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PROJECT CHARIOT

MASTER

MICROCLIMATOLOGY OF THE CHARIOT SITE

Interim Report No. 1

June 1, 1960

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Introduction

The Committee on Environmental Studies for Project Chariot, in its meeting on October 8 and 9, 1959, recommended the addition to the Environmental Program of a study of the micrometeorology of the site and vicinity. The purposes of such a study are: 1) to provide sufficient information on the variation of temperature immediately above and below the ground surface and available precipitation to assist in biological studies, and 2) to provide a sufficient background of climatological data that annual variations may be recognized and their effect on the biosphere be analyzed both before and after the Chariot event.

The Weather Bureau Research Station, Las Vegas, in 1958 began a study for forecasting upper winds at the Chariot site as a part of its responsibilities under Memorandum of Understanding SF-54-351, as amended, with Albuquerque Operations Office USAEC, and in August 1959 had assisted in setting up a cooperative weather station at the site with the H & N caretaker as observer. It was decided by AEC in November 1959 that if possible the microclimatological study should be performed under the same agreement, so the responsibility for this study fell on WBRS. Preliminary plans for the study were reviewed by the Committee on Environmental Studies at its Washington D. C. meeting on December 8, 1959, and funds were made available for procurement of equipment and initial project activities on February 15, 1960.

Objectives and scope of the microclimatological study are determined by the Committee, based on requirements for data submitted by individual environmental studies and on estimates of the possible effects on the environment by departures from normal of temperature, precipitation, cloudiness, wind and other weather elements. Technical supervision is provided by Office of Meteorological Research, USWB, assisted by the Office of Climatology. Technical support is provided by the USWB Regional Administrative Office, Anchorage, and logistical support by Holmes and Narver, the AEC support contractor.

This interim report, being the first formal report of this study will include a brief discussion of the usefulness and scope of the data to be taken, and a very general review of some of the features of the area that are likely to influence the microclimate. Although some data are available from the spring microclimatological effort, analysis has not proceeded far enough to be useful and presentation of data is therefore limited to a tabulation of selected elements from the base camp reports since September 1, 1959. A summary of the large scale climatology of the area is included as an appendix.

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General Concept of Study

Considering that the information desired by most environmental projects is the collective state of the atmosphere over a period of time at given locations short distances from the Chariot site rather than the temperature and winds in individual hours or days, this study is properly called microclimatology(1). Studies of micro-meteorology will be made from the same raw data, mostly to help understand the climatology but partly, since the data will be available, to contribute to solution of forecasting problems in the lowest part of the atmosphere.

The World Meteorological Organization has specified that climatological standard normals are mean values for particular periods of 30 years. The variability of meteorological conditions is such that climatologists are reluctant to establish a normal based upon less than 30 consecutive years of data. Consequently, the data summarized during this study can at best be termed only as means for the period of record. The nearest station for which climatological normal temperatures and precipitation are available is Kotzebue(2), although there are several years of record for Point Hope and Cape Lisburne.

Observations made from the base camp are planned to continue through the duration of Project Chariot and will cover all elements from which conclusions may be drawn concerning the monthly and annual variations of climate. Comparison with concurrent observations at first-order weather stations at Cape Lisburne and Kotzebue and with their long-period means, will provide a rough indication of the degree of abnormality of any period of a month or more. Comparisons for shorter periods are not likely to be valid since the distance between these stations is long relative to short-period atmospheric perturbations. The more persistent large perturbations are much more likely to influence the three stations in the same way, although differences in environment and exposure as well as position will have to be considered in any comparison.

The pattern of climatic variations for a single station follows a statistically normal distribution with high latitude stations having some of the largest deviations in temperature. Interior continental regions show larger temperature ranges, diurnal, seasonal and annual, than coastal areas, particularly windward coasts(1,3). For Kotzebue, being not just coastal but almost surrounded by water, the normal annual temperature is 20.6°F but individual years during the last 16 vary from 16.9° to 24.2° (4). The normal annual precipitation there is 8.02 inches but has varied from 6.91 to 13.22 inches in this 16 year period having 9.29 inches for a mean. August precipitation has varied from 1.68 to 5.18 inches about a 16 year mean of 2.82, which is almost an inch above the normal 1.95 inches. This difference between the normal and the mean of the last 16 years might well be due to better measurement facilities during and following World War II. August mean temperatures ranged from 46.0° to 55.0° and January means from -19.0 to $+8.0^{\circ}\text{F}$.

