I. 2. FREEZING AND THAWING INDICES IN NORTHERN CANADA*

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INTRODUCTION

The degree-day approach has been used successfully for many years to relate temperature data to heating requirements for buildings. Monthly publications of the Meteorological Branch list cumulative seasonal and monthly heating degree-days below 65°F for about fifty representative stations in Canada, while annual summaries include an additional one hundred stations. The growing degree-day concept is familiar to many as a convenient method of linking temperature variations, during a growing season, with plant growth. Calculated normal monthly and annual growing degree-days are listed for about eighty stations in Canada in a paper by Boughner and Kendall (2).

The freezing degree-day and thawing degree-day are logical developments of the degree-day technique, and, as the names imply, are used to relate climatic effects to frost action. Crawford and Boyd (6) mention that, as early as 1930, an empirical relationship involving degree-days below freezing air temperature, and frost penetration into the ground, was used in highway design in the United States.

FREEZING AND THAWING DEGREE-DAYS AND INDICES AS RELATED TO FROST ACTION

Frost action in soils is a problem in practically all sections of Canada in highway, airport and building design. The problem has increased during the past ten to fifteen years with the northward extension of exploration and development into areas of widespread permafrost. To assist in the development of modern engineering techniques in the north, research has been increased in such fields as ground temperature studies, frost penetration, and retreat, in soils, and permafrost distribution and behaviour. During the same period the increasing importance of water transportation in the north has fostered the development of new techniques for forecasting the formation, growth, dissipation and movement of ice in the seas, lakes and rivers. While all elements of climate are interrelated in their effects on each of these manifestations of frost action, temperature is probably the most closely related and temperature data most readily available (10). The most useful expressions of temperature values as they affect soils subject to frost action (7), and influence

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ice growth and dissipation in waterways (11), are thawing and freezing degree-days. Their accumulations during respective thawing and freezing seasons are known as thawing and freezing indices (16).

Whether it is used in determining the heat requirements of buildings or plant growth, the temperature of the ground, the depth of frost penetration, the depth of thaw in permafrost, or the growth and dissipation of ice in waterways, the degree-day method is based entirely on temperature and neglects such variables of climate as wind, solar radiation, precipitation, etc., not to mention the numerous soil and water factors that are involved. However, in most of these fields, the method does represent this climatic parameter in a convenient, simple form, suitable for use in many engineering and design studies.

Workable empirical relationships exist between accumulations of freezing degree-days and depth of frost penetration in the ground (7), and between thawing degree-days and depth of thaw in permafrost (12). In areas of Canada where temperature data are not available, the freezing index map may be used, with empirical curves, to provide first approximations of frost penetration. The rate at which frost enters or leaves the ground has considerable bearing on frost damage to ground installations (6). This, in turn, is measured by the accumulation of degree-days during the first few weeks of freezing or thawing seasons.

Brown (3) notes that, although the occurrence of permafrost is influenced by many climatic, surface, and geothermal factors independent of the temperature régime, there is a very broad relationship between the boundary of permafrost in Canada and the mean annual air temperature. Since the formation and persistence of permafrost depends as much on the frost retreat during the thawing season as on the frost penetration during the freezing season, thawing as well as freezing indices must be considered.

The degree-day method is commonly used to relate air temperature to ice formation, growth and dissipation. Empirical relationships involving ice thickness and accumulated freezing degree-days are used to predict the rate of ice growth (11). Similar formulae using melting degree-days provide break-up information. According to Markham (11), these degree-day relationships are used at the Ice Forecasting Central to determine the effects of temperature on the ice regime of the coastal waterways of Canada. Burbidge and Lauder (4) tested the degree-day technique to link temperature data to dates of break-up and freeze-up of lakes and rivers. At selected stations, it was possible to relate the date of break-up to the number of melting degree-days prior to break-up. There did not, however, appear to be any connection between the date of break-up and the severity of the past winter season as measured by the freezing index.

PREVIOUS WORK ON FREEZING AND THAWING INDICES

During the last decade, freezing degree-day accumulations and freezing indices have been computed for a number of stations in Canada, in connection with special investigations of frost action (3, 4, 6, 13).

In 1954, as part of a runway evaluation programme of the Department of Transport, Wilkins and Dujay (13) used freezing degree-day accumulations for more than one hundred stations, averaged during the ten freezing seasons 1941-1950, to construct a freezing index map of Canada. The degree-day computations were based on mean daily temperatures. In 1959, a map of average thawing indices in Canada was prepared by the Division of Building Research, National Research Council (3). In this case, the thawing indices were calculated from mean monthly temperature data.

SCOPE AND METHOD

Due to the rather sparse climatological station network in northern Canada at the start of the 1941-1950 decade, Wilkins and Dujay (13) did not attempt to extend their freezing index map into the Arctic. As a result of the northward expansion during the late forties, an additional number of stations in northern Canada now have climatological records of more than ten years. This study is an attempt to fill the northern gap in the freezing index map of Canada, to present a thawing index map of northern Canada, and to provide freezing and thawing degree-day accumulations for specified periods of time during each year of the latest decade, for about forty stations. Maps of northern Canada are also presented which indicate the average dates of the start of the freezing season (mean daily temperatures generally below 32°F after this date), and the average dates of the start of the thawing season (mean daily temperatures above 32°F).

In view of increasing requirements for degree-day information on short period, monthly or annual fluctuations of temperature about a daily mean temperature of 32°F, it was decided to use machine methods to prepare degree-day tabulations for selected stations throughout Canada. The northern stations were given priority on this project, and the data presented here summarize the degree-day computations for about forty stations in northern Canada.

Degree-day data were computed for practically all stations in northern Canada which have continuous climatological records during the period from July 1949 to December 1959. This period, which covered ten freezing seasons and ten thawing seasons, represented the most recent decade of observations available at the time on punched cards. While a single decade of observations cannot be considered entirely representative of normal climate, this period does provide a standard for the comparison of degree-day statistics for individual stations.

