THE SUMMER CLIMATE OF THE ST. ELIAS MOUNTAINS REGION

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Department of Meteorology

Master of Science

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The study indicates that:

a) A climatic divide can be located between the Divide and Kaskawulsh stations on the continental slope.

b) Two types of station exist with respect to temperature records.

c) Anomalously low wind speeds are experienced at the Seward and Divide stations and strong glacier winds persist at the Kaskawulsh station.

d) The factors determining the climate of the area can be separated into three scales of influence.

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by

Bea Taylor

A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfillment of the requirements for the degree of Master of Science.

Department of Meteorology
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ACKNOWLEDGEMENTS

This study was carried out as part of the Icefield Ranges Research Project (under the joint sponsorship of the Arctic Institute of North America and the American Geographical Society) and as a part of the graduate program of the Department of Meteorology, McGill University.

I should like to acknowledge the efforts of the many investigators who took part in the IRRP climatology program during the years 1963 to 1965. (See acknowledgements in Havens (12), Marcus (17), and Marcus, Rens, and Taylor (20).) This program could not have operated without the support of Dr. Walter A. Wood, Project Director; Richard H. Ragle, Field Director; and Philip Upton, pilot of the project aircraft. Dr. Melvin G. Marcus of the Department of Geography of The University of Michigan, as leader of the climatology program in 1964 and 1965, was particularly responsible for the collection and reduction of the data and for the initiation of the present study. I am very grateful for the direction and advice he provided both in the field and in later stages of this study.

I am indebted to the Norsk Polarinstitutt, Oslo, Norway, (where I was a "stipendiat" during the 1966-67 term) for the facilities they made available to me during the final stages of this study; to my family who, among other things, acted as "overseas agents" during this time; and to Miss Alyse Chin-A-Loy who prepared this typescript.

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CHAPTER I

INTRODUCTION

Climatological and meteorological discussions of the southwest corner of the Yukon Territory[1] and the adjacent portions of the Alaska Panhandle[2] invariably point to the contrasts in the climatic regimes of these two regions, and observe that the intervening mountain ranges (which form the political as well as topographical boundary between Alaska and the Yukon) are largely responsible for these regimes (see Hare (9), Mitchel (22), Kendrew and Kerr (15), Reed (27), etc.).

Until recently[3] however, discussion has of necessity been confined to the meteorological records from the stations lying well to the east and to the west of the actual mountain barrier (e.g. Whitehorse and Yakutat). In 1961 with the initiation of the Icefield Ranges Research Project it became possible to delve into the climate of the vast areas of ice, snow, and rock (at high elevations) separating the Alaska coast and the southwest Yukon plateau.

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[1] Canada

[2] U.S.A.

[3] Until the initiation of the Icefields Ranges Research Project in 1961 (see section 2) little climatological data had been collected from the area though other types of research had been carried out.

The factors which make such a study desirable are briefly:

1. The investigation of the climate of a little known corner of the world contributes to our overall knowledge of the earth's climate.
2. Climatic studies of high mountain glacerized areas are comparatively few. Due to this and the complexity of climatic regimes of such areas many questions remain unanswered concerning them.
3. Glaciological, biological, and geophysical studies of an area invariably require diverse types of meteorological data as well as a general knowledge of the region's climatic regime.[4]
4. All too often when glaciological or other geophysical studies of an area are carried out the meteorological data collected is not analysed from a climatological stand point. Rather it is utilized only in the particular geophysical study and thus often misused.
5. Finally two entirely different climatic regimes exist in the area within a few hundred miles of each other. Both of these are presumably largely the result of the mountains between them. Thus a climatic profile across this barrier would undoubtedly be useful as an aid to understanding weather conditions to the east and west of it.

[4]Of particular interest is the interaction between meteorological and glaciological phenomena - i.e., heat transfer and mass wasting.

With these factors in mind the aims of this study are:

a) To organize and reduce the meteorological data collected by the members of the Icefield Ranges Research Project during the summers of 1963, 1964, and 1965 and to analyse this data along with the long and short term records of the various permanent stations bordering the mountains (particularly Whitehorse and Yakutat).

b) To probe the problems of mountain climates, of mountain margin climates, as well as problems of collection, reduction and representativeness of the data. In addition, to present a picture of the summer climate of the St. Elias Mountains region.

c) From the above to provide a basis for future meteorological studies and a background for other environmental investigations of the area.

The present study has been divided into the following three parts.

PART A will lay the groundwork first by describing briefly the history of the Icefield Ranges Research Project, the geographical environment of the area and the meteorological program carried out; secondly by reviewing the large scale climafe (i.e. general circulation, temperature fields etc.) of N. W. North America; and thirdly by analysing and comparing the long term seasonal averages and variations of the meteorological parameters recorded at Whitehorse and Yakutat.

PART B will present a parameter by parameter analysis of the Icefield Ranges Research Project data as well as the corresponding Yakutat and Whitehorse records for comparison, a synoptic analysis of selected periods and a discussion of the 1964 and 1965 surface and 500 mb flow.[5]

PART C will attempt to answer the questions, explain the anomolies and probe the problems arising out of Part A and Part B to the extent warranted by the data. In addition Part C will endeavour to interrelate the various findings of the study and point the way for future investigation.

1. THE ICEFIELD RANGES RESEARCH PROJECT (IRRP)[5a]

This research project was initiated in 1961 by Walter A. Wood and under the auspices of the American Geographical Society and the Arctic Institute of North America with the object of studying the total environment of a high mountain glacerized region. In addition it was hoped to offer field training to graduate and undergraduate students in the snow and ice studies and related environmental sciences. The region chosen for the project (as the name suggests) was a portion of the Icefield Ranges in the St. Elias Mountains on the border of Alaska and the Yukon Territory.

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[5] This section will necessarily be rather dry but will form the basis for the more interesting discussions to follow and provide detailed information for those interested in the data for other purposes.

[5a] The project will henceforth be referred to as IRRP.

A reconnaissance was carried out by a field party of seven men in the summer of 1961. It included a series of flights over the St. Elias Mountains resulting in the positioning of the first glacier camp (Divide '61).[6] At this station, occupied from 1 July to 7 August, glaciological and meteorological studies and a topographical survey were carried out.

The program was considerably expanded during the subsequent four[7] summers.

In 1963 a regular climatological program was initiated at the glacier camp (Divide) and the base camp (Kluane).[8] Two new stations were opened in 1964 (Seward and Kaskawulsh)[8] and four automatic stations maintained during this year (Seward Ice, Divide Cache, Divide Cairn-B and Terminus).[8] During the field season of 1965 (at which time the author was a member of the project) the meteorological program was again expanded, though no new stations were opened.[9]

In addition the project by this time involved seismic, crystal structure, motion, stress, mass budget and hydrological studies of the glaciers as well as ecological, zoological, geological, and geographical studies of the adjacent land areas.

---

[6] For location see Map 3. The exact position of this camp varied, however, unless reference is being made to one specific year Divide will be used to refer to all the positions.

[7] The project is still functioning but this study will use data from the years 1963, 1964 and 1965.

[8] See Map 2 and section 3 below.

[9] A more detailed outline of the meteorological program for the years 1963-65 will be given in section 5 and Tables IV and V.

2. GEOGRAPHICAL ENVIRONMENT

Stretching from Central America to the Aleutians and Northern Alaska is an orogenic belt which corresponds closely to the North American Cordillera physiographic division (McKay 21). The Coastal Mountain and Trough Province (subdivided from west to east into - Outer Mountains, Coastal Troughs and Coastal Mountains) borders the Pacific for the entire north-south extent of the Cordillera.

In the north (see Map 1), the Outer Mountains extend northwest from the Queen Charlotte Islands through the lofty St. Elias Mountains to the Chun gach, Kenai, and Kodiak ranges. They are separated from the Coastal Mountains (the dominant feature of which is the Coast Range Batholith) by a series of troughs which include the Inland Passage and the Kluane Lake Basin.

a) The Study Area[10]

The region to be discussed in the present study (shown in Map 2) extends from the Pacific Ocean to east of the Coastal Mountains. Several permanent meteorological stations (marked by squares in Map 2) are situated in this area.

Yakutat is likely the most coastal of the Alaska stations as it is surrounded on three sides by ocean. Sitka and Cape Yakataga are also found west of the Outer Mountains while Juneau, though on the sea coast is situated east of this range which appears here as off-shore islands.

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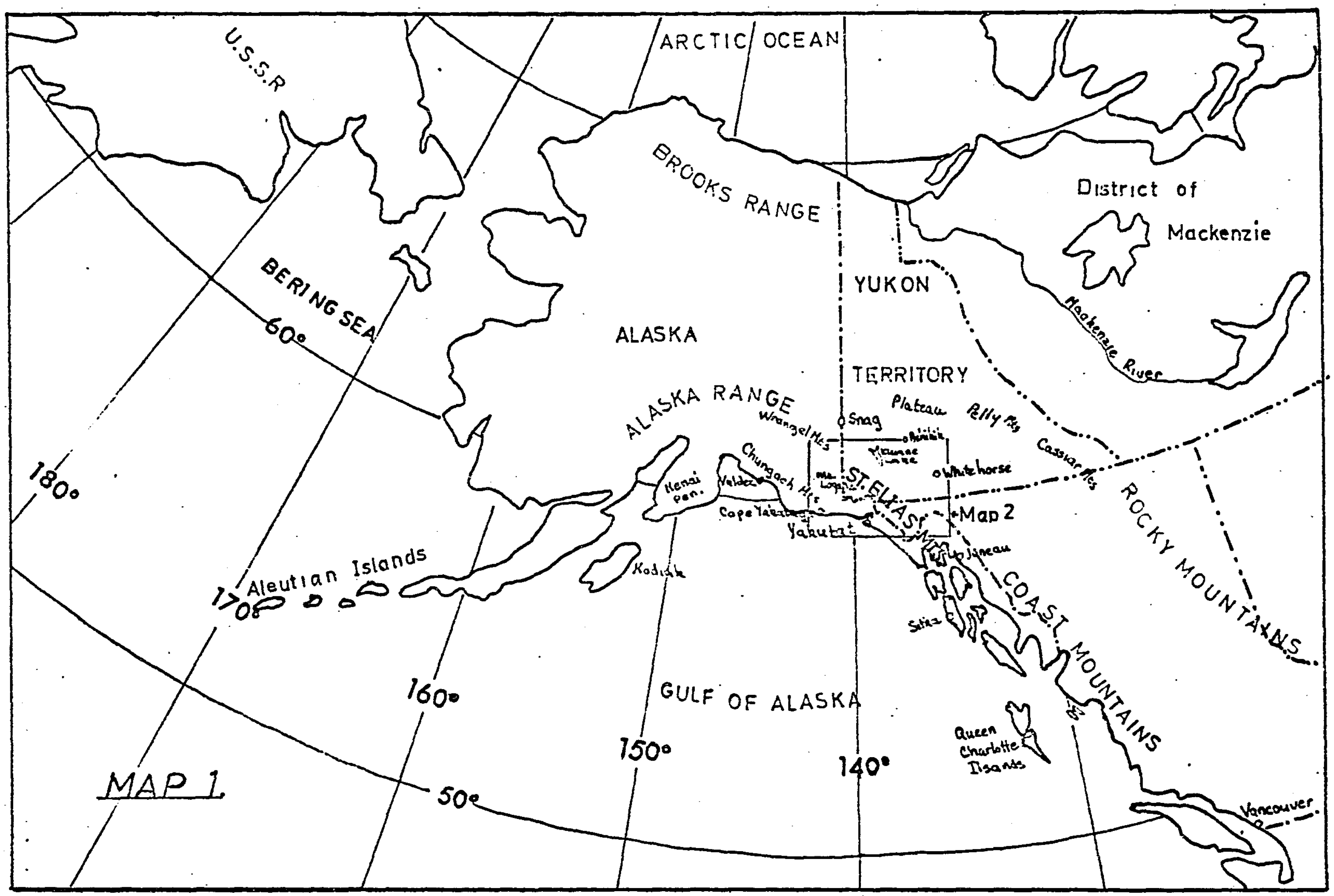
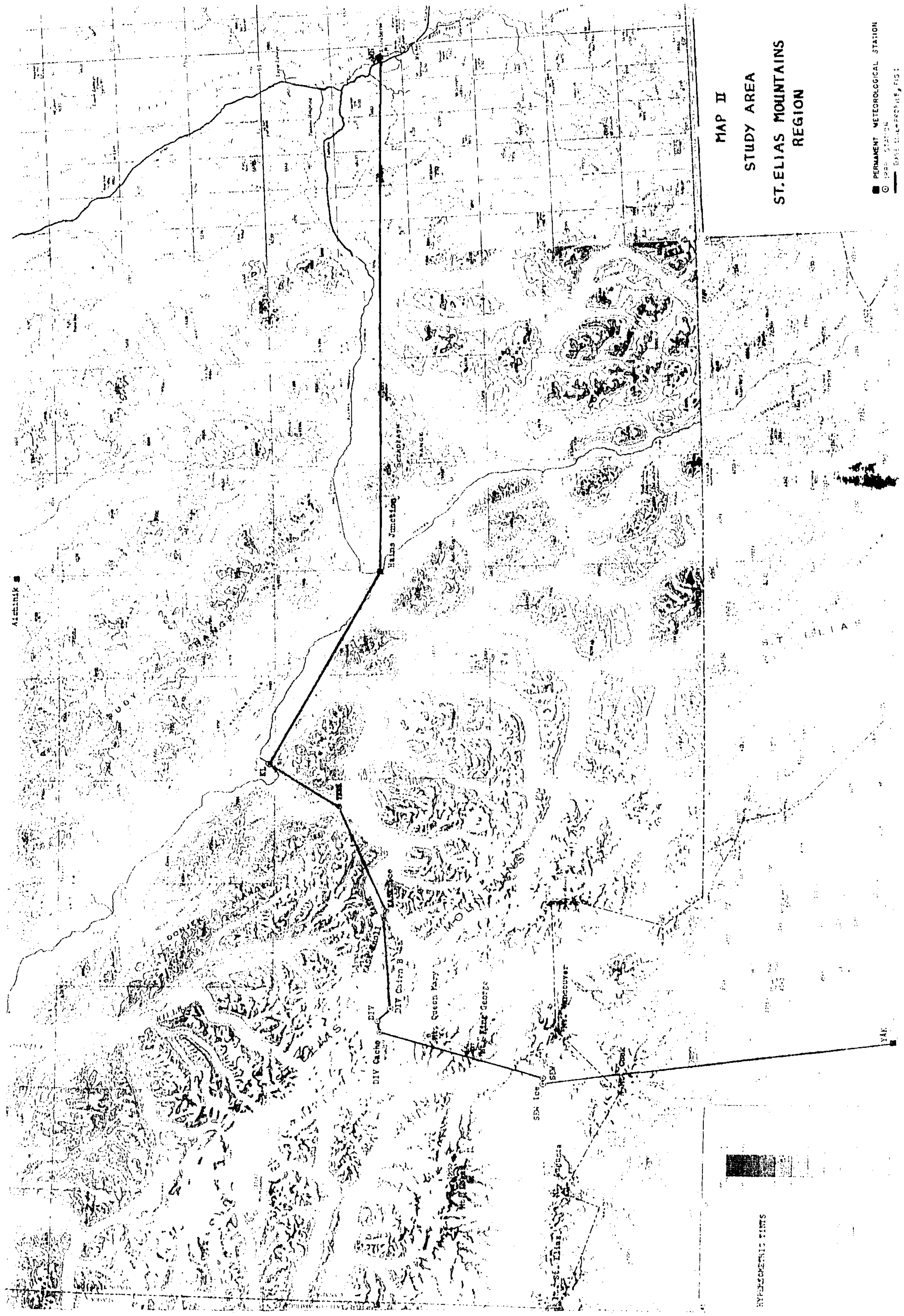
[10] The area represented in Map 2 and described in this section will henceforth be referred to as the study area - see also footnote 11, page 7.


ARCTIC OCEAN
U.S.S.R
BROOKS RANGE
District of Mackenzie
YUKON
TERRITORY
Mackenzie River
BERING SEA
60°
ALASKA
ALASKA RANGE
Wrangel Mts
Snag
Plateau
Pelly Mts
Cassiar Mts
Whitehorse
Map 2
ROCKY MOUNTAINS
180°
Kenai Pen.
Valdez
Chugach Mts
Cape Yakataga
Yakutat
Juneau
Kodiak
Aleutian Islands
170°
COAST MOUNTAINS
Sitka
160°
GULF OF ALASKA
150°
140°
Queen Charlotte Islands
MAP 1
50°
Vancouver

Map 1


MAP II
STUDY AREA
ST. ELIAS MOUNTAINS
REGION
PERMANENT METEOROLOGICAL STATION
Haines Junction
Aishihik
DIV Cache
SEW Ice
Mt. Vancouver
Mt. Queen Mary
Mt. King George
YAK
HYPSOMETRIC TINTS

Snag (notorious as the "cold pole" of North America) lies north of the St. Elias Range in the Yukon in a basin. Hains Junction is located on the Alaska highway in the Coastal Trough and Aishihik is found in a valley on the eastern slope of the Coastal Mountains. Still further east in the valley of the mighty Yukon River lies Whitehorse, capital of the Yukon Territory.

A rough topographical profile from Yakutat through the IRRP stations to Whitehorse is shown in Figure 1 (the base line being drawn on Map 2).

b) The St. Elias Mountains

Wahrhaftig (30, p.41) gives the following description of this range. (See Figures 2-5).

> The St. Elias mountains are probably the most spectacular mountains of North America. Massive isolated blocklike mountains 14,000-19,000 feet in altitude rise at intervals of 5-30 miles from a myriad of narrow ridges and sharp peaks 8,000-10,000 feet in altitude that, seen from a distance, gives the impression of a broad ice dome. The average altitude of the icefields in the interconnected valley system is 3,000-7,000 feet. Local relief is extreme and jagged cliffs abound.
>
> ...Drainage is almost entirely by glaciers. The ice divide between drainages of the Yukon, Copper, and Alsek River and the Pacific Ocean meet in this range.
>
> ...All parts of the range gentle enough to hold snow are sheathed in glacial ice. A continuous network of icefields and glaciers 4-15 miles wide and as much as 80 miles long penetrates the range and feeds piedmont glaciers to the south.

c) The Icefield Ranges[11]

The main range of the St. Elias Mountains (according to Bostock, 3) is the Icefield Ranges. In the heart of this range lies an accumulation

[11] When in the subsequent text the IRRP area is referred to it will mean the area covered by the IRRP stations. The Icefields area will refer more particularly to the glacierized area described in this section and shown in Map 3.

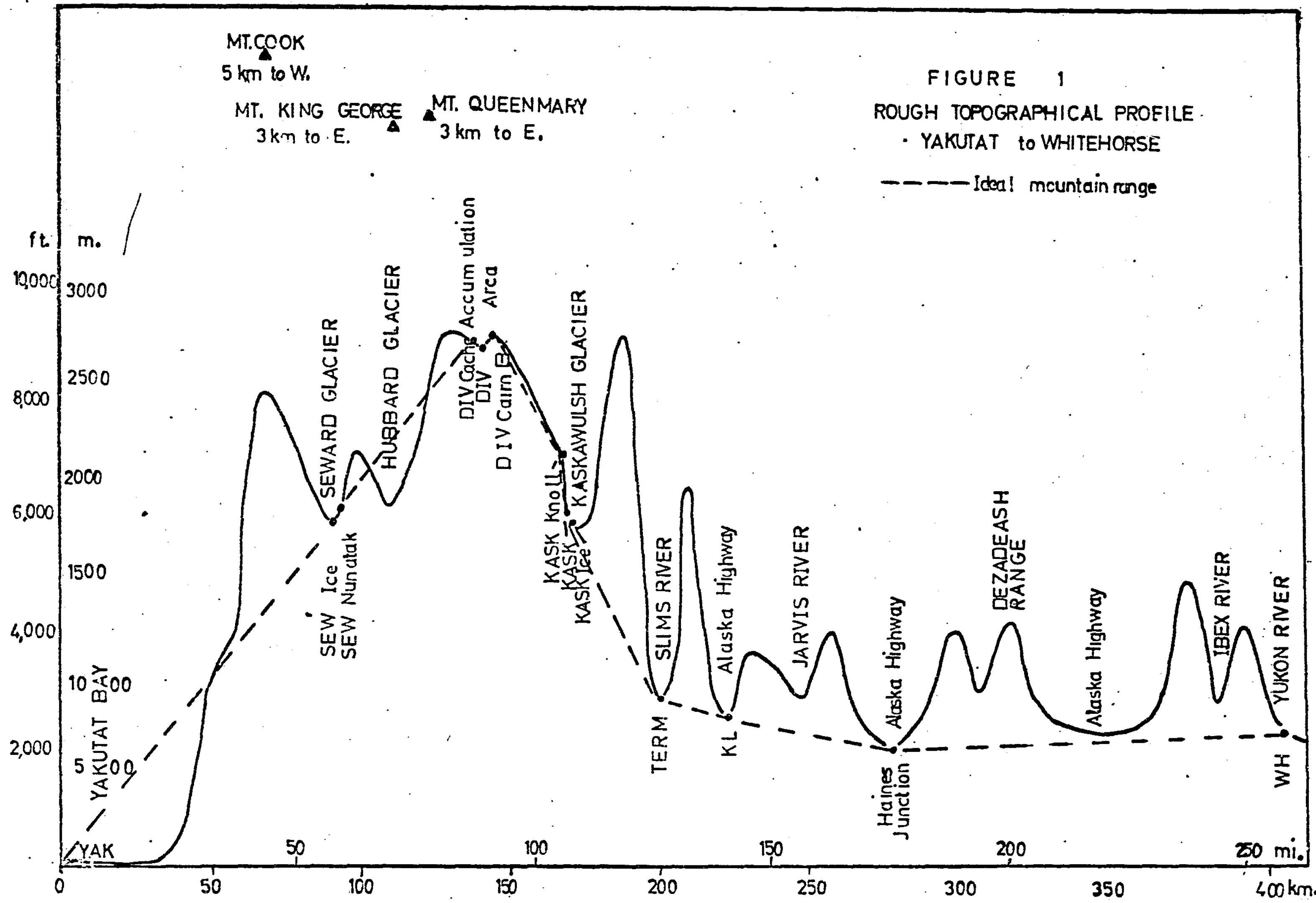
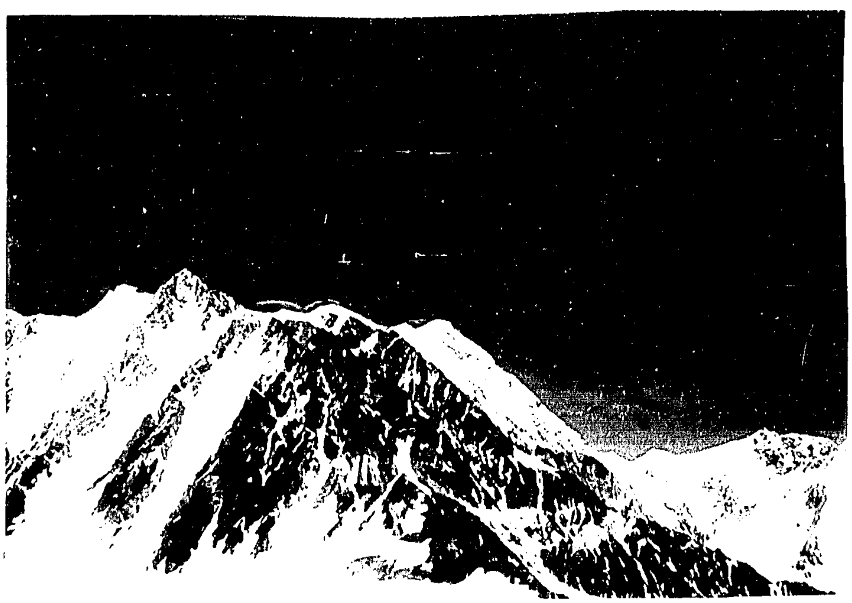


FIGURE 1

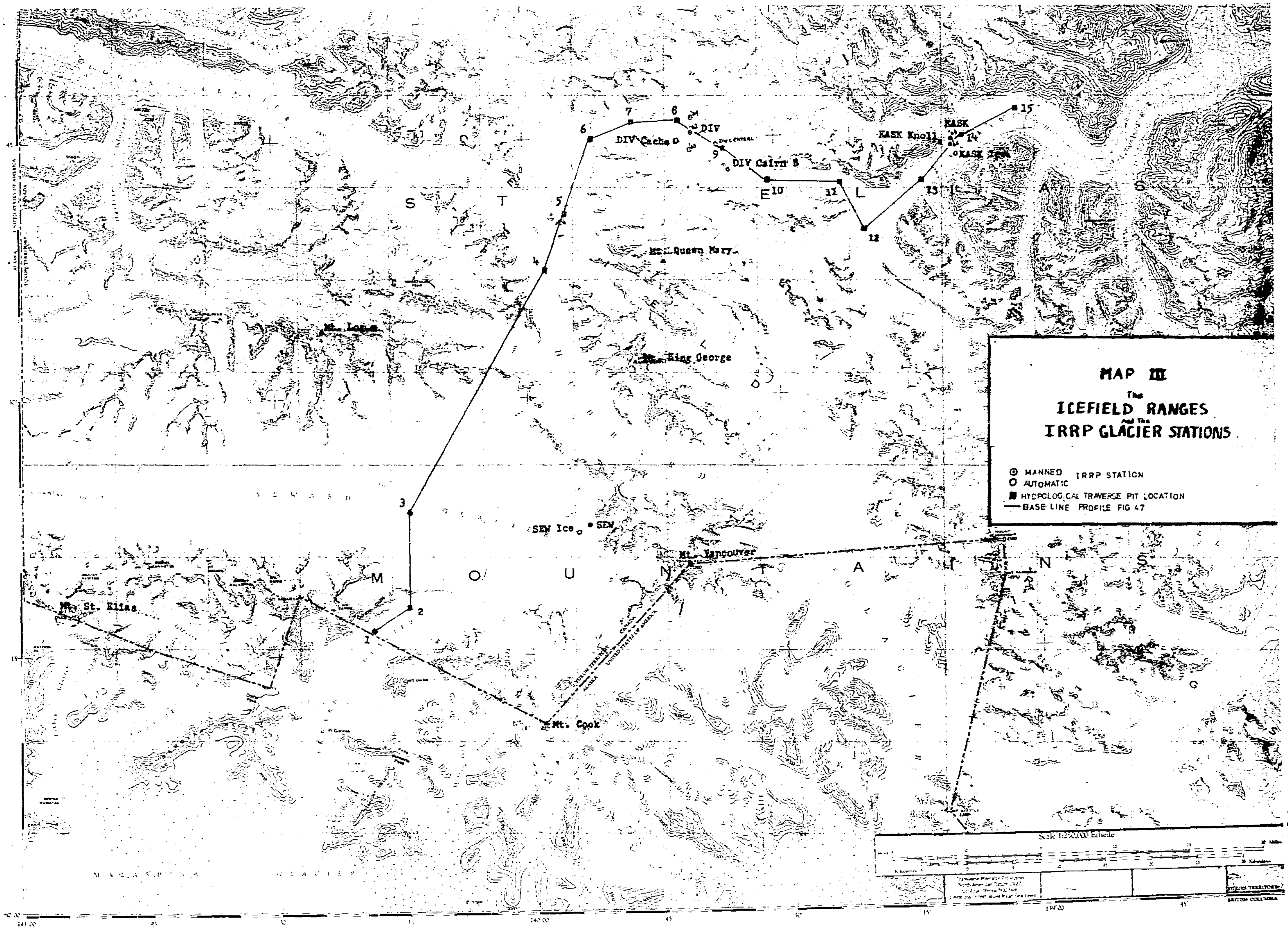
ROUGH TOPOGRAPHICAL PROFILE · YAKUTAT to WHITEHORSE

MOUNT LOGAN 19,850 ft. (from DIV Cache)



MOUNT VANCOUVER 15,700 ft. (from SE W)

Figure 2. Massive peaks of the St. Elias Mountains


MAP III
The ICEFIELD RANGES and The IRRP GLACIER STATIONS.
MANNED IRRP STATION
AUTOMATIC
HYDROLOGICAL TRAVERSE PIT LOCATION
BASE LINE PROFILE FIG 47
ST. ELIAS MOUNTAINS
ICEFIELD
DIV Cache
DIV
DIV Cairn B
KASK Knoll
KASK
KASK Ice
Mt. Queen Mary
Mt. King George
Mt. Logan
SEW Ice
SEW
Mt. Vancouver
Mt. Cook
Mt. St. Elias
1
2
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area of approximately 200 square miles from which radiate several of the longest glaciers outside the polar regions. Table I includes the drainage identification, orientation, length, and elevation of terminus of these.

The great diversification of glacier types (from long valley glaciers to small alpine glaciers) in the Icefield Ranges was one of the reasons for the choice of this area for the project.[12]

3. THE IRRP STATIONS

Table II shows the latitude, longitude, elevation, first record, and type of surface of the manned and automatic stations. There follows a short geographical description of the locations of the manned camps.

a) Kluane (KL)[13]

At the southern end of Lake Kluane on the gravel surface of an abandoned World War II North-West Staging Route air strip is located the base camp. The Alaska highway passes adjacent to the camp in the south east-north west tending valley of the Kluane Lake Basin. Sheep Mountain (7850 ft.) rises to the west across the lake and high land flanks the camp to the N.E. and S. The Slims River drains into the S.E. corner of Lake Kluane through a dusty valley which is frequently the source of blowing loess at KL.

[12] It should be noted that in addition to this the area had in its favor (a) the climatological factors noted on page 1 and 2, (b) historical data pointing to anomolous behavior of its glaciers, (c) the opportunity for environmental studies of the periphery area, and (d) its accessibility - i.e., by bus up the Alaska highway to the base camp.

[13] Henceforth the base camp at Lake Kluane will be referred to as Kluane and abbreviated to KL throughout the text.

b) Kaskawulsk (KASK)[14]

This, the lowest glacier camp (at 5, 800 ft.), is on the medial moraine at the confluence of the central and northern arms of the Kaskawulsh Glacier. The area is below the firn limit and thus very wet during the peak of the ablation season. Less than a quarter of a mile to the west of the station rises a 200 ft. knoll inhabited by gophers and other forms of life. It in turn is part of the weathered peak forming the eastern end of the ridge separating the north and central arms of the glacier. Many alpine and tributary glaciers drain into these arms which are contained by mountains averaging nine to ten thousand feet in height. Figure 3 shows an aerial view of the confluence looking up the Kaskawulsh. (Arrows indicate the approximate position of KASK and the two automatic stations - KASK Ice and Knoll).

c) Divide (DIV)[15]

The exact position of the Divide station has changed from year to year but it has always been on the vast, gently undulating accumulation area (at 8, 500-9, 000 ft.) close to the ice divide between the Kaskawulsh and Hubbard glaciers. (Figure 4 shows an aerial view of the 1965 station.)

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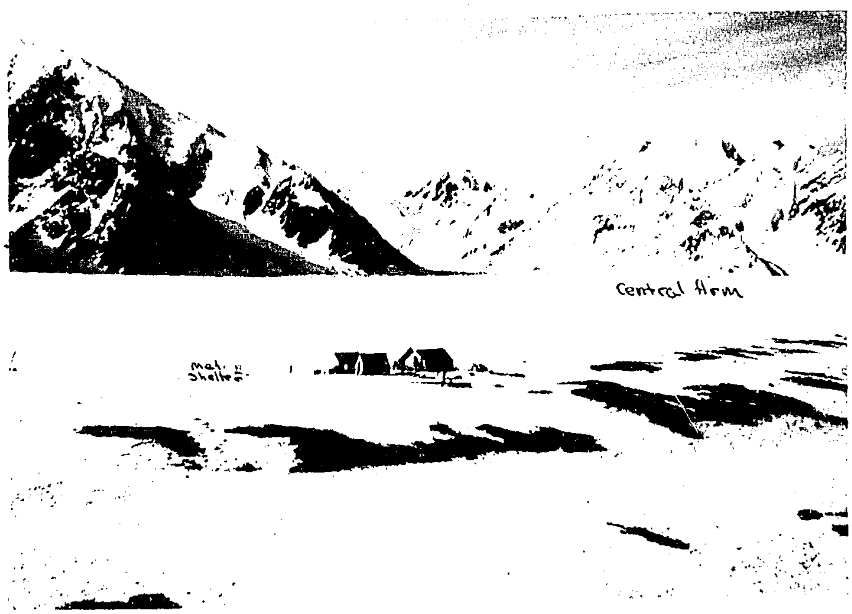
[14] Henceforth the camp on the moraine at the confluence of the two arms of the Kaskawulsh Glacier will be referred to as Kaskawulsh and abbreviated to KASK throughout the text. When it is the intention to point out that it is on the moraine KASK (Moraine) will be used. The ice and knoll stations will be called KASK Ice and KASK Knoll respectively.

[15] Henceforth abbreviated to DIV and automatic stations as DIV Cairn B and DIV Cache. DIV will refer to all three stations - i.e., Divide'63, Divide '64, and Divide '65.

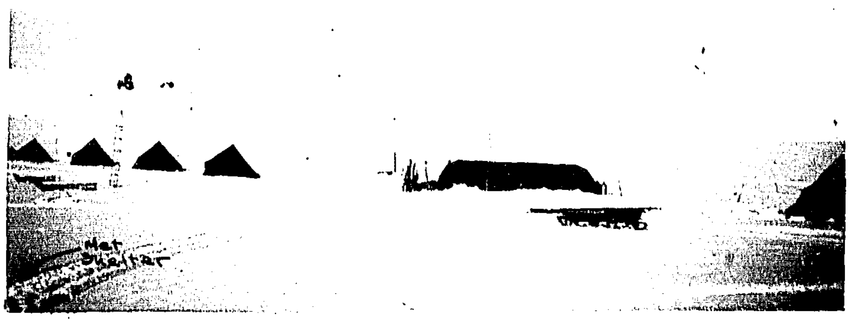
Confluence of North and Central Kuskawulsh Glacier



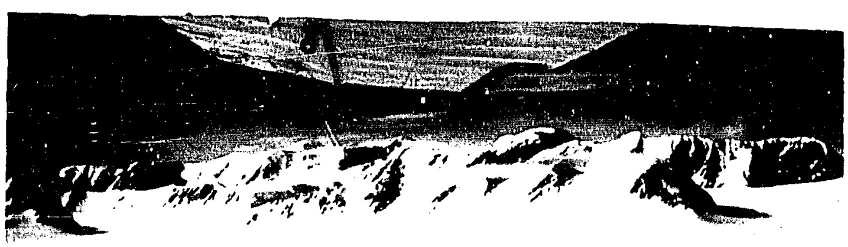
KASK Camp (looking S.)

Figure 3. Kaskawulsh camp and surroundings

DIV Accumulation Area



DIV Camp (looking S.)



Mountains north of DIV

Figure 4. Divide camp and surroundings

Mount Logan, 35 miles to the S.W., dominates the horizon (see Figure 4). To the North approximately 4 miles smaller peaks rise several hundred feet above the station (see Figure 4). A slight rise which has a small area of bare rock is used as a winter cache (DIV Cache) and on a ridge to the east a cairn has been erected for survey purposes (DIV Cairn B). To the south snow ridges (see Figure 4) block the view of Mount Queen Mary rising to 12,750 ft. about 15 miles away.

d) Seward (SEW)[16]

SEW is located on the site of the Project Cornice[17] station (occupied in the late 40's and early 50's) on the ridge of a small nunatak. This nunatak is near the eastern margin of the Seward Glacier Basin at the foot of Mount Vancouver.

To the northwest, a distance of 30 miles, Mount Logan towers 13,750 feet above this 6,100 foot station (see Figure 5). Ice covered Mount Cook (13,760 ft.) dominates the scene to the south (see Figure 5) and avalanches are constantly heard hurtling down the steep slopes of Mt. Vancouver to the northeast.

4. METEOROLOGICAL PROGRAM

A brief description of the meteorological program, during each of the three years,[18] to be used in this study, follows:

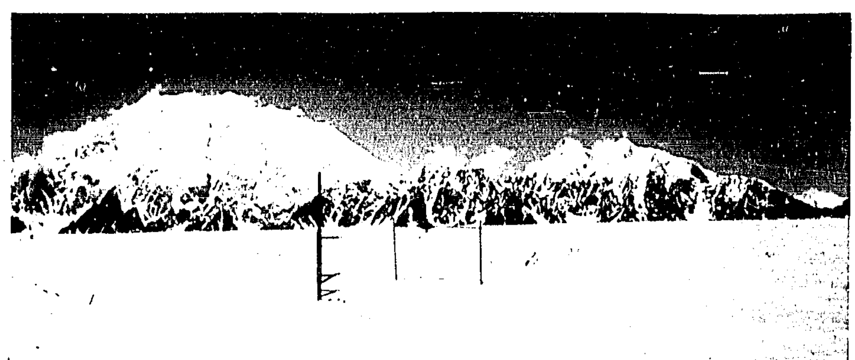
[16] Henceforth referred to as Seward and abbreviated to SEW, the automatic station being called SEW Ice.

[17] Wood (36)

[18] Only in 1963, 1964 and 1965 were the records complete enough to be of use.

SEWARD Accumulation Basin (from Hubbard Glacier)

SEW (nunatuk) Camp & Mt. Cook - 13,760 ft.



Mt. Logan - 19850 ft. (from micro-met station)

Figure 5. Seward camp and surroundings

Tables IV and V show in detail the period of record, frequency of readings, and parameters recorded at each of the manned and automatic stations, for each year. A complete tabulation of this data as well as lists of the equipment used and the observation procedures appear for 1963 in Havens (12), for 1964 in Marcus (17) and for 1965 in Marcus, Rens and Taylor (20).

a) 1963

DIV '63 was the main station. Here two-hourly observations were taken around the clock from 20 June to 23 August. In addition to the regular synoptic observations, air temperatures at various levels were measured by thermocouples, and incoming and reflected shortwave radiation and net radiative flux were recorded. A supporting hygrothermograph was maintained at Glacier Central, two miles from DIV '63.

At KL synoptic observations were taken at 0900 and 2100 Y.S.T.[19] daily and a hygrothermograph was located near the snout of the Kaskawulsh Glacier. This station shall henceforth be called Terminus and abbreviated to TERM.

b) 1964

In order to fit into the normal activities of the camp only 0900, 1500, and 2100 Y.S.T. observations were made at KL. The 0900 and 2100 Y.S.T. readings at KL and DIV '64 were synchronized with the Whitehorse and Yakutat pibal and radiosonde ascents by taking them

[19] Y.S.T. is Yukon Standard Time - 9 hours after Greenwich (or Z).

at 0830 and 2030 Y.S.T., respectively. TERM was again located on the terminal moraine of the Kaskawulsh Glacier. There was a one week interruption in the records in late June when a grizzly bear demolished the shelter.

At DIV '64, three-hourly synoptic observations were taken daily and a short term micro-meteorological study of wind, temperature, and radiation relationships was carried out. At 0900 and 2100 Y.S.T. the observations were coded and relayed to the base camp by short wave radio, whence they and the KL weather were immediately reported to Whitehorse by telephone to be used in local airways forecasting.

Two thermograph stations, DIV Cairn B and DIV Cache, as well as a five stake ablation net were maintained by the DIV '64 personnel.

Irregular observations were taken at KASK by the glaciology-geophysics team who were often forced to be away from the camp at synoptic hours.

SEW's observations were synchronized with those at DIV '64, the period of record being only eleven days shorter. In addition SEW Ice, a thermograph station, was located one mile west and 250 feet below the nunatak, on the glacier.

c) 1965

Synchronized three-hourly readings were taken at KL, DIV '65, KASK, and SEW by the climatological team for the periods shown in Table IV. At the glacier stations, in addition to regular synoptic observations, upper winds were recorded twice daily, during the latter part of the season, by pibal ascents. Ablation stakes were read at 0600 and 1800 Y.S.T. daily during most of the period of record at KASK and DIV.

The 0900 and 2100 Y.S.T. observations were again advanced to 0830 and 2030 Y.S.T. at all stations, and coded synoptic reports from KL and one of the glacier camps relayed to Whitehorse twice daily.

Two new automatic stations were in operation in the vicinity of KASK--KASK Ice and KASK Knoll. DIV Cairn B was re-established.

A ten day micro-meteorological program, including temperature and wind at four levels and long and short wave radiation, was carried out on the glacier about a quarter of a mile northeast of SEW.

As reported in Marcus, Rens, and Taylor (20) the data was coded by the observers and sent to KL where it was put on IBM data cards in an effort to streamline the data reduction process. Due mostly to human error this proved rather unsuccessful. However it is hoped that the revised procedure[20] used in 1966 met with greater success.

d) Permanent Weather Stations

The regular meteorological stations used in this study to represent the weather of the mountain margin are listed in Table VI together with their location, elevation, operating agency, and type and length of record[21].

[20] See Marcus Rens and Taylor (20).

[21] This may not be complete but includes all the data used by this study.

CHAPTER II

CIRCULATION AND RELATED TOPICS

The study area straddles the 60 degree N. latitude. Hence it lies in the subpolar low pressure belt, generally considered to be centred at this latitude in the mean circulation of the lower troposphere.

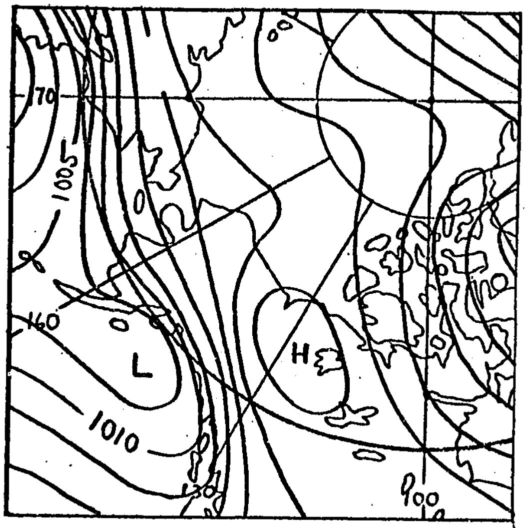
Though it is impossible to find a ri gid boundry between the polar circulation and the mid-latitude zonal westerlies, Hare and Orvig (10, p. 8) note: "Climatologically ... there is much to be said for regarding the 70 degree N. parallel as the average limit of the westerlies." This puts the area to be studied in the normal belt of the tropospheric westerlies.

1. PRESSURE FIELDS

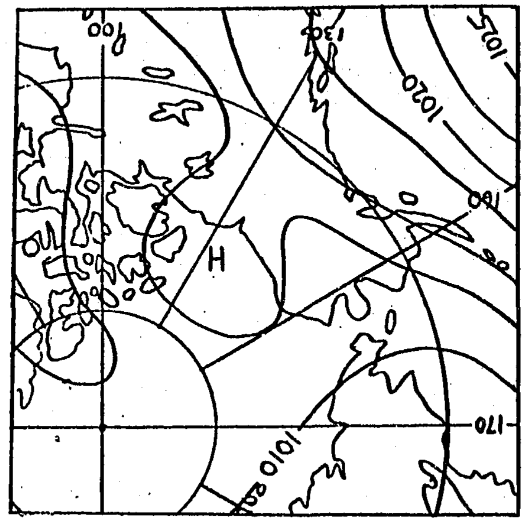
Figure 6 shows the mean sea level pressure for January, April, July, and October for the periods indicated and Figure 7 gives the mean absolute topography of the 700 mb and 500 mb surfaces for January and July.

a) Winter

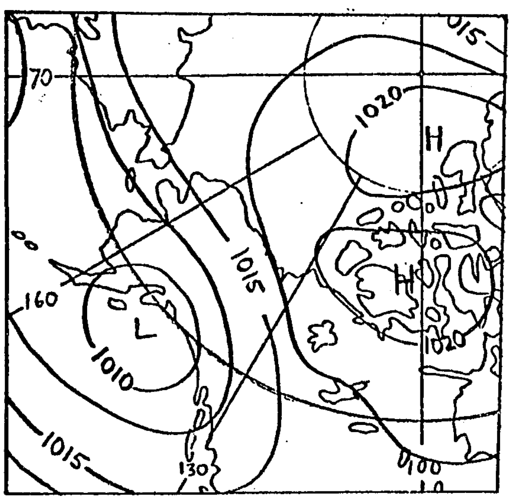
The Aleutian surface low during the years 1948 to 1955 (as seen in Figure 6a) tended to have two low centres, one off Kamchatka and the other over the Gulf of Alaska. This is in fact a good representation



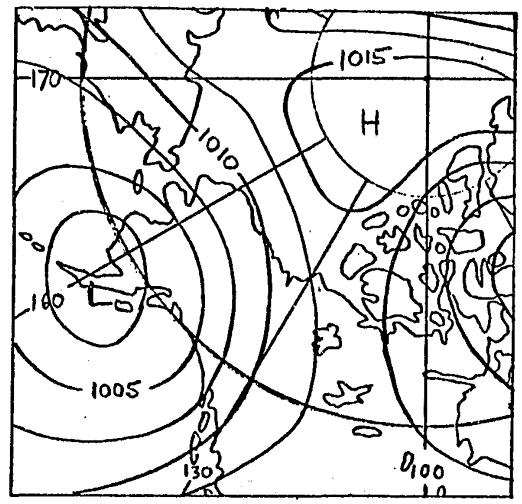
(a) Mean sea-level pressure, 1948-55, after Namias, for January.



(c) Mean sea-level pressure for July (after Namias) for period 1948-55.

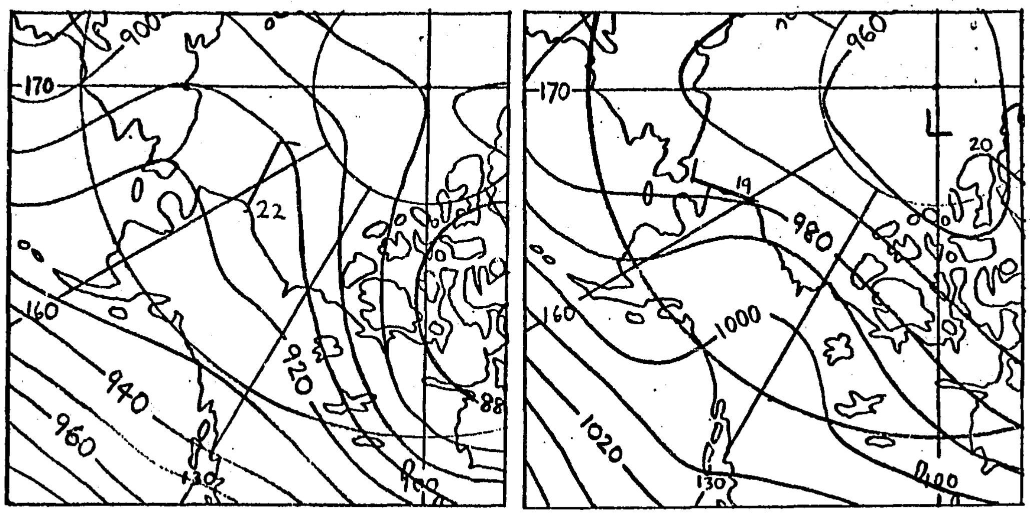


(b) Mean sea-level pressure, 1948-55, after Namias, for April.



(d) Mean sea-level pressure for October (after U.S.W.B. 1952 normals).

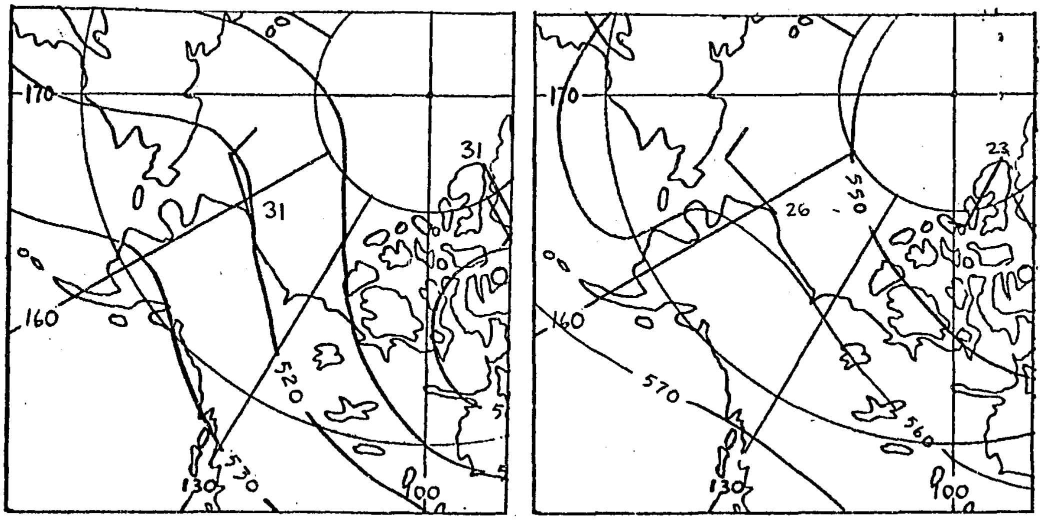
Figure 6. Mean sea-level pressure, from Hare and Orvig (10, pp. 18-19)



JANUARY JULY

Figure 7a

Mean absolute topography (in gp. ft.) of the 700 mb surface, 1948-55 (after Namias). Contours every 100 feet(with final digit omitted). From Hare and Orvig (10, p.20).



JANUARY JULY

Figure 7b

Mean absolute topography of the 500 mb surface, January & July 1949-53 (after Heastie) Contours at 100 geopotential meters (with last digit omitted); equivalents in feet in square brackets, with first and last digits omitted. Vector mean winds (one full feather = 10 knots) for winter season with vector standard deviation in kts. (for 6 km.). From Hare and Orvig (10, pp.43 and 50).

of the short term pattern but longer term means tend to show one elongated low. The polar easterlies can be found N. of the Aleutian low.

Over the Mackenzie basin is the well known N.W. Canadian high.[22]

Between the Aleutian low and the Mackenzie high a strong S.E. flow appears as a feature of the mean circulation.[23]

There is a moderate increase of zonal flow with height (see Figure 7). The upper charts are characterized by a quasi-permanent warm ridge extending across Alaska towards the pole. This produces an upper N.W. flow (i.e., paralleling the valleys of the cordillera region). Possibly the most important feature of the winter pressure field of the lower troposphere is pointed out by the following quote from Hare and Orvig (10, p.24).

> Since the high pressure cells on Figure 2 (Figure 6) coincide with low temperatures and low pressure cells with warmth, the pressure pattern adjusts itself rapidly with height .... The Icelandic and Aleutian lows are replaced by a two- or three- centred vortex directly across the polar basin. The Mackenzie high merges into the semi-permanent warm ridge over Alaska. In short, the patterns of the mean sea-level winter map are extremely shallow being barely discernible above about 5,000 feet.

This is particularly significant to the present study as all the glacier camps are above the 5,000 foot level.

b) Spring

A rapid change begins in late March. By April (see Figure 6b) the Aleutian low in the Gulf of Alaska has filled and moved slightly east.

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[22] Henceforth referred to as the Mackenzie high.

[23] It should be noted however that individual weather maps do not often look exactly like Figure 6a.

The Mackenzie high has also weakened and lies N.E. of the Mackenzie region over the Canadian arctic islands.

c) Summer

By summer the Aleutian low on the mean surface maps has been replaced by a ridge extending from the Pacific north along the Yukon Alaska border (see Figure 6c). The circulation is considerably weaker than that seen in the winter due largely to the disturbed synoptic regime.

The 700 mb and 500 mb charts also show a far weaker gradient in July though they resemble the winter map in shape. The Alaska ridge has in both cases shifted eastward.

The summer features are also very shallow though both the surface and upper mean flow are weak and on-shore at Yakutat.

d) Autumn

Figure 6d shows that the Aleutian low is deeper and slightly further west in autumn than in spring. Otherwise the pattern is very similar to that of April. Wilson (34) however suggests that the weak pattern is just a mean of the rather more intense but unpersistent short term circulation. The November map is quite similar to that of January (Hare and Orvig, 10).

e) Problem

All accounts of the mean circulation are careful to point out that in mountainous regions mean theories are of limited use. In addition mountain barriers create unrealistically large gradients on sea-level pressure charts and flow in mountainous areas is decidedly non-geostrophic.

The former stems largely from the methods used to convert surface pressures to mean sea-level. At very low temperatures the corrections give entirely fictitious results.

Captain Nolan Williams has proposed a method of analysis of surface geostrophic winds in mountainous regions which combines surface and upper level charts. The method was then applied to the mountains of western Canada and Alaska. Reed (27) in summarizing this method says:

> Finally it should be noted that the difficulties considered cannot be eliminated or mitigated by improved reduction formulas. In fact some of the worst fictitious "gradients" in the present study were located in regions where all stations were at or near sea-level. The large pressure differences were sustained by intervening mountain ranges, so what was represented as a pressure gradient was, in reality, a pressure discontinuity. There is some question as to whether this point has been properly appreciated in the synoptic literature, though it is well understood in general circulation studies.

2. SURFACE AIR TEMPERATURES

At these latitudes due to the long summer days and long winter nights diurnal temperature variations are decreased and seasonal variations increased.

a) Winter

The winter temperature distribution (represented by January in Figure 8) shows the greatest packing of winter isotherms on the globe for an area of its size (Kendrew and Kerr, 15). This is caused partially by the intense cold of the orographically trapped air in the

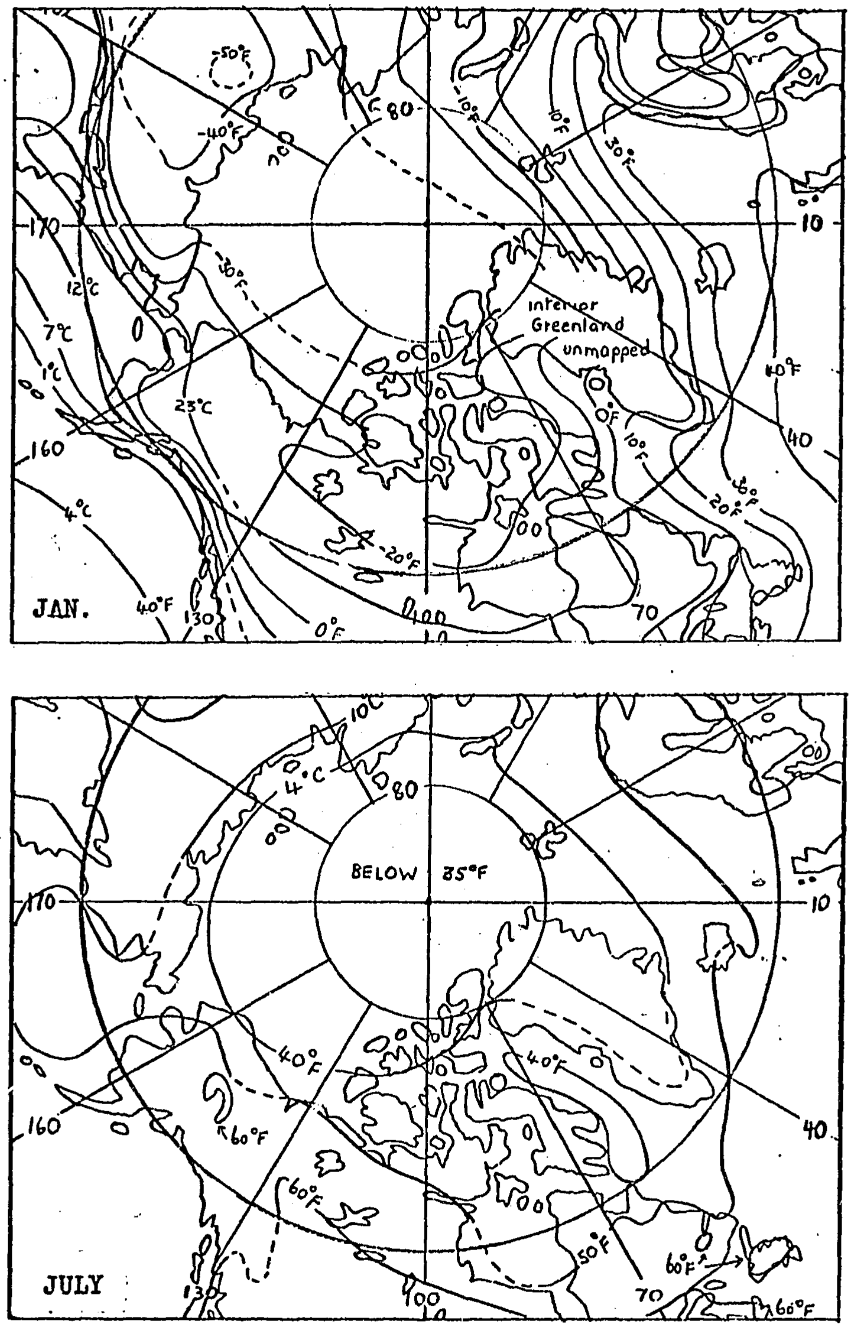

Figure 8

Approximate distribution (ignoring complications due to relief) of mean daily temperature for January and July. From Hare and Orvig (10, p.28).

interior. The extensive moderating effect of the Pacific Ocean is shown by the tendency of the isotherms to follow the British Columbia and Alaska coast lines.

Once again, especially in the mountains, surface patterns may be misleading and 850 mb (or higher) temperatures should certainly be used in air mass identification.

b) Summer

Figure 8 shows that summer gradients are less than half those of January and over the study area their direction is reversed (as continents tend to be warmer than oceans in summer).

c) Seasonal Variation

It is interesting to note that in the free atmosphere from the tropopause down to about 6,500 feet the seasonal temperature difference is less than 20 degrees F. (Hare and Orvig, 10). This might conceivably affect the seasonal variation at the glacier stations (DIV being well above this level).

3. CYCLONES, ANTICYCLONES, AND FRONTS

a) Cyclones

Figure 9 shows the percent frequency of cyclonic 500 mb curvatures in January, February, and December 1955. Combined with Figure 11 (frequencies of centres within grid squares--surface) and Figure 10 (tracks of low centres--January 1955) it indicates frequent cyclonic activity in the Gulf of Alaska at all levels in winter. Concerning this cyclonic activity Mitchel (22) says: "The mountains form a

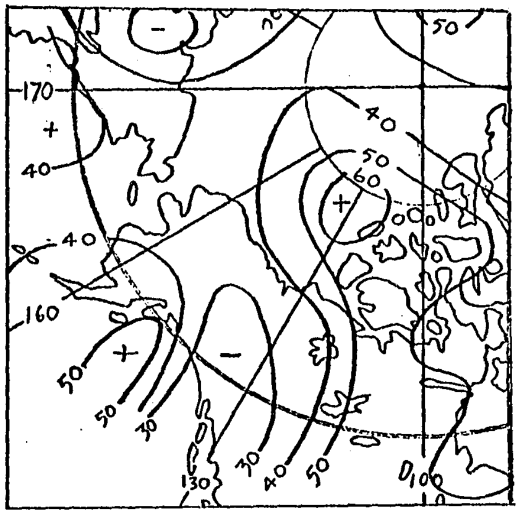

Figure 9

% frequency of cyclonic 500 mb contour curvature, Jan., Feb. and Dec., 1955. From Hare and Crvig (10, p. 89).

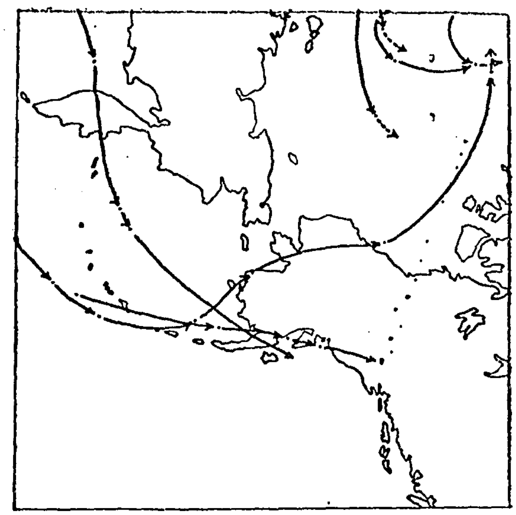

Figure 10

Tracks of low January centres, January, 1955 (after Brunnschweiler). From Hare and Orvig (10, p. 102).

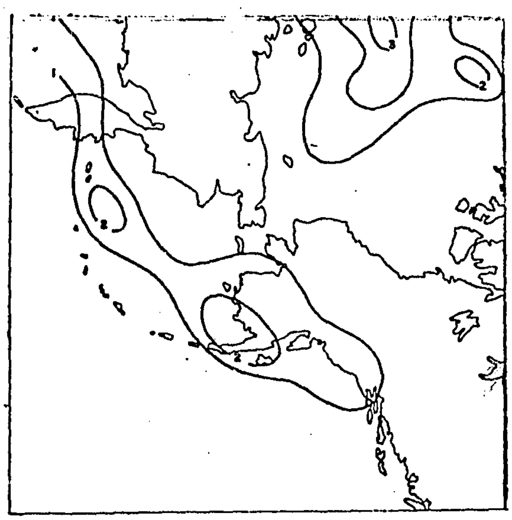

Figure 11

Frequencies of centres within grid-squares, corresponding to Figure 10 (after Brunnschweiler. From Hare and Orvig (10, p. 103).

cradle for the Gulf of Alaska in which the great Pacific cyclones, spawned near the Aleutians, violently spin themselves to death, and where the greatest cyclone frequencies in the entire Northern Hemisphere are to be found."

Figure 12, on the other hand, gives the 1944-55 average frequency of cyclonic passage across 5 degree segments of selected meridians for the four seasons (after Berry, Owens, and Wilson, 1). In all seasons except summer the maximum is found just south of the Aleutians. Summer exhibits a weak maximum north of the Aleutian chain and another opposite northern Alaska. Mention should be made of the tropospheric cold lows (usually extending from 700 mb up, though they can be lower) with which, in these areas, in all seasons, are associated middle and upper tropospheric cloud. Hare and Orvig (10, p. 91) concluded that these lows originate primarily through vertical motion.

b) Anticyclones

Figures 13 and 14 show the 500 mb anticyclonic curvatures and surface high centre frequency, for the summer of 1955. On both, the mean circulation Mackenzie high is quite evident. In winter this area is the most important anticyclonic area in the northern hemisphere (Bodurtha, 2). These intensively cold highs are linked with the warm high level Alaska ridge and frequently accompanied by a Pacific blocking high (Hare and Orvig, 10). In summer the area is warm and highs are usually of Pacific origin.

