Some Features of the Summer Climate of Interior Alaska

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ABSTRACT. A comparative analysis is made of the distribution of long term monthly mean temperature and precipitation data for three representative locations in the Alaska interior basin. Examples of extreme monthly conditions over the region are selected by reference to the record at Tanana dating back to 1903. The characteristics are outlined of the mean monthly orientations of the 700-millibar troughs and ridges and also the patterns of geopotential anomaly associated with summer months which exhibit extremes of warmth, cold, moisture and dryness. A comparison is made between these patterns and those that have been postulated for the time of the maximum Wisconsin glaciation.

RÉSUMÉ. *Quelques caractéristiques du climat estival de l'Alaska intérieur.* L'auteur mène une analyse comparative de la distribution à long terme de la température mensuelle moyenne et des données de précipitation pour trois localités représentatives, dans le bassin intérieur de l'Alaska. Il choisit des exemples de conditions mensuelles extrêmes sur toute la région, par comparaison avec les données de Tanana qui remontent à 1903. Il décrit les caractéristiques des orientations mensuelles moyennes des creux et des crêtes barométriques de 700 millibars et les dessins des anomalies géopotentielles de 700 millibars associées aux mois d'été chauds, froids, secs et humides extrêmes. Il compare ces caractéristiques et celles qui ont été postulées pour le maximum de la glaciation de Wisconsin.

РЕЗЮМЕ. *Некоторые особенности климата Внутренней Аляски в летний период.* Проведен сравнительный анализ распределения многолетних среднемесячных температур и осадков, измерявшихся в трех показательных точках внутреннего бассейна Аляски. Путем сравнения с данными, собранными в Танане за период начиная с 1903 г., отобраны примеры экстремальных месячных величин для всего района. В общих чертах представлены характеристики ориентаций осей ложбин и гребней при 700 миллибарах, а также диаграммы геопотенциальных аномалий при 700 миллибарах, соответствующие экстремальным теплым, холодным, влажным и засушливым летним месяцам. Проведено сравнение полученных диаграмм с теми, которые постулируются для периода максимального висконсинского оледенения.

INTRODUCTION

The interior basin of Alaska (Fig. 1) lying between the Brooks and Alaska Ranges, and drained by the extensive Yukon-Tanana system, represents a region of extreme continentality of climate located at a high latitude. The area is primarily one of low rolling hills and broad river valleys, with spruce and birch forest at low elevations, and tundra type vegetation on the higher hills and on the foothills of the ranges. The wide longitudinal extent of the Brooks range is effective in blocking the intrusion of air from the Arctic Ocean into the interior, and the Coast Mountains, Alaska Range and Kuskokwim Mountains provide a more complex, if less

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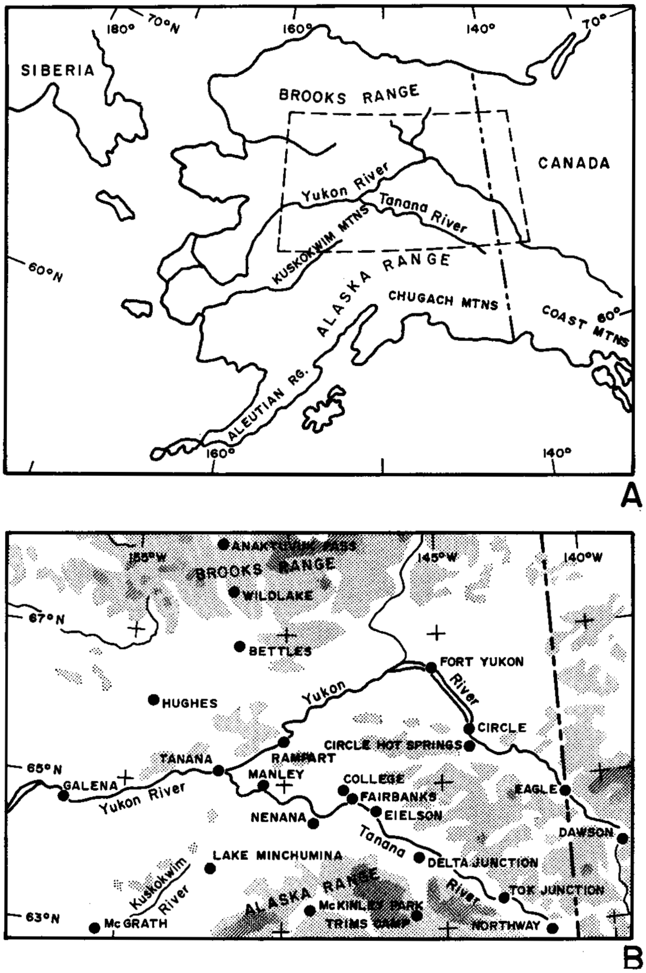

FIG. 1. A) Alaska showing the principal mountain ranges.
B) Topography of the interior basin of Alaska showing selected meteorological observing stations. Light shading indicates land over 3000 feet (915 m.); heavy shading land over 6000 feet (1830 m.).

effective, barrier to the incursion of warmer and moister air from the North Pacific.