The definitions used in these calculations are from the Engineering Manual, Corps of Engineers, U.S. Army (16). On the understanding that the degree-days for any one day are the difference between the average daily air temperature and 32°F, freezing degree-days are accumulated when this value is below 32°F, and thawing degree-days occur when it is above 32°F. In the machine tabulations, freezing degree-days are considered to be minus values, and thawing degree-days are plus values. For these computations, the degree-day totals for each day were derived from mean daily temperatures (in whole degrees F), based on the average of daily maximum and daily minimum temperatures. Three hundred and sixty-five punched cards per station-year were machine processed to give algebraic summations of degree-days measured from 32°F. The degree-day total for each day, and the summation total from January 1st, were indicated in the tabulation. The degree-day totals were cumulative from January 1st to December 31st of each year. It was possible to determine rates of accumulation of degree-days during specified periods of days or months from the time summation tabulation, or from the slope of the time summation curve.

Where the freezing season is considered to include that period of time when the mean daily temperature is generally below 32°F, the Freezing Index may be defined as the number of degree-days between the highest and lowest points on a curve of cumulative degree-days versus time, for one freezing season (16). The Thawing Index measures the number of degree-days between the highest and lowest values on the summation curve during a thawing season. These indices indicate the duration and magnitude of temperatures (with respect to 32°F) during freezing or thawing seasons.

The method used in determining the changeover date between freezing and thawing seasons may be illustrated by referring to the May 1950 degree-day tabulation for Fort Chimo (Table 1). It will be noted that, although the mean daily temperature reached 33°F on May 10th, the maximum accumulation of freezing degree-days did not occur until May 14th. Thus, May 15th was taken as the start of the thawing season.

TABLE 1

Fort Chimo degree-day tabulations - 1950

Date	Mean daily temperature	Degree-days (w.r.t. 32°F)	Degree-day accumulation from January 1st
May 9	28	-4	-4528
" 10	33	1	-4527
" 11	30	-2	-4529
" 12	23	-9	-4538
" 13	20	-12	-4550
" 14	27	-5	-4555
" 15	36	4	-4551
" 16	33	1	-4550

Graphical representations of the duration of freezing and thawing seasons, and the magnitude of freezing and thawing indices, are shown in Figure 5. The cumulative degree-day statistics for Whitehorse during the 1955-56 and 1957-58 thawing and freezing seasons are plotted against time. To facilitate comparison of the curves, the degree-day values of each curve have been adjusted so that they are cumulative from the zero point at the start of each thawing season.

FREEZING INDICES

Figure 1 shows the areal distribution of freezing indices in northern Canada during the period 1949-1959. The map was constructed by averaging the degree-day totals of the ten freezing seasons. Isolines on the map are spaced at 500 degree-day intervals.

As a measure of the combined duration and magnitude of below freezing temperatures during a freezing season, the freezing index is made up of degree-day contributions from several months. Since the months of January, February and March contribute substantially to the freezing index, it would be expected that the mean daily temperatures during these months would be reflected in the pattern of the freezing index map.

Comparison of the freezing index map with mean daily temperature maps for January or February shows a marked similarity in pattern over the Arctic Islands and in the northern continental interior. The dominating cold centre over northern Ellesmere Island, and its southward extension into the Barrens northwest of Hudson Bay, is a feature of both maps. Eureka, the coldest station in Canada during most of the winter months, also has the highest freezing index. The tempering marine influences along Hudson Strait and the east coast of Baffin Island show up as areas of abnormal warmth on each map. Clyde, on the east coast of Baffin Island, has an average freezing index of 8671 degree-days, compared to a figure of 11,093 degree-days at Spence Bay, at roughly the same latitude, but with a more continental type climate. At Resolution Island, near the eastern entrance to Hudson Strait, the average freezing index is only 4434 degree-days.

The freezing index distribution along the east coast of Hudson Bay demonstrates the influence on the freezing index of the open water months of October, November and December. While the mean temperature maps for February and March show only two or three degrees temperature difference between Churchill and Port Harrison, the average freezing index is nearly 1000 degree-days higher at Churchill than at Port Harrison.

The southward bulge of cold air into the Barren Lands to the west of Hudson Bay, as indicated on the January and February mean temperature maps, is considerably modified in southern sections on the freezing index map, where account is taken of the shorter freezing season and the higher temperatures during the Spring and Fall transition months. The influence of the length of the freezing season on the freezing index is further illustrated by the areas of lower indices along the Mackenzie River (Fig. 1), in a section of northwestern Canada where mid-winter temperatures are low. Spring is about two weeks earlier along the Mackenzie River valley than at stations at the same latitude two or three hundred miles further east (Fig. 4).

FREEZING AND THAWING DEGREE-DAYS

While average values of degree-day data may be employed in broad-scale studies of frost action, figures for individual months or seasons are more useful in local investigations. The degree-day statistics for individual years are not included in this paper; however, summaries of the freezing and thawing indices, and of thirty-day accumulations of degree-days at the start of each freezing and thawing season, illustrate, in Tables 2 to 5, the range of these values at each station.

It is interesting to note, in Table 2, that, of the 39 stations, all but 10 reported the lowest freezing index during the 1952-53 freezing season. There is considerable year-to-year variation in the freezing index. Examination of the highest and lowest seasonal values shows that the greatest range may be expected at stations in the Yukon and around Great Slave Lake. To illustrate the magnitude of the variation, the cumulative degree-day curves for Whitehorse, Y. T., covering the 1955-56 and 1957-58 thawing and freezing seasons, are shown in Figure 5. The freezing indices of 5105 degree-days in 1955-56 and 2852 in 1957-58, were respective maximum and minimum figures during the decade. The thawing indices during the preceding thawing seasons were also lowest and highest values. It may be seen from this comparison that, while freezing indices at Whitehorse covered a wide range of degree-days from 2852 to 5105, the variation in thawing indices was considerably less, and ranged from 2865 degree-days in 1955 to 3607 in 1957. During the period April 14th 1957 to March 30th 1958, the thawing index exceeded the freezing index, to show a net accumulation of 755 thawing degree-days. In contrast, during the thawing and freezing seasons in 1955-56, there was a net accumulation of 2240 freezing degree-days.

