX B-22.--Ptarmigan Glacier Data. Test Pit: Upper névé of glacier, 10 m SE of ablation stake #7, elev. 1265 m (4150 ft). Continuous vertical density profile and cumulative water equivalence.

| Depth Interv. (cm) | Density (g/cc) | Cum. $H_2O$ Eq. (cm) |
|---|---|---|
| 0-20 | .56 | 11.2 |
| 20-40 | .58 | 22.8 |
| 40-60 | .61 | 35.0 |
| 60-80 | .60 | 47.0 |
| 80-100 | .59 | 58.8 |
| 100-120 | .59 | 70.6 |
| 120-140 | .61 | 82.8 |
| 140-160 | .60 | 94.8 |
| 160-180 | .61 | 107.0 |
| 180-200 | .61 | 119.2 |
| 220-240 | .61 | 131.4 |
| 240-260 | .60 | 143.4 |
| 260-271 | .60 | 155.4 |
| | .57 | 161.7 |

Stratigraphy

| Depth from Surface (cm) | Ice Lens Thickness (cm) | |
|---|---|---|
| 40 | 1-5 | |
| 168 | 1-3 | Discontinuous |
| 205 | 2 | |
| 272 | 2 | "Dirty" layer |
| 272-280 | 8 | Yellowish, granular firn |

Date: 29 July, 1967

APPENDIX C

GLACIOLOGICAL DATA, PART II

Ablation Records

APPENDIX C-1.--Lemon Glacier Data. Ablation Rates (cm/day) for Summer, 1966.

| Time Interval | Total Abl. (cm) | Rate of Abl. (cm/day) |
|---|---|---|
| Ablation Profile A: Nos. 40-46, Elev. approx. 900 Meters Stakes emplaced 19 June, 1966 | | |
| June 19-25 | 22 | 3.5 |
| 25-Jul 1 | 26 | 4.5 |
| Jul. 1-9 | 33 | 4.0 |
| 9-14 | 24 | 5.0 |
| Ablation Profile B: Nos. 60-68, Elev. approx. 950 Meters. Stakes emplaced 14 June, 1966 | | |
| June 14-19 | 34 | 7.0 |
| 19-Jul 1 | 43 | 3.5 |
| Jul. 1-9 | 33 | 4.0 |
| 9-14 | 19 | 4.0 |
| 14-22 | 54 | 7.0 |
| 22-Aug. 4 | 77 | 6.0 |
| Ablation Profile C: Nos. 80-89, Elev. approx. 1150 Meters Stakes emplaced 11 June, 1966 | | |
| June 11-19 | 41 | 5.0 |
| 19-Jul 1 | 38 | 3.0 |
| Jul. 1-14 | 45 | 3.5 |
| 14-22 | 49 | 6.0 |
| 22-Aug 4 | 77 | 6.0 |
| Aug 4-19 | 63 | 4.0 |
| 19-30 | 57 | 5.0 |

APPENDIX C-2.--Lemon Glacier Data. Ablation Rates (cm/day) for Summer, 1966.

| Time Interval | Total Abl. (cm) | Rate of Abl. (cm/day) |
|---|---|---|
| Ablation Profile D: Nos. 100-108, Elev. approx. 1215 Meters. Stakes emplaced 8 June, 1966 | | |
| June 8-17 | 47 | 5.0 |
| 17-25 | 21 | 3.0 |
| 25-Jul 5 | 34 | 3.5 |
| Jul. 5-14 | 38 | 4.0 |
| 14-19 | 27 | 5.5 |
| 19-Aug. 3 | 91 | 6.5 |
| Aug 3-18 | 60 | 4.0 |
| 18-Sept. 1 | 62 | 4.5 |
| Ablation Profile E: Nos. 110-114, Elev. approx. 1225 Meters. Stakes emplaced 15 June, 1966 | | |
| June 15-25 | 44 | 4.5 |
| 25-Jul 5 | 34 | 3.5 |
| Jul. 5-14 | 40 | 4.5 |
| 14-19 | 35 | 7.0 |
| 19-Aug. 4 | 89 | 6.0 |
| Aug 4-18 | 62 | 4.5 |
| 18-Sept. 1 | 68 | 5.0 |