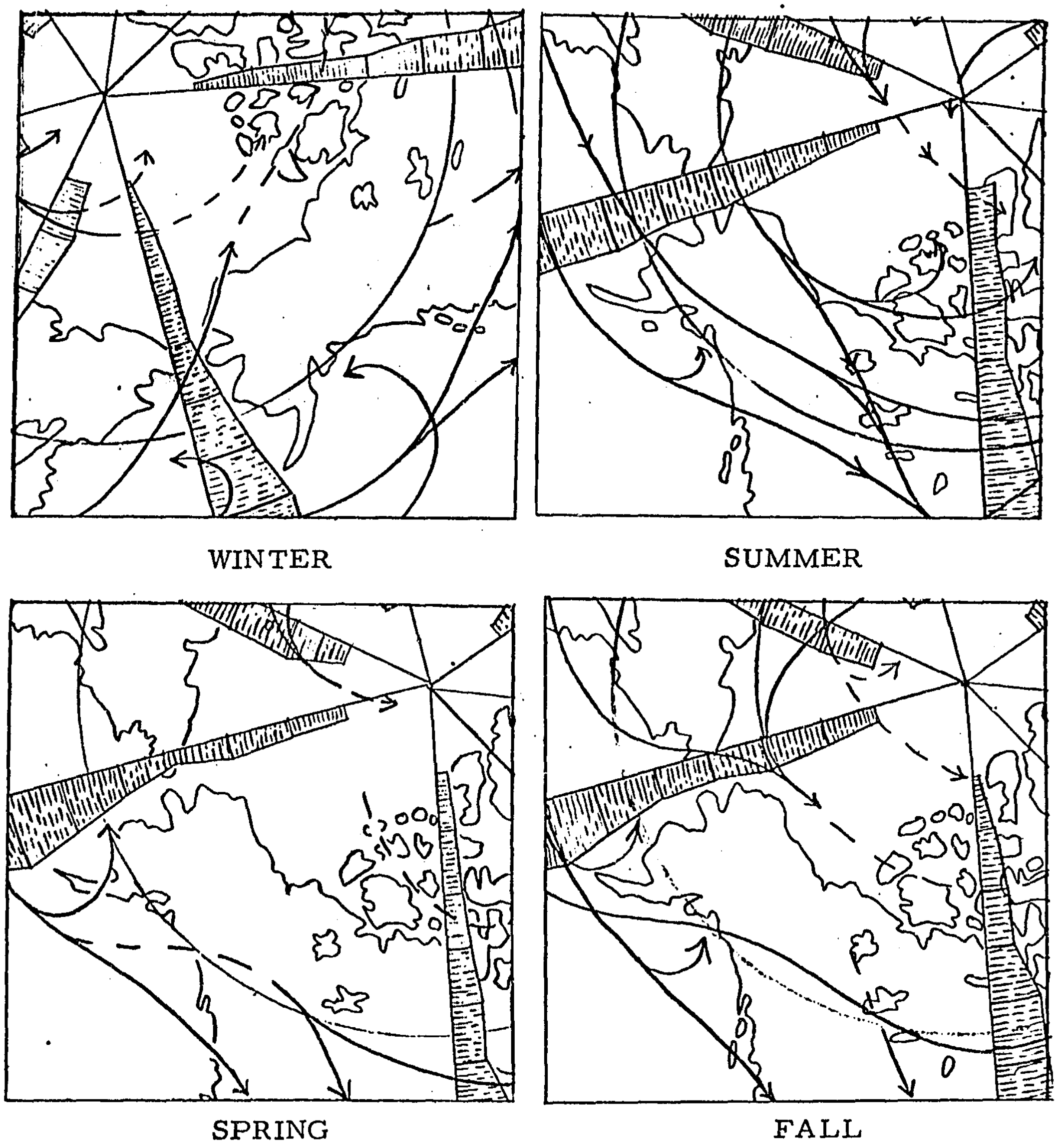

Figure 12

Frequency of cyclone passages across 5^o segments of selected meridians, 1944-51, from data by Berry, Owens and Wilson. The frequency polygons extend eastward from each meridian. The length of each latitudinal arc is proportional to the total of cyclone passages across the 5^o segment centered on the latitude concerned. The arrows give only a qualitative indication of typical steering. From Hare and Orvig (10, p. 108-9).

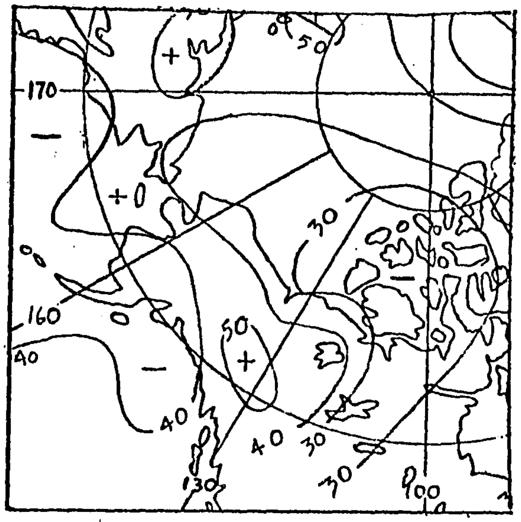

Figure 13

% frequency of anti-cyclonic 500 mb contour curvature, Jan., Feb. and Dec., 1955. From Hare and Orvig (10, p. 89).

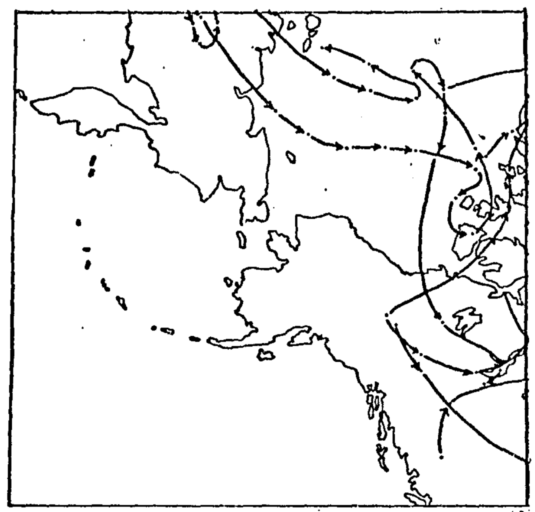

Figure 14

Tracks of high centres, January, 1955 (after Brunnschweiler). From Hare and Orvig (10, p. 102).

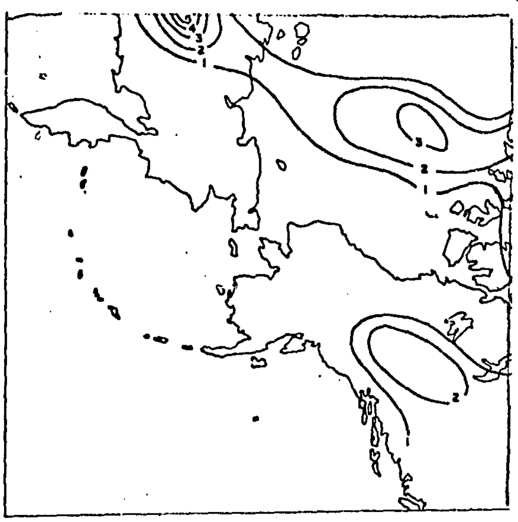

Figure 15

Frequencies of centres within grid-squares, corresponding to Figure 14 (after Brunnschweiler). From Hare and Orvig (10, p. 103).

Though many of the anticyclonic systems found in the area are virtually stationary and often ill-defined, Figure 16 of anticyclonic ducts is of interest. This shows all seasons except summer are characterized by highs coming on the Alaska coast north of the Aleutians and tracking S.E. In summer they invade from north of the Mackenzie delta.

c) Fronts

Figure 17 (after Reed, 26) shows the percentage frequency of fronts in squares of 400,000 km^2 for summer while Figure 18 (after Kendrew and Kerr, 15) show the mean position of fronts in January and July.

The latter shows that the mean frontal positions can be related to the cyclonic track maxima (see Figure 12) in this the "Pacific Stormy Belt".[24]

In summer Figure 17 shows that the study area is characterized by a minimum of frontal frequency.

4. AIR MASSES

a) Sources and Characteristics

Figure 19 (after Petterssen, 25) shows the summer and winter air mass sources for the area.

i) <u>cP and cA--winter</u>:- During winter months continental Arctic and Polar air masses form in the Mackenzie anticyclone. They are

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[24] Hare (9)

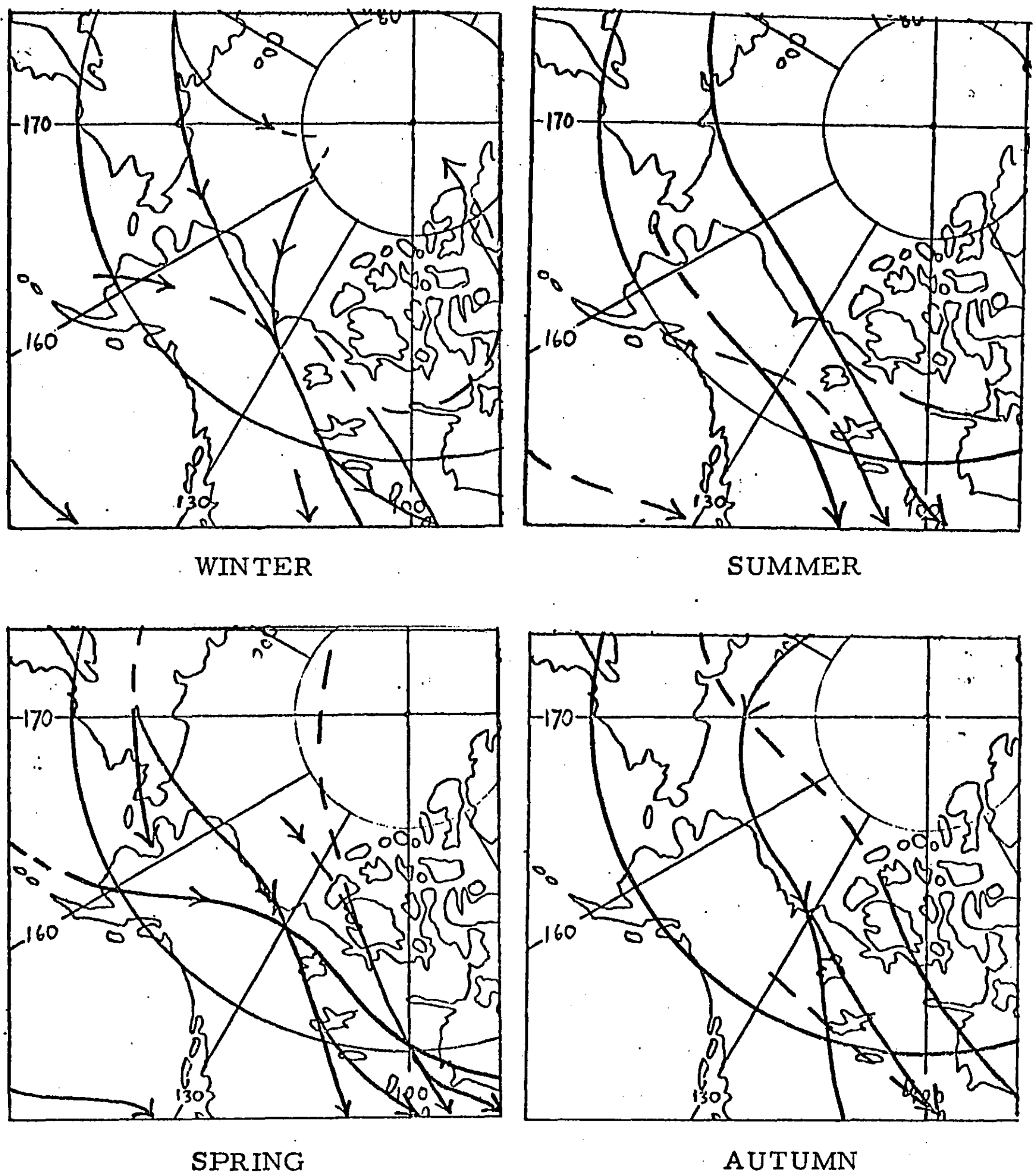


Figure 16

Approximate steering lines for anticyclone centres, 1944-51 (generalized from Berry, Owens and Wilson). From Hare and Orvig (10, pp. 116-7).

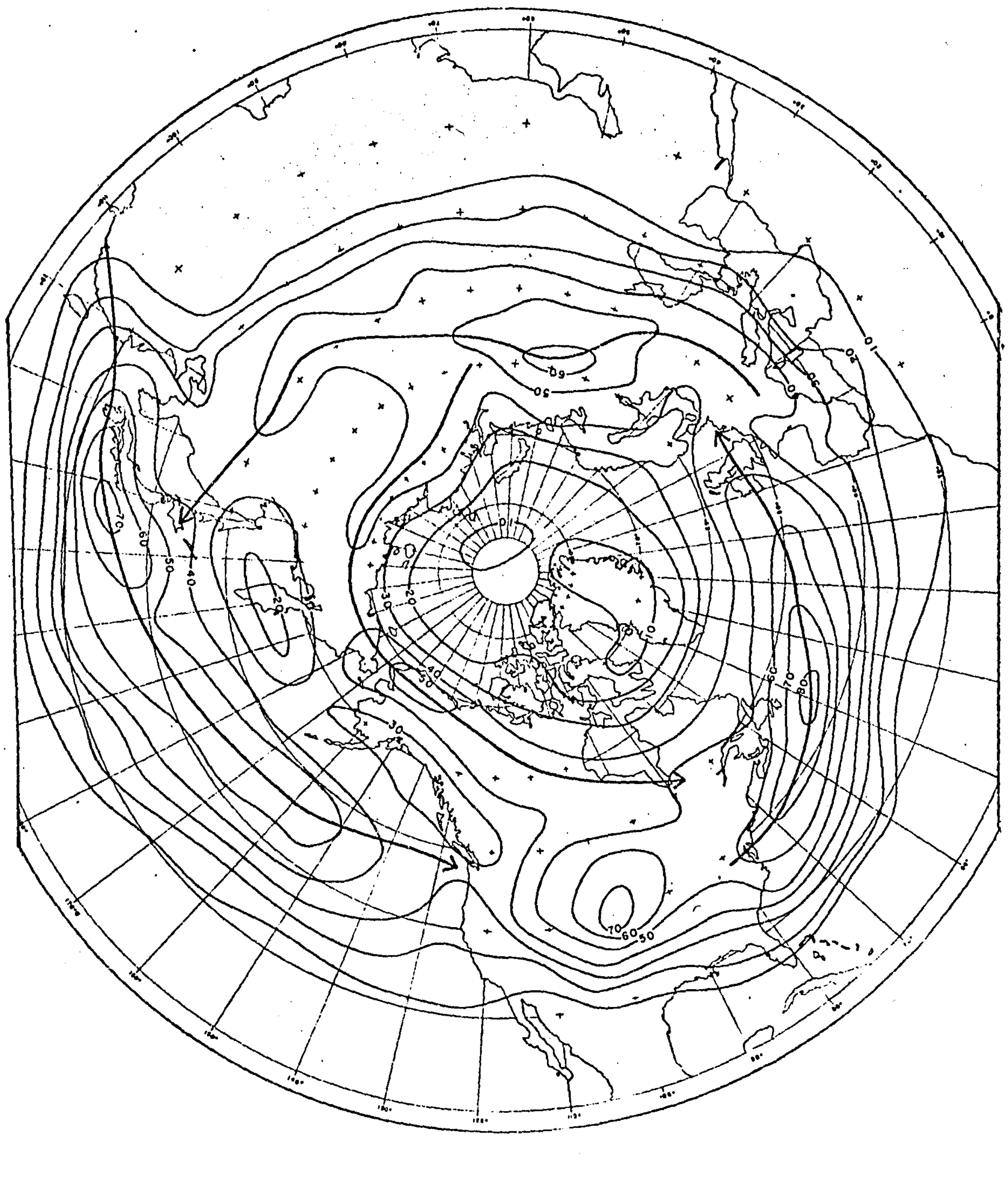


Figure 17. Percentage frequency of fronts in squares of 400,000 km.^{2} in summer (after Reed, 26).

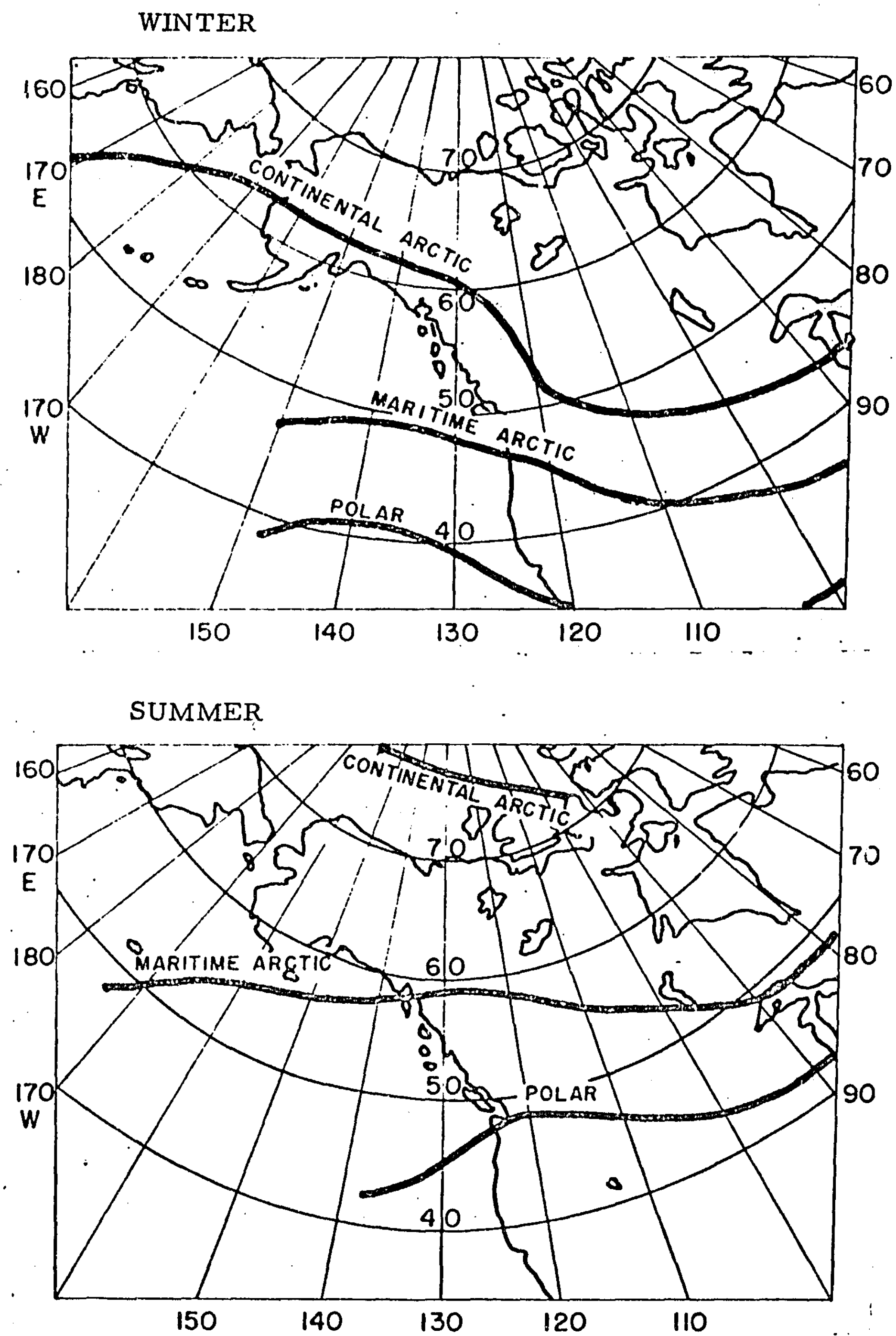
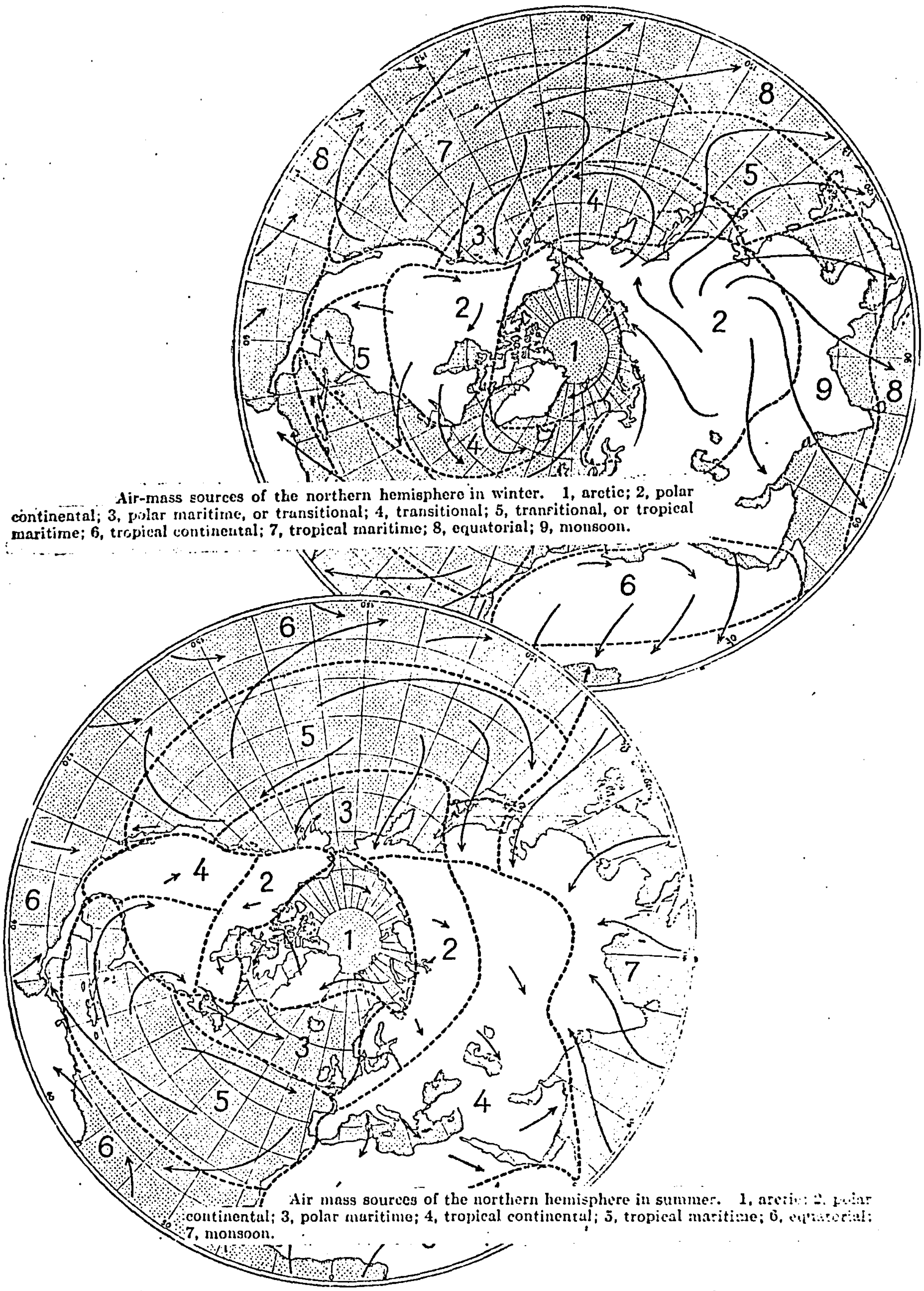


Figure 18. Mean position of the frontal zones in western Canada and the north Pacific region (after Kendrew and Kerr, 15, p.27). It should be noted that other investigators place the summer continental Arctic (or Arctic) front along the north Alaska coast.



Air-mass sources of the northern hemisphere in winter. 1, arctic; 2, polar continental; 3, polar maritime, or transitional; 4, transitional; 5, transitional, or tropical maritime; 6, tropical continental; 7, tropical maritime; 8, equatorial; 9, monsoon.

Air mass sources of the northern hemisphere in summer. 1, arctic; 2, polar continental; 3, polar maritime; 4, tropical continental; 5, tropical maritime; 6, equatorial; 7, monsoon.

Figure 19. Air mass sources in winter (above) and summer (below), after Petterssen (25, pp 160 and 165)

characterized by bitterly cold temperatures (averaging-35 degree F.), little moisture (mixing ratio 0.1 g/kg), and stable conditions with a pronounced surface inversion.

ii) cP--summer:- With the summer decay of the anticyclone, continental Polar air masses are more frequently imported into the area (i.e., transformed mP or mA from the Arctic basin). Summer cP tends to be unstable in the lower levels due to radiative surface heating.

iii) mP--winter:- The Gulf of Alaska is a source for winter maritime Polar air which picks up heat and water vapour from the relatively warm ocean.

iv) mP--summer:- The north Pacific, south of the Arctic front, provides a source region for maritime Polar air which is warm and moist but still cooler than the coastal land surfaces.

b) Modification and Stability

Non-adiabatic processes are of particular importance in air mass modification in high latitudes. Radiative cooling and heating and heat exchanges with the surface (i.e., evaporation and sensible heat flux) are the two main non-adiabatic processes affecting the modification.

Air dragged into the Mackenzie cyclone is cooled largely by radiative heat loss at ground level, creating absolute stability. Cool air in this area, in the summer, is warmed through a similar process and often made unstable in the lower levels.

Ocean surfaces tend, in winter, to supply huge amounts of sensible and latent heat to air travelling over them. Jacobs (14) estimates as much as 300 langlies are transferred, in this situation, per day. This transfer of sensible and latent heat proceeds much more quickly than radiative cooling and continental air need not remain long over the ocean to become the unstable maritime type. Thus continental air sucked into the west side of a Gulf of Alaska low in early winter could, by the time it reached the mountainous S.E. Alaska coast, produce a heavy snow fall.

In general air masses travelling over a warm surface will develop instability resulting in convective type cloud, good visibility, and turbulent gusty winds. Air masses cooled from below will tend to be stable and be accompanied by stratus cloud, poor visibility, and steady or calm winds. (Byers, 4).

The complex problem of air mass identification and modification is further complicated in the study area by the elevation and extensive glacerization of the region.

5. FORECASTING

As would be expected from the foregoing discussions, commonly used mid-latitude dynamical forecast models have failed in the mountains of the Yukon and Mackenzie districts. Estoque (6), using a two-level baroclinic model and graphical integration techniques reports complete failure in this region.

Reed (27), on the other hand, includes, in his two-level graphical prediction model, non-adiabatic and orographic effects and applied this to a major storm in the Gulf of Alaska. The results were considerably better than Estoque's. He further reports that in an attempt to use a dynamical prediction model in the winter, the orographic effects were considerable. On the western slopes heights were higher than those predicted. The error pattern fit the potential vorticity theorem well (i.e., air forced up decreases its vorticity). Reed also found a good quantitative relationship between the elevation and error patterns.

In short, for a region of this sort, special techniques must be applied to produce reliable numerical forecasts.

6. SUMMARY

Briefly the questions suggested by the above chapter are:

a) As surface pressure and temperature fields are very shallow, extending in the free air to approximately the height of the lowest IRRP glacier station, what are the dominant influences, on the surface, at these stations? In other words, do mean sea-level or free atmosphere conditions control the local climate here or, as is more likely, is it a combination of the two?

b) How do frontal systems behave when confronted with a barrier of the magnitude of the St. Elias Range?

c) With the aid of the climatic records from the surrounding area, can any extrapolations be made from the summer records of the IRRP stations about the winter climate of the study area?

The concepts of air mass modification etc. and the mean large scale climatic conditions outlined in this chapter should be kept in mind as the study proceeds. Though forecasting problems are beyond the scope of this study they will be mentioned occasionally.

CHAPTER III

CLIMATE OF THE MOUNTAIN MARGINS

The aims of this chapter are: (1) to discuss the year round climate of Yakutat and Whitehorse, (2) to determine to what extent Yakutat is representative of the coastal climate and Whitehorse of the interior, thus (3) to ascertain the extent of the maritimisity of the coast and the degree of continentality of the immediate interior, and finally (4) to investigate the deviations from the long term average of the three years to be discussed in this study.[25]

1. MARITIME MARGINS

a) Yakutat (YAK)[26]

Eighty miles due south of DIV lies Yakutat (see Map 2), the closest first order weather station upstream[27] of the IRRP area. The U.S. Weather Bureau (29) gives the following description of YAK and area.

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[25] With a view to determining the degree to which they are representative of the normal conditions.

[26] Henceforth abbreviated as YAK.

[27] Mean flow roughly west to east.

> The Yakutat area is surrounded on three sides by the waters of the Gulf of Alaska and Yakutat Bay; ... Although the area in the immediate vicinity of the station is relatively flat, rather rough hilly terrain exists within short distances ... porous gravel ... is exposed as a surface layer over much of the area. The heavy precipitation produces copious growth of various types of vegetation in the surrounding woods, including several types of edible berries. However, the soil is not suitable for agriculture ... and salmon fishing is the main source of income for the natives in the area.

i) Temperature:- The curve of monthly mean temperature (climatological standard normals[28]) at YAK, seen in Figure 20, is smooth, falling slightly more rapidly in the autumn than it rises in the spring. It reaches a maximum of 54.1 degrees F. (ca 12°C) in July (followed by 53.8 degrees F. in August) and is at its maximum of 27.3 degrees F. (ca 13°C) in January (preceded by 28.1 degrees F. in December).

Six degrees on either side of this curve lie the mean maxima and minima curves. This corresponds to a mean daily range of 12 degrees F. (ca 7°C) and a mean annual range of 41 degrees F. (ca 13°C). The extreme maxima and minima curves are as would be expected, less smooth. The minima lies 13 degrees below the mean in July and 42 degrees below in January. Conversely the maxima is 26 degrees above in summer and only 13 degrees above in winter.

The moderating effect of the ocean is doubtless responsible for the fact that YAK averages only ten days a year below 0 degrees F. and has reached 80 degrees F. only in July and August.

[28] Unless otherwise noted all YAK averages are the 30 year normals for 1931 - 1960 obtained from reference (29).

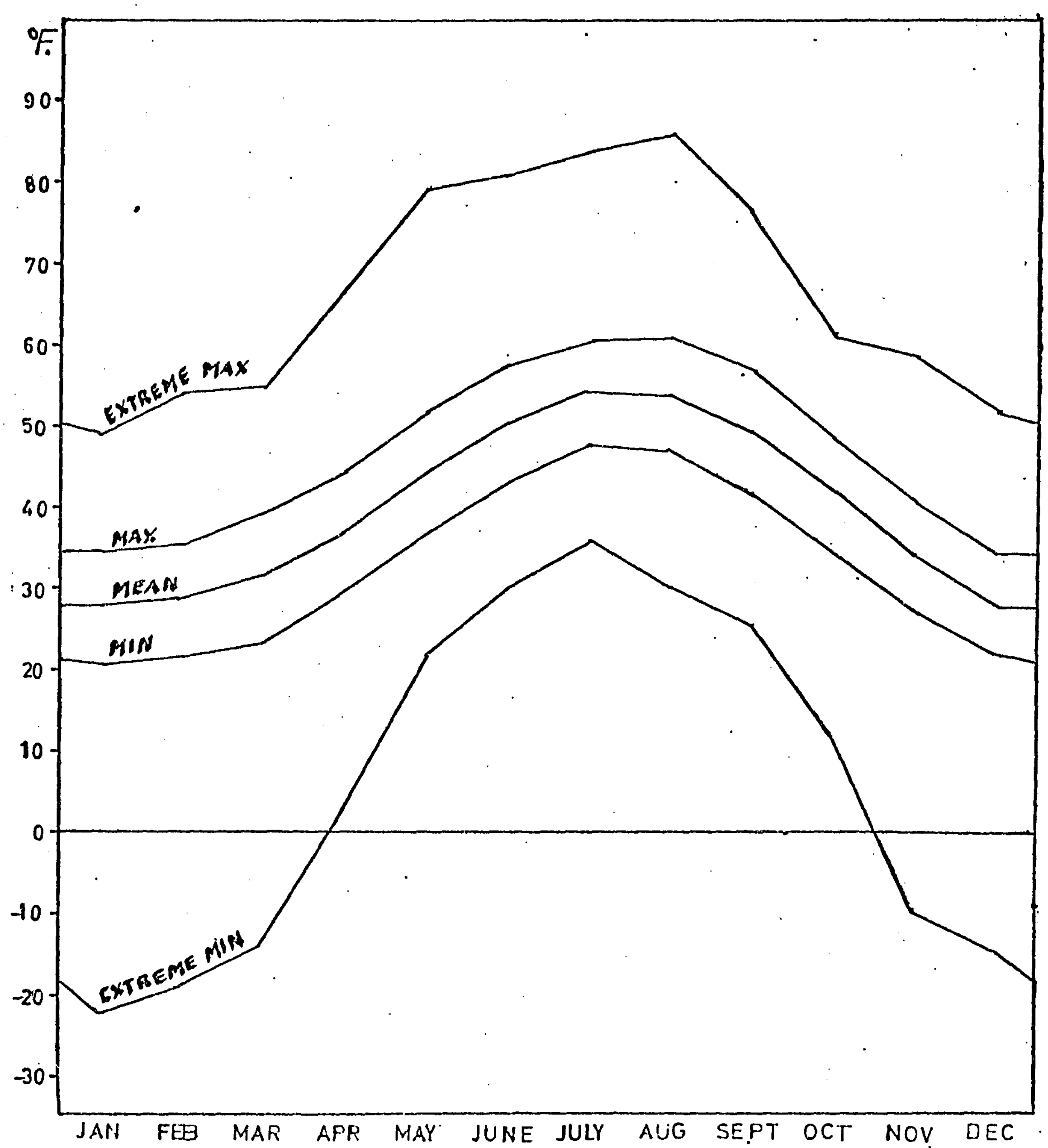

Figure 20. Normal monthly temperature means, maxima, and minima, Yakutat (1931-60).

ii) Precipitation:- The standard normal precipitation curve (monthly totals) is shown in Figure 21.

The annual total of 131.8 in. (3361 mm) is extremely high for a station at this latitude. Critchfield (5) lists the "chief positive influences on world precipitation" as: (1) low pressure belts, (2) wind convergence, (3) prevailing winds with high moisture content, (4) high air temperatures (for that latitude), (5) closeness to water bodies, and (6) mountain barriers (downwind). As all these are present in the YAK area the annual total is not surprising.

An explanation of the mean precipitation cycle can be sought from the mean tropospheric circulation and related phenomena discussed in the preceding chapter. The following is one such explanation.

By October the waters of the Gulf of Alaska[29] have been warmed by insolation during the long summer days. The mean sea-level flow (see Figure 6b) suggests that cool air from the Bering Sea[30] is carried south around the Aleutian low. As it travels over the warm ocean surface it absorbs quantities of heat and moisture (see Ch II, sec 4b). This unstable moisture laden air is steered north. On arrival at the south-eastern Alaska coast it is orographically lifted dumping quantities of precipitation on the coastal areas.

Also contributing to the October rainfall maximum is the frequency of lower troposphere cyclones tracking over the YAK area (see Figure 12).

[29] Henceforth referred to as the Gulf

[30] Cooled here by the outflow from the Arctic Ocean which becomes the cold Oyashio Current.

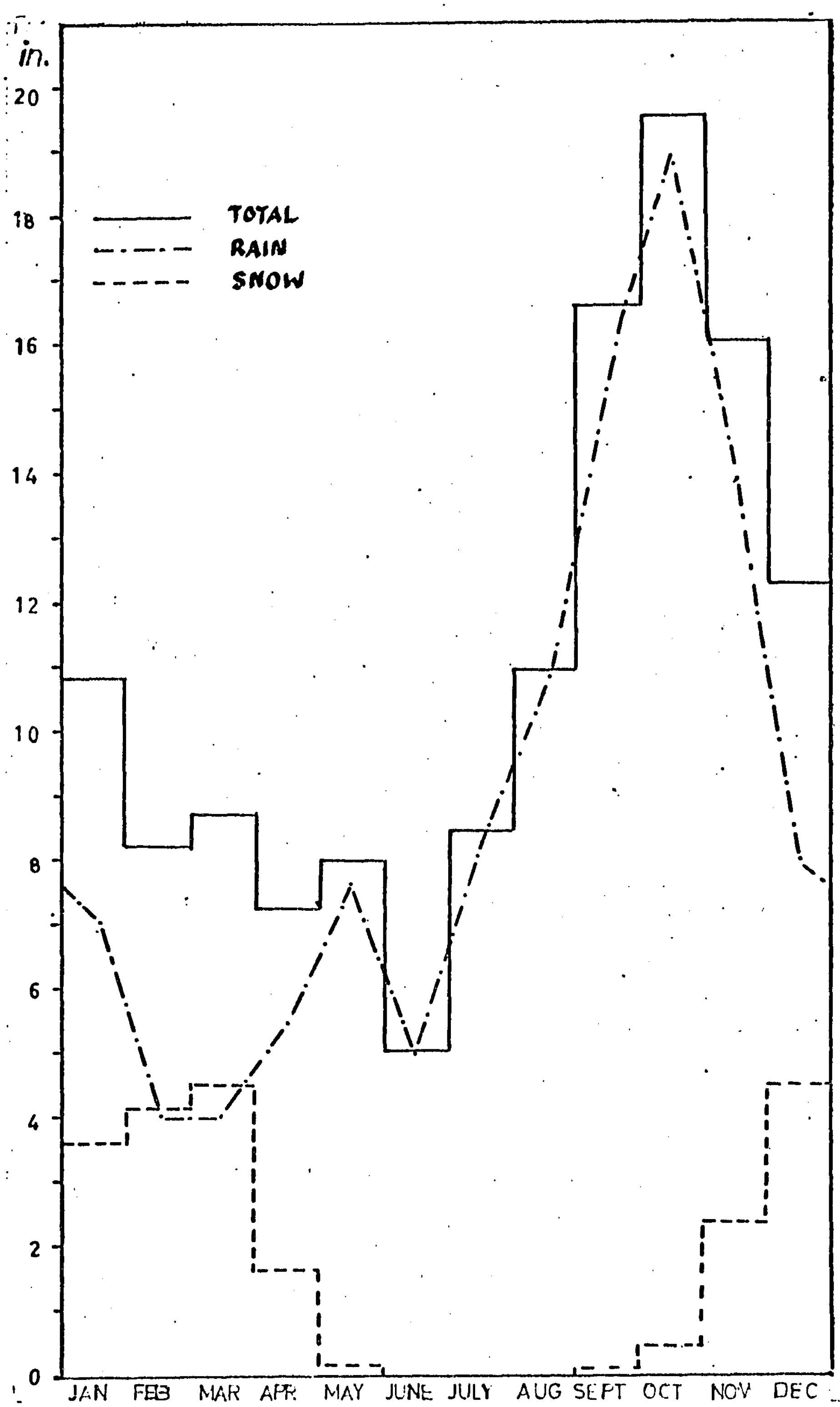

Figure 21. Normal monthly precipitation
Yakutat (1931-60).

As the temperature decreases so does its moisture retention capacity.

By December the mean winter circulation is transporting warm, unstable, mP air from more southerly latitudes tc the St. Elias region.[31] In this area the temperatures are cold enough (see Figure 20) that the resulting precipitation falls as snow--hence the first snow maximum.

The total precipitation continues to decrease as the mean, land and ocean, air temperatures continue to fall. The descent of the precipitation curve is slowed in late March by the S.W. displacement of the Aleutian low (see Figure 6b), resulting in transport of cP and cA air from central Alaska over the more temperate Gulf waters. The arrival of this rather unstable air on the mountainous coast produces a secondary snow maximum.

As the continental air mass source regions warm the temperature gradient between the land and the sea reaches a minimum, and the stability of the maritime air increases. Only when the surface air temperature reaches its annual maximum (July) does the increased capacity of the air for moisture and the local thermally induced convection permanently halt the descent of the precipitation curve.

Table VII of precipitation extremes emphasizes how variable precipitation is.[32]

---

[31] In winter the mean circulation Aleutian low is elongated east - west so it does not bring Bering Sea air to the study area. See Figure 6.

[32] e.g., (a) The snow max. and 2nd total precip. min. come in the same year. (b) The precip. max. and 3rd min. are one month apart. (c) The snow max. and min. are only one year apart.

In fact the precipitation distribution, in any particular year, seldom resembles the mean curve very closely.

It has been seen that the circulation and temperature patterns vary from day to day and year to year. The preceding discussion has illustrated that it is a rather complex interaction of these patterns which determines the precipitation, and thus a small variation of the former may produce a completely different distribution of the latter.

iii) Cloud:- Cloudiness, sunrise to sunset, averages 8.3 tenths. January is the clearest (7.7 tenths) and June, July and September the cloudiest (8.6 tenths). Table VIII shows the average number of days with various cloud amounts. Overcast skies are frequent, as would be expected, from the position of the station (i.e., ocean on three sides and mountains behind). Heavy fog occurs on an average of 31 days a year. Thunder storms are infrequent, averaging 2 days a year.

iv) Wind:- The annual prevailing wind direction is east. In May, June, July and August, however, S.S.E. winds prevail. A possible explanation for the predominance of easterlies in a region of mean westerly flow[33] stems from the fact that YAK is surrounded on three sides by sea. Assuming land and sea breezes are each the dominant influence on the wind direction for half the day, the sea breezes would be spread over three times as many compass points as the land breezes. Thus the easterly land breezes appear to prevail.

[33] See Figures 6 and 7 and Ch.II sec. 1

The relatively low average wind speed of 8.1 m.p.h. (ca. 7 kts.) suggest the presence of these thermodynamically induced winds.[34]

In addition the prevailing easterlies suggests cyclonic passages to the S. of YAK. The maximum mean monthly speed comes in December (9.1 m.p.h.) when cyclonic activity in the area is great[35] and the minimum in August (6.9 m.p.h.) when it is less frequent.

v) Relative humidity:- Relative humidity averages 90 percent at 0300 Y.S.T. and 78 percent at 1500 Y.S.T. The diurnal variation is small in winter and large in summer. As most relative humidity variations (daily, monthly and annual) are merely a reflection of the temperature variations they are of little significance.

b) Juneau Compared to YAK

The YAK and Juneau mean annual and monthly temperatures are very similar (see Figure 22). The only significant difference is that Juneau has a slightly greater annual range.

Though the curves of average precipitation distribution have nearly the same shape (see Figure 23) Juneau Airport only receives an average of 54.6 in. (1386 mm.) annually compared to 131.8 in. at YAK. Rain falls on an average of 223 days of the year at Juneau (226 at YAK) however only 27 days (50 at YAK) record appreciable snow.

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[34] Thermally induced winds are usually not too strong. In addition the land breezes would counteract the geostrophic flow.

[35] See Figures 11 and 12 and Ch. II sec. 3.

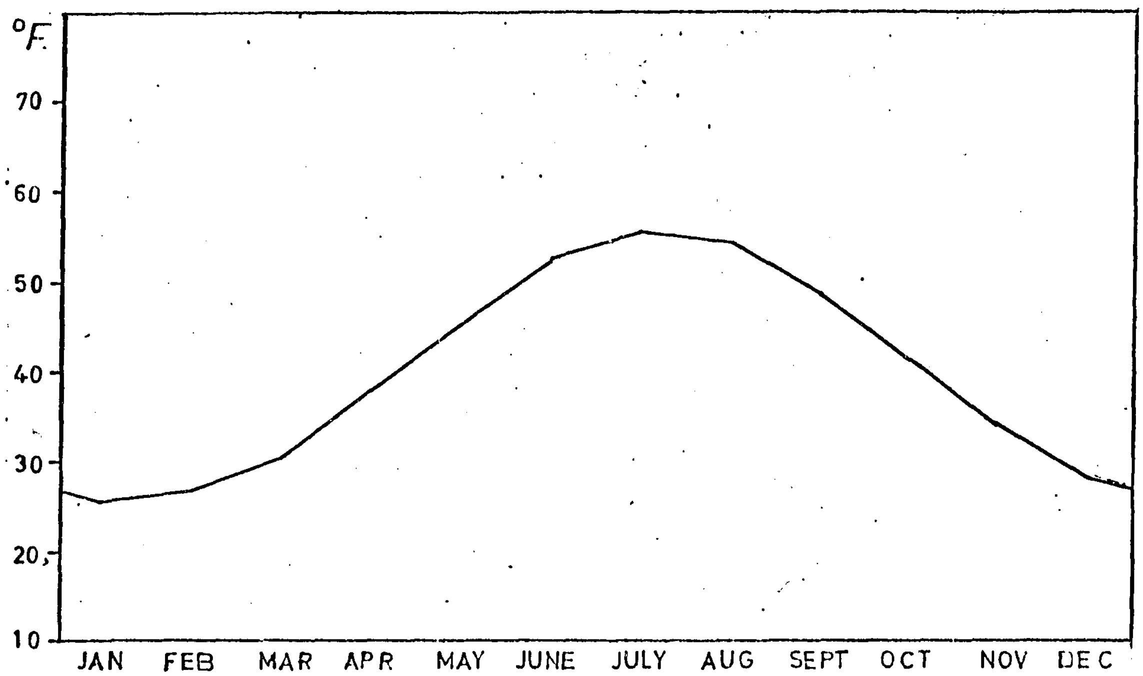

Figure 22. Normal temperature means, Juneau (1931-60).

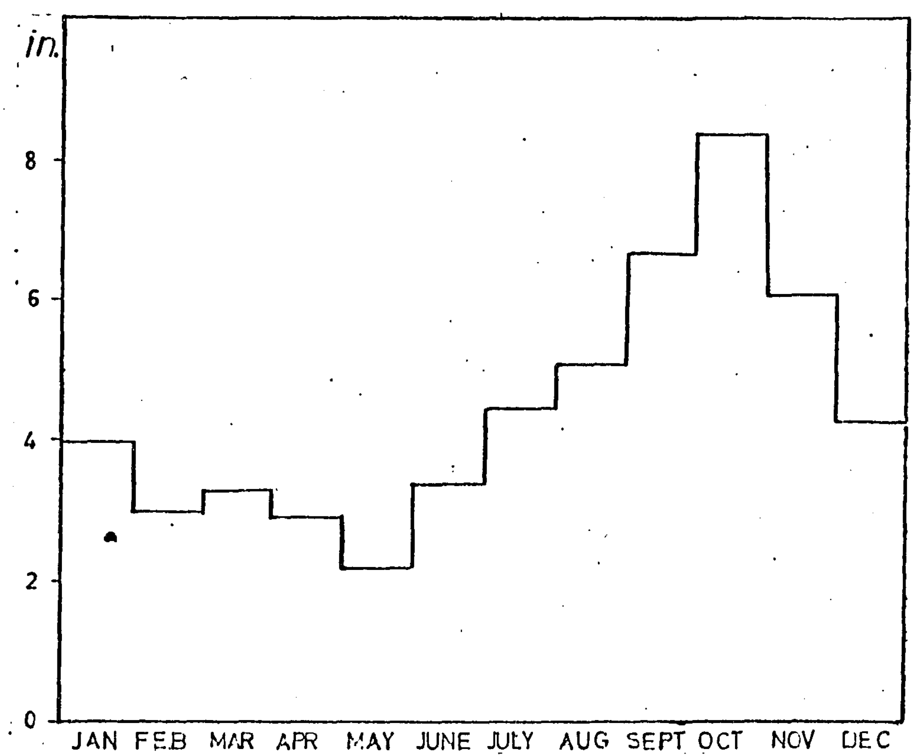

Figure 23. Normal monthly precipitation totals, Juneau (1931-60).

Topography (local and large scale) is likely the major reason for the precipitation regime differences. Juneau Airport is more protected and in fact receives only 65 percent of the precipitation recorded in Juneau city.

In addition Juneau lies further S. than YAK and is less influenced by the Arctic front systems.

As would be expected the relative humidity at Juneau is lower and less variable and fog is less frequent (20 days compared to 31 at YAK).

Winds are slightly stronger and from the E.S.E. most of the year at Juneau.

In short YAK is more maritime than Juneau and should be considered to be representative of the exposed coastal areas. However the trends at YAK are those of the whole coastal region.

c) Climate of the Maritime Margins

The S.E. coast of Alaska is, in general, characterized by mild winters, cool summers, and small annual temperature variations. The area is occasionally subject to periods of extreme cold when air from the Mackenzie high overflows the mountain barrier and sweeps down the glaciers bringing clear skies, gusty winds, and sub-zero temperatures.

Precipitation is appreciable, often over 100 in. (2540 mm.) and is mainly orographic in nature. This, of course, implies amounts are much less in the lee of high ground. Snow amounts increase with altitude, to a certain point,[36] and the snow has a high water equivalent.

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[36] See Ch.VIII sec. 1, e.

Skies are usually cloudy and fog is frequent on the coast.

Winds are not particularly strong and are influenced by topography(being onshore in some cases).

Cyclonic disturbances are frequent in the YAK area especially in autumn and winter.

In short, the climate is that of a northerly maritime area, located in the Sub Arctic low pressure belt, protected from continental weather by a mountain barrier, and warmed by the Alaska current. Tables XII and XIII give the values of several climatic indices for YAK and several other places in the world for comparison. These will be discussed in section 3.

2. CONTINENTAL MARGINS

a) Whitehorse (WH)[37]

The first order meteorological station closest to the IRRP area east of the St. Elias Range is Whitehorse. The "Annual Summary for Whitehorse Airport Yukon" (33) gives the following description of the area's topography.

> The Whitehorse Airport lies on a bench immediately beside the western escarpment of the Yukon River. The city itself lies on the valley floor at the base of this steep 200 foot escarpment. The general valley configuration, including the adjoining mountains run in a northwest-southeast direction with the flow of the river towards the north... Although Whitehorse lies only 80 miles north of the Lynn Canal, the nearest arm of the Pacific Ocean, a series of mountain ranges act as a rain barrier. To the

[37]Henceforth abbreviated to WH.

> south of Whitehorse lies the Coast Range with peaks to 8,000' ... (and to the west) a higher barrier ... the St. Elias Range with elevations up to near 20,000' . The terrain to the east and north of Whitehorse is lower rough highland...

i) Temperature:- The 18 year mean monthly temperature curve (Figure 24) is smooth and almost symmetrical with a July maximum (57.5 degrees F. -- ca. 14 degrees C.) and a January minimum (-0.6 degrees F. -- ca. -21 degrees C.). The annual mean is 30.8 degrees F. (ca.-1 degrees C.)[38]

The mean minimum and maximum curves, also almost symmetrical give a mean monthly range of 22 degrees F. in July, of 15 degrees F. in the autumn, and close to the average range (20 degrees F.) in the winter and spring. The mean annual range is 76.4 degrees F.

The extreme maximum of 91.1 degrees F. (ca. 33 degrees C.) and the extreme minimum of -61.6 degrees F. (-52 degrees C.) give the rather astounding extreme range of 152.7 degrees F. The curves of monthly extremes lie further above and below the mean in winter than in summer.

The temperature drops below 0 degrees F. on about eighty days a year but has reached 80 degrees F. in the months of May, June, July, August, and September.

ii) Precipitation:- The total annual precipitation at WH averages barely over ten inches (10.05 in. = 255 mm.). The curve of mean monthly totals (see Figure 25) rises quickly to the August maximum

[38] 1942 to 1960. All averages will be for this period unless otherwise stated.

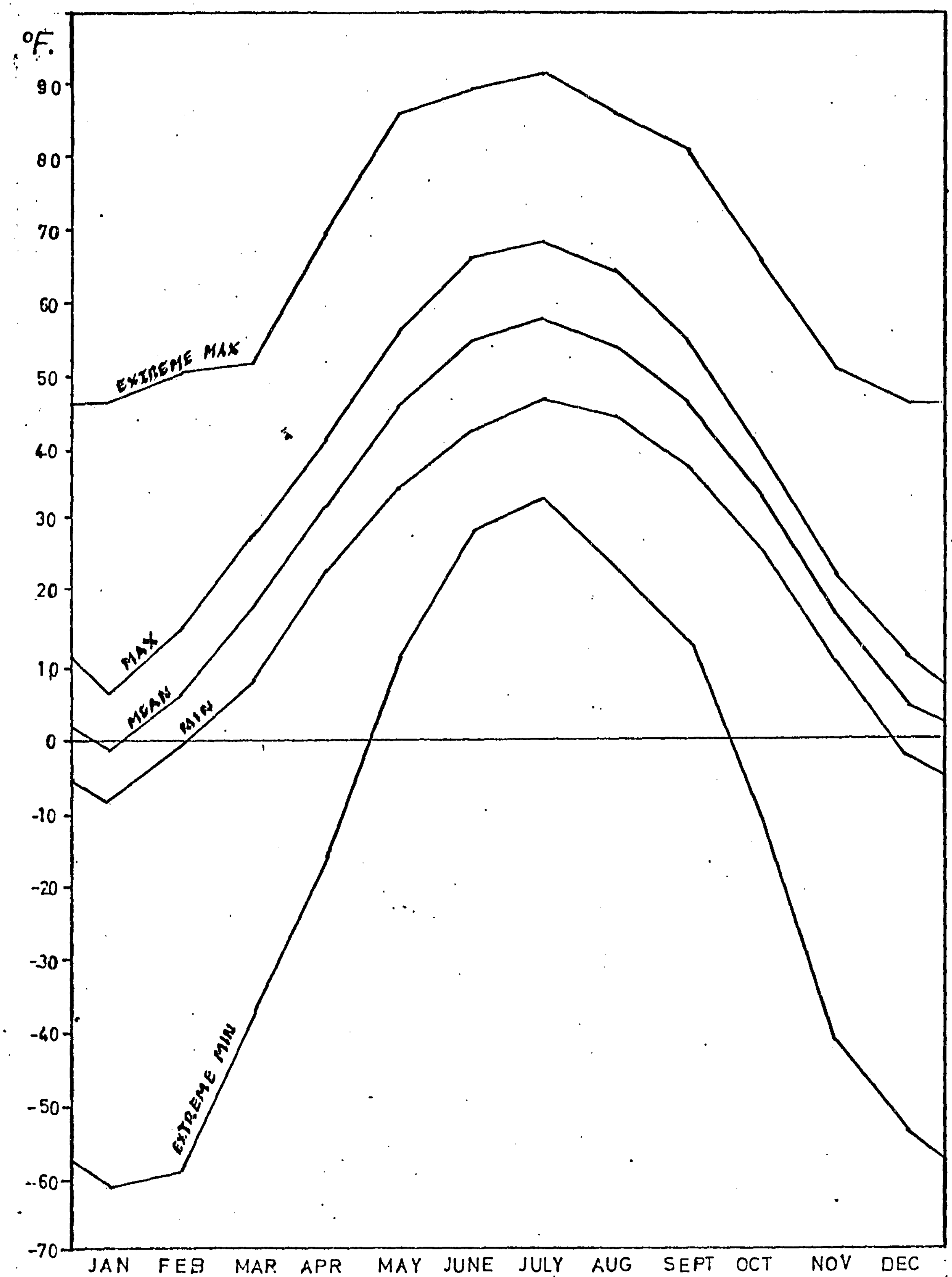

Figure 24. Normal monthly temperature means, maxima, and minima, Whitehorse (1942-60).

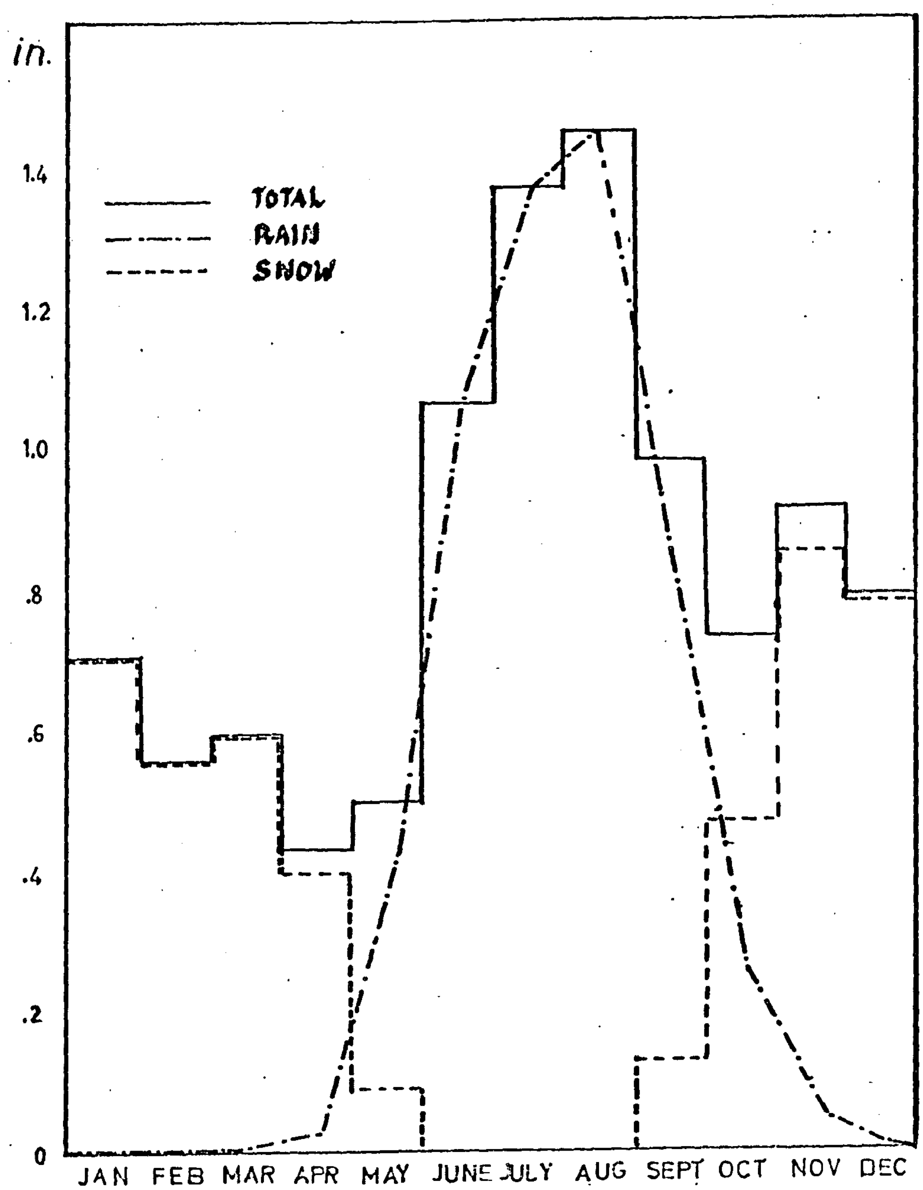

Figure 25. Normal monthly precipitation totals, Whitehorse (1942-60).

(1.44 in. = 37 mm.) and falls slowly, over a secondary maximum in November, to the May minimum (0.50 in. = 12 mm.).

The following is an attempt to explain this curve on the basis of the mean circulation and temperature patterns discussed in Chapter II.

In tensive radiative surface heating, during the summer months, reduces the stability of the lower layer of the cP air and increases its moisture retention capacity. The disappearance of the Mackenzie high allows cyclones to penetrate north of WH forcing Arctic Basin air south over the heated ground. In addition the radiative heating results in formation of considerable convective cloud. Hence in August the precipitation curve reaches its maximum.

Two factors contributing to the November maximum are: (1) Gulf lows more frequently penetrate the area and/or bring with them more moisture than in other seasons. (2) The advection of cold, relatively moist, air (moisture picked up from the open leads) from the icebound Arctic Ocean, south, over the interior produces instability (assuming the interior in November is still warmer than the Arctic Basin).

The winter months in the interior are characterized by extremely cold surface temperatures, a pronounced temperature inversion, and the resulting stability.

These winter conditions persist into early April, by which time cyclonic activity is at a minimum (see Ch.II, sec. 3 a). In addition Figure 6b indicates that air entering the WH area in April has experienced a longer trajectory over land than in any other season and so has attained the same temperature as the surface,--hence the April precipitation minimum.

After April the radiative processes begin to heat the ground decreasing the stability of the overlying cP air.

As noted in section 1, a(ii) above annual variations in the mean circulation and temperature conditions result in considerable annual fluctuations of the monthly precipitation totals from the long term averages.

The precipitation extremes are shown in Table IX.

Over the 19 years of record, July is the only month which has not experienced snow. Rain of 0.01 in. or more falls on an average of fifty days and snow of 0.1 in. or more on about sixty days a year while heavy fog is reported on an average of eighteeen days a year.[39]

iii) <u>Cloud</u>:- Annual cloudiness averages 7.2 tenths,[40] November being the cloudiest and February the clearest month. Two tenths (or less) is reported 19 percent of the time and eight tenths (or less) 64 percent of the time. Afternoons tend to be cloudiest while early morning is clearest. Summer months are characterized by a predominance of convective type cloud (i.e., Sc., Ac., and Cu.) while in winter middle cloud is most common (i.e., As. and Ac.).

iv) <u>Wind</u>:- Over the twenty-two years of record[41] the wind has averaged 9.3 m.p.h. (ca. 8 kts.). The primary maximum occurs in

[39] From Kendrew and Kerr (15) 1944 to 1951.

[40] It should be noted these values apply only to the valley - on the mountains more cloud is experienced normally.

[41] Years 1943 to 1964.

October (10.9 m.p.h.) and a secondary one is recorded in March (9.6 m.p.h.). Similarly two minima are found: one in July (8.3 m.p.h.) and the other in January (9.1 m.p.h.). In other words, speeds are high in seasons of general circulation change (i.e., spring and fall) and low in winter and summer.

The prevailing wind is S.E. in all months except January when it is N.W. The wind direction at WH is due almost entirely to local topography as is shown in Figure 26 (after Kendrew and Kerr, 15). In general up-valley winds are strong and easterlies weak.

v) Relative humidity:- Annual mean relative humidity averages 71 percent at WH with January the most humid month and May the driest (87 and 55 percent respectively).

vi) Pressure[42]:- The mean sea-level pressure for WH is 1013 mb. The monthly pressure means relate well to the wind speeds (i.e., low pressures in spring and autumn and high pressures in summer and winter).

b) Hains Junction, Aishihik, and Snag Compared to WH

The curves of mean monthly temperature for Hains Junction, Aishihik, and Snag (see Figure 27) have generally the same shape as that for WH. Table X compares the annual mean, maximum and minimum temperatures for these stations. Predictably, all are colder than WH.[42a]

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[42] See note 39 page 35.

[42a] Hains Junction because of the absence of lakes in the area, Aishihik due to higher altitude and latitude, while Snag lies in a topographic bowl.