Although climatological normals are assumed to be representative of areas for many miles around the station taking the data, they are accurate for only the precise point of instrument location. Relocation of thermometers over short distances have been known to make large changes in temperature means when the move involved a change in exposure to wind, sun, underlying surface or other modifying influence. Many important differences of this nature exist in the Ogotoruk Valley and while the base

camp station will produce adequate data to establish the variation of temperature, wind and precipitation with time, it could contribute little if anything by itself toward showing climatic differences between different parts of the valley. A network of stations is necessary to do this.

The density of network necessary in any microclimatological study is determined in part by the use to which the information will be put and in part by the available funds. It was pointed out that climatological data are applicable only to the place where taken and the same is true of microclimatological data. Means of observations over a period of time are accurate for that period only. However, some basic principles of air motion, surface condition, and conductivity apply which permit extrapolation and interpolation so long as the basis for such application is explained and the effects of the resulting reduction in accuracy is not too severe. In this study it is desirable that the microclimatological stations be located so as to sample the major differences in climate and the density be sufficient to provide two or more stations per climate type to measure reliability.

At the Chariot site, variations in climate from point to point are expected to be large and to follow well known patterns. Measurements of air and soil temperature, precipitation, snow depth and wind are being made along a line extending from the coast to the pond area to determine the gradients of these elements going inland as shown in Figure 1. The same elements except wind are being measured in two transects of the valley for the slope effects. Small variations of slope exist which are important in the populations and growth of plant and animal species but since the number of variations in slope approaches infinity, the study has been confined to the truly major areas. Solar radiation measurements will establish the amount of energy received at several points and eventually a net radiation measurement will provide a comparison between solar and terrestrial intensities. Wind speeds and directions in the pond, mid-valley, and base camp areas will be compared with those on Crowbill.

Physical Climatology of the Ogotoruk Valley

Coastal effects. The Chukchi Sea, when ice free, is a potential source of heat and moisture which is responsible for large gradients of temperature across the Ogotoruk valley, and which may produce gradients of wind, humidity, precipitation, and clouds also. The influence of the sea varies from day to day depending to a large extent on the direction and speed of the wind. Strong winds toward the sea tend to eliminate its influence almost completely as on numerous days in autumn and winter 1959-60 when subzero temperatures at the base camp coincided with open water and a strong wind from land to sea. Strong winds from sea to land carry mild temperatures and higher humidities far inland. Weak large scale pressure gradients may be associated with weak winds when land and sea are at similar temperatures, but when the temperatures are far different a coastal circulation is likely to develop, with surface winds blowing from the cool to the warm surface, the highest winds occurring at or near the coastline. It is in the cases when a coastal circulation is blowing from sea to land or when winds are parallel to the coast that the largest temperature gradients are likely to occur over the Ogotoruk valley.

When the sea is solidly covered by ice, it still exerts some heating influence by conduction through the ice and thence into the air but the effect is very much less than that of open water. The gradients of wind and temperature over the valley are not likely to be as large when the ice is in as when there is open water.

Altitude Effects. The concept of temperature decreasing with height must be modified when dealing with the climate of the lowest couple of thousand feet of the Arctic atmosphere(4,6). There is a high frequency of low altitude temperature inversions (temperature increasing with height) in the Arctic in all seasons, and the frequency is so high as to be the climatic mean condition in winter. During the long arctic night, conditions are usually favorable for strong terrestrial radiation which lowers temperatures at the surface. In the absence of any appreciable mid-day sun or mechanical upward mixing, the cooling extends upward slowly. Convective currents in sunlight or mechanically induced vertical motion in strong winds may tend to equalize temperatures up to a few hundred feet, and can even produce a lapse (drop in temperature with height) up that far with the inversion remaining in effect just above.

