Research Paper 31-B

Icefield Ranges Climatology Program St. Elias Mountains 1964

PART II
PRESENTATION AND ANALYSIS OF RADIATION DATA

PART III
PRESENTATION AND ANALYSIS OF ABLATION DATA
(U)

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Research Paper 31-B

ICEFIELD RANGES RESEARCH PROJECT
ST. ELIAS MOUNTAINS, 1964

Part II
Presentation and Analysis of Radiation Data

Part III
Presentation and Analysis of Ablation Data

by

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June 1968

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Preface

Environmental studies of the St. Elias Mountains, Yukon Territory, Canada, and surrounding district were initiated by the Icefield Ranges Research Project in 1961 under joint sponsorship of the Arctic Institute of North America and the American Geographical Society. During the summer field seasons of 1961 through 1964, research was carried out in such interrelated earth sciences as glaciology, glacial geology, photogrammetry, sedimentology, and geophysics. An integral and important phase of the larger research program was concentrated in climatological and meteorological research, particularly in terms of regional climatology and the operation of a weather station network.

During the summer field seasons of 1961 and 1962, before a regular climatology team was a part of the Icefield Ranges Research Project, field personnel carried out reconnaissance meteorological observations in the region. In 1963, with support from the Earth Sciences Division, Quartermaster Research and Engineering Command, U.S. Army, a meteorology program was initiated under the direction of James N. Haven, U.S. Army Natick Laboratories. Weather stations were operated at Kluane Lake Base Camp and at Divide Station during that field season.

In 1964, the climatology program was expanded to include four manned weather stations and four automatic stations. Six workers constituted the basic observational team under the direction of Melvin G. Marcus, and seven other project personnel participated on a part-time basis. The basic objectives of the program were to begin the development of a climatological profile of the St. Elias Mountains and all phases of the operation were supported by the Polar and Mountain Section, Earth Sciences Division, Quartermaster Research and Engineering Command, United States Army Natick Laboratories, Natick, Massachusetts, under Contract DA19-129-AMC-312(N). A presentation of the data obtained is Part I of this report (Icefield Ranges Climatology Program, St. Elias Mountains, 1964; Part I: Data Presentation, Arctic Institute of North America Research Paper 31-A, February, 1965).

Early in the 1964 field season, it was recognized that the climatology team would be able to make rudimentary radiation, micrometeorological, and ablation measurements. It was also realized that these observations would not be as sophisticated as we might have wished, due to limited instrumentation. In view of the general lack of such climatic information for high mountain areas, it was decided that the effort would be worthwhile even under limiting circumstances. Parts II and III of this report (Research Paper 31-B) summarize the supplementary programs.

Mr. Tony Brazel, who has analyzed the data and written Parts II and III, has, therefore, had to work under less than ideal conditions. I believe, however, that he has optimized the results of the 1964 supplementary program and provided us with data and conclusions of value to other research workers operating under the Icefield Ranges Research Project in particular and in the St. Elias Mountains in general.

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Part II

PRESENTATION AND ANALYSIS OF RADIATION DATA

ICEFIELD RANGES CLIMATOLOGY PROGRAM
ST. ELIAS MOUNTAINS, 1964
PART II
PRESENTATION AND ANALYSIS OF RADIATION DATA

Introduction

Broad scale mountain barrier effects and local topographic influences are two of the most important factors in glacio-climatological studies.[1] It is common knowledge to climatologists that mountain masses influence regional precipitation patterns and temperature distributions on both flanks of a range. In general, the effect of relief on regional precipitaion and temperature regimes depends on elevation above sea level, relative slope, exposure, and valley orientation and configuration.[2] This effect, though it has been recognized, has been neither easily measured nor even adequately observed, since considerable variation of weather elements occurs across a range. The variation tends to confuse any distinct elevational relationships.

A transect across any mountain range reveals many irregularities in the terrain, and this partially explains the variability in weather conditions in the lower layers of the atmosphere near the earth-air interface. The nature of the interface, type of surface (e.g., snow, bare soil, meadowland), its extent (areal homogeneity), and its physical characteristics (reflectivity, absorptivity, and transmissivity), also varies considerably across

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[1] "Broad scale" and "local" are here loosely defined. Broad scale refers to the scale of air mass climatology (macroscale analysis); local connotes an intermediate scale (mesoscale) between microclimatic and macroclimatic. An example of broad scale is the effect of the Pacific West Coast Mountains in North America on the precipitation regime along the Pacific littoral. An illustration of "local" is the influence of topography on wind patterns over a small area. Anabatic and katabatic winds are diurnal flows primarily caused by the nature of the topography with respect to the sun. See, for example, Buettner and Thyer, "Valley Winds in the Mount Rainer Area," <u>Archiv. fur Mete., Geophy., und Bioklim.</u>, XIV (No. 2, 1966), 125-147.

[2] See, for example, Spreen, "A Determination of the Effect of Topography Upon Precipitation," <u>Transactions, American Geophysical Union,</u> XXVIII, No. 2, 1947, p. 285

a range and plays a significant role in the variation in energy exchange.

Local influences must necessarily be considered in the study of climate-glacier relationships.[1] Exactly how and why a glacier reacts to short-term and long-term climatic variations has long been a topic of concern and these questions remain a basic issue. Explanations are partially masked in the complexity of influences operating at local and broad scales. The study of the distribution, intensity, and sources of energy contributing to glacier responses is a key to understanding the climate-glacier interaction. As Hoinkes has pointed out:

> "The relative importance of... sources of energy must be known at least in order of magnitude before one can hope to find a physically reasonable correlation between the behavior of the glaciers and the oscillations of climate."[2]

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[1] Larsson, for the Chamberlain Glacier (a valley glacier), notes that in the lower layers of the atmosphere (including meteorological screen level) the effects of surface composition and configuration cannot be ignored. Daily temperature ranges reflect local conditions. Larsson, "A Preliminary Investigation of the Meteorological Conditions on the Chamberlain Glacier, 1958," Research Paper No. 2 (Washington: Arctic Institute of North America, 1960), p. 33. Marcus, for the St. Elias Mountains, indicates that local variations of temperature over small regions must be understood before extrapolations and estimates can be made in determining climate-glacier interactions. Nunatak site temperatures were found to generally represent regional air mass regimes, but temperatures recorded over glacier surfaces varied sharply from nunatak values and cannot be employed as estimations of air mass temperatures across the range. Conversely, nunatak temperatures are not accurate approximations of the temperatures over glacier surfaces. Marcus, "Summer Temperatures Relationships Along a Transect in the St. Elias Mountains; Alaska and Yukon Territory," Man and Earth, Series in Earth Sciences, (Boulder: University of Colorado Press, 1965), pp. 15-30.

[2] Hoinkes, "Measurements of Ablation and Heat Balance on Alpine Glaciers," Journal of Glaciology, II, No. 2, 1955, p. 498.

Many past investigations have attempted to determine climatological variables and energy components responsible for glacier wastage.[1] The energy components - radiation (short and long wave), convection, conduction, and latent heat exchange (evaporation and condensation) - all have been examined in the context of climate-glacier interaction, i.e., energy transfer to and from the glacier surface. Preliminary results indicate that marine glacier environments and low elevational zones are predominantly related to advective processes. More remote and higher elevation snow fields are primarily controlled by radiative transfer mechanisms. Hence, climate-glacier relationships, as reflected in the controlling heat budget terms, have been hypothesized and a general model of climate-glacier interaction has been formulated.

However, energy relations over glacier surfaces are as yet not adequately understood. Moreover, meteorological observations have been obtained mostly by the methods of extrapolation from remote sites away from the glacier surface, or from only one or two glacier camp stations. On the other hand, ablation measurements have attained a sophisticated level; over many glaciers large ablation stake networks are established. In order to compare ablation with weather, one must assume that climatic conditions over the network are similar to those measured at the one or two meteorological stations.

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[1] See, for example, Sverdrup, "The Ablation on Isachen's Plateau and on the Fourteenth of July Glacier in Relation to Radiation and Meteorological Conditions," Geografiska Annaler, XXVII (1935), 145-166; Wallen, "Glacial-Meteorological Investigations on the Karsa Glacier in Swedish Lapland: 1942-48," Geografiska Annaler, XXX (1948), 451-672; Orvig, "Glacial-Meteorological Observations on Icecaps in Baffin Island," Geografiska Annaler, XXXVI (1954), 193-318; Hubley, "An Analysis of Surface Energy During the Ablation Season on Lemon Creek Glacier, Alaska," Transactions, American Geophysical Union, XXXVIII (February, 1957), 68-85; Lister and Taylor, "Heat Balance and Ablation on an Arctic Glacier," Medd. om Grønland, Band 158, #7 (1961), 55 pp.; and Keeler, "Relationship Between Climate, Ablation, and Run-off on the Sverdrup Glacier, 1963 Devon Island, N. W. T.," Research Paper 27 (Washington, Arctic Institute of North America, 1964), 80 pp.

The receipt of incoming radiation (global radiation)[1] over a glacier surface varies with the irregularities in the topography and slope aspect with respect to the sun,[2] as well as with elevation above sea level, atmospheric vapor and particles, and overlying cloud layers. The angles which the sun makes with various points on a glacier (and on nearby slopes) during the course of the diurnal and seasonal solar cycle becomes of critical importance the more rugged and irregular the terrain. Extrapolations and/or assumed areal homogeneity of incoming radiation (measured from sites neither located near glacier environments nor situated across or down glacier valleys within glacier environments) will most likely be very unrepresentative of actual radiation transfer in a glacier-strewn mountainous region.

A comparison of short wave incoming radiation between two sites within the confines of the St. Elias Mountain Region in the Yukon Territory, when considered under similar and diverse weather conditions, indicates that not only do elevation and atmospheric transmissivity account for differences, but that site characteristics and local climate are important and can not be disregarded. As indicated by the station comparisons, the role of local influences on the energy exchange is significant.

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[1] Global radiation is defined as the sum of direct solar radiation (not reflected by clouds, absorbed by the atmosphere, or scattered diffusely) and nondirectional sky radiation or diffuse radiation (reaching the surface by multiple reflection).

[2] See, for example, Hoeck, "Influence of Radiation and Temperature on Melting Process of the Snow Cover," Beitrage zur Geologie der Schweiz, Geotechnische Serie, Hydrologie, Lieferung 8, 1952, 1-36, (Translated into English by K. Martinoff of USA SIPRE Bibliography Project, Library of Congress - translation #49, January, 1958); and Geiger, The Climate Near the Ground, (Cambridge, Mass.: Harvard University Press, 1965), pp. 369-374.

IRRP Operations in Icefield Ranges

The Icefield Ranges Research Project (IRRP), a project sponsored jointly by the Arctic Institute of North America and the American Geographical Society, established during the summer months of 1964 a weather network across the glacier-laden St. Elias Mountain Range in the southwest part of the Yukon Territory, Canada.[1] The network was arranged in a linear fashion, representing a transect perpendicular to the longitudinal axis of the mountain range. An accompanying map (Fig. 1) locates all camp sites established in the region during past field seasons. The main purpose of the network was the development of a trans-mountain climatological profile from the drier continental interior to the more moist marine coastal zone.

Prior to 1964, glacier investigations in this region were conducted during the summers of 1948-49 and 1961-63. The first glaciological team effort in the St. Elias Mountains occurred in 1948 on the Upper Seward and Malaspina Glaciers. The Arctic Institute of North America (under the support of the Office of Naval Research, the American Alpine Club, and the California Institute of Technology) initiated scientific work under the project name of "Snow Cornice". A study was made of ablation and accumulation for the purpose of estimating the mass budget of the Seward-Malaspina system.[2] During the summer seasons of 1961 and 1962, preliminary glaciological and meteorological investigations were made under IRRP at the Divide area; Kluane Base Camp was established as a logistical supporting station.

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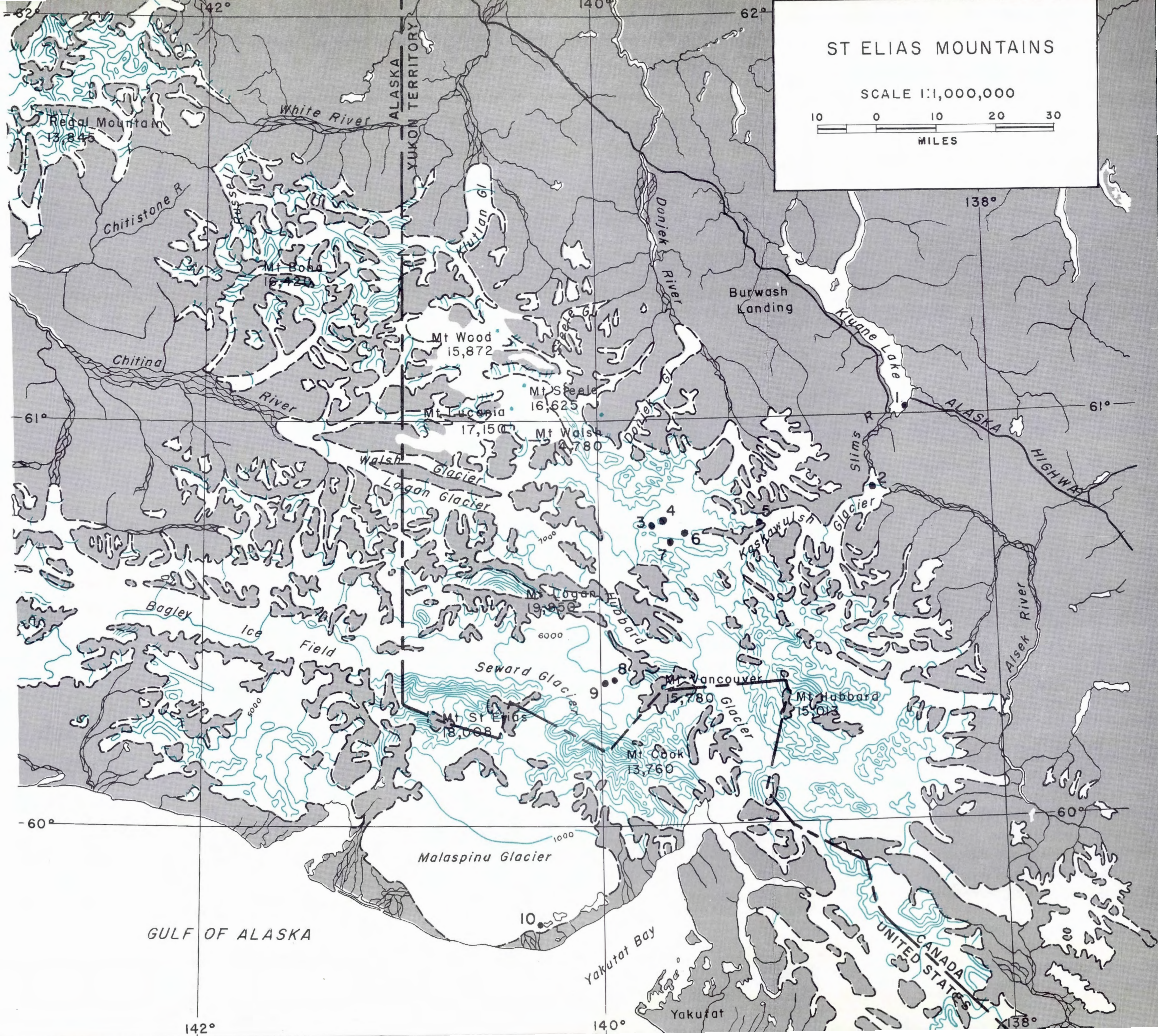
[1] For a description of IRRP aims, goals, and past activities, see W. A. Wood, "The Icefield Ranges Research Project," The Geographical Review, LIII, (1963), 163-184; R.H. Ragle, "The Icefield Ranges Research Project," Arctic, XVII (December, 1964), 286; R.H. Ragle, "Icefield Research Project," Ice, No. 13, (December, 1963), 2; R.H. Ragle, "Icefield Ranges, Y.T.," Ice, No. 17, (April, 1965), 3.

[2] See R. P. Sharp, "Accumulation and Ablation on the Seward-Malaspina Glacier System, Canada-Alaska," Bulletin of the Geological Society of America, LXII (July, 1951), 726-744; and Sharp, "Thermal Regimen of Firn on Upper Seward Glacier, Yukon Territory, Canada," Journal of Glaciology, I (March, 1951), 476-487.

WEATHER STATIONS

1. Base Camp 1963, 64
2. Terminus 1963, 64
3. Cache 1964
4. Divide 1963, 64
5. Kaskawulsh 1964
6. Glacier Central 1963
7. Cairn B 1964
8. Seward Rock 1948, 49, 64
9. Seward Ice
10. Lower Ice Camp 1948, 49



An IRRP climatological program was first organized in 1963,[1] and included three weather station locations: (1) Kluane Base Camp (786 meters above sea level), a manned weather station on the continental side of the mountain range approximately 140 miles west-northwest of Whitehorse, Yukon Territory, and located at the southern end of Lake Kluane; (2) Terminus (c. 825 meters), at the terminal moraine of the Kaskawulsh Glacier and 16 miles up the Slims River from Base Camp; and (3) Glacier Central (2,587 meters) and Divide (2,640 meters), two manned weather stations located at the Divide area of the Kaskawulsh and Hubbard Glaciers. At the Divide Camp, a five stake ablation farm was employed and observations were made of the short and long wave radiation components, in conjunction with wind and temperature measurements made at several heights above the snow surface. Published material on this data is forthcoming.[2]

In 1964, the climatology program was expanded to include sites on both flanks of the Icefield Ranges.[3] Four manned and four automatic stations were operated. Tables 1A and 1B give an

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[1] The 1963 Climatology Program was under the direction of James M. Havens of the U.S. Natick Laboratories. He was assisted by David E. Saarela of the U.S. Marine Corps and Mrs. Linda Upton of the Arctic Institute of North America. The program was supported by the Earth Science Division of the U.S. Army Natick Laboratories, Natick, Massachusetts. For a review of the 1963 weather picture in the St. Elias Region, the reader is referred to James M. Havens and David E. Saarela, "Exploration Meteorology in the St. Elias Mountains, Yukon, Canada," Weather, XIX (1964), 342-352. Detailed weather data are available in project files, but are not at present available in published form.