APPENDIX C-3.--Lemon Glacier Data. Mean Daily Ablation Rates, June-September, 1966.

| Ablation Profile | Approx. Elev. (m) | Abl./Day (cm) |
|---|---|---|
| A (#40-46) | 900 | 4.0 |
| B (#60-68) | 950 | 5.0 |
| C (#80-89) | 1150 | 5.0 |
| D (#100-108) | 1215 | 4.5 |
| E (#110-114) | 1225 | 5.0 |

APPENDIX C-4.--Late Summer Mass Budget Measurements on Lemon Glacier, 1966.

2 Sept.--Remaining depth of previous year's accumulation:

Pit Site B - 170 cm.
Pit Site C - 80 cm.
Pit Site D - 125 cm.

7-8 Sept.--Snow storm left the following average depths of new snow (direct measurement):

| | | |
|---|---|---|
| Center of ablation profile | #100-108 | - 29 cm. |
| " " " " | #110-114 | - 10 cm.* |
| " " " " | # 80-88 | - 7 cm. |

8-14 Sept.--Ablation after snowstorm

| | | |
|---|---|---|
| Center of ablation profile | #110-114 | - 27 cm.** |
| " " " " | #100-108 | - 27 cm.*** |
| " " " " | # 80-88 | - 20 cm.**** |

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*Probably not a very reliable figure. Previous systematic measurements of the ablation stakes were made six days before the storm (1 Sept), and measurements after the storm support the conclusion that high winds both during and after actual snow fall caused extensive redistribution. Thus, actual new snow depths on the ablation surface were highly variable.

**When the area was last observed on 14 Sept., some of the "pre-snowstorm" ablation surface was exposed, but much of it was still covered by new snow.

***A thin covering of new snow remained on 14 Sept.

****New snow had completely melted a few days after the storm, so the ablation figure applies almost totally to "old snow."

APPENDIX C-5.--Lemon Glacier Data. Ice Ablation Rates from 2 August to 17 August, 1967.

| Stake No. | Elevation ft. (m) | Ablation (cm/day) |
|---|---|---|
| A | 3650 (1110) | 10.0 |
| B | 3250 (992) | 15.5 |
| C | 3175 (967) | 10.0 |

APPENDIX C-6.--Lemon Glacier Data. Ice Ablation Rates below Lemon Glacier Icefall (elev. of line of stakes approx. 2000 feet). Stakes emplaced 9 July, 1967.

| Period | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| 9 July to 19 July | 5.0 | 6.5 | 6.5 | 6.5 | 7.5 |
| 19 July to 22 July | 5.0 | 4.5 | 6.0 | | 6.0 |
| 19 July to 4 August | | | | 6.0 | |
| 22 July to 4 August | 6.5 | 6.5 | 5.0 | | 6.5 |
| 4 August to 11 August | 8.5 | 8.5 | 7.0 | 6.5 | 7.5 |
| 11 August to 23 August | 5.5 | 5.5 | 5.0 | 5.0 | 6.0 |
| 23 August to 4 Sept | 6.0 | 6.0 | 5.5 | 6.0 | 7.0 |

NOTE: Stake No. 3 was in clear, blue ice; others were in "bubbly glacier ice".

Measurements given in centimeters/day.