In summer, solar heating raises surface temperatures more rapidly than air temperatures so that convective processes tend to produce strong lapse rates. However, the convective processes are frequently modified by strong winds or thermal advection and then the vertical distribution of temperature near the surface becomes highly variable.

The structure of temperature in the first few centimeters above the dry surface is not expected to be quite as unpredictable as that in the next hundreds of feet above. Shielded somewhat from the wind by vegetation or stones, this thin layer of air is almost certain to have a strong lapse of temperature with height when in strong sunlight, and is likely to have a strong inversion at night when skies are clear. The structure under cloudy conditions will vary with the density of the clouds and with other parameters. Very moist surfaces tend not to have such pronounced vertical temperature gradients immediately above them.

Effect of Exposure to Solar Radiation. The angle of incidence of solar radiation is of primary importance in determining the amount of surface heating produced. References (7,8,15) deal with the effect of slope on temperatures. Higher incidence angles and longer exposures result in higher surface temperatures. The nearly north-south orientation of the Ogotoruk Valley exposes nearly all of the slopes to sunlight at the time the sun is highest in the sky and the largest areas, the valley floor, receive their maximum heating then. Eastward facing slopes, on the west side of the valley receive their maximum heating in the morning, and the opposing slopes in the afternoon. Small sloping areas along the creeks and behind the hills face in northerly directions, never receiving strong solar radiation, and therefore may be expected to have relatively cool climates. The warmest climates will be found on southward facing slopes that are protected from strong winds.

Effect of Soil Heat Conductivity. The distribution of temperature beneath the soil surface will depend on the heating and cooling of the soil surface and the heat conductivity of soil. Solid rock has a high conductivity relative to swamp or wet tundra so that given the same range of surface temperatures the rock will have a higher range beneath the surface than the tundra. Other factors, such as evaporation and the change of soil moisture, can operate to complicate the subsurface temperature distribution. References (7,8) cover this matter in more detail. The proposed classification of soils will be very useful in extrapolating microclimatological data to other parts of the valley.

Effects of Other Meteorological Elements. An interrelationship of climatic and weather elements exists which tends to complicate studies of climate and to seriously hamper the prediction of any one weather element. Fog and clouds interrupt the transmission of solar energy, and wind not only can exchange air masses with different temperatures but together with hills, buildings, and other obstructions cause a redistribution of heat energy within an air mass. Irregular rainfall and snowfall patterns, snow drifts and flooding streams all conspire to superimpose moisture patterns which may never be repeated within the period of interest.

Effect of Surface Condition. The color of the surface, the vegetation, and the moisture at the surface all affect the heat exchange. Dark colored surfaces absorb more radiation than light surfaces. Vegetation not only interrupts the path of radiation but affords a means of evaporative cooling, as does a moist surface. Reference (7) describes "typical" temperature distributions about plants. Both thermal conductivity and heat capacity increase with soil moisture.

Weather Summary - Base Camp

Weather observations were made at the Chariot Site during the summers of 1958 and 1959 by U. S. Geological Survey and have been summarized by them(12). Observations were begun by the Holmes and Narver caretaker in late August 1959. Table 1 summarizes this data by months, the daily summaries having been distributed to program participants on a regular schedule. Mean temperatures for individual months at the Site were well below the means available for Point Hope for about 8 years, except that February and March were above the Point Hope means. Point Hope's position well out in the Chukchi Sea undoubtedly modifies its climate. The base camp, being 120 miles farther north than Kotzebue, would be expected to be colder. The months of September, October and November were within 3.3° of the Kotzebue means for those months in 1959. December and January were significantly colder than Kotzebue while February was significantly warmer. Kotzebue means for March and April have not been received yet.

Project Status

Arrival dates for field personnel at the base camp were Donald Willson on April 15 and Robert Nickerson on May 22, 1960. Mr. Willson immediately took over the weather observation duties that had been handled so well all winter by Mr. Harry Spencer of H & N. Willson began making upper level wind observations using pilot balloons tracked by theodolite and began installation of weather instruments. Summarization and analysis of data at the Las Vegas station are being done by Meteorologist Robert Weedfall and technician Marjorie Davis.

