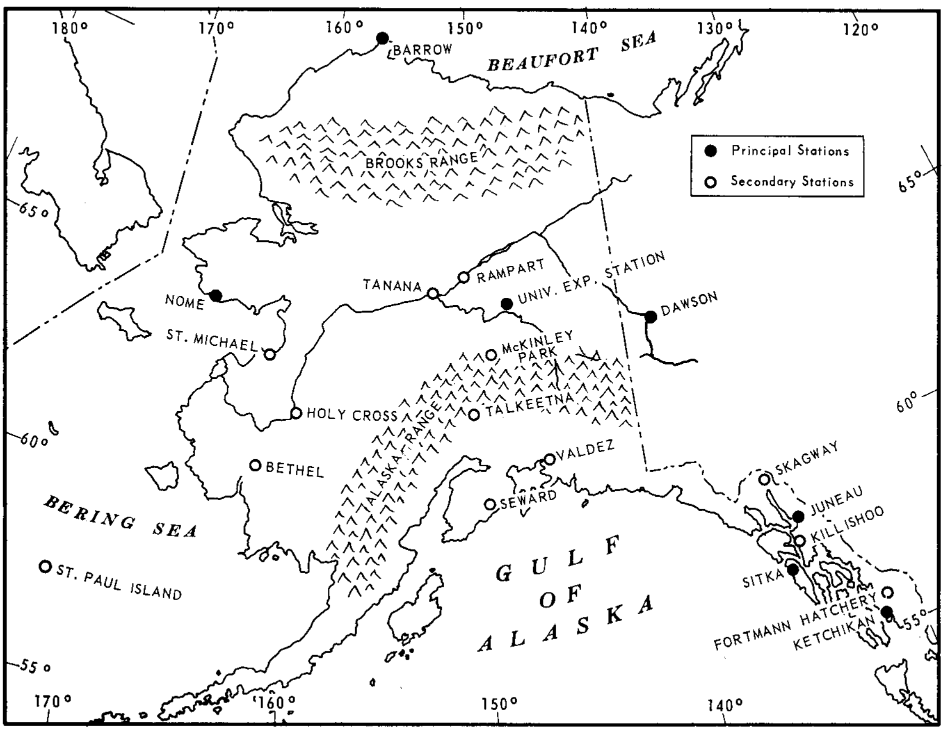

Fig. 2. Location of the principal and secondary stations, Alaska.

ALASKAN TEMPERATURE FLUCTUATIONS AND TRENDS: AN ANALYSIS OF RECORDED DATA

Thomas D. Hamilton*

Introduction

A GENERAL warming, beginning around 1880 and reaching a maximum about 1940, has been documented by the climatic records of stations throughout the world. Regional studies of this warmup have tended to concentrate on the North Atlantic, where climatic records are relatively long and uninterrupted and where the work of Ahlmann (1949, 1953) and others in the Scandinavian countries has provided the stimulus for similar investigations in neighbouring regions. An exhaustive study by Mitchell (1961), based on the temperature records of over 100 stations around the world, indicates that the North Atlantic trends are probably comparable to those elsewhere. Mitchell's data further show that the trends are more pronounced in high latitudes (Fig. 1) and that a decline from the 1940 temperature peak has continued into the late 1950's.

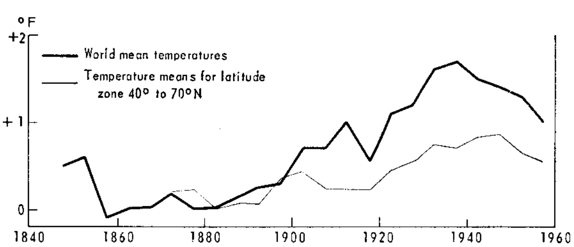

Fig. 1. Trends of annual mean temperature, reduced to successive 5-year means. *After Mitchell (1961).*

Because of their relatively short, sporadic climatic records, the North Pacific and adjacent arctic regions have been poorly represented in the study of recent temperature fluctuations and trends. Most published evidence of such climatic changes in Alaska has been of an indirect nature: based on glacial recession (Lawrence 1950, 1958; Karlstrom 1955, 1961), freezeup-breakup data (Wing 1951; Mackay 1961), and the thermal regime of permafrost (Lachenbruch and Brewer 1961). The following analysis of Alaskan climatic records is thus an attempt to provide a check and a quantitative base for indirect interpretations, as well as a study of the relation of temperature fluctuations and trends in this region to recent world-wide and North Atlantic changes.