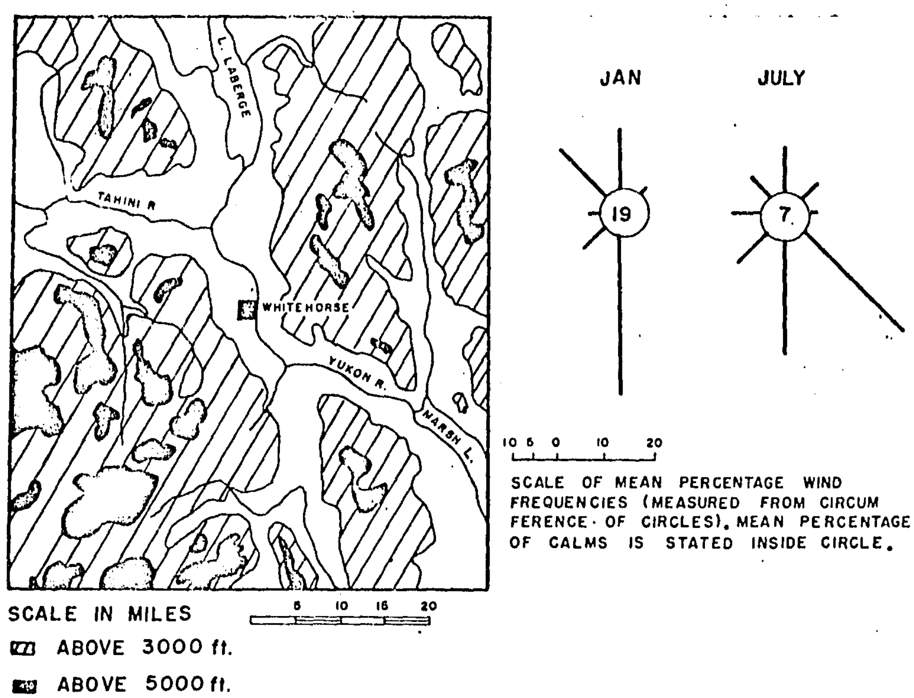

Figure 26. Wind roses and topography, Whitehorse, after Kendrew and Kerr (15, p. 161).

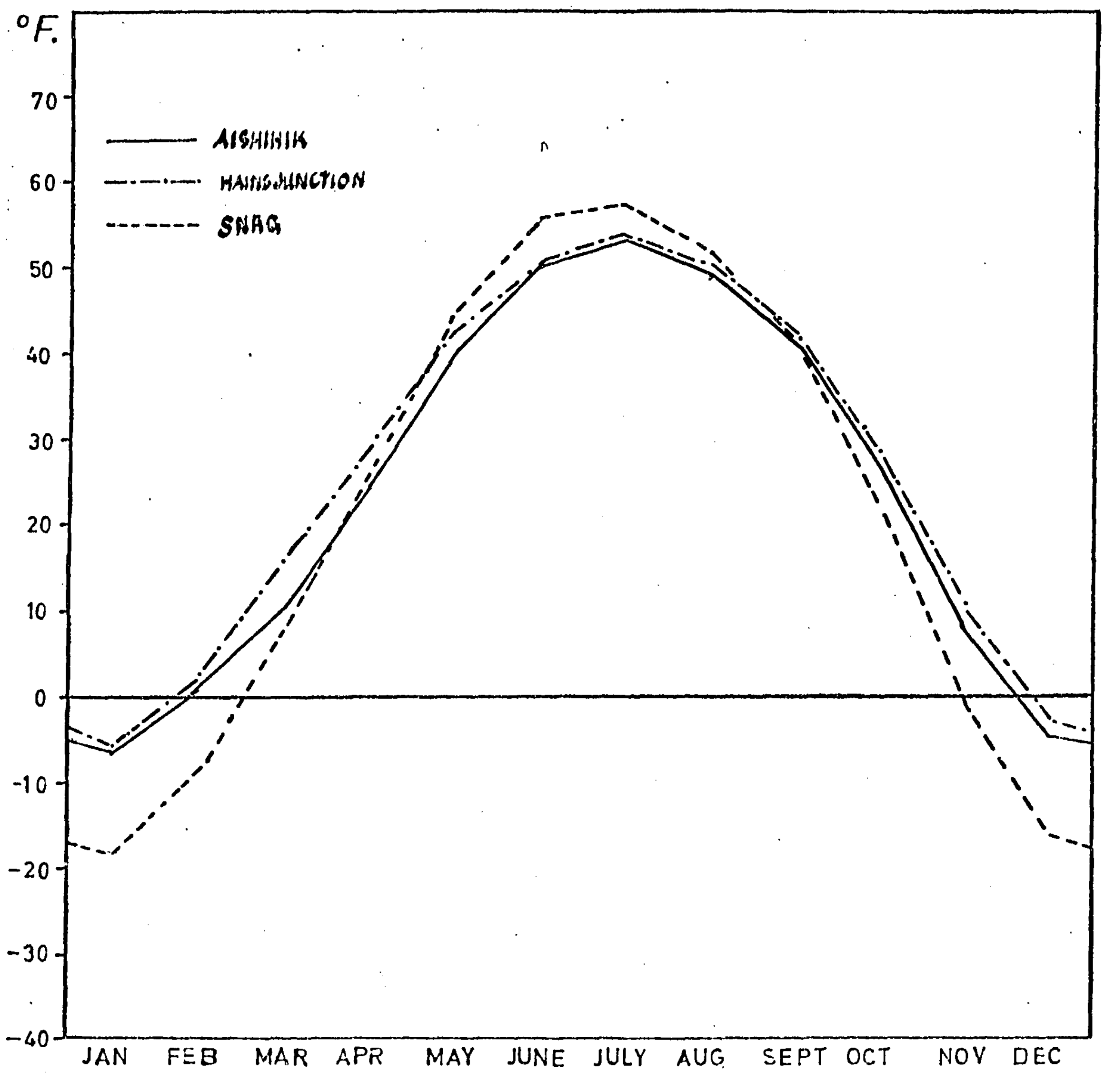

Figure 27. Normal monthly temperature means, Aishihik, Snag, and Hains Junction (1944-60).

Local topography is likely responsible for the difference in precipitation distributions at these stations (see Figure 28). For instance Aishihik receives comparitively more rain in the summer (than WH), due to the prevailing S. winds off Aishihik Lake, and less snow in winter, as a result of the drier down-valley northerlies which prevail in this season.

WH's relative humidity is high in comparison to Aishihik and Snag due possibly to year round prevailing winds off the adjacent lakes.

Wind directions are largely the result of local topography.[43]

Cloud amount averages (also affected by topography) suggest that the WH value of 7.3 tenths is rather high (Snag 7.0 tenths and Aishihik 6.7 tenths).

In short, WH is somewhat warmer and more humid due largely to the moderating effects of the extensive system of lakes and rivers in the immediate area. Nevertheless it can be considered to be fairly representative of the continental margins of the St. Elias region.

c) Climate of the Continental Margins

Winters are cold and clear while summers are warm and short. Annual and diurnal temperature ranges are large. The area is, on the whole, isolated from the Pacific air by the St. Elias and Coastal Mountains, however, the lower Pelly and Cassiar mountains to the east allow the penetration of the Mackenzie high in winter.

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[43] i.e., At Aishihik one finds summer southerlies and winter northerlies due to the N.-S. valley of Seblum Lake and at Snag westerlies for a similar reason.

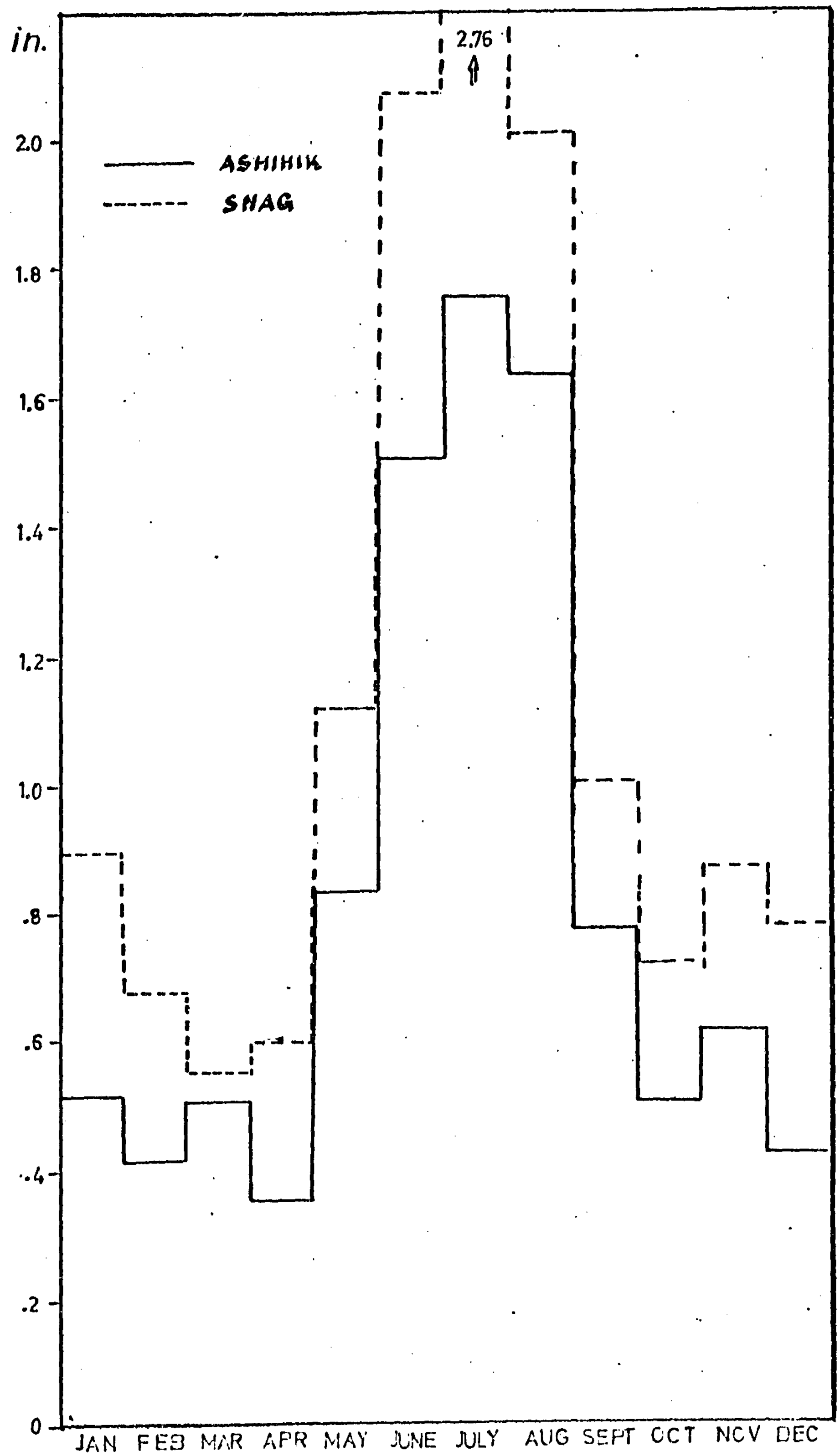

Figure 28. Normal monthly precipitation totals, Aishihik and Snag.

Precipitation is scant and occasionally drought and forest fires result. Snow depths are small but drifting prevalent. Fog does occur and, in winter, ice fogs are not infrequent.

Wind direction, and to some extent cloud and precipitation, are controlled by topography and the records from the meteorological stations are actually only indicative of the valley climates.

In short, the climate of the mountainous S.W. corner of the Yukon is virtually unaffected by the moderating influence of the Pacific Ocean (as little as 80 miles away) and open to the accentuating influence of continental Canada. Tables XII and XIII give the values for WH of several climatic indices.

3. CONTINENTAL VS MARITIME

a) Characteristics of Continental and Maritime Climates

Before comparing the climates of YAK and WH a brief list of the characteristic differences between maritime and continental climates will be given.

(1) Temperature fluctuations (annual, diurnal and interdiurnal) are accentuated over land and damped by ocean surfaces.

(2) Continental temperature curves exhibit greater symmetry than do oceanic curves.

(3) Continental regions tend to have lower mean temperatures.

(4) Relative humidity is a little lower inland in winter but vapour content is considerably less due to lower temperatures. In summer inland relative humidities are likely to be higher

due to higher temperatures.

(5) Skies are more cloudy and precipitation higher on the coast.

(6) Wind speeds are less over land than sea and the sea maximum comes at night while the land maximum is found in the afternoon.

b) Comparison of Synoptic Parameters at WH and YAK

Table XI shows, at a glance, the very impressive differences, in almost all synoptic parameters, between these two stations (situated at almost the same latitude and only two hundred miles apart).

i) Temperature:- Though WH has a lower annual mean temperature, it has experienced 80 degree temperatures in five months of the year compared to only two at YAK. The various temperature ranges at YAK are only 52 to 70 percent of those at WH. Ranges are larger in autumn and winter in the continental region, while on the coast they are almost constant all through the year.

ii) Precipitation:- YAK receives over ten times as much precipitation as WH. Nor are the precipitation cycles in phase. The WH curve appears to lead that of YAK by about two months. In other words, not only is WH in the rain shadow of the St. Elias but it appears to be subject to a different set of precipitation controls than YAK (see discussion of cycles 1, a (ii) and 2, a (ii) above).

iii) Cloud and relative humidity:- The cloud amount and relative humidity means combine with precipitation to illustrate that the air overlying the coastal regions is considerably moister than that usually found over WH.

iv) Wind and pressure:- YAK and WH appear to be under rather different pressure influences. Wind direction at both stations is largely topographically controlled.

c) Degree of "Oceanicity" and "Continentality"

On the basis of factors (1) and (2) of section a) above indices of continentality and oceanicity have been set up by Johansson and Kerner,[44] respectively. These are:

$$K = \frac{1.6A}{\sin \phi} - 14$$

and

$$0 = \frac{100 \ (To - Ta)}{A}$$

where K is the continentality index, 0 the oceanicity index, A the annual range, and To and Ta the monthly mean temperatures for October and April.

Table XII shows the values of these indices for WH and YAK as well as several stations for comparison.

It is interesting to note that WH has almost the same continentality as the North American continent; YAK on the other hand, is more oceanic than Bergen, Norway, or Tokyo, Japan. Though these indices mean little numerically they serve to point out the contrast in the climatic regimes of the stations.

[44] Quoted from Landsberg (16)

d) Climatic Classifications

Koppen (see Harwitz and Austin, 11) and Thornthwaite (28) have each devised a climatic classification based on a station's temperature and precipitation regimes. Table XIII gives the divisions into which YAK and WH fall as well as the indices of stations in other parts of the world for comparison.

The table is to a large extent self-explanatory. Numbers 3 and 8 are particularly helpful in showing the degree of maritimisity and continentality of YAK and WH respectively.

It should be noted that within less than one hundred miles at the same latitude (i.e., Pacific coast to Coastal Ranges) three of the 5 major Köppen climatic types are found (the St. Elias being ET).

However, any classification system must be used with caution in a region such as the study area. They represent on the sea coast sea-level climate, in the mountains the climate of the peaks, and in the interior the plateau climate; but the Pacific slopes are not at sea-level, the mountains are cut by valleys, and the plateau is not flat. Nonetheless such classifications are useful in comparing two stations, and once again there is a considerable difference between WH and YAK.

e) Conclusions

It appears from the above that the St. Elias mountains divide this two hundred mile section of Basin and Range Province into two fundamentally different climatic regimes.

The following three questions present themselves. (1) Does a well defined climatic divide exist between these two regimes? (2) If so, what is the nature of this divide? (3) Where is it to be found or in other words into what regime or regimes do the extensively glacierized area of the mountain barrier fall.

4. 1963, 1964, AND 1965 WEATHER TRENDS

Figure 29 (of annual mean temperatures for 1950-65) show that YAK and WH annual mean temperatures have deviated from the long term mean in a very similar manner during the last 15 years. In general 1962 is close to or above normal, 1963 is above, 1964 below and 1965 just slightly below normal. None of these fluctuations is large compared to those of past years.

The yearly precipitation totals, on the other hand, (Figures 30 and 31) do not exhibit such an agreement. Since 1958 YAK fluctuations seem to lag behind those at WH by about a year. This may be purely coincidence.[45] At YAK in 1963 and 1964 the highest precipitation in 15 years was experienced. The WH 1961-64 above normal annual totals appear to be the result of high winter snow amounts.

The temperature and precipitation curves (Figures 32, 33 and 34) for 1963, 1964, and 1965 show the following.

i) 1963:- At both YAK and WH January and February were warm, March cold and the maximum late, (August) giving a warm autumn.

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[45] Annett and Juneau have shown a decided levelling of precip. totals since 1962, while at YAK in 1963 and 1964 were recorded the highest precip. for the last 15 years. This suggests the YAK values are due to some local effect.

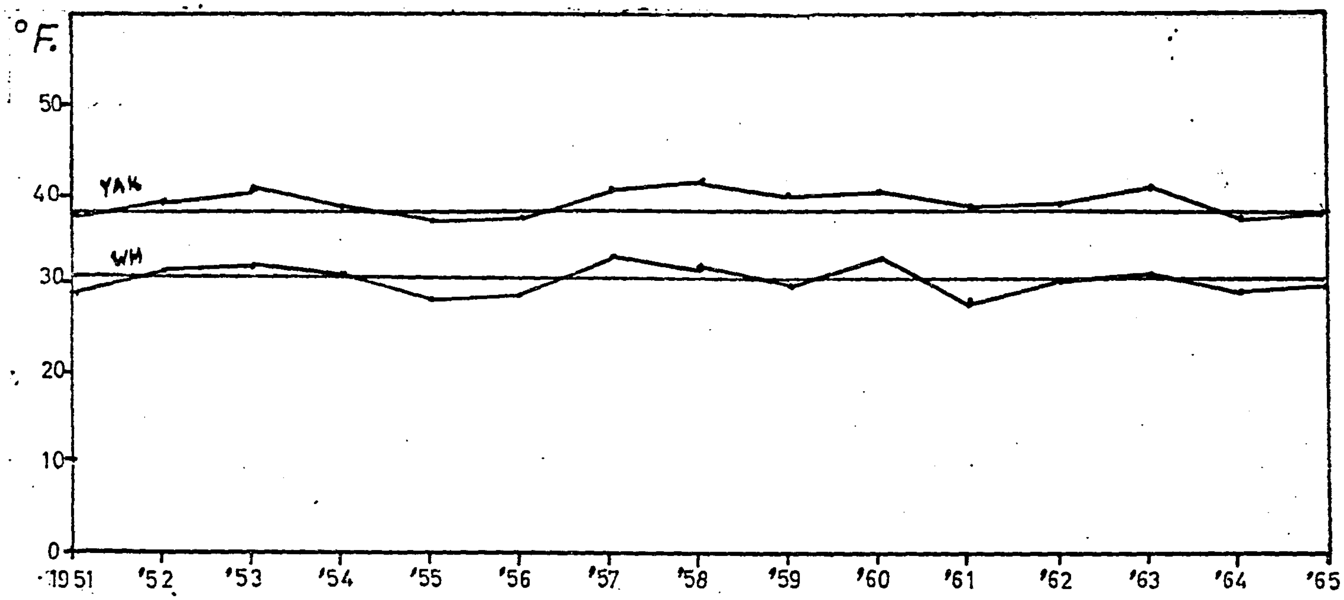

Figure 29. Annual temperature means 1951-1965, Yakutat and Whitehorse. The straight line represents the normal annual mean (1931-60 at Yakutat and 1942-60 at Whitehorse).

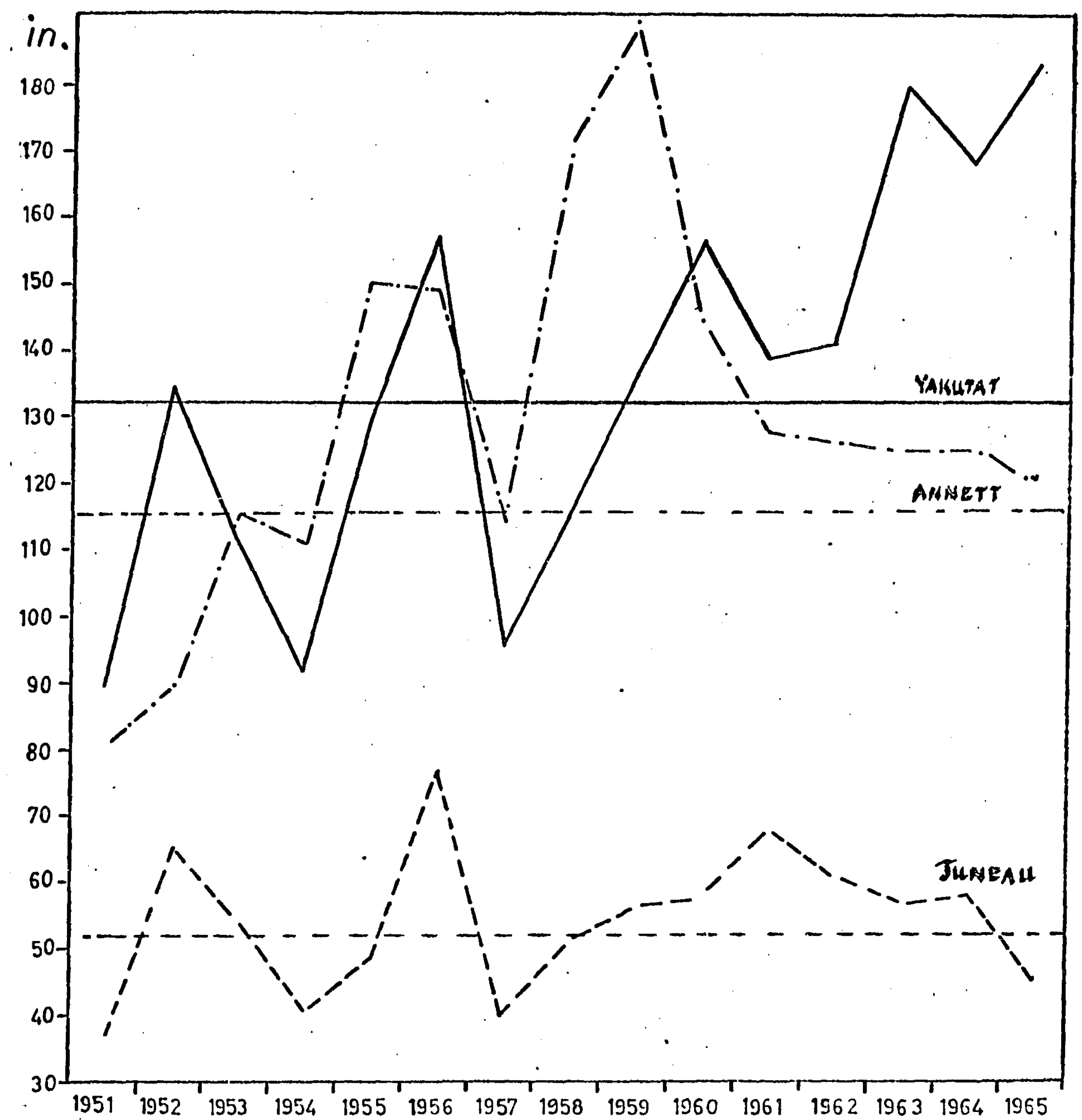

Figure 30. Annual precipitation totals 1951-1965, Yakutat, Annett, and Juneau. The straight lines represent the normal totals (1931-60).

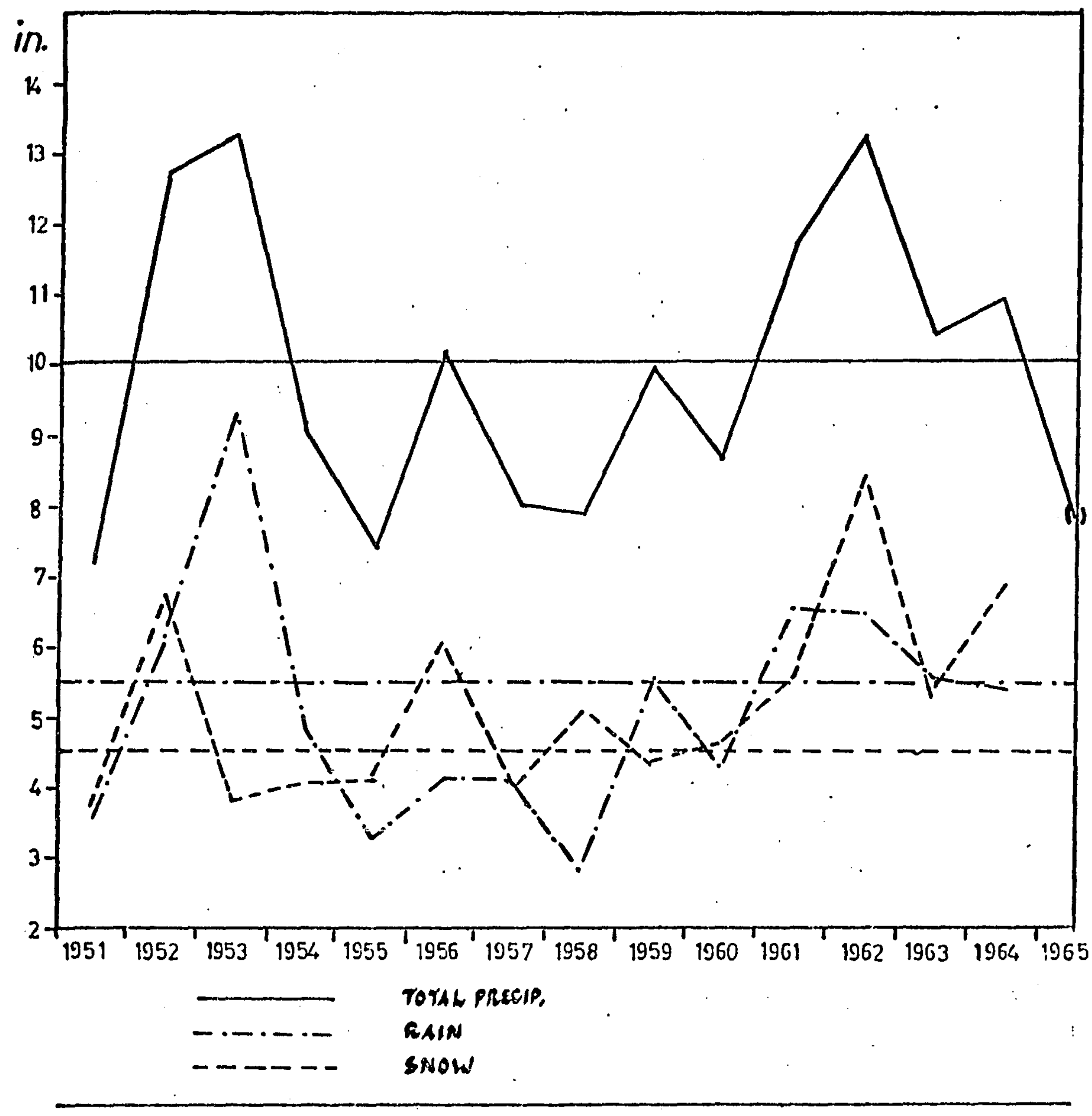

Figure 31. Annual precipitation totals 1951-1965, Whitehorse. (N.B. the 1965 value is only an estimate.) The straight lines represent the normal values (1942-60).

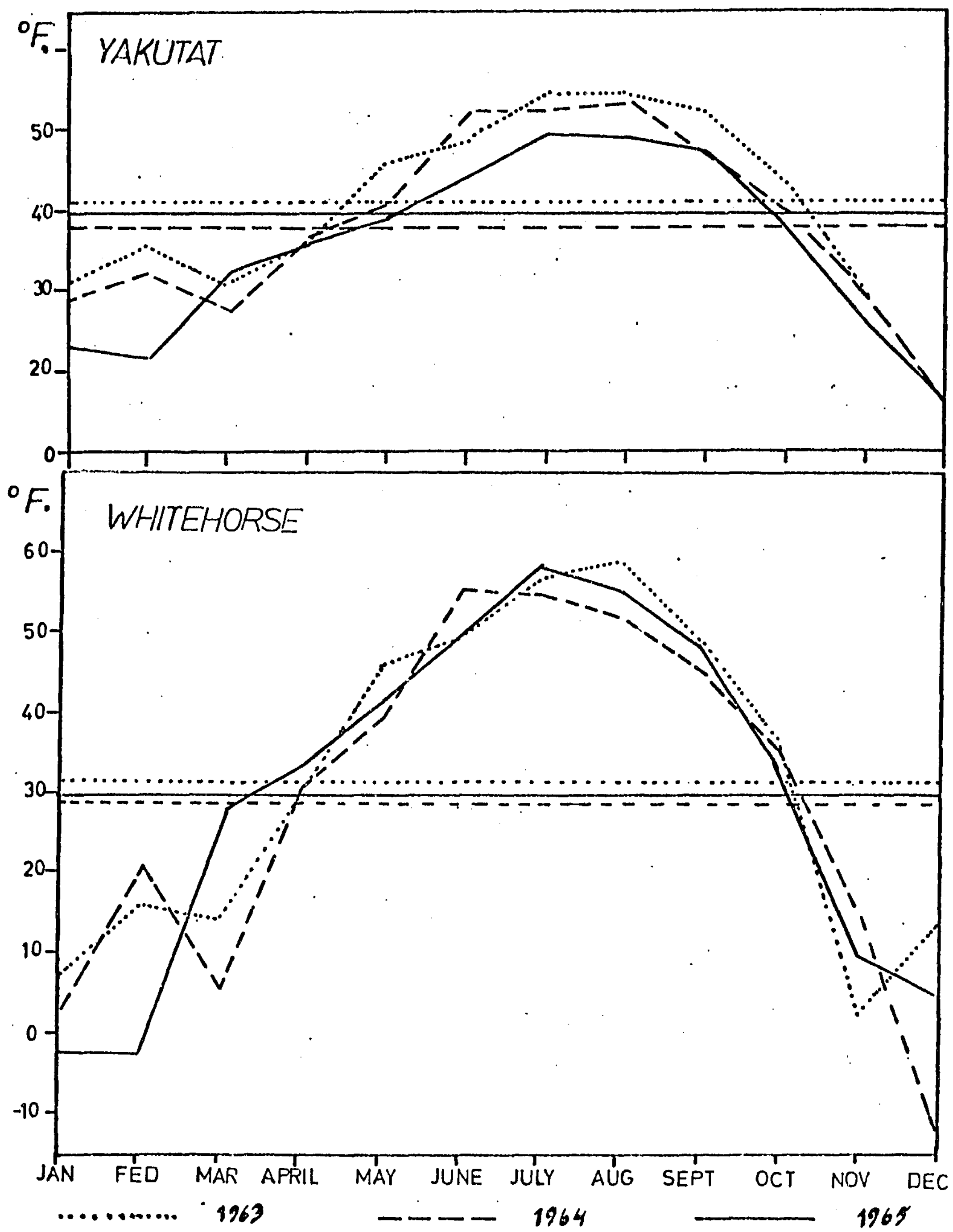

Figure 32. Mean monthly temperature 1963, 1964, and 1965, Yakutat and Whitehorse. The straight lines represent the annual means.

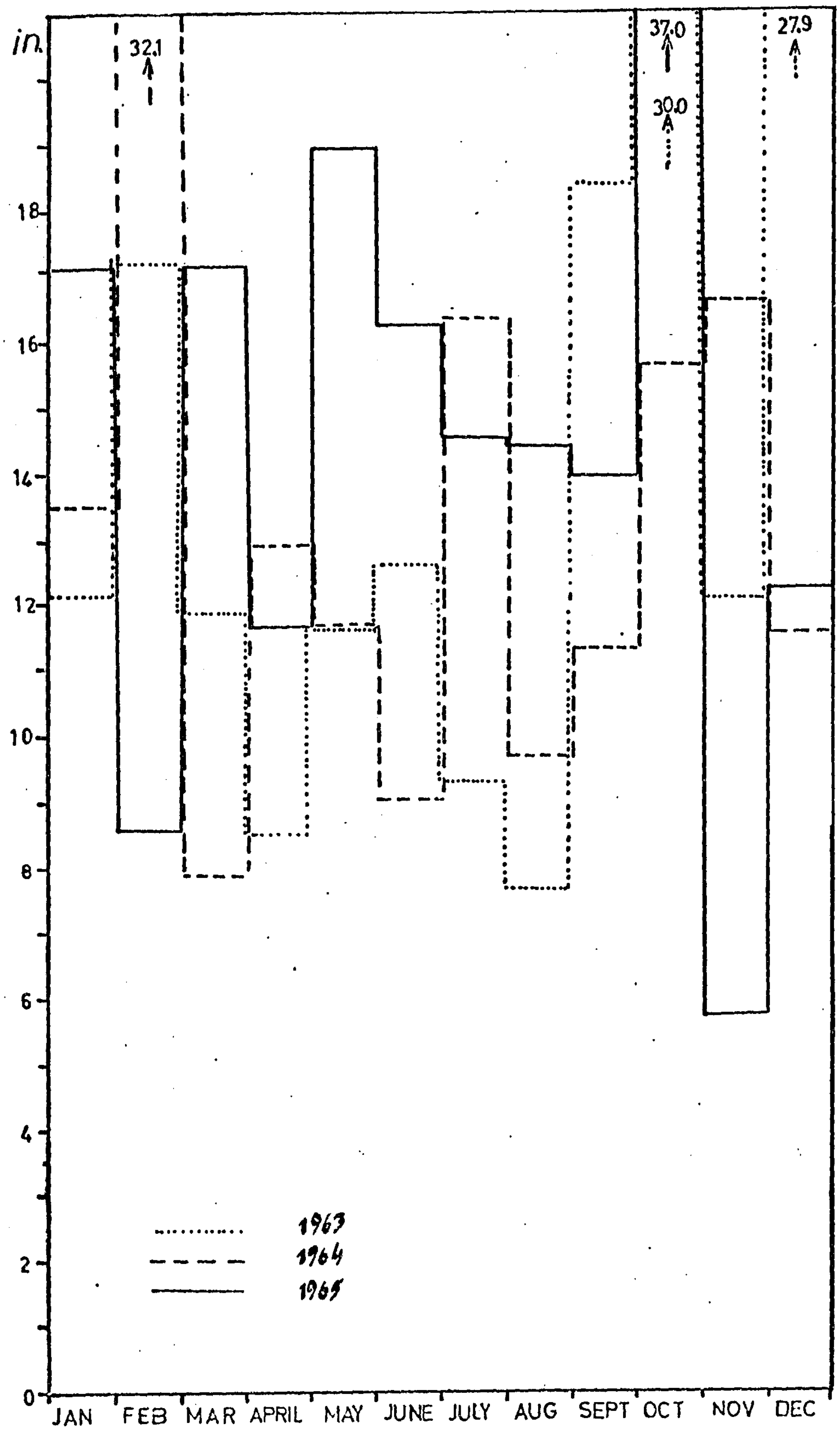

Figure 33. Monthly precipitation totals 1963, 1964, and 1965, Yakutat.

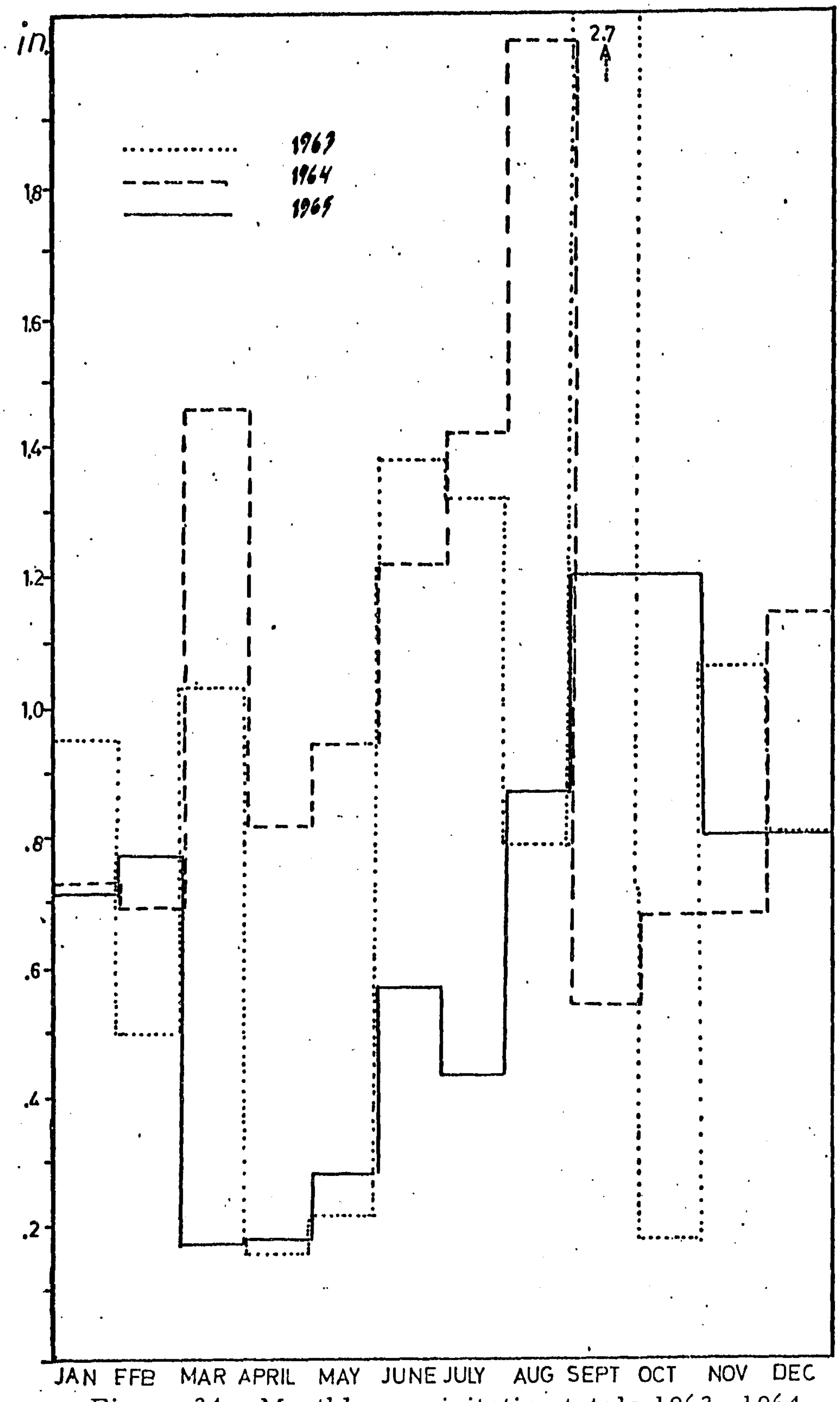

Figure 34. Monthly precipitation totals 1963, 1964, and 1965, Whitehorse. (N.B. 1965, Sept. to Dec. values are only estimates.)

Low August and high winter values are the most striking features of both 1963 precipitation curves.

ii) 1964:- The temperature curves show similar winter and spring deviations as in 1963 but the maximum is early (June).

The YAK precipitation curve bears little resemblance to the mean but at WH it does. Both show high winter values and above normal June and July, while August at WH is considerably above normal and at YAK it is below normal.

iii) 1965:- WH shows a warm March followed by a cool spring and a close to normal July and August. YAK has the normal shape curve about 5 degrees below average for the summer months.

YAK summer precipitation was 3 to 10 inches above normal while WH was considerably below normal from March to August.

iv) Conclusions:- No broad statements can be made concerning the representativeness of the years 1963, 1964, and 1965 of the mean climate of the area. However, except for YAK precipitation, the conditions do not appear to be particularly atypical.

The summer of 1965 may prove interesting in that the precipitation deviates in the opposite direction at YAK and WH, and the WH summer began cool but ended normal or warm while at YAK the whole summer was cold (i.e., marine to continental differences accentuated).

PART B

CHAPTER IV

TEMPERATURE

In the chapters making up Part B of the present study, the data from the IRRP and mountain margin stations as well as various synoptic charts will be analysed in detail for the summer seasons of 1963-1965. (i.e., The means, averages and variations of various parameters will be discussed and then related to wind direction, flow, and synoptic situations.)

Unfortunately surface temperature is recorded at both the permanent and IRRP stations in degrees F. Thus these somewhat unscientific units have been used throughout the study and metric equivalents given for many of the values appearing in the text. Precipitation is recorded in inches by the Canadian and U.S. stations and in a combination of English (rain) and metric (snow) units at the IRRP stations. In this study, for the most part, mm. have been used though the figures in Ch. III are plotted in inches. For all in. values given in the text mm. equivalents have included.

Temperature, perhaps the most important and most frequently measured and used meteorological parameter, will be discussed first. The degree of accuracy attained in temperatures recorded in field studies such as this is relatively good in comparison to that of the other parameters measured. Havens (12), Marcus (18) and others have noted, however that on clear, calm days radiative heating of the unventilated instrument boxes can result in two (or possibly greater) degree ^{o}F. temperatures errors. Such errors are critical to ablation studies but will not be significant in this study as these days are not frequent and the errors will not affect the monthly means to any appreciable extent.

1. TEMPERATURE MEANS

Since the period of temperature records varies from year to year and station to station, the following types of seasonal and monthly means and/or three year averages have been calculated.

(1) Table XIV shows the monthly and seasonal[47] means of daily mean temperatures calculated for each station, for each year, using all the available data. The three year averages[48] of these means[49] and the number of days on which they are based are also included.

(2) Three year seasonal averages were obtained (as tabulated in Table XV) for each station for the period of record common to all years of record at that station. (The periods involved are also given.)

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[47]Henceforth season will refer to the summer season though this will not always be stated.

[48]In some cases of course less than three years are available-this is noted in the table.

[49]In calculating 3 year averages only months having 25 or more days of observation were used.

(3) As will be discussed in Chapter IX daily temperature changes are reflected in a similar manner at all IRRP stations. In order to maximize the length of the season, it therefore seemed justified to extrapolate from the KL records (in every case the longest) to extend the glacier camps' records.

The seasonal means thus obtained for the 65 days from 5 June to 8 August are shown in Table XV. When only one or two averages were available these were corrected[51] to give the three year seasonal averages for all stations.[52]

a) Three Year Temperature Averages

The solid line in Figure 35[54] represents the theoretical temperature of the free atmosphere at heights corresponding to those of the various study stations.[53] The temperature at YAK which is only 39 feet (12 meters) above sea level on the windward side of the St. Elias barrier, was used as the starting point for this curve.[55]

The curve should facilitate comparison between the seasonal average temperatures of these stations which differ so greatly in altitude. It has been noted by several authors (i.e., Marcus (18) and Orvig (23) that, in general, two different station locations exist--the

[51] Using the closest station with a 3 year average.

[52] Henceforth when 3 year seasonal temp. averages are discussed it will be these values.

[53] i.e., a temp. gradient of .6°C / 100 m.

[54] As in Figure 1 the base line is the station to station distance.

[55] This is not entirely satisfactory but was the only alternative open at this point in the study - see Ch. XIV sec. 1 for further discussion.

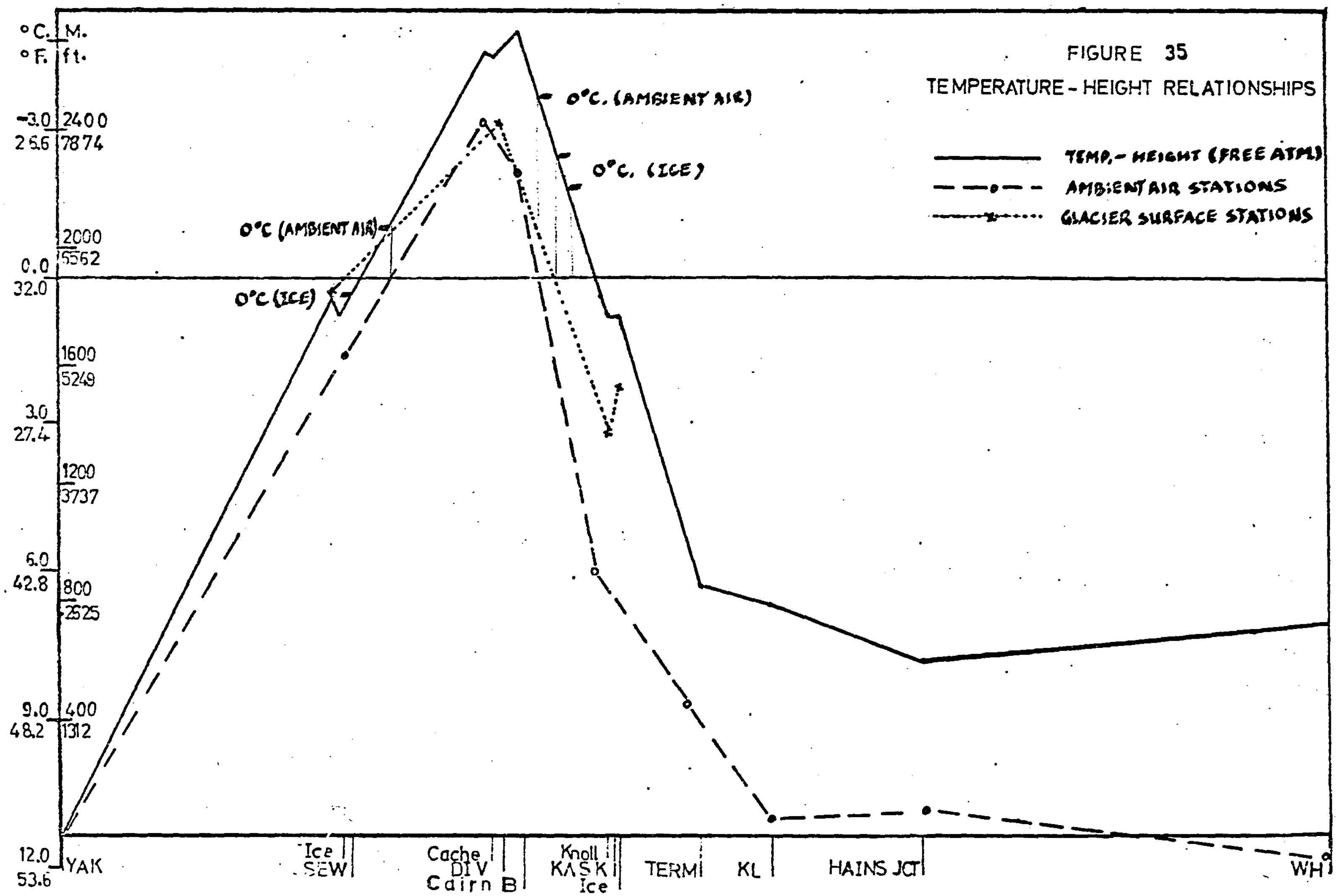

FIGURE 35
TEMPERATURE - HEIGHT RELATIONSHIPS
TEMP. - HEIGHT (FREE ATM.)
AMBIENT AIR STATIONS
GLACIER SURFACE STATIONS
0°C. (AMBIENT AIR)
0°C. (ICE)
0°C (AMBIENT AIR)
0°C (ICE)
°C. M.
°F. ft.
-3.0 2400
26.6 7874
2000
6562
0.0
32.0
1600
5249
3.0
27.4
1200
3737
6.0
42.8
800
2625
9.0 400
48.2 1312
12.0
53.6
YAK
Ice
SEW
Cache
DIV
Cairn
B
Knoll
KASK
Ice
TERM
KL
HAINS JCT
WH

glacier surface station and the nunatak station. The temperature records from these are representative of two separate regimes. The glacier stations represent the layer immediately above the glacier surface which, for instance, is critical in ablation studies. The nunataks tend, rather, to represent the regional air mass characteristics.

Possibly the most immediately obvious result of the presence of two such regimes is the following. During the summer months when nunataks are generally snow free they record higher temperatures than the lower elevation ice stations.

The cause of this anomaly will become obvious in the section that follows. The three year seasonal temperature averages have been plotted in Figure 35 along with the temperature-height curve and the two types of stations joined by two different lines (see legend, Figure 35).

i) Regional air mass temperature characteristics:- In order to isolate the properties of the ambient air the dashed curve of Figure 35 will be considered. This curve joins the land, nunatak, and ridge stations. It can be seen to have the same general shape as the altitude curve, being always below it, with this separation increasing eastward.

Beginning in the west; YAK's temperature (the reference point), of course, agrees with the height curve.

The SEW (nunatak) temperature is higher than the free atmosphere at that altitude despite the surrounding glacier surface. In agreement with previous discussion it is also decidedly warmer than SEW Ice. The snow-free rock of the nunatak is doubtless responsible for considerable day time heating. The nunatak is, in addition, situated well above the major portion of the glacier surface which lies in a decided basin.

The warm upper ridge shown on the general circulation maps may have some effect on the temperatures at SEW and DIV, but to confirm or deny this would require upper air temperature soundings over the glacier. This has not yet been attempted.

The DIV stations all lie below the height - temperature curve (i.e., are warmer than the free atmosphere).

DIV Cache, though on rock slightly above the glacier surface, does not, when compared to DIV, exhibit the anomaly discussed in section 1,a above although the difference between these stations' temperatures is not as great as their elevation difference would indicate. Compared to SEW, DIV Cache is much more likely to be subject to cooling effect from the glacier surface due to the proximity of that surface. The bare rock, on the other hand, will have a definite warming effect.

The daytime radiational heating of a rock surface does not explain the warm temperatures at DIV Cairn B as it is a snow ridge. Rather the following explanation must be invoked.

Nocturnal radiative heat loss at the glacier surface is considerable. The topographic basin formed by glaciers surrounded by towering peaks, or at least high land, trap this radiatively cooled air. Nunataks and ridges will rise above this cold layer which dissipates only slowly due to the lack of wind, strong turbulence, and radiative heating.

This cold pool effect obviously accounts for much of the ice to nunatak difference at SEW as well as DIV Cairn B while DIV Cache is not high enough to escape it.

The separation between the height - temperature curve and the ambient air curve at KASK Knoll is rather extreme (9.9 degrees F.) due to the size, nature, and position of this rocky, thinly vegetated, gopher inhabited knoll.

The curves converge slightly at TERM, located on gravel below the end of the Kaskawulsh Glacier. The predominant, strong, down glacier winds experienced at KASK[56] suggest that TERM would be subject to frequent, relatively cool, winds from the glacier.

There is little evidence of the cooling at KL that might be expected due to the proximity of the icefields. WH (ca. 110 miles to the east) shows about the same deviation from the height curve as KL. (The kink at Hains Junction is possibly a topographic effect or a result of the method of calculating this mean.)

The so-called ambient air curve leaves little doubt that there is a significant change in temperature regime as one moves eastward from YAK, over the St. Elias Mountains to WH. The freezing level of the ambient air on the marine slope (interpolated from Figure 35) is 1280 feet lower than that on the continental slope.

ii) Glacier environment stations:- The stippled curve of Figure 35 shows clearly the height - temperature anomaly discussed above (i.e., ice stations are colder than their higher nunatak counterparts -

[56] See Ch. VI.

with the exception of DIV Cache).

SEW ice due to the exceptionally well developed basin in which it is situated (see Figure 5 and Map 3) is subject to the greatest cooling effects.

The details of the relationship between the DIV stations are covered in Marcus (18). DIV (Ice)is definitely subject to cooling influences.

KASK (moraine), though considerably colder than KASK Knoll, is undoubtedly warmed by radiative heating of the morainal rock, exposed during most of the observation season. The KASK Ice area, on the other hand, is overlaid by air constantly cooled by the melting ice surface, and the predominant, strong, down glacier winds, provide ample turbulence to transport the cool air to screen level.

The freezing level of air immediately above the glacier surface is approximately 6460 feet (1970 meters) on the maritime slope and between 7580 feet (2310 meters) and 7220 feet (2200 meters) on the continental slope.

b) Yearly and Monthly Variation of Mean Temperatures

i) Seasonal means:- At all stations 1964 was the warmest[57] year (see Table XIV). KL and YAK experienced their coldest season in 1963 while WH and YAK were 0.1 degree F. colder in 1965 than 1963.

The yearly deviations from the three year seasonal averages (see Table XVI) indicate that year to year changes are greatest at the glacier stations.

[57] Of the 3 year record.

The three year period, on the whole appears to have been cool, as both the YAK and WH long term means[58] are higher than the three year seasonal averages.

ii) Monthly means:- The following points emerge from the monthly means given in Table XIVA.

July is most often the warmest month. Surprisingly the warmest month at KL does not in any of the three years agree with that at WH. In 1964 the warmest temperatures tended to be earlier in the season on the continental slope than on the maritime slope.

June is, in general, the coldest month. However, on the continental slope in 1964, due to the warm June, the coldest mean monthly temperatures fell to July or August.

It is interesting to note that while the coldest July and August were both recorded in 1964, the warmest June, and because of it, the warmest season also fell in that year.

2. DIURNAL TEMPERATURE VARIATIONS

a) Three Year Averages of Maximum and Minimum Temperatures

The averages of daily mean maxima and minima for 5 June to 8 August (extrapolated as for temperature means--see section 1) are presented in Table XVII and plotted in Figure 36. The number of years used in calculation are included. Table XVIII gives the extreme maxima and minima experienced during the entire period of record at

[58] WH 17 years, 1942-60; and YAK 30 years, 1931-60.

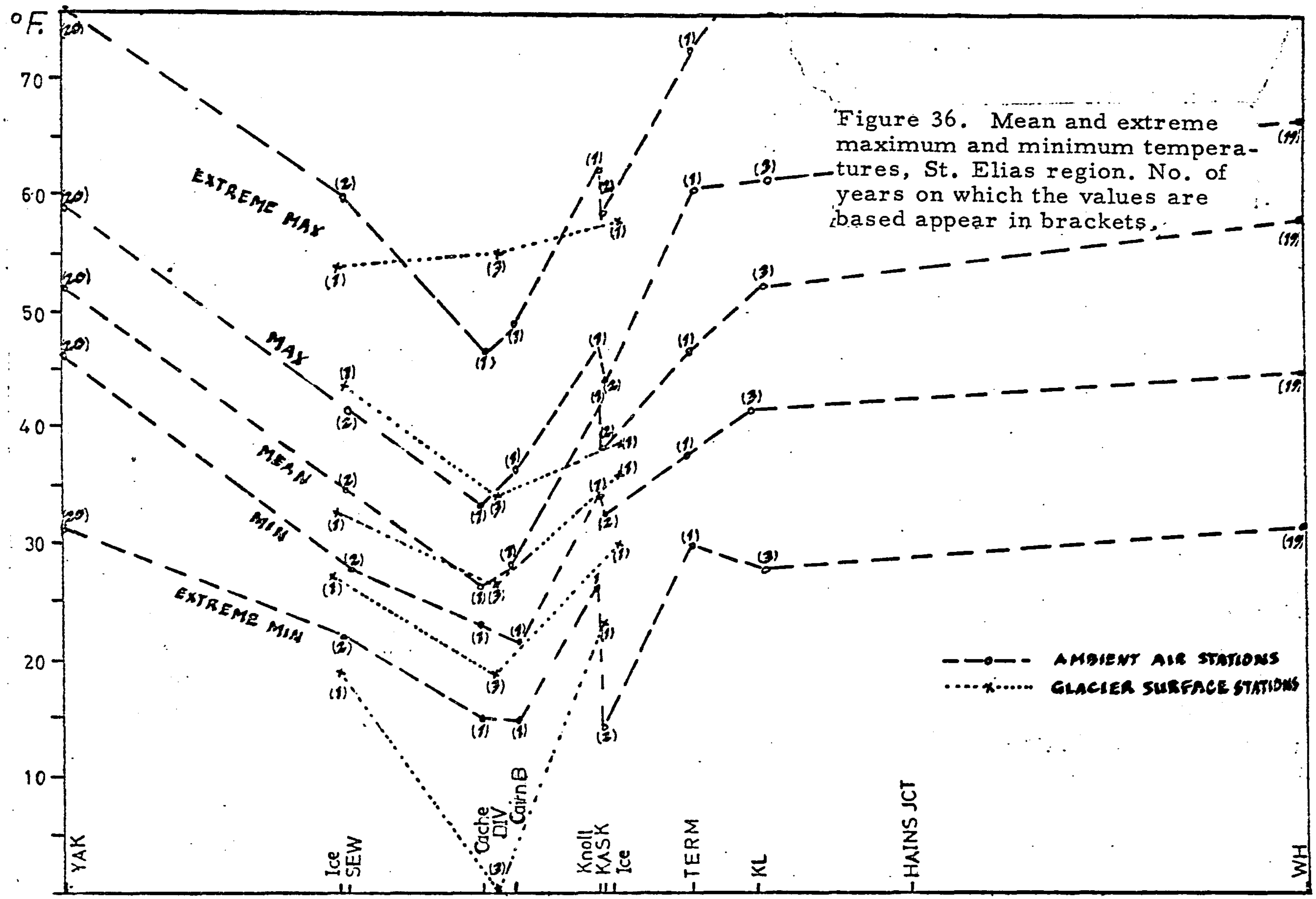

Figure 36. Mean and extreme maximum and minimum temperatures, St. Elias region. No. of years on which the values are based appear in brackets.

each station. These are also plotted in Figure 36.

From these maxima and minima the corresponding ranges have been calculated and are represented in Figure 37.[59]

Considering first the land and nunatak stations,[60] all the curves in Figure 36 except that of the extreme minima are very similar in shape.

Ideally, as one travelled from east to west these curves would diverge. There is little such divergence until west of KASK. In fact, there is a tendency in the glacierized area (more evident in the extreme values) for the curves to converge towards KASK.

Figure 37 shows that the general eastward increase of range is definitely disturbed, and in some cases reversed, in the glacierized region. The glacier surface station maxima and minima curves also show a convergence at KASK. It can be partially attributed to the length of record especially in the case of the extremes.

In the SEW and DIV areas Marcus (18, p. 21) notes: "As a result primarily of the formation of a katabatic cold layer at night, diurnal variations were generally greater over mid-glacier surfaces than over the nunataks. Also, the greatest variations between station temperatures occurred under clear sky conditions; the least differences were associated with a combination of low, heavy clouds and fog."[61]

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[59] It should be noted that in the case of the extreme range a line could be drawn at about 42.5 degrees F. below which would fall all the stations having only one years record.

[60] The inclusion of KASK (Moraine) with the nunatak stations produces a kink in the curve. However, it did not fit well into the ice station curve either.

[61] The first point is well illustrated by Figures 36 & 37 above and the second by Figures 2 & 3 in Marcus (18, p.24).

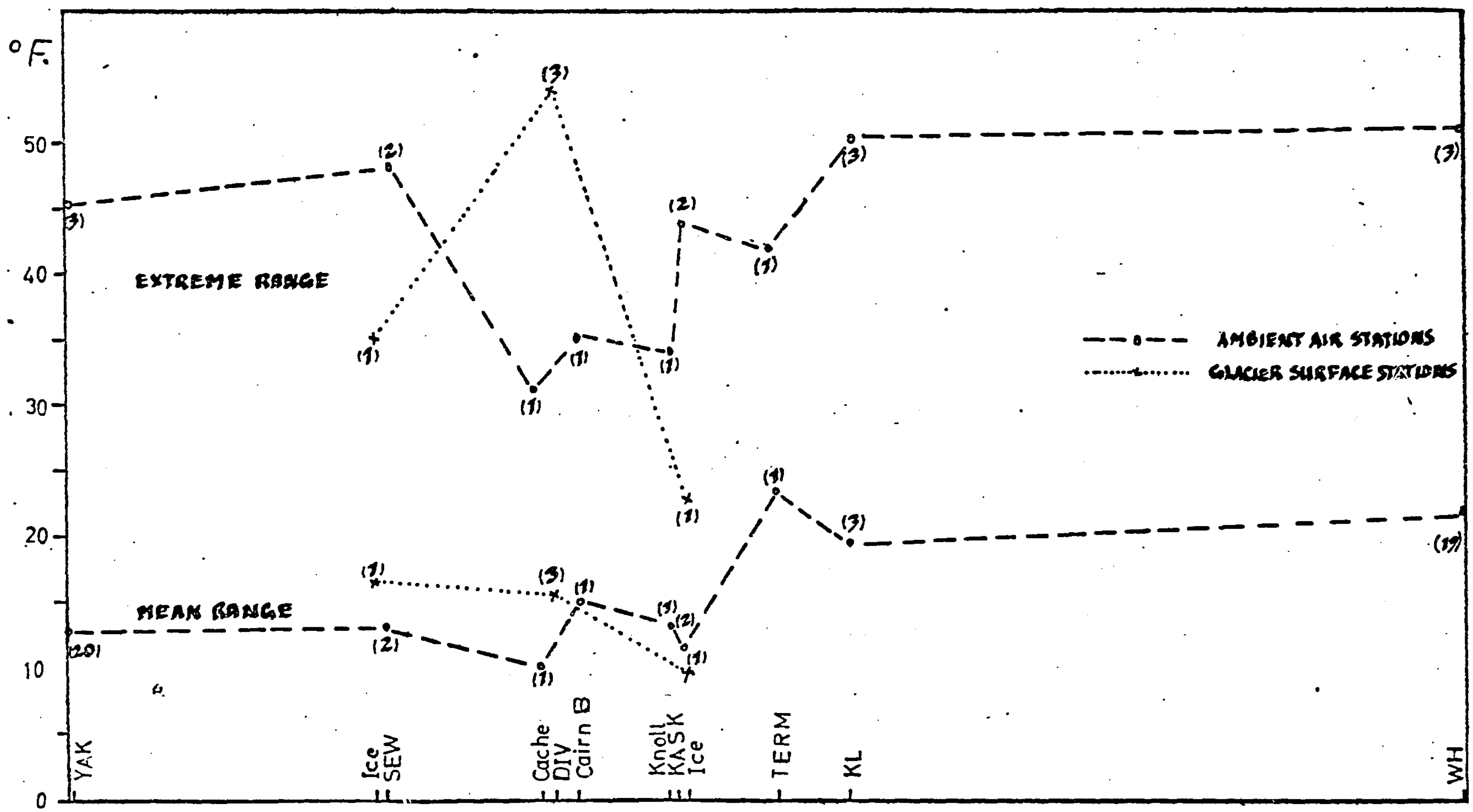

Figure 37. Mean and extreme temperature range, St. Elias region. The no. of years on which the values are based appear in brackets.

At KASK, however, the ice and moraine stations both have lower ranges than the knoll, in contradiction to the above situation.

b) Yearly and Monthly Variation of Maximum and Minimum Temperatures

Tables XVII and XVIII show that 1965 had the lowest mean minima and that all but one of the extreme minima (where three years of record were available) fell in June of that year.

KASK, DIV, and SEW recorded their highest mean maxima in 1964 (same as highest mean temperatures). The extreme maxima fell in August 1963 at YAK and WH and in July 1964 at KL and DIV.

The greatest ranges tend to be in 1965, and August, for the three year period. (KASK and SEW were exceptions--the greatest mean ranges being in 1964)

c) Diurnal Temperature Curves

The diurnal curves for June and July of 1963, 1964 and 1965 (when available) are presented in Figure 38.[62] The curves are all relatively smooth, though not, in the case of SEW and DIV, quite symmetrical.

In general, the minima occur around 0300 Y.S.T. and the maxima at 1500 Y.S.T. There is a tendency for the maxima to be earlier at DIV and SEW. This could be attributed to the moderating effect of the ocean tending to level off the daily temperature march before it reaches its radiatively induced peak.