The soil thermometers that were to be used on the project are being built by the Palmer Thermometer Company and are hydrocarbon-in-steel (hydrocarbon temperature sensitive fluid in a steel casing with a 5-foot flexible steel encased capillary). The hydrocarbon activates a pointer on a dial with max-min pointers. These instruments were selected because they are max-min type, are rugged, portable, reliable and have satisfactory accuracy for microclimatological work (11). Each instrument is checked by the Weather Bureau Instrumental Engineering Division to insure scale error of less than $\pm 1^{\circ}\text{F}$. However, production delays and calibration checking have

prevented installation on schedule. In the meantime, thermocouple systems have been obtained from SIPRE and have been installed subsurface at -5 cm at most of the proposed stations in the Ogotoruk Valley and at all four standard depths at three stations. Daily readings of these do not provide max-min or daily mean temperatures but will permit initial comparisons of soil temperatures in the respective sampling areas. Discussions of various thermometers for this purpose are contained in references 11, 13 and 14. As of the date of this report, except for the Palmer thermometers and sunshine recorders which have not arrived at the site, nearly all of the instruments have been installed as indicated in Figure 1 and Table 2.

Sets of sunrise-sunset tables, duration of sunshine tables, and elevation of sun tables are being prepared for the Chariot site and will be distributed to environmental program participants as well as other programs.

Future Work

Arrangements are being made to start wind, temperature, and sea condition (including ice) observations at Kivalina as soon as equipment can be shipped and installed. Miss Doris Saario, Univ. of Alaska, has agreed to assist in this work.

Continuously recording soil thermometers are scheduled for installation during the summer near the test holes Able and Baker, and at three other stations in the lower end of the valley. Full year temperature traces will be available from these sites if all goes well.

REFERENCES

1. Landsberg, H., Physical Climatology. Gray Printing Co. (1958)
2. Watson, C. E., Climates of the States, Alaska. Climatography of the U. S. No. 60-49. (Sept 1949) U. S. Dept. of Commerce Weather Bureau.
3. U. S. Dept. of Commerce, Weather Bureau. World Weather Records 1941-1950(1959).
4. U. S. Dept. of Commerce, Weather Bureau, Local Climatological Data with Comparative Data, Kotzebue, Alaska, (1958).
5. Reed, Richard J., Arctic Weather Analysis and Forecasting. Univ. of Washington. (1957)
6. Watson, C. E., Alaska Climatologist. U. S. Weather Bureau, Anchorage, Alaska. Private communication. (April 1960)
7. Geiger, R., The Climate Near the Ground. Harvard University Press. (1957)
8. U. S. Air Force, ARDC, AFCRC, GRD. Handbook of Geophysics for Air Force Designers, (1957).
9. Hare, F. Kenneth and Svenn Orvig, The Arctic Circulation. Arctic Met'l. Res. Group, Publ. in Meteor. No. 12. McGill University (June 1958).
10. U. S. Dept. of Commerce, Weather Bureau, Normal Weather Charts for the Northern Hemisphere. USWB Technical Paper No. 21. (1952).
11. Larson, W. E., Burrows, W. C., and Hazen, T. E., Equipment and Methods for Measurement of Soil Temperature. Agricultural Research Service ARS41-27, U. S. Dept. of Agriculture (March 1959).
12. Kachadoorian, R. and others, Geologic investigations in support of Project Chariot in the vicinity of Cape Thompson, Northwestern Alaska, Preliminary Report. USGS, TEI-753 (January 1960).
13. Grinnell, S. W., Micrometeorological Instruments and Methods. Stanford University (June 1955).
14. Thornthwaite, C. W., Micrometeorology of the surface layer of the atmosphere. Johns Hopkins University, Laboratory of Climatology Interim Report series (1948-50).
15. Baw-Puh, F., The Influence of the slope on the sunniness. Scientia Sinica. Vol. VIII, No. 7, 1959.

