Seasonal Climatic Fluctuations on Baffin Island During the Period of Instrumental Records

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ABSTRACT. Temperature and precipitation records for Baffin Island are examined on a seasonal basis for the last 40 to 50 years. Accumulation season temperatures (September to May) during the late 1960s were similar to those which prevailed 30 to 40 years ago. Ablation season temperatures (June, July, August) during the same period were cooler than for at least 30 years. Precipitation variations showed much less spatial coherence, but during the last 10 to 15 years there have been marked increases, mostly during winter months. These increases, accompanied by cooler summers and warmer winters, have led to increased glacierization of the area. The most recent fluctuation of summer temperatures is related to changes in the frequency of synoptic types in the area. Baffin Island is sensitive to small changes in climate which are only revealed by an analysis of temperature and precipitation on a seasonal basis.

RÉSUMÉ. *Fluctuations climatiques saisonnières sur l'île de Baffin pendant la période d'enregistrement des données.* L'auteur examine sur une base saisonnière les données de température et de précipitations pour les dernières 40 à 50 années dans l'île de Baffin. Les températures de la saison d'accumulation (septembre à mai) vers la fin des années 1960 sont semblables à celles qui prévalaient il y a 30 à 40 ans. Les températures de la saison d'ablation (juin, juillet, août) pour la même période sont plus fraîches que depuis au moins 30 ans. Les variations des précipitations montrent beaucoup moins de cohérence spatiale, mais il y a eu des augmentations marquées au cours des derniers 10 à 15 ans, surtout durant les mois d'hiver. Ces augmentations, accompagnées d'étés plus frais et d'hivers plus chauds, ont conduit à une glaciation plus grande de la région. La plus récente fluctuation des températures estivales est liée à des changements dans la fréquence des types synoptiques dans la région. L'île de Baffin est sensible à de petits changements climatiques qui ne sont révélés que par une analyse des températures et des précipitations sur une base saisonnière.

РЕЗЮМЕ. *Сезонные климатические флуктуации на острове Баффи.* Проведено посезонное изучение записей измерений температур и осадков для острова Баффи за последние 40-50 лет. Температуры сезона аккумуляции (с сентября по май) в конце 1960-х годов были такими же, как температуры, преобладавшие 30-40 лет тому назад. Температуры сезона абляции (июнь, июль, август) в течение того же периода времени были ниже, чем в предшествующие по крайней мере 30 лет. Вариации уровня осадков оказались менее закономерными, можно лишь сказать, что за последние 10-15 лет произошло заметное увеличение осадков, особенно в зимние месяцы. Это увеличение, сопровождающееся более холодным летом и более тёплой зимой, привело к возросшему оледенению данного района. Остров Баффи чувствителен к малым изменениям климата, что обнаруживается при анализе температуры и уровня осадков, проводимого на сезонной основе.

INTRODUCTION

A number of studies in recent years have been concerned with climatic fluctuations on a global or hemispheric basis (Putz 1971; Treshnikov and Borisenkov 1971; Mitchell 1961, 1963). A notable feature of these studies is the general

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conclusion that in the Northern Hemisphere the regions of greatest warming from the 1880s to the 1930s or later have been in higher latitude zones. Similarly, areas of greatest cooling over the last 30 years have also been in these regions. Treshnikov and Borisenkov (1971), for example, note that the mean increase in annual temperatures 1881-1920 to 1921-60 for stations between 67°30′ and 77°30′N., and 72°30′ and 88°30′N. was 0.88 degrees C. and 1.11 degrees C. respectively. Flohn (1971) using data from Putz (1971) also shows data, 1961-70, for 10° latitude belts as deviations from the 1931-60 normals. These indicate that the largest negative changes occurred in higher latitudes (> 60°N.), suggesting that a return to conditions of the late nineteenth century is under way. Both the early twentieth century warming trend and the subsequent cooling have been most marked in "winter" months (December, January, and February), a fact also noted by Mitchell 1963. The studies indicate that the arctic and subarctic regions are extremely sensitive to climatic fluctuations and may be considered indicators of hemispheric trends. But it should be noted that latitudinal averaging of climatic data may frequently disguise longitudinal variations which are themselves very significant (Petrov 1959). This is particularly true in areas of sparse data coverage such as the Arctic where zonally averaged data may be based on very few records (for example, Mitchell 1963 uses only 12 stations north of the Arctic Circle).