APPENDIX C-7.--Lemon Glacier Ablation Data. Ablation Rates of Snow (cm/day) for Summer, 1967.

| Time Interval | 26 May to 11 June | 11 June to 18 June | 1 July | 8 July to 23 July | 23 Jul to 3 Aug | 3 Aug to 16 Aug | 16 Aug to 30 Aug | 30 Aug to 11 Sept |
|---|---|---|---|---|---|---|---|---|
| Stake No. | | | | | | | | |
| 1 (1260 m) | 3.5 | 5.5 | 4.0 | 4.5 | 5.0 | 7.0 | 7.0 | |
| 1B | | | | | 5.0 | 6.5 | 6.5 | |
| 1A | 3.5 | 5.5 | 3.0 | 4.5 | 5.5 | 6.0 | 7.0 | |
| 2 | | | | 4.5 | 5.0 | 6.0 | 6.5 | |
| 2A | 4.0 | 6.5 | 3.5 | 4.5 | 5.0 | 6.0 | | |
| 3A | 3.5 | 6.0 | 4.0 | 4.5 | 5.0 | 6.0 | 6.5 | |
| 4B | 3.5 | 5.5 | 4.0 | 4.5 | 5.0 | 6.0 | 6.0 | 4.5* |
| 4C | | | | 4.0 | 5.0 | 6.0 | 6.0 | 4.5 |
| 4D | | | | 4.0 | 5.0 | 6.0 | 5.5 | 5.0 |
| 4E (1175 m) | | | | 4.5 | 5.0 | 5.5 | 5.5 | 5.0** |
| 4F | | | | 4.5 | 5.0 | 6.0 | 5.5 | |
| 4G | | | | 4.5 | 5.5 | 6.0 | | |
| 4H | | | | 4.5 | 5.5 | 6.0 | 6.0 | |
| 4I | | | | | | 6.0 | 5.5 | |
| 5 (1125 m) | 4.0 | 5.5 | 5.5 | 4.5 | 5.5 | 6.0 | 5.5 | |
| 5A | | | | 4.5 | 4.5 | 5.5 | 5.5 | |
| 5B | | | | 4.5 | 4.5 | 5.5 | 5.5 | |
| 5C | | | | 4.5 | | 5.5 | 6.0 | |
| 5D (1090 m) | | | | 4.5 | 4.5 | 5.5 | 6.0 | |
| 6 | 4.0 | 5.5 | 5.0 | | | | | |
| 7 | | 7.0 | 5.5 | | | | | |
| 7A | | 6.5 | 5.0 | | | | | |
| 8 | 3.5 | 8.0 | 5.5 | | | | | |

* 35 cm. of 1966-67 snow remained on 11 Sept.
**125 cm. of 1966-67 snow remained on 11 Sept.

APPENDIX C-8.--Lemon Glacier Data. Total Monthly Snow Ablation.

| Date | Elevation | | |
|---|---|---|---|
| | 1140 m. (3750 ft.) | 1205 m. (3950 ft.) | 1235 m. (4050 ft.) |
| 1967 | | | |
| July | 157 | 149 | 141.5 |
| August | 183.5 | 216 | 211 |
| 1966 | | | |
| July | 163 | 175 | 165 |
| August | 153 | 146.5 | 157 |

Figures in centimeters.

APPENDIX C-9.--Ptarmigan Glacier Data. Ablation Rates (cm/day) for Summer, 1966.

Ablation Profile A: 3 stakes, elev. approx. 3400' (1035 m)

| Stake No. | 10 | 11 | 12 |
|---|---|---|---|
| Time Interval | | | |
| June 21-25 | 3.5 | 3.5 | 3.5 |
| June 25-July 2 | 4.0 | 4.5 | 3.5 |
| July 2-10 | 4.0 | 4.0 | 3.5 |

Ablation Profile B: 4 stakes, elev. approx. 3800-3900' (1160-1190 m)

| Stake No. | 20 | 21 | 22 | 23 |
|---|---|---|---|---|
| Time Interval | | | | |
| June 12-17 | | 1.0 | 1.0 | 1.0 |
| June 17-21 | 11.5 | 9.0 | 10.0 | |
| June 21-25 | | 3.5 | 4.0 | |
| June 25-July 2 | 2.5 | 3.0 | 3.0 | 2.0 |
| July 2-10 | 4.5 | 3.5 | 4.0 | 3.5 |