TABLE 1. WEATHER SUMMARY - CHARIOT SITE

	1959				1960			
	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.
Average monthly temperature	37.4°	21.3°	5.8°	-15.6°	-11.2°	4.0°	2.0°	1.2°
Highest temperature (date)	56(3,4,14)	45(1)	33(12,13)	9(1)	32(24)	34°(18)	39°(3)	44°(30)
Lowest temperature (date)	14(23)	-4(20,31)	-15(21)	-37(30)	-38(15)	-23°(12)	-28°(18)	-21°(5)
Number of days with max 32° or below	1	19	28	31	31	27	31	29
Number of days with min 32° or below	21	28	30	31	31	29	31	30
Number of days with min 0° or below	0	2	19	30	27	18	25	24
Total degree days (base 65°)	821	1327	1736	2415	2406	1767	1949	1916
Total degree days since 9/1/59	821	2148	3884	6299	8705	10,472	12,421	14,337
Total precipitation for the month	0.50	0.46	0.57	trace	0.10	0.12 in.	0.04 in.	0.27 in.
Most precipitation in 24 hrs.(date)	0.50(29)	0.16(1)	0.40(27)	trace	0.05(5)	0.04(5)	0.02(3,4)	0.18(23)
Total snowfall or sleet	trace	5.0	8.0 in.	trace	2.75 in.	1.87 in.	0.5 in.	2.85 in.
Greatest depth on the ground(camp)	trace	2.5 in.	5.0 in.	5 in.	5 in.	6 in.	6 in.	8 in.
Number of days:								
Clear	15	10	19	27	19	12	22	11
Partly cloudy	5	11	4	1	4	10	6	8
Cloudy	10	10	7	3	8	7	3	11
with 0.01 inch or more precip.	0	10	4	0	4	4	2	3
with 0.10 " " "	0	1	1	0	0	0	0	1
with 0.50 " " "	1	0	0	0	0	0	0	0
Aurora reported	0	0	3	9	0	3	6	1
Sea frozen over(except few leads)	0	0	1	12	18	20	31	30
Wind from N, NNW, NNE	20	23	23	30	27	15	25	25
Avg. wind speed 15 knots or more	12	10	21	21	22	22	15	19
" " " 25 " "	3	4	13	7	12	8	4	9
" " " 35 " "	2	1	4	2	7	2	0	2

TABLE 2.

MICROCLIMATE STATION SCHEDULE

<u>Station No.</u>	<u>Location</u>	<u>Instrumentation</u>
37	68° 11' 30" 165° 42' 55"	a b d e f g h i j l
19	68° 09' 06" 165° 38' 25"	a b g h
50	68° 09' 30" 165° 45' 40"	a b g h
49	68° 08' 40" 165° 44' 15"	a b g h i
47	68° 08' 11" 165° 43' 12"	a g g h
45	68° 08' 13" 165° 41' 51"	a b d e f g h i l
51	68° 08' 35" 165° 39' 40"	a b g h
9	68° 07' 09" 165° 47' 00"	a b g h
4	68° 06' 44" 165° 45' 50"	a b c g h
6	68° 06' 37" 165° 44' 54"	a b c g h i
31	68° 06' 30" 165° 43' 30"	a b c g h
101	68° 06' 42" 165° 41' 30"	a b g h
100	Base camp	a b c d e f g h k l m n
102	68° 07' 50" 165° 46' 25"	k
103	68° 06' 18" 165° 48' 08"	b l

INSTRUMENTATION KEY

- a. Palmer Max - Min thermometers, soil, -5, -10, -20, -50 cm.
- b. Palmer Max - Min thermometers, air, +5, +50 cm.
- c. SIPRE soil thermocouples, -5, -10, -20, -50 cm.
- d. Cotton region instrument shelter
- e. Hygrothermograph
- f. Glas. Max - Min thermometers, Townsend support
- g. Precipitation gage
- h. Snow depth and density measurements
- i. Wind speed recorder
- j. Wind direction recorder
- k. Wind speed and direction indicator
- l. Pyrheliograph
- m. Pyrheliometer
- n. Barometer

Figure 1. Microclimatological station network, showing positions relative to creek, lakes, and steep slopes.