The use of annual values to evaluate climatic fluctuations (e.g. Longley 1953), can also be misleading when seasonal trends are opposite. This study examines instrumentally-recorded climatic data on a seasonal basis for Baffin and adjacent islands and illustrates that significant fluctuations have occurred over the past 60 years. A further analysis of data for other parts of the Canadian Arctic Archipelago and West Greenland is at present under way.

SENSITIVITY OF THE AREA TO CLIMATIC CHANGE

Glacio-geomorphological and climatological studies of eastern Baffin Island have been a major research interest of the Institute of Arctic and Alpine Research in recent years. These studies indicate that Baffin Island is extremely sensitive to small climatic shifts (Andrews *et al.* 1972). Much of central Baffin Island is a rolling upland plateau at 400 to 700 m.a.s.l. with a glaciation level of 700 to 900 m.a.s.l. (Andrews and Miller 1972). Thus a change of 200 to 300 m. in the height of the glaciation level would lead to significantly increased glacierization of the island. Work by Ives (1962) and Falconer (1966) indicates that a significant area of North Central Baffin was glacierized in the recent past (330 ± 75 years BP) whereas only 2 per cent of the same area is now glacierized. Furthermore, recent climatic fluctuations have resulted in the growth of snowbanks and glacierets in the mountainous Cumberland Peninsula region (Bradley and Miller 1972). These studies support the suggestion of Tarr (1897) that the climatic conditions of Baffin Island are "wonderfully near those which produce glaciation".

To the author's knowledge, no use has been made of Baffin Island meteorological data for studies of climatic change. Longley (1953) combined data from Resolution and Nottingham islands into a "Hudson Strait" record and found a rise in mean annual temperature during the 1930s and 1940s of approximately 0.5 degrees C. For stations on western Greenland, Putnins (1970) found a general tendency for July temperatures to increase from approximately 1880 to 1930-40, followed by a cooling trend to 1955 when the analysis ends. January temperatures show a similar pattern but differences at some stations are apparent.

STATION DATA

The meteorological station inventory for the Northwest Territories indicates that over 30 stations have been operative on or around Baffin Island since August 1881 when a German scientific expedition kept observations at Kingawa (66°36′N., 67°18′W.) during the first International Polar Year. However, the earliest record of any length is that of Lake Harbour (Fig. 2). Twelve stations have been chosen for detailed analysis; of these 8 are currently operative (see Figs. 1 and 2 and Table 1). For the purposes of this study, two seasons were

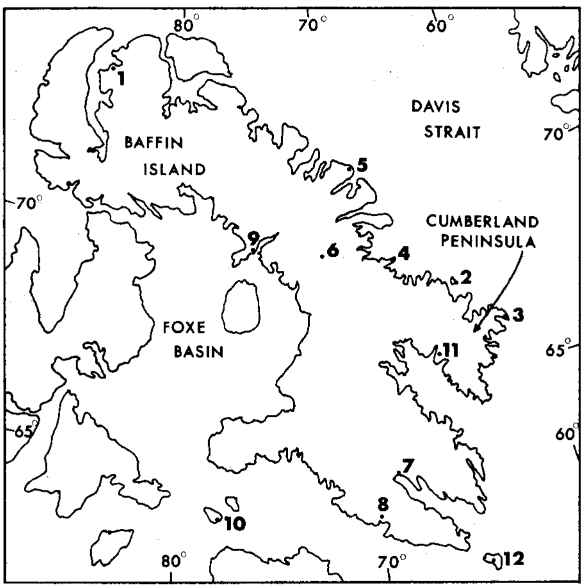

FIG. 1. Location of meterological stations referred to in the text. Numbers refer to stations listed in Table 1.

TABLE 1. Meteorological Stations Referred to in the Text.