[62] Several previously noted features of the temp. regimes show up again (i.e., warm 1964 June, cold 1964 July, and mean temp. range relationships).

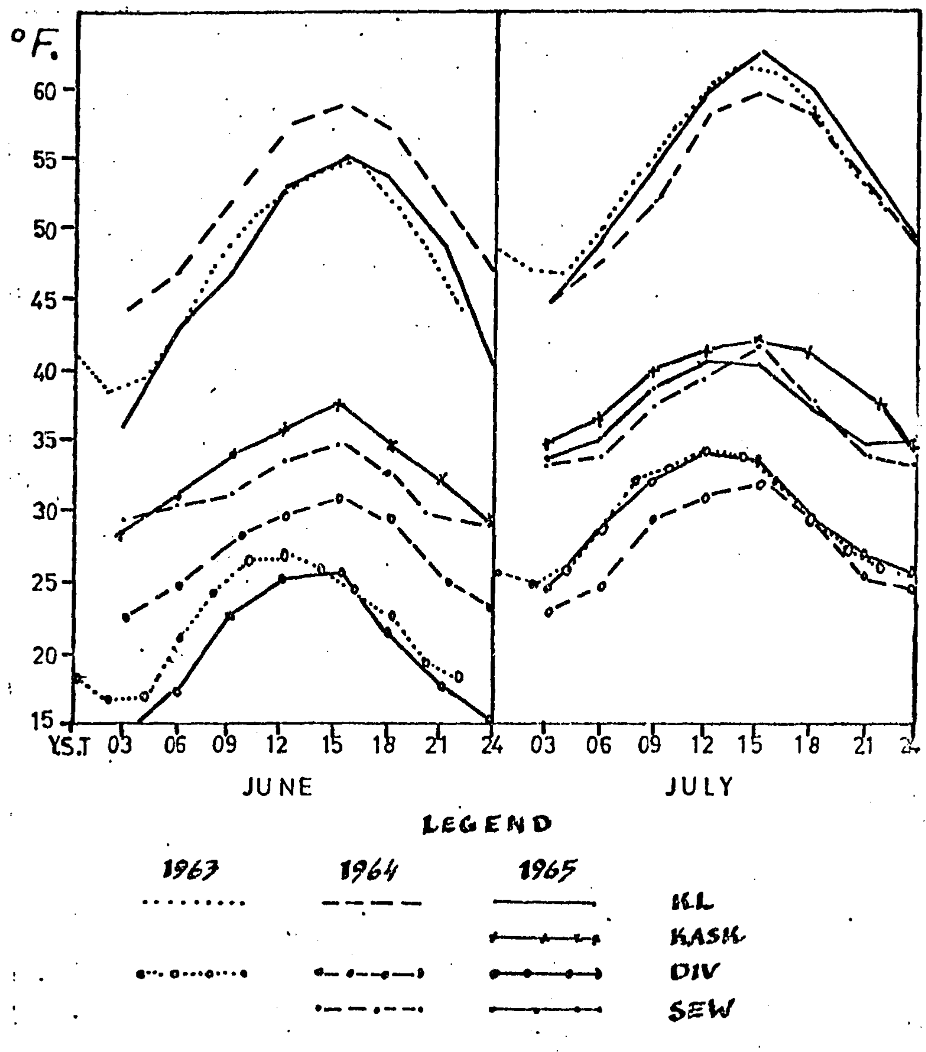

Figure 38. Diurnal temperature curves, IRRP stations, June and July.

3. ATMOSPHERIC LAPSE RATES

Marcus (18) has calculated the atmospheric temperatures for altitudes equivalent to those of the IRRP stations for July 1963 and 1964 at 0300 Y.S.T. and 1500 Y.S.T. These and the environmental lapse rates between the various stations are shown in Table XIX and Figure 39 (after Marcus (18, pp. 26-28)). The following is a portion of Marcus' discussion of these temperature relationships.

> Summer temperature-altitude relationships shown in the tables and graphs are, for the most part, to be expected. The influence of marine and continental locations, over Yakutat and Whitehorse respectively, is apparent in (1) differences in diurnal temperature variations (especially at and near the surface), (2) the lapse rates and their reflection of relative stability and instability in the boundary layer, (3) the effect of inversions on lapse rates and gradients, and (4) the absolute values of temperature recorded. The influence of glacier-covered mountain slopes on environmental temperatures is most pronounced for both marine and continental exposures at 0300 Y.S.T. when nocturnal radiation loss and the downslope movement of cold air are at a cumulative maximum. Finally, it should be noted that land and water effects tend to disappear above 3,000 meters where radiosonde temperature gradients begin to merge. Diurnal influences disappear at even lower levels. Yakutat radiosonde temperatures begin to merge within 600 meters of the surface; Whitehorse values merge within 2,000 meters.
>
> There are, however, important exceptions to the above. For example, the environmental lapse rate between Yakutat and Divide is greater at 0300 Y.S.T. than at 1500 Y.S.T. for all cases cited. This anomaly can be explained by the nocturnally induced bias of Divide Station's environment. Temperatures are lowered, and consequently the lapse rate is increased. The reversal of these values at Cairn B, which is influenced less by the glacier, seems to verify this conclusion.

4. WIND DIRECTION - TEMPERATURE RELATIONSHIPS

Temperature averages were calculated for each of the eight major wind directions by relating the three hourly readings of wind direction

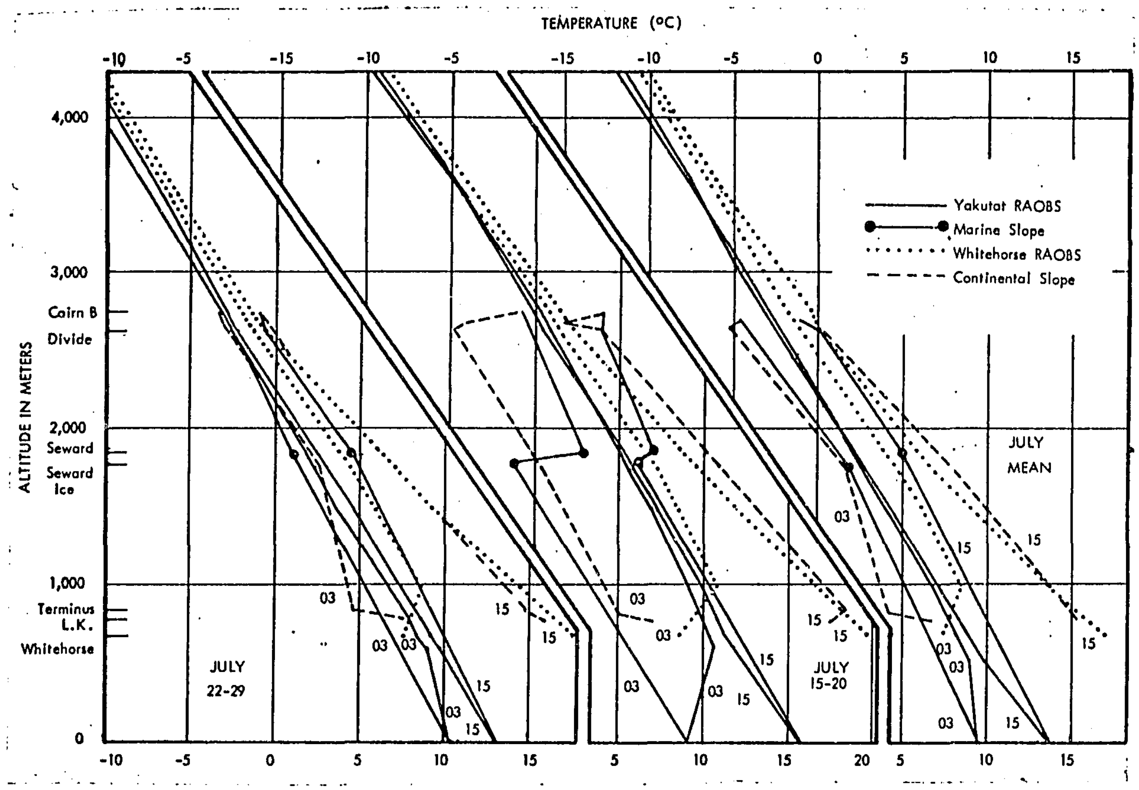

Figure 39. Temperature gradients in the St. Elias region. July 1964. (After Marcus, 18, p. 28)

and temperature. This was done for the stations and months shown in Table XX. The following is a review of the results at each station.

a) Kluane (KL)

At the base camp on Lake Kluane the warmest winds are from the W., S.W., and S. (in that order) in all three months, May, June and July. To the west and south of KL lie the highest mountains of the immediate surroundings. They support little vegetation and lose all their snow by July. It is therefore probable that the W. and S. breezes are warmed by a combination of heat gained from strongly radiatively warmed rock and heat extracted during quasi-adiabatic descent.

The coldest temperatures occur when it is calm or with a wind off Lake Kluane. During calms, which occur most often in early morning hours the effects of nocturnal radiative cooling tend to remain longer near the surface. Lake Kluane is not ice free until early July and even then has a temperature far below that of the adjacent land and air.

b) Kaskawulsh (KASK)

The infrequent, light, up glacier winds at KASK appear to bring the warmest temperatures, as would be expected.

In June the winds from the central arm of the Kaskawulsh glacier are slightly colder than those from the north arm, while in July the reverse is true. Calms are also cool.

c) Divide (DIV)

At DIV the warmest winds appear to come from the S. or S.E.--

i.e. up the S.E. - N.W. tending valley. Only S.E. winds in July average above freezing (32.4 degrees F.).

Cool temperatures are experienced at times of calm as would be expected from the pooling of cold air near the glacier surface. The coldest winds originate in the S.W. in June and the N.E. in July.

It should be noted that warm temperatures are associated with low wind speeds and cold temperatures with high wind speeds.

d) Seward (SEW)

The near-by partially snow free slopes of Mount Vancouver (see Figure 2) appear to be the source of the warmest winds at SEW. The coolest winds blow from the direction of ice covered Mount Cook (see Figure 5) and up the Seward Glacier.

CHAPTER V

RELATIVE HUMIDITY

1. MEANS OF RELATIVE HUMIDITY

Relative humidity readings lack accuracy under the best of conditions (compared to temperature records for instance). Thus when taken with a sling psychrometer in a region where temperatures just below freezing are common they are not very reliable; nor are the hygrothermograph records any better.[63] Due to this lack of accuracy the humidity data have been treated in very general terms only. Table XXI gives the monthly averages of relative humidity for those years and stations which have sufficient data.

In general there is a decrease of relative humidity towards the west.[64] It is likely that the glacier stations appear to have rather high relative humidities due more to low temperatures than the proximity of a frozen water source.

July appears to have been more humid than June in all cases available.

[63] For instance at DIV the hygrothermograph hairs were frequently covered with rime. In addition the calibration of these instruments is easily disturbed.

[64] KASK Knoll being the only exception - here high temperatures combine with an equal or lower water vapour content (than over the ice) to give a low relative humidity.

The high degree of temperature dependency of relative humidity is illustrated in Figure 40 which shows that the diurnal relative humidity curve is almost the exact opposite of the diurnal temperature curve. A plot of mean daily relative humidity showed the same trend.

2. WIND DIRECTION - HUMIDITY RELATIONSHIPS

In Table XXII are the results of averaging relative humidity for various wind directions. Little confidence can be placed in the actual values but some generalizations are possible.

As relative humidities alone can misrepresent the humidity conditions[65] vapour pressures have been calculated[66] and included in the table.

At KL the lowest relative humidities come in every month from the same direction as the highest temperatures and there is a similar, though not as pronounced, relationship between the highest relative humidities and the lowest temperatures. The vapour pressures however reveal that in June the winds from the W., off the glacier, are moister than those from the E., while in July moist cold winds blow from the N. off open Lake Kluane.

The vapour pressure values at KASK indicate, as might be expected, that the warm up glacier winds are moist and the cold, dominant, down glacier winds are dry.

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[65] Because at a lower temperature an equal vapour content will produce a higher relative humidity.

[66] Calculated from temps. in Table XX and relative humidities in Table XXII.

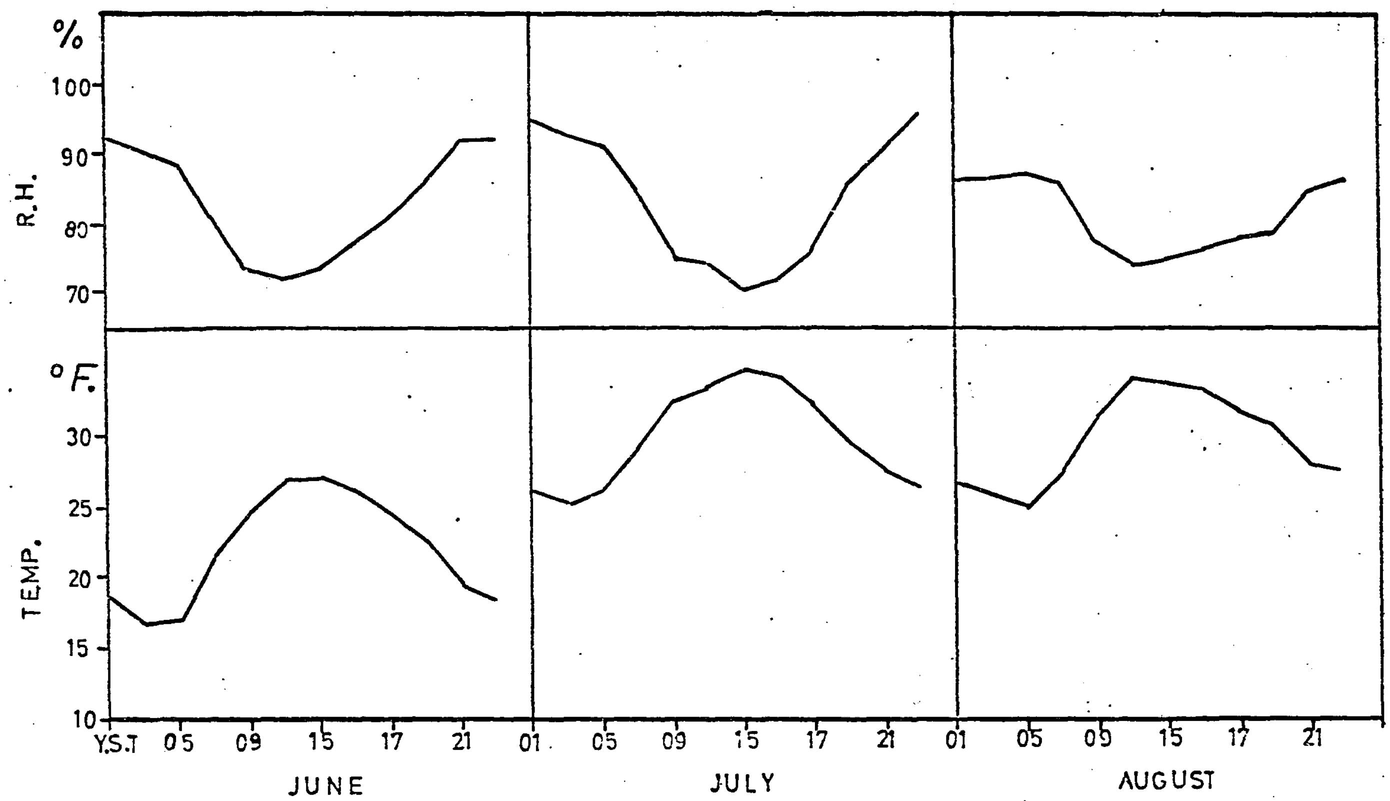

Figure 40. Diurnal temperature and relative humidity curves, July 1963.

The DIV trends are not well defined though there is evidence that the warm S. winds are moist, at least in July.

The sixteen day record at SEW suggests that warm E. winds are moist but have low relative humidities while the cooler winds carry less moisture but at higher relative humidities.

CHAPTER VI

WIND

1. SPEED

a) Monthly and Seasonal Means

As there is little relation between the daily wind speeds at the various stations (see Figures 49 and 50) the wind records were not extrapolated to one uniform season. Instead Table XXIII which gives the monthly and seasonal averages will be examined.

There appears to be no orderly change from east to west suggesting that wind speeds are to a large extent locally controlled. This will be even more evident when direction is discussed.

The most striking feature of the three year seasonal averages is the surprisingly low average speeds recorded at SEW and DIV. Before these stations were occupied it was assumed from upper air charts that winds would be very strong over the 8,700 foot high accumulation area and in the Seward Basin. Climbers challenging the lofty peaks of St. Elias, Logan, and Vancouver have often experienced high winds on these mountain faces. The comparatively high speeds found at KASK also call for some explanation.[67]

[67] This will be attempted in CH. XIV sec. 2.

b) Yearly and Monthly Variations

The summer of 1965 appears to have had the strongest winds, followed by 1963.

June, at all stations, records the highest monthly average wind while August in general experiences slightly lighter winds than July. In June the circulation has not yet completely fallen into the weak pattern characteristic of the summer months (see Figure 6).

c) Maximum Winds

The maximum recorded winds, at each station, for the three years are shown in Table XXIV. Unfortunately the values available were not for equal time periods.[68] It should also be noted that at KASK in 1965 a wind over 40 kts. would likely have been recorded on 16 June had not the anemometer been sticking. Similarly on 25 July 1965 at SEW the last recorded wind was 22 kts before the station was blown down. However, gusts to sixty were estimated and a three minute run would likely have recorded well above 40 kts.[69]

Bearing in mind these corrections (noted in brackets in Table XXIV) 1965 again emerges as the windiest year. The fact that the WH, KL, KASK and DIV maxima all occur on 16 June 1965 (SEW was not in operation) suggests that, at least during passing cyclonic disturbances, there is some overall control of the wind speed. This further is sub-

[68] The IRRP max. are taken from the three minute readings recorded as a part of the 3 hourly observations. The YAK records represent the fastest mile and so are almost equivalent. However at WH in 1965 the fastest 10 minutes was used while in 1964 only the fastest hour was available.

[69] On the basis of the available data no explanation was found for the very high winds experienced at SEW, but not elsewhere, on 25 July.

stantiated by the almost equal values of these compared to the large station to station variation in the average speeds.

Over the three years, six of the maxima were recorded in June, three in July, and two each in May and August. Had more of the stations been occupied in May the bulk of the maxima would likely have fallen in May and June due to the more frequent cyclonic activity in these months.

d) Diurnal Variations

The most obvious feature of the diurnal wind curves (see Figure 41) is that, except at KASK, the July plot is very irregular while in June and sometimes in August the curves tend to be quasi-sinusoidal. Thus it appears that the months with the highest average wind speeds have the smoothest diurnal curves. Furthermore KASK where wind speed averages are high has smooth curves in both months.

2. DIRECTION

As there appears to be little similarity between the wind roses at the various IRRP stations each station will be treated separately.

a) Kluane (KL)

The KL wind roses for 1964 (calculated from readings at 0900, 1500, and 2100 Y.S.T.) are shown in Figure 42. The 1965 wind roses and the prevailing direction for each observation hour (calculated from continuous three hourly observations) are found in Figure 42 and Table XXVA.

In 1964, W. and N. winds appear to predominate while in 1965 S.

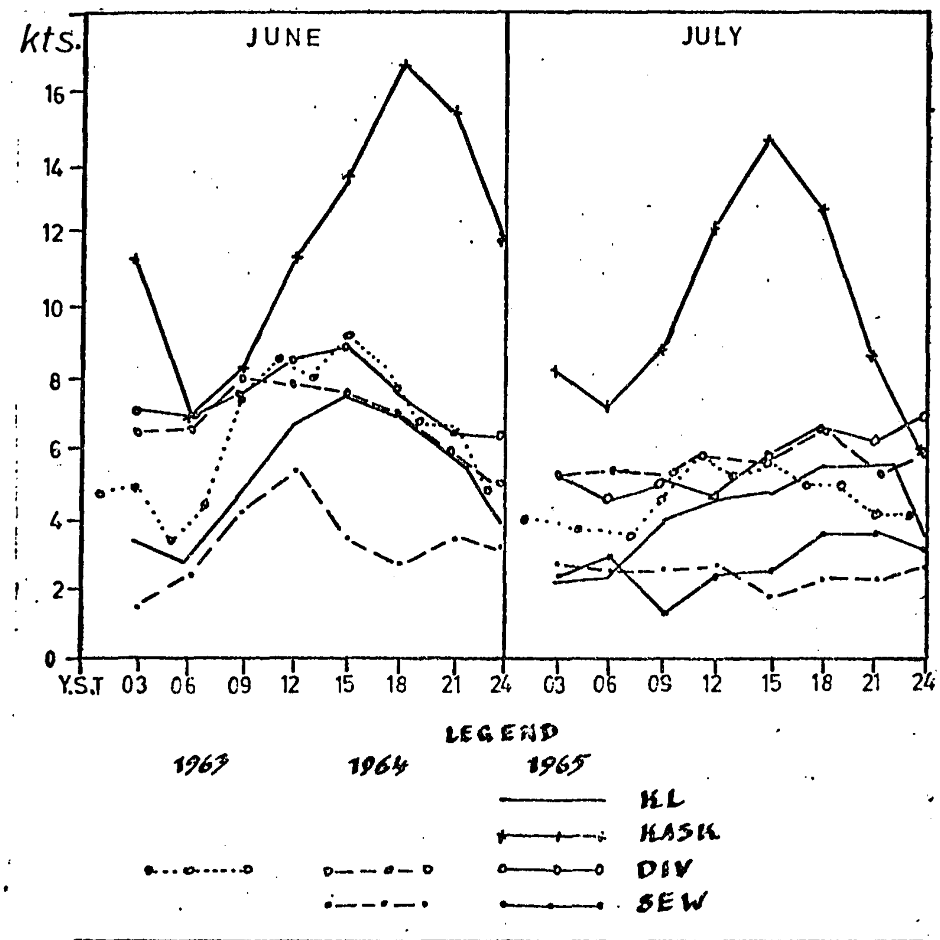

Figure 41. Diurnal wind curves, IRRP stations, June and July.

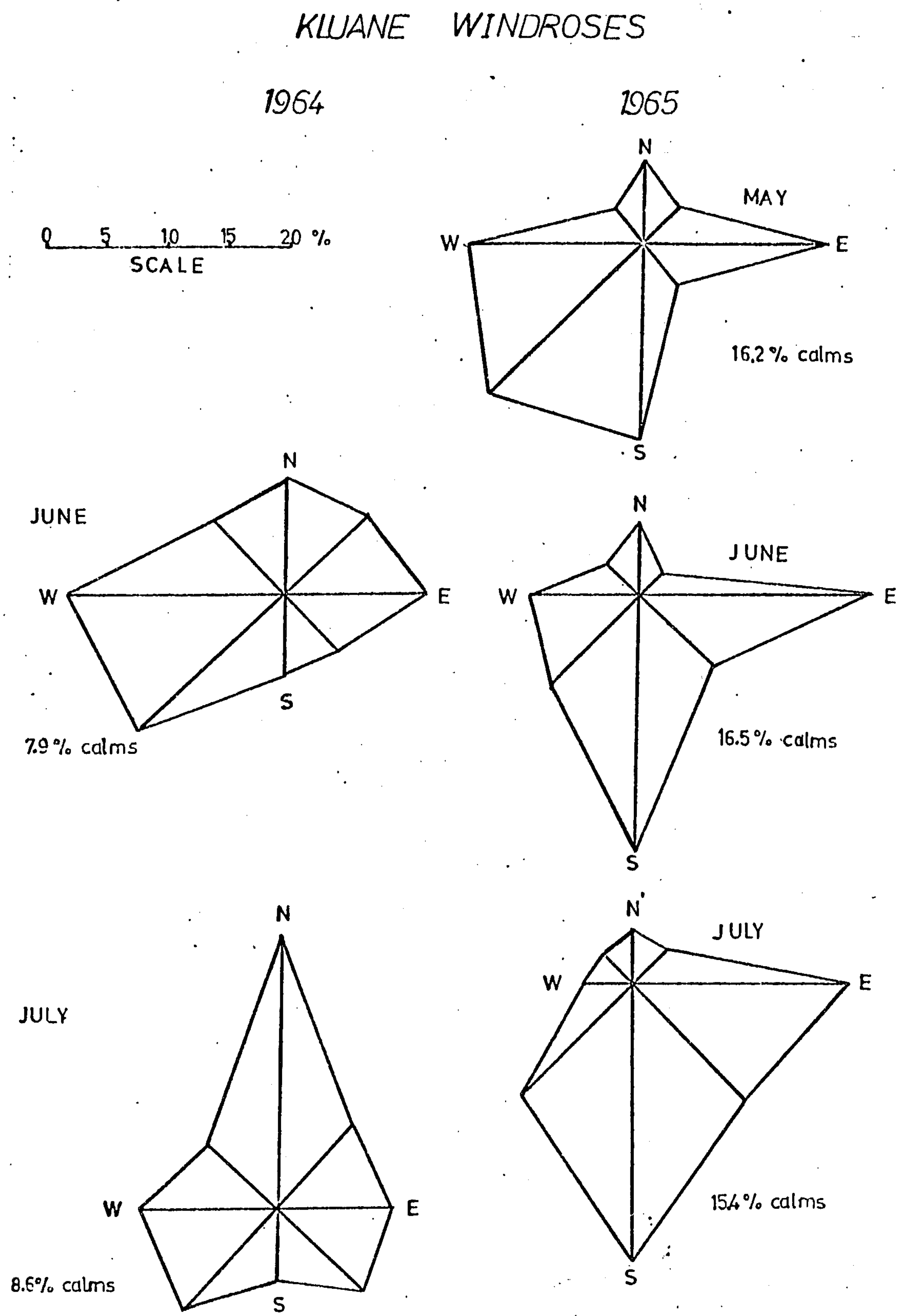
KLUANE WINDROSES
1964
1965
0 5 10 15 20 %
SCALE
N
MAY
W
E
16.2 % calms
S
N
JUNE
W
E
S
7.9 % calms
N
JUNE
W
E
16.5 % calms
S
N
JULY
W
E
8.6% calms
S
N
JULY
W
E
15.4 % calms
S

Figure 42.

and E. are most frequent. This, to a large extent, is a result of the lack of night time records in 1964 - see Table XXVA of diurnal variations.[70] The predominance of N. winds in July may, however, be real as July 1964 was colder than usual.

Considering the 1965 wind roses, a down slope effect from the mountains to the S. and E. is suggested by the nocturnal southerly and easterly winds. The day time southwesterlies may be the result of the strong down glacier winds on the Kaskawulsh glacier.[71]

b) Kaskawulsh (KASK)

The 1964 KASK wind roses (Figure 43) were built up from day time readings, taken at irregular intervals and varying from day to day. The 1965 wind roses and three hourly prevailing directions are shown in Figure 43 and Table XXV respectively.

There is no significant diurnal variation of prevailing direction. The pronounced 1964 westerly maximum may result partially from observational error.[72] As the camp was closer to the north arm in 1964 than in 1965 this predominance of westerlies could be real. There is also some evidence from DIV and the 500 mb flow that there

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[70] Table XXVA shows that the winds tend to shift from easterly at night to southerly then S.W. in the afternoon and back to S. in the evening. It is obvious that in readings taken at 0900, 1500, and 2100 Y.S.T. the nocturnal E. and S. winds would be inadequately represented. The tendency for calms to be most frequent at night will also affect the 1964 calculations.

[71] These are stronger in the day time due to their dependence on loss of heat by the surface of the glacier to the air above.

[72] These induced by the lack of wind vane i.e., possibly all down glacier winds were classed as W.

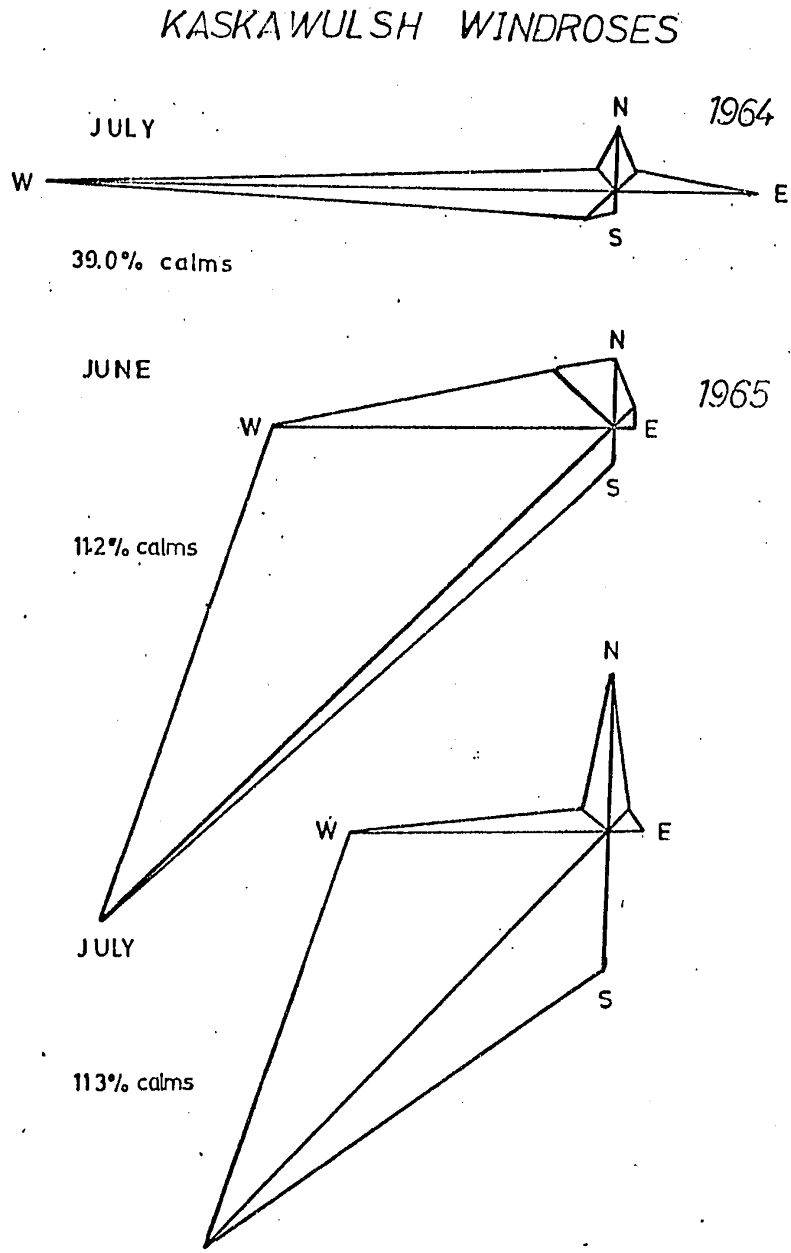
KASKAWULSH WINDROSES
JULY
1964
N
W
E
S
39.0% calms
JUNE
1965
N
W
E
S
11.2% calms
JULY
N
W
E
S
11.3% calms

Figure 43.

were in general less S. and S.W. winds in 1964 than in 1965;[73] these would tend to funnel down the central arm of the Kaskawulsh.

In 1965 KASK shows the least number of calms of any station (see Table XXVB). This is as would be expected from the average wind speed (see Table XXIII). The greatest number of calms occur between 2400 and 0600 Y.S.T. when the glacier wind effect is at a minimum (see Ch. XIV sec. 2,b). The KASK camp in 1964 recorded far more calms than in 1965 (39% compared to 11%). Some explanation beyond the generally stronger winds in 1965 is needed for this difference. Once again the slightly more northerly position of the camp may be the cause.[74]

c) Divide (DIV)

The most complete wind records are available for DIV where wind roses have been constructed from continuous two or three hourly readings for 1963, 1964, and 1965 (see Figures 44a and b).

One might expect to find the least variation in wind rose shape at DIV. All figures for one year are similar but the three years bear little resemblance to each other. Nor is there appreciable similarity between the diurnal variations for the three years (see Table XXVA). For these reasons the years will be dealt with separately and the and the assumption made that DIV winds reflect the synoptic situation

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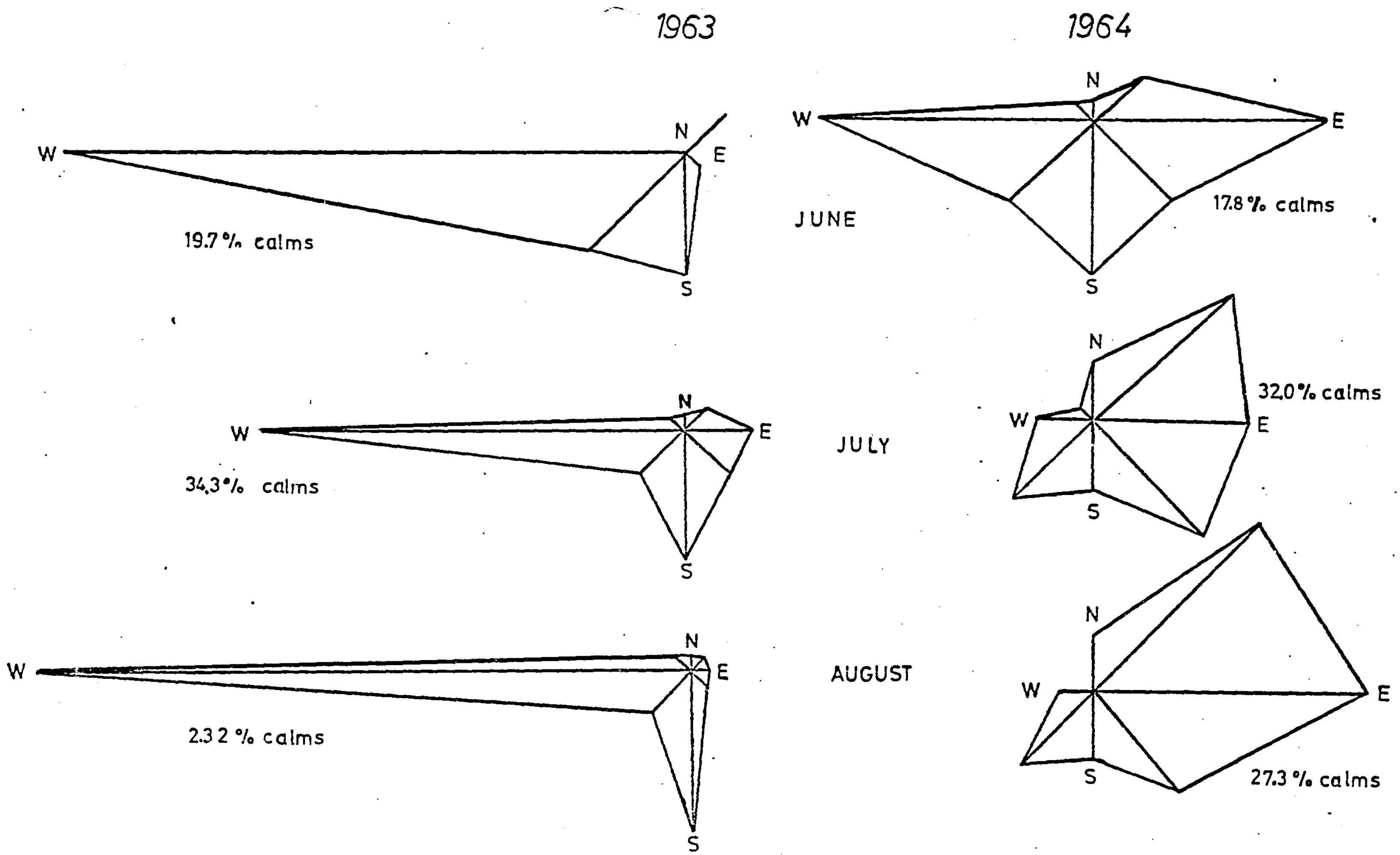
[73]See CH. X and sec. c above.

[74]The camp was likely more sheltered (by the mountains to the west) as well as being nearer the north arm where the velocity appears to be slightly less (see sec. 4 below).

DIVIDE WINDROSES



of each year;[75] at least to a greater extent than do any of the other stations.

i) 1963:- In 1963 the wind blew almost entirely from the W., and there was no diurnal variation of prevailing direction. Thus this year the flow was almost always deflected north of Mount Logan.

These winds suggest the passage of most cyclones well N. of DIV.

ii) 1964:- The 1964 wind roses interpolated from a circulation standpoint reflect a rather disturbed flow which would result from the frequent passage of lows slightly to the south of the DIV region.

No generalizations are possible concerning the diurnal direction variations in 1964.

iii) 1965:- S., W. and E. winds dominate the 1965 figures. Of the three years the 1965 wind roses best fit the large scale topography. The predominantly S.W. upper flow appears to be deflected around Mt. Logan approaching DIV from the west up the Logan and Walsh Glaciers or from the south up the Hubbard Glacier.[76]

Synoptically the 1965 wind roses suggest cyclonic activity passing either N. or S. of DIV.

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[75] Though the station was not in the same place each year it is unlikely that in as flat an area as the accumulation area this alone could create such large differences in direction. Indeed relating the roses to the very local topography only gives contradictory results. (i.e., In 1963 slight ridges to the S. and S.W. might have blocked winds from this direction while in 1965 the ridges - to W., S. and E. are in the direction of the max.).

[76] The only other major outlet being the Kaskawulsh to the E.

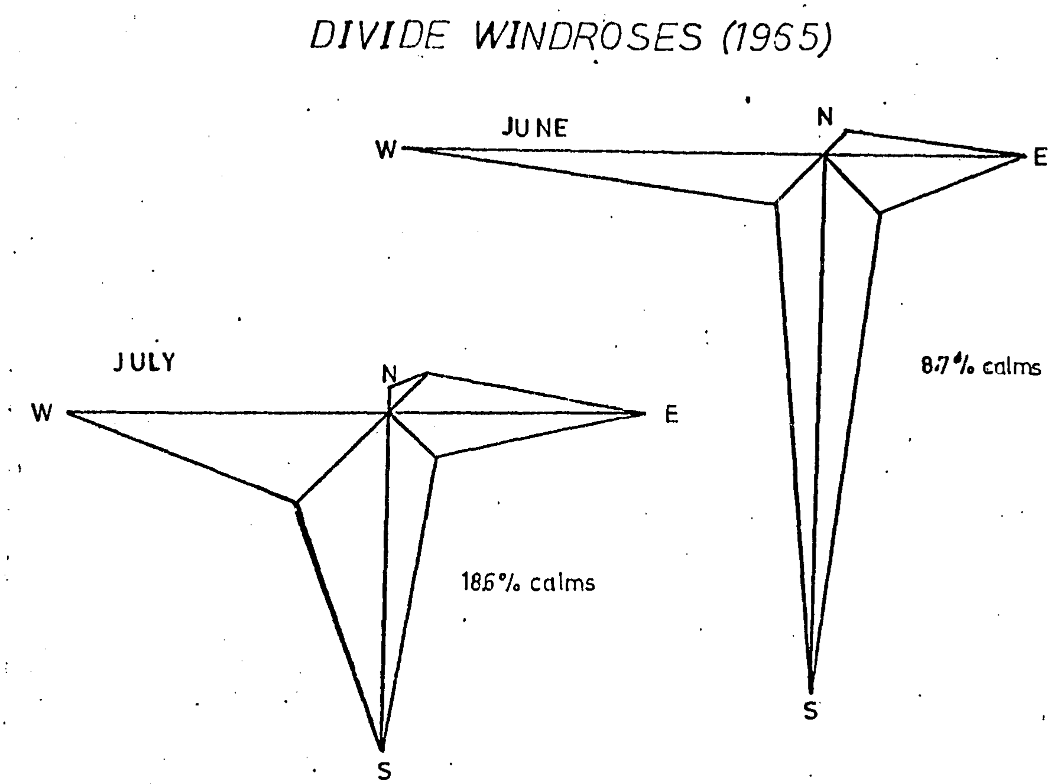

Figure 44b.

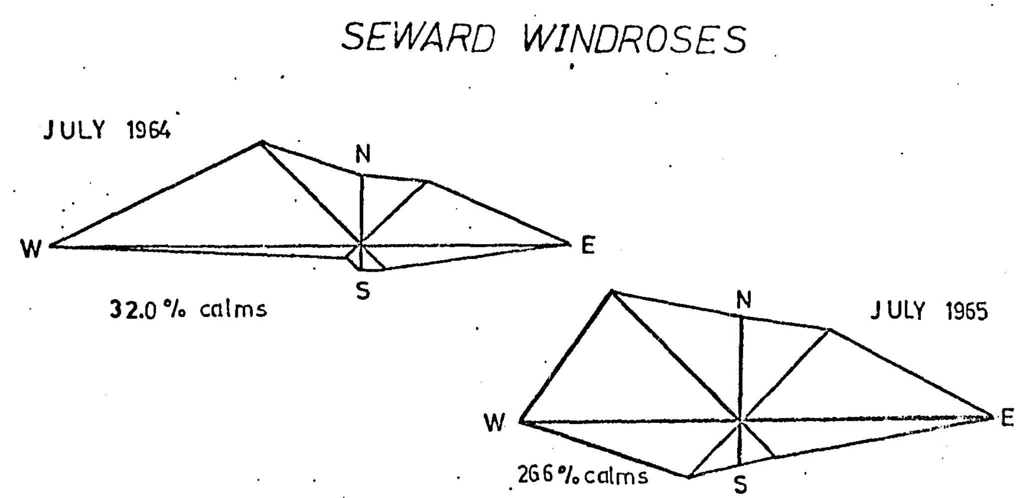

Figure 45.

In June 1965 S. winds predominate during the whole twenty-four hour period while July shows westerlies at night, easterlies in the morning and southerlies after midday.

Analysis of the 1964, 500 mb flow (to be discussed - Ch.X sec. 1 and 2) shows the same relation between 1964 and 1965 flow as do the wind roses.

Calms at DIV are most frequent in July for all years and least frequent in 1965.

d) Seward (SEW)

The SEW wind roses for 1964 and 1965 (see Figure 45) are very similar having W., N.W., and E. maxima and a large percentage of calms.

The westerlies and northwesterlies are easily explained as in this direction stretches the broad expanse of the Seward Glacier.

From the predominance of northwesterlies during the day and easterlies at night (see Table XXV) it would seem that the easterly maximum is due to nocturnal down slope winds off the snow free ridges of Mount Vancouver.

As would be expected from the mean wind speed calms are frequent at SEW, dominating at six of the eight observation times in 1964 and at four in 1965.

3. UPPER WINDS

Using the WH 00 Z and 12 Z radiosonde ascent data for July 1965, the average monthly wind speed at approximately 8,700 ft. (the elevation of DIV) was 12.1 knots. Further investigation showed that the corresponding YAK average would also be considerably higher than either the SEW or DIV July 1965 average wind speeds.

Preliminary results of the pibal ascents suggest no particularly significant increase in speed up to altitudes of five to ten thousand feet above these stations.

4. WIND DIRECTION - SPEED RELATIONSHIPS

The relationships between wind speed and direction are shown in Table XXVI.

a) Kluane (KL)

At KL there is little overall seasonal pattern, rather each month is different.

In May the strongest winds originate from the Slims River valley or from the S.E. along the Alaska Highway. The lightest winds blow from the N. off the ice covered lake.

In June the lightest wind speeds again originate in the N. but now the strongest winds blow from the E. The latter is possibly the result of cyclones passing to the south of KL.

July exhibits a reversal in that the strongest winds blow off the lake and southerly winds have low speeds.

b) Kaskawulsh (KASK)

As would be expected at KASK down glacier winds are considerably stronger than up glacier breezes. It is interesting to note that in both months S.W. winds from the central arm are stronger than W.

winds from the north arm. This may be a result of the position of the station relative to the two glaciers.[77]

Passing systems appear to have little influence on the direction - speed relationships at KASK.

c) Divide (DIV)

Up glacier winds from the Kaskawulsh glacier are lightest in both 1963[78] and 1965.

The prevailing upper southwesterlies, deflected around Mt. Logan, are generally the strongest winds. In July 1965, however, N.E. and E. winds have the highest average speeds seemingly as a result of the passage of several strong disturbances south of DIV during that month.

d) Seward (SEW)

At SEW the down slope winds, from Mt. Vancouver to the N.E., are generally the strongest while the lightest winds blow from the direction of the broad expanses of the Seward Glacier. As N.E. winds are a night time phenomenon these direction - speed relationships tend to minimize diurnal speed variations.

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[77] It was slightly more sheltered from west winds as it was on the central arm side of the moraine.

[78] Similar calculations having been made for DIV in 1963.

CHAPTER VII

CLOUD AND FOG

1. MEAN CLOUD AMOUNTS

Cloud cover amounts (in tenths) have been averaged for all stations having three hourly observations or more and these seasonal and monthly averages presented in Table XXVII. A 1 June to 31 July average has also been included to facilitate the comparison of uniform periods.

There is a steady increase of cloudiness from KASK west to YAK, as would be expected. Summer convective type clouds are frequent over the snow free land around KL and WH resulting in rather high cloud cover averages here.

Over a large cold glacier subsidence tends to reduce the cloud cover. The effects of this were frequently observed at KASK (i.e., skies over the glacier were clear while cloud was dense over the surrounding mountains). SEW and DIV, however, as a result of their marine exposure (especially at SEW) and greater elevation (especially at DIV), experience cloudiness equal to or greater than the average over the ocean at that latitude.[79]

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[79] Quoted as being 6.7 for 50°N to 60°N by Landsberg (16).

May and August are, in general, clearer than June and July. At DIV, the only station having 3 years of record, 1964 experienced the most cloud and 1965 was clearest.

Table XXVIII of cloud frequencies for July 1965 gives added insight into the cloud conditions. Further evidence that subsidence at KASK creates holes in the overcast lies in the relatively high frequency of 7 to 9 tenths cloud and the comparatively low frequency of overcast. DIV and SEW on the other hand tend to be completely overcast or clear with only a few scattered clouds over the distant mountains. DIV experiences the most cloudless skies.

2. DIURNAL VARIATIONS AND DOMINANT CLOUD TYPES

Most of the diurnal cloud cover curves (see Figure 46) have their maxima early in the day. This suggests a dominance of stratiform cloud, the development of which is favored by stable stratification.

At SEW and DIV, indeed, stratus clouds are by far the most frequent type. As. (at SEW) and Ci. (at DIV), from the Pacific, and Sc. formed over the mountains, are also common. On the other hand, at KASK Sc. clouds are most frequent though Ci. and St. drift down from DIV fairly often. KL experiences more middle (As. and Ac.) and high (Ci.) cloud than the glacier stations.

3. WIND DIRECTION - CLOUD AMOUNT RELATIONSHIPS

Cloud cover averages for the eight wind directions, in July 1965 are listed in Table XXIX.

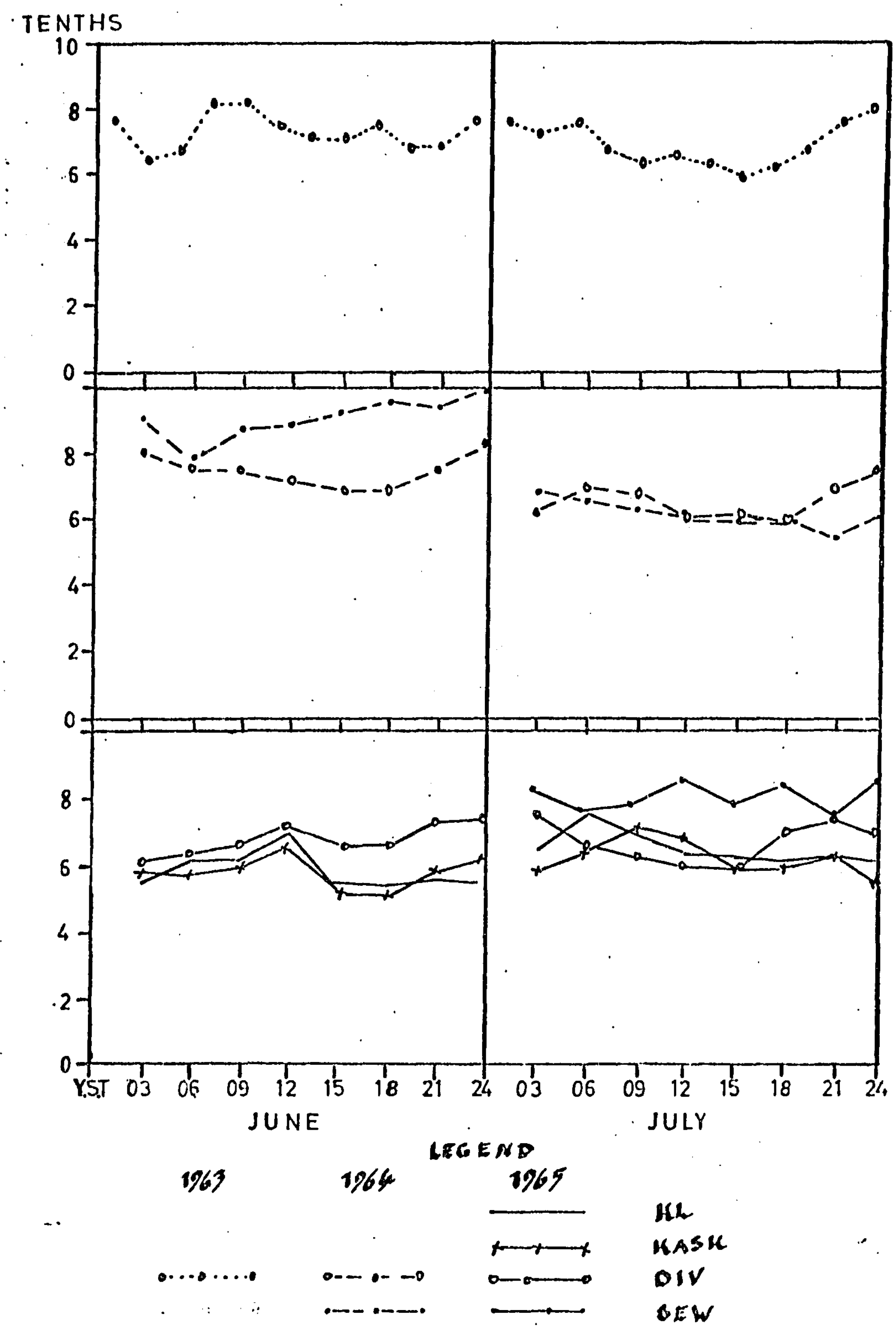

Figure 46. Diurnal cloud curves, IRRP stations, June and July.

a) Kluane (KL)

In general at KL high cloud amounts are associated with winds from the neighbouring mountains while clear skies predominate when winds blow from the valleys. In the latter part of the season a considerable build up of cumulus type cloud was frequently observed beyond the N. end of Lake Kluane.

b) Kaskawulsh (KASK)

At KASK also, winds from the mountains are accompanied by the most extensive cloud cover. Up glacier winds bring less cloud than do down glacier winds.[80] In addition more cloud is present with winds down the north arm than those down the central arm.

c) Divide (DIV)

The N. and N.E. wind cloud maxima are again the result of nearby mountains. Southerly winds on the other hand suggest marine slope cloud formation.

The lowest speeds appear to be associated with the clearest skies suggesting little cloud development occurs locally.[81]

d) Seward (SEW)

Winds up the Seward - Malaspina Glacier system (i.e., from the Pacific) were accompanied by 10 tenths overcast on all occasions. Down slope winds from Mt. Vancouver tended to destroy cloud cover.

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[80] As down glacier winds are so dominant these relationships may not be particularly significant.

[81] Unfortunately (see sec. 4 of preceeding Ch.) July 1965 was somewhat an exception as to speed - direction relationships.

4. FOG

Differentiating between fog and cloud which has run into the glacier surface is very difficult at SEW and DIV. In addition, in 1965, for instance, there were at least 10 different observers at these two stations during the season, so little confidence can be placed in the records of fog versus 10/10 overcast or obscuration. Both stations were subject to frequent fog and low stratus, the former likely more frequent at SEW and the latter at DIV.

It should be noted that, in calculations of cloud amount fog, obscuration, and white outs were considered to be 10/10 cover.

CHAPTER VIII

PRECIPITATION

1. TOTALS

a) Problems

Precipitation, possibly the best indicator of the transition from a maritime to a continental climate, is unfortunately one of the most difficult parameters to measure accurately on a glacier. Rain gauges prove very ineffective in catching snow, especially when it is accompanied by wind.[82] At times it is almost impossible to tell whether snow is falling or merely being blown around. Measuring precipitation amounts from a fixed stake suffers from the effects of ablation and drifting.

Observers, thus, tend to call any snowfall a trace and as the sum of many traces is a trace both the daily and monthly totals are gross underestimates. KASK and DIV are most subject to these inaccuracies.

At DIV in 1965 where the errors seem to have been greatest, the five stake accumulation averages from the ablation records were used

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[82] It is shown in Ch. IX that high winds usually accompanied precip. at KASK and DIV.

to correct the data.[83] As the ablation season was well under way by June at KASK, this method of corection was of little use here.

Bearing these problems in mind, the monthly and seasonal totals and the seasonal averages of precipitation per day, given in Table XXX will be discussed.

b) Snow versus Rain

During the periods of record (for the three years) at DIV only snow fell while at KASK and SEW both rain and snow experienced in June, July, and August. KL and WH recorded snow in May and June and YAK only in May.

c) Precipitation Profile

The average precipitation per day amounts exhibit a general eastward increase.[84] Comparing the glacier stations' values to those at the permanent stations (YAK and WH), however, strongly suggests the former are underestimates.[85]

d) Hydrological Traverse Data

In order to determine the extent of the error (noted above) the results of the hydrological traverse,[86] carried out in late May and early

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[83]On any day when a net accumulation was recorded this value was taken as the precip. amount for the 12 hours preceeding the reading. This is still an underestimate as during the 12 hours some or all of the new snow may have ablated. This effect is greatest in the latter part of the season.

[84]Except KASK where data were unreliable.

[85]Though it will be seen later that the low values at KL may be accurate.

[86]The traverse was carried out by Melvin G. Marcus, John Griffin, Lawrence Nielsen, and Richard Ragle with air support from Phillip Upton, the pilot of the project air craft. It was under the supervision of Walter A. Wood, Director of IRRP. The preliminary results were presented to the VII Inqua Congress of the International Association for Quaternary Research, Bolder, Colorado, Sept. 1, 1965.

June of 1965, will be discussed. The traverse extended from the lower Seward Galcier across the glacier divide of the Hubbard and Kaskawulsh Glaciers to the lower Kaskawulsh glacier. Fifteen pits were excavated, the locations of which are shown in Table XXXI and Map 3. In addition Table XXXI, after Marcus (19), gives the density and centimeters of snow accumulation (1964-1965) measured at these pits and the resulting cm. water equivalents.

These accumulation values were assumed to represent the total accumulation season precipitation[87] and the per day amounts (shown as well in Table XXXI) have been taken as comparable to the average precipitation per day records for the summer season (see Table XXX).[88]

The precipitation values average only 12 percent of the corresponding accumulation amounts. (Compare specifically 5,790 feet (1765 m.) on the continental slope; Divide (2,620 m.), and 5,790 feet (1,765 m.) on the marine slope; with the KASK; DIV; and SEW records respectively.) Differences of this magnitude cannot be distributed to local rain shadow effects.[89]

e) Accumulation Profile

The transmountain profile of precipitation will thus be discussed

[87] An accumulation season of 10 months was assumed. Had the full year been used the discussion which follows would still be justified.

[88] Comparing the accumulation season precip. per day at WH and YAK to those for the ablation season the following was found. At WH ablation season precip. was .62 that during the accumulation season while at YAK the exact opposite was true. It was therefore decided not to make any correction to the data in Table XXXI.

[89] DIV and the Divide pit were quite close together and still the values at the former were only 28% of the latter.

on the basis of the hydrological traverse results, plotted along with a height curve of the pits in Figure 47: (Reference should also be made to Table XXXI and Map 3.)

The overall difference between the maritime and continental precipitation is most obvious when pits 3 and 14, at the same elevation on opposite slopes are compared. Marcus (19) notes there is a better than three to one water differential between these and that below this elevation the differences are accentuated. He continues: "On the Kaskawulsh slope snow completely disappears below 1,400 meters (4,495 feet) except for occasional, thin residual patches. On the lower Seward, however, 174 cm. of water (5.66 mm. per day) was still present at 1,370 meters (4,495 feet) and the transient snowline was observed well below 700 meters (2,297 feet) in late May."

Several factors contribute to the rather complex march of the accumulation curve between these two pits.

Theoretical and practical studies in several mountain regions of the world have shown a precipitation maximum at some altitude below the peak, on the windward slope. Walker's (31) model, for instance, indicates that for a 6,600 ft. (2,015 m.) mountain the maximum precipitation should occur at 4,600 ft. (1,400 m.). The zones of maximum appear to be closely related to the average height of the cloud bases in the area (i.e., the heaviest precipitation results where the clouds first deposit rain or snow).

The major maximum zone of precipitation is placed by Marcus (19) and apparent from Figure 47" in the vicinity of the break between the Upper and Lower Seward Glacier (about 1,500 meters) and onto the

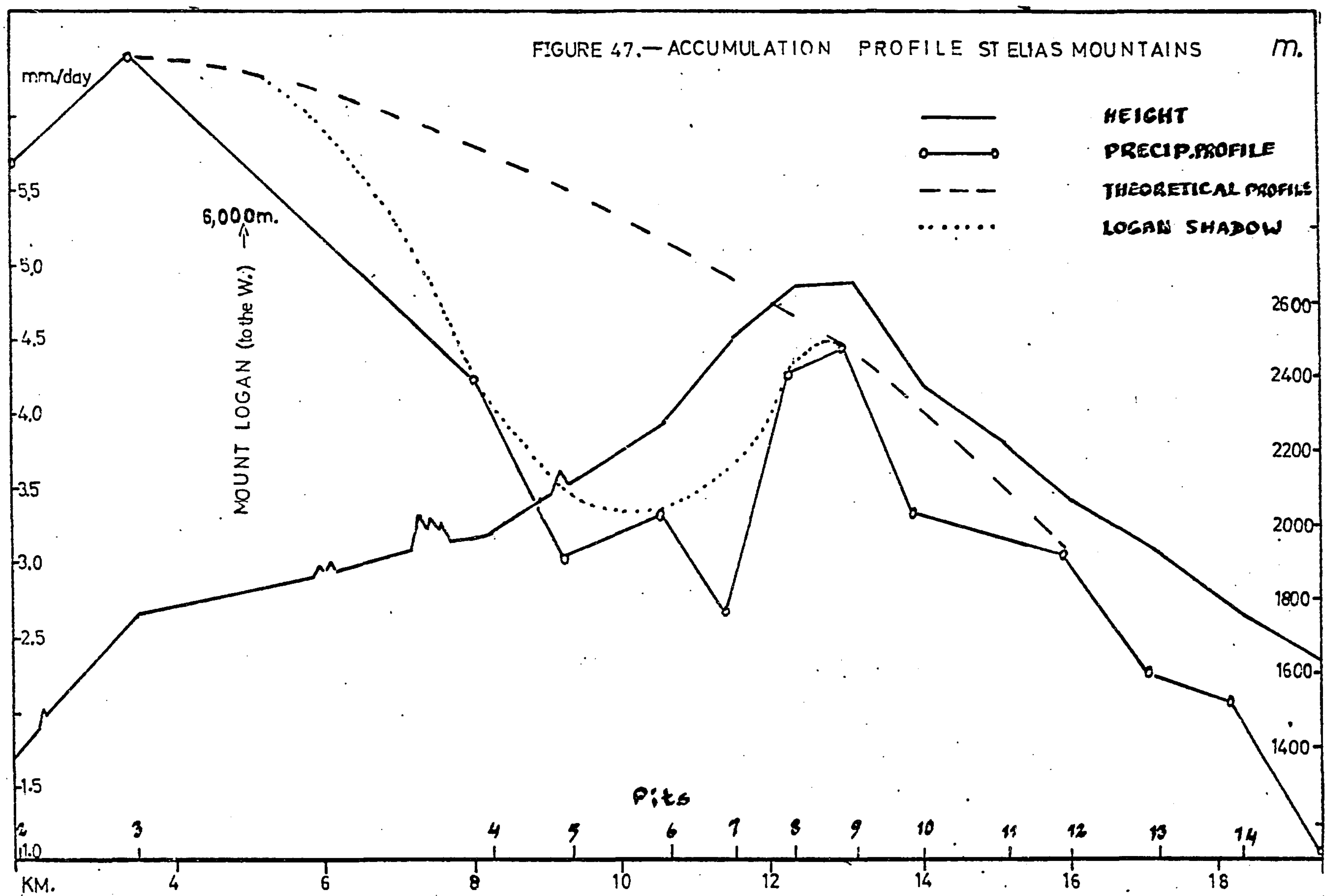

FIGURE 47.— ACCUMULATION PROFILE ST ELIAS MOUNTAINS
m.
mm./day
HEIGHT
PRECIP. PROFILE
THEORETICAL PROFILE
LOGAN SHADOW
6,000m.
MOUNT LOGAN (to the W.)
5.5
5.0
4.5
4.0
3.5
3.0
2.5
1.5
1.0
2600
2400
2200
2000
1800
1600
1400
Pits
2
3
4
5
6
7
8
9
10
11
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KM.
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Upper Seward basin between 1,700 and 1,800 meters". He notes also that the same basic relationships were found by Sharp in 1947-1948 and 1948-1949.

If it is supposed that air flows up the Seward and Hubbard Glaciers to DIV then down the Kaskawulsh (i.e., over a mountain range with DIV as the highest point) then a maximum rain zone around 1,800 meters compares well with Walker's theoretical results. Theoretically there should be a gradual decrease in precipitation from the 1,800 meter level on the windward slope to the base of the leeward slope.

These glaciers however flow between several massive peaks. It has already been shown that the mountains are a major influence on the surface winds and preliminary results of pibal ascents suggest this effect extends to considerable altitudes. The exact pattern of this disturbed flow is unknown. It is reasonable to assume, however, that glacier sites to leeward of barriers such as Mount Logan[90] would receive considerably less precipitation than the altitude precipitation relationships would suggest.

A third factor affecting the distribution of precipitation is undoubtedly the presence of ridges and nunataks on the glacier. That pits 5 and 7 are situated to leeward of such obstructions (see Map 3) is not surprising when their accumulation amounts are compared to that at the more exposed pit 6.

Returning to Table XXX of recorded summer precipitation per day it can be seen that KL and WH would fit into an extension of the continental slope profile (Figure 47).

[90]Possibly largest mountain massif in the world.

Yakutat on the other hand records a summer average daily precipitation well above that of the maximum zone found by the hydrological traverse. Juneau, likely more representative of the coastal precipitation regime, receives an average of 3.8 mm. per day and would fit into an extension of the marine slope curve (Figure 47).

f) Yearly and Monthly Variations

From the seasonal values given in Table XXX, 1964 appears to have been the wettest summer except at DIV where most snow fell in 1963. At all stations 1965 recorded the least precipitation. The 1964 - 1965 winter accumulation was the least recorded in five years at DIV (Marcus, 19).