The topographical influences on the climate are most noticeable in winter when, under conditions of prolonged calm, extremely low temperatures persist in the interior (Searby 1968; Streten 1969), and low-level inversions in the presence of human habitation provide suitable conditions for the development of ice fog (Benson 1965; Wendler and Jayaweera 1972). During the summer also, however, the continentality of the climate and the interaction between the topographical influences and the general hemispheric long wave patterns produce interesting contrasts in monthly mean conditions.

The summer climate at high latitudes (and in particular the mean temperature) is important, not only as the controlling influence on the growing period of natural and artificial vegetation, but also for the study of the disappearance of the seasonal snow cover and the wastage of glaciers. Analysis of the variation in summer climate is critical in attempting to determine the onset or cessation of climatic fluctuations — the shorter warm and cold epochs and, in the longer time span, the major ice ages and interglacials.

For the purpose of examining the temperature and precipitation distribution of the region, three locations having relatively long records in the natural environment have been selected:

(1) Tanana (65°10′N., 152°06′W., elevation 232 ft. (71 m.); record dating from 1903.
(2) Fort Yukon (66°33′N., 145°12′W., elevation 443 ft. (135 m.); record dating from 1917.
(3) McKinley Park (63°43′N., 148°58′W., elevation 2070 ft. (631 m.); record dating from 1923.

These stations were previously used elsewhere (Streten 1969) for examination of winter temperatures in the region.

Tanana and Fort Yukon are fairly representative of temperature conditions in the river valleys, the latter station being more continental by reason of its location on the vast Yukon flats, surrounded by relatively low but meteorologically significant hills. McKinley Park station gives some indication of conditions at higher elevation. Although there are substantial variations in the day-to-day summer distribution of precipitation across the region, induced by the variations in topography and exposure and by the convective nature of the rainfall in this season, the general nature of the records of monthly precipitation is reflected in the observations at the three stations. In particular, Tanana is fairly representative of most of the low-level Tanana and Yukon valleys so far as extremes of monthly precipitation are concerned.

In the following analysis the units which are commonly used in the United States for meteorological purposes have been employed. However, for the annual distributions (Figs. 2 and 7) corresponding metric values have also been included.

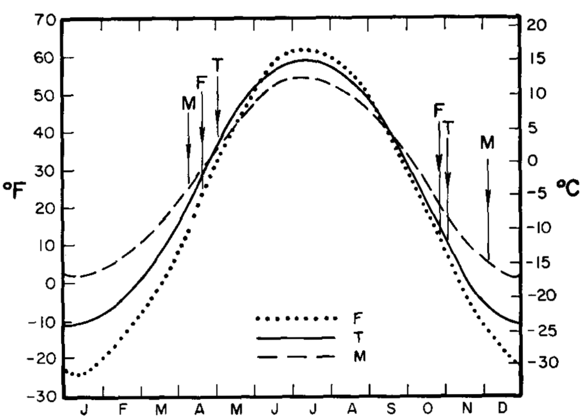

FIG. 2. Annual course of mean monthly temperature (°F and °C) at Tanana (T), McKinley Park (M), Fort Yukon (F), (1931-60 data). Arrows point to mean dates of ice break-up and freezing on the rivers at each site.

TEMPERATURE

The annual course of mean monthly temperature at the three stations, as shown in Fig. 2, is based on the 1931-60 standard period (adjusted from a shorter period for Fort Yukon). The higher level station (McKinley Park) exhibits a mean temperature on the average some 7°F cooler than that at Fort Yukon in July, with a striking reversal in mid-winter when it is over 25°F warmer. Also shown in the figure are the average dates of break up and freezing of the rivers at the three locations — the Nenana at McKinley Park, the Tanana above its junction with the Yukon at Tanana, and the Yukon at Fort Yukon. It will be seen that the duration of the period between breakup and freezing is considerably higher at McKinley Park (239 days) compared with Tanana (185 days) and Fort Yukon (189 days).