Ablation Profile C: 3 stakes, elev. approx. 3900-4100' (1190-1250 m)

| Stake No. | 30 | 31 | 32 |
|---|---|---|---|
| Time Interval | | | |
| June 21-25 | 3.0 | 3.0 | 3.5 |
| June 25-July 3 | 4.0 | 4.5 | 4.0 |
| July 3-10 | 3.5 | | 3.5 |

APPENDIX C-10.--Total Firn Ablation on Lemon Glacier.

| Time | Elevation | | |
|---|---|---|---|
| | 1140 m (3750 ft) | 1205 m (3950 ft) | 1235 m (4050 ft) |
| 1965 | | | |
| July 8-31 | 105 | 120 | |
| August 1-12 | 63 | | |
| 1966 | | | |
| July | 163 | 175 | 165 |
| August | 153 | 146.5 | 157 |
| Sept. 8-14 | 20 | 27 | 27 |
| 1967 | | | |
| July | 157 | 149 | 141.5 |
| August | 183.5 | 216 | 211 |
| Sept. 1-15 | | 71.5 | |

All figures in centimeters.

APPENDIX C-11.--Firn Ablation Rates vs Factors Affecting Ablation on Lemon Glacier.

| | Rate of Ablation (cm/day)* | Mean Daytime Temp. (°F) | Mean Daily Rad'n (cal/cm$^2$) | Average Daily Cloudiness (%) |
|---|---|---|---|---|
| 1965 | | | | |
| July 7-31** | 4.52 | 47 | 382 | 60 |
| Aug. 1-12** | 5.24 | 48 | 355 | 60 |
| 1966 | | | | |
| July | 5.42 | 44.5 | 396 | 75 |
| August | 4.90 | 40 | 240 | 81 |
| Sept. 8-14 | 4.15 | 39.5 | 241 | 74 |
| 1967 | | | | |
| July | 4.82 | 41.5 | 410 | 84 |
| August | 6.57 | 44 | 255 | 74 |
| Sept. 1-11*** | 4.75 | 38 | 127 | 90 |

*Average rate over elevation range 1140 m - 1235 m unless otherwise noted.

**Average rate over elevation range 1100 m - 1200 m.

***Average rate over elevation range 1175 m - 1200 m.

# APPENDIX D

## GLACIOLOGICAL DATA, PART III

### Rammsonde Profiles

## APPENDIX D-1

Sites and Dates of 1966-1967 Rammsonde Records (See Figs. 13, 14, 15).

**1966 -- Ptarmigan Glacier**

June 7 and 17 - 4 sites on a line E-W west from C-17

June 25 - 3 sites on a longitudinal profile on lower névé

**Lemon Glacier**

June 9, 19, 27
July 5, 12
August 4, 25 - 7 sites on a longitudinal profile from elevation 3200 ft. to elevation 4000 ft.

**1967 -- Ptarmigan Glacier**

January 24 - 1 site on upper névé

March (24-30) - 1 site on upper névé

**Lemon Glacier**

January 24 - 3 sites on upper névé

March (24-30) - 3 sites from upper to lower névé

June 13
July 24
August 24 - 1 site (stake #1) on upper névé

Original records on file at the Foundation for Glacier and Environmental Research.

# APPENDIX E

## HYDROLOGICAL DATA

(1965-67 Summer Discharge Records from the Lemon Creek Gaging Station; Juneau Icefield, Alaska)

## APPENDIX E-1

Information on Lemon Creek near Juneau, Alaska (from U.S. Geological Survey Surface Water Records of Alaska):

Gage Location -- on left bank ¼ mile upstream from Canyon Creek, 4½ miles upstream from mouth, and 6 miles north of Juneau.

Drainage Area -- 12.1 sq. miles

Records Available -- August 1951 to November 1953, and July 1954 to September 1967.

Gage -- Water-stage recorder, elevation of gage 650 ft.