At the stations where convective clouds produce a significant portion of the summer precipitation the maximum monthly precipitation occurs in July or August. DIV and SEW, on the other hand, where stratiform cloud accounts for almost all of the precipitation, records a June maximum.

2. PROBABILITIES

The probability of precipitation on any one day is given for each station in Table XXXII. There is a steady east-west increase of percent probability. Precipitation probabilities appear to give a more realistic representation of the precipitation regime of this glacier area than do measured precipitation totals.

The year to year variations of probability are similar to that of the seasonal totals.[91] Probabilities appear to be higher in the early

[91] Except in 1963 where at KL less rain appears to have fallen in more days while at the DIV the reverse is true.

months at most stations as further evidence that the July maxima are a result of rain produced by convective clouds (i.e., it falls in greater quantities in a shorter length of time than rain from stratiform clouds).

3. DIURNAL VARIATIONS

The diurnal curves of rain and snow are shown in Figure 48. The only generalization possible is that the maxima come early in the day. Predictably July at KASK and KL also have a maximum late in the day. At SEW the snow maximum comes earlier than the rain maximum.

4. WIND DIRECTION - PRECIPITATION RELATIONSHIPS

Table XXXIII gives the probability of precipitation with a given wind direction, based on the 1965 three hourly observations.

a) Kluane (KL)

At KL the greatest probability of rain is with winds off the lake. (As noted in Ch. VII sec. 3, cumulus cloud build-ups were often observed at the N. end of the lake in the latter part of the season.) Calms often accompany rain. Precipitation is least likely when winds blow from the Slims Valley off the cool glacier.

b) Kaskawulsh (KASK)

N.W. winds (i.e., from the snow free mountains) are associated with the highest probabilities of precipitation at KASK. Least probability occurs with down glacier winds. Winds funnelling down the north arm direct from the DIV area are more likely to bring precipitation than winds down the central arm.

The relatively wet up glacier winds are likely due to frontal passages.

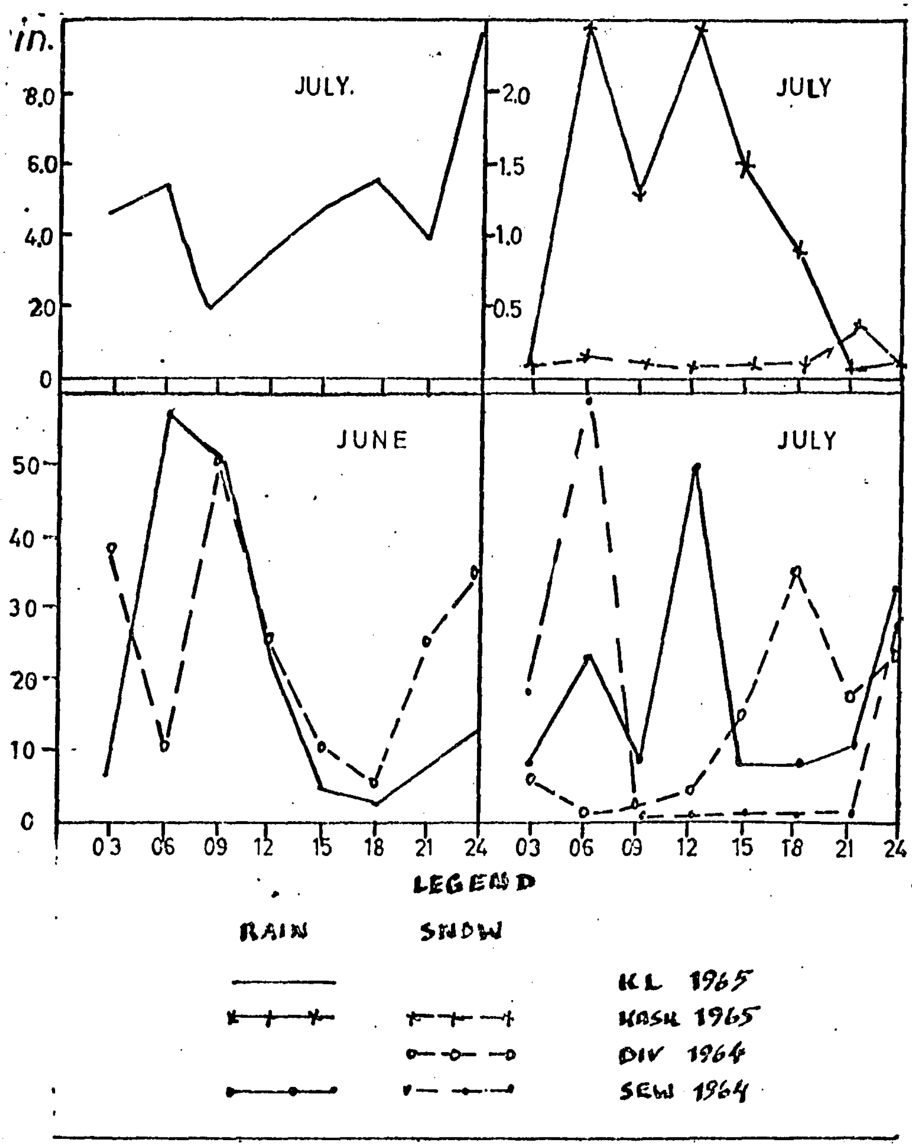

Figure 48. Diurnal precipitation curves, IRRP stations, June and July.

c) Divide (DIV)

Cyclonic disturbances appear to account for much of DIV'S precipitation easterlies exhibiting the highest probabilities while westerlies, indicative of coastal ridge conditions are least likely to bring snow.

d) Seward (SEW)

At SEW, generally the greatest probability of precipitation occurs with N. and N.W. winds from the Seward basin. When winds are from inland less precipitation is experienced.

CHAPTER IX

MARCH OF DAILY MEANS

In Figures 49 and 50a.and b. are plotted the mean daily temperatures, wind and cloud cover recorded at DIV and SEW in 1964 and at all four IRRP stations in 1965. As the march of daily mean pressure is very similar at all stations only those of DIV in 1964 and KL in 1965 are included, and the twelve hourly accumulation-ablation amounts have been plotted for DIV 1965.

There is a close relationship between the variation of mean daily temperatures at all stations in one year. The cloud curves for one season are also similar and precipitation tends to occur on the same days at all stations.

Rather interesting is the close relationship between the wind speed and cloud cover curves, especially evident at DIV in 1964 and also at DIV and KASK 1965. Most precipitation appears to fall during a peak in these two curves.

Associated with every major low pressure period there can be found at DIV and KASK, cloud and wind maxima while at KL and SEW only cloud maxima occur. The same relationships hold for high pressure and low wind and cloud. Approximately a one day lag is evident between the pressure maxima and minima and the corresponding wind or cloud condition. Precipitation accordingly appears to follow a

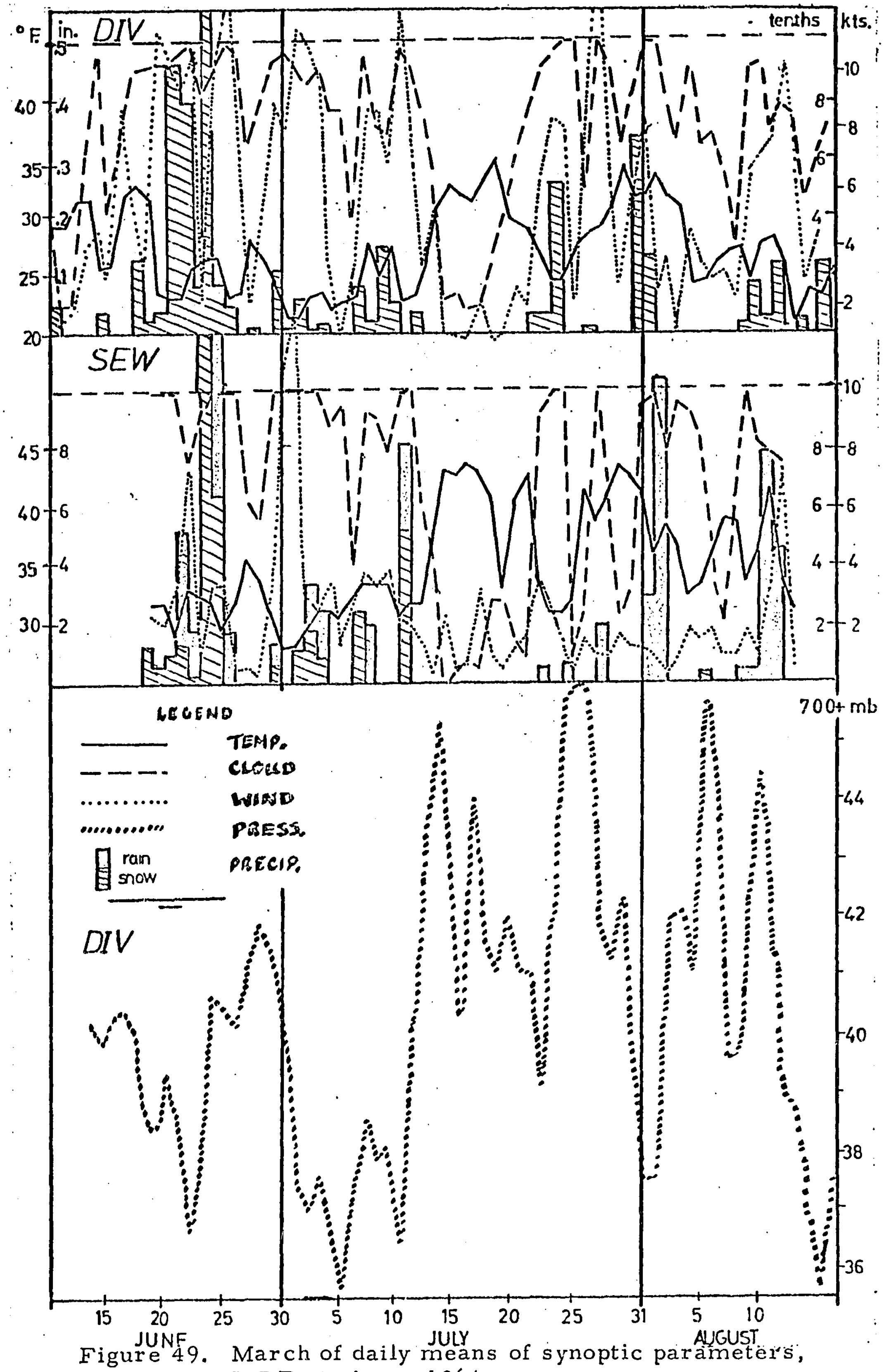

Figure 49. March of daily means of synoptic parameters, IRRP stations, 1964.

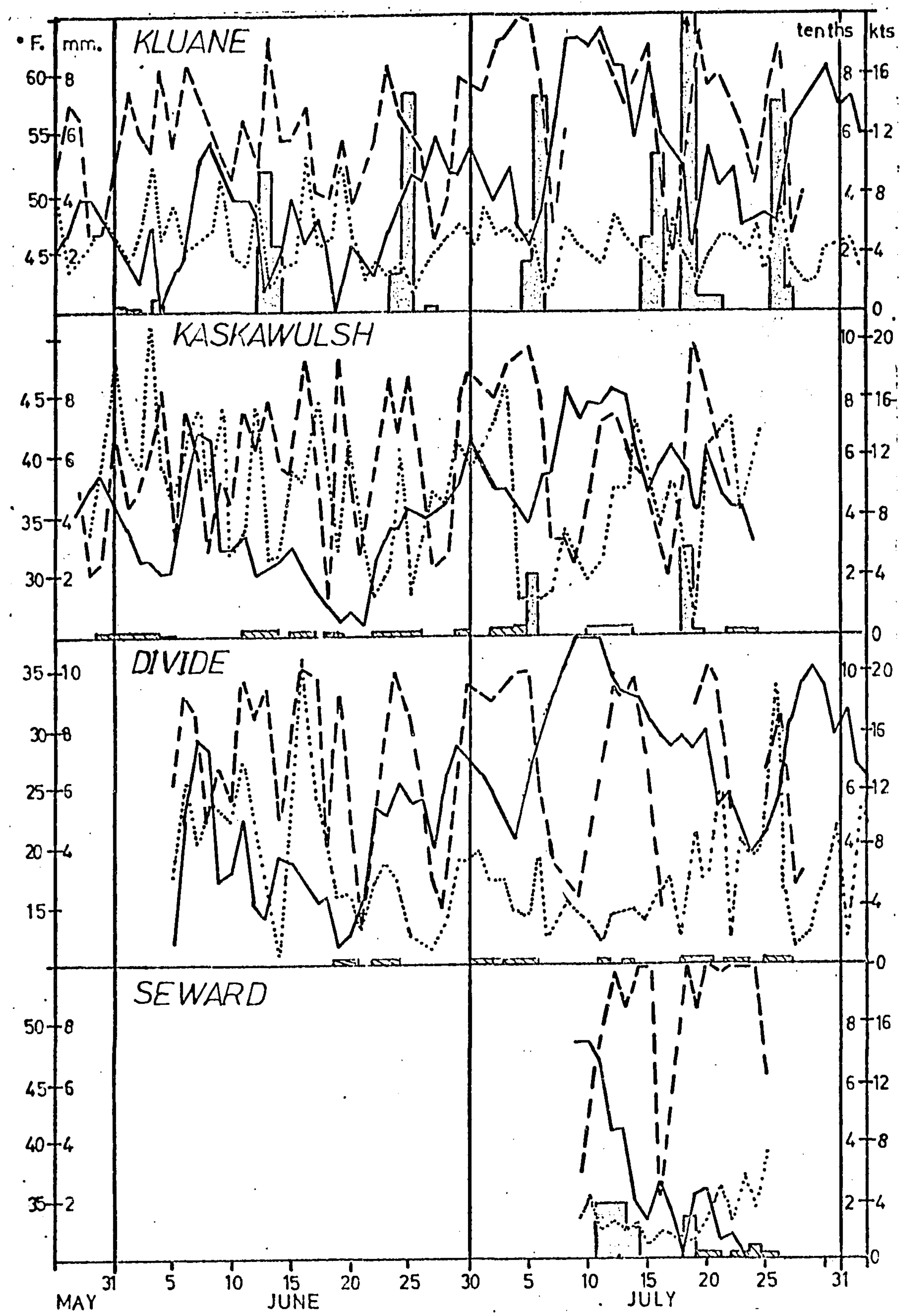

Figure 50a. March of daily means of synoptic parameters, IRRP stations, 1965. (For legend see Figure 49.)

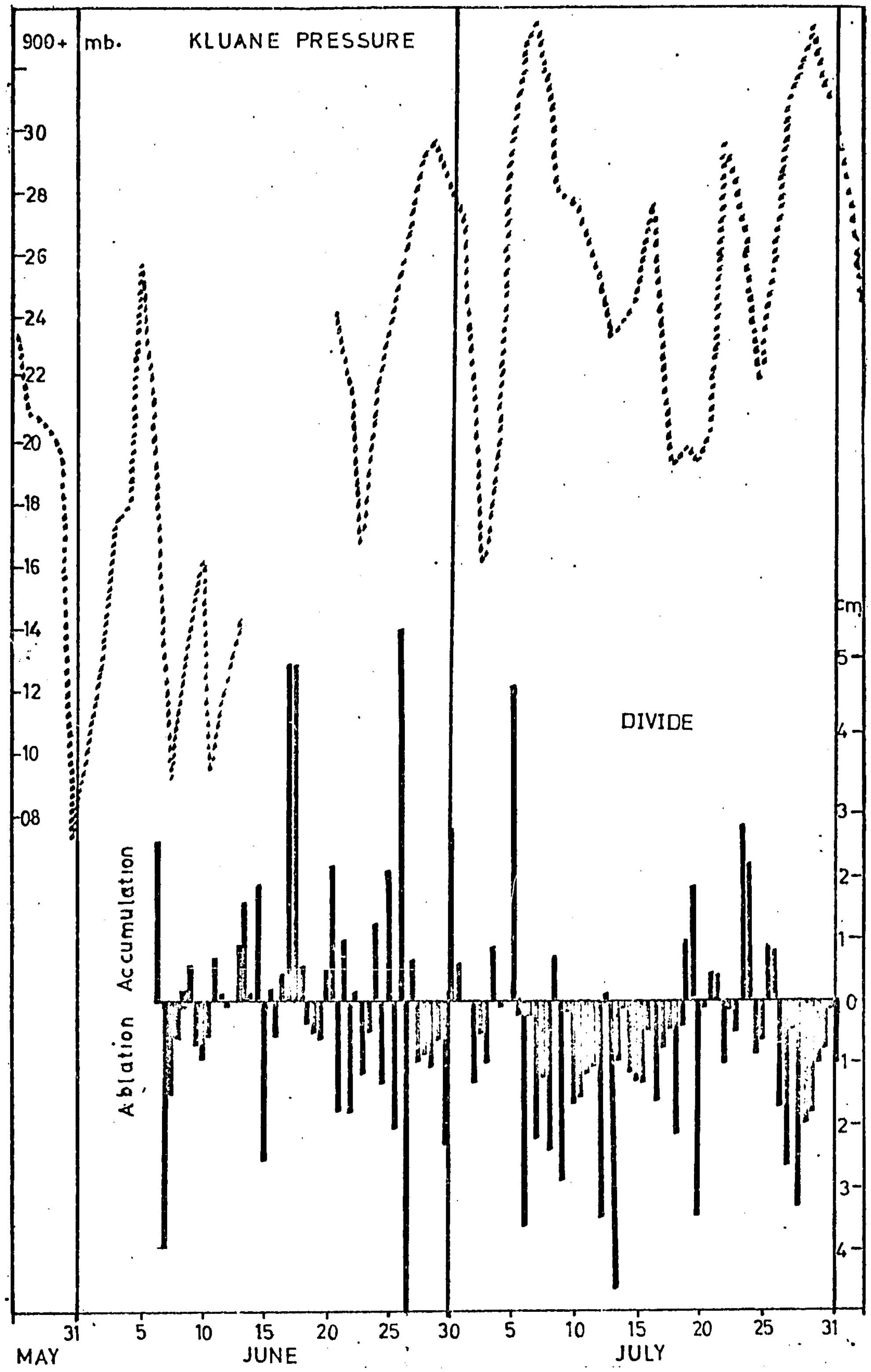

Figure 50b. March of mean daily pressure, Kluane and twelve hour accumulation--ablation amounts, Divide.

pressure drop.

The temperatures do not appear to be related to any of the above parameters. There is, however, a definite relationship between high ablation and high temperatures. Table XXXIV of days below freezing is self-explanatory.

CHAPTER X

FLOW ANALYSIS

1. CLASSIFICATION

Chapter II dealt with the general circulation of N.W. North America and thus presented a mean, long term, large scale picture of the geostrophic flow. It is the object of the present chapter, on the other hand, to classify and discuss the actual geostrophic flow conditions immediately over the IRRP area during the summer seasons of 1964 and 1965.

The flow has been classified according to the type of surface over which it travelled immediately before it reached the IRRP area rather than by compass point directions. Though this results in each flow type covering a different number of compass points (i.e., the segments as shown in Figure 51 are of varying sizes), it is hoped it will give the analysis some physical meaning (i.e., each flow type will represent flow of air which has undergone the same modification processes).

The five categories[92] thus designated are (as shown in Figure 51):

1. Up the S.E. - N.W. tending valleys (ca. S.E.)
2. Off the Pacific Ocean (ca. S. - S.W.)
3. Along the S. coast of Alaska (ca. W.)

[92] The flows will henceforth be referred to as type 1, type 2, etc.

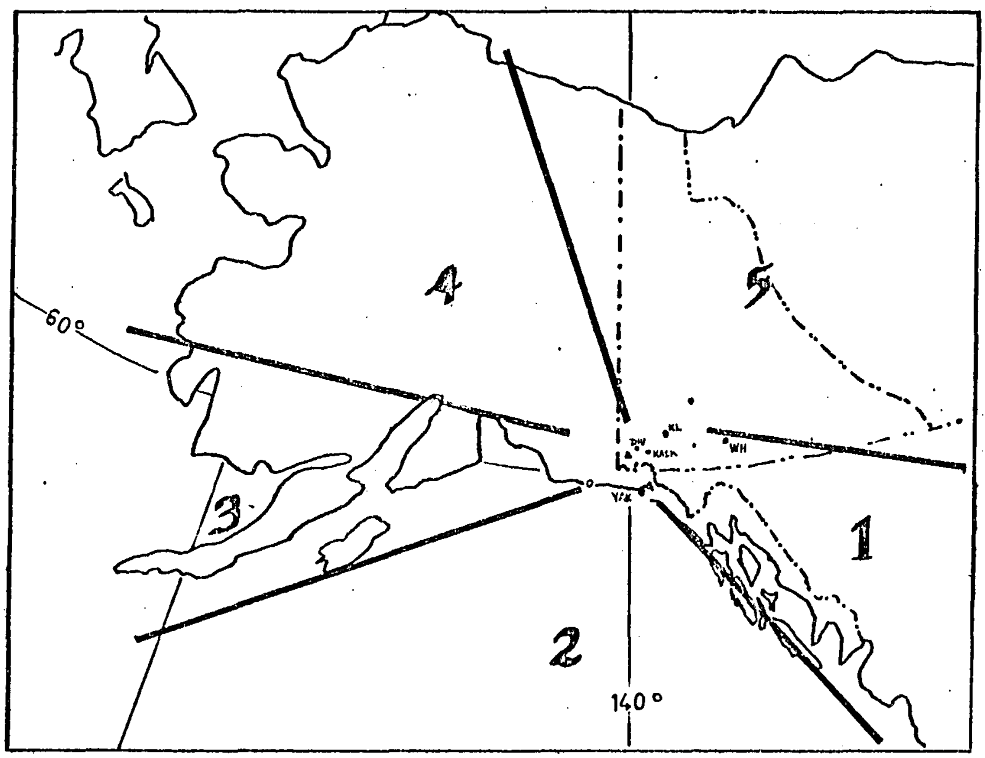

Figure 51. Flow types. Refer to Maps 1 and 2 for details of the topography.

4. Down the N.W. - S.E. tending valleys (ca. N.W.)

5. From inland (ca. N. - E.)

In addition it was found that the following three types of curved flow occurred:

1 to 2, 3, or 4. A ridge slanting with the coast.

2 to 3 or 4. A ridge oriented more N. - S.

Col or neck.[93] Uncertain flow between two lows or highs

2. SURFACE AND 500 MB FLOW

a) 1965[94]

Table XXXV shows the percent frequency of flow types for the period 19 May to 18 August 1965. These were extracted from the C.A.O. 500 mb and surface charts for 00 Z and 12 Z.

At 500 mb 42 percent of the maps showed flow from the ocean while flow of type 1 and ridge conditions were also frequent, these three types together making up 77 percent of the 500 mb flow.

The surface charts were dominated by flow along the northern coast of the Gulf and by ridge conditions. Type 2 flow was less common than at 500 mb, placing third.

Also illustrated by Table XXXV are the relationships between surface and 500 mb flow. As would be expected a surface ridge with 500 mb type 2 flow is the most common combination. (These relationships should be kept in mind during sec. 3 of this chapter.)

[93] The neck of a low i.e.,

[94] 1965 will be treated first as the analysis for this year is more accurate than that for 1964.

b) 1964

Table XXXVI shows the percent frequency of the flow types for 19 May to 8 August 1964, in this case extracted from the U.S. Weather Bureau "Daily Weather Maps" for 00 Z at 500 mb and 18 Z at the surface. The table is self-explanatory.

In order to compare 1965 and 1964, the 1965 flow was also extracted from the U.S. maps. Table XXXVII compares the 1965 C.A.O., 1965 U.S., and 1964 U.S. percent frequencies.

The U.S. maps being smaller and less carefully analysed in this area tend to show fewer ridge conditions and more type 2 flow. Several days were missing in the 1965 U.S. series and these were days with type 5 flow. Keeping this in mind the following differences between the 1964 and 1965 flow can be found.

At 500 mb 1964 tended to have less of flow type 2 and more of type 1 and 5 suggesting more cyclonic activity in this year.

The surface charts in 1964 evidenced more of type 4 flow and less of type 3 and ridge conditons than those for 1965.

3. FLOW - SURFACE SYNOPTIC PARAMETER RELATIONSHIPS

The 1965 surface and 500 mb flow at 00Z and 12Z were related to the corresponding temperature, wind direction and speed, precipitation, and cloud amount at each IRRP station. In addition the relation between the daily means of the above parameters and the flow was obtained.

The quality and quantity of data did not warrant strict mathematical (i.e., statistical) treatment. Instead the graphic mode and median of each parameter as well as the percentage of temperatures above freezing and the probability of precipitation were obtained for each type of flow,[95] from frequency diagrams.[96] These are given in Tables XXXVIII and XXXIX. From these tables (and the frequency diagrams) some generalizations can be made with the following reservations. The conditions represent only the summer of 1965 and the mode or median values may be misleading due to a small number or wide scatter of data.[97]

a) Temperature

During periods of ridge conditions or flow from the interior, at 500 mb, warm temperatures are experienced at all stations. A 500 mb ridge will tend to import, into the IRRP area, air from lower latitudes while type 5 flow carries radiatively warmed air masses.

A similar relationship exists for the surface flow where col or neck conditions, suggesting little or disturbed flow, are also warm.

Five hundred mb flow from the N. down the valleys and from the W. over the rugged glacierized mountains tend to accompany colder temperatures. Flow up the N.E. - S.W. tending valleys also appears to be related to cool temperatures. The explanation of these relationships lies in the type of surface flow associated with type 1, 3, and 4 500 mb flow.

[95] In some cases too few days had flow of a certain type to determine a value.

[96] These frequency diagrams were of course too numerous to include. However in the discussion that follow the author was guided by them as well as the values in Tables XXXVIII and XXXIX.

[97] An attempt was of course made not to depend on them in these cases but this was done only subjectively.

At the surface low temperatures result when flow comes from the cool ocean over the icefields (type 2) or from the north (type 4).

b) Wind Directions

As has been shown surface wind directions vary considerably from station to station. For this reason the flow - surface wind direction relationships will be considered for each station individually.

i) Kluane (KL):- In general, there is a counter clockwise rotation from the geostrophic to the actual surface wind direction at KL. This is due to the large amount of frictional drag exerted by the rough terrain in the area.

At 500 mb however no simple relationship exists. Only in the case of flow type 1 do the 500 mb and actual wind directions tend to agree.

ii) Kaskawulsh (KASK):- At KASK as would be expected from the wind roses (see Figure 43) every type of surface and 500 mb flow is most frequently accompanied by S. W. winds at the surface (i.e., down the central arm). Flow of type 2, in general, produces the most W. winds (i.e., down the north arm).

iii) Divide (DIV):- When 500 mb flow at DIV is up valley or from the ocean S. winds predominate, while type 3, 4, and 5 tend to support W. winds.

There is, on the other hand, a very close relationship between the sea-level geostrophic wind and the actual surface wind at DIV.

iv) Seward (SEW):- No generalizations can be made on the basis of the short record available at SEW.

c) Wind Speed

In general with 500 mb ridges and flow of type 2 higher wind speeds are recorded than with flow from inland or during col or neck conditions.[98]

Concerning the surface flow - wind direction relationships few generalizations hold though ridge conditions do tend to give high winds and col or neck conditions low speeds.

It is interesting to note that at KL and DIV flow from inland produces strong winds while at KASK it does not. These mainly cyclonically produced winds are strong but at KASK they are counter-acted by the prevailing glacier wind.

d) Cloud

The station to station differences in cloud - flow relationships (at both the 500 mb and surface level) reflect the change from a maritime to a continental regime.

At KL the cloudiest skies are accompanied by flow from inland. Convective and frontal cloud is largely responsible for this condition. DIV and SEW on the other hand receive most of their cloud when the flow is off the ocean up the maritime slope.

By the time these clouds reach KL they have dissipated considerably (i.e., type 2 is clear). Clear weather is experienced, at the maritime stations, during flow from the east due to its lack of moisture.

[98] There are several exceptions to this - e.g., at KL type 3 flow has lost much of its energy to friction during its journey over rugged terrain.

KASK appears to be caught in the middle. Here stratiform cloud rolls down the glacier from DIV and convective activity is not uncommon, though less frequent than at KL.

e) Precipitation

The precipitation - flow situation is similar to that of cloud.

At KL the greatest probability of rain occurs with 500 mb flow type 1, 5, or ridge and surface type 1, 4, or 5. The greatest precipitation amounts occur with flow from inland at both levels. In other words precipitation tends to be the result of convective activity[99] or low passages.

KASK also receives the greatest precipitation amounts from the E. at the surface and 500 mb but the greatest probability is related, at 500 mb to flow from the S. and S. W. (i.e., 1 and 2) and to surface flow from S. around to N. W. (i.e., 1, 2, and 3). The latter is a result of stratus imported from the DIV area.

DIV and SEW receive most precipitation during flow from the Pacific. Along with KASK they are least likely to receive rain when a ridge sits over the area or during dry cool flow of type 4.

[99] i.e., A 500 mb ridge gives clear warm weather resulting in convective activity.

CHAPTER XI

SYNOPTIC ANALYSIS

As the climate of an area is a reflection of the synoptic regime, a study of climate is not complete without some mention of the synoptic scale conditions. In the present study the conditions have been classified by the weather they produce at the surface and periods have been chosen for study which, in the author's memory of the field season (1965), had experienced particularly bad,[100] windy, or hot weather. This method of selection, though rather subjective, will reflect the true complexity of the area's synoptic regime.[101] Three of the seven periods examined will be discussed in detail.[102]

For these three periods a brief, note-form summary of the synoptic situation will be given, with the help of weather charts.[103]

[100] "Bad" means a combination of cloud, precipitation, fog or whiteouts, and high winds, etc.

[101] Carefully chosen synoptic configurations are usually selected for their well defined pattern or classical appearance and so will tend to simplify the situation and may not really be representative of the normal situation - they do however allow presentation of a more clear cut set of conclusions.

[102] One each of bad, windy, and hot.

[103] Most of these and the descriptions were taken from the Canadian Meteorological Service C.A.O. weather charts for 500, 700, and 850 mb at 1200Z and 0000 Z and surface at 0600, 1200, 1800, and 0000 Z. The U.S. weather bureau "Daily Weather Maps" were also used to some extent. In all cases the IRRP data was added to these analyses.

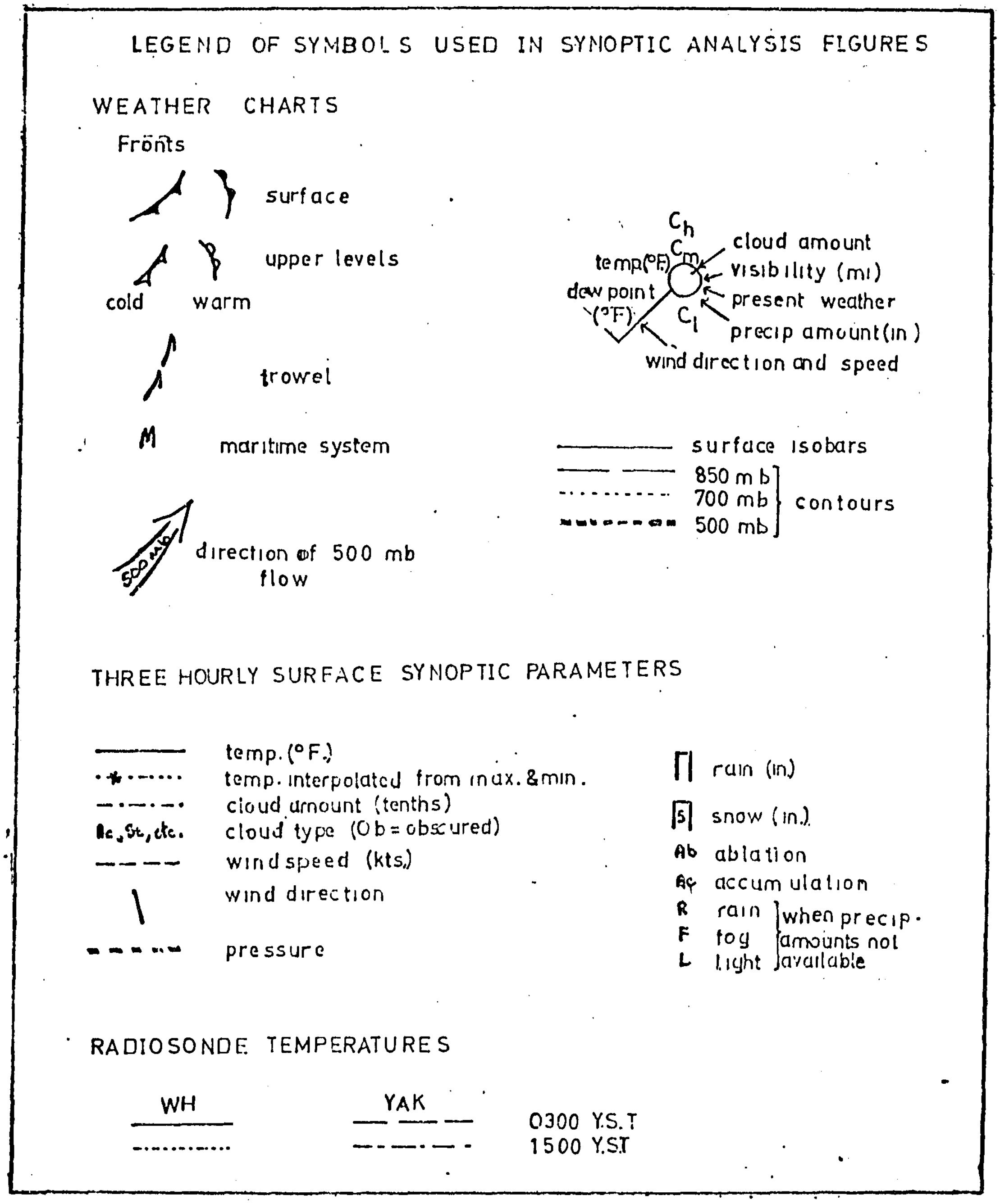
LEGEND OF SYMBOLS USED IN SYNOPTIC ANALYSIS FIGURES
WEATHER CHARTS
Fronts
surface
upper levels
cold
warm
trowel
M
maritime system
500 mb
direction of 500 mb flow
C_h
C_m
C_l
temp(°F)
dew point (°F)
cloud amount
visibility (mi)
present weather
precip amount (in)
wind direction and speed
surface isobars
850 mb
700 mb
500 mb
contours
THREE HOURLY SURFACE SYNOPTIC PARAMETERS
temp. (°F.)
temp. interpolated from max. & min.
cloud amount (tenths)
Ac, St, etc.
cloud type (Ob = obscured)
wind speed (kts.)
wind direction
pressure
rain (in)
5
snow (in.)
Ab ablation
Ac accumulation
R rain
F fog
L Light
when precip. amounts not available
RADIOSONDE TEMPERATURES
WH
YAK
0300 Y.S.T
1500 Y.S.T

Figure 52.

This will be followed by similarly brief description of the surface weather conditions at the stations, accompanied by plots of the three hourly values of the surface synoptic parameters at each station and the YAK and WH radiosonde temperatures. Finally an attempt will be made to form these into a picture of what took place.

1. PERIOD 1 - 29 JUNE TO 1 JULY (BAD WEATHER)[104]

a) Synoptic Situation

Date[105]		Level		Situation
28	-	surface	....	occluded frontal system and low move on coast and dissipate N. of Vancouver Ils. leaving a ridge over coast.
	-	500 mb.	....	weak low over Yukon.
29	-	surface	....	high over N.W. British Columbia.
			....	low (with strongly occluded fronts preceeding it) S.E. of the end of Aleutian Pen.
	-	500 mb.	....	cold low S. of Aleutians.
30(03)	-	surface	....	trowel S. of Valdez and low S. of Aleutians.
	-	500 mb.	....	low S. of Aleutians.
30(15)	-	surface	....	trough // coast well out in Gulf.
			....	top of trowel just S. of YAK in small trough in coastal ridge (see Figure 54a).
	-	500 mb.	....	sharp trough with IRRP on E. side of it.
			....	low S. of Kodiak (see Figure 54b).
1(03)	-	surface	....	maritime cold front over IRRP in small trough.
			....	new low S. of Aleutians
	-	500 mb.	....	low still S. of Kodiak giving slight cold advection over IRRP
1(15)	-	surface	....	ridge with trough in it still over coast - front passed on
			....	low S. of end of Aleutian Pen
	-	500 mb.	....	low over end of Aleutian Pen

[104]On 30 June the menacing clouds shown in Figure 52 streaked the sky over DIV and by the late afternoon the station was socked in. The low stratus lifted only briefly on the night of the 1st. but flying was not possible until late on the 6th. Whiteout conditions were frequent as were snow, obscuration, and very low stratus.

[105]Henceforth the dates and times will be given in the following manner 28(03) - meaning the 28 at 0300 Y.S.T., the month being obvious from the period being discussed. (Note 0300 Y.S.T. corresponds to 1200 Z.)

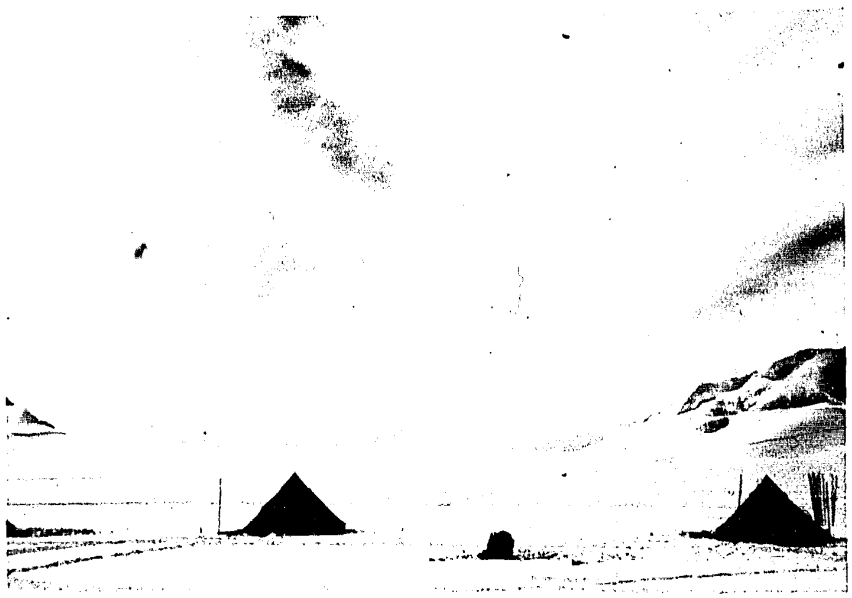

Figure 53. System moving in at Divide 30 June.

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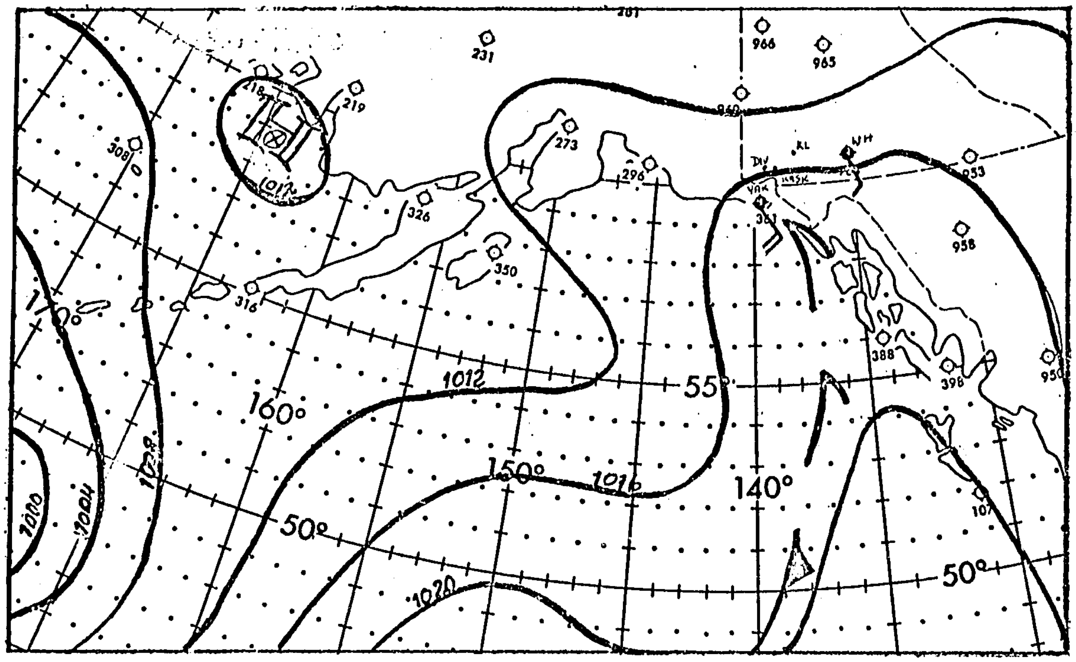

Figure 54a. Surface weather chart for 30 June at 1500 Y.S.T. [30(15)] . (After C.A.O. analysis.)

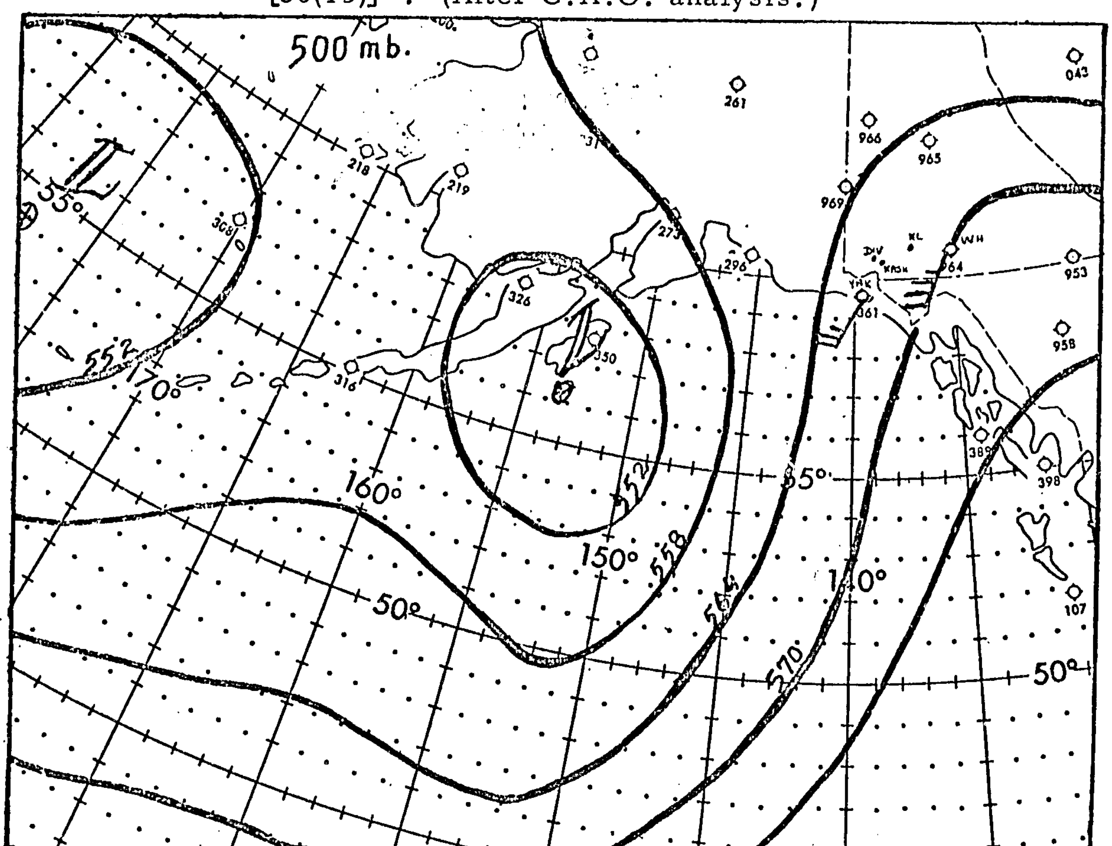

Figure 54b. 500 mb contours for 30 June at 1500 Y.S.T. [30(15)] . (After C.A.O. analysis.)

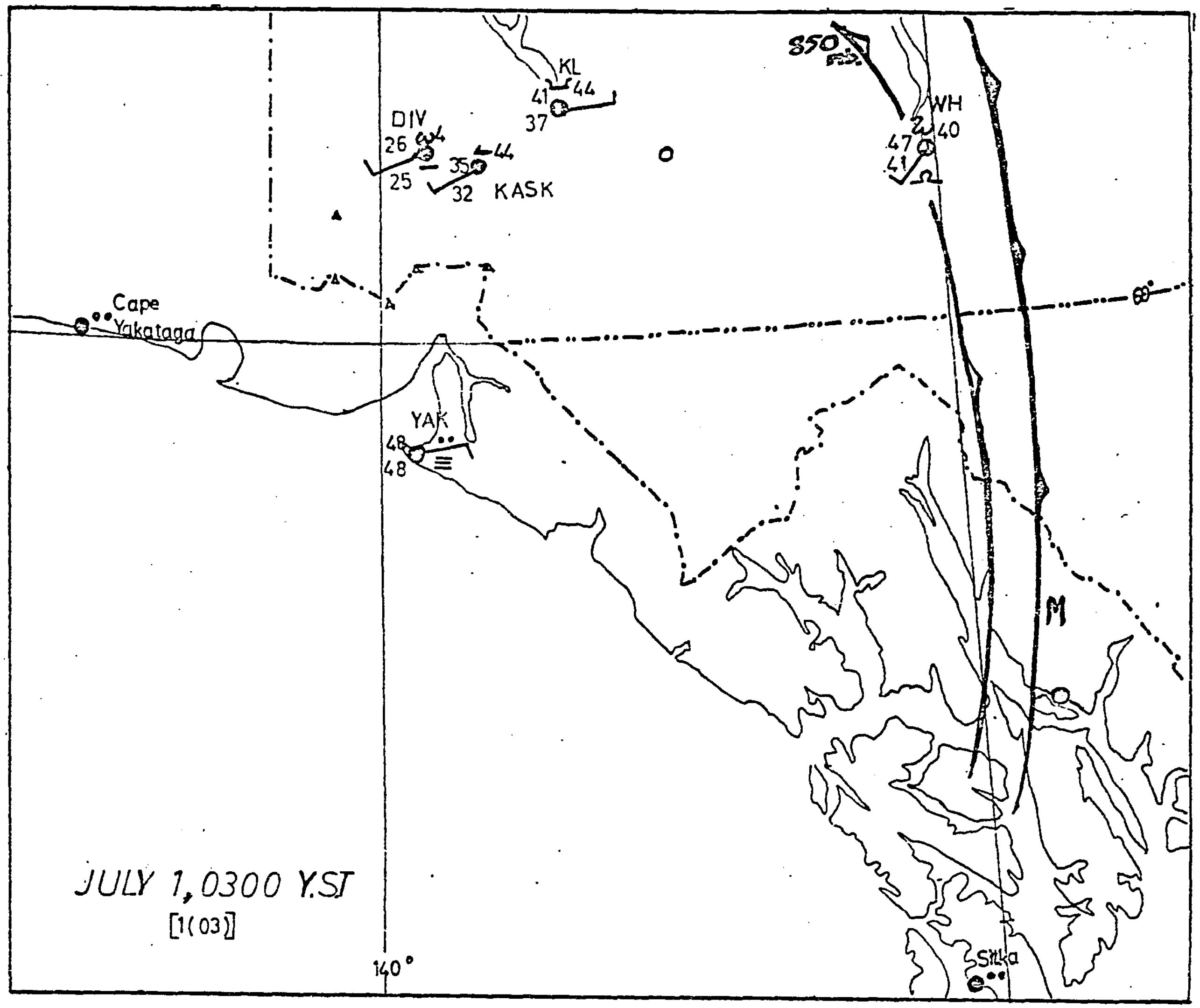

Figure 55. Surface weather for 1 July at 0300 Y.S.T. [1(03)]. From C.A.O. analysis with IRRP weather added. See Figure 52 for legend.

b) Surface Effects

In Figure 56 are shown plots of the synoptic parameters during period 1. Radiosonde temperatures over YAK and WH appear in Figure 57. These figures reveal the following:

i) Clouding:- The clouding over proceeds as would be expected (see Figure 53). It should be noted that Sitka becomes overcast after WH.

ii) Precipitation:- Precipitation is initiated at Cape Yakataga and YAK at 29(15), at DIV by 30(03), at KASK at 30(09), and possibly at WH at 30(15) due to this cloud. KL is not affected.

iii) Warming:- There is evidence of warming aloft at YAK at 30(03). DIV and KASK show warm nights (i.e., 1(00) and 1(03) respectively). KL is not affected and at WH warming aloft can be seen at 1(03) but none is evident at the surface. Sitka and Cape Yakataga show no surface warming.

iv) Precipitation:- Rain continues at YAK while at Cape Yakataga - 30(21) - and Sitka - 1(03) - there is a marked increase in intensity. Snow began again at DIV - 1(03) - and rain fell at WH - 1(15). KASK and KL escaped this time.

v) Cooling:- There is evidence of surface cooling during the night of the 30th - 1st at Cape Yakutaga and YAK, while YAK has cooled in the upper levels by 1(15). There appears to have been sudden cooling at DIV at 1(12) and the diurnal maximum at KASK is flattened. Sitka also has a damped diurnal maximum, and KL and WH cool more rapidly than usual in the evening of the 1st. By 1(15), at 700 mb., cooling has taken place, and by 2(03) there is marked cooling in the 850 to 700 mb. layer.

vi) Clearing:- There is no clearing of the overcast at YAK, Cape Yakataga, or Sitka. DIV clears to 7/10 by 1(18) and the snow stops. KASK, KL, and WH show signs of clearing by 1(15).

vii) Wind:- YAK wind directions suggest passage of a frontal system aligned N. W. - S.E. between 3(03) and 1(03). At DIV wind speed maxima at 30(09) and 1(12-15) corresponding to the warming and the cooling. Wind directions here agree well with the 500 mb. flow at 29(15) and again by 1(15) but between 30(03) and 1(03) there is evidence of a frontal passage.

If the seemingly constant down glacier S. W. winds are subtracted from the KASK wind directions a warm and cold frontal passage can be identified here between 30(03) and 1(15) - see Figure 58.

KL winds are very light until after 1(03) when there is a veering and an increase in speed. WH on the other hand has two maxima in speed - one before the warming and another along with the cooling. The direction variation at WH is much like that at DIV.

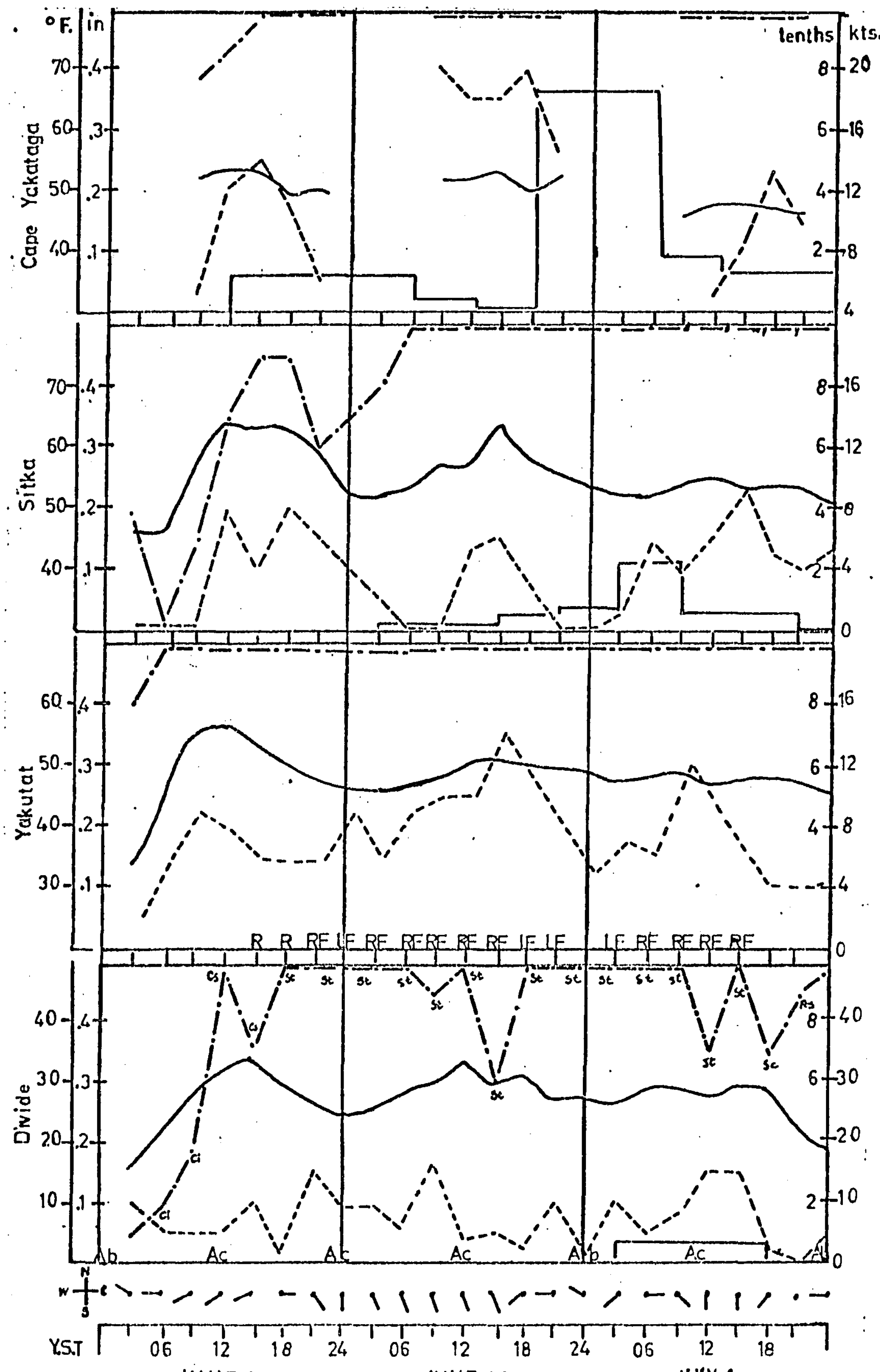

Figure 56. Continued on following page.

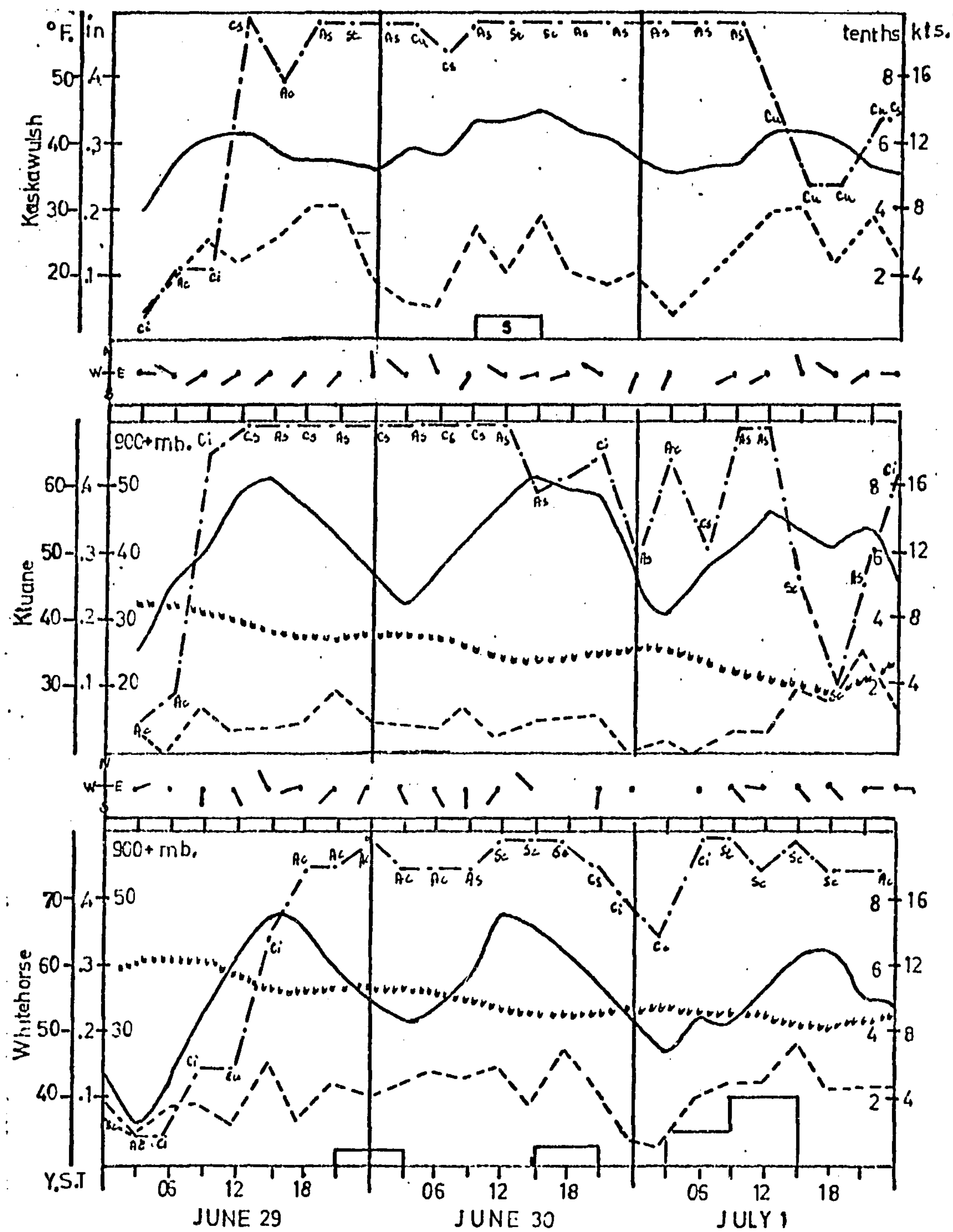

Figure 56. (continued). Three hourly surface synoptic parameters during period 1 (29 June--1 July). See Figure 52 for legend.

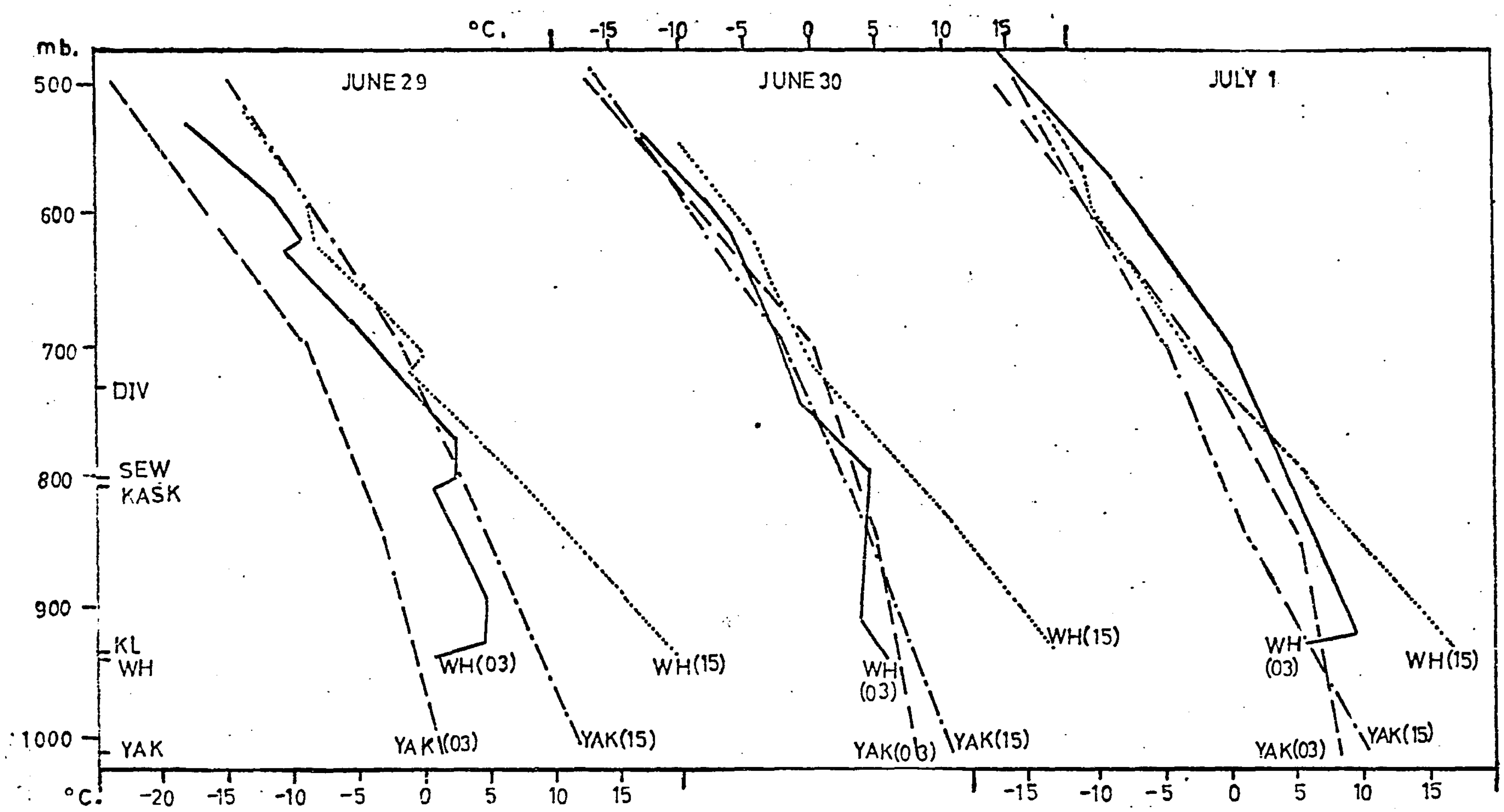

Figure 57. Radiosonde temperatures over Whitehorse and Yakutat for 30 June to 1 July. See Figure 52 for legend. (N.B. for Yakutat only the 850, 700 and 500 mb temperatures were used.)