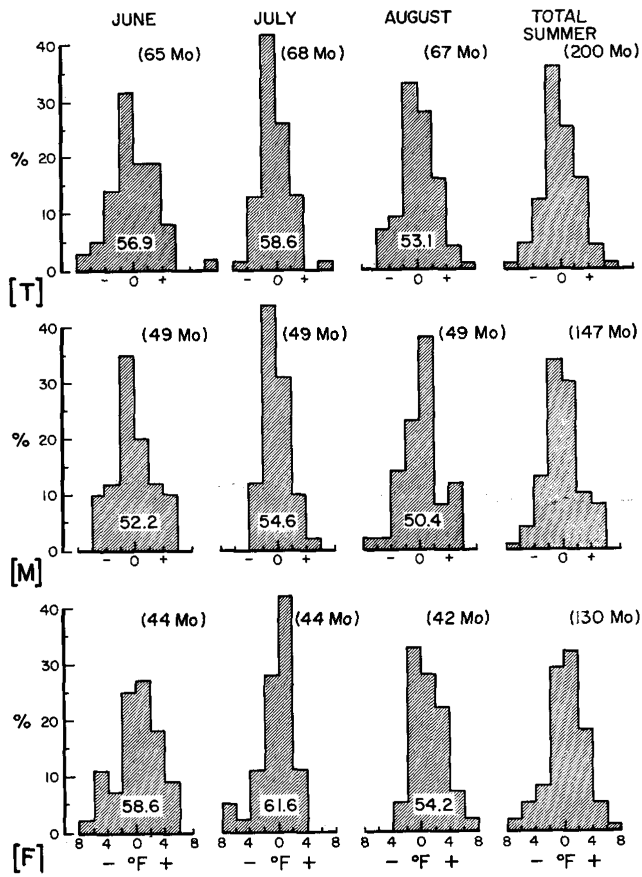

FIG. 3. Histograms of the distributions (per cent) of the departures from normal (°F) of mean monthly temperature for all summer months of record at Tanana (T), McKinley Park (M), Fort Yukon (F). Mean temperature (°F) for the 1931-60 period for each month is shown on the respective histograms.

However, for the purposes of analysis of the warm season temperature distribution summer is defined as the months June, July and August. In Fig. 3 is shown the distribution of the departure from the 30-year normal, for all months of record at the three stations, expressed as percentages of months falling within particular departure ranges. The frequency of larger positive departure (warmer months) is, in general, considerably greater in June and August than in July. Larger negative departures (colder months) occur more frequently in June, corresponding to months with late melting periods. On the average, 13% of summer months at Fort Yukon and McKinley Park have departures from the normal of mean temperature of $\geqq +4°F$, $\leqq -4°F$. The corresponding figure for Tanana is 11%. Departures from normal for the extreme months over the 200 months of the Tanana observations are given in Table 1.

The temperature distribution over the whole region for typical warm (1972) and cold (1969) August months of the Tanana record, when an optimum number of observations are available, are shown in Fig. 4. The warmer air lies along the river valleys, with lower temperatures on the ranges to the north and south.

TABLE 1. Months of extreme mean temperature in summer: departures from normal of ≥ + 4° F, ≤ − 4° F at Tanana.

Warm months			*Cold months*		
Year	Month	Departure from normal (°F)	Year	Month	Departure from normal (°F)
1904	June	+5.7	1904	August	−4.9
1904	July	+6.7	1912	June	−4.4
1906	June	+10.8	1919	June	−7.6
1913	June	+4.3	1922	June	−4.1
1923	August	+6.7	1922	July	−5.7
1941	August	+4.1	1933	June	−5.3
1942	June	+4.1	1947	August	−5.1
1957	June	+4.8	1948	August	−4.1
1957	August	+4.2	1949	June	−7.4
1959	June	+4.0	1952	August	−4.9
1972	August	+4.5	1963	June	−4.5
Average		+5.4	1969	August	−5.2
			Average		−5.3

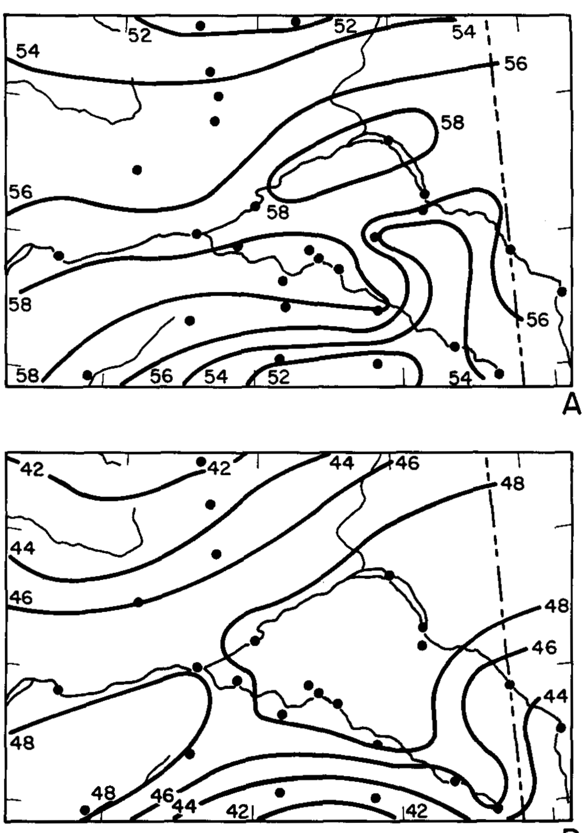

FIG. 4. Mean temperature distribution (°F) in August over central Alaska in 1969 (A) and 1972 (B). Dots show locations of temperature recording stations.