[2] J.M. Havens, (Compilation of Data and Primary Analysis of Summer Weather, IRRP 1963), Natick Report (in press). The report was in press at the time of writing of this research paper. However, 1963 data have been consulted for the purposes of field season comparisons.

[3] The 1964 Climatology team was led by Melvin G. Marcus of the University of Michigan, and constituted six investigators: Dr. Marcus; Tony Brazel and Raymond Lougeay, Rutgers University; Edward Grew, Dartmouth University; David Witter, Clark University; and Mrs. Linda Upton, Arctic Institute of North America. The program was supported by the Earth Sciences Division of the U.S. Army Natick Laboratories, Natick, Massachusetts, under contract # DA19-129-AMC-312 (N).

inventory of the station grid coordinates, elevations, periods of record, and types of surfaces. Marcus has given a summary of instrumentation and weather elements observed at each station;[1] also presented are most of the observed and recorded data for the 1964 field season. Not included in that report are data on radiation and ablation. The first part of this report is a presentation of radiation data and discussion of several points on the measurement and use of the data; a short analysis of Divide and Base Camp radiation is included.[2] The second part presents and analyzes 1964 ablation data in relation to the field season weather. This research paper serves to supplement the 1964 Climatology Report as Parts II and III of that report.

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[1] M. G. Marcus, "Icefield Ranges Climatology Program St. Elias Mountains, 1964 - Part I: Data Presentation," Research Paper 31A, (Washington: Arctic Institute of North America, 1965), 109 pp. In the Appendix to that report, radiation gear is listed for those stations which recorded global radiation.

[2] It should be noted at this point that the section on radiation deals solely with short wave incoming radiation (global radiation).

TABLE 1A

MANNED WEATHER STATIONS, ST. ELIAS MOUNTAINS, 1964

Station	Latitude	Longitude	Elevation in meters	Periods of record	Type Surface
Base Camp (Lake Kluane)	61° 03' N	138° 22' W	786	1 June-26 August	gravel. 50 meters NW of Kluane air strip
Kaskawulsh	60° 44' N	139° 08' N	c. 1,770	4 July-22 August	thin moraine overlying ice.
Divide	60° 47' N	139° 40' W	c. 2,637	10 June-17 August	snow.
Seward	60° 20' N	139° 55' W	c. 1,860	18 June-14 August	rock ridge. c. 20 meters from nearest snow.

TABLE 1B

AUTOMATIC WEATHER STATIONS, ST. ELIAS MOUNTAINS, 1964

Terminus	60° 49' N	138° 38' W	c. 825	11 June-18 August	gravel. On moraine c. 50 m from Slims river floodplain; 1 meter higher than floodplain surface.
Cache-Divide	60° 46' N	139° 42' W	2,674	13 June-16 August	small rock nunatak. 5 meters to nearest snow.
Cairn B-Divide	60° 46' N	139° 38' W	2,741	13 July-15 August	snow. on ridge just east of nunatak summit.
Seward Ice	60° 20' N	139° 56' W	c. 1,780	6 July-13 August	snow. c. 1.5 km west of nunatak.

Description of Radiation Recording Stations

Radiation was recorded at only two of the weather stations during the 1964 summer season - Base Camp and Divide. The same two stations recorded radiation during the 1963 field season.

At the foot of the eastern flanks of the St. Elias Range, Base Camp is situated along the Alaskan Highway at the southern tip of Lake Kluane. Relief to the west and south rises sharply 1,500 meters above camp level within a distance of only 4 to 5 miles; in the northern and eastern directions the topography is relatively level. The effect of mountains to the west and south on receipt of incoming radiation over the summer is strongest in the latter part of the season (middle and late August), since solar altitude decreases and the sun is blocked by high peaks in afternoon hours. On the other hand, Divide Station, located on a snow field whose major axis is aligned east to west, has less contrictions on incoming radiation due to topographic barriers.

Base Camp and Divide represent extremes in the types of environments found across the range. The nature of the interface during summer months at Base Camp presents a picture of subhumid topography and vegetation;[1] Divide Station straddles a drainage divide of five of the longest glaciers on earth outside the Polar Regions.[2]

Temperatures for 1964 are a reflection of environmental differences. Base Camp temperatures were well above freezing throughout the summer period. Daily mean temperatures ranged from a low of 44.0° F (6.7°C) on 21 June to a high of 59.5°F (15.3°C) on 29 July, with a seasonal mean (1 June-27 August) of 51.8°F (11.0°C). At Divide, temperatures ranged from 21.3°F (-6.0°C) on 1 July to 34.6°F(+1.4°C) on 18 July, with a seasonal mean (10 June-17 August) of 26.9°F (-3.2°C).

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[1] Precipitation totals (inches water) for the 1963 and 1964 field seasons (June-August) were 3.23 and 3.42 inches respectively.

[2] Wood, W. A., Op. Cit., p. 166.

Instrumentation, Periods of Observation, and Limitations of a Radiation Analysis.

At Base Camp in 1964, an Instruments Corp. Pyrheliograph (serial 207), with weekly charts, was installed in association with standard meteorological equipment on 1 June and operated without interruption through 27 August. The instrument was periodically calibrated for zero radiation conditions.

The pyrheliograph dome is pyrex glass with a transmission coefficient of 90% for all wave lengths from 0.36 to 2.0 microns. Since precision of recording is 0.1 langleys for 3/32" of chart width, the instrument responded within 5% of actual insolation values;[1] the variance around the zero base line on the chart during periods of no radiation was negligible compared to absolute values of radiation received throughout the season.

The speed of response, accuracy, and precision of recording are not comparable to more refined pyrheliometers, however, the pyrheliograph (actinograph) has the advantage of convenience, simplicity, and low cost. Also, it does not require other recording mechanisms such as a potentiometer.

Appendix A summarizes radiation data for Base Camp and Divide for the 1964 field season. For Base Camp, two-hour totals were calculated from pyrheliograph strip charts by extracting half-hour instantaneous values; the half-hour values (in langleys per minute) were averaged, and the averages multiplied by 120 minutes to give representative two-hour figures. Curve smoothing and planimeter methods were not employed in this case; it is felt that within the accuracy of the instrument, the extraction technique is sufficient.

The radiation totals for two-hour intervals were summed on a daily basis and are listed in the column headed "sum Q_s". Also listed are the theoretical daily incoming radiation values (Q_e) for the top of the atmosphere at 61°N latitude. The last column Q_s/Q_e is the ratio of the actual to the theoretical radiation - the so-called insolation index. This index gives an indication of the role of the atmosphere in deterring radiation from reaching the surface.

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[1] A brief description of the response characteristics of the Instruments Corp. Pyrheliograph is given in Instruction Recording Pyrheliometer, a pamphlet issued by Belfort Instrument Co., catalog no. 5-3850.

Radiation totals over two-hour periods, actual daily totals, theoretical daily totals, and insolation indices were summed, and means were calculated for each month and for the summer field season. The format is comparable to other 1964 meteorological data.[1]

At Divide Station, an Instruments Corp. Pyrheliograph (serial 235) was positioned on a small wooden platform 1 meter above the snow surface, 100 meters west of camp. Installed on 9 June, the recorder was in operation through 16 August; but, because of a malfunction which could not be repaired in the field, the recorded data are believed unreliable. The chart curves could not be reduced with any reasonable degree of accuracy; in many cases the zero base line on the strip charts varied more than 30% of the actual incoming radiation.

In order to estimate daily incoming radiation for the Divide field season, an empirical relationship was used. From a correlation analysis of the sunshine index and insolation index derived by Havens for the 1963 season at Divide,[2] 1964 daily incoming radiation totals were calculated. He expressed the relationship for 1963 as follows:

$$Q_s/Q_e = 0.73 + 0.27\ n/N \qquad (1)$$

where Q_s = the actual daily incoming short wave (global) radiation totals

Q_e = the theoretical daily incoming radiation at the top of the atmosphere for 61°N latitude

n = the actual daily sunshine hour total measured from a Lambrecht sunshine recorder[3]

N = the theoretical daily sunshine hour total (which depends on latitude and site exposure).

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[1] Marcus, M. G., Op. Cit., p. 23-107.

[2] Havens, J. M., "On Insolation and Sunshine in the St. Elias Mountains, Yukon Territory, Canada", (in press), 5 pages, 1 diagram. This paper is presently available in mimeographed form in project files.

[3] The recorder used was a Lambrecht sunshine recorder, type 1605 (45-90° lat.), serial 26515.

The ratio Q_s/Q_e is the insolation index; n/N is the sunshine index. The correlation coefficient of the relationship is 0.89, based on 58 pairs of data; the standard error of the estimate is ± 4.6%.[1] Thus, about 95.0% of the observations of a given value of the sunshine index will be at a particular value of the insolation index ± 9.2%. The above relationship is based on an Eppley Pyrheliometer (50 junction), rather than on a pyrheliograph. A comparative analysis of Eppley data and that from pyrheliograph must not altogether ignore instrumental differences, because at low sun angles and during times of the year when solar altitude is below a critical angle, an Eppley instrument responds differently than an actinograph.[2] Because the 1964 data are based on different instruments and are statistically derived (in the case of Divide), an elevational comparison must be treated with caution.

Since the intensity of solar radiation generally increases with elevation above sea level because of less atmospheric absorption, incoming radiation at Base Camp is expected to be lower than at Divide; but, since a more sensitive instrument was used at Divide (and the 1964 data are based on the response characteristics of that instrument), a greater difference than actually exists would be expected. This is especially true for cloudy conditions and at times of low sun altitude.

Clouds produce another set of radiative exchange conditions at the snow interface. In the Divide area, for example, the albedo of

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[1] Havens, J. M., Op. Cit., p. 4.

[2] Hubley, Op. Cit., p. 70-71, points out that the most serious error in the Eppley instrument (and the most difficult for which to make corrections) is a dependence of the instrument response on angle of incidence of radiation falling on the sensing element. The error is commonly called the "cosine response error", because an instrument set normal to the surface is actually recording the cosine value of a unit of radiation recorded normal to the sun. Hubley discarded data when the sun was 30° or less above the horizon, as the cosine error became very great under those periods. A detailed discussion of the Eppley is given in Fuguay and Buettner, "Laboratory Investigation of Some Characteristics of the Eppley Pyrheliometer," Trans. Amer. Geophy. Union, XXXVIII (Feb., 1957), 38-43.

the glacier snow surface, overlying clouds and nearby slopes increases and becomes more randomly oriented than during clearer weather. Fog (or total whiteout) tends to accentuate diffusion of incoming radiation to an even greater degree, causing a sharp increase in recorded measurements. These factors are, of course, partially dependent on cloud height and thickness. It is assumed, therefore, that although radiation relationships for the 1964 season are based on two different types of recorders, any correlations between Divide and Base Camp reflect strong environmental differences;[1] and, while relationships must be treated with caution, they are not largely dependent on dissimilarities in instrumentation.

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[1] This assumption is not without foundation; many investigators have measured radiation over glacier and snow surfaces and have found that particularly snow albedo and cloud cover have altered incoming radiation regimes from those measured over non-glacial surfaces. For a review of the discussion of dependence of radiation on snow surface, cloud cover, and other factors, see Olsson, "Sunshine and Radiation, Mount Nordenskiold," Geografiska Annaler, XVIII (1936a), 105-106; Olsson, "Scientific Results of the Norwegian-Swedish Spitsbergen Expedition in 1934. Part VII. Radiation Measurements on Isachen's Plateau," Geografiska Annaler, XVIII (1936b), 225-244; Wallen, Op. Cit., p. 492; Hubley, "Measurements of Diurnal Variations in Snow Albedo on Lemon Creek Glacier, Alaska," Jour. Glac., II (Oct., 1955), 561-562; Hubley, Op. Cit., p. 76-77; and Lister & Taylor, Op. Cit., pp 32-34.

Statistical Analysis

From 10 June to 16 August 1964, Divide Station received 44% more incoming short wave radiation than Base Camp. For this 68 day period, the snow camp recorded a grand total of 52,348 langleys; Base Camp totaled 36,429 langleys, or a difference of almost 16,000 langleys. Over this period, Divide averaged 769.8 langleys per day; Base Camp, 535.7 langleys per day. Figs. 2a and 2b illustrate the seasonal variation in daily sunshine and incoming radiation for the two stations. The theoretical incoming radiation curve for 61°N latitude is drawn on both Figs., since there is only a 16' latitudinal difference. Base Camp is the northernmost station. The theoretical sunshine curve[1] for each station is shown by a dotted line.

Base Camp insolation and sunshine indices show a reasonable 1964 correlation (Fig. 3) based on 86 pairs of data (2 June - 26 August). Over the field season, theoretical incoming short wave radiation (Q_e) and theoretical sunshine hours (N) vary - both decreasing through late June, July and August. The indices take into account this temporal variation. A least squares line was fitted to the Fig. 3 scattergram and the linear regression equation was calculated as,

$$Q_s/Q_e = .38 + .40\, n/N, \qquad (2)$$

where, as before, Q_s/Q_e and n/N are the insolation index and sunshine index respectively. A measure of the spread (population variance) about the regression line is the standard error of the least squares equation,[2] and is expressed as:

$$\hat{\sigma}_{Q_s/Q_e|n/N} = \sqrt{\frac{\sum_{i=1}^{j} \left(Q_s/Q_e - \overline{Q_s/Q_e}\right)^2 - b \sum_{i=1}^{j} \left(n/N - \overline{n/N}\right)\left(Q_s/Q_e - \overline{Q_s/Q_e}\right)}{j - 2}}$$

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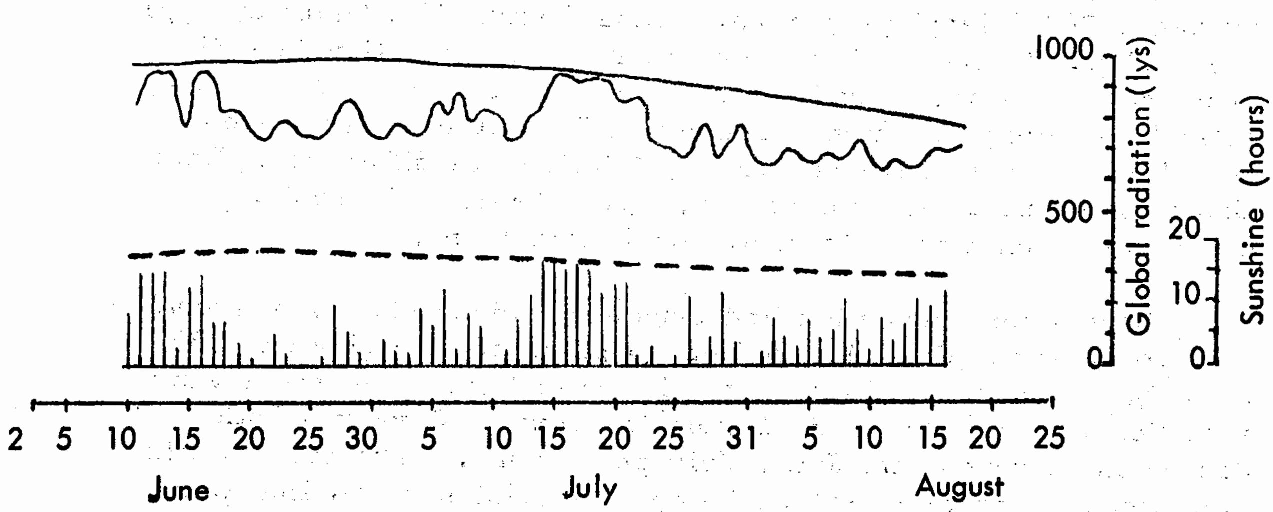
[1] In the case of Divide Station, theoretical sunshine values were obtained from project files. Havens calculated these values for the 1963 field season. For Base Camp, the values were estimated from an approximation curve drawn by connecting 1964 clear day values of actual sunshine hour totals.

[2] Blalock, H. M. Social Statistics. New York: McGraw-Hill, 1960, p. 308.