The cumulative freezing degree-days during the first thirty days of each freezing season are summarized in Table 4. These figures provide a measure of the rate of growth of ice in waterways, or the rate at which frost enters the ground during this period (6, 11). Similar statistics for thawing degree-days are listed in Table 5. It is apparent from these tables that the extreme values are of more interest than the average figures, since they indicate the large year-to-year variation that may be expected in rate of freeze or rate of thaw. Reference to Table 4 and Figure 3 shows that, in general, the highest thirty-day accumulations of freezing degree-days occur in late freezing seasons, while low values usually occur when the start of the freezing season is earlier than the average date.

THAWING INDICES

The map of the average thawing indices in northern Canada during the period 1949-1959 is presented in Figure 2. This map has a pattern similar to the mean daily temperature map for July.

Over the Arctic islands, where temperatures in summer are controlled by the presence of large areas of ice-filled water and where the length of the thawing season varies only a few days with latitude, thawing indices and mean daily temperatures during a typical summer month (July) are closely related. Almost everywhere north of the continental coastline, Foxe Basin and Hudson Strait, the distribution of thawing indices is very uniform with values mostly in the 500 to 1000 degree-day range.

Along the July 50°F isotherm, which extends from the Mackenzie delta to Baker Lake, southern Hudson Bay and Ungava Bay and which is often termed the southern boundary of the Arctic (14), thawing indices average about 1500 degree-days.

Since the zone of higher summer temperatures along the Mackenzie River valley also has a longer thawing season than adjoining areas (Figs. 3 and 4), thawing indices along the Mackenzie are high. Average values of 3476 at Fort Simpson and 2908 at Fort Good Hope contrast with thawing indices of 2465 at Fort Reliance and 2220 at Port Radium at about the same latitudes and only four hundred miles further east.

FREEZING AND THAWING SEASONS

The average dates when the mean daily temperature rises to 32°F in the Spring, and when it falls to 32°F in the Autumn, are charted in Figures 3 and 4. At most stations, the earliest date of the start of the freezing season was about 10 days ahead of the average date. The range was much the same at the start of the thawing season. Latest starting dates were 10 to 12 days after the average starting date.

SUMMARY

The degree-day tabulations for selected stations in northern Canada are summarized in the tables of average and extreme values of freezing and thawing degree-days. The more detailed seasonal and monthly degree-day figures for an increased number of stations will be listed in a future report.

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TABLE 2

Average and extreme values of freezing index (degree-days) - 1949-1959

Station	Ten-year average	High	Season	Low	Season
Aishihik A	5302	6291	1955-56	4114	1952-53
Aklavik	8037	8594	1954-55	6811	1949-50
*Alert	12093	12544	1950-51	11397	1952-53
Arctic Bay	9923	10674	1953-54	8849	1952-53
Baker Lake	9422	10072	1949-50	8891	1952-53
Brochet	6216	7040	1949-50	5417	1952-53
Cambridge Bay	10860	11311	1957-58	10302	1952-53
Cape Hopes Advance	5443	6309	1956-57	4562	1955-56
Chesterfield	8750	9449	1956-57	8151	1952-53
Churchill A	6718	7755	1949-50	6253	1952-53
Clyde	8671	9365	1956-57	7943	1952-53
Coppermine	8882	9439	1957-58	7869	1952-53
Coral Harbour A	8539	9510	1953-54	7666	1952-53
Ennadai Lake	8130	8840	1949-50	7660	1953-54
Eureka	13322	14243	1956-57	12519	1952-53
Fort Chimo A	5381	6176	1949-50	4518	1957-58
Fort Good Hope	7860	8638	1950-51	6877	1949-50
Fort Reliance	7172	7726	1956-57	6337	1952-53
Fort Resolution	5776	6354	1951-52	4618	1952-53
Fort Simpson	6040	6895	1950-51	4916	1952-53
Fort Smith A	5613	6235	1951-52	4567	1952-53
Frobisher Bay A	7052	8096	1956-57	6226	1955-56
Hay River	5548	6332	1955-56	4287	1952-53
*Holman Island	9015	9677	1955-56	7931	1952-53
Isachsen	12753	13486	1955-56	11983	1952-53
Mayo Landing	5881	7020	1950-51	4480	1952-53
Moosonee	3790	4626	1949-50	2810	1952-53
*Mould Bay	11912	12529	1953-54	10987	1952-53
Norman Wells A	7220	7973	1950-51	6137	1952-53
Nottingham Island	6401	7227	1953-54	5547	1952-53
Port Harrison	5804	6527	1949-50	5165	1952-53
Port Radium	6982	7776	1955-56	5713	1952-53
Resolute A	11204	11591	1956-57	10292	1952-53
Resolution Island	4434	5483	1956-57	3791	1952-53
*Spence Bay	11093	11578	1956-57	10524	1954-55
Teslin A	4048	5224	1955-56	2931	1957-58
Watson Lake A	5402	6510	1955-56	4515	1954-55
Whitehorse A	3861	5105	1955-56	2852	1957-58
Yellowknife A	6623	7159	1950-51	5318	1952-53

*Indicates period of record less than ten years.