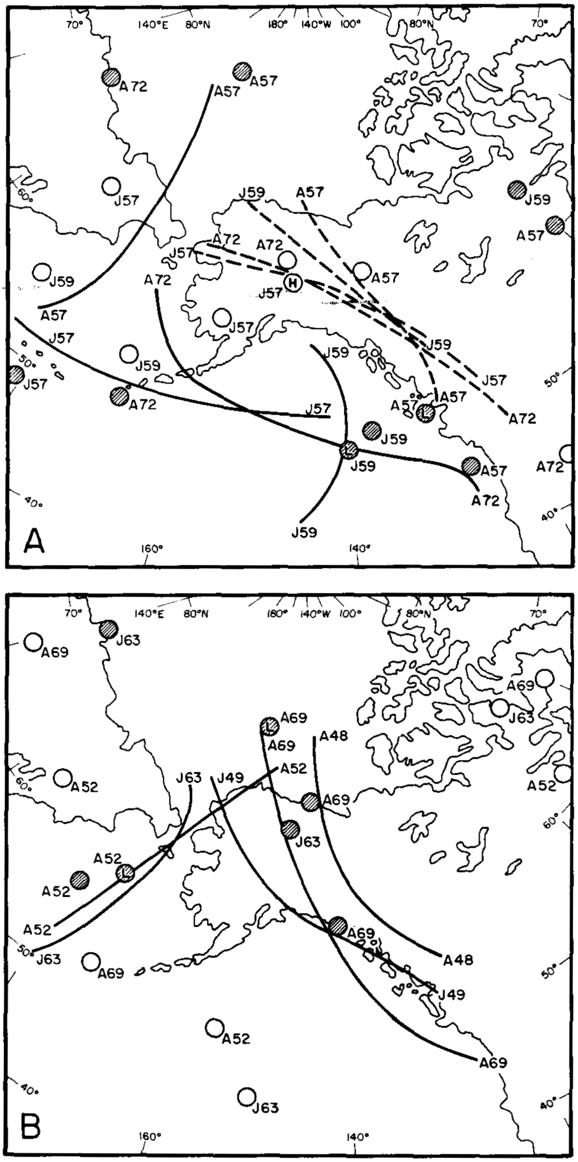

FIG. 5. Location of principal 700-millibar features on maps of mean monthly conditions during: A) "warm" summer months, B) "cold" summer months. Full lines indicate troughs; broken lines — ridges. Shaded circles show location of centres of negative geopotential anomaly and lows (L); open circles show those of centres of positive anomaly and highs (H). Months and year (subscript) are indicated on each feature.

Circulation patterns associated with warm and cold years may be conveniently examined in terms of the mean monthly atmospheric flow at the 700-millibar level and the associated anomalies of geopotential at that pressure. Such data have been published by the U.S. Weather Bureau for many years in the *Monthly Weather Review*. The months in Table 1 which have occurred during the past twenty five years (1948-72), for which reasonably reliable charts are available, have been used for an examination of the characteristics of these patterns. In Fig. 5 are shown the locations of significant 700 mb. trough and ridge axes on the charts of mean conditions for the selected months, and the locations and signs of the corresponding height anomalies.

Warm months (Fig. 5A) are associated with strong mean ridge axes extending from the Yukon Territory to the Bering Strait, and with positive height anomalies across central Alaska extending in some cases to Siberia and the western Bering Sea. Corresponding negative anomaly centres are located near the latitude of 50°N. south of the Gulf of Alaska and, in some cases, quasi-zonally oriented monthly mean troughs lie through this region so as to intensify the ridge pattern over the centre of the State. The wave length is short, and the pattern is associated with the advection of warm air from the southeast to south-southeast and often over a substantial land trajectory. The long hours of incoming radiation of summer and the trajectory of the warmer Pacific air over a number of extensive mountain ranges, with consequent adiabatic warming (Foehn effect) before final movement into the interior basin, results in high mean temperatures. Such a trajectory further results in quite dry air at the lower atmospheric levels over the interior and this effect, combined with the subsidence pattern of the ridge, inhibits the formation of substantial cloud which would effectively reduce incoming shortwave radiation. Individual days with extremely high temperatures are quite frequent in interior Alaska. Mean maximum temperatures over the valleys range from 72°F to 76°F in July, but days with temperatures reaching the mid-nineties over the whole area are sometimes observed. A recent example was the period of 15-16 June 1969, when temperatures over 90°F were observed throughout the region (*e.g.* Fairbanks 96°F, Tanana 94°F, Fort Yukon 92°F, McKinley Park 90°F, Nenana 93°F). Fig 6. is an isobaric chart for 1200 hours G.M.T. on 15 June 1969. Warm air has been advected from low latitudes in the North Pacific under the influence of a large complex depression in the North Pacific and an elongated ridge along the meridian of 130°W. A marked lee trough lies over the Alaska Range, and the warm air is being passed over the highlands and travels down the valleys from the east and southeast. Searby (1968) quotes a temperature of 100°F as having been