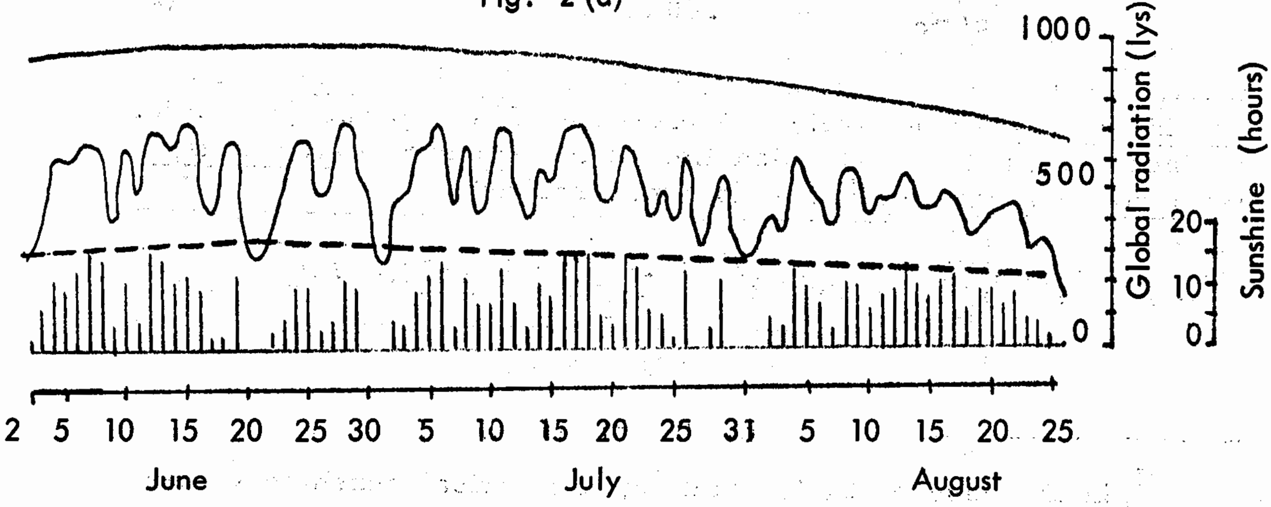
RADIATION AND SUNSHINE AT DIVIDE CAMP, 1964 SEASON

Fig. 2 (b)



RADIATION AND SUNSHINE AT BASE CAMP, 1964 SEASON

Fig. 2 (a)

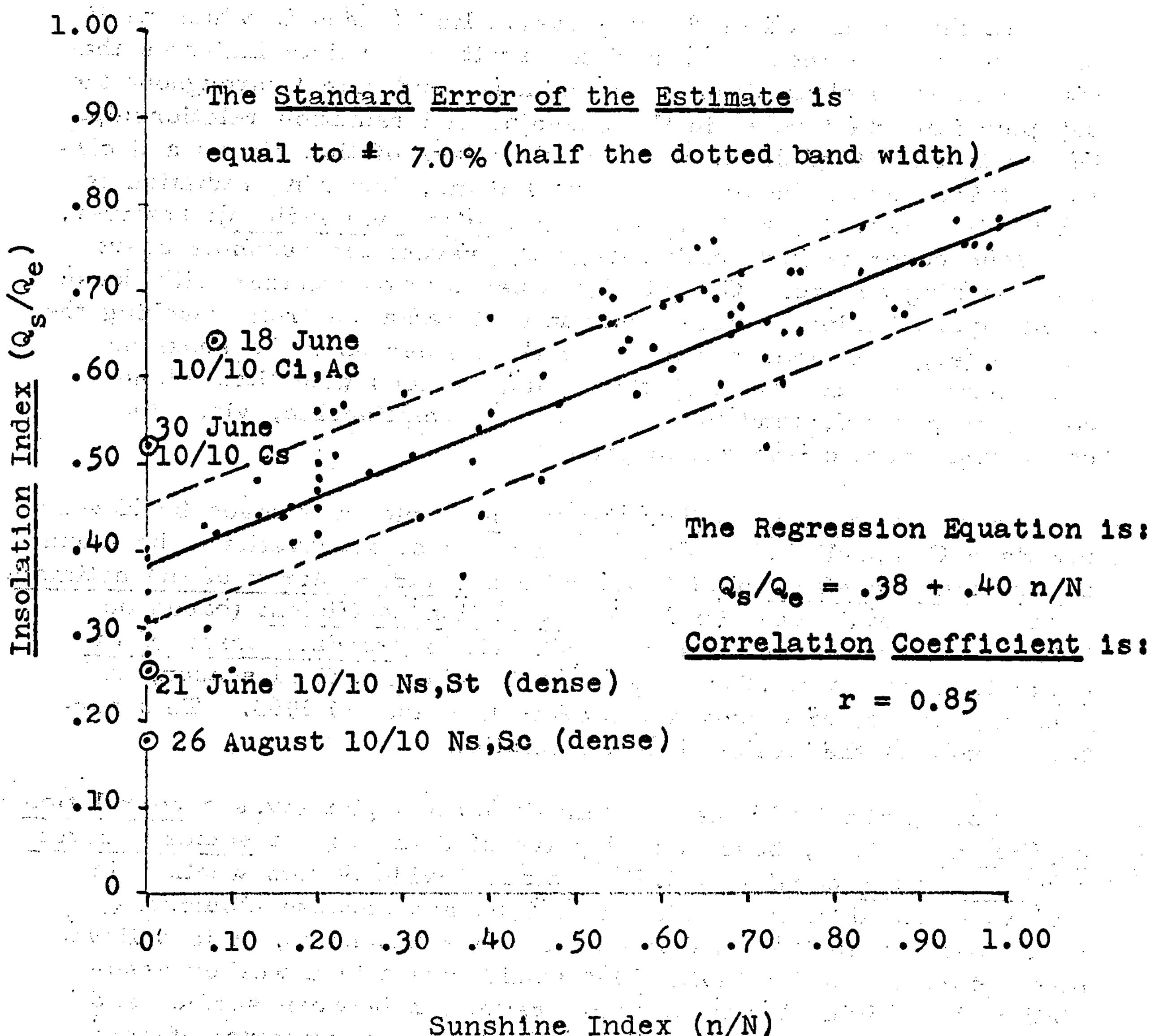


N.B. The smooth curve on both figs. is the theoretical incoming short wave radiation received at the top of the atmosphere at 61°N latitude. Divide radiation is derived from sunshine values. See text for explanation. Dotted line is theoretical sunshine.

Fig. 3

CORRELATION OF SUNSHINE AND RADIATION

FOR BASE CAMP, 1964



N.B. Usually the dotted band diverges at the extremities; here it is assumed that the points are normally distributed about the regression line.

where,

Q_s/Q_e = the individual values of the insolation index.
n/N = the individual values of the sunshine index.
j = the number of observations (86).
b = the slope value in the linear regression equation; it is equal to .40.

At the lower end of the regression line (cases in which negligible sunshine is recorded), a wider scatter of points indicates that the variation in cloud density, patchiness, and extent throughout the day play important roles in the sunshine and radiation relationship. On the 18 and 30 of June, for example, days of thin cirrus and cirrostratus covering the entire celestial dome, incoming radiation is relatively abundant (as shown by larger insolation indices); however, the cloud cover is just thick enough to prevent the sunshine chart from burning an arc. Conversely, when stormy weather with dense cloud layers inhibits abundant amounts of radiation from reaching the surface (e.g., 21 June and 26 August), neither does the sunshine chart burn an arc. On the other hand, periods with little cloud cover, in general, tend to strengthen the relationship, viz., the upper right part of the scattergram.

A sunshine index and insolation index plot was made by Havens for Base Camp, 1963.[1] Based on 44 pairs of observations, he found a correlation coefficient of 0.93, with a standard error of the estimate equal to = 4.6%. For 1964, the correlation coefficient (based on twice as many observations) is 0.85, with a standard error of the estimate equal to = 7.0%. The 1964 Base Camp field season, in general, was more cloudy and stormy than that of 1963. This partially explains the weaker 1964 association.

For Divide 1963, the sunshine-insolation plot gives a correlation coefficient of 0.89, based on 58 pairs of data, with a standard error of the estimate equal to = 5.8%. Since Divide Station weather in 1964 was considerably cloudier than 1963 and because cloudiness tends to diminish the sunshine-insolation relationship, it is believed that a correlation for Divide 1964 would result in a weaker association than Divide 1963. Multiple reflection between surface and cloud layers and cloud density are the two most important factors in the sunshine-insolation relationship for Divide Station.[2]

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[1] Havens, J.M. Op. Cit., p. 4.

[2] Havens, J.M. Op. Cit., p. 5.

Radiation relations with other factors (e.g., sunshine and cloudiness) in snow and glacier environments must be measured accurately at many spots within specific areas to be representative of local environmental conditions, though in most cases this may not be possible from a logistical standpoint. The nature of the terrain, i.e., configuration of local topography, is a factor which contributes to variation in radiation budgets over small areas. Does the Divide sunshine-insolation relationship show the same correlation characteristics at the foot of adjacent slopes at the edge of the snowfield as it does out in central portions? Probably not, since position of the station relative to diurnal and seasonal paths of the sun is of importance in radiation relationships. A study of the question may give insights into climatic relationships over the glacier surface. At any rate, before climatic factors can be employed as estimators of average radiation regimes in rugged mountainous glacier environments, questions such as the above must be explored.

Station Comparisons and Contrasts

The primary factor contributing to the variation between Divide and Base Camp incoming radiation is elevation above sea level (less atmospheric absorption). Divide Station is situated 1,851 meters above Base Camp level and receives, on the average, between 200 and 300 langleys per day more incoming radiation during the summer season than does Base Camp. Table II gives a 1963-64 field season comparison (on a monthly basis) of some weather elements and incoming radiation for the two stations. The field seasons were not equal in length nor did they extend over exactly the same dates, however, the two are made comparable by calculating values over similar time spans. Weather conditions closely correlate with radiation and sunshine data as expected. Receipt of incoming short wave radiation at Base Camp and Divide was much less in 1964. The severity of the 1964 field season weather is especially remembered by those who camped at the Divide area and at Seward Station. Over a span of 23 days (20 June to 13 July) generally cloudy and stormy weather with snow prevailed at all glacier camps. Only for a short period in July (16-18 July) were there any consecutive clear days across the range. During the 1963 season, weather was much less severe.

Tables IIIA and IIIB list clear and cloudy periods[1] during the 1963 and 1964 field seasons, with data on incoming short wave radiation, sunshine, and mean cloud cover. The 1963 periods are selected from data available in project files; these periods are judged by the author to be most representative of clear and cloudy situations for the 1963 field season. For 1964, data are chosen in order to be comparable to a temperature analysis by Marcus,[2] and also because the periods selected are the most illustrative of cloudy and clear conditions for the 1964 field season.

The nature of the environment at both stations is reflected in the intensity of incoming short wave radiation at the surface for the chosen periods. This may be observed by noting that the following inequality holds upon inspection of Tables IIIA and IIIB:

$$(Q_{s_D} - Q_{s_B}) \text{ cloudy} > (Q_{s_D} - Q_{s_B}) \text{ clear}$$

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[1] It has not been determined whether these periods are actually representative of frontal and nonfrontal conditions. It is likely that the clear periods do depict nonfrontal situations, but cloudy periods are more difficult to assess.

[2] Marcus, M.G., <u>Op. Cit.</u>, pp. 15-30.

TABLE II

1963 and 1964 IRRP Season Radiation, Sunshine, and General Weather Summary*

Month	Date	Q_s	$\overline{Q_s}$	$\overline{Q_s/Q_e}$	n	°F (°C) Mean Temp.	Prec. (in. H_2O)
						Base Camp - 1963	
June	7-30	14,460	602.5	.607	-	49.1 (9.5)	1.21
July	1-31	16,549	533.2	.570	-	53.9 (12.1)	1.72
August	1-25	12,644	505.7	.654	-	52.9 (11.6)	0.28
Season		43,653	547.1	.605	-	51.9 (11.0)	3.23
						Base Camp - 1964	
June	7-30	14,073	582.2	.590	173	52.1 (11.1)	0.71
July	1-31	16,464	531.1	.566	227	52.4 (11.3)	1.73
August	1-25	11,144	445.7	.576	178	50.8 (10.4)	1.21
Season		41,680	519.6	.578	578	51.7 (10.9)	3.65

* 1963 data taken from project files; 1964 data extracted from the 1964 Climatology Report (Marcus M.G., Op. Cit.) and from 1964 project files.

TABLE II (con't)

Month	Date	Q_s	$\overline{Q_s}$	$\overline{Q_s/Q_e}$	n	°F (°C) Mean Temp.	Prec. (in. H_2O)
				Divide Camp - 1963			
June	24-30	6,392	913.1	.880	57	21.7 (-5.7)	0.00
July	1-31	25,143	811.1	.870	248	29.6 (-1.3)	0.61
August	1-16	11,414	713.3	.880	140	29.4 (-1.4)	0.02
Season		42,949	812.5	.880	445	26.9 (-2.8)	0.63
				Divide Camp - 1964			
June	24-30	5,335	762.2	.770	45	24.3 (-4.3)	0.25
July	1-31	24,496	790.0	.840	217	27.4 (-2.5)	1.10
August	1-16	10,765	672.8	.840	96	26.3 (-3.2)	0.52
Season		40,596	741.6	.820	358	26.0 (-3.3)	1.87

TABLE IIIA

SELECTED PERIODS OF
INCOMING SHORT WAVE RADIATION, SUNSHINE HOURS, AND MEAN
CLOUD COVER - 1963, ON A DAILY BASIS*

Day Mo.	Divide Camp Inc. Rad. (langleys)	Divide Camp Sunshine Hrs.	Divide Camp Mean Cld Cover (10ths)	BASE CAMP Inc. Rad. (langleys)	BASE CAMP Sunshine Hrs.	BASE CAMP Mean Cld Cover (10ths)	Div.-Kluane Rad. Diff. (langleys)
			Clear Period				
10 Aug.	776.0	15.0	1.4	596.4	-	0.0	179.6
11 Aug.	775.0	15.2	1.9	333.6	-	4.0	441.4
12 Aug.	774.0	15.3	0.2	549.6	-	1.0	224.4
13 Aug.	772.0	15.1	0.0	542.4	-	0.5	229.6
14 Aug.	754.0	15.0	0.0	552.0	-	0.5	202.0
15 Aug.	745.0	14.6	2.8	568.8	-	2.0	176.2
Sum	4596.0	90.0	6.3	3142.8	-	8.0	1453.2
Mean	765.0	15.0	1.1	525.0	-	1.3	242.0
			Cloudy Period				
10 July	555.0	0.2	9.7	310.8	-	10.0	244.2
11 July	797.0	0.1	10.0	409.2	-	10.0	387.8
12 July	714.0	1.5	9.3	218.4	-	10.0	495.6
Sum	2066.0	1.8	29.0	938.4	-	10.0	1127.6
Mean	690.0	0.6	9.6	312.8	-	10.0	375.8

* Periods selected and data compiled from the 1963 field data in project files.

TABLE IIIB

SELECTED PERIODS OF
INCOMING SHORT WAVE RADIATION, SUNSHINE HOURS, AND MEAN
CLOUD COVER - 1964, ON A DAILY BASIS*

	Divide Camp			Base Camp			Div.-Kluane
Day Mo.	Inc. Rad. (langleys)	Sunshine Hrs.	Mean Cld Cover (10ths)	Inc. Rad. (langleys)	Sunshine Hrs	Mean Cld Cover (10ths)	Rad. Diff. (langleys)
			Clear Period				
14 July	950.0	16.5	1.1				
15 July	946.0	16.5	1.3				
16 July	919.4	15.1	0.8	721.2	16.4	1 (Ac)	198.2
17 July	937.0	16.5	0.9	730.8	16.3	1 (Cu)	206.2
18 July	927.3	16.1	2.5	727.2	15.4	2 (Ac)	200.1
Sum**	2883.7	47.7	4.2	2279.2	48.1	4	604.5
Mean***	961.2	15.9	1.4	759.7	16.0	1	201.5
			Cloudy Period				
22 July	691.3	1.7	8.9	592.8	12.2	6 Ci, 1 Ac	98.5
23 July	694.8	2.2	9.6	400.8	5.2	1 Ci, 6 Ac	294.0
24 July	661.2	0.2	10.0	518.4	4.7	5 Ac, 2 Sc	152.8
25 July	667.5	0.9	9.0	380.4	1.3	8 Ac, 3 Sc	287.1
26 July	806.3	10.6	4.8	637.2	11.8	4 Cu	169.1

* Sunshine and Cloud Cover data taken from the 1964 Climatology Report (Marcus, M.G., Op. Cit., pp. 26, 58, 64, and 99).
** Sum includes only 16, 17, 18 July
*** Mean includes only 16, 17, 18 July.

TABLE IIIB (con't)

Day Mo.	Divide Camp Inc. Rad. (langleys)	Divide Camp Sunshine Hrs.	Divide Camp Mean Cld Cover (10ths)	Base Camp Inc. Rad. (langleys)	Base Camp Sunshine Hrs.	Base Camp Mean Cld Cover (10ths)	Div- Kluane Rad. Diff. (langleys)
			Cloudy Period (con't)				
27 July	645.3	0.0	10.0 (fog)	286.8	0.0	10 Ns	358.5
28 July	698.8	3.9	9.1	417.6	2.9	1 Ac, 8 Sc	281.2
29 July	797.9	11.0	6.1	578.4	10.8	9 Cs, 6Ac	219.5
30 July	679.7	3.2	8.0	304.6	0.0	1 Ac, 4 Sc	375.1
31 July	630.2	0.1	10.0 (fog)	271.2	0.0	10 St	359.0
Sum*	6973.0	33.8	84.6	4388.2	38.9	80.0	2594.8
Mean**	697.3	3.4	8.5	438.2	3.9	8.0	259.5
Sum***	2637.8	3.2	38.6	1339.2	6.5	36.0	1298.6
Mean****	659.4	0.8	9.6	344.8	1.6	9.0	324.6

* Sum of all days 22-31 July
** Mean of all days 22-31 July
*** Sum of 23, 25, 27, 31 July - the more distinct cloudy days.
**** Mean of 23, 25, 27, 31 July - the more distinct cloudy days.

where Q_{sD} and Q_{sB} stand for the values of short wave incoming radiation at Divide and Base Camp stations respectively. The subscripts "cloudy" and "clear" denote periods for which the differences are computed. For days when cloudy conditions prevailed at both camps, the difference in receipt of incoming radiation (Divide-Base Camp) was greater than for clear periods. The variation in cloud density, cloud extent, and radiative interaction between local surface and cloud cover contributes to the contrast between the two sites with respect to incoming radiation totals. The relations for 1963 field season may be expressed as follows:

$$(Q_{sD} - Q_{sB})\ \text{clear} = 242\ \text{lys/day}$$

$$(Q_{sD} - Q_{sB})\ \text{cloudy} = 376\ \text{lys/day.}$$

Symbolizing the first difference as d_{clear}, and the second as d_{cloudy},

$$d_{cloudy} - d_{clear} = 134\ \text{lys/day.}$$

This value represents 14% of the value of incoming radiation received at Divide on a clear day in July, and 18% of that received at Base Camp for the same time. Referring to the previous discussion (p. 11-14) on instrumental differences, these percentages are probably greater than actual figures, but are believed to be significant indicators of the importance of local environmental conditions on energy availability.

For 1964, similar relationships hold, particularly when clear day totals are compared with the four day totals which represent the more distinct cloudy situations. Partially cloudy conditions reveal no apparent associations.

Summary

Radiation, which comprises the highest percentage contribution to the energy exchange over most glaciers, must be accurately measured and understood. Point measurements assume areal homogeneity of energy availability. Extrapolations or estimations of radiation, by means other than direct measurement by sensitive instruments, will dilute an understanding of important environmental influences on radiative transfer.