Average Discharge -- 14 years (to 1965), 156 cfs (112,900 acre-ft./yr.)

Extremes -- Maximum discharge, 2,800 cfs on 13 August 1961; minimum not determined.

Remarks -- Records good except for periods of no gage-height record and those for winter months, which are poor. Large diurnal fluctuation caused by glacier melt at the source.

APPENDIX E-2.--Discharge of Lemon Creek, in Cubic Feet Per Second, 1965.

| Day | May | June | July | Aug. | Sept. |
|---|---|---|---|---|---|
| 1 | 27 | 185 | 348 | 416 | 555 |
| 2 | 40 | 205 | 404 | 370 | 505 |
| 3 | 29 | 141 | 464 | 334 | 520 |
| 4 | 26 | 172 | 560 | 303 | 432 |
| 5 | 20 | 192 | 476 | 320 | 362 |
| 6 | 21 | 129 | 373 | 334 | 472 |
| 7 | 26 | 125 | 424 | 352 | 565 |
| 8 | 22 | 163 | 480 | 380 | 436 |
| 9 | 17 | 236 | 460 | 373 | 348 |
| 10 | 16 | 198 | 432 | 388 | 289 |
| 11 | 17 | 266 | 428 | 460 | 248 |
| 12 | 16 | 198 | 416 | 396 | 227 |
| 13 | 16 | 143 | 432 | 282 | 205 |
| 14 | 16 | 143 | 468 | 227 | 175 |
| 15 | 18 | 168 | 392 | 310 | 151 |
| 16 | 25 | 257 | 328 | 384 | 202 |
| 17 | 28 | 266 | 278 | 565 | 257 |
| 18 | 27 | 188 | 248 | 525 | 392 |
| 19 | 33 | 185 | 239 | 535 | 515 |
| 20 | 42 | 182 | 248 | 460 | 917 |
| 21 | 51 | 141 | 266 | 356 | 620 |
| 22 | 50 | 127 | 356 | 376 | 530 |
| 23 | 53 | 175 | 352 | 370 | 444 |
| 24 | 57 | 190 | 488 | 342 | 540 |
| 25 | 91 | 159 | 366 | 296 | 338 |
| 26 | 112 | 151 | 286 | 224 | 239 |
| 27 | 120 | 151 | 356 | 198 | 218 |
| 28 | 147 | 180 | 392 | 195 | 266 |
| 29 | 137 | 185 | 388 | 266 | 185 |
| 30 | 124 | 239 | 396 | 819 | 165 |
| 31 | 161 | | 396 | 668 | |
| TOTAL | 1,585 | 5,440 | 11,940 | 11,824 | 11,318 |
| Mean | 51.1 | 181 | 385 | 381 | 377 |

APPENDIX E-3.--Discharge of Lemon Creek, in Cubic Feet per Second, 1966.

| Day | May | June | July | Aug. | Sept. |
|---|---|---|---|---|---|
| 1 | 23 | 71 | 230 | 656 | 480 |
| 2 | 54 | 108 | 254 | 656 | 359 |
| 3 | 52 | 205 | 233 | 535 | 310 |
| 4 | 39 | 251 | 210 | 448 | 752 |
| 5 | 63 | 230 | 200 | 412 | 492 |
| 6 | 88 | 251 | 210 | 404 | 345 |
| 7 | 119 | 272 | 221 | 424 | 275 |
| 8 | 118 | 292 | 233 | 460 | 208 |
| 9 | 77 | 263 | 266 | 540 | 200 |
| 10 | 57 | 224 | 260 | 428 | 159 |
| 11 | 82 | 208 | 266 | 412 | 161 |
| 12 | 76 | 202 | 251 | 362 | 149 |
| 13 | 61 | 178 | 260 | 362 | 300 |
| 14 | 57 | 185 | 310 | 570 | 428 |
| 15 | 45 | 198 | 373 | 496 | 420 |
| 16 | 44 | 370 | 472 | 448 | 432 |
| 17 | 46 | 404 | 448 | 535 | 342 |
| 18 | 53 | 345 | 436 | 456 | 306 |
| 19 | 51 | 334 | 440 | 396 | 510 |
| 20 | 45 | 257 | 424 | 505 | 328 |
| 21 | 37 | 230 | 420 | 452 | 352 |
| 22 | 42 | 202 | 416 | 359 | 221 |
| 23 | 37 | 180 | 480 | 877 | 248 |
| 24 | 30 | 168 | 535 | 945 | 352 |
| 25 | 27 | 165 | 540 | 540 | 388 |
| 26 | 27 | 178 | 464 | 370 | 692 |
| 27 | 30 | 192 | 535 | 352 | 560 |
| 28 | 27 | 205 | 668 | 303 | 468 |
| 29 | 31 | 200 | 620 | 263 | 373 |
| 30 | 39 | 192 | 565 | 296 | 656 |
| 31 | 56 | | 605 | 452 | |
| TOTAL | 1,633 | 6,760 | 11,845 | 14,714 | 11,266 |
| Mean | 52.7 | 225 | 382 | 475 | 376 |