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Methods of analysis

Mean annual temperatures for Alaskan stations were obtained from U.S. Weather Bureau summaries (Weather Bureau 1922, 1923-62). Location changes of the individual stations, instrument modifications, and other factors affecting the reliability of continuous records were determined from station histories published by the same agency (Weather Bureau 1958). The temperature data and station histories were studied to determine the records of longest continuity and greatest reliability. Twenty stations were selected on these bases and grouped into five regional divisions (Table 1). The regional grouping was initially arbitrary, based on geographic position and intervening physiographic barriers (Fig. 2). It was later checked by comparing the records of stations within each of the divisions for similarity of trends and fluctuations.

Table 1. Alaskan climatic divisions and stations with longest continuous temperature records[1]. Principal stations are in capital letters.

Division	*Station*	*Years of Continuous Record*
Northern (Arctic Ocean)	BARROW	1921-62
Interior	DAWSON, Y.T.[2]	1901-62
	McKinley Park	1925-62
	Rampart	1906-30
	Tanana	1909-42
	UNIVERSITY EXPERIMENT STATION (U.E.S.)	1906-62
Western (Bering Sea)	Bethel	1926-62
	Holy Cross	1918-32; 1935-62
	NOME	1907-62
	St. Michael	1875-85
	St. Paul Island	1916-39; 1944-62
South-Central (Gulf of Alaska)	Seward	1909-24; 1940-62
	Talkeetna	1921-29; 1934-62
	Valdez	1910-22; 1936-62
Southeastern	Coal Harbor	1892-1907
	Fortmann Hatchery	1905-26
	JUNEAU	1905-62
	KETCHIKAN	1913-62
	Killisnoo	1889-1910
	SITKA	1868-87; 1900-62
	Skagway	1903-09; 1918-32

[1]No Aleutian division could be included, as all stations in this region have discontinuous records and have undergone major location shifts.
[2]Added to the Alaskan stations because of its exceptionally long continuous record and location within the interior region only 50 miles from the Alaskan border.

Four-year running means and 3-year weighted means were constructed over the raw temperature data of each of the 20 stations, using a simple geometric method which avoids computing and replotting the mean values (Fig. 3). The running and weighted means effectively decrease the amplitude of random fluctuations between individual years and accentuate respectively the more systematic trends and fluctuations of longer duration. Records from each of the five divisions were studied as units to determine whether these trends and fluctuations were general for each division and to pick out the best representative stations for further detailed study. More extensive running and weighted means (8-year and 5-year, respectively) were then constructed for each of seven "principal stations". The intervals chosen for these means seemed well fitted to the lengths of station records and the desired emphasis on long-term trends and fluctuations, and could be easily constructed from the shorter-term mean curves on hand.

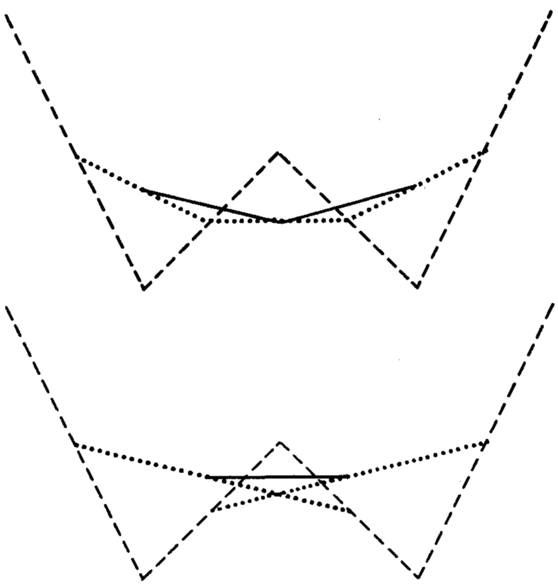


Fig. 3. Geometric construction of 3-year weighted means (top) and 4-year running means (bottom). Dashed lines connect raw data points and solid lines are the plotted means. Construction lines are dotted.