TABLE 3

Average and extreme values of thawing index (degree-days) – 1949-1959

Station	Ten-year average	High	Year	Low	Year
Aishihik A	2412	2715	1951	2035	1955
Aklavik	2261	2859	1958	1761	1959
*Alert	387	612	1956	141	1955
Arctic Bay	808	990	1954	699	1955
Baker Lake	1515	1947	1954	1193	1950
Brochet	2935	3412	1955	2525	1959
Cambridge Bay	1016	1406	1954	767	1959
Cape Hopes Advance	974	1198	1955	822	1958
Chesterfield	1321	1673	1954	1098	1957
Churchill A	2056	2380	1955	1764	1958
Clyde	655	795	1957	550	1959
Coppermine	1362	1620	1954	954	1959
Coral Harbour A	1175	1487	1954	1021	1959
Ennadai Lake	1979	2483	1954	1620	1950
Eureka	701	847	1954	417	1953
Fort Chimo A	2206	2501	1955	1787	1956
Fort Good Hope	2908	3214	1958	2385	1959
Fort Reliance	2465	2924	1955	1768	1959
Fort Resolution	3176	3571	1953	2633	1959
Fort Simpson	3476	3777	1953	2995	1959
Fort Smith A	3365	3685	1955	2806	1959
Frobisher Bay A	1262	1541	1955	1073	1959
Hay River	3171	3472	1952	2573	1959
*Holman Island	1100	1660	1954	820	1959
Isachsen	402	649	1958	136	1953
Mayo Landing	3168	3475	1953	2816	1959
Moosonee	3611	4365	1955	3053	1950
*Mould Bay	422	691	1958	129	1953
Norman Wells A	2996	3354	1958	2531	1959
Nottingham Island	928	1131	1958	780	1950 & 1959
Port Harrison	1677	2293	1954	1288	1959
Port Radium	2220	2799	1954	1582	1959
Resolute A	536	888	1958	322	1955
Resolution Island	552	686	1958	429	1959
*Spence Bay	973	1150	1958	833	1959
Teslin A	2991	3354	1957	2568	1955
Watson Lake A	3388	3683	1953	2965	1959
Whitehorse A	3271	3607	1957	2865	1955
Yellowknife A	3079	3354	1955	2483	1959

*Indicates period of record less than ten years.

TABLE 4

Accumulation of freezing degree-days during first 30 days of freezing season - the period 1949-1959

Station	Average	Highest	From date	Lowest	From date
Aishihik A	289	615	Oct. 14/53	31	Oct. 1/54
Aklavik	314	604	Oct. 5/50	159	Sept. 18/54
Alert	330	597	Sept. 5/58	173	Aug. 13/53
Arctic Bay	255	376	Sept. 19/51	122	Sept. 4/55
Baker Lake	287	617	Sept. 28/56	96	Sept. 17/51
Brochet	419	782	Nov. 4/58	142	Oct. 3/50
Cambridge Bay	338	549	Sept. 28/54	178	Sept. 11/57
Cape Hopes Advance	160	242	Nov. 3/55	98	Sept. 30/54
Chesterfield	296	620	Oct. 9/51	83	Sept. 25/54
Churchill A	356	536	Oct. 30/58	206	Oct. 3/50
Clyde	199	273	Sept. 23/57	72	Sept. 8/55
Coppermine	310	580	Oct. 13/53	73	Sept. 13/57
Coral Harbour A	262	501	Sept. 27/56	32	Sept. 8/55
Ennadai Lake	249	672	Oct. 9/51	25	Sept. 23/53
Eureka	407	564	Sept. 9/58	210	Aug. 22/49
Fort Chimo A	254	442	Oct. 23/54	75	Sept. 29/51
Fort Good Hope	356	749	Oct. 13/53	144	Sept. 26/52
Fort Reliance	357	643	Oct. 29/58	34	Sept. 23/52
Fort Resolution	339	594	Nov. 3/58	141	Oct. 6/49
Fort Simpson	326	570	Oct. 10/56	39	Oct. 6/54
Fort Smith A	346	615	Nov. 3/58	102	Oct. 1/57
Frobisher Bay A	321	713	Nov. 4/55	146	Sept. 20/53
Hay River	362	680	Nov. 3/58	66	Oct. 6/49
Holman Island	290	507	Sept. 22/56	71	Aug. 28/52
Isachsen	334	611	Sept. 7/58	144	Aug. 12/53
Mayo Landing	395	745	Oct. 23/53	138	Oct. 22/52
Moosonee	252	519	Nov. 7/56	36	Oct. 29/53
Mould Bay	211	352	Sept. 6/58	115	Aug. 12/53
Norman Wells A	339	645	Oct. 13/53	92	Sept. 27/52
Nottingham Island	143	210	Sept. 23/52	51	Sept. 21/49
Port Harrison	260	395	Oct. 23/54	104	Oct. 1/58
Port Radium	301	509	Oct. 16/55	64	Sept. 23/52
Resolute A	311	471	Sept. 14/51	129	Aug. 26/57
Resolution Island	119	242	Nov. 5/55	57	Sept. 29/49
Spence Bay	279	493	Sept. 27/54	135	Sept. 6/55
Teslin A	325	451	Oct. 26/53	74	Oct. 6/58
Watson Lake A	444	691	Oct. 20/55	66	Oct. 14/49
Whitehorse A	345	584	Oct. 20/55	148	Oct. 5/58
Yellowknife A	357	508	Oct. 10/56	79	Oct. 6/58

TABLE 5

Accumulation of thawing degree-days during first 30 days of thawing season – 1949-1959