APPENDIX E-4.--Discharge of Lemon Creek, Cubic Feet per Second, 1967.*

| Day | May | June | July | Aug. | Sept. |
|---|---|---|---|---|---|
| 1 | 38 | 161 | 380 | 448 | 550 |
| 2 | 41 | 159 | 356 | 540 | 854 |
| 3 | 43 | 163 | 331 | 448 | 764 |
| 4 | 39 | 163 | 366 | 392 | 476 |
| 5 | 41 | 172 | 370 | 352 | 384 |
| 6 | 33 | 155 | 328 | 334 | 370 |
| 7 | 30 | 145 | 408 | 359 | 484 |
| 8 | 35 | 163 | 338 | 635 | 630 |
| 9 | 45 | 190 | 286 | 791 | 610 |
| 10 | 68 | 198 | 266 | 640 | 400 |
| 11 | 66 | 208 | 320 | 605 | 282 |
| 12 | 63 | 230 | 359 | 464 | 480 |
| 13 | 61 | 272 | 359 | 468 | 662 |
| 14 | 68 | 324 | 345 | 505 | 1030 |
| 15 | 96 | 436 | 362 | 456 | 1080 |
| 16 | 82 | 373 | 362 | 359 | 698 |
| 17 | 80 | 420 | 314 | 356 | 662 |
| 18 | 76 | 452 | 286 | 388 | 996 |
| 19 | 58 | 432 | 260 | 625 | 777 |
| 20 | 71 | 432 | 342 | 746 | 384 |
| 21 | 102 | 404 | 432 | 752 | 251 |
| 22 | 76 | 384 | 408 | 550 | 215 |
| 23 | 67 | 388 | 448 | 408 | 370 |
| 24 | 66 | 428 | 412 | 338 | 236 |
| 25 | 68 | 400 | 356 | 595 | 245 |
| 26 | 71 | 376 | 356 | 662 | 334 |
| 27 | 92 | 472 | 515 | 610 | 362 |
| 28 | 125 | 570 | 580 | 480 | 227 |
| 29 | 135 | 510 | 468 | 535 | 165 |
| 30 | 163 | 448 | 356 | 540 | 145 |
| 31 | 149 | | 396 | 590 | |

*These are provisional records as of 15 January, 1968, provided by U.S. Geological Survey at Juneau, Alaska.