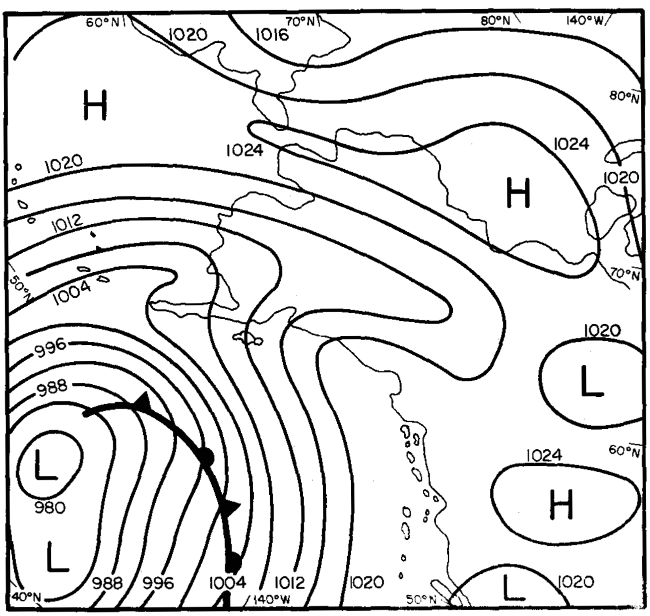

FIG. 6. Surface isobaric chart (millibars) for 1200 hours G.M.T., 15 June 1969.

reached on 27 June 1915 at Fort Yukon — the highest ever recorded under proper exposure conditions in Alaska, though Frost (1934) gives an interesting summary of non-standard observations of higher temperatures by early expeditions into the interior.

The cold months (Fig. 5B) are associated with trough development and with negative geopotential anomalies at 700 mb. over Alaska or to the west in the Bering Strait region. Positive anomalies are in evidence to the south of the Aleutian Chain and to the west over Siberia. 700 mb. anomaly data are not available for August 1948 or June 1949, though the pattern of depression tracks in the latter month clearly points to low surface pressures over the interior of Alaska. The trough orientations are not uniform in location but are, in general, such as to favour inflow of air from the Arctic Ocean or the Bering Sea, with trajectories from the northwest or west. Such cold air advection, with the maintenance of a substantial cloud cover favoured by the vertical motion pattern of the trough, leads to low monthly mean temperatures. In the June 1963 and August 1952 cases the troughs are also in a favourable location for the production of heavy monthly rainfall and cloudiness in the valley. The former month is also a "wet" month at Tanana, as defined below.

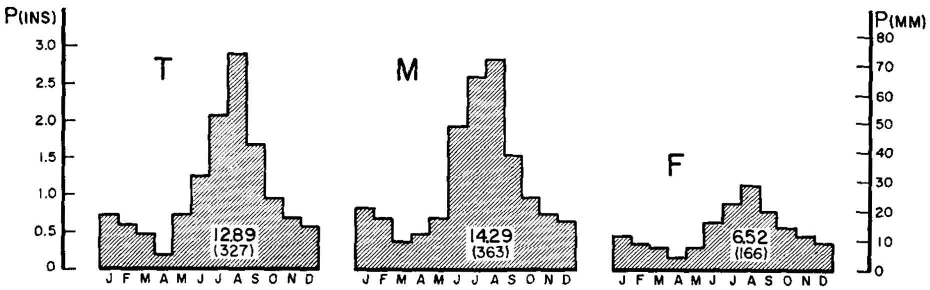

FIG. 7. Mean monthly precipitation distribution in inches and millimetres at Tanana (T), McKinley Park (M), Fort Yukon (F). Annual mean total in inches and mm. is shown on each histogram (1931-60 data).