Station	Average	Highest	From date	Lowest	From date
Aishihik A	232	307	May 13/52	168	April 14/51
Aklavik	236	383	May 27/51	72	May 11/59
Alert	162	315	June 15/56	22	June 14/55
Arctic Bay	243	384	June 15/56	157	June 4/55
Baker Lake	272	362	June 9/58	190	May 28/54
Brochet	201	312	April 12/52	83	April 27/57
Cambridge Bay	258	520	June 16/56	139	June 3/53
Cape Hopes Advance	169	270	June 18/58	33	May 5/52
Chesterfield	227	316	June 9/51	167	May 28/54
Churchill A	254	518	June 4/51	108	April 23/52
Clyde	153	263	June 15/56	15	May 21/50
Coppermine	243	529	June 12/56	69	May 14/55
Coral Harbour	201	309	June 8/56	97	May 28/54
Ennadai Lake	289	515	June 4/51	86	May 25/54
Eureka	247	350	June 5/57	120	June 4/55
Fort Chimo A	242	450	May 25/51	85	April 27/59
Fort Good Hope	325	537	May 11/55	207	April 28/56
Fort Reliance	254	448	May 12/55	89	April 28/50
Fort Resolution	305	430	May 3/58	169	April 22/55
Fort Simpson	334	574	May 3/58	81	April 14/57
Fort Smith A	309	480	May 3/54	90	Mar. 24/58
Frobisher Bay A	138	334	June 8/56	51	May 15/59
Hay River	279	455	May 3/58	162	April 26/57
Holman Island	239	563	June 12/56	60	May 11/53
Isachsen	160	346	June 12/57	57	June 1/52
Mayo Landing	267	444	May 4/59	83	Mar. 24/58
Moosonee	211	426	May 7/50	53	April 15/53
Mould Bay	164	281	June 12/57	42	June 17/53
Norman Wells A	307	500	May 10/55	133	April 21/52
Nottingham Island	143	238	June 7/58	50	May 19/50
Fort Harrison	183	345	May 17/55	3	May 10/58
Port Radium	247	543	May 23/54	103	May 11/59
Resolute A	191	270	June 15/56	120	June 15/55
Resolution Island	67	124	June 8/58	15	May 20/53
Spence Bay	297	364	June 17/56	225	June 13/59
Teslin A	210	364	April 30/54	96	April 9/52
Watson Lake A	267	449	April 30/54	165	April 13/56
Whitehorse A	186	373	April 29/54	98	Mar. 30/51
Yellowknife A	348	546	May 11/55	107	April 26/57

Discussion

J. R. Mackay asked if it is possible to give the approximate relationship which might be expected between freezing and thawing indices measured in a weather screen and those for the ground surface, for example, at a depth of one centimeter. The author replied that all the temperatures used in the computation of freezing and thawing indices were obtained from weather screens. There is no information available on the expected relationship. T. A. Harwood commented that micro-meteorological complications, which are evident at the ground surface, are ironed out at a height of 4 feet above the ground. Therefore, air temperature measurements from the weather screen are a more reliable indicator of meteorological conditions.

In reply to an inquiry by T. A. Harwood on the correspondence existing between mean annual air isotherms and the southern limit of permafrost in Canada, the author replied that there are not enough meteorological stations at present in the area to give a precise answer. The paper by R. J. E. Brown (The Distribution of Permafrost and Its Relation to Air Temperature in Canada and the U. S. S. R., Arctic, Vol. 13, No. 3, Sept. 1960, pp. 163-177, NRC 5941) shows only a broad relationship. Thawing indices, in addition to freezing indices, must be considered, the final result being a consideration of mean annual air temperature. R. J. E. Brown remarked that a broad relationship exists between mean annual air temperature and the southern limit of permafrost. Our present knowledge of the southern limit in Canada indicates that it lies in the zone bounded by the 25^{o}F. and 30^{o}F. mean annual air isotherms. Because of the complex energy exchange regime operative at the ground surface which results in the mean annual ground temperature being several degrees (about 6) warmer than the mean annual air temperature, there is no known instance of the permafrost lying south of the 30^{o}F. mean annual air isotherm. Fluctuations across the country and local variations in permafrost within a small area appear to be influenced by terrain and subsurface features such as vegetation, soil, and others.

N. W. Radforth wondered if it is possible to reconcile the differences existing between isolines of freezing and thawing indices to permafrost. It appears that thawing indices, in addition to freezing indices, should be considered before any comparison can be attempted. Also, the degree day method considers temperature only, as one of many factors of climate affecting the distribution of permafrost. The snow on the ground, vegetation, type of soil, and other features affect the southern boundary considerably.

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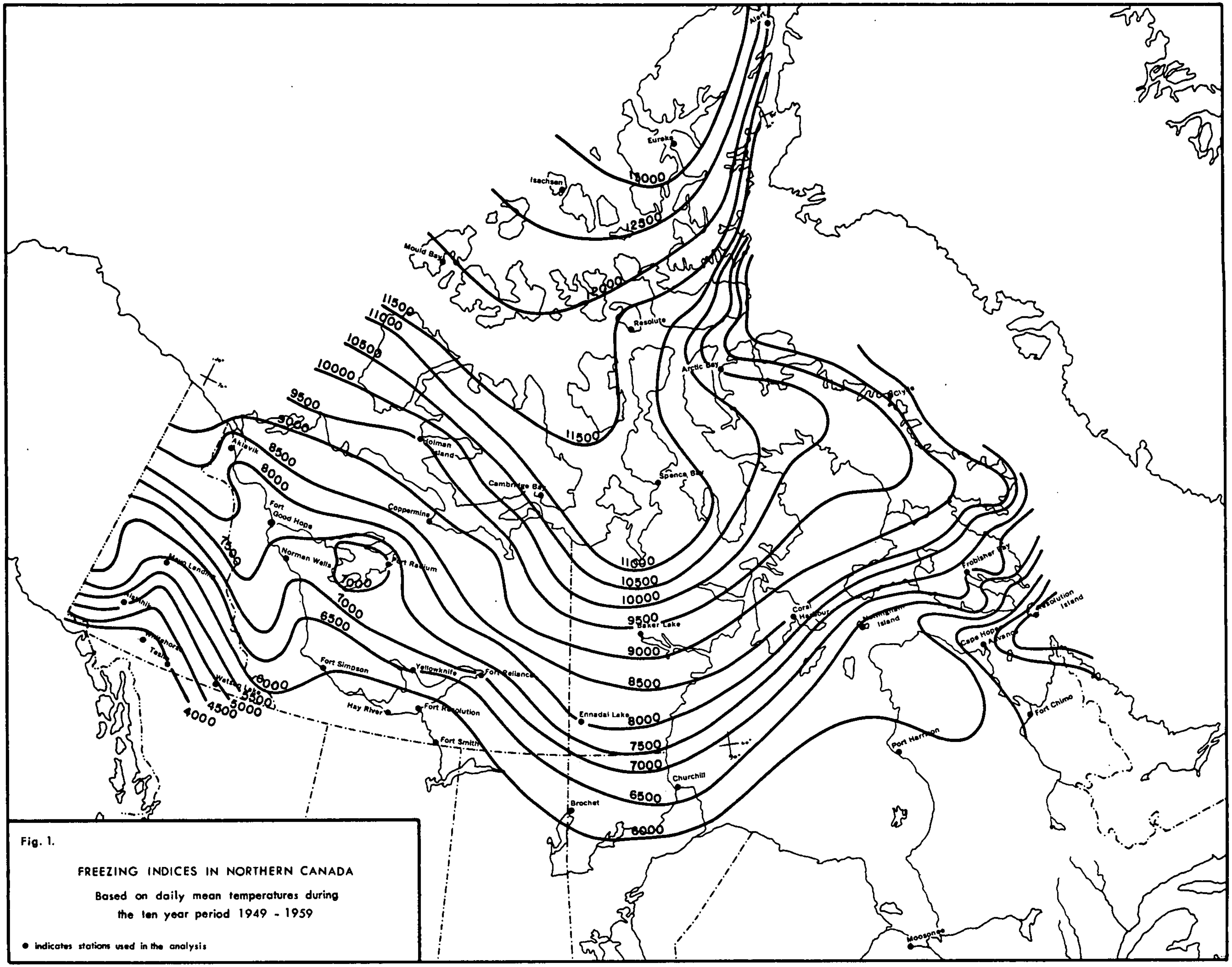