Station	Latitude	Longitude	Elevation (m)	Mean Temperatures (1959-69) (degrees C.) Winter	Summer	Mean Precipitation (cm./w.e.) (1959-69) Winter	Summer
1. Arctic Bay	73°00′	85°18′	11	−20.0*	4.4*	7.7*	4.9*
2. Broughton Island	67°33′	64°03′	581	−15.5	2.6	24.4	6.6
3. Cape Dyer "A"	66°35′	61°37′	376	−14.3	3.6	52.3	13.7
4. Cape Hooper	68°26′	66°47′	401	−16.0	2.3	18.5	7.1
5. Clyde	70°27′	68°33′	3	−16.9	3.0	13.2	7.1
6. Dewar Lakes (mid-Baffin Is.)	68°39′	71°10′	518	−18.2	3.2	10.9	9.4
7. Frobisher Bay "A"	63°45′	68°33′	21	−14.1	5.9	26.9	15.5
8. Lake Harbour	62°50′	69°55′	16	−12.3†	6.8†	22.8†	11.5†
9. Longstaff Bluff (Foley)	68°67′	75°18′	162	−17.9	4.7	10.9	7.9
10. Nottingham Is.	63°07′	77°56′	16	−13.2	4.5	17.0	7.9
11. Pangnirtung	66°08′	65°44′	13	−14.1†	6.1†	25.7†	13.0†
12. Resolution Is.	61°18′	64°53′	39	− 8.8*	2.5*	18.5*	10.6*

*Values of mean temperature and total precipitation for 1951-60.
†Values of mean temperature and total precipitation for 1931-40.

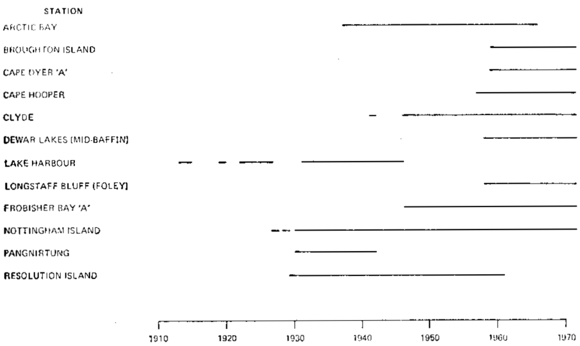

FIG. 2. Periods of meteorological data available for long-term stations on Baffin and adjacent islands.

recognized — a summer or ablation season (June, July and August) and a winter or accumulation season (September to May). For glaciological purposes, this division is adequate; any melting of snow or ice on Baffin Island is almost entirely restricted to the three summer months selected (Jacobs *et al.* In press).

SEASONAL FLUCTUATIONS OF TEMPERATURES AND PRECIPITATION

Seasonal fluctuations of temperature and precipitation were examined by the use of weighted running means. Three- or 5-year periods were weighted depending on the length of record. Weighting was carried out according to the formulae:

$$T_1 = \frac{T_{i-1} + 2T_i + T_{i+1}}{4} \tag{1}$$

for 3-year weighted periods and

$$T_1 = \frac{T_{i-2} + 2T_{i-1} + 4T_i + 2T_{i+1} + T_{i+2}}{10} \tag{2}$$

for 5-year weighted periods, where T_1 is the value plotted at time T. The effect of such weighting is simply to smooth out the higher frequency (short-term) variations while rendering the lower frequency (longer-term) variations more clearly. However, in view of the relatively short periods under consideration and the high variability of the data, care must be taken in interpreting the records. In the following discussion attention has been drawn to those features of the records which are characteristic of most stations in the area unless otherwise indicated. Typical records have been selected and are shown in Figs. 3 to 8.

ABLATION SEASON TEMPERATURES

The 1930s, when a number of stations began operations, were characterized by a cooling trend through to approximately 1943 (1947 at Arctic Bay). This fall in temperatures amounted to a maximum of approximately 1.4 degrees C. at Nottingham Island, 1.1 degrees C. at Resolution Island, 1.8 degrees C. at Lake Harbour and 1.2 degrees C. at Pangnirtung (see Figs. 3 and 4). This was followed by an increase of mean summer temperatures to approximately 1949-50 (by 1.7 degrees C. at Nottingham Island, 1.0 degrees C. at Arctic Bay) followed by a downward trend through to the present time. The 1950s are not completely