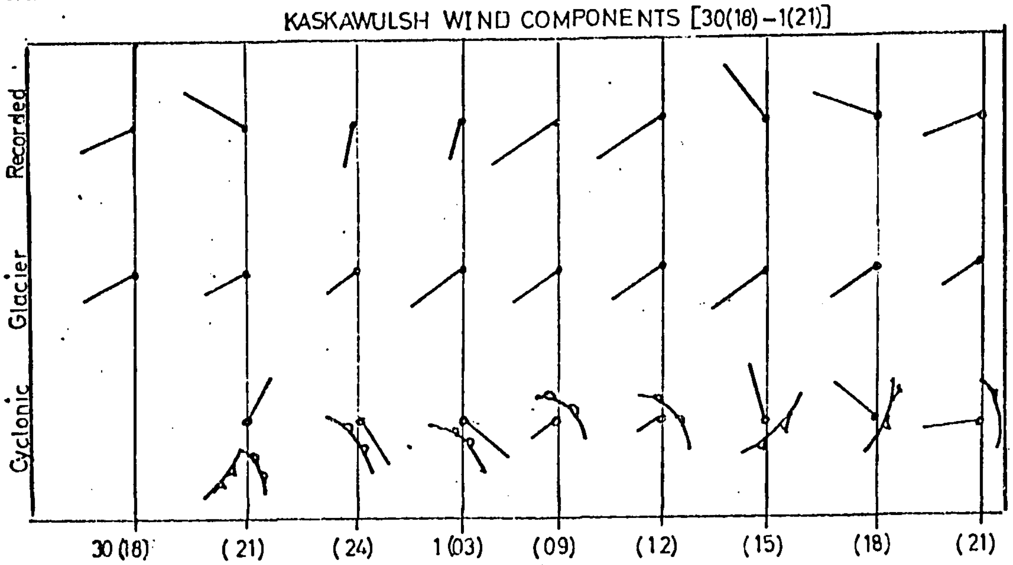
KASKAWULSH WIND COMPONENTS [30(18)-1(21)]
Recorded
Glacier
Cyclonic
30 (18)
(21)
(24)
1 (03)
(09)
(12)
(15)
(18)
(21)

Figure 58.

c) Overall Picture

Figures 59 are schematic vertical crosssections which along with the frontal contour charts in Figures 60 and 61 represent the passage of the system. The reconstructed charts shown in Figures 60 and 61 do not agree with the C.A.O. analysis of the situation. However it is felt by the author that the added data strongly favor the sequence of events represented by these figures.

A surface low supported by a 500 mb low moved into the Gulf and died there. However, the trowel associated with this system continued eastward.

The cloud deck normally associated with a trowel is seen to have approached the coast about parallel to the longitudes.[106] The high and middle cloud preceeded over the mountains but the low cloud definitely did not reach KL.

The trowel, approaching the coast somewhere between 850 and 700 mb, produced precipitation but no warming at the coastal stations. When the northern portion of the trowel ran into the mountains there seems to have been a stalling effect which allowed the southern part (still over the ocean - less friction) to move more quickly. Thus the warm upper trough became aligned with the mountains.[107]

The southwesterly 500 mb flow meanwhile tended to push the system north along the mountains and then finally over them. At this point - 1(00) - the warm air hit the surface at DIV and appears to have

[106] WH clouded over before Sitka

[107] i.e., N.W. - S.E. This orientation is suggested by the YAK and KL winds and the precip. record (began at Sitka before WH).

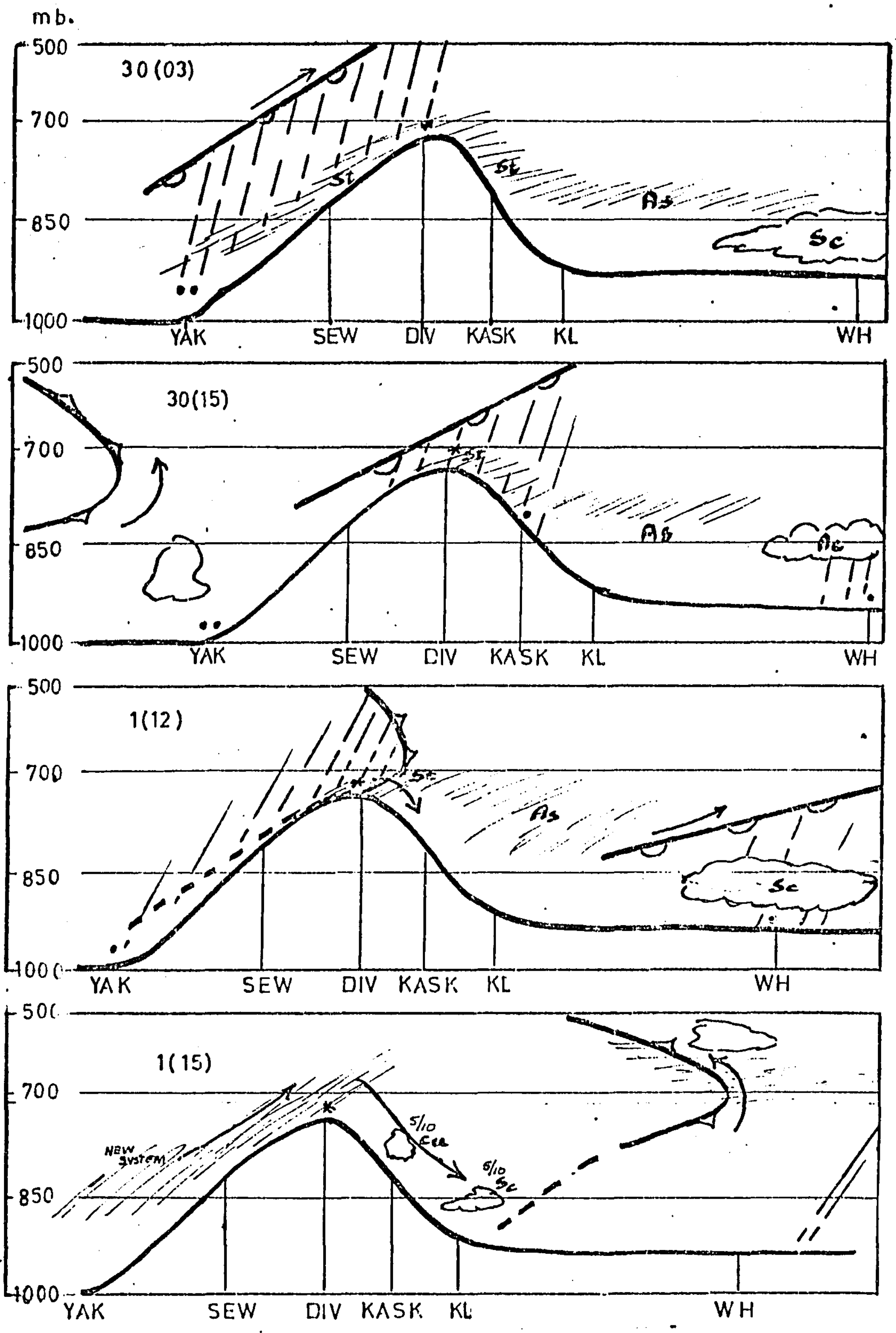

Figure 59. Schematic vertical crossection of the frontal passage between 30 June at 0300 Y.S.T. and 1 July at 1500 Y.S.T. The study stations have been taken as an idealized mountain with Divide at the top. (See Figure 52 for legend.)

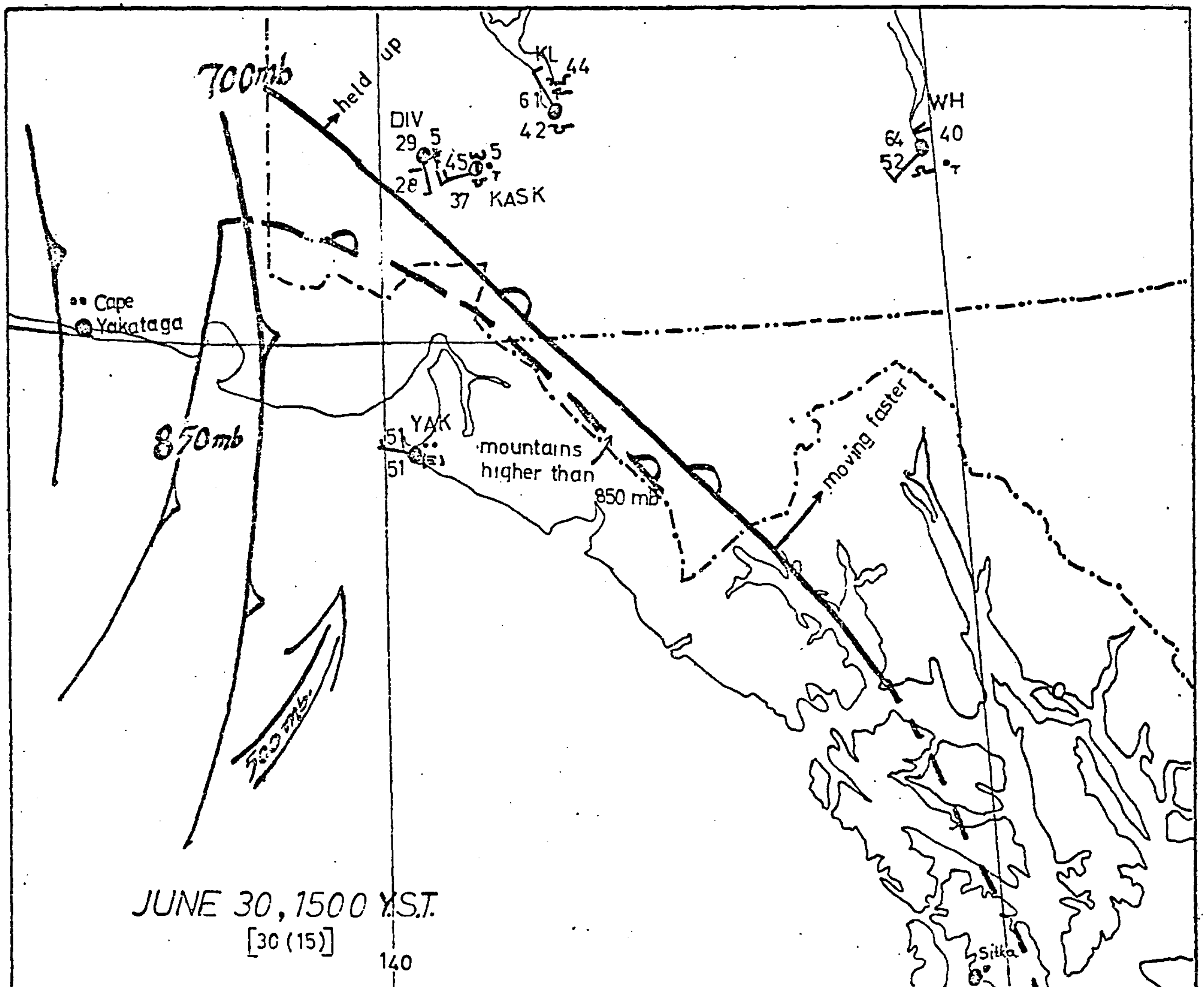

Figure 60. Reconstructed chart of frontal contours, 30 June at 1500 Y.S.T. [30(15)]. See Figure 52 for legend.

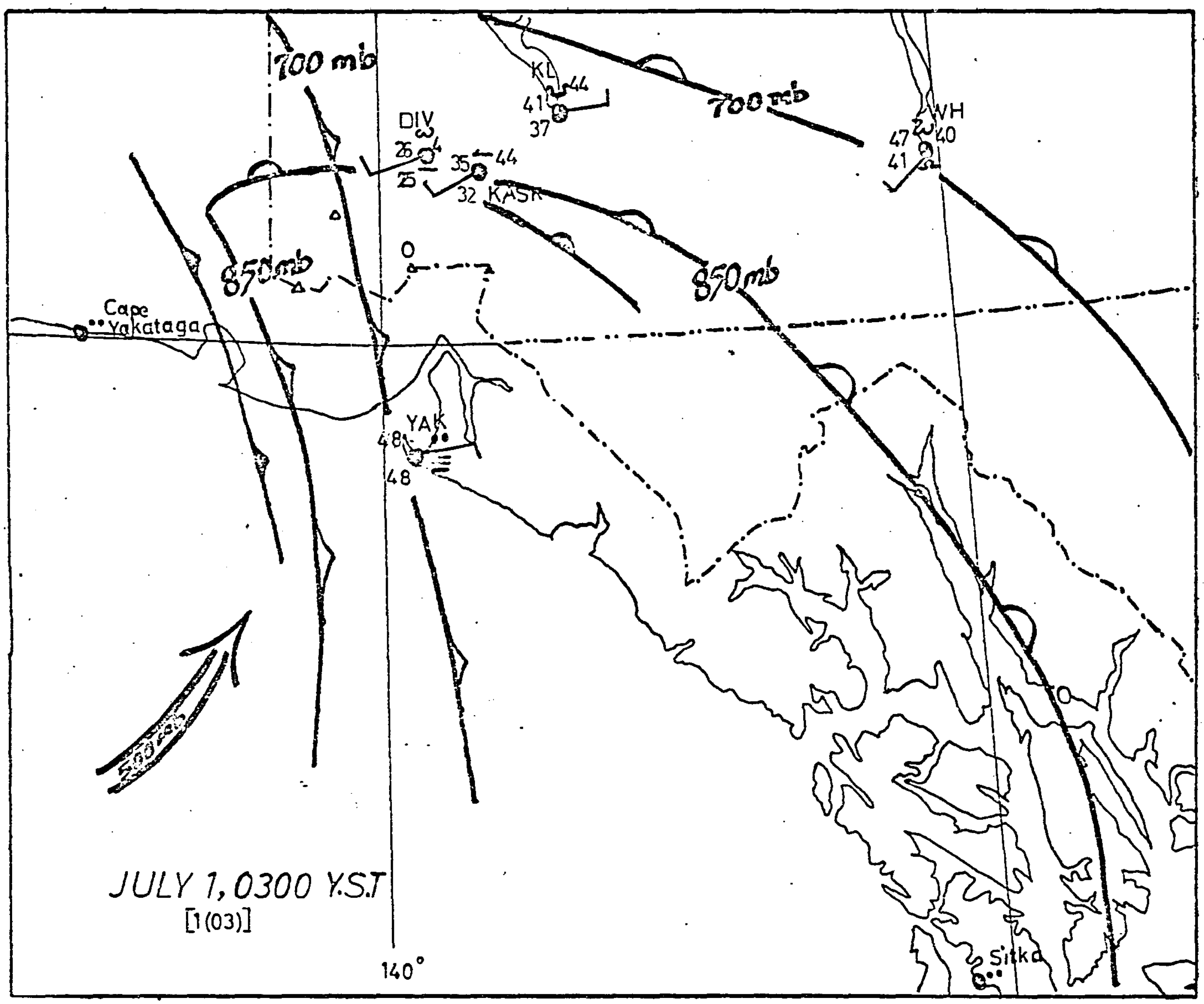

Figure 61. Reconstructed chart of frontal contours, 1 July at 0300 Y.S.T. [1(03)]. See Figure 52 for legend.

spilled down the Kaskawulsh Galcier at least as far as KASK. It did not however reach the elevation of KL; nor does it seem to have descended below the 850 mb level as far east as WH.

Behind the upper warm trough there appears to have been air cooler than that preceeding it. This produced the effects of a cold front at the surface as well as in the upper levels.

The surface effects reached Cape Yakataga around 1(100) and YAK by 1(12). At the latter the upper levels were cooled by 1(15). The cold front (likely rather steep and having some inversion in the lower levels) hit the mountains and the upper part proceeded, accompanied by a band of precipitation, over the top. This created a considerable inversion as indicated by the times at which cooling occurs. (See Figure 59 - WH cooled in the upper levels at the same time as KASK on the surface but did not exhibit substantial surface cooling until some time later.)

Following the passage there was at DIV, KASK, and KL considerable clearing. The rain only let up at the coastal stations as another system approached.

The pressure trough appears to have passed KL and WH almost simultaneously. This, in addition to the records from Sitka, suggest that this front also became aligned with the mountain barrier during its crossing.

It should be noted that although a surface and 500 mb ridge lay over the coast during most of this period it did not produce any clearing until late on the 1st.

2. PERIOD 2 - 15 TO 17 JUNE (HIGH WINDS)[109]

a) Synoptic Situation

Date		Level		Situation
15(15)	-	surface	....	low in Gulf
			....	ridge up the coast
	-	500 mb	....	low trailing surface Gulf low (at 700 and 850 mb also)
16(03)	-	surface	....	well developed low over Cordova with a trowel along the S. coast of Alaska (see Figure 62)
	-	500 mb	....	low moves N.E. to base of Aleutian Pen. (also 700 mb)
	-	850 mb	....	low, accompanied by front, over Kodiak
16(15)	-	surface	....	low onto land N.E. of Anchorage
			....	Maritime front N. of Vancouver Ils. has a trowel stretching N. into the Alaska low. (See Figure 63a)
	-	500 mb	....	low moved E. to Kodiak, see Figure 63b (700 and 850 mb also)
17(03)	-	surface	....	trough joining Mackenzie and Washington lows
			....	high in Pacific becoming ridge up the coast
	-	500 mb	....	weak low in S.E. Yukon

b) Surface Effects

The synoptic parameter values during period 2 are plotted in Figure 64. Figure 65 shows the radiosonde temperatures over YAK and WH. The following can be said on the basis of these.

i) Cloud:- Yak has overcast skies at the outset of the period, while DIV is overcast by 15(15) and KASK by 16(06). KL and WH are only completely overcast briefly around 16(09).

ii) Precipitation:- YAK experiences much rain between 16(03) and 16(15). Snow fell at DIV and KASK and rain was recorded at WH around the same time. KL once again escapes.

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[109] At around 0300 on the 16th. at KASK low stratus began moving in from up glacier and shortly after 0600 snow began and the wind picked up. By 1230 visibility was $\frac{1}{2}$ a mile and very strong winds were blowing wet falling snow almost horizontally. At KL the met. tent blew down and DIV reported very high winds and snow.

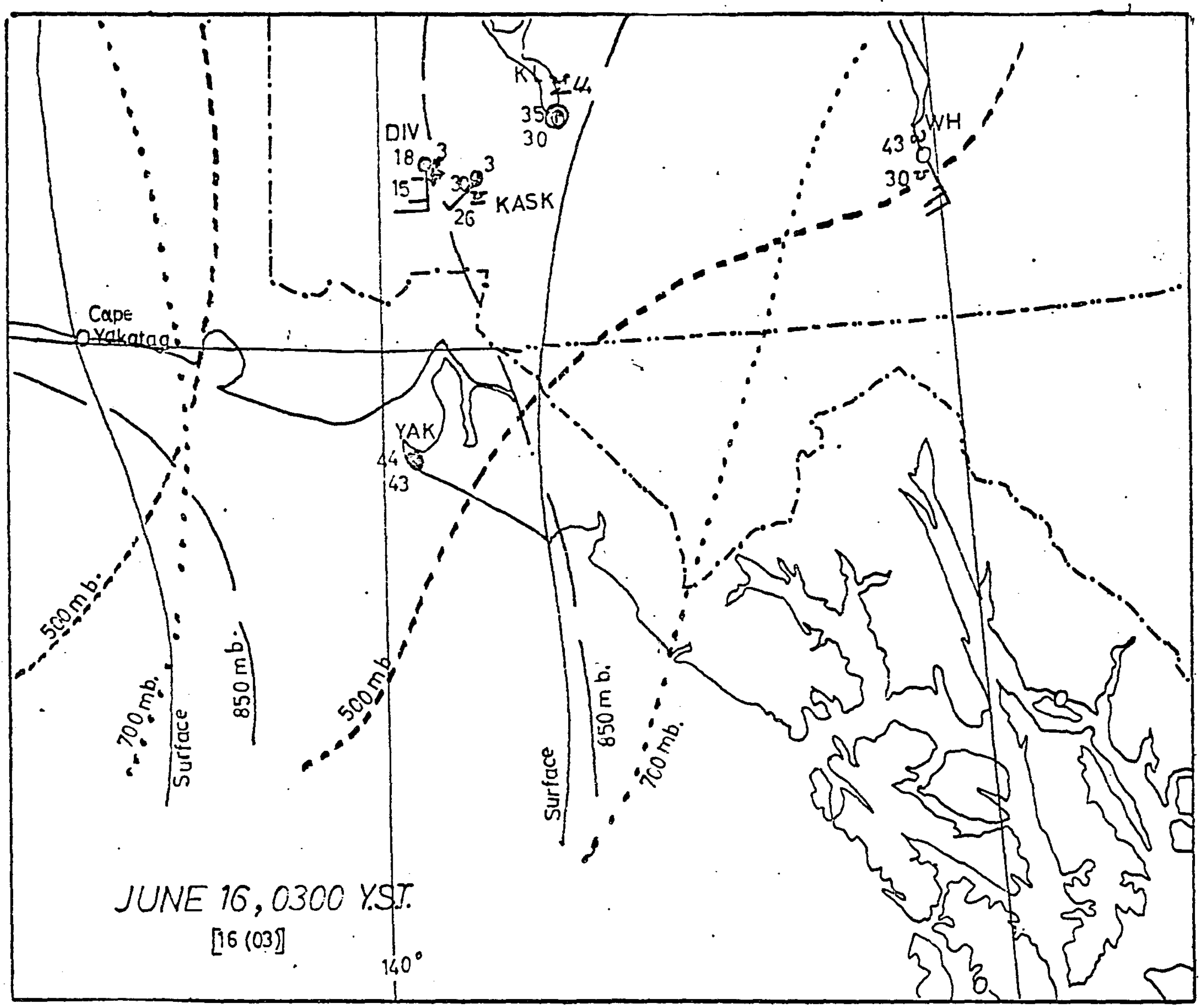

Figure 62. Surface isobars and upper contours over the study area, 16 June at 0300 Y.S.T. [16(03)]. See Figure 52 for legend.

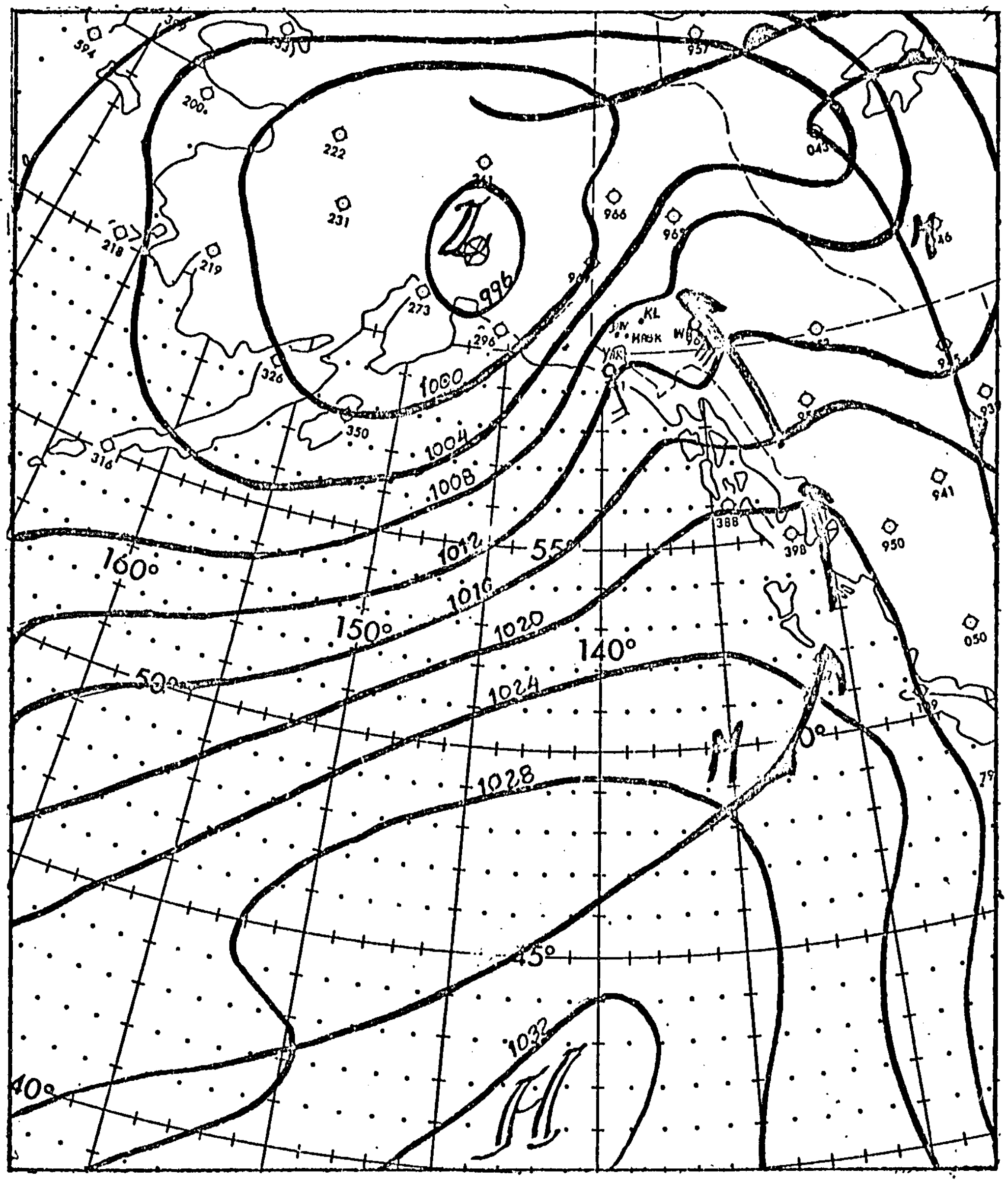

Figure 63a. Surface weather chart 16 June at 1500 Y.S.T. [16(15)]. (After C.A.O. analysis.)

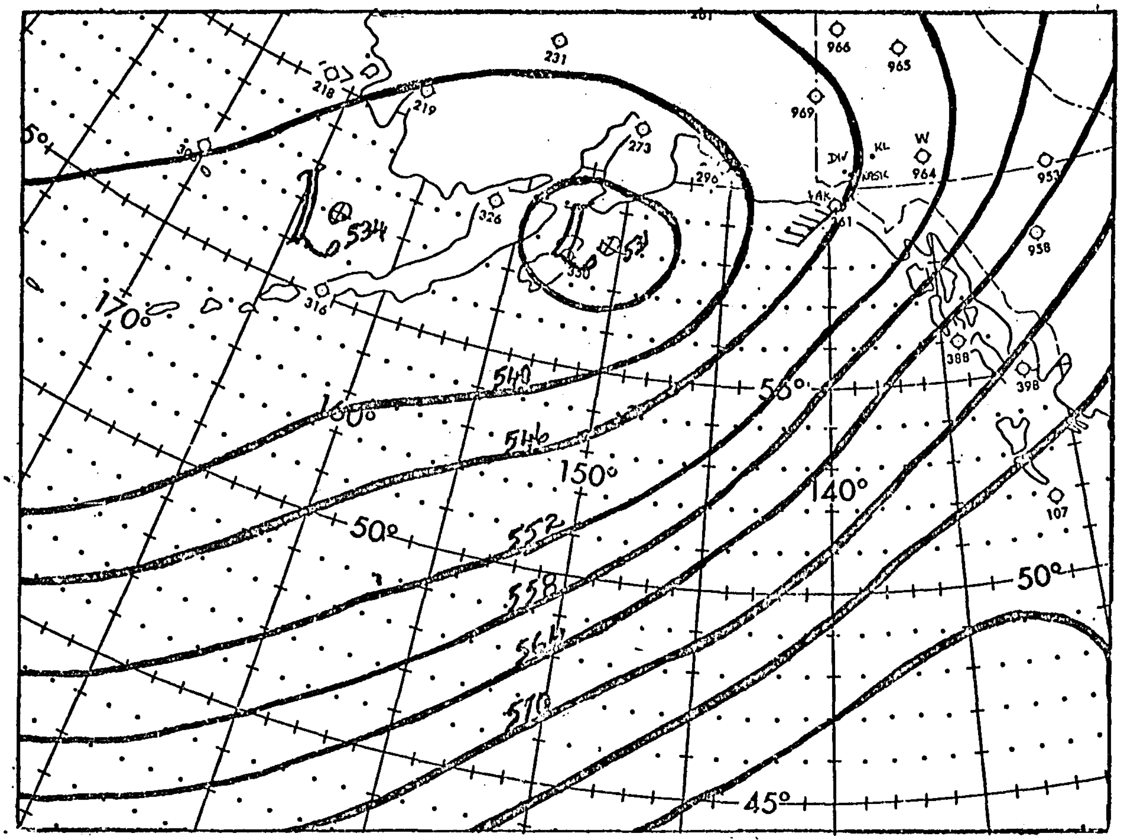

Figure 63b. 500 mb contours, 16 June at 1500 Y.S.T. [16(15)] .
(After C.A.O. analysis.)

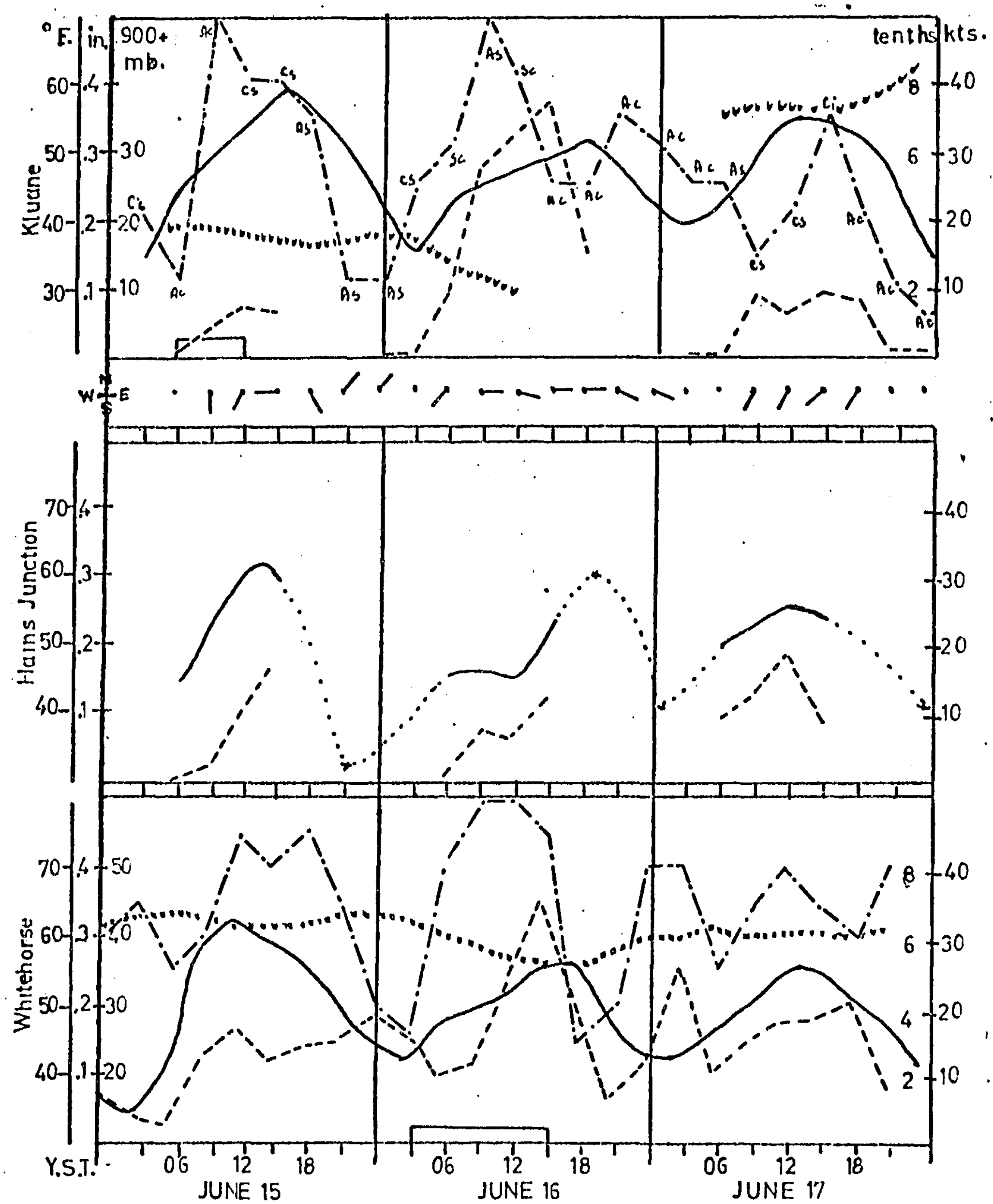

Figure 64. Continued on following page.

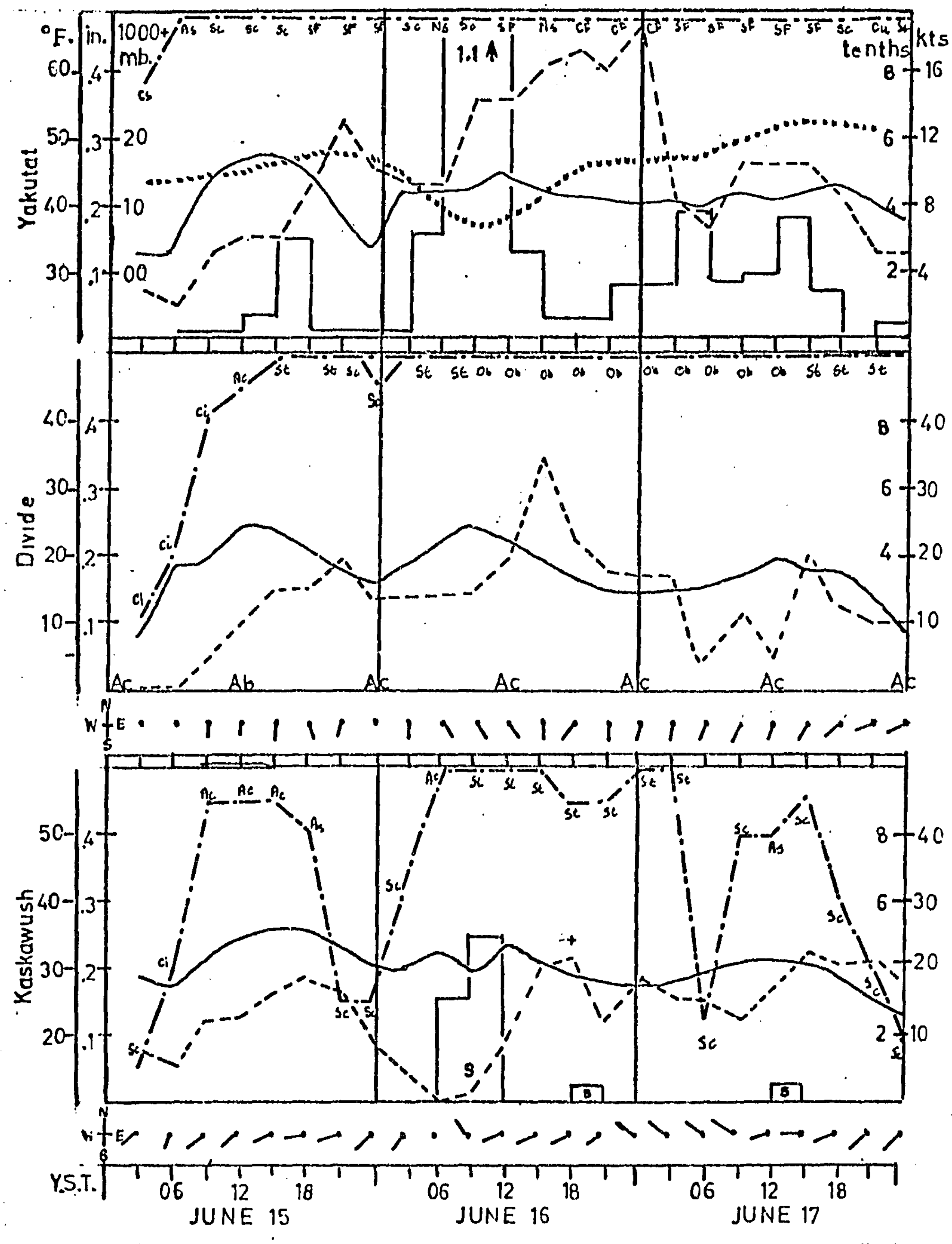

Figure 64 (continued). Three hourly surface synoptic parameters for period 2 (15 to 17 June). See Figure 52 for legend.

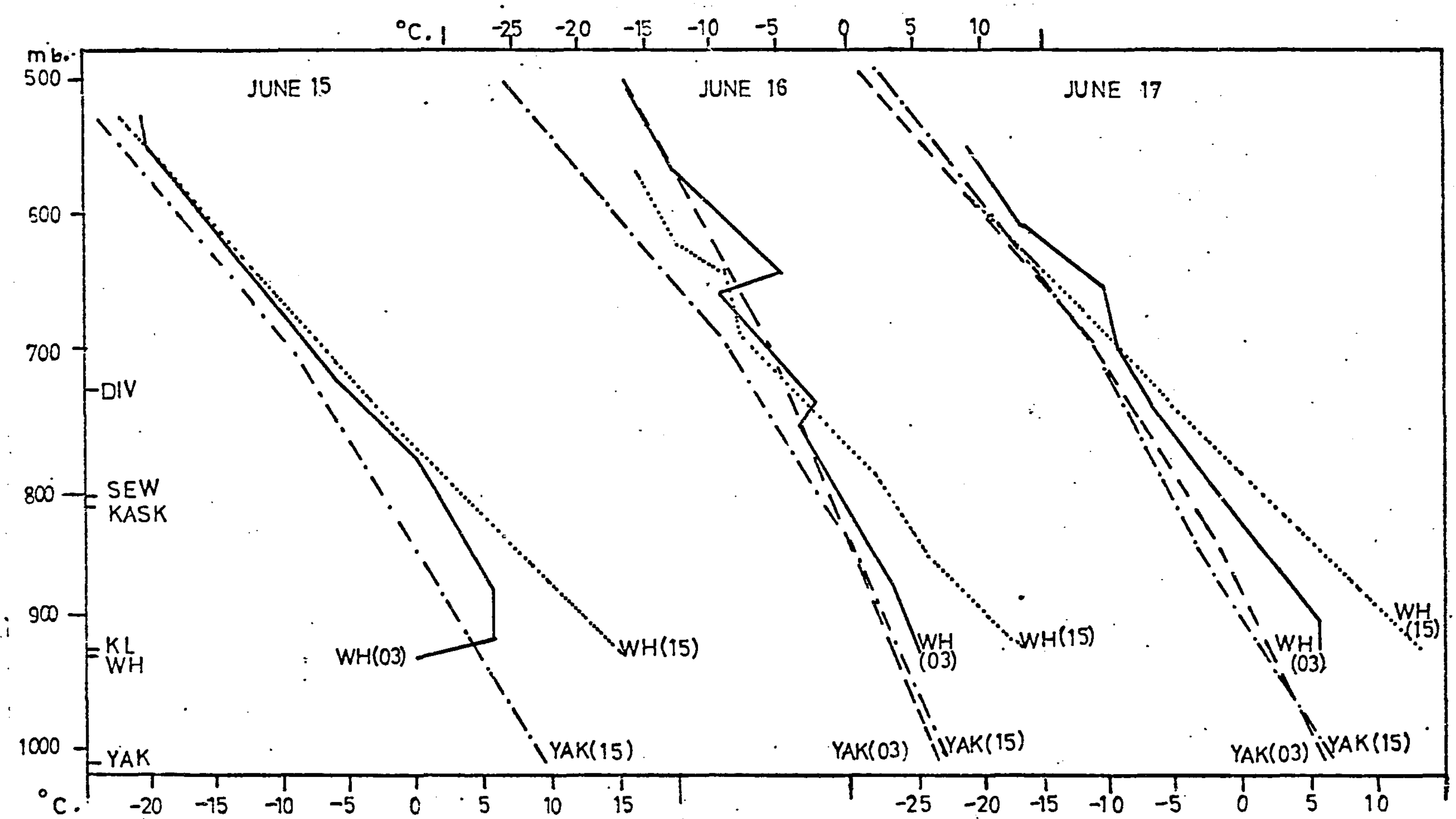

Figure 65. Radiosonde temperatures over Whitehorse and Yakutat, 15 to 17 June. See Figure 53 for legend. (N.B. For Yakutat only the 850, 700, and 500 mb levels were used.)

iii) Wind:- The interesting feature of this passage was, of course, the wind maxima. DIV, KASK, KL, and WH[110] all experienced their seasonal wind maximum at around 16(15).[111] Rather calm winds preceeded this maximum in all cases. (YAK has high winds during the period but they do not follow the same pattern - see Figure 64.)

iv) Cooling:- The temperature effects appear to have been felt, at the surface only, at DIV and KASK where the usual 1500 Y.S.T. maximum is suppressed.

v) Pressure:- At all stations a decided pressure drop was experienced. This occurred at YAK at 16(09-12), KASK at 16(12-15), KL still dropping at 16(12),[113] and at WH at 16(15-18).

vi) Upper winds:- The following should be noted about the upper winds during this period. At 16(03) the 500 mb geostrophic winds were 60 kts or less (actual winds over YAK - 40 kts.); the 700 mb geostrophic winds were 40 kts. (actual wind at this level over YAK 25 kts., over WH 20 kts.); and the 850 mb geostrophic winds were 40 kts. (actual over YAK 40 kts.). At 16(15) the situation was much the same. Compared to the other periods analysed these winds are not particularly strong.[114]

vii) Pressure configurations:- The surface isobars are very crowded and run parallel to the 500 mb flow over most of the IRRP area (see Figure 63a).

c) Overall Picture

The period was dominated by a strong, well supported, surface low with a trough on its S.E. side in which could be found (below 700 mb) a trowel. The N. end of the trowel remained imbedded in the low during its rather swift[115] passage over the area. Meanwhile the southern portion moved more slowly in front of the surface Pacific high.

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[110] SEW not in operation.

[111] Though on all graphs the peak comes at 16(15) the actual peaks were likely spread over the period 16(13) to 16(17) - see pressure.

[112] No pressure records were being kept at DIV at this time.

[113] Cessation of record - met. tent blew down.

[114] e.g., July 3(15) when geostrophic winds of 100 kts. at 500 mb (40 kts. at 700 mb) produced only 10 to 20 kt. winds on the icefields.

[115] Swift (see pressure drops - all between (12) and (18)) due possibly to the nature of the upper flow and the intensity of the system.

DIV and KASK temperatures suggest a cold front passage at about 16(03).[116] The passage of the trough was marked by a sharp pressure drop, very strong winds, and the cessation of precipitation at all stations. At KASK, KL, and WH decided clearing suggests that strong subsidence followed the trough passage. This may partially account for the fact that KL received no precipitation though it was affected by the record breaking winds.

The upper flow during this period was not especially strong but it was aligned with the very strong surface flow when the wind maximum occurred.

This system seems to have been virtually unaltered by its encounter with the St. Elias barrier due to its intensity and depth and the altitude at which the warm trough traversed the barrier (higher than other systems--as seen from the temperature record).

The period was definitely clear, cold, and windy though above average precipitation was received only at DIV and possibly KASK.[117]

3. PERIOD 3 - 7 TO 8 JULY (HOT WEATHER)[118]

a) Synoptic Situation

Date		Level		Situation
7(03)	-	surface	....	ridge - with small trough over WH
			....	low opposite British Columbia in Gulf
	-	500 mb	....	ridge slanting from Gulf into N. Yukon
			....	low over Annett

116 Suggesting the front did not extend much lower than 850 mb.

117 This may be due to its swift passage - i.e., not time to deposit much precip.

118 At SEW clear skies and almost no wind combined with intense reflection from the snow to produce very hot weather.

a) Synoptic Situation (cont'd)

Date		Level		Situation
7(15)	-	surface	....	ridge maintained
			....	trough from E. British Columbia to Juneau
	-	500 mb	....	ridge maintained
8(03)	-	surface	....	col over IRRP (see Figure 66a)
	-	500 mb	....	ridge centred over YAK (see Figure 66b)
8(15)	-	surface & 500 mb	....	little change

b) Surface Effects

Figures 67 and 68 give the march of the surface synoptic parameters and the radiosonde temperatures over YAK and WH for period 3. The following can be seen from these.

Skies are relatively clear (in comparison with 1 and 2 above) though afternoon peaks in the cloud curves occur at most stations.

Temperatures are high and diurnal ranges large.

Winds except at KASK are light and variable. Pressure curves reflect diurnal fluctuations.

c) Overall Picture

A system passing to the south of the area on the 7th resulted in Ci. cloud at the maritime stations. Convective activity was likely responsible for the afternoon cloud maxima at the continental slope stations.

Otherwise the slow moving conditions tended to suck warm air from the southern oceanic regions into the IRRP area and relatively clear skies caused strong diurnal heating (especially at KL and WH).

By the 8th YAK had begun to cloud over again resulting in a lowering of temperature and temperature range.

The period illustrates that when ridge and col conditions are given a chance to take over they produce high temperatures and temperature ranges, clear skies, and light winds. (In contrast to the results of ridge conditions overridden by the passage of an upper front

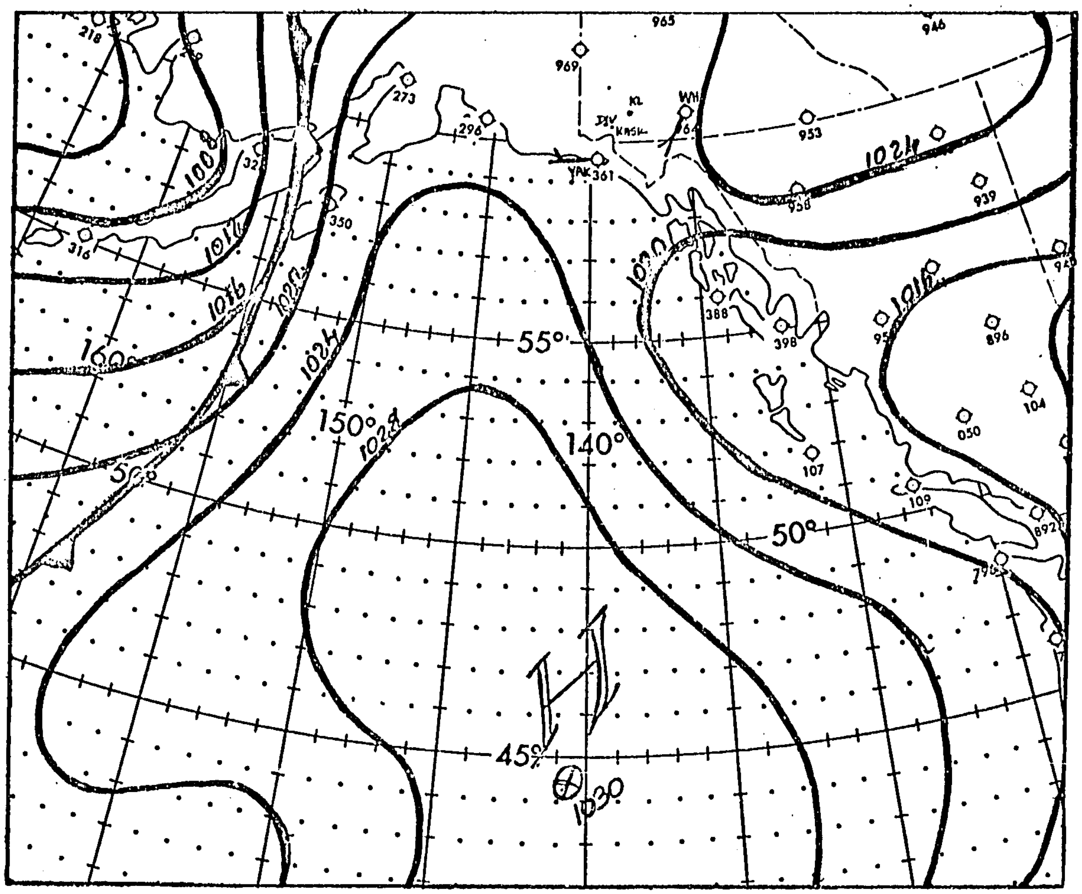

Figure 66a. Surface weather chart 8 July at 0300 Y.S.T. [8(03)] . (After C.A.O. analysis.)

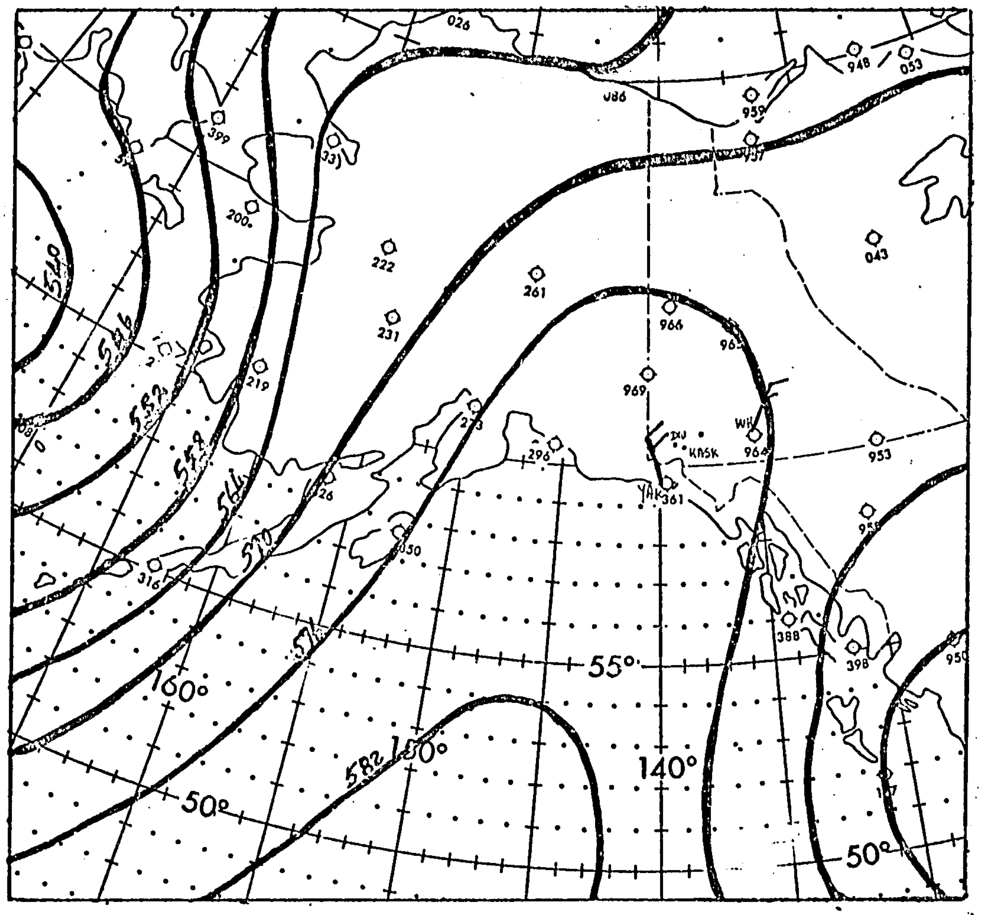

Figure 66b. 500 mb contours, 8 July at 0300 Y.S.T. [8(03)] . (After C.A.O. analysis.)

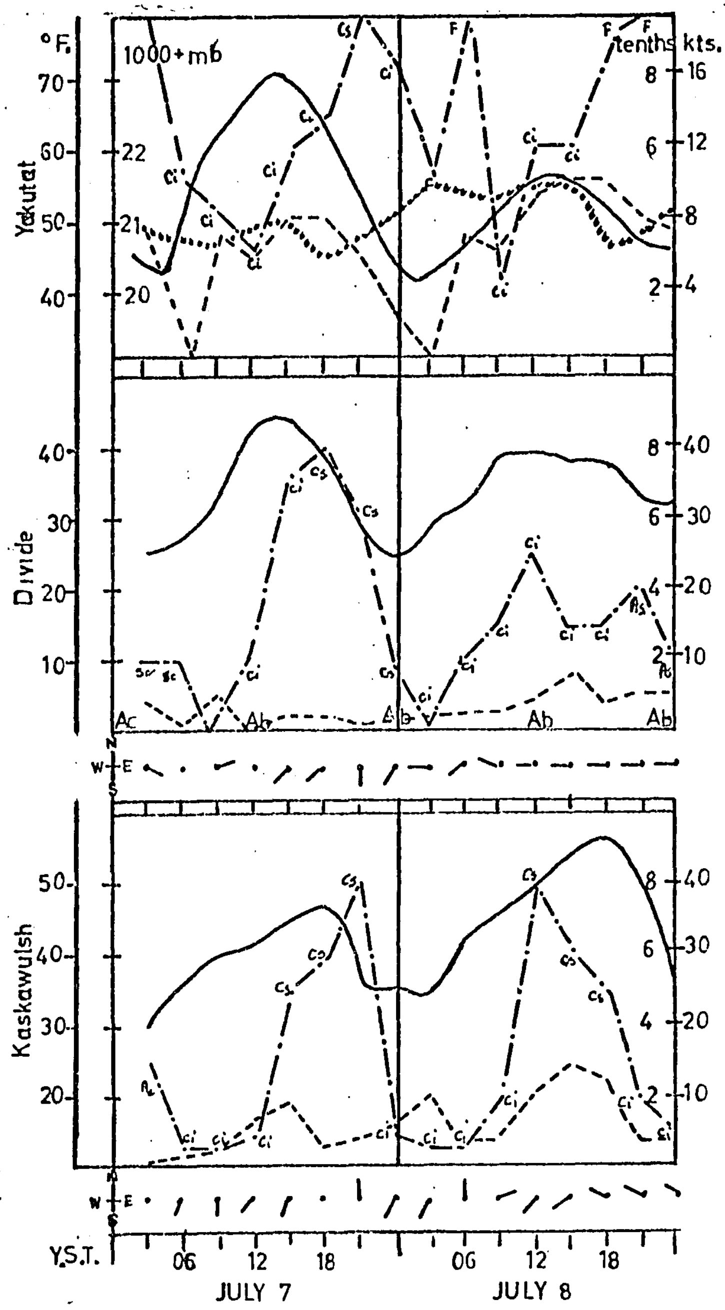

Figure 67. Continued on following page.

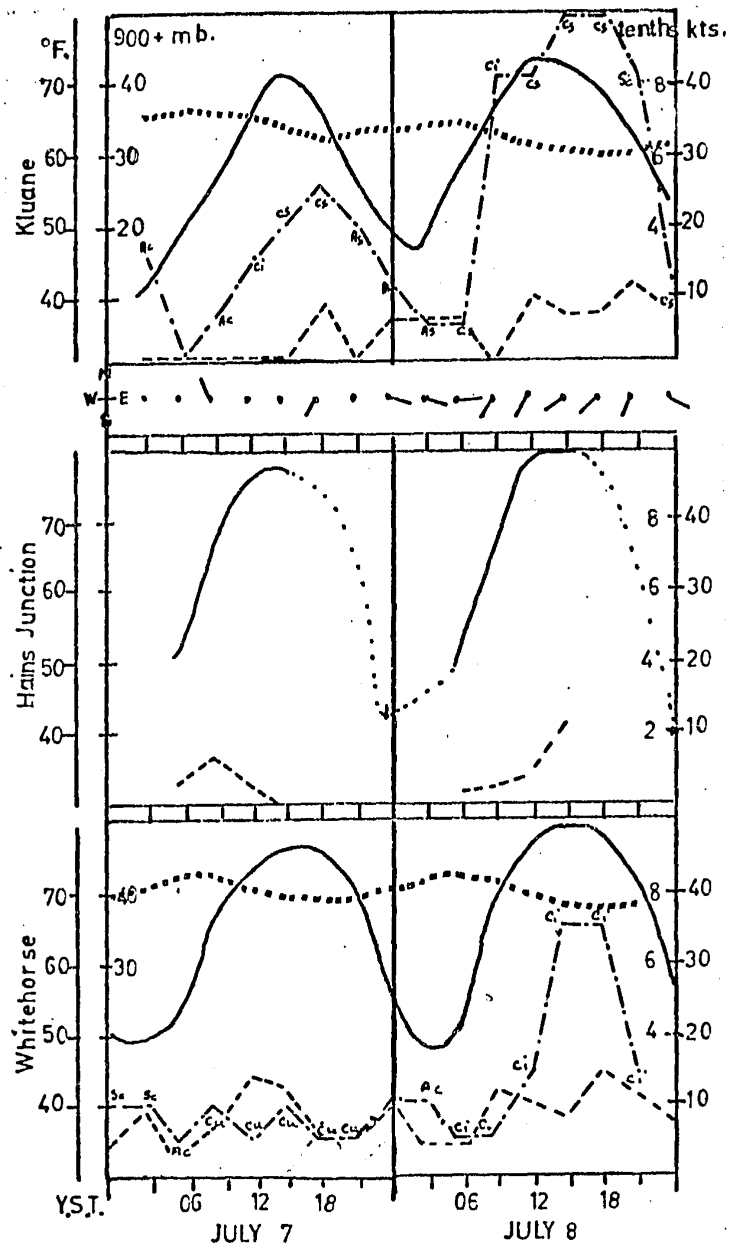

Figure 67 (continued). Three hourly surface synoptic parameters, period 3 (7 to 8 July). See Figure 52 for legend.

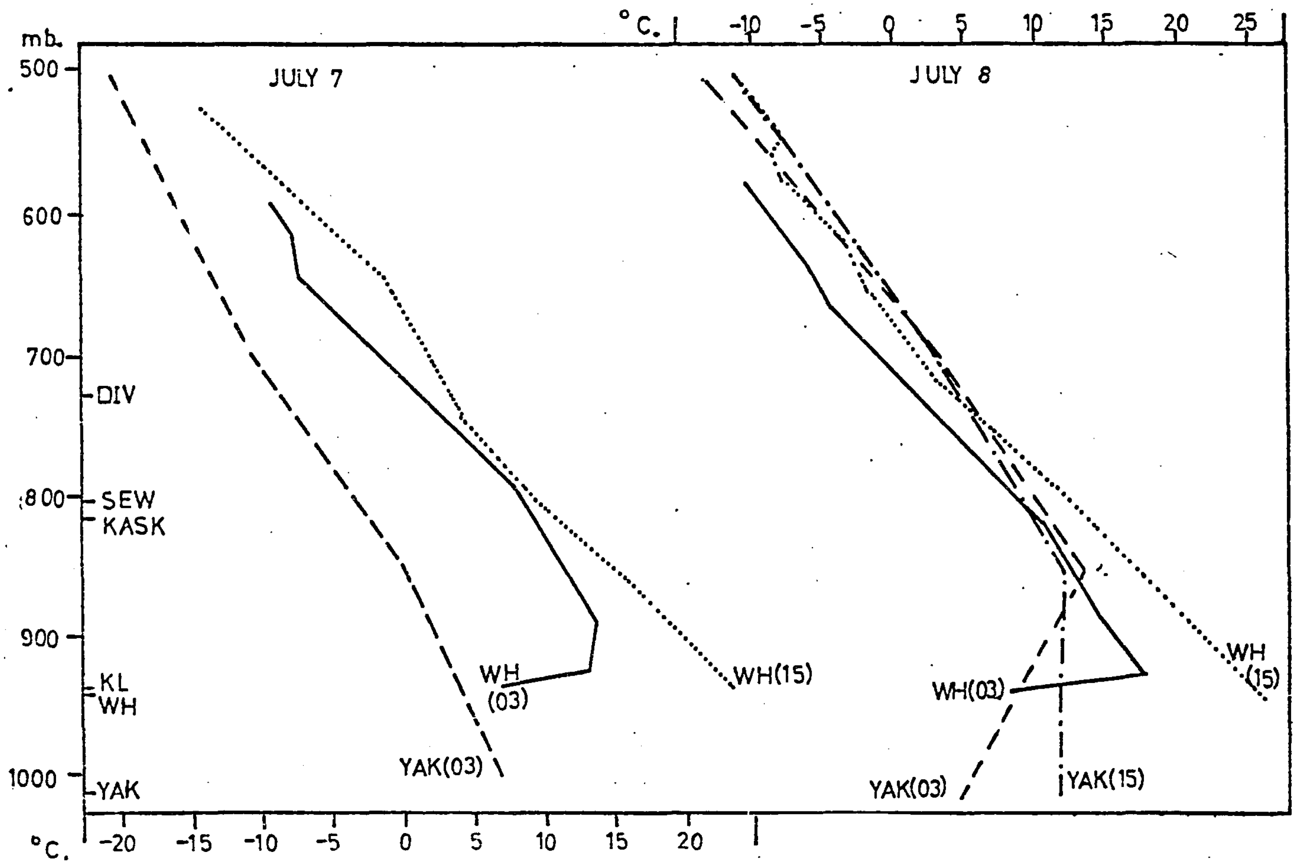

Figure 68. Radiosonde temperatures over Whitehorse and Yakutat, 7 to 8 July. See Figure 52 for legend. (N.B. For Yakutat only the 850, 700, and 500 mb levels were used.)

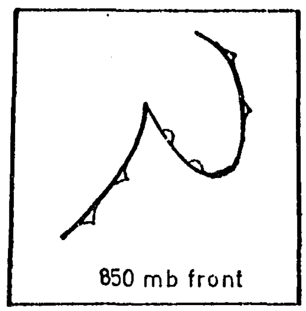

Figure 69. Shape of the 850 mb front which traversed the area during period 4 (2 to 4 July).

as seen in period 1)

4. SUMMARY OF OTHER PERIODS ANALYSED

a) Period 4 - 30 June to 4 July (Bad Weather)

In the wake of system 1 (above) another surface low came into the Gulf and the frontal systems associated with it once again traversed the area in a trough in the surface ridge. This time however the surface low may have reformed east of the mountains in the Yukon while the 500 mb low was deflected south along the coast.

At 850 mb an odd shaped front (see Figure 69) gave cooling at YAK and was followed by a warm front at about 700 mb. The latter was most strongly felt at KASK and appears to have traversed the area from N. to S. aligned perpendicular to the barrier. It was followed by an upper maritime cold front which showed signs of being held back in the lower levels as it crossed the mountains from S.W. to N.E.. Behind this was a diffuse upper Arctic cold front.

b) Period 5 - 17 July to 19 July (Bad Weather)

A surface low passing to the south of the area, accompanied by a 500 mb low in the Gulf, produced the rather uncommon phenomenon of flow from the N. and E..[119] Though no fronts were identified, considerable weather, likely largely orographically induced, accompanied this flow. The continental slope received the weather usually experienced by the marine slope during the cyclonic passage, while the marine slope was cooled little and appears to have been in somewhat of a rain shadow.

[119] See flow Ch. X.

c) Period 6 - 20 July to 21 July (Bad Weather)

The rather complex surface low system which followed 5 above had imbedded in it a surface Maritime (warm and cold) and Arctic (only cold evident) frontal system.

The Maritime system traversed the area from N. W. to S.E. initially aligned almost perpendicular to the mountains but becoming parallel to the longitudes before passing WH.