Fig. 1.

FREEZING INDICES IN NORTHERN CANADA

Based on daily mean temperatures during the ten year period 1949 - 1959

● indicates stations used in the analysis

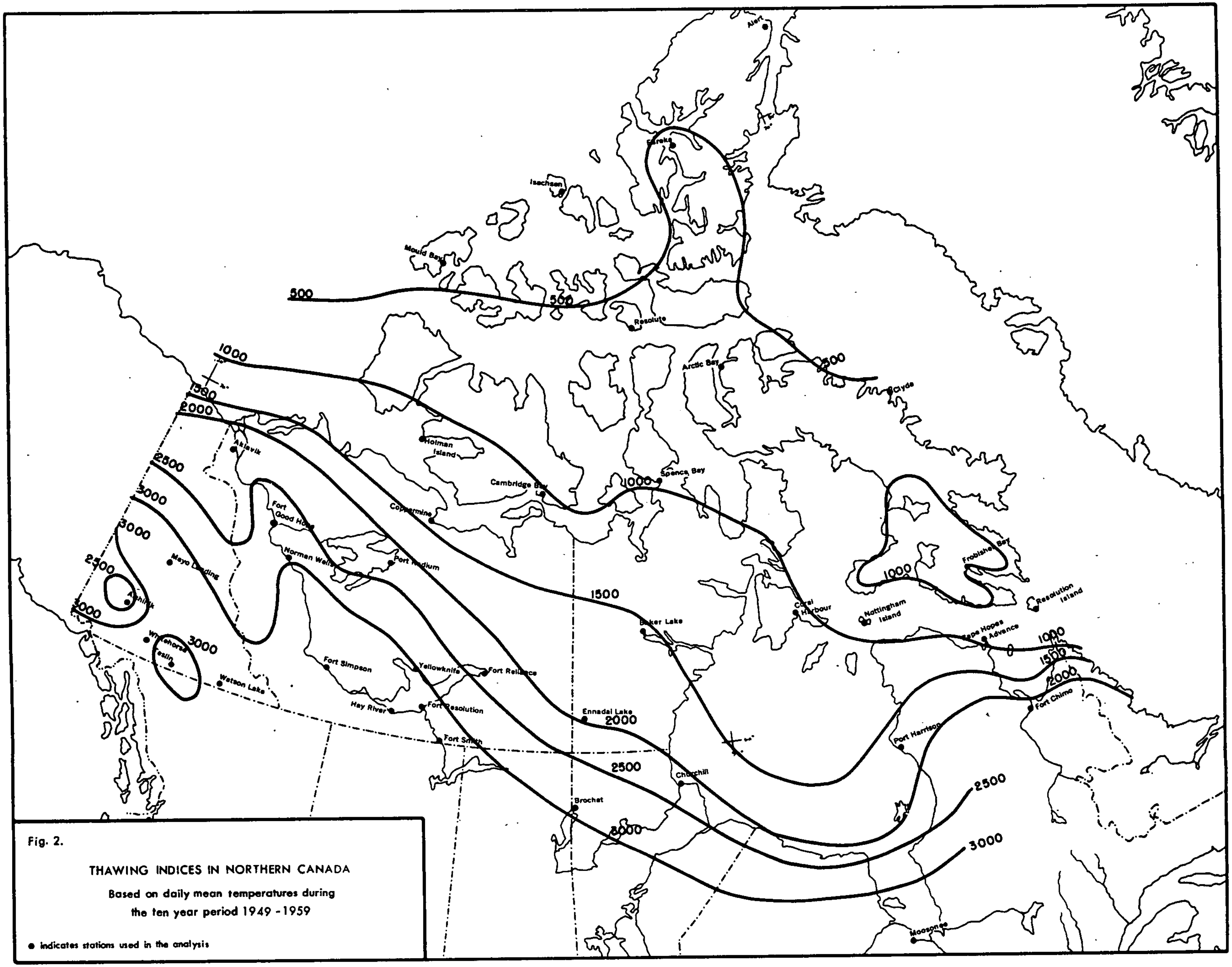

Fig. 2.