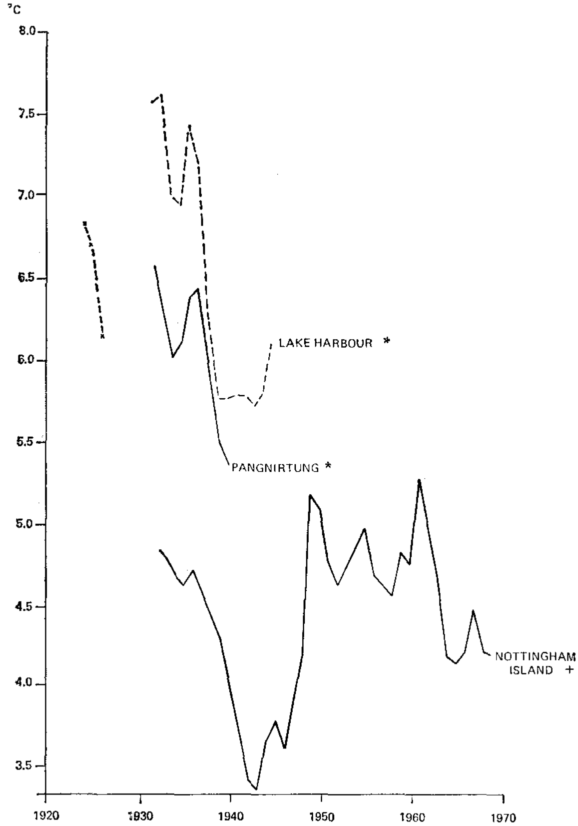

FIG. 3. Ablation season mean temperatures: three* and five+ year weighted running means.

consistent for all stations, some of which show rather indeterminate variations (e.g. Nottingham and Resolution islands). Others, such as Frobisher Bay and Clyde show downward trends amounting to 0.8 degrees C. and 0.6 degrees C. respectively. All stations show a consistent trend towards cooler summers throughout the 1960s amounting to 2.1 degrees C. at Clyde and Longstaff Bluff based on linear regressions for the decade (see Bradley and Miller 1972 for discussion). On the whole, the available data suggest that mean summer temperatures at the close of the 1960s were cooler than they had been for 30 to 40 years.

Although most of the data became available only in the early 1930s, a few ablation season records were compiled before this for Lake Harbour (Fig. 3). Summer temperatures for the middle and late twenties and one complete record for the summer of 1914 are available. These data suggest a period of falling temperatures from the mid-twenties or earlier to the end of the twenties amounting to 0.7 degrees C. or more, followed by increasing temperatures until the early 1930s (1.4 degrees C. or more) when the cooling period already discussed set in. The 1914 summer was 2.2 degrees C. cooler than average temperatures at the station 1930-44. This information alone could be interpreted as simply an anomalously cold summer (although the departure below the mean temperature for 1930-44 amounts to 2.5 standard deviations). However, it is interesting to note that July 1915 and 1916 (the only summer months at this time for which

FIG. 4. Ablation season mean temperatures: five year weighted running means.

data are available) experienced cooler temperatures (5.4 degrees C. and 6.1 degrees C. respectively) than the whole of the rest of the record with the exception of July 1927 (6.1 degrees C.). This suggests that temperatures around 1914 were 1.5 degrees C. to 2.5 degrees C. cooler than in the late 1930s. Observations in many other parts of the world indicate that temperatures rose markedly between 1915 and 1928. Petrov (1959), for example, shows that mean annual temperatures in the European-Asiatic sector of the Arctic rose considerably during that period. Data from west Greenland and Iceland also show a similar pattern (Barry *et al.* in press; Stefansson 1969), suggesting that warming was widespread at that time. If this cooler period prior to 1925 was widespread throughout Baffin, as one might expect, then the actual ablation season or period of melting would have been considerably shorter than it is at present with upland areas (above 600 m.) possibly experiencing mean summer temperatures of < 0 degrees C.

ABLATION SEASON PRECIPITATION (TOTAL AMOUNTS IN WATER EQUIVALENT)

Precipitation data are not nearly as easy to interpret on a regional scale as temperature data, owing to the important influence of topography locally and the considerable problem associated with measuring snowfall consistently. This is evidenced by the mean annual precipitation amounts for Cape Dyer (66.0 cm.)