PRECIPITATION

Interior Alaska experiences very low annual precipitation. The mean (1931-60) monthly totals for the three stations are shown by the histograms of Fig. 7. "Summer" as defined by the temperature curve of Fig. 2 does not coincide with the period of higher precipitation which extends into September, although nearly 50% of the annual total is recorded between June and August. The summer precipitation in the valleys is principally in the form of rain, except for occasional snowfalls on the higher hills. Rainfall is largely derived from activity of a convective type, and thunderstorm falls varying greatly in time and space are a notable feature of the climate of the summer months. Widespread rains are associated with synoptic scale developments — frequently on the zone of baroclinicity lying close to the north coast of Alaska and forming part of the axis of the Arctic Front (Reed and Kunkel 1960). Substantial rainfall requires the invasion of the interior by moisture in considerable depth, and originating in lower latitudes of the North

Pacific. An example of such development, which results in flood rains in the region of the Chena River catchment near Fairbanks, is given elsewhere (Streten 1967).

To examine the variations from normal (1931-60) monthly rainfall, the individual monthly totals for all years of record have been divided into decile ranges, "wet" months being defined as those falling within the tenth decile and "dry" months those falling within the first decile. Data on the rainfall totals are shown in Table 2. The details concerning the extreme months, taken from the long-term Tanana record, are shown in Table 3.

An example of extreme precipitation conditions over the entire area, taken from the lowest and highest decile ranges at Tanana, is given in Fig. 8 for years when a good network of observations was available. It may be noted that, even with heavy

TABLE 2. Monthly precipitation in summer in units of 0.01 inch (0.25 mm.) at interior Alaskan stations.

Pm: 30 year (1931-60) — normal precipitation

Pm_{10}: Mean of monthly totals falling in the highest decile (10)

Pm_1: Mean of monthly totals falling in the lowest decile (1)

Px: Highest monthly total

Pn: Lowest monthly total

Station	Month	Pm	Pm_{10}	Pm_1	Px	(yr.)	Pn	(yr.)
Tanana	June	125	274	19	496	(1932)	7	(1957)
	July	207	481	60	580	(1922)	7	(1950)
	August	291	530	80	683	(1963)	23	(1940)
McKinley Park	June	193	449	40	510	(1970)	8	(1969)
	July	259	584	93	739	(1967)	76	(1955)
	August	281	581	68	684	(1930)	46	(1926)
Fort Yukon	June	64	215	14	269	(1945)	7	(1950)
	July	89	227	8	285	(1960)	0	(1968)
	August	114	260	24	296	(1930)	6	(1949)

TABLE 3. Extreme dry (1st decile) and extreme wet (10th decile) months at Tanana, Alaska.

Dry months			*Wet months*		
Year	Month	Percentage of normal	Year	Month	Percentage of normal
1908	August	39	1904	July	236
1911	June	22	1917	July	250
1913	June	16	1918	June	176
1914	August	25	1922	July	280
1917	August	36	1924	July	187
1921	July	45	1928	June	176
1923	August	15	1930	August	234
1931	July	30	1932	June	395
1940	August	8	1936	June	175
1950	July	3	1938	August	204
1950	August	31	1941	July	217
1951	June	10	1945	August	190
1953	July	44	1948	July	224
1957	June	6	1955	June	178
1968	June	22	1962	August	152
1968	July	24	1963	June	210
1969	June	15	1963	August	170
1969	August	37	1965	August	150
1972	July	27	1967	August	174

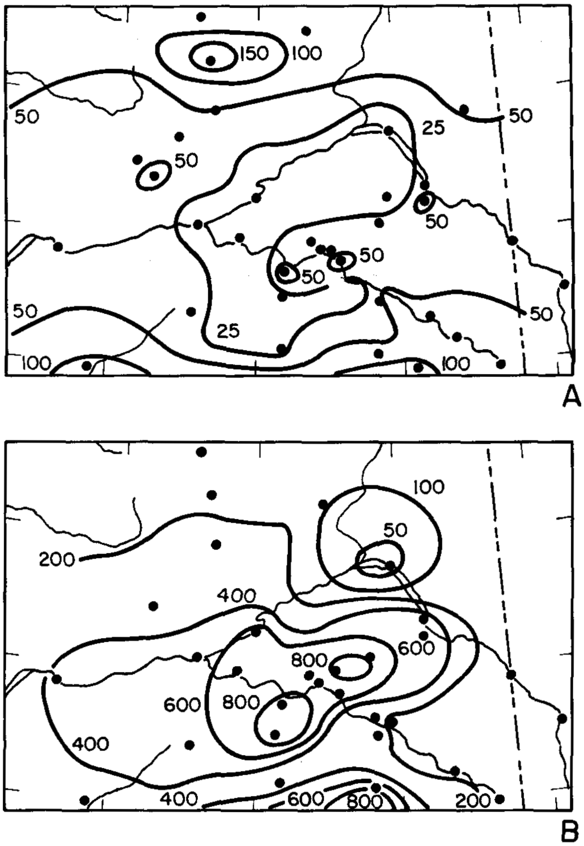

FIG. 8. Monthly precipitation distribution — isohyets in units of 0.01 inch (0.25 mm.) — over central Alaska (A) June 1969, (B) August 1967. Dots show location of precipitation measurements.

falls in the lower valley (Fig. 8B), the monthly total at Fort Yukon is very low. The location of this station within the ring of hills around the Yukon flats prevents many low-level weather systems from reaching it and decreases the inflow of low-level moisture as a source for the regular thunderstorm activity.