THAWING INDICES IN NORTHERN CANADA

Based on daily mean temperatures during the ten year period 1949 - 1959

● indicates stations used in the analysis

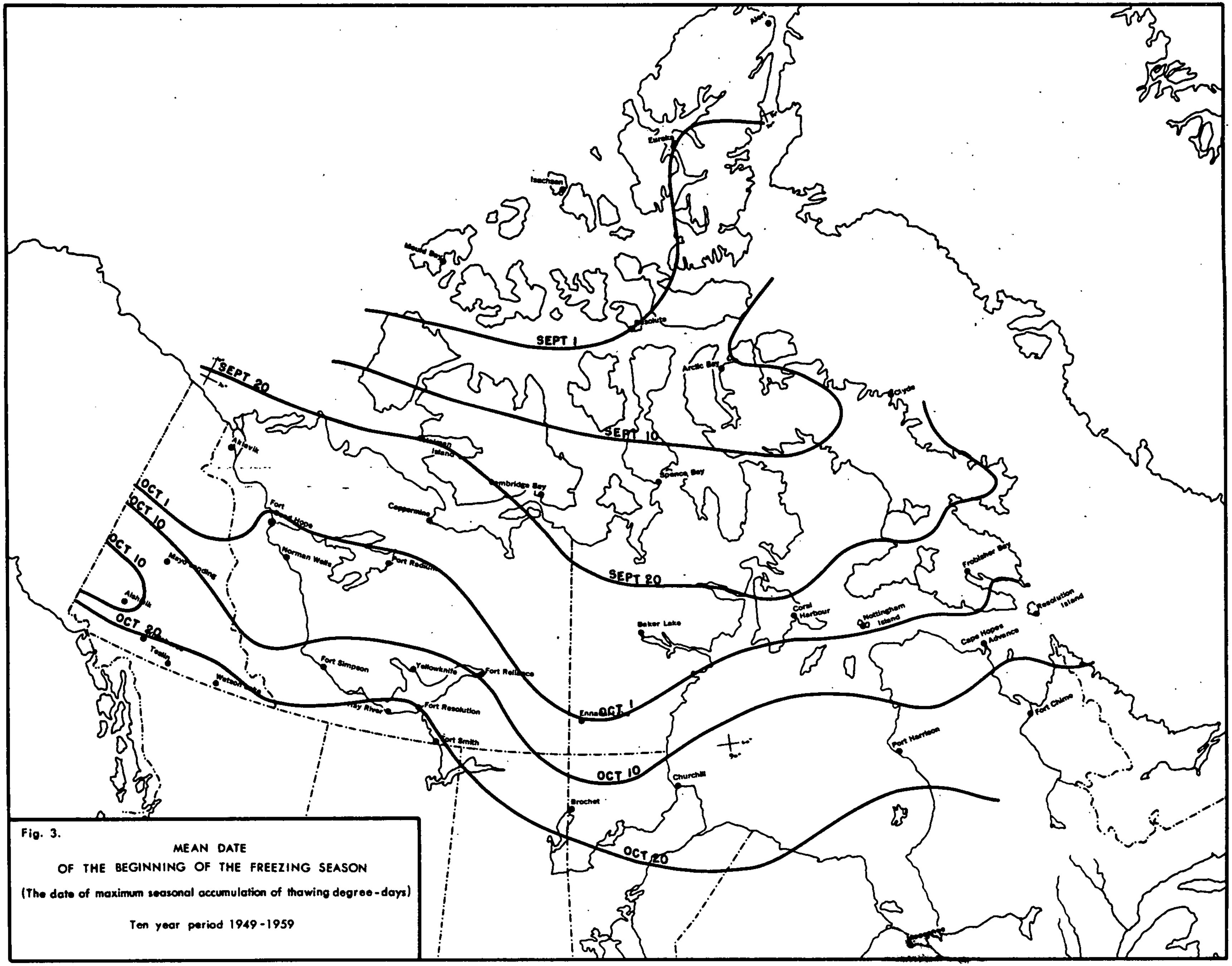

Fig. 3.

MEAN DATE
OF THE BEGINNING OF THE FREEZING SEASON
(The date of maximum seasonal accumulation of thawing degree-days)
Ten year period 1949-1959