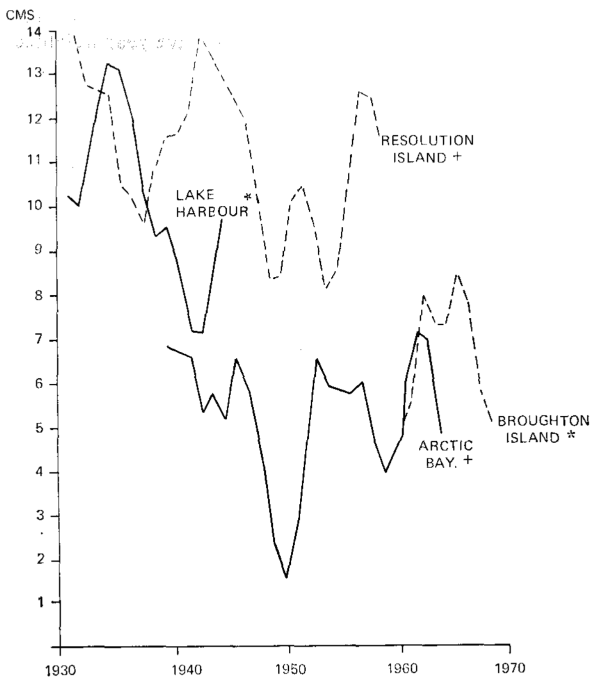

FIG. 5. Ablation season total precipitation: three* and five+ year weighted running means.

TABLE 2. Summary of Ablation Seasons.

Temperature:	1914 — early 1920's:	Marked warming
	1932 (or earlier) to approx. 1943:	Cooling
	1943 to *c.* 1950:	Warming
	1950 to present:	General cooling particularly accentuated in the last 10 years.
Precipitation:	1930's:	Indeterminate
	1940's to early 1950's:	Downward (?)
	1960's to present:	Upward trend for some stations.

and for Broughton Island (31.0 cm.) only 150 km. to the north (values for 1959-69 inclusive; see Table 1). Thus a spatially coherent pattern is very difficult to perceive (Fig. 5). Lake Harbour, for example, shows decreasing precipitation in the 1930s whereas Pangnirtung shows an upward trend. The records for Arctic Bay and Frobisher Bay in the fifties and sixties show an upward trend in precipitation which would seem to fit with a falling temperature trend at these stations for the same period (higher precipitation generally resulting from cyclonic situations when temperatures are below average). In the 1960s some stations show increasing precipitation but this is not true in all areas. Patterns of temperature and precipitation fluctuations during the ablation season are summarized in Table 2.

ACCUMULATION SEASON TEMPERATURES

Accumulation season temperatures are characterized by very large fluctuations over the last 40 to 50 years at a number of stations (Fig. 6 and 7). From the one

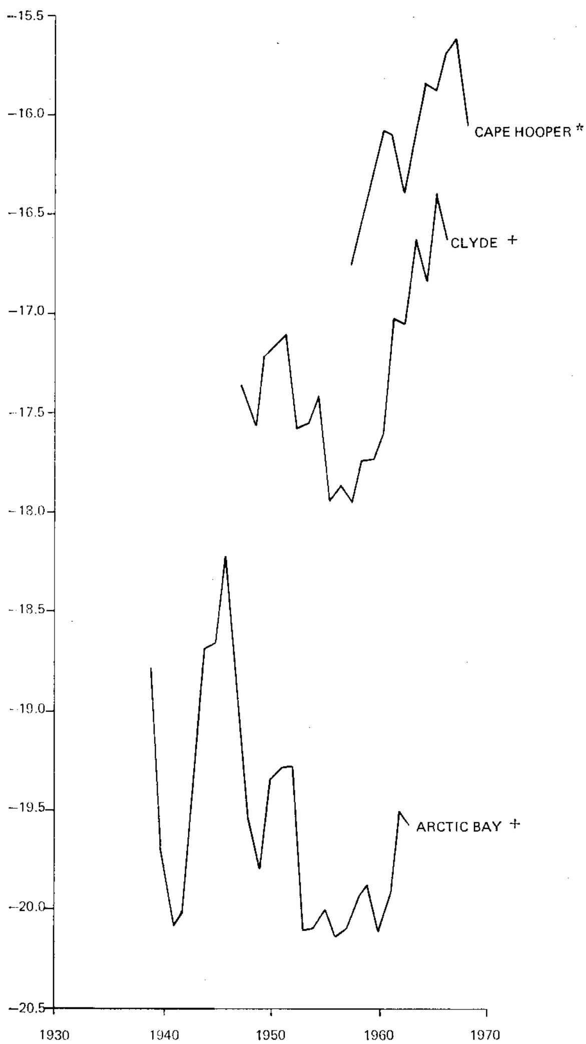

FIG. 6. Accumulation season mean temperatures: three* and five+ year weighted running means.