TESLIN
ATLIN
SKAGWAY
HAINES
JUNEAU
GUSTAVUS
HOONAH
GLACIER BAY
LYNN CANAL
EDMONTON FIR
COUGHLAN ISLAND
POINT RETREAT
HAWK INLET
SISTERS ISLAND
HAYES PEAK
MENATATULINE RANGE
50
90
100
110
120
130
140
180
170
200
150
190
160
80
70

FIG. 33

# Glaciers in the Lemon Creek Valley, Alaska

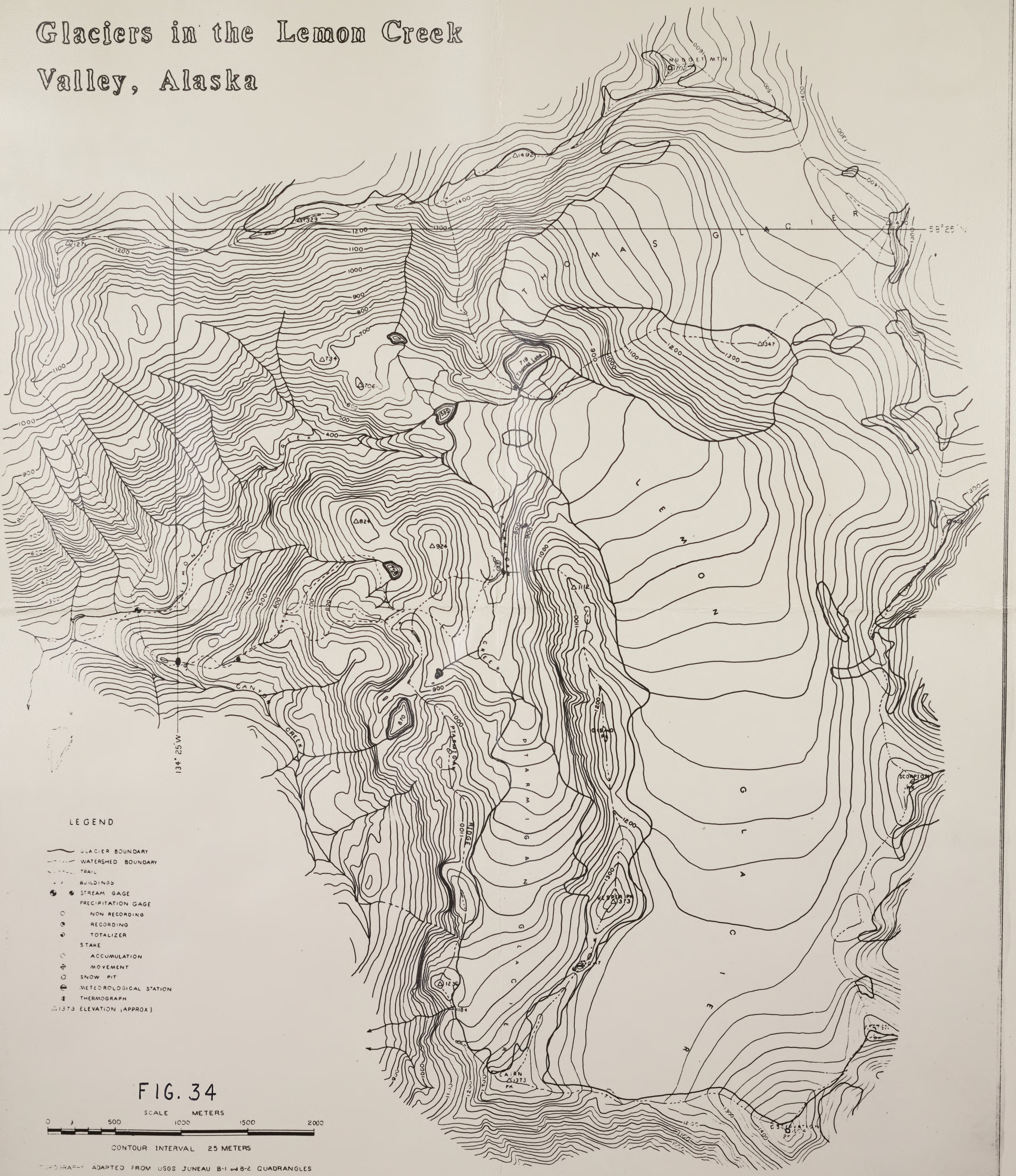


FIG. 34