APPENDIX

Climate of Northwestern Alaska

The climate of Alaska is divided roughly into four major divisions:

1. Southern Maritime Division; 2. West Central Division; 3. Interior Basin Division; 4. Arctic Drainage Division. Northwestern Alaska is in the Arctic Drainage Division(2)*. Geographically, this Division includes all land bordering on the Arctic Ocean and the Chukchi Sea to the southwest, and includes the northern half of the Seward Peninsula (the point of the Alaskan mainland closest to Siberia), the Kotzebue drainage area, and the area including and to the northwest and north of the Brooks Range. This low range of mountains (average elevation 5000 feet, with a few peaks to 10,000 feet) divides the Arctic Drainage Division from the more continental-type Interior Basin Division, which adjoins northwestern Canada, and is where the most pronounced temperature extremes exist. Otherwise, the tundra land is composed of low hills varying in elevation from 1000 to 2000 feet.

Although the Arctic Drainage Division exhibits some characteristics of a continental climate, its temperature extremes, although large, do not show the variation that the inland Interior Basin has. These winter temperatures, especially north of the Brooks Range, are lower than would ever be experienced in a truly maritime climate where an open body of water exists. The first ice generally appears along the shore at Barrow in late September and becomes fast in early October, breaking up by mid or late July. Ice first appears in Kotzebue Sound in mid-October, with the freezeup in late October or early November, and the breakup in late June. Somewhat limited reports indicate sea ice normally to be safe for man at Point Hope and Kivalina by late November(6). Spring breakup is normally around May 19 at Kivalina and June 24 at Point Hope. Although some heat appears to escape through the vast ice layer covering the Arctic Ocean in winter, the adjoining coastal areas naturally exhibit more features of a continental type climate, with extreme cooling of the air by uninterrupted terrestrial radiation during the long winter periods of darkness. Extreme lows for individual stations range generally between -45° and -60°F. Only one station in five has a record low of -60°F or colder, and about two in five have failed to reach -50°F. In contrast, in the Interior Basin Division, only one station in 10 has failed to go below -50°F, while Tanana holds the record low of -76°F and Fort Yukon follows closely with -75°F. The coastal area of Kotzebue Sound has less severe cold than the areas north of the Brooks Range; none of the stations near Kotzebue have ever experienced temperatures below -50°F. The lowest ever recorded at Kotzebue was -48°F.

The extreme high temperatures are also less pronounced in Northwest Alaska than the Interior Basin stations. They have never risen above the eighties except at Shungnak (66° 54' N, 157° 02' W), where 90°F was recorded in 1916. Kotzebue had an all-time high of 82°F in July of that year, whereas inland Fort Yukon holds the record high temperature for all of Alaska with 100°F. Readings in the nineties in the Interior Basin are common. About half of the stations in the Arctic Drainage Division have never reached 80°F. Thus, it can be seen that the cold Arctic Ocean has a somewhat modifying effect on temperature extremes and average temperatures, especially in the summer months. This in spite of the prolonged period of continual daylight and a greater amount of possible sunshine. However, during these longer summer days, little surface heating is realized because of the low angles of the sun's rays.

* See reference list following Interim Report.

It may be appropriate to note the varying periods of total daylight and darkness in the Arctic Drainage Division. In the Kotzebue area, the sun is above the horizon from June 2 through July 9. It does not fall below the horizon in winter, although on December 21, the shortest day, it rises at 1059 and sets at 1239. At the northernmost station, Barrow, the sun is above the horizon from May 10 through August 1, and is below the horizon from November 19 through January 23. It can be seen that each degree of north latitude has quite a bit more total sunshine and total dark days because of the extreme angles of the sun.

Summarizing the temperature regimes more in line with the points of view of the agronomist and biologist, the length of the growing seasons (if any) should be mentioned here. The average freeze-free season at Kotzebue is just below 90 days, while in the Shungnak area, upriver from Kotzebue, it averages 65 days. The coastal areas north of the Brooks Range, however, have average minimum temperatures below freezing all months of the year. Umiat, 75 miles from the coast, has a freeze-free season of about 40 days, and sub-freezing temperatures every month every other year. By way of contrast, the freeze-free season in the Interior Basin Division starts about May 20 and ends in late August.