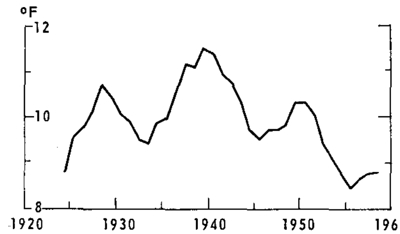
Absence of pronounced regional variations in temperature trends suggests that a composite running mean may be more representative of Alaskan trends than are the less continuous data of individual stations. A composite 8-year running temperature mean was therefore constructed for the period of record from 1870 to 1962. An attempt was made to verify the questionable pre-1910 portion of this composite by supplementary precipitation, freezeup-breakup, and sea-ice records.

Regional analysis and station selection

Northern Alaska

Barrow (Fig. 4) is the only station in this division with any length of record. Its complete monthly temperature averages from 1921 to the present indicate a fairly stable operational program, and station shifts have been relatively minor. Barrow was therefore selected as representative of northern Alaska, although unfortunately no other stations in this division have records of sufficient length to check its data adequately.

Fig. 4. Mean annual temperatures, Barrow, Alaska. Reduced to 8-year running means.



Interior Alaska

Comparison of means from the five stations in this division shows that fluctuations are nearly identical among them, but that two regional subgroups can be distinguished on the basis of temperature trends. Data from University Experiment Station (U.E.S.) indicate that a temperature peak in 1925-30 was nearly as great as that of the early 1940's, and that the entire 1925-45 interval was distinctly warmer than the preceding and following periods. McKinley Park and Tanana show trends similar to those of U.E.S. The sharply contrasting Dawson and Rampart data show relatively low temperatures in 1925-30, with warmer intervals in 1912-15 and 1940-43. Dawson and U.E.S. (Fig. 5) were selected as representatives of the two subgroups because of their relatively long continuous records.

Western Alaska

Nome (Fig. 6) appears to be typical of the region in all but minor components of the temperature peak centred around 1940, and has by far the longest continuous record among the western stations. It is considered

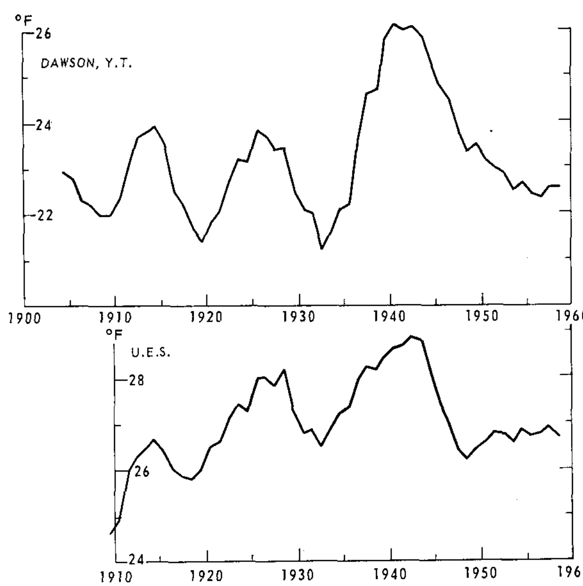


Fig. 5. Mean annual temperatures, Interior stations. Reduced to 8-year running means.

the principal representative station for this division, with the earlier Holy Cross and St. Michael records as supplements to reconstruct the temperature changes of the late 19th century.

South-central Alaska

The three stations in this division have records too incomplete to be considered as representative of the region. Trends are almost impossible to assess on account of strong fluctuations during the short periods of record, and net changes for all three stations seem to be relatively minor. Fluctuations agree closely among the three stations and are similar to those of the other divisions.

Southeastern Alaska

Sitka, Juneau, and Ketchikan differ from each other in several major aspects of the temperature record. All three have long records and are considered principal stations for the region since no one alone is representative (Fig. 7). Fortmann Hatchery and Skagway appear to differ from the other stations in a number of details, but their records are too short to allow precise comparisons or inclusion as principal stations. Neither Coal Harbor nor Killisnoo have long records, but data segments extend back to 1892 and 1889 respectively and serve as important supplements to the pre-1910 temperature data.

Histories of the principal stations

Barrow

Weather records have been taken intermittently since 1881, and both temperature and precipitation data are essentially complete since 1921. Station position was shifted in 1942, 1944, and 1955, but the moves were all minor and partly compensating (Table 2). No pronounced changes in the temperature record coincide with these station movements.