The Arctic front, on the other hand, approached parallel to the longitudes but traversed the area lying perpendicular to the mountains moving S.E. and giving most precipitation to SEW. The fronts seem to have maintained their identity throughout the passage.

d) Period 7 - 14 July - 15 July (Bad Weather)

A surface low with a trowel extending north of it went on the coast S. of the study area. At the 850 mb level a cold front preceeding the warm upper trough appears to have affected SEW, DIV and KASK at the surface.

There is less contact between the upper warm trough and the mountain barrier than in 1 and 4 and only a slight cooling was felt from YAK to KASK. Some precipitation along with fog and stratus cloud on the maritime slope resulted from the passage, likely at about 700 mb.

PART C

CHAPTER XII

CLIMATOLOGY

In Parts A and B the available meteorological data from the study area have been compiled, described, and manipulated. The purpose of Part C, which follows, is to assemble the salient facts emerging from this data. This will be accomplished by examining the climatological regimes and variations, the individual climatological parameters, the synoptic scale behavior, and finally the synoptic climatology of the area.

1. LOCAL CLIMATES

The geographic environments of the four manned IRRP stations differ greatly from one another though the distance between them is never more than 35 miles. These variations are of course reflected in the local climate of each station. For this reason the principal features of each station's climate will be put forth below.

a) Kluane (KL)

The temperature regime at KL is definitely continental, averaging around 50[120] degrees F. (10 degrees C.) with a daily range of

[120] Average mean daily temperature (1963 - 1965) was 51.7 degrees F.

approximately 20 degrees F.[121] During the three summers[122] the mercury rose to 78 degrees F. and descended to 28 degrees F. Relative humidity averaged in the low 60's.[123] There is little evidence of cooling caused by the proximity of the icefields.[124]

Generalizations concerning wind speed and direction conditions are difficult, possibly because of an ill defined mixing of local and synoptic scale influences. Winds are, however, comparatively light (average 4.0 kts.[125]) and tend to be S. and E. at night and S. W. by day.

The continentality of the station is reflected in the relatively low cloud amounts,[126] a predominance of middle and high cloud, and the presence of convective type cloud after midday.

KL, with a daily average precipitation of .90 mm. and a probability of rain on any one day of 34 percent, appears to receive less precipitation than does WH . This rather unexpected condition will be discussed in connection with the synoptic analysis (see Ch. XV sec. 2, a(v)). The precipitation falls mainly as rain though snow has been recorded in May and June.[127]

Due to the rather confused wind patterns at KL only the following uncertain generalizations can be made from wind direction - parameter

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[121] Average mean daily range (1963-65) was 10.5 degrees F.

[122] 1963, 1964 & 1965.

[123] Average relative humidity; June - 58%, July - 67% (1963 & 1965)

[124] Figure 35.

[125] 1963, 1964 & 1965.

[126] May, June, July & August (1963-65) average cloud amount 5.8/10. June & July (1963-65) average cloud amount 6.4/10.

[127] During the 3 years 1963-65.

relationships. S. and W. winds off the mountains tend to be warm and are accompanied by cloudy skies. Winds from the lake are cold, at times moist, and bring precipitation. Winds from the valleys, on the other hand, tend to import relatively less cloud and rain.

KL, then, has a well defined continental climate, ill defined wind patterns, and is in a precipitation shadow.

b) Kaskawulsh (KASK)

KASK, at an elevation of 5800 ft., has an average temperature around 40 degress F.[128] (ca. 40 degrees C.). The diurnal range is comparatively low (11.5 degrees F.[129]). The two summers have produced an extreme minimum of 14 degrees F. and an extreme maximum of 58 degrees F. Relative humidity averages in the low 80's. KASK Knoll and KASK Ice prove from the temperature and relative humidity records to be more and less continental respectively than KASK (Moraine).

Compared to the other IRRP stations synoptic wind patterns are very poorly represented at KASK. Strong thermally induced down glacier winds[131] exist a large percent of the time, the average speed being close to ten knots.[132] In addition the diurnal speed curve is quasi-sinusoidal and there is little evidence of diurnal direction variation. In 1965 calms were infrequent.[133]

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[128] Average mean daily temperature (1964 & 1965) 39.9 degrees F.
[129] Two year average 1964 and 1965
[131] See CH.XIV sec. 2b
[132] 1965 average wind speed 9.9 kts.
[133] This was not so however in 1964 - the reasons for this are discussed in Ch. VI sec. 2b.

Cloud cover at KASK appears to be somewhat decreased by thermally induced subsidence[134] though the average cover (6/10) is still relatively high for this latitude. Sc. clouds are the most common though Ci. and St. also contribute significantly.

Precipitation records at KASK are inadequate but the hydrological traverse data point to a daily average precipitation of ca.2.0 mm.[135] KASK lies below the firn limit. There seems to be a 50-50 chance of precipitation on any one day. Snow and rain have been recorded in all of the summer months.[136]

Wind direction relationships are as follows: The infrequent up glacier winds tend to be warm, moist, light, and bring less cloud and more precipitation than the predominant down glacier winds. High precipitation and cloud amounts appear to accompany winds from the mountains though data are rather sparse.

The most outstanding feature of the KASK climate appears to be the strong down glacier winds. In addition the temperature range is surprisingly low.

c) Divide (DIV)

DIV, at 8700 ft., is well above the climatological freezing level. Temperatures here average in the high 20's (F.) and vary about 15 degrees (F.) diurnally. The record high is 55 degrees F. while the low is 1 degree F.[137] Relative humidities are in the mid 80's. The

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[135] Pits 13 and 14 at 1.915 m. and 1,765 m. show 2.23 and 2.09 mm./day.

[136] June, July, and August

[137] Over 3 years, 1963-65

[134] See Ch. VI sec.1a

The differences between DIV, DIV Cache, and DIV Cairn B are elucidated elsewhere.[138]

Winds are surprisingly low at DIV, averaging only 4.9 kts.[137] DIV appears to be more influenced by the synoptic situation than the other stations though the large scale mountain - glacier configuration plays a role in determining the direction. There is a backing tendency in the day time. W. winds predominate over the three year period.[139]

Average cloudiness at DIV is 6.7 tenths or the same as the average at that latitude over the ocean. Skies tend to be almost clear or completely overcast. Orographic uplift is doubtless responsible for much of the overcast. St. is by far the most dominant cloud type, followed by Ci.

Once again the hydrological traverse data must be used to obtain a representative picture of the precipitation amounts. Pit 12 near DIV yielded a result of 4.5 mm. per day. To date[140] snow alone has been recorded in all summer months. The probability of snow on any one day is about 65 percent.

S. W. winds are generally the strongest except when cyclonic passages bring strong easterlies. Strong winds tend to be cold while light winds are accompanied by warm temperatures and clear skies. Southerlies tend to be warm and moist. Cloud comes mainly up the marine slope but also from the mountains. Precipitation, on the other hand, accompanies easterly cyclonically induced winds while wester-

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[137] Over 3 years, 1963-65

[138] See Ch. IV sec. 1a, and Ch. XIV sec. 1b.

[139] The summer months only are considered.

[140] 1963-65

lies drop least snow.

In Chapter XI (see Figures 49 & 50) it was noted that at DIV there was a close relationship between low pressure, cloud and wind maxima, and precipitation. This was not necessarily so at the other stations. Similarly high pressure was followed by low wind and cloud. This suggests that DIV best represents the synoptic scale situation.

c) Seward (SEW)

SEW, at 6100 ft. on the marine slope, has a temperature of 35.2 degrees F.[141] (ca. 2 degrees C.) with a mean daily range of 12.8 degrees F.[141] Temperatures here have been as high as 60 degrees F.[141] (the highest at the glacier stations) and only descended to 22 degrees F.[141] (also the highest). The relative humidity averages close to 90 percent.[142]

Perhaps the most outstanding feature of SEW's climate is the extremely low average wind speed of 2.6 kts.[141] During the day very light winds blow up the Seward Glacier while at night relatively stronger down slope winds originate to the N.E. on the slopes of Mount Vancouver. Calms are frequent. These observations point to a very locally controlled wind regime.

Cloudiness averages close to 8/10 and fog and completely overcast skies are frequent. St. is, of course, the dominant cloud type followed by As.

As at KASK both rain and snow have been recorded in all of the

[141] Two years of record, 1964 & 1965

[142] In 1965, 89%

summer months.[141] The probability of rain is the same as DIV (65%) but judging from the findings of the hydrological traverse SEW lies near the zone of maximum precipitation and should average about 5 mm. a day.[143]

Unfortunately, the 1965 record was so short that little can be said with certainty about the wind direction relationships. However it appears that downslope winds from the mountains to the N. and N.E. are warm, moist, and strong but tend to destroy cloud cover, while winds up the Seward-Malaspina and Seward glaciers are cool, light, and bring much cloud and precipitation.

SEW thus exhibits a maritime climate and has even lower wind speeds than those at DIV.

e) Mountain Margins

The climates of the mountain margins, as represented by YAK on the west and WH on the east, are discussed in Chapter III, sections 1 and 2. (see particularly the summaries).

2. YEARS

A brief comparison of the climate of the summer months in 1963, 1964, and 1965 follows.[144]

a) 1963

Generally the lowest temperatures were experienced in 1963

[141] Two years of record, 1964 & 1965

[143] See pits 3 & 4

[144] For temp. averages see Table XIVA, wind- Table XXIII, precip.- Table XXX and cloud amounts - Table XXVII.

though in August of that year the extreme maximum for the three summers occurred at YAK and WH.

Skies were cloudy and DIV received the most snow of the three years.

The predominance of W. winds at DIV suggests the majority of cyclonic systems passed well to the north of the area.

b) 1964

A very warm June was responsible for this year having the highest mean temperature as well as the highest mean maximum temperature. In addition the lowest wind speeds occurred in 1964.

The clearest skies of the three summers appear to have produced the most precipitation except at DIV. The wind pattern suggests disturbed conditions with cyclonic passages just to the south of the area.

c) 1965

Low minimum temperatures gave 1965 the largest diurnal range.

At DIV the wind directions appear to relate well to the large scale topography suggesting a rather random distribution of cyclonic tracks.

3. MONTHS

Several comments can be made about the relative climate of the three summer months.[144]

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[144] For temp. averages see Table XIVA, wind - Table XXIII, precip. - Table XXX and cloud amounts - Table XXVII.

a) June

As would be expected June is the coldest month, with the exception of the continental slopes in 1964.

Winds are strongest and most of the seasonal maxima were recorded in this month.

Where stratiform cloud dominates (i.e., SEW and DIV) precipitation is most plentiful in June. June and July share the cloud maxima.

b) July

Warm, moist cloudy conditions characterize July. Convective activity is greatest in July and August, producing most precipitation for the summer months at WH, KL, and KASK.

c) August

The greatest temperature ranges and lightest winds occur in August along with the convective precipitation.

4. DIURNAL VARIATIONS

The temperature maxima tend to be around 1500 Y.S.T. and the minima at 0300 Y.S.T.

Stations and months with high wind speeds (i.e., June and KASK) show quasi-sinusoidal diurnal wind speed curves with the maxima during the day. Otherwise these curves are decidedly irregular.

Cloud and precipitation maxima are early in the day. KASK and KL as might be expected have secondary maxima in the afternoon.

CHAPTER XIII

CLIMATOLOGICAL DIVIDE[145]

The extremely pronounced differences between the year round climate of YAK and WH discussed in Chapter III[146] prompted the following three questions.

1) Does a climatic divide exist?

2) If so, what is the nature of this divide?

3) Where is it to be found?

An attempt will now be made to answer these questions by considering the evidence offered by each of the synoptic parameters.

1. EVIDENCE

a) Temperature

i) On the basis of Figure 35 of summer mean temperatures for the three seasons and the discussion accompanying it, it is evident that YAK and SEW are under a maritime influence (in summer this means cool temperatures) while WH and KL are strongly heated (a summer effect of continentality).

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[145] When the Divide station is being referred to "DIV" will be used otherwise "divide" or "the divide" will refer to the climatological divide under consideration.

[146] e.g., Temp. ranges at YAK are 52% to 70% of those at WH; YAK receives over 10 times as much precip. as WH; YAK has a relative humidity of 84% and WH of 71% etc.

TERM does not exhibit as large a warming as KL and WH due to cool glacier winds. However there is little doubt that KASK moraine and KASK Knoll are subject to continental temperature influences.

The status of the various DIV stations is somewhat more difficult to determine on the basis of mean summer seasonal temperatures alone, at least until some quantitative evaluation is possible of the factors to be discussed in Chapter XIV section 1, c.

ii) Considering next diurnal temperature variations reference shall be made to Figure 38 of diurnal temperature march and Figures 36 and 37 depicting the mean and extreme maxima, minima, and ranges.

The temperature range considerations taken at face value would place the divide between KASK and TERM. However it will be shown (Chapter XIV section 1, b) that pronounced local moderating effects are present at KASK. The division again appears to lie between KASK and DIV.

iii) Figure 39 of atmospheric lapse rates (Chapter IV section 3) sheds some light on the nature of the temperature divide. That is, it does not extend much above 3,000 meters (ca. 10,000 ft.) where the temperature soundings above WH and YAK tend to merge.

iv) In addition it should be kept in mind that, despite the fact that a definite division may be made on the basis of average mean temperature and temperature range records, daily trends are the same at all stations (see Chapter IX Figures 49 and 50). As noted by Marcus (18) this rules out a strict "blockage of air mass, frontal systems, or both by the St. Elias massif."

b) Relative Humidity

Though there is a steady westward increase in relative humidity, the effects of the icefields[147] coupled with the inadequacy of relative humidity as a true indication of the moisture regime[148] prohibit the identification of a humidity divide.

c) Wind

Similarly winds are of little use as local effects play too great a role at all stations.

d) Cloud

Cloud cover amounts (see Table XXVII) increase gradually westward but exhibit no sharp change. However Table XXVIII of cloud frequencies show a decided difference between KASK and DIV, the former being much like KL and the latter closely resembling SEW.

Similarly SEW and DIV both exhibit a predominance of stratus cloud while at KASK, KL and WH cumuliform clouds predominate. The flow - cloud amount relationships (see Ch. X) show a definite similarity between the cloud regimes at SEW and DIV. In addition fog is far more frequent at DIV and SEW than at the continental slope stations.

e) Precipitation

From the results of the hydrological traverse it was seen that a

[147] See Ch. V sec 1.
[148] See Ch. III sec. 1.

radical difference in precipitation amounts exists between the approximate elevation of SEW on the marine slope and that of KASK on the continental slope.[149] For reasons of physics[150] the precipitation maximum[151] should occur on the windward slope at some altitude below the peak. It would not however be correct to interpret this maximum as being synonymous with the division between the two precipitation regimes.

On the other hand the fact that the probability of precipitation on any one day is the same at DIV as at SEW[152] suggests that precipitation at these stations is subject to the same controls. Flow - precipitation relationships are similar at DIV and SEW in contrast to KASK and KL.

In addition, Figure 48 of diurnal precipitation march indicates that afternoon convectivity is of significant importance in producing precipitation at KASK, KL and WH but not at DIV and SEW. This is further illustrated by the fact that KASK and KL receive most precipitation in July and August when thermally induced precipitation is at a maximum.

2. CONCLUSIONS

From the preceeding section the answer to the three questions[153] appear to be the following.

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[149] Pit 3 and pit 14 - see Table XXXI and Figure 47 - show a 3 to 1 ratio

[150] See Ch. VIII sec. 1e for reference and discussion.

[151] Considering an idealized infinitely long mountain range.

[152] DIV - 65.7%; SEW - 65.8%; YAK close at 72.8%: while on the continental slope WH - 43.0%; KL - 34.0%; and KASK - 47.6%.

[153] See page 110.

1) Yes. Temperature, cloud, and precipitation considerations definitely point to the existence of some form of climatological divide.

2) This does not, however, take the form of a blockage of air mass and frontal systems but is rather a complex modification of these or at least the surface effects of these systems.

The divide is not, of course, a simple line but rather a zone much like a synoptic front though likely much broader. The effectiveness of this divide appears to die out above 10, 000 ft. in the free atmosphere. (This is only just over 1, 000 ft. above DIV.)

3) All factors point to this divide lying between DIV and KASK on the eastern slope of the idealized mountain barrier (shown in Figure 1). This is only the mean position and it will be seen in Chapter XV that it oscilates back and forth, depending on the synoptic situation --much like a synoptic front.

CHAPTER XIV

CLIMATIC PARAMETERS

1. TEMPERATURE

a) Regimes

Throughout the discussion of temperature in Chapter IV it was obvious that the various IRRP stations were strongly affected by the degree to which they were ice or nunatak stations. Briefly the main indications of this were found in:[154]

i) The summer temperature averages -- nunatak stations despite greater elevations had higher temperatures.

ii) The average and extreme temperature ranges -- ice stations, except at KASK (see sec. b below) had greater ranges than their nunatak counterparts.

iii) The atmospheric lapse rates -- the DIV - YAK environmental lapse rate compared to that of DIV Cairn B - YAK showed decided nocturnal cooling at DIV.

iv) Station to station differences under various sky conditions--greatest under clear sky conditions.

v) Relative humidity -- KASK Knoll very low due to high temperature.

[154] Also noted in Marcus (18)

The causes of these phenomena vary, at least in magnitude, from station to station making it difficult to draw a sharp line between the two types of stations.

In addition it was shown in the foregoing chapter that another set of larger scale influences exist, creating two broader regimes -- the maritime and the continental.

The basic physical processes effective in producing both the local and large scale regimes are in many cases the same. (For instance, radiative heating of rock and continental surfaces contrasted with moderating influences of a fairly constant temperature water or ice surface.) As the large scale climatological divide has been located it would seem advisable to reconsider Figure 35 of three year mean temperature and free atmosphere temperature in an attempt to isolate the small scale influences.

In this figure, there being no obvious alternative, YAK was used as the starting point. However YAK is appreciably cooled in the summer by the adjacent cool ocean so a more accurate picture might be given by choosing the climatological divide as the reference level. That is, saying that at the divide the free atmosphere and actual temperatures correspond while west of it they are lower and to the east higher.

One problem arises in that the divide has not and likely cannot be pin-pointed. The situation is further complicated by the existence of three different stations in the vicinity of both DIV and KASK.

DIV Cairn B and KASK (moraine) were chosen as representative

DIV Cairn B due to its snow cover is not subject to the strong radiational heating experienced by the rock nunataks (i.e., KASK Knoll). It does, however, escape the cold-pool effect. KASK (moraine) is the middle of two extremes (KASK Ice and the very extreme nunatak station KASK Knoll) and is raised sufficiently above the glacier surface to be useful. Possibly the best reason for the choice of these stations is that the line joining their mean temperatures has a slope almost identical to that of the mean free atmosphere curve.

Thus raising the point half way -- in the horizontal -- between KASK and DIV Cairn B, so that it coincides with the height curve, produces the revised picture seen in Figure 70.

b) Various Stations' Regimes

From this figure and factors noted in Chapter IV it is now possible to make the following statements about the local temperature regimes of the various IRRP stations.

i) Seward (SEW):- The expected nunatak - ice station relationships (see a, above) are best illustrated at SEW where an impressive basin is created by a ring of lofty peaks. The effectiveness of this basin will be further illustrated in the discussion of wind speeds.

ii) Divide (DIV):- DIV Cairn B, as has already been pointed out, appears to be rather a good indicator of the ambient air temperature[155] as it rises above the cold layer but is not subject to undue radiational heating.

[155] DIV Cairn B falls exactly on the ambient air curve - this would not have been so had the Cairn B to KASK slope not been the same as that of the ambient air curve slope - thus it is of some significance.

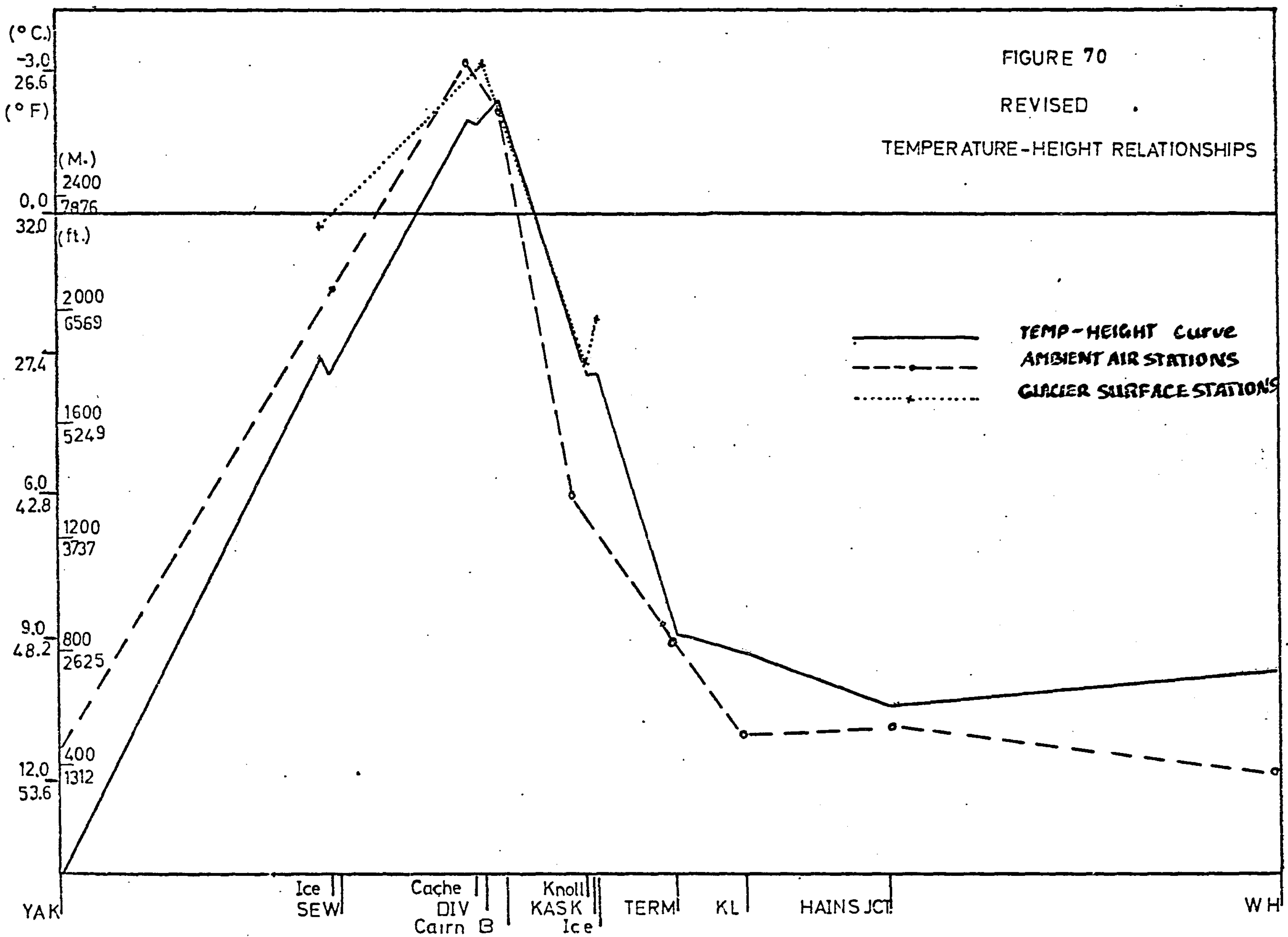
FIGURE 70
REVISED
TEMPERATURE-HEIGHT RELATIONSHIPS
TEMP-HEIGHT Curve
AMBIENT AIR STATIONS
GLACIER SURFACE STATIONS
(°C.)
-3.0
26.6
(°F)
0.0
32.0
27.4
6.0
42.8
9.0
48.2
12.0
53.6
(M.)
2400
7876
(ft.)
2000
6569
1600
5249
1200
3737
800
2625
400
1312
YAK
Ice
SEW
Cache
DIV
Cairn B
Knoll
KASK
Ice
TERM
KL
HAINS JCT
WH

117a

DIV Cache on the other hand appears to be somewhat heated by its rock surface but not to escape the katabatic cold layer.

DIV (ice) is undoubtedly subject to cooling from the cold-pool. However, as the ambient air or the free atmosphere here (i.e., at this elevation) is below freezing (see Figure 70), it is questionable as to how effective the snow surface is in cooling the air by convective and conductive processes.

iii) Kaskawulsh (KASK):- Figure 70 shows KASK Knoll as being even more strongly heated than KL or WH. In addition to the above mentioned factors effective in heating these and the nunatak stations (i.e., no cold-pool, low albedo, and distance from the ice surface) it may be assumed that:

1) Additional reflected radiation is received from the glacier below (not present at KL and WH).

2) The size of the snow free surface is large (compared to DIV and SEW).

3) This snow free surface is almost bare rock (in contrast to the treed slopes and vegetated valleys at KL and WH).

4) In all likelihood the station is above the effects of the cold down glacier winds -- and in any event sheltered from the very predominant W. and S.W. winds by the mountain rising to the S.S.W. of it (unlike KASK and KASK Ice).

Two other notable features of the KASK temperature regime are:

1) The range (both mean and extreme) at these stations is surprisingly low (see Figures 36 and 37 and Ch. IV sec. 2, a).

2) In contrast to DIV and SEW the range at KASK Ice is less than that at either KASK Knoll or KASK (moraine).[156]

Both these anomalies can be contributed to the same factors.[157] Namely:

1) During much of the summer season the KASK area is below the firn line. It is thus virtually water covered. (Streams are extremely numerous and melting so rapid that pools cover much of the surface.) In other words, water surfaces exert a greater moderating effect on the air temperature than do ice surfaces.

2) Constant, strong, down glacier winds do not allow temperature extremes to develop (i.e., nocturnal cold layer or radiative day time heating).

3) Air passing over KASK has likely experienced a longer trajectory over snow or ice than that at any other station (i.e., a cumulative moderating effect).

iv) Others:- Figure 70 shows that TERM is definitely cooled by the adjacent glacier or winds blowing off it.

KL and WH are heated to about the same degree as would be expected from the relative similarity of the surrounding terrain.

Too little is know by the author about the Hains Junction station to explain the relatively cool temperatures here.

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[156] Had it been only less than KASK Knoll the extreme continentality of this station may have been the explanation.

[157] Note Figure 37 shows it is KASK Ice which is low rather than the other two high.

c) Factors Determining the Temperature

It is now possible to list some of the factors of importance in determining the temperature regime of the stations in the study area. No definite statements can be made concerning their relative importance until a detailed quantitative study has been undertaken.[158]

1) The altitude of the station.
2) The radiative properties of the surface -- i.e., the albedo and black body temperature and effectiveness. (These are effective on both a large and small scale and achieve both heating and cooling. They are very important and have many manifestations.)[160]
3) The position of the station with respect to a topographically created basin.[161]
4) The direction and magnitude of the gradient between the surface and screen level temperatures.[162]
5) The wind conditions -- i.e., mixing and transport of cool or warm air.[163]

And on a broader scale:

6) The latitude of the station.
7) The general circulation patterns of the area.

---

[158] A start has been made on this in the form of a micro-meterological program.

[160] See temp. ranges, Ch. IV sec. 1; KASK Knoll, sec. 1b above; nunatak vs. ice stations, sec 1 above; continental vs. maritime, Ch. III and Ch. XII; etc.

[161] The importance of this is shown mainly at SEW and Cairn B.

[162] See KASK range and DIV, sec. 1b above.

[163] See KASK Knoll, TERM, and SEW basin- 1b above.

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[161] The importance of this is shown mainly at SEW and Cairn B.

[162] See KASK range and DIV, sec. 1b above.

[163] See KASK Knoll, TERM, and SEW basin- 1b above.

8) The behaviour over the area of synoptic systems -- i.e., fronts, lows, cols, etc.[164]

9) Finally, a complex interaction of all meteorological parameters (i.e., cloud and wind) doubtless has an effect though it is too complex to show up on a plot of daily means.

2. WIND

Possibly the two most outstanding facts revealed by the wind records are:

1) The low average speeds experienced at DIV and SEW.

2) The strong down glacier winds which are an almost constant feature at KASK.

Until a complete analysis of the upper winds over YAK, SEW, DIV, KASK and WH has been carried out, along with a study of thermodynamically induced winds in these regions, it is unlikely that these anomalies can be explained. Such investigations were beyond the scope of this study. It is hoped, however, that some light will be shed on the factors at work, in the following sections.

a) Low Average Speeds at DIV and SEW

First to reiterate the problem: The average wind speeds at DIV and SEW (5.9 and 2.7 kts. respectively) are appreciably lower than either; (1) the recorded upper winds, at the altitude of DIV, over YAK and WH (averaging 12.1 kts. at WH) or (2) the geostrophic winds at the

[164] To be discussed Ch. XV.

700 mb level (altitude of SEW). This is not merely a surface effect but extends to significant altitudes above the station.[166]

There are two seemingly obvious explanations for this. Whether they are sufficient is not known. Both relate to the large scale topography of the areas.

i) Divide (DIV):- DIV sits near the centre of two hundred square miles of open accumulation area. This relatively flat undulating plain is surrounded by towering peaks, especially to the S. and S. W. From the accumulation area several glaciers flow down to lower elevations (see Map 2 & Figure 3).

Thus:

(1) As the upper flow appears from the general circulation patterns (see Figures 6 & 7) and the analysis of 500 mb flow in 1964 and 1965 (see Ch. X) to be predominantly from the S. W., it is quite possible that the huge massif of Mount Logan (see Figure 3) blocks or deflects this flow. The flow would thus be diverted north or south around Logan, losing much of its "punch", or pass above it leaving DIV untouched. The predominance of W. and S. winds at DIV (see Figure 44) tend to support this theory.[167]

(2) Temperature considerations showed a tendency for

[166] Preliminary pibal data showed no significant increase in wind speed up to altitudes of five to ten thousand feet above both SEW and DIV.

[167] Map 2 shows that such deflected flow would eventually approach DIV from the S. or W.

the development of a cold-pool near the surface in area. This suggests stability in the lower levels. In addition this cold air must try to escape to lower elevations down the Kaskawulsh, Hubbard, and other glaciers, flowing from the accumulation area.

The result might be a small version of the much-sought-after but non-existent "Greenland Anticyclone". Light winds would thus be expected at DIV due to (a) its position near the centre of this and (b) the tendency of down glacier winds to counteract winds invading the area up the glacier outlets (i.e., the Kaskawulsh and Hubbard).

ii) Seward (SEW):- SEW lies in an even more impressive basin surrounded on all sides by twelve to nineteen thousand foot peaks (see Figure 5). The two outlets to the ocean (the Seward and Seward-Malaspina glaciers) are relatively narrow and ineffective (due partially to the height of the mountains bordering them) and only occasionally do west winds encroach up the Seward arm (see Figure 45).

Thus as at DIV:

(1) Prevailing flow passes either high above the secluded basin or reaches it by such indirect channels that it no longer has any appreciable speed.

(2) Thermodynamically induced down glacier flow counteracts these winds.

This leaves the Seward basin air to be moved by up and down slope effects (note - slope not glacier winds). All data at SEW points to a dominance of such diurnal wind systems.

b) High Winds at Kaskawulsh

It is likely necessary to exercise more caution when theorizing as to the causes of an unexpectedly strong wind than when dealing with the absence of expected velocities. This is especially true in very mountainous terrain where the complexity of the wind patterns and the influences on them are staggering. For this reason only the seeemingly obvious factors involved will be outlined below in the hope that they contribute to some extent to the predominant strong down glacier winds at KASK.

(1) Katabatic (gravity) winds -- i.e., winds resulting from nocturnal radiative surface cooling and a subsequent downward motion of the cooled air near the surface, and conversely day time surface heating and a subsequent progression up slope of the warmed air.

The latter can be disregarded here as the glacier surface is not heated appreciably. Down slope and down valley winds (the latter likely being more significant), however likely contribute to the nocturnal winds at KASK.

(2) Glacier winds are much like down valley winds, but the cooling is achieved by conduction of heat away from the overlying air to the cold ice surface. These are most significant during the day when the ice-to-air temperature difference is greatest.

At KASK, where temperature averages over 6 degrees F. above freezing, diurnal maxima average 12 degrees F. above freezing, and the mean minimum is 32.7 degrees F., glacier winds are presumably rather important.

(3) Due to the rather perfect channels formed by the steep mountains bordering the north and central arms of the Kaskawulsh Glacier and their confluence at KASK, some passive wind influences[168] are also present. The Venturi or funnelling effect is possibly the one most immediately suggested by the topography. Others more complex undoubtedly exist.

These decided channels are certainly responsible for the wind direction (possibly in combination with 1 and 2 above). In addition the position of the station relative to the two arms appears to be of significance to both speed and direction (compare 1964 and 1965 KASK wind records).

c) Cyclonic Systems

The table and discussion of maximum wind speeds leaves little doubt that cyclonic systems can to a considerable extent override the local effects. The degree to which this occurs naturally varies from

[168] Term used by Geiger and quoted in Watchman (32) to refer to effects on wind or flow by an obstacle or the topography - as opposed to thermal effects.

station to station, likely being greatest at DIV.

3. CLOUD

Cloud considerations show that cloud types and cloud amount frequencies are of more use in isolating the climate of a station than cloud amount averages. This suggests that cloud photography might yield useful results.[169]

4. PRECIPITATION

a) Problems

The errors inherent in precipitation measurements at glacier stations have been discussed elsewhere in detail.[170] It suffices to join many previous authors in noting that, as yet, no method of obtaining accurate precipitation measurements on a glacier has been found.

Probabilities (see Ch. VIII sec. 2) proved more useful than recorded total precipitation amounts and would have been even more so had it been possible to obtain three hourly rather than daily probabilities.[171]

b) Influences

The use of winter accumulation totals to discuss summer precipitation averages is perhaps not entirely justified. Nevertheless they

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[169] This was attempted during the 1966 field season.

[170] See Ch. VIII sec. 1.

[171] This was not possible due to the variety of observation times used over the years.

give some insight into the mechanisms at work producing precipitation over the glacier region. The following is a brief summary of these findings. (Reference should be made to Figure 47).

The accumulation amounts recorded at pits 1 to 15 are the result of three separate scales of influence.

The largest scale influence is the comparitively gradual rise in altitude from pit 1 to pit 9 and the subsequent drop to pit 15. This would ideally result in a distribution of accumulation having the form of the dashed curve in Figure 47.

On a smaller horizontal scale is the precipitation shadow caused by Mount Logan, represented by the dotted curve in Figure 47.

Finally the individual pit sites are influenced by the small scale local topography as in the case of pits 5 and 7.

KL and WH it was seen would fit well into an extension of the continental slope profile (Figure 47).

YAK, it has previously been noted (see Ch. III sec. 2, b), receives an unrepresentatively high amount of precipitation. However, the Juneau precipitation value of 3.8 mm. per day, for summer months, fits well into the maritine slope.

c) Other

Several other points which should be noted about precipitation are briefly:

i) The greatest precipitation is not always associated with the highest cloud amounts.

ii) The type of precipitation (i.e., falling from convective or stratiform cloud) is an integral part of a station's precipitation regime.

iii) Figure 50 of daily means of each parameter shows, as would be expected, precipitation tends to follow wind and cloud maxima especially at DIV and to a lesser degree at KASK.

iv) Precipitation records suggest the following about the IRRP station.

(a) DIV gives the best representation of the synoptic situation.

(b) KASK likely receives much of its precipitation and cloud from the DIV area so exhibits some of the same tendencies as DIV.

(c) SEW situated close to the zone of maximum precipitation likely receives much of its precipitation from orographic effects.

(d) KL on the other hand appears to be under somewhat different influences than the rest of the IRRP stations. (This will be discussed in the next chapter.)

No particularly startling discoveries have emerged from this study of the data obtained during the various field seasons, but it is hoped that the preceding discussion has shed some light on the summer climatic regime of the St. Elias mountains.

CHAPTER XV

SYNOPTIC SUMMARY

In Chapter XI three periods were examined in detail from a synoptic viewpoint and the results of similar analyses of four other periods presented briefly. Some aspects of the behaviour of these systems are tabulated in Table XL . No two of the seven systems examined were identical making generalizations difficult. However the discussion of synoptic effects which follows is at least applicable to the conditions during these seven periods.

1. EFFECTS OF THE MOUNTAIN BARRIER ON THE WEATHER

There is no doubt that the St. Elias range which lies almost perpendicular to the normal flow (see Ch. X) has a considerable effect on the area's climate. This has been well illustrated in the previous discussions (see Ch. XIII). The synoptic analysis suggests the following:

(a) The degree to which the area's weather is orographically induced is perhaps best illustrated by period 5 during which easterly flow (an uncommon phenomenon) produced, to the east of the barrier, all the effects normally associated with the marine slope (during a cyclonic passage) -- i.e., large amounts of cloud and precipitation and general cooling.

Further this period suggested the presence of a föhn or chinook effect on the marine slopes (from the fact that the YAK temperature was unusually high compared to WH). Also DIV appeared to behave as a windward slope station (i.e., classing it with KL and KASK).

(b) During the upper cold frontal passage of 1 and 4 there is definite evidence of stalling in the lower levels of the front due to its contact with the mountain ridge. (See Figure 59).

(c) The barrier seems to have had several different effects on the horizontal alignment and motion of the fronts and trowels. This depended on the direction of the flow and initial positioning of the front.

It appears (see 1, 4, and 6) that a front approaching the coast travelling perpendicular to it, unless well imbedded in a low system, will tend to be deflected N. or S. (depending on the upper flow) along the mountains before crossing and to be more or less aligned with them during passage. On the other hand, fronts initially travelling parallel to the barrier will be less affected as will fronts accompanying very strong systems.

(d) The repeated lack of clearing after cold frontal passage found on the marine slope suggests a sort of piling up effect, i.e., the barrier holds back a system; once it crosses, however, it moves on relatively quickly (allowing continental slope clearing). Meanwhile the next system is affecting the marine slope stations.

(e) Time and again KL escapes the temperature and precipitation effects of a trowel passage to a greater degree than even WH (see Table XL). In addition, though the high and middle cloud associated with these systems is reported at KL the low cloud is seldom present. Thus it appears KL lies in a decided weather shadow of the St. Elias. Three suggestions as to the mechanisms involved in this shadowing effect follow.

In some cases the weather crossing the barrier passes KL at upper levels only, but descends slowly (or reforms) so it is felt at the surface by WH.

On several occasions when KL escaped there was evidence that the frontal effects spilt down over the saddle, in which DIV is located, at least as far as KASK. This suggests that by the time KL is reached the cloud and precipitation have been destroyed by subsidence. There may also be present a real föhn or chinook effect but further investigation would be needed to verify this.

On a much smaller scale, it is likely that the large cold Kluane Lake produces some local clearing.

Briefly the weather from the Gulf as it crosses the barrier is (i) orographically lifted, (ii) possibly deflected and aligned, and/or (iii) stalled in the lower levels. Then it (iv) spills over the top and (v) either descends steeply to KL being partially destroyed by subsidence in the process or descends slowly (or reforms) being felt at the surface further to the east (i.e., WH).

2. BEHAVIOR OF FRONTS

(a) As noted above fronts are in some cases aligned with the barrier or stalled by it, in their lower levels. Cold fronts appear to have been most subject to these effects.

(b) It is evident that upper features (i.e., upper warm troughs) will become surface features during their passage over the mountains. As noted in Ch. II a satisfactory way of representing the synoptic situation over a mountainous area has not really been found.

It is possible to visualize and represent, by a combination of vertical and horizontal diagrams, the behaviour and modification of a frontal system crossing the barrier. However, to represent these happenings mathematically (i.e., for numerical prediction) is an extremely complex matter. Until this is achieved numerical forecasts will continue to misrepresent the conditions over a mountain barrier such as the St. Elias and for some distance down wind from it.

(c) It should be noted that only in the case of periods 6 and 2 did the frontal systems appear to maintain their identity completely during passage. In the first case surface fronts passed the area aligned perpendicular to the barrier, while in the second the surface low was very strong, fast moving, and well supported.

3. WINDS

Both the actual and geostrophic 700 and 500 mb winds at WH and YAK were frequently considerably greater than those recorded at the glacier stations. Nor do the highest winds at the IRRP stations correspond to the highest upper or geostrophic winds.[173] Once again the very local character of the stations' wind regimes is evident.

[173]See period 2 especially sec. b (iii) on winds.

However there does seem to be, on some occasions,[174] a fairly good relationship between the 500 mb flow and the surface wind direction at DIV. Generally, during the passage of a frontal system, DIV's direction agrees better with the surface flow.

Period 2 suggests that the strongest winds result when the 500 mb and surface configurations are not shallow but extend at least to the 500 mb level.

4. IMPORTANCE OF THE 850 AND 700 MB LEVELS

During the discussion in this and the eleventh chapter it has become obvious that the 700 and 850 levels play a significant role in the surface weather of the study area. Not only do upper frontal systems produce surface effects when they hit the ground (especially evident at DIV) but they also initiate considerable weather on either side of the mountains (i.e, YAK and WH).

From a synoptic point of view it appears that (for the IRRP glacier stations in particular) the 850 or even the 700 mb weather charts are a better representation of the situation than the rather fictitiously constructed sea-level charts.[175]

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[174] e.g., Period 1 sec. b (vii) on wind.

[175] See pressure and general circulation discussions Ch. II sec. 1 and 5

CHAPTER XVI

SYNOPTIC CLIMATOLOGY

The preceding chapters have examined the general circulation, climatological regimes, and characteristics of synoptic systems in the study area. Relating these facets of the study should facilitate the development of a composite picture of each summers' climate and speculation about the winter climate of the region. This will be attempted in sections 2 and 3 of the present chapter.[177]

1. SUNDRY SYNOPTIC CLIMATOLOGICAL CONSIDERATIONS

a) Tables XXXV and XXXVI of 1964 and 1965 flow and Figures 6 and 7 of surface and 500 mb mean pressure fields show that a good agreement exists between the most frequent flow,in these years, and the mean circulation patterns. The 500 mb flow suggests that (at least in 1964 and 1965) the Alaska ridge extends as far south as the study area (i.e., the 550 contour would resemble the 560 rather than the 570).

b) Figure 12 (discussed in Ch. II) shows that in summer the frequency of cyclone passages, across a longitude west of the study

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[177] See particularly Chs. II and X; Chs. XII, XIII, and XIV ; and Ch. XV.

area, varies little with latitude. The summer 1965 cyclonic tracks[176] show a scattered distribution of tracks and indicate (as noted by Mitchel 22) that many lows spin themselves to death in the Gulf.

c) Sea-level general circulation features were seen to be very shallow and the climatic divide appeared, from YAK and WH radiosonde temperatures, to die out around 10,000 ft. above m.s.l. (i.e., these phenomena extend at most a few thousand feet above DIV). There has been some indication that surface pressure systems can be lifted almost intact over the mountains (from periods 2 and 6 and DIV wind direction influence considerations). Thus the circulation features and climatic divide may in fact be deeper than indicated by data from the mountain margins (i.e., the surfaces of these may to some extent follow the topography).

The position of the divide under various synoptic situations varied - at times being E. of KASK (period 1) and at others W. of DIV (period 5). Thus its climatological position likely varies from year to year (though it is probably always between KASK and DIV), according to the characteristics of the circulation etc. in that year. In 1965, for example it was conceivably closer to DIV than in the other two years due to the more efficient blocking in this year (see 2c below).

d) Reed's suggestion (see Ch. II sec. 5) that the large trans-mountain pressure gradients are in fact discontinuities is interesting in view of the pronounced shadow in which KL is found. The results

[176] Plotted by the author but not included in this study.

of the present study definitely do not rule out the possibility of trans-mountain discontinuities in the moisture (i.e., cloud and precipitation) and wind (including pressure) fields. Temperature was seen however to undergo a modification rather than a strict blocking effect.

2. INVESTIGATIONS OF SEASONAL CLIMATIC VARIATIONS

Table XLI summarizes the flow - parameter relationships over the study area, and Table XLII reviews the yearly variations of the climatic parameters and circulation conditions. The following synoptic-climatological picture[179] of each summers' climate draws on these and other relationships emergent from the preceeding chapters of the study.

a) 1963

Though no flow analysis was carried out for 1963 and the records for this year are somewhat incomplete the following synoptic-climatological picture can be drawn from the DIV wind roses and the relationships discussed above.

The cyclone maximum north of the Aleutians appears to have been the most important one this year and the surface and upper ridges were likely further west than in the other years. Possibly the weak summer Arctic front[180] (usually found along the N. coast of Alaska - see legend of Figure 18) was displaced south this summer.

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[179] As these pictures are purely speculative they may well be incorrect in some aspects, however, they serve to show the feasibility of deducing the surface weather from the circulation or vice versa.

[180] The synoptic systems (1965) analysed in detail were accompanied by either Arctic or Maritime fronts (from the C.A.O. analysis) suggesting that the Polar (Pacific) front does not have much influence in the summer and systems are either Maritime from the south or Arctic from the north. The analysis is of course too limited to verify this but this concept will be assumed in the discussion that follows.

At any rate the area was under the influence of rather more northerly flow than was experienced in the following two years.

These circulation conditions caused the coldest summer seasonal temperature averages.[181] This agrees with the temperature - flow relationships - i.e., surface 2 and 3 and 500 mb 3 and 4 are the coldest. Not until August did temperatures reach the summer maximum. Relatively clear skies (resulting in increased radiative heating) and/or an increase in the importance or frequency of Maritime systems in the area (importing warm air from southern regions) were likely responsible for the warm August.

Precipitation was above normal in May, June and July consistent with the tendency of flow type 2 and 3 to have the highest probability of precipitation. The more northerly 500 mb flow likely resulted from a tendency for cyclones to invade the area from the north with the following consequences. (1) As seen from the WH mean precipitation, advection of Polar Basin air over the warm interior produces relatively large amounts of precipitation. (2) Fronts and systems would tend to travel parallel to the barrier resulting in a decrease in the effectiveness of the shadow (see period 6). KL received more precipitation in this year than in those that followed.

August, on the other hand, experienced a precipitation minimum and above normal wind speeds. This, along with the warm temperatures, suggests the dominance in August of a ridge at both

[181] Henceforth in this sec. the coldest etc. will refer to the coldest etc. of the summers of 1963, 1964 and 1965.

surface and upper levels (i.e., coinciding flow - strong;[182] import of warm air; and relatively clear skies). It also points to the possibility of passage of lows of type 2 (i.e., strong--high winds; fast moving--little precipitation; and Maritime--warm). The late temperature maximum may contribute to the low precipitation at YAK (i.e., ocean to air temperature gradient low--stability).

Above normal winter precipitation at WH may be partially explained by the above normal temperature. YAK's high late precipitation maximum may well result from the late temperature maximum (i.e., the ocean would have high temperatures late in the season).

b) 1964

The following picture of the circulation emerges from the flow analysis and DIV wind roses for 1964.

In June the area was influenced by the passage of lows both to the north and south.[183] By July however, surface lows, likely associated with the Maritime front and going on the coast south of the area (i.e., over British Columbia), dominated the circulation. The 500 mb flow suggests a similar situation in upper levels (i.e., more of flow type 1 which indicates a low in the southern Gulf).[184]

From the high number of east winds it would seem more lows managed to penetrate the barrier in 1964 than in 1965. The fronts

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[182] Prevailing (i.e., type 2) and coinciding flow both were seen to be related to high wind speeds.

[183] All of the type 4 flow (an increase of this noted in 1964) occurred in June. See wind roses - similar to July 1965. So both A. and M. fronts were important.

[184] Similar to the general circulation winter cyclone though likely further south.

(most frequently upper features) associated with these lows were likely pushed north by the 500 mb flow, as in system 4.[185] There may also have been situations similar to period 5, especially in August, when east winds produced orographic precipitation east of the mountains.

Temperatures were high due to the import of warm air from the south in the trowels etc. traversing the area and the general northerly position of the Maritime front.[180] Temperature-flow relationships show warm light winds come from the interior, agreeing with the situation in this year.[186]

Precipitation was generally high and likely largely associated with upper features as in periods 1 and 4. The especially high August precipitation at KL and WH suggest, as do the wind roses, the presence of situations similar to period 5 when orographic precipitation was produced east of the mountains. The above normal continental precipitation, experienced throughout the season, was likely a result of the tendency of fronts to travel parallel to the barrier (i.e., S.E. to N.W. - less blocking effect) and the increased convective cloud due to high temperatures.

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[180] The synoptic systems (1965) analysed in detail were accompanied by either Arctic or Maritime fronts (from the C.A.O. analysis) suggesting that the Polar (Pacific) front does not have much influence in the summer and systems are either Maritime from the south or Arctic from the north. The analysis is of course too limited to verify this but this concept will be assumed in the discussion that follows.

[185] Possibly the lows hitting to the south where the mountains are not quite so high.

[186] As these were calculated for 1965 - this is significant.

c) 1965

Flow in this year appears to have had the greatest frequency of ridge conditions at both surface and upper levels (see wind roses and flow analysis). This ridge likely was positioned (in the mean) east of the 1963 and 1964 positions,[187] the winds being almost equally deflected north and south of Mount Logan.

Plots of cyclone tracks[176] and the DIV wind roses suggest a rather more random distribution of cyclones (i.e., both N. and S. of DIV). In addition there appears to frequently have been a low sitting or dying in the Gulf without crossing the barrier (i.e., period 1). In general the 1965 circulation agrees best with the picture of mean general circulation presented in Chapter II.[188]

Temperatures are generally low at YAK, possibly as the result of a very high frequency of overcast skies due to the ever-present Gulf system and the piling up of systems west of the barrier (see synoptic analysis).

Continental temperatures are about average (WH having a cool spring and average July and August). Temperature ranges were large in 1965 due to the diversity of cyclonic types (i.e., neither those north or south dominated).

Precipitation at YAK was above normal[189] in accord with the

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176 Plotted by the author but not included in this study.

187 S.W. flow and a ridge to the E. of IRRP can result from a low dying in the Gulf.

188 Both the Arctic and Maritime fronts are frequent - summer fronts tend not to be well defined in the mean due to small temp. gradients.

189 YAK lowest for 3 years but other years very much above normal. Long term normals (WH - 1942-60 and YAK - 1931-60).

high average cloud cover (a result of the piling up of Gulf lows). WH precipitation on the other hand was below normal and KL received the least precipitation of the three years. Temperatures were average so convective activity was not as great as in 1964. The main reason for the low continental precipitation would seem to be that the fronts and cyclones approached the barrier travelling perpendicular to it (not from the north or south as in 1963 and 1964) and thus did not penetrate the interior as often as in the other years. The barrier was in other words more effective.

Winds were high due to the predominance of S. W. flow at both surface and upper levels;[190] systems not as shallow as in the other years. In addition it is possible that the tracking of more cyclones at the latitude of the study area contributed to the high winds.[192]

In general the summer of 1965 seems to have been most representative of the mean situation.[191] This is fortunate as most of the detailed analyses carried out (i.e., wind direction - parameter relationships) were for 1965.

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190 If you count all the occurences one square up or down from the diagonal in Tables XXXV and XXXVI (surface vs. 500 mb flow) you find in 1965, 70% of the total no. of occurences while in 1964 only 52%. Further if you group type 2 to 3, or 4 with type 2 (as the 1964 and 1965 analyses differ, see Ch. X sec. 2) then you find 83% in 1965 and 53% in 1965 so there is a significant difference.

191 The flow and cyclonic system situation compare best to the picture in Ch. II; YAK and WH recorded closest to normal precip., and YAK temp. low but WH close to normal. Winds were slightly high.

192 These lows not necessarily penetrating the area - but coming into the IRRP area rather than passing north or south.

3. EXTRAPOLATION TO WINTER CLIMATE

The present study has of necessity dwelt on the summer climate of the St. Elias region. In this section on the basis of the known differences between the summer and winter mean fields, summarized below, several inferences and questions concerning the winter climate (of the IRRP stations) will be put forth.

a) Known Differences

i) Circulation:- Rather than the relatively weak coinciding flow of summer the winter circulation is characterized by (1) strong gradients; (2) at the surface, a low in the Gulf and a high in the Mackenzie basin resulting in S.E. flow over the IRRP area; (3) at upper levels a warm W. Alaska ridge resulting in N.W. flow over the study area: and (4) a maximum of cyclonic passages south of the Aleutians roughly over the study region.

ii) Air masses:- While in summer most air masses are imported into the area, in winter the region west of the mountains (i.e., the Gulf) is a source of warm moisture laden mP air masses, and the region east of the barrier (i.e., Mackenzie basin) is a most important source of bitterly cold, dry, stable (strong surface inversion) cP air masses.

iii) Temperature:- As seen in Chapter II section 2 and Figure 8 the area in winter is characterized by extremely strong temperature gradients of the opposite sign to those in summer.

iv) Precipitation:- The precipitation gradient from the coast inland does not appear to change significantly in the winter (from summer). WH receives a greater percent of its winter precipitation as snow than does YAK.

v) Local topography:- Lake Kluane is frozen over and snow covered in winter. Most of the mountains (bare rock in summer) are also snow covered. The area is thus more uniform.

vi) Climate of the mountain margins:- The winter climates of YAK and WH were treated in Chapter III. Briefly:

(1) YAK is relatively warm, receives much snow and rain, is for the most part protected by the mountains from the cold Mackenzie high, is clearest in January and windiest in December and has prevailing S.E. winds.

(2) WH is extremely cold, has a high temperature range, receives small amounts of snow which drift extensively, is clearest in February and windiest in October and March, and occasionally experiences the passage of a low from the Gulf.

b) The Winter Climate of the IRRP Area -- Inferences and Questions

i) As the mean winter flow is up valley at the surface and down valley at upper levels it is presumably less affected by the mountains than its cross-valley summer counterpart.

ii) Due to the uniform snow surface, covering the glaciers, mountains and mountain margins, many of the large and small scale climatic differences will disappear or be decidedly reduced. In addition as the snow surface is no longer colder than the air above it the local thermal regimes will be altered, affecting other parameters (i.e., winds at KASK and SEW which were dependent on thermal differences).

iii) The mean circulation surface Gulf low (representing the high frequency of lows tracking into the area south of the Aleutians) indicates relatively few lows are able to penetrate the barrier though the frontal systems associated with them may cross as in period 1.

iv) The Mackenzie high is an extremely constant feature of the winter synoptic situation. No doubt it is partially responsible for the inability of the Gulf lows to penetrate the interior.

v) When systems do succeed in penetrating the barrier they bring warm wet conditions (as opposed to cold wet in summer). These systems likely behave somewhat as period 2 (i.e., they move swiftly, giving the expected cyclonic system effects and passing relatively unaltered by the mountains).

vi) As systems are cooled rather than warmed (as in summer) by passage over land possibly warm fronts show up better than cold fronts. (The opposite seemed to be the case in summer.)

vii) The strong reversed temperature gradients (in comparison to summer) no doubt have a considerable effect on the IRRP area. The nature of this effect is not immediately obvious (and likely will not be until winter meteorological records can be obtained for some of the IRRP stations). As the temperatures are caused and maintained by completely different circulation phenomena to the east and west of the mountains, and due to the strength and consistency of these circulation patterns it is quite possible that there is in winter a discontinuity (or sharp divide) in the temperature field over the St. Elias region. This pronounced blocking effect likely extends to the other synoptic parameters, excluding cloud. In fact, the winter weather charts are often characterized by a semi-permanent Arctic front in the study area.

viii) The winter surface circulation patterns are possibly even more shallow than the summer features. This suggests the glacier stations are more influenced by the 850 and 700 mb levels than they were in summer. On the other hand the stronger surface flow may dominate, at least part of the time, as in the case of period 2.

ix) As the upper flow is from the N. W. (down the valleys) the IRRP region may in effect sit between the two distinct regimes and receive its weather from the N. W. (i.e., central Alaska). In all probability however the marine or continental conditions from period to period encroach more or less over the mountains depending on their relative strength. As a climatological divide could be found in summer when the differences were not so extreme undoubtedly one exists in winter. It might not be the same position as the summer divide but topographic considerations would place it somewhere between KASK and DIV, though likely closer to DIV than in summer.[196]

[196] As the general motion is W. to E., and considering DIV as the top of a mountain, it is logical that weather from the W. encroaches at least up to the top of this mountain and likely somewhat over the top. In winter there is a strong system to the east of the mountain so weather likely does not get much over the top i.e., the climatic divide is closer to the topographical divide in winter.

x) While in summer the barrier exerts an orographic blocking influence on the air passing over it (i.e., raising it, extracting the precipitation, deflecting it, etc.) in winter it seems rather to be responsible for the maintainance of two distinct general circulation regimes and to discourage interaction between these. It is these two distinct regimes which in turn are responsible for the contrasting weather conditions to the east and west of the St. Elias Mountains.

xi) Two further questions are suggested by the present study about the winter climate (likely unanswerable until some winter data is available).

(1) Do the low DIV and SEW wind speeds persist into winter or are the stronger circulations able to overcome the basin and thermal effects.

(2) At KL in winter is as decided an orographic shadow in evidence or does the Mackenzie high dominate the whole area (giving the same weather at KL and WH -- not always the case in summer).

Due to the extreme transmountain gradients (or discontinuities) the winter climate of the study area would conceivably be even more interesting to investigate than the somewhat less extreme summer situation.

CHAPTER XVII

CONCLUSIONS

In this study the means, variations, and interrelationships of the various climatological parameters have been discussed from a number of viewpoints.[197] From these and the analysis of general circulation and specific synoptic situations a picture of the summer climate of the St. Elias Mountains region has been built up.[198] The three years used in the study appeared to be fairly representative of the normal conditions.[199]

1. THREE SCALES OF INFLUENCE

There is evidence that the area's climate is subject to three scales of influence. Consequently the most important manifestations of these influences as indicated by the climatological and synoptic analysis in this study will be discussed on these three scales -- (a) large or synoptic scale, (b) large scale local topography, and (c) small scale local topography.

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[197] i.e., Parameter by parameter, station by station, in regard to the climatological divide, etc.

[198] As these means etc. have been summarized etc. above they will not be resummarized. However, an attempt shall be made to outline the influences responsible for these conditions.

[199] Longer term means would likely differ somewhat numerically but the physical processes at work and the relations will not likely change significantly.

a) Synoptic or Large Scale

The study area extends from sea-level (YAK) on the Pacific coast across the extremely high extensively glacerized St. Elias Range and the lower Coastal Range to WH.[200]

Superimposed on the variation of temperature with height is a gradual eastward warming; from the cool coastal region to the heated interior. There is a possibility of a föhn effect west of the St. Elias Range. Temperatures were more closely related to surface than upper geostrophic flow.

DIV appears to best represent the synoptic scale winds. Wind directions here were more easily related to surface than upper flow. Wind speeds on the other hand appeared more related to 500 mb flow and surface synoptic period 1 suggested surface flow was the dominant factor in wind direction during a cyclonic passage but that the 500 mb situation controlled it before and after.

Cloud frequencies and types showed two definite regimes (one on either side of the barrier) and cloud amounts appeared to relate better to upper than surface geostrophic flow.

The transmountain precipitation profile and the position of the precipitation maximum agrees reasonably well with Walker's (31) theoretical model (for an ideal mountain range). Precipitation probabilities exhibit once again the existence of two distinct regimes.

The St. Elias barrier was seen to have a considerable effect

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[200] See Map 2 and Figure 1.

on synoptic systems invading the area.

KL, it was seen experiences a greater shadow than WH.[201]

In short, a climatological, and to some extent a synoptic, divide can be found between DIV and KASK. This position is physically reasonable if the YAK to WH crossection (see Figure 1) is considered to be a simple solid mountain range with the DIV accumulation area as the effective ridge -- i.e., the weather is carried up the windward slope[202] spills some distance over the top but generally leaves the continental slope in a decided shadow.

Conditions over the high glacierized region appeared at times to be a direct result of the 850 or 700 mb level situation (i.e., during a trowel passage) while at other times the sea-level geostrophic flow seemed to be more significant (i.e., periods 2 and 5). Presumably then the depth of the surface features at any particular time largely determines the relative importance of sea-level and upper flow to the glacier stations weather.

b) Large Scale Local Topography

The large scale topography (i.e, the mountain - glacier or mountain - valley distribution) in the vicinity of each IRRP station is responsible for many of the station to station differences and two interesting wind anomalies discussed in this study (see Ch. XIV).

Temperature was likely least subject to this scale influence. However Lake Kluane and the valley-mountain configuration in the

[201] See particularly precipitation, cloud and synoptic analysis.
[202] Lo.sing much of its moisture.

area appear to have had some influence on KL temperatures. At KASK due mainly to the nature of the wind regime temperatures could be related to large scale local topography.[203]

There is no doubt that the wind regime is most strongly influenced by topography on this scale. KASK presents an extreme example of a topographically controlled wind regime -- both speed and direction resulting from the channelling effect of the mountains bordering the north and central arms of the Kaskawulsh glacier and the air to glacier temperature difference.

Similarly the surprisingly low wind speeds at SEW and DIV result from their position in a topographic bowl and a thermally produced miniature anticyclone effect. At DIV in 1965 wind directions relate well to the distribution of mountains and glaciers around the accummulation area. SEW's wind directions are definitely locally induced.

Cloud is only slightly influenced by the large scale local distribution of snow and bare rock surfaces (i.e., convective clouds over mountains and dissipating power of cold glacier surfaces).

The transmountain profile of precipitation illustrates the precipitation shadow produced by the presence of a mountain the size of Logan in the path of the prevailing flow. It would be interesting to chart the horizontal extent of the precipitation and wind shadow caused by mountain massifs such as Logan, St. Elias, and Cook.

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[203] Similar relationships exist at DIV and SEW but these were not as well developed.

c) Small Scale Topography

It was seen that the presence of a relatively small amount of bare rock in the vicinity of a temperature recording station or the elevation of that station above the glacier surface can have a considerable effect on the temperatures recorded. SEW Ice and KASK Knoll proved to be rather extreme examples of ice and nunatak stations, respectively.

Pits downwind of relatively small obstructions (i.e., snow ridges) showed significantly less accumulation. Thus wind and precipitation regimes can also be influenced by small scale topography.[204]

d) Most Important Processes

Though the climatic influences can be separated into the three scales discussed above it should be remembered that the same physical processes are effective on all scales.

This study indicates that for the area under consideration the two major processes are:

(1) Radiative heating and cooling -- e.g., responsible for (a) continental summer heating which in turn results in convective cloud and precipitation etc., (b) mountain to glacier temperature differences which in turn influence the wind and temperature regimes, and (c) nunatak to ice station temperature

[204] No wind records on this scale. However the KASK 1964 to 1965 difference seemed to be attributable to the different position. In addition the existence of precip. shadows suggests the existence of of a wind shadow also.

differences.

(2) Orographic effects -- e.g., large middle and small scale wind and precipitation shadows (i.e., cyclonic systems produce precipitation but where and how much is orographically determined).

Sensible and latent heat transfer effects were also observed but are not particularly important on a climatological scale (though of vital importance in micro-meteorology and related ablation studies).