Some indication of the distribution of daily rainfall totals in wet months is given in Table 4 for the three stations. It will be seen that the wet months are associated, in general, with moderate falls on a considerable number of wet days and not with very large falls on one or two days. Such a pattern of rainfall distribution reflects the importance of frequent precipitation of localized convective origin in the region.

TABLE 4. Percentages of total numbers of rain days — *i.e.* those days with more than 0.01 inches (0.25 mm.) — in wet summer months having falls within specific ranges, at interior Alaskan stations.

Station	Number of months of record	Rainfall ranges (units of 0.01 inch) 1-9,	10-49,	50-99,	100-199,	200	Average number of wet days
Tanana	18	38	47	14	1	*	18
McKinley Park	15	27	50	15	6	1	16
Fort Yukon	14	53	34	10	3	*	11

*Indicates less than 1.

In order to examine the mean monthly circulation features occurring in extreme years, the 1948-72 records of 700 mb. charts of mean conditions and geopotential anomalies, as published in the *Monthly Weather Review,* have again been employed (see Fig. 9).

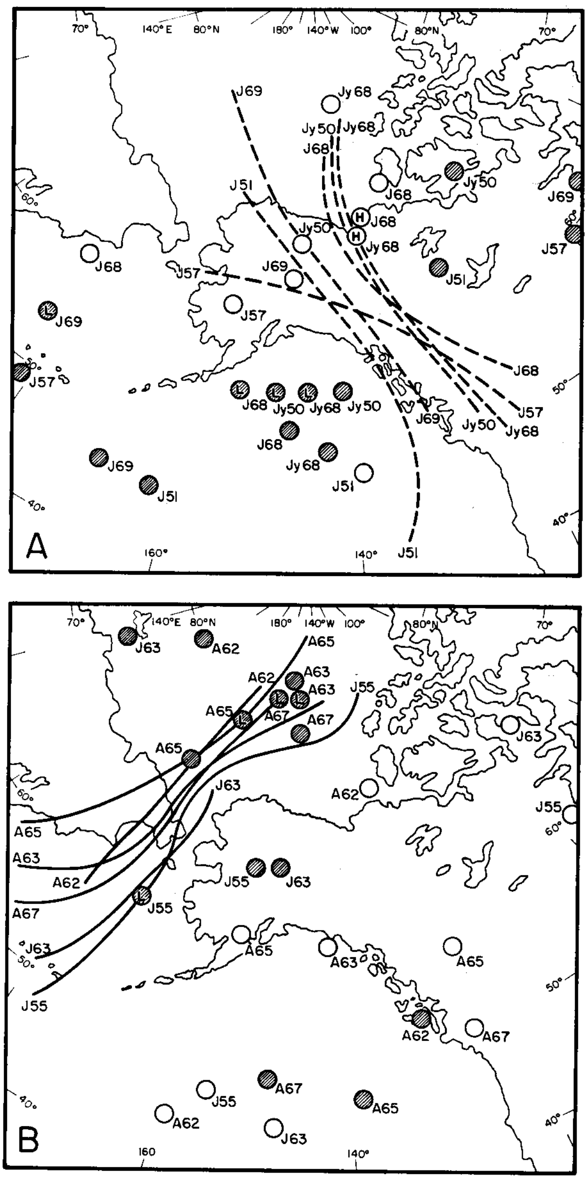

FIG. 9. Location of principal 700-millibar features on mean monthly maps: A) "dry" summer months, B) "wet" summer months. Symbols as in Fig. 5.

Dry months (Fig. 9A) are associated with very strong and well-defined ridge areas over Alaska, extending from southern British Columbia to the Beaufort Sea. Negative geopotential anomalies are prominent from 45°N. to 50°N. in the North Pacific and also over the eastern part of the Northwest Territories of Canada.

The Aleutian low is further east in terms of monthly mean pressure, and the trajectory of air penetrating to the interior is from the south or southeast where passage over the ranges effectively results in depletion of moisture available for precipitation inland. The more protected sites (*e.g.* Fort Yukon), lying in the lee of several successive mountain masses, are the ones most influenced by this process.