Dawson, Y.T.

Records are continuous since 1901, but I have no information on station changes during the interval of record. One month each is missing from the

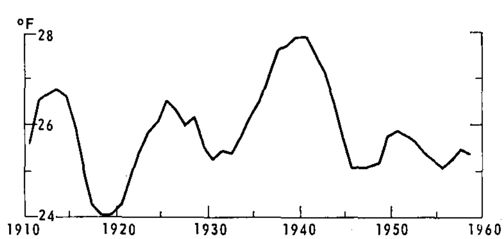


Fig. 6. Mean annual temperatures, Nome, Alaska. Reduced to 8-year running means.

temperature records of 1913, 1933, and 1954, 2 months from 1953, and 3 months from the 1913 records. Mean values for each of these missing months were averaged from the records of the same months over the two preceding and the two following years, a procedure carried out in all subsequent cases where data of individual months are missing.

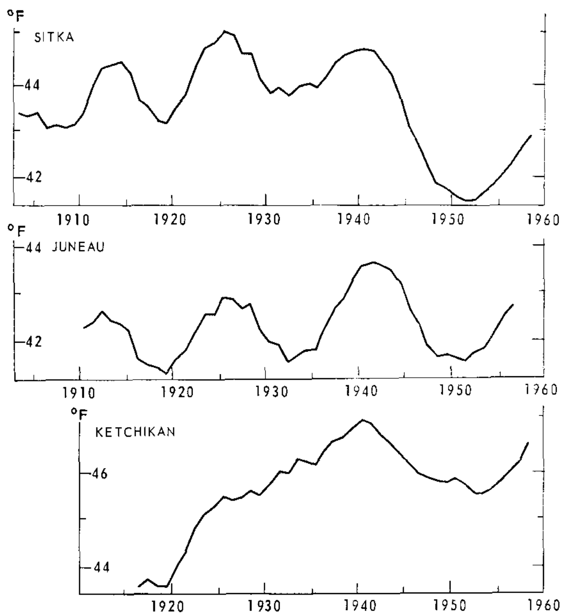


Fig. 7. Mean annual temperatures, Southeastern Alaska. Reduced to 8-year running means.

University Experiment Station (U.E.S.)

Temperature and precipitation records are essentially complete from 1906 to the present, but there is no record of station position prior to 1911. The station was moved slightly in 1933 and 1953, but the effect of these shifts appears to be negligible. One month is missing from the 1933 temperature record.

Nome

Records are continuous since 1907 except for 3 months missing from 1915 and 1 month missing from the 1916 temperature data. Station position has been shifted 9 or 10 times, but the only major permanent move was that of 1946. No noticeable displacements of the data reflect these movements.

Juneau

Intermittent temperature and precipitation data have been taken since 1881 and both records are continuous after 1905. The station has been shifted four times within the city, but none of these moves had any obvious effect on the data. One month is missing from the 1953 and 1958 temperature records.

Table 2. Movements of the principal stations.

Station	*Movement date (month/year)*	*Horizontal shift*	*Vertical shift (ft.)*	*Remarks*
Barrow	12/42	¼ mi. W	0	
	7/44	810 ft. ESE	+ 9	
	2/55	150 ft. SE	0	
U.E.S.	8/33	113 ft.	− 25	Direction unknown
	5/53	273 ft. ENE	+ 6	
Nome	7/16(?)	?	?	Prior position unknown
	11/24	500 ft. NE	+ 2	
	6/25	500 ft. SW	− 2	Returned to previous location
	9/25	500 ft. NE	+ 2	Returned to previous location
	7/28	2½ mi. E	+ 21	Moved outside city
	8/30	2½ mi. W	− 21	Moved back to city
	7/34	¼ mi. E	0	
	1/39	800 ft. S	0	
	3/46	1¼ mi. NW	+ 1	Moved outside city
	12/50	¼ mi. E	0	
Juneau	1/17	?	?	
	5/22	¼ mi. NW	+123	
	7/28	800 ft. WSW	− 14	
	2/31	750 ft. SE	− 57	
Ketchikan	10/29	2½ mi. NW	− 59	
	2/38	900 ft. E	− 1	
Sitka	9/30	?	− 34	
	3/41	150 ft. E	− 6	
	4/42	1 mi. E	+ 42	

Ketchikan

Records are continuous since 1913. The station has been shifted twice, but temperature data show no indication of displacements following either move.