2. OTHER FACTORS EMERGING FROM THE STUDY

The study clearly points out the necessity of exercising great care in the choice and analysis of data in an area such as this to insure the records used are representative of the regime being investigated -- e.g., (a) ablation studies must use ice surface temperatures, (b) air mass identification on the other hand should use nunatak or higher (altitude) temperatures, (c) local influences must be subtracted from wind data if they are to be used in synoptic analysis (and vice versa) and (d) all scales of topography must be taken into account in evaluating accumulation amounts.

The network of stations maintained by IRRP appears to be reasonably diversified and is quite suitable for a detailed synoptical climatological study. That they can be treated as a profile of a mountain range with DIV situated near the top is also useful to such a study.

As orographic and non-adiabatic processes were found to be of prime importance in the study area it is not surprising that normal forecast methods when applied to this region fail rather badly. This will remain the case until some satisfactory way is found to include these effects in the forecasts (either numerically or subjectively).

A systematic analysis of the relative importance, to the surface weather, of the standard pressure level configurations (i.e., sea-level, 850, 700 and 500 mb) under various synoptic conditions would doubtless shed some light on this problem.

Considerations of winter climate suggest that in this season the two distinct general circulation pattern (the maintainance of which is likely largely due to the St. Elias barrier) may result in a sharp divide or discontinuity in the synoptic parameter fields (except cloud). However winter and summer general circulation conditions differ so greatly from each other that little can be said with certainty about the glacier stations' winter climate on the basis of summer data only.

3. SUGGESTIONS FOR FUTURE RESEARCH

The results of this study suggest the following course of action for the IRRP meteorological program.

a) The collection of regular synoptic parameter records should be continued with improved accuracy, continuity, and processing methods.

b) An effective way of measuring precipitation amounts in a high elevation, glacierized region, must be sought.

c) Regular soundings of temperature, humidity, and wind of at least the first few thousand feet above all IRRP stations should be initiated and utilized.

d) Temperature humidity and wind at two levels near the surface (i.e., 30 and 90 cm.) should be recorded along with the screen level synoptic parameters and a sufficient ablation net maintained in the vicinity of each glacier station at least.

e) For the present it would seem most advisable to improve the quality and quantity of records from the stations already established rather than spreading the resources available out over more stations.

f) Use should be made of the surface, 850, 700, and 500 mb synoptic charts (for all summer seasons during which sufficiently complete records were kept at the IRRP stations) as well as the YAK and WH synoptic and upper air data (for these periods).

The implementation of a) to f) above (all of which are within the scope of a project such as IRRP) would facilitate a study along the following lines.

i) Continued processing and analysis of climatological parameter data to obtain reliable means and averages.

ii) Quantitative analysis of the factors determining the climate of the area (i.e., the three scales of influence etc.) and the relation of these (especially the small scale factors) to the mass budget of the glaciers involved.

iii) a systematic (possibly statistical) analysis on a synoptic climatological level of each season. (i.e., What are the surface effects of the typical synoptic situations in the area).

Inter-relating i) to iii) above could yield a method of estimating the health of a glacier (or glacier complex) -- previously studied in detail but no longer having daily meteorological or ablation records -- from the synoptic conditions of the preceeding budget year.

Finally a whole new fascinating set of problems could be investigated were it possible to establish a manned or automatic station on the glacier (preferably in the area of DIV) during the winter season.

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APPENDIX

TABLES I - XLII

TABLE I

SPECIFICATIONS OF LONG VALLEY GLACIERS, ST. ELIAS MOUNTAINS[a]

NAME	DRAINAGE	DIRECTION OF FLOW	LENGTH	ELEVATION OF TERMINUS
Kaskawulsh	Kaskawulsh and Slims Rivers	E.	ca. 40 mi.	below 3000 ft.
Hubbard	Disenchantment Bay	S.	ca. 65-75 mi.	tidal
Walsh	Copper River	W.	ca. 60 mi.	....
Donjek	Donjeck to Yukon River	N.E.	ca. 35 mi.	below 4000 ft.
Kluane	Donjek to Yukon River	N.E.	ca. 19-30 mi.	below 4000 ft.
Seward - Malaspina	Yakutat Bay Pacific Ocean Icy Bay	(from Seward Glacier Accumulation) S.W.	ca. 70 mi.	below 250 ft.

a) From Field (7 p. 2a.2.16)

TABLE II

MANNED WEATHER STATIONS ST.ELIAS MOUNTAINS (1963-1965)

STATION	LATITUDE	LONGITUDE	ELEV. in FT.	FIRST RECORD	TYPE OF SURFACE [a]
KLUANE (Base Camp)	61°02'N	138°25'W	2,580	5 June 1963	Gravel
DIVIDE					
Glacier Central	60°45'N	139°36'W	8,485	1 July 1963	Snow
Divide '63	60°46'N	139°40'W	8,659	19 June 1963	
Divide '64	60°47'N	139°40'W	8,650	10 June 1964	
Divide '65	60°45'N	139°40'W	8,760	4 June 1965	
KASKAWULSH	60°44'N	139°08'W	c 5,800	4 July 1964	Thin moraine overlaying ice
SEWARD	60°20'N	139°55'W	c 6,100	18 June 1964	Rock ridge c. 50 ft. from nearest snow

a) Further details concerning position of station can be found in Marcus, Rens and Taylor (20).

TABLE III

AUTOMATIC WEATHER STATIONS ST. ELIAS MOUNTAINS (1963-1965)

STATION	LATITUDE	LONGITUDE	ELEV. in FT.	FIRST RECORD	TYPE OF SURFACE [a]
DIVIDE CACHE	60°46'N	139°42'W	8,774	13 June 1964	small rock nunatak 10 ft. to snow
DIVIDE CAIRN B	60°46'N	139°38'W	8,994	13 July 1964	snow ridge
KASKAWULSH ICE	60°43'N	139°08'W	c 5,800	7 July 1965	variable snow to ice
KASKAWULSH KNOLL	60°44'N	139°09'W	c 6,000	25 June 1965	tundra
SEWARD ICE	60°20'N	139°56'W	c 5,850	6 July 1964	snow
TERMINUS	60°49'N	138°38'W	c 2,709	15 July 1963	gravel

a) Further details concerning the position of the stations available in Marcus, Rens and Taylor (20).

TABLE IV

METEOROLOGICAL PROGRAM - MANNED WEATHER STATIONS (1963 - 1965)

STATION		PERIOD OF RECORD	OBSERVATION TIMES[a] (YST)	PARAMETERS RECORDED[b]							
KLUANE	1963	5 June - 24 Aug.	0900 and 2100	Temp.,	RH,	Cloud,	Vis.,	Wind,	Precip.,	Press.	
	1964	1 June - 26 Aug.	0900, 1500 & 2100	"	"	"	"	"	"	"	Insolation, Sunshine
	1965	14 May - 9 Aug.	3 hourly	"	"	"	"	"	"	"	Insolation
KASKAWULSH	1964	4 July - 22 Aug.	Irregular (3 hourly)	"	"	"	"	"	"	—	
	1965	4 June - 8 Aug.	3 hourly	"	"	"	"	"	"	"	Insolation, Ablation, Upper Wind
DIVIDE	1963	19 June - 23 Aug.	2 hourly	"	"	"	—	"	"	"	Sunshine, Snow, Met. Phenomena
	1964	10 June - 17 Aug.	3 hourly	"	"	"	—	"	"	"	Insolation, Sunshine, Ablation, Micromet
	1965	4 June - 8 Aug.	3 hourly	"	"	"	—	"	"	"	Insolation, Ablation, Upper Wind
SEWARD	1964	18 June - 14 Aug.	3 hourly	"	"	"	"	"	"	"	Upper Wind, Micromet
	1965	9 July - 25 July.	3 hourly	"	"	"	"	"	"	—	

a) 3 hourly is 03, 06, 09, 12, 15, 18, 21, 24 YST
2 hourly is 02, 04, 06, 08, 10, 12, 14, 16, 18, 20, 22, 24 YST

b) Temp. - Air shelter temperature (degrees F.)
RH - Relative humidity (of Air)
Cloud - Cloud type, cover (tenths and height in ft.)
Wind - Wind direction (ol to 36) and speed (kts.)
Vis. - Visibility (miles)
Precip. - Precipitation (in. and mm. rain, cm. snow)
Press. - Air pressure (mb)
Insolation - Incoming radiation - short wave (cal mm^{-1} cm^{-2})
Sunshine - Duration of sunshine
Ablation - Ablation and accumulation (cm)
Upper Winds - Upper wind direction and speed - pibal
Micromet - Temperature and wind at 4 levels, net radiation balance
Snow - Snow surface classifications
Met Phenomena - Meteorological phenomena

TABLE V

METEOROLOGICAL PROGRAM - AUTOMATIC STATIONS (1963-1965)

STATION	PERIOD OF RECORD	PARAMETERS RECORDED[a]
CACHE - DIVIDE	1945 13 June-16 Aug.	Temp.
CAIRN B DIVIDE	1964 13 July-15 Aug.	Temp., R H
	1965 7 June-11 Aug.	Temp.
KASKAWULSH ICE	1965 7 July-26 July	Temp., R H
KASKAWULSH KNOLL	1965 25 June-26 July	Temp.
SEWARD ICE	1964 6 July-15 Aug.	Temp., R H
TERMINUS	1963 15 July-23 Aug.	Temp., R H
	1964 11 June-18 Aug.	Temp.

a) See footnote (a) TABLE IV.

TABLE VI

PERMANENT WEATHER STATIONS IN VICINITY OF STUDY AREA

STATION	LATITUDE	LONGITUDE	ELEVATION ABOVE MSL IN FT.	OPERATING AGENCY	TYPE OF RECORD	PERIOD OF RECORD OF CLIMATOLOGICAL NORMALS
AISHIHIK	61 37'N	137 31'W	3,170	Meteorological Branch Canadian Dept. of Transport	Surface synoptic	1943 - 1960 (18 years)
HAINS JUNCTION EXPERIMENTAL FARM	60 45'N	137 35'W	1,965	Canadian Dept. of Agriculture	Irregular surface synoptic	1944 - 1960 (17 years)
SNAG	62 22'N	140 24'W	1,925	Met. Branch D.O.T.	Surface synoptic	1944 - 1960 (17 years)
WHITEHORSE (A.P.)	60 43'N	135 05'W	2, 289	Met. Branch D.O.T.	Surface and upper Air Data (1st Class Station)	1942 - 1960 (19 years)
CAPE YAKATAGA				U.S. Weather Bureau	Daytime surface synoptic	
ANNE H	55 02'N	131 34'W	110	U.S. Weather Bureau	Surface synoptic	1931 - 1960 (30 years)
SITKA				U.S. Weather Bureau	Surface synoptic	
JUNEAU (A.P.)	58 22'N	134 35'W	12	U.S. Weather Bureau	Surface synoptic	1931 - 1960 (30 years)
YAKUTAT (A.P.)	59 31'N	139 40'W	39	U.S. Weather Bureau	Surface and upper air data	1931 - 1960 [illegible]

TABLE VII

YAKUTAT PRECIPITATION EXTREMES

	EXTREME MONTHLY TOTAL PRECIP. AMOUNTS		EXTREME MONTHLY SNOW AMOUNTS	
	Precip. Amount (in.)	Month and Year of occurrence	Snow Depth (in.)	Month and Year of occurrence
1st Max.	36.45	March 1948	111.0	March 1959
2nd Max.	32.13	Feb. 1964		
1st Min.	0.52	June 1964	2.7	March 1958
2nd Min.	0.68	June 1959		
3rd Min.	0.75	April 1948		

TABLE VIII

YAKUTAT CLOUD AMOUNT FREQUENCIES

CLOUD AMOUNT (in tenths)	NUMBER OF DAYS
0-3	41
4-7	44
8-10	280

TABLE IX

WHITEHORSE PRECIPITATION EXTREMES[a]

			1st	2nd	3rd
Total Precip.	(in.)	Monthly Max.	3.38 (June 1953)	3.40 (June 1961)	3.33 (Aug. 1949)
Total Precip.	(in.)	Yearly Max.	13.85 (1948)	13.60 (1944)	13.48 (1953)
Rain	(in.)	Monthly Max.	3.38 (June 1953)	3.44 (June 1961)	3.33 (Aug. 1949)
Snow Depth	(in.)	Monthly Max.	20.40 (Nov. 1944)	20.30 (Dec. 1962)	
Total Precip.	(in.)	Yearly Min.	6.70 (1947)		
Rain	(in.)	August Min.	.05 (1945)		
Snow Depth	(in.)	November Min.	2.1 (1957)		

a) Date of occurrence given in brackets.

TABLE X

TEMPERATURE MEANS - WHITEHORSE, HAINS JUNCTION, AISHIHIK AND SNAG (°F.)

	ANNUAL MEAN TEMP.	ANNUAL MEAN MAX.	ANNUAL MEAN MIN.
Whitehorse	30.8	39.7	21.8
Hains Junction	26.4	39.1	13.8
Aishihik	24.5	36.0	13.2
Snag	21.5	33.5	9.8

TABLE XI

COMPARISON WHITEHORSE AND YAKUTAT

TEMPERATURE (°F)	WHITEHORSE	YAKUTAT
Mean Annual	30.8	40.0
Max. Mean (value)	57.5	54.1 (53.8)
(month)	July	July (Aug.)
Min. Mean (value)	-0.6	27.3 (28.1)
(month)	Jan.	Jan. (Dec.)
Extreme Max. (value)	91.1	86
(date)	July 1951	Aug. 1957
(shape of curve)	> Dev. Jan.	> Dev. Jan.
Extreme Min. (value)	-61.1	-22
(date)	Jan. 1947	Jan. 1952
(shape of curve)	> Dev. Jan.	> Dev. Aug.
Range (mean annual)	76.4	40.3
(mean monthly)	20°F	12°F
(extreme annual)	152.7	108
(monthly variation)	July 22°F to Autumn 15°F	Steady at 12°F
Days below 0°F	~78	~10
Months extreme over 80°F	May - Sept.	July & Aug.

RELATIVE HUMIDITY (%)	WHITEHORSE	YAKUTAT
Mean Annual	84	71

a) From Kendrew and Kerr (15)

PRECIPITATION (in.)	WHITEHORSE	YAKUTAT
Annual Mean	10.05	131.8
Max. Mean (value)	1.44	19.35
(month)	Aug.	Oct.
Min. Mean (value)	.43	5.68
(month)	April	June
Snow Max. (value)	8.5	45.0 / 44.8
(month)	Nov.	Mar. / Dec.
No. Precip. Days	~120 [a]	223

CLOUD (tenths)	WHITEHORSE	YAKUTAT
Annual cover	7.2 [a]	8.3
Max. Month (value)	7.9	8.6
(month)	Nov.	June & July
Min. Month (value)	6.6	7.7
(month)	Feb.	Jan.
Days Heavy Fog	18	31

WIND (mph.)	WHITEHORSE	YAKUTAT
Speed	9.3	8.1
Max.	Oct.	Dec.
Min.	July	Sept.
Direction	SE	E

TABLE XII

OCEANICITY AND CONTINENTALITY INDICES[a]

STATION OR AREA	CONTINENTALITY	OCEANICITY
Whitehorse	46.0	6.7
Yakutat	13.5	18.6
North American Average	48.0 (max. 67.0)	
All Continents in N. Hemisphere	52	
Winnipeg, Manitoba		4.0
Bergen, Norway	14	14.0
Honolulu, Hawaii		49.0

a) See Landsberg (16 pp. 290-1)

TABLE XIII

KÖPPEN[a] AND THORNTHWAITE[b] INDICES

	STATION	APPROX. LATITUDE	KÖPPEN INDICES	THORNTHWAITE INDICES	COMMENTS
(1)	Whitehorse	60°N	Dfb	D'	
(2)	Stockholme	60°N	Dfb	BC'r - -	Similar position to Whitehorse
(3)	Omsk, Siberia	60°N	Dfb	D' - -	Very land locked
(4)	N. Quebec	60°N	ET	E' - -	E. coast - same latitude
(5)	Montreal	50°N	Dfb	BC'r	
(6)	Yakutat	60°N	Cfb	AC'r	
(7)	Bergen	60°N	Cfb	AC'r - -	Similar position to Yakutat
(8)	W. Ireland	55°N	Cfb	AC'r -	Island
(9)	60°S	60°S	ET or EF	(E')[c] -	S. hemisphere - same latitude
(10)	Vancouver	50°N	Cfb	AC'r	

a) For explanation of symbols see Harwitz and Austin (11).
b) For explanation of symbols see Thornthwaite (28)
c) Only over land

TABLE XIV A

MONTHLY AND SEASONAL TEMPERATURE (°F) MEANS (ALL DATA)

STATION	1963 June	1963 July	1963 Aug.	1963 Season	1964 June	1964 July	1964 Aug.	1964 Season	1965 May	1965 June	1965 July	1965 Aug.	1965 Season	3 YR. AVE.[c] June	3 YR. AVE.[c] July	3 YR. AVE.[c] Aug.
WHITEHORSE	49.6 (30)[a]	57.5 (31)	58.3 (31)	55.1 (91)	55.9 (30)	55.2 (31)	52.8 (31)	54.6 (91)	41.4 (31)	49.9 (30)	58.0 (31)	55.4 (31)	51.2 (122)	51.8 54.6[b]	56.9 57.5[b]	55.5 54.3[b]
KLUANE	47.0 (26)	53.9 (31)	52.9 (25)	51.4 (82)	51.9 (30)	52.4 (31)	50.8 (27)	51.8 (88)	42.0 (18)	47.0 (30)	54.0 (31)	56.9 (9)	49.5 (88)	48.6	53.5	51.6 (2)
KASKAWULSH	--	--	--	--	--	40.2 (24)	39.5 (10)	39.9 (34)	36.7 (4)	32.8 (30)	38.2 (25)	--	35.4 (59)	32.8 (1)	39.2 (2)	39.5 (1)
DIVIDE	21.9 (10)	29.6 (31)	29.9 (23)	28.4 (64)	26.6 (21)	27.4 (31)	26.3 (17)	26.9 (69)	--	20.0 (26)	29.4 (31)	30.9 (8)	25.8 (65)	23.3 (2)	28.8	29.9 (1)
SEWARD	--	--	--	--	31.4 (11)	36.3 (31)	35.9 (14)	35.2 (56)	--	--	37.0 (17)	--	37.0 (17)	31.4 (1)	36.3 (1)	35.9 (1)
YAKUTAT	48.3 (30)	54.6 (31)	54.8 (31)	52.6 (92)	52.4 (30)	52.9 (31)	53.2 (31)	52.8 (92)	39.2 (31)	44.3 (30)	50.0 (31)	49.3 (31)	45.7 (122)	48.3 50.5[b]	52.5 54.1[b]	52.3 53.8[b]

a) Number of days of record for every mean is given in brackets below it.

b) Normals for YAK (1931-60) and WH (1942-60).

c) For averages of less than 3 years no. of years is shown in brackets.

TABLE XIV B

SEASONAL TEMPERATURE (°F.) MEANS AND AVERAGES (COMMON PERIODS)

STATION	1963	1964	1965	2 YRS.	3 YRS.	PERIOD
Kluane	51.0	52.4	51.0	52.1	51.7	5 June - 8 August
Kaskawulsh	–	40.9	39.0	39.9	–	9 July - 24 July
Divide	27.5	26.8	28.3	27.6	27.5	20 June - 8 August
Seward	–	37.0	37.2	37.1	–	9 July - 25 July

TABLE XV

SEASONAL TEMPERATURE (°F.) MEANS AND AVERAGES (5 JUNE - 8 AUG.)

STATION	1963	1964	1965	AVE.	NO.YRS.	3YR.AVE.	C
Whitehorse [a]	54.4	55.1	54.4	54.6	3	54.6 [b]	
Hains Junction	–	–	–	51.9	2	51.5	10.83
Terminus	–	48.2	–	48.2	1	47.5	8.61
Kluane	51.0	52.4	51.8	51.7	3	51.7	10.94
Kaskawulsh Ice	–	–	35.3	35.3	1	36.2	2.33
Kaskawulsh	–	39.5	36.9	38.2	2	37.8	3.22
Kaskawulsh Knoll	–	–	40.8	40.8	1	41.7	5.59
Divide Cairn B	–	29.1	–	29.1	1	28.1	-2.17
Divide	26.0	27.4	25.9	26.4	3	26.4	-3.11
Divide Cache	–	27.3	–	27.3	1	26.3	-3.17
Seward	–	35.9	34.5	35.2	2	34.9	1.61
Seward Ice	–	34.0	–	34.0	1	33.0	.56
Yakutat [a]	52.2	52.7	52.1	52.3	3	52.3 [c]	11.39

a) YAK and WH means were found by weighting the monthly averages (i.e. 26 June + 31 July + 8 August) as the daily means were not available.

b) WH long term mean (i.e. 1942 - 60) for same period = 55.9

c) YAK long term mean (i.e. 1931 - 60) for same period = 52.5

TABLE XVI

TEMPERATURE DEVIATIONS FROM THE 3 YEAR SEASONAL AVERAGES ($T_x - \bar{T}$)

STATION	1963	1964	1965	$\Sigma \lvert T_x - \bar{T}$
Whitehorse	-.2	+.5	-.2	.9
Kluane	-.7	+.7	+.1	1.5
Kaskawulsh	(-.4)[a]	+1.3	-.9	2.2 (2.5)
Divide	-.4	+1.0	-.5	1.9
Seward	(-.5)[a]	+1.0	-.4	1.4 (2.0)
Yakutat	-.1	+.4	-.2	.7

a) Calculated - not recorded - assuming one can extrapolate KASK and SEW 1963 temp. from KL and DIV.

TABLE XVII

MEAN MAXIMUM AND MINIMUM TEMPERATURE (°F) AND TEMPERATURE RANGE

STATION	1963 Max.	1963 Min.	1963 Range	1964 Max.	1964 Min.	1964 Range	1965 Max.	1965 Min.	1965 Range	AVE. Max.	AVE. Min.	AVE. Range	NO. of YEARS
WHITEHORSE										66.9	44.8	22.1	17
KLUANE	59.0	41.1	17.9	61.4	43.6	17.8	62.9	40.6	22.3	61.1	41.6	19.5	3
TERMINUS				60.4	37.1	23.5				60.6	37.1	23.5	1
KASKAWULSH ICE							38.7	29.0	9.7	38.7	29.0	9.7	1
KASKAWULSH				46.3	34.7	11.6	41.8	30.3	11.5	44.0	32.5	11.5	2
KASKAWULSH KNOLL							47.3	34.2	13.1	47.3	34.2	13.1	1
DIVIDE CAIRN B				36.5	21.3	15.2				36.5	21.3	15.2	1
DIVIDE	33.1	18.3	14.8	35.5	20.0	15.5	33.8	17.0	16.8	34.1	18.4	15.8	3
DIVIDE CACHE				33.3	22.7	10.6				33.3	22.7	10.6	1
SEWARD				43.4	29.5	13.9	39.2	27.5	11.7	41.3	28.5	12.8	2
SEWARD ICE				44.4	27.0	17.4				44.4	27.0	17.4	1
YAKUTAT										59.3	46.6	12.7	30

TABLE XVIII

EXTREME MAXIMUM AND MINIMUM TEMPERATURE (°F) AND TEMPERATURE RANGE

STATION	1963 Max.	1963 Min.	1964 Max.	1964 Min.	1965 Max.	1965 Min.	Period of Record Max.	Date[a]	Min.	Date[a]	Range
WHITEHORSE	82.3	32.2	79.5	30.6	79	32	82	Aug.'63	31	Aug.'64	51
KLUANE	72.0	30.0	74.6	34.6	78	28	78	July'65	28	June '65	50
TERMINUS			72.2	30.4			72	July	30	June	42
KASKAWULSH ICE					51	28	51	July	28	July	23
KASKAWULSH			58.1	29.8	56	14	58	July'64	14	June'65	44
KASKAWULSH KNOLL					62	28	62	July	28	July	34
DIVIDE CAIRN B			49.2	13.7			49	July	14	Aug.	35
DIVIDE	51.8	2.6	51.3	9.8	55	1	55	July'65	1	June'65	54
DIVIDE CACHE			46.2	14.9			46	July	15	July	31
SEWARD			54.0	25.1	60	24	60	July	22	June	36
SEWARD ICE			53.8	19.8			54	July	19	Aug.	35
YAKUTAT	76.0	35.0	74.0	39.0	72	31	76	Aug.'63	31	June'65	45

a) Year given only when two or more years of record are available.

TABLE XIX

ENVIRONMENTAL AND ATMOSPHERIC LAPSE RATES (°C/100 Meters)[a]

PERIOD OF RECORD AND TIME	MARINE SLOPE		CONTINENTAL SLOPE	
	RAOBS: YAK to 2,637 m.	ENVIRONMENTAL: YAK to 2,637 m. (DIV)	RAOBS: WH to 2,637 m.	ENVIRONMENTAL: KL to 2,637 m. (DIV)
1964				
Mean July				
0300 Y.S.T.	0.46	0.56	0.44	0.66
1500 Y.S.T.	0.62	0.52	0.88	0.83
July 15-20				
0300 Y.S.T.	0.32	0.54 (0.36)[b]	0.38	0.65 (0.49)
1500 Y.S.T.	0.58	0.45 (0.43)	0.93	0.74 (0.70)
July 22-29				
0300 Y.S.T.	0.50	0.54 (0.50)	0.47	0.61 (0.55)
1500 Y.S.T.	0.58	0.53 (0.49)	0.97	0.84 (0.70)
1963				
Mean July				
0300 Y.S.T.	0.44	0.55	0.45	0.64
1500 Y.S.T.	0.57	0.51	0.88	0.81

a) Table after Marcus (18 p. 27)

b) Environmental lapse rates for DIV. CAIRN B (2,741 m.) are given in parentheses. Atmospheric lapse rates for CAIRN B are the same as those for DIV.

TABLE XX

WIND DIRECTION - TEMPERATURE (°F) RELATIONSHIPS (1965)

WIND DIRECTION	KLUANE May	KLUANE June	KLUANE July	KASKAWULSH June	KASKAWULSH July	DIVIDE June	DIVIDE July	SEWARD July
N	38.9	46.4	51.3	35.7	41.9	--	--	33.0
NE	42.3	43.4	52.1	32.7	41.1	--	26.0	40.6
E	39.2	43.6	49.8	31.8	42.6	21.8	24.9	42.2
SE	49.6	47.4	51.5	--	--	18.5	32.4	32.2
S	43.4	48.1	56.0	34.3	37.6	22.6	27.8	32.4
SW	48.1	51.8	59.2	30.0	38.4	15.5	30.8	33.8
W	49.7	53.0	61.6	31.7	41.8	20.7	26.8	33.2
NW	45.1	47.3	54.7	31.8	36.7	--	--	32.8
CALM	35.6	43.4	52.5	31.7	35.1	17.6	26.7	38.0

TABLE XXI

MONTHLY RELATIVE HUMIDITY MEANS AND AVERAGES

STATION	1963 June	1963 July	1963 Aug.	1964 June	1964 July	1964 Aug.	1965 May	1965 June	1965 July	AVERAGE June	AVERAGE July	VAPOUR PRESS. July
Whitehorse	-	-	-	58	63	66	-	53	55	56	59	.28
Kluane	60	71	65	-	-	-	67	56	64	58	67	.28
Kaskawulsh Ice	-	-	-	-	-	-	-	-	83	-	83	.19
Kaskawulsh	-	-	-	-	-	-	77	76	82	76	82	.20
Kaskawulsh Knoll	-	-	-	-	-	-	-	-	62	-	62	.17
Divide	84	84	-	-	85	-	-	83	89	84	86	.13
Seward	-	-	-	-	-	-	-	-	89	-	89	.19
Yakutat	-	-	-	81	84	87	87	87	92	84	88	.37

TABLE XXII

WIND DIRECTION - HUMIDITY RELATIONSHIPS (1965)[a]

DIRECTION	KLUANE						KASKAWULSH				DIVIDE				SEWARD	
	May		June		July		June		July		June		July		July	
	RH	VP	RH	VP	RH	VP	RH	VP	RH	VP	RH	VP	RH	VP	RH	VP
N	73	.17	51	.16	72	.29	89	.19	84	.23	-	-	-	-	91	.17
NE	62	.17	54	.15	70	.28	84	.16	82	.22	-	-	86	.12	76	.19
E	69	.17	56	.16	68	.24	69	.12	84	.23	85	.10	91	.12	81	.22
SE	72	.26	55	.18	69	.26	-	-	-	-	88	.09	87	.16	90	.16
S	57	.16	56	.19	60	.27	75	.15	85	.19	82	.10	88	.13	97	.18
SW	67	.23	49	.19	52	.26	73	.12	78	.18	81	.08	82	.14	92	.18
W	57	.20	43	.17	46	.26	76	.14	75	.20	86	.11	88	.13	95	.18
NW	67	.20	65	.21	64	.27	81	.14	88	.19	-	-	-	-	97	.18
CALM	72	.15	61	.17	74	.29	85	.15	91	.19	85	.08	85	.15	87	.19

a) Relative Humidity (RH in %) and Vapour Pressure (VP in mb)

TABLE XXIII

MONTHLY AND SEASONAL WIND SPEED MEANS AND AVERAGES (kts)

STATION	1963 June	July	Aug.	Season	1964 June	July	Aug.	Season	1965 May	June	July	Aug.	Season	AVE. May	June	July	Aug.	Season
WHITEHORSE [a]	10.7	8.8	9.3	9.6	9.1	9.3	9.5	9.3		12.1	9.5	8.9	10.2	9.4	8.5	8.3	8.5	8.4
KLUANE	3.8	3.9	3.4	3.7	--	--	--	--	4.1	4.9	4.1	3.1	4.3	4.1	4.3	4.0	3.3	4.0
KASKAWULSH	--	--	--	--	--	--	--	--	--	11.2	10.2	9.3	9.9	--	11.2	10.2	9.9	9.9
DIVIDE	6.2	4.3	7.2	5.7	6.7	5.5	4.3	5.6	--	7.2	5.2	6.3	6.3	--	6.4	5.1	5.9	5.9
SEWARD	--	--	--	--	3.2	3.3	1.9	2.4	--	--	2.7	--	2.7	--	3.2	2.5	1.9	2.6
YAKUTAT [a]	--	--	--	--	6.4	7.1	7.0		8.9	9.0	7.4	--	8.4	8.1	7.8	7.2	6.9	7.5

a) WH and YAK AVE are for the normal periods (i.e. 1942-60 and 1931-60 respectively)

TABLE XXIV

MAXIMUM WIND SPEEDS (kts)

STATION	1963 Max.	1963 Date	1964 Max.	1964 Date	1965 Max.	1965 Date	3 YEARS Max.	3 YEARS Date
WHITEHORSE			26	May 11 Aug.23	39	June 16	39	1965
KLUANE	16	July 27	17	July 8	40	June 16	40	1965
KASKAWULSH			30	Aug.18	36 (ca.40)	June 3 (June 16)	36 (ca.40)	1965 (1965)
DIVIDE	25	Aug. 5	20	July 27	35	June 16	35	1965
SEWARD			29	June 22	22+	July 25	29 (22+)	1964 (1965)
YAKUTAT			29	May 18	35	May 23 June 19	35	1965

TABLE XXV A

DIURNAL PREVAILING WIND DIRECTION VARIATIONS[a]

1963

HOUR (YST)		03	07	11	15	19	23
Divide	July	W(c)	W(c)	W(c)	W	W	W(c)
	Aug.	W	W	W	W	W	W

1964

HOUR (YST)		03	06	09	12	15	18	21	24
Divide	June	W(c)	W	W	W & E	E	W(c)	W(c)	E
	July	SE(c)	E(c)	NE(c)	NE(c)	SE & E(c)	SW	SE & E(c)	NE(c)
Seward	July	E & NW(c)	E & NW(c)	NW(c)	NW	NW(c)	NW(c)	E(c)	E(c)

1965

HOUR(YST)		03	06	09	12	15	18	21	24
Kluane	May	E	N & S(c)	SW	SW	SW & W	W	S & E	E(c)
	June	E	S(c)	S	SW	N & SW	S	S	E
	July	E	S(c)	S	S	SW	SW	E	SE
Kaskawulsh	June	SW	SW(c)	SW	SW	SW	SW	SW	W(c)
	July	SW	SW	SW	SW	SW	SW	SW	W(c)
Divide	June	S	S	S & W	S	S	S & W	S	S
	July	W	E(c)	E	E & S(c)	S	S & W	S	W
Seward	July	E & NE(c)	E	NE(c)	NW(c)	NW(c)	NW & E	E	W

a) When calms most frequent this noted by (c)

TABLE XXV B

PERCENTAGE OF CALMS

		1963	1964	1965
KLUANE	May	-	-	17.0
	June	-	7.9	17.3
	July	-	8.6	15.8
KASKAWULSH	June	-	-	11.2
	July	-	39.0	11.3
DIVIDE	June	19.7	17.8	8.9
	July	34.3	32.0	18.6
	Aug.	23.2	27.3	-
SEWARD	July	-	32.0	26.6

TABLE XXVI

WIND DIRECTION - WIND SPEED (kts.) RELATIONSHIPS (1965)

WIND DIRECTION	KLUANE May	KLUANE June	KLUANE July	KASKAWULSH June	KASKAWULSH July	DIVIDE June	DIVIDE July	SEWARD July
N	5.0	4.9	6.0	5.0	4.7	-	-	3.6
NE	3.2	4.7	4.9	5.7	4.0	-	15.7	4.7
E	3.9	8.3	4.1	3.8	3.6	7.5	7.1	4.4
SE	8.8	5.1	3.8	-	-	8.3	4.1	2.7
S	5.1	5.5	5.2	9.0	13.2	8.3	6.6	4.0
SW	5.4	5.1	5.9	12.0	12.6	11.3	5.1	2.0
W	5.0	6.2	4.0	11.3	4.9	7.8	5.2	3.7
NW	4.7	3.2	6.6	13.6	-	-	-	-

TABLE XXVII

MONTHLY AND SEASONAL CLOUD AMOUNT MEANS AND AVERAGES

STATION	1963 June	1963 July	1963 Aug.	1963 Season	1964 June	1964 July	1964 Aug.	1964 Season	1965 May	1965 June	1965 July	1965 Aug.	1965 Season
KLUANE	6.8	6.4	4.2	5.8	-	-	-	-	4.4	6.0	6.5	4.9	5.7
KASKAWULSH	-	-	-	-	-	-	-	-	4.1	5.9	6.6	-	6.1
DIVIDE	7.2	6.8	6.1	6.7	7.4	6.6	7.0	6.9	-	6.9	6.8	4.3	6.0
SEWARD	-	-	-	-	9.1	5.9	7.6	7.2	-	-	8.0	-	8.0
YAKUTAT	-	-	-	-	-	-	-	-	-	-	-	-	-

AVERAGES

	May	June	July	Aug.	Season	June & July
KLUANE	4.4	6.4	6.5	4.3	5.8	6.5
KASKAWULSH	4.1	5.9	6.6	-	6.1	6.3
DIVIDE	-	7.2	6.7	5.8	6.5	7.0
SEWARD	-	9.1	7.0	7.6	7.6	8.1
YAKUTAT [a]	8.2	8.6	8.6	8.5	8.5	8.6

a) YAK AVERAGE is the 1931-60 normal

TABLE XXVIII

CLOUD AMOUNT (TENTHS) FREQUENCIES (%) - JULY 1965

STATION	CAVU	1 - 3	4 - 6	7 - 9	10
KLUANE	.8	17.5	32.4	23.6	25.6
KASKAWULSH	1.5	21.5	22.0	35.4	19.5
DIVIDE	4.9	19.0	14.0	19.5	44.6
SEWARD	0	12.5	10.1	19.9	57.4

TABLE XXIX

WIND DIRECTION - CLOUD AMOUNT (TENTHS) RELATIONSHIPS (JULY 1965)

WIND DIRECTION	KLUANE	KASKAWULSH	DIVIDE	SEWARD
N	8.3	6.3	-	8.9
NE	7.9	8.5	8.9	7.3
E	6.1	5.2	6.6	6.9
SE	3.3	-	6.1	2.5
S	6.9	4.0	7.8	10.0
SW	5.5	6.1	6.0	10.0
W	4.6	7.1	6.6	9.2
NW	5.9	8.4	-	9.7
CALM	7.3	7.8	6.0	7.3

TABLE XXX

MONTHLY AND SEASONAL PRECIPITATION TOTALS (mm). AND PER DAY AVERAGES

1963

<table>
<tr><th rowspan="2">STATION</th><th colspan="2">June[a]</th><th colspan="2">July</th><th colspan="2">August</th><th colspan="2">Season</th><th rowspan="2">No.Days</th><th rowspan="2">Per Day</th></tr>
<tr><th>R</th><th>S</th><th>R</th><th>S</th><th>R</th><th>S</th><th>R</th><th>S</th></tr>
<tr><td>Whitehorse</td><td>28.4</td><td>4.4</td><td>33.5</td><td></td><td>20.2</td><td></td><td>82.1</td><td>4.4</td><td>92</td><td>.94</td></tr>
<tr><td>Kluane</td><td colspan="2">31.2</td><td colspan="2">43.8</td><td colspan="2">7.1</td><td colspan="2">82.0</td><td>82</td><td>.93</td></tr>
<tr><td>Kaskawulsh</td><td colspan="2">--</td><td colspan="2">--</td><td colspan="2">--</td><td colspan="2">--</td><td>--</td><td>--</td></tr>
<tr><td>Divide</td><td></td><td>27.5</td><td></td><td>32.5</td><td></td><td>35.5</td><td></td><td>95.5</td><td>64</td><td>1.50</td></tr>
<tr><td>Seward</td><td colspan="2">--</td><td colspan="2">--</td><td colspan="2">--</td><td colspan="2">--</td><td>--</td><td>--</td></tr>
<tr><td>Yakutat</td><td colspan="2">325.0</td><td colspan="2">236.5</td><td colspan="2">192.2</td><td colspan="2">753.7</td><td>92</td><td>8.17</td></tr>
</table>

1964

<table>
<tr><th rowspan="2">STATION</th><th colspan="2">June</th><th colspan="2">July</th><th colspan="2">August</th><th colspan="2">Season</th><th rowspan="2">No.Days</th><th rowspan="2">Per Day</th></tr>
<tr><th>R</th><th>S</th><th>R</th><th>S</th><th>R</th><th>S</th><th>R</th><th>S</th></tr>
<tr><td>Whitehorse</td><td>31.0</td><td></td><td>33.5</td><td></td><td>51.4</td><td></td><td>115.9</td><td></td><td>92</td><td>1.26</td></tr>
<tr><td>Kluane</td><td colspan="2">21.8</td><td colspan="2">33.6</td><td colspan="2">31.5</td><td colspan="2">86.9</td><td>88</td><td>.99</td></tr>
<tr><td>Kaskawulsh</td><td colspan="2">--</td><td colspan="2">--</td><td colspan="2">--</td><td colspan="2">--</td><td>--</td><td>--</td></tr>
<tr><td>Divide</td><td></td><td>52.8</td><td></td><td>27.5</td><td></td><td>13.1</td><td></td><td>93.4</td><td>69</td><td>1.35</td></tr>
<tr><td>Seward</td><td>16.9</td><td>26.1</td><td>14.7</td><td>11.1</td><td>23.1</td><td>.3</td><td>54.8</td><td>37.5</td><td>56</td><td>1.65</td></tr>
<tr><td>Yakutat</td><td colspan="2">230.0</td><td colspan="2">415.0</td><td colspan="2">245.9</td><td colspan="2">890.9</td><td>92</td><td>9.68</td></tr>
</table>

1965

<table>
<tr><th rowspan="2">STATION</th><th colspan="2">May</th><th colspan="2">June</th><th colspan="2">July</th><th colspan="2">Season</th><th rowspan="2">No.Days</th><th rowspan="2">Per Day</th></tr>
<tr><th>R</th><th>S</th><th>R</th><th>S</th><th>R</th><th>S</th><th>R</th><th>S</th></tr>
<tr><td>Whitehorse</td><td colspan="2">14.4</td><td colspan="2">10.9</td><td colspan="2">36.6</td><td colspan="2">62.1</td><td>92</td><td>.42</td></tr>
<tr><td>Kluane</td><td>T</td><td>.2</td><td>16.0</td><td>.1</td><td>37.5</td><td></td><td>53.5</td><td>.3</td><td>80</td><td>.67</td></tr>
<tr><td>Kaskawulsh</td><td></td><td>T</td><td></td><td>.6</td><td>8.8</td><td>.5</td><td>8.8</td><td>1.1</td><td>39</td><td>.15</td></tr>
<tr><td>Divide</td><td colspan="2">--</td><td></td><td>36.4</td><td></td><td>15.2</td><td></td><td>41.6</td><td>57</td><td>.78</td></tr>
<tr><td>Seward</td><td colspan="2">--</td><td colspan="2">--</td><td>6.3</td><td>.9</td><td></td><td>7.2</td><td>17</td><td>.44</td></tr>
<tr><td>Yakutat</td><td colspan="2">202.2</td><td colspan="2">128.5</td><td colspan="2">214.0</td><td colspan="2">544.7</td><td>92</td><td>5.93</td></tr>
</table>

3 YEARS

STATION	Total	No.Days	Per Day
Whitehorse	113.2	123	.92
Kluane	222.7	258	.90
Kaskawulsh	9.9	59	.15
Divide	230.5	198	1.21
Seward	99.5	73	1.36
Yakutat	1018.0	123	8.28

a) R = Rain S = Snow When available data did not distinguish between these, the figure is entered in the centre of the two columns.

b) 3 years where available - except YAK & WH where normals used (1931-60, 1942-60 respectively).

TABLE XXXI

HYDROLOGICAL TRAVERSE [a]

PRELIMINARY DATA: PIT LOCATIONS AND DENSITIES, ICEFIELD RANGES (MAY-JUNE, 1965) [b]

PIT	GLACIER	ELEVATION (meters)	LAT. N.	LONG. W.	DATE	1964-65 ACCUMULATION cm. SNOW	$\bar{\rho}$ gms/cm^3	WATER EQUIVALENT (cm.)	WATER EQUIVALENT (mm. per day)
1	Lower Seward	1,220	60°16'	140°19'	May 23	Data not yet available for presentation			
2	Lower Seward	1,370	60°18'	140°13'	May 21-22	460	0.378	173.9	5.65
3	Upper Seward	1,765	60°23'	140°15'	May 21-22	580	0.366	212.0	6.92
4	Hubbard	1,980	60°37'	139°57'	June 9	310	0.419	130.0	4.24
5	Hubbard	2,135	60°40'	139°54'	June 9	212	0.437	92.8	3.02
6	Hubbard	2,285	60°45'	139°51'	May 30	260	0.392	101.8	3.32
7	Hubbard	2,500	60°46'	139°47'	May 29	210	0.388	81.5	2.66
8	Divide	2,620	60°46'	139°41'	May 31	320	0.407	130.2	4.25
9	Kaskawulsh	2,640	60°44'	139°35'	May 28	370	0.409	151.3	4.93
10	Kaskawulsh	2,380	60°42'	139°31'	May 27	260	0.394	102.4	3.33
11	Kaskawulsh	2,225	60°42'	139°24'	May 26	270	0.364	98.3	3.20
12	Kaskawulsh	2,070	60°39'	139°20'	May 24	240	0.388	93.2	3.04
13	Kaskawulsh	1,915	60°42'	139°13'	May 19	178	0.385	68.5	2.23
14	Kaskawulsh	1,765	60°44'	139°08'	May 17	165	0.390	64.3	2.09
15	Kaskawulsh	1,615	60°45'	139°01'	May 17	91	0.342	31.1	1.01

a.) After Marcus (19)

b) It should be noted that the density data is of a preliminary nature.

TABLE XXXII

MONTHLY AND SEASONAL PRECIPITATION PROBABILITIES (DAILY)[a]

	1963				1964				1965					AVE.
STATION	June	July	Aug.	Season	June	July	Aug.	Season	May	June	July	Aug.	Season	Season
WHITEHORSE	-	-	-	-	-	-	-	-	-	40.0	45.2	45.2	43.0	43.0
KLUANE	42.4	51.5	20.0	39.0	36.6	35.5	33.3	35.3	16.6	40.0	35.5	0	29.6	34.5
KASKAWULSH	-	-	-	-	-	50.0	45.5	47.8	33.3	50.0	48.0	-	47.4	47.6
DIVIDE	90.0	66.5	39.0	61.0	85.6	58.6	82.5	72.5	-	75.8	51.1	62.5	63.0	65.7
SEWARD	-	-	-	-	82.0	58.0	78.6	62.0	-	-	58.9	-	58.9	65.8
YAKUTAT	-	-	-	-	-	-	-	-	77.5	76.6	64.5	-	72.8	72.8

a) Probability of precipitation on any one day. No. of days of record used in calculations can be found in TABLE XXX.

TABLE XXXIII

WIND DIRECTION - PRECIPITATION PROBABILITY RELATIONSHIPS (JULY 1965)

WIND DIRECTION	KLUANE	KASKAWULSH	DIVIDE	SEWARD
N	40.0	27.7	-	20.0
NE	20.0	-	18.2	38.5
E	8.7	-	38.1	21.8
SE	17.6	-	9.1	-
S	8.6	-	28.0	33.0
SW	6.2	11.1	10.0	33.0
W	1.1	19.5	7.7	62.0
NW	-	37.8	-	55.5
CALM	28.0	41.0	9.1	33.0

TABLE XXXIV

DAYS WITH TEMPERATURE MEANS BELOW FREEZING (1965)

STATION	NO. OF DAYS	TOTAL NO. OF DAYS
KLUANE	0	65
KASKAWULSH	13	50
DIVIDE	44	58
SEWARD	4	16

TABLE XXXV

1965 SURFACE AND 500 MB FLOW FREQUENCIES [a]

SURFACE \ 500 MB	TYPE 1	TYPE 2	TYPE 3	TYPE 4	TYPE 5	RIDGE	COL and NECK	SURFACE PERCENT FREQUENCY
TYPE 1	8	1				3	2	9
TYPE 2	9	16				5		19
TYPE 3	4	19	6	2	4	4	9	27
TYPE 4	4	1	2	2	1	3		9
TYPE 5	4		1	1	3	3		7
RIDGE	2	27	2			5	2	23
COL and NECK	2	1			2			5
500 MB PERCENT FREQUENCY	21	42	7	3	6	14	7	

a) Actual number of occurrences given except where otherwise stated.

TABLE XXXVI

1964 SURFACE AND 500 MB FLOW FREQUENCIES [a]

SURFACE \ 500 MB	TYPE 1	TYPE 2	TYPE 3	TYPE 4	TYPE 5	RIDGE	COL and NECK	SURFACE PERCENT FREQUENCY
TYPE 1	5	3	1		1	1		18
TYPE 2	6	14	1	1				29
TYPE 3	7	5	2	1	1		1	23
TYPE 4	4	3	2		1	1		14
TYPE 5					2			5
RIDGE		1	1		1			4
COL and NECK		1	1		1			5
500 MB PERCENT FREQUENCY	28	34	11	3	9	3	3	

a) See note TABLE XXXV

TABLE XXXVII

COMPARISON OF 1964 (U.S.), 1965 (U.S.), AND 1965 (CAO) FLOW FREQUENCIES

	TYPE	1	2	3	4	5	2 to 3	1 to 2	Col&Neck	Others
SURFACE	1964 (US)	18	29	23	14	5	4	-	4	3
	1965 (US)	16	24	41	3	-	12	-	6	-
	1965 (CAO)	9	19	27	9	7	23		5	-
500 MB	1964 (US)	28	34	11	3	9	1	3	3	7
	1965 (US)	15	65	9	1	3	1	-	1	4
	1965 (CAO)	21	42	7	3	6	14		7	-

TABLE XXXVIII

SURFACE FLOW - PARAMETER RELATIONSHIPS (1965)[a]

FLOW TYPE		Temperature (°F) (00 & 12Z)	Temperature (°F) (daily means)	Wind Speed (kts) (00 & 12Z)	Wind Speed (kts) (daily means)	Wind Direction (00 & 12Z)	Cloud (tenths) (00 & 12Z)	Cloud (tenths) (daily means)	Precipitation (mm) (daily total)	% Temp. <32°F (00 & 12Z)	% Temp. <32°F (daily means)	Precip.-Probability(%) (daily)	Temperature (°F) (00 & 12Z)	Temperature (°F) (daily means)	Wind Speed (kts) (00 & 12Z)	Wind Speed (kts) (daily means)	Wind Direction (00 & 12Z)	Cloud (tenths) (00 & 12Z)	Cloud (tenths) (daily means)	Precipitation (mm) (daily total)	% Temp. <32°F (00 & 12Z)	% Temp. <32°F (daily means)	Precip.Probability(%) (daily)
							KLUANE											**KASKAWULSH**					
1	Mode	46	46	4	2	c	9	8	T	0	0	66.6	30	34	7	4	23	9	8	T	60.0	20.0	100.0
	Median	46	52	2.5	3		6.5	6.5	.3				30	34	7	5		9	8	T			
2	Mode	34	48	3	4	11	5	5	T	9.3	0	29.0	30	30	14	15	23&25	10	6	T	50.0	40.0	55.5
	Median	42	46	3	4		5	5	T				31	30	13.5	11		7	6	T			
3	Mode	54	46	2	4	c	7	2	T	6.5	0	32.6	36	36	19	11	25	8	5	T	29.8	37.5	63.4
	Median	48	46	3.5	4		6	4	2.0				34	34	13	11		6	5.5	T			
4	Mode	42	42	4	3	c	10	5	T	6.2	0	37.5	34	30	16	11	23	3	4	–	43.5	32.0	25.0
	Median	48	48	3.5	3		7	5.5	T				32	32	12	10		5	4	–			
5	Mode	46	60	4	4	9	10	7	7.0	0	0	35.7	42	38	4	5	c	9	4	–	10.0	10.0	30.0
	Median	52	56	3	3		6	7	7.0				40	37	4	4		6	4	4.0			
1 to 2,	Mode	–	50	0	3	c&11	4	4	0	0	0	0	38	–	–	6	23	3	5	0	25.0	0	0
3, or 4	Median	41	50	3	3		4	4.5	0				37	36	12	6		3	5	0			
2 to 3	Mode	52	50	4	5	c	2	10	.5	0	0	3.3	36	38	20	13	23	6	7	T	9.5	43.6	52.5
or 4	Median	53	52	4	5		5	6	.5				36	38	15	13		6	7	T			
Col or	Mode	70	60	–	3	10	10	6	T	16.6	0	33.3	–	44	0	6	c	–	–	–	50.0	25.0	25.0
Neck	Median	47	60	3.5	3		6	5.5	T				31	37	0	6		–	–	–			
							DIVIDE											**SEWARD**					
1	Mode	26	22	3	4	11	10	7	T	83.3	61.5	54.5	–	–	–	–	–	–	–	–	–	–	–
	Median	26	30	5	4		7.5	7	T														
2	Mode	14	14	3	8	18	10	9	.5	100.0	90.0	92.0	30	30	2	5	–	fog	10	T	66.6	75.0	100.0
	Median	18	18	5	7		9	9.5	.5				30	30	2	5	–	fog	10	T			
3	Mode	26	24	10	3	27	10	9	.5	85.0	93.5	57.5	30	34	0	1	c	10	10	T	45.0	30.0	63.5
	Median	24	24	6.5	4		9	8	1.0				32	33	2	2		7	8	T			
4	Mode	24	30	10	6	26	10	4	T	77.8	100.0	57.2	–	–	–	–	–	–	–	–	–	–	–
	Median	24	29	8	6		5	4	T														
5	Mode	26	36	8	3	10	7	5	–	61.0	41.8	58.9	42	48	1	2	6	10	6	T	0	0	42.9
	Median	28	32	6	4		5.5	4.5	.5				42	48	2	2		7	5.5	T			
1 to 2,	Mode	26	28	2	9	24	9	4	–	85.8	100.0	25.5	–	30	1	–	–	–	–	–	–	–	–
3, or 4	Median	26	28	7	6		6.5	4.5	–				–	30	1.5	–							
2 to 3	Mode	30	28	10	3	c	10	9	T	77.1	68.0	50.0	40	40	2	2	9	10	8.5	1.5	0	0	62.5
or 4	Median	26	28	5	5.5		7	8	T				40	40	2	2		10	8	1.5			
Col or	Mode	30	34	–	4	18&27	1	2	–	71.5	40.0	33.0	–	–	–	–	–	–	–	–	–	–	–
Neck	Median	30	32	3	4		2	2	–				–	–	–	–		–	–	–			

a) Modes and Medians were obtained graphically and should not be relied on numerically but rather as an indication of the relative values. When two or more Mode existed the one closest to the Median value was entered in the table.

TABLE XXXIX

500 MB FLOW - PARAMETER RELATIONSHIPS (1965)[a]

KLUANE

		Temperature (°F) (00 & 12Z)	Temperature (°F) (daily means)	Wind Speed (kts) (00 & 12Z)	Wind Speed (kts) (daily means)	Wind Direction (00 & 12Z)	Cloud (tenths) (00 & 12Z)	Cloud (tenths) (daily means)	Precipitation (mm) (daily total)	% Temp. <32°F (00 & 12Z)	% Temp. <32°F (daily means)	Precip. Probability (%) (daily)
1	Mode	46	48	4	3	0	6	6	T	58.9	0	58.4
	Median	46	48	3	3		6	6	.5			
2	Mode	54	50	2	5	9	5	5	T	1.6	0	24.6
	Median	48	48	4	4.5		5	6	T			
3	Mode	32	42	2	4	0	5	4	-	10.0	0	0
	Median	35	44	2	4		5.5	4	-			
4	Mode	-	42	-	6	-	-	6	-	33.0	0	0
	Median	32	42	3	6		3	6	-			
5	Mode	-	-	0	1	0	10	-	7.0	0	0	55.5
	Median	50	54	2	1		6	6	7.0			
Ridge	Mode	42	54	4	4	11	1	5	T	16.8	0	77.0
	Median	49	50	3	4		3	5	T			
Low, Col	Mode	40	48	5	5	23&25	10	2	1.5	0	0	50.0
& Neck	Median	49	47	5	5		9	5	1.5			

KASKAWULSH

		Temperature (°F) (00 & 12Z)	Temperature (°F) (daily means)	Wind Speed (kts) (00 & 12Z)	Wind Speed (kts) (daily means)	Wind Direction (00 & 12Z)	Cloud (tenths) (00 & 12Z)	Cloud (tenths) (daily means)	Precipitation (mm) (daily total)	% Temp. <32°F (00 & 12Z)	% Temp. <32°F (daily means)	Precip. Probability (%) (daily)
1	Mode	36	34	16	7	23	9	5	T	71.5	25.8	46.9
	Median	35	34	8	7		5.5	5	T			
2	Mode	36	36	15	11	23	8	5	T	33.3	32.8	50.0
	Median	34	36	14	11		6	6	T			
3	Mode	30	36	8	11	23	3	5	T	57.2	42.9	33.3
	Median	30	36	8	11		5.5	5	T			
4	Mode	-	-	-	-	-	-	-	-	-	-	-
	Median	-	-	-	-	-	-	-	-			
5	Mode	36	38	0	2	0	5	3	4.0	22.2	0	44.5
	Median	44	38	4	3		5.5	3	2.0			
Ridge	Mode	34	42	7	15	23	10	5	T	15.4	14.3	23.5
	Median	38	37	13	11		6	5	T			
Low, Col	Mode	-	34	0	2	25	10	10	T	40.0	20.0	53.5
& Neck	Median	30	34	13	5		8	6	T			

DIVIDE

		Temperature (°F) (00 & 12Z)	Temperature (°F) (daily means)	Wind Speed (kts) (00 & 12Z)	Wind Speed (kts) (daily means)	Wind Direction (00 & 12Z)	Cloud (tenths) (00 & 12Z)	Cloud (tenths) (daily means)	Precipitation (mm) (daily total)	% Temp. <32°F (00 & 12Z)	% Temp. <32°F (daily means)	Precip. Probability (%) (daily)
1	Mode	20	22	3	5	27&18	10	9	1.0	87.0	84.5	81.3
	Median	24	22	4.5	5		7	7	1.0			
2	Mode	30	24	0	7	18	10	9	T	85.0	82.0	62.5
	Median	24	24	6	7		9	8	.5			
3	Mode	-	-	10	-	26	fog	4	2.5	83.5	75.5	44.5
	Median	18	26	8	6.5		9.5	5	2.5			
4	Mode	-	-	-	-	26	-	-	-	-	-	-
	Median	-	-	-	-		-	-	-			
5	Mode	32	30	2	4	27	5	-	2.0	44.4	55.5	44.5
	Median	32	30	3	4		5	3	1.0			
Ridge	Mode	26	28	-	8	27	10	8	.5	66.6	56.2	38.5
	Median	26	28	6	4.5		6	8	.5			
Low, Col	Mode	32	26	3.5	3	26&36	10	9	5.0	71.5	100.0	83.3
& Neck	Median	24	23	0	3		7	9	2.5			

SEWARD

		Temperature (°F) (00 & 12Z)	Temperature (°F) (daily means)	Wind Speed (kts) (00 & 12Z)	Wind Speed (kts) (daily means)	Wind Direction (00 & 12Z)	Cloud (tenths) (00 & 12Z)	Cloud (tenths) (daily means)	Precipitation (mm) (daily total)	% Temp. <32°F (00 & 12Z)	% Temp. <32°F (daily means)	Precip. Probability (%) (daily)
1	Mode	30	34	-	1	0	10	8	1.5	36.3	0	71.5
	Median	36	34	2	1		10	8	.5			
2	Mode	36	34	-	2	0	10	10	T	33.3	36.4	66.7
	Median	36	30	2.5	2		10	9	T			
3	Mode	-	-	-	-	-	10	10	-	66.7	33.3	0
	Median	30	32	1	2		10	10	-			
4	Mode	-	-	-	-	-	-	-	-	-	-	-
	Median	-	-	-	-		-	-	-			
5	Mode	-	-	-	-	-	-	-	-	-	-	-
	Median	-	-	-	-		-	-	-			
Ridge	Mode	42	48	2	2	27	-	10	T	20.0	40.0	11.1
	Median	42	48	2	2		5.5	6	T			
Low, Col	Mode	-	-	-	-	0	10	-	T	50.0	50.0	50.0
& Neck	Median	-	-	-	-		10	-	T			

a) See footnote TABLE XXXVIII

TABLE XL

SUMMARY OF SYNOPTIC SITUATION DURING ANALYSED PERIODS (1965)[a]

PERIOD	PRESSURE CONFIGURATION	FRONTS: Number and Type	FRONTS: Relation to Pressure System	FRONTS: Deflection, Alignment and Stalling	STATIONS AFFECTED BY: Temperature	STATIONS AFFECTED BY: Precipitation	STATIONS AFFECTED BY: Clearing	PERIOD IN GENERAL (compared to averages)
1	Surface: low died in Gulf 500 mb : low died on S coast of Alaska	Trowel at 850-700 mb Upper warm and cold	Preceeded low Passed area in trough in surface ridge	Forced north Became aligned with mountains Cold portion stalled in lower levels	Warming: DIV, KASK WH only 850 mb Cooling: YAK,DIV KASK, KL & WH	YAK to KASK All but KL	DIV,KASK & KL	Continental slope warm Marine slope cool Windy Cloudy
2	Surface: well developed low with trough on SE side - crosses mountains 500 mb : deep low in good position to support surface low	Trowel at ca 700 mb	In trough to SE of low	Passed unaltered Initially $\parallel$ to coast Finally $\parallel$ to longitudes	Cooling: DIV & KASK	All except KL	KASK, KL & WH	Cold Windy (seasonal maxes) Cloudy
3	Surface: ridge 500 mb : ridge and col	None						Warm (except YAK) Clear
4	Surface: low died in Gulf or reformed over Yukon 500 mb : low gives fair support	Odd M front at 850 mb (Trowel) Diffuse cold A front ca. 850 mb.	Preceeded low Passed area in trough in the surface ridge	Warm M: Forced N Initially aligned $\perp$ barrier Cold M: Aligned somewhat $\perp$ barrier during passage Retarded in lower levels	M warming: DIV, & KASK - upper YAK & WH M cooling: All (but only atrend at KL and WH) A cooling: diffuse	YAK, DIV, WH YAK, KASK All but WH	None DIV to WH	Continental slope warm Marine slope cool Windy Cloudy
5	Surface: low S of IRPP - Flow N and E 500 mb : low off YAK - Flow E	None			Cooling: WH, KL, KASK and DIV	All (YAK rather small amount)	All but SEW and DIV	Cool continental slope Windy (except KASK) Cloudy Precip. (high continental slope)
6	Surface: dipole low	M warm, M cold, A cold } at surface	Fronts to S of low moving faster than it	M Warm & Cold: Moved SE Initially $\perp$ barrier Finally $\parallel$ longitudes A Cold: Initially $\parallel$ longitudes. Finally $\perp$ barrier (pivoted by surface flow)	M cooling: All A cooling: All but WH (not yet reached)	All but KASK & KL SEW & YAK		Cool Cloudy Windy
7	Surface: not well defined 500 mb : low S of YAK	Odd 850 (Trowel)	Proceeding to S and moving faster than surface features	1st cold: bulges	1st cold: DIV & KASK (YAK & WH slowly) 2nd cold: All but WH	All but KL YAK & SEW SITKA	KASK, KL & WH KASK & DIV	Cool, Windy } (except for YAK) Cloudy except KASK

a) See Chapter XI for dates

TABLE XLI

SUMMARY OF FLOW - PARAMETER RELATIONSHIPS

	TEMPERATURE		WIND			CLOUD	PRECIPITATION
			SPEED		DIRECTION		
	High	Low	High	Low	(Divide)	(High)	(High)
500 MB	Ridge and from interior	Type 4, 5 and 1	Type 2 or ridge (i.e. prevailing)	From interior col and neck	W.winds -Type 3, 4 and 5 S.winds -Type 1 and 2	Maritime slope - Type 2 Continental slope - Type 5	Maritime slope - from ocean Continental slope Type 1, 5 & ridge
SURFACE	Ridge, from interior and col or neck	Type 2 and 4	Ridge	Col or neck	Flow to wind good direct relationship	Maritime slope - Type 2 Continental slope - Type 5	Maritime slope - from ocean Continental slope Type 1, 5 & ridge

TABLE XLII

SUMMARY OF YEARLY PARAMETER VARIATIONS

YEAR	SUMMER SEASON					ANNUAL	
	Temperature	Wind Speed	Cloud	Precipitation	Circulation	Temperature	Precipitation
1963	Coldest (Aug.hot)		KL cloudy	KL & DIV high	Most northerly cyclones north	Above normal	YAK - very high WH
1964	Warmest (warm June)	Lowest	DIV cloudy SEW clear	Generally high	More cyclones penetrate pass to south	Below normal	YAK - very high WH
1965	Large range	Highest	DIV clear SEW cloudy	KL very low	Cyclone tracks scattered (best agreement with		YAK WH