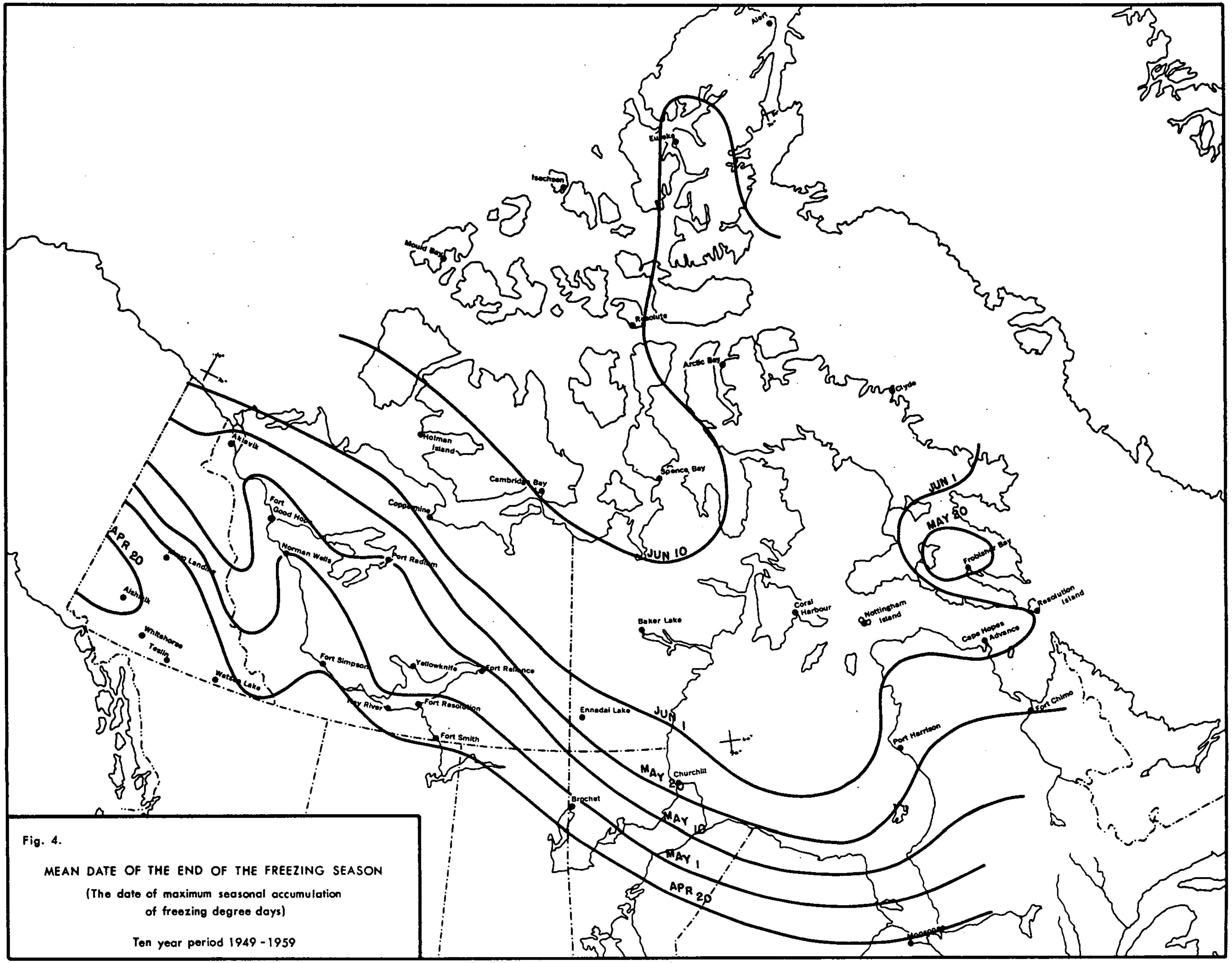

Fig. 4.

MEAN DATE OF THE END OF THE FREEZING SEASON

(The date of maximum seasonal accumulation of freezing degree days)

Ten year period 1949 - 1959

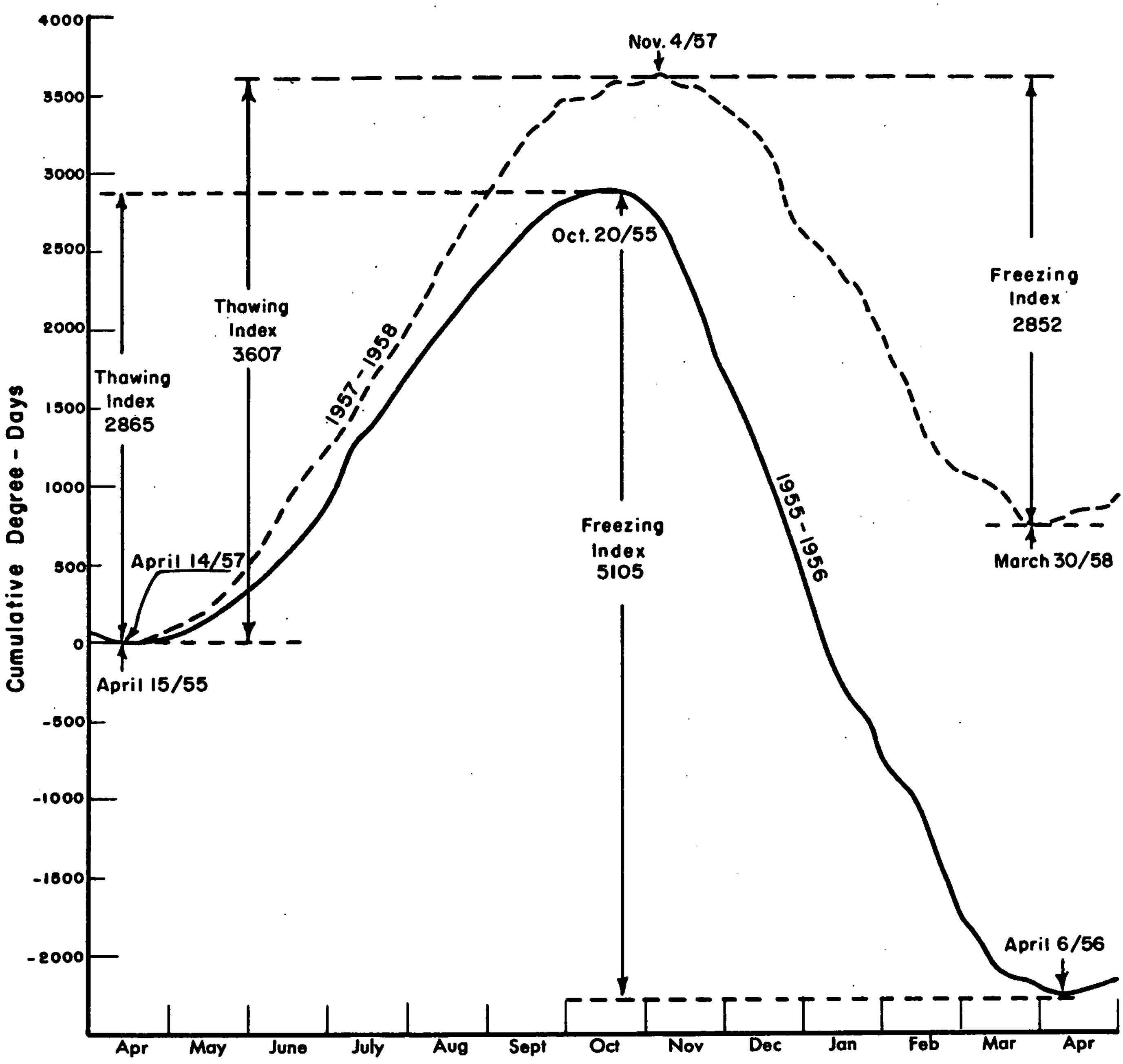

Fig. 5 - Degree-day Accumulations at Whitehorse, Yukon. (Base temperature 32 deg. F.)