Divide and Base Camp stations represent extremes in the types of environments across the mammoth St. Elias Range. Elevation primarily explains the difference in receipt of incoming short wave radiation at the two stations. A closer inspection reveals that environmental conditions (e.g., cloud density, cloud extent, types of surfaces and albedo relations) are reflected in the radiation data by the contrast in langley values under clear and cloudy periods.

A better understanding of the energy exchange over glacier surfaces will come only when a larger network of recording stations are placed transversely and longitudinally across a range. Microclimatic and local analyses of the heat budget also must be explored in conjunction with the broader scale analysis in order to comprehend the connection between lower layers of the atmosphere near the earth-air interface and air masses which prevail across the range.

BIBLIOGRAPHY

Blalock, H. M., Social Statistics. New York: McGraw-Hill, 1960.

Buettner, K. J. K. and Thyer, N., "Valley Winds in the Mount Rainer Area," Archiv. fur Meteorologie, Geophysik und Bioklimatologie, Series B, XIV (1966), 125-147.

Fuguay, D. and Buettner, K. J. K., "Laboratory Investigation of Some Characteristics of the Eppley Pyrheliometer," Transactions, American Geophysical Union, XXXVIII (February, 1957), 38-43.

Geiger, R., The Climate Near the Ground. Cambridge, Mass.: Harvard University Press, 1965, 3rd ed.

Havens, J. M. and Saarela, D. E., "Exploration Meteorology in the St. Elias Mountains, Yukon, Canada," Weather, XIX (1964), 342-352.

Havens, J. M., "On Insolation and Sunshine in the St. Elias Mountains, Yukon Territory, Canada," (in press), 5 pages, 1 diagram, Natick Report.

__________. "Compilation of Data and Primary Analysis of Summer Weather," IRRP 1963, Natick Report (in press).

Hoinkes, H., "Measurements of Ablation and Heat Balance on Alpine Glaciers," Journal of Glaciology, II, (1955), 497-501.

Hoeck, E., "Influence of Radiation and Temperature on Melting Process of the Snow Cover," Beitrage zur Geologie der Schweiz, Geotechnische Serie Hydrologie, Lieferung 8, pp 1-36 (1952), Translated into English by K. Martinoff of USA SIPRE Bibliography Project, Library of Congress - Translation # 49, January, 1958.

Hubley, R. C., "Measurements of Diurnal Variations in Snow Albedo on Lemon Creek Glacier, Alaska," Journal of Glaciology, II (Oct., 1955), 560-563.

__________. "An Analysis of Surface Energy During the Ablation Season on Lemon Creek Glacier, Alaska," Transactions, American Geophysical Union, XXXVIII (February, 1957), 68-85.

BIBLIOGRAPHY (con't)

Instructions Recording Pyrheliometer, Belfort Instrument Company, Catalog N. 5-3850.

Keeler, C. M., "Relationship Between Climate, Ablation, and Run-off on the Sverdrup Glacier, 1963 Devon Island, N. W. T.," Research Paper # 27 (Washington: Arctic Institute of North America, 1964), 80 pp.

Larsson, P., "A Preliminary Investigation of the Meteorological Conditions on the Chamberlain Glacier, 1958," Research Paper # 2 (Washington: Arctic Institute of North America, 1960), 89 pp.

Lister, H. and Taylor, P., "Heat Balance and Ablation on an Arctic Glacier," Medd. om Grønland, Band 158, # 7 (1961).

Marcus, M. G., "Icefield Ranges Climatology Program St. Elias Mountains, 1964 - Part I: Data Presentation," Research Paper # 31-A (Washington: Arctic Institute of North America, 1965), 109 pp.

__________. "Summer Temperature Relationships Along a Transect in the St. Elias Mountains; Alaska and Yukon Territory," Man and Earth, Series in Earth Sciences, (Boulder: University of Colorado Press, 1965), pp. 15-30.

Olsson, H., "Sunshine and Radiation, Mount Nordenskiold," Geografiska Annaler, XVIII (1936a), 93-118.

__________. "Scientific Results of the Norwegian-Swedish Spitsbergen Expedition in 1934. Part VII. Radiation Measurements on Isachen's Plateau," Geografiska Annaler, XVIII (1936b), 225-244.

Orvig, S., "Glacial-Meteorological Observations on Icecaps in Baffin Island," Geografiska Annaler, XXXVI, (1954), 193-318.

Ragle, R. H., "Icefield Research Project," Ice, (Dec., 1963), 2.

__________. "The Icefield Ranges Research Project," Arctic, (Dec., 1964), 286.

__________. "Icefield Ranges, Y. T.," Ice, (April, 1965), 3.

BIBLIOGRAPHY (con't)

Sharp, R. P., "Accumulation and Ablation on the Seward-Malaspina Glacier System, Canada-Alaska," Bulletin of the Geological Society of America, LXII (July, 1951), 726-744.

__________. "Thermal Regimen of Firn on Upper Seward Glacier, Yukon Territory, Canada," Journal of Glaciology, I, (March, 1951), 476-487.

Spreen, W. C., "A Determination of the Effect of Topography Upon Precipitation," Transactions, American Geophysical Union, XXVIII (April, 1947), 285-290.

Sverdrup, H. U., "The Ablation on Isachen's Plateau and on the Fourteenth of July Glacier in Relation to Radiation and Meteorological Conditions," Geografiska Annaler, XXVII (1935), 145-166.

Wallen, C. C., "Glacial-Meteorological Investigations on the Karsa Glacier in Swedish Lapland: 1942-48," Geografiska Annaler, XXX (1948), 451-672.

Wood, W. A., "The Icefield Ranges Research Project," The Geographical Review, LIII (1963), 163-184.

APPENDIX A

RADIATION DATA FOR THE 1964 FIELD SEASON

BASE CAMP AND DIVIDE

INCOMING SHORT WAVE RADIATION (lys)
BASE CAMP (LAKE KLUANE), ST. ELIAS MOUNTAINS
YUKON TERRITORY, CANADA

Lat. : 61° 03' N
Long. : 138° 22' W Elevation: 786 meters Date: June, 1964

Date	YUKON STANDARD TIME (two-hour period ending)							
	02	04	06	08	10	12	14	16
1								114.6
2		1.8	16.8	43.2	26.4	40.8	45.6	62.4
3			10.8	49.2	38.4	34.8	36.0	64.8
4			19.2	63.6	109.2	103.2	139.2	127.2
5			14.4	54.0	98.4	116.4	116.4	90.0
6			13.2	38.4	67.2	118.0	138.0	118.8
7			9.6	56.4	108.0	129.6	141.6	115.2
8			10.8	50.4	106.8	140.4	138.0	101.6
9		3.6	22.8	61.3	79.2	87.6	70.8	45.6
10		3.6	19.2	69.6	115.2	140.4	128.4	115.2
11		2.4	9.6	28.8	93.6	86.4	111.6	93.6
12		1.2	18.0	64.8	115.2	118.8	104.4	130.8
13			14.4	57.6	116.4	135.6	115.2	99.6
14		2.4	15.6	55.2	94.8	147.6	124.8	104.4
15			15.6	51.6	110.4	157.2	142.8	126.0
16			15.6	44.4	110.4	140.4	147.6	105.6
17			9.6	16.8	58.8	85.2	87.6	64.8
18			15.6	46.8	84.0	132.0	147.6	96.0
19			14.4	46.8	78.0	123.6	145.2	128.4
20			7.2	15.6	22.8	37.2	50.4	56.4
21			7.2	18.0	40.8	56.4	44.4	37.2
22			4.8	20.4	55.2	93.6	118.8	67.2
23			10.8	75.6	74.4	100.8	110.4	90.0
24			7.2	28.8	98.4	135.6	128.4	126.0
25			12.0	54.0	98.4	118.8	140.4	128.4
26			8.4	22.8	55.2	121.2	102.0	84.0
27			10.8	40.8	67.2	126.0	103.2	92.4
28			19.2	55.2	112.8	141.6	140.4	134.4
29			14.4	25.2	85.2	128.4	128.4	115.2
30		1.2	14.4	62.4	116.4	106.8	91.2	67.2
31								
Sum		16.2	381.6	1317.7	2437.2	3204.4	3238.8	2788.4
Mean		.6	13.1	45.5	84.0	110.1	111.6	96.3

June, 1964 (con't)

YUKON STANDARD TIME (two-hour period ending)							Date
18	20	22	24	Sum Q_s	Q_e	Q_s/Q_e	
76.8	38.8	19.2					1
40.8	14.4	2.4		294.6	965.0	.306	2
70.8	46.8	8.4		360.0	968.0	.372	3
55.2	16.4	8.4		641.6	972.0	.660	4
80.0	40.8	8.4		618.8	974.0	.636	5
82.8	45.6	13.2		635.2	977.0	.653	6
64.8	46.8	12.0		684.0	980.0	.698	7
74.4	32.4	8.4		663.2	982.0	.675	8
28.8	12.0	4.8		416.5	984.0	.423	9
60.0	20.4	6.0		678.0	986.0	.688	10
44.4	22.8	9.6		502.8	988.0	.508	11
94.8	54.0	15.6		717.6	990.0	.725	12
92.4	57.6	20.4		709.2	991.0	.715	13
57.6	49.2	24.0		675.6	993.0	.680	14
87.6	43.2	10.8		745.2	994.0	.750	15
79.2	43.2	9.4		695.8	995.0	.700	16
56.4	34.8	10.8		424.8	996.0	.427	17
58.8	44.4	14.4		639.6	997.0	.642	18
86.4	44.4	19.2		686.4	997.0	.688	19
51.6	24.0	10.8		276.0	998.0	.277	20
26.8	22.8	9.6		263.2	998.0	.264	21
43.2	27.6	4.8		435.6	998.0	.437	22
75.6	32.4	1.2		571.2	998.0	.573	23
88.8	39.6	12.0		664.8	997.0	.667	24
93.6	30.0	9.6		685.2	997.0	.687	25
51.6	26.4	9.6		481.2	996.0	.483	26
58.8	55.2	1.2		555.6	995.0	.558	27
99.6	45.6	9.6		758.4	993.0	.764	28
78.0	38.4	15.6		628.8	992.0	.634	29
33.6	12.0	9.6		514.8	990.0	.519	30
							31
1916.4	1023.2	299.8		16623.3	28681.0		
66.2	35.4	10.3		574.0	989.0	.581	

INCOMING SHORT WAVE RADIATION (lys)
BASE CAMP (LAKE KLUANE), ST. ELIAS MOUNTAINS
YUKON TERRITORY, CANADA

Lat. : 61° 03' N
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	02	04	06	08	10	12	14	16
1			8.4	19.2	26.4	49.2	45.6	36.0
2		4.8	33.6	75.6	42.8	74.4	54.0	50.4
3			3.6	50.4	105.6	123.6	75.6	63.6
4		2.4	22.8	52.8	100.8	116.4	121.2	118.8
5		1.2	27.6	75.6	127.2	118.8	135.6	81.6
6			30.0	75.6	115.2	138.0	147.6	123.6
7			8.4	20.4	48.0	75.6	99.6	104.4
8		1.2	19.2	62.4	114.0	174.0	106.8	74.4
9			12.0	60.0	110.4	99.6	56.4	33.6
10			1.2	9.6	33.6	86.4	123.6	120.0
11			9.6	50.4	106.8	135.6	146.4	132.0
12			8.4	21.6	48.0	88.8	150.0	147.6
13			1.2	13.2	58.8	68.4	72.0	104.4
14		1.2	20.4	52.8	104.4	129.6	140.4	72.0
15		1.2	20.4	80.4	124.8	140.4	63.6	44.4
16		1.2	22.8	80.4	122.4	140.4	134.4	108.0
17		1.2	25.2	81.6	122.4	133.2	136.8	110.4
18		1.2	22.8	75.6	121.2	138.0	136.8	110.4
19		1.2	13.2	27.6	62.2	78.0	66.0	81.6
20			7.2	19.2	45.6	102.0	123.6	117.6
21			15.6	62.4	111.6	130.8	130.8	115.2
22			25.2	61.2	82.8	112.8	117.6	84.0
23		1.2	15.6	40.8	38.4	43.2	51.6	93.6
24		1.2	13.2	32.4	58.8	68.4	106.8	120.0
25			10.8	20.4	38.4	67.2	64.8	91.2
26			13.2	58.8	74.4	128.4	128.4	111.6
27			8.4	28.8	67.2	56.4	37.2	45.6
28			4.8	43.2	75.6	79.2	91.2	62.4
29			12.0	60.0	98.4	118.8	120.0	92.4
30			1.0	14.4	39.6	76.8	66.0	67.2
31			1.2	14.4	28.8	50.4	58.8	64.8
Sum		19.3	439.0	1880.2	2524.6	3142.8	3109.2	2782.8
Mean		.6	15.1	64.8	81.4	101.5	100.0	89.7

July, 1964 (con't)

YUKON STANDARD TIME (two-hour period ending)							Date
18	20	22	24	Sum Q_s	Q_e	Q_s/Q_e	
37.2	27.6	10.8		260.4	988.0	.264	1
34.8	25.2	2.4		468.0	987.0	.474	2
43.2	21.6	2.4		489.6	985.0	.497	3
76.8	34.8	3.6		650.4	983.0	.664	4
64.8	16.8	1.2		650.4	980.0	.665	5
81.6	27.6	8.4		747.6	978.0	.765	6
68.4	15.6			440.4	975.0	.453	7
64.8	45.6	14.4		676.8	972.0	.696	8
28.8	20.4			421.2	969.0	.435	9
99.6	52.8	16.8		543.6	966.0	.563	10
102.0	52.8	8.4		744.0	962.0	.774	11
103.2	56.4	15.6		639.6	958.0	.667	12
46.8	21.6	1.2		387.6	954.0	.406	13
60.0	25.2	1.2		607.2	950.0	.639	14
27.6	21.6	2.4		526.8	946.0	.567	15
73.2	31.2	7.2		721.2	941.0	.767	16
75.6	37.2	7.2		730.8	937.0	.780	17
76.8	37.2	7.2		727.2	932.0	.781	18
84.0	34.8	7.2		455.8	928.0	.490	19
67.2	20.4	12.0		514.8	923.0	.558	20
74.4	30.0	1.2		672.0	918.0	.733	21
74.4	31.2	3.6		592.8	912.0	.649	22
79.2	34.8	2.4		400.8	907.0	.442	23
84.0	31.2	2.4		518.4	902.0	.575	24
61.2	26.4			380.4	896.0	.424	25
72.0	48.0	2.4		637.2	890.0	.717	26
28.8	14.4			286.8	884.0	.324	27
43.2	16.8	1.2		417.6	879.0	.475	28
52.8	21.6	2.4		578.4	873.0	.663	29
33.6	6.0			304.6	867.0	.351	30
31.2	19.2	2.4		271.2	861.0	.315	31
1951.2	906.0	147.6		16463.6	29003.0		
63.0	29.2	4.7		531.0	937.0	.566	

INCOMING SHORT WAVE RADIATION (lys)
BASE CAMP (LAKE KLUANE), ST. ELIAS MOUNTAINS
YUKON TERRITORY, CANADA

Lat. : 61° 03' N
Long. : 138° 22' W Elevation: 786 meters Date: Aug., 1964

YUKON STANDARD TIME (two-hour period ending)

Date	02	04	06	08	10	12	14	16
1			6.0	19.2	45.6	70.8	62.4	55.2
2				12.0	36.0	63.6	106.8	88.8
3			7.4	14.4	40.8	57.6	78.0	66.0
4			13.2	58.8	108.0	130.8	129.6	104.4
5			10.8	50.4	70.8	100.8	121.2	105.6
6			14.4	63.6	98.4	87.6	91.2	69.6
7			9.6	54.0	90.0	46.8	56.4	73.2
8			8.4	39.6	94.8	127.2	126.0	98.4
9			16.8	55.2	103.2	123.6	98.4	58.8
10			8.4	27.6	85.2	118.8	86.4	52.8
11			9.6	31.2	43.2	109.2	126.0	94.8
12			6.0	31.2	45.6	95.8	112.8	102.0
13			9.6	54.0	92.0	124.8	124.8	97.2
14			10.8	54.0	104.4	128.4	93.6	38.4
15			8.4	38.4	72.0	91.2	87.6	76.8
16			8.4	45.6	93.6	118.8	84.0	86.4
17			1.2	16.8	81.6	121.2	111.6	80.4
18			12.0	45.6	57.6	61.2	78.0	73.2
19			14.4	44.4	79.2	44.4	76.8	78.0
20			13.2	34.8	57.6	91.2	111.6	76.8
21			12.0	60.0	75.6	109.2	96.0	60.0
22			12.0	43.5	78.0	118.8	112.8	73.2
23			8.4	42.0	82.8	90.0	48.0	19.2
24			4.8	25.2	69.6	92.4	98.4	39.6
25				9.6	34.8	92.4	62.4	61.2
26			4.8	9.6	21.6	30.0	24.0	15.6
27			4.8	15.6	92.4	144.8	97.2	81.6
28								
29					end of season			
30								
31								
Sum			235.4	996.3	1934.4	2591.4	2502.0	1927.2
Mean			8.7	36.9	71.7	96.0	92.9	71.5
Sum for Season		35.5	1056.0	4194.2	6896.2	8939.6	8850.0	7498.4
Mean for Season		.4	12.1	48.2	79.2	102.6	101.8	86.1

Aug., 1964 (con't)

YUKON STANDARD TIME (two-hour period ending)							Date
18	20	22	24	Sum Q_s	Q_e	Q_s/Q_e	
50.4	22.8	1.2		333.6	855.0	.390	1
84.0	39.6	1.2		432.0	849.0	.508	2
46.8	33.6	6.0		350.6	842.0	.417	3
64.8	18.0	1.0		628.6	836.0	.750	4
60.0	22.8	1.2		543.6	830.0	.654	5
42.0	26.4			493.2	824.0	.598	6
25.2	13.2			368.4	818.0	.450	7
69.6	21.6			585.6	812.0	.721	8
78.8	14.4			549.2	805.0	.682	9
38.4	14.4			432.0	797.0	.541	10
52.8	12.0			478.8	790.0	.606	11
55.2	15.6			464.2	783.0	.594	12
60.0	15.6			578.0	776.0	.745	13
25.2	14.4	1.2		470.4	769.0	.617	14
51.6	18.0			444.0	761.0	.584	15
51.6	15.6			504.0	754.0	.670	16
38.4	6.0			457.2	747.0	.613	17
22.8	4.8			355.2	739.0	.481	18
42.0				379.2	732.0	.518	19
36.0	4.8			426.0	723.0	.589	20
33.6	6.0			452.4	715.0	.632	21
27.6	4.8			470.7	706.0	.666	22
12.0	3.6			306.0	698.0	.439	23
12.0	1.0			343.0	690.0	.497	24
32.4	4.8			297.6	682.0	.436	25
12.0	1.0			118.6	674.0	.176	26
38.4	4.8			479.6	666.0	.720	27
							28
	end of season						29
							30
							31
1163.6	359.6	11.8		11741.7	20673.0		
43.2	13.4	.4		435.0	764.0	.569	
5031.2	2288.8	459.2		44828.6	78357.0		
57.8	26.3	5.4		515.0	900.0	.572	

ESTIMATED INCOMING SHORT WAVE RADIATION (lys)* DIVIDE STATION, ST. ELIAS MOUNTAINS YUKON TERRITORY, CANADA

Lat. : 60° 47' N
Long. : 139° 40' W Elevation: 2,637 meters Date: June, 1964

Date	n	n/N	Q_e	Q_s
1				
2				
3				
4				
5				
6				
7				
8				
9				
10	8.0	.473	987.0	846.8
11	14.8	.876	988.0	954.4
12	14.5	.853	990.0	950.4
13	14.9	.876	992.0	958.2
14	1.7	.100	993.0	751.7
15	12.1	.708	995.0	916.3
16	13.9	.813	996.0	946.2
17	6.1	.357	997.0	823.5
18	6.6	.386	997.0	831.4
19	2.8	.163	998.0	772.4
20	0.1	.006	998.0	729.5
21	0.0	.000	999.0	729.3
22	4.3	.250	998.0	796.4
23	1.1	.064	998.0	745.5
24	0.0	.000	997.0	727.8
25	0.2	.012	997.0	730.8
26	0.6	.035	996.0	736.0
27	9.4	.550	995.0	873.6
28	4.7	.276	993.0	798.4
29	1.4	.082	992.0	745.9
30	0.0	.000	990.0	722.7
31				
Sum	117.7	6.880	20886.0	17087.2
Mean	5.6	.328	994.0	813.7

* Derivation of Q_s is explained in text.