Sitka

Sitka has the longest record of any Alaskan station, with temperature records fairly complete since 1868 and precipitation since 1842. Both records are continuous after 1898, but there is no record of location prior to 1908. The station was moved in 1930 and 1941 without any noticeable effect on the data. It was moved 1 mile out of town in 1942, causing a pronounced displacement to lower temperatures in the following years. One month each is missing from the 1932, 1936, and 1959 temperature records.

Discussion

Because of repeated movements, missing data segments, and the unknown effect of microclimatic variables, none of the Alaskan stations have records that are wholly reliable for the determination of long-term temperature changes. To avoid serious errors, the records used were first examined for displacements across the years of station changes, then compared with the records of adjacent stations to determine whether variations between their respective fluctuations and trends could relate to these shifts. The plotted station records were later composited to decrease the influence of minor unnoticed displacements.

Temperature fluctuations

Five-year weighted means were used to accentuate the major temperature fluctuations of the principal stations. Peaks and troughs on the mean curves were arbitrarily considered dominant (D, d), secondary (2), or minor (m) according to their relationship to the overall record of each of the stations, and the intervals included within the peaks and troughs were designated as those years where mean temperatures were within 0.5°F. of the extreme point of each fluctuation. Peak and trough intervals were tabulated for the stations and plotted graphically (Fig. 8). Only the post-1910 data could be considered on account of the scarcity of continuous records in the earlier years.

The plotted fluctuations of the 1910-62 period indicate a close similarity between the records of all stations, and the following consistent peaks and troughs:

Average central year	Fluctuation type	Usual order of importance
1914	peak	D
1919	trough	d
1926	peak	D
1933	trough	d
1940	peak	D
1948	trough	d
1952	peak	2
1955	trough	2
1958	peak	2

The fluctuation extremes occur at intervals of roughly seven years until the 1948 peak. Subsequent fluctuations have been relatively minor and are spaced only 3 to 4 years apart.

Although most of the variations between the station records are minor and apparently random, there are some indications of latitudinal and longitudinal differences.

1) Nome, U.E.S., and Dawson lie on a west-east line extending 800 miles and embracing 26 degrees of longitude. Minor offsets between peaks and troughs among the three stations show some indication of fluctuations moving from west to east. Of the nine major fluctuations, two begin later at Dawson than at U.E.S. and four begin later at U.E.S. than at Nome. None begin earlier at Dawson, and only one may begin earlier at U.E.S. than at Nome. There is also an indication of decreasing complexity in an eastward direction. The peak centred around 1926-27 has 2 maxima at Nome and extends over 5 years; at U.E.S. it has a single maximum but also extends over 5 years, while at Dawson it extend over only 2 years as a relatively sharp extreme. The peak centred around 1940 has two maxima at Nome and U.E.S., and only a single maximum at Dawson.