record at Lake Harbour the mid to late twenties appear to have experienced a cooling trend followed by a rapid rise to the start of the 1930s. Marked cooling occurred in the first few years of the 1930s followed by equally marked warming to 1940-41; mean winter temperatures at Lake Harbour fell 1.8 degrees C. in the early 1930s and rose 3.6 degrees C. by 1940-41. Mean temperatures also fell by 1.0 degrees C. at Pangnirtung in the early 1930s and at Nottingham Island by at least 0.8 degrees C. Mean temperatures 1934-40 increased 2.2 degrees C. at Nottingham Island and 1.3 degrees C. at Resolution Island, but a period of cooler temperatures began in the late 1940s and early 1950s with mean temperatures falling by 1.7 degrees C. at Arctic Bay and 0.8 degrees C. at Clyde. All stations except Cape Dyer then show warming in the 1960s which has generally resulted in mean winter temperatures at the end of the last decade similar to those prevailing 30 to 40 years ago.

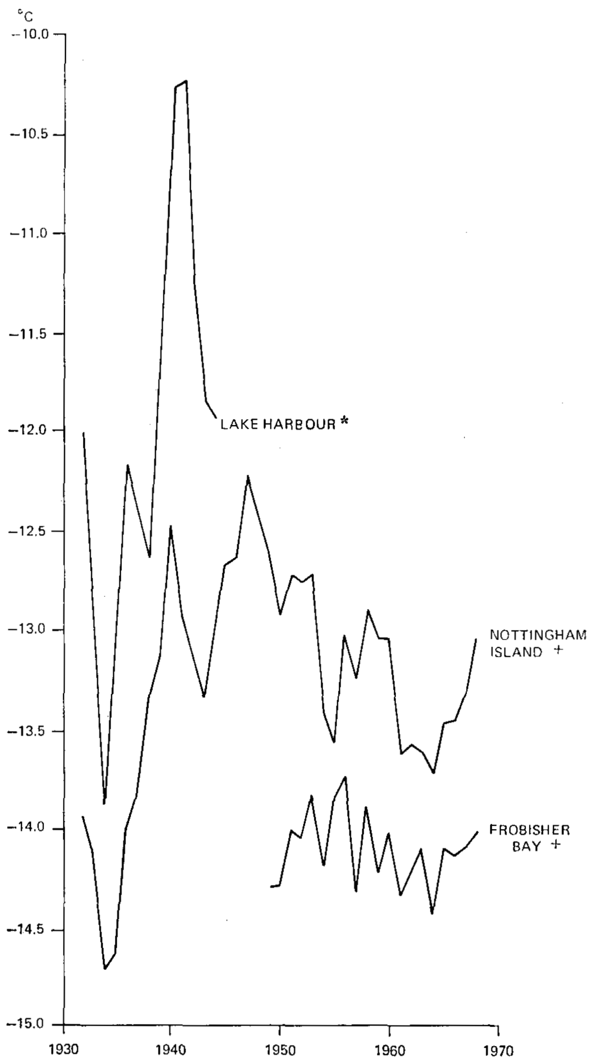

FIG. 7. Accumulation season mean temperatures: three* and five+ year weighted running means.

ACCUMULATION SEASON PRECIPITATION (TOTAL AMOUNTS IN WATER EQUIVALENT)

As in the case of ablation season precipitation, accumulation seasons show wide variations over time and from station to station. There is some coherence in the record post-1954 when precipitation amounts began to increase; this trend has continued to the present (Fig. 8). Resolution Island, however, shows a very marked downward trend throughout the record (0.6 cm. mean decrease per year). For the 1930s, Lake Harbour shows a downward trend while Pangnirtung shows increasing precipitation, similar to the ablation season records at each station. During the 1960s, all stations except Frobisher Bay showed increases in precipitation amounting to an average increase of 34 per cent for the region (based on linear regressions for all stations; see Bradley and Miller 1972, Table 1).