ESTIMATED INCOMING
SHORT WAVE RADIATION (lys)
DIVIDE STATION, ST. ELIAS MOUNTAINS
YUKON TERRITORY, CANADA

Lat. : 60° 47' N
Long. : 139° 40' W Elevation: 2,637 meters Date: July, 1964

Date	n	n/N	Q_e	Q_s
1	3.3	.195	988.0	773.6
2	1.2	.071	987.0	739.2
3	0.8	.047	985.0	731.8
4	8.7	.518	983.0	855.2
5	5.5	.327	980.0	801.6
6	12.1	.724	978.0	904.6
7	1.9	.114	975.0	742.0
8	7.5	.449	972.0	827.2
9	5.6	.335	969.0	794.6
10	0.0	.000	966.0	705.2
11	1.8	.108	962.0	730.2
12	6.5	.390	958.0	799.9
13	10.5	.632	954.0	859.6
14	16.5	1.000	950.0	950.0
15	16.5	1.000	946.0	946.0
16	15.1	.915	941.0	919.4
17	16.5	1.000	937.0	937.0
18	16.1	.981	932.0	927.3
19	11.2	.683	928.0	848.2
20	12.4	.756	923.0	862.1
21	13.1	.799	918.0	868.4
22	1.7	.104	912.0	691.3
23	2.2	.135	907.0	694.8
24	0.2	.012	902.0	661.2
25	0.9	.055	896.0	667.5
26	10.6	.654	890.0	806.3
27	0.0	.000	884.0	645.3
28	3.9	.241	879.0	698.8
29	11.0	.683	873.0	797.9
30	3.2	.199	867.0	679.7
31				
Sum	216.6	13.133	29003.0	24496.1
Mean	7.0	.424	935.5	790.2

ESTIMATED INCOMING
SHORT WAVE RADIATION (lys)
DIVIDE STATION, ST. ELIAS MOUNTAINS
YUKON TERRITORY, CANADA

Lat. : 60° 47'N
Long. : 139° 40'W Elevation: 2,637 meters Date: Aug., 1964

Date	n	n/N	Q_e	Q_s
1	1.6	.100	855.0	647.2
2	7.0	.440	849.0	720.8
3	3.6	.228	842.0	666.9
4	2.5	.158	836.0	646.2
5	7.1	.450	830.0	707.2
6	4.0	.256	824.0	658.4
7	5.2	.335	818.0	670.8
8	11.1	.716	812.0	749.5
9	4.5	.292	805.0	651.2
10	2.2	.143	797.0	612.9
11	7.0	.457	790.0	673.9
12	3.4	.222	783.0	618.6
13	6.1	.404	776.0	651.1
14	10.1	.673	769.0	701.3
15	9.1	.601	761.0	678.8
16	11.7	.785	754.0	710.3
17				
18		end of season		
19				
20				
Sum	96.2	6.260	12901.0	10765.1
Mean	6.0	.391	806.3	672.8
Sum for Season	430.0	26.273	62790.0	52348.4
Mean for Season	6.4	.387	924.0	760.0

Part III

PRESENTATION AND ANALYSIS OF ABLATION DATA

Measurement Sites

Snow ablation and accumulation were measured from stake networks and snow pits at three sites in the St. Elias Mountains during the 1964 field season: Divide, Seward Rock, and Seward Ice (Fig. 1). The locations and coordinates of these stations are given in Parts I & II of this report. Snow measurements were accomplished in conjunction with meteorological observations at all three stations. The locations and coordinates of the three weather stations are given in Part I of this report.[I]

The essential difference between locations is that the Seward stations are situated on the windward, more marine exposure of the St. Elias Mountains, while Divide station is located at the watershed boundary of the Kaskawulsh and Hubbard glaciers and is transitional between the marine and continental slopes.

Although the two Seward stations are in close proximity, their local environments are quite different. Weather observations at Seward Rock (1860 m.) were taken on a nunatak generally characterized by an exposed rock surface throughout the field season. Snow measurements were made at a site some 30 meters north of the nunatak and weather station. Seward Ice (1780 m.) was an automatic weather station located 1.5 Km west and 80 m. lower than the nunatak. The Seward stations are only 37 Km northwest of the head of Yakutat Bay, but a large mountain

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[I] M. G. Marcus, "Icefield Ranges Climatology Program St. Elias Mountains, 1964- Part I: Data Presentation," Research Paper 3IA, (Washington: Arctic Institute of North America, 1965), p.5.

barrier intervenes. The Upper Seward glacier is surrounded - with the exception of its narrow outlet to the Malaspina glacier - on all sides by mountain masses. The most prominent peaks are Mt. Logan (6050 m.), Mt. St. Elias (5488 m.), Mt. Augusta (4206 m.), Mt. Cook (4128 m.), and Mt. Vancouver (4710 m.).

Although the Upper Seward glacier is only a short distance from the Gulf of Alaska, it has been suggested that the high mountains shield the Seward stations from the direct influences of moist air masses. Sharp's 1948-49 study of the Seward-Malaspina glacier system indicates that there is a transition from a marine to a more continental environment from the Malaspina to the Upper Seward Basin.[1] Pit data from a hydrological traverse of the St. Elias Mountains during the summer of 1965 reveals that there is a 3 to 1 water differential between sites at 1765 m. on the windward Upper Seward Basin and the leeward Kaskawulsh glacier.[2] The water differential between the Divide and Seward locations was calculated to be approximately 1 to 2 for the 1964-65 Accumulation Season.[3] In general, therefore, Seward precipitation characteristics would be classified as more marine than continental in relation to stations at higher elevations towards the divide and to the leeward slope of the St. Elias Mountains.

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[1] R.P. Sharp, "Accumulation and Ablation on the Seward-Malaspina Glacier System, Canada-Alaska," Bulletin of the Geological Society of America, LXII (July, 1951), 728.

[2] M.G. Marcus, "A Hydrological Traverse of Glaciers in the Icefield Ranges, St. Elias Mountains, Alaska-Yukon Territory," A paper presented at the VII INQUA CONGRESS of the International Association for Quaternary Research Boulder, Colorado September 1, 1965, p.4.

[3] Ibid., see preliminary data at end of paper.

On the local scale, rugged mountainous terrain influences precipitation patterns to a considerable degree and distorts the variations in precipitation which might be expected with an increase in elevation above sea level. Data from the 1965 hydrological traverse provides a case in point. Pit measurements on the Hubbard Glacier, where it is blocked by east-west trending ridges and nunataks, displayed much lower water equivalent values immediately to the north of these barriers than to the south.[1] The abrupt relief produced a rain shadow and variations in accumulation locally which in magnitude equalled that between marine and continental legs of the hydrological traverse.

Instrumentation, Periods of Observation and local site factors.

Divide

At Divide Station, a stake farm was established approximately 100 m. west of camp and 30 m. north of the weather station. The ablation farm consisted of five aluminum conduit poles positioned in a 15 m. square formation with one pole in the center of the square. The poles were placed in 4" by 4" wooden bases and then were implanted in 3 meter deep holes drilled by a SIPRE snow corer. The holes were packed with snow in the upper 1 meter zone. This procedure was followed with the expectation that the poles would not show appreciable vertical movement within the snow layer. Measurements of surface change were made to the nearest 0.1 cm from the top of the exposed part of the conduit pole to the snow surface. The difference (minus or plus)

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[1] *Ibid.*, p.5

over each period was taken to be the lowering or raising of the snow surface during that time. To partially eliminate the drifting effect around stakes, a board was gently placed on the snow surface adjacent and to the right of each pole; the distance from the top of a stake to the bottom of the board was measured. This method was undertaken twice for each stake - once with the board placed with its longer dimensions extending from left to right, and a second time with the longer dimensions placed perpendicular to the board's first position. The two readings for each stake were averaged. The mean value was then calculated for the five stakes. This figure is assumed to be representative of ablation or accumulation conditions over the measurement period.[1]

Commencing at 0600 on 14 June observations were made every 12 hours. The program terminated on 17 August. Mean values for the 12 hour periods are presented in Table I for each 12 hour and 24 hour period. Daily and 12 hourly values are cumulated throughout the season. It should be emphasized that the data in Table I give only daily fluctuations in the surface level. Since snow pit studies were not made on a daily basis, compaction and water equivalent values are only available for the field season period.

At the beginning and end of the 1964 field season, snow pits were excavated adjacent to the ablation farm and snow density profiles were determined. For the purposes of estimating mass gain or loss, data from the two pits give an approximation of actual values for the field season.

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[1] For periods of little or no ablation, the variance of stake readings for each observational period was generally between 20% and 30%. This shows good agreement with results obtained by Keeler. See Keeler, C.M. "Relationship Between Climate, Ablation, and Run-Off on the Sverdrup Glacier, 1963 Devon Island, N.W.T.," Research Paper #27 (Washington: Arctic Institute of North America, 1964), p. 47.

TABLE I

VERTICAL SNOW SURFACE CHANGES AT DIVIDE STATION, ST. ELIAS MOUNTAINS YUKON TERRITORY, CANADA*

Lat.: 60° 47' N
Long.: 139° 40' W

Elevation: 2,637 meters

Date: June, 1964

Date	YUKON STANDARD TIME					
	Daily values (cms)					
	06-18	18-06	06-06	06-18	18-06	06-06
1-2						
2-3						
3-4						
4-5						
5-6						
6-7						
7-8						
8-9						
9-10						
10-11						
11-12						
12-13						
13-14						
14-15	- 0.62	- 0.30	- 0.92	- 0.62	- 0.30	- 0.92
15-16	- 0.85	- 0.13	- 0.98	- 1.47	- 0.43	- 1.90
16-17	- 1.50	2.00	0.50	2.97	1.57	1.40
17-18	- 2.84	- 0.38	- 3.22	- 5.81	1.19	- 4.62
18-19	- 1.78	- 0.17	- 1.95	- 7.59	1.02	- 6.57
19-20	- 0.17	0.27	0.10	- 7.76	1.29	- 6.47
20-21	2.57	3.90	6.47	- 5.19	5.19	0.00
21-22	- 0.04	0.35	0.31	- 5.23	5.54	0.31
22-23	- 1.02	7.52	6.50	- 6.25	13.06	6.81
23-24	- 3.99	3.36	- 0.63	-10.24	16.42	6.18
24-25	- 1.73	1.87	0.14	-11.97	18.29	6.32
25-26	2.00	0.67	2.67	- 9.97	18.96	8.99
26-27	- 1.39	0.24	- 1.15	-11.36	19.20	7.84
27-28	- 2.82	0.75	- 2.07	-14.18	19.95	5.77
28-29	- 1.39	0.17	- 1.22	-15.57	20.12	4.55
29-30	- 0.53	0.73	0.20	-16.10	20.85	4.75
30- 1	2.41	1.27	3.68	-13.69	22.12	8.43
Total abl.	-20.67	- 0.98	- 12.14	-13.69		
Total accum.	6.98	23.10	20.57		22.12	
Net abl. or acc.	-13.69	22.12	8.43			8.43

*The values are average lowering or raising of the snow surface as indicated by a five stake ablation farm. Minus values indicate ablation.

TABLE I (con't)

VERTICAL SNOW SURFACE CHANGES
AT DIVIDE STATION, ST. ELIAS MOUNTAINS
YUKON TERRITORY, CANADA*

Lat.: 60° 47' N
Long.: 139° 40' W   Elevation: 2,637 meters   Date: July, 1964

Date	YUKON STANDARD TIME					
	Daily values (cms)			Cumulative values (cms)		
	06-18	18-06	06-06	06-18	18-06	06-06
1-2	- 0.18	0.28	0.10	- 13.87	22.40	8.53
2-3	- 0.05	1.42	1.37	- 13.92	23.82	9.90
3-4	0.22	0.18	0.40	- 13.70	24.00	10.30
4-5	- 0.21	- 0.30	- 0.51	- 13.91	23.70	9.79
5-6	- 0.14	- 0.14	- 0.28	- 14.05	23.56	9.51
6-7	- 0.45	- 0.17	- 0.62	- 14.50	23.39	8.89
7-8	- 1.72	2.73	1.01	- 16.22	26.12	9.90
8-9	- 0.21	0.02	- 0.19	- 16.43	26.14	9.71
9-10	0.03	2.14	2.17	- 16.40	28.28	11.88
10-11	- 0.14	0.68	0.54	- 16.54	28.96	12.42
11-12	- 0.57	- 0.27	- 0.84	- 17.11	28.69	11.58
12-13	- 0.61	0.48	- 0.13	- 17.72	29.17	11.45
13-14	- 2.37	- 0.05	- 2.42	- 20.09	29.12	9.03
14-15	- 1.24	0.01	- 1.23	- 21.33	29.13	7.80
15-16	-	-	(- 1.00)**	-	-	6.80
16-17	- 1.20	- 0.22	- 0.42	- 22.53	28.91	6.38
17-18	- 0.44	- 0.39	- 0.83	- 22.97	28.52	5.55
18-19	- 2.74	0.63	- 2.11	- 25.71	29.15	3.44
19-20	- 1.22	1.14	- 0.08	- 26.93	30.29	3.36
20-21	- 0.84	0.11	- 0.73	- 27.77	30.40	2.63
21-22	- 1.37	0.70	- 0.67	- 28.74	30.70	1.96
22-23	- 0.16	- 0.12	- 0.28	- 28.90	30.58	1.68
23-24	0.13	0.68	0.81	- 28.77	31.26	2.49
24-25	- 0.04	- 0.30	- 0.34	- 28.81	30.96	2.15
25-26	4.13	2.92	7.05	- 24.68	33.88	9.20
26-27	- 5.08	- 0.29	- 5.37	- 29.76	33.59	3.83
27-28	3.77	2.22	5.99	- 25.99	35.81	9.82
28-29	- 5.68	- 0.07	- 5.75	- 31.67	35.74	4.07
29-30	- 2.64	- 0.23	- 2.87	- 34.31	35.51	1.20
30-31	- 2.27	- 0.10	- 2.37	- 36.58	35.41	- 1.17
31-1	3.99	5.00	8.99	- 32.59	40.41	7.82
Total abl.	-31.17	- 2.65	-29.04	- 32.59		
Total accum.	12.27	20.94	28.43		40.41	
Net abl. or acc	-18.90	18.29	- 0.61			7.82

* Cumulative values are continued on from the previous month and run over the whole field season.