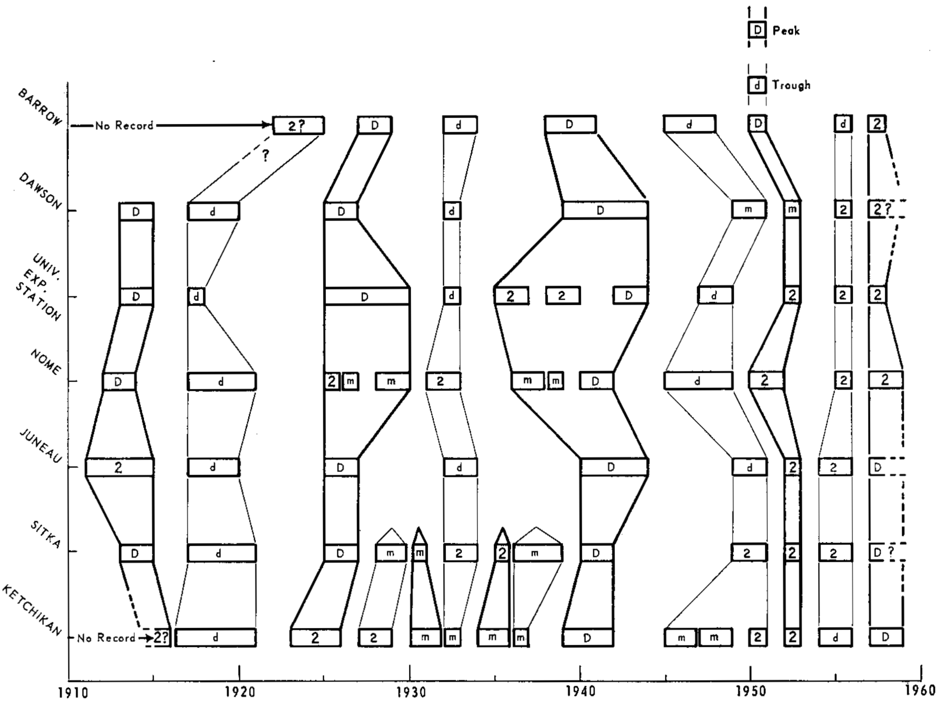


Fig. 8. Comparison of temperature fluctuations among the principal stations, 1910-1962.

2) The coastal stations, Sitka, Nome, and Barrow, are located respectively at 57°10′, 64°25′, and 71°15′ North, with roughly seven degrees of latitude separating each of the pairs of adjacent stations. Barrow and Nome agree almost exactly in the timing of the major fluctuations, while Sitka appears to lag 1 to 2 years behind them in two and possibly four of the 1930-53 peaks and troughs. The maxima centred around 1926-27 and 1940 decrease in complexity northward. At Sitka they consist of minor and secondary fluctuations not definitely related to the dominant 1926 and 1941 peaks, the groups extending over intervals of six and seven years. At Nome they are represented by secondary maxima that are integral parts of major peaks covering 5- and 7-year intervals. These peaks at Barrow consist only of single dominant maxima of 2 and 3 years duration.

3) Comparisons of minor fluctuation differences within and between the climatic divisions tend to break down divisional boundaries and to favour the influence of latitudinal and longitudinal gradients. The number of discrepancies in timing, relative importance, and complexity between the nearest stations of adjacent divisions is no greater than that between stations within the divisions, and greater differences appear only when the more distant stations are compared.

Temperature trends

Regional effects, 1910-62

Analysis of 8-year running means of the principal stations (Figs. 4-7) indicates 4 major trend segments for nearly all of the records. The trends (Table 3) show a gentle rise from 1910 to 1935, followed by a more rapid rise to a peak around 1941. Temperature trends then decline sharply until about 1947, after which most become relatively horizontal. Strongly anomalous 1935-41 and 1941-48 running means for Sitka were considered to be the result of a major station change in 1942, so trend segments for these intervals were not tabulated. Lack of early data from Barrow and Ketchikan has resulted in incomplete 1910-35 trend segments for each, and this initial interval was not tabulated for the two stations.

Table 3. Trends and net changes of mean annual temperature, 1910-62.

	1910-35	*1935-41*	*1941-47*	*1947-62*	*Net change*
Barrow	—	+1.5°F	−1.7°F	−0.6°F	—
Dawson	+0.2°F	+3.0	−2.4	−0.9	−0.1°F
U.E.S.	+1.9	+1.2	−2.5	+0.5	+1.1
Nome	+0.7	+2.0	−2.5	−0.1	+0.1
Juneau	+0.4	+1.2	−1.8	+0.6	+0.4
Sitka	+0.6	—	—	+0.8	—
Ketchikan	—	+1.0	−1.1	+0.2	—
Average	+0.8	+1.6	−2.0	+0.1	+0.4°F

U.E.S. shows an unusually great warming for the 1910-35 interval. The record of nearby Tanana checks that of U.E.S. for this interval however, indicating that a strong 1910-35 temperature rise is probably representative for this portion of interior Alaska. The interior stations, Dawson and U.E.S., show very steep gradients to the 1941 peak, but these are equalled by corresponding temperature drops in the 1941-47 interval. An accentuated fluctuation rather than a trend appears to be the cause. Nome behaves in a manner similar to that of U.E.S. and Dawson, indicating that its proximity to the Siberian mainland may make it behave climatically as an interior station. No other significant divergences appear among the coastal stations, and areas as far apart as Barrow and Juneau have closely similar records.

The absence of pronounced regional trend differences indicates that a composite of the Alaskan data would probably yield a record fairly representative for the state as a whole.