By contrast, in the wet years (Fig. 9B), substantial upper troughs extend meridionally from the Arctic basin to the western Aleutians, with negative anomalies over central Alaska and the east Siberian Sea. Positive anomalies tend to extend over southern Alaska and between 40°N. and 50°N. south of the Aleutians. A mean circulation pattern is implied wherein the pressure gradient is strengthened over the western Aleutians, and warm moist air from the western North Pacific enters southwest Alaska eastward of the upper troughs on a trajectory closely parallel to that of the southern ranges. This air thus gains ready access, with minimum modification to the interior, via the corridors between the Alaska Range and the Kuskokwim Mountains and the latter range and the Brooks Range. Such air provides a ready source of moisture for the thunderstorm activity generated by long hours of summer surface heating. On some occasions temporary inflow of colder air from the Arctic Ocean permits the sharpening and southward extension of the zone of baroclinicity across northern Alaska, and synoptic or subsynoptic development may occur with intensified amounts of precipitation over the interior valleys. The inner Yukon flats lying northeastward of the White and Ray mountains are located in the lee of such flow from the southwest, and consequently are least influenced by the moisture inflow. The effect is readily shown by the results of observations taken at Fort Yukon (Figs. 7 and 8B).

CONCLUDING REMARKS

It is notable that the interior basin of Alaska was not ice covered during the height of the Wisconsin glaciation (Flint 1971), though the ice cover of the Brooks and Alaska Ranges is known to have been considerably more extensive. A review of palaeoecological evidence (Hopkins 1972) indicates that the interior at this time had a very dry climate with short warm summers, and supported a treeless tundra-steppe vegetation of sufficient density to maintain herds of grazing animals. This fact indicates that the general pattern of circulation at that time must have been such as to maintain summer temperatures in the valleys sufficiently high to enable ablation of the winter snowfall to take place. Moreover, the annual precipitation must have been sufficiently light to inhibit total advance of the mountain glaciers across the lowlands. The elevation of the extensive mountain region of northwest North America was basically the same at the time of maximum Wisconsin glaciation (about 20,000 years before the present) as it is today. However, Alaska was at that earlier time joined to Siberia across the present Bering Strait, sea ice was extensive and the overall temperature was, of course, much lower than it is today.

Lamb (1970) has attempted a tentative reconstruction of the general patterns of circulation for January and July over the Northern Hemisphere at the time of maximum glaciation. His results indicate little difference in the strength of the circulation between summer and winter, but with a probable reversal of the direction of circulation in the inner Arctic and the main entry of warmer lower latitude air to the Polar Basin occurring via the Alaska region. The latter conditions are in marked contrast to the present situation where most of the warmer air enters over the Atlantic and European sectors. Lamb's July patterns indicate a deep mean low at a latitude of about 50°N. to the south of the Alaska region, and strong cyclonic development close to the continental coast of the present British Columbia. A further deep low lies in the region of the present Mackenzie delta and a smaller and weaker low lies near the 180° meridian in the region of the present Bering Sea. However, the dominant pressure control south of the Brooks Range would appear to be the strong system centred near 50°N., 140°W. The overall lower ocean temperatures at the time of the glaciation would result in a cooler air mass with lower absolute humidity in the source regions to the south. Such air, being moved over the mountains and through interior Alaska under the control of this deep low pressure system, would result in conditions of low precipitation and yet of relative warmth in the lee of the mountain mass. The weaker low to the west would also contribute to a warmer flow across central Alaska, but as this system would then be located close to the land-bridge area it would not be in as favourable a position as today to control a strong flow of warm moist air from the south. Evidence from aeolian deposits in central Alaska (Hopkins 1972) points to strong winds (or perhaps winds of high constancy of direction) during this period, and would not be directly inferred from Lamb's charts. However, it is likely that the primary winds associated with these deposits were of katabatic origin. Such winds would be strong and with directions largely controlled by the ranges which were then more heavily glaciated.

It is interesting to note (Figs. 5A and 9A) that the anomaly patterns found in the course of the present study for abnormally dry and warm years in interior Alaska are associated with lower than normal pressures in the region near 50°N. latitude south of the Gulf of Alaska, and with pronounced air flow from the south and southeast over the region.

The main pattern occurring in these abnormal summer months thus bears considerable similarity to that suggested by Lamb for the time of the maximum Wisconsin glaciation. The inference is that, with lower global sea and air temperatures and with a drastically changed pattern of circulation over eastern North America and Europe, it required an intensified pattern of circulation over western North America similar to that of the present extreme warm and dry years to maintain ice-free lowlands in interior Alaska.

ACKNOWLEDGEMENT

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