** No obs. were taken on 15-16 July. A value of -1.00 is assigned.

TABLE I (con't)

VERTICAL SNOW SURFACE CHANGES
AT DIVIDE STATION ST. ELIAS MOUNTAINS
YUKON TERRITORY, CANADA

Lat.: 60^{0} 47' N
Long.: 139^{0} 40' W   Elevation: 2,637 meters Date: August, 1964

YUKON STANDARD TIME

Date	Daily values (cms)			Cumulative values (cms)		
	06-18	18-06	06-06	06-18	18-06	06-06
1-2	- 6.31	- 0.53	- 6.84	- 38.90	39.88	0.98
2-3	- 1.79	- 0.26	- 2.05	- 40.69	39.62	- 1.07
3-4	- 0.74	- 0.08	- 0.82	- 41.43	39.54	- 1.89
4-5	- 0.46	0.04	0.50	- 41.89	39.58	- 2.31
5-6	- 0.17	0.03	- 0.14	- 42.06	39.61	- 2.45
6-7	- 0.12	0.00	- 0.12	- 42.18	39.61	- 2.57
7-8	- 0.31	- 0.03	- 0.34	- 42.49	39.58	- 2.91
8-9	- 0.27	0.15	- 0.12	- 42.76	39.73	- 3.03
9-10	- 0.13	0.00	- 0.13	- 42.89	39.73	- 3.16
10-11	0.03	0.42	0.45	- 42.86	40.15	- 2.71
11-12	- 1.14	0.22	- 0.92	- 44.00	40.37	- 3.63
12-13	- 0.39	- 0.05	- 0.34	- 43.61	40.32	- 3.29
13-14	- 0.30	- 0.00	- 0.30	- 43.91	40.32	- 3.59
14-15	0.11	- 0.12	- 0.12	- 43.91	40.20	- 3.71
15-16	0.13	0.12	0.25	- 43.78	40.32	- 3.46
16-17	- 0.24	1.96	1.72	- 43.54	42.28	- 1.26
17-18						
18-19						
19-20						
20-21						
21-22						
22-23						
23-24						
24-25						
25-26						
26-27						
27-28						
28-29						
29-30						
30-31						
31-1						
Total abl.	-11.50	- 1.07	-12.00	- 43.54		
Total acc.	0.55	2.94	2.92		42.28	
Net abl. or acc.	-10.95	1.87	- 9.08			- 1.26

Seward Rock

Ablation stakes employed at Seward Rock consisted of one foot long wooden pegs which were driven into the snow in such a manner that the top of each peg was made level with the snow surface. At the end of a 12 hour period, the lowering of the surface down from the top of each peg was measured; they were reset at a nearby undisturbed spot. Six pegs were arrayed in a linear fashion on a snow ridge 30 m. to the north of and slightly downslope from the meteorology station.[1] The pegs were set 25 m. apart at the end of each 12 hour period. Located approximately 3 meters down the eastern slope of the ridge, the stakes were set in line with the strike of the ridge. The eastern side of the nunatak slopes gradually to a large basin at the foot of the vast Mt. Vancouver mountain system. The nunatak's west slope descends abruptly to the Upper Seward Glacier surface roughly 100 m. below the crest of the snow ridge. Measurements were taken from 0600, 26 June to 0600 13 August. Data are presented in Table II.

Snow pits were excavated to the east of the nunatak. Density profiles were determined at the beginning and end of the field season. The first pit, dug on 23 June, extended to 240 cms. On 29 July, the second snow density profile was made to 300 cms depth. The latter pit was located about ½ Km east of the nunatak and 50 m. below camp level; the first pit was dug just NE of camp and not more than 20 m. east of the ablation pegs.

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[1]Sharp measured ablation with meter sticks (surface lowering) which were reset every day in order to minimize the effects of local ablation and compaction settling. See Sharp, R.P., Op. Cit., p. 733.

TABLE II

VERTICAL SNOW SURFACE CHANGES
AT SEWARD NUNATAK STATION, ST. ELIAS MOUNTAINS
YUKON TERRITORY, CANADA

Lat.: 60° 20' N
Long.: 139° 55' W   Elevation: 1,860 meters   Date: June, 1964

YUKON STANDARD TIME

Date	Daily values (cms)			Cumulative values (cms)		
	06-18	18-06	06-06	06-18	18-06	06-06
1-2						
2-3						
3-4						
4-5						
5-6						
6-7						
7-8						
8-9						
9-10						
10-11						
11-12						
12-13						
13-14						
14-15						
15-16						
16-17						
17-18						
18-19						
19-20						
20-21						
21-22						
22-23						
23-24						
24-25						
25-26						
26-27	0.46	- 0.64	- 0.18	0.46	- 0.64	- 0.18
27-28	-1.26	- 0.21	- 1.47	- 0.80	- 0.85	- 1.65
28-29	-1.72	0.69	- 1.03	- 2.52	- 0.16	- 2.68
29-30	-1.91	0.34	- 1.57	- 4.43	0.18	- 4.25
30-1	-0.13	1.68	1.55	- 4.56	1.86	- 2.70
Total abl.	- 5.02	- 0.85	- 4.25	- 4.56		
Total acc.	0.46	2.71	1.55		1.86	
Net abl. or acc.	-4.56	1.86	- 2.70			- 2.70

TABLE II (con't)

VERTICAL SNOW SURFACE CHANGES
AT SEWARD MUNATAK STATION, ST. ELIAS MOUNTAINS
YUKON TERRITORY, CANADA

Lat.: 60° 20' N
Long.: 139° 55' W Elevation: 1,860 meters Date: July, 1964

YUKON STANDARD TIME

Date	Daily values (cms) 06-18	18-06	06-06	Cumulative values (cms) 06-18	18-06	06-06
1-2	0.89	1.52	2.41	- 3.67	3.38	- 0.29
2-3	3.84	2.62	6.46	0.17	6.00	6.17
3-4	- 2.54	- 0.51	- 3.05	- 2.37	5.49	3.12
4-5	- 2.16	- 0.66	- 2.82	- 4.53	4.83	0.30
5-6	0.08	- 0.39	- 0.31	- 4.45	4.44	- 0.01
6-7	- 1.17	- 0.97	- 2.14	- 5.62	3.47	- 2.15
7-8	- 1.52	2.31	0.79	- 7.14	5.78	- 1.36
8-9	- 3.25	0.31	- 2.94	-10.39	6.09	- 4.30
9-10	- 2.06	5.08	3.02	-12.45	11.17	- 1.28
10-11	1.60	0.51	2.11	-10.85	11.68	0.83
11-12	- 3.38	- 0.30	- 3.68	-14.23	11.38	- 2.85
12-13	- 1.80	0.40	- 1.40	-16.03	11.78	- 4.25
13-14	- 1.67	- 0.18	- 1.85	-17.70	11.60	- 6.10
14-15	- 1.93	- 0.25	- 2.18	-19.63	11.35	- 8.28
15-16	- 2.31	- 1.09	- 3.40	-21.94	10.26	- 11.68
16-17	- 4.31	- 1.53	- 5.84	-26.25	8.73	- 17.52
17-18	- 6.02	- 1.54	- 7.56	-32.27	7.19	- 25.08
18-19	- 6.47	- 0.85	- 7.32	-38.74	6.34	- 32.40
19-20	- 0.66	- 0.66	- 1.32	-39.40	5.68	- 33.72
20-21	- 1.96	- 0.30	- 2.26	-41.36	5.38	- 35.98
21-22	- 4.77	- 0.64	- 5.41	-46.13	4.74	- 41.39
22-23	- 2.97	2.74	- 0.23	-49.10	7.48	- 41.62
23-24	- 2.54	1.52	- 1.02	-51.64	9.00	- 42.64
24-25	- 2.21	4.06	1.85	-53.85	13.06	- 40.79
25-26	- 7.54	0.94	- 1.60	-56.39	14.00	- 42.39
26-27	- 4.24	- 0.21	- 4.45	-60.63	13.79	-46.84
27-28	- 1.83	- 0.63	- 2.46	-62.46	13.16	-49.30
28-29	- 5.03	- 0.45	- 5.48	-67.49	12.71	-54.78
29-30	- 4.75	0.00	- 4.75	-72.24	12.71	-59.53
30-31	- 3.00	- 0.32	- 3.32	-75.24	12.39	-62.85
31-1	- 2.11	- 2.34	- 4.45	-77.35	10.05	-67.30
Total abl.	-79.20	-13.82	-81.24	-77.35		
Total acc.	6.41	22.01	16.64		10.05	
Net abl. or acc.	-72.79	8.19	-64.60			-67.30

TABLE II (con't)

VERTICAL SNOW SURFACE CHANGES
AT SEWARD NUNATAK STATION, ST. ELIAS MOUNTAINS
YUKON TERRITOY, CANADA

Lat.: 60° 20' N
Long.: 139° 55' W   Elevation: 1,860 meters   Date: August, 1964

YUKON STANDARD TIME

Date	Daily values (cms) 06-18	18-06	06-06	Cumulative values (cms) 06-18	18-06	06-06
1-2	- 1.60	- 0.43	- 2.03	- 78.95	9.62	- 69.33
2-3	- 7.75	- 0.46	- 8.21	- 86.70	9.16	- 77.54
3-4	- 3.51	0.00	- 3.51	- 90.21	9.16	- 81.05
4-5	- 4.01	- 0.44	- 4.45	- 94.22	8.72	- 85.50
5-6	- 3.51	0.33	- 3.18	- 97.73	9.05	- 88.68
6-7	- 4.11	- 0.01	- 4.12	-101.84	9.04	- 92.80
7-8	- 4.32	- 0.13	- 4.45	-106.16	8.91	- 97.25
8-9	- 3.30	0.00	- 3.30	-109.46	8.91	-100.55
9-10	- 3.58	2.16	- 1.42	-113.04	11.07	-101.97
10-11	- 4.49	- 4.45	- 8.94	-117.53	6.62	-110.91
11-12	- 1.96	2.54	0.58	-119.49	9.16	-110.33
12-13	0.20	0.76	0.96	-119.29	9.92	-109.37
13-14	- 0.84	0.31	- 0.53	-120.13	10.23	-109.90
14-15						
15-16						
16-17						
17-18						
18-19						
19-20						
20-21						
21-22						
22-23						
23-24						
24-25						
25-26						
26-27						
27-28						
28-29						
29-30						
30-1						
Total abl.	-42.98	- 5.92	-44.14	-120.13		
Total acc.	0.20	6.10	1.54		10.23	
Net abl. or acc.	-42.78	0.18	-42.60			-109.90

Seward Ice

An ablation network similar to the one used at Divide was installed $1\frac{1}{2}$ Km west of Seward Rock and out on the glacier surface. The stakes were implanted on 13 July and readings were made weekly until the close of the field season on 13 August. A hygrothermograph, with weekly charts, was placed immediately to the north of the Seward Ice stakes. Surface lowering measurements were made in conjunction with the changing of the hygrothermograph charts. The network enclosed a square area 4 times that of the Divide Station network. Ablation stakes consisted of the same type conduit poles and the same methods of installation were followed. Data are presented in Table III.

Analysis of 1964 Field Season

Weather and Ablation

Seward Rock and Seward Ice

The most striking aspect of the 1964 Ablation Season at Seward Rock and Seward Ice locations is the rapid and almost constant rate of snow surface lowering (Fig. 2), which commenced in mid-July and proceeded to the close of the field season. Prior to this sudden increase, ablation showed no definite trend, but from mid-July on daily melting took place regularly. This is a reflection of the deterioration of the chilled layer which was also noted by Sharp for this location.[1]

Snow surface lowering at Seward Rock was 104 cms compared to 49 cms at Seward Ice over the period 13 July to 13 August. Snow pit

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[1] Sharp noted that a sudden amelioration began July 3 and lasted throughout the 1949 field season. See Sharp, R.P. "Thermal Regimen of Firn on Upper Seward Glacier, Yukon Territory, Canada," Journal of Glaciology, I (March, 1951), p. 484.

TABLE III

VERTICAL SNOW SURFACE CHANGES AT SEWARD ICE STATION, ST. ELIAS MOUNTAINS YUKON TERRITORY, CANADA*

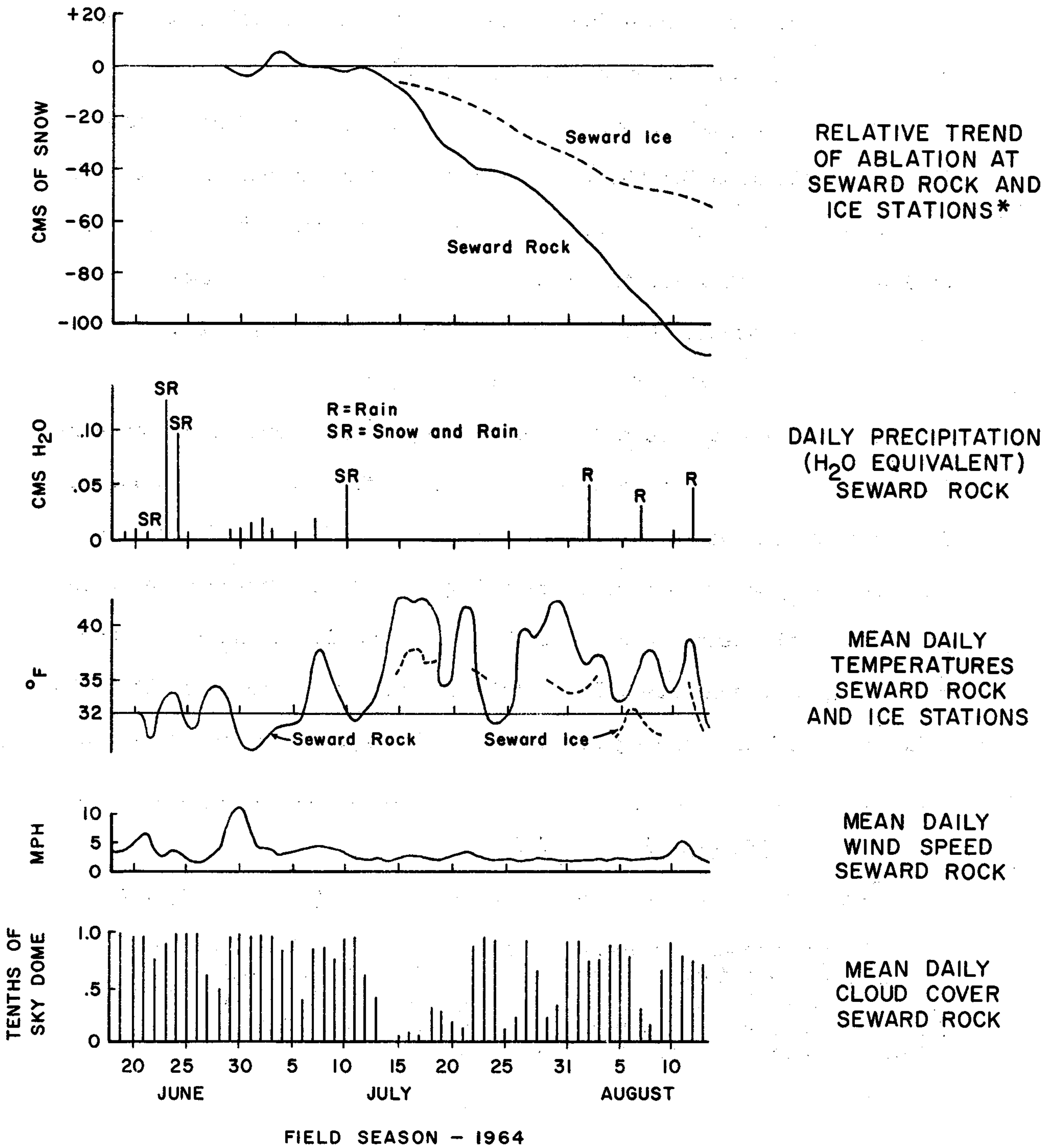
Lat.: 60° 20' N
Long.: 139° 57' W   Elevation: c. 1,780 meters

Date	Time of obs. (YST)	Net lowering (cms)	Cumulative net lowering (cms)
7/13	1030		0
7/20	1030	- 8.92	- 8.92
7/27	1430	-13.34	-22.26
8/3	1330	-16.32	-38.58
8/10	1300	- 6.72	-45.30
8/13	1045	- 3.54	-48.84

* Values are average lowering or raising of the snow surface as indicated by a five stake ablation farm just south of Seward Ice Meteorological shelter (containing a hygrothermograph) and approximately 1½ Kms west of and 80 meters lower than Seward Nunatak Station. The height of the stakes was read once each week (in conjunction with the changing of the hygrothermograph chart) beginning 13 July and ending 13 August.

FIG. 2

WEATHER AND ABLATION
SEWARD ROCK AND SEWARD ICE STATIONS
1964



* Plus values indicate accumulation, minus values are ablation.

measurements at Seward Rock indicate that the average bulk density for the season was 0.51 gm/cm^3. Assigning water equivalent values to both stations based on this figure results in a value of 56 cms for Seward Rock and 25 cms for Seward Ice. Sharp gives a 1949 Ablation Season value of 44 cms for the Upper Seward Basin.[1]

From an analysis of two snow pit density profiles for Seward Rock (Fig. 3), mass loss for the field season was calculated. By this method mass loss for the field season at Seward Rock is equal to 30 cms water equivalent, a much lower figure than that obtained from stake measurements. It is assumed that the actual mass loss at Seward Ice is likewise less than that from stake measurements.