Composite trends

A composite 8-year running mean for 1910-62 was based on the annual mean temperatures of the 7 principal stations. Running means for the individual stations were fitted to a zero point (1936), then temperature differences from this base were averaged for each individual year. The composite running mean was plotted as a solid curve (Fig. 9). To extend the curve farther back in time, less continuous earlier data from Skagway, Sitka, St. Michael, Juneau, Rampart, and Fortmann Hatchery were reduced

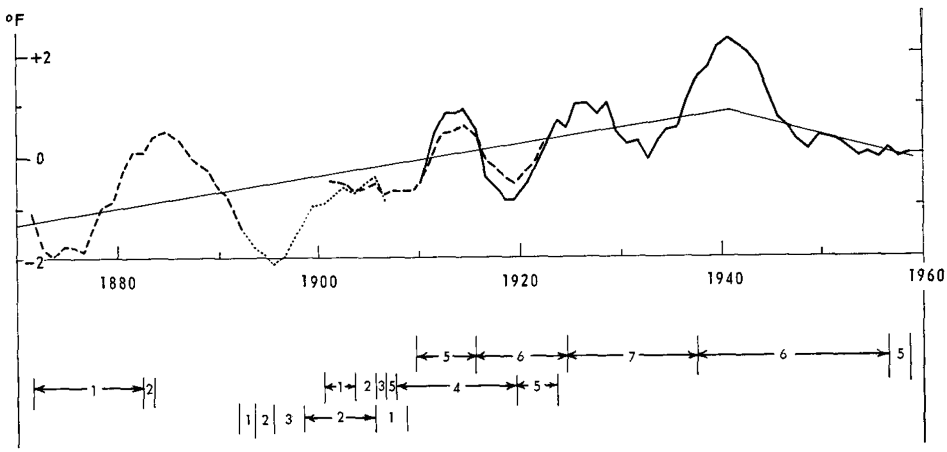


Fig. 9. Mean annual temperatures, Alaska composite, 8-year running means. Numbers below the curves indicate the minimum number of stations represented in each segment of the reconstruction: top line refers to the solid curve, middle line to the dashed curve, bottom line to the closely dotted curve.

to 4-year running means and matched at a 1924 base point. Temperature changes from the base year were averaged, plotted, and reduced to 8-year running means. The resulting curve (dashed segment, Fig. 9) has a 13-year overlap with the 1910-62 means which allows it to be fitted to the later data with considerable accuracy. Earlier data from Sitka and St. Michael could also be related to the base line, allowing the 1871-84 interval to be plotted. The 1892-1907 segment (dotted, Fig. 9) was obtained from the data of Holy Cross, Killisnoo, and Coal Harbor, averaged from an 1897 base, then fitted to the dashed curve across the 1901-07 overlap. No station data are available for 1888. This gap was bridged by plotting the raw data of Sitka and Killisnoo, then constructing a combined running mean across the end points of these record segments. The interval of running means affected by the missing data is represented in Fig. 9 by broadly spaced dots.

The composite shows a net gain of 0.7°F. from the 1902-10 to the post-1953 temperature level. There has been a probable net gain of 1-1½°F. from the more questionable data of the late 19th century to those of the present. The temperature peak centred around 1941 is best regarded as a major fluctuation, in which a gain of nearly 2°F. in the 1935-41 running means is balanced by an equal temperature loss over the 6 following years. One possible interpretation of overall trends (solid straight lines, Fig. 9) is a net rise of 2.1°F. from 1897 to 1941, followed by a net loss of 0.9°F. from 1941 to the present.

Supplementary data

In an attempt to verify the pre-1910 temperature curves, records of precipitation, freezeup-breakup, and opening and closing to coastal navigation were reduced to running and weighted means and compared to the 1910-62 temperature curves. A close correspondence across this interval would indicate that the supplementary records might provide valid checks on the earlier temperature data.

Precipitation

Fluctuations in annual precipitation totals of the principal stations are generally similar in number and spacing, but individual peaks and troughs show apparently random displacements in timing. Fluctuations are more numerous in the precipitation than in the temperature records, and show no direct correlations. There is little agreement among the stations in major precipitation trends, and net changes from 1910 to the present vary from negligible (Nome) to a gain of over 10% (U.E.S.). Precipitation and temperature trends do not appear to be related.