As the Arctic Ocean does not display a typical maritime influence on the Arctic Drainage Division because it is frozen most of the colder months of the year, the low amount of precipitable water vapor in the air (in all seasons of the year) does not produce the excessive amounts of precipitation characteristic of a truly maritime climate. It is difficult to measure the true amount of snowfall during windy periods because a considerable amount of drifting snow may be collected, but the accepted precipitation totals show extremely light precipitation over the Arctic Drainage Division. The annual total received in the Cape Lisburne station is about 16 inches and is the greatest for the Division, as annual totals over most stations average from 4 to 10 inches. Kotzebue, although sheltered from moisture-laden southwesterly winds, still receives an annual average of 8 inches. Kotzebue receives only 40 inches of snow annually, as a lesser proportion of its precipitation is snowfall, because of its higher average temperatures. Cape Lisburne averages 65 inches of snow, while the area to the east of Cape Lisburne to the Brooks Range averages 50 inches annually.

Precipitation is brought into the Arctic Drainage Division by the migratory low pressure systems which occasionally frequent the area(5). In summer, a major zone of frontal activity associated with strong cyclonic disturbances appears along the rim of the Polar Basin from Siberia, moving just north of Alaska and then eastward to the Canadian Archipelago. Another minor storm track is from the Bering Sea, directly across the Arctic Drainage Division, to the north of the Brooks Range, and then eastward into Baffin Bay. The broad thermal contrasts set up between the land and ice boundaries are the ultimate cause of most of these storms. These summer frontal systems behave quite similar to the mid-latitude winter systems. In the colder months, the main storm tracks with their associated frontal systems are much further south. The systems which do enter the Arctic Ocean area are generally remnants of old occlusions which, because of the extremely cold air over the ice surface layer, move across as upper fronts. During the past decade, synoptic analysis of the Arctic Ocean area has made important strides, but is still hampered by the scarcity of reporting stations in the Arctic Ocean. The persistent low-level inversion makes it difficult to spot frontal systems. The old occluded cyclones or cold lows are more common in polar regions, but since they do not possess the

sharp features of the maturing disturbances, they can be difficult to delineate, especially in regions of sparse data. In the winter months, many of the main Pacific storms reach their greatest development in the Bering Sea or the Gulf of Alaska and move easterly into the North American coast, having little effect on the Arctic Drainage Division. A minor storm track from a cold low in the Bering Sea occasionally moves northwestward over the Chukchi peninsula of Siberia just north of the Drainage Area and on into Baffin Bay. Another minor storm track will move out from a cold low in the Kara Sea (north of Russia), and swing northward across the pole and on into Baffin Bay, but its track is much further north of the Arctic Drainage Division. These storm tracks are based on a limited record and have not been completely verified yet.

No climatological discussion would be complete without mention of wind, of which there is an abundance in the Drainage Area. More high surface winds exist in the Drainage Division than the other Divisions of Alaska and can mostly be accounted for by the pressure gradient existing over the area. The topography plays a part in enhancing the velocity from a preferred direction in many places. Thus, as a general rule, when the pressure gradient is relatively strong and orientated in a preferred direction with respect to the local topography, strong winds may be expected. For instance the coast from Barrow to Barter Island is occasionally visited by strong, persistent winds in winter which blow parallel to the coast, either easterly or westerly, with the Brooks Range to the south acting as a barrier. Speeds of 50-60 mph are not uncommon. To the west of the Brooks Range, from Cape Lisburne to the Kotzebue area, the preferred direction based on limited records, seems to be northeasterly or northerly. These winds result in prolonged periods of blowing and drifting snow which makes the winter season in the Arctic Drainage Division one of very disagreeable weather.

* Observers of sea ice conditions at the Chariot Site and other stations from Kotzebue to Barrow during the autumn of 1959 concur that the ice became firmly established much later than usually, becoming safe for man well after January 1st 1960 south of Cape Lisburne. Two possible explanations have been offered for this. With mean temperatures for Oct. 1959 to Feb. 1960 being near or below normal (6) the late ice might have been due to short periods when temperatures were raised much above seasonal. A more likely explanation is found in the season's pressure gradients which were at least twice as strong as the 10 year mean (9,10), tending to produce stronger winds toward the sea, keeping the ice blown away from the coast.

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