Although the two Seward sites are only 1½ Km apart, there appears to be an appreciable difference in mass loss for the field season. It is hypothesized that a considerable proportion of this difference can be attributed to exposed rocks which supply a local source of heat to portions of the Seward Rock nunatak during the middle and latter parts of the field season, i.e., later July and August;[2] and also attributable to a cold air ponding effect over the large Upper Seward Glacier.[3]

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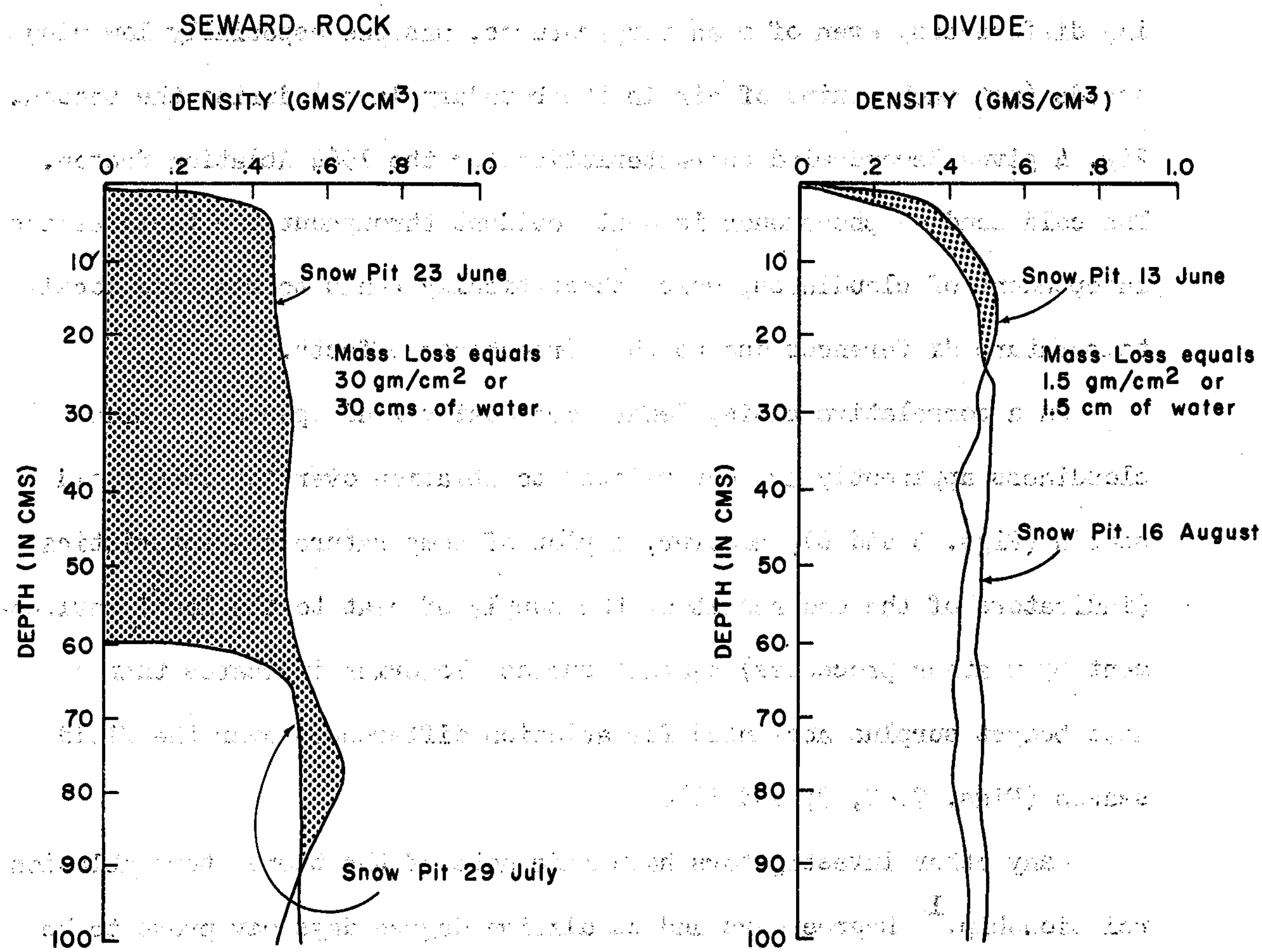
[1]Sharp, R.P. Op. Cit., p. 738

[2]This phenomenon was noted by Sharp, R. P., Op. Cit., p. 736.

[3]Marcus presents a short analysis in Marcus, M.G., "Summer Temperature Relationships Along a Transect in the St. Elias Mountains Alaska and Yukon Territory," Man and the Earth, Series in Earth Sciences No. 3, University of Colorado Studies, University of Colorado Press, Boulder, 1965, p. 25.

FIG. 3

SNOW DENSITY PROFILES* FOR SEWARD ROCK AND DIVIDE STATIONS
1964 FIELD SEASON



*For the techniques in analyzing mass loss by snow pit studies, see LaChapelle E. "Errors in Ablation Measurements from Settlement and Sub Surface Melting" Journal of Glaciology, III (No. 26), 1959, 459.

Located on the glacier surface, Seward Ice is much more affected by cold air drainage and ponding than Seward Rock. These local conditions are expressed in the mean daily temperatures for both sites (Fig. 2). Temperatures at Seward Ice were considerably lower during most of the field season. One of the principal reasons for the striking differences, even of mean temperatures, was the especially low wind speeds (not much mixing of air in the boundary layer) during the season. Fig. 4 gives Seward wind characteristics for the 1964 Ablation Season. The cold ponding phenomenon is quite evident throughout the field season, independent of cloudiness, which theoretically tends to minimize local temperature differences due to the "Greenhouse effect".

On a correlative basis, Seward mean daily wind speeds and mean cloudiness apparently are not related to ablation over the 1964 field season (Figs. 5 and 6); however, a plot of temperature characteristics (indicators of the end result of the supply of heat to the local environment by weather processes) against surface lowering indicates that a heat budget surplus accounted for ablation differences over the field season (Figs. 7, 8, 9, and 10).

Many other investigators have made note of the temperature ablation relationship.[1] Degree days and cumulative degree days may prove to be

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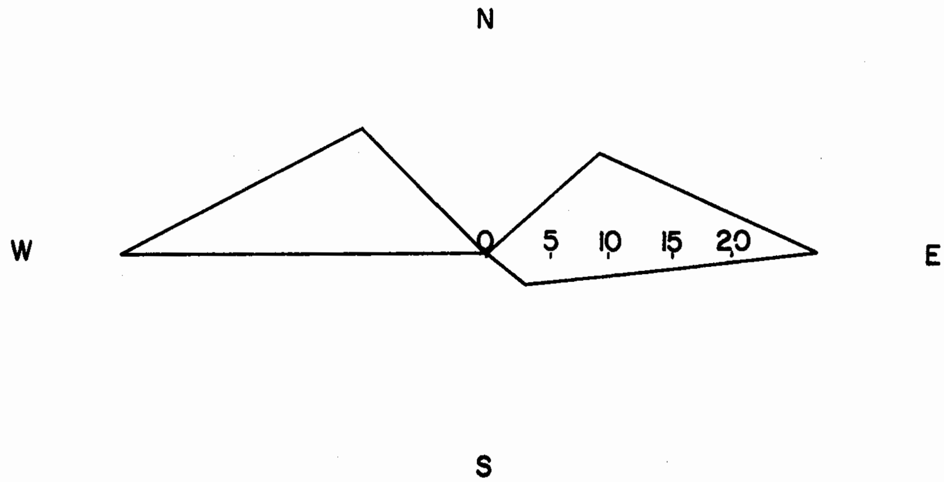
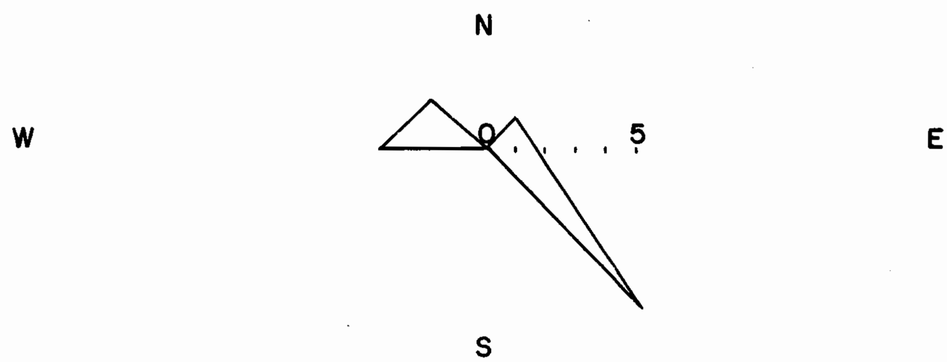
[1] See, for example, Larsson, P. "A Preliminary Investigation of the Meteorological Conditions on the Chamberlain Glacier, 1958," Research Paper No. 2 (Washington: Arctic Institute of North America, 1960), p. 67; Hoeck, E. "Influence of Radiation and Temperature on Melting Process of the Snow Cover," Beitrage zur Geologie der Schweiz, Geotechnosche Serie, Hydrologie, Lieferung 8, 1952, p. 51; Nobles, L.H. "Glaciological Investigations, Nunatarssuaq Ice Ramp, Northwestern Greenland," Technical Report #66, U.S. Army S.I.P.R.E., May, 1960 p.16; Keeler, C.M. Op. Cit., p.76, and Marcus, M.G., Climate-Glacier Studies in the Juneau Ice Field Region, Alaska. Research Paper No. 88 (Chicago: University of Chicago, 1964), pp. 75-79.

FIG. 4

SEWARD ROCK WIND CHARACTERISTICS
SUMMER 1964



WIND DIRECTION FREQUENCY
(PERCENT)



AVERAGE WIND SPEEDS FROM GIVEN DIRECTIONS
(MILES PER HOUR)

FIG. 5

MEAN DAILY CLOUDINESS VERSUS DAILY ABLATION*
SEWARD ROCK – 1964

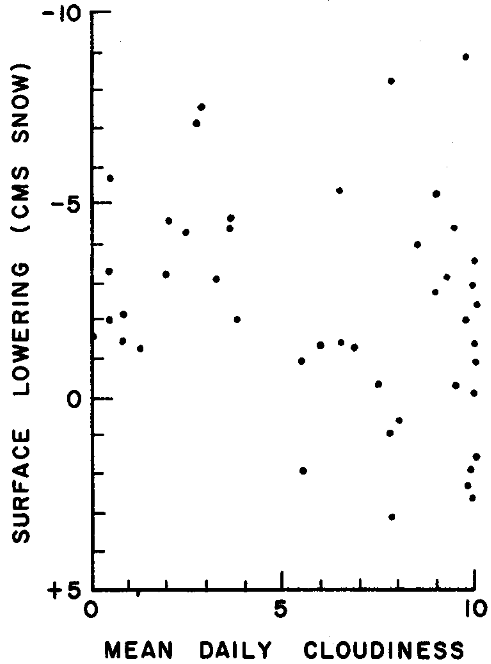
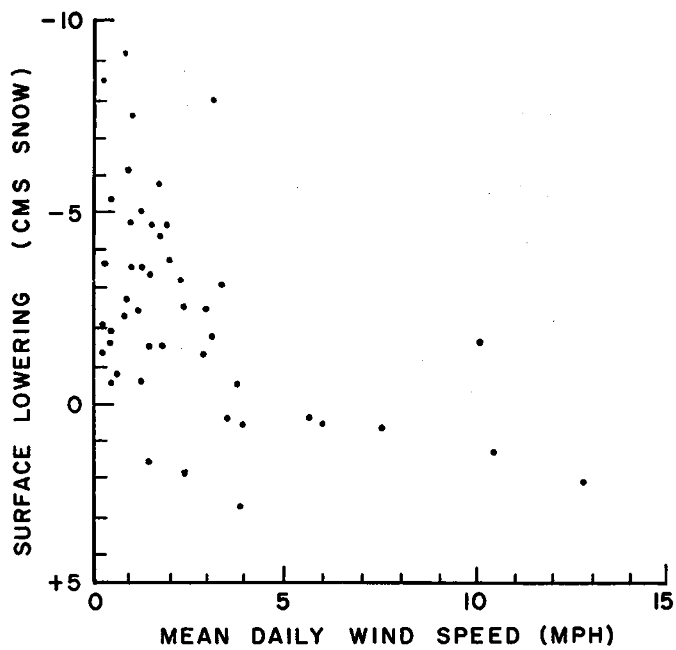


FIG. 6

MEAN DAILY WIND SPEED VERSUS DAILY ABLATION
SEWARD ROCK – 1964



*Plus values indicate accumulation, minus are ablation.

FIG. 7

DAILY NOON TEMPERATURES VERSUS DAILY ABLATION* (0600-1800)
SEWARD ROCK — 1964 FIELD SEASON

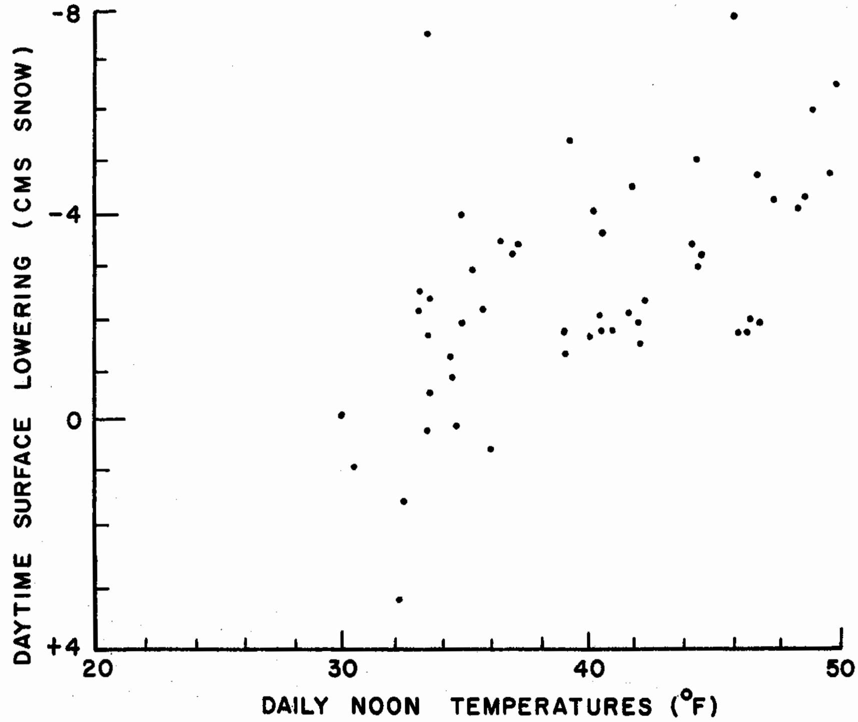
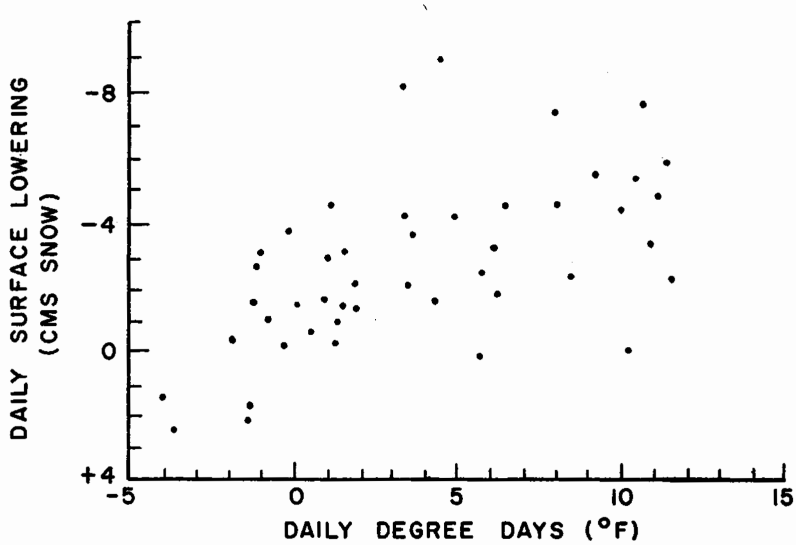


FIG. 8

DAILY DEGREE DAYS** VERSUS DAILY ABLATION
SEWARD ROCK — 1964 FIELD SEASON



*Plus values indicate accumulation, minus are ablation.
**To calculate degree days take the difference (plus or minus) of the mean daily temperature and 32°F for each day.

FIG. 9

CUMULATIVE DEGREE DAYS VERSUS CUMULATIVE ABLATION
SEWARD ROCK - 1964 FIELD SEASON

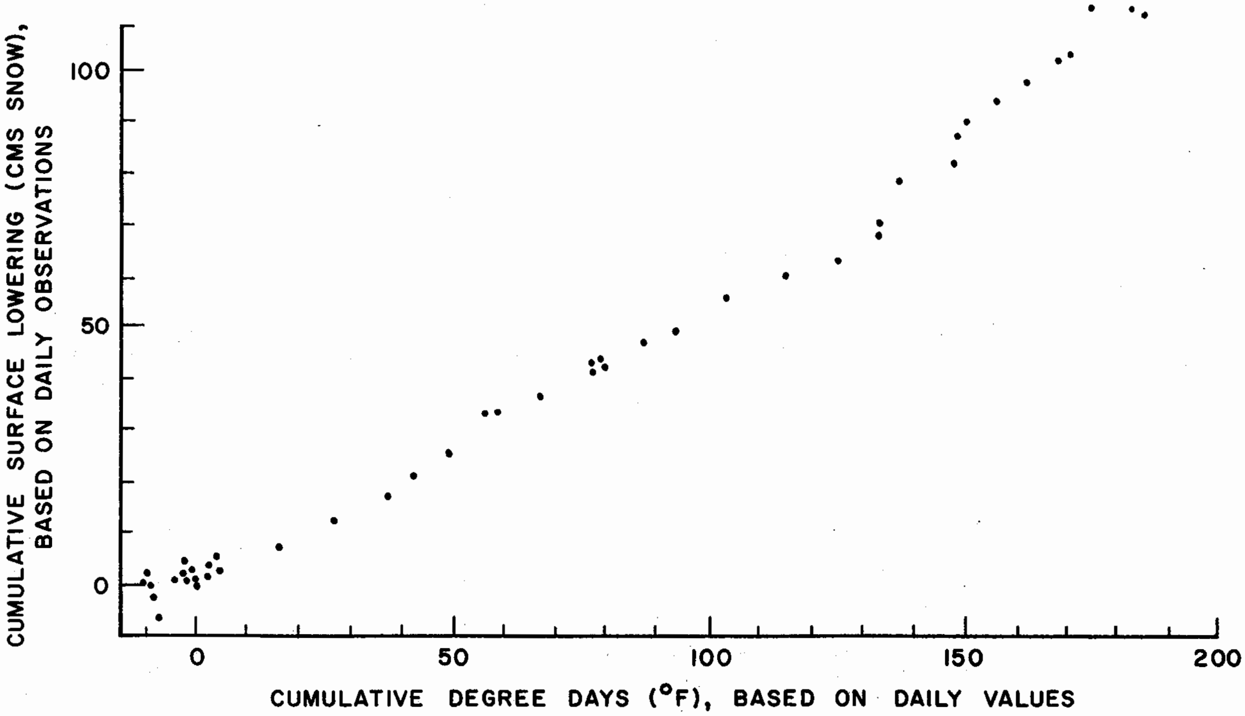
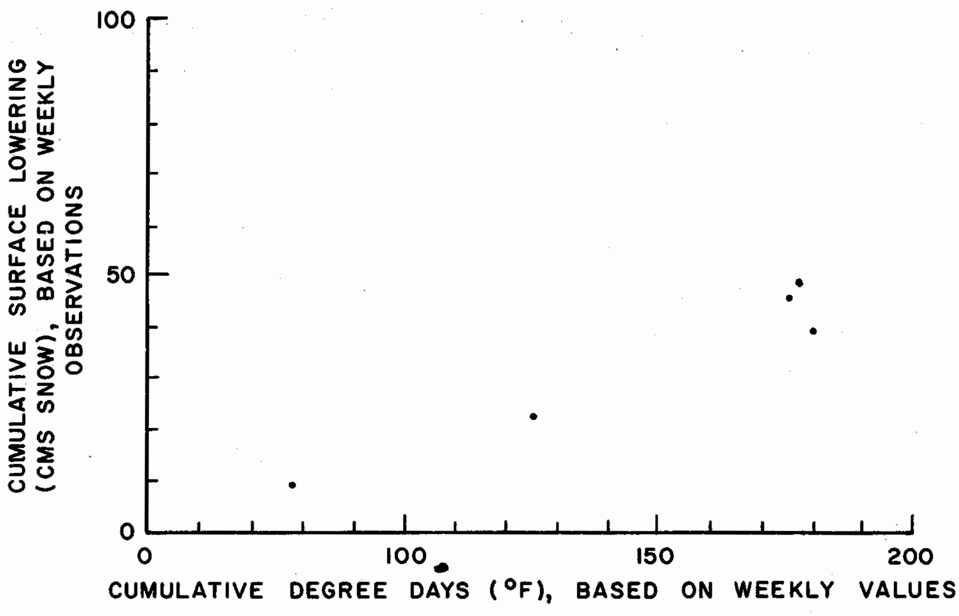


FIG. 10

CUMULATIVE DEGREE DAYS VERSUS CUMULATIVE ABLATION
SEWARD ICE - 1964 FIELD SEASON



accurate estimators of the temporal and spatial variations of mass loss throughout an ablation season.