Freezeup and Breakup

Records of breakup of the Yukon River at Holy Cross are continuous from 1889, but the freezeup data are less complete and the fragmentary local temperature record can be used only for direct comparisons in the post-1938 period. Breakup and temperature records agree fairly closely in trends around the 1941 temperature peak, but differ radically elsewhere. Comparison with the composite temperature curve indicates further major differences from the breakup record. Although breakup trends agree with the composite in some respects, they cannot be considered closely representative of temperature trends.

An average of freezeup and breakup trends yields a curve which is closer to that of the temperature composite, but still differs from it in several important respects. The fragmentary freezeup data from the post-1910 interval do not permit a close enough correlation with the temperature record to allow a check on the earlier data.

Opening and closing to navigation

Opening and closing records of the port of St. Michael are complete from 1875 to 1918, covering the most questionable interval on the temperature composite and overlapping enough of the later record to allow comparison of the two curves. Running means of the opening and closing dates and of their average were compared with the temperature composite and the St. Michael temperature records. The 1876-84 segment of the St. Michael record, the only interval that can be directly compared, does not appear to agree with any of the opening-closing curves, and no part of the temperature composite shows any close relation.

Conclusions

1) The Alaskan temperature record is dominated by a series of major fluctuations leading up to a maximum centred around 1941. The fluctuations show some indication of time lag and decreasing complexity inland from the North Pacific.

2) Post-1910 temperature trends for all stations are characterized by gradual warming from 1910 to 1935, then pronounced rises to maxima around 1941. Comparably sharp declines from the temperature peaks continued to 1947, and have been followed by relatively horizontal trends. Net temperature gain from 1902-10 temperature levels to those of the late 1950's has been ca. 0.7°F.

3) Alaskan station records agree closely in the major features of temperature fluctuations and trends, permitting construction of a mean annual temperature composite which is considered representative for nearly all of the state. Composited running means of 11 stations yield a combined curve that is probably accurate back to 1910 and fairly reliable to about 1895. The curve segments prior to 1895 are based on only 1 to 2 stations, are tenuously connected to the later curve, and are supported by no records of station locations and shifts.

4) The early segments of the composite could not be verified by supplementary data. Precipitation and sea-ice records show no relation to temperature changes, and only the discontinuous freezeup-breakup composite shows any similarity to temperature trends.

5) There has been a probable net gain in the order of 1-1½°F. from temperatures of the late 1800's to those of the present. Both the net change and its major components show a general agreement with world and regional trends determined by previous investigators.

References

Ahlmann, H. W., 1949. The present climatic fluctuation. Geog. J. 112:165-95.

——————1953. Glacier variations and climatic fluctuations. Am. Geog. Soc., Bowman Memorial Lect., Ser. 3, 51 pp.

Karlstrom, T. N. V., 1955. Late-Pleistocene and Recent glacial chronology of south-central Alaska. Geol. Soc. Am. Bull. 66:1581-2.

——————1961. The glacial history of Alaska: Its bearing on paleoclimatic theory. Ann. N.Y. Acad. Sci., 95:290-340.

Lachenbruch, A. H. and M. C. Brewer, 1961. Geothermal evidence for recent climatic change near Barrow, Alaska. Geol. Soc. Am. Spec. Pap. 68:117.

Lawrence, D. B., 1950. Glacier fluctuations for six centuries in southeastern Alaska and its relation to solar activity. Geog. Rev. 40:191-223.

——————1958. Glaciers and vegetation in southeastern Alaska. Am. Scientist 46:89-122.

Mackay, J. R., 1961. Freezeup and breakup of the lower Mackenzie River, N.W.T. *In* Geology of the Arctic, Univ. Toronto Press, 2:1119-34.

Mitchell, Jr., J. M., 1961. Recent secular changes of global temperature. Ann. N.Y. Acad. Sci. 95:235-50.

Wing, L. W., 1951. Cyclic trends in arctic seasons. Jour. Cycle Res., 1:19-25.

Weather Bureau, 1922. Summary of the climatological data for Alaska, by sections. U.S. Dept. Agriculture, Washington, D.C. 47 pp.

——————1923-62. Yearly summaries of Alaskan climatological data. U.S. Dept. Commerce, Washington, D.C.

——————1958. Substation and station histories, Alaska. U.S. Dept. Commerce, Washington, D.C. 85 pp.