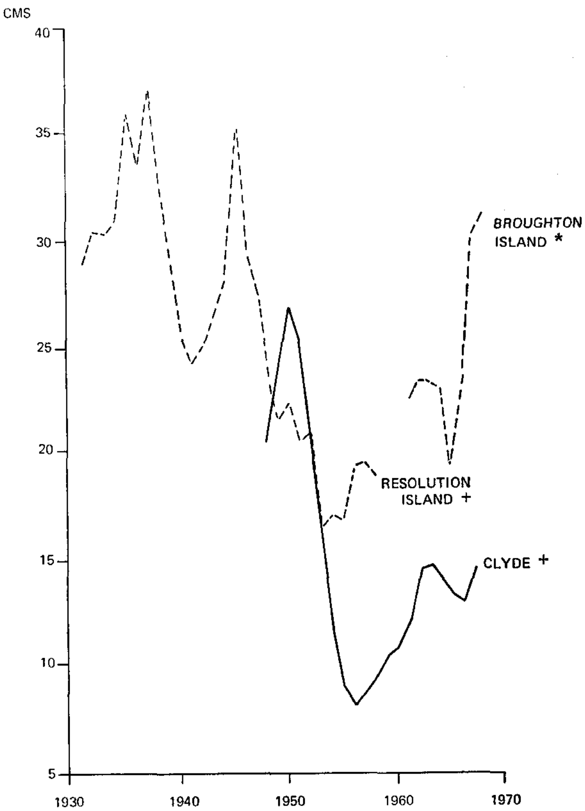

FIG. 8. Accumulation season total precipitation: three* and five+ year weighted running means.

Although Nipher snow gauges were introduced at some stations on Baffin Island at different times during the 1960s, there is no indication that the records have been unduly influenced by the change in recording techniques. If the introduction of Nipher gauges greatly affected the snowfall catch, discontinuities in the records would appear. Inspection of each record shows this is not the case. Furthermore, the increases of winter precipitation *and* temperature during the 1960s suggest the changes are related to increased advection of relatively warm moist air from the south into the region. Fluctuations of precipitation and temperature for accumulation seasons are summarized in Table 3.

Thus it is clear that in the last decade an extremely significant climatic fluctuation has occurred. Winter temperatures are now similar to those of 30 to 40 years ago as a result of the relatively marked warming trend in recent years which has been accompanied by large increases in winter precipitation. Summer temperatures on the other hand have fallen to a level probably below those of the previous 30 to 40 years. Hence the net effect has been for more snow to be deposited on the island and for less to be removed, resulting in notably increased glacierization of the region (Bradley and Miller 1972). Such a change may have serious implications for life in the area, if the climatic conditions of the 1960s persist, as suggested by Namias (1970). For example, snow drifts on the road to Cape Hooper DEW line site at one time posed no problem to travel, but over the last few years the road has frequently been blocked and has had to be ploughed (G. H. Miller,

TABLE 3. Summary of Accumulation Seasons.

Temperature:	Late 1920's	Cooling then warming to *c.* 1930(?)
	1932-34	Rapid cooling
	1934-40	Marked warming
	1940-48	Warming (?)
	1948-60	Cooling
	1960-70	Marked warming
Precipitation:	1930's and 1940's	Incoherent and indeterminate
	Early 1950's to present	Upward trend accentuated in the last 10 years.

personal communication, 1972). Clearly more consideration should be given to precipitation records in the Arctic as precipitation changes are frequently associated with temperature fluctuations.

ANALYSIS OF SYNOPTIC TYPES FOR BAFFIN ISLAND

In the light of the previous discussion, changes in the frequency of certain synoptic types over Baffin Island were examined for the last decade using a catalogue of synoptic types developed by Barry (In press). The classification is based on a static view of the mean sea level pressure pattern over the sector 55° to 80°N., 50° to 100°W., although particular attention was focused on Baffin Island itself.