Divide Station

The Divide area, at a higher elevation and at the head of the accumulation zones of the Hubbard and Kaskawulsh Glaciers, lies just above the temperate-subpolar glacier transition zone.[1] Measurements of snow temperatures have been recorded in all years as late as early August towards the close of the ablation Season.[2]

Net surface lowering at the Divide for the 1964 field season was only 1.3 cms. From snow pit studies at the beginning and completion of the field season, mass loss is estimated to be only 1.5 cms water equivalent (Fig. 3). Only during clear weather in July was the rate of surface lowering substantial (Fig. 11). During this period sunshine was at a maximum, wind speeds were very low, and daytime temperatures were well above freezing. Mean daily temperatures were considerably less than daytime temperatures because of a large diurnal temperature range. This is due in part to local cooling brought on by outgoing long wave radiation from the snow surface during clear evening hours. This phenomenon caused freezing and crusting of the upper snow layer. It is significant to note from Table I that nighttime ablation measurements showed a net raising of the surface relative to ablation stakes. This same relationship appears for the Seward stations.

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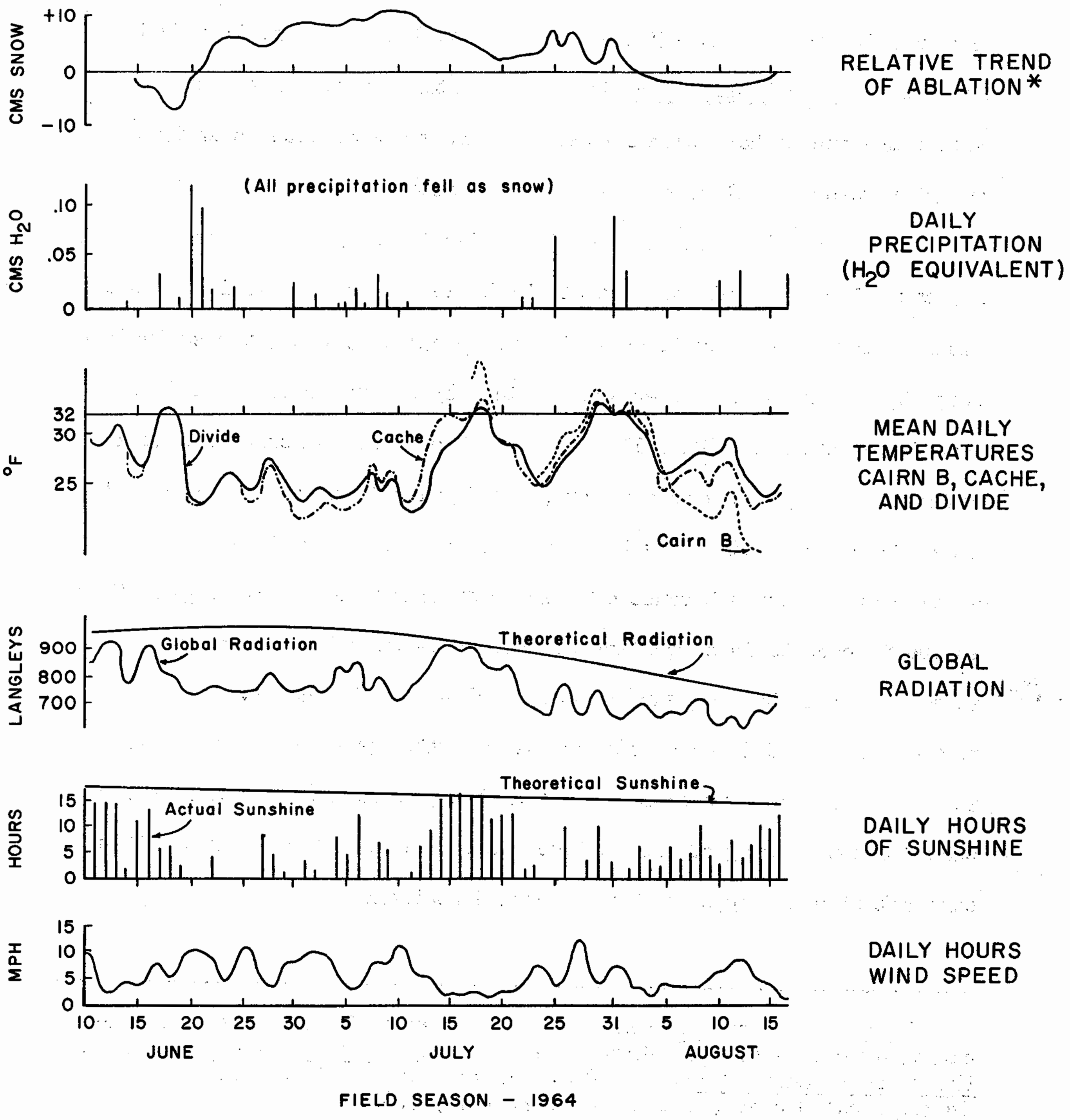
[1] Temperate - subpolar are defined in terms of Ahlmann's classification of glaciers. See Ahlmann, Hans W:Son, Glaciological Research on the North Atlantic Coasts. R.G.S. Research Series: No. 1 The Royal Geographical Society, London, S.W. 7, 1948, p.66.

[2] Marcus, M.G., "A Hydrological Traverse......," p. 4.

FIG. 11

WEATHER AND ABLATION
DIVIDE STATION
1964



*Plus values indicate accumulation, minus values are ablation.

Other than the short July clear weather period at Divide, ablation-weather relationships are unclear.

Comparisons and Contrasts Between Seward and Divide.

From mid-July to the close of the field season, the trend of ablation at all three stations was similar (Fig. 12). The slopes of the curves express the difference in geographic site and situations. The slope of the Divide curve is much less than those of Seward. This is primarily due to higher elevation, cooler temperatures, and the severity of the 1964 weather at the Divide compared to stations at lower elevations. On a correlative basis (Fig. 13) the relationship reveals the expected pattern - greater ablation at Seward per ablation at Divide as the Ablation Season progresses. A least squares parabola was fitted to the scattergram and the equation of the curve is given by:

$$S_a = -65.4 + 10.7D_a - .50D_a^2$$

where S_a = Seward cumulative ablation (snow surface lowering)

D_a = Divide cumulative ablation (snow surface lowering).

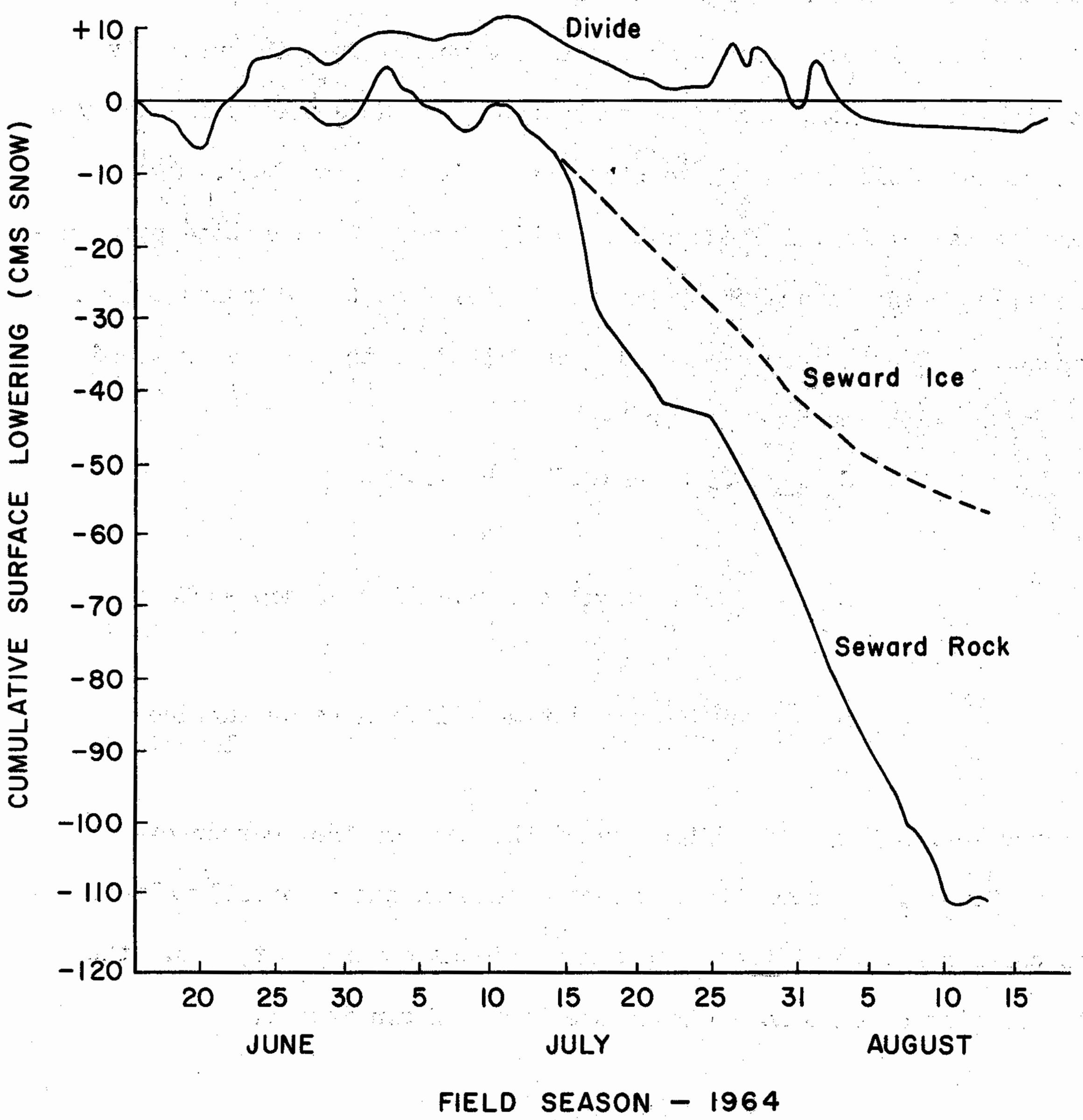
The relationship is a reflection of the more marine, warmer exposure of Seward. However, this expected pattern can be greatly altered by the complex nature of this rugged mountainous environment, viz., the local variation of mass loss within the Seward Basin itself.

Summary

On a broad scale, the climate across the St. Elias Mountain Range SW to NE changes from marine to continental in character, although locally vast differences in relief, orientation, terran configuration,

FIG. 12

COMPARISONS OF RELATIVE TRENDS OF ABLATION*
DIVIDE AND SEWARD STATIONS
1964



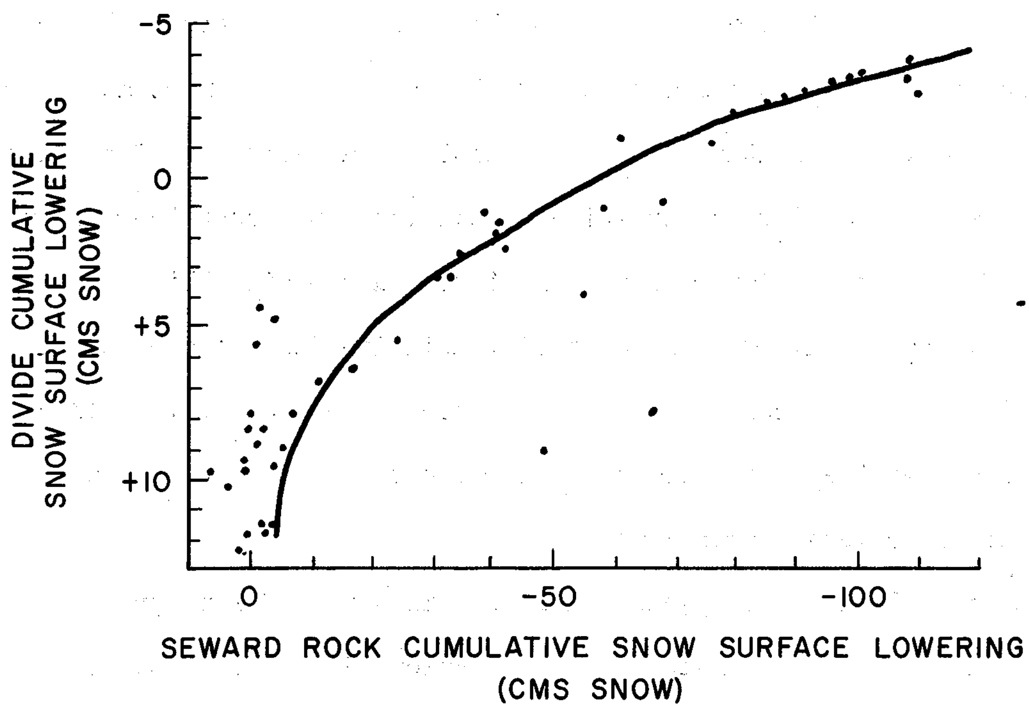
* Plus values indicate accumulation, minus are ablation.

FIG. 13

CORRELATION OF CUMULATIVE ABLATION*

DIVIDE VERSUS SEWARD ROCK

1964



* Plus values indicate accumulation, minus are ablation.

and type of surface alter the expected variation.

Accumulation and ablation, which inevitably determine the health of the immense snowfields and glaciers across the range, show, for the most part, the expected variations with climate on both large and small scales. Ablation at Seward for the 1964 field season was approximately 30-50 cms water equivalent, while at the topographic divide, ablation was only 1.5 cms. The water differential between Seward and Divide during the 1964-65 Accumulation Season was estimated at 2 to 1; during the 1964 Ablation Season the loss of water from the glacier interface to lower elevations and/or to the atmosphere was at least 30 times more at Seward than at Divide. Correlations between ablation and estimates of the amount of heat available during the Ablation Season indicates that the warmer marine environment and lower elevation of Seward explains this large ablation differential. On a local scale, ablation differs over small areas primarily in response to local climatic processes, e.g., cold air ponding and heat transfer from warmer air sources. Seward Rock and Ice illustrate these local variations.

Whether only a few stations can be utilized in order to provide insights into accurate climate-glacier relationships remains to be determined. In an area with so great a dimension as the St. Elias Range, it appears that a large weather and ablation network would be needed in determining accurate environmental relationships.

BIBLIOGRAPHY

Ahlmann, Hans W:Son. Glaciological Research on the North Atlantic Coasts. R.G.S. Research Paper: No.1, The Royal Geographical Society, London, 1948.

Hoeck, E. "Influence of Radiation and Temperature on Melting Process of the Snow Cover," Beitrage zur Geologie der Schweiz, Geotechnische Serie Hydrologie, Lieferung 8, pp 1-36 (1952), Translated into English by K. Martinoff of USA SIPRE Bibliography Project, Library of Congress - Translation #49, January 1958.

Keeler, C. M. "Relationship Between Climate, Ablation, and Run-off on the Sverdrup Glacier, 1963 Devon Island, N.W.T.," Research Paper #27 (Washington: Arctic Institute of North America, 1964), 80 pp.

Larsson, P. "A Preliminary Investigation of the Meteorological Conditions on the Chamberlain Glacier, 1958," Research Paper #2 (Washington: Arctic Institute of North America, 1960), 89 pp.

Marcus, M. G. "A Hydrological Traverse of Glaciers in the Icefield Ranges, St. Elias Mountains, Alaska-Yukon Territory," (A paper presented at the VII INQUA CONGRESS of the International Association for Quaternary Research, Boulder, Colorado, Sept. 1, 1965), 7 pp.

__________. Climate-Glacier Studies in the Juneau Ice Field Region, Alaska. Research Paper No. 88 (Chicago: Univ. of Chicago, 1964), 128 pp.

__________. "Icefield Ranges Climatology Program St. Elias Mountains, 1964 - Part I: Data Presentation," Research Paper #31-A (Washington: Arctic Institute of North America, 1965), 109 pp.

__________. "Summer Temperature Relationships Along a Transect in the St. Elias Mountains; Alaska and Yukon Territory," Mand and Earth, Series in Earth Sciences (Boulder: Univ. of Colorado Press, 1965) pp. 15-30.

Nobles, L. H. "Glaciological Investigations, Nunatarssuag Ice Ramp, Northwestern Greenland," Technical Report #66, U.S. Army S.I.P.R.E., May 1960.

Sharp, R.P. "Accumulation and Ablation on the Seward-Malaspina Glacier System, Canada-Alaska," Bulletin of the Geological Society of America, LXII (July, 1951), 726-744.

__________. "Thermal Regimen of Firn on Upper Seward Glacier, Yukon Territory, Canada," Journal of Glaciology, I (March, 1951), 476-487.

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