The types identified by Barry have been amalgamated into two groups: those situations where the dominant circulation control is cyclonic and those situations where it is anticyclonic. The frequency of occurrence in each group was calculated for the months of July and August, 1961-65 and 1966-70 (Table 4) and shows that the frequency of anticyclonically-controlled situations increased between the periods at the expense of the cyclonically-dominated situations. In view of the downward trends of temperature in those months, noted above, it is

TABLE 4. Frequency of Synoptic Types for Baffin Island July and August (Barry, in press).

Definition*	1961-65	1966-70	
Cyclonic Control	*Total of Occurrences*	*Total of Occurrences*	*Difference*
Central low/Trough	59	38	−21
Davis Strait low	35	23	−12
Baffin Bay low	14	15	+1
Low to SW	33	30	−3
Low to SE or S with other lows	24	33	+9
Total	165	139	−26
Anticyclonic Control			
Anticyclone	19	43	+24
Ridge Situations	24	28	+4
Ridge, low to S	25	39	+14
High in E, low to W	25	36	+11
Ridge: Baffin Bay low (NE flow)	14	9	−5
Ridge; Baffin Bay low, (N,N,W. flow)	38	16	−22
Total	145	171	+26

*For classification number and schematic diagrams of types see Barry (in press) at first rather surprising to find that anticyclonic situations have increased. However, the answer lies in airflow associated with each type. The classification scheme of Barry covers a much larger area than Baffin Island alone and thus an anticyclonically-controlled synoptic type may in fact bring cold northerly airflow over most of Baffin Island (if, for example, a ridge is present to the west of Baffin Island). Thus a further breakdown of the types on an airflow basis was made (Table 5) dividing those types with a northerly and southerly component, and those types with an easterly and westerly component. The analysis is crude but makes the best use of available data. Airflow was defined as large-scale airflow over central and eastern Baffin and was taken from the schematic charts for each type according to Barry (In press).

Table 5 shows that the frequency of days with airflow having a westerly component, particularly a southwesterly component, has decreased by approximately 29 per cent between the two periods (1961-65; 1966-70). A concurrent increase in the frequency of easterly, particularly northeasterly flow is also apparent. An analysis of synoptic patterns typical of cool summer days using temperature data from eastern Baffin (Andrews *et al.* 1970) indicated that such days were associated with an easterly flow component over the area. A similar analysis of warm summer conditions revealed southwesterly flow was dominant. Thus it is clear that the summer cooling trend over the last decade is related to a higher frequency of cold air being advected into the area from the east and northeast and a lower frequency of west and southwesterly flow advecting relatively warm air into the region. Further analysis of climatic parameters associated with each synoptic type is at present under way for a number of stations and will no doubt shed more light on this problem.

TABLE 5. Frequency of "Airflow Types" for central and eastern Baffin, 1960-1969 (after Barry, in press).

		a) 1961-65	*b) 1966-70*	*(b−a)*
Southerly airflow with westerly component		63	41	−22
Northerly airflow with westerly component		64	50	−14
Southerly airflow with easterly component		78	91	+13
Northerly airflow with easterly component		52	76	+24
Total Change: Westerly airflow	−36 days (−29%)			
Easterly airflow	+37 days (+29%)			

CONCLUDING REMARKS

It is clear from the foregoing discussion that Baffin Island has recently experienced large seasonal climatic fluctuations which on the whole do not support evidence elsewhere of an overall cooling trend post-1940. Significant changes in the climate of the area have occurred during the last decade. This is of interest in view of evidence that a new climatic regime for the northern hemisphere began in the early 1960s (Namias 1969). It has been suggested elsewhere (Bradley 1973; Bradley and Miller 1972) that this hemispheric change in atmospheric circulation has been the cause of the most recent change in the climate of Baffin Island. If the recent climatic fluctuation persists as seems quite possible (Namias 1970) then two contrasting trends will be apparent on Baffin Island over the next few years. As a response to the overall warming trend since the 1880s (Mitchell 1963; Willett 1950) large glaciers and ice-caps with a relatively long response time will continue to recede, whereas smaller snow and ice bodies (which respond to contemporary shifts in climate more rapidly) will continue to expand. Should the present trend intensify and/or persist over the next two or three decades, then small glaciers and ice-caps can be expected to respond, resulting in a period of glacial advance. However, in view of the variability of the climate of Baffin Island over the past several decades caution should be exercised in extrapolating any current trends very far into the future.

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